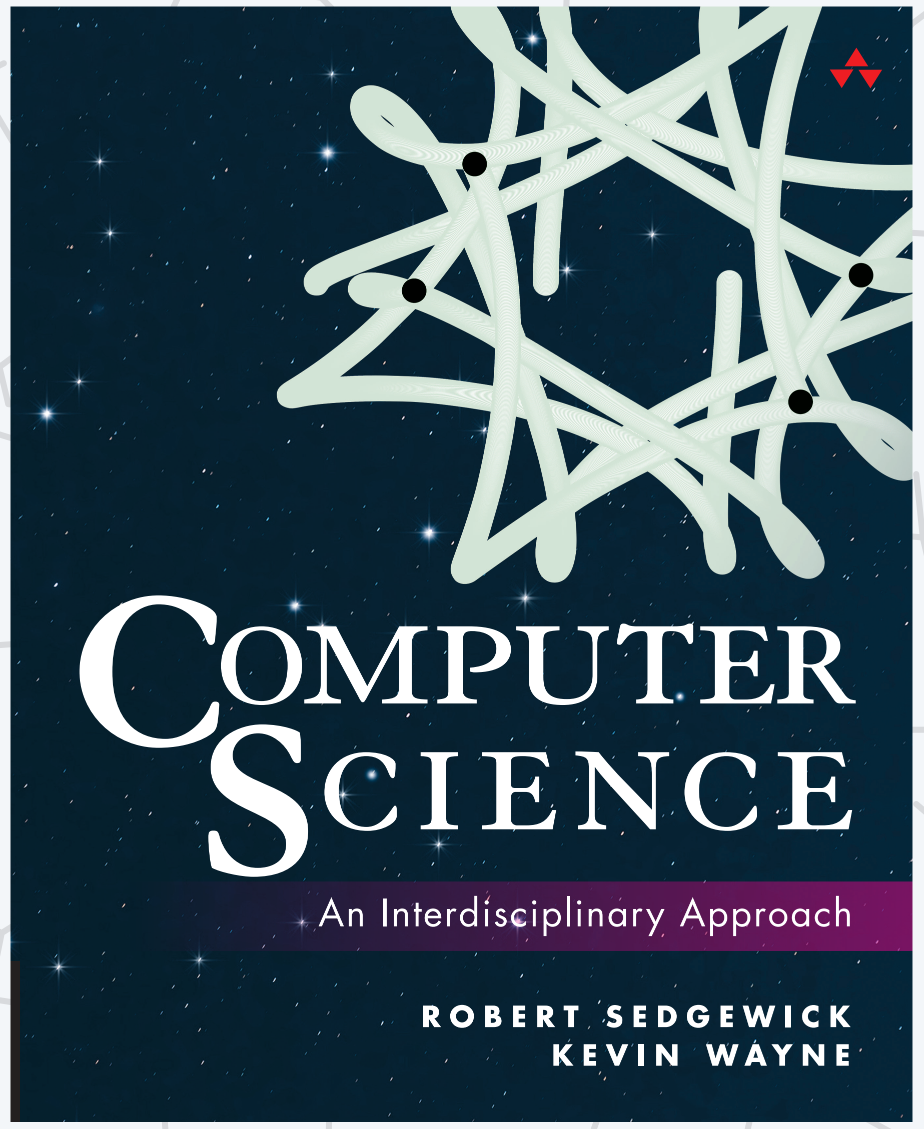

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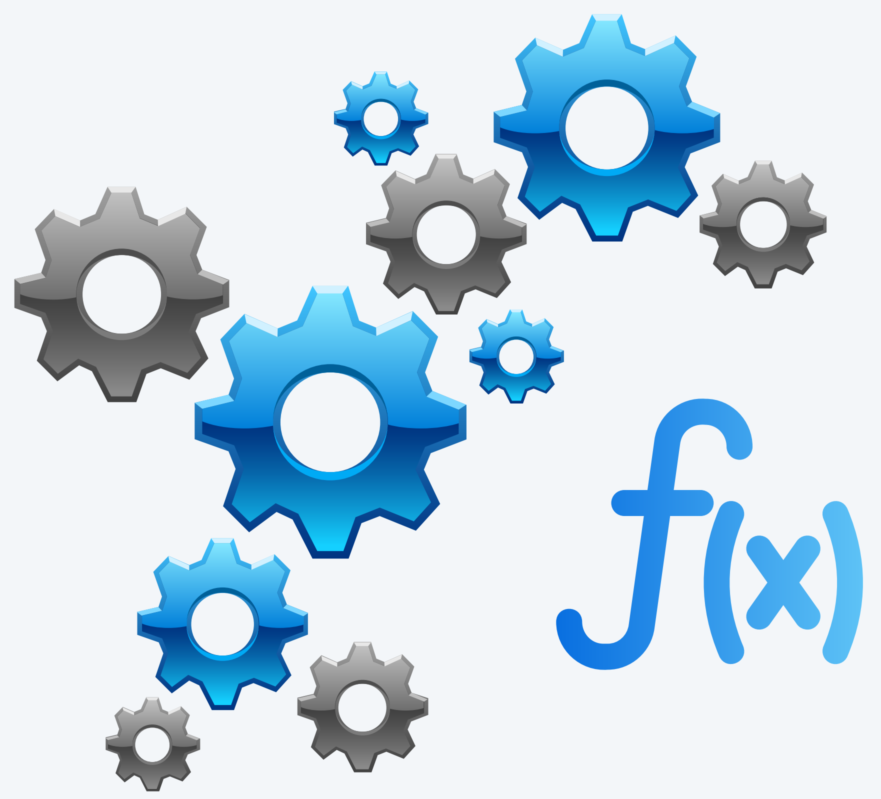
2.1 FUNCTIONS

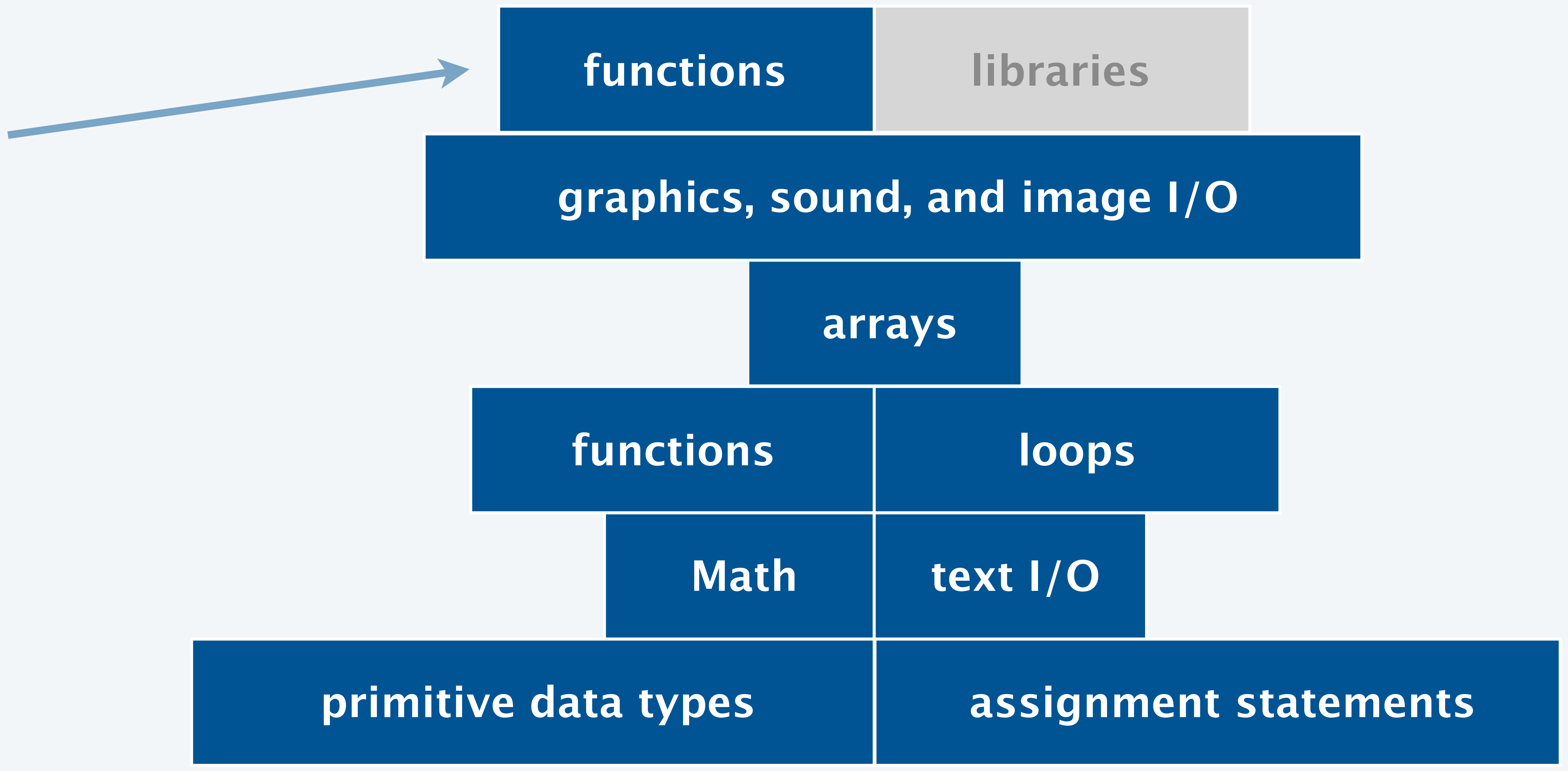
- *flow-of-control*
- *properties*
- *call stack and scope*
- *APIs and libraries*

Last updated on 8/6/24 11:47AM

Basic building blocks for programming



divide a program into functions

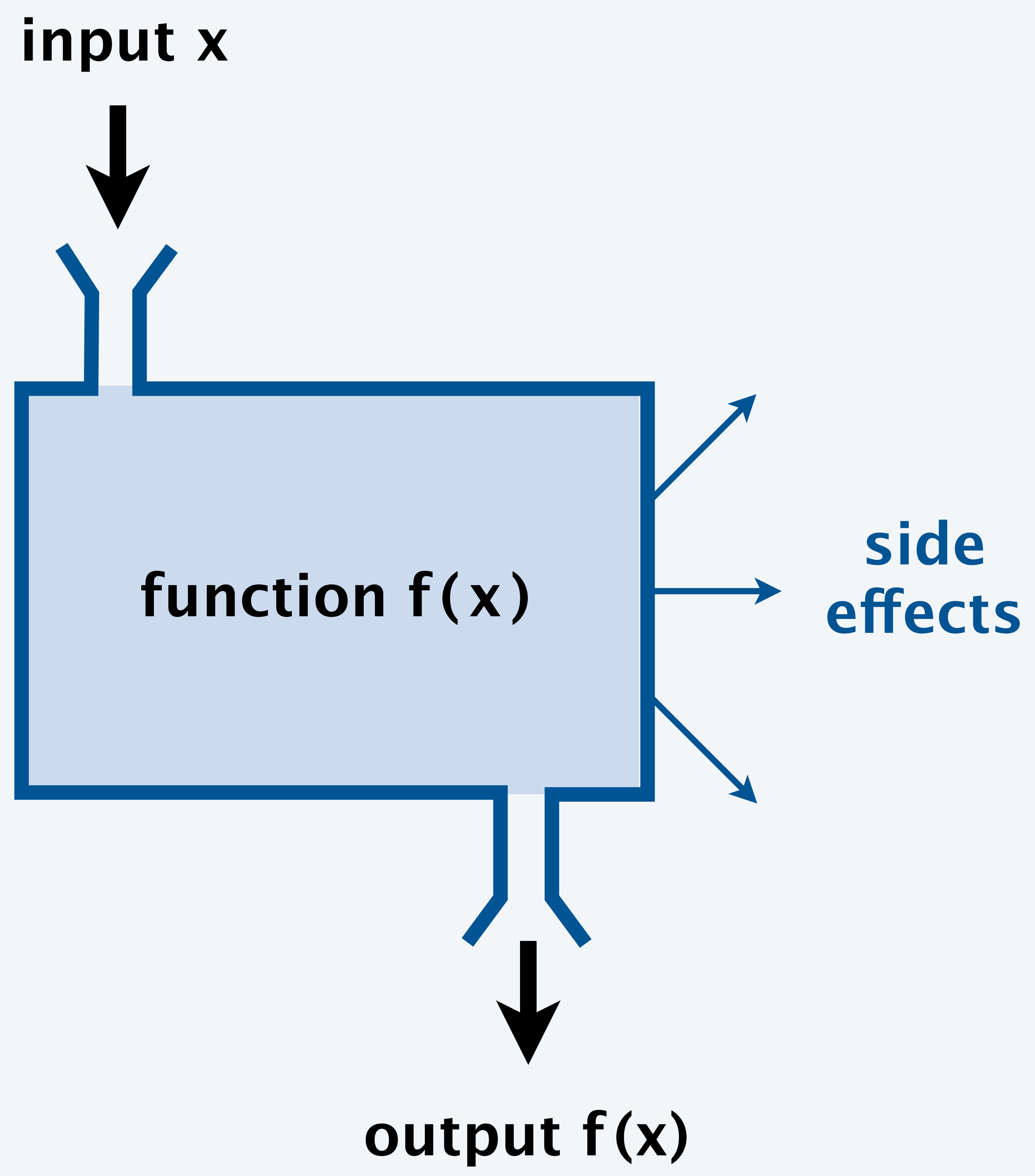


Functions

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()`, `StdAudio.play()`.
- User-defined functions: `main()`.

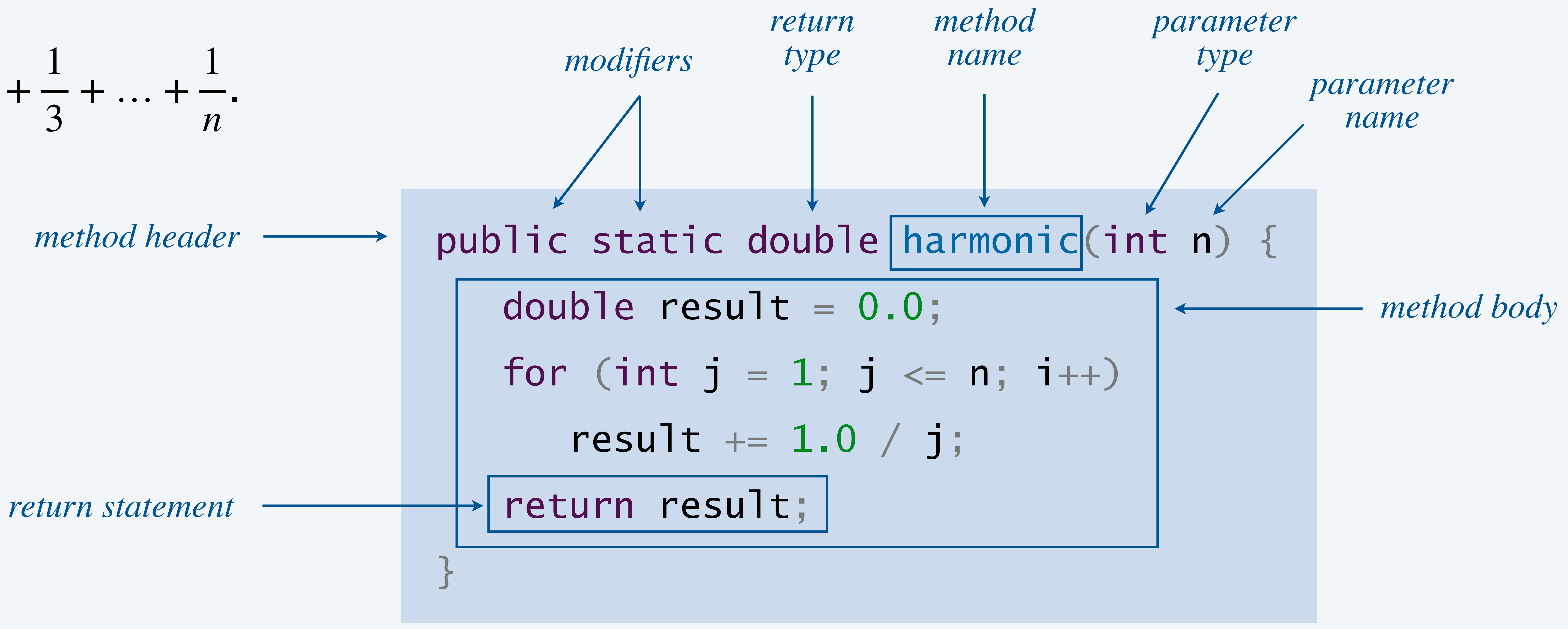
Anatomy of a Java function (static method)

To implement a Java function:

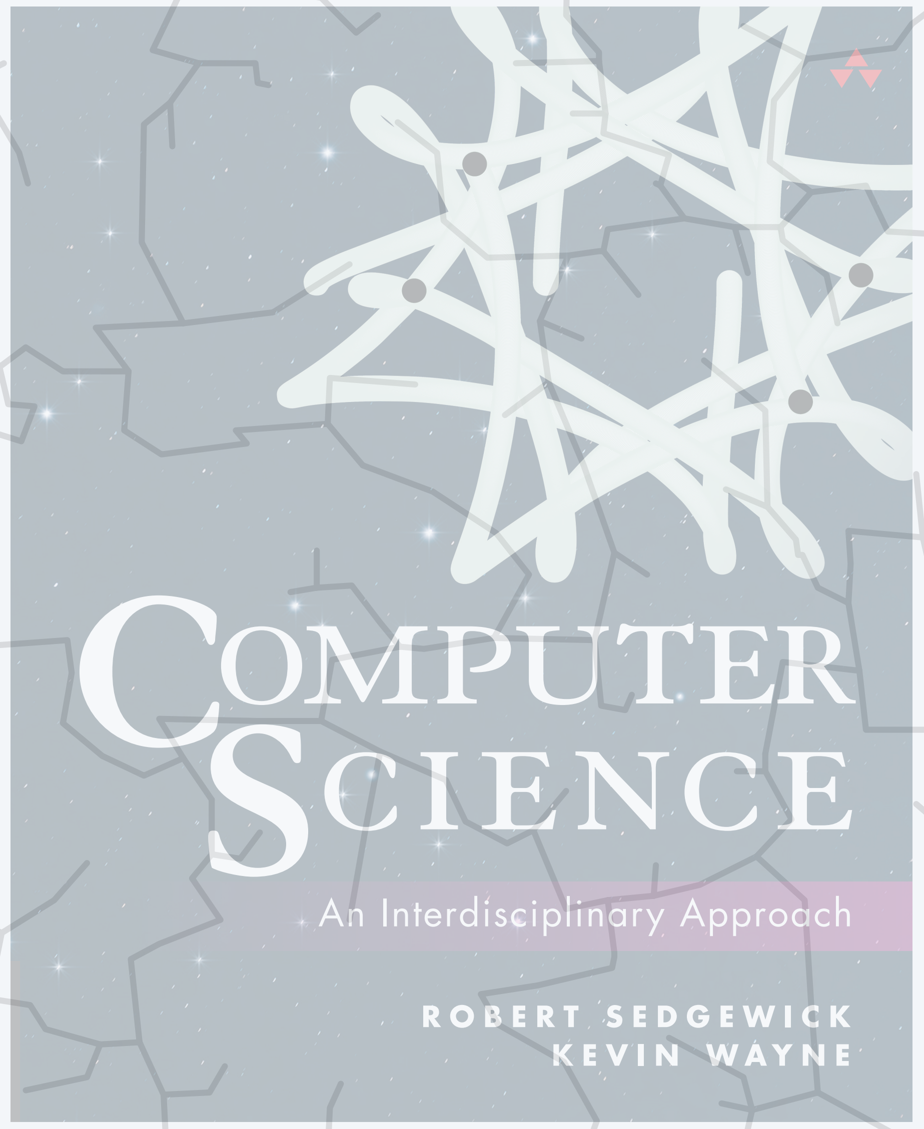
- Choose a *method name*.
- Declare type and name of each *parameter variable*.
- Specify type for *return value*.
- Include *modifiers*. ← *for now, always* `public` *and* `static`
- Implement *method body*,
  including a *return statement*.

← *method header*

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



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



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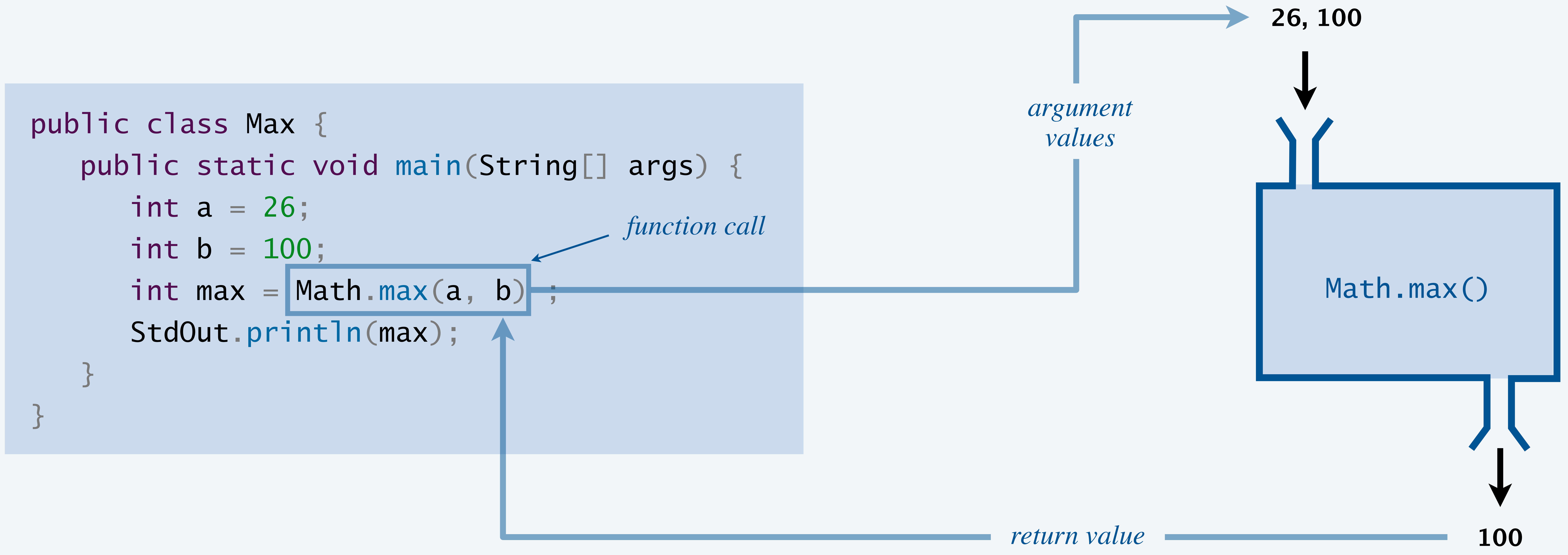
2.1 Functions

- *flow-of-control*
- *properties*
- *call stack and scope*
- *APIs and libraries*

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);
   }
}
```

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

Function call trace

```
public class MaxMany {
   public static int max(int a, int b) {
      if (a > b)
         return a;
      else
         return b;
   }

   public static void main(String[] args) {
     int result = Integer.parseInt(args[0]);
     for (int i = 1; i < args.length; i++)
         result = max(result, Integer.parseInt(args[i]));
     StdOut.println(result);
   }
}
```

args	i	result
["1", "5", "3"]		
["1", "5", "3"]		1
["1", "5", "3"]	1	1
["1", "5", "3"]	1	5
["1", "5", "3"]	2	5
["1", "5", "3"]	2	5
["1", "5", "3"]		5

variable trace in *main*()

```
~/cos125/functions> java-introcs MaxMany 1 5 3
5
```

Functions: quiz 1

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

A. 10

B. 11

C. Compile-time error.

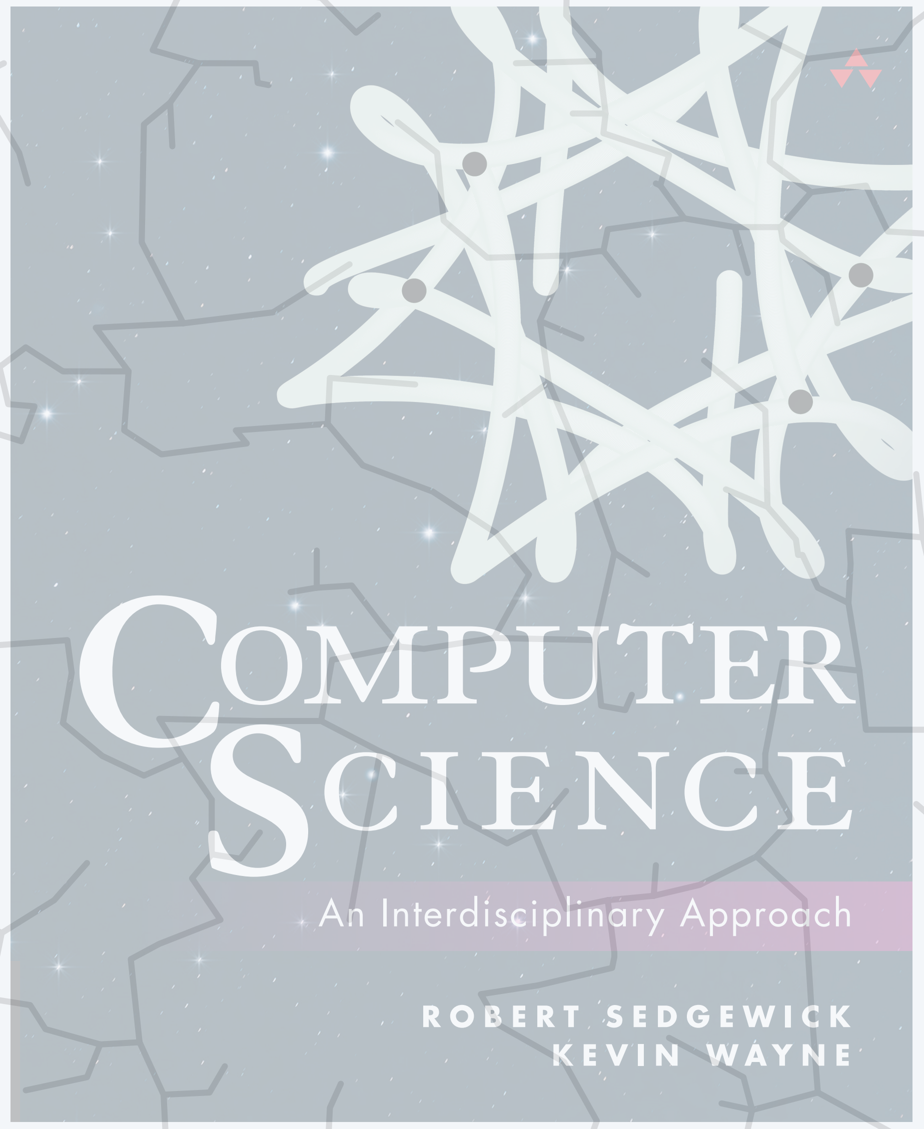
D. Run-time error.

```java
public class Mystery {

   public static int increment(int x) {
      return x + 1;
   }

   public static void main(String[] args) {
      int x = Integer.parseInt(args[0]);
      increment(x);
      StdOut.println(x);
   }
}
```

```
~/cos125/functions> java-introcs Mystery 10
```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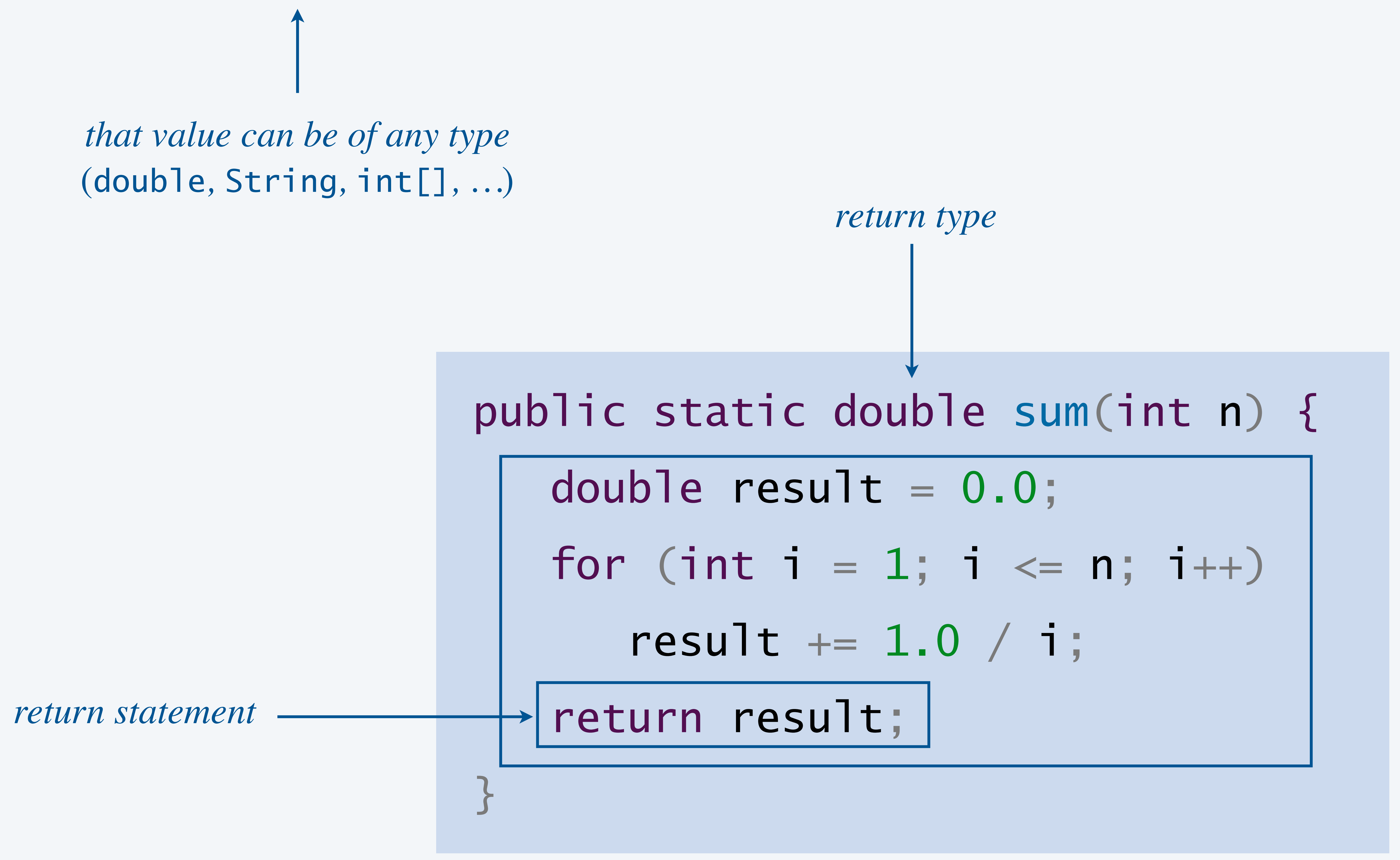
2.1 Functions

- ‣ *flow-of-control*
- ‣ *properties*
- ‣ *call stack and scope*
- ‣ *APIs and libraries*

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.



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

Multiple *return* statements

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

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

absolute value function

multiple `return` *statements*

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

equivalent function

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. Polynomial evaluation: $p(x) = a_n x^n + a_{n-1}x^{n-1} + \cdots + a_1 x + a_0$.

```
eval([1.0, 2.0, 1.0], 1.0)
```

```
public static double eval(double[] a, double x) {
   double result = 0.0, monomial = 1.0;
      for (int i = a.length - 1; i >= 0; i--, monomial *= x)
         result += a[i] * monomial;
   return result;
}
```

function takes one `double[]` *and one* `double` *argument*

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

Multiple functions

You can define many functions in a class.

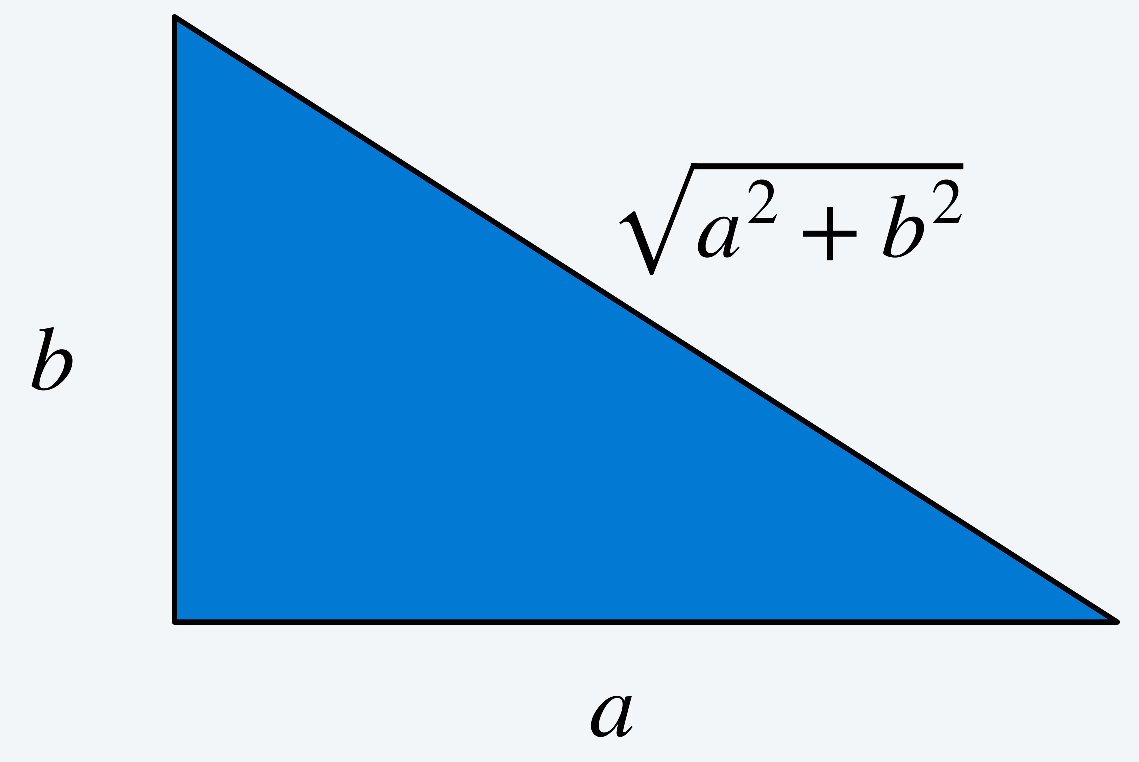
- One function can call another function.
- The order in which the functions are defined in the file is unimportant.

```
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



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.

Another example: *`StdAudio.play(String filename)`* and *`StdAudio.play(double[] samples)`*

Overloaded functions

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

```
public class Polynomial {
   public static double eval(double[] a, double x) {
      double result = 0.0, monomial = 1.0;
         for (int i = a.length - 1; i >= 0; i--, monomial *= x)
            result += a[i] * monomial;
      return result;
   }

   public static int eval(int[] a, int x) {
      int result = 0, monomial = 1;
         for (int i = a.length - 1; i >= 0; i--, monomial *= x)
            result += a[i] * monomial;
      return result;
   }
}
```

`evaluate(new double[] {1.0, -2.0, 1.0}, 1.0)`
calls this function (and evaluates to `0.0`*)*

`evaluate(new int[] {1, -2, 1}, 1)`
calls this function (and evaluates to `0`*)*

Functions: quiz 2

Which value does *`eval(new double[] {1.0, 0.0, 0.0}, 2)`* **return?**

A. `2.0`

B. `4.0`

C. `4`

D. Compile-time error.

E. Run-time error.

Functions: quiz 3

Which value does *`eval(new int[] {1, 0, 0}, 2.0)`* **return?**

A. `2.0`

B. `4.0`

C. `4`

D. Compile-time error.

E. Run-time error.

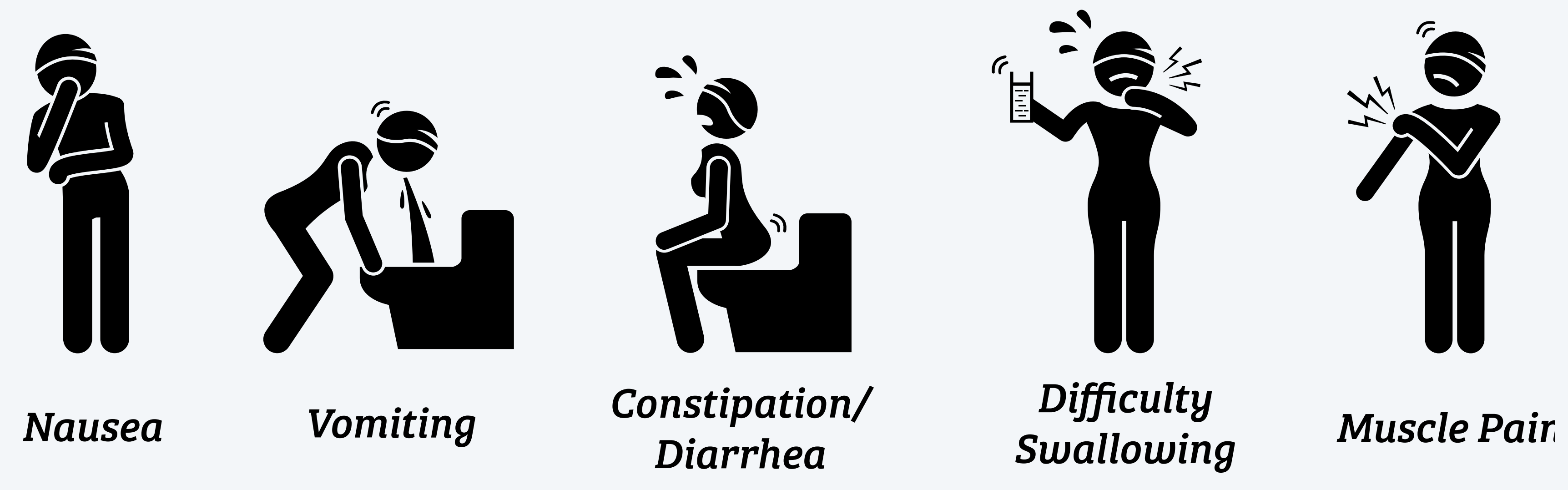
Side effects

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*

← *stay tuned*



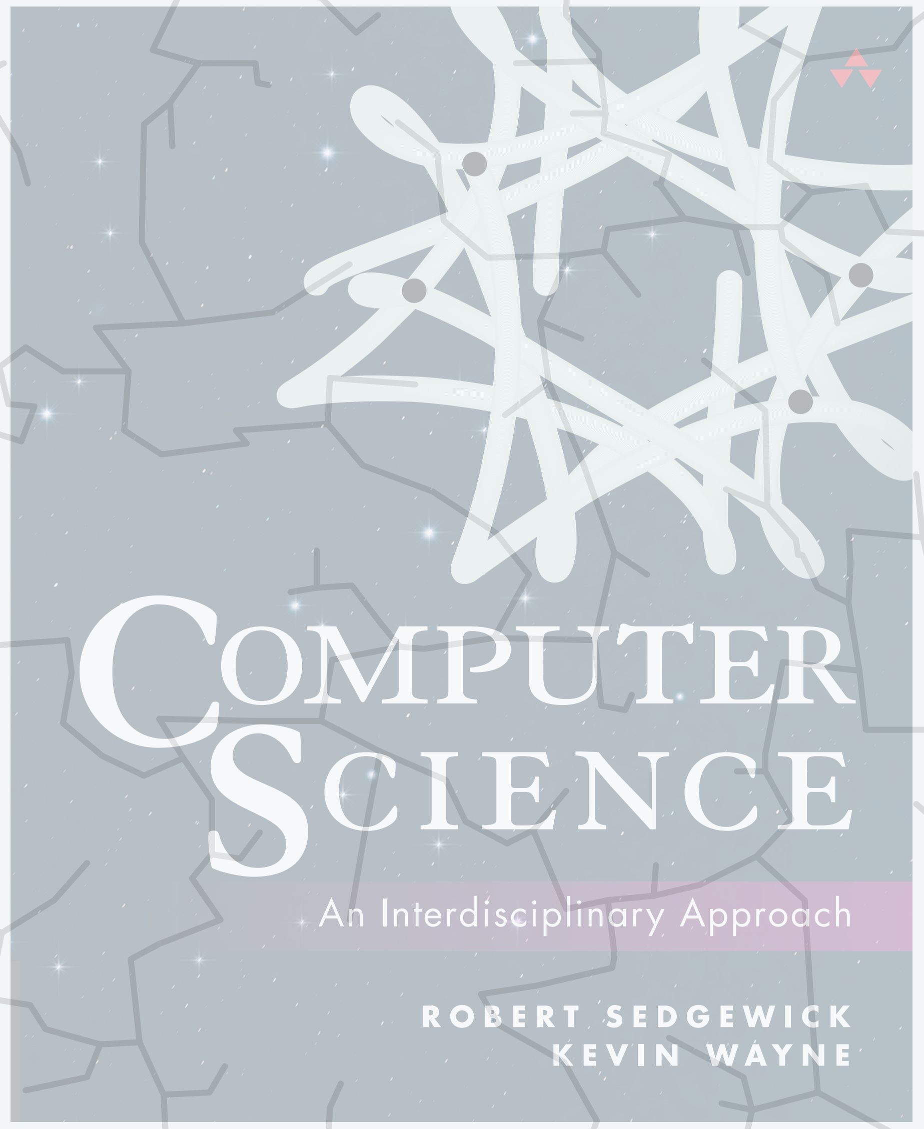
Note. The primary purpose of some methods is to produce side effects, not return values.

differs from medicine

Functions: quiz 4

Which of these functions both produces a side effect and returns a value?

- **A.** *`Integer.parseInt()`*
- **B.** *`StdAudio.play()`*
- **C.** *`StdIn.readInt()`*
- **D.** All of the above.
- **E.** None of the above.



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2.1 Functions

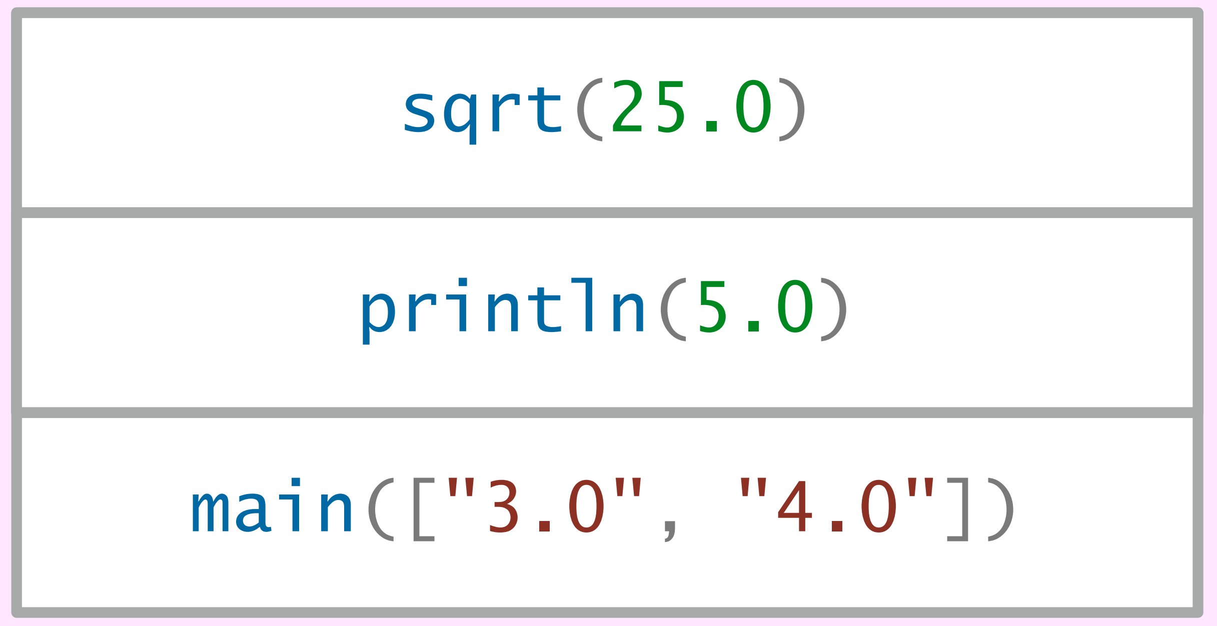
- ‣ *flow-of-control*
- ‣ *properties*
- ‣ *call stack and scope*
- ‣ *APIs and libraries*

Mechanics of function calls

```java
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));
  }

  public static void main(String[] args) {
   int a = Double.parseDouble(args[0]);
   int b = Double.parseDouble(args[1]);
   StdOut.println(hypotenuse(a, b));
  }
}
```



function-call stack

Function-call trace

Function-call trace.

- Print name and argument values when each function is called.
- Print function's return value just before returning.
- Add indentation on function calls and subtract on returns.

```
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));
   }

   public static void main(String[] args) {
      int a = Double.parseDouble(args[0]);
      int b = Double.parseDouble(args[1]);
      StdOut.println(hypotenuse(a, b));
   }
}
```

```
main("3.0", "4.0")
   parseDouble("3.0")
      return 3.0
   parseDouble("4.0")
      return 4.0
   hypotenuse(3.0, 4.0)
      square(3.0)
         return 9.0
      square(4.0)
         return 16.0
      sqrt(25.0)
         return 5.0
      return 5.0
   println(5.0)
      return
   return
```

function-call trace for ***RightTriangle***

Functions: quiz 5

Which value does *cube*(3) return?

A. 0.0

B. 1.0

C. 27.0

D. Compile-time error.

E. Run-time error.

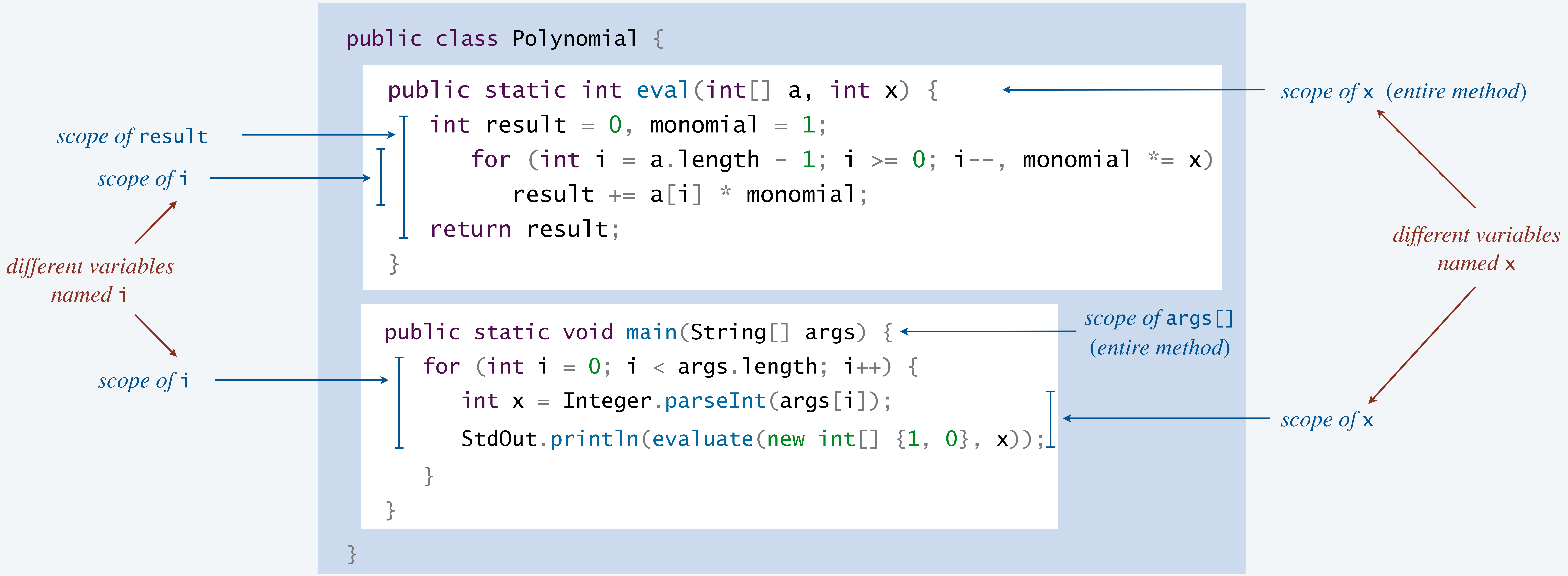
```
public static double cube(double i) {
   i = i * i * i;
   return i;
}
```

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 Polynomial {
  public static int eval(int[] a, int x) {
     int result = 0, monomial = 1;
        for (int i = a.length - 1; i >= 0; i--, monomial *= x)
           result += a[i] * monomial;
     return result;
  }

  public static void main(String[] args) {
     for (int i = 0; i < args.length; i++) {
        int x = Integer.parseInt(args[i]);
        StdOut.println(evaluate(new int[] {1, 0}, x));
     }
  }
}
```

scope of x (entire method)
scope of result
scope of i
different variables named i
scope of i
different variables named x
scope of args[] (entire method)
scope of x

Functions: quiz 6

How many different variables named *i* are created when executing *java-introcs Polynomial 5 2*?

A. 0

B. 1

C. 2

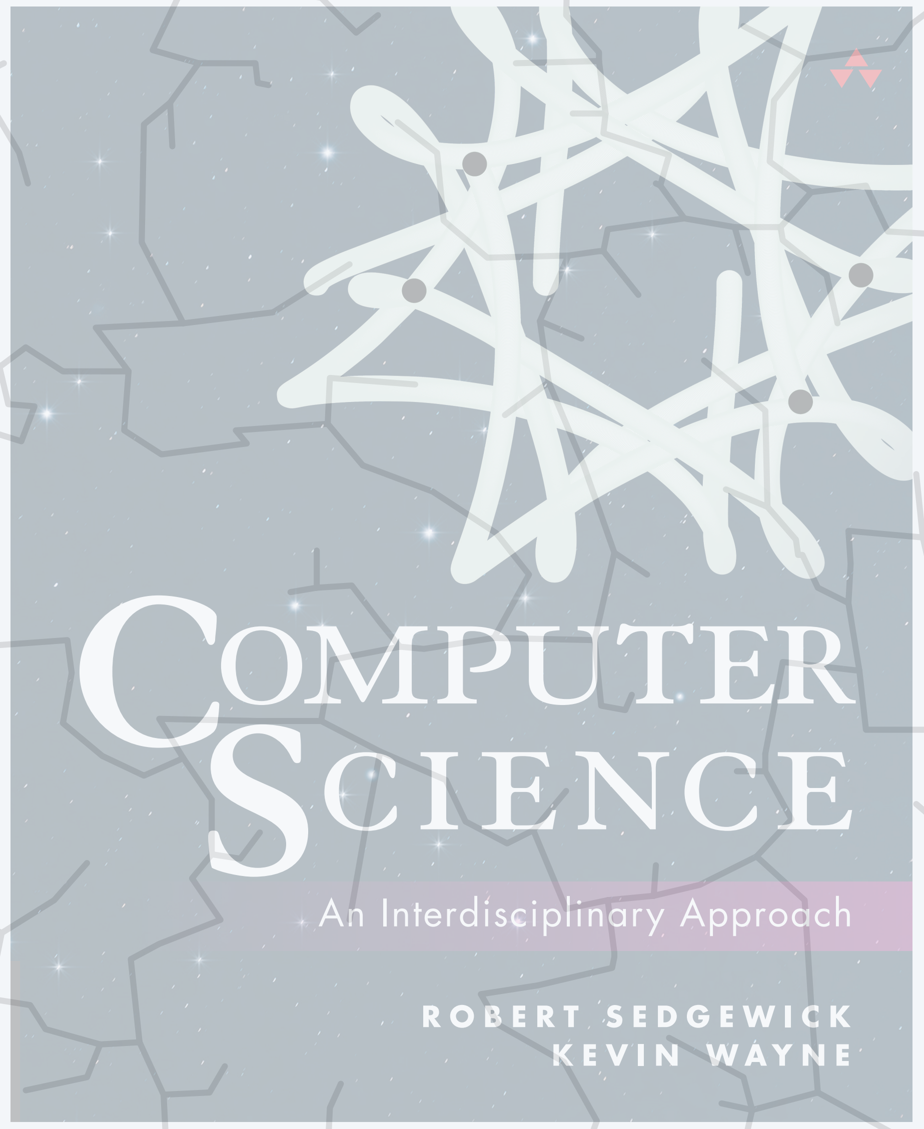
D. 3

E. 4

```
public class Polynomial {

  public static int evaluate(int[] a, int x) {
     int result = 0, monomial = 1;
        for (int i = a.length - 1; i >= 0; i--, monomial *= x)
           result += a[i] * monomial;
     return result;
  }

  public static void main(String[] args) {
     for (int i = 0; i < args.length; i++) {
        int x = Integer.parseInt(args[i]);
        StdOut.println(evaluate(new int[] {1, 0}, x));
     }
  }
}
```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2.1 Functions

- *flow-of-control*
- *properties*
- *call stack and scope*
- *APIs and libraries*

Application Programming Interface

API. An interface between provider and client programs. $\longleftarrow$ *"contract" between software provider and other software*

Examples.

Application Programming Interface

API. An interface between provider and client programs. ← *"contract" between software provider and other software*

This course. Concise description of the functions available to the client.

Examples.

`public class StdIn`		description
`static boolean`	`isEmpty()`	`true` *if no more values,* `false` *otherwise*
`static int`	`readInt()`	*read a value of type* `int`
`static double`	`readDouble()`	*read a value of type* `double`
`static boolean`	`readBoolean()`	*read a value of type* `boolean`
`static String`	`readString()`	*read a value of type* `String`
	⋮	⋮

Application Programming Interface

API. An interface between provider and client programs. ← *"contract" between software provider and other software*

This course. Concise description of the functions available to the client.

Examples.

`public class StdOut`	**description**
`static void print(String s)`	*print* `s` *on the output stream*
`static void println()`	*print a newline on the output stream*
`static void println(String s)`	*print* `s`*, then a newline on the stream*
`static void printf(String f, ...)`	*print formatted output*
⋮	⋮

Application Programming Interface

API. An interface between provider and client programs. ← *"contract" between software provider and other software*

This course. Concise description of the functions available to the client.

Examples.

public class StdMidi		description
static void	play()	*plays the specified MIDI file*
static void	setInstrument()	*sets the MIDI instrument to the specified value*
static void	setTempo()	*sets the tempo to the specified number of beats per minute*
static void	playNote()	*plays the specified note for the given duration (measured in beats)*
static void	noteOn()	*turns the specified note on*
⋮	⋮	⋮

Application Programming Interface

API. An interface between provider and client programs. ← *"contract" between software provider and other software*

This course. Concise description of the functions available to the client.

Examples.

public class Synth	
`static int`	`length(double duration)`
`static double`	`sine(double frequency, double t)`
`static double`	`square(double frequency, double t)`
`static double`	`saw(double frequency, double t)`
`static double[]`	`sineWave(double frequency, double amplitude, duble duration)`
`static double[]`	`squareWave(double frequency, double amplitude, duble duration)`
`static double[]`	`sawWave(double frequency, double amplitude, duble duration)`
`static double[]`	`whiteNoise(double amplitude, duble duration)`
`static double[]`	`add(double[] a, double[] b)`
`static double[]`	`multiply(double[] a, double[] b)`
`static double[]`	`fade(double[] a, double lambda)`
`static void`	`main(String[] args)` ← `main()` *not called by the client; use for unit testing!*

A *Polynomial* library

Goal. Provide useful operations on non-zero polynomials.

public class Polynomial		description
static int	eval(int[] a, int x)	*evaluate polynomial with coefficients a[] on x*
static double	eval(double[] a, double x)	*evaluate polynomial with coefficients a[] on x*
static void	print(int[] a)	*print polynomial with coefficients a[]*
static void	print(double[] a)	*print polynomial with coefficients a[]*
static double	linearRoot(double[] a)	*root of linear polynomial (degree must be 1)*
static double[]	derivative(double[] a)	*derivative of polynomial with coefficients a[]*
static double	nearestRoot(double[] a, double start)	*root obtained by Newton's method at start point*
static double[]	quadraticRoots(double[] a)	*all roots of quadratic polynomial (degree must be 2)*
static double[]	cubicRoots(double[] a)	*all roots of cubic polynomial (degree must be 3)*
static double[]	quarticRoots(double[] a)	*all roots of quartic polynomial (degree must be 4)*
⋮	⋮	⋮
static void	main(String[] args)	*unit testing*

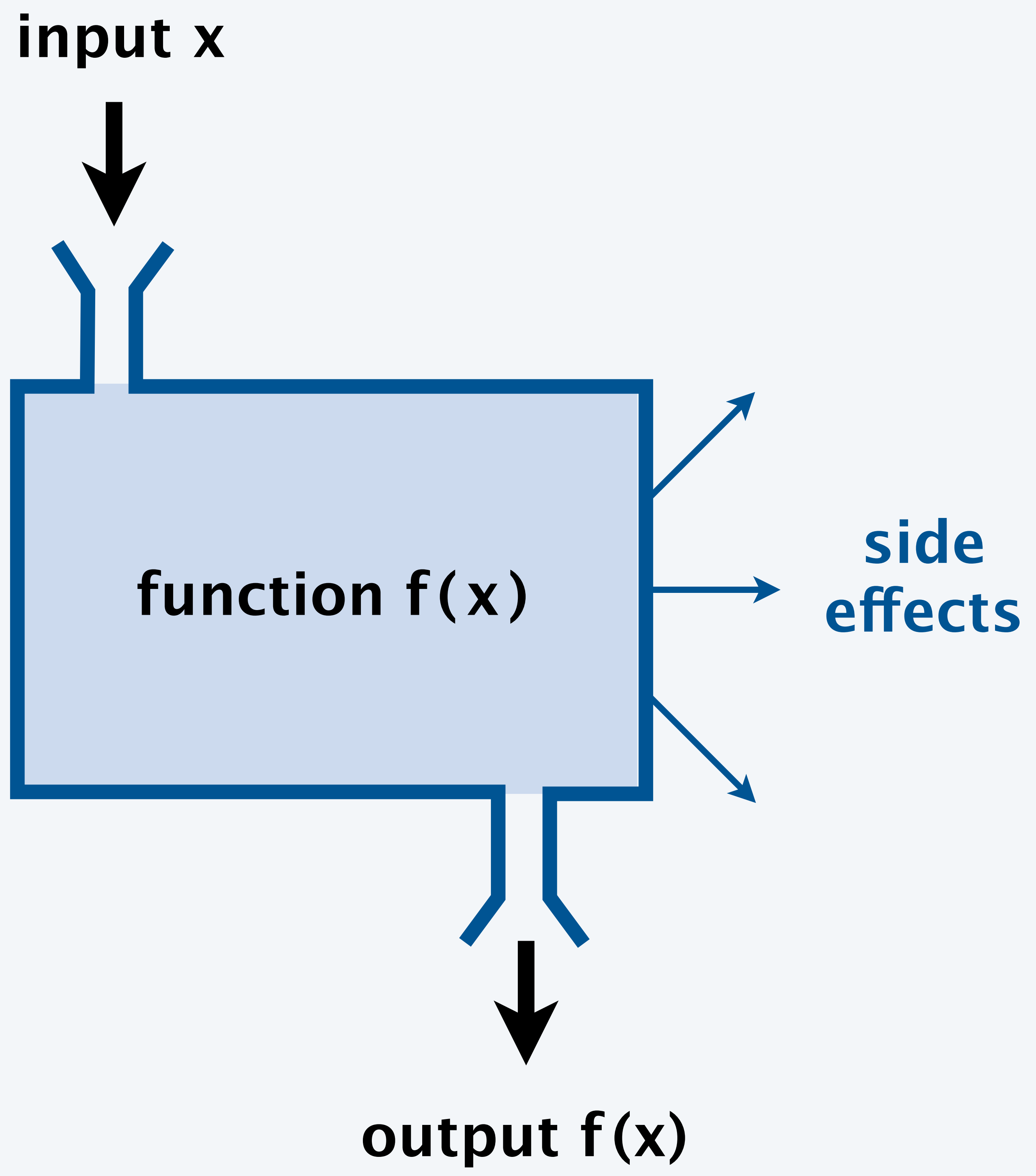
Summary

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

- Java evaluates the arguments and passes by value to function. ← *stay tuned!*
- 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.



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