

Lecture 22: Static Analysis

CS 5150, Spring 2025

Administrative Reminders

- Peer Evaluation 2 is out. Submit by next week.

Lecture Goals

- Understanding relative strengths and weaknesses of static analysis
- Explore several popular analysis tools
- Understand how analysis tools are used in large Open-source software

What are program analysis tools?



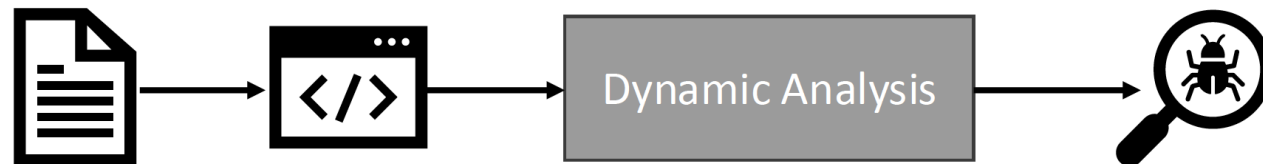
```
src/controllers/accounts/posts.js
```

```
136 ...  
137 ...  
138 ...  
139 ...  
140 ...  
141 ...  
142 ...  
143 ...  
144 ...  
145 ...  
146 ...
```

postsController.getBookmarks = async function (req, res, next) {
 await getPostsFromUserSet('account/bookmarks', req, res, next);
};

postsController.getPosts = async function (req, res, next) {
 await getPostsFromUserSet('account/posts', req, res, next);
};

This function expects 3 arguments, but 4 were provided.



```
COVERALLS
```

```
65  
66 Auth.reloadRoutes = async function (params) {  
67   loginStrategies.length = 0;  
68   const { router } = params;  
69  
70   // Local Logins  
71   if (plugins.hooks.hasListeners('action:auth.overrideLogin')) {  
72     winston.warn('[authentication] Login override detected, skipping login strategy.');73     plugins.hooks.fire('action:auth.overrideLogin');74   } else {  
75     passport.use(new passportLocal({ passReqToCallback: true },  
76       controllers.authentication.localLogin));  
77   }  
78   // HTTP Bearer authentication  
79   passport.use('core.api', new BearerStrategy(), Auth.verifyToken);  
80  
81   // Additional logins via SSO plugins  
82   try {  
83     loginStrategies = await plugins.hooks.fire('filter:auth.init',  
84       loginStrategies);  
85   } catch (err) {  
86     winston.error('[authentication] ${err.stack}');87   }  
88   loginStrategies = loginStrategies || [];  
89   loginStrategies.forEach((strategy) => {
```

What static analysis can/cannot do

- Type-checking
 - Set of data types taken any variable at any point
 - Can be used to prevent type errors (e.g., java) or warn about potential type errors (e.g., Python)
- Checking for problematic patterns in syntax is easy and fast
 - Is there a comparison of two java strings using `==`?
 - Is there an array access `a[i]` without an enclosing bounds check for `i`?
- Reasoning about termination is impossible in general
 - Halting problem
- Reasoning about exact values is hard, but conservative analysis via abstraction is possible
 - Is the bounds check before `a[i]` guaranteeing that `i` is within bounds?
 - Can the divisor ever take on zero value?
 - Could the result of function call be `42`?
 - Will this multi-threaded program give me a deterministic result?
 - Be prepared for “MAYBE”
- Verifying some advanced properties is possible but expensive
 - CI-based static analysis usually over-approximates conservatively

Static Analysis is well suited to detecting certain defects

- Security: Buffer overruns, improperly validated input...
- Memory safety: Null dereference, uninitialized data...
- Resource leaks: Memory, OS resources...
- API Protocols: Device drivers; real time libraries; GUI frameworks
- Exceptions: Arithmetic/library/user-defined
- Encapsulation: Accessing internal data, calling private functions...
- Data races: Two threads access the same data without synchronization

The Bad News: Rice's Theorem

Every static analysis is necessarily incomplete, unsound, undecidable, or a combination thereof

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

Henry Gordon Rice, 1953

Static Analysis: Broad classification

- Linters
 - Shallow syntax analysis for enforcing code styles and formatting
- Pattern-based bug detectors
 - Simple syntax or API-based rules for identifying common programming mistakes
- Type-annotation validators
 - Check conformance to user-defined types
 - Types can be complex (e.g., “Nullable”)
- Data-flow analysis / Abstract interpretation)
 - Deep program analysis to find complex error conditions (e.g., "can array index be out of bounds?”)

Static analysis can be applied to all attributes

- Find bugs
- Refactor code
- Keep your code stylish!
- Identify **code smells** (long method names, duplicated code, ...)
- Measure quality
- Find usability and accessibility issues
- Identify bottlenecks and improve performance

Activity: Analyze the Python program statically

```
def n2s(n: int, b: int):  
    if n <= 0: return '0'  
    r = ''  
    while n > 0:  
        u = n % b  
        if u >= 10:  
            u = chr(ord('A') + u - 10)  
        n = n // b  
        r = str(u) + r  
    return r
```

1. What is the type of variable `u`?
2. Will the variable `u` be a negative number?
3. Will this function always return a value?
4. Will the program divide by zero?
5. Will the returned value ever contain a minus sign '-'?

Answers can be Yes/No/Maybe (depends on the input)

Dynamic analysis reasons about program executions

- Tells you properties of the program that were definitely observed
 - Code coverage
 - Performance profiling
 - Type profiling
 - Testing
- In practice, implemented by program instrumentation
 - Think “Automated logging”
 - Slows down execution speed by a small amount

Static Analysis vs Dynamic Analysis

- Requires only source code
 - Conservatively reasons about all possible inputs and program paths
 - Reported warnings may contain false positives
 - Can report all warnings of a particular class of problems
 - Advanced techniques like verification can prove certain complex properties, but rarely run in CI due to cost
- Requires successful build + test inputs
 - Observes individual executions
 - Reported problems are real, as observed by a witness input
 - Can only report problems that are seen. Highly dependent on test inputs. Subject to false negatives
 - Advanced techniques like symbolic execution can prove certain complex properties, but rarely run in CI due to cost

Tools for static analysis



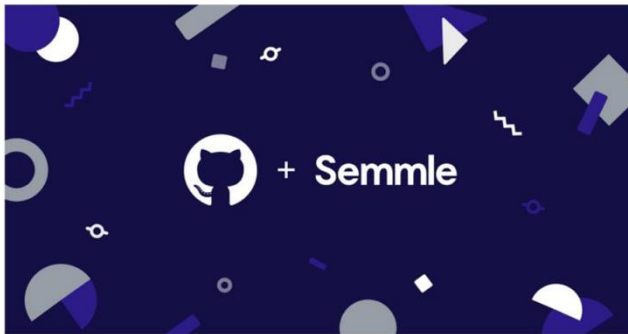
LLVM (C++)

Static analysis is now heavily commercialized

GitHub acquires code analysis tool Semmle

Frederic Lardinois @frederic / 1:30 pm EDT • September 18, 2019

Comment



Marketplace Search results

Types

Apps

Actions

Categories

API management
Chat
Code quality
Code review
Continuous integration
Dependency management
Deployment
IDEs
Learning
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Publishing

Search for apps and actions

Apps

Build on your workflow with apps that integrate with GitHub

306 results filtered by Apps

- Zube** Agile project management that lets the entire team work with developers on GitHub
- Crowdin** Agile localization for your projects
- BackHub** Reliable GitHub repository backup, set up in minutes
- Codacy** Automated code reviews to help developers ship better software, faster
- Semaphore** Test and deploy at the push of a button
- DeepScan** Advanced static analysis for automatically finding runtime errors in JavaScript code
- WhiteSource Bolt** Detect open source vulnerabilities in real time with suggested fixes for quick remediation
- Slack + GitHub** Connect your code without leaving Slack
- GitLocalize** Continuous Localization for GitHub projects
- Code Climate** Automated code review for technical debt and test coverage
- Flaptastic** Manage flaky unit tests. Click a checkbox to instantly disable any test on all branches. Works with your current test suite
- Deplu** Automated dependency updates done right



News

Snyk Secures \$150M, Snags \$1B Valuation



Sydney Sawaya | Associate Editor

January 21, 2020 1:12 PM

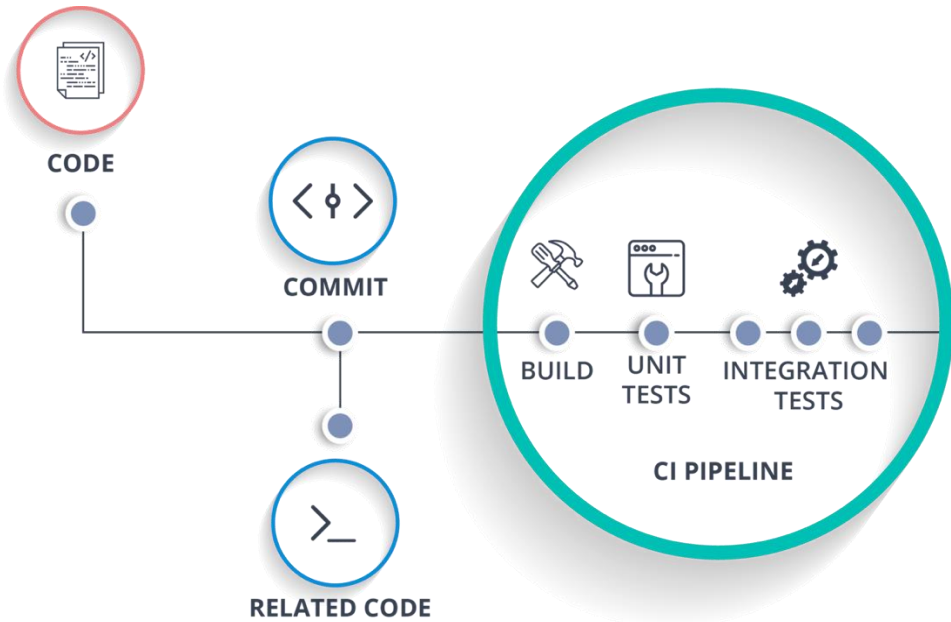
Share this article:



Snyk, a developer-focused security startup that identifies vulnerabilities in open source applications, announced a \$150 million Series C funding round today. This brings the company's total investment to \$250 million alongside reports that put the company's valuation at more than \$1 billion.



Static analysis is a key part of continuous integration



Travis CI



GitHub Actions



Static Analysis is also integrated into IDEs



```
cppcoreguidelines.cpp
1 // To enable only C++ Core Guidelines checks
2 // go to Settings/Preferences | Editor | Inspections | C/C++ | Clang-Tidy
3 // and provide: -*,cppcoreguidelines-* in options
4
5 void fill_pointer(int* arr, const int num) {
6     for(int i = 0; i < num; ++i) {
7         arr[i] = 0;
8     }
9     Do not use pointer arithmetic
10
11 void fill_array(int ind) {
12     int arr[3] = {1,2,3};
13     arr[ind] = 0;
14 }
15
16 void cast_away_const(const int& magic_num)
17 {
18     const_cast<int&>(magic_num) = 42;
19 }
20
```

```
new Todo({
  content: item,
  updated_at: Date.now(),
}).save(function (err, todo, count) {
  if (err) return next(err);

  /*
  res.setHeader('Data', todo.content.toString('base64'));
  res.redirect('/');
  */

  res.setHeader('Location', '/');
  res.status(302).send(todo.content.toString('base64'));

  // res.redirect('/#' + todo.content.toString('base64'));
});
};
```

Cross-site Scripting (XSS)
Vulnerability CWE-79
Unsanitized input from the HTTP request body flows into send, where it is used to render an HTML page returned to the user. This may result in a Scripting attack (XSS).

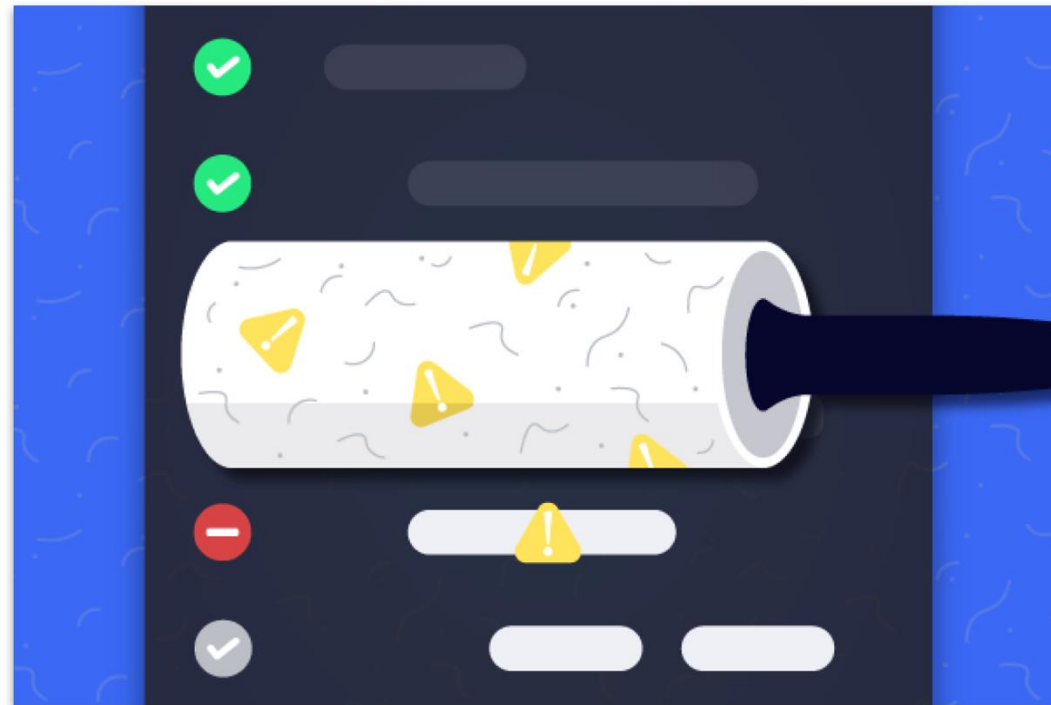
Data Flow - 12 steps

```
1 index.js:10 | var item = req.body.content;
2 index.js:10 | if (typeof(item) === 'string' && item.match(/<script>/)) {
3 index.js:9 | Click to show in the Editor
4 index.js:55 | function parse(todo) {
5 index.js:55 | var t = todo;
6 index.js:59 | var reminder = t.toString().indexOf(reminderToken);
7 index.js:61 | var time = t.slice(reminder + reminderToken.length);
8 index.js:69 | t = t.slice(0, reminder);
9 index.js:74 | return t;
```


What makes a good static analysis tool?

- Static analysis should be **fast**
 - Don't hold up development velocity
 - This becomes more important as code scales
- Static analysis should report **few false positives**
 - Otherwise developers will start to ignore warnings and alerts, and quality will decline
- Static analysis should be **continuous**
 - Should be part of your continuous integration pipeline
 - Diff-based analysis is even better – don't analyze the entire codebase; just the changes
- Static analysis should be **informative**
 - Messages that help the developer to quickly locate and address the issue
 - Ideally, it should suggest or automatically apply fixes

(1) Linters: *Cheap, fast, and lightweight static source analysis*



Use linters to enforce style guidelines

- Don't rely on manual inspection during code review!



RuboCop



<https://checkstyle.sourceforge.io/>

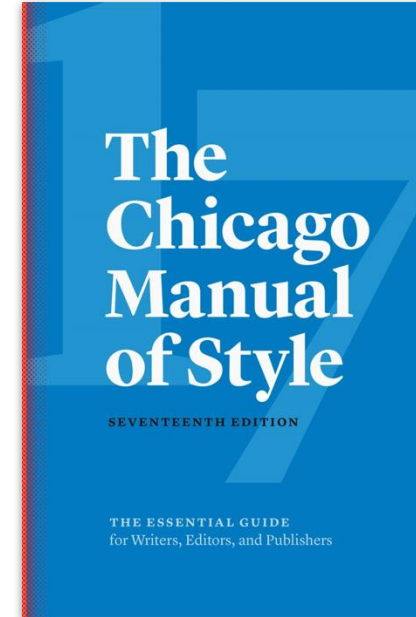
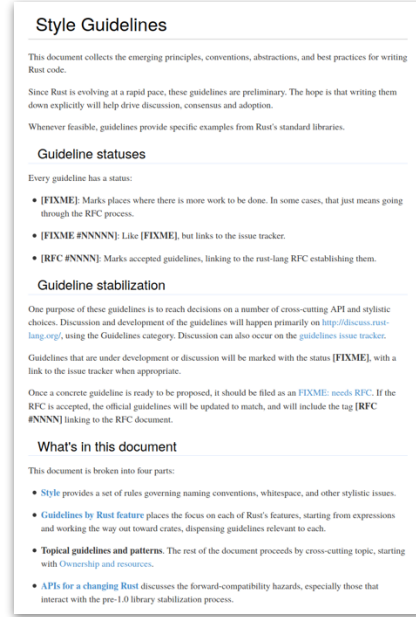
Linters use very “**shallow**” static analysis to enforce formatting rules

- Ensure proper indentation
- Naming convention
- Line sizes
- Class nesting
- Documenting public functions
- Parenthesis around expressions
- What else?

Use linters to improve maintainability

- Why? We spend more time reading code than writing it
 - Various estimates of the exact %, some as high as 80%
- Code ownership is usually shared
- The original owner of some code may move on
- Code conventions make it easier for other developers to quickly understand your code

Use Style Guidelines to facilitate communication



- Guidelines are inherently opinionated, but consistency is the important point
- Agree to a set of conventions and stick to them

Take-Away Message:

Style is an easy way to improve readability

- Everyone has their own opinion (e.g., tabs vs. spaces)
- Agree to a convention and stick to it
 - Use continuous integration to enforce it
- Use automated tools to fix issues in existing code

(2) Pattern-based Static Analysis Tools

- Bad Practice
- Correctness
- Performance
- Internationalization
- Malicious Code
- Multithreaded Correctness
- Security
- Dodgy Code

<https://spotbugs.readthedocs.io/en/latest/bugDescriptions.html#l-an-apparent-infinite-recursive-loop-il-infinite-recursive-loop>



Docs and Info
FindBugs 2.0
Demo and data
Users and supporters
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Fact sheet
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Manual(ja/日本語)
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Development

Open bugs
Reporting bugs
Contributing
Dev team
API [no frames]
Change log
SF project page
Browse source
Latest code changes

FindBugs Bug Descriptions

This document lists the standard bug patterns reported by [FindBugs](#) version 3.0.1.

Summary

Description	Category
BC: Equals method should not assume anything about the type of its argument	Bad practice
BIT: Check for sign of bitwise operation	Bad practice
CN: Class implements Cloneable but does not define or use clone method	Bad practice
CN: clone method does not call super.clone()	Bad practice
CN: Class defines clone() but doesn't implement Cloneable	Bad practice
CNT: Rough value of known constant found	Bad practice
Co: Abstract class defines covariant compareTo() method	Bad practice
Co: compareTo()/compare() incorrectly handles float or double value	Bad practice
Co: compareTo()/compare() returns Integer.MIN_VALUE	Bad practice
Co: Covariant compareTo() method defined	Bad practice
DE: Method might drop exception	Bad practice
DE: Method might ignore exception	Bad practice
DMI: Adding elements of an entry set may fail due to reuse of Entry objects	Bad practice
DMI: Random object created and used only once	Bad practice
DMI: Don't use removeAll to clear a collection	Bad practice
Dm: Method invokes System.exit(...)	Bad practice
Dm: Method invokes dangerous method runFinalizersOnExit	Bad practice
ES: Comparison of String parameter using == or !=	Bad practice
ES: Comparison of String objects using == or !=	Bad practice
Eq: Abstract class defines covariant equals() method	Bad practice
Eq: Equals checks for incompatible operand	Bad practice
Eq: Class defines compareTo(..., ...) and uses Object.equals()	Bad practice
Eq: equals method fails for subtypes	Bad practice
Eq: Covariant equals() method defined	Bad practice
FI: Empty finalizer should be deleted	Bad practice
FI: Explicit invocation of finalizer	Bad practice
FI: Finalizer nulls fields	Bad practice
FI: Finalizer only nulls fields	Bad practice
FI: Finalizer does not call superclass finalizer	Bad practice
FI: Finalizer nullifies superclass finalizer	Bad practice
FI: Finalizer does nothing but call superclass finalizer	Bad practice
FS: Format string should use %n rather than \n	Bad practice
GC: Unchecked type in generic call	Bad practice
HE: Class defines equals() but not hashCode()	Bad practice
HE: Class defines equals() and uses Object.hashCode()	Bad practice
HE: Class defines hashCode() but not equals()	Bad practice
HE: Class defines hashCode() and uses Object.equals()	Bad practice
HE: Class inherits equals() and uses Object.hashCode()	Bad practice
IC: Superclass uses subclass during initialization	Bad practice
IMSE: Dubious catching of IllegalMonitorStateException	Bad practice
ISC: Needless instantiation of class that only supplies static methods	Bad practice
It: Iterator next() method can't throw NoSuchElementException	Bad practice
J2EE: Store of non serializable object into HttpSession	Bad practice
JCIP: Fields of immutable classes should be final	Bad practice
ME: Public enum method unconditionally sets its field	Bad practice

Bad Practice:

```
String x = new String("Foo");  
String y = new String("Foo");  
if (x == y) {  
    System.out.println("x and y are the same!");  
} else {  
    System.out.println("x and y are different!");  
}
```

Bad Practice: ES_COMPARING_STRINGS_WITH_EQ

Comparing strings with ==

```
String x = new String("Foo");  
String y = new String("Foo");  
if (x == y) { if (x.equals(y)) {  
    System.out.println("x and y are the same!");  
} else {  
    System.out.println("x and y are different!");  
}
```

How do we check for equality in JS?

- `if (a=b) {`
- `if (a==b) {`
- `if (a===b) {`
- `if (Object.is(a,b)) {`

How do we check for equality in JS?

- `if (a=b) {`
 - No
- `if (a==b) {`
 - Loose equality : `1=='1'` is true (type coercion)
- `if (a===b) {`
 - Correct! Checks for both value and type! So, `1==='1'` is false
- `if (Object.is(a,b)) {`
 - More precise for cases like NaN or -0
 - `Object.is(NaN, NaN): true`, `Object.is("1", 1): false`
 - `Object.is(-0, 0): false`
 - `Object.is(obj, {}): false`

Performance:

```
public static String repeat(String string, int times)
{
    String output = string;
    for (int i = 1; i < times; ++i) {
        output = output + string;
    }
    return output;
}
```

Performance: SBSC_USE_STRINGBUFFER_CONCATENATION Method concatenates strings using + in a loop

```
public static String repeat(String string, int times)
{
    String output = string;
    for (int i = 1; i < times; ++i) {
        output = output + string;
    }
    return output;
}
```

The method seems to be building a String using concatenation in a loop. In each iteration, the String is converted to a StringBuffer/StringBuilder, appended to, and converted back to a String. **This can lead to a cost quadratic in the number of iterations, as the growing string is recopied in each iteration.**

Performance: SBSC_USE_STRINGBUFFER_CONCATENATION Method concatenates strings using + in a loop

```
public static String repeat(String string, int times)
{
    int length = string.length() * times;
    StringBuffer output = new StringBuffer(length);
    for (int i = 0; i < times; ++i) {
        output.append(string);
    }
    return output.toString();
}
```

Correctness:

```
@Override
public Connection getConnection() throws SQLException {
    QwicsConnection con = new QwicsConnection(host, port);
    try {
        con.open();
    } catch (Exception e) {
        new SQLException(e);
    }
    return con;
}
```


Correctness: Missing “throw” before “new Exception”

```
@Override
public Connection getConnection() throws SQLException {
    QwicsConnection con = new QwicsConnection(host, port);
    try {
        con.open();
    } catch (Exception e) {
        throw new SQLException(e);
    }
    return con;
}
```

Challenges with pattern-based static analysis

- The analysis must produce zero false positives
 - Otherwise developers won't be able to build the code!
- The analysis needs to be really fast
 - Ideally < 100 ms
 - If it takes longer, developers will become irritated and lose productivity
 - Practically, this means the analysis needs to focus on “shallow” bugs rather than verifying some complex logic spanning multiple functions/classes.
- You can't just “turn on” a particular check
 - Every instance where that check fails will prevent existing code from building
 - There could be thousands of violations for a single check across large codebases

(3) Use type annotations to detect common errors

- Uses static types to prevent meaningless operations from executing in the first place (instead of dealing with bad results later)
- Annotations can enhance type system already in the language
- Examples: Java Checker Framework, MyPy, TypeScript



Example: MyPy Type System

- Add type hints to programs
- Mix static and dynamic typing
- Makes code much safer!
- Avoids invalid operations statically!

From Python...

```
def fib(n):  
    a, b = 0, 1  
    while a < n:  
        yield a  
        a, b = b, a+b
```

...to statically typed Python

```
def fib(n: int) -> Iterator[int]:  
    a, b = 0, 1  
    while a < n:  
        yield a  
        a, b = b, a+b
```

Example: Detecting null pointer exceptions

- **@Nullable** indicates that an expression may be null
- **@NonNull** indicates that an expression must never be null
- Guarantees that expressions annotated with **@NonNull** will never evaluate to null, forbids other expressions from being dereferenced

// return value

@NonNull String toString() { ... }

// parameter

int compareTo(**@NonNull** String other)
{ ... }

```
import org.checkerframework.checker.nullness.qual.*;
```

```
public class NullnessExampleWithWarnings {
```

```
    public void example() {
```

```
        @NonNull String foo = "foo";
```

```
        String bar = null;
```

```
        foo = bar;
```

```
        println(foo.length());
```

```
    }
```

```
}
```

@Nullable is applied by default

Error: [assignment.type.incompatible] incompatible types in assignment.

found : @Initialized @Nullable String

required: @UnknownInitialization@NonNull String

```
import org.checkerframework.checker.nullness.qual.*;
```

```
public class NullnessExampleWithWarnings {
```

```
    public void example() {
```

```
        @NonNull String foo = "foo";
```

```
        String bar = null; //@Nullable
```

```
        if (bar != null){
```

```
            foo = bar;
```

```
        }
```

```
        println(foo.length());
```

```
    }
```

```
}
```



bar is refined to @NonNull

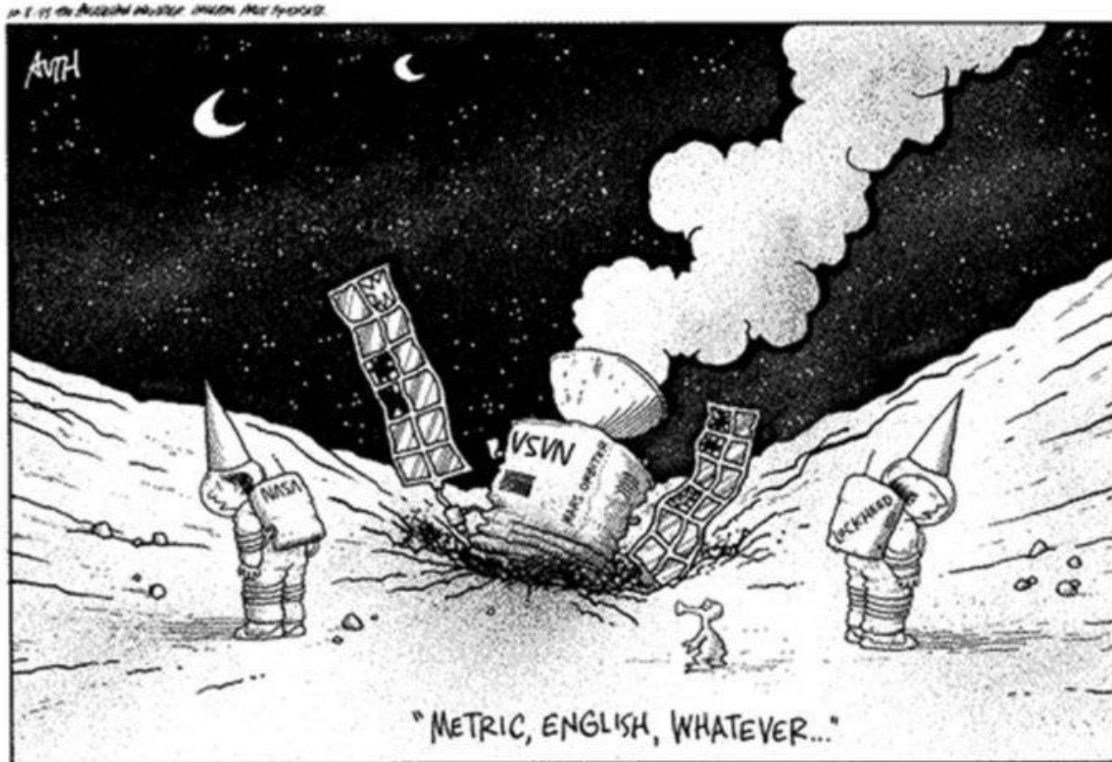
DEMO

- <http://eisop.uwaterloo.ca/live/#mode=edit>

Another example: Units checker

- Guarantees that operations are performed on the same kinds and units
- Kind annotations
 - @Acceleration, @Angle, @Area, @Current, ...
- SI Unit annotation
 - @m, @km, @mm, @kg, ...






Remember the Mars Climate Orbiter incident from 1999?

NASA's Mars Climate Orbiter (cost of \$327 million) was lost because of a discrepancy between use of metric unit Newtons and imperial measure Pound-force.

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When NASA Lost a Spacecraft Due to a Metric Math Mistake

WRITTEN BY
Ajay Harish

UPDATED ON
March 10th, 2020

APPROX READING TIME
11 Minutes

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In September of 1999, after almost 10 months of travel to Mars, the Mars Climate Orbiter burned and broke into pieces. On a day when NASA engineers were expecting to celebrate, the ground reality turned out to be completely different, all because someone failed to use the right units, i.e., the metric units! The Scientific American Space Lab made a brief but interesting video on this very topic.

NASA'S LOST SPACECRAFT

The Metric System and NASA's Mars Climate Orbiter

The Mars Climate Orbiter, built at a cost of \$125 million, was a 338-kilogram robotic space probe launched by NASA on December 11, 1998 to study the Martian climate, Martian atmosphere, and surface changes. In addition, its function was to act as the communications relay in the Mars Surveyor '98 program for the Mars Polar Lander. The navigation team at the Jet Propulsion Laboratory (JPL) used the metric system of millimeters and meters in its calculations, while

```
import static org.checkerframework.checker.units.UnitsTools.m;  
import static org.checkerframework.checker.units.UnitsTools.mPERs;  
import static org.checkerframework.checker.units.UnitsTools.s;  
void demo() {
```

```
@m int x;
```

@m indicates that x represents meters

```
x = 5 * m;
```

```
@m int meters = 5 * m;
```

```
@s int seconds = 2 * s;
```

```
@mPERs int speed = meters / seconds;
```

```
@m int foo = meters + seconds;
```

```
@s int bar = seconds - meters;
```

```
}
```

To assign a unit, multiply appropriate unit constant from UnitTools

Does this program compile?

```
import static org.checkerframework.checker.units.UnitsTools.m;
import static org.checkerframework.checker.units.UnitsTools.mPERs;
import static org.checkerframework.checker.units.UnitsTools.s;
void demo() {
    @m int x;
    x = 5 * m;
    @m int meters = 5 * m;
    @s int seconds = 2 * s;
    @mPERs int speed = meters / seconds;
    @m int foo = meters + seconds;
    @s int bar = seconds - meters;
}
```

@m indicates that x represents meters

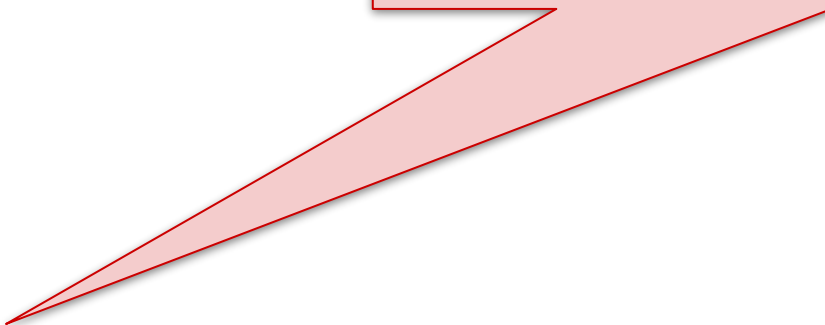
To assign a unit, multiply appropriate unit constant from UnitTools

Does this program compile?

```
import static org.checkerframework.checker.units.UnitsTools.m;
import static org.checkerframework.checker.units.UnitsTools.mPERs;
import static org.checkerframework.checker.units.UnitsTools.s;
void demo() {
    @m int x;
    x = 5 * m;
    @m int meters = 5 * m;
    @s int seconds = 2 * s;
    @mPERs int speed = meters / seconds;
    @m int foo = meters + seconds;
    @s int bar = seconds - meters;
}
```

Does this program compile? No

```
import static org.checkerframework.checker.units.UnitsTools.m;  
import static org.checkerframework.checker.units.UnitsTools.mPERs;  
import static org.checkerframework.checker.units.UnitsTools.s;  
void demo() {  
    @m int x;  
    x = 5 * m;  
    @m int meters = 5 * m;  
    @s int seconds = 2 * s;  
    @mPERs int speed = meters / seconds;  
    @m int foo = meters + seconds;  
    @s int bar = seconds - meters;  
}
```



Addition and subtraction between meters and seconds is physically meaningless

Limitations of Type-based Static Analysis

- Can only analyze code that is annotated
 - Requires that dependent libraries are also annotated
 - Can be tricky to retrofit annotations into existing codebases
- Only considers the signature and annotations of methods
 - Doesn't look at the implementation of methods that are being called
- Can't handle dynamically generated code well
 - Examples: Spring Framework, Templates
- Can produce false positives!
 - Byproduct of necessary approximations

More Advanced Tools

- **CodeQL**
 - Mostly focused on detecting deep security bugs via data flow/taint analysis
 - Write SQL-like queries for each vulnerability
 - Provides 1000s of custom queries across languages
- Key techniques: Data flow analysis, Control flow analysis, ...
- Other tools: **Semgrep**, **Snyk**, **SonarQube**

JavaConverter.java

```
public static Object deserialize (InputStream is)
    throws IOException {
    ObjectInputStream ois = new ObjectInputStream(is);
    return ois.readObject();
}
```

UnsafeDeserialization.ql

```
from PathNode source, PathNode sink
where flowPath(source, sink)
select sink.getNode().(UnsafeDeserializationSink)
    .getMethodAccess(),
    source, sink, "Unsafe deserialization of $@.",
    source.getNode(), "user input"
```

QL Query Results

alerts ▾

> ☰ Unsafe deserialization of [user input](#).

▾ ☰ Unsafe deserialization of [user input](#).

▾ Path

1 [getContent\(...\) : InputStream](#)

2 [getContentAsStream\(...\) : InputStream](#)

3 [toBufferedInputStream\(...\) : InputStream](#)

4 [getInputStream\(...\) : InputStream](#)

5 [is : InputStream](#)

6 [ois](#)

> Path

> ☰ Unsafe deserialization of [user input](#).

Best QA strategies employ a combination of tools

How Many of All Bugs Do We Find? A Study of Static Bug Detectors

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ABSTRACT

Static bug detectors are becoming increasingly popular and are widely used by professional software developers. While most work on bug detectors focuses on whether they find bugs at all, and on how many false positives they report in addition to legitimate warnings, the inverse question is often neglected: How many of all real-world bugs do static bug detectors find? This paper addresses this question by studying the results of applying three widely used static bug detectors to an extended version of the Defects4J dataset that consists of 15 Java projects with 594 known bugs. To decide which of these bugs the tools detect, we use a novel methodology that combines an automatic analysis of warnings and bugs with a manual validation of each candidate of a detected bug. The results of the study show that: (i) static bug detectors find a non-negligible amount of all bugs, (ii) different tools are mostly complementary to each other, and (iii) current bug detectors miss the large majority of the studied bugs. A detailed analysis of bugs missed by the static

International Conference on Automated Software Engineering (ASE '18), September 3–7, 2018, Montpellier, France. ACM, New York, NY, USA, 12 pages.
<https://doi.org/10.1145/3238147.3238213>

1 INTRODUCTION

Finding software bugs is an important but difficult task. For average industry code, the number of bugs per 1,000 lines of code has been estimated to range between 0.5 and 25 [21]. Even after years of deployment, software still contains unnoticed bugs. For example, studies of the Linux kernel show that the average bug remains in the kernel for a surprisingly long period of 1.5 to 1.8 years [8, 24]. Unfortunately, a single bug can cause serious harm, even if it has been subsisting for a long time without doing so, as evidenced by examples of software bugs that have caused huge economic losses and even killed people [17, 28, 46].

Given the importance of finding software bugs, developers rely on several approaches to reveal programming mistakes. One ap-

Tool	Bugs
Error Prone	8
Infer	5
SpotBugs	18
Total:	31
Total of 27 unique bugs	

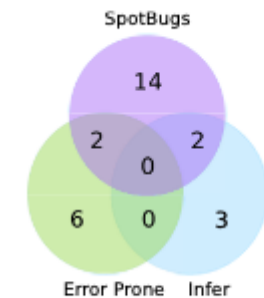


Figure 4: Total number of bugs found by all three static checkers and their overlap.

Which tool to use?

- Depends on use case, available resources
- **Linters**: Fast, cheap, easy to address issues or set ignore rules
- **Pattern-based bugs**: Intuitive, but need to deal with false positives.
- **Type-annotation-based checkers**: More manual effort required; needs overall project commitment. But good payoff once adopted.
- **Deep analysis tools**: Can find tricky issues, but can be costly. Might need some awareness of the analysis to deal with false positives.
- The best QA strategy involves multiple analysis and testing techniques!