Extended Static Checking for Java

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Outline

Motivation for static checking

Why check a program's behaviour?

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- Errors / program does not do what we want
- Testing is incomplete and unsound
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Why ESC/JAVA?

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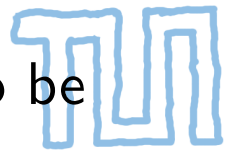
Why ESC/JAVA?

- First static checker for Java
- Architecture and working principle very clear and structured
- Is applicable in practice
- Annotation language allows to specify design that can also be checked



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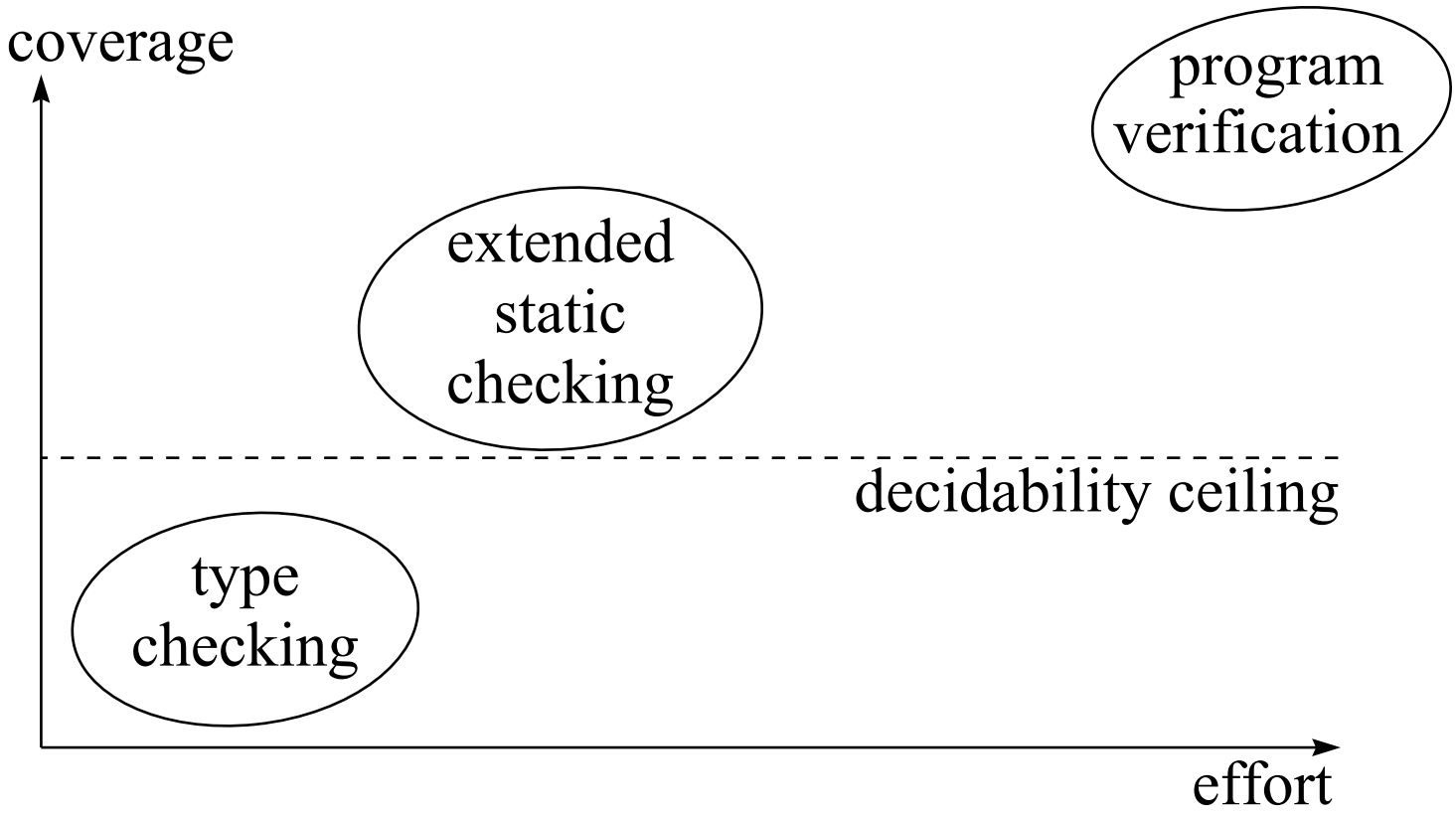
Extended static checking uses annotations and generic formal methods to show whether a program behaves within the constraints of its specification.

Comparison of checking methods



ESC/JAVA history

- Developed at Compaq Systems Research by Flanagan, Leino, Lillibridge, Nelson, Saxe, and Stata
- Descended from ESC/Modula-3
- Developed as practical tool to check programs for semantic errors, specification violations, and synchronization errors in concurrent programs
- Exploits the space between fast, but primitive syntactic checkers like lint and comprehensive, but costly formal program verification

ESC/Java example

```
1  public class Bag {
2    int[] elements;
3    int size;
4
5    Bag(int[] input) {
6      size = input.length;
7      elements = new int[size];
8      System.arraycopy(input, 0, elements, 0, size);
9    }
10
11   ..
12 }
```

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```
Bag.java:6: Warning: Possible null dereference (Null)
    size = input.length;
           ^
```

ESC/Java example

```
1  public class Bag {
2    /*@non_null*/ int[] elements;
3    int size;
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5    Bag(/*@non_null*/ int[] input) {
6      size = input.length;
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ESC/Java example

```
1   public class Bag {
2     int[] elements; int size;
3     ..
4     int extractMin() {
5       int m = Integer.MAX_VALUE;
6       int mindex = 0;
7       for (int i = 0; i < size; i++) {
8         if (elements[i] < m) {
9           mindex = i;
10          m = elements[i];
11        }
12      }
13      size--;
14      elements[mindex] = elements[size];
15      return m;
16    }
17  }
```

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```

```
Bag1.java:8: Warning: Array index possibly too large (IndexTooBig)
      if (elements[i] < m) {
                      ^
```

ESC/Java example

```
    /*@invariant size >= 0 && size <= elements.length; */
1   public class Bag {
2     int[] elements; int size;
3     ..
4     int extractMin() {
5       int m = Integer.MAX_VALUE;
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7       for (int i = 0; i < size; i++) {
8         if (elements[i] < m) {
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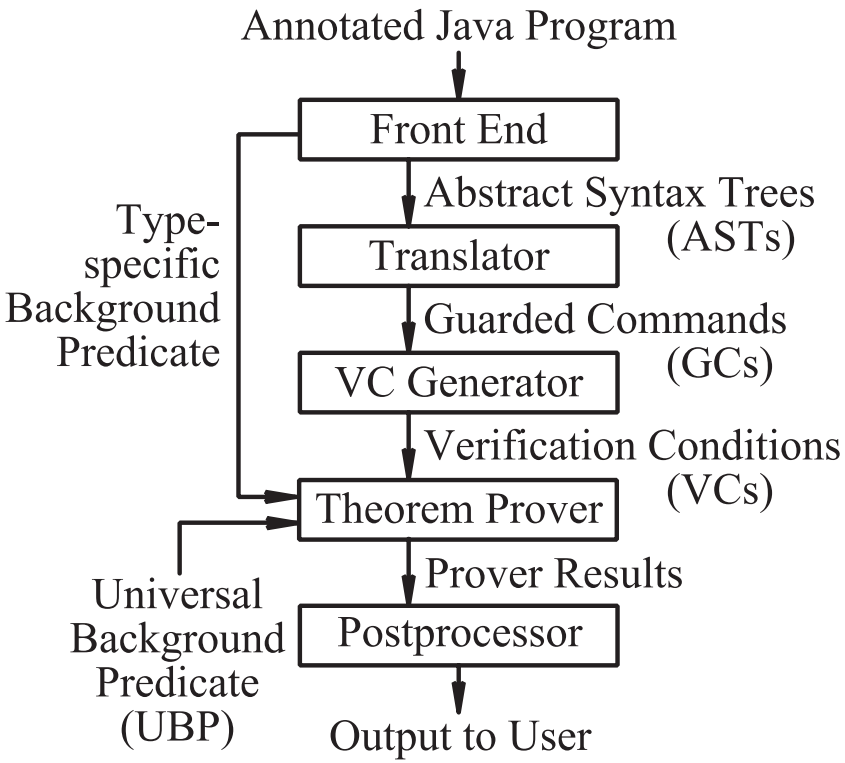
Recap: Examples

- non_null: Forces assigners to always assign a valid instance - allows users to assume that instance is always valid
- invariant: introduces the invariant as precondition and post-condition to every method call
- precondition: forces caller to establish precondition before calling
- postcondition: forces method to establish post-condition before returning

ESC/JAVA architecture



The basic steps in ESC/Java's operation.

Guarded Command Language

- Originally designed by Dijkstra (1975)
- Contains only variable declarations and assignments, assertions, assumptions, and constructs to handle sequential composition, branching, and exceptions
- Routines are translated into guarded commands that capture the relevant semantics of the routine. Guarded command "goes wrong" when it hits an assertion that evaluates to false.
- Soundness: A guarded command G translated from a routine R goes wrong iff R can be invoked from a state satisfying its stated preconditions and then behaves erroneously by causing an error or terminating in a state violating its specified postconditions

VC generator

- Verification condition: First-order predicate that holds for precisely the program states from which execution of a guarded command does not go wrong.
- Weakest liberal precondition (*wlp*) derived directly from a routine's GC
- Global information (about Java) and class-scope information forms "Background predicate" (*BP*)
- $BP \Rightarrow wlp$

Simplify

- Automatic theorem prover developed for ESC/JAVA
- Verifies the $BP \Rightarrow wlp$ predicate
- Limited runtime, caution issued if exceeded
- Results used by post-processor to generate warnings
- Incomplete (cannot prove all valid formulas), but sound (does not erroneously prove invalid formulas)

ESC/JAVA annotation language

The annotation language is used to specify usage contracts, encode design properties that are not expressed in the programme code, and assist ESC/JAVA. Annotations are called “pragmas”:

- Basic pragmas: nowarn / assume, assert / unreachable
- Routine pragmas: requires, modifies, ensures, exsures, also_...
- Invariant pragmas: non_null, invariant, axiom, loop_invariant
- Accessibility pragmas: spec_public, readable_if, uninitialized
- Ghost variable pragmas: ghost, set
- Synchronization pragmas: monitored_by, monitored

Specification expressions

- Superset of side-effect-free Java expressions, plus syntax to express lock hierarchy and type expressions
- Additional keywords: \old, \modifies, \typeof, \lockset

JML

- Java Modelling Language, inspired by ESC/JAVA annotation language
- Allows to specify behaviour and contracts of Java programs and APIs
- Used by a big ecosystem of static checkers, testing engines, documentation tools
- Readable and writeable by Java programmers

What ESC/JAVA checks

- Errors: Runtime type errors (array assignment, cast), unchecked exceptions, array bounds violations, null dereference, zero division
- Concurrency problems: deadlocks, races
- Violated invariants, pre and post-conditions, loop invariants
- Violated assertions, non-null pragmas, accessibility pragmas

ESC/JAVA does not check:

- Whether a loop invariant holds past the first iteration of a loop
- Arithmetic overflow