Objects Analysis Threads Design

15-214

toad

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School of Computer Science
institute for SOFTWARE RESEARCH

Principles of Software Construction: Objects, Design, and Concurrency

Functional Correctness – A Broader Perspective

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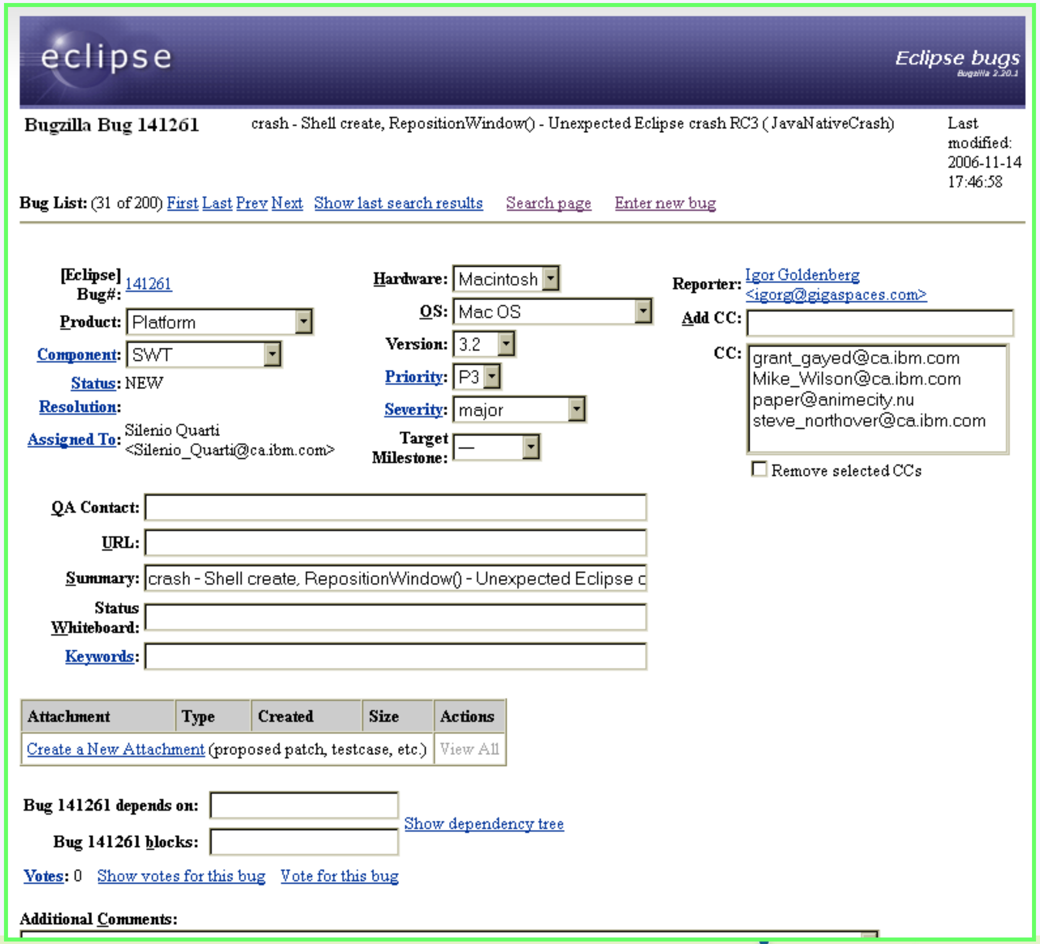
Learning Goals

- Writing bug reports
- Apply Hoare-style verification to object-oriented programs
- Reason about inheritance with behavioral subtyping
- Apply static analysis tools
- Understand the tradeoffs among testing, formal verification and static analysis

Bug Reports

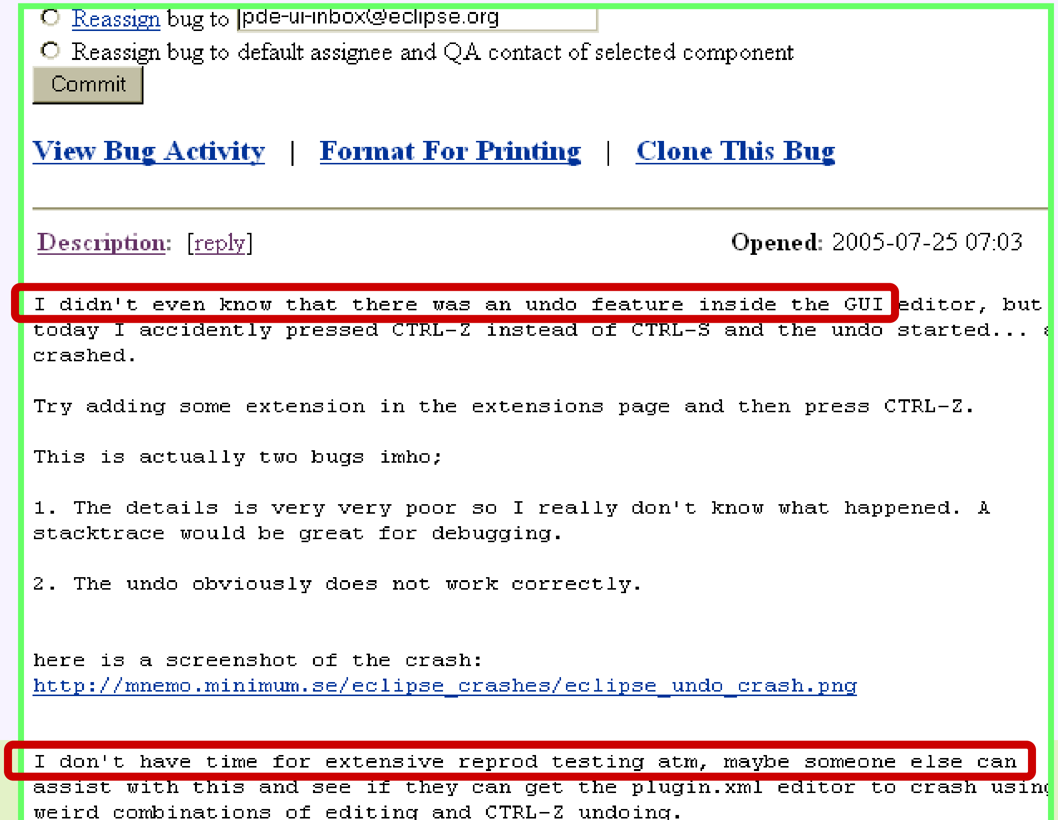
Reporting Defects

- Reproducible defects
  - Easier to find and fix
  - Easier to validate
  - Increased confidence
- Simple and general
  - More value doing the fix
- Non-antagonistic
  - State the problem
  - Don't blame



Social Issues in Defect Reporting

- There are differences between developer and tester culture
- Acknowledge that testers often deliver bad news
- Work hard to detect defects locally
  - Easier to narrow scope and responsibility
  - Less adversarial
- Don't measure performance in terms of defect reports



Reassign bug to pde-ui-inbox@eclipse.org

Reassign bug to default assignee and QA contact of selected component

Commit

View Bug Activity | Format For Printing | Clone This Bug

Description: [reply] Opened: 2005-07-25 07:03

I didn't even know that there was an undo feature inside the GUI editor, but today I accidently pressed CTRL-Z instead of CTRL-S and the undo started... a crashed.

Try adding some extension in the extensions page and then press CTRL-Z.

This is actually two bugs imho;

1. The details is very very poor so I really don't know what happened. A stacktrace would be great for debugging.

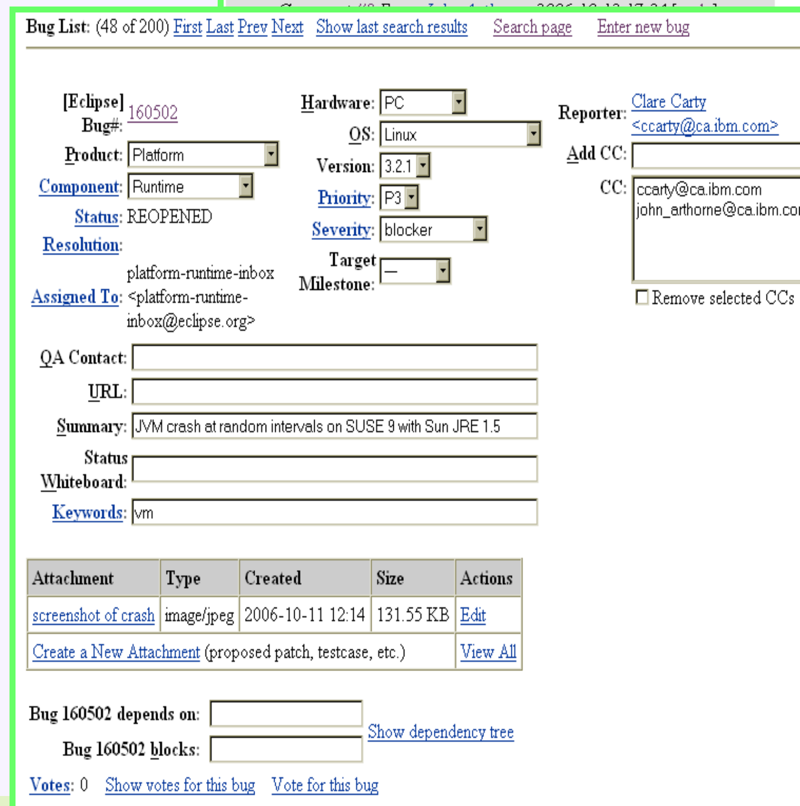
2. The undo obviously does not work correctly.

here is a screenshot of the crash:
http://mnemo.minimum.se/eclipse_crashes/eclipse_undo_crash.png

I don't have time for extensive reprod testing atm, maybe someone else can assist with this and see if they can get the plugin.xml editor to crash using weird combinations of editing and CTRL-Z undoing.

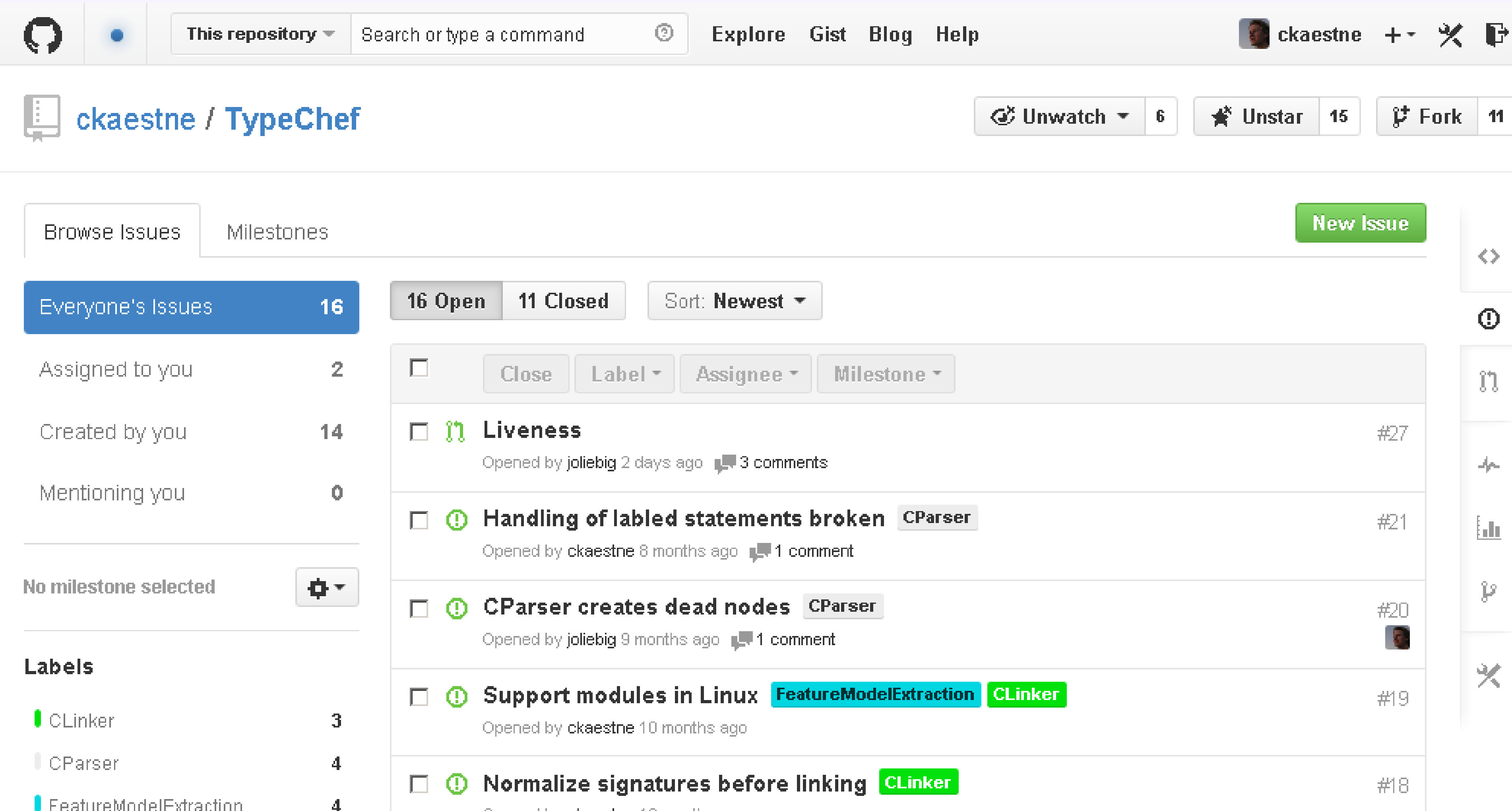
Defect Tracking

- Always track defects and issues
- Issue: Bug, feature request, or query
  - May not know which of these until analysis is done, so track in the same database (Bugzilla, github)
- Provides a basis for measurement
- Provides a basis for division of effort
- Facilitates communication
  - Organized record for each issue
  - Ensures problems are not forgotten



Bug Tracking on GitHub

- Every GitHub project has own issue tracker (and wiki); enable in project settings



Formal Verification of Object-Oriented Programs

Formal Verification

- Proving the correctness of an implementation with respect to a formal specification, using formal methods of mathematics.
- Formally prove that all possible executions of an implementation fulfill the specification
- Manual effort; partial automation; not automatically decidable

Formal Specifications

```
/*@ requires len >= 0 && array != null && array.length == len;
  @
  @ ensures \result ==
  @             (\sum int j;  0 <= j && j < len;  array[j]);
  @*/
int total(int array[], int len);
```

Advantage of formal specifications:

* runtime checks for free
* basis for formal verification
* assisting automatic analysis tools

JML (Java Modelling Language) as specifications language in Java (inside comments)

Recap: Hoare-Style Verification

- Formal reasoning about program correctness using pre- and postconditions

- Syntax: {P} S {Q}
  - P and Q are predicates
  - P is the precondition
  - S is a program
  - Q is the postcondition

- Semantics
  - If we start in a state where P is true and execute S, then S will terminate in a state where Q is true

Recap: Hoare-Logic Rules

Assignments

```
{ P[E/x] } x:= E { P }
```

Composition

```
{ P } S { Q }     { Q } T { R }
----------------------------------
      { P } S; T { R }
```

If statement

```
{ B & P } S { Q }     { !B & P } T { Q }
----------------------------------------------
     { P } if (B) S else T { Q }
```

While loop with loop invariant P

```
      { P & B } S { P }
-----------------------------------
 { P } while (B) S { !B & P }
```

Consequence

```
P -> P'     { P } S { Q }     Q -> Q'
------------------------------------------
          { P' } S { Q' }
```

Hoare Triples – Examples

- { true } x := 5 { }
- { } x := x + 3 { x = y + 3 }
- { } x := x * 2 + 3 { x > 1 }
- { x=a } if (x < 0) then x := -x { }
- { false } x := 3 { }
- { x < 0 } while (x!=0) x := x-1 { }

Hoare Triples – Examples

- { true } x := 5 { x=5 }
- { x = y } x := x + 3 { x = y + 3 }
- { x > -1 } x := x * 2 + 3 { x > 1 }
- { x=a } if (x < 0) then x := -x { x=|a| }
- { false } x := 3 { x = 8 }
- { x < 0 } while (x!=0) x := x-1 { }
  - no such triple!

Recap: 122 midterm

```
int find_peak_bin(int[] A, int n)
//@requires 0 < n && n <= \length(A);
//@requires is_peaked(A, 0, n);
//@ensures 0 <= \result && \result < n;
//@ensures gt_seg(A[\result], A, 0, \result);
//@ensures gt_seg(A[\result], A, \result+1, n);
{
int lower = 0;
int upper = n-1;
while (lower < upper)
    //@loop_invariant ______________________________ ;
    //@loop_invariant ______________________________ ;
{
    int mid = lower + (upper-lower)/2;
    //@assert _________________ ; /* optional */
    if (A[mid] < A[mid+1])
        lower = mid+1;
    else //@assert ______ ; /* optional */
        upper = mid;
}
//@assert _________________________ ; /* optional */
return lower;
}
```

Class Invariants

- Properties about the fields of an object
- Established by the constructor
- Should always hold before and after execution of public methods
- May be invalidated temporarily during method execution

```
public class SimpleSet {

    int contents[];
    int size;

    //@ ensures sorted(contents);
    SimpleSet(int capacity) { … }

    //@ requires sorted(contents);
    //@ ensures sorted(contents);
    boolean add(int i) { … }

    //@ requires sorted(contents);
    //@ ensures sorted(contents);
    boolean contains(int i) { … }
}
```

```
public class SimpleSet {

    int contents[];
    int size;

    //@invariant sorted(contents);

    SimpleSet(int capacity) { … }

    boolean add(int i) { … }

    boolean contains(int i) { … }
}
```

Behavioral Subtyping (Liskov Substitution Principle)

> Let q(x) be a property provable about objects x of type T. Then q(y) should be provable for objects y of type S where S is a subtype of T.
>
> Barbara Liskov

- An object of a subclass should be substitutable for an object of its superclass
- Known already from types:
  - May use subclass instead of superclass
  - Subclass can add, but not remove methods
  - Overriding method must return same or subtype
  - Overriding method may not throw additional exceptions
- Applies more generally to behavior:
  - A subclass must fulfill all contracts that the superclass does
  - Same or stronger invariants
  - Same or **stronger** postconditions for all methods
  - Same or **weaker** preconditions for all methods

Behavioral Subtyping (Liskov Substitution Principle)

```
abstract class Vehicle {
    int speed, limit;
    //@ invariant speed < limit;

    //@ requires speed != 0;
    //@ ensures |speed| < |\old{speed}|
    void break();
}
```

```
class Car extends Vehicle {
    int fuel;
    boolean engineOn;
    //@ invariant fuel >= 0;

    //@ requires fuel > 0 && ! engineOn;
    //@ ensures engineOn;
    void start() { … }

    void accelerate() { … }

    //@ requires speed != 0;
    //@ ensures |speed| < |\old{speed}|
    void break() { … }
}
```

Subclass fulfills the same invariants (and additional ones)
Overridden method has the same pre and postconditions

Behavioral Subtyping (Liskov Substitution Principle)

```
class Car extends Vehicle {
        int fuel;
        boolean engineOn;
        //@ invariant fuel >= 0;

        //@ requires fuel > 0 && ! engineOn;
        //@ ensures engineOn;
        void start() { … }

        void accelerate() { … }

        //@ requires speed != 0;
        //@ ensures |speed| < |\old{speed}|
        void break() { … }
}
```

```
class Hybrid extends Car {
        int charge;
        //@ invariant charge >= 0;

        //@ requires (charge > 0 || fuel > 0)
                    && ! engineOn;
        //@ ensures engineOn;
        void start() { … }

        void accelerate() { … }

        //@ requires speed != 0;
        //@ ensures |speed| < |\old{speed}|
        //@ ensures charge > \old{charge}
        void break() { … }
}
```

Subclass fulfills the same invariants (and additional ones)
Overridden method start has weaker precondition
Overridden method break has stronger postcondition

Behavioral Subtyping (Liskov Substitution Principle)

```
class Rectangle {
        int h, w;

        Rectangle(int h, int w) {
                this.h=h; this.w=w;
        }

        //methods
}
```

```
class Square extends Rectangle {
        Square(int w) {
                super(w, w);
        }
}
```

Is Square a behavior subtype of Rectangle?

Behavioral Subtyping (Liskov Substitution Principle)

```
class Rectangle {
        //@ invariant h>0 && w>0;
        int h, w;

        Rectangle(int h, int w) {
                this.h=h; this.w=w;
        }

        //methods
}
```

```
class Square extends Rectangle {
        //@ invariant h==w;
        Square(int w) {
                super(w, w);
        }
}
```

Is Square a behavior subtype of Rectangle?

Behavioral Subtyping (Liskov Substitution Principle)

```
class Rectangle {
        //@ invariant h>0 && w>0;
        int h, w;

        Rectangle(int h, int w) {
                this.h=h; this.w=w;
        }

        void scale(int factor) {
                w=w*factor;
                h=h*factor;
        }
}
```

```
class Square extends Rectangle {
        //@ invariant h==w;
        Square(int w) {
                super(w, w);
        }
}
```

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                this.h=h; this.w=w;
        }

        void scale(int factor) {
                w=w*factor;
                h=h*factor;
        }

        void setWidth(int neww) {
                w=neww;
        }
}
```

```
class Square extends Rectangle {
        //@ invariant h==w;
        Square(int w) {
                super(w, w);
        }
}
```

Is Square a behavior subtype of Rectangle?

Behavioral Subtyping (Liskov Substitution Principle)

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class Rectangle {
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        Rectangle(int h, int w) {
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        }

        void scale(int factor) {
                w=w*factor;
                h=h*factor;
        }

        void setWidth(int neww)
                w=neww;
        }
}
```

```
class Square extends Rectangle {
        //@ invariant h==w;
        Square(int w) {
                super(w, w);
        }
}
```

```
class GraphicProgram {
    void scaleW(Rectangle r, int factor) {
        r.setWidth(r.getWidth() * factor);
    }
}
```

With these methods, Square is not a behavior subtype of Rectangle

Formal Verification of Object-Oriented Programs

- Analogue to verification of imperative programs
- Class invariants simplify specifications
- Behavioral subtyping ensures substitutability

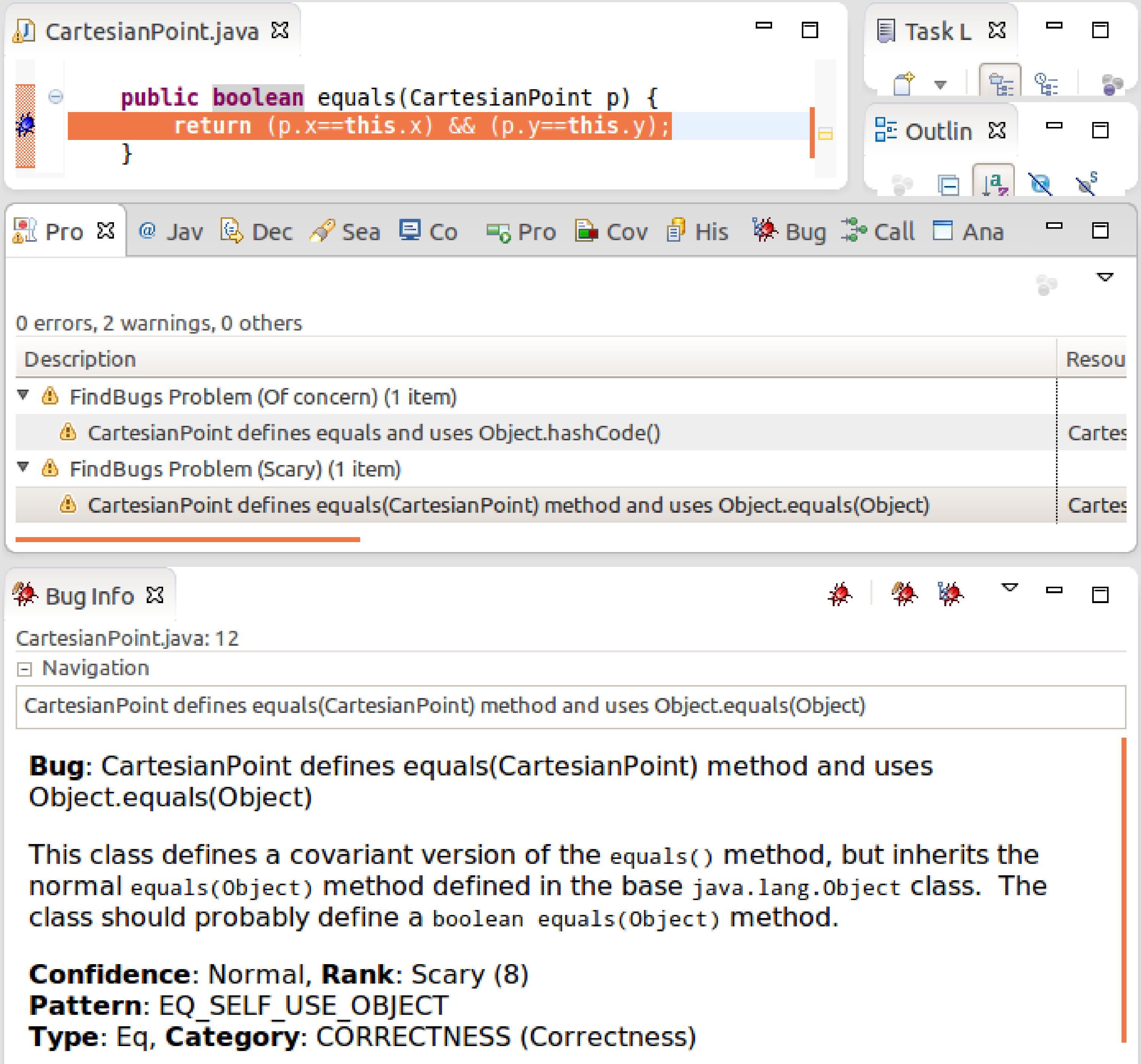
- Proof of correctness
  - All possible executions will fulfill the formal specifications
  - Pen and paper proof
  - Support for partially automated proofs available (full automation not possible)

Static Analysis

Stupid Bugs

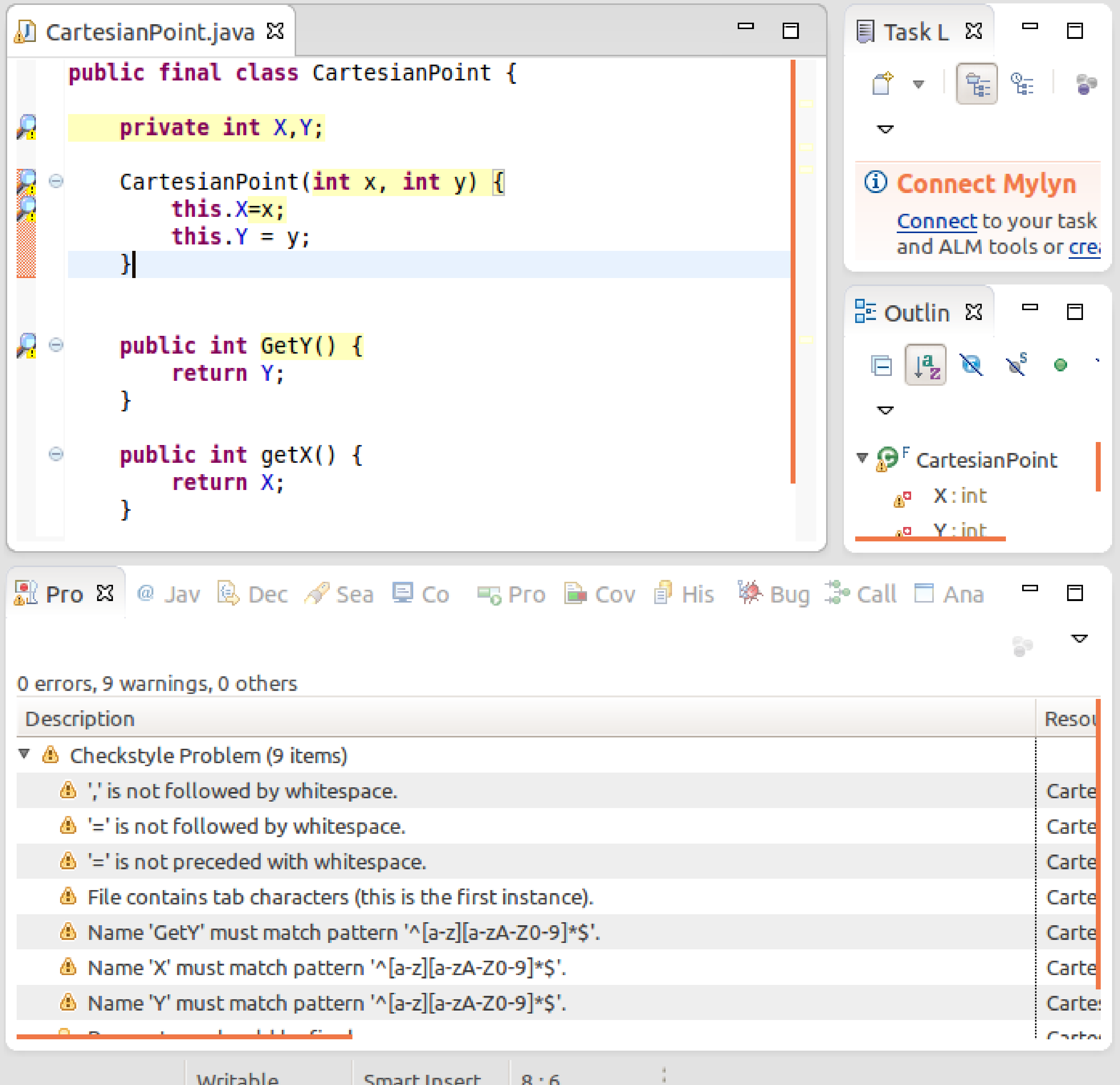
```
public class CartesianPoint {
    private int x, y;
    int getX() { return this.x; }
    int getY() { return this.y; }
    boolean equals(CartesianPoint that) {
            return (this.getX()==that.getX()) &&
                   (this.getY() == that.getY());
    }
}
```

FindBugs



CartesianPoint.java
public boolean equals(CartesianPoint p) {
return (p.x==this.x) && (p.y==this.y);
}
Task L
Outlin
Pro
Jav
Dec
Sea
Co
Pro
Cov
His
Bug
Call
Ana
0 errors, 2 warnings, 0 others
Description
Resou
FindBugs Problem (Of concern) (1 item)
CartesianPoint defines equals and uses Object.hashCode()
Cartes
FindBugs Problem (Scary) (1 item)
CartesianPoint defines equals(CartesianPoint) method and uses Object.equals(Object)
Cartes
Bug Info
CartesianPoint.java: 12
Navigation
CartesianPoint defines equals(CartesianPoint) method and uses Object.equals(Object)
Bug: CartesianPoint defines equals(CartesianPoint) method and uses Object.equals(Object)
This class defines a covariant version of the equals() method, but inherits the normal equals(Object) method defined in the base java.lang.Object class. The class should probably define a boolean equals(Object) method.
Confidence: Normal, Rank: Scary (8)
Pattern: EQ_SELF_USE_OBJECT
Type: Eq, Category: CORRECTNESS (Correctness)

CheckStyle


CartesianPoint.java
public final class CartesianPoint {
private int X,Y;
CartesianPoint(int x, int y) {
this.X=x;
this.Y = y;
}
public int GetY() {
return Y;
}
public int getX() {
return X;
}
Task L
Connect Mylyn
Connect to your task
and ALM tools or
Outlin
CartesianPoint
X : int
Y : int
Pro
Jav
Dec
Sea
Co
Pro
Cov
His
Bug
Call
Ana
0 errors, 9 warnings, 0 others
Description
Checkstyle Problem (9 items)
',' is not followed by whitespace.
'=' is not followed by whitespace.
'=' is not preceded with whitespace.
File contains tab characters (this is the first instance).
Name 'GetY' must match pattern '^[a-z][a-zA-Z0-9]*$'.
Name 'X' must match pattern '^[a-z][a-zA-Z0-9]*$'.
Name 'Y' must match pattern '^[a-z][a-zA-Z0-9]*$'.
Writable
Smart Insert
8 : 6

Static Analysis

- Analyzing code without executing it (automated inspection)
- Looks for bug patterns
- Attempts to formally verify specific aspects
- Point out typical bugs or style violations
  - NullPointerExceptions
  - Incorrect API use
  - Forgetting to close a file/connection
  - Concurrency issues
  - And many, many more (over 250 in FindBugs)
- Integrated into IDE or build process
- FindBugs and CheckStyle open source, many commercial products exist

Example FindBugs Bug Patterns

- Correct equals()
- Use of ==
- Closing streams
- Illegal casts
- Null pointer dereference
- Infinite loops
- Encapsulation problems
- Inconsistent synchronization
- Inefficient String use
- Dead store to variable

Bug finding

```java
public Boolean decide() {
    if (computeSomething()==3)
        return Boolean.TRUE;
    if (computeSomething()==4)
        return false;
    return null;
}
```

Problem | Javadoc | Declarati | Search | Console | Coverag | History | Bug Info | Bug Expl

A.java: 69

Navigation

Bug: FBTest.decide() has Boolean return type and returns explicit null

A method that returns either Boolean.TRUE, Boolean.FALSE or null is an accident waiting to happen. This method can be invoked as though it returned a value of type boolean, and the compiler will insert automatic unboxing of the Boolean value. If a null value is returned, this will result in a NullPointerException.

Confidence: Normal, **Rank**: Troubling (14)
Pattern: NP_BOOLEAN_RETURN_NULL
Type: NP, **Category**: BAD_PRACTICE (Bad practice)

Abstract Interpretation

- Static program analysis is the **systematic examination** of an **abstraction of a program's state space**
- Abstraction
  - Don't track everything! (That's normal interpretation)
  - Track an important abstraction
- Systematic
  - Ensure everything is checked in the same way

Details on how this works in 15-313

Comparing Quality Assurance Strategies

	Error exists	No error exists
Error Reported	True positive (correct analysis result)	False positive (annoying noise)
No Error Reported	False negative (false confidence)	True negative (correct analysis result)

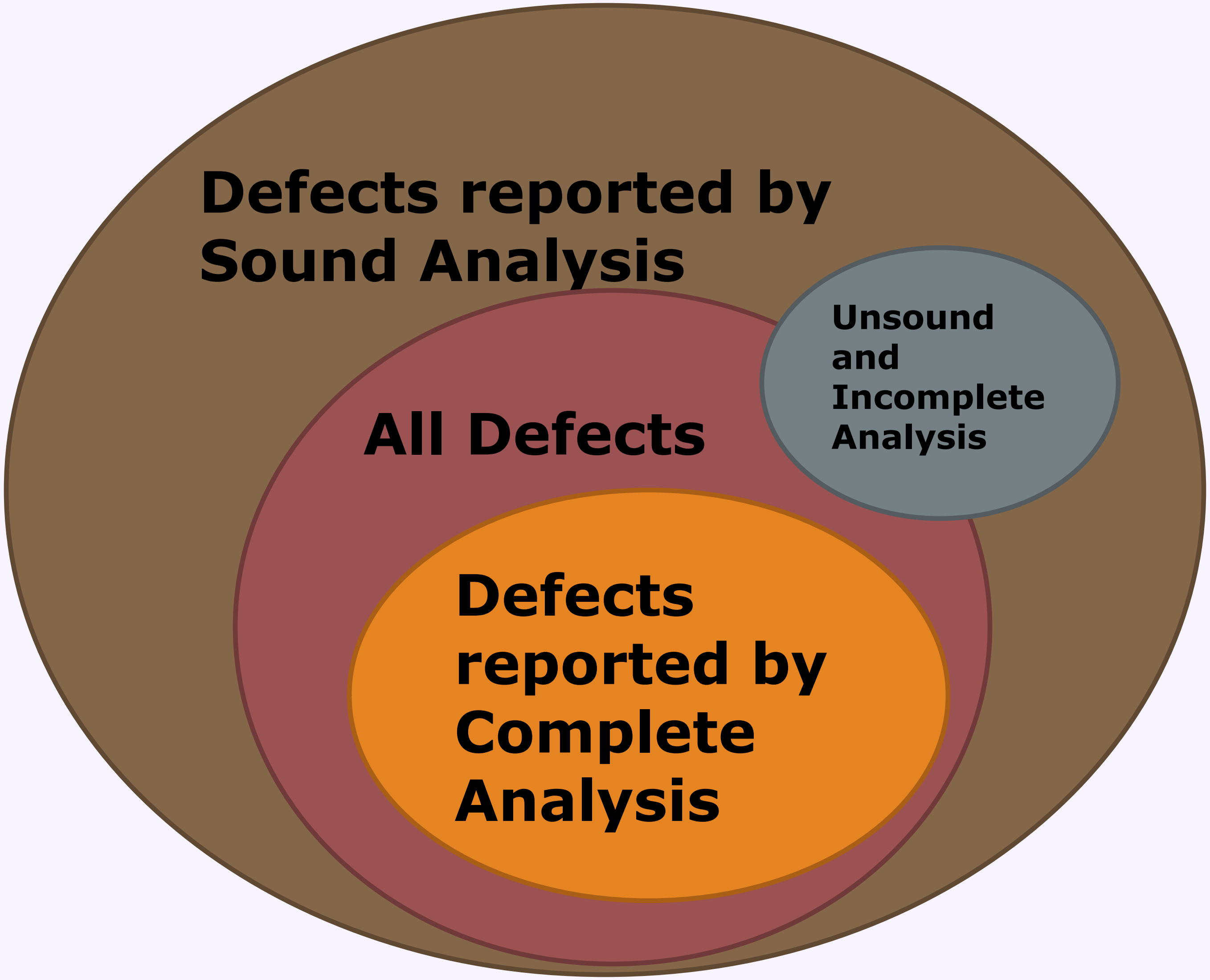
Sound Analysis:

reports all defects
-> no false negatives
typically overapproximated

Complete Analysis:

every reported defect is an actual defect
-> no false positives
typically underapproximated

How does testing relate? And formal verification?


Defects reported by Sound Analysis
All Defects
Unsound and Incomplete Analysis
Defects reported by Complete Analysis

The Bad News: Rice's Theorem

"Any nontrivial property about the language recognized by a Turing machine is undecidable."

Henry Gordon Rice, 1953

- Every static analysis is necessarily incomplete or unsound or undecidable (or multiple of these)
- Each approach has different tradeoffs

Soundness / Completeness / Performance Tradeoffs

- Type checking does catch a specific class of problems (sound), but does not find all problems
- Compiler optimizations must err on the safe side (only perform optimizations when sure it's correct; -> complete)
- Many practical bug-finding tools analyses are unsound and incomplete
  - Catch typical problems
  - May report warnings even for correct code
  - May not detect all problems
- Overwhelming amounts of false negatives make analysis useless
- Not all "bugs" need to be fixed

Testing and Proofs

- Testing
  - Observable properties
  - Verify program for one execution
  - Manual development with automated regression
  - Most practical approach now
  - Does not find all problems (unsound)

- Proofs (Formal Verification)
  - Any program property
  - Verify program for all executions
  - Manual development with automated proof checkers
  - Practical for small programs, may scale up in the future
  - Sound and complete, but not automatically decidable

- So why study proofs if they aren't (yet) practical?
  - Proofs tell us how to think about program correctness
  - Important for development, inspection, dynamic assertions
  - Foundation for static analysis tools
  - These are just simple, automated theorem provers
  - Many are practical today!

Testing, Static Analysis, and Proofs

- Testing
  - Observable properties
  - Verify program for one execution
  - Manual development with automated regression
  - Most practical approach now
  - Does not find all problems (unsound)
- Static Analysis
  - Analysis of all possible executions
  - Specific issues only with conservative approx. and bug patterns
  - Tools available, useful for bug finding
  - Automated, but unsound and/or incomplete
- Proofs (Formal Verification)
  - Any program property
  - Verify program for all executions
  - Manual development with automated proof checkers
  - Practical for small programs, may scale up in the future
  - Sound and complete, but not automatically decidable

What strategy to use in your project?

Quality Assurance Summary

- Reporting and tracking bugs/issues
- Select a quality assurance strategy for functional correctness
- Testing can find faults in specific executions
- Formal verification (Hoare-style pre/post-conditions) can ensure correctness of all executions
  - Class Invariants and Behavioral Subtyping
- Static analysis can find issues for classes of problems
- Soundness vs. Completeness vs. Automation