

Principled Programming

Introduction to Coding in Any Imperative Language

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Specifications and Implementations

We describe the specification of various kinds of programming-language constructs, and how their implementations contribute to a program that meets its requirements:

- *Statements*, which define effects.
- *Declarations*, which create program variables.
- *Methods*, which group *statements* and *declarations* into meaningful operations.
- *Classes*, which aggregate *methods* and *declarations* into coherent modules.

Programs serve a **purpose**. They satisfy a **requirement**.

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Some requirements are small: Square a number.

Some requirements are large: Control a rocket to the moon.

Regardless, our goal is to write a program that satisfies a requirement.

A **specification**, written as comment, is a precise articulation of a requirement.

```
/* Specification. */
```

An **implementation**, indented beneath it, says how meet the requirement.

```
/* Specification. */  
  Implementation
```

Write specifications as **imperatives** that say **what** must be accomplished.

```
/* Specification. */  
Implementation
```

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```
/* Specification. */  
Implementation
```

Sample program-segment derivations starting with the *specification-implementation pattern*.

Write specifications as **imperatives** that say **what** must be accomplished.

```
/* Specification. */  
Implementation
```

```
/* Specification. */  
Implementation
```

Write specifications as **imperatives** that say **what** must be accomplished.

```
/* Specification. */  
Implementation
```

```
/* Output the square of an integer that is provided as input. */  
Implementation
```

Write implementations that say **how** to do so.

```
/* Specification. */  
Implementation
```

Example

```
/* Output the square of an integer that is provided as input. */  
int n = in.nextInt();  
System.out.println( n*n );
```

A given specification can be implemented in **multiple ways**.

```
/* Specification. */  
Implementation
```

Example

WAY 1

```
/* Output the square of an integer that is provided as input. */  
int n = in.nextInt();  
System.out.println( n*n );
```

A given specification can be implemented in **multiple ways**.

```
/* Specification. */  
Implementation
```

Example

WAY 2

```
/* Output the square of an integer that is provided as input. */  
int n = in.nextInt();  
/* Let s be the square of n. */  
System.out.println( s );
```

A given specification can be implemented in **multiple ways**.

```
/* Specification. */  
Implementation
```

Example

WAY 2a

```
/* Output the square of an integer that is provided as input. */  
int n = in.nextInt();  
/* Let s be the square of n. */  
    s = n*n;  
System.out.println( s );
```

A given specification can be implemented in **multiple ways**.

```
/* Specification. */  
Implementation
```

Example

WAY 2b

```
/* Output the square of an integer that is provided as input. */  
int n = in.nextInt();  
/* Let s be the square of n. */  
    int m = Math.abs(n);  
    int s = 0;  
    for (int k=0; k<m; k++) s = s + m;  
System.out.println( s );
```

Write specifications as **imperatives**.

```
/* Output the square of an integer that is provided as input. */  
int n = in.nextInt(); System.out.println( n*n );
```

Avoid meandering descriptions.

Be succinct. Eliminate needless words.

```
/* Output the square of an integer that is provided as input. */  
int n = in.nextInt(); System.out.println( n*n );
```

 **Repeatedly improve comments by relentless copy editing.**

By convention, state input before output.

```
/* Input an integer, and output the square of that integer. */  
int n = in.nextInt(); System.out.println( n*n );
```

Use **pronouns**.

```
/* Input an integer, and output its square. */  
int n = in.nextInt(); System.out.println( n*n );
```

Use letters as **pronouns**.

```
/* Input integer k, and output k squared. */  
  int n = in.nextInt(); System.out.println( n*n );
```

Use letters as **pronouns**.

```
/* Input integer j, and output j squared. */  
  int n = in.nextInt(); System.out.println( n*n );
```

The scope of such a pronoun is local to the specification.

Use letters as pronouns, or as the **names of variables**.

```
/* Input integer n, and output n squared. */  
  int n = in.nextInt(); System.out.println( n*n );
```

Use letters as pronouns, or as the names of variables.

```
/* Input integer n, and output n squared. */  
System.out.println( Math.pow(in.nextInt(),2) );
```

But in this implementation there is no variable `n`, so `n` is a **pronoun**.

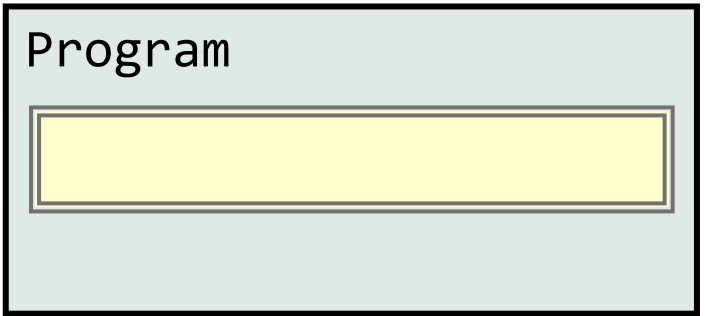
Use programming-language *expressions*, if you wish.

```
/* Input integer n, and output  $n*n$ . */  
int n = in.nextInt(); System.out.println( n*n );
```


But an *expression* in a specification isn't necessarily computed.

```
/* Input integer x, and output the number n such that  $n*n=x$ . */  
System.out.println( Math.sqrt(in.nextInt()) );
```

Suppose, in a program, you need to exchange the values of variables x and y .

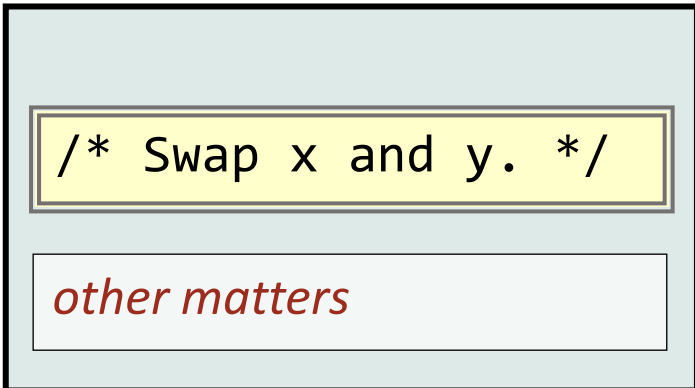


Write the specification as if in a higher-level programming language.

```
/* Swap x and y. */
```

 **Write comments as an integral part of the coding process, not as afterthoughts.**

Defer implementation so you don't get distracted. Move on to **other matters**.



 **Write comments as an integral part of the coding process, not as afterthoughts.**

Or implement it now, if simple enough to not get distracted.

```
/* Swap x and y. */  
int temp = x;  
x = y;  
y = temp;
```

other matters

👉 **Write comments as an integral part of the coding process, not as afterthoughts.**

Then ignore it in considering the specification's relationship to other matters.

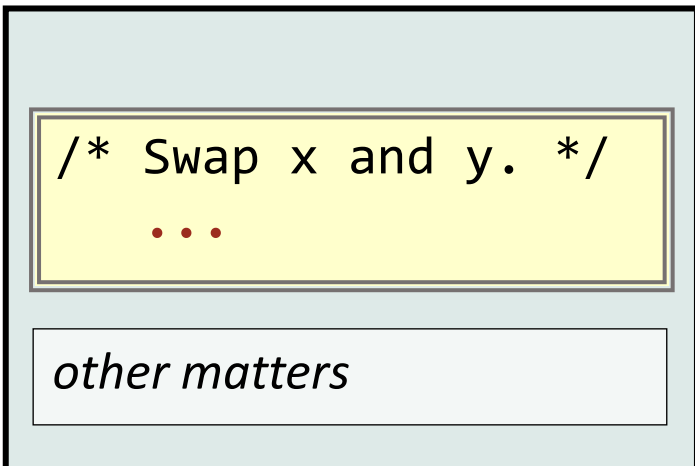
```
/* Swap x and y. */  
  int temp = x;  
  x = y;  
  y = temp;
```

other matters

Let your eye **skip over the indented implementation**

👉 **Write comments as an integral part of the coding process, not as afterthoughts.**

Then ignore it in considering the specification's relationship to other matters.



Let your eye skip over the indented implementation **as if it were elided**.



Write comments as an integral part of the coding process, not as afterthoughts.

An implementation can include another specification

```
/* Swap x and y. */
```

```
/* Declare int variable temp and initialize it to x. */
```

```
x = y;
```

```
y = temp;
```

```
other matters
```


which is then implemented.

```
/* Swap x and y. */
```

```
/* Declare int variable temp and initialize it to x. */  
int temp = x;
```

```
x = y;
```

```
y = temp;
```

other matters



A specification faces two directions, like the Roman god Janus.

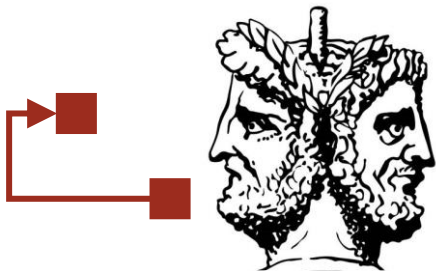
```
/* Swap x and y. */
```

```
/* Declare int variable temp and initialize it to x. */  
int temp = x;
```

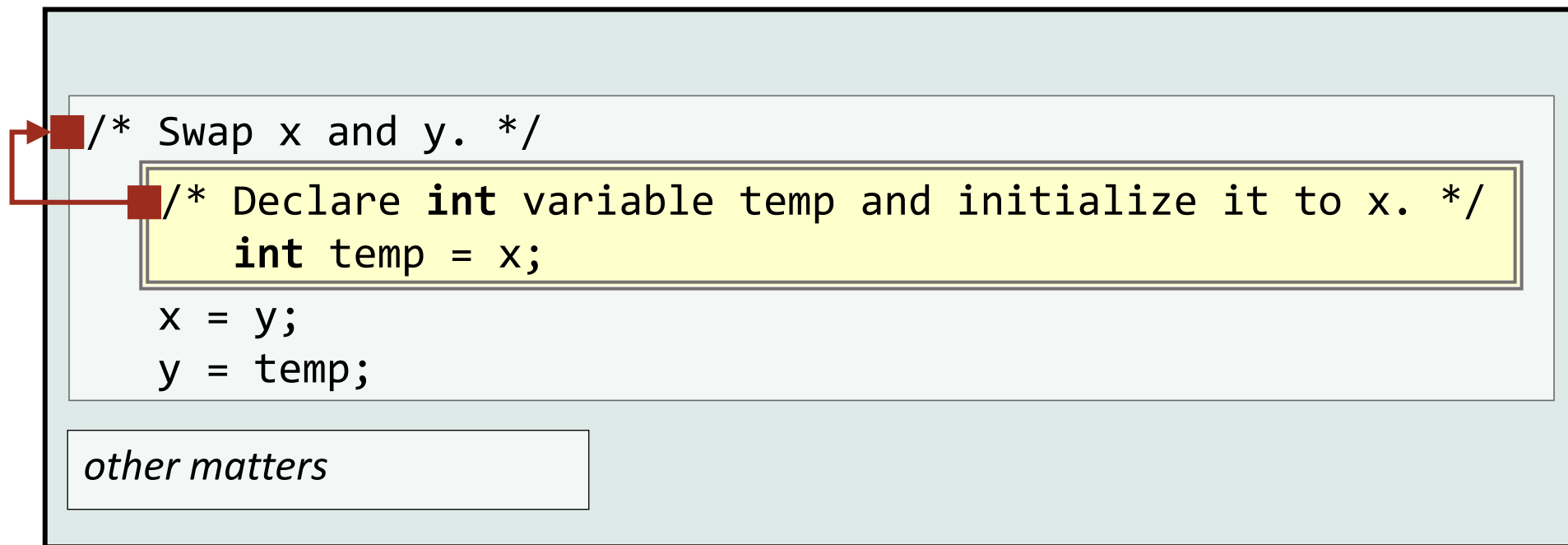
```
x = y;
```

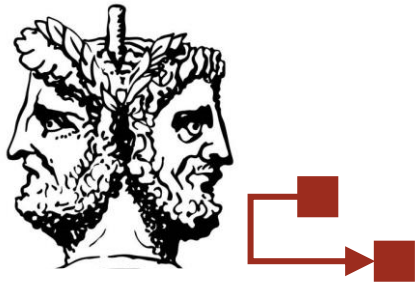
```
y = temp;
```

other matters



Outward, it is part of the implementation of an encompassing specification.





Inward, it is a specification that is being implemented.

```
/* Swap x and y. */
```

```
/* Declare int variable temp and initialize it to x. */  
int temp = x;
```

```
x = y;
```

```
y = temp;
```

other matters

Avoid redundant specifications that say the obvious.

```
/* Declare int variable temp and initialize it to x. */  
int temp = x;
```

other matters

👉 **Omit specifications whose implementations are at least as brief and clear as the specification itself.**

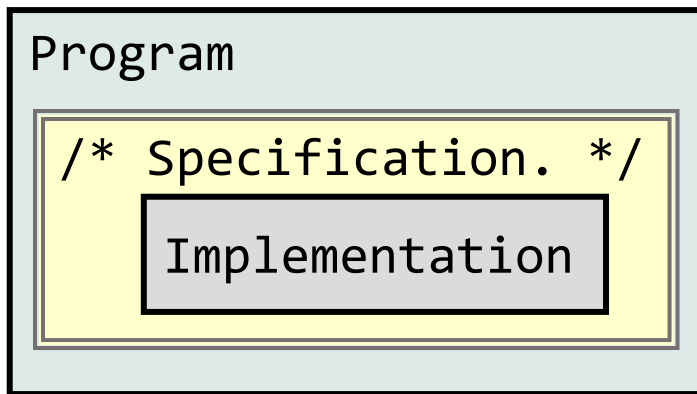
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```
int temp = x;
```

other matters

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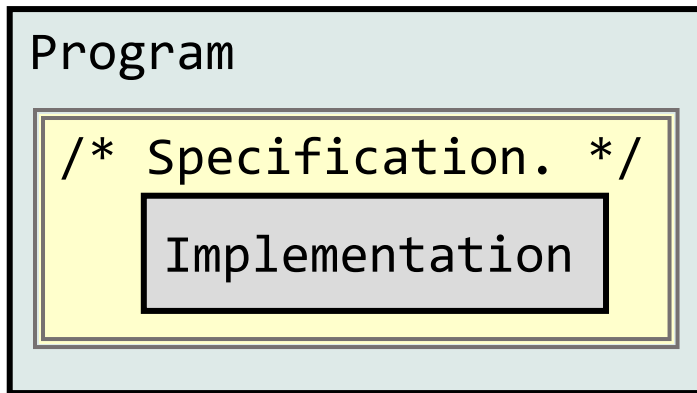
A specification is a **contract** with the rest of the program that says *what* must be accomplished, not *how* to do so.



Proviso: As long as the **program** does this and that.

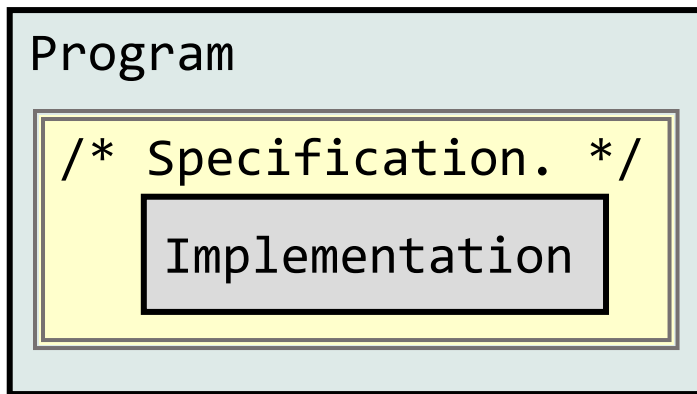
Promise: The **specification** (and its implementation) will do thus and such.

A specification helps to **control complexity**.



The contract (double line) **partitions code** into the specification and its implementation (on the one hand), and the rest of the program (on the other).

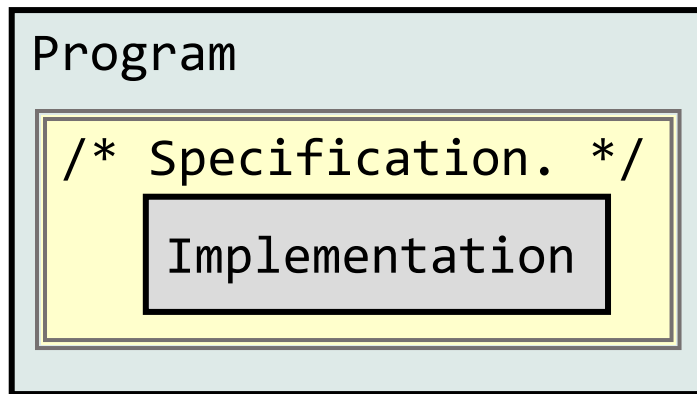
A specification is both **constraining** and **liberating**.



Constraining: (If the proviso is met) then it **must** do what is required.

Liberating: But its implementation is **free** to do so in any way it wants.

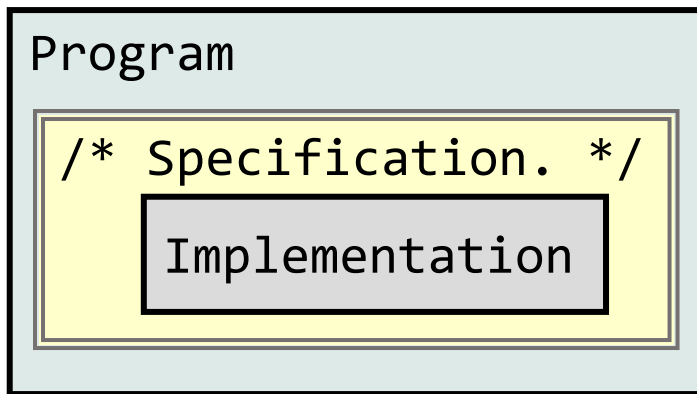
A specification promotes **pliability** and **comprehensibility**.



Pliability: The implementation can be changed without affecting the rest of the program.

Comprehensibility: The program can ignore implementation details not mentioned by the specification.

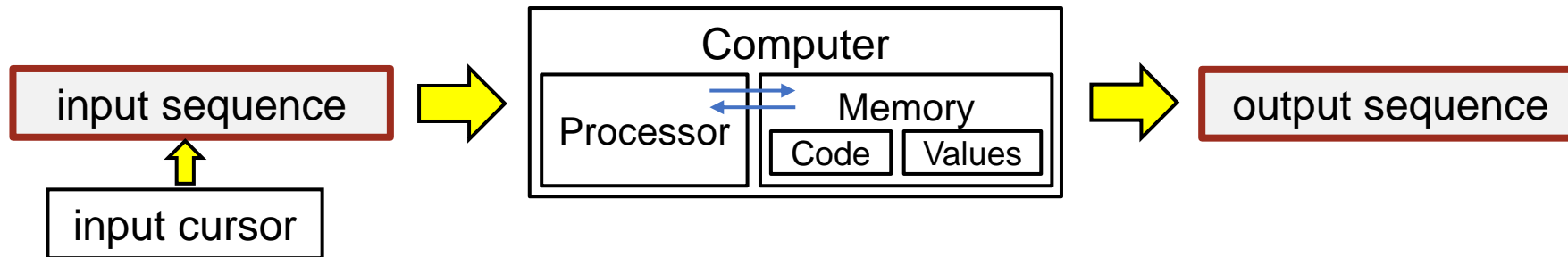
Specifications **encapsulate details** and **hide information** behind **abstraction barriers**.



These notions are central to object-oriented programming (discussed later, but already relevant at the level of **statement specifications**).

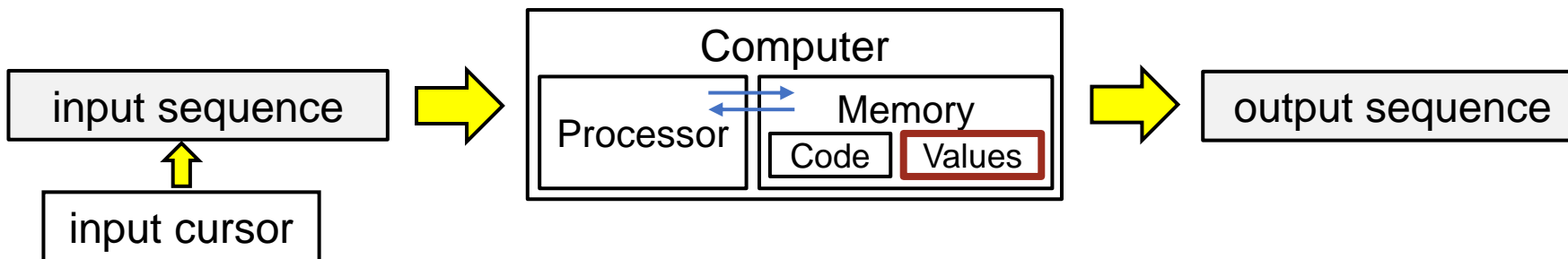
An Input/Output specification (“I/O spec”) reads and writes **external** data

```
/* Input integer n, and output n squared. */
```



Alternatively, an I/O spec sets values of some **variables** from values of other **variables**, leaving the external data unchanged.

```
/* Given integer variable n, let variable s be n squared. */
```



Alternatively, an I/O spec sets values of some **variables** from values of other **variables**, leaving the external data unchanged.

```
/* Given integer variable n, let variable s be n squared. */
```

Before

n **input variable**

s

After

n

s **output variable**

In general, an I/O spec requires changing a **before** state into an **after** state.

```
/* Given before state, establish after state. */
```

In general, an I/O spec requires changing a **before** state into an **after** state.

```
/* Given precondition, establish postcondition. */
```

Before

described by **precondition**

After

described by **postcondition**

Use pronouns to distinguish the before and after values of a variable that is both input and output

```
/* Swap x and y. */
```

Before

x input variable

y input variable

After

x output variable

y output variable

Use pronouns to distinguish the before and after values of a variable that is both input and output

```
/* Given x=X and y=Y, establish x=Y and y=X. */
```

Before

x input variable

y input variable

After

x output variable

y output variable

A specification says what **must** happen when the **precondition** holds

```
/* Given  $x \geq 0$ , let  $y$  be the square root of  $x$ . */
```

Before

x input variable

y

After

x

y output variable

But says **nothing** about what may happen **otherwise**.

```
/* Given  $x \geq 0$ , let  $y$  be the square root of  $x$ . */
```

Before

x input variable

y

After

x

y output variable

But says **nothing** about what may happen **otherwise**.

```
/* Given  $x \geq 0$ , let  $y$  be the square root of  $x$ . */
```

Before

x input variable

y

After



Reaching a specification whose precondition doesn't hold is indicative of an error, e.g., we expect x to be nonnegative, so it was incorrectly computed.

```
/* Given  $x \geq 0$ , let  $y$  be the square root of  $x$ . */
```

Before

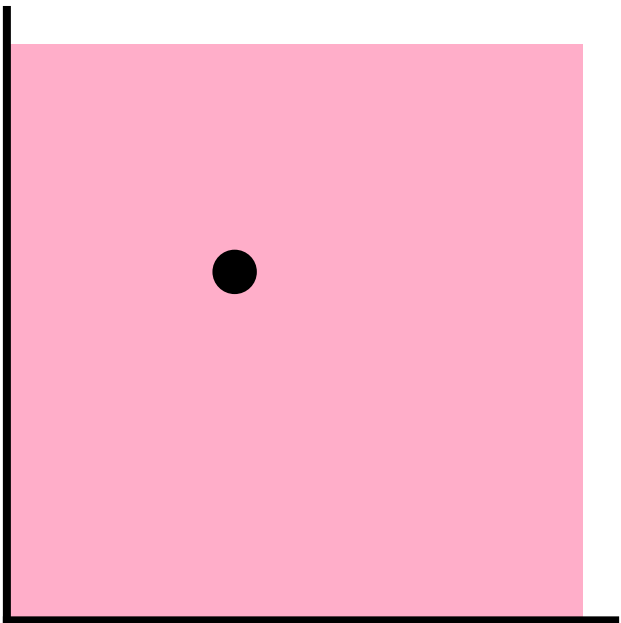
x input variable

y

After

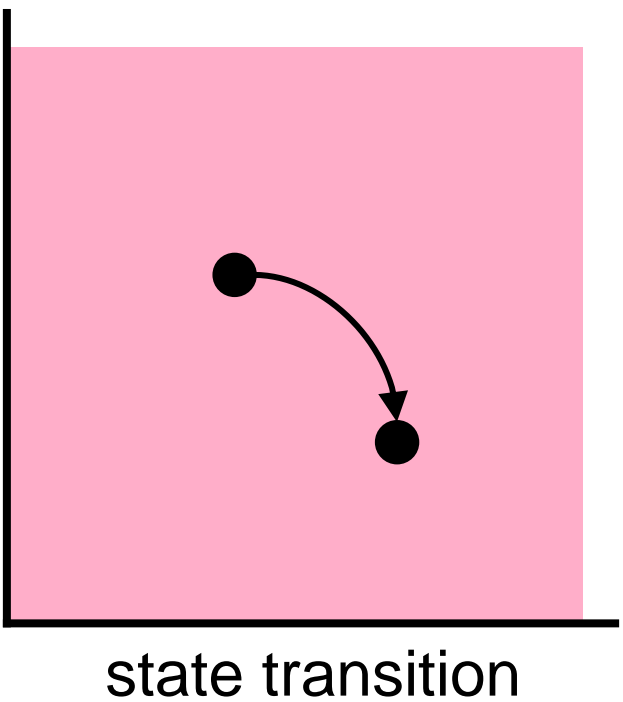
arbitrary

Interrupt a program's execution. Before powering the computer down, save all that you will need to resume later. This is the **state**.

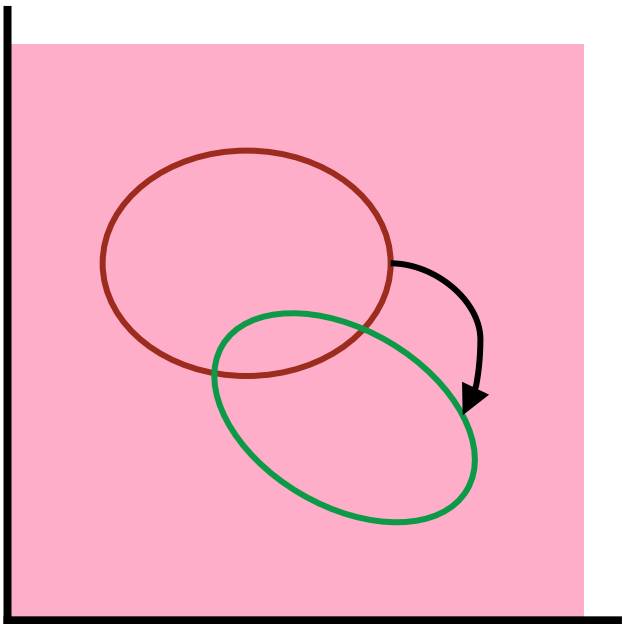


state and state space

The **effect** of executing code is to **transition** from one state to another.



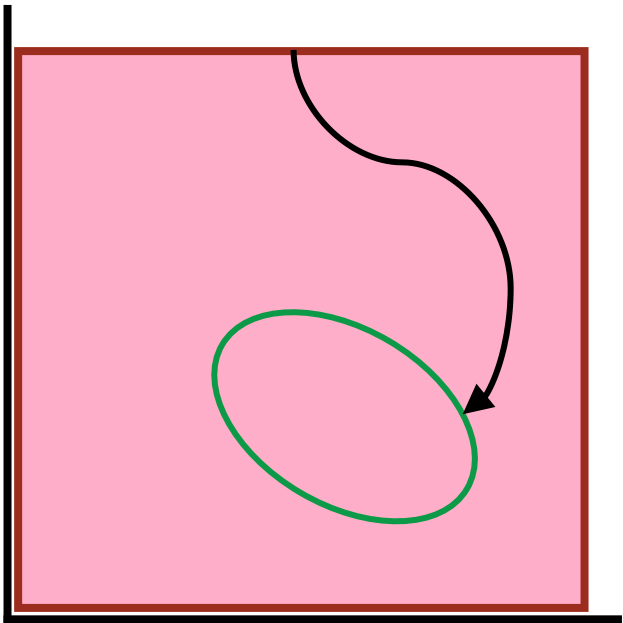

```
/* Given precondition, establish postcondition . */
```



The specification requires transition from any state satisfying the **precondition** to some state satisfying the **postcondition**.

precondition to **postcondition**

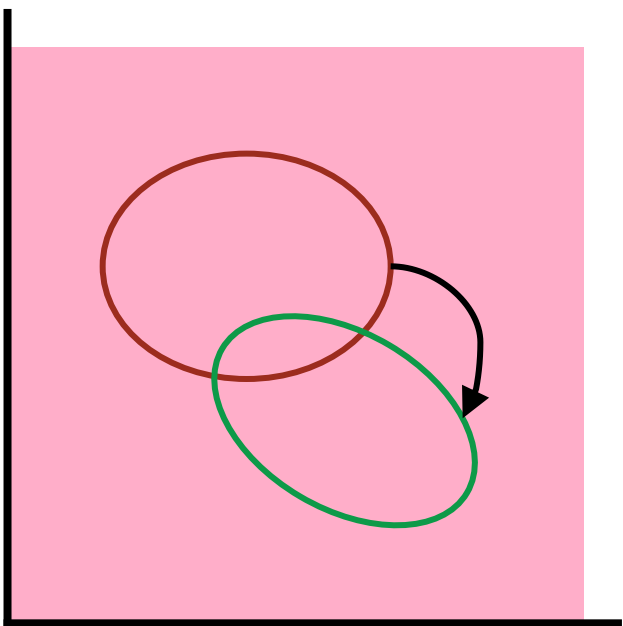
```
/* Output "Hello World". */
```



precondition to postcondition

The specification requires transition from **any state whatsoever** to a **state where the output ends with "Hello World"**.

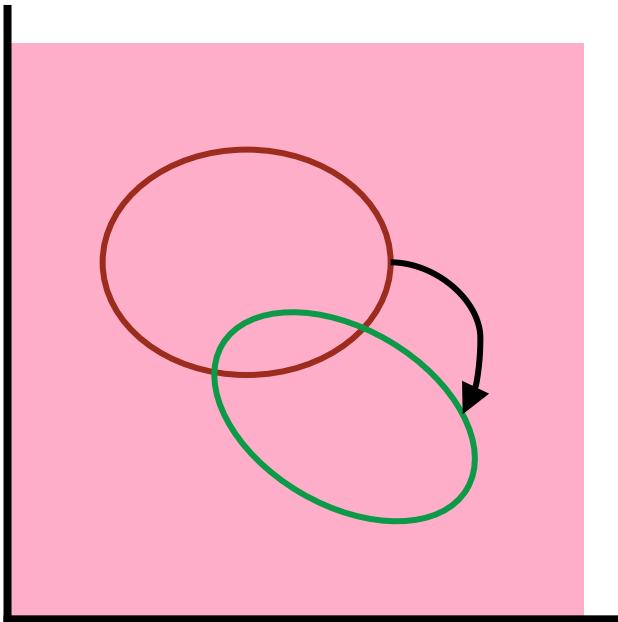
```
/* Swap x and y. */
```



precondition to postcondition

The specification requires transition from any state containing variables x and y to a state where the contents of x and y have been exchanged.

Define sets of states either in English, or using Boolean expressions.

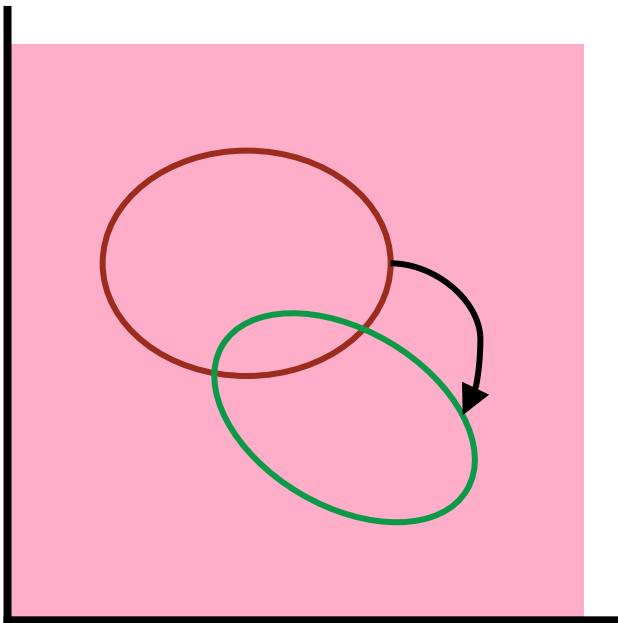


precondition to postcondition

In code, Boolean expressions control execution flow:

```
/* Set y to the square root of x if x is  
not negative, and 0 otherwise. */  
if (  $x \geq 0$  ) y = Math.sqrt(x); else y = 0;
```

Define sets of states either in English, or using Boolean expressions.



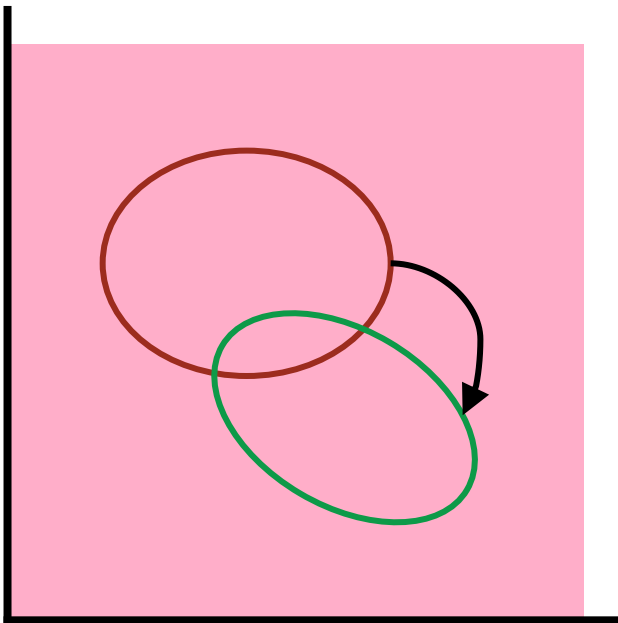
precondition to postcondition

In specifications, Boolean expressions define state sets:

```
/* Given  $x \geq 0$ , let  $y$  be the square root of  $x$ . */
```

Specifically, the set of all states in which the given Boolean expression is **true**.

Transition to *any* state satisfying the **postcondition** is allowed.



precondition to **postcondition**

For example,

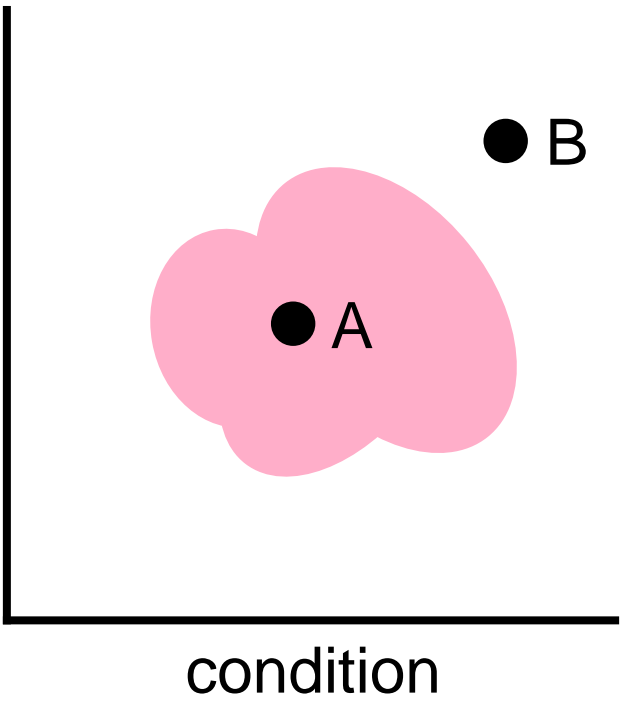
```
/* Given  $x \geq 0$ , let  $y$  be the square root of  $x$ . */  
y = Math.sqrt(x);
```

or

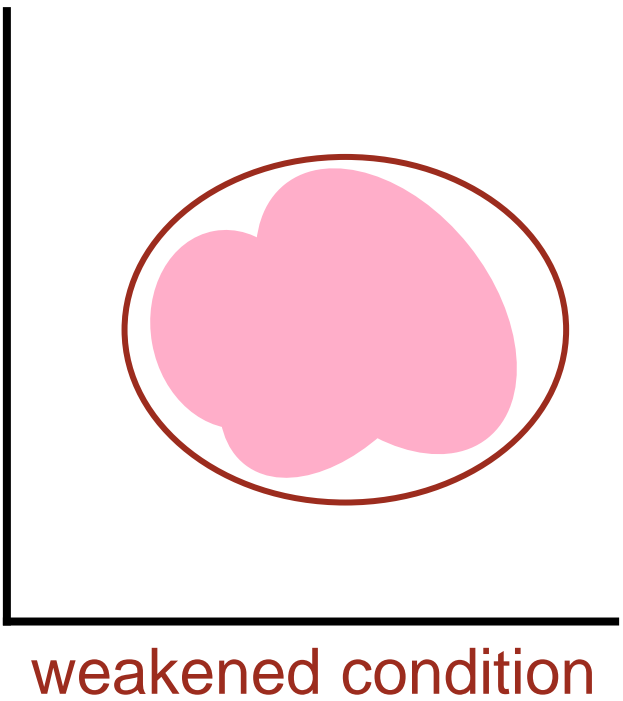
```
/* Given  $x \geq 0$ , let  $y$  be the square root of  $x$ . */  
y = -Math.sqrt(x);
```

Conditions and Sets of States

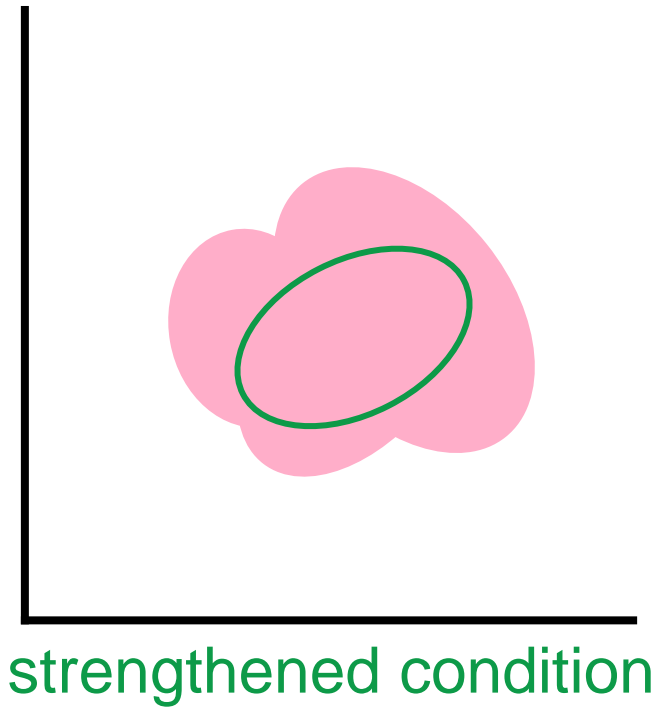
A state either satisfies a condition, or it doesn't.



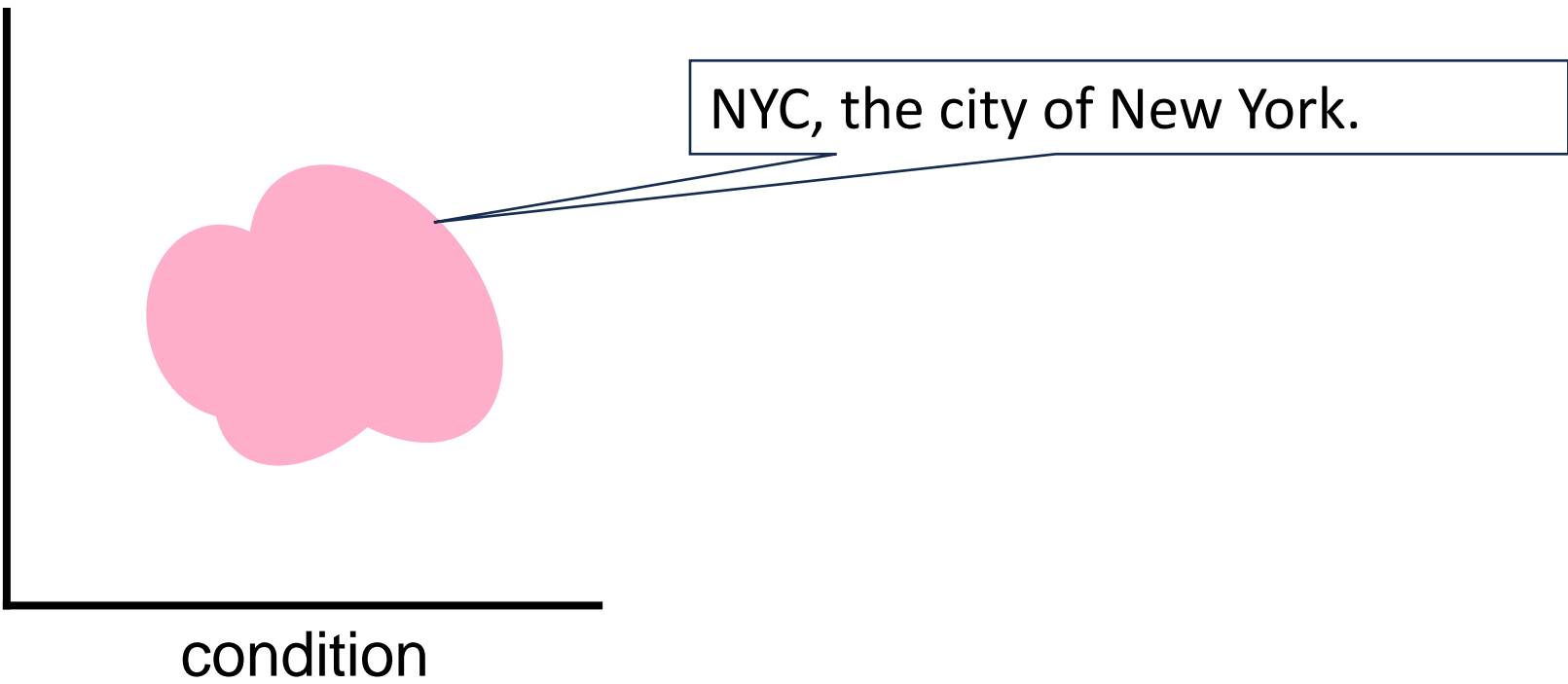
A **weakened** condition satisfies more states than the original condition.



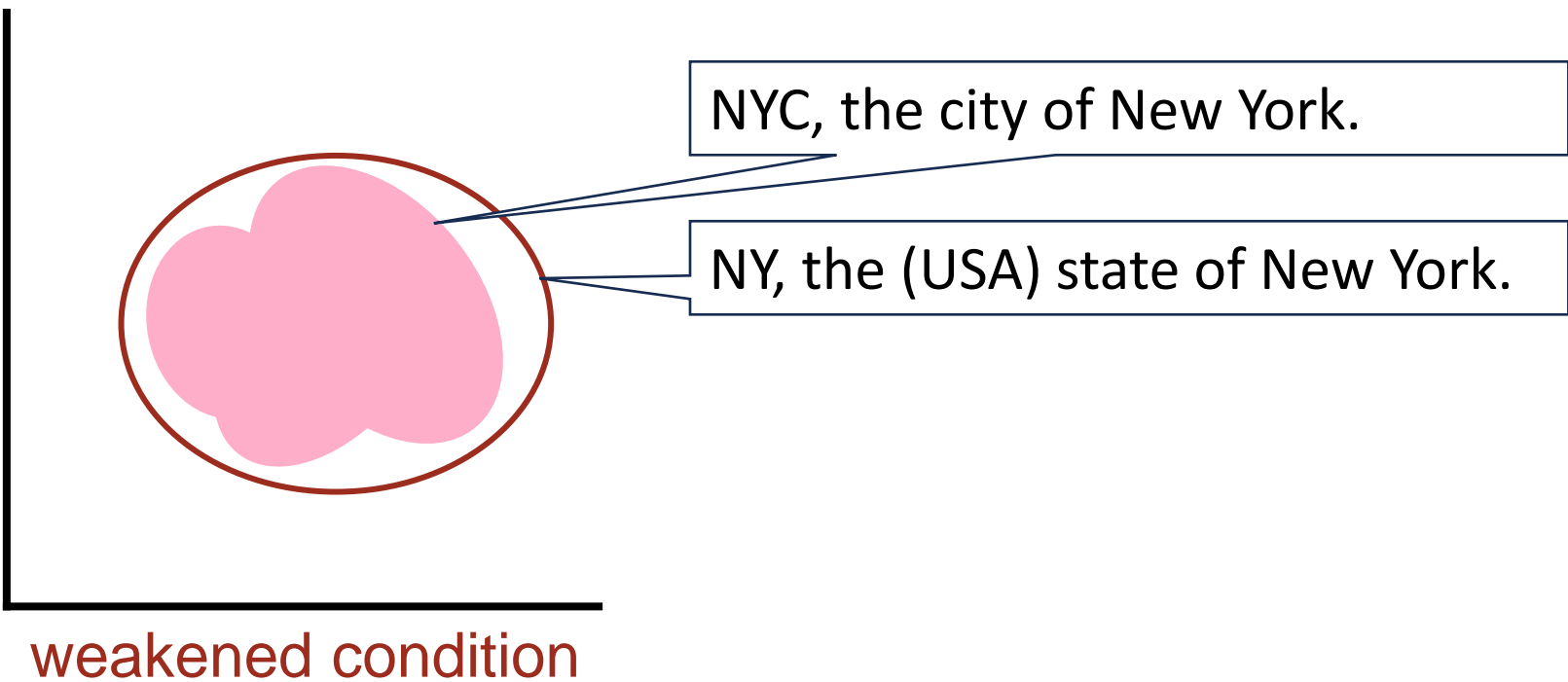
A **strengthened** condition satisfies fewer states than the original condition.



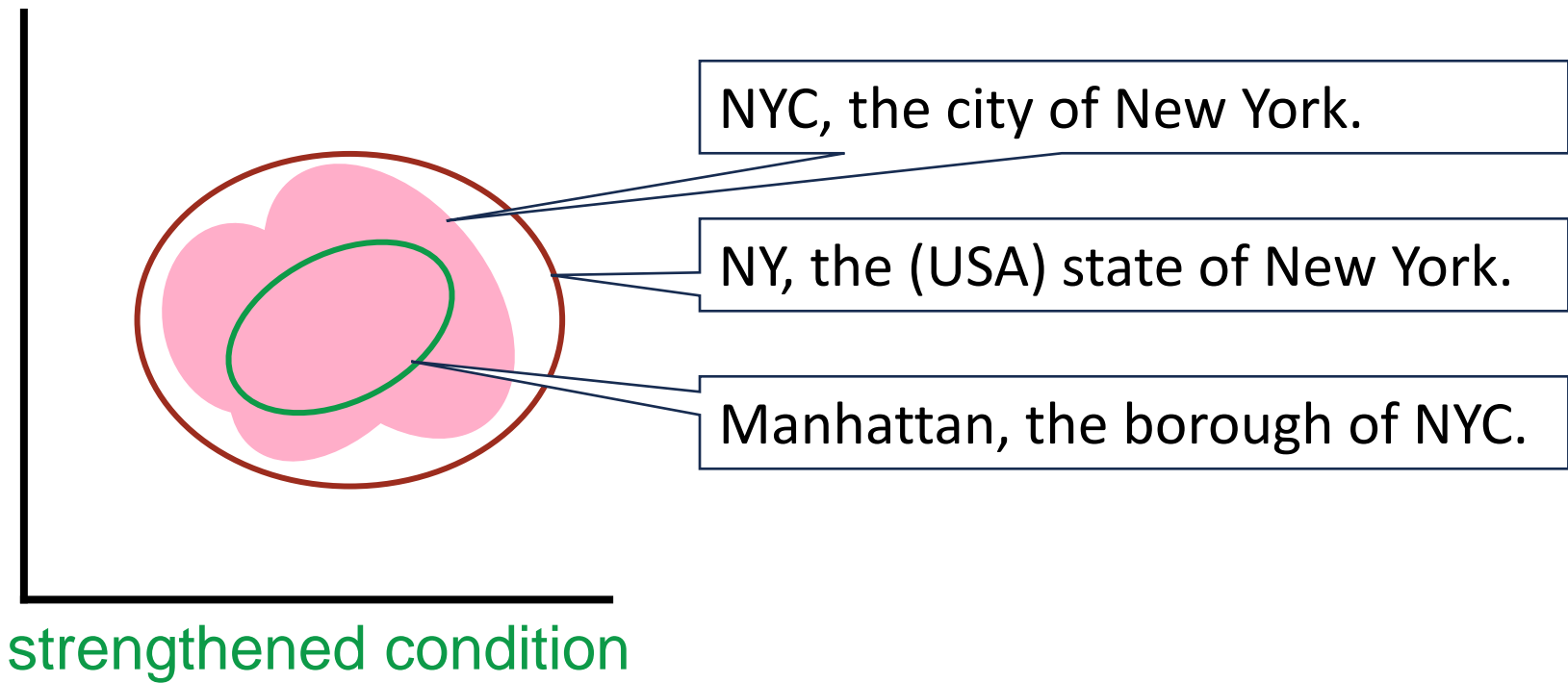
A geographical example:



A geographical example:



A geographical example:



Methods can protect themselves from misuse by their clients by explicitly checking the validity of their arguments, and aborting execution if any are invalid.

Such a protection may derive from a built-in check, e.g., integer division by 0 aborts execution:

```
/* Given  $n \neq 0$ , return  $x/n$ . */  
static int nth(int x, int n) { return x/n; }
```

Consider this computation. If n turns out to be 0 by mistake, `nth` will abort execution:

```
/* Compute  $n \neq 0$  such that blah blah. */  
...
```

```
/* Given  $n \neq 0$ , let  $y$  be the  $n$ th part of  $x$ . */  
y = nth(x, n);
```

```
/* Whatever. */  
...
```



Aborting execution early is far better than having `Whatever` crash (possibly) much later due to a crazy value of n .

This similar code is just as vulnerable to the error in the computation of n , but without the protection of $n \neq 0$, will likely crash in Whatever.

```
/* Compute  $n \neq 0$  such that blah blah. */  
...
```

```
/* Given  $n \neq 0$ , do Whatever. */  
...
```

It can protect itself by doing the same check as `nth` using an **assert**:

```
/* Compute  $n \neq 0$  such that blah blah. */  
...
```

```
/* Given  $n \neq 0$ , do whatever. */  
  assert  $n \neq 0$ : "blah blah computed a zero n";  
...
```



Abort execution early if the precondition of `whatever` doesn't hold

It can protect itself by doing the same check as `nth` using an **assert**:

```
/* Compute  $n \neq 0$  such that blah blah. */  
...  
assert  $n \neq 0$ : "blah blah computed a zero n";
```

```
/* Given  $n \neq 0$ , do Whatever. */  
...
```



or if the postcondition of `blah blah` doesn't hold.

It can protect itself by doing the same check as `nth` using an **assert**:

```
/* Compute  $n \neq 0$  such that blah blah. */  
...  
assert  $n \neq 0$ : "blah blah computed a zero n";
```

```
/* Given  $n \neq 0$ , do Whatever. */  
...
```



Use of **assert** is preferable to debugging.

Declaration Specifications take a data-centric perspective.

```
Declaration-of-one-variable // Specification
```

or

```
/* Specification. */  
Declarations-of-related-variables
```

A declaration specification provides a **representation invariant** for the variable(s) that characterizes the value(s) contained therein, and is a global precondition for every statement (except for brief moments before the variable(s) have been updated).

It is akin to a glossary entry, and can be used as such.

Example: Suppose input values are to be read and “processed”.

```
int count; // # of input values read so far.
```

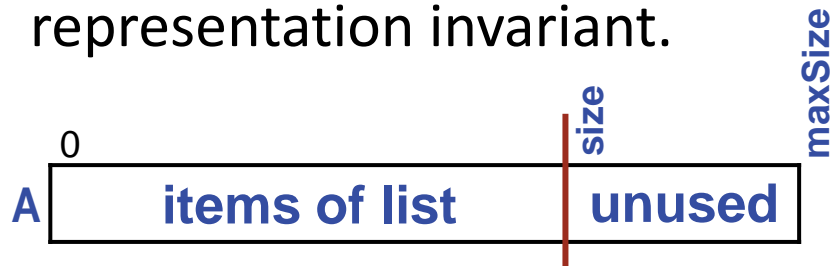
vs

```
int count; // # of input values processed so far.
```

The two specifications provide different **representation invariants** for the variable `count`.

In the first case, `count` should be incremented immediately upon reading a value. In the second case, `count` is only incremented when the program gets around to processing the value it has already read.

Example: A group of related variables, called a *data structure*, may share a representation invariant.



```

/* A[0..size-1] are the current items in A[0..maxSize-1],  $0 \leq \text{size} \leq \text{maxSize}$ . */
int A[];      // receptacle for items in a list.
int size;     // current # of elements in list,  $0 \leq \text{size} \leq \text{maxSize}$ .
int maxSize; // maximum # of elements storable in the list.

```

An item is inserted into the list (if there is room) at $A[\text{size}]$, and then size is incremented. The representation invariant characterizes how A , size , and maxSize relate to one another.

A **method specification** describes the effects (if any) and the return value (if any) of the method in terms of its parameters. This is its **postcondition**.

```
/* Specification. */  
Method definition
```

A method specification describes the effects (if any) and the return value (if any) of the method in terms of its parameters. This is its **postcondition**.

```
/* Specification. */  
Method definition
```

Examples

```
/* Rearrange array A[0..n-1] to be in non-decreasing order. */  
void sort( int A[], int n) { <body of sort> }
```

```
/* Return the larger of the values x and y. */  
int max(int x, int y) { if ( x<y ) return y; else return x; }
```

A **method specification** may restrict its parameters. This is its **precondition**.

```
/* Specification. */  
Method definition
```

Example

```
/* Given int array A[0..n-1] sorted in non-decreasing order, and int v,  
   return an index where A[k]==v, or return n if v does not occur in A. */  
int find( int A[], int n, int v) { <body of find> }
```


A class specification summarizes the class's purpose and functionality. The specifications of the class's public declarations and methods are implicitly part of the class specification.

```
/* Specification. */  
Class definition
```

Class specifications are often more descriptive and historical than the other forms of specification.

```
/* Rational. A module for the manipulation of rationals, including operations
   for +, -, *, /, conversion to String, and equality.
   Author: Joe Blow.
   Created: 12/25/2022.
   Revision History: Converted to use unbounded integers, 12/25/2023. */
class Rational {
    ...
} /* Rational */
```