NIT: a non-null Annotation Inferencer for Java Bytecode

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PASTE'08 - Atlanta, USA

Examples of annotations

```
class C extends A{
  @NN O f;

  C(){
   this.f = new O();
  }

  static @NN O m(@NN C x){
   return x.f;
  }
}
```

Motivations for nullness analysis

- Avoid `NullPointerExceptions`
  - if used by the developer
- Allow more optimizations
  - if used by the compiler to native code (*e.g.* JIT)
- Improve the precision of other analyses
  - if the other analyses rely on the control flow graph

Some nullness analyses

- Bug-finding oriented analyses
  1) Flanagan and Leino. FME'01.
  2) Hovemeyer *et al.*. PASTE'05.
  3) Hovemeyer and Pugh. PASTE'07.
- Certification oriented analyses
  - By checking annotations
    4) Fähndrich and Leino. OOPSLA'03.
    5) Male *et al.*. CC'08.
  - By inference
    6) Hubert *et al.*. FMOODS'08.

In this talk

- Motivations
- The non-null annotation inference analysis
- Improvements to the former analysis for the bytecode
  - Alias analysis
  - New domain for `instanceof`
  - *NullableInit* abstract value
- Results of the implementations

Object initialization

Problem 1: all fields are null by default

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class C extends A{
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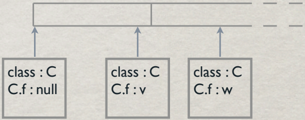

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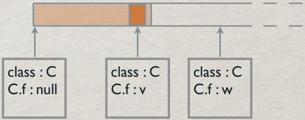

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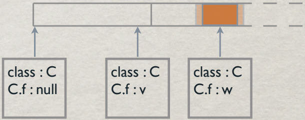


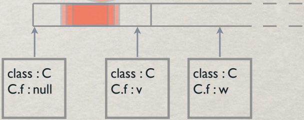
Object initialization

```
class C extends A {
  @NN O f;

  C(){
   C.m(this);
   this.f = new O();
  }

  static @NN O m(@NN C x){
   return x.f;
  }
}
```

Problem 2: the **object under construction can be accessed** before the invariant is established.



OBJECT INITIALIZATION

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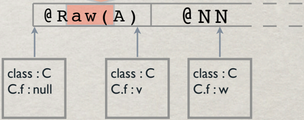


Object references are annotated with @Raw(A) if they may be in construction

Automatic inference

- Annotating a program is not trivial
- Manual annotations
  - cannot guarantee correctness...
    - ...except with a checker
  - can be a burden on the programmer...
    - ...specially for legacy code

Automatic inference

- How does it work ?
  - Annotations are given a lattice structure
  - The analysis is specified as data flow constraints
  - The solution is a fixpoint
- For more details, cf. Hubert *et al.*. FMOODS'08.

Turning theory into practice

From an intermediate language to the bytecode level

- The former analysis
  - Specified on an intermediate language
  - Focused on field annotation inference
  - Correctness proof checked with the Coq proof assistant
- The tool must be at the bytecode level
  - Exceptions, static fields and arrays are conservatively handled
  - How to handle `ifnull`? `instanceof` ?
  - How to recover good information from nullness tests on Nullable values ?

Handling ifnull instructions

- Problem: Java Bytecode is a stack language
- Solution: a simple must-alias analysis

Handling instanceof instructions

- Why is it difficult?
  - Java bytecode is a stack language
  - The result of the `instanceof` instructions is an integer (0 if the reference is null, 0 or 1 otherwise)
  - `instanceof` instructions are very often followed by a conditional, not always

Handling instanceof instructions

- Solution
  - We have added an abstract domain to represent the results of `instanceof` instructions

> *We abstract a stack variable by a set of local variables that must be non-null if the stack variable is 1.*

Handling instanceof instructions

```java
static int m_io(Object x){
  if(x instanceof String)
    return ((String)x).length();
  return -1;
}
```

```
static int m_io(Object)
  Code:
   0:  aload x
   1:  instanceof java/lang/String
   4:  ifeq   15
   7:  aload x
   8:  checkcast java/lang/String
   11:invokevirtual String.length()I
   14:ireturn
   15:iconst_m1
   16:ireturn
```

HANDLING INSTANCEOF INSTRUCTIONS

Stack variable ∈ Alias# x InstanceOf# x Nullness#

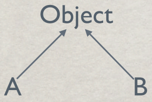
Alias# = Locals²

InstanceOf# = Locals²

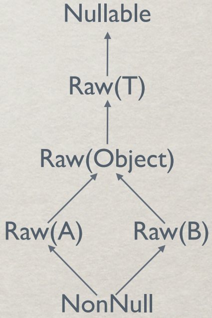
```
static int m_io(Object)
 Code:
```

	Locals	Stack		
0: aload x	Nullable			
1: instanceof java/lang/String	Nullable	{x}	Top	Nullable
4: ifeq 15	Nullable	Top	{x}	Top
7: aload x	NonNull			
8: checkcast java/lang/String	NonNull	{x}	Top	NonNull
11: invokevirtual String.length()I	NonNull	{x}	Top	NonNull
14: ireturn	NonNull	Top	Top	Top
15: iconst_m1	Nullable			
16: ireturn	Nullable	Top	Top	Top

Efficiently using nullness tests

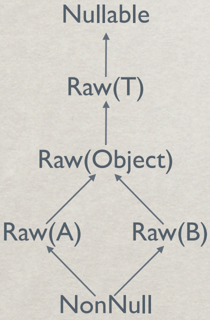


Class hierarchy of a program

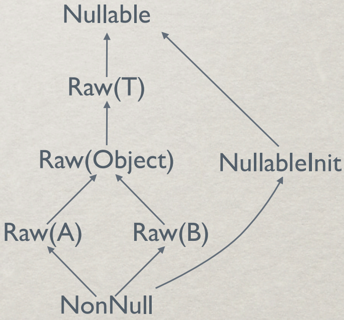


Corresponding annotation lattice structure

Efficiently using nullness tests



Former lattice structure



Improved lattice structure

NIT: Nullness Inference Tool

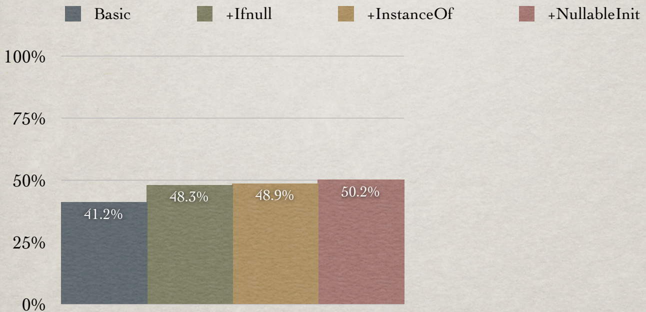
- Free and open source (GPL)
  http://nit.gforge.inria.fr
- Implements in OCaml the basic analysis and the improvements discussed herein while
  - lazily parsing the methods
  - carefully managing memory
- Usual restrictions apply to native methods and reflection is not handled

Results

		Program size (methods)	Space (MB)	Time (s)
Jess		25 686	878	138
Soot		17 895	662	120
ESC/Java		10 845	428	51
Julia		11 248	414	49
JavaCC		8 098	319	33
JDTCore		4 246	341	34
Jasmin		4 316	118	11
TightVNC		3 445	89	7
SPEC JVM98	sum	33 503	888	76
	max	3 818	119	12

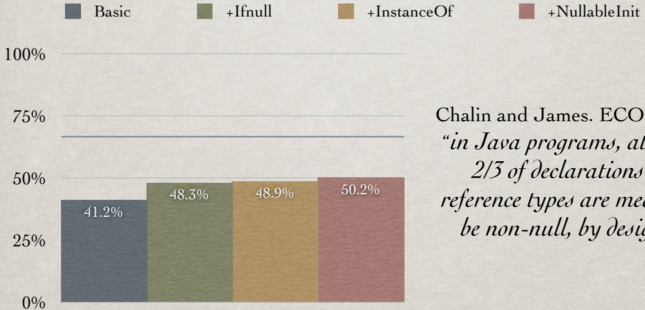
Average of 200 methods per second

Results



% of non-null annotations out of the total number of annotations

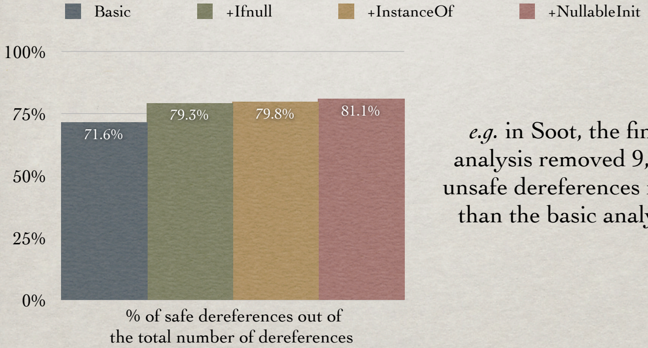
Results



% of non-null annotations out of the total number of annotations

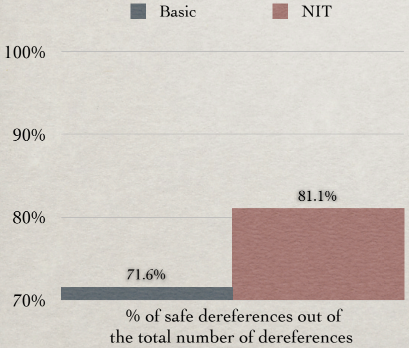
Chalin and James. ECOOP'07.
"in Java programs, at least 2/3 of declarations of reference types are meant to be non-null, by design."

Results



e.g. in Soot, the final analysis removed 9,500 unsafe dereferences more than the basic analysis

Results



The improvements we propose allow to reduce by a third the number of unsafe dereferences

Conclusion and Future work

- We enriched a provably sound analysis to handle Java bytecode: alias analysis, abstract domain for `instanceof`, *NullableInit*
- We provide NIT, a scalable implementation (NIT analyses Soot (17 k.meth) within 2 min)
- Future work
  - Make the domain relational
    - cf. Spoto, SEFM'08. Tomorrow, Cape Town
  - Certify a checker in a proof assistant
  - Integrate a checker in the bytecode verifier?

Thank you

NIT can be downloaded at

http://nit.gforge.inria.fr

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