Accurate Interprocedural Null-Dereference Analysis for Java

Mangala Gowri Nanda and Saurabh Sinha

{mgowri,saurabhsinha}@in.ibm.com.

IBM India Research Lab

Interprocedural Null-Dereference

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scanDir(File srcDir, File dest, JspMangler mangler, String files[]) {
  [499]  if (i < files.length)
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  [502]  javaFile = mapToJavaFile(mangler, srcFile, srcDir, dest);

  [509]  shouldCompile = isCompileNeeded(srcFile, javaFile);
}
mapToJavaFile(JspMangler mangler, File srcFile, File srcDir, File dest) {
  [565]  if (!srcFile.getName().endsWith(".jsp"))
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isCompileNeeded(File srcFile, File javaFile) {
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- Salsa performs sound interprocedural analysis

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- Such bugs often involve interactions among multiple procedures
- Yet, widely used Java static-analysis tools, such as FindBugs, JLINT and ESC/JAVA perform limited interprocedural analysis
- Salsa performs sound interprocedural analysis
- Tomb et al apply interprocedural analysis but limit the call depth explored

Contributions

- **A context- and path-sensitive interprocedural analysis for identifying potential null dereferences that is demand-driven and parametrized for cost-accuracy trade-offs**

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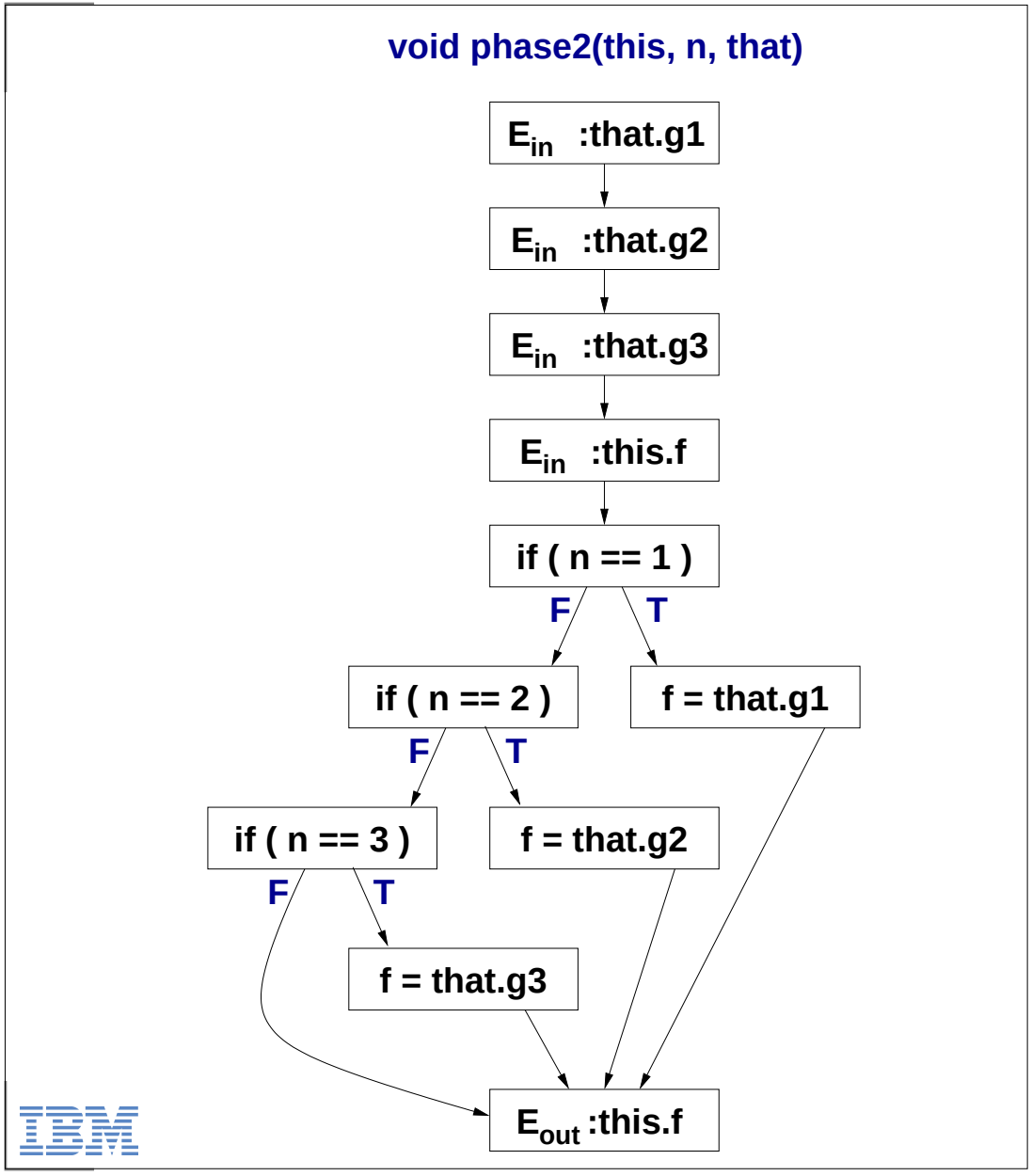
- **A context- and path-sensitive interprocedural analysis for identifying potential null dereferences that is demand-driven and parametrized for cost-accuracy trade-offs**
- **Empirical studies, using large open-source and commercial products, that illustrate the effectiveness, efficiency, and usefulness of our approach.**

Outline

- Predicates - generation, transformation, states etc.
- Interprocedural analysis
- Scaling the analysis
  - Parameterized exploration
  - Simplified predicate handling
- Empirical evaluation
- Conclusion

Preliminaries



- **Control Flow Graph with Formalin and Formalout**
- **Escape and Pointer analysis**
- **Control dependence analysis**

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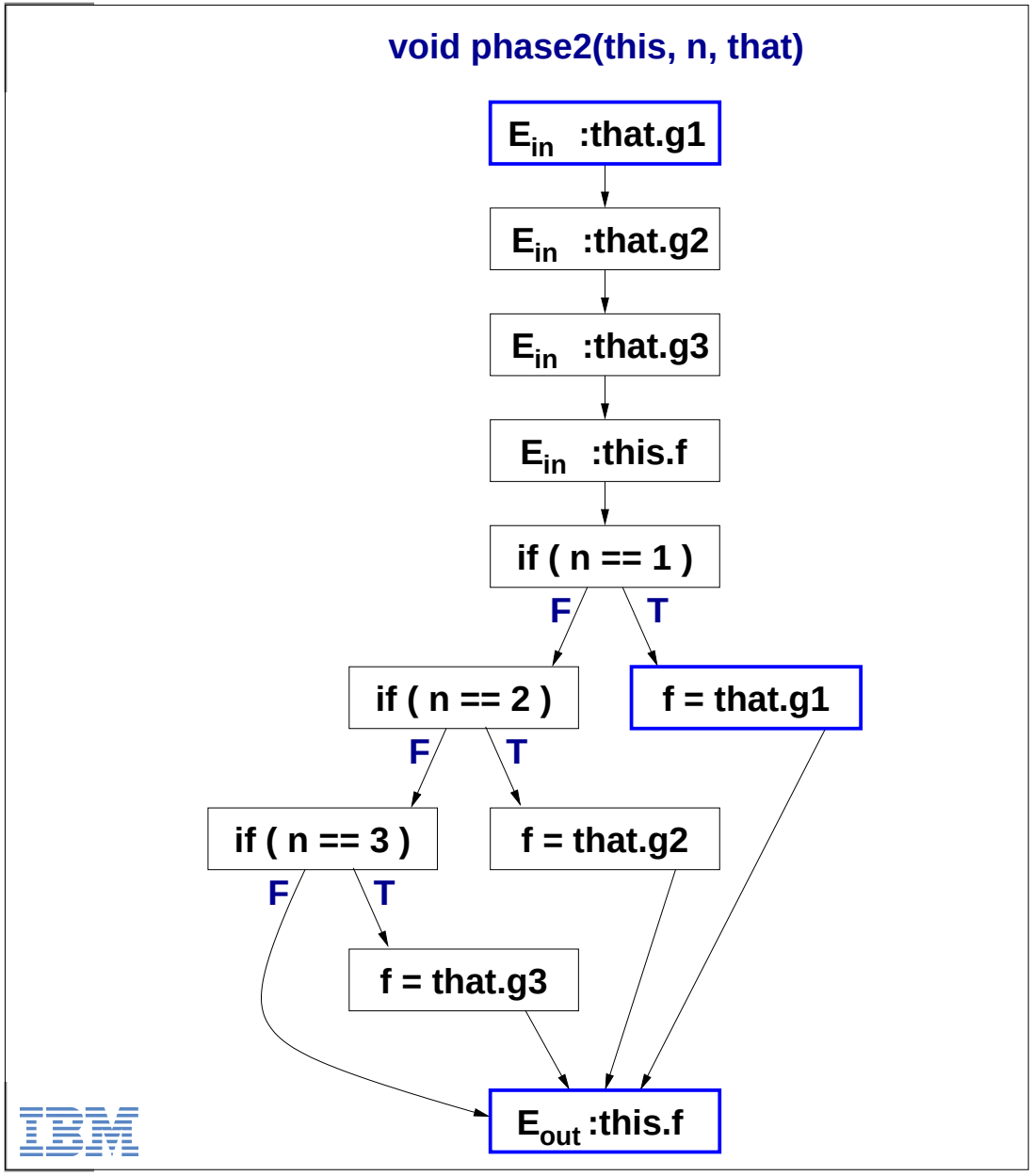

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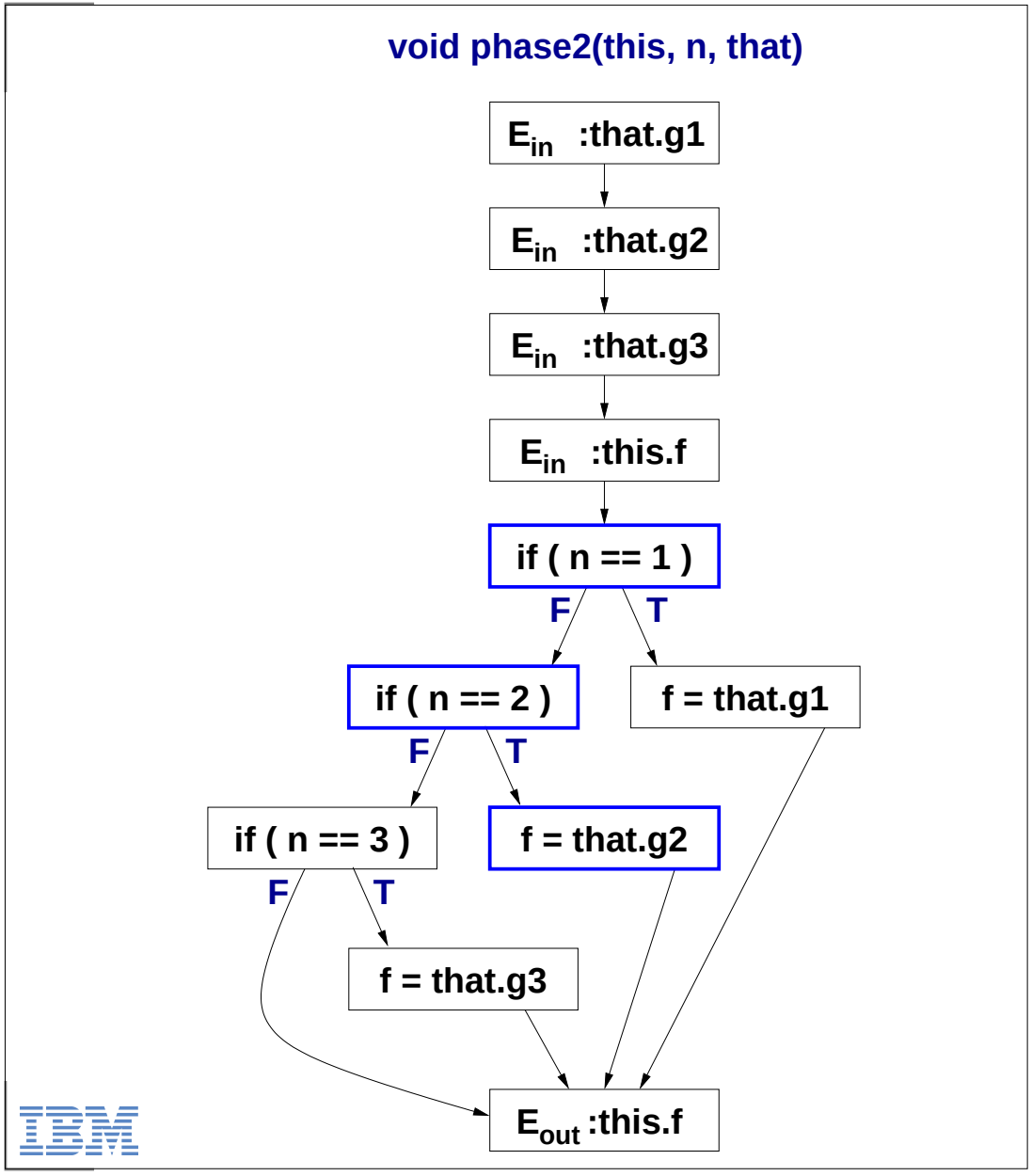

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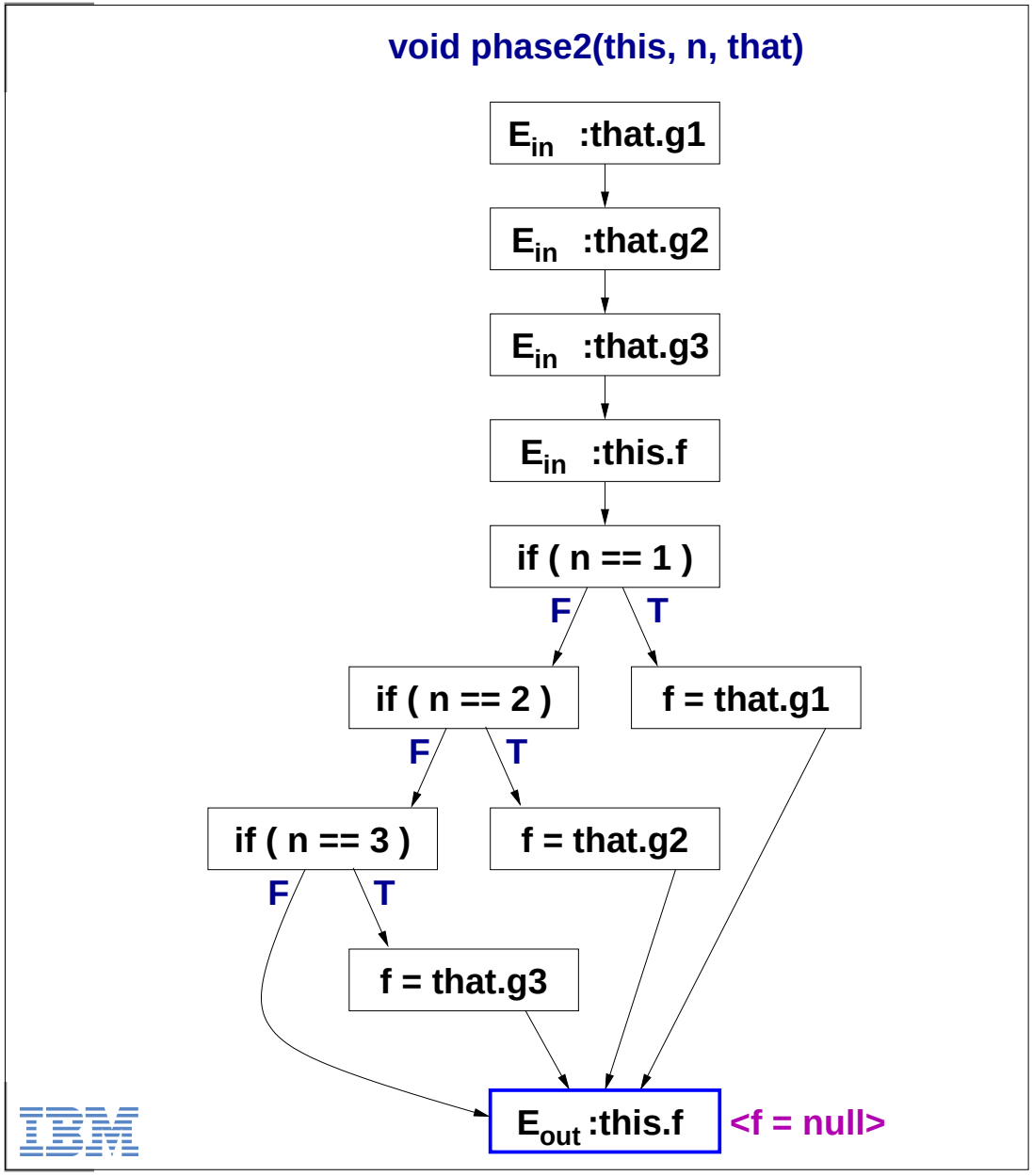
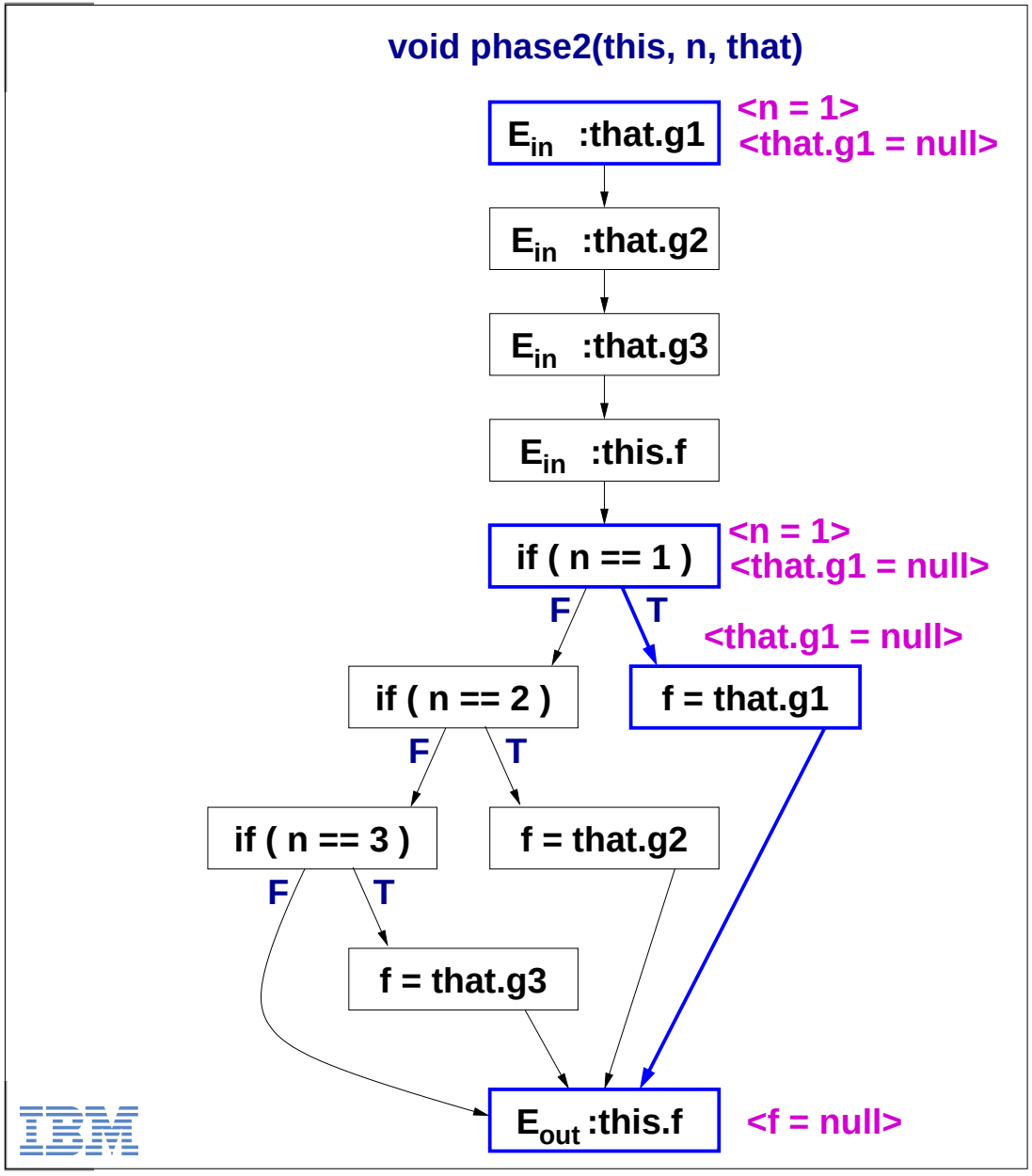
Predicates, Transformations, States, and Consistency



- **Root predicate**
- **Transformations**
- **States**
- **Consistency**

Predicates, Transformations, States, and Consistency



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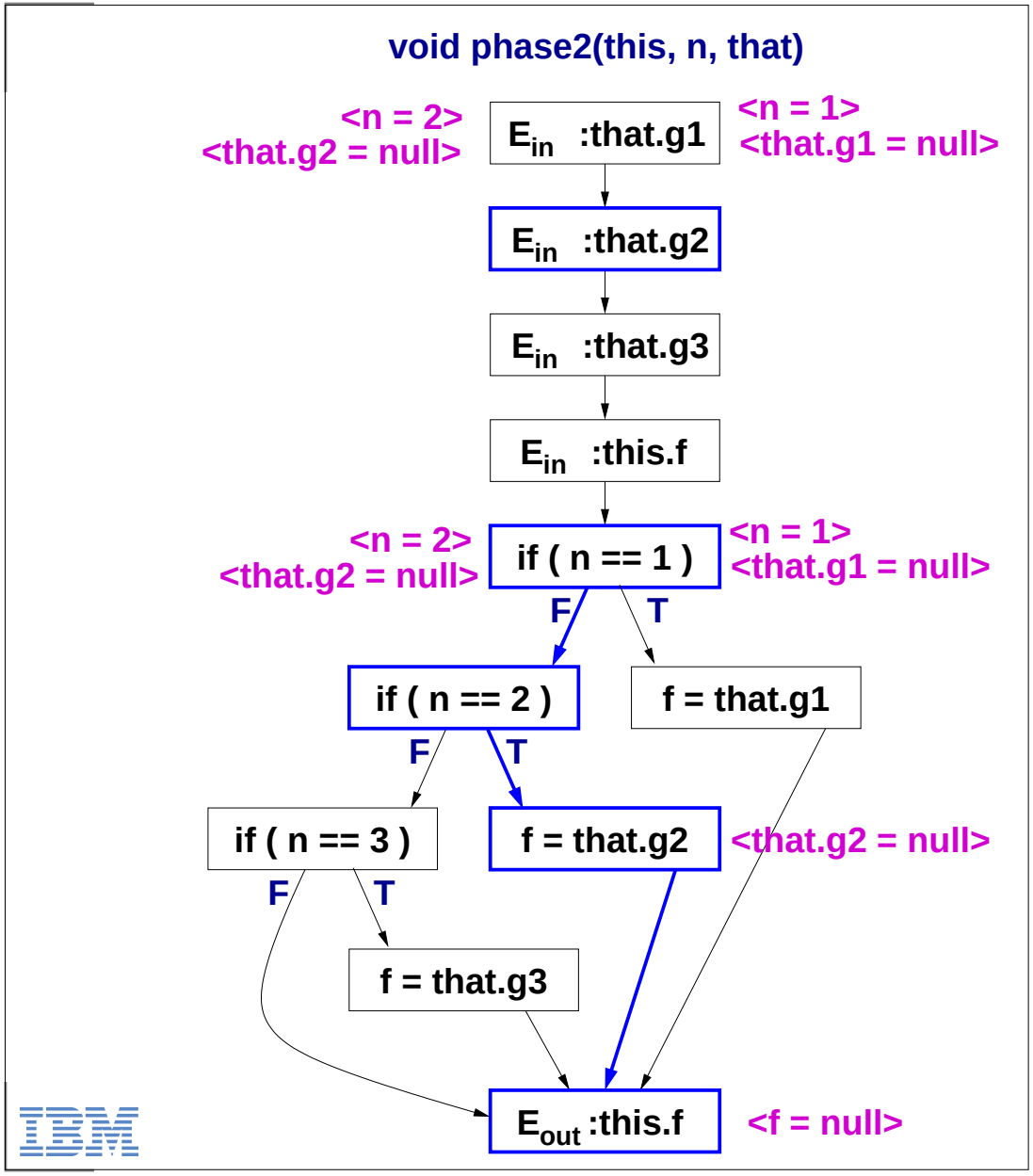

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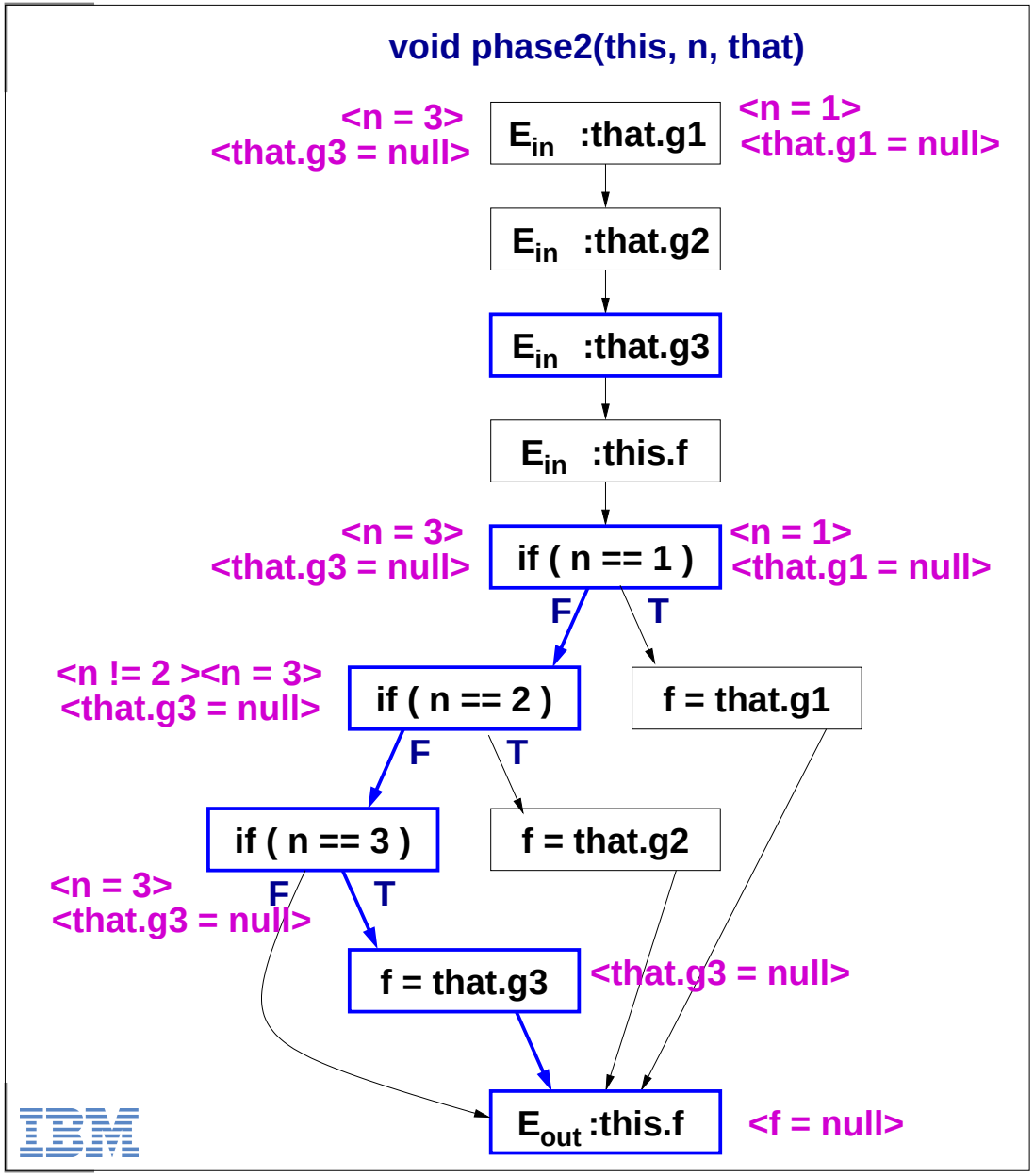

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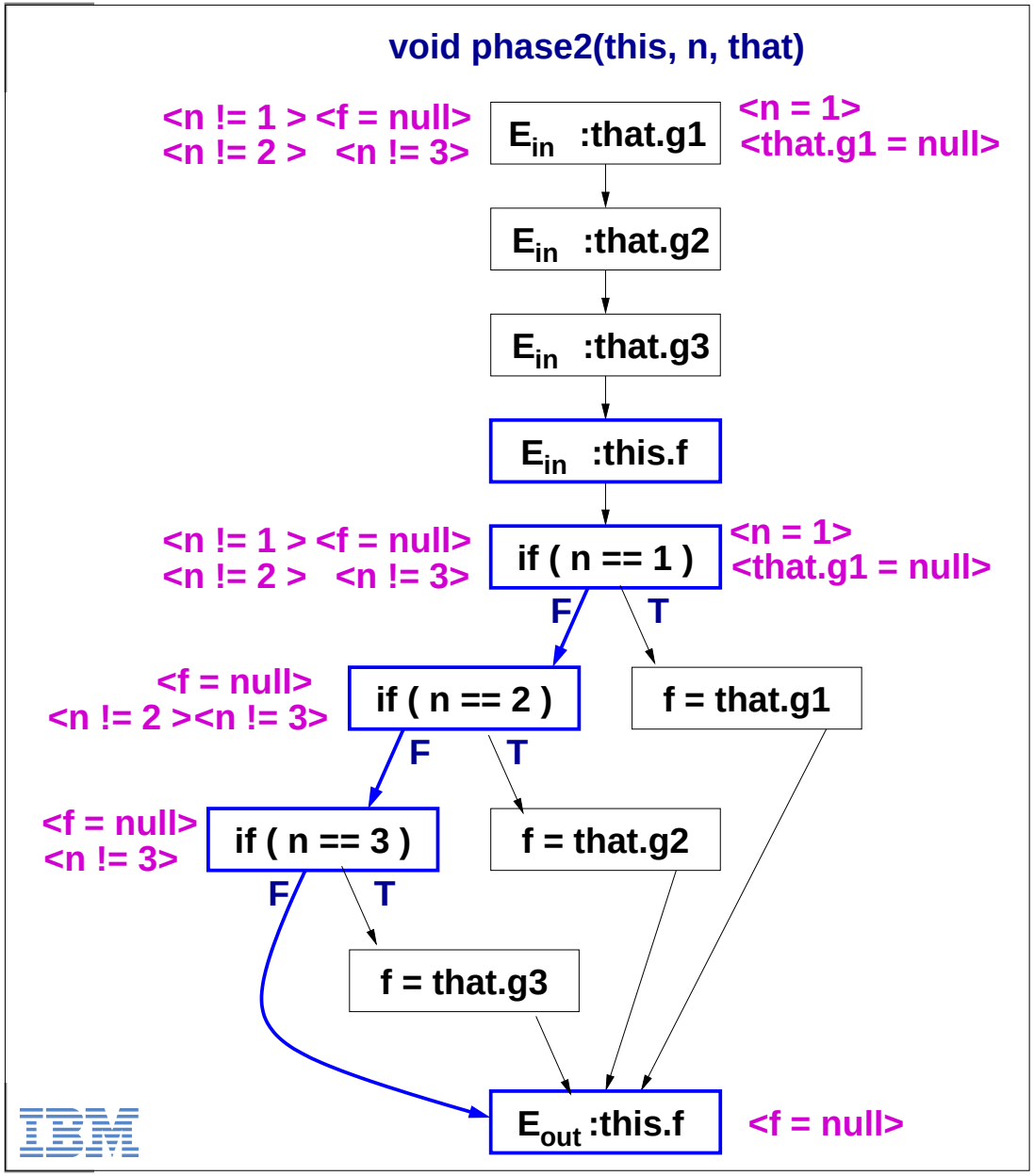
Method Summary



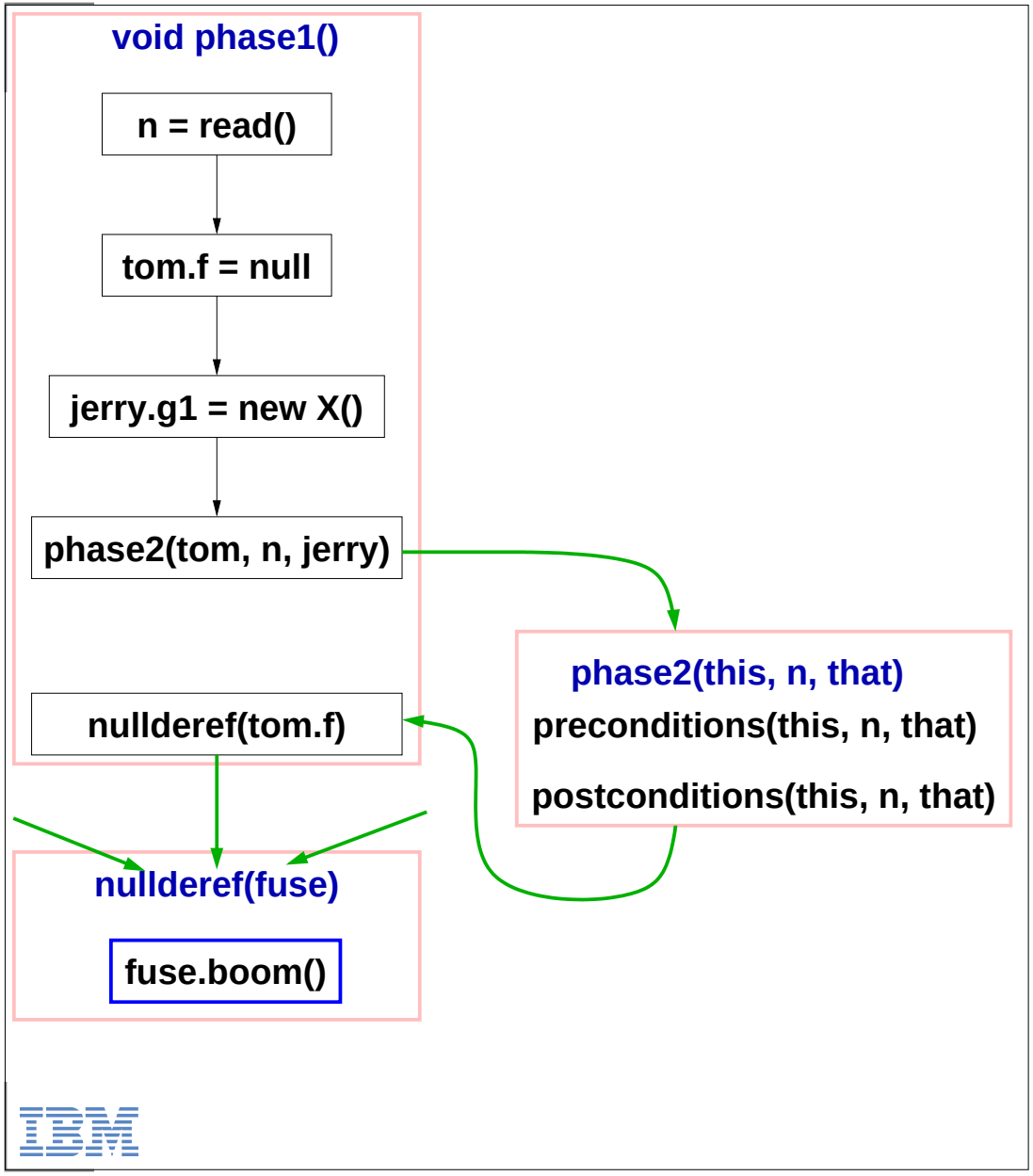
Postconditions

- ⟨ this.f = null ⟩

Preconditions

- ⟨ n = 1 ⟩ ⟨ that.g1 = null ⟩
- ⟨ n = 2 ⟩ ⟨ that.g2 = null ⟩
- ⟨ n = 3 ⟩ ⟨ that.g3 = null ⟩
- ⟨ n ≠ 3 ⟩ ⟨ n ≠ 2 ⟩ ⟨ n ≠ 1 ⟩ ⟨ this.f = null ⟩

Interprocedural Analysis and Method Summary



Method boundaries

- Phase1 - ascend into a calling method
- Phase2 - descend into a called method. Maintan stack for context-sensitivity
- Recursion

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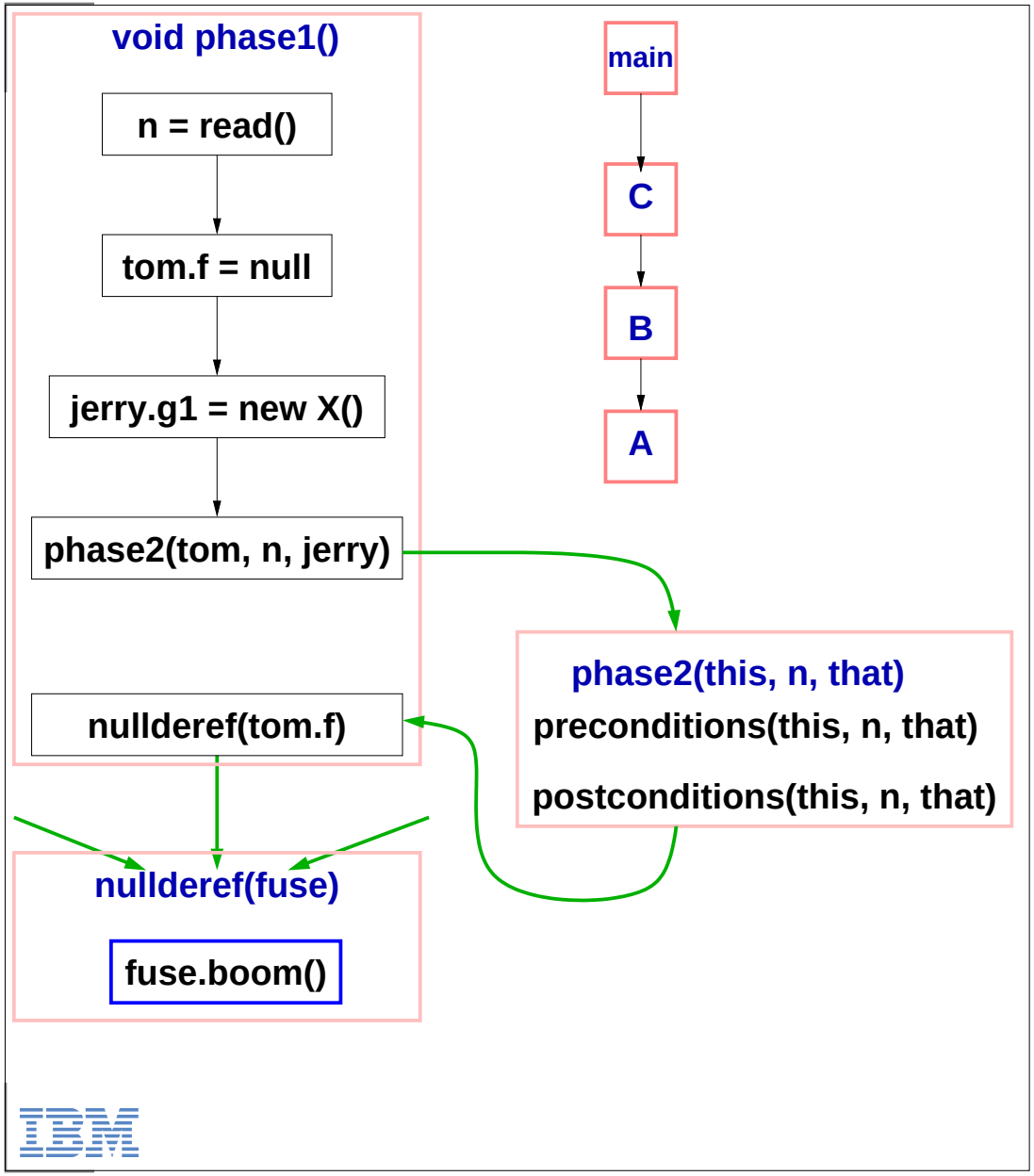

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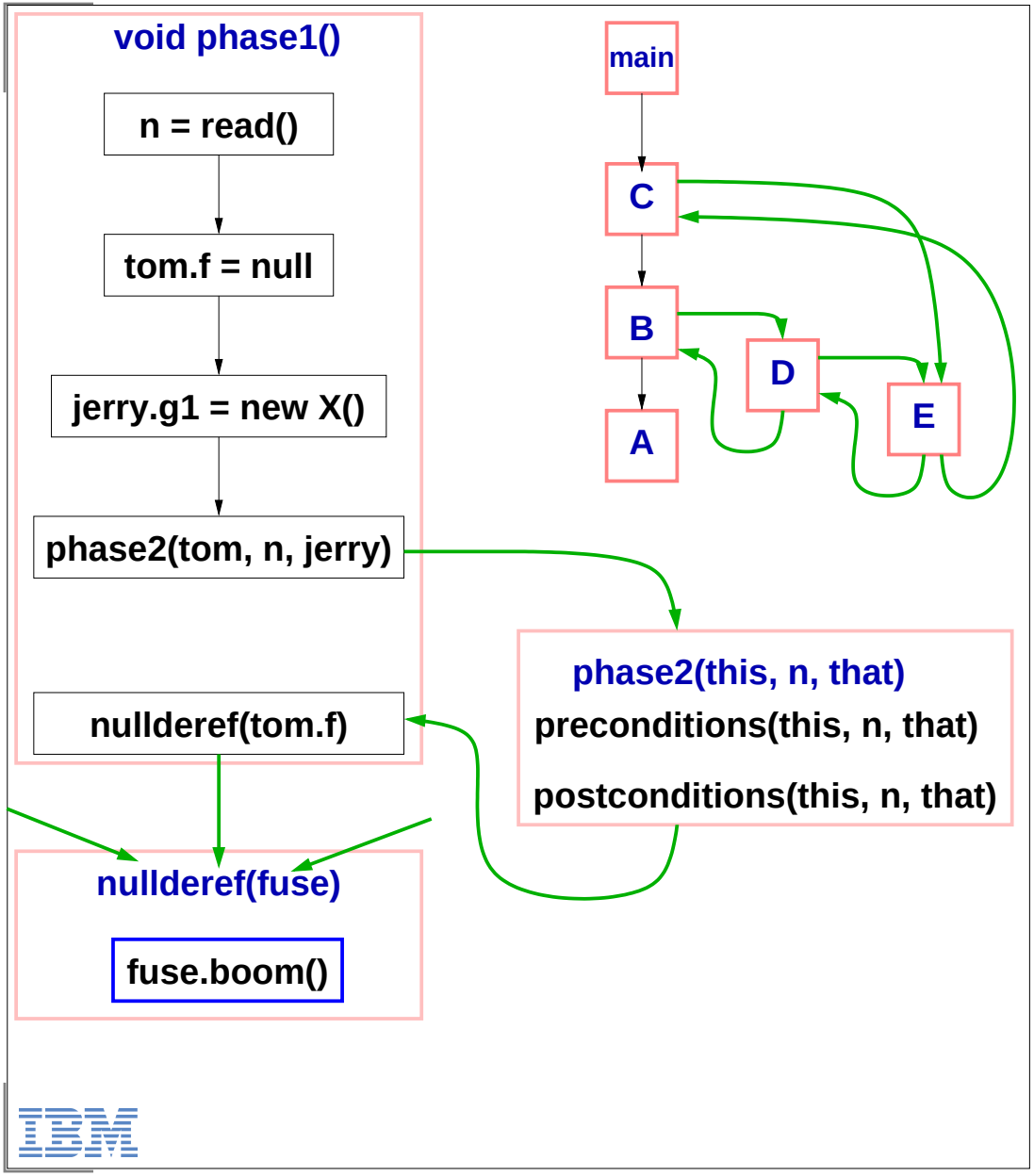

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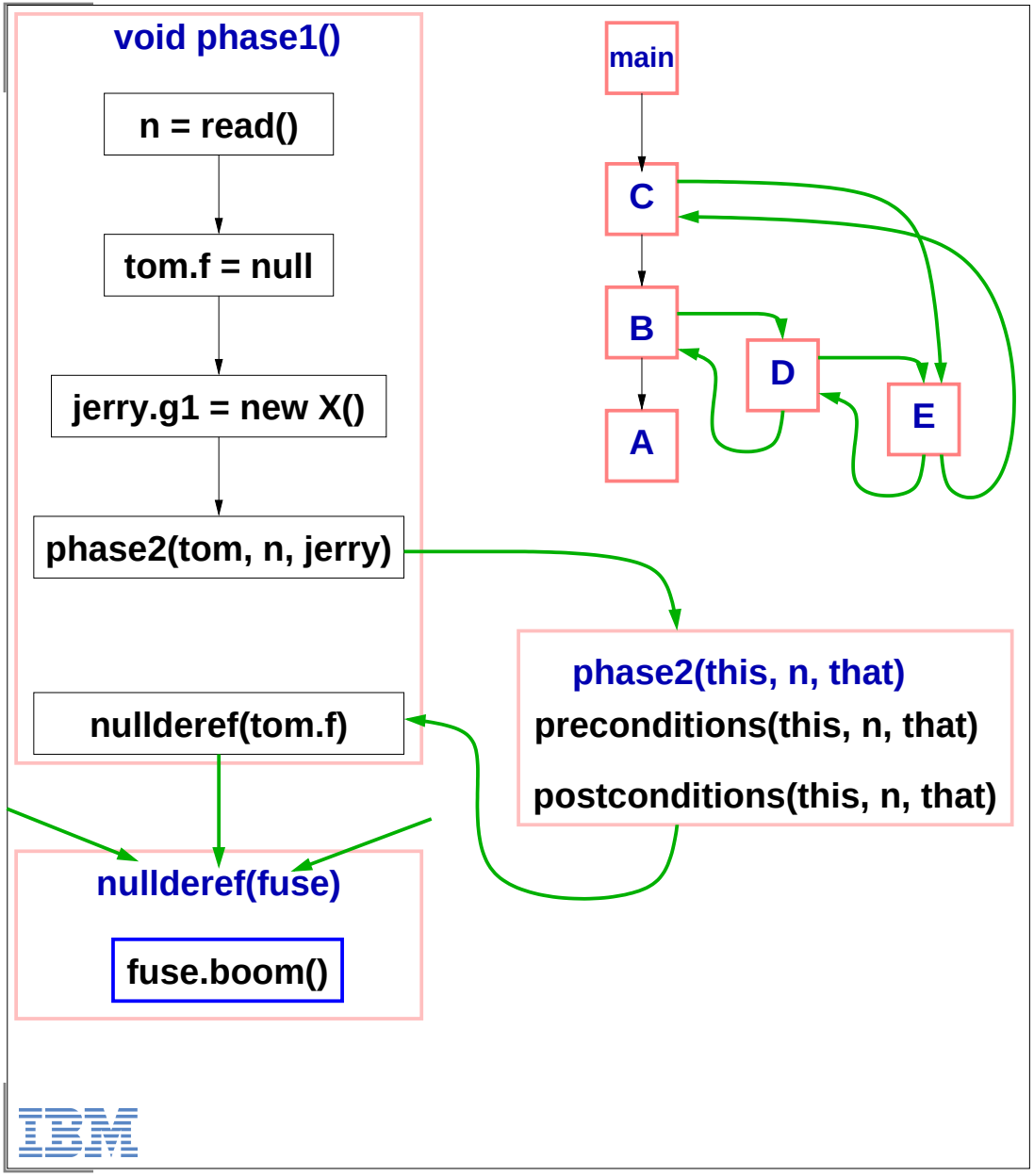

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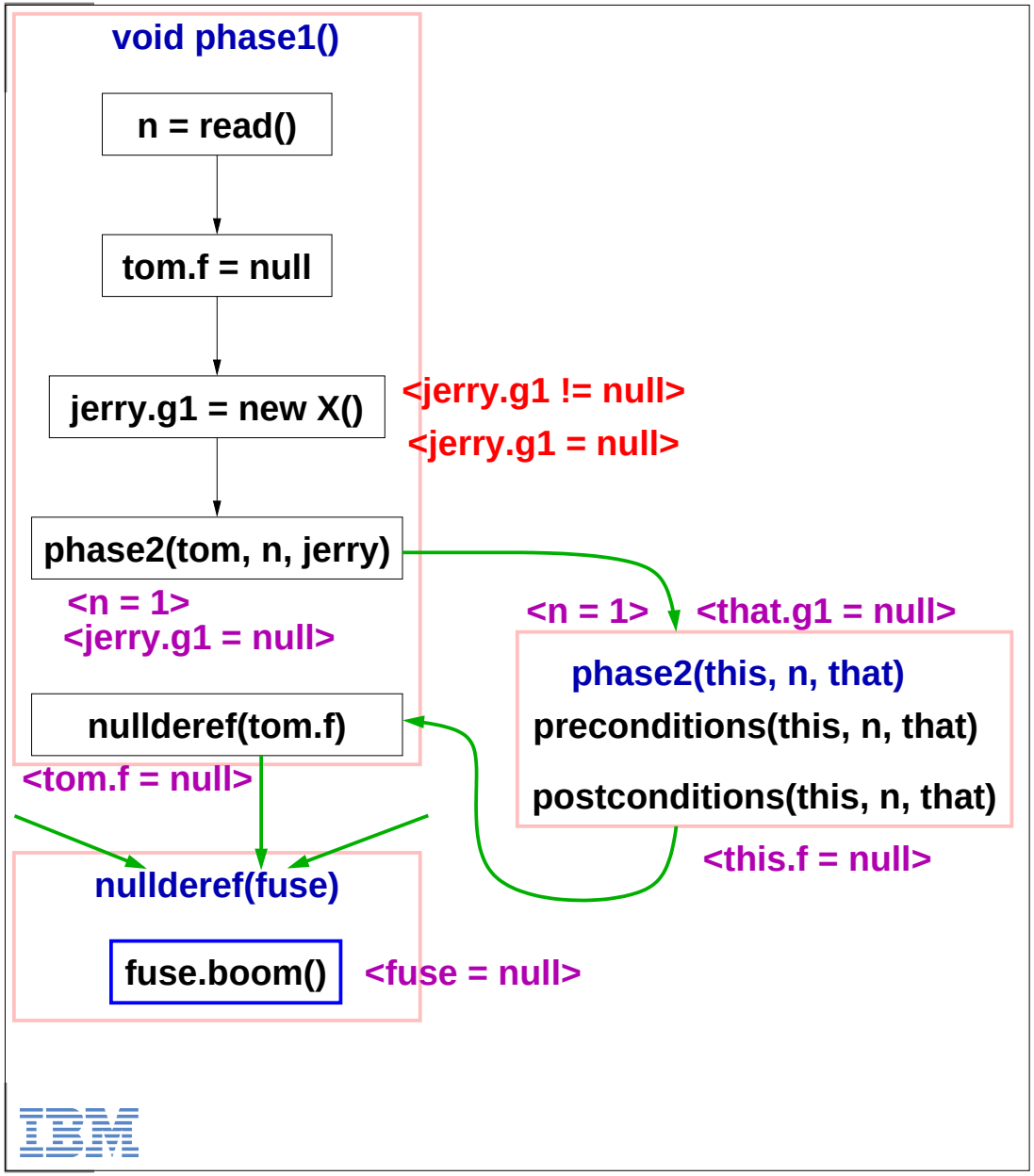

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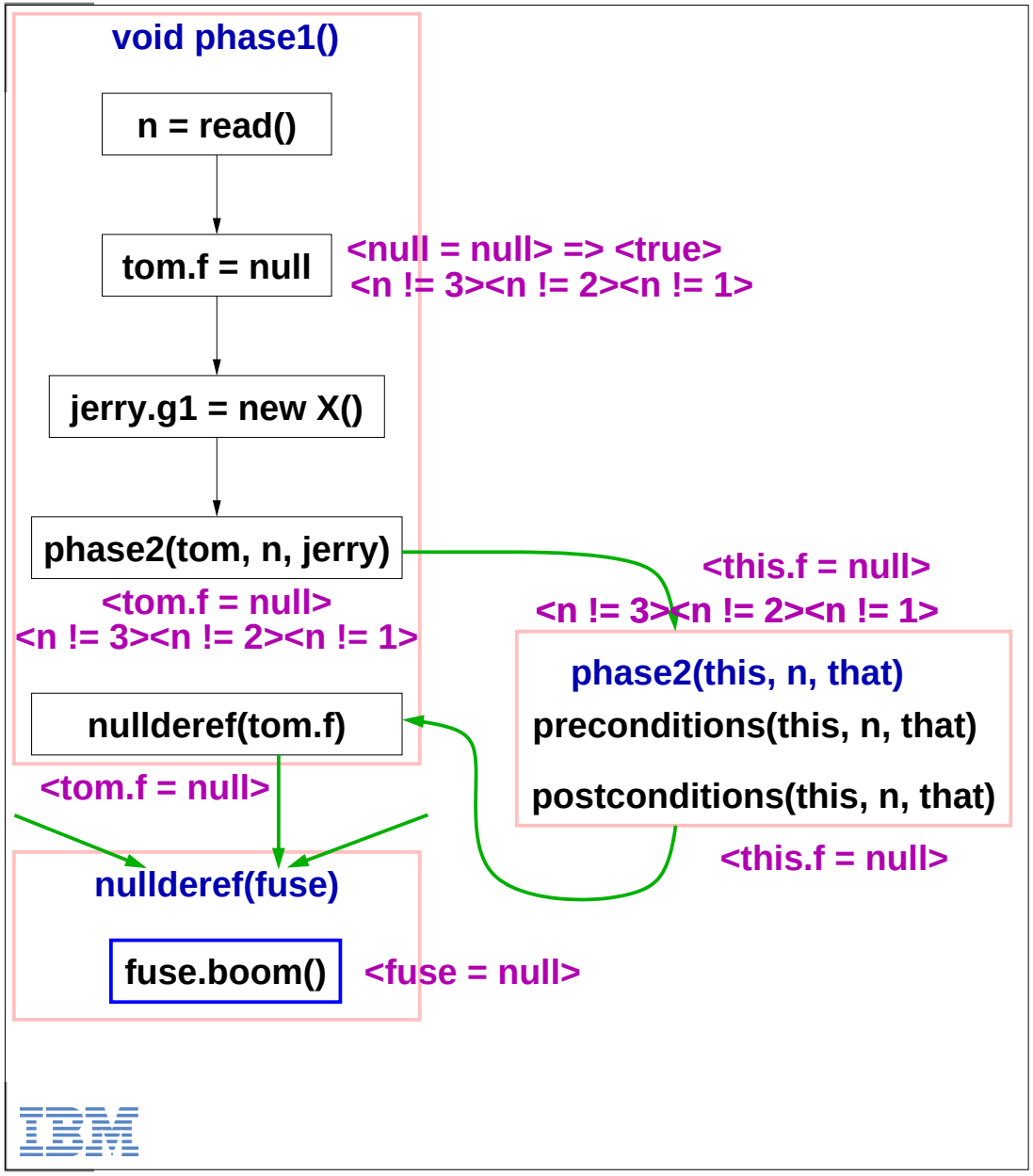

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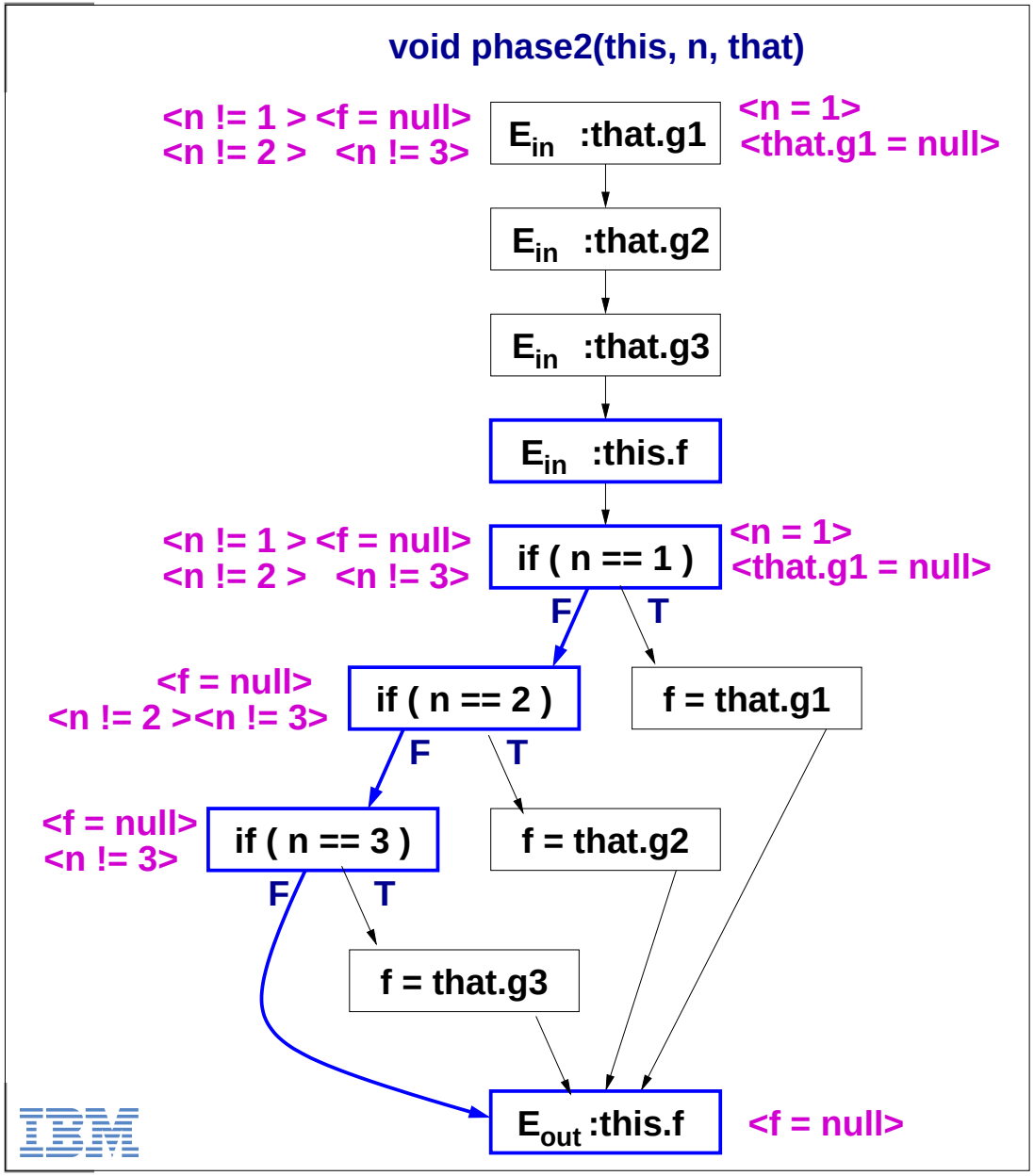
Scaling up the Analysis



- Parameterized exploration
  - Paths in a method: the number of postcondition to precondtion mappings per method (7)
  - States per node (80)
  - Time per traversal (2sec)
- Simplified predicate handling
- Postconditions
  - ⟨ this.f = null ⟩
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Integer Arithmetic

P_1	P_2	test	T	F
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$x = v_1$	$x \neq v_2$	$v_1 \neq v_2$	P_1	X
$x = v_1$	$x < v_2$	$v_1 < v_2$	P_1	X
$x = v_1$	$x \leq v_2$	$v_1 \leq v_2$	P_1	X
$x = v_1$	$x > v_2$	$v_1 > v_2$	P_1	X
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$x \neq v_1$	$x < v_2$	$v_1 \geq v_2$	P_2	P_1
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$x \neq v_1$	$x \geq v_2$	$v_1 < v_2$	P_2	P_1

$x = 10$ **and** $x < 15 \implies x = 10$

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$x = 10$ **and** $x < 15 \implies x = 10$

$x = 10$ **and** $x < 5 \implies X$

Integer Arithmetic

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$x \neq 10$ **and** $x < 8 \implies x < 8$

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$x \neq 10$ **and** $x < 8 \implies x < 8$

$x \neq 10$ **and** $x < 15 \implies$

$x \neq 10$ **and** $x < 15$

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$x = v_1$	$x \leq v_2$	$v_1 \leq v_2$	P_1	X
$x = v_1$	$x > v_2$	$v_1 > v_2$	P_1	X
$x = v_1$	$x \geq v_2$	$v_1 \geq v_2$	P_1	X
$x \neq v_1$	$x = v_2$	$v_1 \neq v_2$	P_2	X
$x \neq v_1$	$x \neq v_2$	-	$P_{1,2}$	$P_{1,2}$
$x \neq v_1$	$x < v_2$	$v_1 \geq v_2$	P_2	P_1
$x \neq v_1$	$x \leq v_2$	$v_1 > v_2$	P_2	P_1
$x \neq v_1$	$x > v_2$	$v_1 \leq v_2$	P_2	P_1
$x \neq v_1$	$x \geq v_2$	$v_1 < v_2$	P_2	P_1

```
[1] if (x == null)
[2]     y = 0;          ⟨ x = null ⟩ ⟨ 0 < 0 ⟩
[3] i = 0;              ⟨x = null⟩⟨0 < y⟩
[4] while(i < y)        ⟨x = null⟩⟨i < y⟩
[5]     x.foo();        ⟨x = null⟩
```

Integer Arithmetic

P_1	P_2	test	T	F
$x = v_1$	$x = v_2$	$v_1 = v_2$	P_1	X
$x = v_1$	$x \neq v_2$	$v_1 \neq v_2$	P_1	X
$x = v_1$	$x < v_2$	$v_1 < v_2$	P_1	X
$x = v_1$	$x \leq v_2$	$v_1 \leq v_2$	P_1	X
$x = v_1$	$x > v_2$	$v_1 > v_2$	P_1	X
$x = v_1$	$x \geq v_2$	$v_1 \geq v_2$	P_1	X
$x \neq v_1$	$x = v_2$	$v_1 \neq v_2$	P_2	X
$x \neq v_1$	$x \neq v_2$	-	$P_{1,2}$	$P_{1,2}$
$x \neq v_1$	$x < v_2$	$v_1 \geq v_2$	P_2	P_1
$x \neq v_1$	$x \leq v_2$	$v_1 > v_2$	P_2	P_1
$x \neq v_1$	$x > v_2$	$v_1 \leq v_2$	P_2	P_1
$x \neq v_1$	$x \geq v_2$	$v_1 < v_2$	P_2	P_1

```
[1]  if (x == null)
[2]      y = 0;          ⟨ x = null ⟩ ⟨ 0 < 0 ⟩
[3]  i = 0;              ⟨x = null⟩⟨0 < y⟩
[4]  while(i < y)        ⟨x = null⟩⟨i < y⟩
[5]      x.foo();        ⟨x = null⟩

[6]  if (x == null)      False Positive
[7]      y = 1;
[8]  else
[9]      y = z+1;
[10] i = 0;              ⟨x = null⟩
[11] t = y-1;            ⟨x = null⟩⟨true⟩
[12] while(i < t)        ⟨x = null⟩⟨i < t⟩
[13]     x.foo();        ⟨x = null⟩
```

Dual Variable Predicates

P_{double}	P_i	**gen**
$x_1 = x_2$	x_1 **op** $const$	x_2 **op** $const$
	x_2 **op** $const$	x_1 **op** $const$
$x_1 \neq x_2$	$x_1 = const$	$x_2 \neq const$
	$x_2 = const$	$x_1 \neq const$

Dual Variable Predicates

P_{double}	P_i	**gen**
$x_1 = x_2$	x_1 **op** $const$	x_2 **op** $const$
	x_2 **op** $const$	x_1 **op** $const$
$x_1 \neq x_2$	$x_1 = const$	$x_2 \neq const$
	$x_2 = const$	$x_1 \neq const$

[1] **b = x.foo();** $\langle$ **x** $\neq$ **null** $\rangle$ $\langle y = null \rangle$ $\langle$ **x** $=$ **null** $\rangle$

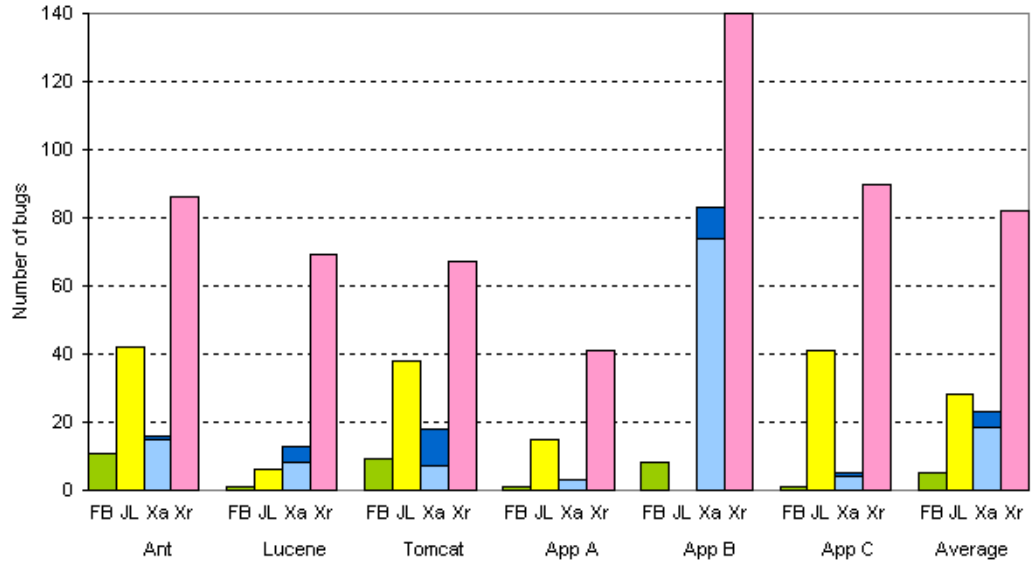
[2] **if (x == y)** $\langle y = null \rangle \langle x = null \rangle$

[3] **y.bar();** $\langle y = null \rangle$

Instanceof

$[1]$	**if (el instanceof T)**	$\langle$ **el** $\neq$ **null** $\rangle$ $\langle$ **el** $=$ **null** $\rangle$
$[2]$	**T ta = (T) el;**	$\langle el = null \rangle$
$[3]$	**ta.get();**	$\langle ta = null \rangle$

Empirical Evaluation - Accuracy



XYLEM**-inter detects 16 times as many bugs as** FINDBUGS **and 3 times as many bugs as** JLINT**.**

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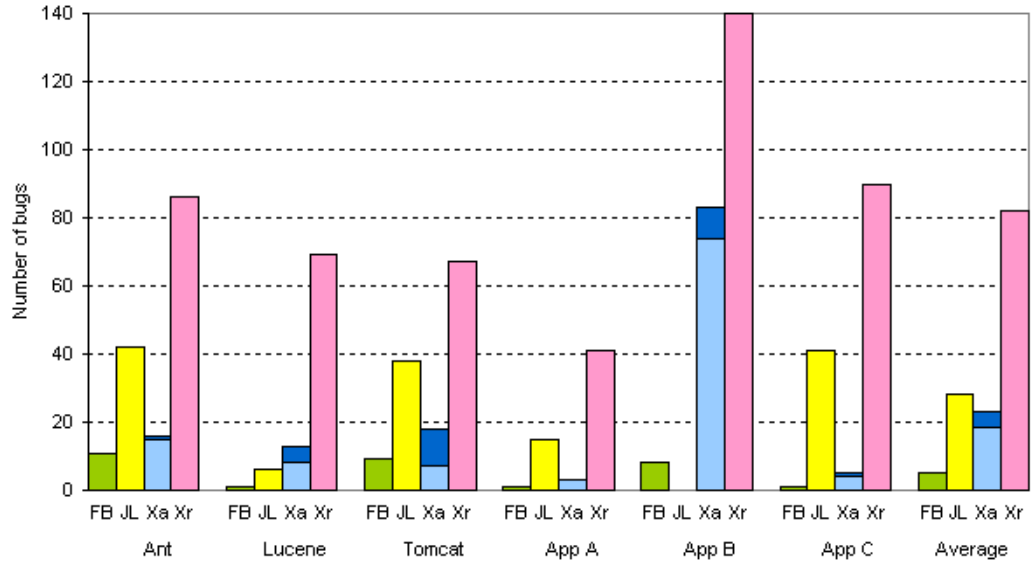

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- less than 5% of the intraprocedural bugs were invalidated by interprocedural analysis.

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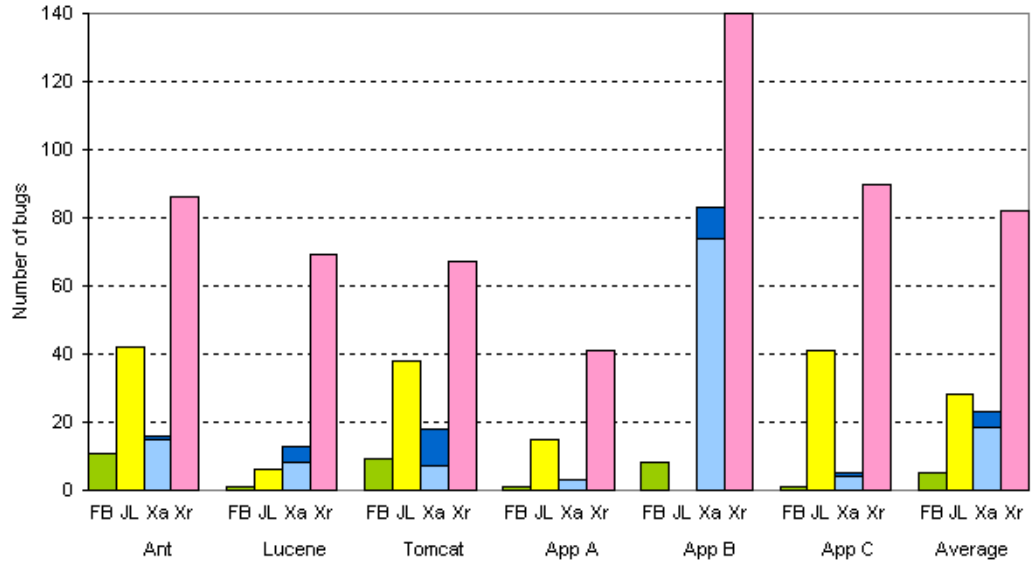

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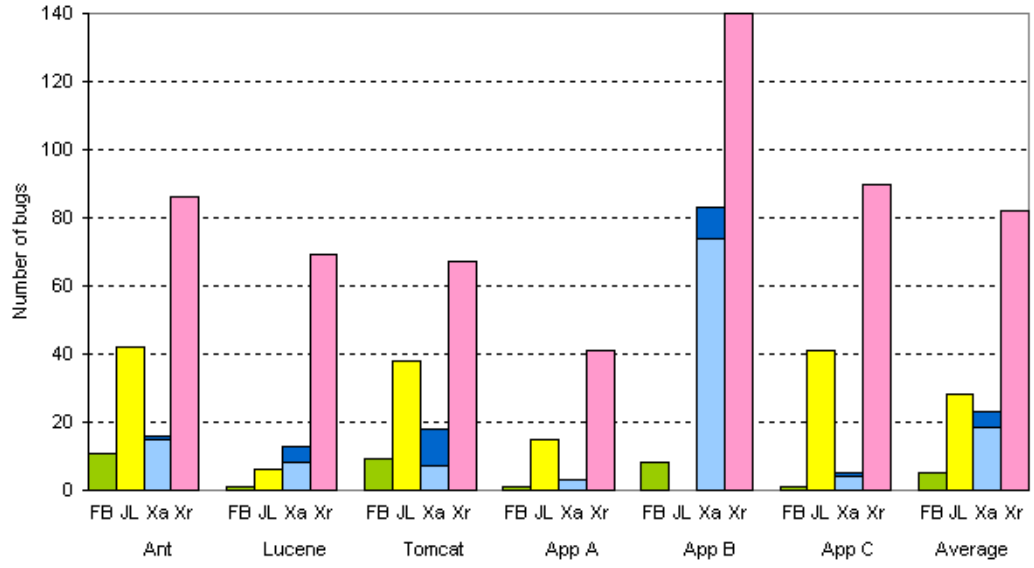

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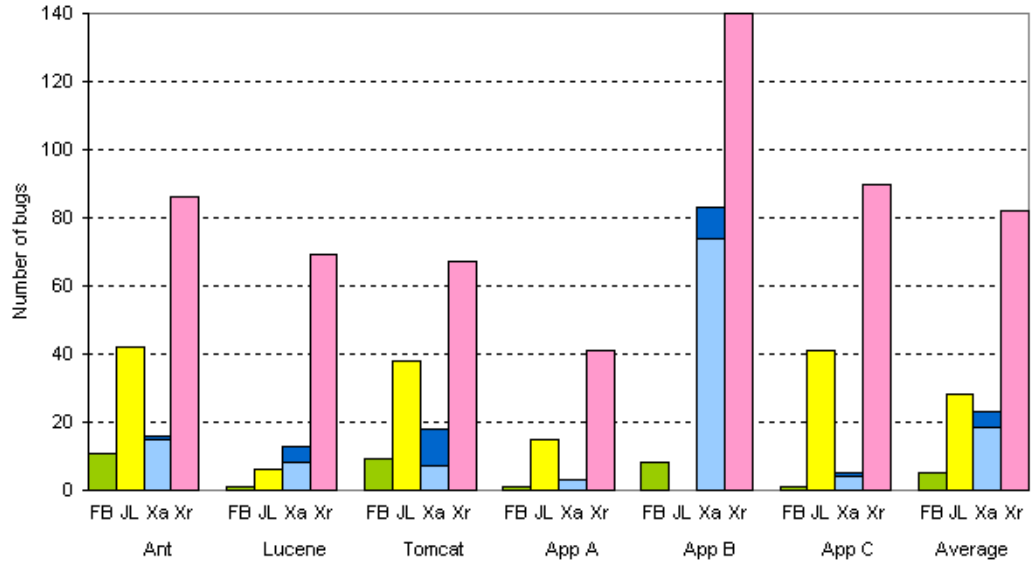

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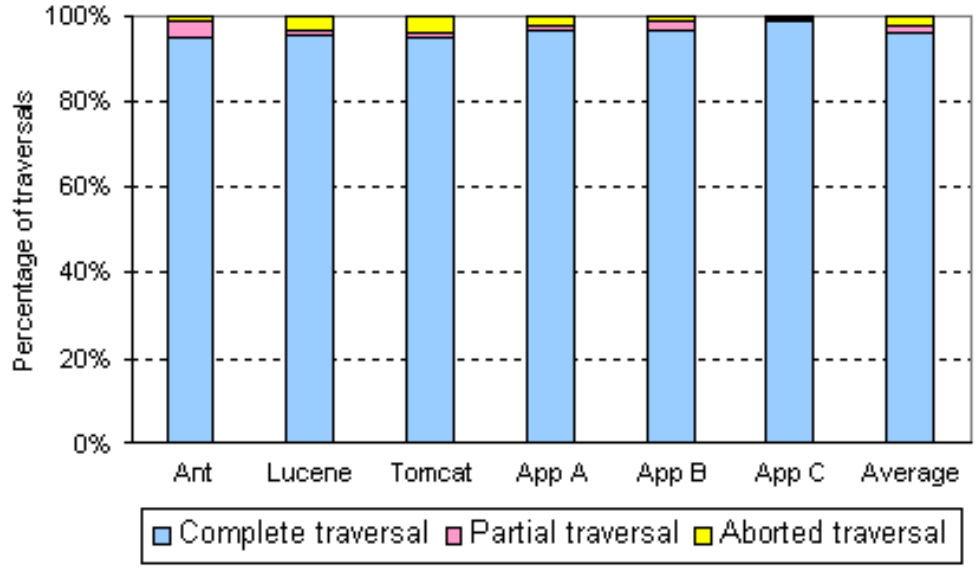
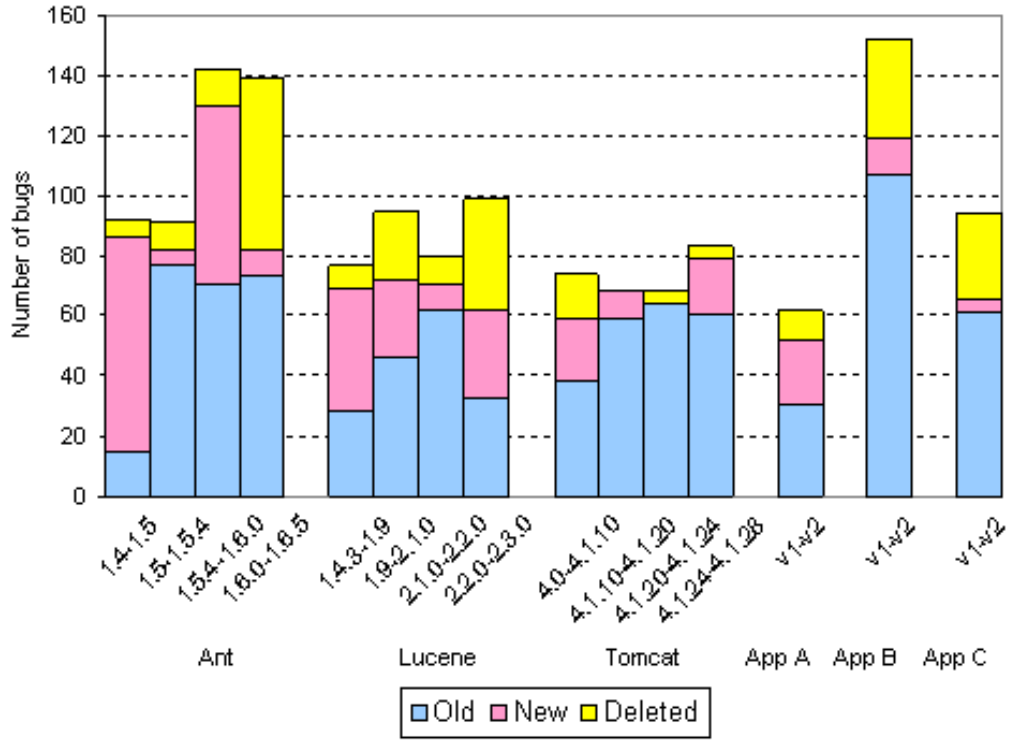
- FINDBUGS reported one interprocedural bug. JLINT reported 7. XYLEM-inter reported 66.
- XYLEM-inter detected each true positive (intra or interprocedural) reported by either FINDBUGS or JLINT, and invalidated each false positive reported by FINDBUGS and JLINT.

Empirical Evaluation - Efficiency



- **The two-second time limit caused less than 1% of the traversals to abort.**
- **Partial traversals, caused by path and state limits, overall, were about 2%.**
- **For three subjects, more than 97% of the traversals were complete**
- **The largest application analyzed by XYLEM contains over 1,009,000 lines of code. The analysis completed in approximately 3 hours and 30 minutes.**

Empirical Evaluation - Relevance



- **The number of deleted bugs is an indicator of the relevance of the identified bugs.**
- FINDBUGS **reported bugs, 11 (10%) were deleted. For** XYLEM **257 (24%) bugs were deleted.**

Conclusions and Future Work

- We have presented an accurate analysis for detecting null-dereference bugs in Java programs.
- Our analysis detects bugs that many commonly used tools miss, and it eliminates the false positives that other tools report.
- Our studies illustrate the efficiency of the analysis and the relevance of the detected bugs.
- Our tool has been deployed with several product-development teams in IBM, and preliminary feedback has been positive

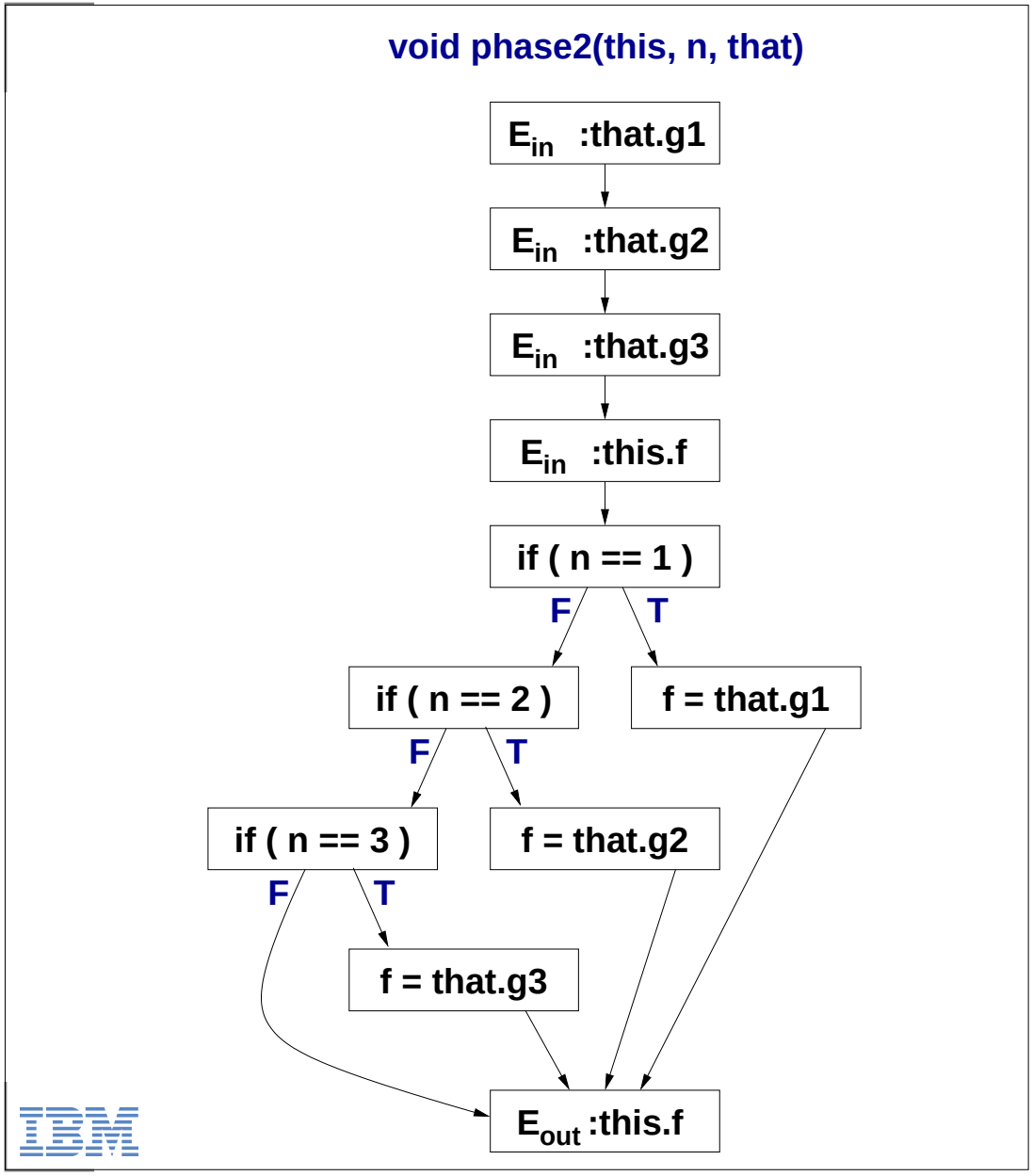
Future Work

- Comparison with sound analysis
- Prioritization of true positives
- Extension to other types of bugs, example resource-leak bugs

Genesis of the name Xylem

- XYLEM **is the transport tissue in plants whose basic function is to transport water from the root through the branches of the plant.**

Genesis of the name Xylem



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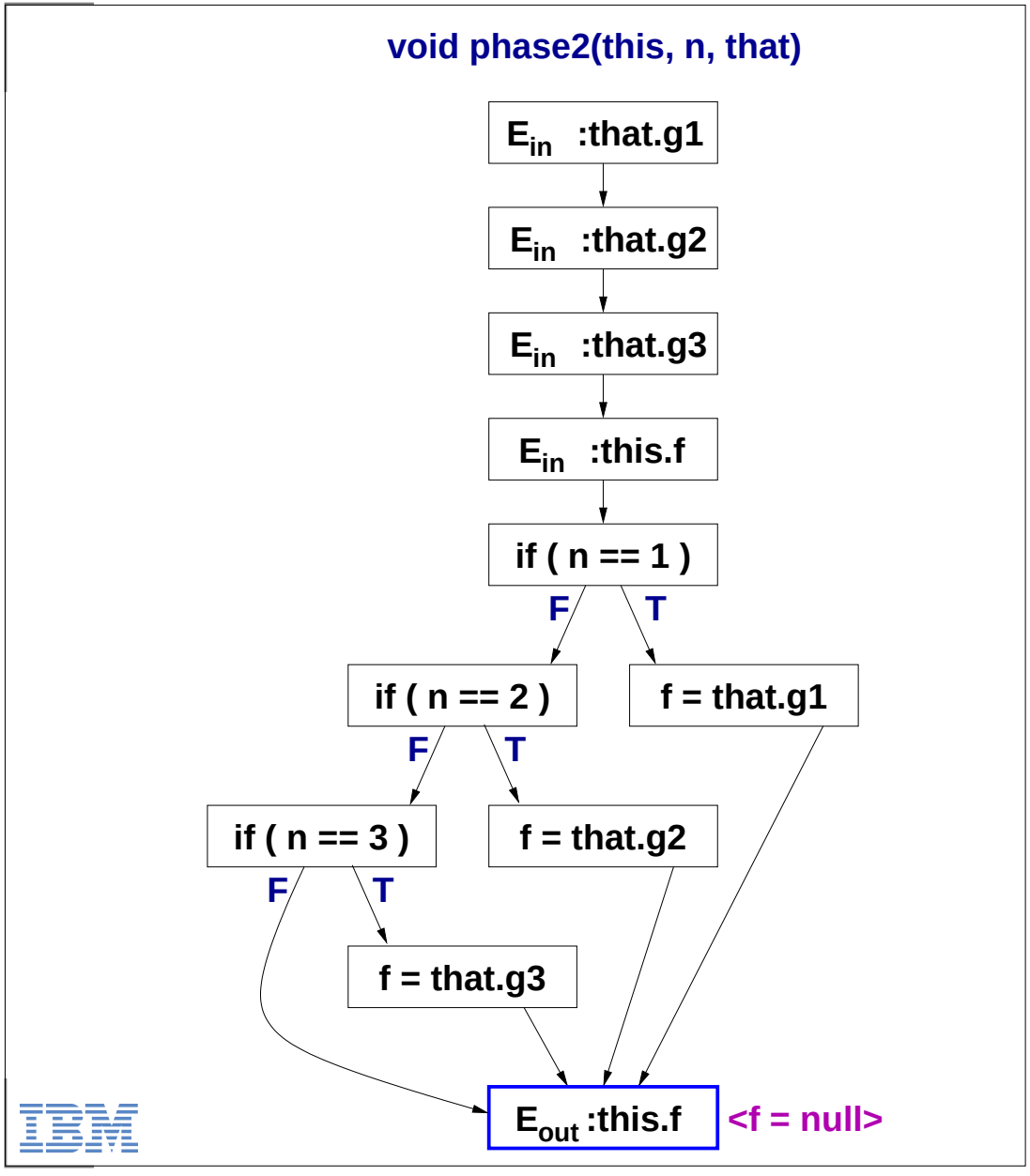

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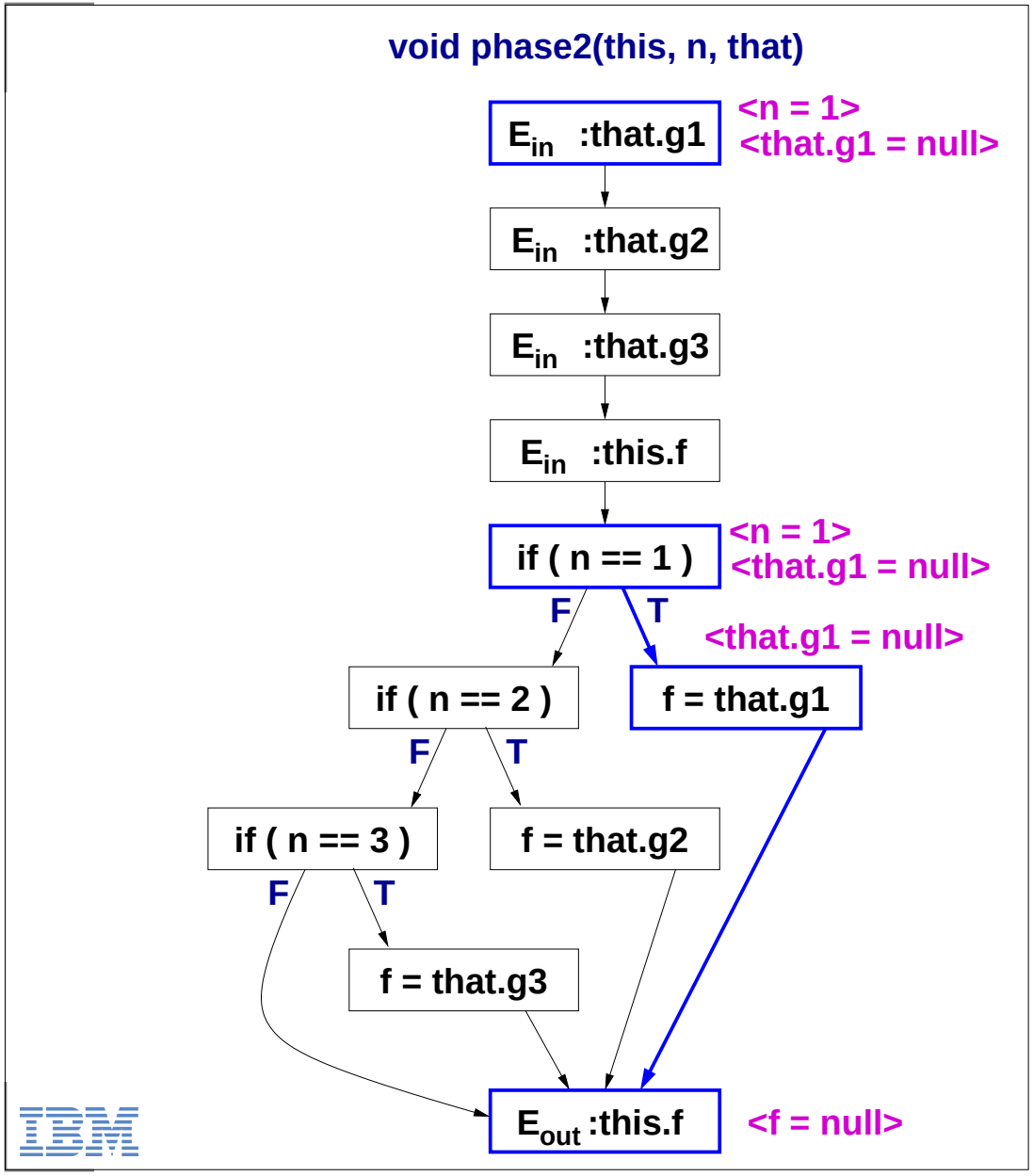

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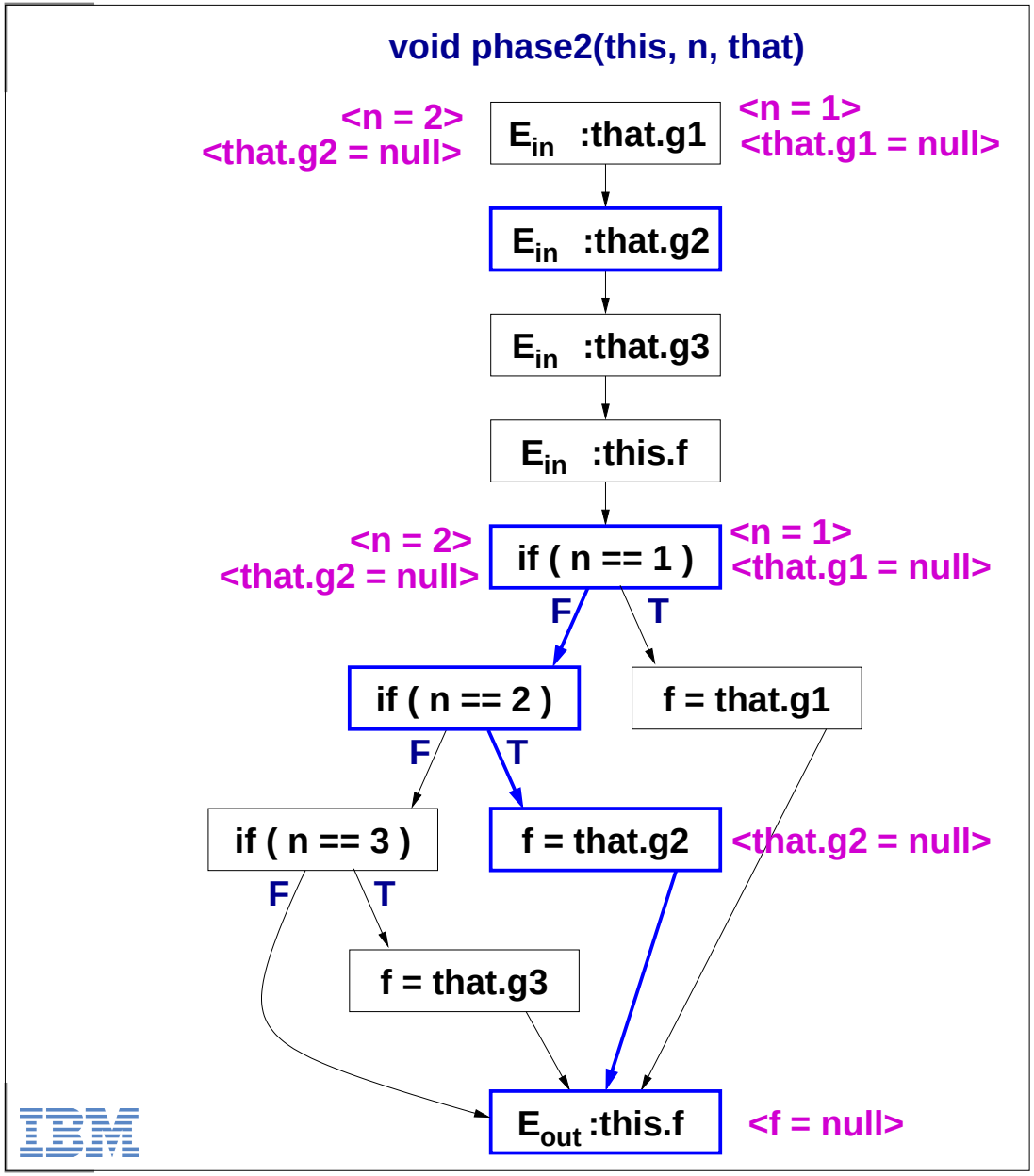

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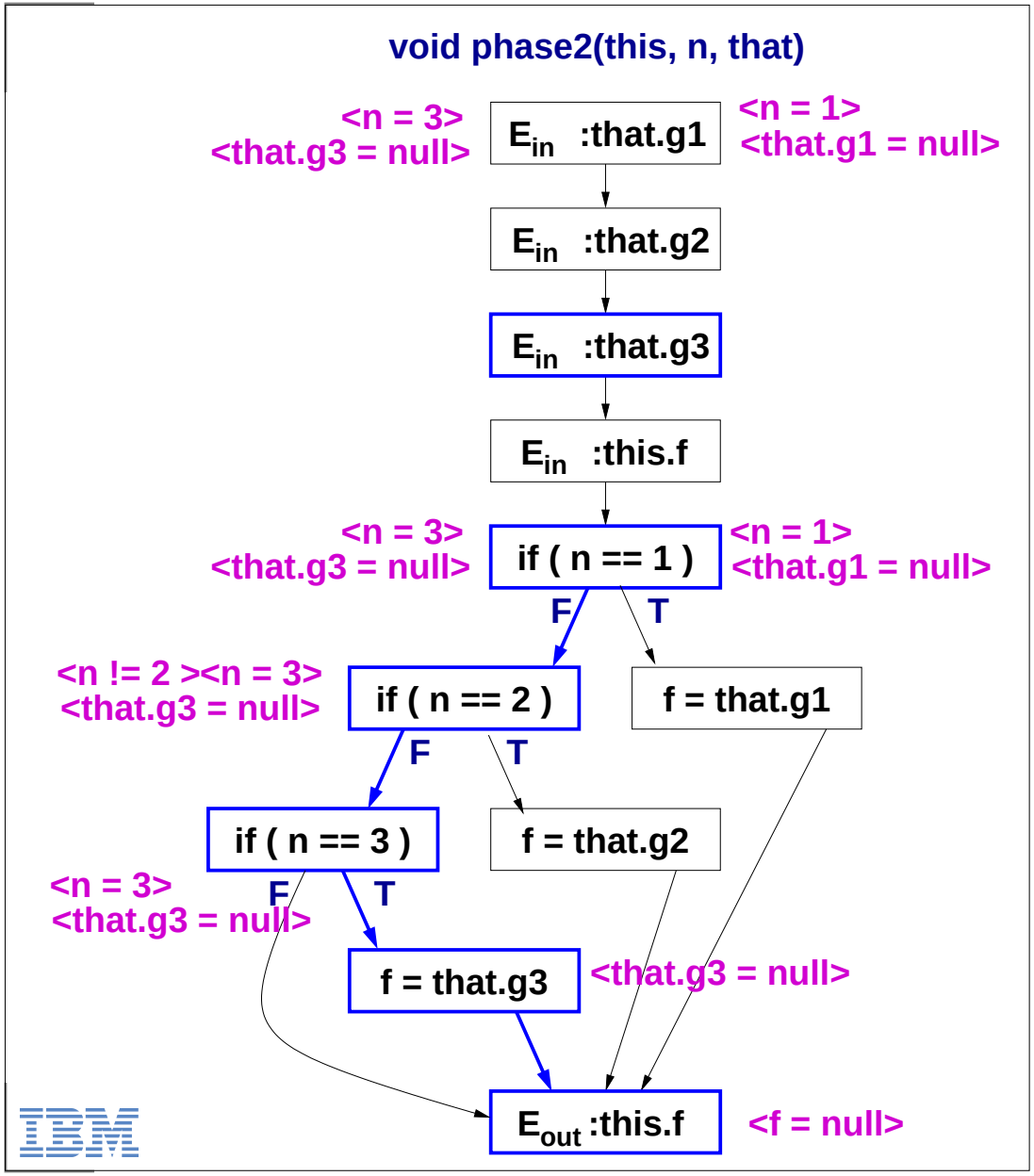

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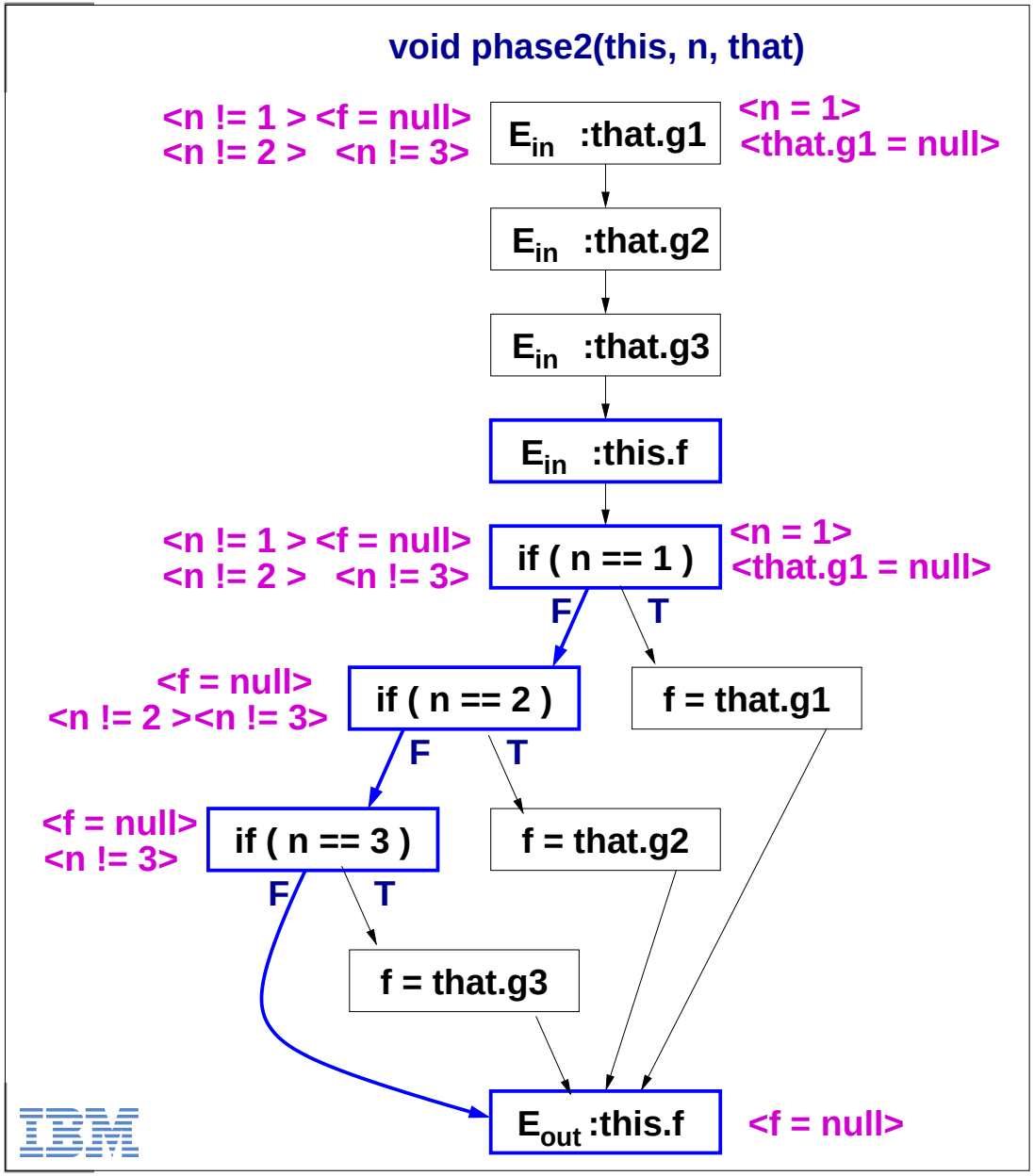

Questions