Non-null References by Default in the Java Modeling Language

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Outline

- Introduction
  - Null pointer exceptions
  - Better detecting them statically using JML …
- …

Null Pointer Dereference

- Quite a common symptom of a software bug in C based languages:
  - Java: results in a NullPointerException.

- Static analysis tools
  - Code analysis
  - Detect possible null pointer dereferences.
  - Limited success if given only code.

Code + Specs = Better Detection

- Analysis tools can detect a large proportion of null pointer exceptions when programs are suitable annotated.
- Some tools support a minimal set of annotations (e.g. declaration modifiers)
  - FindBugs: @NonNull
- Our focus: the Java Modeling Language …

Java Modeling Language (JML)

- #1 Behavioral Interface Specification Language (BISL) for Java.
- Supports
  - declaration modifiers, e.g. non_null.
  - Contract-based specification
    - Class invariants
    - Method specifications via pre-, post-conditions
  - More general: BIS

JML Tools

- Various levels of checking (Tool)
  - Run-time assertion checking (JML RAC)
  - Extended static checking (ESC/Java2)
  - (Full) Program verification (LOOP)
- ESC/Java2
- What does JML look like …?

JML Example

```
public abstract class Greeting {
   // …
}
```

- Illustrates JML.
- Illustrates means by which declarations can be constrained to be non-null.

Greeting Class – declaration modifiers

```
private /*@ spec_public non_null */
    String nm;

/*@ public normal_behavior
  @
  @  requires !aNm.equals("");
  @  modifies nm;
  @  ensures nm == aNm;
  @*/
public void set(/*@ non_null @*/ String aNm)
{
   nm = aNm;
}
```

Greeting Class – non-null assertions

```
private /*@ spec_public non_null */
    String nm;

/*@ public normal_behavior
  @  requires aNm != null &&
  @           !aNm.equals("");
  @  modifies nm;
  @  ensures nm == aNm;
  @*/
public void set(String aNm)
{
   nm = aNm;
}
```

Experiences Writing JML

- JML, like Java assumes references can be null.
  - Extra annotation required to constrain as non-null
- Notice that in the previous example:
  - Two reference type declarations.
  - Both constrained to be non-null.

Hypothesis

- After having written JML for a few case studies it seemed that we were writing

  ```
  /*@ non_null @*/
  ```

  very often.

- Study conducted to test hypothesis:
  - *By design, the majority of reference type declarations that are meant to be non-null.*

Study Overview

- Choose a (random) sampling of Java source files from four projects.
- Added non-null annotations (JML) based on our understanding of the design.
- Measured proportion of non-null declarations.

Study

We now explain

- Metrics
- Tool
- Study subjects
- Procedure
- Results
- (Threats to validity)

Study: Metrics (principal ones)

Number of declarations (per file)

- that are of a reference type (*d*)
- specified to be non-null (*m*, hence $m \leq d$).

Study: Main Statistic

- Proportion of reference type declarations that are non-null.
- $x = m / d$

Measuring d, number of ref. decl.

Count:

- Fields
  - Instance
  - Static
- Methods (return types)
- Method parameters.

Excluding: local variables

Measuring m, number of non-null d

- Declaration modifier
  - `/*@ non_null @*/`
- Assertions
  - `o != null` and variants `!(null == o)`, …
  - `o instanceof C`
  - `\fresh(o)`
  - `\nonnullelements(o)`

Measuring m for Fields

```
/*@ non_null @*/ Object o1;

Object o2;
//@ invariant o2 != null;

static Object a[];
//@ static invariant
//@    \nonnullelements(a);
```

Measuring m for Methods & Param.

- Some challenges
  - Multiple specification blocks.
  - Normal and exceptional behavior.

Measuring m for Methods

```
/*@  normal_behavior
  @    requires i == 0
  @    ensures  \result != null
  @          && \result.equals("zero");
  @ also
  @  normal_behavior
  @    requires i > 0;
  @    ensures  \result != null
  @          && \result.equals("positive");
  @ also
  @  exceptional_behavior
  @    requires i < 0;
  @    signals(Exception e) true;
  @*/
/*@ pure @*/ String m(int i) {    ... }
```

[TBC] Measuring m for Parameters

- Similar to previous case …
  - Except that parameter is not counted as non_null if there is a signals only clause.

Measuring m for Overriding Methods

- Cannot only examine specification of method.
- Must consider method specification as given in ancestor classes.

Measuring m for Overriding Methods

```
class Greeting {
//@ ensures \result != null;
//@       && !\result.equals(""); public
  abstract /*@ pure @*/ String greeting();
}

class FrenchGreeting extends Greeting {
  //@ also
  //@ ensures \result.equals("Bonjour ");
  public /*@pure non_null*/
  String greeting() { return "Bonjour "; }
}
```

Tool

- Adapted the ISU JML checker
  - Uses tool to parse and type check.
  - Accumulates metrics during/after type checking.

Study Subjects

1. ISU JML checker
2. ESC/Java2
3. Tallying subsystem of Koa
   - Dutch internet voting application
   - Used in 2004 European parlementary elections.
4. Web-based Enterprise Application framework and samples (SoenEA) used at Concordia.

Study Subjects: Encompassing System

	ISU Tools	ESC Tools	SoenEA	Koa e-Voting	Total
# of files	831	455	52	459	1797
LOC (K)	243	124	3	87	457
SLOC (K)	140	75	2	62	278

Study Subjects: Overall Project

	ISU Tools	ESC Tools	SoenEA	Koa	Total
# of files	831	455	52	459	1797
LOC (K)	243	124	3	87	457
SLOC (K)	140	75	2	62	278

Study subject	Checker	ESC/ Java2	SoenEA	Koa TS	Total
# of files	217	216	52	29	514
LOC (K)	86	63	3	10	161
SLOC (K)	58	41	2	4	104

Study Subjects

- Why these?
  - They were partly annotated already.
  - We were familiar or knew someone familiar with the design and implementation.
  - Offer an interesting selection
    - Web apps are a common use for Java.

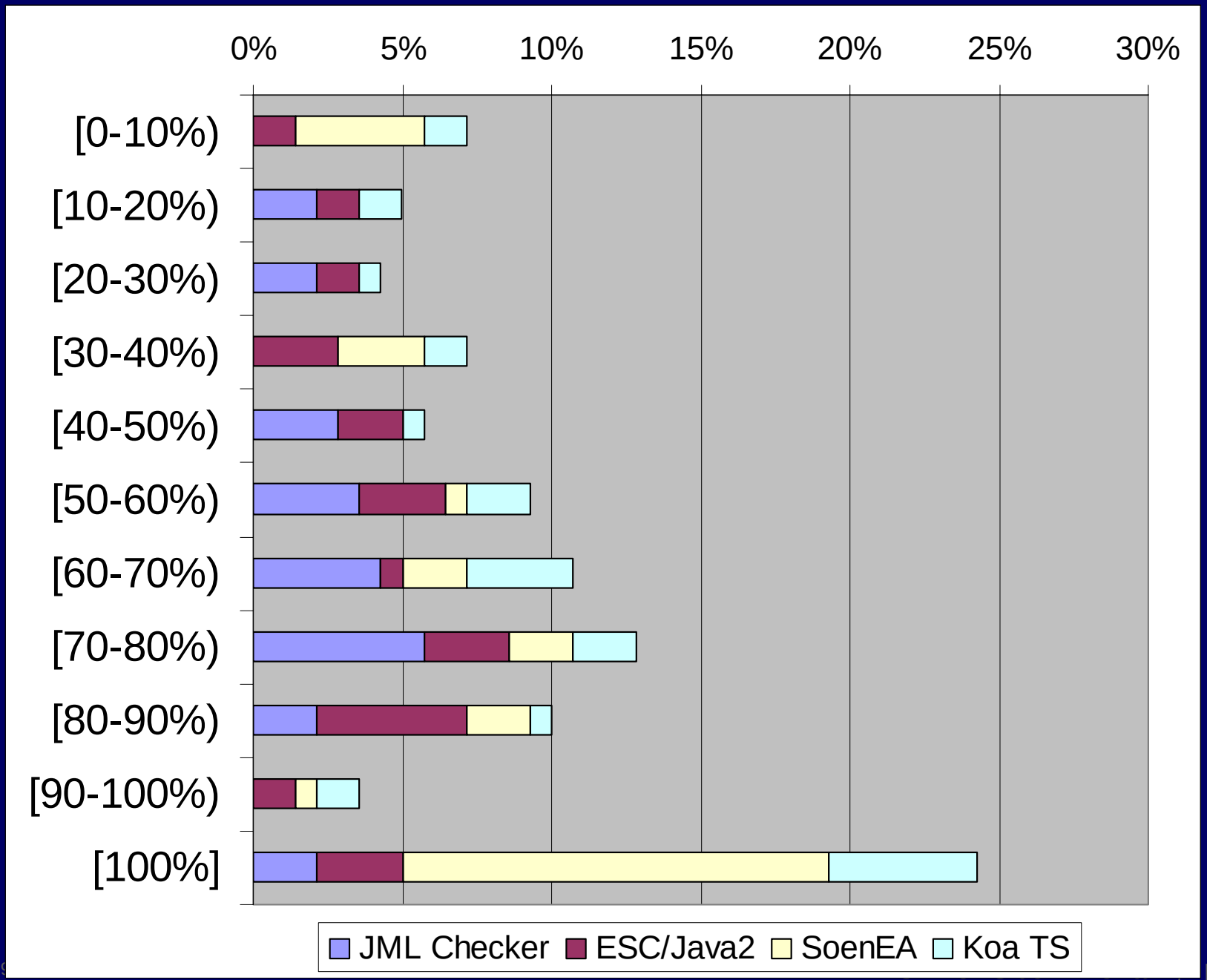
Procedure

- Choose source files:
  - Either used entire component in study, or took a random election of 35 files.
- Annotated source files by adding non-null constraints.
  - Stop annotating once mean – error > 50%.

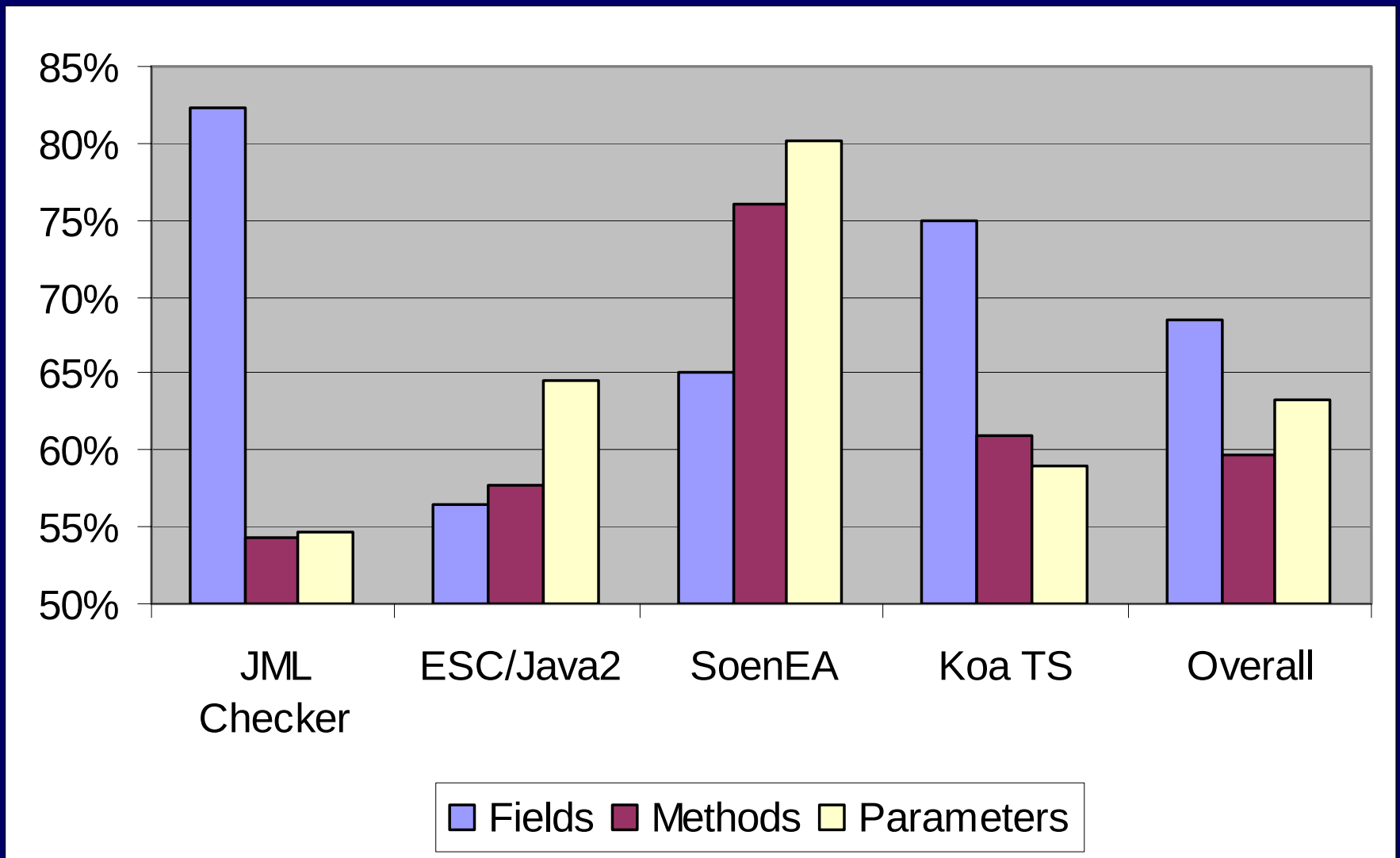
Results: Summary

	JML Checker	ESC/ Java2	Soen-EA	Koa TS	Sum or Av.
n	35	35	41	29	140
N	217	216	41	29	503
$\sum d_i$	376	807	231	564	1978
$\sum m_i$	210	499	177	368	1254
$\sum d_i / \sum m_i$	56%	62%	*77%*	65%	63%
mean $(\underline{x})$	59%	60%	*72%*	64%	64%
std.dev.(s)	0.24	0.31	0.37	0.32	-
E (α=5%)	7.4%	9.3%	-	-	-
μ_{min}	52%	51%	72%	64%	60%

Results: % of files having a value for x in given range



Mean of x by kind of declaration



Threats to (Internal) Validity

- Main threat: we were wrong in annotating a declaration as non-null.
- Mitigation: we were conservative in our annotation exercise.
- Solution: run ESC/Java2 ESC/Java2 on the study subjects to validate our specifications. (50% done)

Improving JML

- If well over 50% of decl. are non-null, why not adopt non-null as the default?

Advantages:

- Non-null is a safer default.
- Without any effort, unannotated source files would be over 50% correct.
- Much less effort to correct remaining declarations by marking them *nullable*.

Language design goals of JML

- Adhere to the semantics of Java to the extent possible.
- Do not surprise Java developers when semantics differ …
  - i.e. Give some explicit indication

JML: Declaration Modifiers

- Class modifier warning developer of different default:
  - `/*@ non_null_by_default @*/`
  - Un annotated declarations would be implicitly declared `non_null`.

- To override default:
  - `/*@ nullable @*/`

JML Tool Help

- Help developers learn about the new default.
- JML checker to warn if class default is not explicitly specified as either:
  - `non_null_by_default`
  - `nullable_by_default`

Feature Support

- JML checker and RAC:
  - 97% complete
  - (keyword change from “null” to “nullable”)
- ESC/Java2
  - 40% complete

Other Languages / Tools ...

- Supporting non-null types and/or annotations.

Splint

- Static checker for C.
- Mainly supports annotation pragmas.
- Default: non-null.
- Declaration modifier: @null.

Nice

- Essentially an enriched variant of Java.
- Supporting
  - parametric types,
  - multi-methods, and
  - contracts
  - among other features
- Default: non-null.
- ?*T* denotes the type of nullable *T*.

ECMA Eiffel Standard (2005)

- Introduces notion of
  - Attached types.
  - Detachable types.

- Default: non-null (attached).
- ?*T* denotes a detachable *T*.

Spec#

- A superset of C# supporting:
  - contracts,
  - checked exceptions and
  - non-null types.
- For backwards compatibility: default is nullable types.
- *T*! denotes non-null type of *T*.

Summary

- Null pointer exceptions can practically be eliminated from properly JML annotated Java code.
- Study: over 50% of decl. non-null in Java.
- JML:
  - New declaration modifiers to support
  - New default of non-null
- Others also believe this is a good idea.

Thank you

- Questions / Remarks?

Greeting Class (part 2)

```
//@ ensures
  \result.equals(greeting()+nm);
public /*@ pure non_null @*/ String
  welcome() {
    return greeting() + nm;
}

//@ ensures \result != null;
//@       && !\result.equals("");
  public abstract /*@ pure @*/ String
  greeting();
```