Lazy Heap Analysis with Symbolic Memory Graphs

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Outline

1. Motivation
2. CPAchecker and Symbolic Memory Graphs
3. Abstractions of Symbolic Memory Graphs
4. Using counterexample guided abstraction refinement with Symbolic Memory Graphs
5. Challenges and conclusion
Motivation

- Use symbolic memory graphs to verify programs with complex heap structures
- Use abstraction to be able to check all possible states of a program for the specified safety property
- Use abstraction refinement to find a level of abstraction that is as coarse as possible while still fine enough to eliminate all spurious safety property violation
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program + specification

1 int main() {
2    int a = nondet_int();
3    a = 7;
4  } else {
5    a = 6;
6 }}
7 int a = nondet_int();
8 if(a == 5) {
9    a = 6;
10  }
11 }
Symbolic Memory Graph (SMG)

- Represents sets of heap graphs of a program at a program location
- Supports read and write operations, join of smgs, checking values for equality and inequality, and list abstraction
- Detects memory leaks and invalid read, write or free operations
#2: int foo(int x);

Stack

REGION(x, 4B) level=0
REGION(p, 4B) level=0
REGION(__cpa_temp_result_var__, 4B) level=0
REGION(a, 4B) level=0

[0B-4B] type: signed int
#4481 : 15

[0B-4B] type: (struct node)*
#4483

+0B, reg
REGION(malloc_ID4482_Line:1201, 8B) level=0

[4B-8B] type: signed int

#4484 : 1

Location: line 22: N24 -{p->i = 1;}-> N25 on N25
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List Abstraction

- Used to handle infinitely recursive list segments
- Heap objects are abstracted to list segments and the sub-graphs of the heap objects are joined together
- Whether to execute a possible list abstraction depends on the number of heap objects that can be abstracted into a list, and the loss of information when joining their sub graphs
Stack

#1: int main();

REGION(a, 4B) level=0
REGION(t, 4B) level=0

[0B-4B]
type: (struct node)*

#2
+0B, reg

REGION(concrete sll segment ID 48, 8B) level=0

[4B-8B]
type: (struct node)*

#50
+0B, fst

[0B-4B]
type: signed int
SLL(id=49 size=8, hfo=0, nfo=4, len=1, level=0)

[0B-4B]
type: signed int

#47 : 1

[0B-4B]
type: signed int

#36
+0B, reg

REGION(malloc_ID35_Line:1212, 8B) level=0
SMG Precision

- Determines the level of abstraction of a program verification with symbolic memory graphs
- Consist of sets of memory locations, memory paths and locks for list abstractions for every program location
- Adjusts symbolic memory graphs of abstract states in the ARG after each calculation of new abstract states for the ARG
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Counterexample guided abstraction refinement

- Method to obtain a good level of abstraction for an analysis for a program
- 1 Step Abstraction: Construct an abstract model of the program
- 2 Step Verification: Check if the model violates a chosen safety property
- 3 Step Refinement: Refine the level of abstraction based on a found spurious counterexample
CEGAR with Symbolic Memory Graphs

- Use SMG precision to determine the level of abstraction for Step 1
- Use the full SMG precision on a path to check if a found counterexample is feasible for Step 2
- Use the flow dependence of the SMGs of the spurious counterexample to calculate the new SMG precision for step 3
Lazy Abstraction

- Used to improve performance of Counterexample guided abstraction refinement
- Instead of continuously recalculating the abstract model after each refinement step, calculate the model and the refinement of the model on the fly
Lazy Abstraction

ARG

precision 0

ARG

precision 0

pivot state

precision 1
Example
b[1] = 1;
int c = (b[1]) + 5;
int d = c + (b[3]);
int e = c + 5;
int f = (c + d) + e;
int g = c + 4;
![g == 10]]
free(b);
[b][b, 0, (malloc_ID251, 8)]

6

b[1] = 1;

[b, c][b, 0, (c, 0)]

7

int c = (b[1]) + 5;

[c][c, 0]

8

int d = c + (b[3]);

[c][c, 0]

9

int e = c + 5;

[c][c, 0]

10

int f = (c + d) + e;

[g][g, 0]

12

int g = c + 4;

[]

13

!(g == 10)

[]

14

free(b);

[b][b->0][]

6

b[1] = 1;

[b][b->0, b->0->8][]

7

int c = (b[1]) + 5;

[b, main:c][b->0, c->0][]

8

int d = c + (b[3]);

[b, main:c][c->0][]

9

int e = c + 5;

[b, main:c][c->0][]

10

int f = (c + d) + e;

[b, main:g][g->0][]

12

int g = c + 4;

[]

13

!(g == 10)

[]

14

free(b);
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Challenges And Conclusion

- Finding a better refinement method for list abstractions
- A method to reduce the loss of information when writing to program location that is not known at the current level of abstraction
- Heap abstraction for trees and other data structures