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Inference of Security-Sensitive Entities in Libraries

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Access Control in JDK*

```
public final class Class<T> … {
  …
  public java.security.ProtectionDomain getProtectionDomain() {
    SecurityManager sm = System.getSecurityManager();
    if (sm != null) {
      sm.checkPermission(new RuntimePermission("getProtectionDomain"));
    }
    java.security.ProtectionDomain pd = getProtectionDomain0();
    …
    return pd;
   }

  private native java.security.ProtectionDomain getProtectionDomain0();
}
```

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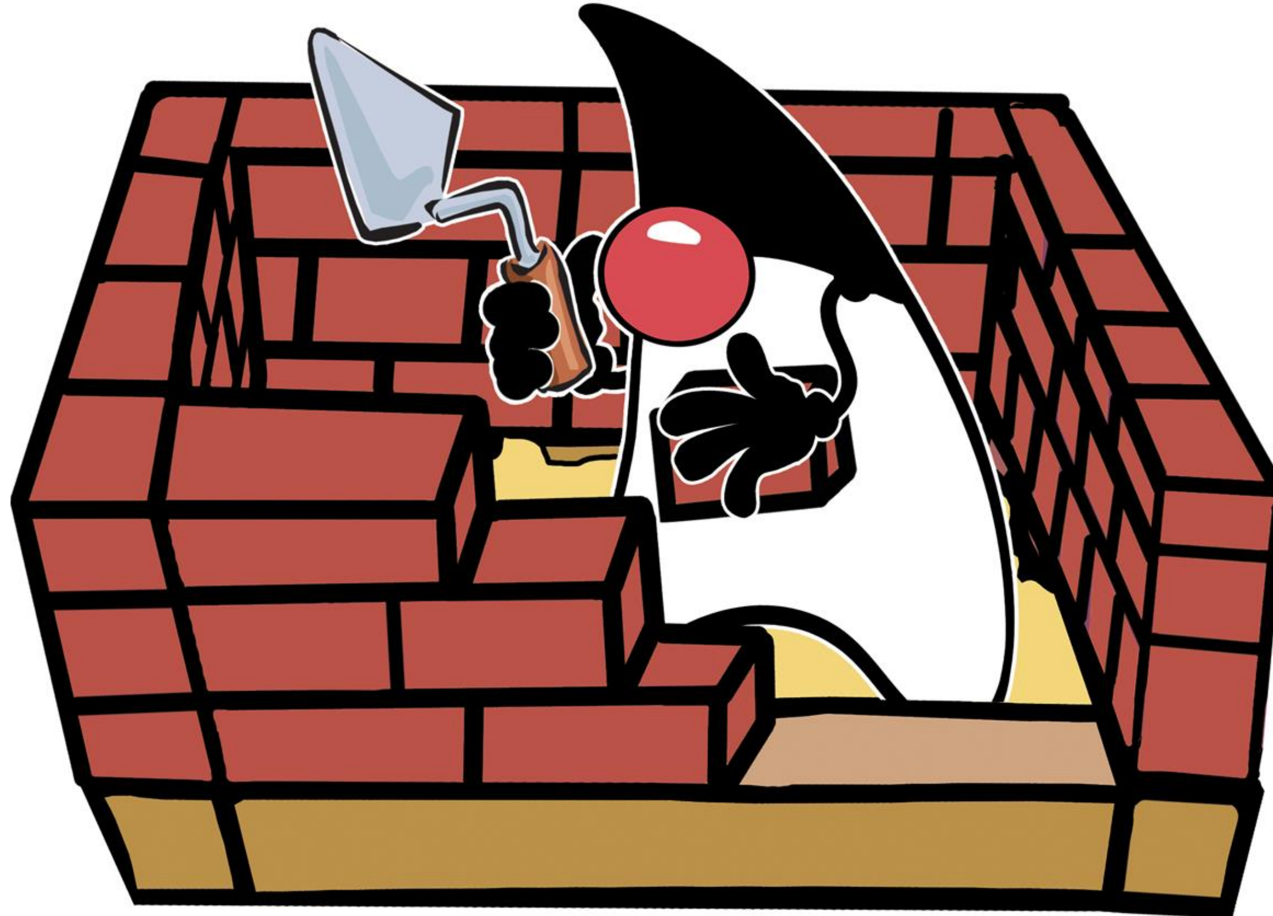
Defend by Carefully Handcrafted Sandbox



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Java’s Security Model Overview

- Libraries encapsulate security-sensitive entities
  - Prevent unauthorised access by using fine-grained permissions
- Relies on programmer discipline
  - Cannot defend against implementation bugs
- How do we guarantee security?
  - Ideally by automatic tools

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Security-Sensitive Entities

- Can directly access low-level system resources
- Not specified or documented in JDK
- Important for manual and automatic analyses of security-related bugs
  - E.g. to detect unauthorised accesses, information leaks, tainted sensitive operations

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Inference of Security Specification

- *Goal*: recover security design decision of JDK to help reason about security bugs
- *Intuition*: security-sensitive entities are consistently guarded by specific permissions from public accesses
- *Approach*: analyse control dependency on permission checks

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Inference Algorithm Overview

- Candidates are selected from *publicly inaccessible* methods in JDK
- From call sites of each candidate, perform backward control dependence analysis to find previous permission checks
- A candidate is security-sensitive if *consistently* guarded by a permission

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Challenges in Inferring Security Specification for JDK

- No standard definition of security-sensitive entities
- Security-sensitive entities are not always guarded
- Permission checks are not lexically scoped
- Permission objects may contain results of some computations

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Challenges in Inferring Security Specification for JDK

- No standard definition of security-sensitive entities
  - Interprecedual control dependence analysis on permission checks
- Security-sensitive entities are not always guarded
  - Probabilistic coverage analysis to tolerate inconsistency
- Permission checks are not lexically scoped
  - Probabilistic proximity analysis to find more relevant permission checks
- Permission objects may contain results of some computations
  - Data flow analysis to resolve permission objects

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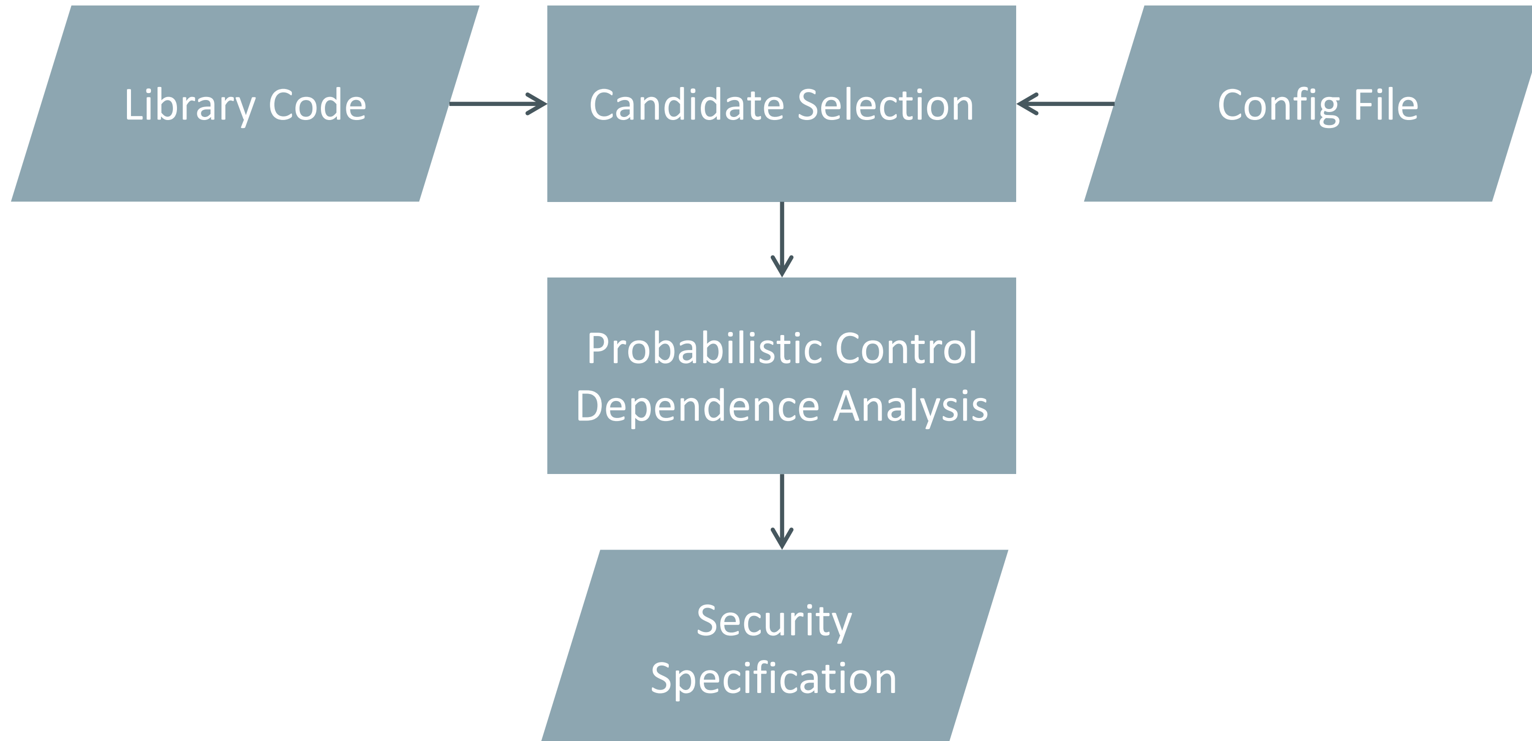
High-level Work Flow



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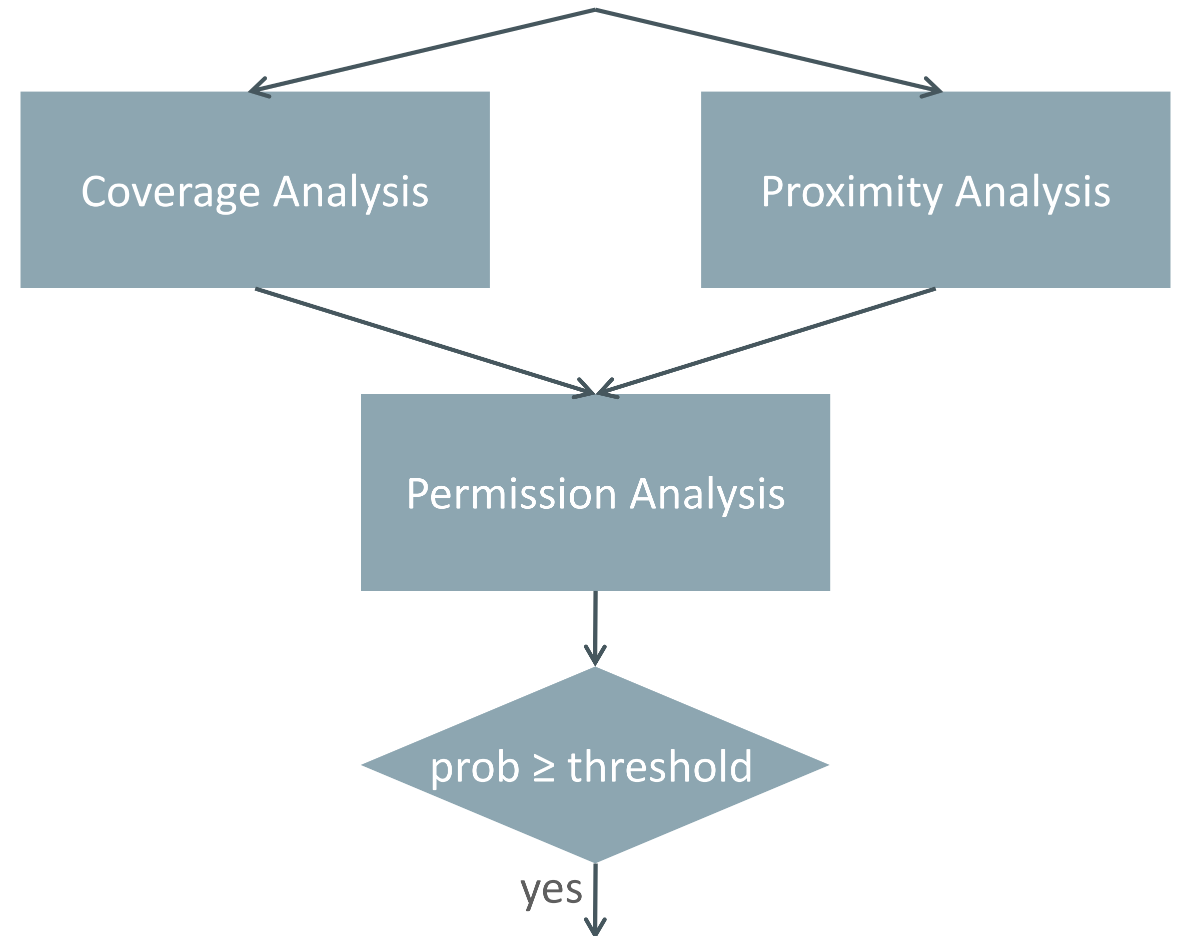
Probabilistic Control Dependence Analysis

- Finds permission checks guarding a candidate
  - Follow control flow graphs and call graph backward till reaching public entries

- Compute the *probability* of permission checks based on branches in control flow graphs



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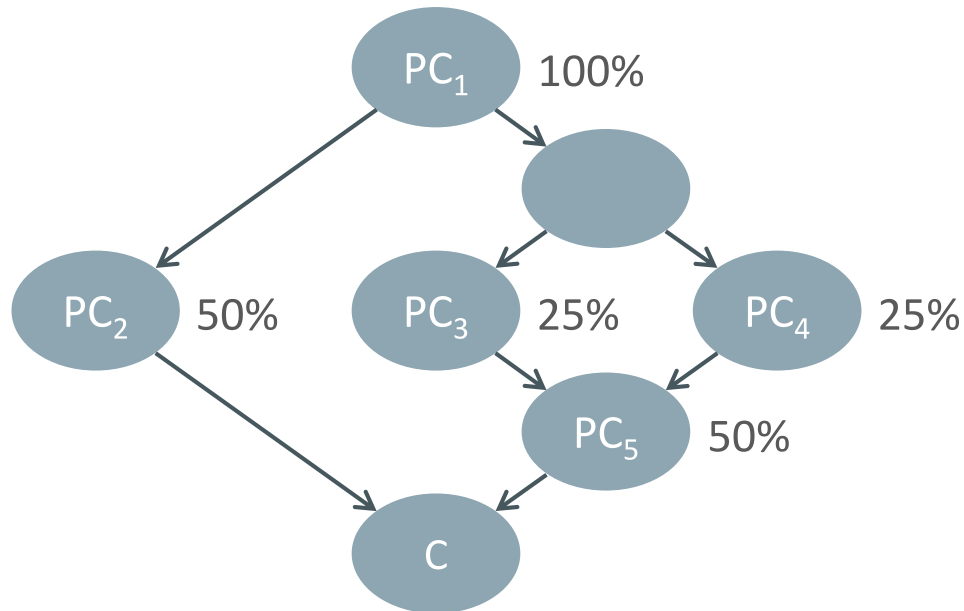
Probabilistic Control Dependence Analysis

- Coverage analysis
  - How likely candidate (C) is guarded by permission check (PC)



- Proximity analysis
  - How close are between candidate and permission check in the call graph
    - Reduce undesired shadow of non-lexically scoped permission checks

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Permission Analysis

- Resolves permissions from permission checks
  - Limited alias reasoning in the implementation due to the lack of points-to analysis in the analysis framework

- Computes the probability for permissions
  - Probabilities of different permission checks are aggregated for the same permission
  - A threshold is used to determine the relevance of the permissions

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Experiment

- Framework: Oracle Parfait
- Benchmark: OpenJDK7-b147
- OS: Solaris
- Hardware
  - CPU speed: 2993MHz
  - Core: 8
  - RAM: 131072 Mb

- The analysis takes average ~40 minutes to run

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Experimental Results

- Choice of thresholds

Inferred SSEs (*False Positives*)		Proximity	
		≤ 2	≤ 3
Coverage	≥ 0.5	109 (*28*)	238 (*117*)
	≥ 0.75	86 (*22*)	187 (*86*)
	≥ 1	83 (*20*)	173 (*77*)

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Sample Inferred Security Specification

Coverage >= 0.5 and proximity ≤ 2

Security-Sensitive Entity	Inferred Permission	Coverage	Proximity
getProtectionDomain0()	RuntimePermission (“getProtectionDomain”)	1	1
open(String name)	FilePermission(name, “read”)	1	1
delete(File f)	FilePermission(f.path, “delete”)	1	1
RandomAccessFile. open(String name, int mode)	FilePermission(name, “write”)	0.5	1
	FilePermission(name, “read”)	1	1
receive(…)	SocketPermission(?, “accpet”)	0.667	1

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Sources of False Reports

- False positives
  - Undesired shadow of non-lexically scoped permission checks
  - Conservative aggregation of probabilities of irresolvable permissions

- False negatives
  - Incomplete call graph in the framework
  - Some permission checks depend on complex semantics

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Sample False Report: State-Dependent Permission Checks

```
public class DatagramSocket implements java.io.Closeable {
   int connectState = ST_NOT_CONNECTED;

   public void connect(SocketAddress addr) … {
      …
      AccessController.checkPermission(
         new SocketPermission(host, "accept"));
       …
      connectState = ST_CONNECTED;
   }
   public synchronized void receive(DatagramPacket p) … {
      …
      if (connectState == ST_NOT_CONNECTED) {
         AccessController.checkPermission(
            new SocketPermission(host, "accept"));
      }
      …
      getImpl().receive(p);
}
```

```
abstract class AbstractPlainDatagramSocketImpl
                                        extends DatagramSocketImpl {
   …
   protected synchronized void receive(DatagramPacket p)
                                        throws IOException {
      receive0(p);
   }
   protected abstract void receive0(DatagramPacket p)
                                        throws IOException;
}

Class PlainDatagramSocketImpl
                              extends AbstractPlainDatagramSocketImpl {
   …
   protected synchronized native void receive0 (DatagramPacket p)
                                        throws IOException;
}
```


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Conclusion

- Security of software libraries often rely on programmer discipline

- Tools for precisely identifying security-related bugs must understand the security design intent of libraries

- Security specification of libraries may be inferred by static program analysis on security checks used in libraries

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Q&A

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