# Table of Contents

1. **P2 — Object-Oriented Programming**
   - Principle Texts: 2
   - Overview: 3
   - Goals of this course: 4
   - Goals ...: 5
   - What is programming?: 6
   - Programming and Software Development: 7
   - Programming activities: 8
   - What is a software system?: 9
   - What is good (bad) design?: 10
   - A procedural design: 11
   - An object-oriented approach: 12
   - Object-Oriented Design: 13
   - Responsibility-Driven Design: 14
   - Responsibility-Driven Design ...: 15
   - Refactoring: 16
   - What is Software Quality?: 17
   - Software Quality ...: 18
   - How to achieve software quality: 19
   - How to achieve software quality ...: 20
   - What is a programming language?: 21
   - Communication: 22
   - Why use object-oriented programming?: 23
   - Why use OOP? ...: 24
   - Why Java?: 25
   - History: 26
   - What you should know!: 27
   - Can you answer these questions?: 28

2. **Design by Contract**
   - Contracts: 29
   - Exceptions, failures and defects: 30
   - Stacks: 31
   - Example: Balancing Parentheses: 32
   - A simple algorithm: 33
   - Using a Stack to match parentheses: 34
   - The ParenMatch class: 35
   - A declarative algorithm: 36
   - A cluttered algorithm: 37
   - Helper methods: 38
   - What is Data Abstraction?: 39
   - StackInterface: 40
   - Interfaces in Java: 41
   - Exceptions: 42
   - Why are ADTs important?: 43
   - Why are ADTs important? ...: 44
   - Stacks as Linked Lists: 45
   - LinkStack Cells: 46
   - Private vs Public instance variables: 47
   - Naming instance variables: 48
   - LinkStack ADT: 49
   - Class Invariants: 50
   - LinkStack Class Invariant: 51
   - Programming by Contract: 52
   - Pre- and Postconditions: 53
   - Benefits and Obligations: 54
   - Stack pre- and postconditions: 55
   - Assertions: 56
   - Testing Assertions: 57
assert() in java 1.4
Testing Invariants
Disciplined Exceptions
Checking pre-conditions
Checking post-conditions
Running parenMatch
Running parenMatch ...
What you should know!
Can you answer these questions?

3. Testing and Debugging

Testing
Regression testing
Caveat: Testing and Correctness
Testing a Stack
Build simple test cases
Check that failures are caught
When (not) to use static methods
When (not) to use static variables
ArrayStack
Handling overflow
Checking pre-conditions
Testing ArrayStack
The Run-time Stack
The run-time stack in action ...
The Stack and the Heap
Fixing our mistake
java.util.Stack
Wrapping Objects
A Wrapped Stack
A Wrapped Stack ...
A contract mismatch
Fixing the problem ...

4. Iterative Development

The Classical Software Lifecycle
Iterative Development
What is Responsibility-Driven Design?
How to assign responsibility?
Example: Tic Tac Toe
Setting Scope
Setting Scope ...
Tic Tac Toe Objects
Tic Tac Toe Objects ...
Missing Objects
Scenarios
Version 1.0 (skeleton)
Version 1.1 (simple tests)
Checking pre-conditions
Testing the new methods
Testing the application
Printing the State
TicTacToe.toString()
Refining the interactions
Tic Tac Toe Contracts
Version 1.2 (functional)
Supporting test Players
Invariants
Delegating Responsibilities
Delegating Responsibilities ...
Small Methods
Accesor Methods
getters and setters in Java
Code Smells — TicTacToe.checkWinner()
Code Smells ...
Code Smells ...
GameDriver
The Player
Player constructors ...
Player constructors ...
Defining test cases
Checking test cases
Running the test cases
What you should know!
Can you answer these questions?

5. Inheritance and Refactoring
What is Inheritance?
Inheritance mechanisms
The Board Game
Uses of Inheritance
Uses of Inheritance ...
Class Diagrams
A bad idea ...
Class Hierarchy
Iterative development strategy
Iterative development strategy ...
Version 1.3 (add interface)
Speaking to an Interface
Quiet Testing
Quiet Testing (2)
NullPrintStream
TicTacToe adaptations
Version 1.4 (add abstract class)

Refactoring
Refactoring strategies
Version 1.5 (refactor for reusability)
AbstractBoardGame 1.5
BoardGame 1.5
Player 1.5
Version 1.6 (Gomoku)
Keeping Score
A new responsibility ...
The Runner
Top-down decomposition
Recursion
More helper methods
BoardGame 1.6
Gomoku
What you should know!
Can you answer these questions?

6. Programming Tools
Make
A Typical Makefile
Running make
Ant
A Typical build.xml
Running Ant
Version Control Systems
Version Control
RCS command overview
Using RCS
Additional RCS Features
CVS
Using CVS
7. A Testing Framework

The Problem

Testing Practices

JUnit

Frameworks vs. Libraries

The JUnit Framework

A Testing Scenario

Testing Style

Representing multiple currencies

Money

MoneyTest

8. Software Components: Collections

Components

The Jumble Puzzle

Naive Solution

Rethinking the Jumble Problem

Rethinking the Jumble Problem ...

An Efficient Solution

The Collections Framework

Collection Interfaces

Implementations

Interface and Abstract Classes

Maps

Jumble

Jumble constructor

Algorithms
Array algorithms 252
Sorting arrays of characters 253
Loading the dictionary 254
Loading the dictionary ... 255
The input loop 256
Running theunjumbler ... 257
Searching for anagrams 258
Iterators 259
Iterating through the key set 260
Running Jumble.maxAnagrams 261
How to use the framework 262
What you should know! 263
Can you answer these questions? 264

9. GUI Construction 265
A Graphical TicTacToe? 266
Applets 267
The Hello World Applet 268
The Hello World Applet 269
Accessing the game as an Applet 270
Model-View-Controller 271
AWT Components and Containers 272
The GameApplet 273
Laying out the GameApplet 274
Helper methods 275
Events and Listeners (I) 276
Events and Listeners (II) 277
Listening for Button events 278
Listening for mouse clicks 279
The PlaceListener 280
The PlaceListener ... 281
Observers and Observables 282
Observing the BoardGame 283
Observing the BoardGame ... 284
Communicating changes 285
Setting up the connections 286
Playing the game 287
Refactoring the BoardGame 288
Refactoring the BoardGame ... 289
GUI objects in practice ... 290
What you should know! 291
Can you answer these questions? 292

10. Clients and Servers 293
A Networked TicTacToe? 294
The concept 295
The problem 296
Remote Method Invocation 297
Why do we need RMI? 298
Developing an RMI application 299
Developing an RMI application ... 300
Designing client/server interfaces 301
BoardGame client/server interfaces 302
Identifying remote interfaces 303
Specifying remote interfaces 304
RemoteGameFactory 305
RemoteGame 306
RemoteObserver 307
Serializable objects 308
Implementing Remote objects 309
Implementing Remote objects ... 310
A simple view of synchronization 311
Registering a remote object 312
Registering a remote object ... 313
GameProxy 314
Using Threads to protect the server 315
Using Threads to protect the server ... 316
Refactoring the BoardGame ... 317
Compiling the code 318
Generating Stubs and Skeletons 319
Running the application 320
Playing the game 321
Caveat! 322
Other approaches 323
What you should know! 324
Can you answer these questions? 325

11. Guidelines, Idioms and Patterns 326
Sources 327
Style 328
Refactoring 329
What are Idioms and Patterns? 330
Delegation 331
Delegation example 333
Super 334
Super example 336
Interface 337
Interface example 339
Adapter 340
Adapter example 342
Proxy 343
Proxy example 345
Template Method 346

12. Common Errors, a few Puzzles 357
Trap 1 358
Trap 2 359
Trap 3 360
Trap 4 361
Trap 5 362
Trap 6 363
Trap 7 364
Avoiding Off-by-1 errors 365
Trap 8 366
Some other common errors 367
Puzzle 1 368
Static and Dynamic Types 369
Puzzle 2 (part I) 370
Puzzle 2 (part II) 371
Puzzle 3 372
Puzzle 4 (part I) 373
Puzzle 4 (part II) 374
Puzzle 5 375
What you should know! 376
Can you answer these questions? 377
Patterns, Rules and Guidelines

1. P2 — Object-Oriented Programming

2. Design by Contract

- How can clients accept multiple implementations of an ADT?
  - Make them depend only on an interface or an abstract class.
- When should instance variables be public?
  - Always make instance variables private or protected.
- How should you name a private or protected instance variable?
  - Pick a name that reflects the role of the variable.
  - Tag the name with an underscore (_).
- What should an object do if an assertion does not hold?
  - Throw an exception.
- When should an object throw an exception?
  - If and only if an assertion is violated.
- When should you check pre-conditions to methods?
  - Always check pre-conditions, raising exceptions if they fail.
- When should you check post-conditions?
  - Check them whenever the implementation is non-trivial.

3. Testing and Debugging

- What do you do with an object whose interface doesn’t fit your expectations?
  - You wrap it.
- Complexity aside, how can you tell which implementation strategy will perform best?
  - Run a benchmark.
# 4. Iterative Development

- Which responsibilities should an object accept? .............................................. 100
  - "Don't do anything you can push off to someone else." .................................. 100
- How much state should an object expose? ......................................................... 100
  - "Don't let anyone else play with you." ......................................................... 100
- How much functionality should you deliver in the first version of a system? .......... 103
  - Select the minimal requirements that provide value to the client. ...................... 103
- How can you tell when you have the “right” set of objects? ................................. 105
  - Each object has a clear and natural set of responsibilities. ............................... 105
- How can you tell if there are objects missing in your design? ............................ 106
  - When there are responsibilities left unassigned. ............................................. 106
- How do you iteratively “grow” a program? ....................................................... 108
  - Always have a running version of your program. ............................................. 108
- How do you make an object printable? .............................................................. 113
  - Override Object.toString(). ........................................................................... 113
- When should instance variables be public? ....................................................... 123
  - Almost never! Declare public accessor methods instead. .................................. 123

# 5. Inheritance and Refactoring

- When should you run your (regression) tests? ..................................................... 147
  - After every change to the system. ..................................................................... 147
- When should a class be declared abstract? ......................................................... 154
  - Declare a class abstract if it is intended to be subclassed, but not instantiated. .... 154
- Which methods should be public? ...................................................................... 168
  - Only publicize methods that clients will really need, and will not break encapsulation. 168

# 6. Programming Tools

- When should you use a version control system? .................................................. 181
  - Use it whenever you have one available, for even the smallest project! .............. 181
When should you use a debugger? ................................................................. 188
    When you are unsure why (or where) your program is not working. 188
When should you use a profiler? ........................................................ .......... 196
    Always run a profiler before attempting to tune performance. 196
How early should you start worrying about performance? ....................... 196
    Only after you have a clean, running program with poor performance. 196
7. A Testing Framework ................................................................................. 208
8. Software Components: Collections ....................................................... 237
    How do you iterate through a Collection whose elements are unordered? 258
        Use an iterator. 258
9. GUI Construction .................................................................................... 265
10. Clients and Servers ................................................................................... 293
    How can servers protect their state from concurrent requests? ............... 311
        Declare their public methods as synchronized. 311
11. Guidelines, Idioms and Patterns ............................................................ 326
    How can an object share behaviour without inheritance? ...................... 331
        Delegate some of its work to another object. 331
    How do you extend behaviour inherited from a superclass? .................. 334
        Overwrite the inherited method, and send a message to “super” in the new method. 334
    How do you keep a client of a service independent of classes that provide the service? 337
        Have the client use the service through an interface rather than a concrete class. 337
    How do you use a class that provide the right features but the wrong interface? 340
        Introduce an adapter. 340
    How do you hide the complexity of accessing objects that require pre- or post-processing? 343
        Introduce a proxy to control access to the object. 343
    How do you implement a generic algorithm, deferring some parts to subclasses? 346
        Define it as a Template Method. 346
How do you manage a part-whole hierarchy of objects in a consistent way?  

*Define a common interface that both parts and composites implement.*

How can an object inform arbitrary clients when it changes state?  

*Clients implement a common Observer interface and register with the “observable” object; the object notifies its observers when it changes state.*

12. Common Errors, a few Puzzles

© O. Nierstrasz — U. Berne
# 1. P2 — Object-Oriented Programming

| **Lecturer:** | Prof. Oscar Nierstrasz  
|              | Schützenmattstr. 14/103 |
| **Tel:**     | 031 631.4618 |
| **Email:**   | Oscar.Nierstrasz@iam.unibe.ch |
| **Assistants:** | Markus Gaelli <gaelli@iam.unibe.ch>  
|              | Marc Hugi, Joel Marbach, Andreas Wullimann |
| **WWW:**     | [www.iam.unibe.ch/~scg/Teaching/P2/](http://www.iam.unibe.ch/~scg/Teaching/P2/)  
|              | (includes full examples) |
Principle Texts:

## Overview

1. 03-28 Introduction
2. 04-04 Design by Contract
3. 04-11 Testing and Debugging
   04-18 **Good Friday**
4. 04-25 Iterative Development
5. 05-02 Inheritance and Refactoring
6. 05-09 Programming Tools
7. 05-16 A Testing Framework
8. 05-23 Collections
9. 05-30 GUI Construction
10. 06-06 Clients and Servers
11. 06-13 Guidelines, Idioms and Patterns
12. 06-20 Common Errors, a few Puzzles
   06-27 **Final Exam**
Goals of this course

Object-Oriented Design
- How to use responsibility-driven design to split systems into objects
- How to exploit inheritance to make systems generic and flexible
- How to iteratively refactor systems to arrive at simple, clean designs

Software Quality
- How to use design by contract to develop robust software
- How to test and validate software

...
Goals …

Communication

- How to keep software as *simple* as possible
- How to write software that *communicates* its design
- How to *document* a design

Skills, Techniques and Tools

- How to use debuggers, version control systems, profilers and other tools
- How and when to use standard software *components* and *architectures*
- How and when to apply common *patterns, guidelines* and *rules of thumb*
What is programming?

- Implementing data structures and algorithms?
- Writing instructions for machines?
- Implementing client specifications?
- Coding and debugging?
- Plugging together software components?
- Specification? Design?
- Testing?
- Maintenance?

Which of these are “not programming”?
Programming and Software Development

- How do you get your requirements?
- How do you know that the documented requirements reflect the user’s needs?
- How do you decide what priority to give each requirement?
- How do you select a suitable software architecture?
- How do you do detailed design?
- How do you know your implementation is “correct”? 
- How, when and what do you test?
- How do you accommodate changes in requirements?
- How do you know when you’re done?

Is “programming” distinct from “software development”?
Programming activities

- Documentation
- Prototyping
- Interface specification
- Integration
- Reviewing
- Refactoring
- Testing
- Debugging
- Profiling
- ...

What do these activities have in common?
What is a software system?

A *computer program* is an application that solves a *single task*:

- requirements are typically well-defined
- often single-user at a time
- little or no configuration required

A *software system* supports *multiple tasks*.

- open requirements
- multiple users
- implemented by a set of programs or modules
- multiple installations and configurations
- long-lived (never “finished”)

*Programming techniques address systems development by reducing complexity.*
What is good (bad) design?

Consider two programs with *identical behaviour*.

- Could the one be well-designed and the other badly-designed?
- What would this mean?
A procedural design

Problem: compute the total area of a set of geometric shapes

public static long sumShapes(Shape shapes[]) {
    long sum = 0;
    for (int i=0; i<shapes.length; i++) {
        switch (shapes[i].kind()) {
            case Shape.CIRCLE:
                sum += shapes[i].circleArea();
                break;
            case Shape.RECTANGLE:
                sum += shapes[i].rectangleArea();
                break;
            ...  // more cases
        }
    }
    return sum;
}
An object-oriented approach

A typical object-oriented solution:

```java
public static long sumShapes(Shape shapes[]) {
    long sum = 0;
    for (int i=0; i<shapes.length; i++) {
        sum += shapes[i].area();
    }
    return sum;
}
```

What are the advantages and disadvantages of the two solutions?
Object-Oriented Design

**OO vs. functional design ...**

*Object-oriented [design] is the method which bases the architecture of any software system on the objects it manipulates* (rather than “the” function it is meant to ensure).

*Ask not first what the system does: ask what it does it to!*

— Meyer, OOSC
Responsibility-Driven Design

RDD factors a software system into objects with well-defined responsibilities:

- Objects are responsible to maintain information and provide services:
  - Operations are always associated to responsible objects
  - Always delegate to another object what you cannot do yourself

- A good design exhibits:
  - high cohesion of operations and data within classes
  - low coupling between classes and subsystems

...
Responsibility-Driven Design ...

- Every method should perform **one, well-defined task**:
  - Separation of concerns — reduce complexity
  - High level of abstraction — *write to an interface, not an implementation*

- **Iterative Development**
  - *Refactor* the design as it evolves
Refactoring

Refactor your design whenever the code starts to hurt:

- methods that are too long or hard to read
  - decompose and delegate responsibilities
- duplicated code
  - factor out the common parts (template methods etc.)
- violation of encapsulation, or
- too much communication between objects (high coupling)
  - reassign responsibilities
- big case statements
  - introduce subclass responsibilities
- hard to adapt to different contexts
  - separate mechanism from policy

...
What is Software Quality?

**Correctness** is the ability of software products to perform their exact tasks, as defined by their specifications.

**Robustness** is the ability of software systems to react appropriately to abnormal conditions.

**Extendibility** is the ease of adapting software products to changes of specification.

**Reusability** is the ability of software elements to serve for the construction of many different applications.

...
Software Quality ...

Compatibility is the ease of combining software elements with others

Efficiency is the ability of a software system to place as few demands as possible on hardware resources

Portability is the ease of transferring software products to various hardware and software environments

Ease of use is the ease with which people of various backgrounds and qualifications can learn to use software products

— Meyer, OOSC, ch. 1
How to achieve software quality

Design by Contract
- **Assertions** (pre- and post-conditions, class invariants)
- Disciplined exceptions

Standards
- Protocols, components, libraries, frameworks with standard **interfaces**
- Software **architectures**, design **patterns**

...
How to achieve software quality ...

Testing and Debugging

- Unit tests, system tests ...
- Repeatable regression tests

Do it, do it right, do it fast

- Aim for simplicity and clarity, not performance
- Fine-tune performance only when there is a demonstrated need!
What is a programming language?

A programming language is a tool for:

- specifying instructions for a computer
- expressing data structures and algorithms
- communicating a design to another programmer
- describing software systems at various levels of abstraction
- specifying configurations of software components

A programming language is a tool for communication!
Communication

How do you write code that communicates its design?

❑ Do the simplest thing you can think of (KISS)
  ❆ Don't over-design
  ❆ Implement things *once and only once*

❑ Program so your code is (largely) self-documenting
  ❆ Write *small methods*
  ❆ Say what you want to do, not how to do it

❑ Practice reading and using other people’s code
  ❆ Subject your code to *reviews*
Why use object-oriented programming?

Modelling
- complex systems can be naturally decomposed into software objects

Data abstraction
- Clients are protected from variations in implementation

Polymorphism
- clients can uniformly manipulate plug-compatible objects

...
Why use OOP? ...

Component reuse
- client/supplier contracts can be made explicit, simplifying reuse

Evolution
- classes and inheritance limit the impact of changes
Why Java?

Special characteristics
- Resembles C++ minus the complexity
- Clean integration of many features
- Dynamically loaded classes
- Large, standard class library

Simple Object Model
- “Almost everything is an object”
- No pointers
- Garbage collection
- Single inheritance; multiple subtyping
- Static and dynamic type-checking

Few innovations, but reasonably clean, simple and usable.
What you should know!

✎ What is the difference between a computer program and a software system?
✎ What defines a good object-oriented design?
✎ When does software need to be refactored? Why?
✎ What is “software quality”?
✎ How does OOP attempt to ensure high software quality?
Can you answer these questions?

✎ What does it mean to “violate encapsulation”? Why is that bad?
✎ Why shouldn’t you try to design your software to be efficient from the start?
✎ Why (when) are case statements bad?
✎ When might it be “all right” to duplicate code?
✎ How do you program classes so they will be “reusable”? Are you sure?
✎ Which is easier to understand — a procedural design or an object-oriented one?
2. Design by Contract

Overview
- Declarative programming and Data Abstraction
- Abstract Data Types
- Class Invariants
- Programming by Contract: pre- and post-conditions
- Assertions and Disciplined Exceptions

Source
Contracts

Service Contract:
if
precondition fulfilled
then
postcondition guaranteed

If either client or server does not (or cannot) respect the contract, exception is signalled.
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.

Contracts may fail due to defects in the client or server code. Failure should be signalled by raising an exception.
Stacks

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

<table>
<thead>
<tr>
<th>Operation</th>
<th>Stack</th>
<th>isEmpty()</th>
<th>size()</th>
<th>top()</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[]</td>
<td>true</td>
<td>0</td>
<td>(error)</td>
</tr>
<tr>
<td>push(6)</td>
<td>6</td>
<td>false</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>push(7)</td>
<td>6 7</td>
<td>false</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>push(3)</td>
<td>6 7 3</td>
<td>false</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>pop()</td>
<td>6 7</td>
<td>false</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>push(2)</td>
<td>6 7 2</td>
<td>false</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>pop()</td>
<td>6 7</td>
<td>false</td>
<td>2</td>
<td>7</td>
</tr>
</tbody>
</table>

Stacks support two mutating methods: push and pop.
Example: Balancing Parentheses

Problem:

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

Examples:

<table>
<thead>
<tr>
<th>balanced</th>
<th>if (a.b()) { c[d].e(); }</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>else { f[g][h].i(); }</td>
</tr>
<tr>
<td>not balanced</td>
<td>((a+b()))</td>
</tr>
</tbody>
</table>
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: “( [ { } ] ]”

<table>
<thead>
<tr>
<th>Input</th>
<th>Case</th>
<th>Op</th>
<th>Stack</th>
</tr>
</thead>
<tbody>
<tr>
<td>(</td>
<td>left</td>
<td>push )</td>
<td>(</td>
</tr>
<tr>
<td>[</td>
<td>left</td>
<td>push ]</td>
<td>) ]</td>
</tr>
<tr>
<td>{</td>
<td>left</td>
<td>push }</td>
<td>) ]</td>
</tr>
<tr>
<td>}</td>
<td>match</td>
<td>pop</td>
<td>} ]</td>
</tr>
<tr>
<td>]</td>
<td>match</td>
<td>pop</td>
<td>) ]</td>
</tr>
<tr>
<td>]</td>
<td>mismatch</td>
<td>^false</td>
<td>) ]</td>
</tr>
</tbody>
</table>
The ParenMatch class

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

```java
public class ParenMatch {
    String line_;  
    StackInterface stack_; 

    public ParenMatch (String line,  
                        StackInterface stack) 
    {
        line_ = line; 
        stack_ = stack; 
    }
} 
```
A declarative algorithm

We implement our algorithm at a **high level of abstraction**:

```java
public boolean parenMatch() ... {
    for (int i=0; i<line_.length(); i++) { ...
        if (isLeftParen(c)) { // expect match later
            stack_.push(...(matchingRightParen(c)));
        } else {
            if (isRightParen(c)) { // should equal top
                if (stack_.isEmpty()) { return false; }
                if (stack_.top().equals(new Character(c))) {
                    stack_.pop();
                } else { return false; } }
        } } 
    return stack_.isEmpty(); // balanced if empty
}
```
public boolean parenMatch() throws AssertionException {
    for (int i=0; i<line_.length(); i++) {
        char c = line_.charAt(i);
        switch (c) {
        case '{' : stack_.push(new Character('}')); break;
        case '(' : stack_.push(new Character(')')); break;
        case '[' : stack_.push(new Character(']')); break;
        case ']' : case ')' : case '}' :
            if (stack_.isEmpty()) { return false; }
            if (((Character) stack_.top()).charValue() == c) {
                stack_.pop();
            } else { return false; }
            break;
        default : break;
    }
    return stack_.isEmpty();
}
Helper methods

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

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

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

...
What is Data Abstraction?

An implementation of a stack consists of:

- a data structure to represent the state of the stack
- a set of operations that access and modify the stack

Encapsulation means bundling together related entities.

Information hiding means exposing an abstract interface and hiding the rest.

An Abstract Data Type (ADT):

- encapsulates data and operations, and
- hides the implementation behind a well-defined interface.
StackInterface

Interfaces let us *abstract* from concrete implementations:

```java
public interface StackInterface {
    public boolean isEmpty();
    public int size();
    public void push(Object item) throws AssertionError;
    public Object top() throws AssertionError;
    public void pop() throws AssertionError;
}
```

**How can clients accept multiple implementations of an ADT?**

✔ *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 ADT that will have more than one implementation
Exceptions

*All Exception classes look like this!*

Define your own exception class to *distinguish* your exceptions from any other kind.

```java
public class AssertionException extends Exception {
    AssertionException() { super(); }
    AssertionException(String s) { super(s); }
}
```

The implementation consists of a default constructor, and a constructor that takes a simple message string as an argument. Both constructors *call super()* to ensure that the instance is *properly initialized.*
Why are ADTs important?

Communication

- An ADT exports *what a client needs to know*, and nothing more!
- By using ADTs, you communicate *what you want to do*, not how to do it!
- ADTs allow you to *directly model your problem domain* rather than how you will use to the computer to do so.

...
Why are ADTs important? …

Software Quality and Evolution

- ADTs help to decompose a system into manageable parts, each of which can be separately implemented and validated.
- ADTs protect clients from changes in implementation.
- ADTs encapsulate client/server contracts.
- Interfaces to ADTs can be extended without affecting clients.
- New implementations of ADTs can be transparently added to a system.
Stacks as Linked Lists

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

- size = 2, top = 7
- size = 3, top = 3

stack.push(3)

stack.pop()
LinkStack Cells

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

```java
public class LinkStack implements StackInterface {
    private Cell top_;

    public class Cell {
        public Object item;
        public Cell next;
        public Cell(Object 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!
Naming instance variables

➤ How should you name a private or protected instance variable?

✔ Pick a name that reflects the role of the variable.
✔ Tag the name with an underscore (_).

Role-based names tell the reader of a class what the purpose of the variables is.

A tagged name reminds the reader that a variable represents hidden state.
LinkStack ADT

The constructor must construct a *valid initial state*:

```java
public class LinkStack implements StackInterface {
    ...
    private int size_;  
    public LinkStack() {
        // Establishes the 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 \(\geq 0\)**

...
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
Programming by Contract

Every ADT is designed to provide certain services given certain assumptions hold.

An ADT establishes a contract with its clients by associated a precondition and a postcondition to every operation O, which states:

“If you promise to call O with the precondition satisfied, then I, in return, promise to deliver a final state in which the postcondition is satisfied.”

Consequence:

- if the precondition does not hold, the ADT is not required to provide anything!
Pre- and Postconditions

The precondition **binds clients:**
- it defines what the ADT **requires** for a call to the operation to be legitimate.
- it may involve initial state and arguments.

The postcondition, in return, **binds the supplier:**
- it defines the conditions that the ADT **ensures** on return.
- it may only involve the initial and final states, the arguments and the result.
## Benefits and Obligations

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

<table>
<thead>
<tr>
<th>Obligations</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Client</strong></td>
<td></td>
</tr>
<tr>
<td>Only call <code>pop()</code> on a non-empty stack!</td>
<td>Stack size decreases by 1. Top element is removed.</td>
</tr>
<tr>
<td><strong>Supplier</strong></td>
<td></td>
</tr>
<tr>
<td>Decrement the <code>size</code>. Remove the top element.</td>
<td>No need to handle case when stack is empty!</td>
</tr>
</tbody>
</table>
# Stack pre- and postconditions

Our Stacks should deliver the following contract:

<table>
<thead>
<tr>
<th>Operation</th>
<th>Requires</th>
<th>Ensures</th>
</tr>
</thead>
<tbody>
<tr>
<td>isEmpty()</td>
<td>-</td>
<td>no state change</td>
</tr>
<tr>
<td>size()</td>
<td>-</td>
<td>no state change</td>
</tr>
<tr>
<td>push(Object item)</td>
<td>item != null</td>
<td>not empty, size == old size + 1, top == item</td>
</tr>
<tr>
<td>top()</td>
<td>not empty</td>
<td>no state change</td>
</tr>
<tr>
<td>pop()</td>
<td>not empty</td>
<td>size == old size -1</td>
</tr>
</tbody>
</table>
Assertions

An **assertion** is any boolean expression we expect to be true at some point:

**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
Testing Assertions

It is easy to add an assertion-checker to a class:

```java
private void assert(boolean assertion) throws AssertionException {
    if (!assertion) {
        throw new AssertionException("Assertion failed in LinkStack");
    }
}
```

➤ What should an object do if an assertion does not hold?
✔ Throw an exception.
assert() in java 1.4

assert is a keyword in Java as of version 1.4

assert expression;

will raise an AssertionError if expression is false.

See java.sun.com for more details
Testing Invariants

Every class has its own invariant:

```java
private boolean invariant() {
    return (size_ >= 0) &&
    ( (size_ == 0 && this.top_ == null)
    || (size_ > 0 && this.top_ != null));
}
```
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

*It is not acceptable to return control to the client without special notification.*

➤ **When should an object throw an exception?**
✔ **If and only if an assertion is violated**

*If it is not possible to run your program without raising an exception, then you are abusing the exception-handling mechanism!*
Checking pre-conditions

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

```java
public Object top() throws AssertionException {
    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 post-conditions

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

```java
public void push(Object item)
    throws AssertionException {
    assert(item != null);
    top_ = new Cell(item, top_);
    size_++;
    assert(!this.isEmpty());  // post-condition
    assert(this.top() == item);  // post-condition
    assert(invariant());
}
```

➤ When should you check post-conditions?
✔ Check them whenever the implementation is non-trivial.
Running parenMatch

```java
public static void parenMatchLoop(StackInterface stack) {
    BufferedReader in =
        new BufferedReader(new InputStreamReader(System.in));
    String line;
    try {
        System.out.println("Enter a parenthesized expression");
        System.out.println("(empty line to stop)" tool);  
        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 ...

```
java -cp stack.jar TestStack
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!

g️ Which contract is being violated?
```
What you should know!

✎ How can helper methods make an implementation more declarative?
✎ What is the difference between encapsulation and information hiding?
✎ What is an assertion?
✎ 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?
✎ How can exceptions be used to improve program robustness?
✎ What situations may cause an exception to be raised?
Can you answer these questions?

✎ Why is strong coupling between clients and suppliers a bad thing?
✎ When should you call super() in a constructor?
✎ When should you use an inner class?
✎ How would you write a general assert() method that works for any 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?
3. Testing and Debugging

Overview

- Testing — definitions
- Testing various Stack implementations
- Understanding the run-time stack and heap
- Wrapping — a simple integration strategy
- Timing benchmarks

Source

## Testing

<table>
<thead>
<tr>
<th><strong>Unit testing:</strong></th>
<th>test <em>individual</em> (stand-alone) components</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Module testing:</strong></td>
<td>test a <em>collection of related</em> components (a module)</td>
</tr>
<tr>
<td><strong>Sub-system testing:</strong></td>
<td>test sub-system <em>interface mismatches</em></td>
</tr>
<tr>
<td><strong>System testing:</strong></td>
<td>(i) test <em>interactions</em> between sub-systems, and (ii) test that the complete systems fulfils <em>functional</em> and <em>non-functional</em> requirements</td>
</tr>
<tr>
<td><strong>Acceptance testing (alpha/beta testing):</strong></td>
<td>test system with <em>real</em> rather than simulated <em>data</em>.</td>
</tr>
</tbody>
</table>

*Testing is always iterative!*
Regression testing

Regression testing means testing that everything that used to work still works after changes are made to the system!

- tests must be deterministic and repeatable
- should test “all” functionality
  - every interface
  - all boundary situations
  - every feature
  - every line of code
  - everything that can conceivably go wrong!

It costs extra work to define tests up front, but they pay off in debugging & maintenance!
Caveat: Testing and Correctness

Testing can only reveal the presence of defects, not their absence!
Testing a Stack

We define a simple regression test that exercises all StackInterface methods and checks the boundary situations:

```java
static public void testStack(StackInterface stack) {
    try {
        System.out.print("Testing "+ stack.getClass().getName() + " ... ");
        // asserts stack.isEmpty()
        System.out.println("passed all tests!");
        ... // more tests here ...
        System.out.println("passed all tests!");
    } catch (Exception err) { // NB: any kind!
        err.printStackTrace();
    }
}
```
Build simple test cases

Construct a test case and check the obvious conditions:

```java
for (int i=1; i<=10; i++) {
    stack.push(new Integer(i));
}
assert(!stack.isEmpty());
assert(stack.size() == 10);
assert(((Integer) stack.top()).intValue() == 10);
```

What other test cases do you need to fully exercise a Stack implementation?
Check that failures are caught

How do we check that an assertion *fails* when it should?

```java
... assert(stack.isEmpty()); //
boolean emptyPopCaught = false;
try {
    // we expect pop() to raise an exception
    stack.pop();
} catch(AssertionException err) {
    // we should get here!
    emptyPopCaught = true;
}
assert(emptyPopCaught); // should be true
```
When (not) to use static methods

A **static** method *belongs to a class*, not an object.

- Static methods can be called without instantiating an object
  - necessary for *starting the main program*
  - necessary for *constructors and factory methods*
  - useful for *test methods*

- Static methods are *just procedures!*
  - avoid them in OO designs!
  - (counter-)example: *utilities* (java.lang.Math)

...
When (not) to use static variables

A **static** instance variable also *belongs to a class*, not an object.

- Static instance variables can be accessed without instantiating an object
  — useful for representing data *shared by all instances* of a class

- Static variables are **global variables**!
  🚫 avoid them in OO designs!
ArrayStack

We can also implement a (variable) Stack using a (fixed-length) array to store its elements:

```java
public class ArrayStack implements StackInterface {
    Object store_[] = null; // default value
    int capacity_ = 0;       // current size of store
    int size_ = 0;           // number of used slots
    ...
}
```

What would be a suitable class invariant for ArrayStack?
Handling overflow

Whenever the array runs out of space, the Stack “grows” by allocating a larger array, and copying elements to the new array.

```java
public void push(Object item)
    throws AssertionException
{
    if (size_ == capacity_)
        grow();
    store_[++size_] = item;  // NB: subtle error!
}
```

✎ How would you implement the grow() method?
Checking pre-conditions

public boolean isEmpty() { return size_ == 0; }
public int size() { return size_; }

public Object top() throws AssertionException {
    assert(!this.isEmpty());
    return store_[size_-1];
}
public void pop() throws AssertionException {
    assert(!this.isEmpty());
    size_--;
}

NB: we only check pre-conditions in this version!
◆ Should we also shrink() is the Stack gets too small?
Testing ArrayStack

When we test our ArrayStack, we get a surprise:

Testing ArrayStack ...

```
ge.java.lang.ArrayIndexOutOfBoundsException: 2
  at ArrayStack.push(ArrayStack.java:28)
  at TestStack.testStack(Compiled Code)
  at TestStack.main(TestStack.java:12)
  at com.apple.mrj.JManager.JMStaticMethodDispatcher.run(JM-AWTContextImpl.java:796)
  at java.lang.Thread.run(Thread.java:474)
```

Exception.printStackTrace() tells us exactly where the exception occurred ...
The Run-time Stack

The run-time stack is a fundamental data structure used to record the context of a procedure that will be returned to at a later point in time. This context (AKA "stack frame") stores the arguments to the procedure and its local variables.

Practically all programming languages use a run-time stack:

```java
public static void main(String args[]) {
    System.out.println( "fact(3) = " + fact(3));
}

public static int fact(int n) {
    if (n<=0) { return 1; } else { return n*fact(n-1); }
}
```
The run-time stack in action ...

A stack frame is *pushed* with each procedure call ...

```
main ...

fact(3) = n=3; ...

fact(3) = n=3; fact(2) = n=2; fact(2) ...

fact(3) = n=3; fact(2) = n=2; fact(1) = n=1; fact(1) ...

fact(3) = n=3; fact(2) = n=2; fact(1) = n=1; fact(0) = n=0; fact(0) ...

fact(3) = n=3; fact(2) = n=2; fact(1) = n=1; fact(0) = return 1

fact(3) = n=3; fact(2) = n=2; fact(1) = return 1

fact(3) = n=3; fact(2) = return 2

fact(3) = return 6

fact(3) = 6
```

... and *popped* with each return.
The Stack and the Heap

The Heap grows with each new Object created, and shrinks when Objects are garbage-collected.
Fixing our mistake

We erroneously used the *incremented* size as an index into the store, instead of the *new* size - 1:

```java
public void push(Object item) ... {
    if (size_ == capacity_) { grow(); }  
    store_[size_++] = item;  // old size = new size-1
    assert(this.top() == item);  
    assert(invariant());
}
```

*NB: perhaps it would be clearer to write:*

```java
store_[this.topIndex()] = item;
```
java.util.Stack

Java also provides a Stack implementation, but it is not compatible with our interface:

```java
public class Stack extends Vector {
    public Stack();
    public Object push(Object item);
    public synchronized Object pop();
    public synchronized Object peek();
    public boolean empty();
    public synchronized int search(Object o);
}
```

*If we change our programs to work with the Java Stack, we won't be able to work with our own Stack implementations ...*
Wrapping Objects

Wrapping is a fundamental programming technique for systems integration.

➤ What do you do with an object whose interface doesn’t fit your expectations?
✔ You wrap it.

℧ What are possible disadvantages of wrapping?
A Wrapped Stack

A wrapper class implements a required interface, by delegating requests to an instance of the wrapped class:

```java
import java.util.Stack;
public class SimpleWrappedStack implements StackInterface {
    protected Stack stack_; public SimpleWrappedStack() {
        stack_ = new Stack(); // wrapped instance
    }
    public boolean isEmpty() {
        return stack_.isEmpty(); // delegation
    }
    ...
```
A Wrapped Stack ...

```java
public int size() {
    return stack_.size();
}
public Object top() throws AssertionError {
    return stack_.peek();
}
public void pop() throws AssertionError {
    stack_.pop();
}
... // similar for push()
```

✎ Do you see any flaws with our wrapper class?
A contract mismatch

But running `testStack(new SimpleWrappedStack())` yields:

```
Testing SimpleWrappedStack ...
java.util.EmptyStackException
at java.util.Stack.peek(Stack.java:78)
at java.util.Stack.pop(Stack.java:60)
at SimpleWrappedStack.pop(SimpleWrappedStack.java:29)
at TestStack.testStack(Compiled Code)
at TestStack.main(TestStack.java:13)
at com.apple.mrj.JManager.JMStaticMethodDispatcher.run(JMAWTContextImpl.java:796)
at java.lang.Thread.run(Thread.java:474)
```

What went wrong?
Fixing the problem ...

Our tester expects an empty Stack to throw an exception when it is popped, but java.util.Stack doesn't do this — so our wrapper should check its preconditions!

```java
public class WrappedStack extends SimpleWrappedStack {

    public Object top() throws AssertionException {
        assert(!this.isEmpty());
        return super.top();
    }

    public void pop() throws AssertionException {
        assert(!this.isEmpty());
        super.pop();
    }

    ...
```
Timing benchmarks

Which of the Stack implementations performs better?

```java
timer.reset();
for (int i=0; i<iterations; i++) {
    stack.push(item);
}
elapsed = timer.timeElapsed();
System.out.println(elapsed + " milliseconds for " + iterations + " pushes");
...
➤ Complexity aside, how can you tell which implementation strategy will perform best?
✔ Run a benchmark.
```
import java.util.Date;

public class Timer {
    protected Date startTime_; // Abstract from the details of timing
    public Timer() {
        this.reset();
    }
    public void reset() {
        startTime_ = new Date();
    }
    public long timeElapsed() {
        return new Date().getTime() - startTime_.getTime();
    }
}

// Abstract from the details of timing
### Sample benchmarks (milliseconds)

<table>
<thead>
<tr>
<th>Java VM</th>
<th>Stack Implementation</th>
<th>100K pushes</th>
<th>100K pops</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Apple MRJ</strong></td>
<td>LinkStack</td>
<td>2809</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>ArrayStack</td>
<td>474</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>WrappedStack</td>
<td>725</td>
<td>293</td>
</tr>
<tr>
<td><strong>Metrowerks</strong></td>
<td>LinkStack</td>
<td>5151</td>
<td>1236</td>
</tr>
<tr>
<td></td>
<td>ArrayStack</td>
<td>1519</td>
<td>681</td>
</tr>
<tr>
<td></td>
<td>WrappedStack</td>
<td>8748</td>
<td>8249</td>
</tr>
<tr>
<td><strong>MW JIT</strong></td>
<td>LinkStack</td>
<td>3026</td>
<td>189</td>
</tr>
<tr>
<td></td>
<td>ArrayStack</td>
<td>877</td>
<td>94</td>
</tr>
<tr>
<td></td>
<td>WrappedStack</td>
<td>5927</td>
<td>5318</td>
</tr>
</tbody>
</table>

 пен Can you explain these results? Are they what you expected?
What you should know!

- What is a regression test? Why is it important?
- When should you (not) use static methods?
- What strategies should you apply to design a test?
- What are the run-time stack and heap?
- How can you adapt client/supplier interfaces that don’t match?
- When are benchmarks useful?
Can you answer these questions?

🔹 Why can’t you use tests to demonstrate absence of defects?
🔹 How would you implement ArrayStack.grow()?
🔹 Why doesn’t Java allocate objects on the run-time stack?
🔹 What are the advantages and disadvantages of wrapping?
🔹 What is a suitable class invariant for WrappedStack?
🔹 How can we learn where each Stack implementation is spending its time?
🔹 How much can the same benchmarks differ if you run them several times?
4. Iterative Development

Overview

- Iterative development
- Responsibility-Driven Design
  - How to find the objects ...
  - TicTacToe example ...

Sources

The Classical Software Lifecycle

The classical software lifecycle models the software development as a step-by-step “waterfall” between the various development phases.

The waterfall model is unrealistic for many reasons, especially:

- requirements must be “frozen” too early in the life-cycle
- requirements are validated too late
Iterative Development

In practice, development is always iterative, and all software phases progress in parallel.

If the waterfall model is pure fiction, why is it still the standard software process?
What is Responsibility-Driven Design?

Responsibility-Driven Design is
- a method for deriving a software design in terms of collaborating objects
- by asking what responsibilities must be fulfilled to meet the requirements,
- and assigning them to the appropriate objects (i.e., that can carry them out).
How to assign responsibility?

Pelrine’s Laws:

➤ Which responsibilities should an object accept?
✔ “Don’t do anything you can push off to someone else.”

➤ How much state should an object expose?
✔ “Don’t let anyone else play with you.”

RDD leads to \textit{fundamentally different} designs than those obtained by functional decomposition or data-driven design. \textit{Class responsibilities} tend to be more \textit{stable over time} than functionality or representation.
Example: Tic Tac Toe

Requirements:

“A simple game in which one player marks down only crosses and another only ciphers [zeroes], each alternating in filling in marks in any of the nine compartments of a figure formed by two vertical lines crossed by two horizontal lines, the winner being the first to fill in three of his marks in any row or diagonal.”

— Random House Dictionary

We should design a program that implements the rules of Tic Tac Toe.
Setting Scope

Questions:
- Should we support other games?
- Should there be a graphical UI?
- Should games run on a network? Through a browser?
- Can games be saved and restored?

*A monolithic paper design is bound to be wrong!*

...
Setting Scope ...

An iterative development strategy:

- limit initial scope to the minimal requirements that are interesting
- grow the system by adding features and test cases
- let the design emerge by refactoring roles and responsibilities

➤ How much functionality should you deliver in the first version of a system?
✔ Select the minimal requirements that provide value to the client.
Tic Tac Toe Objects

Some objects can be identified from the requirements:

<table>
<thead>
<tr>
<th>Objects</th>
<th>Responsibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Game</td>
<td>Maintain game rules</td>
</tr>
<tr>
<td>Player</td>
<td>Make moves</td>
</tr>
<tr>
<td></td>
<td>Mediate user interaction</td>
</tr>
<tr>
<td>Compartment</td>
<td>Record marks</td>
</tr>
<tr>
<td>Figure (State)</td>
<td>Maintain game state</td>
</tr>
</tbody>
</table>

Entities with clear responsibilities are more likely to end up as objects in our design.

...
Others can be eliminated:

<table>
<thead>
<tr>
<th>Non-Objects</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crosses, ciphers</td>
<td>Same as Marks</td>
</tr>
<tr>
<td>Marks</td>
<td>Value of Compartment</td>
</tr>
<tr>
<td>Vertical lines</td>
<td>Display of State</td>
</tr>
<tr>
<td>Horizontal lines</td>
<td>ditto</td>
</tr>
<tr>
<td>Winner</td>
<td>State of Player</td>
</tr>
<tr>
<td>Row</td>
<td>View of State</td>
</tr>
<tr>
<td>Diagonal</td>
<td>ditto</td>
</tr>
</tbody>
</table>

➤ How can you tell when you have the “right” set of objects?
✔ Each object has a clear and natural set of responsibilities.
Missing Objects

Now we check if there are *unassigned responsibilities*:

- Who starts the Game?
- Who is responsible for displaying the Game state?
- How do Players know when the Game is over?

Let us introduce a *Driver* that supervises the Game.

➤ How can you tell if there are objects missing in your design?
✔ When there are responsibilities left unassigned.
Scenarios

A scenario describes a typical sequence of interactions:

Are there other equally valid scenarios for this problem?
Version 1.0 (skeleton)

Our first version does very little!

```java
class GameDriver {
    static public void main(String args[]) {
        TicTacToe game = new TicTacToe();
        do { System.out.print(game); } 
        while(game.notOver());
    }

    public class TicTacToe {
        public boolean notOver() { return false; }
        public String toString() { return("TicTacToe\n"); }
    }
}
```

➤ How do you iteratively “grow” a program?
✔ Always have a running version of your program.
Version 1.1 (simple tests)

The state of the game is represented as a 3x3 array of chars marked "", 'X', or 'O'. We index the state using chess notation, i.e., column is 'a' through 'c' and row is '1' through '3'.

```java
public class TicTacToe {
    private char[][] gameState_;
    public TicTacToe() {
        gameState_ = new char[3][3];
        for (char col='a'; col <= 'c'; col++)
            for (char row='1'; row <= '3'; row++)
                this.set(col, row, ' ');
    }
    ...
```

Checking pre-conditions

set() and get() translate from chess notation to array indices.

```java
private void set(char col, char row, char mark) {
    assert(inRange(col, row)); // NB: precondition
    gameState_[col-'a'][row-'1'] = mark;
}
private char get(char col, char row) {
    assert(inRange(col, row));
    return gameState_[col-'a'][row-'1'];
}
private boolean inRange(char col, char row) {
    return ('a'<=col) && (col<='c')
             && ('1'<=row) && (row<='3'));
}
```
Testing the new methods

For now, we just exercise the new set() and get() methods:

```java
public void test() {
    System.err.println("Started TicTacToe tests");
    assertEquals(this.get('a','1') == ' ');
    assertEquals(this.get('c','3') == ' ');
    this.set('c','3','X');
    assertEquals(this.get('c','3') == 'X');
    this.set('c','3',' '); 
    assertEquals(this.get('c','3') == ' ');
    assertEquals(!this.inRange('d','4'));
    System.err.println("Passed TicTacToe tests");
}
```
Testing the application

If each class provides its own test() method, we can bundle our unit tests in a single driver class:

```java
class TestDriver {
    static public void main(String args[]) {
        TicTacToe game = new TicTacToe();
        game.test();
    }
}
```
Printing the State

By re-implementing `TicTacToe.toString()`, we can view the state of the game:

```
   3    |   |   
   ---+---+---
   2    |   |    ---+---+---
   1    |   |     a   b   c
   1    |   |    ---+---+---
   a    |   |   
```

➤ How do you make an object printable?
✔ Override `Object.toString()`
TicTacToe.toString()

Use a StringBuffer (not a String) to build up the representation:

```java
public String toString() {
    StringBuffer rep = new StringBuffer();
    for (char row='3'; row>='1'; row--) {
        rep.append(row);
        rep.append("   ");
        for (char col='a'; col <= 'c'; col++) {
            ...
        }
    }
    rep.append("   a   b   c
    ");
    return(rep.toString());
}
```
Refining the interactions

We will want both *real* and *test* Players, so the *Driver* should create them.

*Updating* the Game and *printing* it should be *separate operations*.

The Game should *ask* the Player to make a move, and then the Player will *attempt* to do so.
Tic Tac Toe Contracts

Explicit invariants:
- turn (current player) is either X or O
- X and O swap turns (turn never equals previous turn)
- game state is 3×3 array marked X, O or blank
- winner is X or O iff winner has three in a row

Implicit invariants:
- initially winner is nobody; initially it is the turn of X
- game is over when all squares are occupied, or there is a winner
- a player cannot mark a square that is already marked

Contracts:
- the current player may make a move, if the invariants are respected
Version 1.2 (functional)

We must introduce state variables to implement the contracts

```java
public class TicTacToe {
    private char[][] gameState_;
    private Player winner_ = new Player(); // = nobody
    private Player[] player_;
    private int turn_ = X; // initial turn
    private int squaresLeft_ = 9;
    static final int X = 0; // constants
    static final int O = 1;
    ...
```
Supporting test Players

The Game no longer instantiates the Players, but accepts them as constructor arguments:

```java
public TicTacToe(Player playerX, Player playerO)
    throws AssertionException
{
    // ...
    player_ = new Player[2];
    player_[X] = playerX;
    player_[O] = playerO;
}
```
Invariants

These conditions may seem obvious, which is exactly why they should be checked ...

```java
private boolean invariant() {
    return (turn_ == X || turn_ == O)
        && (this.notOver() ||
            this.winner() == player_[X] ||
            this.winner() == player_[O] ||
            this.winner().isNobody())
        && (squaresLeft_ < 9 // else, initially:
            || turn_ == X && this.winner().isNobody());
}
```

Assertions and tests often tell us what methods should be implemented, and whether they should be public or private.
Delegating Responsibilities

When Driver updates the Game, the Game just asks the Player to make a move:

```java
public void update() throws IOException {
    player_[turn_].move(this);
}
```

*Note that the Driver may not do this directly!*
Delegating Responsibilities …

The Player, in turn, calls the Game’s move() method:

```java
public void move(char col, char row, char mark)
    throws AssertionException {
    assert(notOver());
    assert(inRange(col, row));
    assert(get(col, row) == ' ');
    System.out.println(mark + " at " + col + row);
    this.set(col, row, mark);
    this.squaresLeft--;this.swapTurn();
    this.checkWinner();
    assert(invariant());
}
```
Small Methods

Introduce methods that make the *intent* of your code clear.

```java
public boolean notOver() {
    return this.winner().isNobody() && this.squaresLeft() > 0;
}

private void swapTurn() {
    turn_ = (turn_ == X) ? O : X;
}
```

*Well-named variables and methods typically eliminate the need for explanatory comments!*
Accessor Methods

Accessor methods protect clients from changes in implementation:

```java
public Player winner() {
    return winner_
}
public int squaresLeft() {
    return this.squaresLeft_
}
```

➤ When should instance variables be public?
✔ Almost never! Declare public accessor methods instead.
getters and setters in Java

Accessors in Java are known as “getters” and “setters”.

- Accessors for a variable $x$ should normally be called $\text{get}x()$ and $\text{set}x()$

*Frameworks such as EJB depend on this convention!*
Code Smells — TicTacToe.checkWinner()

Check for a winning row, column or diagonal:

```java
private void checkWinner()
    throws AssertionException
{
    char player;
    for (char row='3'; row>='1'; row--) {
        player = this.get('a',row);
        if (player == this.get('b',row) && player == this.get('c',row)) {
            this.setWinner(player);
            return;
        }
    }
    ... 
```
Code Smells …

More of the same …

…

```java
for (char col='a'; col <='c'; col++) {
    player = this.get(col,'1');
    if (player == this.get(col,'2')
        && player == this.get(col,'3')) {
        this.setWinner(player);
        return;
    }
}

... and yet some more ...
```
Code Smells ...

```
player = this.get('b','2');
if (player == this.get('a','1')
    && player == this.get('c','3')) {
    this.setWinner(player);
    return;
}
if (player == this.get('a','3')
    && player == this.get('c','1')) {
    this.setWinner(player);
    return;
}
```

⚠️ Duplicated code stinks! How can we clean it up?
GameDriver

In order to run test games, we separated Player instantiation from Game playing:

```java
public class GameDriver {
    public static void main(String args[]) {
        try {
            Player X = new Player('X');
            Player O = new Player('O');
            TicTacToe game = new TicTacToe(X, O);
            playGame(game);
        } catch (AssertionException err) {
            ...
        }
    }
}
```
The Player

We use *different constructors* to make real or test Players:

```java
public class Player {
    private final char mark_;
    private final BufferedReader in_;  

    A real player reads from the standard input stream:
    public Player(char mark) {
        this(mark, new BufferedReader(new InputStreamReader(System.in)));
    }
    
    This constructor just calls another one ...
    ...
```
Player constructors ...

But a Player can be constructed that reads its moves from any input buffer:

```java
protected Player(char mark, BufferedReader in) {
    mark_ = mark;
    in_ = in;
}
```

This constructor is not intended to be called directly.

...
Player constructors ...

A test Player gets its input from a String buffer:

```java
public Player(char mark, String moves) {
    this(mark, new BufferedReader(new StringReader(moves)));
}
```

The default constructor returns a dummy Player representing “nobody”

```java
public Player() {
    this(' ');
}
```
Defining test cases

The TestDriver builds games using test Players that represent various test cases:

```java
public class TestDriver {
    private static String testX1 = "a1\nb2\nc3\n";
    private static String testO1 = "b1\nc1\n";
    // + other test cases ...

    public static void main(String args[]) {
        testGame(testX1, testO1, "X", 4);
        // ...
    }

    ...//
```
Checking test cases

The TestDriver checks if the results are the expected ones.

```java
public static void testGame(String Xmoves,
   String Omoves, String winner, int squaresLeft)
{
    try {
        Player X = new Player('X', Xmoves);
        Player O = new Player('O', Omoves);
        TicTacToe game = new TicTacToe(X, O);
        GameDriver.playGame(game);
        assert(game.winner().name().equals(winner));
        assert(game.squaresLeft() == squaresLeft);
    } catch (AssertionException err) { ... }
}
```
Running the test cases

Started testGame test

3 |   |    ---+---+---
   |   |    ---+---+---
2 |   |     a   b   c

Player X moves: X at a

3 |   |    ---+---+---
   |   |    ---+---+---
2 | X |     a   b   c

Player O moves: O at c

3 |   |    ---+---+---
   |   |    ---+---+---
1  X | O | O   a   b   c

Player X moves: X at c

3 |   |    ---+---+---
   |   |    ---+---+---
2 | X |     a   b   c

game over!

Passed testGame test
What you should know!

- **What is Iterative Development**, and how does it differ from the Waterfall model?
- How can identifying responsibilities help you to design objects?
- Where did the **Driver** come from, if it wasn’t in our requirements?
- Why is **Winner** not a likely class in our TicTacToe design?
- Why should we evaluate assertions if they are all supposed to be true anyway?
- What is the point of having **methods** that are only one or two lines long?
Can you answer these questions?

✎ Why should you expect requirements to change?
✎ In our design, why is it the Game and not the Driver that prompts a Player to move?
✎ When and where should we evaluate the TicTacToe invariant?
✎ What other tests should we put in our TestDriver?
✎ How does the Java compiler know which version of an overloaded method or constructor should be called?
5. Inheritance and Refactoring

Overview

- Uses of inheritance
  - conceptual hierarchy, polymorphism and code reuse
- TicTacToe and Gomoku
  - interfaces and abstract classes
- Refactoring
  - iterative strategies for improving design
- Top-down decomposition
  - decomposing algorithms to reduce complexity

Source

What is Inheritance?

_Inheritance_ in object-oriented programming languages is a mechanism to:

- derive new _subclasses_ from existing classes
- where subclasses _inherit all the features_ from their parent(s)
- and may _selectively override_ the implementation of some features.
## Inheritance mechanisms

**OO languages realize inheritance in different ways:**

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>self</strong></td>
<td><strong>dynamically</strong> access subclass methods</td>
</tr>
<tr>
<td><strong>super</strong></td>
<td><strong>statically</strong> access overridden, inherited methods</td>
</tr>
<tr>
<td><strong>multiple inheritance</strong></td>
<td>inherit features from <strong>multiple superclasses</strong></td>
</tr>
<tr>
<td><strong>abstract classes</strong></td>
<td><strong>partially defined classes</strong> (to inherit from only)</td>
</tr>
<tr>
<td><strong>mixins</strong></td>
<td>build classes from partial <strong>sets of features</strong></td>
</tr>
<tr>
<td><strong>interfaces</strong></td>
<td><strong>specify</strong> method argument and return types</td>
</tr>
<tr>
<td><strong>subtyping</strong></td>
<td>guarantees that subclass instances can be <strong>substituted</strong> for their parents</td>
</tr>
</tbody>
</table>
The Board Game

Tic Tac Toe is a pretty dull game, but there are many other interesting games that can be played by two players with a board and two colours of markers.

Example: Go-moku

“A Japanese game played on a go board with players alternating and attempting to be first to place five counters in a row.”

— Random House

We would like to implement a program that can be used to play several different kinds of games using the same game-playing abstractions (starting with TicTacToe and Go-moku).
Uses of Inheritance

Inheritance in object-oriented programming languages can be used for (at least) three different, but closely related purposes:

Conceptual hierarchy:
- Go-moku is-a kind of Board Game; Tic Tac Toe is-a kind of Board Game

Polymorphism:
- Instances of Gomoku and TicTacToe can be uniformly manipulated as instances of BoardGame by a client program

...
Uses of Inheritance …

Software reuse:

- Gomoku and TicTacToe reuse the BoardGame interface
- Gomoku and TicTacToe reuse and extend the BoardGame representation and the implementations of its operations

Conceptual hierarchy is important for analysis; polymorphism and reuse are more important for design and implementation.

Note that these three kinds of inheritance can also be exploited separately and independently.
The TicTacToe class currently looks like this:

```
TicTacToe
-gameState : char [3][3]
-winner: Player
-turn : Player
-player : Player[2]
-squaresLeft : int
+create( Player, Player)
+update( )
+move(char, char, char)
+winner( ) : Player
+notOver( ) : boolean
+squaresLeft( ) : int
-set(char, char, char)
-get(char, char) : char
-swapTurn( )
-checkWinner( )
-inRange(char col, char row) : boolean
```

<table>
<thead>
<tr>
<th>Key</th>
<th>TicTacToe</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>private feature</td>
</tr>
<tr>
<td>#</td>
<td>protected feature</td>
</tr>
<tr>
<td>+</td>
<td>public feature</td>
</tr>
<tr>
<td>create( )</td>
<td>static feature</td>
</tr>
<tr>
<td>checkWinner( )</td>
<td>abstract feature</td>
</tr>
</tbody>
</table>
A bad idea ...

Why not simply use inheritance for incremental modification?

Exploiting inheritance for code reuse without refactoring tends to lead to:

- duplicated code (similar, but not reusable methods)
- conceptually unclear design (arbitrary relationships between classes)

Gomoku is not a kind of TicTacToe
Both Go-moku and Tic Tac Toe are kinds of Board games (IS-A). We would like to define a common interface, and factor the common functionality into a shared parent class.

Behaviour that is not shared will be implemented by the subclasses.
Iterative development strategy

We need to find out which TicTacToe functionality will:
- already work for both TicTacToe and Gomoku
- need to be adapted for Gomoku
- can be generalized to work for both

**Example:** set() and get() will not work for a 19×19 board!

...
Iterative development strategy …

Rather than attempting a “big bang” redesign, we will iteratively redesign our game:

- introduce a BoardGame interface that TicTacToe implements
- move all TicTacToe implementation to an AbstractBoardGame parent
- fix, refactor or make abstract the non-generic features
- introduce Gomoku as a concrete subclass of AbstractBoardGame

After each iteration we run our regression tests to make sure nothing is broken!

➤ When should you run your (regression) tests?
✔ After every change to the system.
Version 1.3 (add interface)

We specify the interface both subclasses should implement:

```java
public interface BoardGame {
    public void update() throws IOException;
    public void move(char col, char row, char mark)
        throws AssertionException;
    public Player currentPlayer(); // NB: new method
    public Player winner();
    public boolean notOver();
    public int squaresLeft();
    public void test();
}
```

Initially we focus only on abstracting from the current TicTacToe implementation
**Speaking to an Interface**

*Clients* of TicTacToe and Gomoku should only depend on the BoardGame *interface*:

```java
public class GameDriver {
    public static void main(String args[]) {
        try {
            Player X = new Player('X');
            Player O = new Player('O');
            BoardGame game = new TicTacToe(X, O);
            playGame(game);
            ...
        }
        public static void playGame( ) { ... }

        Speak to an interface, not an implementation.
    }
```
Quiet Testing

Our current TestDriver prints the state of the game \textit{after each move}, making it hard to tell when a test has failed.

\textbf{Tests should be silent \textit{unless} an error has occurred!}

\begin{verbatim}
public static void playGame(BoardGame game, boolean verbose)
{
    ...
    if (verbose) {
        System.out.println();
        System.out.println(game);
    }
    ...
}
\end{verbatim}

\textit{NB: we must shift \underline{all} responsibility for printing to playGame().}
Quiet Testing (2)

A more flexible approach is to let the client supply the PrintStream:

```java
public static void playGame(BoardGame game, PrintStream out) {
    ...
    out.println(game);
    ...
}
```

The TestDriver can simply send the output to a Null stream:

```java
playGame(game, System.out); // normal printing
playGame(game, new NullPrintStream()); // testing
```
NullPrintStream

A Null Object implements an interface with null methods:

```java
public class NullPrintStream extends PrintStream {
    NullPrintStream() { super(System.out); }
    public void print() { }
    public void print(Object x) { }
    public void print(String s) { }
    public void println() { }
    public void println(Object x) { }
    public void println(String s) { }
    ...
}
```

Null Objects are useful for eliminating flags and switches.
TicTacToe adaptations

In order to pass responsibility for printing to the GameDriver, a BoardGame must provide a method to export the current Player:

```java
public class TicTacToe implements BoardGame {
    ...
    public Player currentPlayer() {
        return player_[turn_];
    }
}
```

Now we run our regression tests and (after fixing any bugs) continue.
Version 1.4 (add abstract class)

AbstractBoardGame will provide *common variables* and *methods* for TicTacToe and Gomoku.

```java
public abstract class AbstractBoardGame implements BoardGame {
    protected char[][] gameState_;
    protected Player winner_ = new Player();
    protected Player[] player_;
    ...
    protected void set(char col, char row, char mark)
    ...

➤ When should a class be declared abstract?

✔ Declare a class abstract if it is intended to be subclassed, but not instantiated.
```
Refactoring

Refactoring is a process of moving methods and instance variables from one class to another to improve the design, specifically to:

- reassign responsibilities
- eliminate duplicated code
- reduce coupling: interaction between classes
- increase cohesion: interaction within classes
Refactoring strategies

We have adopted one possible refactoring strategy, first moving everything except the constructor from TicTacToe to AbstractBoardGame, and changing all private features to protected:

```java
public class TicTacToe extends AbstractBoardGame {
    public TicTacToe(Player playerX, Player playerO) {
        ...
    }

    // More methods...

    We could equally have started with an empty AbstractBoardGame and gradually moved shared code there.
```
Version 1.5 (refactor for reusability)

Now we must check which parts of AbstractBoardGame are generic, which must be repaired, and which must be deferred to its subclasses:

- the number of rows and columns and the winning score may vary
  - introduce instance variables and an init() method
  - rewrite toString(), invariant(), inRange() and test()
- set() and get() are inappropriate for a 19×19 board
  - index directly by integers
  - fix move() to take String argument (e.g., “f17”)
  - add methods to parse String into integer coordinates
- getWinner() must be completely rewritten ...
AbstractBoardGame 1.5

We introduce an init() method for arbitrary sized boards:

```java
public abstract class AbstractBoardGame ... {
    protected void init(int rows, int cols, int score, Player playerX, Player playerO) {
    }
}
```

And call it from the constructors of our subclasses:

```java
public TicTacToe(Player playerX, Player playerO) {
    // 3x3 board with winning score = 3
    this.init(3, 3, 3, playerX, playerO);
}
```

Or: introduce a constructor for AbstractBoardGame!
BoardGame 1.5

Most of the changes in AbstractBoardGame are to protected methods.

The only public (interface) method to change is move():

```java
public interface BoardGame {
    ...
    public void move(String coord, char mark)
        throws AssertionException;
    ...
}
```
**Player 1.5**

The Player's move() method is now radically simplified:

```java
public void move (BoardGame game) throws IOException {
    String line = in_.readLine();
    if (line == null)
        throw new IOException("end of input");
    try {
        game.move(line, this.mark());
    } catch (AssertionException err) {
        System.err.println("Invalid move ignored (" + line + ")");
    }
}
```

How can we make the Player responsible for checking if the move is valid?
Version 1.6 (Gomoku)

The final steps are:

- rewrite checkWinner()

- introduce Gomoku
  - modify TestDriver to run tests for both TicTacToe and Gomoku
  - print game state whenever a test fails

- modify GameDriver to query user for either TicTacToe or Gomoku
Keeping Score

The Go board is too large to search exhaustively for a winning Go-moku score.

We know that a winning sequence must include the last square marked. So, it suffices to search in all four directions starting from that square to see if we find 5 in a row.

Whose responsibility is it to search?
A new responsibility …

Maintaining the state of the board and searching for a winning run seem to be unrelated responsibilities. So let’s introduce a new object (a Runner) to run and count a Player’s pieces.

protected void checkWinner(int col, int row) {...
    char player = this.get(col,row);
    Runner runner = new Runner(this, col, row);
    // check vertically
    if (runner.run(0,1) >= this.winningScore_)
        { this.setWinner(player); return; }
    // check horizontally
    if (runner.run(1,0) >= this.winningScore_)
        { this.setWinner(player); return; }
    ...
}
The Runner

The Runner must know its *game*, its *home* (start) position, and its current *position*:

```java
public class Runner {
    BoardGame game_;
    int homeCol_, homeRow_;  // Home col and row
    int col_=0, row_=0;      // Current col & row

    public Runner(BoardGame game, int col, int row) {
        game_ = game;
        homeCol_ = col;
        homeRow_ = row;
    }

    ...
```
Top-down decomposition

Implement algorithms abstractly, introducing helper methods for each abstract step, as you decompose:

```java
public int run(int dcol, int drow)
    throws AssertionException
{
    int score = 1;
    this.goHome();
    score += this.forwardRun(dcol, drow);
    this.goHome();
    score += this.reverseRun(dcol, drow);
    return score;
}
```

Well-chosen names eliminate the need for most comments!
Recursion

Many algorithms are more naturally expressed with recursion than iteration.

Recursively move forward as long as we are in a run. Return the length of the run:

```java
private int forwardRun(int dcol, int drow) throws AssertionException {
    this.move(dcol, drow);
    if (this.samePlayer())
        return 1 + this.forwardRun(dcol, drow);
    else
        return 0;
}
```
More helper methods

Helper methods keep the main algorithm clear and *uncluttered*, and are mostly *trivial to implement*.

```java
private int reverseRun(int dcol, int drow) ... {
    return this.forwardRun(-dcol, -drow);
}

private void goHome() {
    col_ = homeCol_;
    row_ = homeRow_;
}

✎ How would you implement move() and samePlayer()?
BoardGame 1.6

The Runner now needs access to the get() and inRange() methods so we make them public:

```java
public interface BoardGame {
    ...
    public char get(int col, int row)
        throws AssertionException;
    public boolean inRange(int col, int row);
    ...
}
```

➤ Which methods should be public?
✔ Only publicize methods that clients will really need, and will not break encapsulation.
Gomoku

Gomoku is similar to TicTacToe, except it is played on a 19x19 Go board, and the winner must get 5 in a row.

```java
public class Gomoku extends AbstractBoardGame {
    public Gomoku(Player playerX, Player playerO) {
        // 19x19 board with winning score = 5
        this.init(19, 19, 5, playerX, playerO);
    }
}
```

In the end, Gomoku and TicTacToe could inherit everything (except their constructor) from AbstractGameBoard!
What you should know!

✎ How does polymorphism help in writing generic code?
✎ When should features be declared protected rather than public or private?
✎ How do abstract classes help to achieve code reuse?
✎ What is refactoring? Why should you do it in small steps?
✎ How do interfaces support polymorphism?
✎ Why should tests be silent?
Can you answer these questions?

✎ What would change if we didn’t declare `AbstractBoardGame` to be abstract?
✎ How does an `interface` (in Java) differ from a class whose methods are all abstract?
✎ Can you write `generic toString()` and `invariant()` methods for `AbstractBoardGame`?
✎ Is TicTacToe a `special case` of Gomoku, or the other way around?
✎ How would you reorganize the class hierarchy so that you could run Gomoku with boards of different sizes?
6. Programming Tools

Overview
- Managing dependencies — make and Ant
- Version control — RCS and CVS
- Debuggers
- Profilers
- Documentation generation — Javadoc
- Integrated Development Environments

Sources
- Ant: [jakarta.apache.org/ant/](http://jakarta.apache.org/ant/)
- CVS: [www.cvshome.org](http://www.cvshome.org)
Make

Make is a Unix and Windows-based tool for managing dependencies between files.

You can specify in a “Makefile”:
- Which files various targets depend on
- Rules to generate each target
- Macros used in the dependencies and rules
- Generic rules based on filename suffixes

When files are modified, make will apply the minimum set of rules to bring the targets up-to-date.
A Typical Makefile

.SUFFIXES: .class .java

.java.class :
    javac $<  # generic rule

CLASS = AbstractBoardGame.class AssertionException.class \ 
    BoardGame.class GameDriver.class Gomoku.class Player.class \ 
    Runner.class TestDriver.class TicTacToe.class

all : TicTacToe.jar Test.jar  # default target

TicTacToe.jar : manifest-run $(CLASS)  # target and dependents
    jar cmf manifest-run $@ $(CLASS)

Test.jar : manifest-test $(CLASS)
    jar cmf manifest-test $@ $(CLASS)

clean :
    rm -f *.class *.jar
Running make

%% make
javac AbstractBoardGame.java
javac GameDriver.java
javac TestDriver.java
jar cmf manifest-run TicTacToe.jar AbstractBoardGame.class AssertionException.class BoardGame.class GameDriver.class Gomoku.class Player.class Runner.class TestDriver.class TicTacToe.class
jar cmf manifest-test Test.jar AbstractBoardGame.class AssertionException.class BoardGame.class GameDriver.class Gomoku.class Player.class Runner.class TestDriver.class TicTacToe.class

%% touch Runner.java
%% make Test.jar
javac Runner.java
jar cmf manifest-test Test.jar AbstractBoardGame.class AssertionException.class BoardGame.class GameDriver.class Gomoku.class Player.class Runner.class TestDriver.class TicTacToe.class
Ant

Ant is a Java-based make-like utility that uses XML to specify dependencies and build rules.

You can specify in a “buildfile.xml”:
- the *name* of a project
- the *default target* to create
- the *basedir* for the files of the project
- *dependencies* for each target
- *tasks* to execute to create targets
A Typical build.xml

```
<project name="TicTacToe" default="all" basedir="."/>

<!-- set global properties for this build -->
<property name="src" value="."/>
<property name="build" value="build"/>
<property name="runjar" value="TicTacToe.jar"/>
<property name="testjar" value="Test.jar"/>

<target name="all" depends="${runjar},${testjar}"/>
<target name="init">
  <!-- Create the time stamp -->
  <tstamp/>
  <mkdir dir="${build}"/>
</target>

<target name="compile" depends="init">
  <!-- Compile the java code from ${src} into ${build} -->
  <javac srcdir="${src}" destdir="${build}"/>
</target>
```
<target name="${runjar}" depends="compile">
  <!-- Compile the java code from ${src} into ${build} -->
  <jar jarfile="${runjar}" manifest="manifest-run"
       basedir="${build}"/>
</target>

<target name="${testjar}" depends="compile">
  <jar jarfile="${testjar}" manifest="manifest-test"
       basedir="${build}"/>
</target>

<target name="clean">
  <!-- Delete the ${build} directory -->
  <delete dir="${build}"/>
</target>
</project>
Running Ant

% ant
Buildfile: build.xml
init:
  [mkdir] Created dir: /Scratch/TicTacToe/1.6/build
compile:
  [javac] Compiling 10 source files to /Scratch/TicTacToe/1.6/build
${runjar}:
  [jar] Building jar: /Scratch/TicTacToe/1.6/TicTacToe.jar
${testjar}:
  [jar] Building jar: /Scratch/TicTacToe/1.6/Test.jar
all:
  BUILD SUCCESSFUL
Total time: 2 seconds
Version Control Systems

A version control system keeps track of multiple file revisions:

- check-in and check-out of files
- logging changes (who, where, when)
- merge and comparison of versions
- retrieval of arbitrary versions
- “freezing” of versions as releases
- reduces storage space (manages sources files + multiple “deltas”)

SCCS and RCS are two popular version control systems for UNIX. CVS is popular on Mac, Windows and UNIX platforms (see www.cvshome.org)
Version Control

Version control enables you to make radical changes to a software system, with the assurance that you can always go back to the last working version.

➤ When should you use a version control system?
✔ Use it whenever you have one available, for even the smallest project!

Version control is as important as testing in iterative development!
## RCS command overview

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ci</td>
<td>Check in revisions</td>
</tr>
<tr>
<td>co</td>
<td>Check out revisions</td>
</tr>
<tr>
<td>rcs</td>
<td>Set up or change attributes of RCS files</td>
</tr>
<tr>
<td>ident</td>
<td>Extract keyword values from an RCS file</td>
</tr>
<tr>
<td>rlog</td>
<td>Display a summary of revisions</td>
</tr>
<tr>
<td>merge</td>
<td>Merge changes from two files into a third</td>
</tr>
<tr>
<td>rcsdiff</td>
<td>Report differences between revisions</td>
</tr>
<tr>
<td>rcsmerge</td>
<td>Merge changes from two RCS files into a third</td>
</tr>
<tr>
<td>rcsclean</td>
<td>Remove working files that have not been changed</td>
</tr>
<tr>
<td>rcsfreeze</td>
<td>Label the files that make up a configuration</td>
</tr>
</tbody>
</table>
Using RCS

When file is checked in, an RCS file called \texttt{file,v} is created in the RCS directory:

\begin{verbatim}
mkdir RCS       # create subdirectory for RCS files
ci file        # put file under control of RCS
\end{verbatim}

Working copies must be checked out and checked in.

\begin{verbatim}
co -l file      # check out (and lock) file for editing
ci file        # check in a modified file
co file        # check out a read-only copy
ci -u file      # check in file; leave a read-only copy
ci -l file      # check in file; leave a locked copy
crcsdiff file   # report changes between versions
\end{verbatim}
Additionally RCS Features

Keyword substitution

- Various keyword variables are maintained by RCS:

  - $Author$ — who checked in revision (username)
  - $Date$ — date and time of check-in
  - $Log$ — description of revision (prompted during check-in)

Revision numbering:

- Usually each revision is numbered release.level
- Level is incremented upon each check-in
- A new release is created explicitly:
  
  ```
  ci -r2.0 file
  ```
CVS

CVS is comparable to RCS, but is more suitable for large projects.

- Understands RCS-style keywords
- Shared repository for teamwork
  - Manages hierarchies of files
  - Manages parallel development branches
- Uses optimistic version control
  - no locking
  - merging on conflict
- Offers network-based CVS server
Using CVS

mkdir CVS
mkdir CVS/CVSROOT
setenv CVSROOT /.../CVS

cd TicTacToe/1.0
cvs import -m "P2 TicTacToe" p2/tictactoe p2 start
...
cd working
cvs checkout p2/tictactoe
cd p2/tictactoe/
...
cvs add AssertionException.java TestDriver.java
cvs commit
...
cvs update
cvs history
cvs release
Debuggers

A debugger is a tool that allows you to examine the state of a running program:

- *step* through the program instruction by instruction
- *view* the source code of the executing program
- *inspect* (and modify) values of variables in various formats
- *set and unset breakpoints* anywhere in your program
- *execute* up to a specified breakpoint
- *examine* the state of an aborted program (in a “core file”)
Using Debuggers

Interactive debuggers are available for most mature programming languages.

Classical debuggers are line-oriented (e.g., jdb); most modern ones are graphical.

➤ When should you use a debugger?
✔ When you are unsure why (or where) your program is not working.

NB: debuggers are object code specific, so can only be used with programs compiled with compilers generating compatible object files.
Using jdb

```bash
% java -Xdebug \
  -Xrunjdwp:transport=dt_socket,address=8000,server=y,suspend=n \
  -jar TicTacToe.jar
Hi! Would you like to play TicTacToe (t) or Gomoku (g)?: t
```

```bash
% jdb -attach 8000
Initializing jdb...
> stop in AbstractBoardGame.move
Set breakpoint AbstractBoardGame.move
Breakpoint hit: thread="main", AbstractBoardGame.move(), line=94, bci=0
  94      assert(this.notOver());
main[1] where
  [1] AbstractBoardGame.move (AbstractBoardGame.java:94)
  [2] Player.move (Player.java:68)
  [4] GameDriver.playGame (GameDriver.java:54)
  [5] GameDriver.playGame (GameDriver.java:29)
  [6] GameDriver.main (GameDriver.java:17)
```
public void move(String coord, char mark) throws AssertionException {
    assert(this.notOver());
    int col = getCol(coord);
    int row = getRow(coord);
}

Step completed: thread="main", AbstractBoardGame.move(), line=95, bci=8
    int col = getCol(coord);

Method arguments:
    coord = "b2"
    mark = X

Local variables:

print this._gameState[1][1]
this._gameState[1][1] =
...
Debugging Strategy

Develop tests as you program

- Apply Design by Contract to decorate classes with invariants and pre- and post-conditions

- Develop unit tests to exercise all paths through your program
  - use assertions (not print statements) to probe the program state
  - print the state only when an assertion fails

- After every modification, do regression testing!

...
Debugging Strategy ...

If errors arise during testing or usage

- Use the test results to track down and fix the bug

- If you can’t tell where the bug is, then
  - use a debugger to identify the faulty code
  - fix the bug
  - identify and add any missing tests!

All software bugs are a matter of false assumptions.

If you make your assumptions explicit, you will find and stamp out your bugs.
Profilers

A profiler (e.g., java -prof) tells you where a terminated program has spent its time.

1. your program must first be instrumented by
   (i) setting a compiler (or interpreter) option, or
   (ii) adding instrumentation code to your source program
2. the program is run, generating a profile data file
3. the profiler is executed with the profile data as input

The profiler can then display the call graph in various formats

Caveat: the technical details vary from compiler to compiler

...
Using java -Xprof

% java -Xprof -jar TicTacToe.jar
...

<table>
<thead>
<tr>
<th>Interpreted + native</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>98.20% 0 + 696</td>
<td><code>java.io.FileInputStream.readBytes</code></td>
</tr>
<tr>
<td>0.10% 1 + 0</td>
<td><code>java.util.zip.ZipEntry.initFields</code></td>
</tr>
<tr>
<td>0.10% 0 + 1</td>
<td><code>java.util.zip.Inflater.inflateBytes</code></td>
</tr>
<tr>
<td>0.10% 0 + 1</td>
<td><code>java.io.FileOutputStream.writeBytes</code></td>
</tr>
<tr>
<td>0.10% 1 + 0</td>
<td><code>AbstractBoardGame.get</code></td>
</tr>
<tr>
<td>0.10% 1 + 0</td>
<td><code>sun.io.CharToByteSingleByte.getNative</code></td>
</tr>
<tr>
<td>0.10% 0 + 1</td>
<td><code>sun.misc.Launcher$AppClassLoader.loadClass</code></td>
</tr>
<tr>
<td>0.10% 1 + 0</td>
<td><code>java.lang.StringBuffer.append</code></td>
</tr>
<tr>
<td>0.10% 0 + 1</td>
<td><code>java.lang.Package.getSystemPackage</code></td>
</tr>
<tr>
<td>0.10% 0 + 1</td>
<td><code>java.io.UnixFileSystem.normalize</code></td>
</tr>
<tr>
<td>0.10% 0 + 1</td>
<td><code>GameDriver.main</code></td>
</tr>
<tr>
<td>0.10% 0 + 1</td>
<td><code>com.sun.net.ssl.internal.ssl.Provider$1.run</code></td>
</tr>
<tr>
<td>0.10% 0 + 1</td>
<td><code>java.util.zip.ZipFile.open</code></td>
</tr>
<tr>
<td>100.00% 5 + 704</td>
<td><strong>Total interpreted</strong></td>
</tr>
</tbody>
</table>
Using java -Xrunhprof

% java -Xrunhprof:cpu=times,file=log.txt,depth=10 -jar Test.jar

<table>
<thead>
<tr>
<th>rank</th>
<th>self</th>
<th>accum</th>
<th>count</th>
<th>trace</th>
<th>method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.26%</td>
<td>5.26%</td>
<td>272</td>
<td>18</td>
<td>sun.io.CharToByteSingleByte.getNative</td>
</tr>
<tr>
<td>2</td>
<td>5.26%</td>
<td>10.53%</td>
<td>1</td>
<td>24</td>
<td>java.util.Properties.load</td>
</tr>
<tr>
<td>3</td>
<td>5.26%</td>
<td>15.79%</td>
<td>106</td>
<td>9</td>
<td>java.io.BufferedReader.readLine</td>
</tr>
<tr>
<td>4</td>
<td>2.63%</td>
<td>18.42%</td>
<td>5</td>
<td>27</td>
<td>TestDriver.testGame</td>
</tr>
<tr>
<td>5</td>
<td>2.63%</td>
<td>21.05%</td>
<td>5</td>
<td>31</td>
<td>java.lang.Throwable.&lt;init&gt;</td>
</tr>
<tr>
<td>6</td>
<td>2.63%</td>
<td>23.68%</td>
<td>40</td>
<td>26</td>
<td>AbstractBoardGame.move</td>
</tr>
<tr>
<td>7</td>
<td>2.63%</td>
<td>26.32%</td>
<td>509</td>
<td>38</td>
<td>java.lang.String.charAt</td>
</tr>
<tr>
<td>8</td>
<td>2.63%</td>
<td>28.95%</td>
<td>40</td>
<td>42</td>
<td>java.io.BufferedReader.readLine</td>
</tr>
<tr>
<td>9</td>
<td>2.63%</td>
<td>31.58%</td>
<td>128</td>
<td>15</td>
<td>java.lang.StringBuffer.append</td>
</tr>
<tr>
<td>10</td>
<td>2.63%</td>
<td>34.21%</td>
<td>361</td>
<td>21</td>
<td>AbstractBoardGame.set</td>
</tr>
<tr>
<td>11</td>
<td>2.63%</td>
<td>36.84%</td>
<td>1</td>
<td>30</td>
<td>java.lang.ClassLoader.defineClass</td>
</tr>
<tr>
<td>12</td>
<td>2.63%</td>
<td>39.47%</td>
<td>10</td>
<td>13</td>
<td>java.io.BufferedWriter.ensureOpen</td>
</tr>
<tr>
<td>13</td>
<td>2.63%</td>
<td>42.11%</td>
<td>1</td>
<td>10</td>
<td>java.lang.String.concat</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>...</td>
</tr>
</tbody>
</table>
Using Profilers

➤ When should you use a profiler?
✔ Always run a profiler before attempting to tune performance.

➤ How early should you start worrying about performance?
✔ Only after you have a clean, running program with poor performance.

NB: The call graph also tells you which parts of the program have (not) been tested!
Javadoc

Javadoc generates API documentation in HTML format for specified Java source files.

Each class, interface and each public or protected method may be preceded by “javadoc comments” between /** and */. Comments may contain special tag values (e.g., @author) and (some) HTML tags.
import java.io.*;
/**
 * Manage interaction with user.
 * @author Oscar.Nierstrasz@acm.org
 * @version 1.5 1999-02-07
 */
public class Player { ...
/**
 * Constructor to specify an alternative source
 * of moves (e.g., a test case StringReader).
 */
public Player(char mark, BufferedReader in) { ...
Javadoc output

View it with your favourite web browser!
Other tools

Be familiar with the programming tools in your environment!

- **memory inspection tools**: like ZoneRanger help to detect other memory management problems, such as "memory leaks"
- **zip/jar**: store and compress files and directories into a single "zip file"
- **awk, sed and perl**: process text files according to editing scripts/programs
Integrated Development Environments

An Integrated Development Environment (IDE) provides a common interface to a suite of programming tools:

- project manager
- browsers and editors
- compilers and linkers
- make utility
- version control system
- interactive debugger
- profiler
- memory usage monitor
- documentation generator

Many of the graphical object-oriented programming tools were pioneered in Smalltalk.
**CodeWarrior**

*CodeWarrior* is a popular IDE for multiple languages and platforms.

The *Project Browser* organizes the source and object files belonging to a project, and lets you modify the project settings, edit source files, and compile and run the application.
CodeWarrior Class Browser

The Class Browser provides one way to navigate and edit project files...
CodeWarrior Hierarchy Browser

A **Hierarchy Browser** provides a view of the class hierarchy.

**NB:** no distinction is made between **interfaces** and **classes**. Classes that implement multiple interfaces appear multiple times in the hierarchy!
Setting Breakpoints

You can set breakpoints by simply clicking next to selected statements.

Execution will be interrupted every time breakpoint is reached, displaying the current program state.
What you should know!

- How do make and Ant support **system building**?
- What functionality does a **version control system** support?
- When should you use a **debugger**?
- What are **breakpoints**? Where should you set them?
- What should you do **after** you have fixed a bug?
- When should you use a **profiler**?
- What is an **IDE**?
Can you answer these questions?

✎ When should you use Ant rather than make?
✎ When should you use CVS rather than RCS?
✎ How often should you checkpoint a version of your system?
✎ When should you specify a version of your project as a new “release”?
✎ How can you tell when there is a bug in the compiler (rather than in your program)?
✎ How can you tell if you have tested every part of your system?
7. A Testing Framework

Overview

- What is a framework?
- JUnit — a simple testing framework
- Money and MoneyBag — a testing case study
- Double Dispatch — how to add different types of objects
- Testing practices

Sources

- JUnit 3.7 documentation (from www.junit.org)
The Problem

“Testing is not closely integrated with development. This prevents you from measuring the progress of development — you can't tell when something starts working or when something stops working.”

Interactive testing is tedious and seldom exhaustive. Automated tests are better, but,

- how to introduce tests interactively?
- how to organize suites of tests?
Testing Practices

During Development

❑ When you need to add new functionality, write the tests first.
   You will be done when the test runs.

❑ When you need to redesign your software to add new features, refactor in small steps, and run the (regression) tests after each step.
   Fix what’s broken before proceeding.

...
During Debugging

- When someone discovers a defect in your code, first write a test that will succeed if the code is working. Then debug until the test succeeds.

"Whenever you are tempted to type something into a print statement or a debugger expression, write it as a test instead."

Martin Fowler
JUnit

JUnit is a simple “testing framework” that provides:

- classes for writing Test Cases and Test Suites
- methods for setting up and cleaning up test data (“fixtures”)
- methods for making assertions
- textual and graphical tools for running tests

JUnit distinguishes between failures and errors:

- A failure is a failed assertion, i.e., an anticipated problem that you test.
- An error is a condition you didn’t check for.
Frameworks vs. Libraries

In traditional application architectures, user code makes use of library functionality in the form of procedures or classes:

A framework reverses the usual relationship between generic and application code. Frameworks provide both generic functionality and application architecture:

Essentially, a framework says: “Don’t call me — I’ll call you.”
The JUnit Framework

- **Test**
  - `countTestCases() : int`  
  - `run(TestResult)`

- ** TestCase**
  - `create(String)`
  - `fail()`
  - `runBare()`
  - `runTest()`
  - `setUp()`
  - `tearDown()`
  - `name() : String`

- ** TestSuite**
  - `create()`
  - `create(Class)`
  - `addTest(Test)`

- ** TestResult**
  - `create()`
  - `addError(Test, Throwable)`
  - `addFailure(Test, Throwable)`
  - `errors() : Enumeration`
  - `failures() : Enumeration`

- **Assert**
  - `assertTrue(boolean)`
  - `assertEquals(Object, Object)`

A Test can run a number of concrete test cases

All errors and failures are collected into a TestResult.

A TestSuite bundles a set of Tests
A Testing Scenario

The framework calls the test methods that you define for your test cases.
Testing Style

“The style here is to write a few lines of code, then a test that should run, or even better, to write a test that won’t run, then write the code that will make it run.”

- write unit tests that thoroughly test a single class
- write tests as you develop (even before you implement)
- write tests for every new piece of functionality

“Developers should spend 25-50% of their time developing tests.”
Representing multiple currencies

The problem ...

“The program we write will solve the problem of representing arithmetic with multiple currencies. Arithmetic between single currencies is trivial, you can just add the two amounts. ... Things get more interesting once multiple currencies are involved.”
Money

We start by designing a simple Money class to handle a single currency:

```java
public class Money {
    ...
    public Money add(Money m) {
        return new Money(...);
    }
    ...
}
```

NB: The first version does not consider how to add different currencies!
To test our Money class, we define a **TestCase** that exercises some test data (the **fixture**):

```java
import junit.framework.*;
public class MoneyTest extends TestCase {
    private Money f12CHF;
    private Money f14CHF;
    public MoneyTest(String name) { super(name); }

    protected void setUp() { // create the test data
        f12CHF = new Money(12, "CHF");
        f14CHF = new Money(14, "CHF");
    }
    ...
}
```
Some basic tests

We define methods to test what we expect to be true ...

```java
public void testEquals() {
    assertTrue(!f12CHF.equals(null));
    assertEquals(f12CHF, f12CHF);
    assertEquals(f12CHF, new Money(12, "CHF"));
    assertTrue(!f12CHF.equals(f14CHF));
}

public void testSimpleAdd() {
    Money expected = new Money(26, "CHF");
    Money result = f12CHF.add(f14CHF);
    assertEquals(expected, result);
}
```
Building a Test Suite

... and we bundle these tests into a Test Suite:

```java
public static Test suite() {
    TestSuite suite = new TestSuite();
    suite.addTest(new MoneyTest("testEquals");
    suite.addTest(new MoneyTest("testSimpleAdd");
    return suite;
}
```

A Test Suite:

- bundles together a bunch of named TestCase instances
- by convention, is returned by a static method called `suite()`
The TestRunner

junit.ui.TestRunner is a GUI that we can use to instantiate and run the suite:
MoneyBags

To handle *multiple currencies*, we introduce a MoneyBag class that can hold *several instances* of Money:

<table>
<thead>
<tr>
<th>MoneyBag</th>
</tr>
</thead>
<tbody>
<tr>
<td>- fMonies : HashTable</td>
</tr>
<tr>
<td>+ create(Money, Money)</td>
</tr>
<tr>
<td>+ create(Money [ ])</td>
</tr>
<tr>
<td>- appendMoney(Money)</td>
</tr>
<tr>
<td>+ toString() : String</td>
</tr>
</tbody>
</table>

...
class **MoneyBag** {
    private Hashtable fMonies = new Hashtable(5);
    MoneyBag(Money[] bag) {
        for (int i = 0; i < bag.length; i++)
            appendMoney(bag[i]);
    }
    private void appendMoney(Money aMoney) {
        Money m = (Money) fMonies.get(aMoney.currency());
        if (m != null) { m = m.add(aMoney); }
        else { m = aMoney; }
        fMonies.put(aMoney.currency(), m);
    }
}
Testing MoneyBags (I)

To test MoneyBags, we need to extend the fixture ...

```java
public class MoneyTest extends TestCase {
...

    protected void setUp() {
        f12CHF = new Money(12, "CHF");
        f14CHF = new Money(14, "CHF");
        f7USD = new Money(7, "USD");
        f21USD = new Money(21, "USD");
        fMB1 = new MoneyBag(f12CHF, f7USD);
        fMB2 = new MoneyBag(f14CHF, f21USD);
    }
```
Testing MoneyBags (II)

... define some new (obvious) tests ...

```java
public void testBagEquals() {
    assertTrue(!fMB1.equals(null));
    assertEquals(fMB1, fMB1);
    assertTrue(!fMB1.equals(f12CHF));
    assertTrue(!f12CHF.equals(fMB1));
    assertTrue(!f12CHF.equals(fMB1));
    assertTrue(!fMB1.equals(fMB2));
}

... add them to the test suite ...

public static Test suite() {
    suite.addTest(new MoneyTest("testBagEquals"));
    return suite;
}
```
Testing MoneyBags (III)

and run the tests.
Adding MoneyBags

We would like to freely *add together arbitrary Monies and MoneyBags*, and be sure that *equals behave as equals*:

```java
public void testMixedSimpleAdd() {
    // [12 CHF] + [7 USD] == {[12 CHF][7 USD]}
    Money bag[] = { f12CHF, f7USD };
    MoneyBag expected = new MoneyBag(bag);
    assertEquals(expected, f12CHF.add(f7USD));
}
```

That implies that *Money* and *MoneyBag* should *implement a common interface* ...
The IMoney interface (I)

Monies know how to be added to other Monies

Do we need anything else in the IMoney interface?
Double Dispatch (I)

How do we implement `add()` without breaking encapsulation?

```java
class Money implements IMoney {
    public IMoney add(IMoney m) {
        return m.addMoney(this); // add me as a Money
    }
}

class MoneyBag implements IMoney {
    public IMoney add(IMoney m) {
        return m.addMoneyBag(this); // add as a MoneyBag
    }
}
```

“The idea behind double dispatch is to use an additional call to discover the kind of argument we are dealing with...”
Double Dispatch (II)

The rest is then straightforward ...

class Money implements IMoney {
    public IMoney addMoney(Money m) {
        if (m.currency().equals(currency()))
            return new Money(amount() + m.amount(),
                               currency());
        else
            return new MoneyBag(this, m);
    }
    public IMoney addMoneyBag(MoneyBag s) {
        return s.addMoney(this);
    }
} ...

and MoneyBag takes care of the rest.
The IMoney interface (II)

So, the common interface has to be:

```java
public interface IMoney {
    public IMoney add(IMoney aMoney);
    IMoney addMoney(Money aMoney);
    IMoney addMoneyBag(MoneyBag aMoneyBag);
}
```

NB: `addMoney()` and `addMoneyBag()` are only needed within the `Money` package.
A Failed test

This time we are not so lucky ...
The fix ...

It seems we forgot to implement $\text{MoneyBag.equals()}$!

We fix it:

```java
class MoneyBag implements IMoney {
    public boolean equals(Object anObject) {
        if (anObject instanceof MoneyBag) {
            ...
        } else {
            return false;
        }
    }
}
```

... test it, and continue developing.
What you should know!

✎ How does a framework differ from a library?
✎ Why do TestCase and TestSuite implement the same interface?
✎ What is a unit test?
✎ What is a test “fixture”?
✎ What should you test in a TestCase?
✎ What is “double dispatch”? What does the name mean?
Can you answer these questions?

- How does implementing `toString()` help in debugging?
- How does the MoneyTest suite know which test methods to run?
- How does the TestRunner invoke the right `suite()` method?
- Why doesn’t the Java compiler complain that `MoneyBag.equals()` is used without being declared?
8. Software Components: Collections

Overview

- Example problem: The Jumble Puzzle
- The Java 2 collections framework
- Interfaces: Collections, Sets, Lists and Maps
- Implementations ...
- Algorithms: sorting ...
- Iterators

Source

- “Collections 1.2”, by Joshua Bloch, in The Java Tutorial, java.sun.com
Components

Components are **black-box** entities that:

- import required services and
- export provided services
- must be designed to be composed

Components may be fine-grained (classes) or coarse-grained (applications).
The Jumble Puzzle

The Jumble Puzzle tests your English vocabulary by presenting four jumbled, ordinary words. The circled letters of the unjumbled words represent the jumbled answer to a cartoon puzzle.

Since the jumbled words can be found in an electronic dictionary, it should be possible to write a program to automatically solve the first part of the puzzle (unjumbling the four words).
The obvious, naive solution is extremely inefficient: a word with $n$ characters may have up to $n!$ permutations. A five-letter word may have 120 permutations and a six-letter word may have 720 permutations. “rupus” has 60 permutations.

Exactly how many permutations will a given word have?
Rethinking the Jumble Problem

Observation: if a jumbled word (e.g. “rupus”) can be unjumbled to a real word in the list, then these two words are jumbles of each other (i.e. they are anagrams).

Is there a fast way to tell if two words are anagrams?

...
Rethinking the Jumble Problem ...

Two words are anagrams if they are made up of the same set of characters.

We can assign each word a unique “key” consisting of its letters in sorted order. The key for “rupus” is “prsuu”.

Two words are anagrams if they have the same key.

We can unjumble “rupus” by simply looking for a word with the same key.
An Efficient Solution

1. Build an *associative array* of keys and words for every word in the dictionary:

2. Generate the key of a jumbled word:
   - key("rupus") = "prsuu"

3. Look up and return the words with the same key.

<table>
<thead>
<tr>
<th>Key</th>
<th>Word</th>
</tr>
</thead>
<tbody>
<tr>
<td>aabcsu</td>
<td>abacus</td>
</tr>
<tr>
<td>aabelno</td>
<td>abalone</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>prsuu</td>
<td>usurp</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>chiruz</td>
<td>zurich</td>
</tr>
<tr>
<td>egotyz</td>
<td>zygote</td>
</tr>
</tbody>
</table>

To implement a software solution, we need *associative arrays*, *lists*, *sort routines*, and possibly other components.
The Collections Framework

The Java Collections framework contains interfaces, implementations and algorithms for manipulating collections of elements.

- `Collection`
- `Map`
- `Set`
- `List`
- `SortedSet`
- `SortedMap`

Sets and Lists are kinds of collections.

Maps manage mappings from keys to values.
Collection Interfaces

- **interface** Collection
  + size() : int
  + isEmpty() : boolean
  + contains(Object) : boolean
  + add(Object) : boolean
  + remove(Object) : boolean
  + iterator() : Iterator
  + toArray() : Object[]

- **interface** Set

- **interface** SortedSet
  + subSet(Object from, to) : SortedSet
  + first() : Object
  + last() : Object

- **interface** List
  + get(int) : Object
  + set(int, Object) : Object
  + add(int, Object)
  + remove(int) : Object
  + indexOf(Object) : int
  + listIterator() : ListIterator
  + subList(int from, to) : List

Lists may contain duplicated elements. Sets may not.
Implementations

The framework provides at least two implementations of each interface.

Can you guess how the standard implementations work?
Interface and Abstract Classes

Principles at play:

❑ Clients depend only on interfaces, not classes

❑ Classes may implement multiple interfaces

❑ Single inheritance doesn’t prohibit multiple subtyping

❑ Abstract classes collect common behaviour shared by multiple subclasses but cannot be instantiated themselves, because they are incomplete
Maps

A *Map* is an object that manages a set of (key, value) pairs.

Map is implemented by HashMap and TreeMap.

A *Sorted Map* maintains its entries in ascending order.

<table>
<thead>
<tr>
<th>«interface»</th>
<th>Map</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ put(Object key, value) : Object</td>
<td></td>
</tr>
<tr>
<td>+ get(Object key) : Object</td>
<td></td>
</tr>
<tr>
<td>+ remove(Object key) : Object</td>
<td></td>
</tr>
<tr>
<td>+ containsKey(Object key) : boolean</td>
<td></td>
</tr>
<tr>
<td>+ containsValue(Object value) : boolean</td>
<td></td>
</tr>
<tr>
<td>+ size() : int</td>
<td></td>
</tr>
<tr>
<td>+ isEmpty() : boolean</td>
<td></td>
</tr>
<tr>
<td>+ keySet() : Set</td>
<td></td>
</tr>
<tr>
<td>+ values() : Collection</td>
<td></td>
</tr>
<tr>
<td>+ entrySet() : Set</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>«interface»</th>
<th>SortedMap</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ first() : Object</td>
<td></td>
</tr>
<tr>
<td>+ last() : Object</td>
<td></td>
</tr>
</tbody>
</table>
Jumble

We can implement the Jumble dictionary as a kind of HashMap:

```java
public class Jumble extends HashMap {
    public static void main(String args[]) {
        if (args.length == 0) { ... }
        Jumble wordMap = null;
        try {
            wordMap = new Jumble(args[0]);
        } catch (IOException err) {
            System.err.println("Can't load dictionary");
            return;
        }
        wordMap.inputLoop();
    }
    ...
```
Jumble constructor

A Jumble dictionary knows the file of words to load ...

private String wordFile_;

Jumble(String wordFile) throws IOException {
    super(); // NB: establish superclass invariant!
    wordFile_ = wordFile;
    loadDictionary();
}

Before we continue, we need a way to generate a key for each word ...
The Collections framework provides various algorithms, such as sorting and searching, that work uniformly for all kinds of Collections and Lists. (Also any that you define yourself!)

These algorithms are static methods of the Collections class.

As a general rule, static methods should be avoided in an OO design. Are there any good reasons here to break this rule?
Array algorithms

There is also a class, Arrays, consisting of static methods for searching and sorting that operate on Java arrays of basic data types.

Which sort routine should we use to generate unique keys for the Jumble puzzle?

<table>
<thead>
<tr>
<th>Arrays</th>
</tr>
</thead>
<tbody>
<tr>
<td>...</td>
</tr>
<tr>
<td>+ sort(char[])</td>
</tr>
<tr>
<td>+ sort(char[], int, int)</td>
</tr>
<tr>
<td>+ sort(double[])</td>
</tr>
<tr>
<td>+ sort(double[], int, int)</td>
</tr>
<tr>
<td>+ sort(float[])</td>
</tr>
<tr>
<td>+ sort(float[], int, int)</td>
</tr>
<tr>
<td>+ sort(int[])</td>
</tr>
<tr>
<td>+ sort(int[], int, int)</td>
</tr>
<tr>
<td>+ sort(Object[])</td>
</tr>
<tr>
<td>+ sort(Object[], Comparator)</td>
</tr>
<tr>
<td>+ sort(Object[], int, int)</td>
</tr>
<tr>
<td>+ sort(Object[], int, int, Comparator)</td>
</tr>
<tr>
<td>...</td>
</tr>
</tbody>
</table>
Sorting arrays of characters

The easiest solution is to convert the word to an array of characters, sort that, and convert the result back to a String.

```java
public static String sortKey(String word) {
    char[] letters = word.toCharArray();
    Arrays.sort(letters);
    return new String(letters);
}
```

What other possibilities do we have?
Loading the dictionary

Reading the dictionary is straightforward ...

```java
private void loadDictionary() throws IOException {
    BufferedReader in =
        new BufferedReader(new FileReader(wordFile_));
    String word = in.readLine();
    while (word != null) {
        this.addPair(sortKey(word), word);
        word = in.readLine();
    }
}
...
Loading the dictionary …

... but there may be a List of words for any given key!

```java
private void addPair(String key, String word) {
    List wordList = (List) this.get(key);
    if (wordList == null)
        wordList = new ArrayList();
    wordList.add(word);
    this.put(key, wordList);
}
```
The input loop

Now the input loop is straightforward ...

```java
public void inputLoop() {
    System.out.print("Enter a word to unjumble: ");
    String word;
    while ((word = in.readLine()) != null) {
        List wordList =
            (List) this.get(sortKey(word));
        if (wordList == null) {
            System.out.println("Can't unjumble ...");
        } else {
            System.out.println(
                word + " unjumbles to: " + wordList);
        }
    }
}
```
Running the unjumbler ...

Enter a word to unjumble: **rupus**
rupus unjumbles to: [usurp]
Enter a word to unjumble: **hetab**
hetab unjumbles to: [bathe]
next word: **please**
please unjumbles to: [asleep, elapse, please]
next word: **java**
Can't unjumble java
next word:
Quit? (y/n): **y**
bye!
Searching for anagrams

We would now like to know which word in the list has the largest number of anagrams — i.e., what is the largest set of words with the same key.

➤ How do you iterate through a Collection whose elements are unordered?
✔ Use an iterator.
Iterators

An **Iterator** is an object that lets you walk through an *arbitrary collection*, whether it is ordered or not.

Lists additionally provide **ListIterators** that allows you to traverse the list in *either direction* and *modify* the list during iteration.

```text
«interface»
Iterator
+ hasNext() : boolean
+ next() : Object
+ remove()

«interface»
ListIterator
+ add(Object)
+ hasPrevious() : boolean
+ nextIndex() : int
+ previous() : Object
+ previousIndex() : int
+ set(Object)
```
Iterating through the key set

public List maxAnagrams() {
    int max = 0;
    List anagrams = null;
    Iterator keys = this.keySet().iterator();
    while (keys.hasNext()) {
        String key = (String) keys.next();
        List words = (List) this.get(key);
        if (words.size() > max) {
            anagrams = words;
            max = words.size();
        }
    }
    return anagrams;
}
Running Jumble.maxAnagrams

Printing wordMap.maxAnagrams() yields:

[caret, carte, cater, crate, trace]
How to use the framework

- If you need collections in your application, stick to the standard interfaces.
- Use one of the default implementations, if possible.
- If you need a specialized implementation, make sure it is compatible with the standard ones, so you can mix and match.
- Make your applications depend only on the collections interfaces, if possible, not the concrete classes.
- Always use the least specific interface that does the job (Collection, if possible).
What you should know!

✎ How are Sets and Lists similar? How do they differ?
✎ Why is Collection an interface rather than a class?
✎ Why are the sorting and searching algorithms implemented as static methods?
✎ What is an iterator? What problem does it solve?
Can you answer these questions?

- Of what use are the `AbstractCollection`, `AbstractSet` and `AbstractList`?
- Why doesn't `Map` extend `Collection`?
- Why does the Jumble constructor call `super()`?
- Which implementation of `Map` will make Jumble run faster? Why?
9. GUI Construction

Overview

- Applets
- Model-View-Controller
- AWT Components, Containers and Layout Managers
- Events and Listeners
- Observers and Observables

Sources

A Graphical TicTacToe?

Our existing TicTacToe implementation is very limited:

- single-user at a time
- textual input and display

We would like to migrate it towards an interactive, network based game:

- players on separate machines
- running the game as an “applet” in a browser
- with graphical display and mouse input

As first step, we will migrate the game to run as an applet
Applet classes can be downloaded from an HTTP server and instantiated by a client.

The Applet instance may make (restricted) use of

1. standard API classes
   (already accessible to the virtual machine)
2. other Server classes to be downloaded dynamically.

java.applet.Applet extends java.awt.Panel and can be used to construct a UI ...
The Hello World Applet

The simplest Applet:

```java
import java.awt.*; // for Graphics
import java.applet.Applet;
public class HelloApplet extends Applet {
    public void init() {
        repaint(); // request a refresh
    }
    public void paint(Graphics g) {
        g.drawString("Hello World!", 30, 30);
    }
}
```

The Applet will be initialized and started by the client.
The Hello World Applet

<HTML>
<HEAD><TITLE>HelloApplet</TITLE></HEAD>
<BODY>
<APPLET
  CODEBASE = "."
  ARCHIVE = "HelloApplet.jar"
  CODE = "HelloApplet.class"
  NAME = "HelloApplet"
  WIDTH = 400
  HEIGHT = 300
>
</APPLET>
</BODY>
</HTML>
Accessing the game as an Applet

The compiled TicTacToe classes will be made available in a directory “AppletClasses” on our web server.

```html
<title>GameApplet</title>
<applet
    codebase="AppletClasses"
    code="tictactoe.GameApplet.class"
    width=200
    height=200>
</applet>
```

GameApplet extends java.applet.Applet. Its init() will instantiate and connect the other game classes
Model-View-Controller

Version 1.6 of our game implements a *model* of the game, without a GUI. The GameApplet will implement a graphical *view* and a *controller* for GUI events.

The MVC paradigm separates an application from its GUI so that multiple views can be dynamically connected and updated.
**AWT Components and Containers**

The java.awt package defines GUI components, containers and their layout managers.

**A Container is a component that may contain other components.**

**A Panel is a container inside another container. (E.g., an Applet inside a browser.)**

**A Window is a top-level container.**

NB: There are also many graphics classes to define colours, fonts, images etc.
The GameApplet

The GameApplet is a Panel using a BorderLayout (with a centre and up to four border components), and containing a Button ("North"), a Panel ("Center") and a Label ("South").

The central Panel itself contains a grid of squares (Panels) and uses a GridLayout.

Other layout managers are FlowLayout, CardLayout and GridBagLayout …
Laying out the GameApplet

```java
public void init() {
    game_ = makeGame();           // instantiate game
    setLayout(new BorderLayout()); // initialize view
    setSize(MINSIZE*game_.cols(),
            MINSIZE*game_.rows());
    add("North", makeControls());
    add("Center", makeGrid());
    label_ = new Label();
    add("South", label_);
    game_.addObserver(this);        // connect to model
    showFeedBack(game_.currentPlayer().mark() + " plays");
}
```
Helper methods

As usual, we introduce helper methods to hide the details of GUI construction ...

```java
private Component makeControls() {
    Button again = new Button("New game");
    ...
    return again;
}
```
Events and Listeners (I)

Instead of actively checking for GUI events, you can define *callback methods* that will be invoked when your GUI objects receive events:

AWT Components *publish* events and (possibly multiple) Listeners *subscribe* interest in them.
Events and Listeners (II)

Every AWT component publishes a variety of different events (see java.awt.event) with associated Listener interfaces.

<table>
<thead>
<tr>
<th>Component</th>
<th>Events</th>
<th>Listener Interface</th>
<th>Listener methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Button</td>
<td>ActionEvent</td>
<td>ActionListener</td>
<td>actionPerformed()</td>
</tr>
<tr>
<td></td>
<td>MouseEvent</td>
<td>MouseListener</td>
<td>mouseClicked() mouseEntered() mouseExited() mousePressed() mouseReleased()</td>
</tr>
<tr>
<td>Component</td>
<td>MouseMotionListener</td>
<td>mouseDragged() mouseMoved()</td>
<td></td>
</tr>
<tr>
<td>KeyEvent</td>
<td>KeyListener</td>
<td></td>
<td>keyPressed() keyReleased() keyTyped()</td>
</tr>
</tbody>
</table>

...
Listening for Button events

When we create the “New game” Button, we attach an **ActionListener** with the Button.addActionListener() method:

```java
private Component makeControls() {
    Button again = new Button("New game");
    again.addActionListener(new ActionListener() {
        public void actionPerformed(ActionEvent e) {
            showFeedBack("starting new game ...");
            newGame();  // NB: has access to methods
        }
    });
    return again;
}
```

We instantiate an **anonymous inner class** to avoid defining a named subclass of ActionListener.
**Listening for mouse clicks**

We also *attach a MouseListener* to each Place on the board.

```java
private Component makeGrid() { ...
    Panel grid = new Panel();
    grid.setLayout(new GridLayout(rows, cols));
    place_s = new Place[cols][rows];
    for (int row=rows-1; row>=0; row--) {
        for (int col=0; col<cols; col++) {
            Place p = new Place(col, row, xImage, oImage);
            p.addMouseListener(
                new PlaceListener(p, this));
        }
    }
    return grid;
}
```
The PlaceListener

MouseListener is a convenience class that defines empty MouseListener methods (!)

public class PlaceListener extends MouseAdapter {
    private final Place place_;
    private final GameApplet applet_;
    public PlaceListener(...) {
        place_ = place;
        applet_ = applet;
    }
    ...
}
The PlaceListener …

We only have to define the mouseClicked() method:

```java
public void mouseClicked(MouseEvent e) {
    ...
    if (game.notOver()) {
        try {
            ((AppletPlayer) game.currentPlayer()).move(col, row);
            applet_.showFeedBack(game.currentPlayer().mark() + " plays");
        } catch (AssertionException err) {
            applet_.showFeedBack("Invalid move ignored ...");
        }
        if (!game.notOver()) {
            applet_.showFeedBack("Game over -- " + game.winner() + " wins!");
        }
    } else {
        applet_.showFeedBack("The game is over!");
    }
}
```
Observers and Observables

A class can implement the `java.util.Observer` interface when it wants to be informed of changes in `Observable` objects.

An `Observable` object can have one or more `Observers`.

After an observable instance changes, calling `notifyObservers()` causes all observers to be notified by means of their `update()` method.
Observing the BoardGame

In our case, the GameApplet represents a View, so plays the role of an Observer:

```java
public class GameApplet extends Applet implements Observer {
    { ... 
        public void update(Observable o, Object arg) {
            Move move = (Move) arg;
            showFeedBack("got an update: "+ move);
            place_s[move.col][move.row].setMove(move.player); 
        }
    }
    ...
```
Observing the BoardGame ...

The BoardGame represents the *Model*, so plays the role of an *Observable*:

```java
public abstract class AbstractBoardGame extends Observable implements BoardGame {
    ...
    public void move(int col, int row, Player p) throws AssertionException {
        ...
        setChanged();
        notifyObservers(new Move(col, row, p));
    }
}
```
Communicating changes

A Move instance bundles together information about a change of state in a BoardGame:

```java
public class Move {
    public final int col, row; // NB: public, but final
    public final Player player;
    public Move(int col, int row, Player player) {
        this.col = col; this.row = row;
        this.player = player;
    }
    public String toString() {
        return "Move(" + col + "," + row
                + "," + player + ")";
    }
}
```
Setting up the connections

When the GameApplet is loaded, its init() method is called, causing the **model, view and controller** components to be instantiated.

The GameApplet **subscribes** itself as an **Observer** to the game, and **subscribes** a PlaceListener to **MouseEvents** for each Place on the view of the BoardGame.
Playing the game

Mouse clicks are propagated from a Place (controller) to the BoardGame (model):

If the corresponding move is valid, the model’s state changes, and the GameApplet updates the Place (view).
Refactoring the BoardGame

Adding a GUI to the game affects many classes. We iteratively introduce changes, and *rerun our tests* after every change ...

- *Shift responsibilities* between BoardGame and Player (both should be passive!)
  - introduce Player interface, InactivePlayer and StreamPlayer classes
  - move `getRow()` and `getCol()` from BoardGame to Player
  - move `BoardGame.update()` to `GameDriver.playGame()`
  - change BoardGame to hold a matrix of Players, not marks

...
Refactoring the BoardGame ...

- Introduce *Applet classes* (GameApplet, Place, PlaceListener)
  - Introduce AppletPlayer
  - PlaceListener triggers AppletPlayer to move

- BoardGame must be *observable*
  - Introduce Move to communicate changes from BoardGame to Observer
GUI objects in practice …

Use Java webstart, not applets
- avoid browser problems by downloading whole applications in a secure way

Use Swing, not AWT
- javax.swing provides a set of “lightweight” (all-Java language) components that (more or less!) work the same on all platforms.

Use a GUI builder
- Interactively build your GUI rather than programming it — add the hooks later.
What you should know!

✎ Why doesn’t an Applet need a `main()` method?
✎ What are `models`, `view` and `controllers`?
✎ Why does `Container` extend `Component` and not vice versa?
✎ What does a `layout` `manager` do?
✎ What are `events` and `listeners`? Who publishes and who subscribes to events?
✎ The TicTacToe game `knows nothing` about the `GameApplet` or `Places`. How is this achieved? Why is this a good thing?
Can you answer these questions?

✎ How could you get Applets to download objects instead of just classes?
✎ How could you make the game start up in a new Window?
✎ What is the difference between an event listener and an observer?
✎ The Move class has public instance variables — isn’t this a bad idea?
✎ What kind of tests would you write for the GUI code?
10. Clients and Servers

Overview
- RMI — Remote Method Invocation
- Remote interfaces
- Serializable objects
- Synchronization
- Threads
- Compiling and running an RMI application

Sources
- David Flanagan, *Java Examples in a Nutshell*, O'Reilly, 1997
A Networked TicTacToe?

We now have a usable GUI for our game, but it still supports only a single user.

We would like to support:

- players on separate machines
- each running the game as an applet in a browser
- with a “game server” managing the state of the game
The concept

Client “X”

Client “O”

Server

© O. Nierstrasz — U. Berne

Clients and Servers
The problem

Unfortunately *Applets alone are not enough* to implement this scenario!

We must answer several questions:

- Who *creates* the GameFactory?
- How does the *Applet connect* to the GameFactory?
- How do the *server objects connect* to the client objects?
- How do we *download objects* (rather than just classes)?
- How do the server objects *synchronize* concurrent requests?
Remote Method Invocation

RMI allows an application to register a Java object under a public name with an RMI registry on the server machine.

A client may look up the service using the public name, and obtain a local object (stub) that acts as a proxy for the remote server object (represented by a skeleton).
Why do we need RMI?

RMI

- hides complexity of network protocols
- offers a standard rmiregistry implementation
- automates marshalling and unmarshalling of objects
- automates generation of stubs and skeletons
Developing an RMI application

There are several steps to using RMI:

1. Implement a server
   - Decide which objects will be remote servers and specify their interfaces
   - Implement the server objects

2. Implement a client
   - Clients must use the remote interfaces
   - Objects passed as parameters must be serializable

...
Developing an RMI application ...

3. **Compile** and **install** the software
   - Use the rmic compiler to **generate stubs and skeletons** for remote objects

4. **Run** the application
   - **Start** the RMI **registry**
   - **Start** and **register** the servers
   - **Start** the **client**
Designing client/server interfaces

Interfaces between clients and servers should be *as small as possible.*

**Low coupling:**
- simplifies development and *debugging*
- maximizes *independence*
- reduces *communication overhead*
BoardGame client/server interfaces

We split the game into three packages:

- **client** — contains the GUI components (view), the EventListeners and the Observer

- **server** — contains the server interfaces and the communication classes

- **tictactoe** — contains the model and the server implementation classes

**NB:** The client’s Observer must be updated from the server side, so is also a “server”!
Identifying remote interfaces

To implement the distributed game, we need three interfaces:

RemoteGameFactory
- called by the client to **join a game**
- implemented by tictactoe.GameFactory

RemoteGame
- called by the client to **query the game state** and to **handle moves**
- implemented by tictactoe.Gameproxy
  - we simplify the game interface by hiding Player instances

RemoteObserver
- called by the server to **propagate updates**
- implemented by client.GameObserver
Specifying remote interfaces

To define a remote interface:

- the interface must extend java.rmi.Remote
- every method must be declared to throw java.rmi.RemoteException
- every argument and return value must:
  - be a primitive data type (int, etc.), or
  - be declared to implement java.io.Serializable, or
  - implement a Remote interface
RemoteGameFactory

This interface is used by clients to *join a game*. If a game already exists, the client joins the existing game. Else a new game is made.

```java
public interface RemoteGameFactory extends Remote {
    public RemoteGame joinGame() throws RemoteException;
}
```

The object *returned* implements the RemoteGame interface.

*RMI will automatically create a stub on the client side and skeleton on the server side for the RemoteGame
RemoteGame

RemoteGame exports only what is needed by the client:

```java
public interface RemoteGame extends Remote {
    public boolean ready() throws RemoteException;
    public char join() ...;
    public boolean move(Move move) ...;
    public int cols() ...;
    public int rows() ...;
    public char currentPlayer() ...;
    public String winner() ...;
    public boolean notOver() ...;
    public void addObserver(RemoteObserver o) ...;
}
```
RemoteObserver

This is the only interface the client exports to the server:

```java
public interface RemoteObserver extends Remote {
    public void update(Move move)
        throws RemoteException;
}
```

**NB:** RemoteObserver is not compatible with java.util.Observer, since update() may throw a RemoteException ...

We will have to bridge the incompatibility on the server side.
Serializable objects

Objects to be passed as values must be declared to implement java.io.Serializable.

```java
public class Move implements java.io.Serializable {
    public final int col;
    public final int row;
    public final char mark;
    public Move(int col, int row, char mark) { ... }
    public String toString() { ... }
}

Move encapsulates the minimum information to communicate between client and server.
```
Implementing Remote objects

Remote objects should extend java.rmi.server.UnicastRemoteObject:

```java
public class GameFactory extends UnicastRemoteObject
    implements RemoteGameFactory
{
    private RemoteGame game_;
    public static void main(String[] args) { ... }
    public GameFactory() throws RemoteException {
        super();
    }
    ...
}

NB: All constructors for Remote objects must throw RemoteException!
Implementing Remote objects ...

...  
public synchronized RemoteGame joinGame() throws RemoteException {
   RemoteGame game = game_;  
   if (game == null) {  // first player => new game
      game = new GameProxy(new Gomoku(...));
      game_ = game;
   } else { game_ = null; }
   // second player => join existing game
   return game;
}

A simple view of synchronization

A *synchronized* method obtains a *lock* for its object before executing its body.

How can servers protect their state from concurrent requests?

✔ Declare their public methods as synchronized.
Registering a remote object

The server must be started by an ordinary `main()` method:

```java
public static void main(String[] args) {
    if (System.getSecurityManager() == null) {
        System.setSecurityManager(new RMISecurityManager());
        System.out.println("Set new Security manager");
    }

    ...

    There must be a security manager installed so that RMI can safely download classes!
```
Registering a remote object ...

The main() method must instantiate a GameFactory and register it with a running RMI registry.

```java
... if (args.length != 1) { ... }
String name = "//" + args[0] + "/GameFactory";
try {
    RemoteGameFactory factory = new GameFactory();
    Naming.rebind(name, factory);
} catch (Exception e) { ... }
```

The argument is the host id and port number of the registry (e.g., www.iam.unibe.ch:2001)
GameProxy

The GameProxy interprets Moves and protects the client from any AssertionExceptions:

```java
public class GameProxy extends UnicastRemoteObject implements RemoteGame {
    ...
    public synchronized boolean move(Move move) throws RemoteException {
        Player current = game_.currentPage();
        if (current.mark() != move.mark) return false;
        try {
            game_.move(move.col, move.row, current);
            return true; // the move succeeded
        } catch (AssertionException e) { return false; }
    }
    ...
```
Using Threads to protect the server

We must prevent the server from being blocked by a call to the remote client.

WrappedObserver *adapts* a RemoteObserver to implement java.util.Observer:

```java
class WrappedObserver implements Observer {
    private RemoteObserver remote_

    WrappedObserver(RemoteObserver ro) {
        remote_ = ro;
    }

    ...
```
Using Threads to protect the server ...

```java
public void update(Observable o, Object arg) {
    final Move move = (Move) arg; // for inner class
    Thread doUpdate = new Thread() {
        public void run() {
            try {
                remote_.update(move);
            } catch(RemoteException err) { }
        }
    };
    doUpdate.start(); // start the Thread
    // and ignore results
}

Even if the Thread blocks, the server can continue ...
```
Refactoring the BoardGame ...

Most of the changes were on the GUI side:

- defined separate client, server and tictactoe packages
- no changes to Drivers, Players, Runner, TicTactoe or Gomoku from 2.0 (except renaming AppletPlayer to PassivePlayer)
- added BoardGame methods player() and addObserver()
  - added WrappedObserver to adapt RemoteObserver
- added remote interfaces and remote objects
- changed all client classes
  - separated GameApplet from GameView (to allow multiple views)
  - view now uses Move and RemoteGame (not Player)
Compiling the code

We compile the source packages as usual, and install the results in a *web-accessible location* so that the GameApplet has access to the client and server .class files.
Generating Stubs and Skeletons

In addition, the client and the server need access to the stub and skeleton class files.

On Unix, chdir to the directory containing the client and tictactoe class file hierarchies

```bash
rmic -d . tictactoe.GameFactory
rmic -d . tictactoe.GameProxy
rmic -d . client.GameObserver
```

This will generate stub and skeleton class files for the remote objects. (I.e., GameFactory_Skel.class etc.)

**NB: Move is not a remote object, so we do not need to run rmic on its class file.**
Running the application

We start the RMI registry on the host (www.iam.unibe.ch):
\texttt{rmiregistry 2001 &}

We start and register the servers:
\texttt{setenv CLASSPATH ./classes}
\texttt{java -Djava.rmi.server.codebase=http://www.iam.unibe.ch:2001/tictactoe.GameFactory}
\texttt{www.iam.unibe.ch:2001}

And start the clients with a browser or an appletviewer ...

\textbf{NB: the RMI registry needs the codebase so it can instantiate the stubs and skeletons!}
Playing the game

1.1a: mouseClicked() 1b: move() 1.2b: move() 1c: update() 1.2.1b: move() 1.1d: update() 1.1.1d: setMove() 1a: mouseClicked() 1.1a: move() 1b: move() click

- :GameObserver
- :Place
- :PlaceListener
- :GameView
- :WrappedObserver
- :Gomoku
- :PassivePlayer
- :GameProxy
Caveat!

This only works with JDK 1.1:

- Most web browsers are not Java 1.2 enabled
- Applets can only connect to the host of their codebase
- Security is more complex in Java 1.2
  - clients must specify a policy file

*Web browsers, Applets, RMI and Java security don’t mix well.*

If you plan to use RMI and Java 2, stay away from applets!
Other approaches

**CORBA**
- for non-java components

**COM (DCOM, Active-X ...)**
- for talking to MS applications

**Sockets**
- for talking other TCP/IP protocols

**Software buses**
- for sharing information across multiple applications
What you should know!

✎ How do you make a **remote object** available to clients?
✎ How does a client **obtain access** to a remote object?
✎ What are **stubs and skeletons**, and where do they come from?
✎ What requirements must a **remote interface** fulfil?
✎ What is the difference between a **remote object** and a **serializable object**?
✎ Why do servers often **start new threads** to handle requests?
Can you answer these questions?

✎ Suppose we modified the view to work with Players instead of Moves. Should Players then be remote objects or serializable objects?
✎ Why don’t we have to declare the AbstractBoardGame methods as synchronized?
✎ What kinds of tests would you write for the networked game?
✎ How would you extend the game to notify users when a second player is connected?
✎ What exactly happens when you send an object over the net via RMI?
11. Guidelines, Idioms and Patterns

Overview
- Programming style: Code Talks; Code Smells
- Idioms, Patterns and Frameworks
- Basic Idioms
  - Delegation, Super, Interface
- Basic Patterns
  - Adapter, Proxy, Template Method, Composite, Observer
Sources

- Kent Beck, *Smalltalk Best Practice Patterns*, Prentice Hall, 1997
Style

Code Talks

❑ Do the *simplest* thing you can think of (KISS)
  ❆ Don't over-design
  ❆ Implement things *once and only once*
  ❆ *First* do it, *then* do it right, *then* do it fast
    (don't optimize too early)

❑ Make your *intention* clear
  ❆ Write *small methods*
  ❆ Each method should do *one* thing only
  ❆ Name methods for *what* they do, not how they do it
  ❆ Write to an *interface*, not an implementation
Refactoring

Redesign and refactor when the code starts to “smell”

Code Smells

- Methods too long or too complex
  - decompose using helper methods
- Duplicated code
  - factor out the common parts (e.g., using a Template method)
- Violation of encapsulation
  - redistribute responsibilities
- Too much communication (high coupling)
  - redistribute responsibilities

Many idioms and patterns can help to improve your design...
What are Idioms and Patterns?

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Idioms</strong></td>
<td>Idioms are common programming <em>techniques</em> and <em>conventions</em>. They are often language-specific.</td>
</tr>
<tr>
<td><strong>Patterns</strong></td>
<td>Patterns document <em>common solutions to design problems</em>. They are language-independent.</td>
</tr>
<tr>
<td><strong>Libraries</strong></td>
<td>Libraries are <em>collections of functions</em>, procedures or other software components that can be used in many applications.</td>
</tr>
<tr>
<td><strong>Frameworks</strong></td>
<td>Frameworks are open libraries that define the <em>generic architecture</em> of an application, and can be <em>extended</em> by adding or deriving new classes.</td>
</tr>
</tbody>
</table>

Frameworks typically make use of common idioms and patterns.
Delegation

➤ How can an object share behaviour without inheritance?

✔ Delegate some of its work to another object

Inheritance is a common way to extend the behaviour of a class, but can be an inappropriate way to combine features. Delegation reinforces encapsulation by keeping roles and responsibilities distinct.
Delegation

Example

❑ When a TestSuite is asked to run(), it delegates the work to each of its TestCases.

Consequences

More flexible, less structured than inheritance.

Delegation is one of the most basic object-oriented idioms, and is used by almost all design patterns.
Delegation example

```java
public class TestSuite implements Test {
    ...
    public void run(TestResult result) {
        for (Enumeration e = fTests.elements();
             e.hasMoreElements();)
        {
            if (result.shouldStop())
                break;
            Test test = (Test) e.nextElement();
            test.run(result);
        }
    }
```
Super

How do you extend behaviour inherited from a superclass?

Overwrite the inherited method, and send a message to “super” in the new method.

Sometimes you just want to extend inherited behaviour, rather than replace it.
Super

Examples

❑ WrappedStack.top() extends Stack.top() with a precondition assertion.
❑ Constructors for subclasses of Exception invoke their superclass constructors.

Consequences

*Increases coupling* between subclass and superclass: if you change the inheritance structure, super calls may break!

Never use super to invoke a method different than the one being overwritten — use “this” instead!
Super example

class WrappedStack extends SimpleWrappedStack {
    ...
    public Object top() throws AssertionException {
        assert(!this.isEmpty());
        return super.top();
    }
    public void pop() throws AssertionException {
        assert(!this.isEmpty());
        super.pop();
    }
}
Interface

➤ How do you keep a client of a service independent of classes that provide the service?

✔ Have the client use the service through an interface rather than a concrete class.

If a client names a concrete class as a service provider, then only instances of that class or its subclasses can be used in future.

By naming an interface, an instance of any class that implements the interface can be used to provide the service.
Interface

Example
❑ Any object may be registered with an Observable if it implements the Observer interface.

Consequences
Interfaces reduce coupling between classes.
They also increase complexity by adding indirection.
Interface example

public class GameApplet extends Applet

    implements Observer

{ ...

    public void update(Observable o, Object arg) {
        Move move = (Move) arg;
        showFeedBack("got an update: " + move);
        places_[move.col][move.row]
            .setMove(move.player);
    }

}
Adapter

➤ How do you use a class that provide the right features but the wrong interface?

✔ Introduce an adapter.

An adapter converts the interface of a class into another interface clients expect.
Adapter

Examples

- A WrappedStack adapts java.util.Stack, throwing an AssertionException when top() or pop() are called on an empty stack.
- An ActionListener converts a call to actionPerformed() to the desired handler method.

Consequences

The client and the adapted object remain independent. An adapter adds an extra level of indirection.

Also known as Wrapper
Adapter example

```java
private Component makeControls() {
    Button again = new Button("New game");
    again.addActionListener(new ActionListener() {
        public void actionPerformed(ActionEvent e) {
            showFeedBack("starting new game ...");
            newGame();
        }
    });
    return again;
}
```
Proxy

How do you hide the complexity of accessing objects that require pre- or post-processing?

Introduce a proxy to control access to the object.

Some services require special pre or post-processing. Examples include objects that reside on a remote machine, and those with security restrictions.

A proxy provides the same interface as the object that it controls access to.
Proxy

Example

- A Java “stub” for a remote object accessed by Remote Method Invocation (RMI).

Consequences

A Proxy *decouples* clients from servers. A Proxy *introduces* a level of *indirection*.

*Proxy differs from Adapter in that it does not change the object’s interface.*
Proxy example

```
Machine A

1:doit() :ServiceStub 1.1:doit() :Service

Machine B
```
Template Method

➤ How do you implement a generic algorithm, deferring some parts to subclasses?

✔ Define it as a Template Method.

A Template Method factors out the common part of similar algorithms, and delegates the rest to:

- hook methods that subclasses may extend, and
- abstract methods that subclasses must implement.
Template Method

Example
- `TestCase.runBare()` is a template method that calls the hook method `setUp()`.

Consequences
Template methods lead to an *inverted control structure* since a parent classes calls the operations of a subclass and not the other way around.

*Template Method is used in most frameworks to allow application programmers to easily extend the functionality of framework classes.*
**Template method example**

Subclasses of `TestCase` are expected to *override hook method `setUp()` and possibly `tearDown()` and `runTest()`.*

```java
public abstract class TestCase implements Test {
  ...
  public void runBare() throws Throwable {
    setUp();
    try { runTest(); } // empty by default
    finally { tearDown(); }
  }
  protected void setUp() { } // empty by default
  protected void tearDown() { }
  protected void runTest() throws Throwable { ... }
}
```
Composite

How do you manage a part-whole hierarchy of objects in a consistent way?

Define a common interface that both parts and composites implement.

Typically composite objects will implement their behaviour by delegating to their parts.
Examples

- A TestSuite is a composite of TestCases and TestSuites, both of which implement the Test interface.
- A Java GUI Container is a composite of GUI Components, and also extends Component.

Consequences

Clients can uniformly manipulate parts and wholes.
In a complex hierarchy, it may not be easy to define a common interface that all classes should implement ...
Composite example

A TestSuite is a Test that bundles a set of TestCases and TestSuites.

<table>
<thead>
<tr>
<th>TestCase</th>
<th>abstract</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ create(String)</td>
<td></td>
</tr>
<tr>
<td>+ assert(boolean)</td>
<td></td>
</tr>
<tr>
<td>+ assertEquals(Object, Object)</td>
<td></td>
</tr>
<tr>
<td>+ fail()</td>
<td></td>
</tr>
<tr>
<td>+ void runBare()</td>
<td></td>
</tr>
<tr>
<td># void runTest()</td>
<td></td>
</tr>
<tr>
<td># void setUp()</td>
<td></td>
</tr>
<tr>
<td># void tearDown()</td>
<td></td>
</tr>
<tr>
<td>+ name() : String</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>“interface” Test</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>+ countTestCases() : int</td>
<td></td>
</tr>
<tr>
<td>+ run(TestResult)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TestSuite</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>+ create()</td>
<td></td>
</tr>
<tr>
<td>+ create(Class)</td>
<td></td>
</tr>
<tr>
<td>+ addTest(Test test)</td>
<td></td>
</tr>
<tr>
<td>+ setUp()</td>
<td></td>
</tr>
<tr>
<td>+ tearDown()</td>
<td></td>
</tr>
</tbody>
</table>
Observer

➤ How can an object inform arbitrary clients when it changes state?

✔ Clients implement a common Observer interface and register with the “observable” object; the object notifies its observers when it changes state.

An observable object publishes state change events to its subscribers, who must implement a common interface for receiving notification.
Observer

Examples
- The GameApplet implements java.util.Observable, and registers with a BoardGame.
- A Button expects its observers to implement the ActionListener interface.  
  *(see the Interface and Adapter examples)*

Consequences
Notification can be slow if there are many observers for an observable, or if observers are themselves observable!
What Problems do Design Patterns Solve?

Patterns:
- document *design experience*
- enable widespread *reuse* of software *architecture*
- *improve communication* within and across software development teams
- *explicitly capture knowledge* that experienced developers already understand implicitly
- *arise from practical experience*
- help *ease the transition* to object-oriented technology
- facilitate *training* of new developers
- help to transcend “programming language-centric” viewpoints

What you should know!

✎ What’s wrong with long methods? How long should a method be?
✎ What’s the difference between a pattern and an idiom?
✎ When should you use delegation instead of inheritance?
✎ When should you call “super”?
✎ How does a Proxy differ from an Adapter?
✎ How can a Template Method help to eliminate duplicated code?
Can you answer these questions?

✧ What idioms do you regularly use when you program? What patterns do you use?
✧ What is the difference between an interface and an abstract class?
✧ When should you use an Adapter instead of modifying the interface that doesn’t fit?
✧ Is it good or bad that java.awt.Component is an abstract class and not an interface?
✧ Why do the Java libraries use different interfaces for the Observer pattern (java.util.Observer, java.awt.event.ActionListener etc.)?
12. Common Errors, a few Puzzles

Overview

- Common errors:
  - Round-off
  - == vs. equals()
  - Forgetting to clone objects
  - Dangling else
  - Off-by-1 ...

- A few Java puzzles ...

Sources

- The Java Report, April 1999
Trap 1

What does this print?

double f = 2e15 + 0.13;
double g = 2e15 + 0.02;

println(100*(f-g));
Trap 2

When are two Strings equal?

```java
String s1 = new String("This is a string");
String s2 = new String("This is a string");
test("String==", s1 == s2);
test("String.equals", s1.equals(s2));
```

```java
static void test(String name, boolean bool) {
    println(name + ": " + (bool?"true":"false"));
}
```
Trap 3

When are two Objects equal?

Object x = new Object();
Object y = new Object();
test("object==", x == y);
test("object.equals", x.equals(y));
Tran 4

When are two Strings equal?

String s3 = "This is a string";
String s4 = "This is a string";
test("String==", s3 == s4);
test("String.equals", s3.equals(s4));
Trap 5

Is “now” really before “later”?

```java
Date now = new Date();
Date later = now;
later.setHours(now.getHours() + 1);
if (now.before(later))
    println("see you later");
else
    println("see you now");
```
Trap 6

static void checkEven(int n) {
    boolean result = true;
    if (n>=0)
        if ((n%2) == 0)
            println(n + " is even");
        else
            println(n + " is negative");
    }

What is printed when we run these checks?
    checkEven(-1);
    checkEven(0);
    checkEven(1);
Trap 7

The binomial coefficient \( \binom{n}{k} \) is
\[
\frac{n}{1} \times \ldots \times \frac{n-k+1}{k}.
\]

Is this a correct implementation?

```java
static int binomial(int n, int k) {
    int bc = 1;
    for (int i=1; i<k; i++)
        bc = bc * (n+1-i) / i;
    return bc;
}
```
Avoiding Off-by-1 errors

To avoid off-by-1 errors:

1. *Count the iterations* — do we always do k multiplications? (no)

2. *Check boundary conditions* — do we start with n/1 and finish with (n-k+1)/k? (no)

*Off-by-1 errors are among the most common mistakes in implementing algorithms.*
Trap 8

For which values does this function work correctly?

```java
static int brokenFactorial(int n) {
    int result=1;
    for (int i=0; i!=n; i++)
        result = result*(i+1);
    return result;
}
```
Some other common errors

Magic numbers
- Never use magic numbers; declare *constants* instead.

Forgetting to set a variable in some branch
- If you have non-trivial control flow to set a variable, make sure it starts off with a *reasonable default value*.

Underestimating size of data sets
- Don’t write programs with *arbitrary built-in limits* (like line-length); they will break when you least expect it.

Leaking encapsulation
- Never return a private instance variable! (*return a clone* instead)

*Bugs are always matter of invalid assumptions not holding*
Puzzle 1

Are private methods inherited?

class \texttt{A} {
    public void \texttt{m()} { this.p(); } \\
    \texttt{private void p()} { println("A.p()"); } \\
}

class \texttt{B} extends \texttt{A} {
    \texttt{private void p()} { println("B.p()"); } \\
}

Which is called? \texttt{A.p()} or \texttt{B.p()}?

\texttt{A} \texttt{b} = \texttt{new B();} \\
\texttt{b.m();}
Static and Dynamic Types

Consider:

```java
A a = new B();
```

The *static type* of variable `a` is `A` — i.e., the statically declared class to which it belongs.  
*The static type never changes.*

```
A a = new A();
```

Now the dynamic type is also `A`!

The *dynamic type* of `a` is `B` — i.e., the class of the object currently bound to `a`.  
*The dynamic type may change throughout the program.*
Puzzle 2 (part I)

How are overloaded method calls resolved?

class A { }
class B extends A { }
void m(A a1, A a2) { println("m(A,A)"); };
void m(A a1, B b1) { println("m(A,B)"); };
void m(B b1, A a1) { println("m(B,A)"); };
void m(B b1, B b2) { println("m(B,B)"); };
B b = new B(); A a = b;

Which is considered: the static or dynamic argument type?

m(a, a);
m(a, b);
m(b, a);
m(b, b);
Puzzle 2 (part II)

What happens if we comment out:

☐ m(A,A)?

☐ m(B,B)?

☐ m(A,B)?

Will the examples still compile?
If so, which methods are called?
Puzzle 3

How do static and dynamic types interact?

```java
class A {
    void m(A a) { println("A.m(A)"); }
}
class B extends A {
    void m(B b) { println("B.m(B)"); }
}
B b = new B(); A a = b;
```

In which cases will B.m(B) be called?

- a.m(a);
- a.m(b);
- b.m(a);
- b.m(b);
Puzzle 4 (part I)

How do default values and constructors interact?

class C {
    int i = 100, j = 100, k = init(), l = 0;
    C() { i = 0; k = 0; }
    int init() { j = 0; l = 100; return 100; }
}

What gets printed? 0 or 100?

C c = new C();
println("C.i = " + c.i);
println("C.j = " + c.j);
println("C.k = " + c.k);
println("C.l = " + c.l);
Puzzle 4 (part II)

abstract class A {
    int j = 100;
    A() { init(100); j = 200; }
    abstract void init(int value);
}

class B extends A {
    int i = 0, j = 0;
    B() { super(); }
    void init(int value) { i = value; }
}

What gets printed? 0, 100 or 200?

B b = new B();
println("B.i = " + b.i);
println("B.j = " + b.j);
Puzzle 5

Does try or finally return?

class A {
    int m() {
        try { return 1; }
        catch (Exception err) { return 2; }
        finally { return 3; }
    }
}

Prints 1, 2, or 3?

A a = new A();
println(a.m());
What you should know!

✎ When can you trust floating-point arithmetic?
✎ To which “if” does an “else” belong in a nested if statement?
✎ How can you avoid off-by-1 errors?
✎ Why should you never use equality tests to terminate loops?
✎ Are private methods inherited?
✎ What are the static and dynamic types of variables?
✎ How are they used to dispatch overloaded methods?
Can you answer these questions?

✎ When is method dispatching *ambiguous*?
✎ Is it better to use *default values* or *constructors* to *initialize* variables?
✎ If both a *try* clause and its *finally* clause throw an *exception*, which exception is really thrown?