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Points-To Analysis: Provenance Generation

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Points-To Analysis

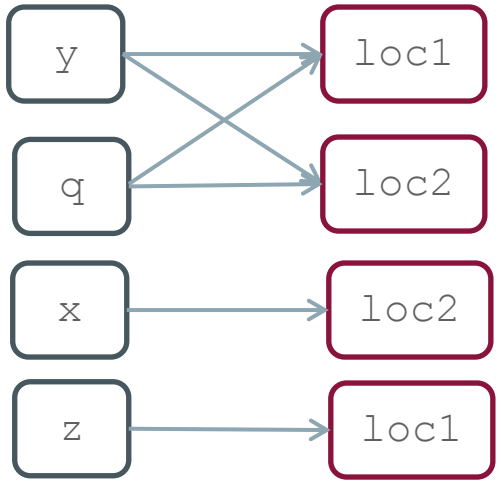
Object-Oriented Languages

- Which variables “may point-to” which objects
  - Andersen: Flow-Insensitive, subset based
  - Steensgaard: Flow-Insensitive, equality based
  - Allocation site abstraction
  - Access-path abstraction
- Basis of other analyses
  - Taint, Escape
- Tutorial by Yannis Smaragdakis

Andersen's Points-to

Example

- Allocation site abstraction




```
public void bar() {
    z = new T();    // loc1
    foo(z);
}

public void baz() {
   x = new T();    // loc2
   foo(x);
}

private void foo (T q) {
     T y = q;
}
```

- Scales for large code bases
  - JDK: 2M variables/500K allocation sites

Points-To Analysis

Implementation

- Declarative specification: Datalog

```
VarPointsTo(x, obj) :- VarPoints(y, obj), Assign(x, y).
```

- Taint Analysis

```
Tainted(x) :- VarPointsTo(x, obj), TaintedObject(obj).
```

- Escape Analysis:

```
Escapes(obj) :- VarPointsTo(x, obj), ReturnVar(x, method),
                Public(method).
```

- DOOP framework from Yannis Smaragdakis
  - Soufflé engine

Points-To Analysis

Implementation

- Propagates/Uses points-to information
  - Reason/Provenance not explicit stored
  - ✓ `VarPointsTo(x,obj)`
  - ✗ `Assign(x,y), Assign(y,z), "z = new obj()"`

- Infeasible to explicitly store all provenance information
  - Preliminary Investigation: Each tuple requires about 50 more tuples for provenance

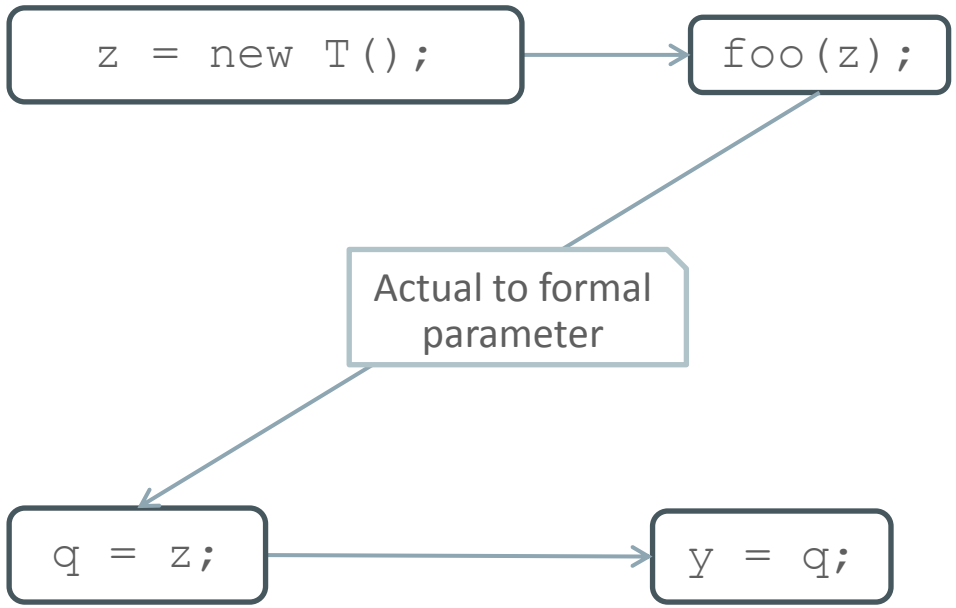
Points-To Analysis

Usability Issues/Challenges

- Debugging: Classify results as True Positives or False positives
  - Why does variable x point to object o?
- Visualisation
  - Show me a taint/escape trace?
- Requires *provenance information*
- Challenge: Provenance generation for large code-bases
  - At least 1 million variables and 300 thousand allocation sites
  - Motivated by various subsets of the JDK

Provenance

Example

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```

Problem Statement

- Given
  - Results of context sensitive points-to analysis
  - **Client** specified queries: Variable `var` points to location `loc`
- Find "*all provenance traces*" for each of the queries *using pre-computed results*
  - May points-to: All traces must be infeasible for report to be a False Positive
- Resource limits
  - Typical clients: Provenance generation less than 10% of points-to analysis

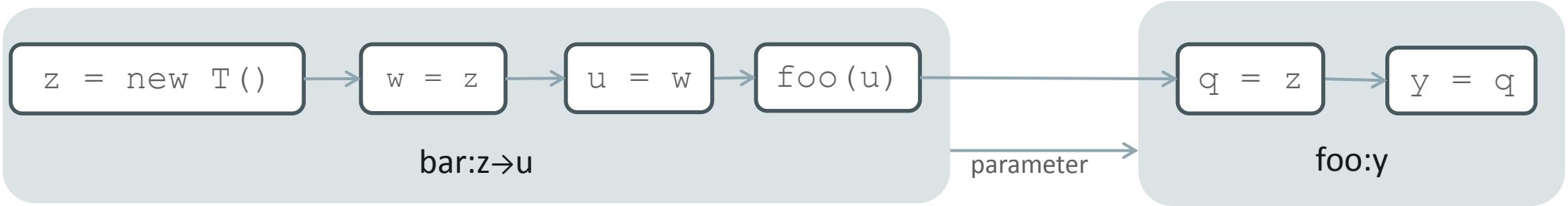
Solution: Abstract Actual Trace

Interprocedural Flow

- Track only flows between method boundaries

```
public void bar() {
   z = new T();
   w = z;
   u = w;
   foo(u);
}
```

```
private void foo(T q)
{
   T y = q;
}
```



Solution: Abstract Actual Trace

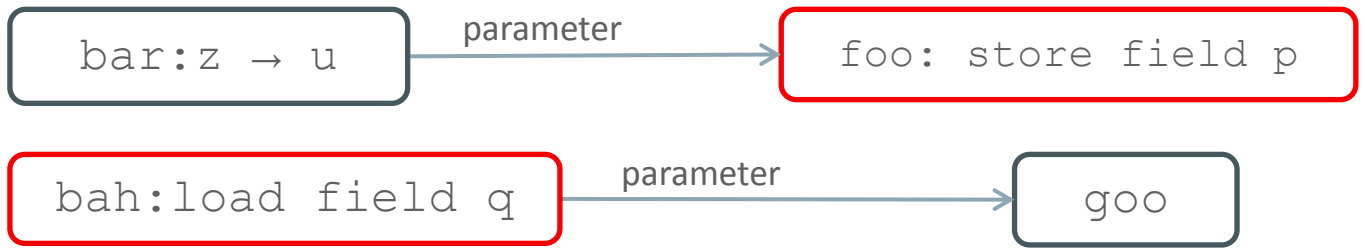
Dataflow via Fields: Alias of base objects

- Load/Store also between method boundaries

```
public void bar() {
   z = new T();
   w = z;
   u = w;
   foo(u);
}
```

```
private void foo(T p){
   field = p;
}
```

```
public void bah(){
   T q = field;
   goo(q);
}
```



Dataflow via Fields: Alias

Depth Limitation

- Alias of base variables can depend on alias of other variables
- Cascading alias
  - Expensive to compute
  - Hard to visualise
  - Increases FPs
- Solution:
  - Limit depth to 1 or 2
  - Sufficient for most traces

Reusing Information

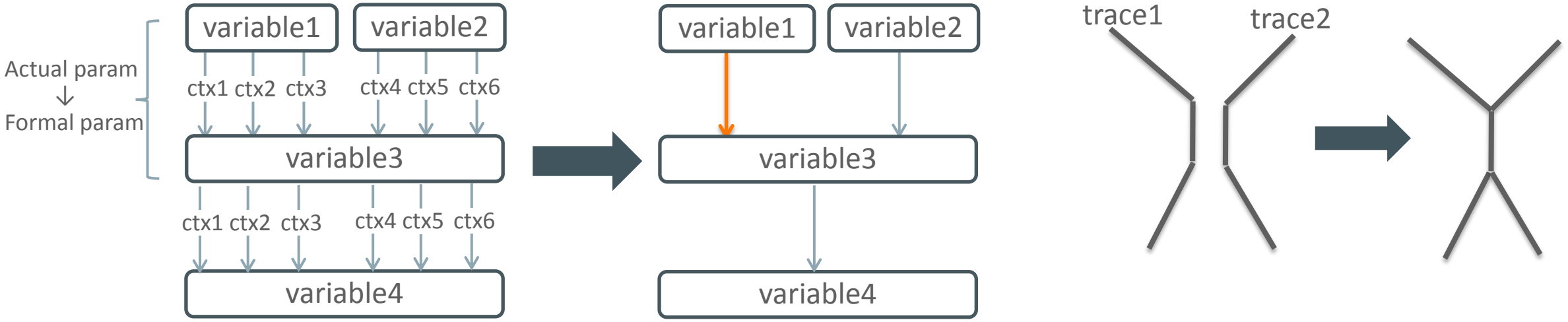
- Method boundaries: Identified using computed call-graph edge
- Load/Store pairs: Alias computed using points-to information
- Provenance: Identifies only such methods/variables/fields
- Optimisation: Remove irrelevant methods
  - Methods that return parameter

```
public T check(T v) {
      if (v != null) return v;
      throw new Exception("error");
}
```

Context Sensitivity

- Context in traces: Not scalable
- Solution: Contexts not part of the trace; but used to construct trace

$\exists ctx, ctx', hctx: (hctx, loc, ctx, variable1) \in VP \;\&\; (hctx, loc, ctx', variable2) \in VP$ & CallGraphEdge(ctx, …, ctx', …)



Results

Subsets of Various Versions of the JDK

Code-Base	VarPointsTo Size (tuples)	Client	#Client Queries	Provenance Graph			Time Overhead	Memory Overhead
				Nodes	Edges	Max Degree		
Subset Version-1	539Million	Taint	836	4287	8538	112	25%	3.4%
		Escape	10	13	14	2	1%	9.0%
Subset Version-2	871Million	Taint	900	4563	6774	105	23%	2.2%
		Escape	445	1115	6663	33	3.0%	8.8%

Results: Alias Graph

Context-Sensitive Points-To Analysis: Depth 1

Code-Base	Client	Alias Graph		
		Nodes	Edges	Max Degree
Subset Version-1	Taint	23,791	98,245	136
	Escape	0	0	0
Subset Version-2	Taint	12,484	16,443	35
	Escape	7,588	28,180	37

Presentation

- Graphviz
- Parfait: Internal format
- Shortest path
- Acyclic path
- Time/Output: Depends on size provenance graph
  - Taint analysis: Computing acyclic paths times-out

Graphviz: Example

```
public class Test {
  public static class Value {}
  public static class Holder {
    public Value v;
  }

  public static void entryPoint() {
    Holder h = new Holder();
    setup(h);
    read(h);
  }

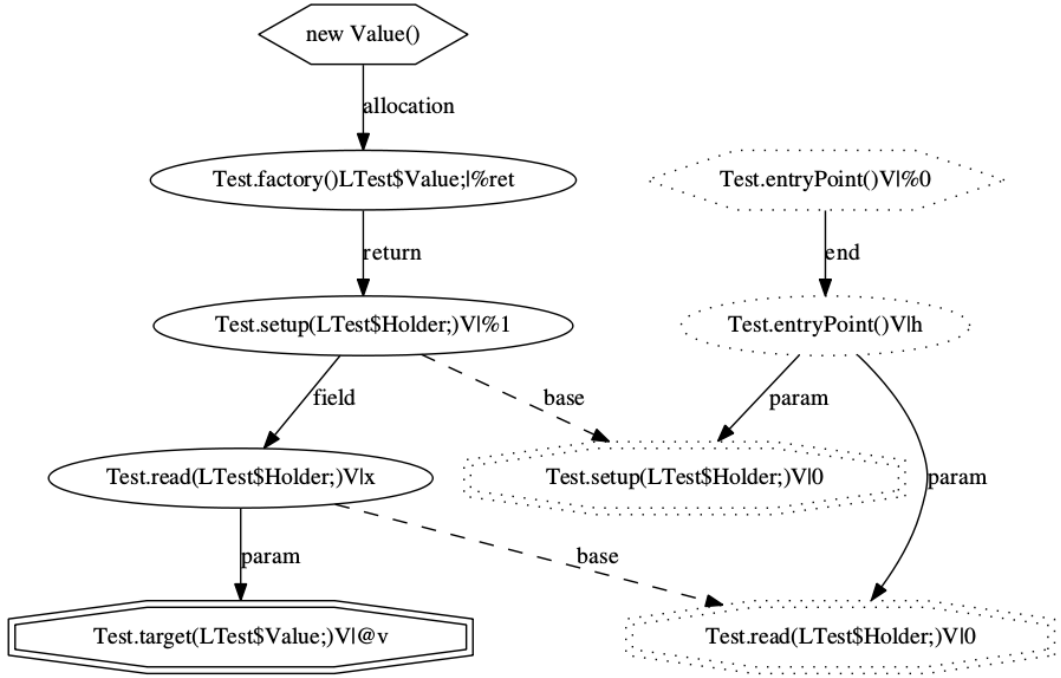
  private static Value factory() {
    return new Value(); }

  private static void setup(Holder h) {
    h.v = factory(); }

  private static void read(Holder h) {
    Value x = forward(h.v);
    target(x); }

  private static void target(Value v) { ... }

  private static Value forward(Value v) {
    return v; }
}
```



Conclusion

- Provenance using sequence of method invocations
  - Limited control flow paths
- Reuse points-to for call-graph and alias analysis
- Scales for JDK
  - Time threshold of 10% not met: Further optimisations required
- Challenges
  - Support flow-sensitive analysis
  - Dynamic Traces: Querying mechanism of provenance information
  - Better UI for trace representation

Questions

Points-To Analysis: Provenance Generation

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