```
print(@Readonly Object x) {
  List<@NonNull String> lst;
  …
}
```

# Preventing bugs with pluggable type checking


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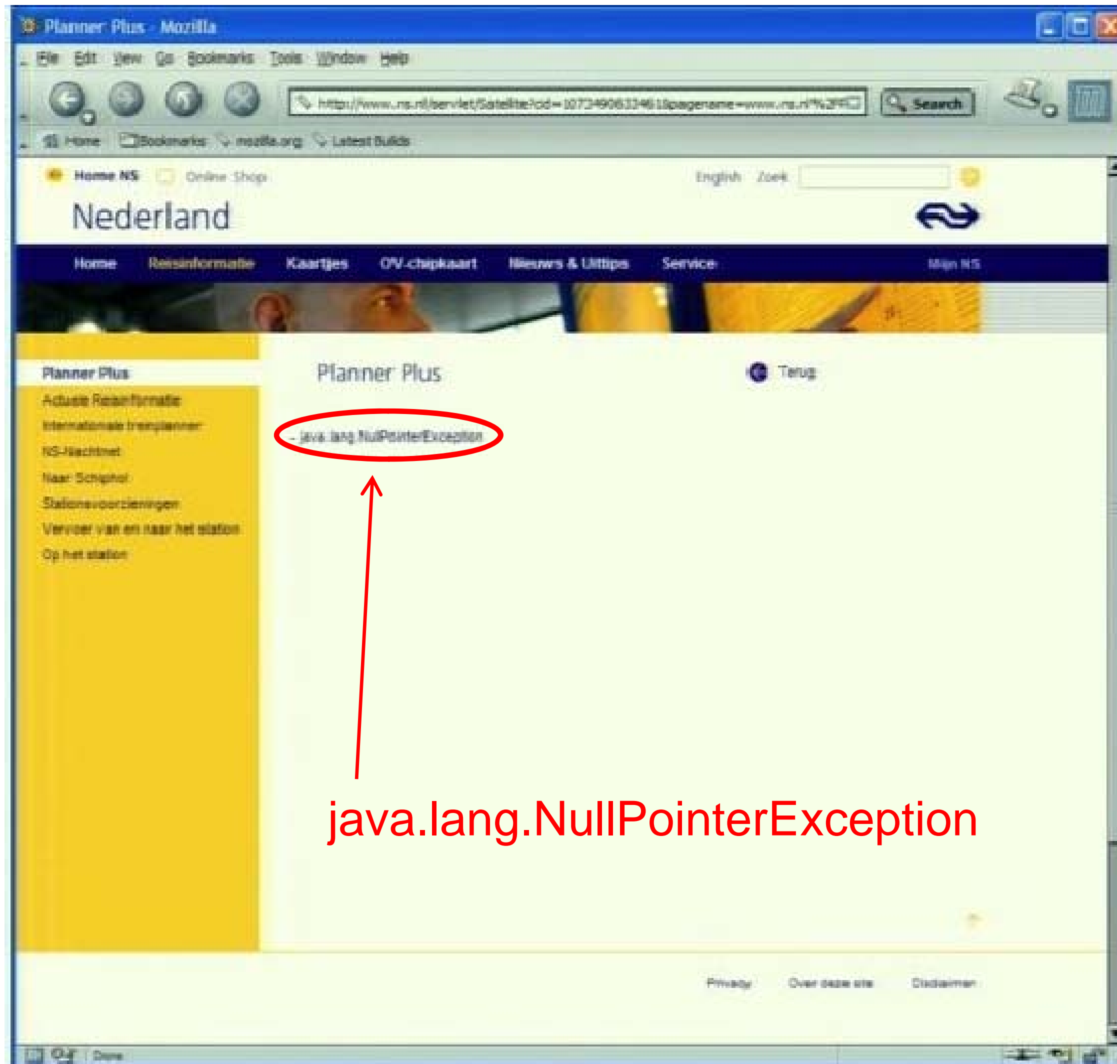
# Motivation



# Java’s type checking is too weak

- Type checking prevents many bugs

```
int i = “hello”;   // type error
```

- Type checking doesn’t prevent enough bugs

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

$\Rightarrow$ NullPointerException

```
Collections.emptyList().add(“One”);
```

$\Rightarrow$ UnsupportedOperationException

# Some errors are silent

```
Date date = new Date(0);
myMap.put(date, “Java Epoch”);
date.setYear(70);
myMap.put(date, “Linux Epoch”);
```

⇒ Corrupted map

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

⇒ UnsupportedOperationException

Equality tests, initialization, data formatting, …

# Solution: Pluggable type systems

- Design a type system to solve a specific problem
- Write type qualifiers in your code (or, type inference)

```
@Immutable Date date = new Date(0);
date.setTime(70);     // compile-time error
```

- Type checker warns about violations (bugs)

```
% javac -processor NullnessChecker MyFile.java

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

# Outline

- Type qualifiers
- Pluggable type checkers
- Writing your own checker
- Conclusion

# Type qualifiers

- **Java 7** annotation syntax

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

- **Backward-compatible**: compile with any Java compiler

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

# Benefits of type qualifiers

- **Improve documentation**
- **Find bugs** in programs
- Guarantee the **absence of errors**
- Aid compilers and analysis tools
- Reduce the need for assertions and run-time checks

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# Sample checkers

- `@NonNull`: null dereference
- `@Interned`: incorrect equality tests
- `@Immutable`: incorrect mutation and side-effects
- Many other simple checkers
  - Security: encryption, tainting, access control
  - Encoding: SQL, URL, ASCII/Unicode
- Under construction:
  - CMU, ETH Zurich, MIT, Radboud U., U. of Buenos Aires, U. of California at Los Angeles, U. of Saarland, U. of Washington, U. of Wisconsin, Washington State U., ……

# Nullness and mutation demo

# Checkers are effective

- Scales to > 200,000 LOC
- Each checker found errors in each code base it ran on
  - Verified by a human and fixed

# 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 a 4KLOC program
- False warnings are suppressed via an annotation or assertion

# Checkers are featureful

- Full type systems:  inheritance, overriding, etc.
- Generics (type polymorphism)
  - Also qualifier polymorphism
- Flow-sensitive type qualifier inference
- Qualifier defaults
- Warning suppression

# Checkers are usable

- Integrated with toolchain
  - javac, Ant, Eclipse, Netbeans
- Few false positives

- Annotations are not too verbose
  - **`@NonNull`**: 1 per 75 lines
  - **`@Interned`**: 124 annotations in 220KLOC revealed 11 bugs
  - Possible to annotate part of program
  - Fewer annotations in new code
  - Inference tools: nullness, mutability

# What a checker guarantees

- The program satisfies the type property
  - There are no bugs (of particular varieties)
- Caveat: only for code that is checked
  - Native methods
  - 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

# Annotating libraries

- Each checker includes JDK annotations
  - Typically, only for signatures, not bodies
  - Finds errors in clients, but not in the library itself
- Inference tools for annotating new libraries

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# SQL injection attack

- Server code bug: SQL query constructed using unfiltered user input

```
query = "SELECT * FROM users "
        + "WHERE name='" + userInput + "';";
```

- User inputs: **a' or 't'='t**
- Result:

```
query ⇒ SELECT * FROM users
           WHERE name='a' or 't'='t';
```

- Query returns information about all users

# Tainting checker

```
@TypeQualifier
@SubtypeOf(Unqualified.class)
@ImplicitFor(trees = {STRING_LITERAL})
public @interface Untainted { }
```

To use it:

1. Write **`@Untainted`** in your program

   ```
   List getPosts(@Untainted String category) { … }
   ```

2. Compile your program

   ```
   javac -processor BasicChecker -Aquals=Untainted
     MyProgram.java
   ```

# Tainting checker demo

# Defining a type system

```
@TypeQualifier
public @interface NonNull { }
```

# Defining a type system

1. Type qualifier hierarchy
2. Type introduction rules
3. Other type rules

```
@TypeQualifier
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# Defining a type system

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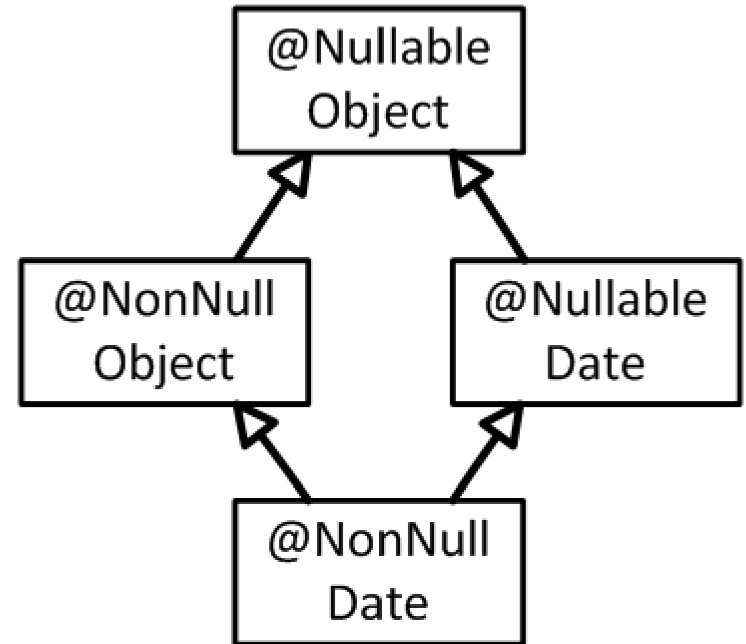


```
@TypeQualifier
@SubtypeOf( Nullable.class )
public @interface NonNull { }
```

# Defining a type system

1. Type qualifier hierarchy
2. Type introduction rules
3. Other type rules

```
new Date()
"hello " + getName()
Boolean.TRUE
```

```
@TypeQualifier
@SubtypeOf( Nullable.class )
@ImplicitFor(trees={ NEW_CLASS,
                     PLUS,
                     BOOLEAN_LITERAL, ... } )
public @interface NonNull { }
```

# Defining a type system

1. Type qualifier hierarchy
2. Type introduction rules
3. Other type rules

```
synchronized(expr) {
  …
}
```

Warn if expr may be null

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

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# Research results

- First practical system for pluggable types
  - This lack held back research and practice
- Significant case studies led to:
  - new type systems
  - new insights about old ones
- Linear-time inference algorithm
- See paper “Practical pluggable types for Java” (in ISSTA 2008)

# My other research

Making it easier (and more fun!) to create reliable software

**Security**:

- Finding and exploiting web vulnerabilities
- Automatically patching vulnerabilities
- Quantitative information-flow

**Programming languages**:

- Type systems: immutability, canonicalization
- Type inference: abstractions, polymorphism, immutability

**Testing**:

- Creating complex test inputs
- Generating unit tests from system tests
- Classifying test behavior

**More**: Reproducing in-field failures; combined static & dynamic analysis; analysis of version history; refactoring; …

# Contributions

- Checker Framework for creating type checkers
  - Featureful, effective, easy to use, scalable
- Prevent bugs at compile time
- Create custom type-checkers
- Download: [http://pag.csail.mit.edu/jsr308](http://pag.csail.mit.edu/jsr308)