CS 520

Theory and Practice of Software Engineering

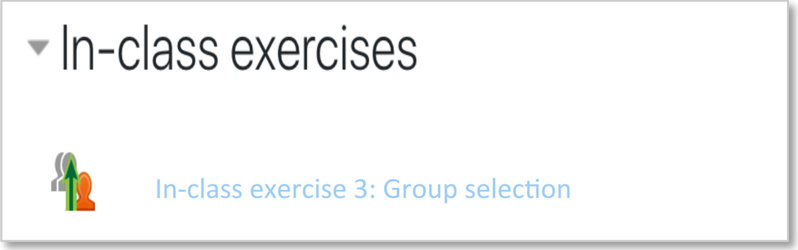
Spring 2021

Debugging

March 23, 2021

Thursday (March 25)

- Third in-class exercise on debugging
- Form 3-, 4-, or 5-person teams
  - Use Moodle to self-select a team; open from today until Thursday at 9 PM



In-class exercises

In-class exercise 3: Group selection

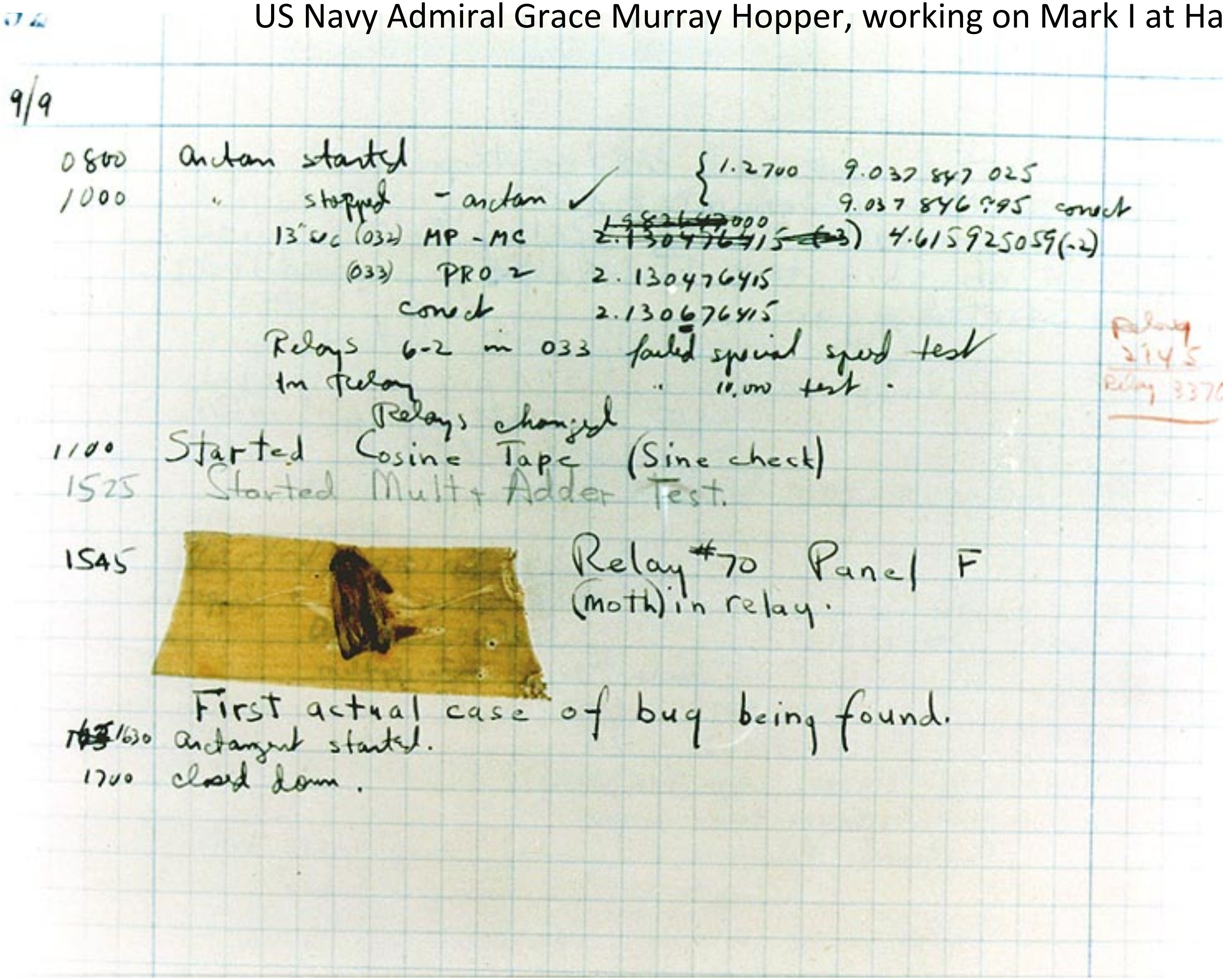
  - After closing, the remaining students will be randomly assigned to groups
- Due: Wednesday March 31, 9 AM

Ways to get your code right

- **Validation (e.g., code reviews, testing, model checking)**
  - Purpose is to uncover problems and increase confidence
- **Debugging**
  - Finding out why a program is not functioning as intended
- **Defensive programming**
  - Programming with validation and debugging in mind
- **Validation ≠ debugging**
  - Validation: Reveals existence of problem
  - Debugging: Pinpoints location + cause of problem

A bug – September 9, 1947

US Navy Admiral Grace Murray Hopper, working on Mark I at Harvard



9/9

0800 Antan started

1000 " stopped - antan ✓ {1.2700 9.037 847 025

9.037 846 995 correct

13" uc (032) MP - MC ~~1.982147000~~ ~~2.130476415~~ (-3) 4.615925059(-2)

(033) PRO 2 2.130476415

correct 2.130676415

Relays 6-2 in 033 failed special speed test

In relay " 10,000 test .

Relays changed

1100 Started Cosine Tape (Sine check)

1525 Started Mult + Adder Test.

1545 Relay #70 Panel F

(moth) in relay.

First actual case of bug being found.

1630 Antangent started.

1700 closed down.

Relay 2145

Relay 3370

Bug Reporting: Bug tracking systems

- Commonly provide support for:
  - Logging in and out
  - Writing a new bug report
  - Searching through existing bug reports
  - Reading existing bug reports and updating their status

- Examples: Bugzilla, mantis, trac

Example: Bugzilla UI

Bugzilla – Main Page version 3.0.5

Home | New | Search | ☐ Find | Reports | My Requests | My Votes | Preferences | Log out hconboy@cs.umass.edu

Welcome to Bugzilla. To see what's new in this version of Bugzilla, see the release notes! You may also want to read the Bugzilla User's Guide to find out more about Bugzilla and how to use it.

Most common actions:

Search existing bug reports
Enter a new bug report
Summary reports and charts

Change password or user preferences
Log out hconboy@cs.umass.edu

Add to Sidebar (requires a Mozilla browser like Mozilla Firefox)
Install the Quick Search plugin (requires Firefox 2 or Internet Explorer 7)

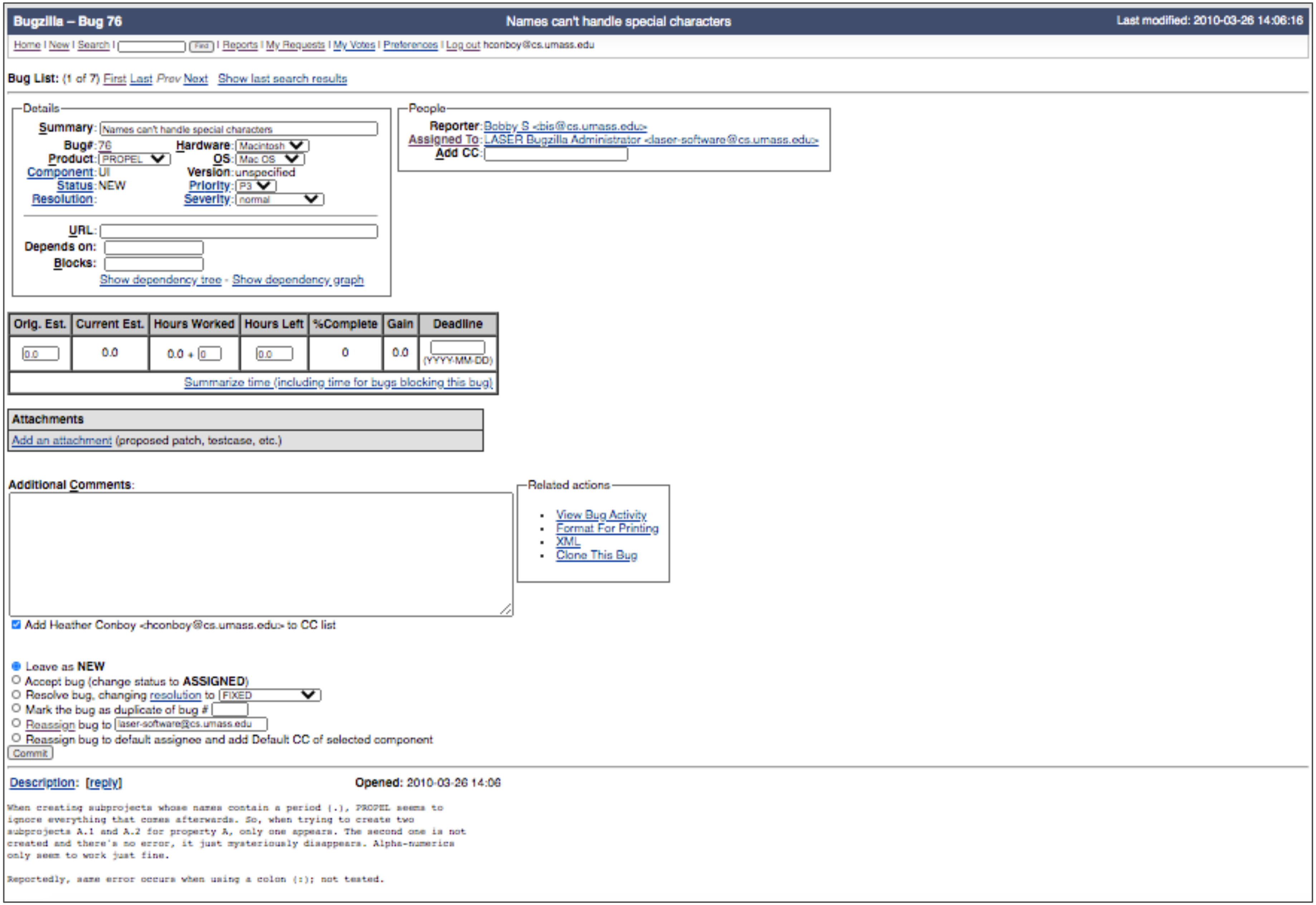
Enter a bug # or some search terms:
☐ Find [Help]

Actions: Home | New | Search | ☐ Find | Reports | My Requests | My Votes | Preferences | Log out hconboy@cs.umass.edu
Edit: Parameters | Default Preferences | Sanity Check | Users | Products | Flags | Custom Fields | Field Values | Groups | Keywords | Whining
Saved Searches: My Bugs

Bug Reporting:
Common bug report format

- Brief description
- Reporter and reporting date
- Environment: Operating system, application's version
- Severity and priority (e.g., a small integer range, enum type for LOW/MEDIUM/HIGH)
- Steps to reproduce along with expected and actual result descriptions (e.g., text, screenshot)
- Comments
- Status (e.g., new, team responsible, fixed)

Example: Bugzilla bug report



Bugzilla – Bug 76 Names can't handle special characters Last modified: 2010-03-26 14:06:16

Home | New | Search | Find | Reports | My Requests | My Votes | Preferences | Log out hconboy@cs.umass.edu

Bug List: (1 of 7) First Last *Prev* Next Show last search results

Details

Summary: Names can't handle special characters
Bug#: 76
Product: PROPEL
Component: UI
Status: NEW
Resolution:
Hardware: Macintosh
OS: Mac OS
Version: unspecified
Priority: P3
Severity: normal

URL:
Depends on:
Blocks:

Show dependency tree - Show dependency graph

People

Reporter: Bobby S <bis@cs.umass.edu>
Assigned To: LASER Bugzilla Administrator <laser-software@cs.umass.edu>
Add CC:

Orig. Est.	Current Est.	Hours Worked	Hours Left	%Complete	Gain	Deadline
0.0	0.0	0.0 + 0	0.0	0	0.0	(YYYY-MM-DD)

Summarize time (including time for bugs blocking this bug)

Attachments

Add an attachment (proposed patch, testcase, etc.)

Additional Comments:

Related actions

- View Bug Activity
- Format For Printing
- XML
- Clone This Bug

☑ Add Heather Conboy <hconboy@cs.umass.edu> to CC list

● Leave as **NEW**
○ Accept bug (change status to **ASSIGNED**)
○ Resolve bug, changing resolution to FIXED
○ Mark the bug as duplicate of bug #
○ Reassign bug to laser-software@cs.umass.edu
○ Reassign bug to default assignee and add Default CC of selected component

Description: [reply] **Opened**: 2010-03-26 14:06

```
When creating subprojects whose names contain a period (.), PROPEL seems to
ignore everything that comes afterwards. So, when trying to create two
subprojects A.1 and A.2 for property A, only one appears. The second one is not
created and there's no error, it just mysteriously disappears. Alpha-numerics
only seem to work just fine.

Reportedly, same error occurs when using a colon (:); not tested.
```

A Bug's Life

- **Defect** – mistake committed by a human
- **Error** – incorrect computation
- **Failure** – visible error: program violates its specification
- **Debugging** starts when a failure is observed, e.g.,
  - Manual code review
  - Testing: unit, integration, system
  - Model checking
  - In the field

Defense in depth

1. **Make errors impossible**
   - e.g., Java makes memory overwrite bugs impossible

2. **Don’t introduce defects**
   - Correctness: get things right the first time

3. **Make errors immediately visible:** Local visibility of errors: best to fail immediately
   - e.g., assertions to check rep(resentation) invariants

Defense in depth (cont.)

4. **Last resort is debugging**
   - Needed when effect of bug is distant from cause
   - Design experiments to gain information about bug
     - Fairly easy in a program with good design, e.g., modularity, representation hiding, specs, unit tests, etc.
     - Much harder and more painstaking with a poor design, e.g., no decomposition, representation exposure, no unit tests, etc.

First defense: Impossible by design

- In the language
  - e.g., Java makes memory overwrite bugs impossible
- In the protocols/libraries/modules
  - e.g., BigInteger will guarantee that there will be no overflow
- In self-imposed conventions
  - e.g., unmodifiable collections will guarantee behavioral equality
  - Caution: You must maintain the discipline

Second defense: correctness

- **Get things right the first time**
  - Don’t code before you think! Think before you code.
  - If you're making lots of easy-to-find bugs, you're also making hard-to-find bugs
  - don't use compiler as crutch

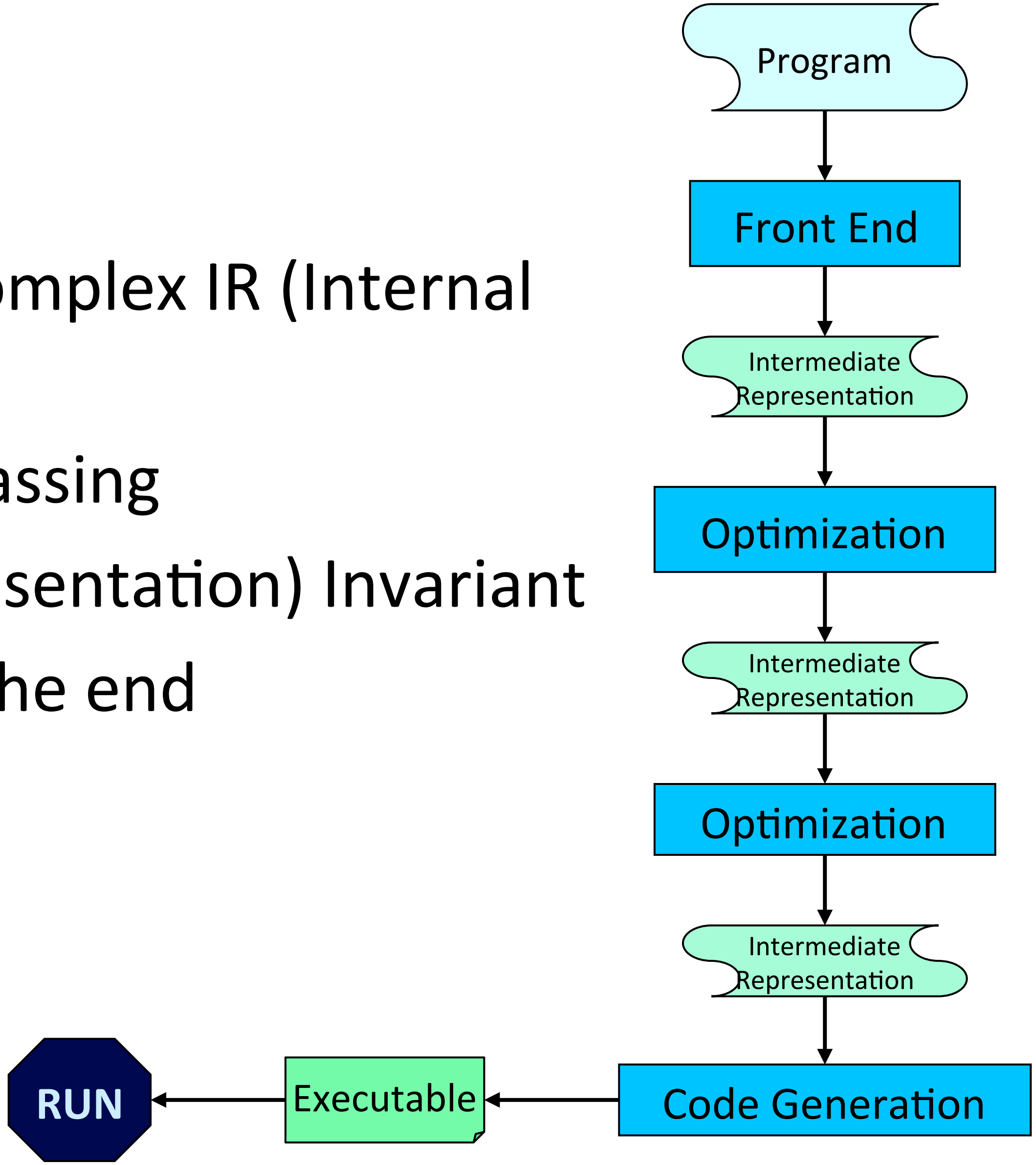
- **Especially true, when debugging is going to be hard, e.g.,**
  - Concurrency, non-determinism
  - Difficult test and instrument environments
  - Program must meet timing deadlines

Second defense: correctness (cont.)

- **Simplicity is key, e.g.,**
  - Modularity
    - Divide program into chunks that are easy to understand
    - Use abstract data types with well-defined interfaces
    - Use defensive programming; avoid rep exposure
  - Specification
    - Write specs for all modules, so that an explicit, well-defined contract exists between each module and its users

Example: Common compiler architecture

- Multiple passes
  - Each operate on a complex IR (Internal Representation)
  - Lot of information passing
  - Very complex Rep(resentation) Invariant
  - Code generation at the end



Third defense: immediate visibility

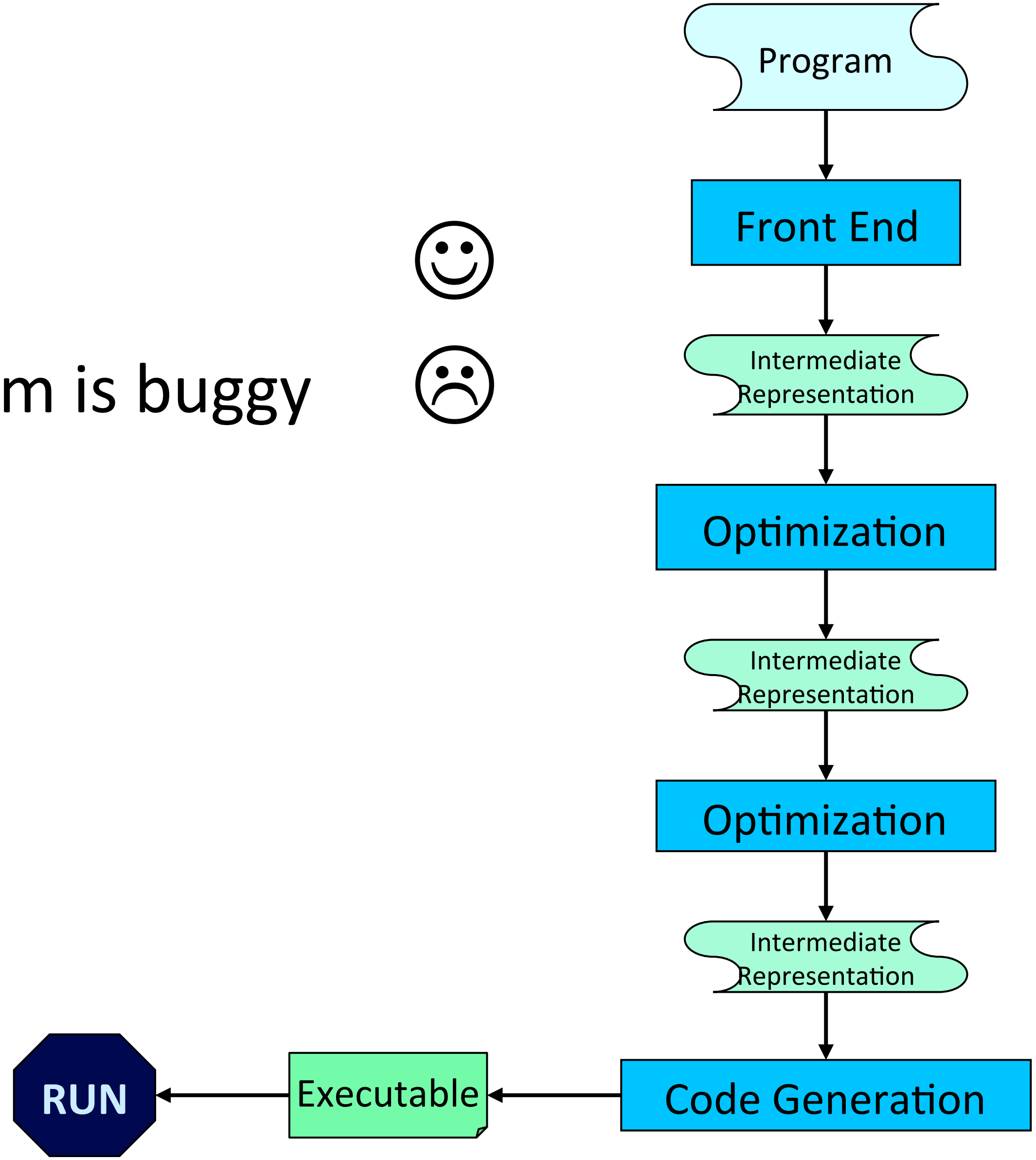
- If we can't prevent bugs, we can try to **localize** them to a small part of the program, e.g.,
  - **Assertions**
  - **Unit testing**
  - **Regression testing**
- When localized to a single method or small module, bugs can be found simply by studying the program text

Benefits of immediate visibility

- **Key difficulty of debugging is to find the code fragment responsible for an observed problem**
  - e.g., a method may return an erroneous result, but be itself error free, if there is prior corruption of representation
- **The earlier a problem is observed, the easier it is to fix**
  - e.g., frequently checking the rep invariant helps the above problem
- **General approach: fail-fast**
  - Check invariants, don't just assume them
  - Don't try to recover from bugs – this just obscures them

Example: Immediate visibility

- Bug types:
  - Compiler crashes ☺
  - Generated program is buggy ☹



Program

Front End

Intermediate Representation

Optimization

Intermediate Representation

Optimization

Intermediate Representation

Code Generation

Executable

RUN

Don't hide bugs (v1)

```
// k is guaranteed to be present in array a
int i = 0;
while (true) {
    if (a[i]==k) break;
    i++;
}
```

- If that guarantee is broken (by a bug),
  the code will throw an exception and die.
- Temptation: make code more “robust” by not failing

Don't hide bugs (v2)

```
// k is guaranteed to be present in a
int i = 0;
while (i<a.length) {
    if (a[i]==k) break;
    i++;
}
```

- Now at least the loop will always terminate
  - But no longer guarantees that `a[i]==k`
  - If rest of code relies on this, then problems arise later
  - *All we've done is obscure the link between the bug's origin and the eventual erroneous behavior it causes.*

Don't hide bugs (v3)

```
// k is guaranteed to be present in a
int i = 0;
while (i<a.length) {
    if (a[i]==k) break;
    i++;
}
assert (i<a.length) : "key not found";
```

- Assertions let us document and check invariants
- Abort program as soon as problem is detected

Inserting Checks

- **Insert checks galore with an intelligent checking strategy, e.g.,**
  - Pre- and post-condition checks
  - Consistency checks
  - Bug-specific checks

- **Goal: stop the program as close to bug as possible**
  - Use debugger to see where you are, explore program a bit

Checking For Preconditions

```
// k is guaranteed to be present in a
         int i = 0;
         while (i<a.length) {
            if (a[i]==k) break;
            i++;
         }
         assert (i<a.length) : "key not found";
```

Precondition violated? Get an assertion!

Downside of Assertions

```
static int sum(Integer a[], List<Integer> index) {
    int s = 0;
    for (e:index) {
            assert(e < a.length, “Precondition violated”);
            s = s + a[e];
    }
    return s;
}
```

- Assertion not checked until we use the data
- Fault occurs when bad index inserted into list
- May be a long distance between fault activation and error detection

Data Structure Consistency Checks

```
static void checkRep(Integer a[], List<Integer> index) {
    for (e:index) {
        assert(e < a.length, “Inconsistent Data Structure”);
    }
}
```

- Perform check after all updates to minimize distance between bug occurrence and bug detection
- Can also write a single procedure to check ALL data structures, then scatter calls to this procedure throughout code

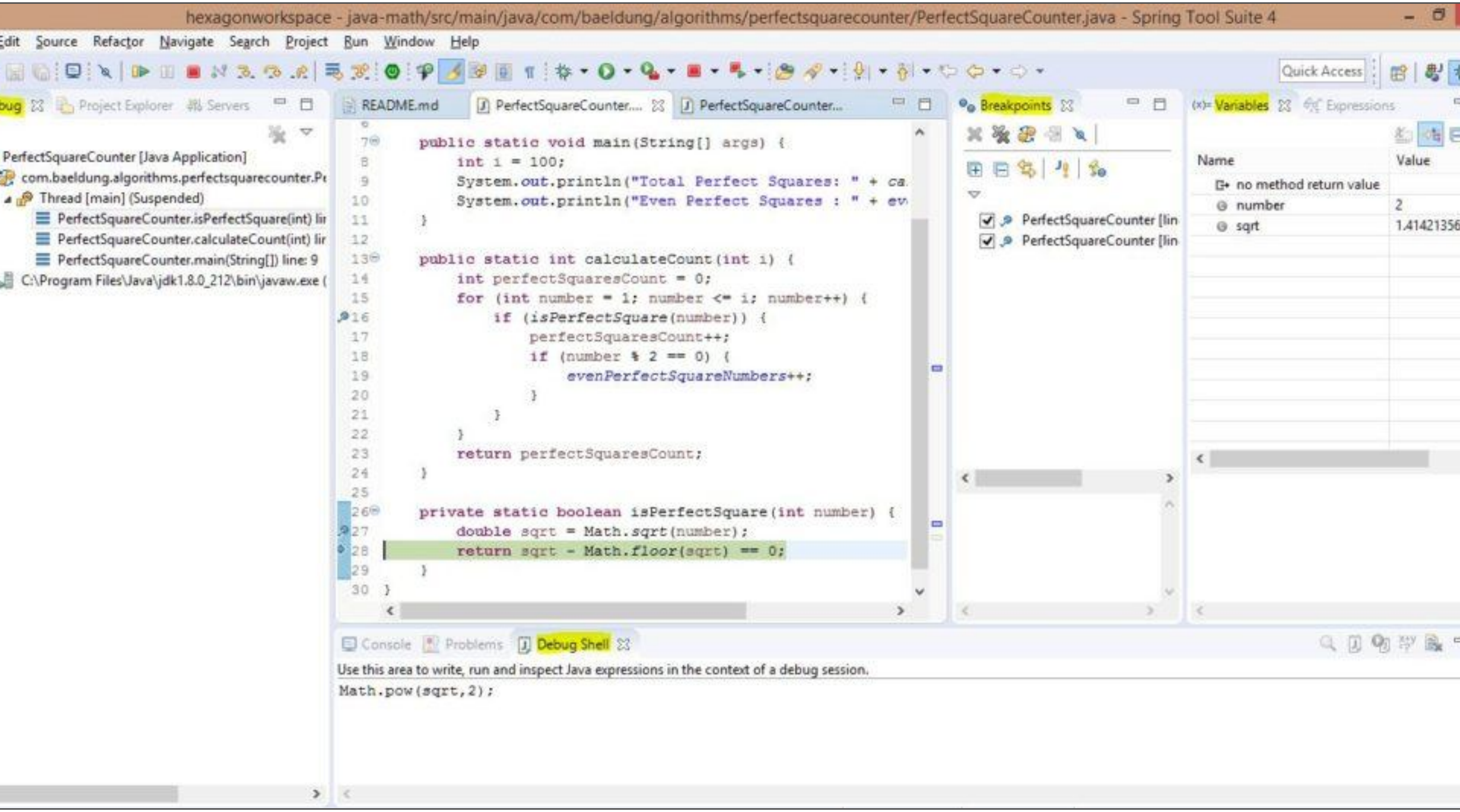
Bug-Specific Checks

```
static void check(Integer a[], List<Integer> index) {
    for (e:index) {
        assert(e != 1234, “Inconsistent Data Structure”);
    }
}
```

Bug shows up as 1234 in list

Check for that specific condition

Debugger: Eclipse IDE



hexagonworkspace - java-math/src/main/java/com/baeldung/algorithms/perfectsquarecounter/PerfectSquareCounter.java - Spring Tool Suite 4

```
PerfectSquareCounter [Java Application]
  com.baeldung.algorithms.perfectsquarecounter.Pe
    Thread [main] (Suspended)
      PerfectSquareCounter.isPerfectSquare(int) lir
      PerfectSquareCounter.calculateCount(int) lir
      PerfectSquareCounter.main(String[]) line: 9
  C:\Program Files\Java\jdk1.8.0_212\bin\javaw.exe (
```

```java
    public static void main(String[] args) {
        int i = 100;
        System.out.println("Total Perfect Squares: " + ca
        System.out.println("Even Perfect Squares : " + ev
    }

    public static int calculateCount(int i) {
        int perfectSquaresCount = 0;
        for (int number = 1; number <= i; number++) {
            if (isPerfectSquare(number)) {
                perfectSquaresCount++;
                if (number % 2 == 0) {
                    evenPerfectSquareNumbers++;
                }
            }
        }
        return perfectSquaresCount;
    }

    private static boolean isPerfectSquare(int number) {
        double sqrt = Math.sqrt(number);
        return sqrt - Math.floor(sqrt) == 0;
    }
}
```

☑ PerfectSquareCounter [lin

☑ PerfectSquareCounter [lin

Name	Value
no method return value	
number	2
sqrt	1.41421356

Use this area to write, run and inspect Java expressions in the context of a debug session.

```
Math.pow(sqrt,2);
```

https://www.baeldung.com/eclipse-debugging

Checks In Production Code

- **Should you include assertions and checks in production code?**

Checks In Production Code

- **Should you include assertions and checks in production code?**
  - Yes: stop program if check fails – don’t want to take chance program will do something wrong
  - No: may need program to keep going, maybe bug does not have such bad consequences
  - Correct answer depends on context!

Example: Ariane 5 rocket (1996)

Program halted because of overflow in unused value, exception thrown but not handled until top level, rocket crashes…

Bug Fixing

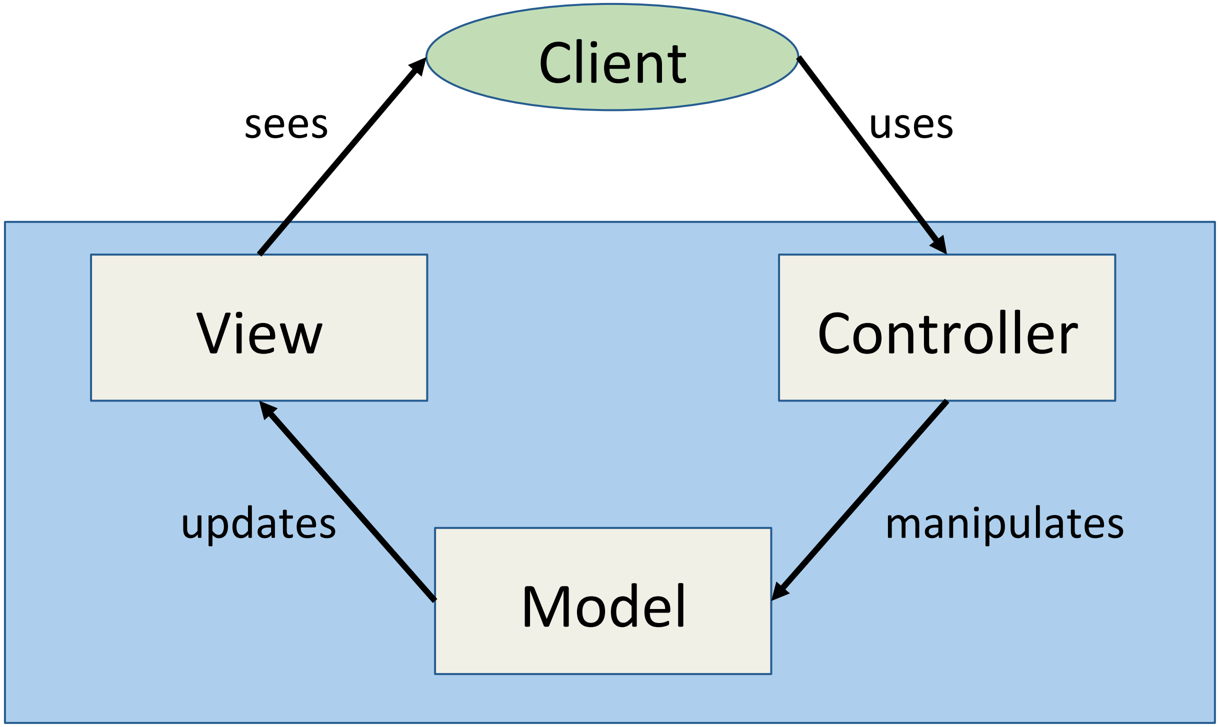
- Manual
- Automated program repair (APR) techniques commonly consist of 3 main components:
  - Fault Localization
  - Patch (or Repair) Generation
  - Patch Validation

Homework 2

- Re-design, re-implement, and test the Row game app
- MVC architecture pattern, Observer design pattern, Strategy (or template method) design pattern, Code review proposed fixes
- Due: Thursday April 1, 2021, 9 AM

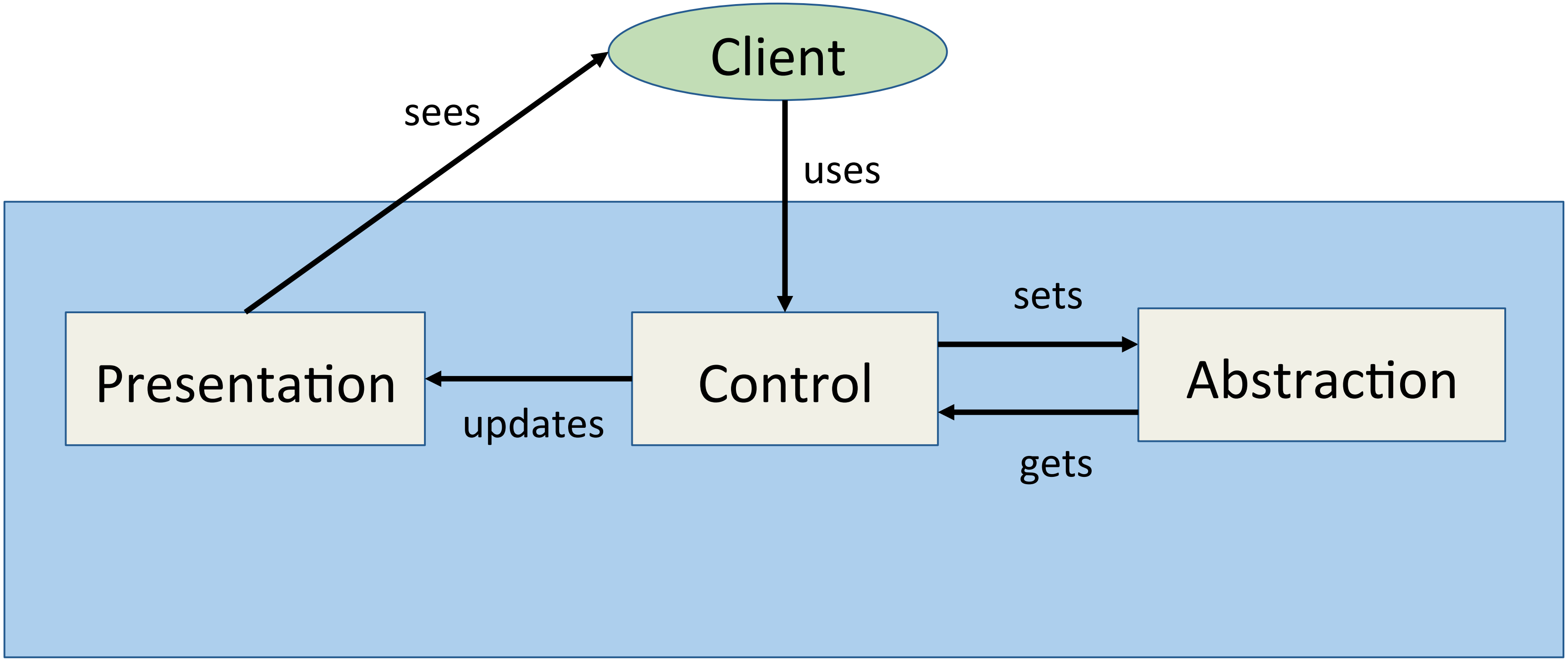
https://people.cs.umass.edu/~hconboy/class/2021Spring/CS520/hw2.pdf

Architecture pattern:
MVC (Model View Controller)



Separates data representation (Model), visualization (View), and client interaction (Controller)

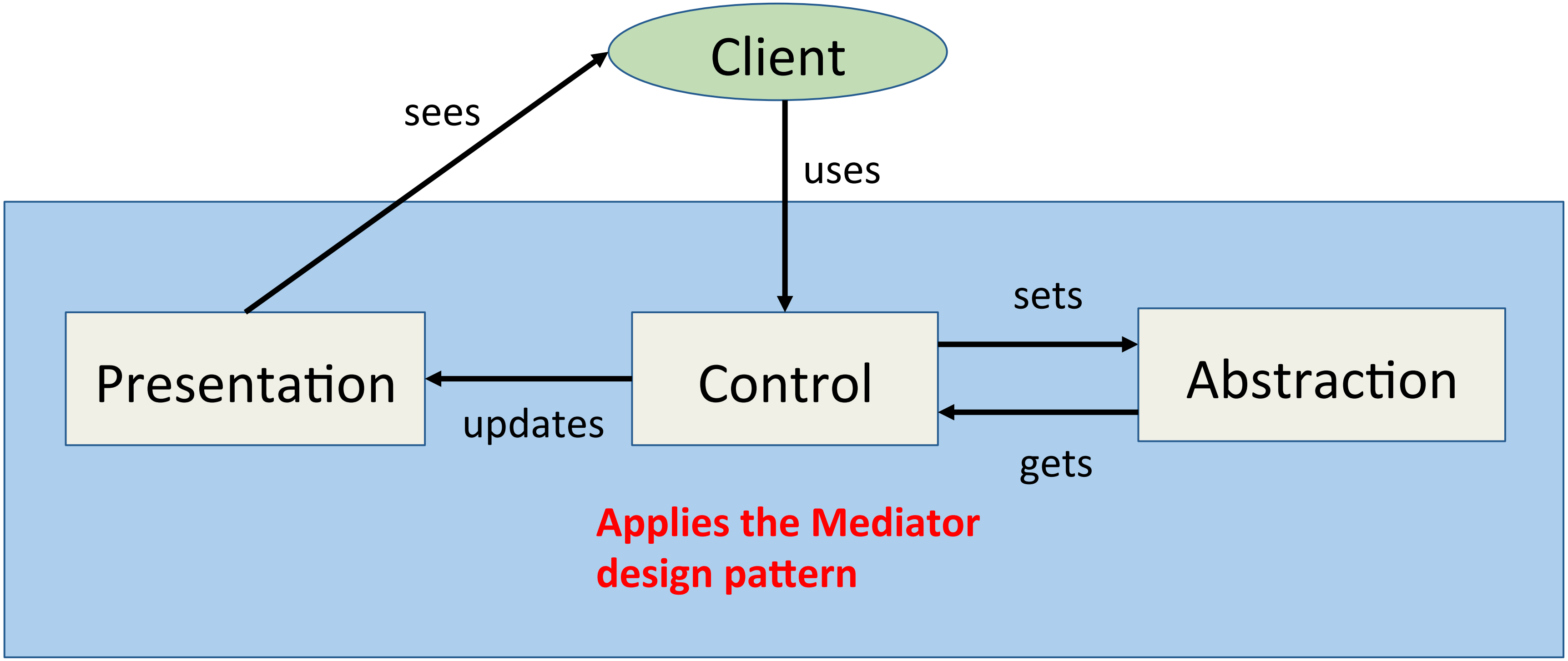
Architecture pattern:
PAC (Presentation Abstraction Control)



Separates data representation (Abstraction),
visualization (Presentation), and client interaction (Control)

https://en.wikipedia.org/wiki/Presentation%E2%80%93abstraction%E2%80%93control

Architecture pattern:
PAC (Presentation Abstraction Control)



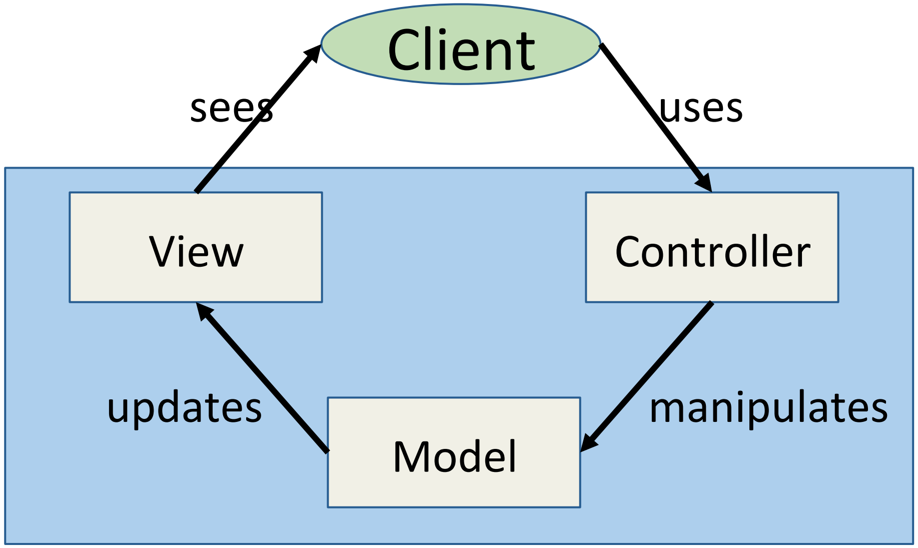
Applies the Mediator design pattern

Separates data representation (Abstraction), visualization (Presentation), and client interaction (Control)

https://en.wikipedia.org/wiki/Presentation%E2%80%93abstraction%E2%80%93control

Which architecture?

MVC:



Client

sees

uses

View

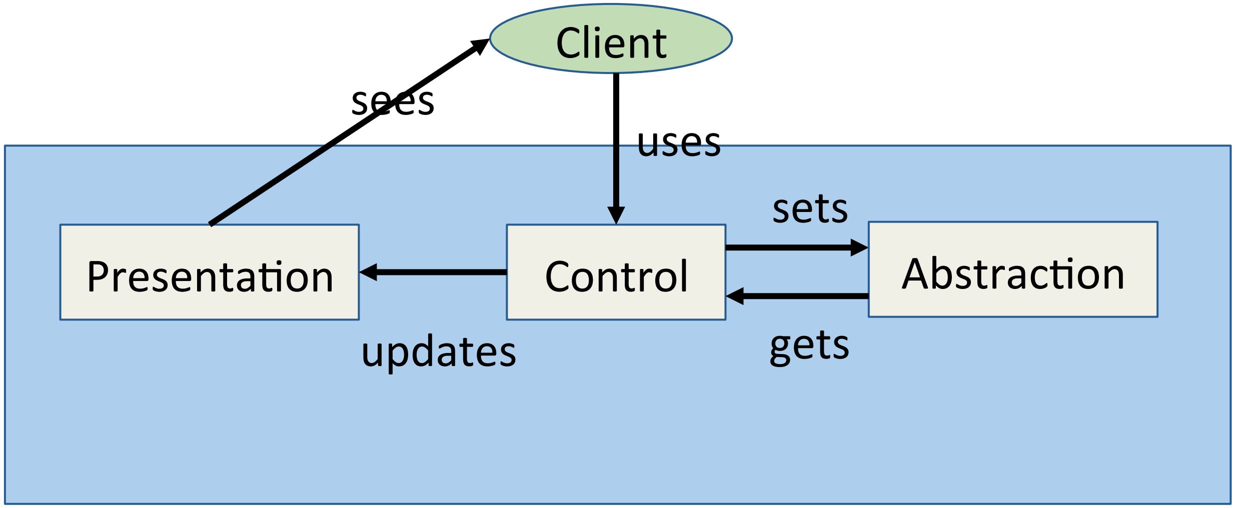
Controller

updates

manipulates

Model

PAC:



Client

sees

uses

sets

Presentation

Control

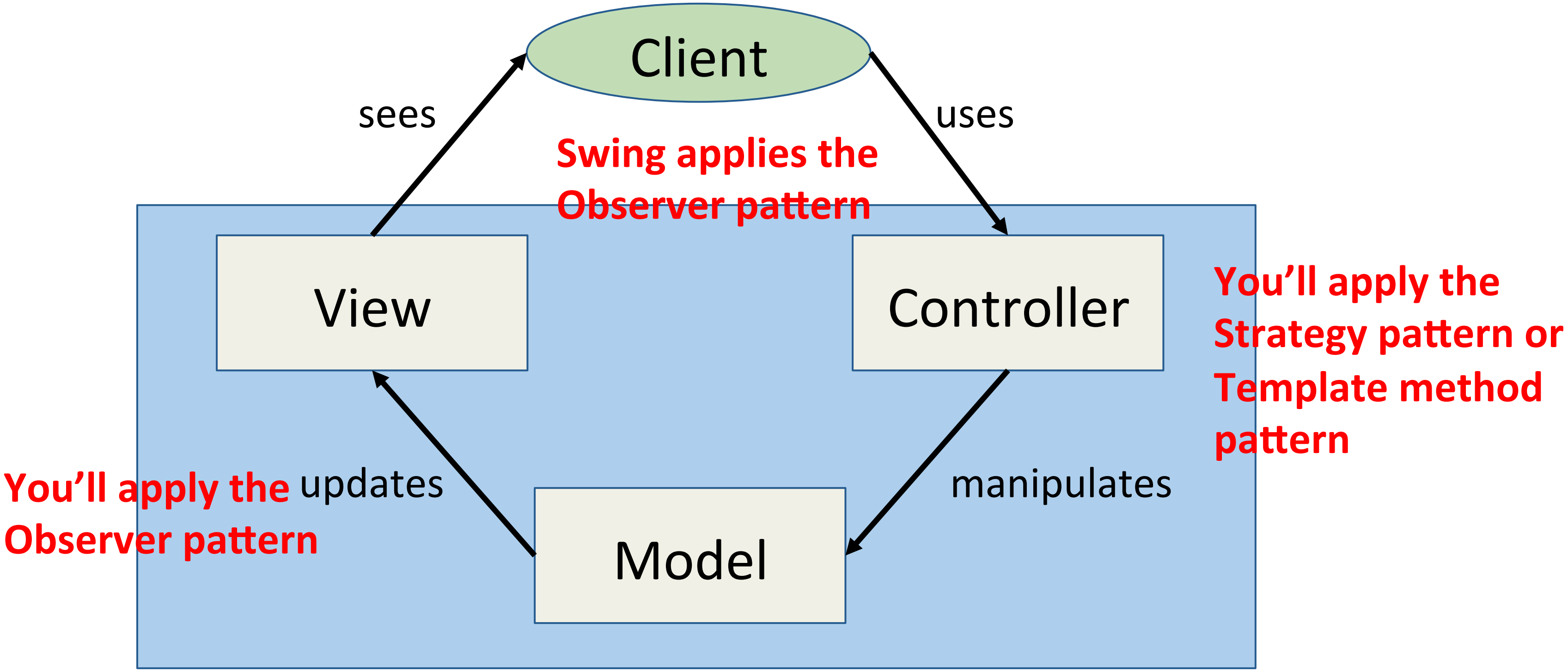
Abstraction

updates

gets

Design patterns:

Observer and Strategy (or Template Method)



Client

sees

uses

Swing applies the Observer pattern

View

Controller

You'll apply the Strategy pattern or Template method pattern

You'll apply the Observer pattern

updates

manipulates

Model

Separates data representation (Model), visualization (View), and client interaction (Controller)

JUnit test case: Input/Output pairs

```
@Test(expected = IllegalArgumentException.class)
 public void testNewBlockViolatesPrecondition()
 {
   RowBlockModel block = new RowBlockModel(null);
 }
```

JUnit test case: Class invariants

```
@Test
public void testNewGame() {
  RowGameModel gameModel = new RowGameModel();
  // Check for the expected initial configuration
  //TODO: For all blocks, …
  assertEquals ("1", gameModel.player);
  assertEquals (9, gameModel.movesLeft);
}
```