Principles of Software Construction: Objects, Design, and Concurrency (Part 2: Designing (Sub-)Systems)

Design for Robustness

Christian Kästner **Bogdan Vasilescu**

School of Computer Science

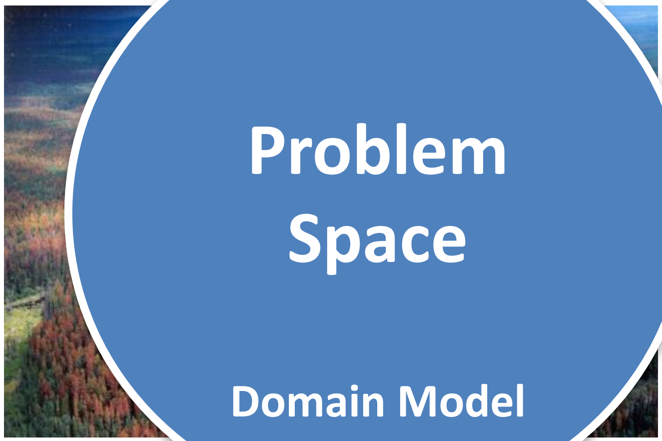
institute for SOFTWARE RESEARCH

Administrativa

- Midterm 1: Thursday here
- Practice midterm on Piazza
- Review session tomorrow, 6:30pm GHC4401

- HW 2 grades
- HW 4 out, Milestone A due Feb 23
  - Do not underestimate design

Review



Problem Space

Domain Model

inspires objects and names

PineTree

- age
- size

- harvest()

n

1

Solution Space

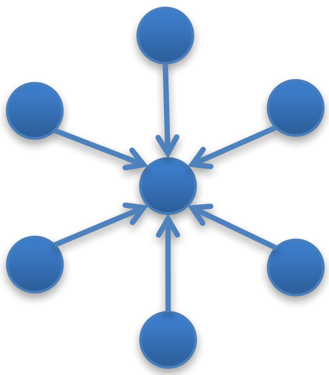
Object Model

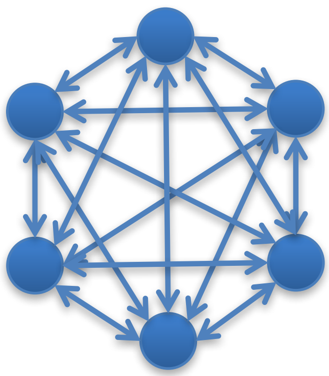
RangerAgent

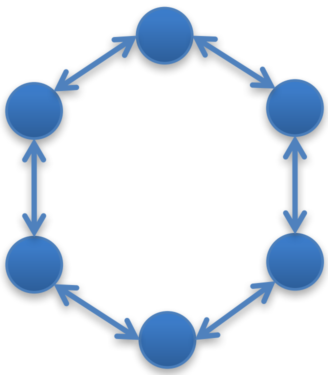
- sanitation(Forest)
- salvage(Forest)

Design principle for reuse: *low coupling*

Review

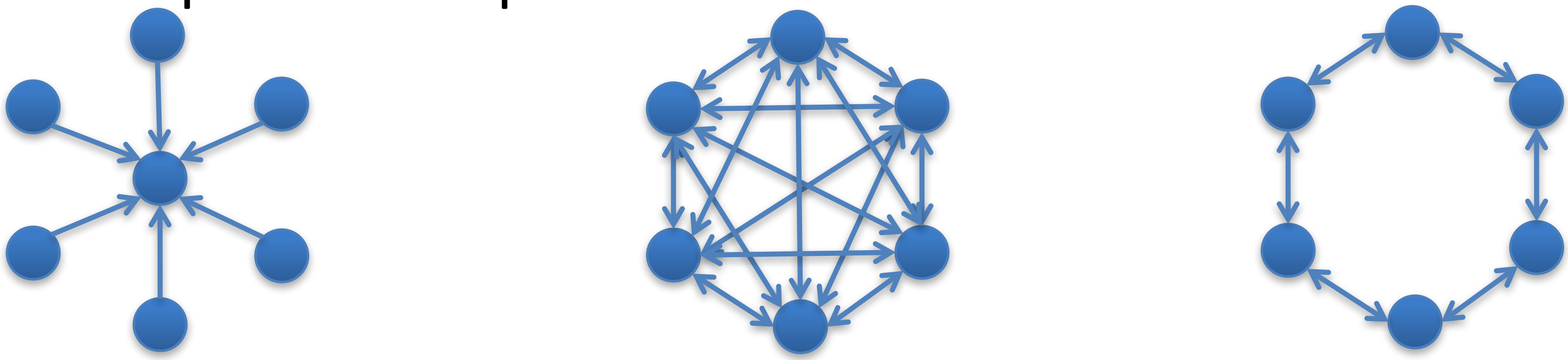






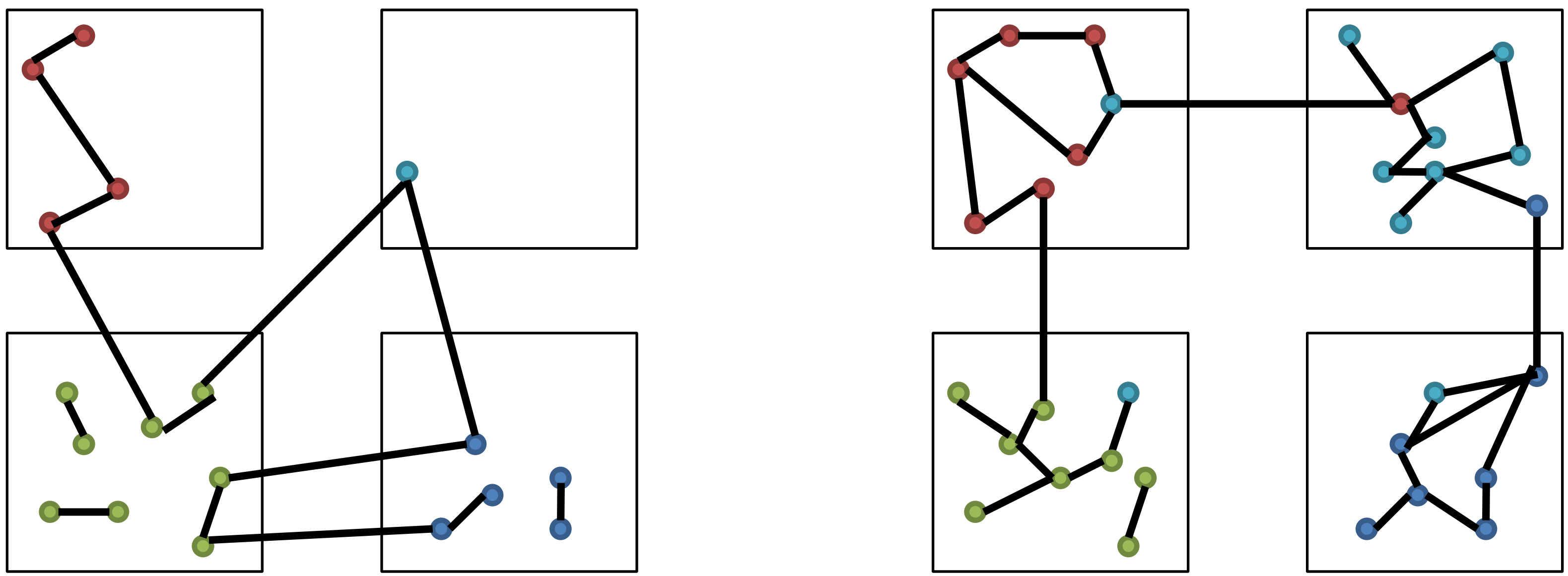
Design principle for reuse: *low coupling*

- Each component should depend on as few other components as possible



- Benefits of low coupling:
  - Enhances understandability
  - Reduces cost of change
  - Eases reuse

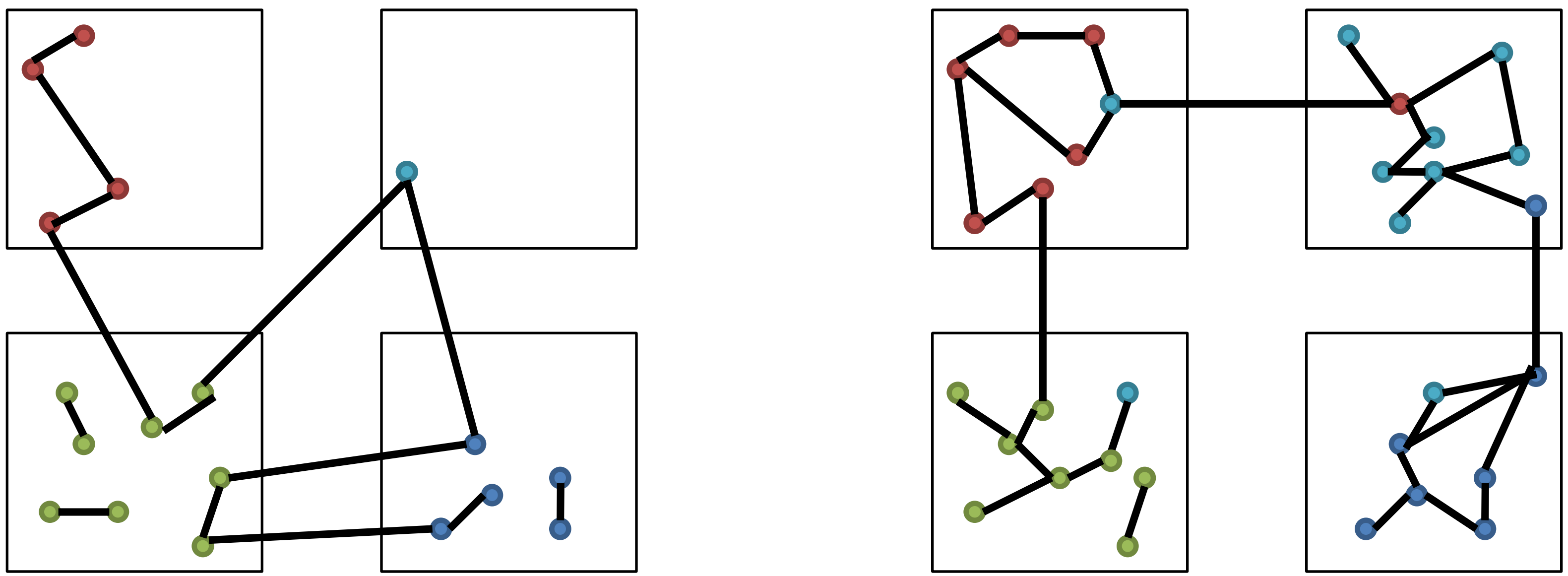
Design principle for reuse: *high cohesion*



Design principle for reuse: *high cohesion*

Review

- Each component should have a small set of closely-related responsibilities



- Benefits:
  - Facilitates understandability
  - Facilitates reuse
  - Eases maintenance

Information Expert (GRASP Pattern/Design Heuristic)

- Heuristic: **Assign a responsibility to the class that has the information necessary to fulfill the responsibility**
- Start assigning responsibilities by clearly stating responsibilities!
- Typically follows common intuition
- Software classes instead of Domain Model classes
  - If software classes do not yet exist, look in Domain Model for fitting abstractions (-> correspondence)

Creator
(GRASP Pattern/Design Heuristic)

- Problem: Who creates an A?
- Solution: **Assign class responsibility of creating instance of class A to B if**
  - B aggregates A objects
  - B contains A objects
  - B records instances of A objects
  - B closely uses A objects
  - B has the initializing data for creating A objects
- the more the better; where there is a choice, prefer
  - B aggregates or contains A objects
- Key idea: Creator needs to keep reference anyway and will frequently use the created object

Learning Goals

- Use exceptions to write robust programs
- Make error handling explicit in interfaces and contracts
- Isolate errors modularly
- Test complex interactions locally
- Test for error conditions

Design Goals, Principles, and Patterns

- Design Goals
  - Design for robustness
- Design Principle
  - Modular protection
  - Explicit interfaces
- Supporting Language Features
  - Exceptions

EXCEPTION HANDLING

What does this code do?

```
FileInputStream fIn = new FileInputStream(filename);
if (fIN == null) {
  switch (errno) {
  case _ENOFILE:
     System.err.println("File not found: " + …);
     return -1;
  default:
     System.err.println("Something else bad happened: " + …);
     return -1;
  }
}
DataInput dataInput = new DataInputStream(fIn);
if (dataInput == null) {
  System.err.println("Unknown internal error.");
  return -1;  // errno > 0 set by new DataInputStream
}
int i = dataInput.readInt();
if (errno > 0) {
  System.err.println("Error reading binary data from file");
  return -1;
}  // The slide lacks space to close the file.  Oh well.
return i;
```

Compare to:

```java
try {
    FileInputStream fileInput = new FileInputStream(filename);
    DataInput dataInput = new DataInputStream(fileInput);
    int i = dataInput.readInt();
    fileInput.close();
    return i;
} catch (FileNotFoundException e) {
    System.out.println("Could not open file " + filename);
    return -1;
} catch (IOException e) {
    System.out.println("Error reading binary data from file "
                       + filename);
    return -1;
}
```

Exceptions

- Exceptions notify the caller of an exceptional circumstance (usually operation failure)
- Semantics
  - An exception propagates up the function-call stack until main() is reached (terminates program) or until the exception is caught
- Sources of exceptions:
  - Programmatically throwing an exception
  - Exceptions thrown by the Java Virtual Machine

Exceptional control-flow in Java

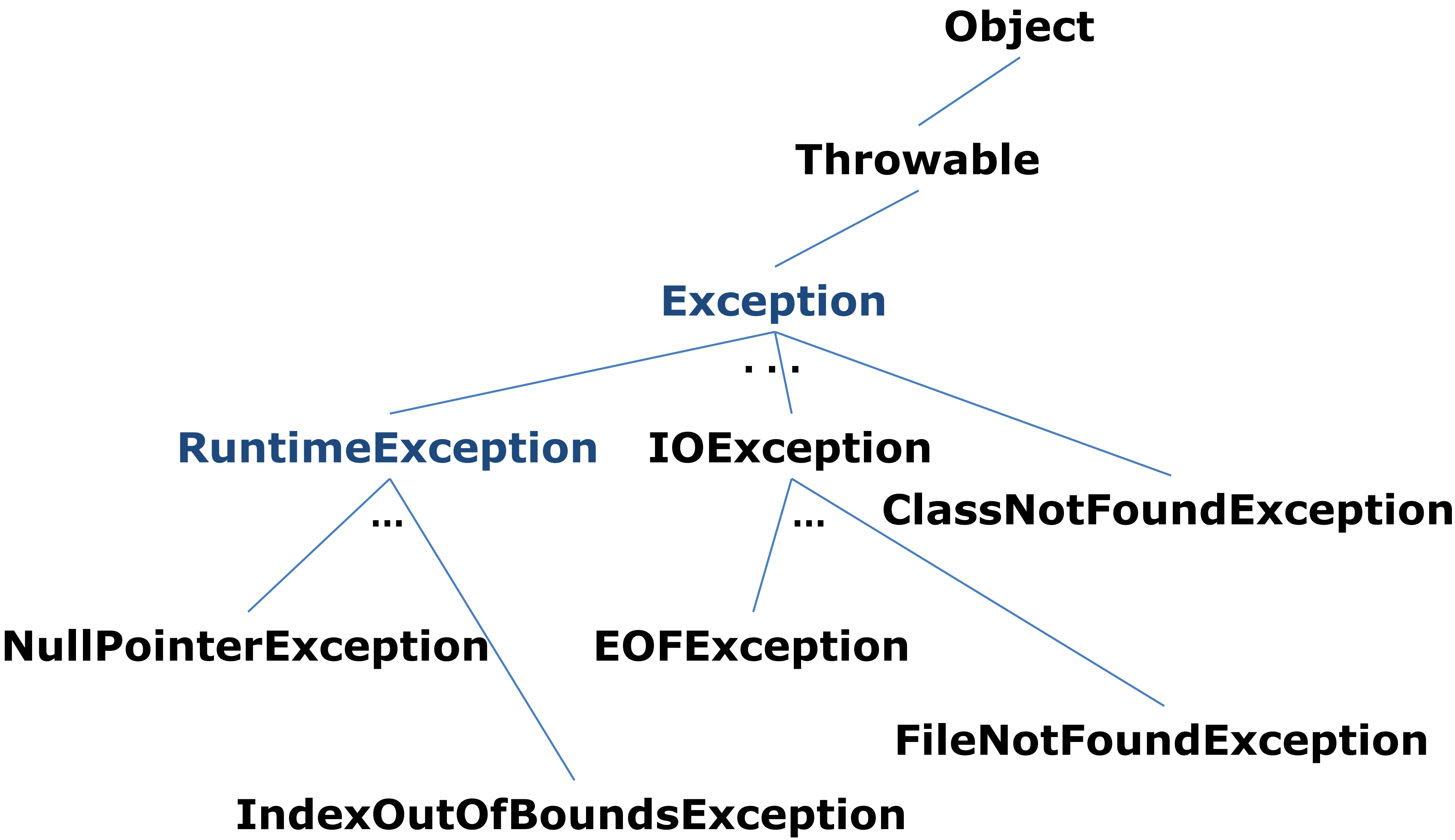
```
public static void test() {
    try {
        System.out.println("Top");
        int[] a = new int[10];
        a[42] = 42;
        System.out.println("Bottom");
    } catch (NegativeArraySizeException e) {
        System.out.println("Caught negative array size");
    }
}

public static void main(String[] args) {
    try {
        test();
    } catch (IndexOutOfBoundsException e) {
        System.out.println"("Caught index out of bounds");
    }
}
```

Java: The **finally** keyword

- The finally block always runs after try/catch:

```
try {
    System.out.println("Top");
    int[] a = new int[10];
    a[2] = 2;
    System.out.println("Bottom");
} catch (IndexOutOfBoundsException e) {
    System.out.println("Caught index out of bounds");
} finally {
    System.out.println("Finally got here");
}
```

The exception hierarchy in Java



Design choice: Checked and unchecked exceptions and return values

- *Unchecked exception*: any subclass of RuntimeException
  - Indicates an error which is highly unlikely and/or typically unrecoverable
- *Checked exception*: any subclass of Exception that is not a subclass of RuntimeException
  - Indicates an error that every caller should be aware of and explicitly decide to handle or pass on
- Return values (boolean, empty lists, null, etc): If failure is common and expected possibility

Design Principle: Explicit Interfaces (contracts)

Creating and throwing your own exceptions

- Methods must declare any checked exceptions they might throw
- If your class extends java.lang.Throwable you can throw it:
  - if (someErrorBlahBlahBlah) {
  -   throw new MyCustomException(“Blah blah blah”);
  - }

Benefits of exceptions

- Provide high-level summary of error and stack trace
  - Compare: core dumped in C
- Can't forget to handle common failure modes
  - Compare: using a flag or special return value
- Can optionally recover from failure
  - Compare: calling System.exit()
- Improve code structure
  - Separate routine operations from error-handling (see Cohesion)
- Allow consistent clean-up in both normal and exceptional operation

Guidelines for using exceptions

- Catch and handle all checked exceptions
  - Unless there is no good way to do so…
- Use runtime exceptions for programming errors
- Other good practices
  - Do not catch an exception without (at least somewhat) handling the error
  - When you throw an exception, describe the error
  - If you re-throw an exception, always include the original exception as the cause

Testing for presence of an exception

```
import org.junit.*;
import static org.junit.Assert.fail;

public class Tests {

        @Test
        public void testSanityTest(){
                try {
                        openNonexistingFile();
                        fail("Expected exception");
                } catch(IOException e) { }
        }

        @Test(expected = IOException.class)
        public void testSanityTestAlternative() {
                openNonexistingFile();
        }
}
```

DESIGN PRINCIPLE: MODULAR PROTECTION

Modular Protection

- Errors and bugs unavoidable, but exceptions should not leak across modules (methods, classes), if possible
- Good modules handle exceptional conditions locally
  - Local input validation and local exception handling where possible
  - Explicit interfaces with clear pre/post conditions
  - Explicitly documented and checked exceptions where exceptional conditions may propagate between modules
  - Information hiding/encapsulation of critical code (likely bugs, likely exceptions)

Examples

- Printer crash should not corrupt entire system
  - E.g., printer problem handled locally, logged, user informed
- Exception/infinite loop in Pine Simulation should not freeze GUI
  - E.g., decouple simulation from UI
- Error in shortest-path algorithm should not corrupt graph
  - E.g., computation on immutable data structure

TESTING WITH COMPLEX ENVIRONMENTS

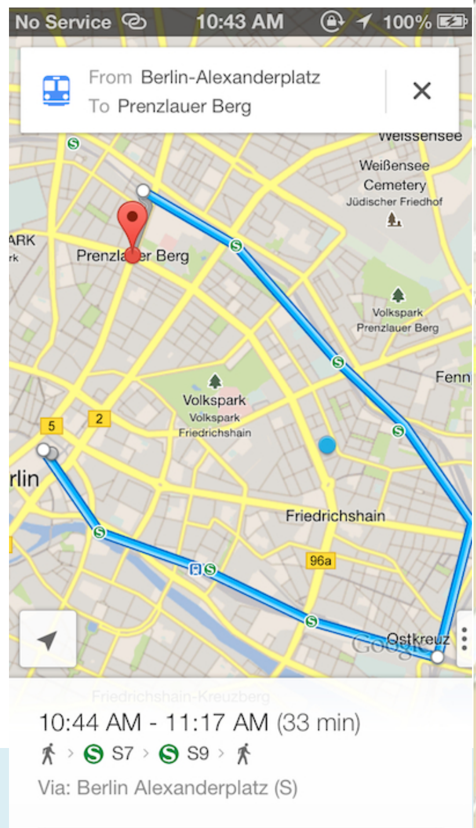
Problems when testing (sub-)systems

- User-facing applications
  - Users click, drag, etc., and interpret output
  - Timing issues
- Testing against big infrastructure
  - Databases, web services, etc.
- Real world effects
  - Printing, mailing documents, etc.

- Collectively comprise *the test environment*

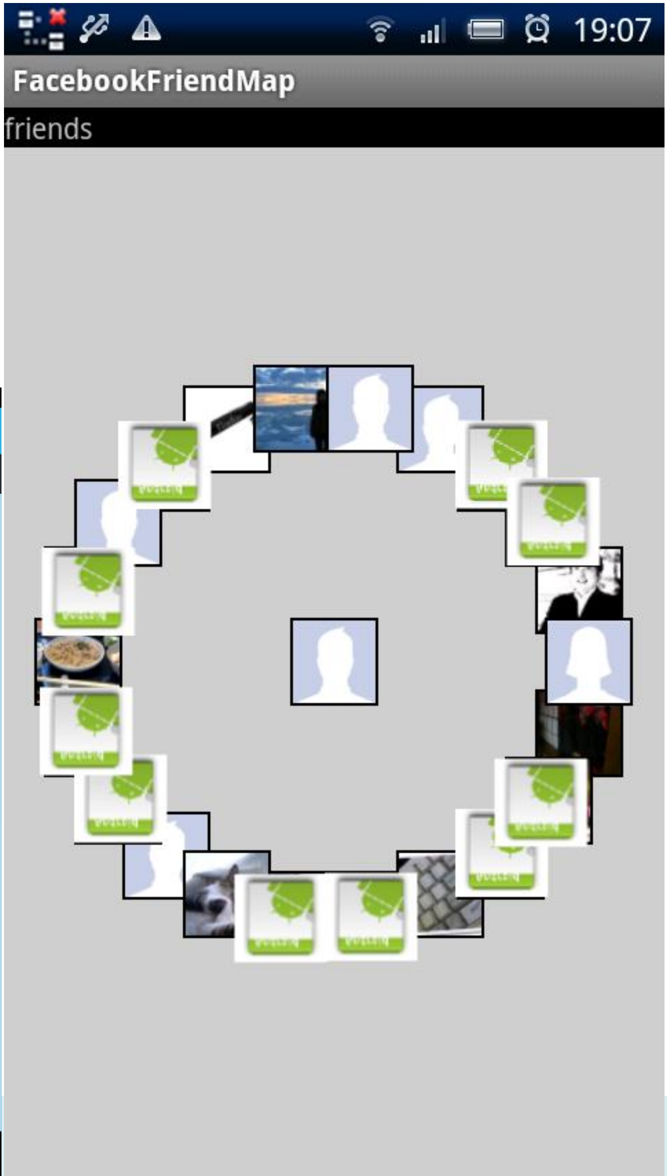
Example – Tiramisu app

- Mobile route planning app
- **Android UI**
- **Back end uses live PAT data**

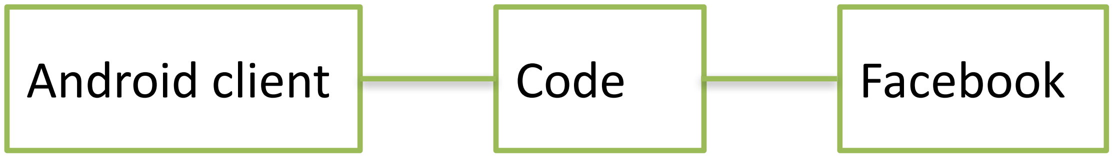


Another example

- 3rd party Facebook apps
- **Android user interface**
- **Backend uses Facebook data**

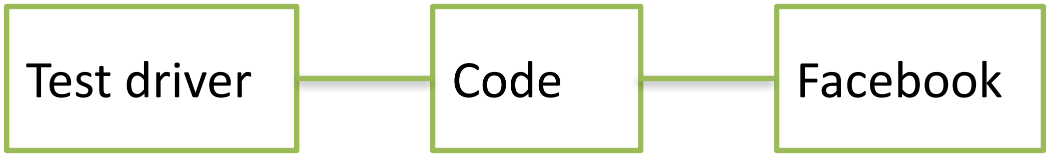


Testing in real environments




```
void buttonClicked() {
   render(getFriends());
}
List<Friend> getFriends() {
   Connection c = http.getConnection();
   FacebookAPI api = new FacebookAPI(c);
   List<Node> persons = api.getFriends("john");
   for (Node person1 : persons) {
       for (Node person2 : persons) {
      …
       }
   }
   return result;
}
```

Eliminating Android dependency

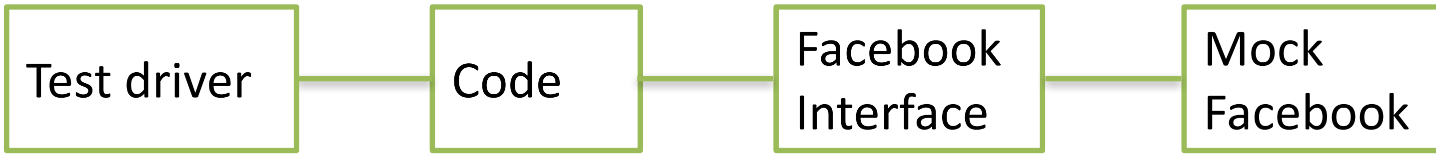



```
@Test void testGetFriends() {
   assert getFriends() == ...;
}
List<Friend> getFriends() {
   Connection c = http.getConnection();
   FacebookAPI api = new FacebookAPI(c);
   List<Node> persons = api.getFriends("john");
   for (Node person1 : persons) {
       for (Node person2 : persons) {
      …
       }
   }
   return result;
}
```

That won't quite work

- **GUI applications process *thousands* of events**
- Solution: automated GUI testing frameworks
  - Allow streams of GUI events to be captured, replayed
- These tools are sometimes called *robots*

Eliminating Facebook dependency



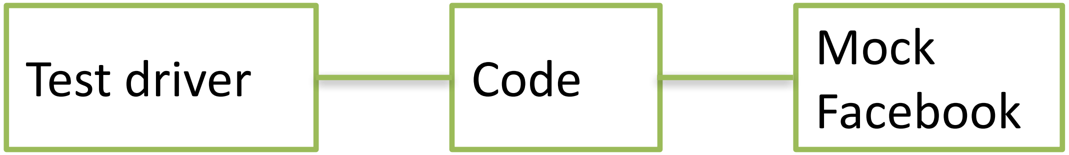

```
@Test void testGetFriends() {
   assert getFriends() == …;
}
List<Friend> getFriends() {
   Connection c = http.getConnection();
   FacebookAPI api = new MockFacebook(c);
   List<Node> persons = api.getFriends("john");
   for (Node person1 : persons) {
       for (Node person2 : persons) {
         …
       }
   }
   return result;
}
```

```
class MockFacebook implements FacebookInterface {
    void connect() {}
    List<Node> getFriends(String name) {
        if ("john".equals(name)) {
            List<Node> result=new List();
            result.add(…);
            return result;
        }
    }
}
```

That won't quite work!

- **Changing production code for testing unacceptable**
- Problem caused by constructor in code
- Use tools to facilitate this sort of testing
  - *Dependency injection* tools, e.g., Dagger, Guice
  - Mock object frameworks such as Mockito

Fault injection



- Mocks can emulate failures such as timeouts
- Allows you to verify the robustness of system

Advantages of using mocks

- Test code locally without large environment
- Enable deterministic tests
- Enable fault injection
- Can speed up test execution
  - e.g., avoid slow database access
- Can simulate functionality not yet implemented
- Enable test automation

Design Implications

- Think about testability when writing code
- When a mock may be appropriate, design for it
- Hide subsystems behind an interface
- Use factories, not constructors to instantiate
- Use appropriate tools
  - Dependency injection or mocking frameworks

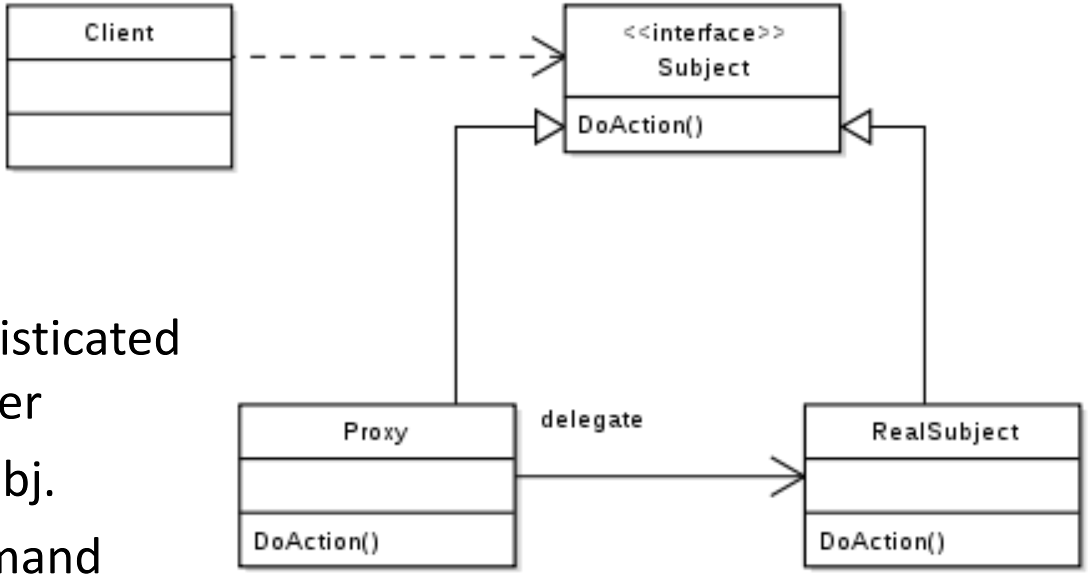
More Testing in 15-313

Foundations of Software Engineering

- Manual testing
- Security testing, penetration testing
- Fuzz testing for reliability
- Usability testing
- GUI/Web testing
- Regression testing
- Differential testing
- Stress/soak testing

DESIGN PATTERN: PROXY

Proxy Design Pattern



Applicability

- Whenever you need a more sophisticated obj reference than a simple pointer
- Local representative for remote obj.
- Create/load expensive obj on demand
- Control access to an object
- Extra error handling, failover
- Caching
- Reference count an object

Consequences

- Introduces a level of indirection
- Hides distribution from client
- Hides optimizations from client
- Adds housekeeping tasks

Example: Caching

```
interface FacebookAPI {
	List<Node> getFriends(String name);
}
class FacebookProxy implements FacebookAPI {
	FacebookAPI api;
	HashMap<String,List<Node>> cache = new HashMap…
	FacebookProxy(FacebookAPI api) { this.api=api;}

	List<Node> getFriends(String name) {
		result = cache.get(name);
		if (result == null) {
			result = api.getFriends(name);
			cache.put(name, result);
		}
		return result;
	}
}
```

Example: Caching and Failover

```
interface FacebookAPI {
	List<Node> getFriends(String name);
}
class FacebookProxy implements FacebookAPI {
	FacebookAPI api;
	HashMap<String,List<Node>> cache = new HashMap…
	FacebookProxy(FacebookAPI api) { this.api=api;}

	List<Node> getFriends(String name) {
		try {
			result = api.getFriends(name);
			cache.put(name, result);
			return result;
		} catch (ConnectionException c) {
			return cache.get(name);
		}
	}
```

Example: Redirect to Local Service

```
interface FacebookAPI {
        List<Node> getFriends(String name);
}
class FacebookProxy implements FacebookAPI {
        FacebookAPI api;
        FacebookAPI fallbackApi;
        FacebookProxy(FacebookAPI api, FacebookAPI f) {
                this.api=api; fallbackApi = f; }

        List<Node> getFriends(String name) {
                try {
                        return api.getFriends(name);
                } catch (ConnectionException c) {
                        return fallbackApi.getFriends(name);
                }
        }
```

Further alternatives: other error handling, redirect to other/local service, default values, etc

Summary

- Design for Robustness as Design Goal
- Explicit Interfaces as Design Principle
  - Error handling explicit in interfaces (declared exceptions, return types)
  - Exceptions in Java as supporting language mechanism
- Modular Protection as Design Principle
  - Handle Exceptions Locally
- Local testing with stubs and drivers
- Proxy design pattern for separate error handling

ASSERTIONS

What is an assertion?

- Statement containing boolean expression that programmer believes to be true:

```
assert speed <= SPEED_OF_LIGHT;
```

- Evaluated at run time – throws `Error` if `false`
- Disabled by default - no performance effect
- Typically enabled during development
- Can enable in the field when problems occur!

Syntax

```
AssertStatement:
    assert Expression1 ;
    assert(Expression1, Expression2) ;
```

- *$Expression_1$* - asserted condition (boolean)
- *$Expression_2$* - detail message of `AssertionError`

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Why use assertions?

- Document & test programmer's assumptions
  - e.g., class invariants
- Verify programmer’s understanding
- Quickly uncover bugs
- Increase confidence that program is bug-free

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Look for “assertive comments”

```
int remainder = i % 3;
if (remainder == 0) {
    ...
} else if (remainder == 1) {
    ...
} else { // (remainder == 2)
    ...
}
```

Replace with real assertions!

```
int remainder = i % 3;
if (remainder == 0) {
    ...
} else if (remainder == 1) {
    ...
} else {
    assert remainder == 2;
    ...
}
```


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Use second argument for *failure capture*

```
if (i % 3 == 0) {
    ...
} else if (i % 3 == 1) {
    ...
} else {
    assert (i % 3 == 2, i);
    ...
}
```


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Look for switch with no default

```
switch(flavor) {
  case VANILLA:
    ...
    break;
  case CHOCOLATE:
    ...
    break;
  case STRAWBERRY:
    ...
}
```

Add an “assertive default”

```
switch(flavor) {
  case VANILLA:
    ...
    break;
  case CHOCOLATE:
    ...
    break;
  case STRAWBERRY:
    ...
    break;
  default:
    assert (false, flavor);
}
```

Do not use assertions for *public* preconditions

```
/**
 * Sets the refresh rate.
 *
 * @param  rate refresh rate, in frames per second.
 * @throws IllegalArgumentException if rate <= 0
 *         or rate > MAX_REFRESH_RATE.
 */
public void setRefreshRate(int rate) {
    if (rate <= 0 || rate > MAX_REFRESH_RATE)
        throw new IllegalArgumentException(...);
    setRefreshInterval(1000 / rate);
}
```

Do use assertions for *non-public* preconditions

```
/**
 * Sets the refresh interval (which must correspond
 * to a legal frame rate).
 *
 * @param  interval refresh interval in ms
 */
private void setRefreshInterval(int interval) {
    assert interval > 0 && interval <= 1000, interval;
    ... // Set the refresh interval
}
```

Do use assertions for postconditions

```
/**
 * Returns BigInteger whose value is (this-1 mod m).
 * @throws ArithmeticException  if m <= 0, or this
 *          BigInteger is not relatively prime to m.
 */
public BigInteger modInverse(BigInteger m) {
    if (m.signum() <= 0)
        throw new ArithmeticException(m + "<= 0");
    ... // Do the computation
    assert this.multiply(result).mod(m).equals(ONE);
    return result;
}
```


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Complex postconditions

```
void foo(int[] a) {
    // Manipulate contents of array
    ...

    // Array will appear unchanged
}
```

Assertions for complex postconditions

```
void foo(final int[] a) {
    class DataCopy {
        private int[] aCopy;
        DataCopy() { aCopy = (int[]) a.clone(); }
        boolean isConsistent() {
            return Arrays.equals(a, aCopy);
        }
    }
    DataCopy copy = null;
    assert (copy = new DataCopy()) != null;
    ... // Manipulate contents of array
    assert copy.isConsistent();
}
```


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Caveat – asserts must not have *side effects* visible outside other asserts

Do this:

```
boolean modified = set.remove(elt);
assert modified;
```

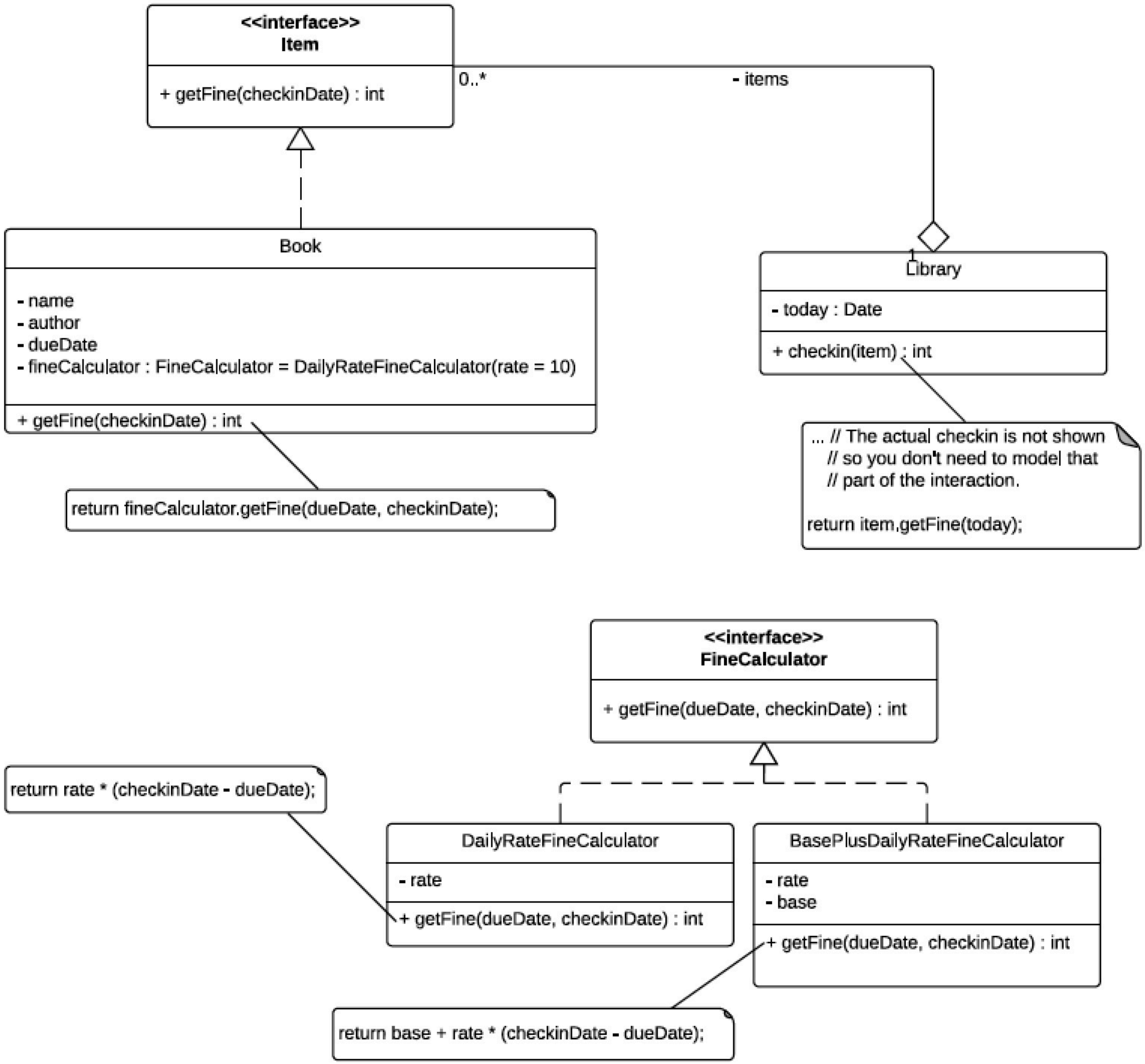
Not this:

```
assert set.remove(elt);  //Bug!
```

Sermon: accept assertions into your life

- Programmer’s interior monologue:
  - “Now at this point, we know...”
- During, not after, development
- Quickly becomes second nature
- Pays big code-quality dividends

IN-CLASS EXERCISE


<<interface>>
Item
+ getFine(checkinDate) : int
0..*
- items
1
Book
- name
- author
- dueDate
- fineCalculator : FineCalculator = DailyRateFineCalculator(rate = 10)
+ getFine(checkinDate) : int
return fineCalculator.getFine(dueDate, checkinDate);
Library
- today : Date
+ checkin(item) : int
... // The actual checkin is not shown
// so you don't need to model that
// part of the interaction.
return item.getFine(today);
<<interface>>
FineCalculator
+ getFine(dueDate, checkinDate) : int
return rate * (checkinDate - dueDate);
DailyRateFineCalculator
- rate
+ getFine(dueDate, checkinDate) : int
BasePlusDailyRateFineCalculator
- rate
- base
+ getFine(dueDate, checkinDate) : int
return base + rate * (checkinDate - dueDate);

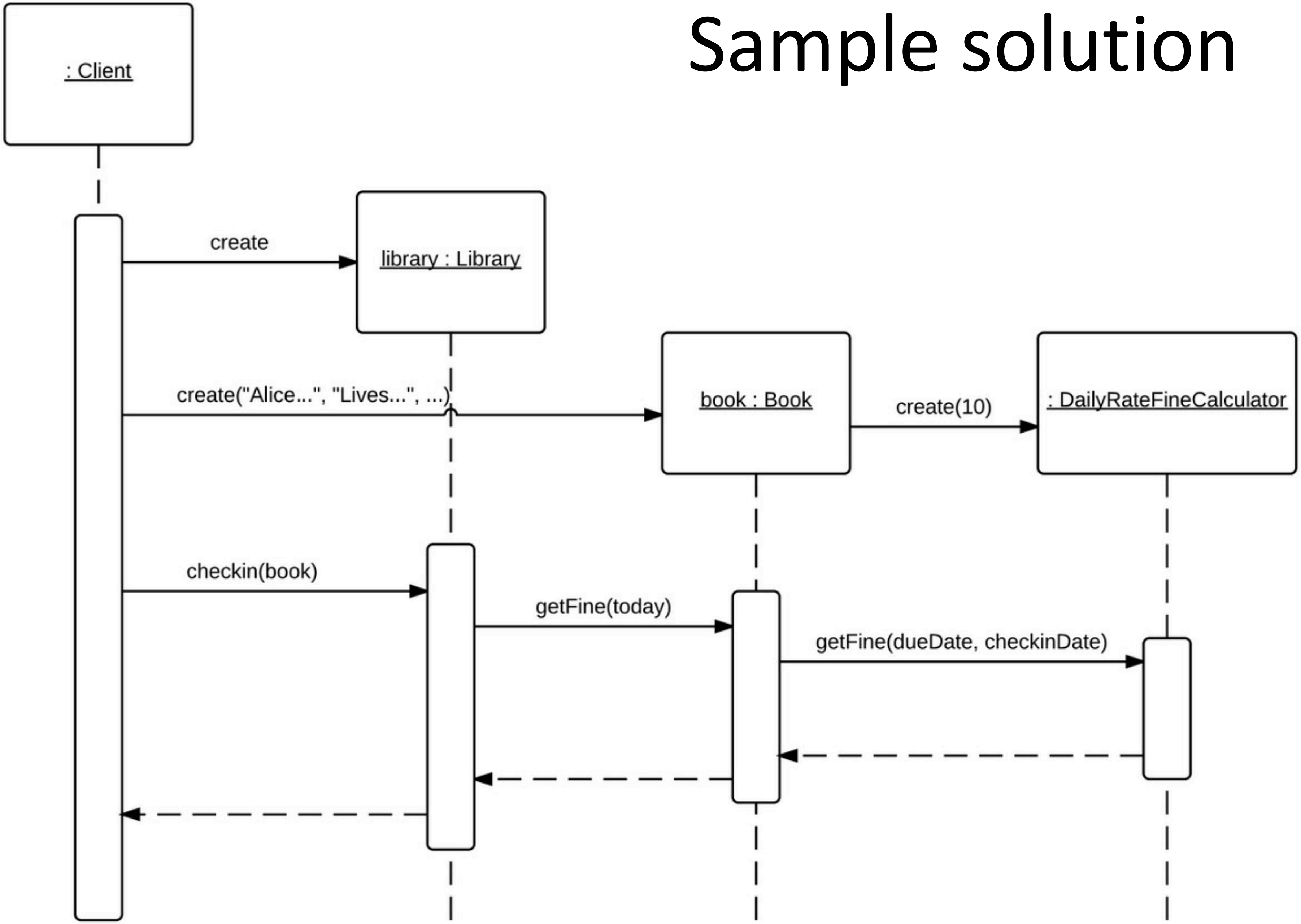
UML interaction diagrams

1. Using the UML class diagram for reference, sketch a **UML sequence diagram** for:

```
public class Client {
    public static void main(String[] args) {
        Library library = new Library();
        Item book = new Book("Alice…", "Lives…" …);
        library.checkin(book);
    }
}
```

2. Name any design patterns in the UML class diagram.

Sample solution



Sample solution, version 2