

Kex: how we are using SMT solvers to generate tests

Azat Abdullin

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Kex — white-box fuzzer for JVM bytecode

- based on symbolic execution
- uses kfg for bytecode manipulation and transformation
- uses PredicateState for program representation
- currently works with z3, boolector and cvc4

???

Motivating example

```
class ListExample {
  class Point(
    val x: Int,
    val y: Int
  )
  fun foo(a: List<Point>) {
    if (a.size == 2) {
      if (a[0].x == 10) {
        if (a[1].y == 11) {
          error("a")
        }
      }
    }
  }
}

(
  @S %1 = arg$0.size()
  @S %3 = %1 != 2
  @P %3 = false
  @S %5 = arg$0.get(0)
  @S %7 = (%5 as Point)
  @S %9 = %7.getX()
  @S %11 = %9 != 10
  @P %11 = false
  @S %13 = arg$0.get(1)
  @S %15 = (%13 as Point)
  @S %17 = %15.getY()
  @S %19 = %17 != 11
  @P %19 = false
)
```

Problem of symbolic execution

```
Model {  
    this = 131072  
    arg$0 = 4  
    %0.inlined0 = 2  
    arg$0.size = 4  
    %5 = false  
    %0.inlined7 = 27  
    (274)<3> = 121  
    (260)<3> = 101  
    type(0)<1> = 0  
    length(258)<2> = 11  
    String.value(273)<2> = 274  
    type(0)<2> = 5  
    ...  
    type(1)<12> = 2  
    ArrayList.elementData(4)<11> = 1  
}
```

How to create a test case
from the model?

Easy way: reflection

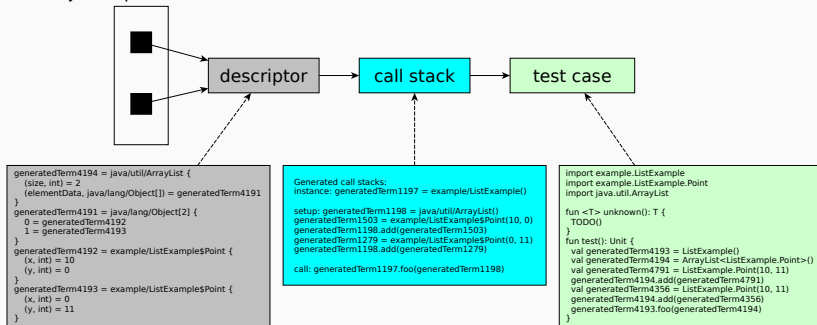
- test are hard to comprehend and maintain
- can generate invalid objects

todo

- an approach to generate valid code snippets using only public API
 - can't produce invalid objects
- works in reasonable time
- applicable in any automatic test generation tool
- can be used in any programming language

Reanimator

object representation



Descriptor example

```
instance: generatedTerm4193 = example/ListExample {}  
args: generatedTerm4194 = java/util/ArrayList {  
  (size, int) = 2  
  (elementData, java/lang/Object[]) = generatedTerm4191  
}  
generatedTerm4191 = java/lang/Object[2] {  
  0 = generatedTerm4192  
  1 = generatedTerm4193  
}  
generatedTerm4192 = example/ListExample$Point {  
  (x, int) = 10  
  (y, int) = 0  
}  
generatedTerm4193 = example/ListExample$Point {  
  (x, int) = 0  
  (y, int) = 11  
}
```

Call stack generation

- generation of constants and arrays is stright forward
- objects are problematic:
 - there may be no direct access to fields
 - some states of an object are unreachable during normal execution

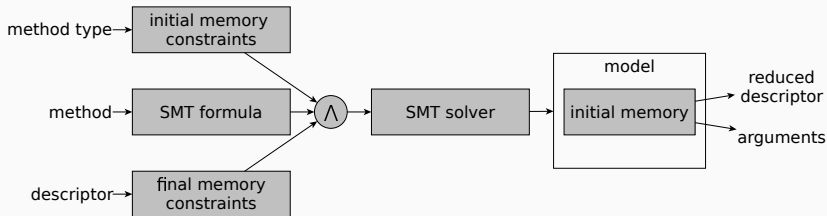
Object generation

- each field of the descriptor imposes new constraints
- more fields means more complex generation
- by gradually reducing descriptor we can find a constructor-like call to create an object
 - at each step try to find a method that initializes one or more fields

Checking methods

- `execAsCtor` and `execAsMethod` check how the method affects the descriptor using SMT solver
- method need to be represented as SMT formulae
 - predicate state
- method basically transforms memory state
- descriptor defines final memory
- *need to find initial memory*

Symbolic execution



Method types:

- constructor — initial memory is uninitialized
- setter — setted fields are uninitialized
- method — no constraints for initial memory

Call stack example

Generated call stacks:

```
instance: generatedTerm1197 = example/ListExample()
```

```
setup: generatedTerm1198 = java/util/ArrayList()  
generatedTerm1503 = example/ListExample$Point(10, 0)  
generatedTerm1198.add(generatedTerm1503)  
generatedTerm1279 = example/ListExample$Point(0, 11)  
generatedTerm1198.add(generatedTerm1279)
```

```
call: generatedTerm1197.foo(generatedTerm1198)
```

not enough type information

Test case example

```
import example.ListExample
import example.ListExample.Point
import java.util.ArrayList

fun <T> unknown(): T {
    TODO()
}

fun test(): Unit {
    val generatedTerm4193 = ListExample()
    val generatedTerm4194 = ArrayList<ListExample.Point>()
    val generatedTerm4791 = ListExample.Point(10, 11)
    generatedTerm4194.add(generatedTerm4791)
    val generatedTerm4356 = ListExample.Point(10, 11)
    generatedTerm4194.add(generatedTerm4356)
    generatedTerm4193.foo(generatedTerm4194)
}
```

Experimental setup

- implemented Reanimator as a part of Kex
- using Z3 for query solving
- custom string generator
- generation depth is limited to 5

- Symstra
 - builds valid method sequence during analysis
- JBSE
 - uses reflection utilities to create tests
- Sushi & Tardis
 - use EvoSuite (search-based approach) to generate tests

Conclusion

Future work

- more thorough investigation of Reanimator failures
- improved support of built-in types, such as collections
- higher order functions

Contact information

abdullin@kspt.icc.spbstu.ru

<https://github.com/vorpal-research/kex>

