Scalable Context-Sensitive Points-To Analysis

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Motivation

- Principal aim: Security analysis of JDK
- Security analysis: Flow of objects through the program
  - Objects created by untrusted code may not flow to a security sensitive operation
  - Sensitive objects may not escape to untrusted code

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Solution

- Value Flow Analysis
- Points-to analysis: Objects a variable may reference
  - Result of value flow analysis
- Points-to analysis: Security analysis
  - Taint: Variable in trusted code points to object created by untrusted code
  - Escape: Object created by trusted code pointed to by variable in untrusted code

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Points-To: Choices

- Context-insensitive
  - Not sufficiently precise: Numerous false positives
- Context-sensitive
  - Numerous choices: callsite, receiver/allocator object
  - 2-Object+1-Heap: *Does not scale for JDK*

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Problem Size: Open JDK7-b147

- 1.3 Million variables
- 200,000 methods
- 600,000 potential invocations
- 400,000 object creation sites

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Points-To: Open JDK7-b147

Intel Xeon E5-2660 (2.2GHz) 256GB RAM, Using DOOP and the LogicBlox Engine

Analysis	Time	Size of Result/Outcome
Context-Insensitive	20 minutes	≈ 1 Gigatuples
1-Callsite-Sensitive	20 hours	Does not terminate
1-Object-Sensitive	20 hours	Does not terminate
2-Heap+1-Object	20 hours	Runs out of memory

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Constraining Problem Space

Motivation: Security

- Computing points-to information **not** the ultimate goal
  - Client analysis needs points-to information to answer a query
  - Potential queries: Call-graph, Escape, Null, Taint
- Solution: Demand-driven analysis
  - Only compute information required to answer the query

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Approach

- Static program slicing and compaction
  - Client's queries as starting point
- Compute points-to in stages
  - Refinement approach
- Reduce program to semantically equivalent for points-to queries

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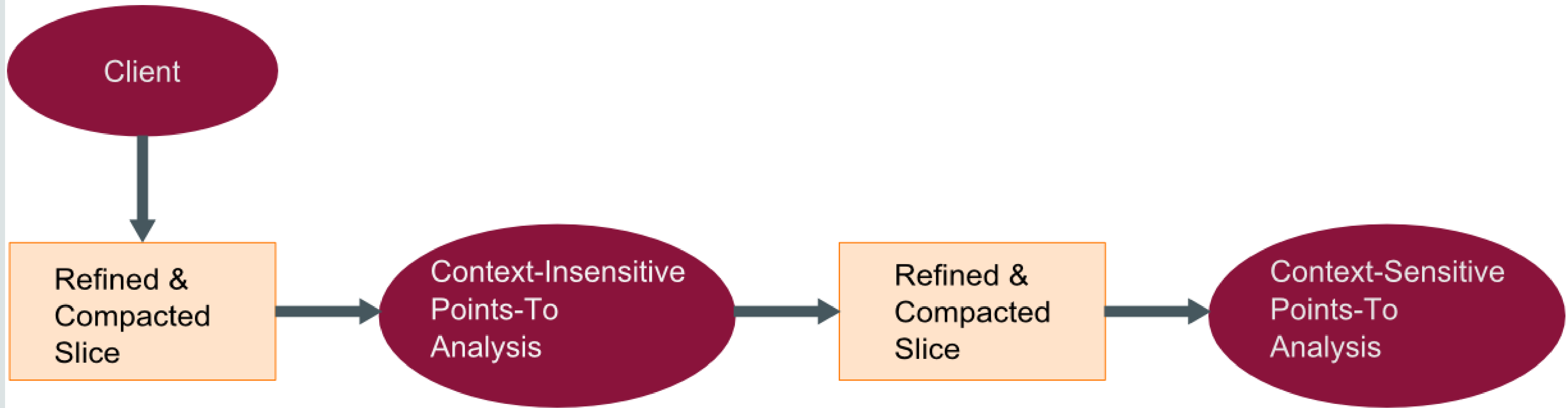
Architecture



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Slicing/Refinement

Three Steps

- Slicing using variables of interest
  - Very cheap and imprecise (no points-to), removes variables
  - Context-insensitive points-to computed on this slice
- Slicing using context-insensitive points-to information
  - More expensive but also more effective
  - Removes variables and object creation sites
- Context-sensitive points-to analysis
  - Computes final result

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Step 1

- Client identifies required variables
- Over-approximated call graph based on class hierarchy analysis (CHA)
- Sound/Imprecise backwards value-flow trace from the required variables
- Variables not involved in the value-flow trace removed

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Step 2

- Context-insensitive points-to is computed
- Backwards trace from required points-to locations
  - Similar to step 1
  - Points-to provides more precise call graph and value-flow information
  - Variables and heap objects not involved in the trace removed

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Example

```
class SecurityApplication {

    private static void doSecurity(SecurityObject secObj1,
                                   SecurityObject secObj2) {

      SecurityAction action1 = new SecurityAction();
      SecurityAction action2 = new SecurityAction();
      action1.object = secObj1;
      action2.object = secObj2;

      Object res1 = action1.invoke();
      Object res2 = action2.invoke();

      doOtherThings(res1, res2);
    }
```

Any call to `invoke` with an untrusted `object` field?

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Example: Backward Slice

```
class SecurityApplication {

    private static void doSecurity(SecurityObject secObj1,
                                   SecurityObject secObj2) {

      SecurityAction action1 = new SecurityAction();
      SecurityAction action2 = new SecurityAction();
      action1.object = secObj1;
      action2.object = secObj2;

      Object res1 = action1.invoke();
      Object res2 = action2.invoke();

      doOtherThings(res1, res2);
    }
```

Any call to `invoke` with an untrusted field?

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Example: Caller of Relevant Methods

```
class SecurityApplication {

    public static void main(String[] args) {
      String result = setup(args);
      System.out.println(result);

      SecurityFactory uFactory = new UntrustedSecurityFactory();
      SecurityFactory tFactory = new TrustedSecurityFactory();

      SecurityObject uObject = uFactory.getSecurityObject();
      SecurityObject tObject = tFactory.getSecurityObject();

      doSecurity(uObject, tObject);
    }
```

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Example: Slicing Callers

```
class SecurityApplication {

    public static void main(String[] args) {
      String result = setup(args);
      System.out.println(result);

      SecurityFactory uFactory = new UntrustedSecurityFactory();
      SecurityFactory tFactory = new TrustedSecurityFactory();

      SecurityObject uObject = uFactory.getSecurityObject();
      SecurityObject tObject = tFactory.getSecurityObject();

      doSecurity(uObject, tObject);
    }
```

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Example: Propagate Slicing Information

```
class SecurityApplication {

    private static void doSecurity(SecurityObject secObj1,
                                   SecurityObject secObj2) {

      SecurityAction action1 = new SecurityAction();
      SecurityAction action2 = new SecurityAction();
      action1.object = secObj1;
      action2.object = secObj2;

      Object res1 = action1.invoke();
      Object res2 = action2.invoke();

      doOtherThings(res1, res2);
    }
```

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Final Slice

```
class SecurityApplication {
    public static void main() {
      SecurityFactory uFactory = new UntrustedSecurityFactory();
      SecurityObject uObject = uFactory.getSecurityObject();
      doSecurity(uObject);
    }

    private static void doSecurity(SecurityObject secObj1) {
      SecurityAction action1 = new SecurityAction();
      action1.object = secObj1;
      Object res1 = action1.invoke();
   }
}
```

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Experimental Results

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Experiment: OpenJDK 7-b147

Using the DOOP Framework and the LogicBlox Engine

- Clients derived from Java Secure Coding Guidelines
  - Caller Sensitive Methods (e.g., `Class.forName()`)
  - `AccessController.doPrivileged()`
  - Identify locations of interest
  - Combine with Escape and Taint analysis
- Aim: To compute context-sensitive points-to for these clients
  - Security analysis beyond the scope of this work

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Experiment: Clients

- Four clients chosen for experimentation
  1. Caller-sensitive-methods with tainted input, and escaping values
  2. Caller-sensitive-methods with only tainted input
  3. Caller-sensitive-methods with only escaping values
  4. `AccessController.doPrivileged()` with tainted inputs

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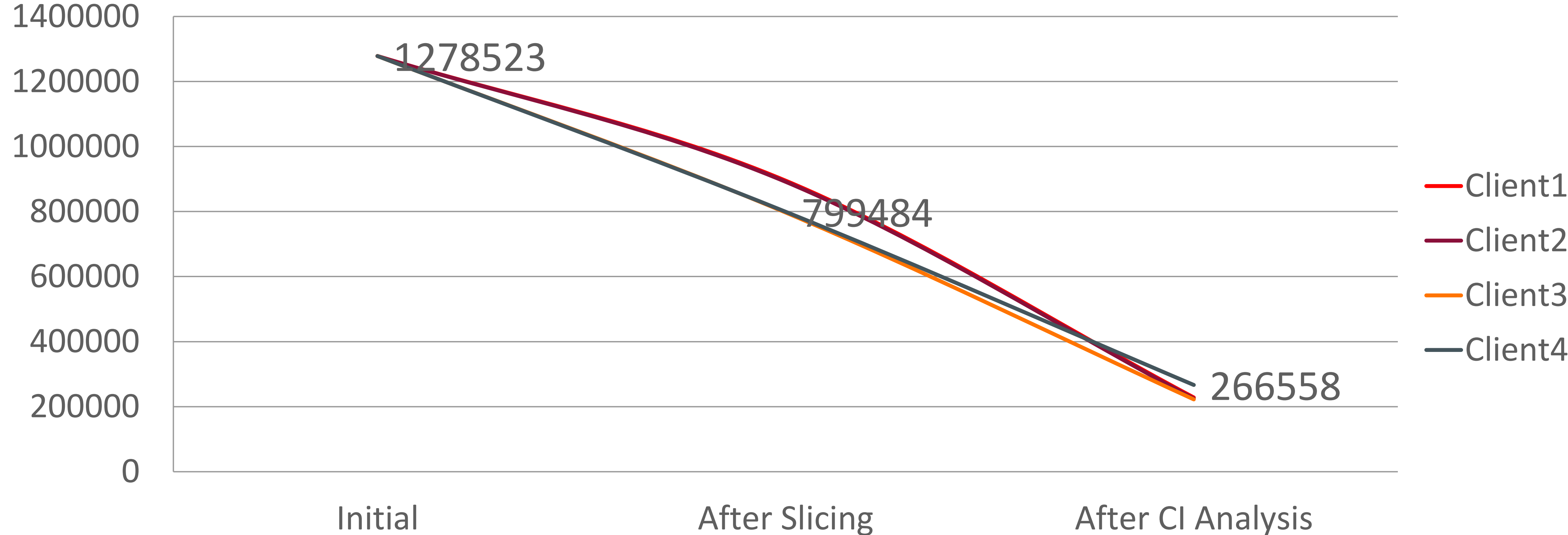
Results

Reduction in Number of Variables



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Results

Reduction in Number of Object Creation-Sites

	Initial	After CI Analysis
Client1		
Client2		
Client3		
Client4		

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Other Results

	Context-Insensitive	Context Sensitive	Context-Sensitive (Without Contexts)
Size of Points-To	120 Million	430 Million	2 Million
# Objects per Variable	140	-	8
# Call-graph Edges	330,000	80 Million	145,000

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Runtime

Intel Xeon E5-2660 (2.2GHz) 256GB RAM

Stage	Average Time
Variable Slicing	5 minutes
Context-Insensitive Analysis/Slicing	37 minutes
2-Heap+1-Object Analysis	3 hrs 53 minutes
Total	4 hrs 35 minutes

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Scalable Context-Sensitive Points-To Analysis

Demand-Driven, Slicing/Compaction Approach

Questions?

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