3. Design by Contract

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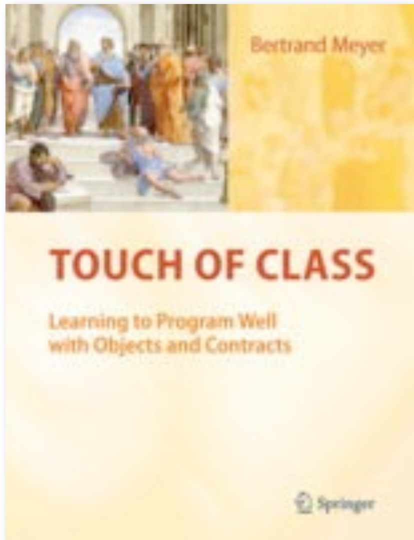
Design by Contract

Bertrand Meyer, *Touch of Class — Learning to Program Well with Objects and Contracts*, Springer, 2009.



Roadmap

> Contracts
> Stacks
> Design by Contract
> A Stack Abstraction
> Assertions
> Example: balancing parentheses

Roadmap

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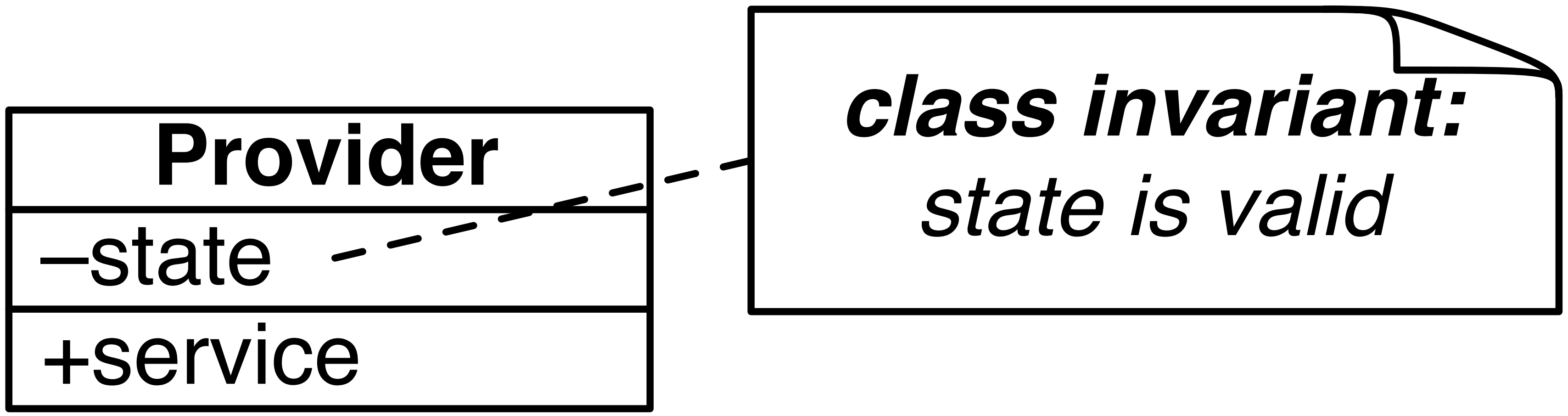
Class Invariants

An <u>invariant</u> is a predicate that *must hold* at certain points in the execution of a program

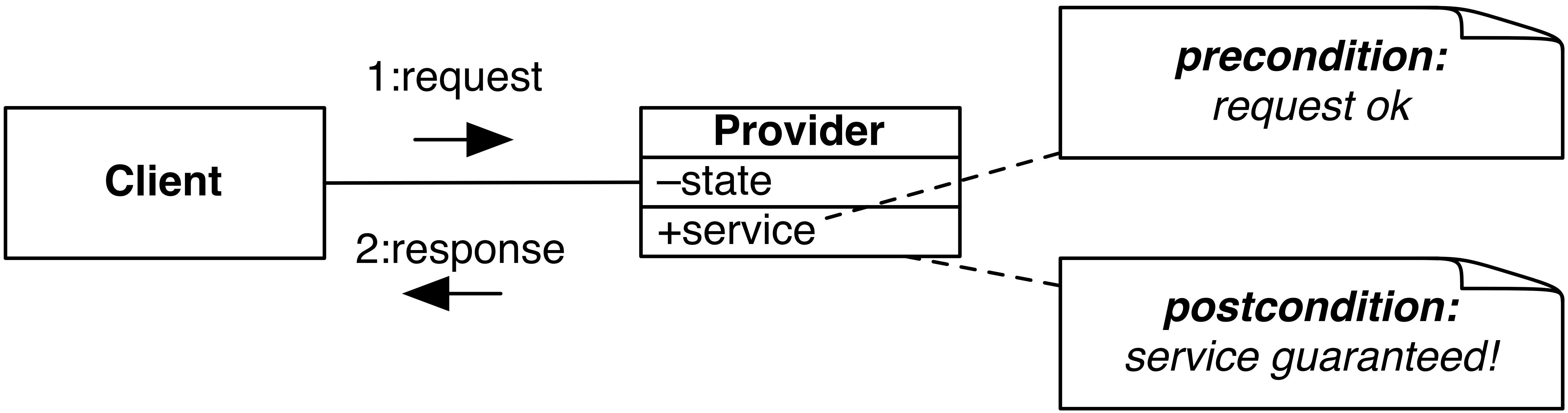


A <u>class invariant</u> characterizes the *valid states of instances*
It must hold:

1. *after construction*
2. *before and after every public method*

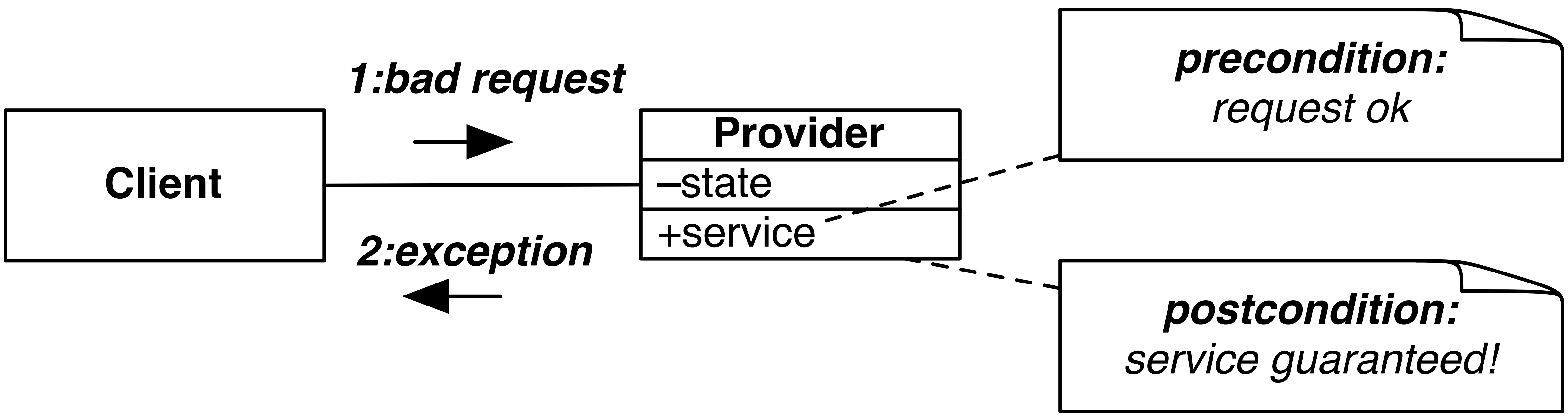
Contracts

A <u>contract</u> *binds the client* to pose valid requests, and *binds the provider* to correctly provide the service.



Contract violations

If either the client or the provider violates the contract, an *exception* is raised.



NB: The service does not need to implement any special logic to handle errors — it simply raises an exception!

Exceptions, failures and defects

- An exception is the occurrence of an *abnormal condition during the execution of a software element.*
- A failure is the *inability of a software element to satisfy its purpose*.
- A defect (AKA “bug”) is the *presence in the software of some element not satisfying its specification.*

Disciplined Exceptions

> There are only two reasonable ways to react to an exception:
  1. clean up the environment and *report failure* to the client ("organized panic")
  2. attempt to *change the conditions* that led to failure and *retry*

A failed assertion often indicates presence of a software defect, so "organized panic" is usually the best policy.

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Stacks

A Stack is a classical data abstraction with many applications in computer programming.

Stacks support two mutating methods: push and pop.

Operation	***Stack***	***isEmpty()***	***size()***	***top()***
		TRUE	0	(error)
push(6)	6	FALSE	1	6
push(7)	6 7	FALSE	2	7
push(3)	6 7 3	FALSE	3	3
pop()	6 7	FALSE	2	7
push(2)	6 7 2	FALSE	3	2
pop()	6 7	FALSE	2	7

Stack pre- and postconditions

Stacks should respect the following contract:

service	***pre***	***post***
`isEmpty()`	-	*no state change*
`size()`	-	*no state change*

`push(Object item)`	-	not empty,
		`size == old size + 1,`
		`top == item`

`top()`	not empty	*no state change*
`pop()`	not empty	`size == old size -1`

Stack invariant

> The only thing we can say about the Stack class invariant is that the size is always ≥ 0
>
> —we don't know anything yet about its state!

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Design by Contract

When you design a class, each service S provided must specify a clear contract.

> *"If you promise to call S with the precondition satisfied, then I, in return, promise to deliver a final state in which the post-condition is satisfied."*

Consequence:

—if the precondition does not hold, *the object is not required to provide anything!* (in practice, an exception is raised)

In other words …

Design by Contract =

Don't accept anybody else's garbage!

Pre- and Post-conditions

The pre-condition binds clients:

—it defines what the data abstraction *requires* for a call to the operation to be legitimate

—it may involve *initial state and arguments*

—example: *stack is not empty*

The post-condition, in return, binds the provider:

—it defines the conditions that the data abstraction *ensures* on return

—it may only involve the *initial and final states, the arguments and the result*

—example: *size = old size + 1*

Benefits and Obligations

A contract provides *benefits and obligations* for both clients and providers:

	Obligations	***Benefits***
Client	Only call pop() on a non-empty stack!	Stack size decreases by 1. Top element is removed.
Provider	Decrement the size. Remove the top element.	No need to handle case when stack is empty!

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StackInterface

Interfaces let us *abstract* from concrete implementations:

```
public interface StackInterface<E> {
    public boolean isEmpty();
    public int size();
    public void push(E item);
    public E top();
    public void pop();
}
```

✎ How can clients accept multiple implementations of a data abstraction?

✔ *Make them depend only on an interface or an abstract class.*

Interfaces in Java

Interfaces *reduce coupling* between objects and their clients:

> A class can implement multiple interfaces
  — ... but can only extend one parent class

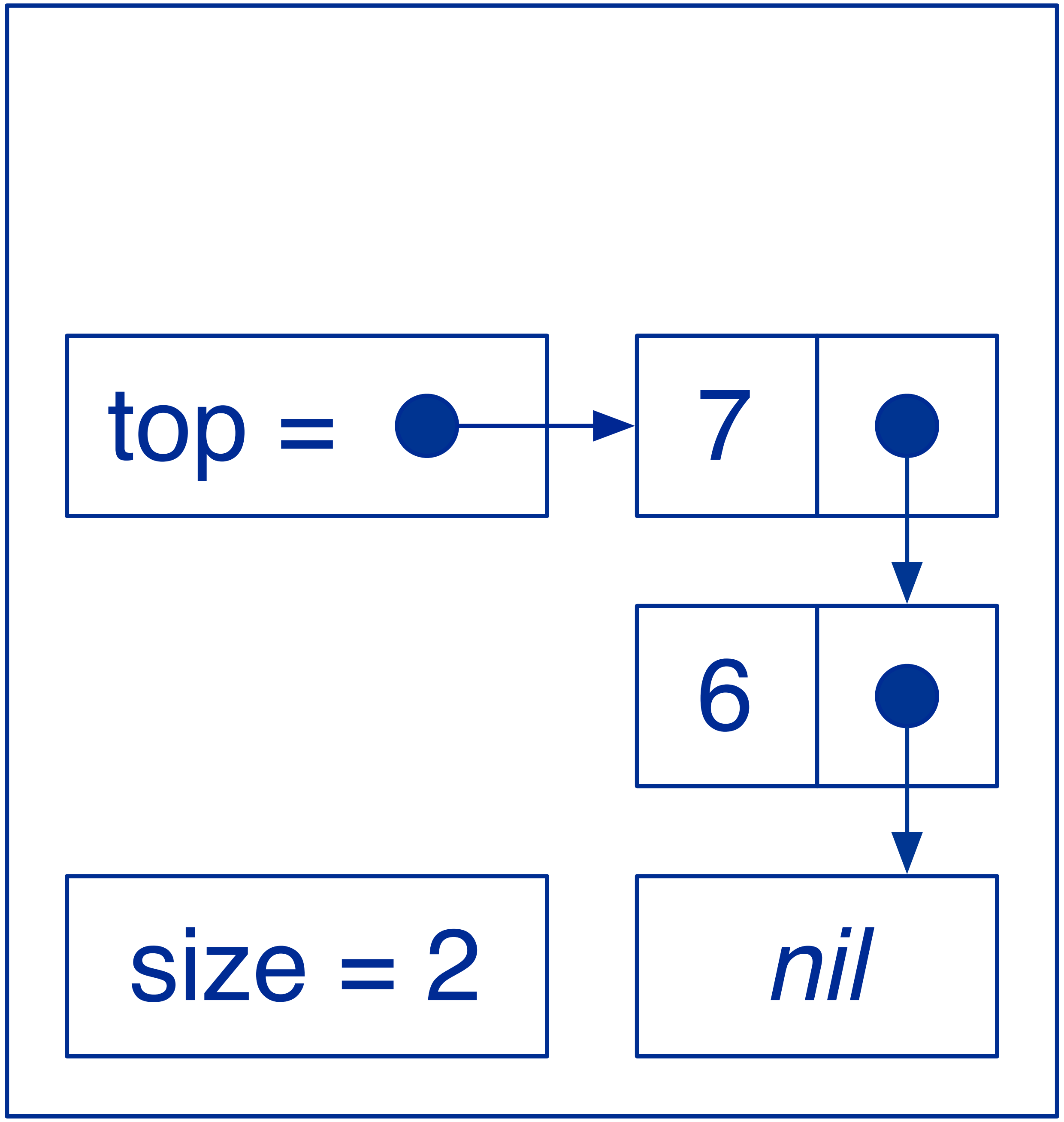
> Clients should depend on an interface, not an implementation
  — ... so implementations don't need to extend a specific class

Define an interface for any data abstraction that will have more than one implementation

Stacks as Linked Lists

A Stack can easily be implemented by a linked data structure:

```
stack = new Stack();
stack.push(6);
stack.push(7);
stack.push(3);
stack.pop();
```



LinkStack Cells

We can define the Cells of the linked list as an *inner class* within `LinkStack`:

```
public class LinkStack<E> implements StackInterface<E> {
   private Cell top;
   private class Cell {
      E item;
      Cell next;
      Cell(E item, Cell next) {
         this.item = item;
         this.next = next;
      }
   }
   ...
}
```

Private vs Public instance variables

✎ When should instance variables be public?

✔ *Always make instance variables private or protected.*

The Cell class is a special case, since its instances are strictly private to LinkStack!

LinkStack abstraction

The constructor must construct a *valid initial state*:

```
public class LinkStack<E> implements StackInterface<E> {
   ...
   private int size;
   public LinkStack() {
      // Establishes the class invariant.
      top = null;
      size = 0;
   }
   ...
```

Class Invariants

A class invariant is any condition that expresses the *valid states* for objects of that class:

> it must be *established* by every constructor

> every public method

—may *assume* it holds when the method starts

—must *re-establish* it when it finishes

Stack instances must satisfy the following invariant:

> size ≥ 0

> ...

LinkStack Class Invariant

A valid `LinkStack` instance has an integer `size`, and a `top` that points to a sequence of linked `Cells`, such that:

- `size` is always ≥ 0
- When `size` is zero, `top` points nowhere (== `null`)
- When `size` > 0, `top` points to a `Cell` containing the top item

When to check invariants?

> In principle, check invariants:

—at the end of each *constructor*

—at the end of every *public mutator*

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Assertions

> An assertion is a declaration of a *boolean expression* that the programmer believes *must hold* at some point in a program.
  - —Assertions should not affect the logic of the program
  - —If an assertion fails, an *exception* is raised

```
x = y*y;
assert x >= 0;
```

Assertions

Assertions have four principle applications:

1. Help in writing correct software
   — formalizing invariants, and pre- and post-conditions
2. Documentation aid
   — specifying contracts
3. Debugging tool
   — testing assertions at run-time
4. Support for software fault tolerance
   — detecting and handling failures at run-time

Assertions in Java

`assert` is a keyword in Java since version 1.4

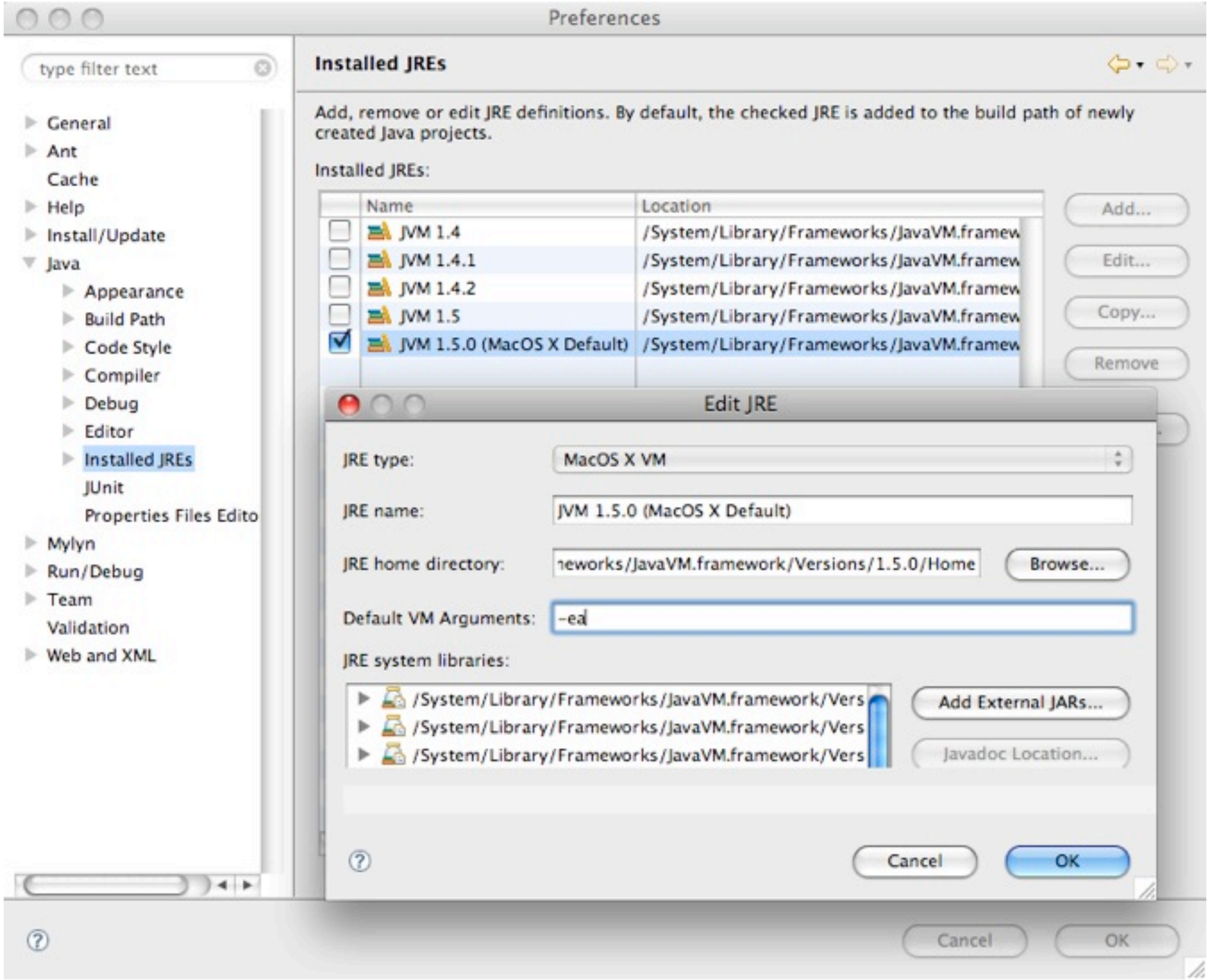
```
assert expression;
```

will raise an `AssertionError` if *`expression`* is false.

— *NB:* Throwable *Exceptions* must be declared; *Errors* need not be!

✔ *Be sure to enable exceptions in eclipse! (And set the vm flag -enableassertions [-ea])*

Enabling assertions in eclipse



Checking pre-conditions

Assert pre-conditions to inform clients when *they* violate the contract.

NB: This is all you have to do!

```
public E top() {
    assert !this.isEmpty();    // pre-condition
    return top.item;
}
```

✎ When should you check pre-conditions to methods?

✔ *Always check pre-conditions, raising exceptions if they fail.*

Checking class invariants

Every class has its own invariant:

```
protected boolean invariant() {
   return (size >= 0) &&
      ( (size == 0 && this.top == null)
      || (size > 0 && this.top != null));
}
```

Why protected and not private?

Checking post-conditions

Assert post-conditions and invariants to inform yourself when *you* violate the contract.

```
public void push(E item)  {
    top = new Cell(item, top);
    size++;
    assert !this.isEmpty();            // post-condition
    assert this.top() == item;         // post-condition
    assert invariant();
}
```

NB: This is all you have to do!

✎ When should you check post-conditions?

✔ *Check them whenever the implementation is non-trivial.*

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Example: Balancing Parentheses

Problem:

> Determine whether an expression containing parentheses ( ), brackets [ ] and braces { } is correctly balanced.

Examples:

> balanced:

```
if (a.b()) { c[d].e(); }
else { f[g][h].i(); }
```

> not balanced:

```
((a+b())
```

A simple algorithm

Approach:

> when you read a *left* parenthesis, *push the matching parenthesis* on a stack

> when you read a *right* parenthesis, *compare it* to the value on top of the stack
>
> —if they *match*, you *pop and continue*
>
> —if they *mismatch*, the expression is *not balanced*

> if the *stack is empty* at the end, the whole expression is *balanced*, otherwise not

Using a Stack to match parentheses

Sample input: “([{ }]]”

Input	*Case*	*Op*	*Stack*
(	left	push)	)
[	left	push]	)]
{	left	push }	)]}
}	match	pop	)]
]	match	pop	)
]	mismatch	^false	)

The ParenMatch class

A `ParenMatch` object *uses a stack* to check if parentheses in a text String are balanced:

```
public class ParenMatch {
   private String line;
   private StackInterface<Character> stack;

   public ParenMatch(String aLine,
                     StackInterface<Character> aStack) {
   {
      line = aLine;
      stack = aStack;
   }
```

A declarative algorithm

We implement our algorithm at a high level of abstraction:

```
public boolean parenMatch() {
   for (int i=0; i<line.length(); i++) {
      char c = line.charAt(i);
      if (isLeftParen(c)) { // expect matching right paren later
         stack.push(matchingRightParen(c)); // Autoboxed to Character
      } else {
         if (isRightParen(c)) {
            // empty stack => missing left paren
            if (stack.isEmpty()) { return false; }
            if (stack.top().equals(c)) { // Autoboxed
               stack.pop();
            } else { return false; } // mismatched paren
         }
      }
   }
   return stack.isEmpty(); // not empty => missing right paren
}
```

Ugly, procedural version

```
public boolean parenMatch() {
   char[] chars = new char[1000]; // ugly magic number
   int pos = 0;
   for (int i=0; i<line.length(); i++) {
      char c = line.charAt(i);
      switch (c) { // what is going on here?
      case '{' : chars[pos++] = '}'; break;
      case '(' : chars[pos++] = ')'; break;
      case '[' : chars[pos++] = ']'; break;
      case ']' : case ')' : case '}' :
         if (pos == 0) { return false; }
         if (chars[pos-1] == c) { pos--; }
         else { return false; }
         break;
      default : break;
      }
   }
   return pos == 0; // what is this?
}
```

Helper methods

The helper methods are trivial to implement, and their details only get in the way of the main algorithm.

```
private boolean isLeftParen(char c) {
   return (c == '(') || (c == '[') || (c == '{');
}

private boolean isRightParen(char c) {
   return (c == ')') || (c == ']') || (c == '}');
}
```

Running parenMatch

```
public static void parenTestLoop(StackInterface<Character> stack) {
    BufferedReader in =
        new BufferedReader(new InputStreamReader(System.in));
    String line;
    try {
        System.out.println("Please enter parenthesized expressions to test");
        System.out.println("(empty line to stop)");
        do {
            line = in.readLine();
            System.out.println(new ParenMatch(line, stack).reportMatch());
        } while(line != null && line.length() > 0);
        System.out.println("bye!");
    } catch (IOException err) {
    } catch (AssertionException err) {
        err.printStackTrace();
    }
}
```

Running ParenMatch.main ...

```
Please enter parenthesized expressions to test
(empty line to stop)
(hello) (world)
"(hello) (world)" is balanced
()
"()" is balanced
static public void main(String args[]) {
"static public void main(String args[]) {" is not balanced
()
"()" is not balanced
}
"}" is balanced

"" is balanced
bye!
```

Which contract has been violated?

What you should know!

- *What is an abstract data type?*
- *What is the difference between encapsulation and information hiding?*
- *How are contracts formalized by pre- and post-conditions?*
- *What is a class invariant and how can it be specified?*
- *What are assertions useful for?*
- *What situations may cause an exception to be raised?*
- *How can helper methods make an implementation more declarative?*

Can you answer these questions?

- ✎ *When should you call super() in a constructor?*
- ✎ *When should you use an inner class?*
- ✎ *What happens when you pop() an empty java.util.Stack? Is this good or bad?*
- ✎ *What impact do assertions have on performance?*
- ✎ *Can you implement the missing LinkStack methods?*

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