Using Type Annotations to Improve Your Code

Birds-of-a-Feather Session

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Open for questions

Survey:

Did you attend the tutorial?

Which of these best describes you?

- Specific question / concern / feedback
- Specific problem / use case / tool
- Curious, want to learn more

Please raise questions / issues

Schedule

Java 8 syntax for type annotations

Pluggable types: a use of type annotations

Questions and discussion

Since Java 5: declaration annotations

Only for **declaration** locations:

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

class

field

method

Java 8 adds type annotations

Annotations on all occurrences of types:

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

How Java 8 treats type annotations

Stored in classfile

Handled by javac, javap, javadoc, …

Writing type annotations has no effect unless you run an annotation processor

Write annotations before the element

Write declaration annotations before the decl.

Write type annotations before the type

```
@Override
public @NonNull String toString() {…}
```

Don’t split them up:

```
@NonNull
public String toString() {…}
```

Array annotations

```
String [] [] a;
```

An array of arrays of strings

Array annotations

```
String[][] a;
```

An array of arrays of strings

Array annotations

```
String          []          [] a;
```

A read-only array of
non-empty arrays of
English strings

Array annotations

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

A read-only array of
    non-empty arrays of
        English strings

Rule: write the annotation before the type

Explicit method receivers

```
class MyClass {
  public String toString() {}
  public boolean equals(Object other) {}

}
```

Explicit method receivers

```
class MyClass {
  public String toString() {}
  public boolean equals(Object other) {}

}


myval.toString();
myval.equals(otherVal);
```

Explicit method receivers

```
class MyClass {
  public String toString(MyClass this) {}
  public boolean equals(MyClass this,
                        Object other) {}
}

myval.toString();
myval.equals(otherVal);
```

No impact on method binding and overloading

Explicit method receivers

```
class MyClass {
  public String toString(@ReadOnly MyClass this) {}
  public boolean equals(@ReadOnly MyClass this,
                        @ReadOnly Object other) {}
}
```

```
myval.toString();
myval.equals(otherVal);
```

Rationale: need a syntactic location for type annotations

Constructor return & receiver types

Every constructor has a return type

```
class MyClass {
  @TReturn MyClass(@TParam String p) {...}
```

Inner class constructors also have a receiver

```
class Outer {
  class Inner {
    @TReturn Inner(@TRecv Outer Outer.this,
                   @TParam String p) {...}
```

Why were type annotations added to Java?

Annotations are a specification

- More concise than English text or Javadoc
- Machine-readable
- Machine-checkable

- Improved documentation
- Improved correctness

Pluggable Type Systems

- Use Type Annotations to express properties
- Prevent errors at compile time

`http://CheckerFramework.org/`

Twitter: @CheckerFrmwrk

Facebook/Google+: CheckerFramework

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”;
```

Type checking doesn't prevent enough errors

NullPointerException

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

```
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

Solution: Pluggable Type Checking

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

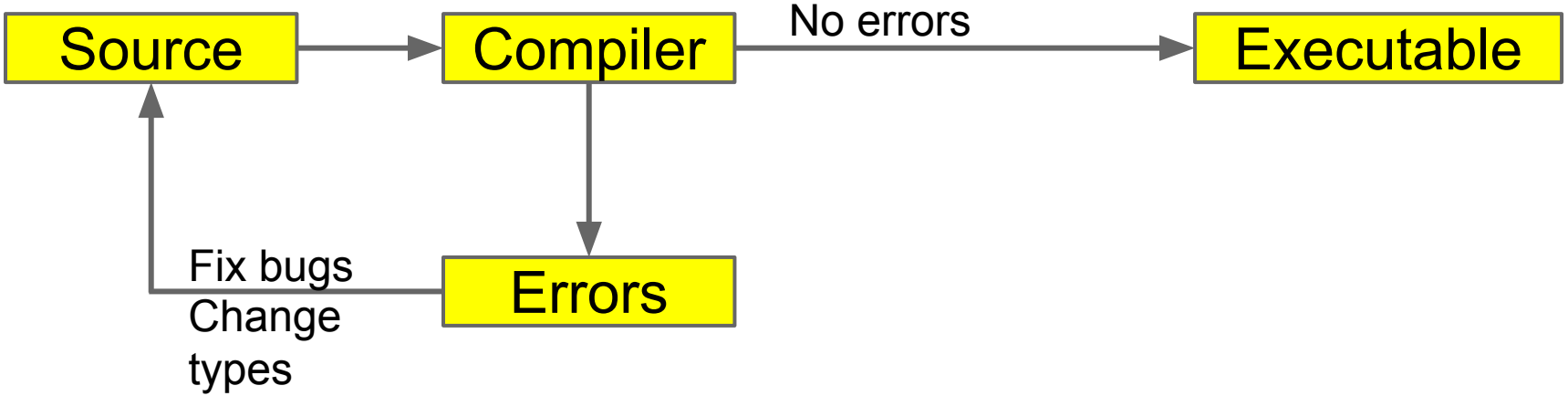
```
@Immutable Date date = new Date();
date.setSeconds(0);  // compile-time error
```

3. Type checker warns about violations (bugs)

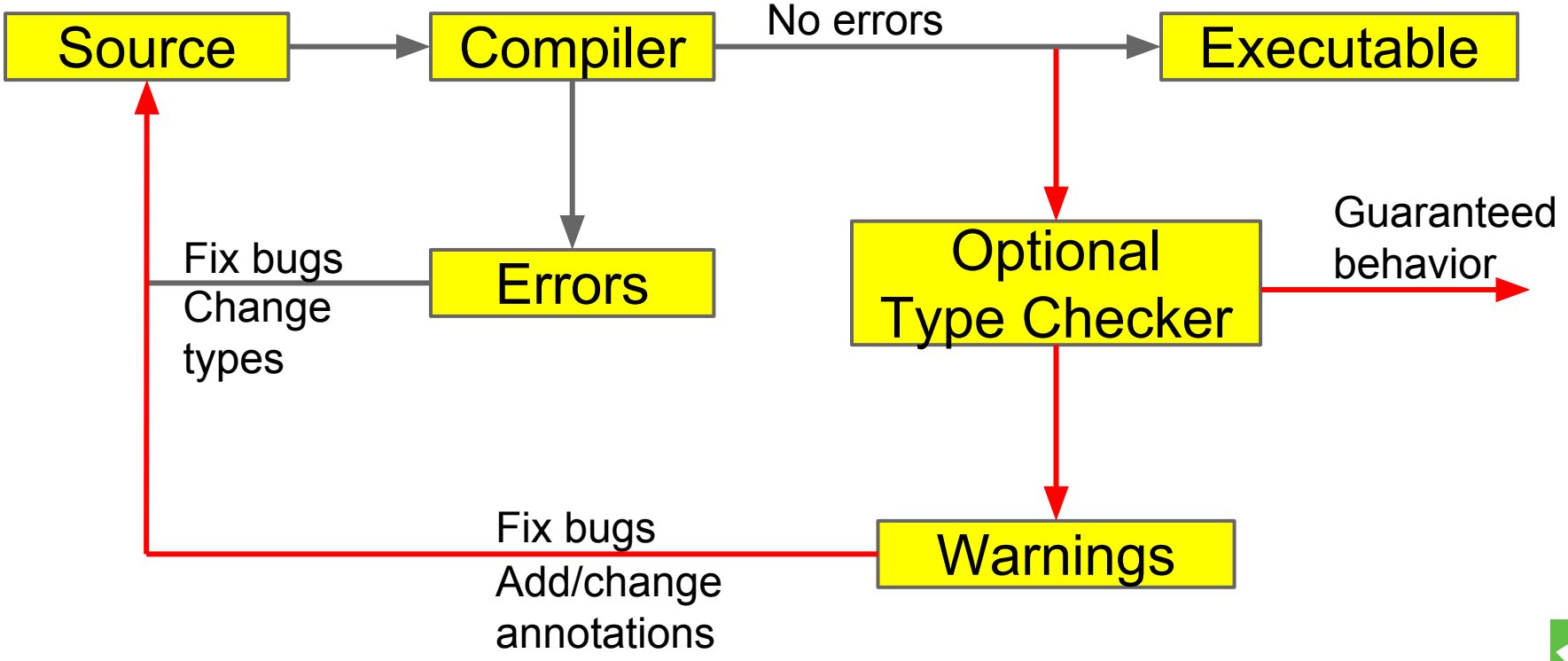
```
% javac -processor NullnessChecker MyFile.java

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

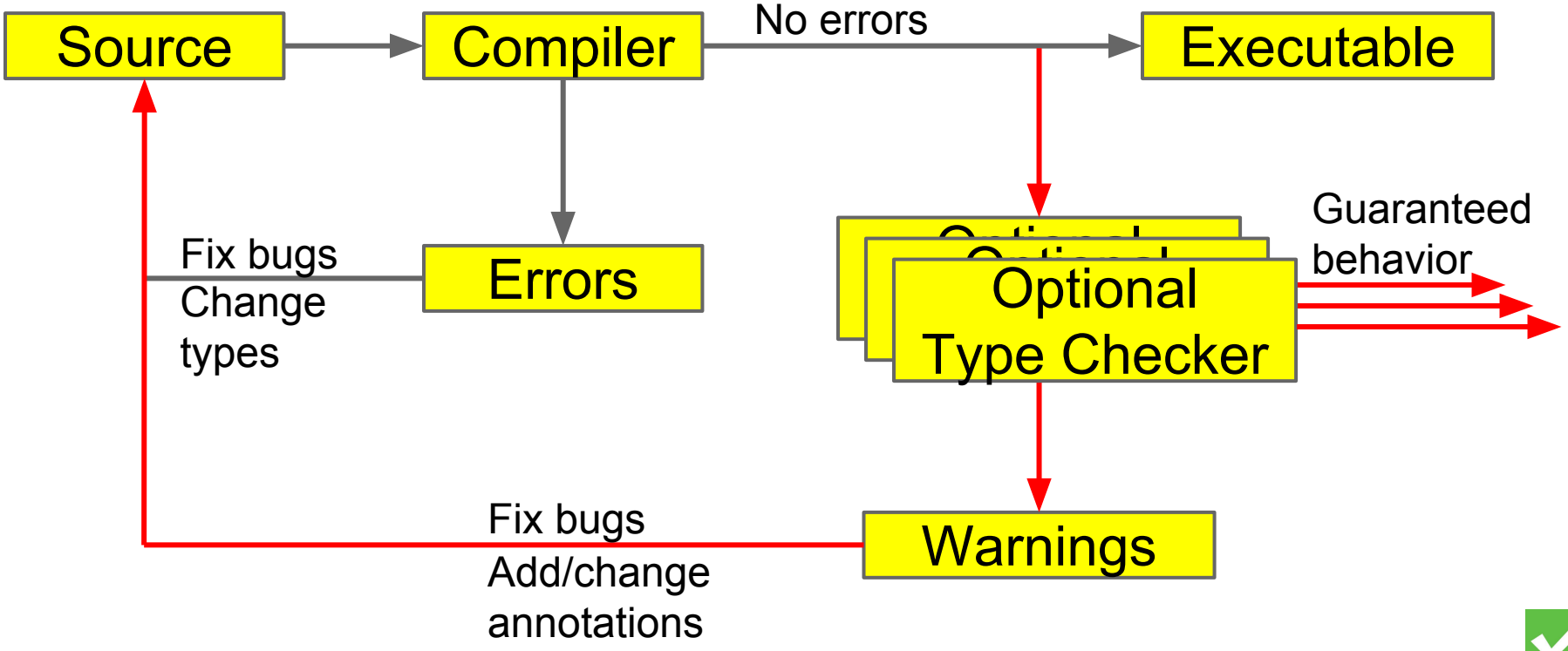
Type Checking



Optional Type Checking



Optional Type Checking



Example type systems

Null dereferences (`@NonNull`)

Equality tests (`@Interned`)

Concurrency / locking (`@GuardedBy`)

Command injection vulnerabilities (`@OsTrusted`)

Privacy (`@Source`)

Regular expression syntax (`@Regex`)

printf format strings (`@Format`)

Signature format (`@FullyQualified`)

Compiler messages (`@CompilerMessageKey`)

Fake enumerations (`@Fenum`)

You can write your own checker!

CF: Java 6 & 7 compatibility
(+ no dependence on Checker Framework)

Annotations in comments

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

Comments for arbitrary source code

```
/*>>> import myquals.TRecv; */
…
int foo(/*>>> @TRecv MyClass this,*/
        @TParam String p) {…}
```

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)

Checker Framework facilities

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

Static type system

Plug-in to the compiler

Doesn’t impact:

- method binding
- memory consumption
- execution

A future tool might affect run-time behavior

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 use in Silicon Valley, on Wall Street, etc.

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

Problem: annotation effort

Programmer must write type annotations

- on program code
- on libraries

Very few: 1 per 100 lines, often much less

- depends on the type system

Solution: type inference

Type inference within a method

- Called “flow-sensitive refinement”
- A variable can have different types on different lines of code
- Low overhead
- Always used

```
x.toString();   // warning:  possible NPE
if (x!=null) {
  x.toString();   // no warning
}
x.toString();   // warning:  possible NPE
```

Does not affect type signatures

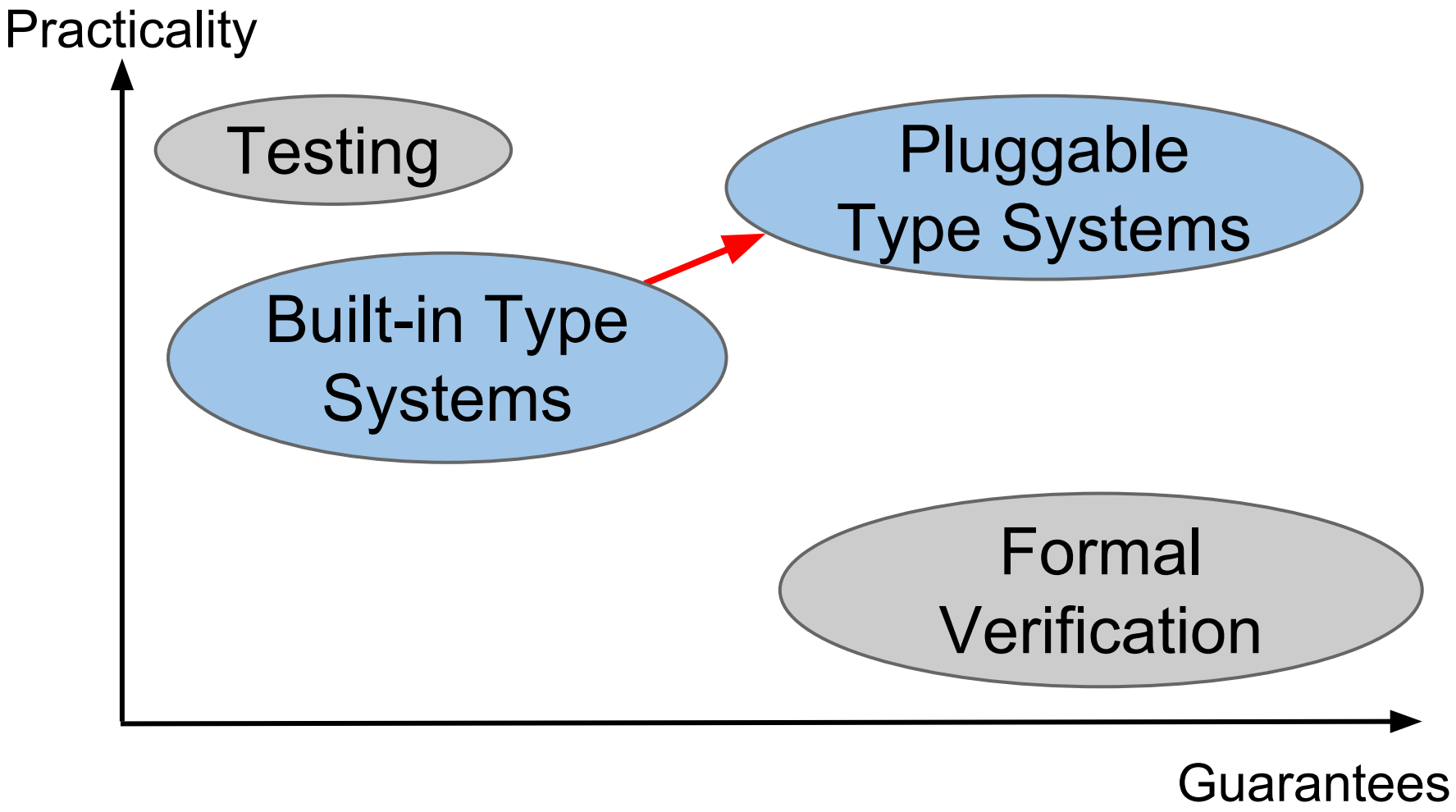
Whole-program type inference

- Analyze **all** the code at once
- Determine the globally optimal annotations

Approach:

- Introduce placeholder for each location
- Use the same type rules to generate constraints
- Use a solver to find a solution

Available (beta) with the Checker Framework


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

Checker Framework Community

Open source project:

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

- Monthly release cycle
- >12,800 commits, 75 authors
- Welcoming & responsive community

Checker Framework Plans

More type systems:

- Index-out-of-bounds
- `Optional` type
- Signed vs. unsigned numbers
- Immutability
- Determinism

Type inference

Combined static & dynamic enforcement

Present and Future of Type Annotations

Java 9

Type annotation implementation improvements

Java >9

What annotation-related language feature are you missing?

- Statement annotations
- More expressive annotation attributes
- Annotation inheritance

Conclusions

Type Annotations added in Java 8

Checker Framework for creating type checkers

- Featureful, effective, easy to use, scalable

Prevent bugs at compile time

Improve your code!

`http://CheckerFramework.org/`