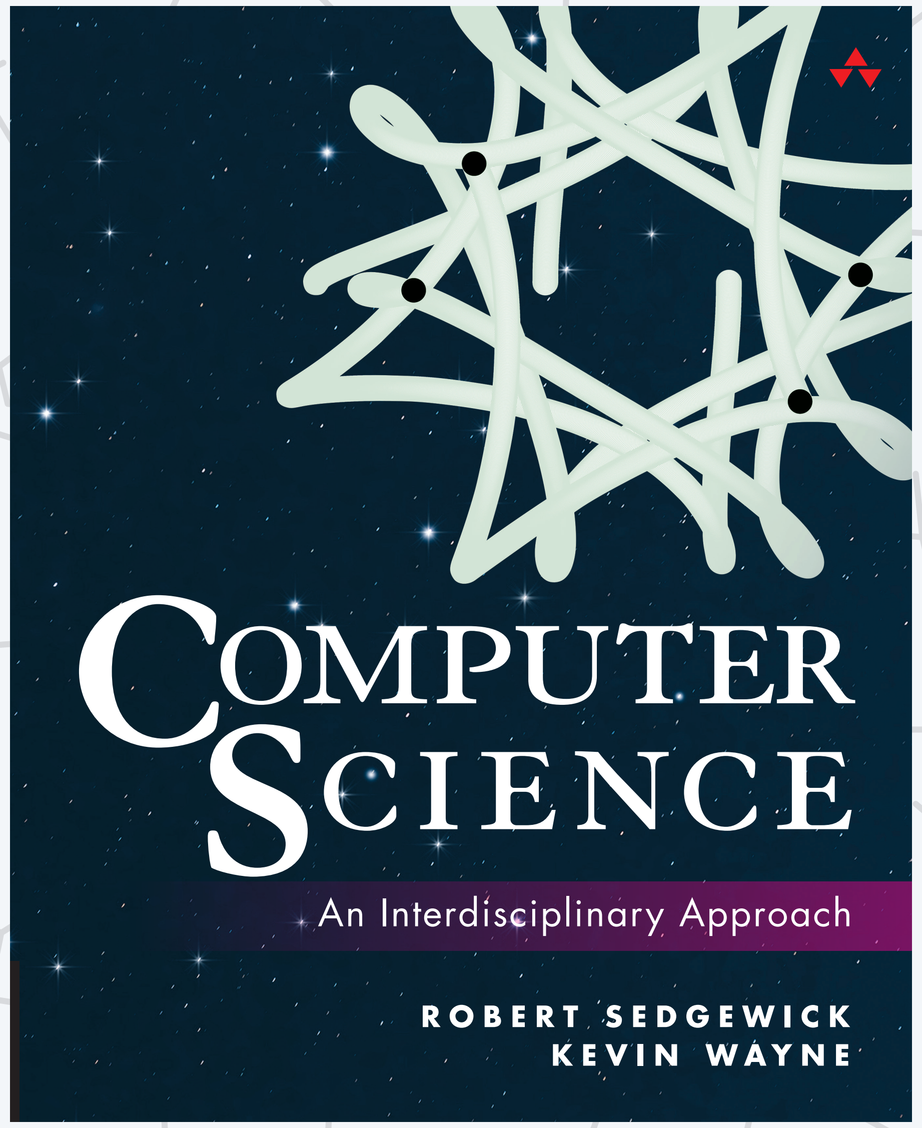

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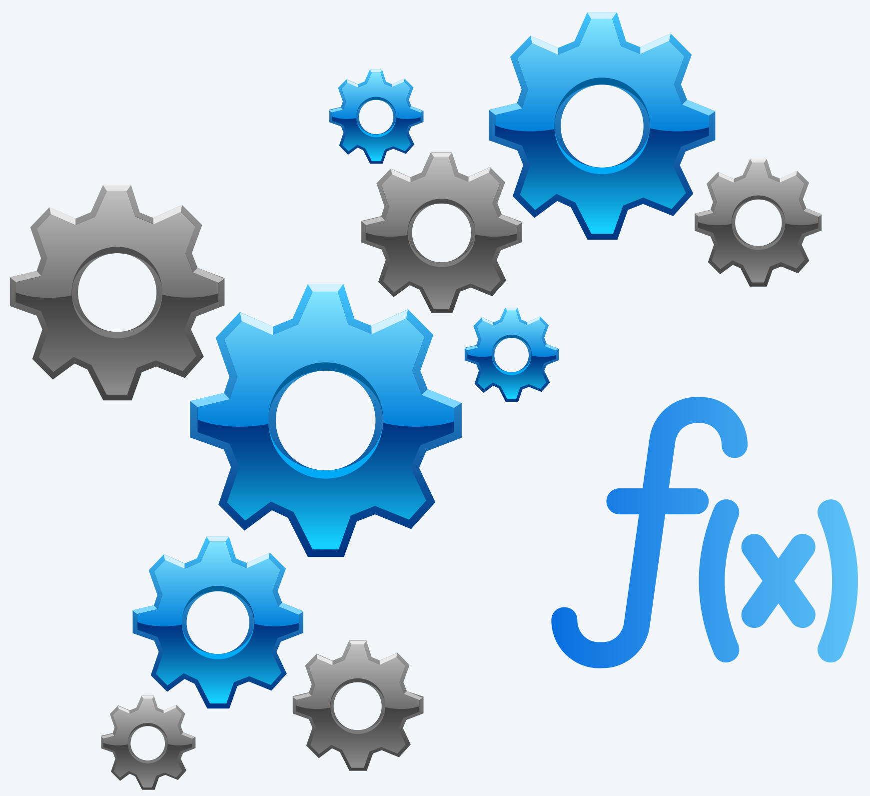
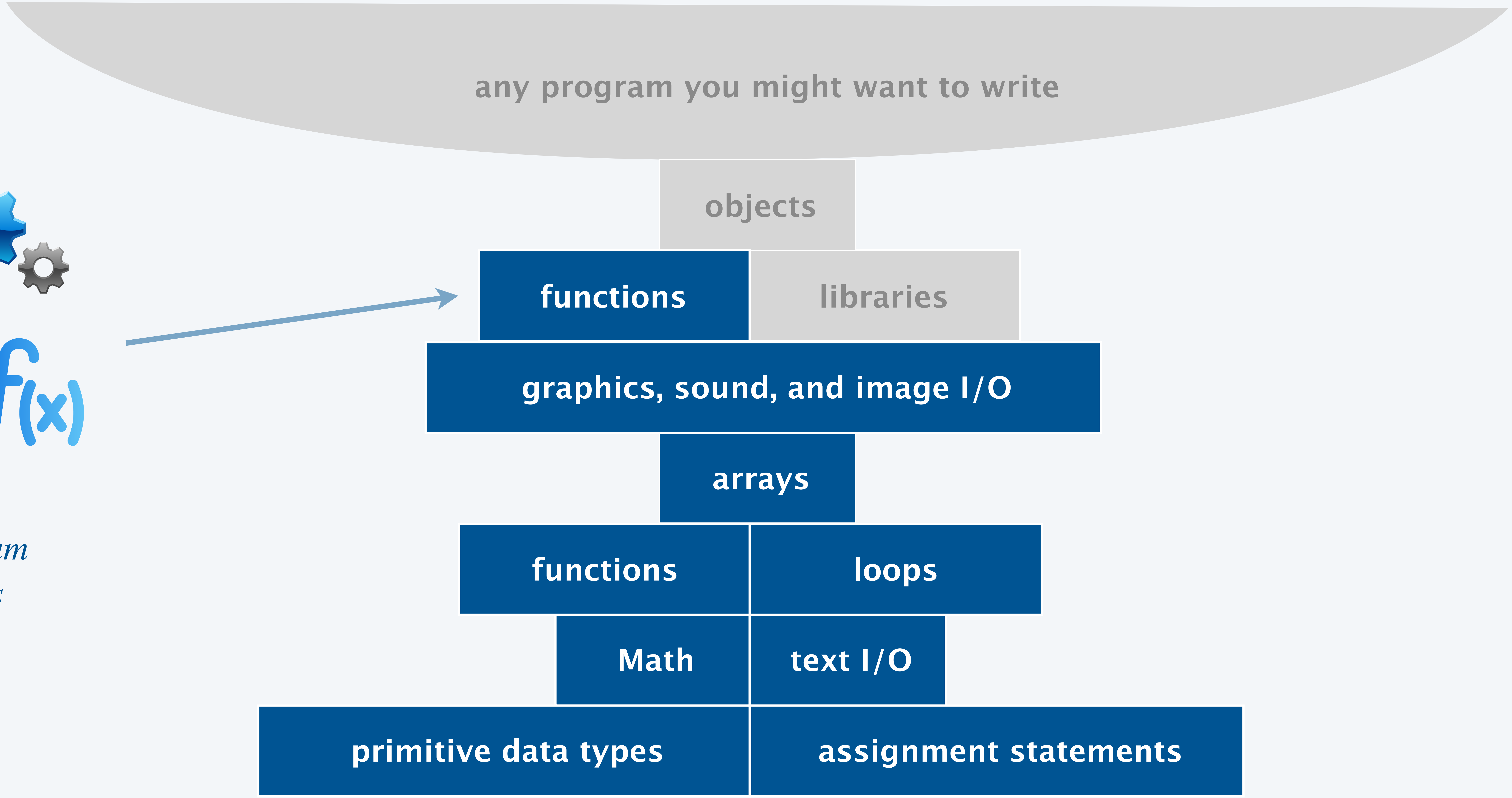
2.1 Functions

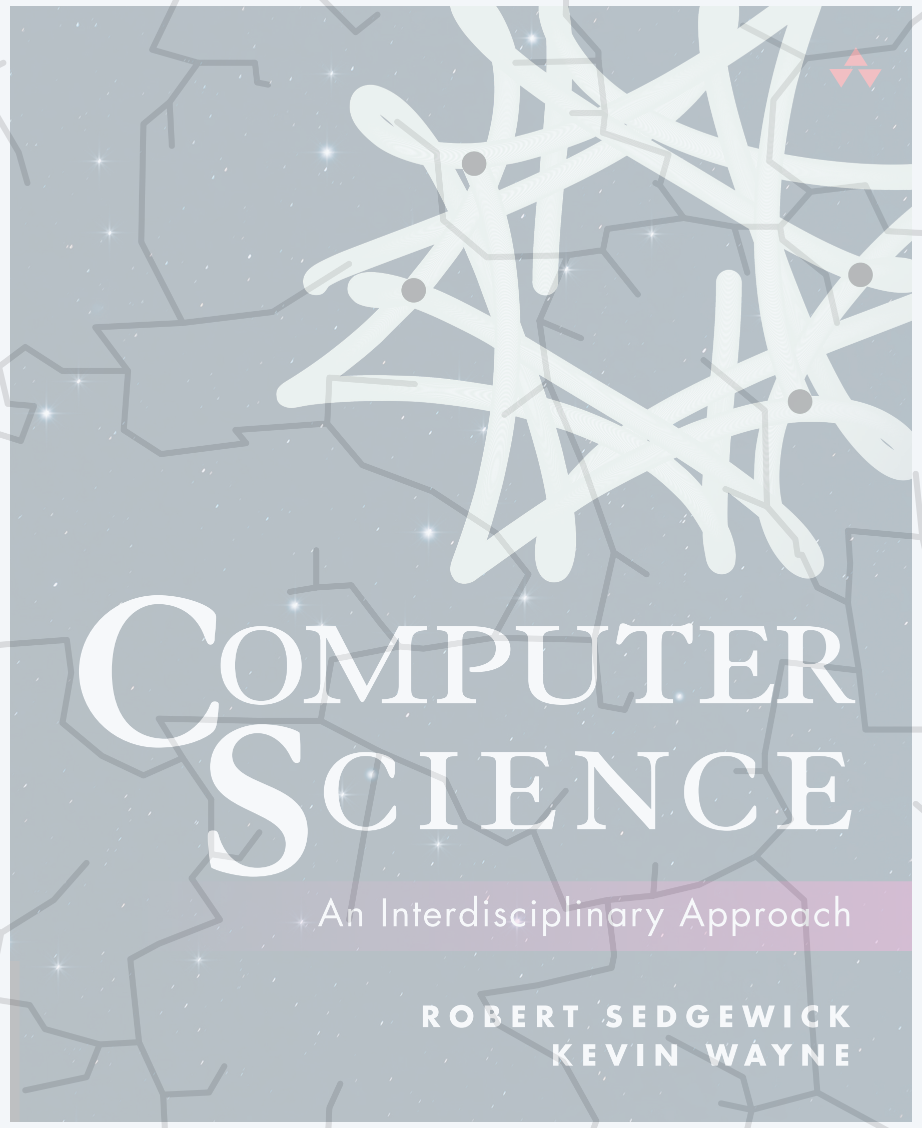
- *flow-of-control*
- *properties*
- *call by value*
- *number-to-speech*

Basic building blocks for programming



divide a program
into functions





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2.1 Functions

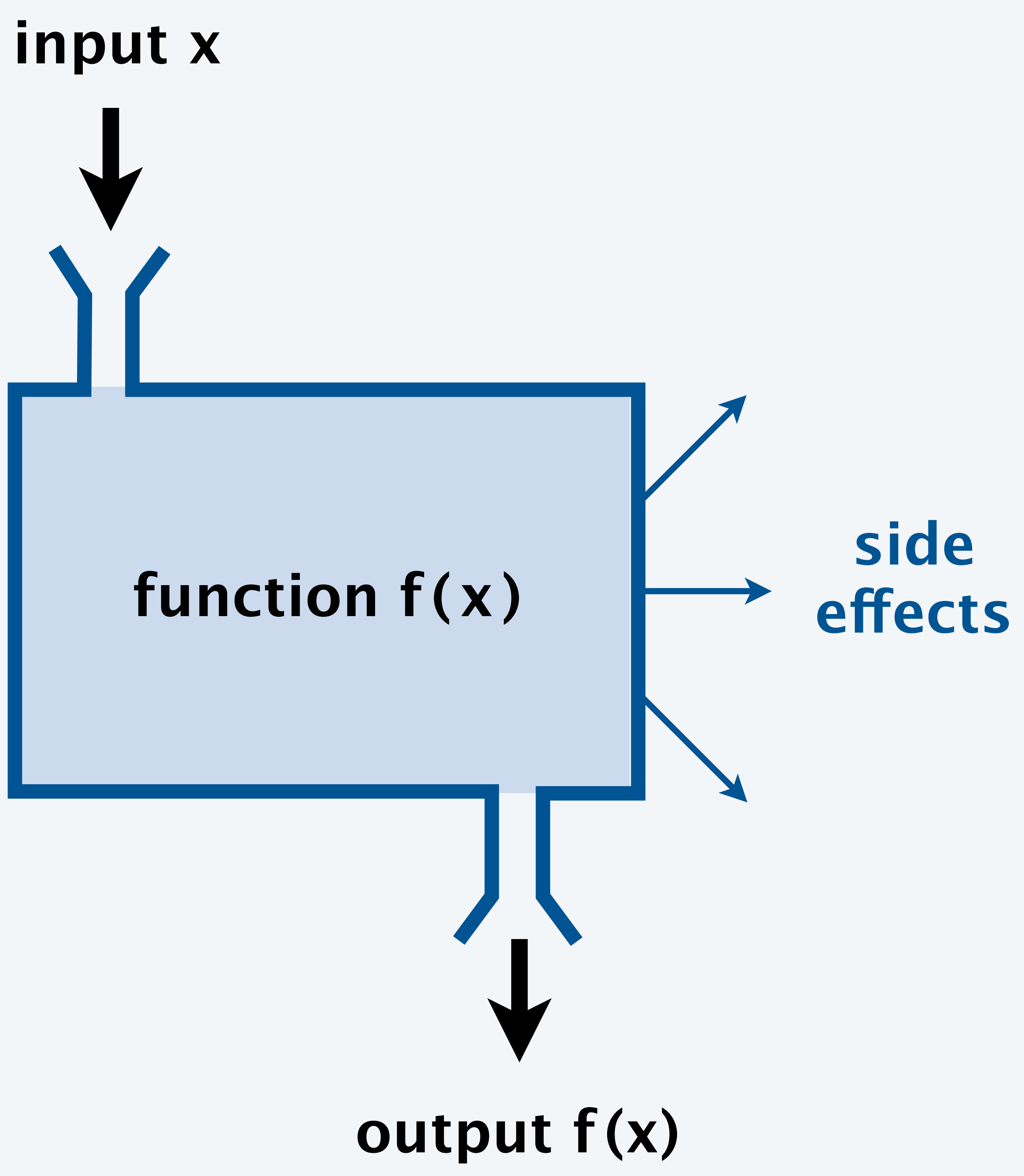
- *flow-of-control*
- *properties*
- *call by value*
- *number-to-speech*

Functions

Java function (static method).

- Takes zero or more input arguments.
- Returns zero or one output value.
- May cause side effects.

more general than mathematical functions



Benefits. Makes code easier to read, test, debug, reuse, and extend.

Familiar examples.

- Built-in functions: `Math.random()`, `Math.abs()`, `Integer.parseInt()`.
- Our I/O libraries: `StdIn.readInt()`, `StdDraw.line()`, `StdAudio.play()`.
- User-defined functions: `main()`.

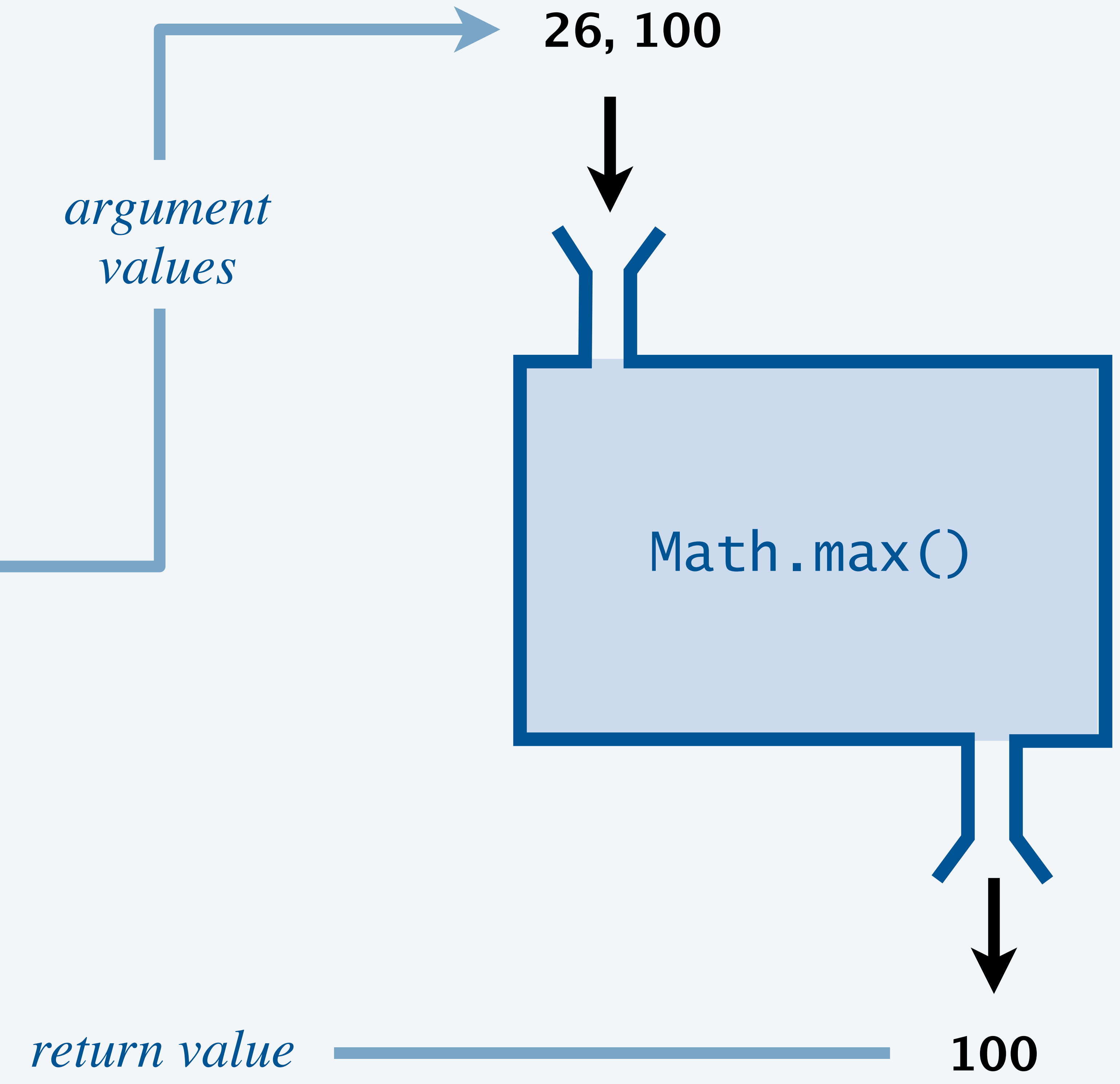
Flow of control

Mechanics of a function call.

- Control transfers from calling code to function code, passing argument values.
- Function code executes, producing a return value.
- Control transfers back to calling code. ← *function-call expression evaluates to return value*

```
public class Max {
   public static void main(String[] args) {
      int a = 26;
      int b = 100;
      int max = Math.max(a, b);
      StdOut.println(max);
   }
}
```

function call



Bottom line. Functions provide a useful *way* to control the flow of execution.

Anatomy of a Java function (static method)

To implement a Java function:

- Choose a *method name*.
- Declare type and name of each *parameter variable*.
- Specify type for *return value*.
- Include *modifiers*. ← *for now, always* `public` *and* `static`
- Implement *method body*, including a *return statement*.

(first four items ← *method header*)

Ex. Harmonic sum: $H_n = 1 + \frac{1}{2} + \frac{1}{3} + \ldots + \frac{1}{n}$.

modifiers · *return type* · *method name* · *parameter type* · *parameter name*

method header →

```java
public static double sum(int n) {
   double result = 0.0;
   for (int j = 1; j <= n; i++)
      result += 1.0 / j;
   return result;
}
```

← *method body*

return statement →

Function call trace (i = 0)

```
public class Harmonic {

   public static double sum(int n) {
      double result = 0.0;
      for (int j = 1; j <= n; j++)
         result += 1.0 / j;
      return result;
   }

   public static void main(String[] args) {
     for (int i = 0; i < args.length; i++) {
         int arg = Integer.parseInt(args[i]);
         double value = sum(arg);
         StdOut.println(value);
      }
   }
}
```

i	arg	value
0	1	1.0

variable trace in *main*()

j	n	result
	1	0.0
1	1	1.0

variable trace in *sum*()

```
~/cos126/functions> java-introcs Harmonic 1 2 5
1.0
```

Function call trace (i = 1)

```
public class Harmonic {

   public static double sum(int n) {
      double result = 0.0;
      for (int j = 1; j <= n; j++)
         result += 1.0 / j;
      return result;
   }

   public static void main(String[] args) {
      for (int i = 0; i < args.length; i++) {
         int arg = Integer.parseInt(args[i]);
         double value = sum(arg);
         StdOut.println(value);
      }
   }
}
```

i	arg	value
0	1	1.0
1	2	1.5

variable trace in *main*()

j	n	result
	2	0.0
1	2	1.0
2	2	1.5

variable trace in *sum*()

```
~/cos126/functions> java-introcs Harmonic 1 2 5
1.0
1.5
```

Function call trace (i = 2)

```
public class Harmonic {

   public static double sum(int n) {
      double result = 0.0;
      for (int j = 1; j <= n; j++)
         result += 1.0 / j;
      return result;
   }

   public static void main(String[] args) {
      for (int i = 0; i < args.length; i++) {
         int arg = Integer.parseInt(args[i]);
         double value = sum(arg);
         StdOut.println(value);
      }
   }
}
```

i	arg	value
0	1	1.0
1	2	1.5
2	5	2.2833

variable trace in *main*()

j	n	result
	5	0.0
1	5	1.0
2	5	1.5
3	5	1.8333
4	5	2.0833
5	5	2.2833

variable trace in *sum*()

```
~/cos126/functions> java-introcs Harmonic 1 2 5
1.0
1.5
2.283333333333333
```

What is the result of executing this program with the given command-line argument?

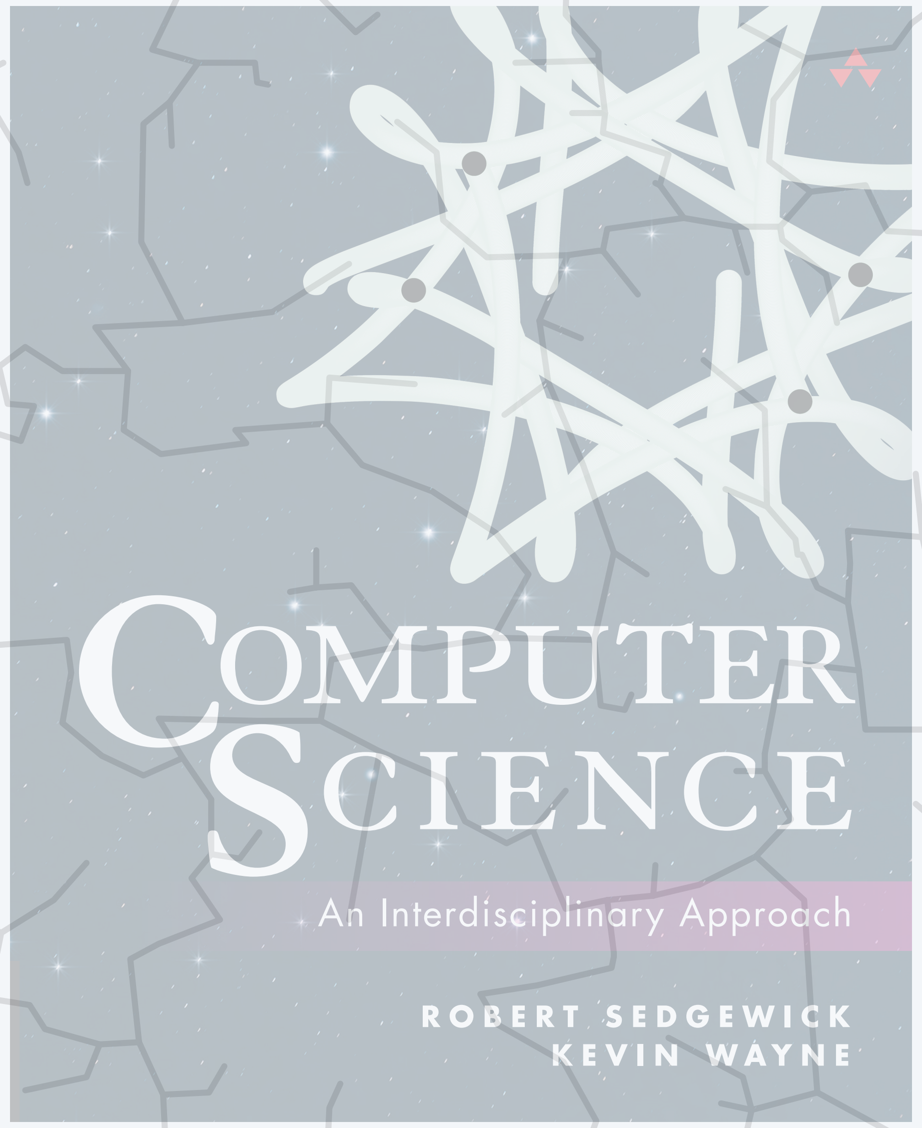
- **A.** 126.0
- **B.** 378.0
- **C.** Compile-time error.
- **D.** Run-time error.

```
public class Mystery {

   public static double triple(double x) {
      return 3*x;
   }

   public static void main(String[] args) {
      double x = Double.parseDouble(args[0]);
      triple(x);
      StdOut.println(x);
   }
}
```

```
~/cos126/functions> java-introcs Mystery 126.0
```



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2.1 FUNCTIONS

- *flow-of-control*
- *properties*
- *call by value*
- *number-to-speech*

Single *return* value

When a function reaches a return statement, it transfer control back to code that invoked it.

- The type of the return value must be compatible with the function's return type.
- Java returns a single return value to the calling code.

that value can be of any type (`double`, `String`, `int[]`, …)

return type

```java
public static double sum(int n) {
  double result = 0.0;
  for (int i = 1; i <= n; i++)
     result += 1.0 / i;
  return result;
}
```

return statement

Multiple *return* statements

Control is transferred back to calling code upon reaching the first *return* statement.

```
public static double signum(double x) {
   if      (x <  0.0) return -1.0;
   else if (x >  0.0) return +1.0;
   else if (x == 0.0) return  0.0;
   else return Double.NaN;
}
```

multiple `return` *statements*

sign (signum) function

```
public static double signum(double x) {
   if (x <  0.0) return -1.0;
   if (x >  0.0) return +1.0;
   if (x == 0.0) return  0.0;
   return Double.NaN;
}
```

equivalent function

$$signum(x) = \begin{cases} -1 & \text{if } x < 0 \\ 0 & \text{if } x = 0 \\ +1 & \text{if } x > 0 \end{cases}$$

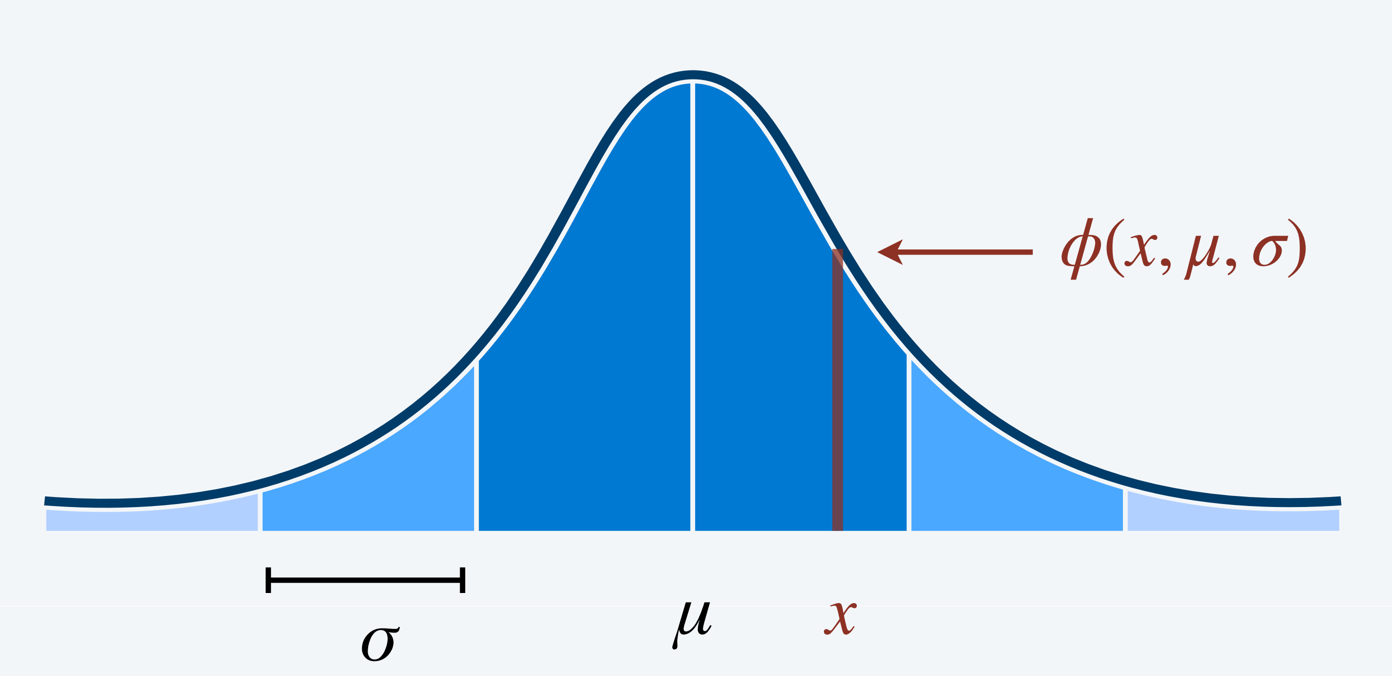
Note. This function appears in Java's *Math* library.

Multiple arguments

A function can take multiple arguments.

- Each parameter variable has a type and a name.
- The argument values are assigned to the corresponding parameter variables.

Ex. Gaussian (normal) probability distribution function: $\phi(x, \mu, \sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$.




```
pdf(88.0, 90.0, 10.0)
```

```
public class Gaussian {

   public static double pdf(double x, double mu, double sigma) {
      double z = (x - mu) / sigma;
      return Math.exp(-z*z / 2) / (sigma * Math.sqrt(2 * Math.PI));
   }

}
```

function takes three `double` *arguments*

Multiple functions

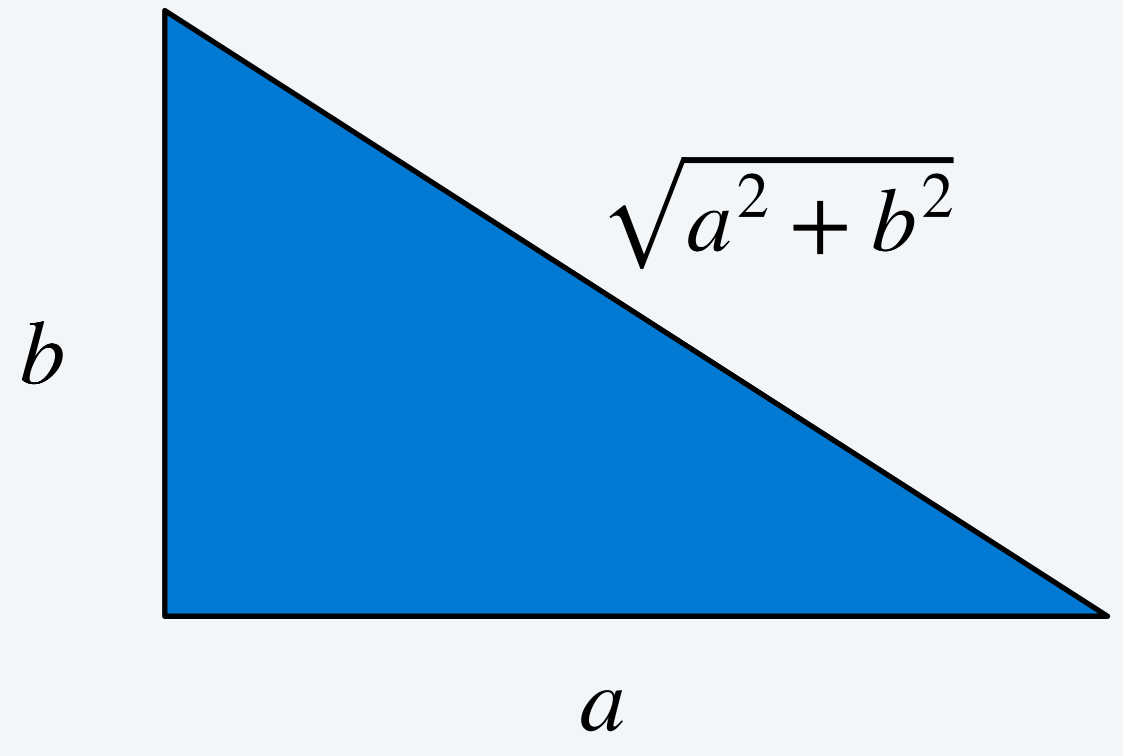
You can define many functions in a class.

- One function can call another function.
- The order in which the functions are defined in the file is unimportant.

```
public class RightTriangle {

   public static double square(double x) {
      return x*x;
   }

   public static double hypotenuse(double a, double b) {
      return Math.sqrt(square(a) + square(b));
   }

}
```

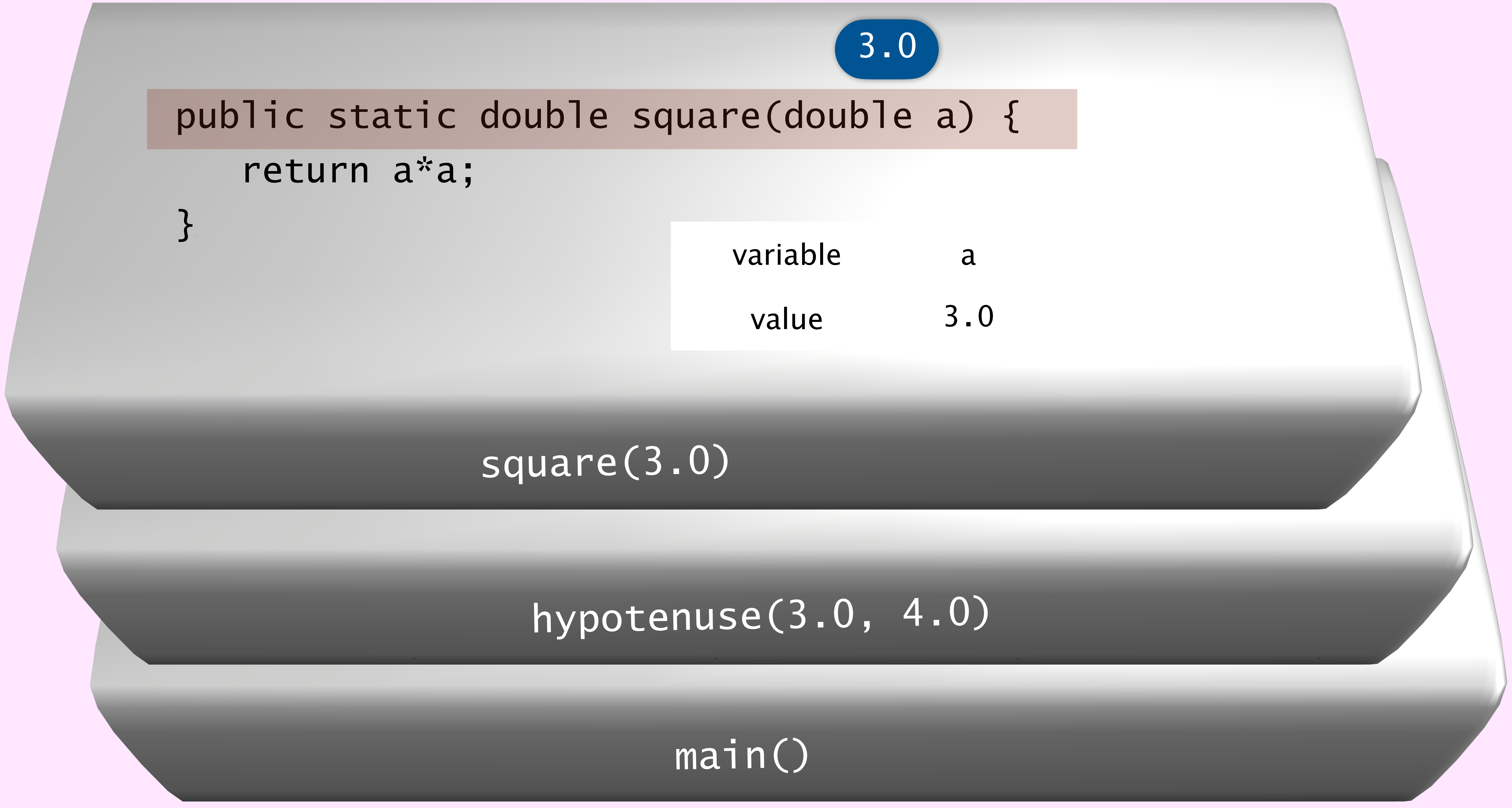
function calls a function defined in a different class

function calls a function defined in the same class



$\sqrt{a^2 + b^2}$

Mechanics of a function call



function-call stack

Overloaded functions

Overloading. Two functions with the same name (but different ordered list of parameter types).

```
public class Math {

   public static int abs(int x) {
      if (x < 0) return -x;
      else       return  x;
   }

   public static double abs(double x) {
      if (x < 0) return -x;
      else       return  x;
   }

}
```

`abs(-126)` *calls this function (and evaluates to* `126`*)*

`abs(-126.0)` *calls this function (and evaluates to* `126.0`*)*

Note. These two overloaded functions appear in Java's *Math* library.

Overloaded functions

Overloading. Two functions with the same name (but different ordered list of parameter types).

```
public class Gaussian {

   public static double pdf(double x) {
      return pdf(x, 0.0, 1.0);
   }

   public static double pdf(double x, double mu, double sigma) {
      double z = (x - mu) / sigma;
      return Math.exp(-z*z / 2) / (sigma * Math.sqrt(2 * Math.PI));
   }

}
```

pdf(3.0) *calls this function*

pdf(3.0, 0.0, 1.0) *calls this function*

pdf(3.0, 0.0, "126") *is incompatible (compile-time error)*

Bottom line. Java determines which function to call based on list of arguments.

Which value does *triple*(126) return?

A. 378

B. 378.0

C. "126126126"

D. Compile-time error.

E. Run-time error.

```
public class Mystery {

   public static double triple(double x) {
      return 3*x;
   }

   public static String triple(String x) {
      return x + x + x;
   }

}
```

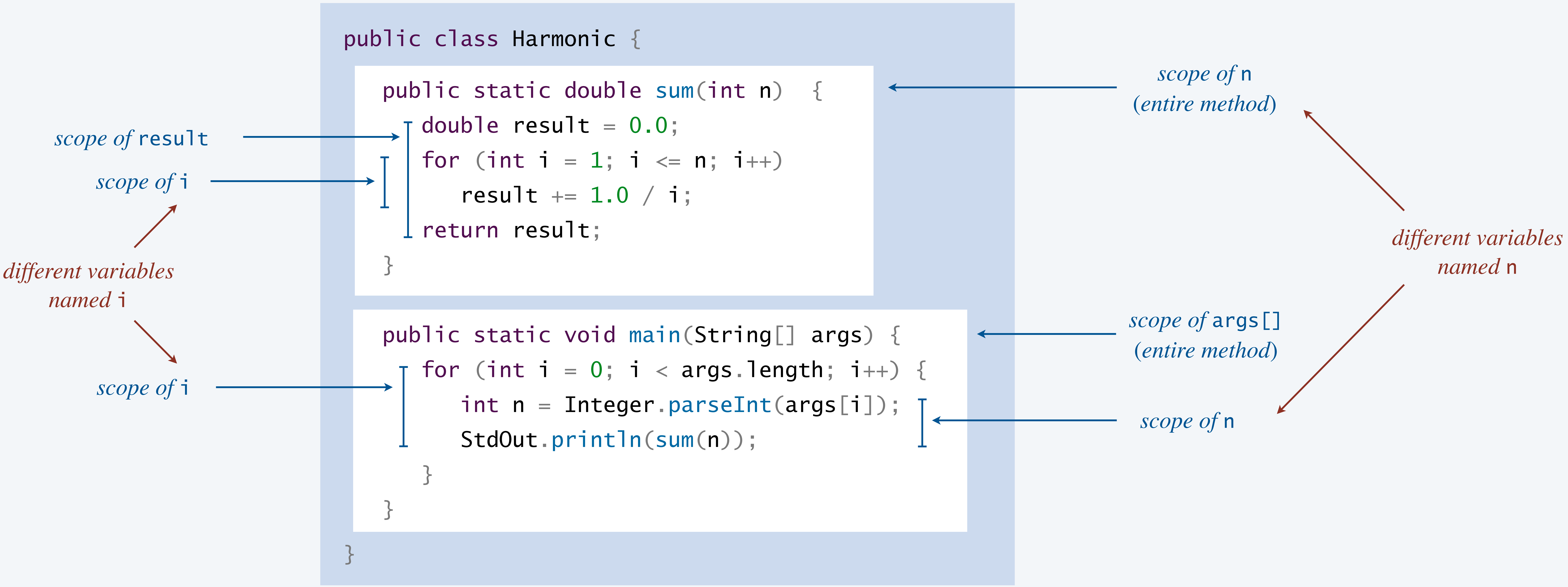
Scope of a variable

Def. The scope of a variable is the code that can refer to it by name. ← *code following its declaration, in the same block*

Significance. Can develop functions independently. ← *variables defined in one function do not interfere with variables defined in another*

Best practice. Declare variables so as to limit their scope.

```
public class Harmonic {
   public static double sum(int n)  {
      double result = 0.0;
      for (int i = 1; i <= n; i++)
         result += 1.0 / i;
      return result;
   }

   public static void main(String[] args) {
      for (int i = 0; i < args.length; i++) {
         int n = Integer.parseInt(args[i]);
         StdOut.println(sum(n));
      }
   }
}
```



How many different variables named *n* are created when *Harmonic* is execute with 10 command-line arguments?

A. 1

B. 2

C. 10

D. 11

E. 20

```
public class Harmonic {
   public static double sum(int n)  {
      double result = 0.0;
      for (int i = 1; i <= n; i++)
         result += 1.0 / i;
      return result;
   }

   public static void main(String[] args) {
      for (int i = 0; i < args.length; i++) {
         int n = Integer.parseInt(args[i]);
         StdOut.println(sum(n));
      }
   }
}
```

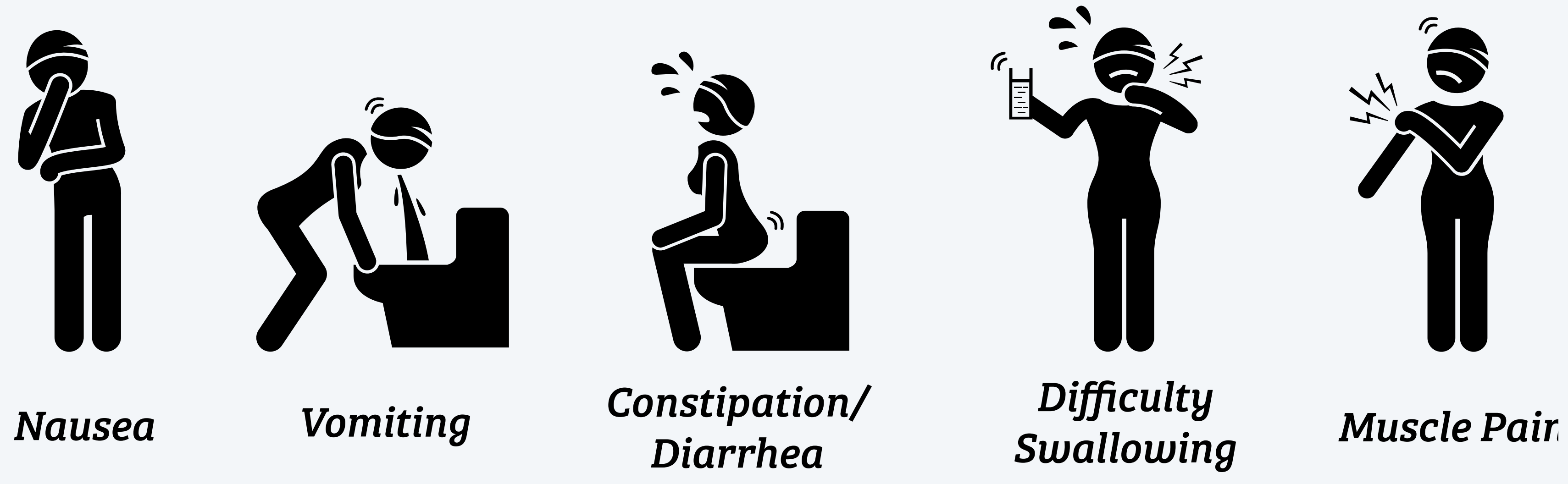
Side effects

Def. A side effect of a method is anything it does besides computing and returning a value.

- Print to standard output.
- Draw a circle.
- Play an audio file.
- Display a picture.
- Launch a missile.
- Consume input.
- Mutate an array.
- …

← *produce output* (Print to standard output, Draw a circle, Play an audio file, Display a picture, Launch a missile)

← *stay tuned* (Mutate an array)



Note. The primary purpose of some methods is to produce side effects, not return values.

↑ *differs from medicine*

Void functions

A method need not return a value.

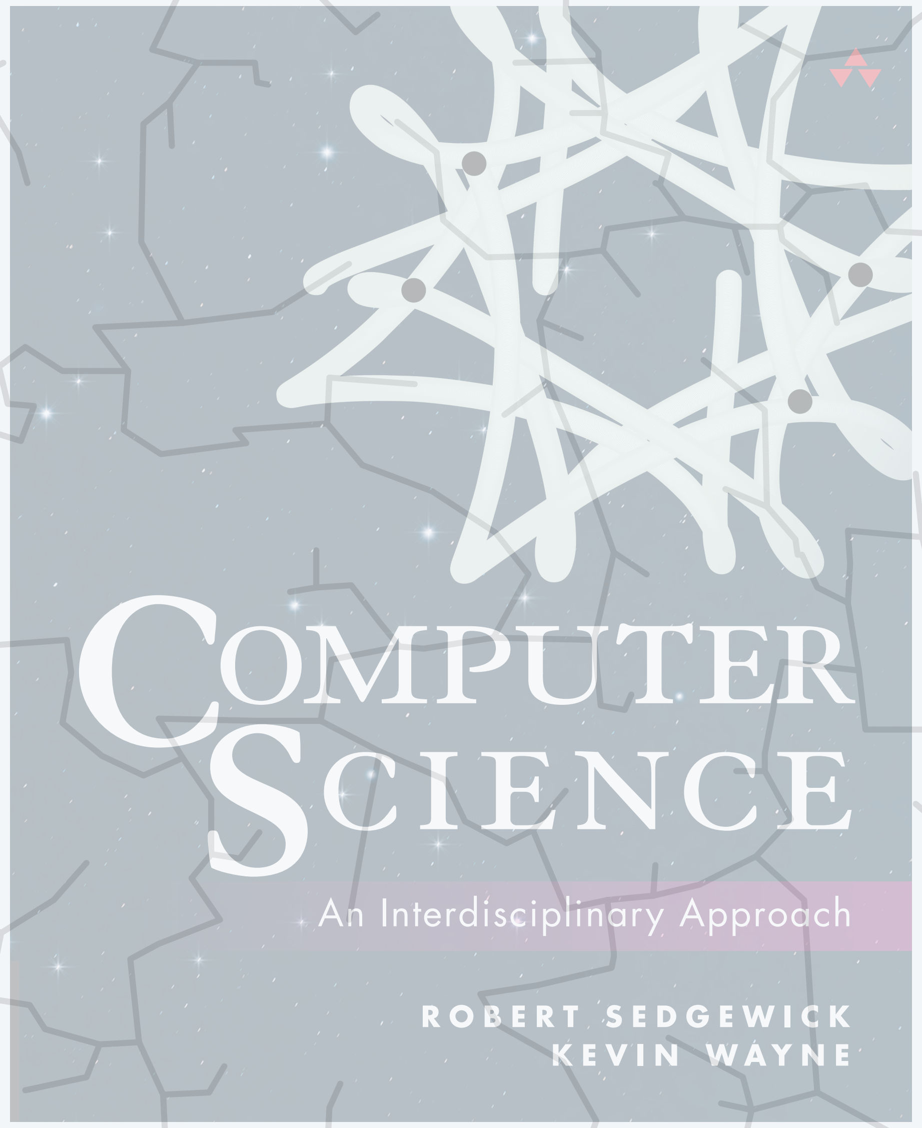
- Its purpose is to produce side effects.
- Use keyword *void* as return type.
- No explicit *return* statement needed. ← *upon reaching the end of method, control returns to calling code*

```
public static void loop(String filename, int n) {
   for (int i = 0; i < n; i++) {
      StdAudio.play(filename);
   }
}
```

loop an audio file n times

```
public static void main(String[] args) {
   int n = Integer.parseInt(args[0]);
   if (n <= 0) {
      StdOut.println("n must be positive");
      return;
   }
   ...
}
```

abort if the wrong number of command-line arguments



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2.1 FUNCTIONS

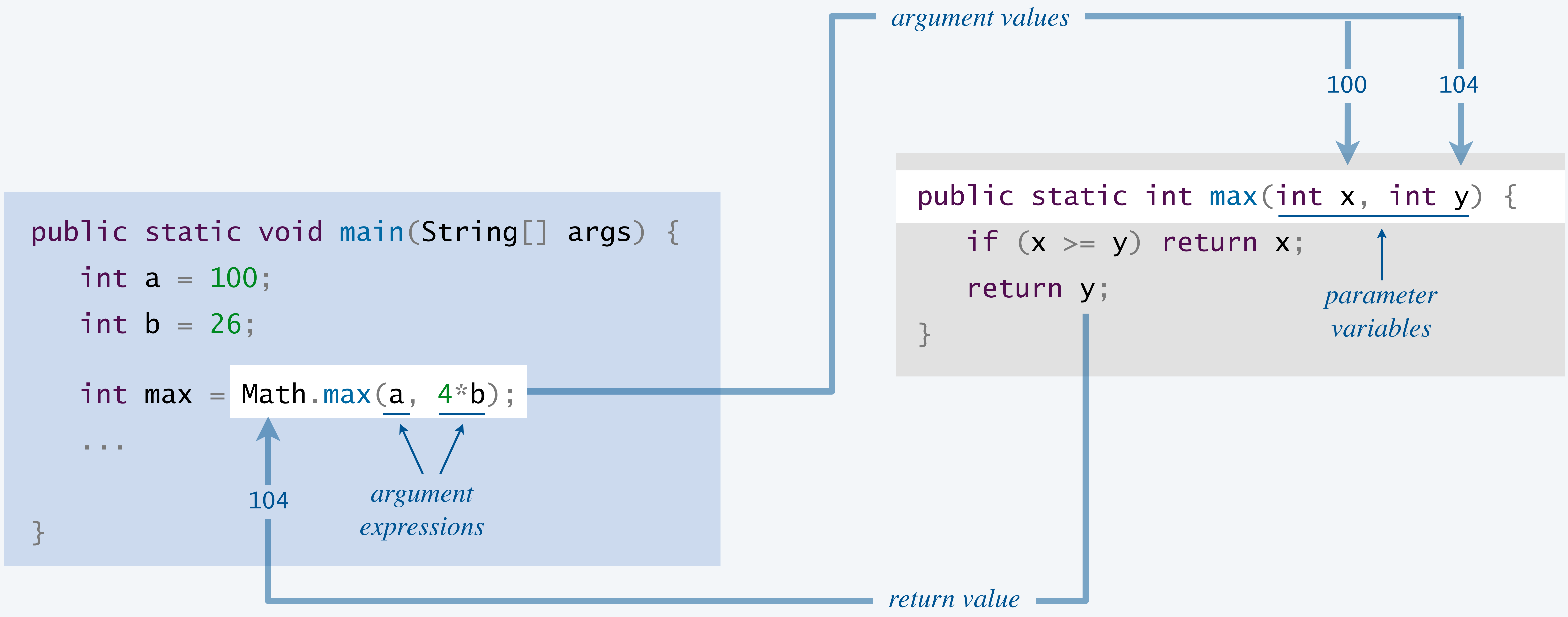
- *flow-of-control*
- *properties*
- *call by value*
- *number-to-speech*

Call by value

Java uses call by value to pass arguments to methods.

- Java evaluates each argument expression to produce a value.
- Java assigns each value to the corresponding parameter variable.

for primitive types, the value is the data-type value;
for arrays (and other non-primitive types),
the value is an "object reference"



What does the following program print?

A. -126

B. 126

C. Compile-time error.

D. Run-time error.

```
public class Mystery1 {

   public static void negate(int a) {
      a = -a;
   }

   public static void main(String[] args) {
      int a = 126;
      negate(a);
      StdOut.println(a);
   }
}
```

negate() cannot change the value stored in the variable a in main()

primitive variable in *main()*

primitive variable in *negative()*

What does the following program print?

A. 12 6

B. -12 -6

C. Compile-time error.

D. Run-time error.

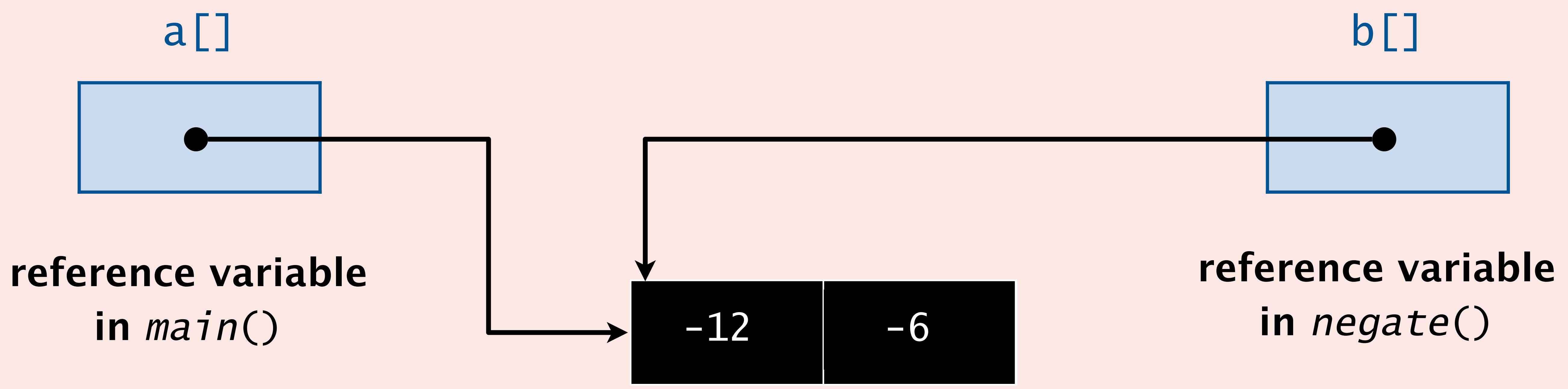
```
public class Mystery2 {

   public static void negate(int[] b) {
      for (int i = 0; i < b.length; i++)
         b[i] = -b[i];
   }

   public static void main(String[] args) {
      int[] a = { 12, 6 };
      negate(a);
      StdOut.println(a[0] + " " + a[1]);
   }
}
```

negate() cannot change the value stored in the variable a[] in main() (e.g., length or type of a[])

but negate() can change the array elements that a[] references



Side effects with arrays

Functions and arrays.

- A function can have the side effect of changing the elements in an argument array. ← *shuffle, reverse, sort, shift, ...*
- But the function cannot change the argument array itself. ← *to refer to a different array (e.g., of a different length or type)*

```
public class Mutate {

   public static void shuffle(String[] a) {
      int n = a.length;
      for (int i = 0; i < n; i++) {
         int r = (int) (Math.random() * (i+1));
         String temp = a[r];
         a[r] = a[i];
         a[i] = temp;
      }
   }

   public static void main(String[] args) {
      shuffle(args);
      for (int i = 0; i < args.length; i++)
         StdOut.println(args[i]);
   }
}
```

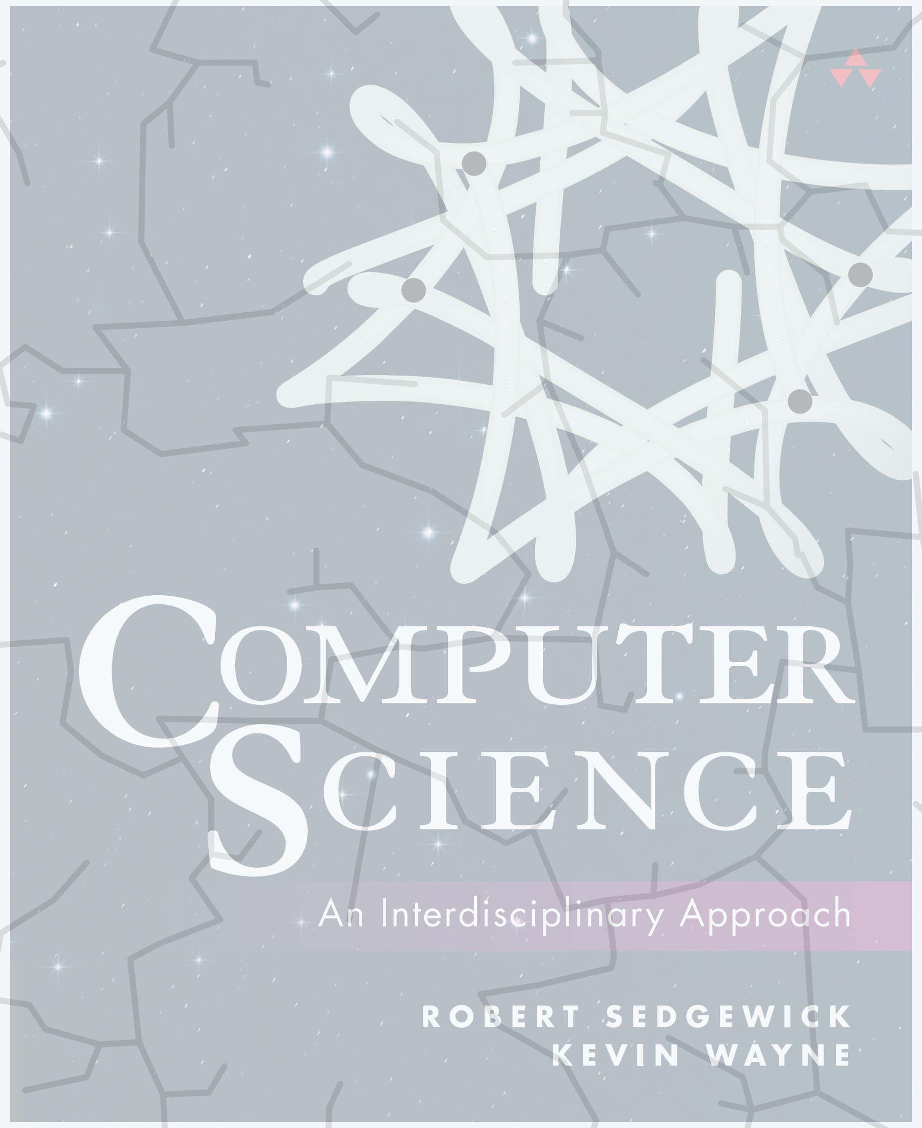
a[] and args[] refer to the same array

swaps a[r] and a[i]

```
~/cos126/functions> java-introcs Mutate A B C D
C
A
B
D

~/cos126/functions> java-introcs Mutate A B C D
B
A
C
D

~/cos126/functions> java-introcs Mutate COS 126
126
COS
```



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2.1 Functions

- *flow-of-control*
- *properties*
- *call by value*
- *number-to-speech*

Number-to-speech

Goal. Write a program to say/print a positive integer. ← *use U.S. conventions*

Place Value											
Billions			Millions			Thousands			Ones		
2	8	6	4	0	1	0	0	0	4	5	6

Algorithm.

- Split into 3-digit groups, from right-to-left.
- For each group, from left-to-right:
  - say 3-digit integer ← *see algorithm on next slide*
  - if 3-digit integer is not 0, say group name (*billion*, *million*, *thousand*)

↑ *but not for ones group*

number	spoken
126	*one hundred twenty six*
2,024	*two thousand twenty four*
401,000,011	*four hundred one million eleven*

Number-to-speech: procedural decomposition

Small-integer rule. If number is 1–19, say number; if 0, say nothing.

Two-digit rule.

- If number is 0–19, say number. ← *small-integer rule*
- Otherwise, break up into tens and ones digits.
  - say tens digit as *twenty*, *thirty*, …, *ninety*
  - say ones digit ← *small-integer rule*

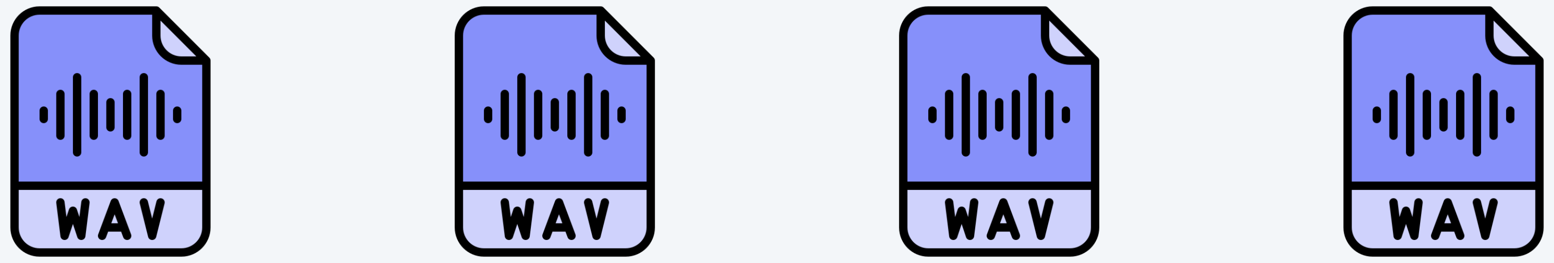
Three-digit rule. Break up into hundreds digit and 2-digit remainder.

- If hundreds digit is not 0, say digit, followed by *hundred*. ← *small-integer rule*
- Say 2-digit remainder. ← *two-digit rule*

number	spoken
6	*six*
0	[*nothing*]
26	*twenty six*
126	*one hundred twenty-six*

Text-to-speech approach

Domain-specific synthesis. Concatenate pre-recorded words to form desired output.



1.wav hundred.wav 20.wav 6.wav

speaking the number 126

word	audio file
1, 2, 3, …, 19	`1.wav`, `2.wav`, `3.wav`, …
20, 30, 40, …, 90	`20.wav`, `30.wav`, `40.wav`, …
hundred	`hundred.wav`
thousand	`thousand.wav`
million	`million.wav`
billion	`billion.wav`

vocabulary

Live coding

```java
public class SayNumber {

   // play audio file corresponding to word
   public static void sayWord(String word) {
      StdOut.print(word + " ");
      StdAudio.play(word + ".wav");
   }

   // say integer n for 1-19, nothing for 0
   public static void saySmallInteger(int n) {
      if (n > 0) sayWord("" + n);
   }

   // say integer n for 1-99, nothing for 0
   public static void sayTwoDigitInteger(int n) {
      if (n < 20) saySmallInteger(n);
      else {
         int tensDigit = n / 10;
         int onesDigit = n % 10;
         sayWord("" + (10 * tensDigit));
         saySmallestInteger(onesDigit);
      }
   }

   public static void main(String[] args) {
      int n = Integer.parseInt(args[0]);
      sayPositiveInteger(n);
   }

   // say integer n for 1-999, nothing for 0
   public static void sayThreeDigitInteger(int n) {
      int hundredsDigit = n / 100;
      int twoDigits = n % 100;
      if (hundredsDigit > 0) {
         saySmallInteger(hundredsDigit);
         sayWord("hundred");
      }
      sayTwoDigitInteger(twoDigits);
   }

   // say integer n > 0
   public static void sayPositiveInteger(int n) {
      String[] PLACES = { "", "thousand", "million", "billion" };
      int[] groups = new int[PLACES.length];

      for (int i = 0; i < groups.length; i++) {
         groups[i] = n % 1000;
         n = n / 1000;
      }

      for (int i = groups.length - 1; i >= 0; i--) {
         sayThreeDigitInteger(groups[i]);
         if (i > 0 && groups[i] > 0) sayWord(PLACES[i]);
      }
   }
}
```

extract the 3-digit groups (right-to-left)

process 3-digit groups (left-to-right)

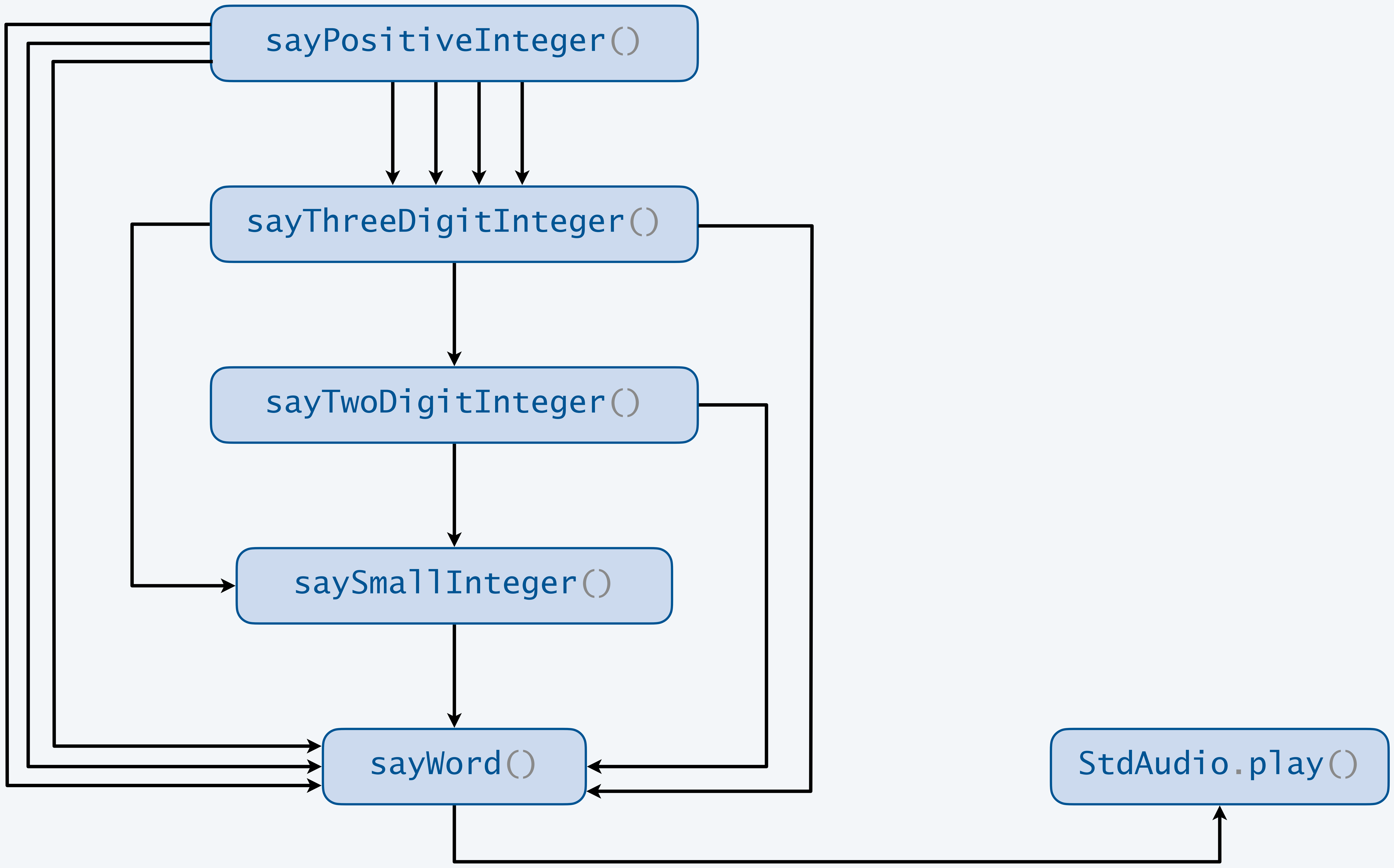
Testing

Principle. Supply inputs that activate all possible execution paths through program. ← *so that all code gets tested*

```
~/cos126/functions> java-introcs SayNumber 6          ← one-digit number
[speaks "six"]

~/cos126/functions> java-introcs SayNumber 26         ← two-digit number
[speaks "twenty six"]

~/cos126/functions> java-introcs SayNumber 126        ← three-digit number
[speaks "one hundred twenty six"]

~/cos126/functions> java-introcs SayNumber 2024       ← typical case
[speaks "two thousand twenty four]


~/cos126/functions> java-introcs SayNumber 401000011  ← no thousands unit
[speaks "four hundred one million eleven"]
```

Function call graph

Function call graph. Graphical representation of different function calls within a program.



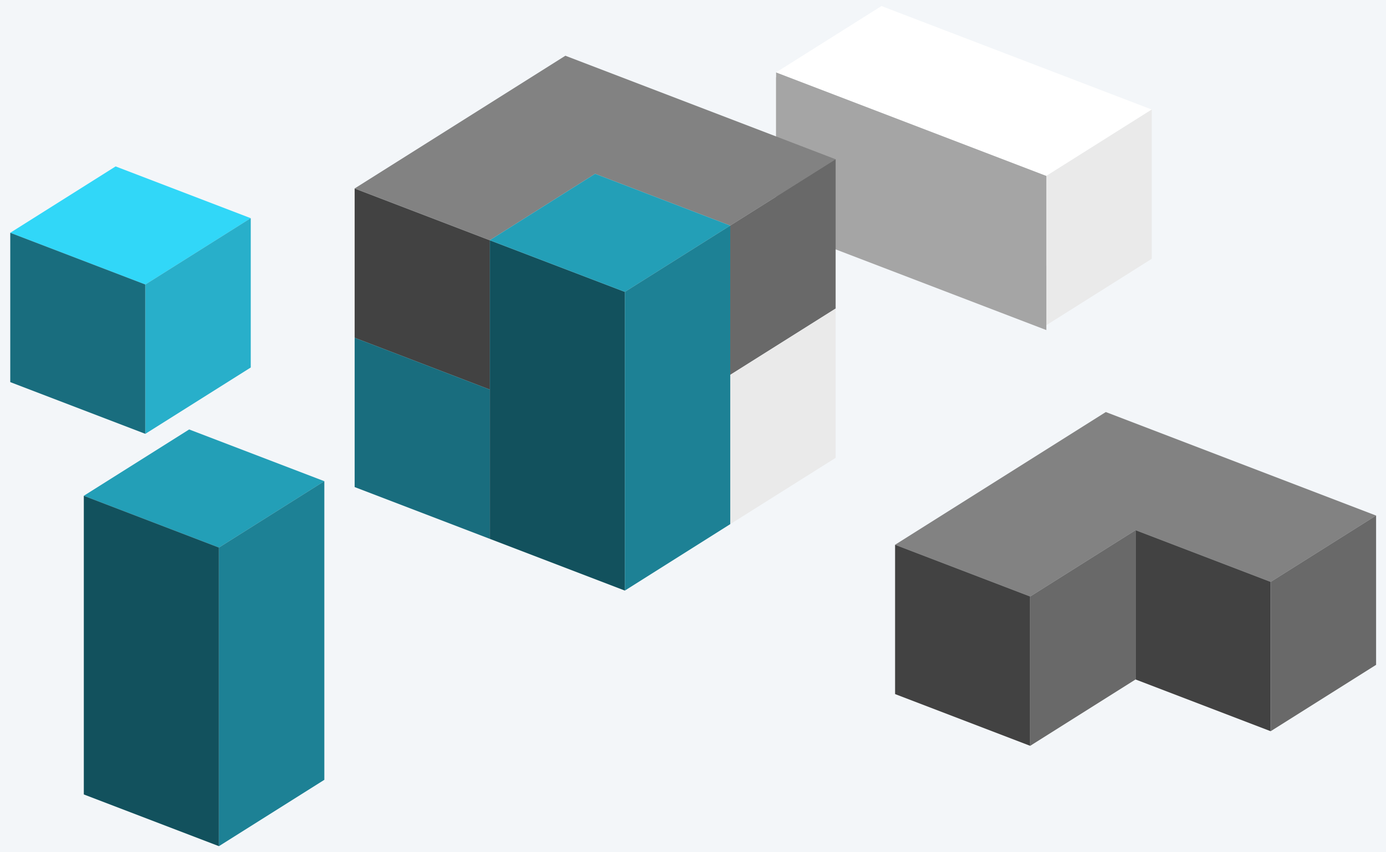
Procedural decomposition

Decomposition. Break up a complex programming problem into smaller functional parts.

Procedural decomposition. Implement each part as a separate function.

Ex. Say a positive integer.

- Play an audio file corresponding to a word.
- Say a small integer.
- Say a two-digit integer.
- Say a three-digit integer.



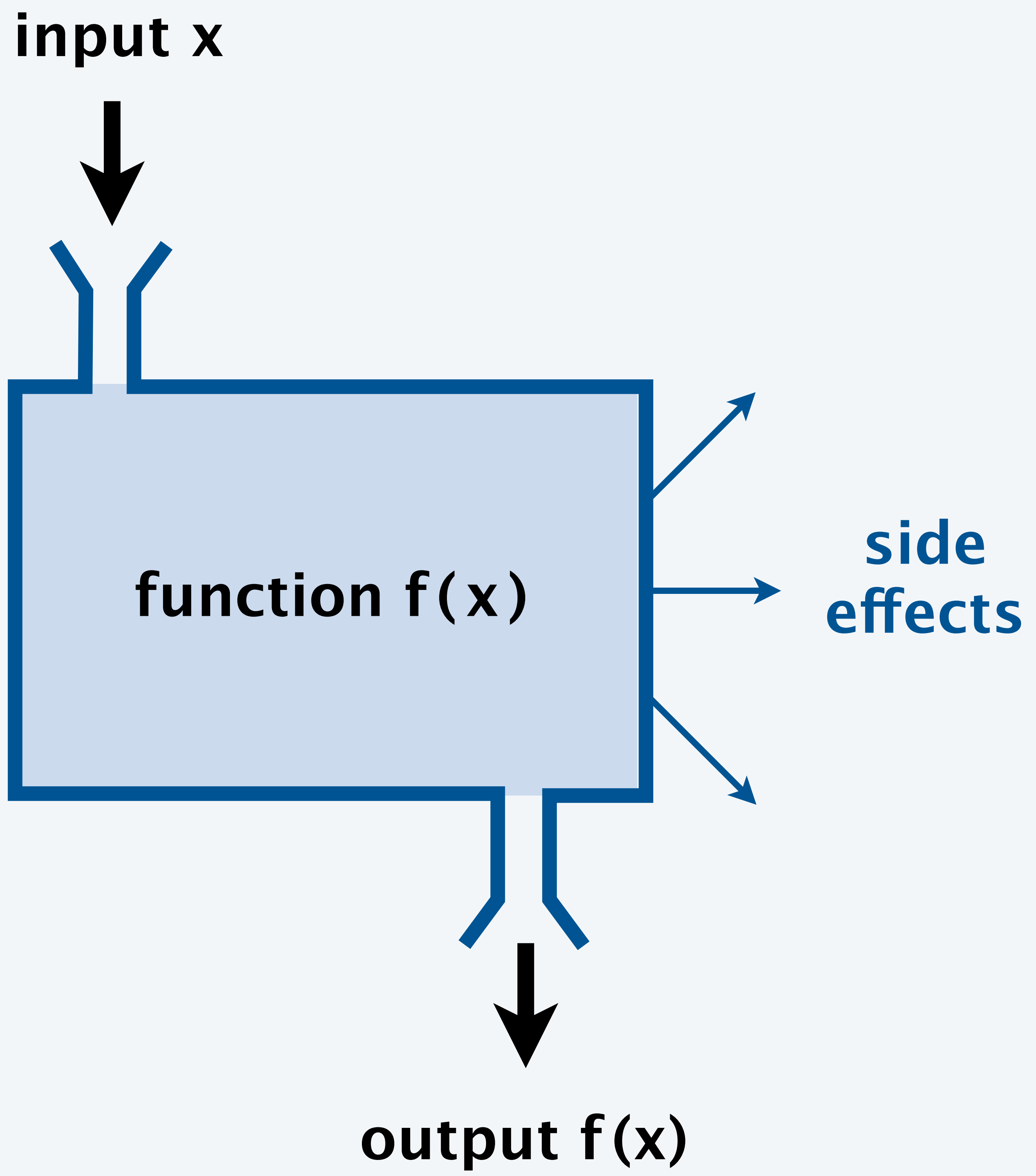
Benefits. Supports the 3 Rs:

- Readability: understand and reason about code.
- Reliability: test, debug, and maintain code.
- Reusability: reuse and share code.

Summary

Functions. Provide a fundamental way to change flow of control of program.

- Java evaluates the arguments and passes by value to function.
- Function initializes parameter variables with corresponding argument values.
- Function computes a single return value and returns it to caller.



Applications.

- Scientists use mathematical functions to calculate formulas.
- Programmers use functions to build modular programs.
- You use functions for both.

This lecture. Write your own functions.

Next lecture. Build reusable libraries of functions.

Credits

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