Combining Type-Analysis with Points-To Analysis for Analyzing Java Library Source-Code

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Agenda

• Motivation: Security analysis of libraries
• Background: Points-to, Static analysis
• Types and Most General Application
• Experiments
• Future Work & Conclusion
Motivation

• Context: Security vulnerabilities in the JDK library
  – Reason about JDK library without an application

• Security enforced by library
  – Enforcement transparent to application
  – Library code is known vs. application code is unknown
Static Program Analysis Challenge for OO-Programs

• Major building block for security analysis
  – Points-to analysis reasoning about heap and program variables

• Open/closed world problem
  – Application code is unknown
  – JDK Library code is known

• How to reason about unknown applications?
  – Abstractions for interactions between application & library
  – Heap Abstractions for the library for all applications
  – Points-to relationship between variables and heap objects
Background

Context-insensitive, flow-insensitive Anderson’s style points-to for Java
Points-To Analysis

• Flow-insensitive, inclusion-based, context-insensitive points-to
• Abstract domain
  – Program variables
    • Local, actual/formal parameters, return-values, bases, this-variables
  – Heap-allocated objects
    • Creation-site as an abstraction for dynamically created objects with fields
Points-To Analysis in Datalog

<table>
<thead>
<tr>
<th></th>
<th>Java Code</th>
<th>Datalog Encoding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allocations</td>
<td>h: v = new C() ;</td>
<td>vP(v,h) :- “h: v = new C()”.</td>
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<tr>
<td>Store</td>
<td>v₁.f = v₂;</td>
<td>hP(h₁,f,h₂) :- “v₁.f = v₂”, vP(v₁,h₁), vP(v₂,h₂).</td>
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• (v,h) ∈ vP if variable v may point to an object of creation-site h
• (h₁,f,h₂) ∈ hP if object of h₁ may point to an object of h₂ via field f
Points-To Example

```
a: x = new Foo()
y = x;
if (cond) {
    z = y;
} else {
    b: z = new G();
    z.f = y;
}
...
```
Types and Most General Application

Context-insensitive Anderson’s style points-to for Java
Extending Points-To for Unknown Applications

• Applications have a contract how they interact with the library
  – *Via Types and via public interfaces*
  – Enforced by the programming language

• Extend the points-to analysis with types
  – Abstract domain is extended
  – Semantic equations are altered

• New Abstract Domain
  – Object-creation sites can be summarized by their classes/types
  – Reason about objects from unknown application code
Amalgamate Points-To with Type Analysis

• Assume creation-site A and B create instances of class X
**Classes**: Universal Quantifiers for Object-Creation sites

- **Interpretation of a class $X$ in abstract domain:**
  - Subsumes all object-creation sites of class $X$ and its sub-classes
  - May subsume unknown and known object-creation sites
  - Sub-classes may be known or unknown

- **Heap-Abstraction**
  - Classes (vs. object-creation sites) produce higher abstraction level
  - If there exists an edge between two classes $X$ and $Y$ via field $f$
    - there exist two object creation sites of type $X$ and $Y$ connected by field $f$

- **Lattice permits co-existence of type- and points-to analysis**
## Points-To Analysis with Types

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<td>v₁.f = v₂;</td>
<td>hP(o,f,h₂) :- “v₁.f = v₂”, vP(v₁,h₁), isOf(o,h₁), vP(v₂,h₂).</td>
</tr>
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- Relations \( vP \) and \( hP \) extended for types,
- Adapt store semantics: if type \( t \) ➔ update all creation-sites of type \( t \)
Interactions with Unknown Applications

• Construct Most General Application
  – Mimicking the behaviour of all applications
  – Over-approximation

• Worst-case assumptions
  – All public interfaces are called by MGA
  – Parameters of invocations are types
  – However, no program variables in MGA

• Which heap-abstraction as an initial state?
Initial State for Most General Application (MGA)

• Construction
  – Nodes of the initial heap abstractions are public classes
  – Connect class with public accessible fields in heap abstraction with their type
  – Public sub-classes inherit connection

• Private fields are excluded
  – Only library can change field contents

• Less connection in the initial state produce makes points-to more precise

• Assumption
  – Object/Root class is owned by library
Example: Initial State

class A {
    public B f1;
    private C f2;
}

class B extends A {
    public A f3;
    private A f4 ;
}

class C {
    public A f5;
}
Experiments
Experimental Setup

- Extended DOOP framework for open/closed world assumption
- DOOP runs on Logicblox
- Analysis of OpenJDK library: version 7, build 147
- Machine: Intel Xeon E5-2660 (2.2GHz), 256GB Ram

Work flow:
Experiment with OpenJDK 7 / build 147

<table>
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<tr>
<th></th>
<th>CHA</th>
<th>without MGA</th>
<th>with MGA</th>
</tr>
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<tr>
<td>Call-Graph Edges (#)</td>
<td>3,030,157</td>
<td>378,495</td>
<td>851,127</td>
</tr>
<tr>
<td>Points-To (#)</td>
<td>n/a</td>
<td>384,207,724</td>
<td>661,970,750</td>
</tr>
<tr>
<td>Runtime (seconds)</td>
<td>30</td>
<td>1719</td>
<td>3662</td>
</tr>
</tbody>
</table>

- Class Hierarchy Analysis (CHA)
  - Type analysis of objects

- Points to analysis with Most General Application (MGA)
  - 124% more call graph edges in call graph
  - 73% more variable/object relations in points-to set
Future Work

• How to deal with reflection?
• Can the notion of MGA be extended to security properties?
• How to prove the semantic correctness?
• How to improve precision and runtime of the specifications?
Conclusion

• Amalgamate type-analysis with points-to
• Types used to summarize unknown objects in application
• Analysis handles types and creation-sites uniformly
• Over-approximating applications with Most General Application
• Overhead for large code is manageable
Hardware and Software
Engineered to Work Together