Purity Analyses

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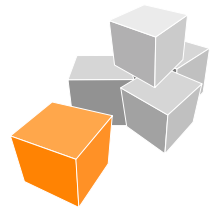

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Definitions

Methods can be free of side-effects and/or deterministic

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Side-effect freeness (SEF):

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Can use this distinction for:

- Program comprehension (interference with rest of program)
- Bug/code smell detection (e.g. unused return value)
- Optimizations (e.g. code motion)
- Formal specification/verification

Examples

```
static double radius, area;

void computeAreaImpure(){
    area = radius * radius * Math.PI;
}

double computeAreaSEF(){
    return radius * radius * Math.PI;
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static double radius, area;

void computeAreaImpure(){
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double computeAreaSEF(){
    return radius * radius * Math.PI;
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double computeAreaPure(double _radius){
    return _radius * radius * Math.PI;
}
```

Definitions (recap)

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While these may be sufficient for the uses cases mentioned, valuable extensions exist

External Purity [BF09]

Only (observable) side-effect is modification of receiver object

- field setters, initialization methods, ...
- respects abstraction boundaries
- allows finding confined side-effects

[BF09] Benton, W.C. and Fischer, C.N.
Mostly-functional behavior in Java programs, VMCAI'09

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Generalization to **contextual purity**:

- side-effects restricted to parameters
- e.g. `System.arraycopy`
- allows finding more confined side-effects

[BF09] Benton, W.C. and Fischer, C.N.
Mostly-functional behavior in Java programs, VMCAI'09

Domain-Specific Purity

- restricted forms of impurity
- relevant for some but not all domains
- e.g. logging [SCD16], exceptions

```
int divide(int a, int b) {
    Log.log("Performing division");
    return a/b; //Potential ArithmeticException
}
```

[SCD16] Stewart, A., Cardell-Oliver, R., Davies, R.
Fine-grained classification of side-effect free methods in real-world Java code and applications to software security, ACSW'16

Compile-Time Purity

Even pure methods may not simply be elided at compile time:

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private final long startupTime =
    System.currentTimeMillis();

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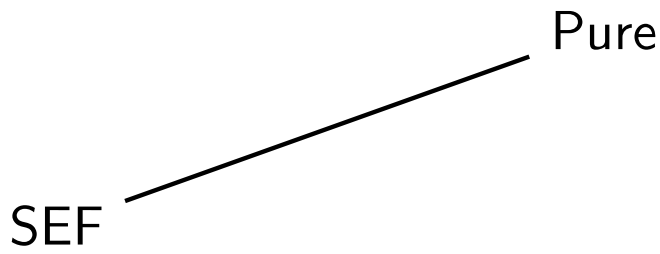
Requires another level of purity: **Compile-time purity**

Purity Lattice



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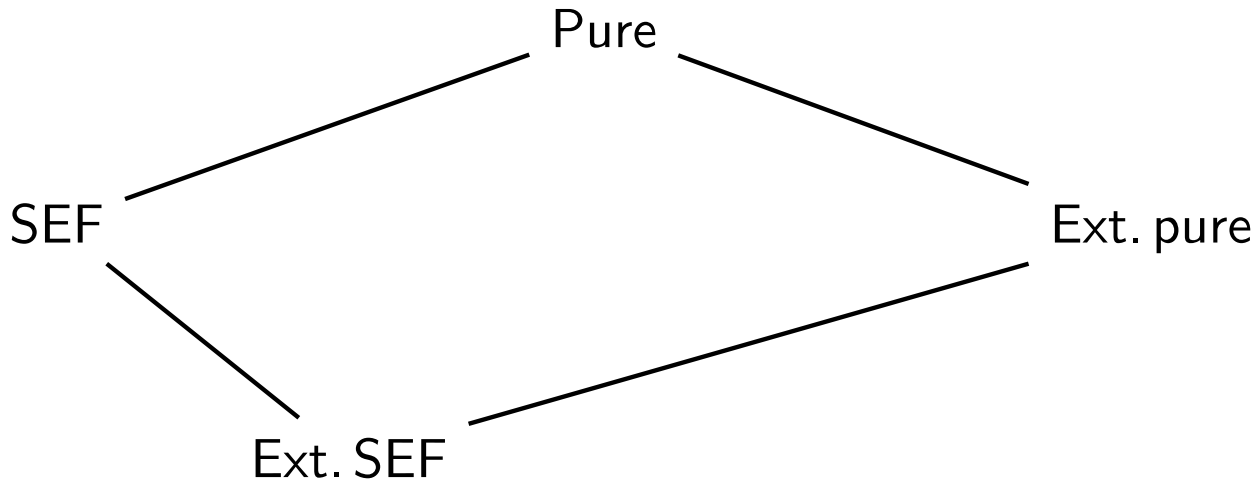

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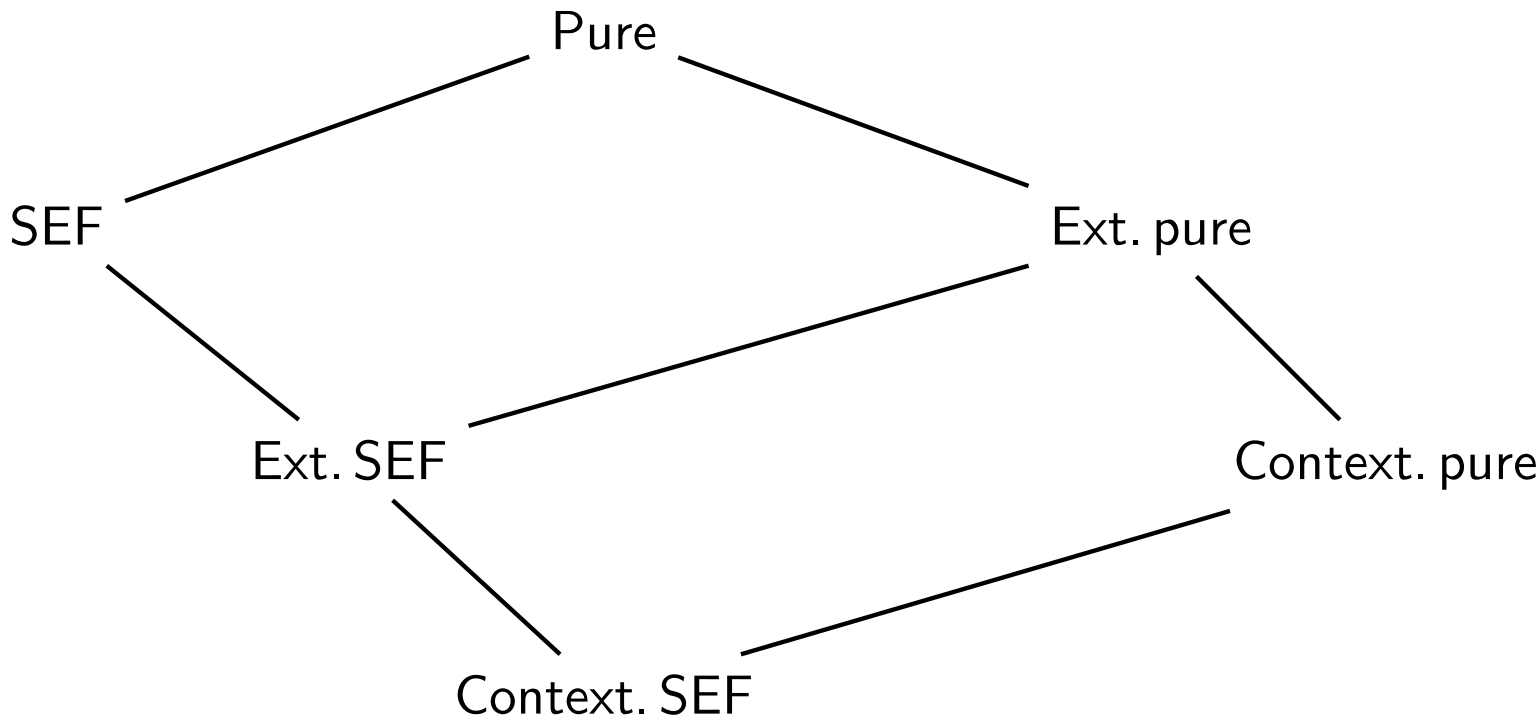

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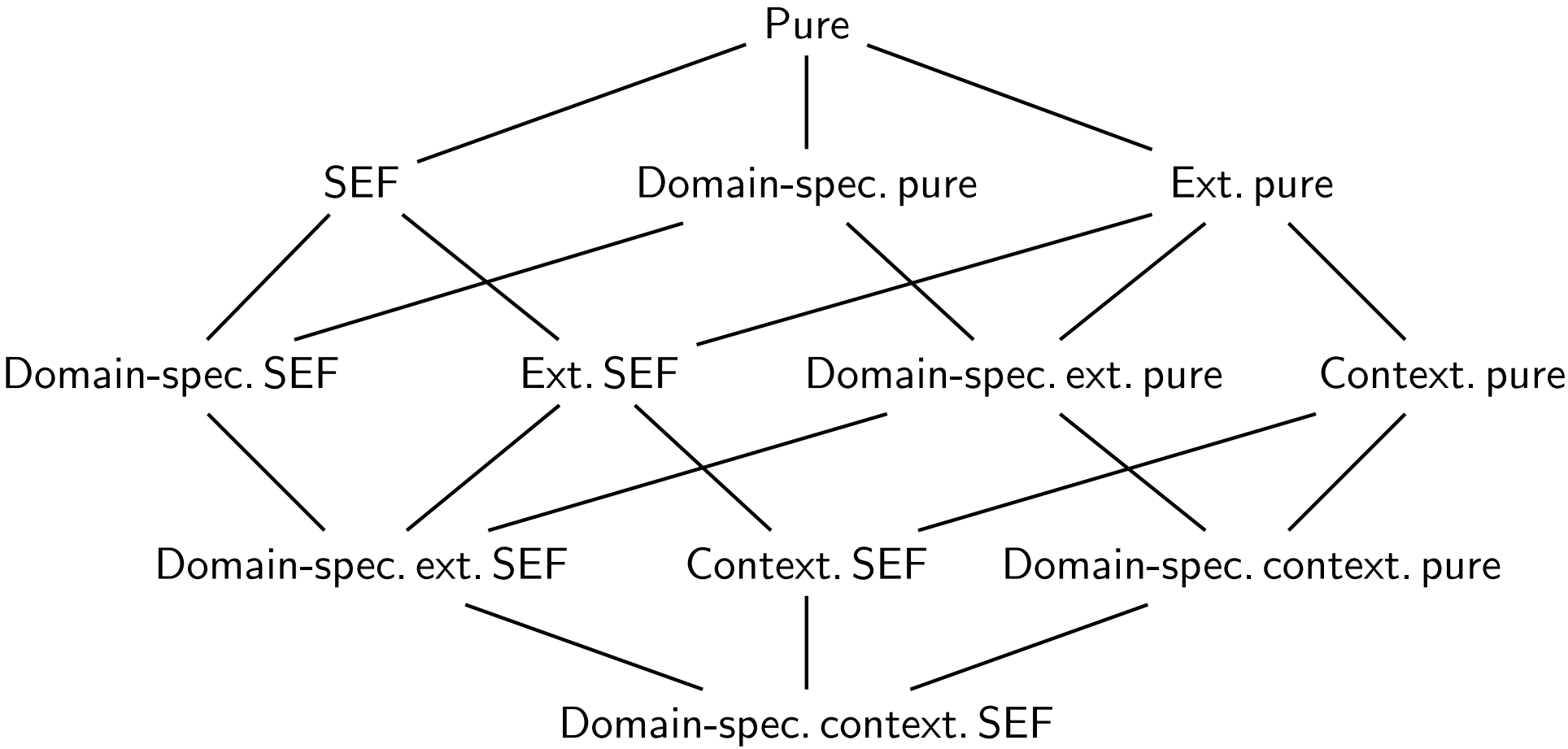

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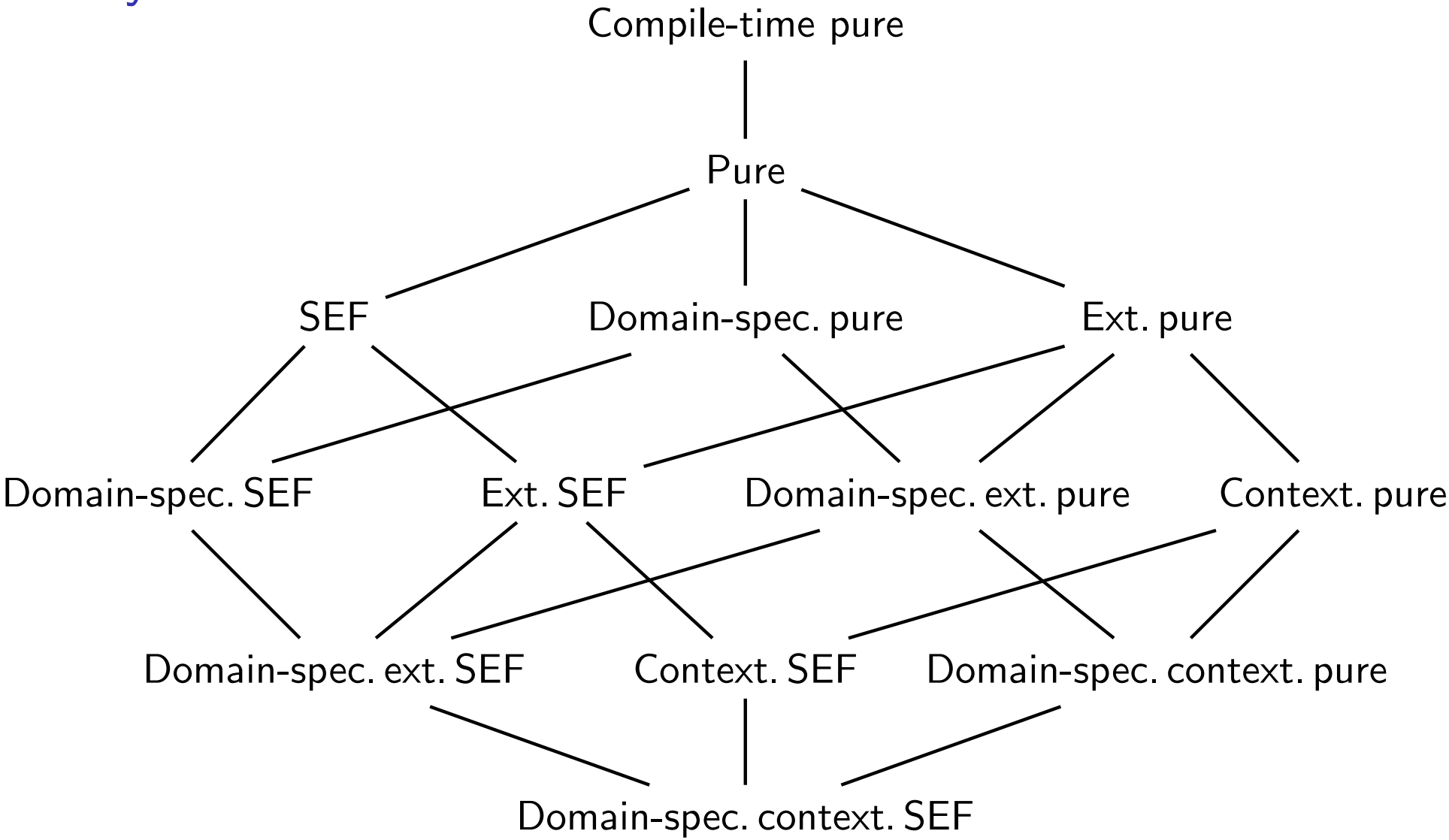

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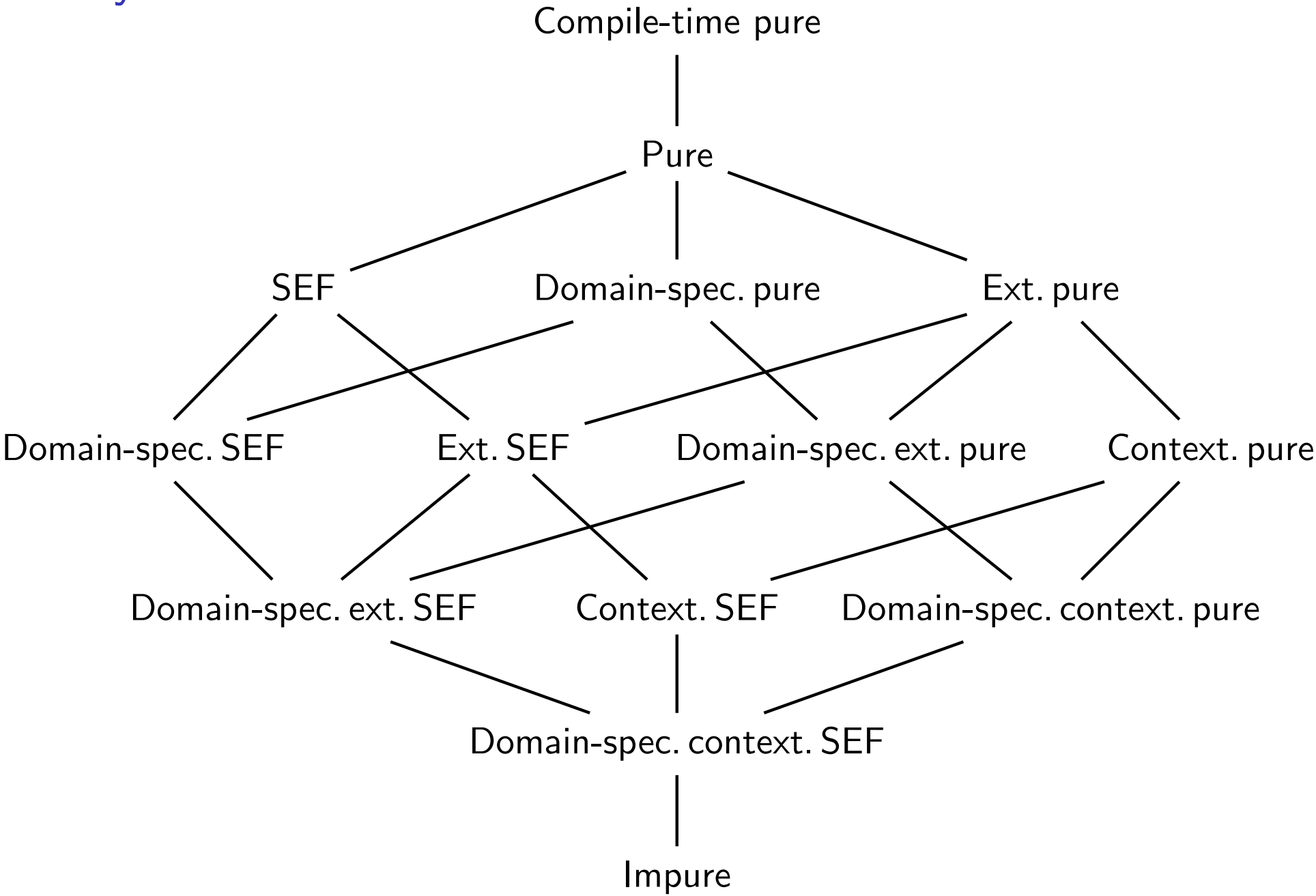

OPAL

OPAL's purity analysis

- analyses each method assuming **purity**
- scans the intermediate representation, enriched with abstract interpretation results (refined types, def-use chains, ...)
- searching for counterexamples
- and collecting dependencies

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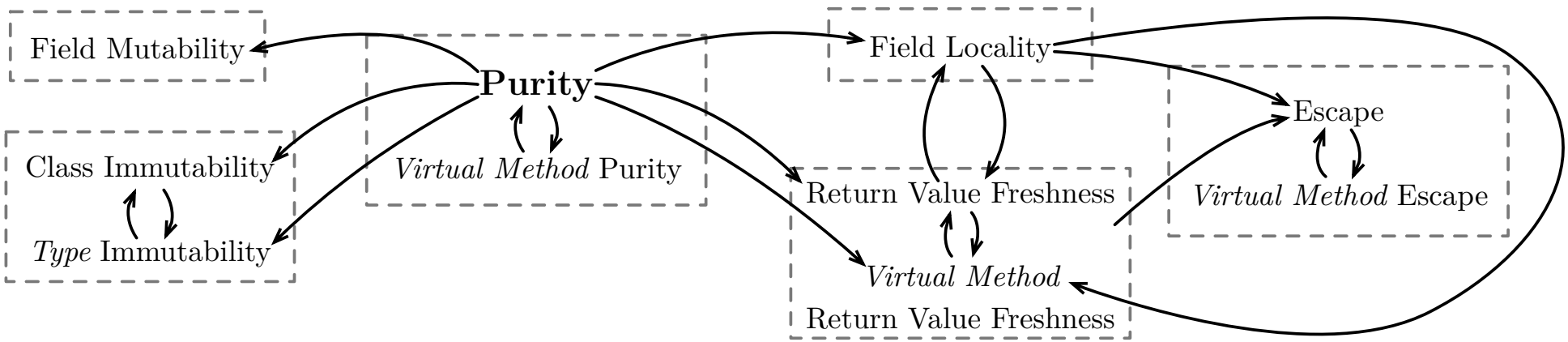

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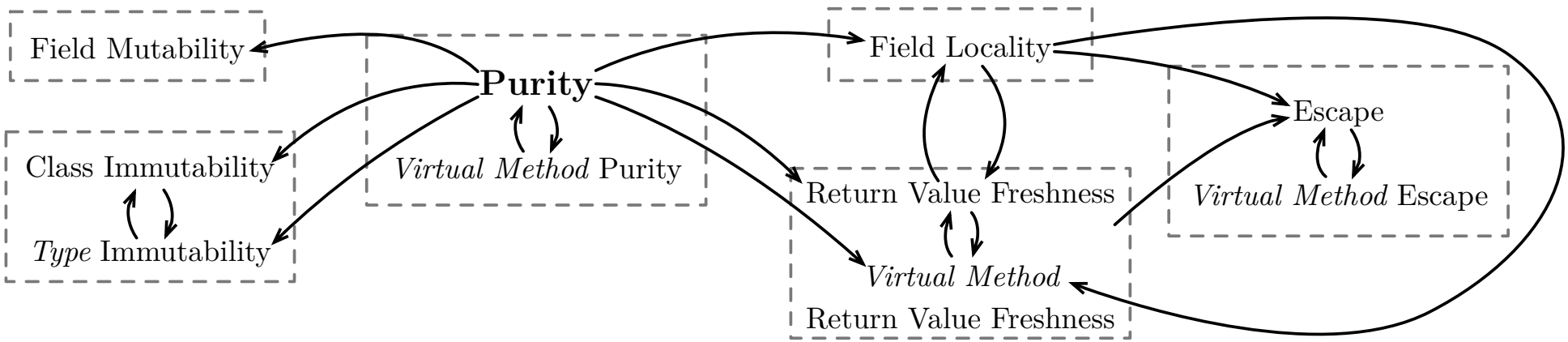
- and collecting dependencies
- which are resolved automatically



Corpus	**XCorpus**		**JDK8**	
Methods	469 727		253 282	
Pure	73 701	(15.69%)	44 378	(17.52%)
Domain-specific pure	9 628	(2.05%)	8 250	(3.26%)
Side-Effect Free	45 268	(9.64%)	18 234	(7.20%)
Domain-spec. SEF	22 056	(4.70%)	14 717	(5.81%)
Externally pure	19 467	(4.14%)	4 229	(1.67%)
Externally SEF	2 380	(0.51%)	3 414	(1.35%)
Domain-spec. ext. pure	639	(0.14%)	354	(0.14%)
Domain-spec. ext. SEF	2 467	(0.53%)	1 738	(0.69%)
Contextually pure	4	(0.00%)	7	(0.00%)
Contextually SEF	7	(0.00%)	48	(0.02%)
Dom.-spec. cont. pure	522	(0.11%)	547	(0.22%)
Dom.-spec. cont. SEF	1 523	(0.32%)	1 277	(0.50%)
Impure	292 065	(62.18%)	156 089	(61.63%)

Program	Batik	Xalan
ReIm [HM12]		
Analyzed methods	16 029	10 386
At least Side-Effect Free	6 072 (37.88%)	3 942 (37.95%)
Execution time	103s	140s
OPIUM (our tool)		
Analyzed methods	15 911	10 763
At least Side-Effect Free	6 780 (42.61%)	4 390 (40.79%)
Pure	4 009 (25.20%)	2 492 (23.15%)
Ext./Context. Pure/SEF	+987 (6.20%)	+748 (6.95%)
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ReImInfer: Method purity inference for Java FSE'12

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Recap

- Definitions for side-effect freeness and purity
- External and contextual purity
- Domain-specific purity
- Unified lattice model
- Fast and precise analysis

Try it yourself: http://www.opal-project.de/OPIUM.html

Current and Future Work

- Modularize and improve more analyses
  - Call graphs
  - Immutability of Classes/Fields
  - Points-To/Alias analysis
  - ...
- New concepts for IFDS/IDE analysis
- Parallelizing computations in FPCF