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Dynamic Symbolic Execution for Object-Oriented Libraries

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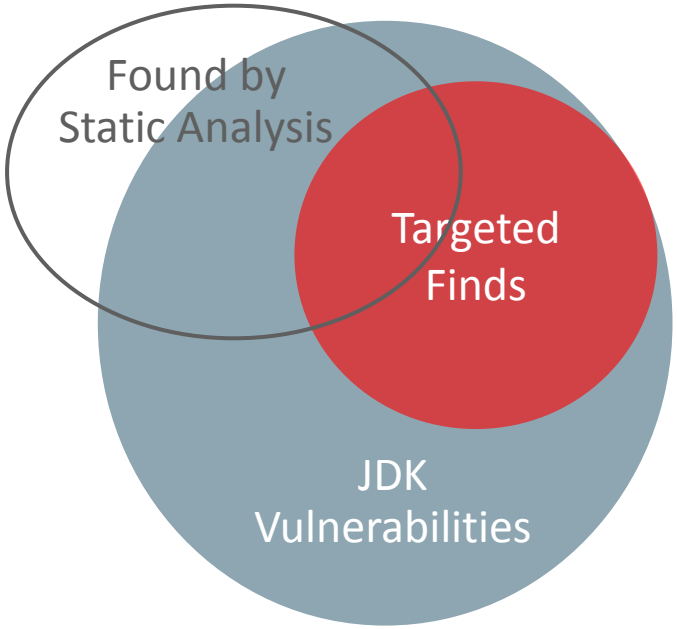
Why Fuzzing?

Hybrid symbolic-analysis exercising vulnerable execution traces

- Address static analysis limitations
  - False positives due to over approximation
  - Complex language aspects: Exception, aliasing
  - Dynamic features of Java: class loading, reflection
- Test generation based on symbolic execution
  - Exercise vulnerable execution traces



Dynamic Symbolic Execution

- Symbolic Execution
  - Program inputs represented as symbols
  - Instructions interpreted as constraints on symbols
  - Solve constraints to generate tests exercising program path

- Dynamic symbolic execution (Con-colic execution)
  - Perform symbolic execution at runtime, together with concrete execution
  - Program path induced by concrete execution
  - Mutate path condition to explore different paths

Challenges in JDK Symbolic Execution

- The complexity of JDK
  - Native library
  - Reflection
  - Exception handling
- Symbolic execution of method invocations
  - Mutation of invocation targets
  - Critical for testing object-oriented libraries and for finding JDK vulnerabilities

Symbolic Execution Example

```
public class InterfaceAddress {
    private InetAddress address;
    private InetAddress broadcast;
    . . .
    public boolean equals (Object obj) {
1       if (!(obj instanceof InterfaceAddress))
2          return false;
3       InterfaceAddress cmp = (Interface) obj;
4       if (!address.equals(cmp.address))
5           return false;
6        if (!broadcast.equals(cmp.broadcast))
7           return false;
        . . .
   }
};
```

Null Pointer Exception

Bug 6628576 in
http://bugs.java.com

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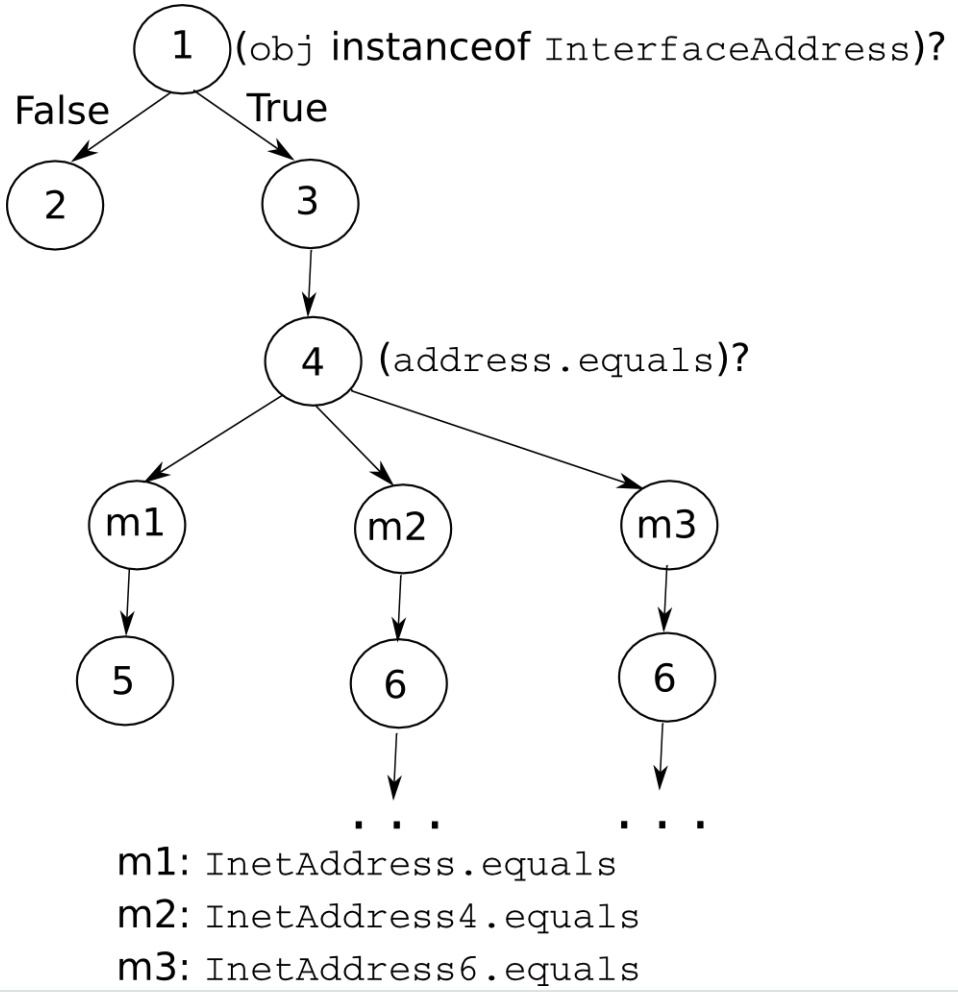
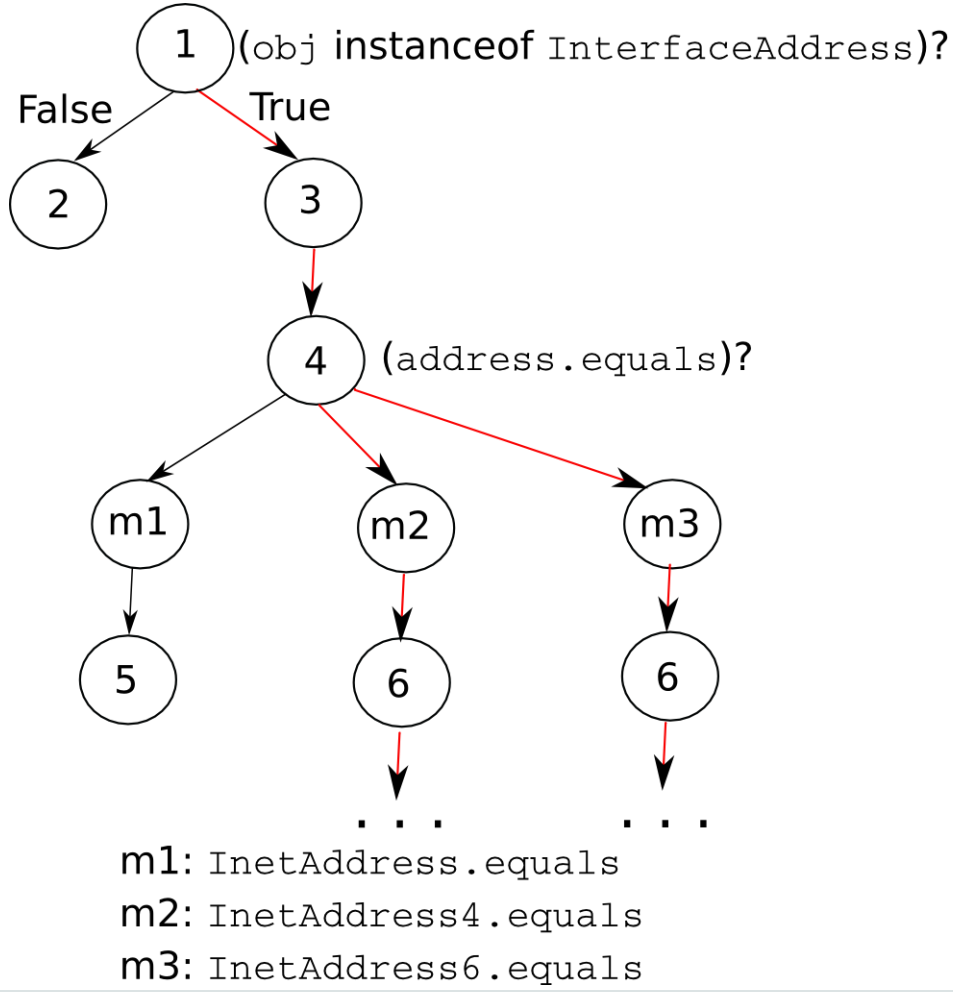


Symbolic Execution Example

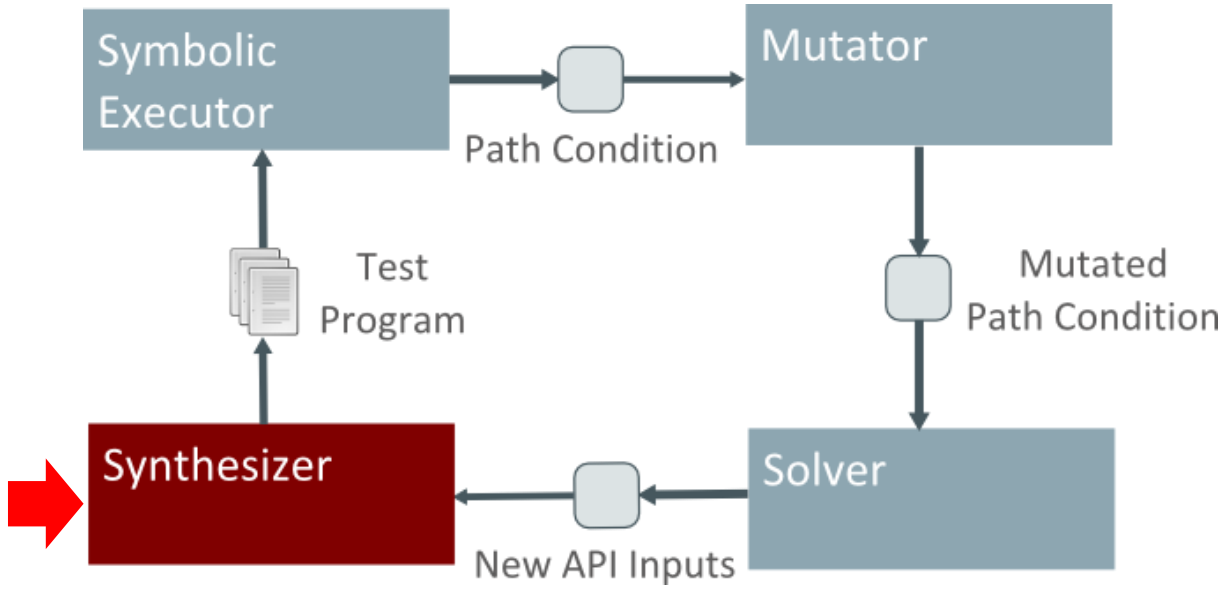
- Mutating types to explore invocation targets
  - `obj` of type `InterfaceAddress`
  - `address` of type `InetAddress4` or `InetAddress6`



Infrastructure for JDK Symbolic Execution

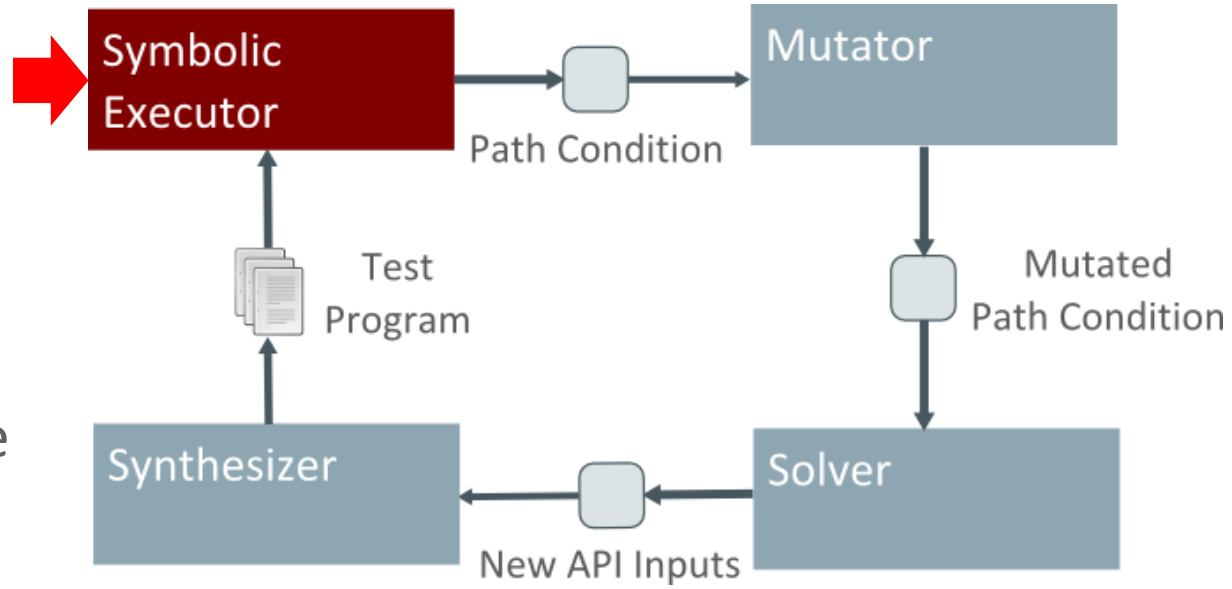
Starting point: Synthesizer

- Synthesizes test programs to invoke JDK API



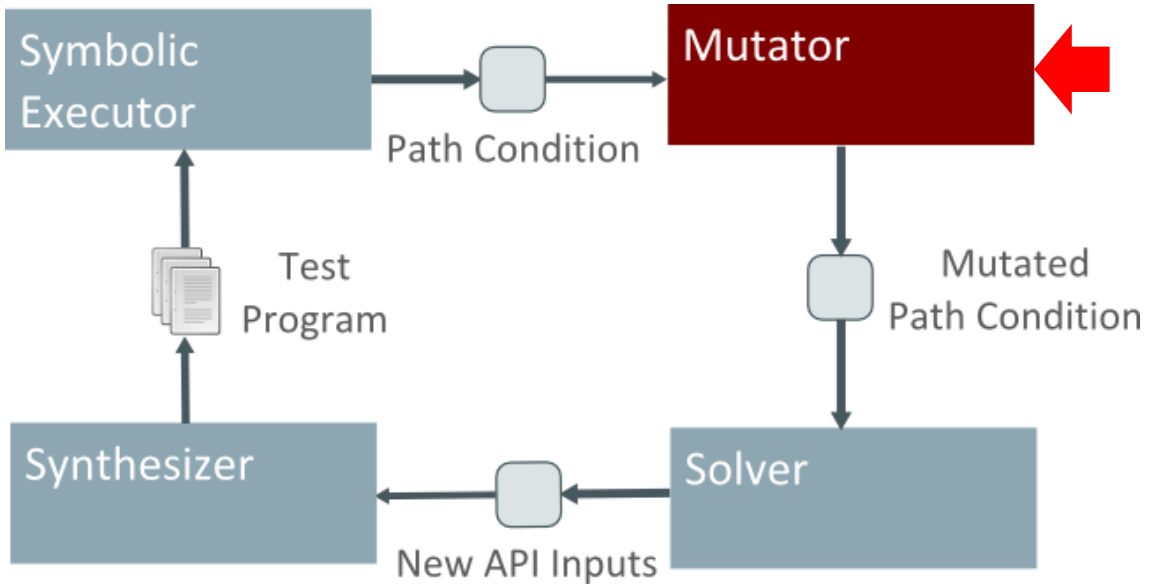
The Symbolic Executor

- Synthesizes test programs to invoke JDK API
- Symbolic execution of synthesized programs
  - Symbolic types for objects referenced by parameters of reference types
  - Generate path condition to represent the execution trace



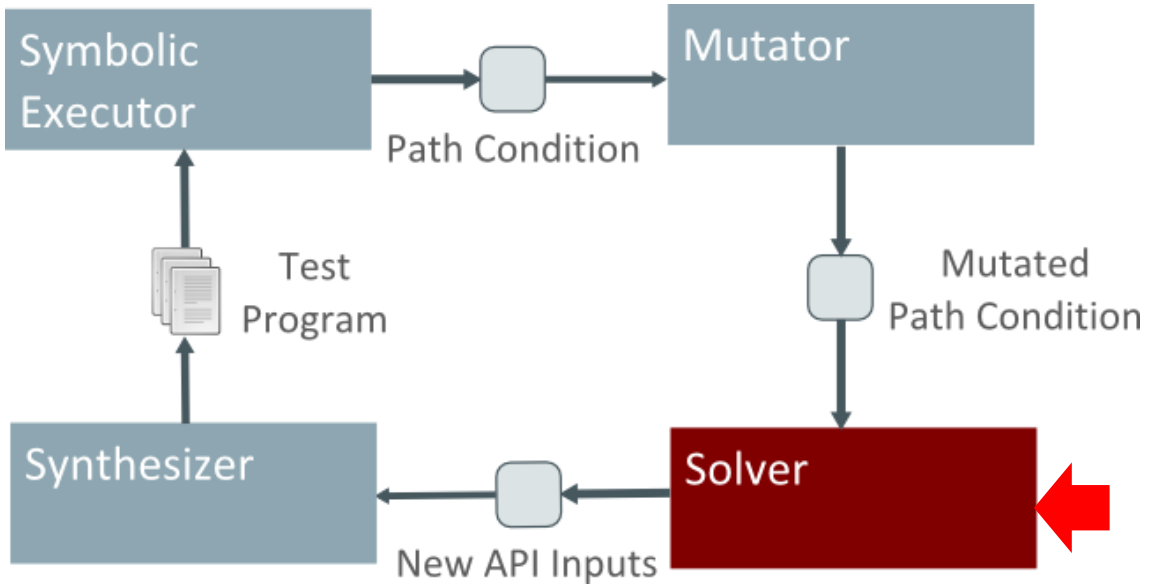
The Mutator

- Synthesizes test programs to invoke JDK API
- Symbolic execution of synthesized programs
- Mutates path conditions to explore new execution paths



The Solver

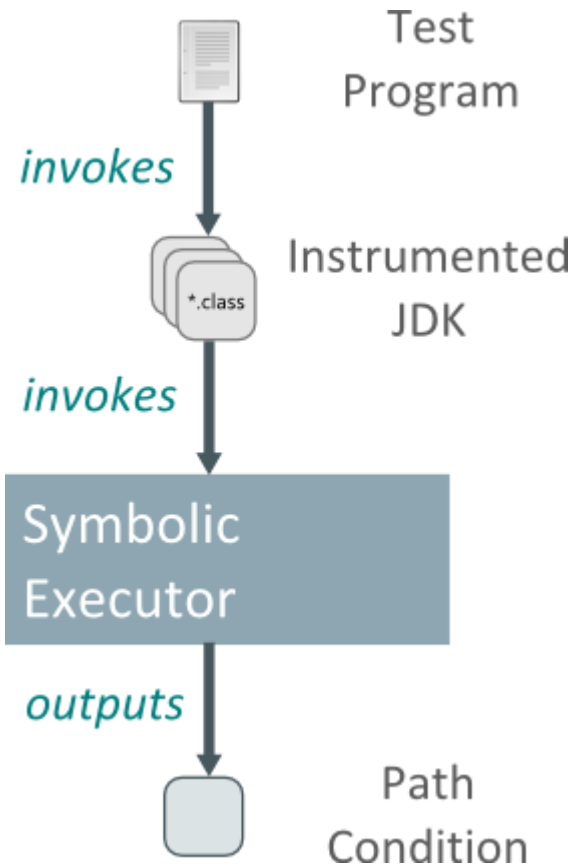
- Synthesizes test programs to invoke JDK API
- Symbolic execution of synthesized programs
- Mutates path conditions to explore new execution paths
- Solves mutated path conditions to generate new tests



Core Component: The Symbolic Executor

Dynamic Symbolic Execution of JDK via Instrumentation

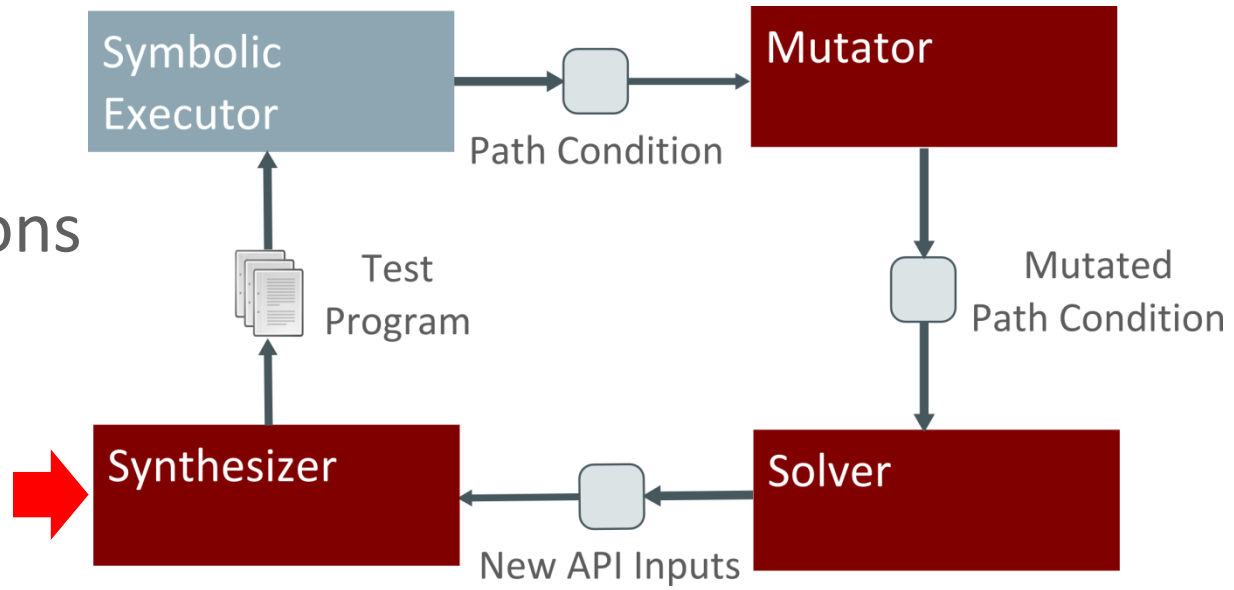
- Introduces symbolic values and types for inputs
- Generates path conditions with ***symbolic types***
- Explores virtual invocation symbolically
- Supports reflection partially
  - Symbolic methods and symbolic fields
- Works with JNI calls



Current Status: Other Components

All Components Functioning

- Synthesizer generates Java byte-code
  - Creates objects using public constructors
- Mutator generates new path conditions
  - Explores different invocation targets
- Solver handles type constraints
  - Generates concrete input types and values



Preliminary Results for Fuzzing OpenJDK-7u7b31

Automatically generate tests using the current infrastructure

Package	#Classes (#Tested/#Total)	#Methods (#Tested/#Total)	Block Coverage (%) For Tested Method	Time
java.lang	91 / 267	978 / 3775	70.1	464m 46s
java.text	28 / 63	273 / 664	58.5	117m 38s
java.nio	47 / 173	147 / 1715	62.0	4m 5s
java.beans	28 / 128	191 / 629	58.8	34m 32s
java.sql	12 / 16	33 / 81	41.5	3m 25s
Total	**206 / 647**	**1622 / 6864**	**Avg: 57.35**	**623m 25s**

Summary

- Infrastructure designed for JDK
  - Symbolically representing types and values
  - Functioning on OpenJDK
- Future work for JDK vulnerability detection
  - Full reflection library support
  - Better synthesis algorithm using static analysis
  - More efficient constraint solver
  - Test generation to expose access control violations in JDK

Hardware and Software
Engineered to Work Together