# Preventing Errors Before They Happen
# **The Checker Framework**

`http://CheckerFramework.org/`

Twitter: @CheckerFrmwrk

Live demo: `http://eisop.uwaterloo.ca/live`

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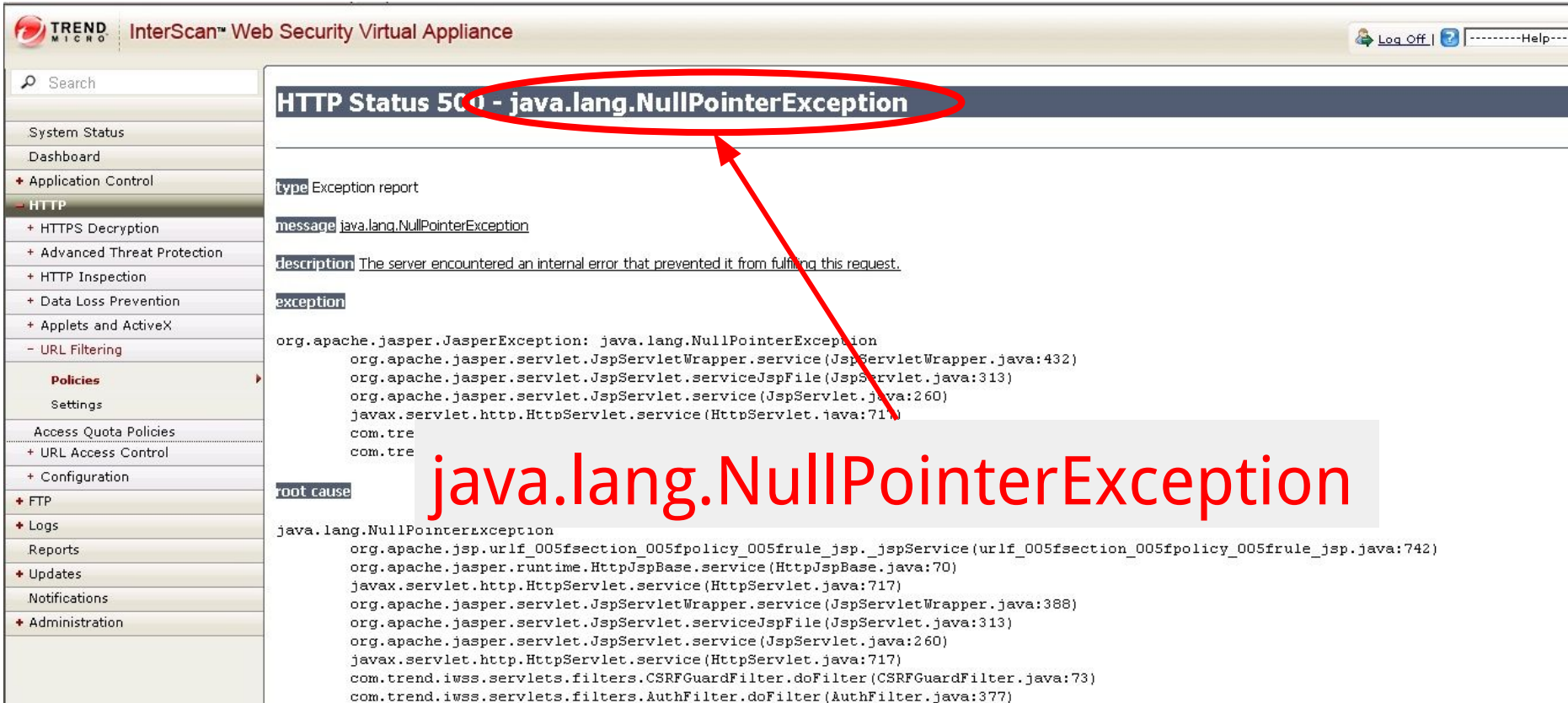
# Motivation


TREND MICRO
InterScan™ Web Security Virtual Appliance
Log Off |
Help
Search
System Status
Dashboard
Application Control
HTTP
HTTPS Decryption
Advanced Threat Protection
HTTP Inspection
Data Loss Prevention
Applets and ActiveX
URL Filtering
Policies
Settings
Access Quota Policies
URL Access Control
Configuration
FTP
Logs
Reports
Updates
Notifications
Administration
HTTP Status 500 - java.lang.NullPointerException
type Exception report
message java.lang.NullPointerException
description The server encountered an internal error that prevented it from fulfilling this request.
exception
org.apache.jasper.JasperException: java.lang.NullPointerException
org.apache.jasper.servlet.JspServletWrapper.service(JspServletWrapper.java:432)
org.apache.jasper.servlet.JspServlet.serviceJspFile(JspServlet.java:313)
org.apache.jasper.servlet.JspServlet.service(JspServlet.java:260)
javax.servlet.http.HttpServlet.service(HttpServlet.java:717)
com.tre
com.tre
root cause
java.lang.NullPointerException
org.apache.jsp.urlf_005fsection_005fpolicy_005frule_jsp._jspService(urlf_005fsection_005fpolicy_005frule_jsp.java:742)
org.apache.jasper.runtime.HttpJspBase.service(HttpJspBase.java:70)
javax.servlet.http.HttpServlet.service(HttpServlet.java:717)
org.apache.jasper.servlet.JspServletWrapper.service(JspServletWrapper.java:388)
org.apache.jasper.servlet.JspServlet.serviceJspFile(JspServlet.java:313)
org.apache.jasper.servlet.JspServlet.service(JspServlet.java:260)
javax.servlet.http.HttpServlet.service(HttpServlet.java:717)
com.trend.iwss.servlets.filters.CSRFGuardFilter.doFilter(CSRFGuardFilter.java:73)
com.trend.iwss.servlets.filters.AuthFilter.doFilter(AuthFilter.java:377)
java.lang.NullPointerException

# Cost of software failures

**$312 billion per year** global cost of software bugs (2013)

**$300 billion** dealing with the Y2K problem

**$440 million** loss by Knight Capital Group Inc. in 30 minutes in August 2012

**$650 million** loss by NASA Mars missions in 1999; unit conversion bug

**$500 million** Ariane 5 maiden flight in 1996; 64 bit to 16 bit conversion bug

# Software bugs can cost lives

1997: **225 deaths**: jet crash caused by radar software
1991: **28 deaths**: Patriot missile guidance system
2003: **11 deaths**: blackout
1985-2000: **>8 deaths**: Radiation therapy

2011: Software cause for 25% of all medical device recalls

# Outline

- Solution:  Pluggable type-checking
- Tool:  Checker Framework
- How to use it
- Creating your own type system

# Java's type system is too weak

Type checking prevents many errors

```
int i = "hello";
```

Type checking doesn't prevent enough errors

```
System.console().readLine();
```

```
Collections.emptyList().add("one");
```

# Java's type system is too weak

Type checking prevents many errors

```
int i = "hello";
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Type checking doesn't prevent enough errors

NullPointerException

```
System.console().readLine();
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Collections.emptyList().add("one");
```

# Java's type system is too weak

Type checking prevents many errors

```
int i = "hello";
```

Type checking doesn't prevent enough errors

```
System
Collections.emptyList().add("one");
```

UnsupportedOperationException

# Some errors are silent

```
Date date = new Date();
myMap.put(date, "now");
date.setSeconds(0);   // round to minute
myMap.get(date);
```

# Some errors are silent

```
Date date = new Date();
myMap.put(date, "now");
date.setSeconds(0);   // round to minute
myMap.get(date);
```

Corrupted map

# Some errors are silent

```
dbStatement.executeQuery(userInput);
```

# Some errors are silent

```
dbStatement.executeQuery(userInput);
```

SQL injection attack

Initialization, data formatting, equality tests, …

# Solution: Pluggable Type Checking

1. Design a type system to solve a specific problem
2. Write type qualifiers in code (or, use type inference)

```
@Immutable Date date = new Date();
date.setSeconds(0);  // compile-time error
```

3. Type checker warns about violations (bugs)

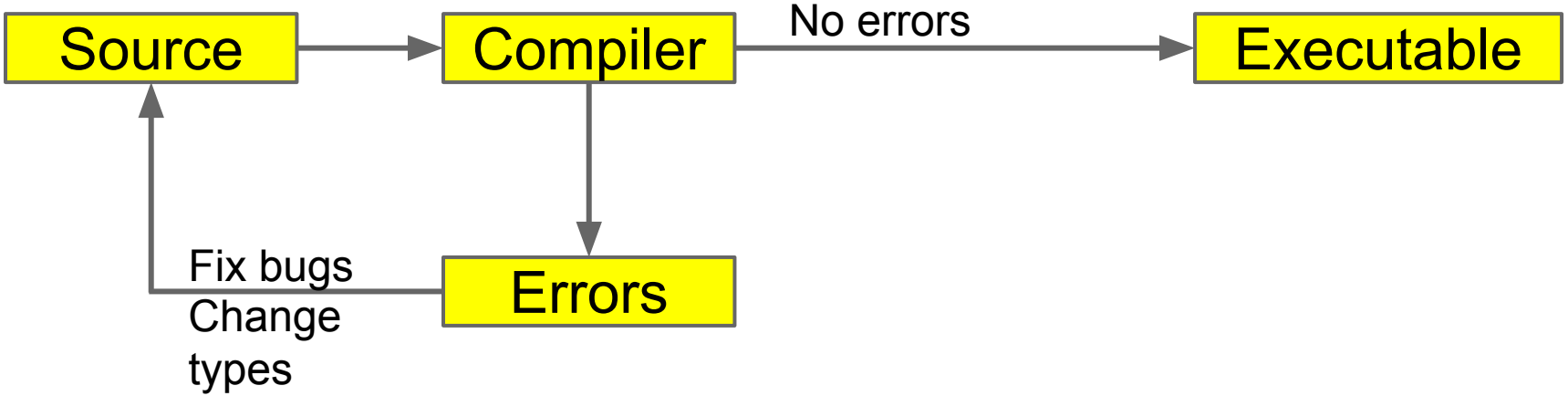
```
% javac -processor NullnessChecker MyFile.java

MyFile.java:149: dereference of possibly-null reference bb2
      allVars = bb2.vars;
                ^
```

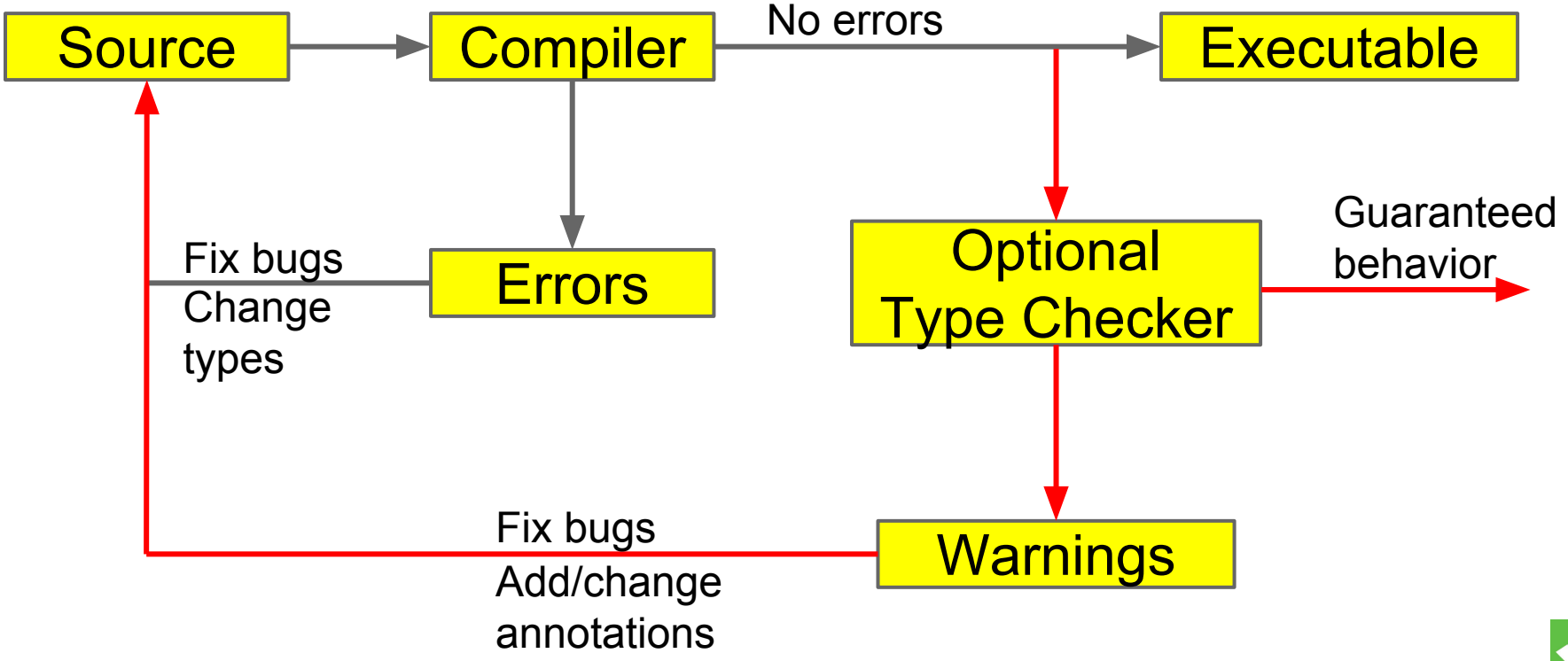
# Nullness and mutation demo

- Detect errors
- Guarantee the absence of errors
- Verify the correctness of optimizations

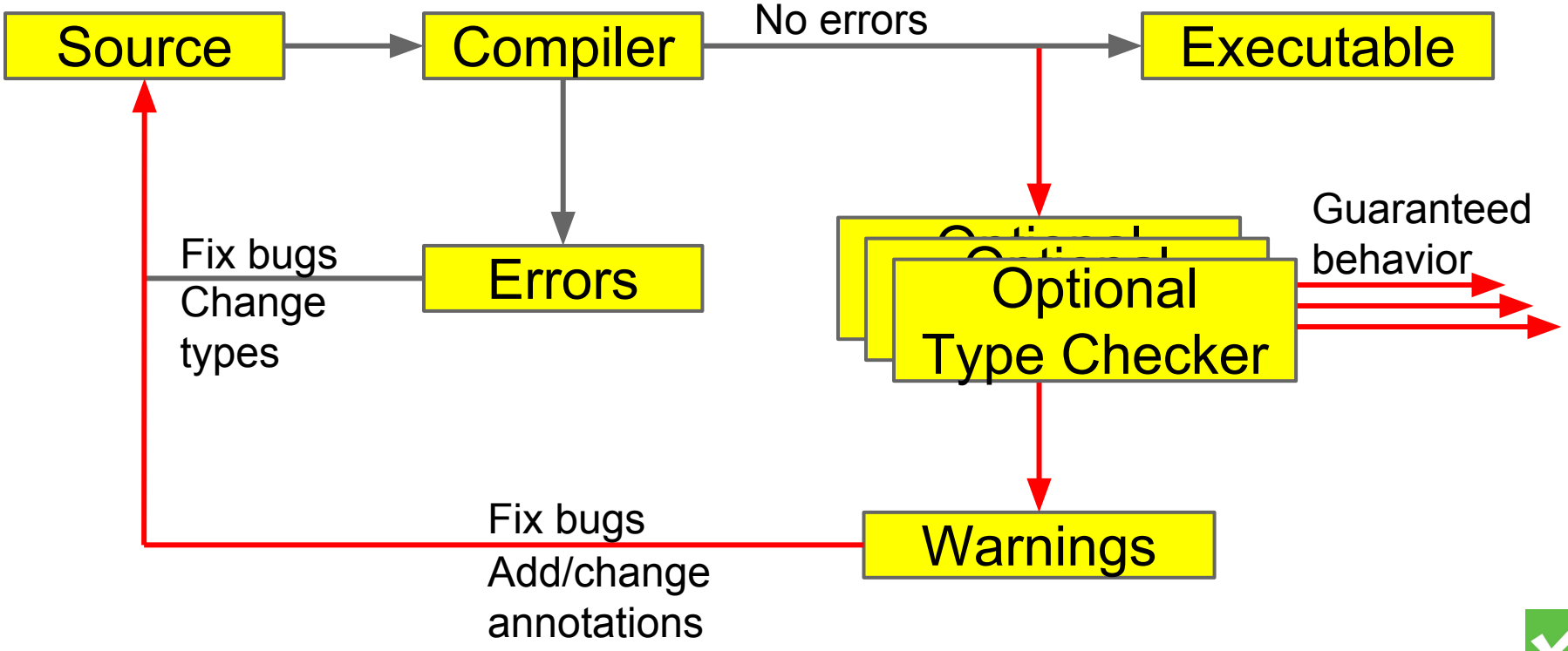
# Type Checking




# Optional Type Checking



# Optional Type Checking



# Prevent null pointer exceptions

Type system that statically guarantees that:

the program only dereferences known non-null references

Types of data:

| | |
|---|---|
| `@NonNull` | reference is never null |
| `@Nullable` | reference may be null |

# Null pointer exception

```
String op(Data in) {
  return "transform: " + in.getF();
}
…
String s = op(null);
```

# Null pointer exception

**Where is the defect?**

```
String op(Data in) {
  return "transform: " + in.getF();
}
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String s = op(null);
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# Null pointer exception

**Where is the defect?**

```
String op(Data in) {
  return "transform: " + in.getF();
}
…
String s = op(null);
```

**Can’t decide without specification!**

# Specification 1: non-null parameter

```
String op(@NonNull Data in) {
  return "transform: " + in.getF();
}
…
String s = op(null);
```

# Specification 1: non-null parameter

```
String op(@NonNull Data in) {
  return "transform: " + in.getF();
}
…
String s = op(null);      // error
```

# Specification 2: nullable parameter

```
String op(@Nullable Data in) {
  return "transform: " + in.getF();
}
…
String s = op(null);
```

# Specification 2: nullable parameter

```
String op(@Nullable Data in) {
  return "transform: " + in.getF();
}                                  // error
…
String s = op(null);
```

# Benefits of type systems

- **Find bugs** in programs
  - Guarantee the **absence of errors**
- **Improve documentation**
  - Improve code structure & maintainability
- Aid compilers, optimizers, and analysis tools
  - E.g., could reduce number of run-time checks

- Possible negatives:
  - Must write the types (or use type inference)
  - False positives are possible (can be suppressed)

# Input Format Validation

Demo: ensure that certain strings contain **valid regular expressions**.

# Regular Expression Example

```
public static void main(String[] args) {
  String regex = args[0];
  String content = args[1];
  Pattern pat = Pattern.compile(regex);
  Matcher mat = pat.matcher(content);
  if (mat.matches()) {
    System.out.println("Group: " + mat.group(1));
  }
}
```

# Regular Expression Example

```
public static void main(String[] args) {
   String regex
   String conten
   Pattern pat = Pattern.compile(regex);
   Matcher mat =
   if (mat.match
      System.out.println("Group: " + mat.group(1));
   }
}
```

PatternSyntaxException

IndexOutOfBoundsExceptionon

# Fixing the Errors

`Pattern.compile` only on valid regex
`Matcher.group(i)` only if > i groups

```
...
if (!RegexUtil.isRegex(regex, 1)) {
  System.out.println("Invalid: " + regex);
  System.exit(1);
}
...
```

# The Checker Framework

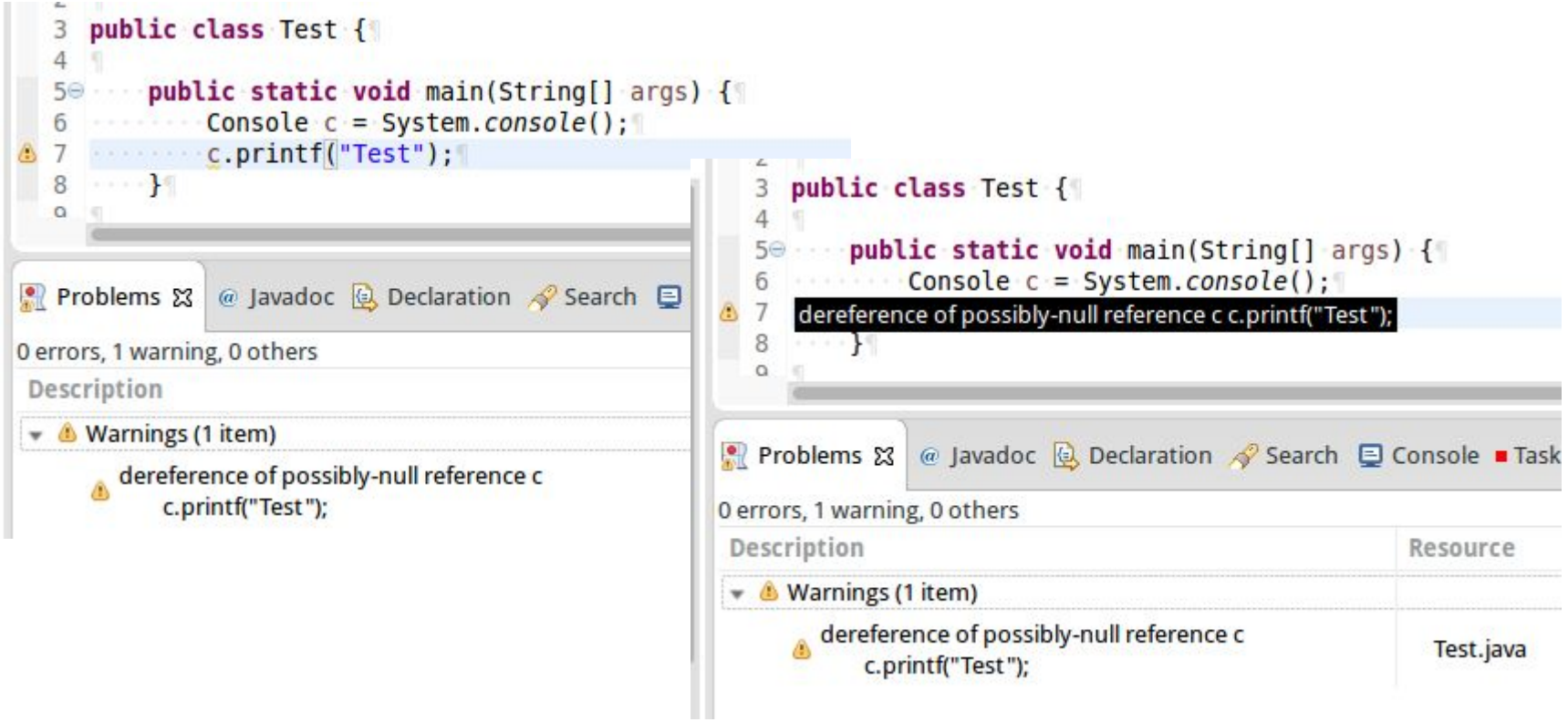
A framework for pluggable type checkers

“Plugs” into the OpenJDK or OracleJDK compiler

```
javac -processor MyChecker ...
```

Standard error format allows tool integration

# Eclipse plug-in

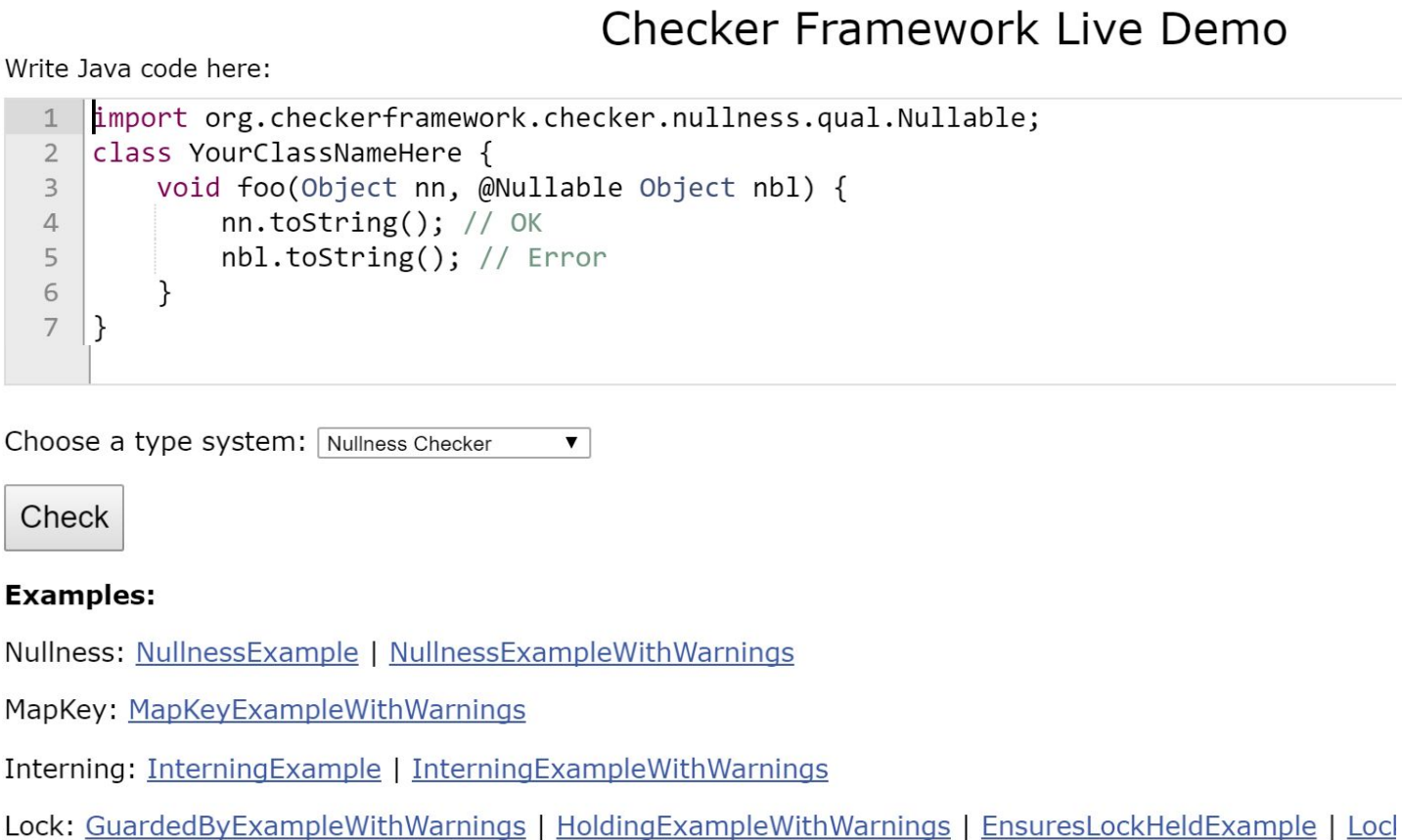


# Ant and Maven integration

```
<presetdef name="jsr308.javac">
  <javac fork="yes"
    executable="${checkerframework}/checker/bin/${cfJavac}" >
    <!-- JSR-308-related compiler arguments -->
    <compilerarg value="-version"/>
    <compilerarg value="-implicit:class"/>
  </javac>
</presetdef>
```

```
<dependencies>
  ... existing <dependency> items ...
  <!-- annotations from the Checker Framework:
          nullness, interning, locking, ... -->
    <dependency>
      <groupId>org.checkerframework</groupId>
      <artifactId>checker-qual</artifactId>
      <version>1.9.7</version>
    </dependency>
</dependencies>
```

# Live demo: http://eisop.uwaterloo.ca/live/



# Example type systems

Null dereferences (`@NonNull`)

>200 errors in Google Collections, javac, ...

Equality tests (`@Interned`)

>200 problems in Xerces, Lucene, ...

Concurrency / locking (`@GuardedBy`)

>500 errors in BitcoinJ, Derby, Guava, Tomcat, ...

Fake enumerations / typedefs (`@Fenum`)

problems in Swing, JabRef

# String type systems

Regular expression syntax (`@Regex`)

56 errors in Apache, etc.; 200 annos required

printf format strings (`@Format`)

104 errors, only 107 annotations required

Signature format (`@FullyQualified`)

28 errors in OpenJDK, ASM, AFU

Compiler messages (`@CompilerMessageKey`)

8 wrong keys in Checker Framework

# Security type systems

Command injection vulnerabilities (`@OsTrusted`)

- 5 missing validations in Hadoop

Information flow privacy (`@Source`)

- SPARTA detected malware in Android apps

You can write your own checker!

# Checkers are usable

- Type-checking is familiar to programmers
- Modular:  fast, incremental, partial programs
- Annotations are not too verbose
  - **`@NonNull`**:  1 per 75 lines
  - **`@Interned`**:  124 annotations in 220 KLOC revealed 11 bugs
  - **`@Format`**:  107 annotations in 2.8 MLOC revealed 104 bugs
  - Possible to annotate part of program
  - Fewer annotations in new code
- Few false positives
- First-year CS majors preferred using checkers to not
- **Practical**:  in daily use at Google, on Wall Street, etc.

# Comparison: other nullness tools

| | Null pointer errors | | False warnings | Annotations written |
|---|---|---|---|---|
| | Found | Missed | | |
| Checker Framework | 8 | 0 | 4 | 35 |
| FindBugs | 0 | 8 | 1 | 0 |
| Jlint | 0 | 8 | 8 | 0 |
| PMD | 0 | 8 | 0 | 0 |

Checking the Lookup program for file system searching (4kLOC)

False warnings are suppressed via an annotation or assertion

# What a checker guarantees

The program satisfies the type property. There are:

- no bugs (of particular varieties)
- no wrong annotations

- Caveat 1: only for code that is checked
  - Native methods (handles reflection!)
  - Code compiled without the pluggable type checker
  - Suppressed warnings
    - Indicates what code a human should analyze

  Checking part of a program is still useful
- Caveat 2: The checker itself might contain an error

# Formalizations

$$
\begin{array}{rcll}
\mathtt{P} & \in & \text{Program} & ::= \ \overline{\mathtt{Class}},\ \mathtt{ClassId},\ \mathtt{Expr} \\
\mathtt{Cls} & \in & \text{Class} & ::= \ \mathtt{class\ ClassId}\langle\overline{\mathtt{TVarId}}\rangle \\
 & & & \quad \mathtt{extends\ ClassId}\langle\overline{{}^{\mathtt{s}}\mathtt{Type}}\rangle \\
 & & & \quad \{\ \overline{\mathtt{FieldId}\ {}^{\mathtt{s}}\mathtt{Type};}\ \overline{\mathtt{Met}} \\
{}^{\mathtt{s}}\mathtt{T} & \in & {}^{\mathtt{s}}\text{Type} & ::= \ {}^{\mathtt{s}}\mathtt{NType} \mid \mathtt{TVarId} \\
{}^{\mathtt{s}}\mathtt{N} & \in & {}^{\mathtt{s}}\text{NType} & ::= \ \mathtt{OM\ ClassId}\langle\overline{{}^{\mathtt{s}}\mathtt{Type}}\rangle \\
\mathtt{u} & \in & \text{OM} & ::= \\
\mathtt{mt} & \in & \text{Meth} & ::= \\
 & & \mathtt{MethSig} & ::= \\
\mathtt{w} & \in & \text{Purity} & ::= \\
\mathtt{e} & \in & \text{Expr} & ::= \\
 & & & \quad \mathtt{Expr.MethId}\langle{}^{\mathtt{s}}\mathtt{Type}\rangle\mathtt{(Expr)} \mid \\
 & & & \quad \mathtt{new}\ {}^{\mathtt{s}}\mathtt{Type} \mid \mathtt{(}{}^{\mathtt{s}}\mathtt{Type}\mathtt{)\ Expr} \\
{}^{\mathtt{s}}\Gamma & \in & {}^{\mathtt{s}}\text{Env} & ::= \ \overline{\mathtt{TVarId}\ {}^{\mathtt{s}}\mathtt{NType};}\ \overline{\mathtt{ParId}\ {}^{\mathtt{s}}\mathtt{Type}}
\end{array}
$$

$$
\begin{array}{rcll}
\mathtt{h} & \in & \text{Heap} & = \ \mathtt{Addr} \to \mathtt{Obj} \\
\iota & \in & \text{Addr} & = \ \text{Set of Addresses} \cup \{\mathtt{null}_a\} \\
\mathtt{o} & \in & \text{Obj} & = \ {}^{\mathtt{r}}\mathtt{Type},\ \mathtt{Fields} \\
{}^{\mathtt{r}}\mathtt{T} & \in & {}^{\mathtt{r}}\text{Type} & = \ \mathtt{OwnerAddr\ ClassId}\langle\overline{{}^{\mathtt{r}}\mathtt{Type}}\rangle \\
\mathtt{Fs} & \in & \text{Fields} & = \ \mathtt{FieldId} \to \mathtt{Addr} \\
\iota & \in & \text{OwnerAddr} & = \ \mathtt{Addr} \cup \{\mathtt{any}_a\} \\
{}^{\mathtt{r}}\Gamma & \in & {}^{\mathtt{r}}\text{Env} & = \ \overline{\mathtt{TVarId}\ {}^{\mathtt{r}}\mathtt{Type};}\ \overline{\mathtt{ParId\ Addr}}
\end{array}
$$

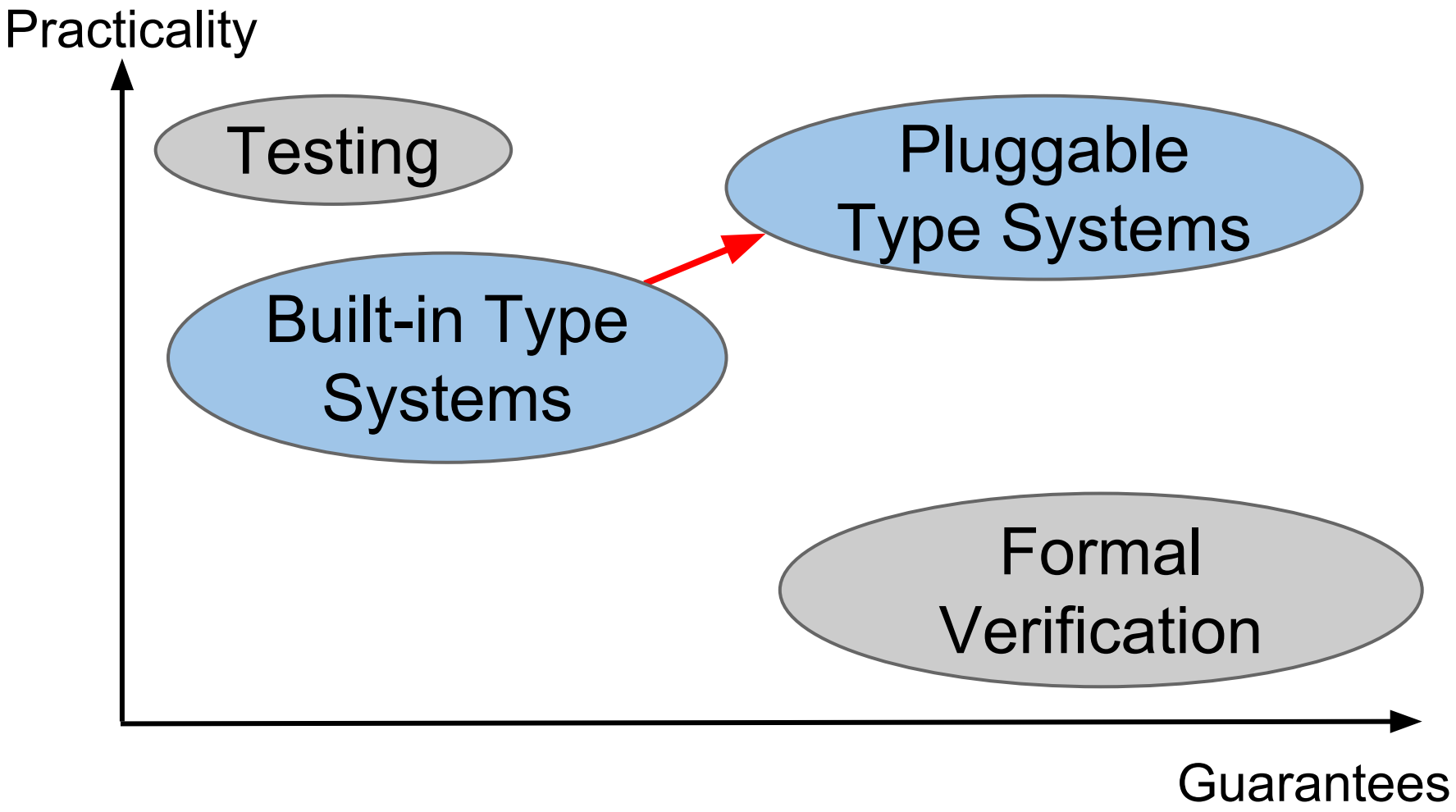
$$
\text{OS-Upd}\ \frac{\begin{array}{c}\mathtt{h}, {}^{\mathtt{r}}\Gamma, \mathtt{e}_0 \rightsquigarrow \mathtt{h}_0, \iota_0 \\ \iota_0 \neq \mathtt{null}_a \\ \mathtt{h}_0, {}^{\mathtt{r}}\Gamma, \mathtt{e}_2 \rightsquigarrow \mathtt{h}_2, \iota \\ \mathtt{h}' = \mathtt{h}_2[\iota_0.\mathtt{f} := \iota]\end{array}}{\mathtt{h}, {}^{\mathtt{r}}\Gamma, \mathtt{e}_0.\mathtt{f}{=}\mathtt{e}_2 \rightsquigarrow \mathtt{h}',}
$$

$$
\text{OS-Read}\ \frac{\begin{array}{c}\mathtt{h}, {}^{\mathtt{r}}\Gamma, \mathtt{e}_0 \rightsquigarrow \mathtt{h}', \iota_0 \\ \iota_0 \neq \mathtt{null}_a \\ \iota = \mathtt{h}'(\iota_0)\downarrow_2(\mathtt{f})\end{array}}{\mathtt{h}, {}^{\mathtt{r}}\Gamma, \mathtt{e}_0.\mathtt{f} \rightsquigarrow \mathtt{h}', \iota}
$$

$$
\text{GT-Read}\ \frac{\Gamma \vdash \mathtt{e}_0 : \mathtt{N}_0 \qquad \mathtt{N}_0 = \_\ \langle}{\Gamma \vdash \mathtt{e}_0.\mathtt{f} : \mathtt{N}_0 \rhd fType(\mathtt{C}_0, \mathtt{f})}
$$

$$
\text{GT-Upd}\ \frac{\begin{array}{c}\Gamma \vdash \mathtt{e}_0 : \mathtt{N}_0 \qquad \mathtt{N}_0 = \mathtt{u}_0\ \mathtt{C}_0\langle\_\rangle \\ \mathtt{T}_1 = fType(\mathtt{C}_0, \mathtt{f}) \\ \Gamma \vdash \mathtt{e}_2 : \mathtt{N}_0 \rhd \mathtt{T}_1 \\ \mathtt{u}_0 \neq \mathtt{any} \qquad rp(\mathtt{u}_0, \mathtt{T}_1)\end{array}}{\Gamma \vdash \mathtt{e}_0.\mathtt{f}{=}\mathtt{e}_2 : \mathtt{N}_0 \rhd \mathtt{T}_1}
$$

$$
\text{DYN}\ \frac{\begin{array}{l}\mathtt{h} \vdash {}^{\mathtt{r}}\Gamma : {}^{\mathtt{s}}\Gamma \\ \mathtt{h} \vdash \iota_1 : dyn({}^{\mathtt{s}}\mathtt{N}, \mathtt{h}, {}^{\mathtt{r}}\iota_1) \\ \mathtt{h} \vdash \iota_2 : dyn({}^{\mathtt{s}}\mathtt{T}, \iota_1, \mathtt{h}(\iota_1)\downarrow_1) \\ {}^{\mathtt{s}}\mathtt{N} = \mathtt{u}_N\ \mathtt{C}_N\langle\_\rangle \\ \mathtt{u}_N = \mathtt{this}_u \Rightarrow {}^{\mathtt{r}}\Gamma(\mathtt{this}) \\ free({}^{\mathtt{s}}\mathtt{T}) \subseteq dom(\mathtt{C}_N)\end{array}}{\left.\begin{array}{l}\\ \\ \\ \\ \\ \\ {}^{\mathtt{r}}\mathtt{T} = \iota'\ \_\langle\_\rangle \qquad \iota \vdash {}^{\mathtt{r}}\mathtt{T}\ {}^{\mathtt{r}}{<:}\ \iota'\ \mathtt{C}\langle\overline{{}^{\mathtt{r}}\mathtt{T}}\rangle \qquad \iota \vdash {}^{\mathtt{r}}\mathtt{T}\ {}^{\mathtt{r}}{<:}\ \iota'\ \mathtt{C}\langle\overline{{}^{\mathtt{r}}\mathtt{T}_a}\rangle \Rightarrow \iota \vdash \overline{{}^{\mathtt{r}}\mathtt{T}}\ {}^{\mathtt{r}}{<:}\ \overline{{}^{\mathtt{r}}\mathtt{T}_a} \\ \mathrm{dom}(\mathtt{C}) = \overline{\mathtt{X}} \qquad \mathrm{free}({}^{\mathtt{s}}\mathtt{T}) \subseteq \overline{\mathtt{X}} \circ \overline{\mathtt{X}'}\end{array}\right\} \implies \mathtt{h} \vdash \iota_2 : dyn({}^{\mathtt{s}}\mathtt{N} \rhd {}^{\mathtt{s}}\mathtt{T}, \mathtt{h}, {}^{\mathtt{r}}\Gamma)}{dyn({}^{\mathtt{s}}\mathtt{T}, \iota, {}^{\mathtt{r}}\mathtt{T}, (\overline{\mathtt{X}'\ {}^{\mathtt{r}}\mathtt{T}'}; \_)) = {}^{\mathtt{s}}\mathtt{T}[\iota'/\mathtt{this}, \iota'/\mathtt{peer}, \iota/\mathtt{rep}, \mathtt{any}_a/\mathtt{any}_u, \overline{{}^{\mathtt{r}}\mathtt{T}/\mathtt{X}}, \overline{{}^{\mathtt{r}}\mathtt{T}'/\mathtt{X}'}]}
$$


Practicality
Testing
Pluggable
Type Systems
Built-in Type
Systems
Formal
Verification
Guarantees

# Since Java 5: declaration annotations

Only for declaration locations:

```
@Deprecated
class Foo {
   @Getter @Setter private String query;
   @SuppressWarnings("unchecked")
   void foo() { … }
}
```

# But we couldn’t express

A non-null reference to my data

An interned String

A non-null List of English Strings

A non-empty array of English strings

# With Java 8 Type Annotations we can!

A non-null reference to my data

```
@NonNull Data mydata;
```

An interned String

```
@Interned String query;
```

A non-null List of English Strings

```
@NonNull List<@English String> msgs;
```

A non-empty array of English strings

```
@English String @NonEmpty [] a;
```

# Java 8 extends annotation syntax

Annotations on all occurrences of types:

```
@Untainted String query;
List<@NonNull String> strings;
myGraph = (@Immutable Graph) tmp;
class UnmodifiableList<T>
  implements @Readonly List<T> {}
```

Stored in classfile

Handled by javac, javap, javadoc, …

# Java 6 & 7 compatibility
## (or avoid dependency on Checker Framework)

Annotations in comments:

```
List</*@NonNull*/ String> strings;
```

(Requires use of jsr308-langtools compiler.)

# Annotating external libraries

When type-checking clients, need library spec.

Can write manually or automatically infer

Two syntaxes:

- As separate text file (stub file)
- Within its .jar file (from annotated partial source code)

# Dataflow Framework

Goal: Compute properties about expressions

- More accurate types than the user wrote
- Constant value analysis
- Many other uses, e.g. by Google error-prone

User provides:

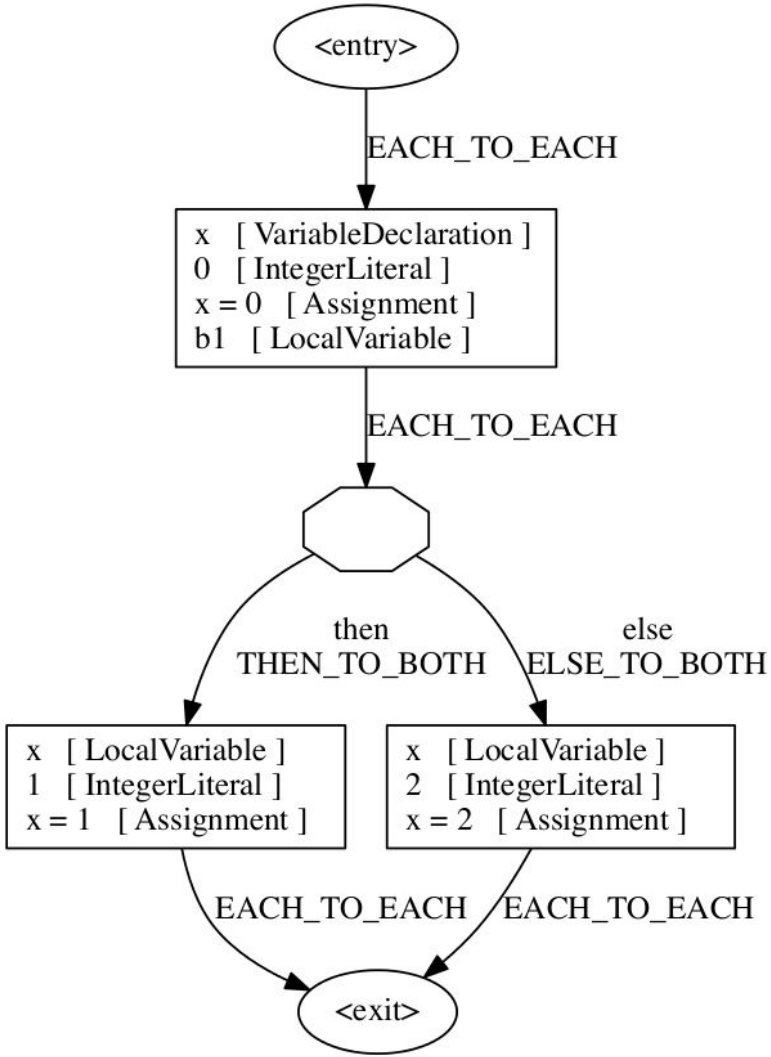
- Abstract value — What are we tracking?
- Transfer functions — What do operations do?
- Store — What are intermediate results?

Dataflow framework does all the work!

# Dataflow Framework

Explicit representation of implicit Java constructs

- Unboxing, implicit type conversions, etc.
- Analyses do not need to worry about these things
- All control flow explicitly modeled (e.g. exceptions on field access)


<entry>
EACH_TO_EACH
x [ VariableDeclaration ]
0 [ IntegerLiteral ]
x = 0 [ Assignment ]
b1 [ LocalVariable ]
EACH_TO_EACH
then
THEN_TO_BOTH
else
ELSE_TO_BOTH
x [ LocalVariable ]
1 [ IntegerLiteral ]
x = 1 [ Assignment ]
x [ LocalVariable ]
2 [ IntegerLiteral ]
x = 2 [ Assignment ]
EACH_TO_EACH
EACH_TO_EACH
<exit>

# Checker Framework facilities

- Full type systems:  inheritance, overriding, ...
- Generics (type polymorphism)
  - Also qualifier polymorphism
- Qualifier defaults
- Pre-/post-conditions
- Warning suppression
- Testing infrastructure

# Brainstorming new type checkers

What runtime exceptions to prevent?

What properties of data should always hold?

What operations are legal and illegal?

Type-system checkable properties:

- Dependency on values
- Not on program structure, timing, ...

# Example: Nullness Checker

What runtime exceptions to prevent?

What properties of data should always hold?

What operations are legal and illegal?

# Example: Nullness Checker

What runtime exceptions to prevent?

NullPointerException

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# Example: Nullness Checker

What runtime exceptions to prevent?

NullPointerException

What properties of data should always hold?

@NonNull references always non-null

What operations are legal and illegal?

Dereferences only on @NonNull references

# Example: Regex Checker

What runtime exceptions to prevent?

What properties of data should always hold?

What operations are legal and illegal?

# Example: Regex Checker

What runtime exceptions to prevent?

PatternSyntaxException,
IndexOutOfBoundsException

What properties of data should always hold?

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# Example: Regex Checker

What runtime exceptions to prevent?

PatternSyntaxException,
IndexOutOfBoundsException

What properties of data should always hold?

Whether a string is a regex and number of groups

What operations are legal and illegal?

# Example: Regex Checker

What runtime exceptions to prevent?

PatternSyntaxException,
IndexOutOfBoundsException

What properties of data should always hold?

Whether a string is a regex and number of groups

What operations are legal and illegal?

Pattern.compile with non-@Regexp, etc,

# New type system

What runtime exceptions to prevent?

1

What properties of data should always hold?

2

What operations are legal and illegal?

3

# New type system

What runtime exceptions to prevent?

1

What properties of data should always hold?

2

What operations are legal and illegal?

3

# New type system

What runtime exceptions to prevent?

1

What properties of data should always hold?

2

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3

# New type system

What runtime exceptions to prevent?

1

What properties of data should always hold?

2

What operations are legal and illegal?

3

# New type system

What runtime exceptions to prevent?

1

What properties of data should always hold?

2

What operations are legal and illegal?

3

# Building a checker is easy

Example: Ensure encrypted communication

```
void send(@Encrypted String msg) {...}
@Encrypted String msg1 = ...;
send(msg1);    // OK
String msg2 = ....;
send(msg2);    // Warning!
```

# Building a checker is easy

Example: Ensure encrypted communication

```
void send(@Encrypted String msg) {…}
@Encrypted String msg1 = ...;
send(msg1);   // OK
String msg2 = ....;
send(msg2);   // Warning!
```

The complete checker:

```
@Target(ElementType.TYPE_USE)
@SubtypeOf(Unqualified.class)
public @interface Encrypted {}
```

# Encrypted Checker Demo

Let’s build it!

# Defining a type system

1. Qualifier hierarchy
   - defines subtyping
2. Type introduction rules
   - types for expressions
3. Type rules
   - checker-specific errors
4. Flow-refinement
   - better types than the programmer wrote

# Defining a type system

1. Qualifier hierarchy
    - subtyping, assignments

```
@SubtypeOf(UnknownRegex.class)
public @interface Regex {
```

# Defining a type system

2. Type introduction rules
   - types for expressions

```
@ImplicitFor( trees = {
      Tree.Kind.NEW_CLASS,
      Tree.Kind.NEW_ARRAY, ... })
@DefaultQualifierInHierarchy
@DefaultForUnannotatedCode({
      DL.PARAMETERS, DL.LOWER_BOUNDS })
```

# Defining a type system

3. Type rules
   - checker-specific errors

```
void visitSynchronized(SynchronizedTree node) {
   ExpressionTree expr = node.getExpression();
   AnnotatedTypeMirror type =
         getAnnotatedType(expr);
   if (!type.hasAnnotation(NONNULL))
      checker.report(Result.failure(...), expr);
}
```

# Defining a type system

4. Flow-refinement
    - better types than the programmer wrote

```
if (ElementUtils.matchesElement(method,
        IS_REGEX_METHOD_NAME,
        String.class, int.class)) {
    …
}
```

# Testing infrastructure

jtreg-based testing as in OpenJDK

Lightweight tests with in-line expected errors:

```
String s = "%+s%";
//:: error: (format.string.invalid)
f.format(s, "illegal");
```

# Tips

- Start by type-checking part of your code
- Only type-check properties that matter to you
- Use subclasses (not type qualifiers) if possible
- Write the spec first (and think of it as a spec)
- Avoid warning suppressions when possible
- Avoid raw types such as `List`; use `List<String>`

# Verification

- **Goal**:
  prove that no bug exists
- **Specifications**:
  user provides
- **False negatives**:
  none
- **False positives**:
  user suppresses warnings
- **Downside**: user burden

# Bug-finding

- **Goal**:
  find some bugs at low cost
- **Specifications**:
  infer likely specs
- **False negatives:**
  acceptable
- **False positives**:
  heuristics focus on most important bugs
- **Downside**: missed bugs

Neither is “better”; each is appropriate in certain circumstances.

# Community

Open source project:

`https://github.com/typetools/checker-framework`

- Monthly release cycle
- 11,000 commits, 75 authors

Issue tracker:

- 110 issues closed in releases since June 1

Mailing lists:

- to reach developers
- to reach whole community

# More at JavaOne 2016

Disciplined Locking: No More Concurrency Errors

CON5739, today, 17:30 to 18:30

Continental Ballroom 1/2/3

Using Type Annotations to Improve Your Code

BoF3427, tonight, 19:00 to 19:45

Continental Ballroom 4

# Pluggable type-checking improves code

Checker Framework for creating type checkers

- Featureful, effective, easy to use, scalable

Prevent bugs at compile time

Create custom type-checkers

Improve your code!

`http://CheckerFramework.org/`