UFRR

Hunting Memory Bugs in C Programs with Map2Check (Competition Contribution)

UFAM

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Competition on Software Verification (SV-COMP)

Verification and Testing Software

In **software testing:**

- ✓ a significant human effort is required to generate effective test cases
- ✓ subtle bugs are difficult to detect

In **software model checking**:

- ✓ limited scalability to large software
- ✓ missing tool-supported integration into the development process

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- ✓ a significant human effort is required to generate effective test cases
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- ✓ missing tool-supported integration into the development process

The integration aims to alleviate the weaknesses from those strategies

Hunting Memory Bugs with Map2Check

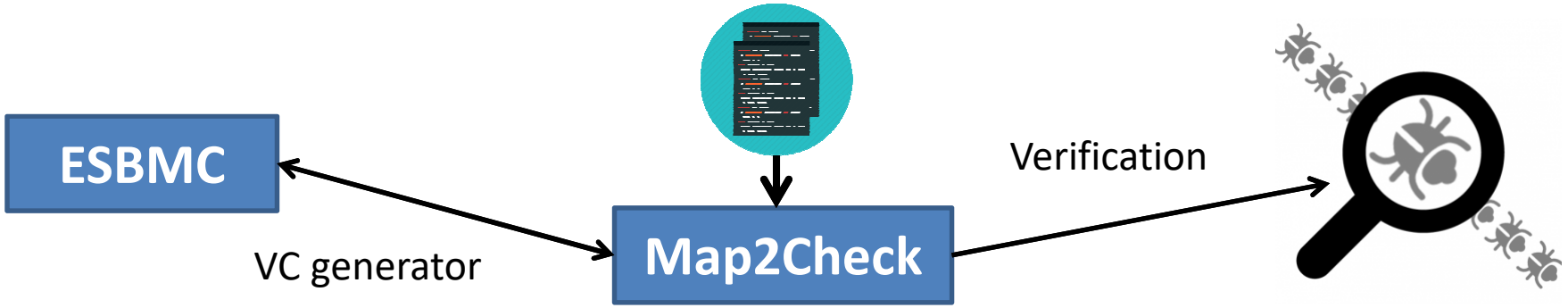
- ✓ Map2Check automatically generates and checks:
  - **memory management test cases** for structural unit tests for C programs
  - assertions from **safety properties** generated by **BMC tools**

- ✓ Map2Check aims to improve the unit testing environment, adopting features from (bounded) model checkers

- ✓ Map2Check adopts **source code instrumentation to:**
  - monitor the program's executions
  - validate assertions with **safety properties**

Hunting Memory Bugs with Map2Check

Map2Check method **checks** the program **out of the BMC tools flow**



- ✓ It is based on dynamic analysis and assertion verification
- ✓ The assertions contain a set of specifications
- ✓ The **BMC is adopted as verification condition** (VC) generator
- ✓ Checks for SV-COMP properties **"invalid-free", "invalid-deference", and "memory-leak"**

Hunting Memory Bugs with Map2Check

960521–1_false-valid-free.c

SV-COMP 2016

```
 3.  int *a, *b;
 4.  int n;
 5.
 6.  #define BLOCK_SIZE 128
 7.
 8.  void foo (){ ... }
16.
17.  int main ()
18.  {
19.    n = BLOCK_SIZE;
20.    a = malloc (n * sizeof(*a));
21.    b = malloc (n * sizeof(*b));
22.    *b++ = 0;
23.    foo ();
24.    if (b[-1])
25.    { /* invalid free (b was iterated) */
26.    free(a); free(b); }
27.    else
28.    { free(a); free(b); } /* ditto */
29.
30.    return 0;
31.  }
```

Step 1: Identification of safety properties

```
$ esbmc --64 --no-library --show-claims
960521-1_false-valid-free.c
file 960521-1_false-valid-free.c: Parsing
Converting
Type-checking 960521-1_false-valid-free
Generating GOTO Program
Pointer Analysis
Adding Pointer Checks
Claim 1:
file 960521-1_false-valid-free.c line 12 function foo
dereference failure: dynamic object lower bound
!(POINTER_OFFSET(a) + i < 0) || !(IS_DYNAMIC_OBJECT(a))
```

Dereferencing operation is a dynamic object

Claims generated automatically by ESBMC do not necessarily correspond to errors

Step 2: Extract information from safety properties

Claims	Comments	Line	Property
Claim 1	dereference failure: dynamic object lower bound	12	!(POINTER_OFFSET(a) + i < 0) || !(IS_DYNAMIC_OBJECT(a))
Claim 2	dereference failure: dynamic object upper bound	12	!(POINTER_OFFSET(a) + i >= DYNAMIC_SIZE(a)) || !(IS_DYNAMIC_OBJECT(a))
Claim 3	dereference failure: dynamic object lower bound	14	!(POINTER_OFFSET(b) + i < 0) || !(IS_DYNAMIC_OBJECT(b))
Claim 4	File sum_array line 14 function main array `a' upper bound	14	!(POINTER_OFFSET(b) + i >= DYNAMIC_SIZE(b)) || !(IS_DYNAMIC_OBJECT(b))
...	...	...	...

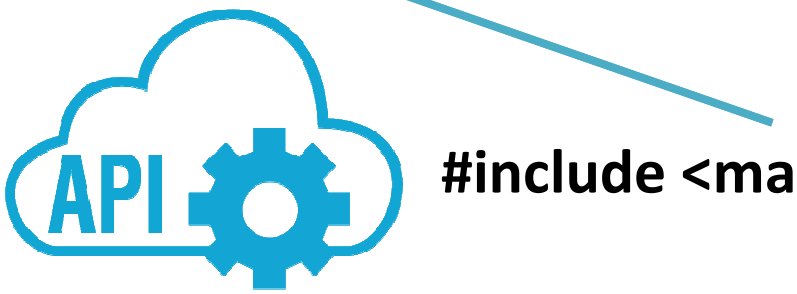
Step 3: Translation of safety properties

Translate claims provided by ESBMC into assertions written in C code:

- ✓ **INVALID-POINTER**.

$$INVALID - POINTER(i + pat)\ \boldsymbol{to}$$

IS _VALID_POINTER_MF (*LIST_LOG*, (*void*∗)&(*i*+*pat*), (*void*∗)(*intptr_t*)(*i*+*pat*))



#include <map2check.h>

Map2Check provides a library to the C program, which offers support to execute the functions generated by the translator.

Step 4: Memory tracking

```
 3.  int *a, *b;
 4.  int n;
 5.
 6.  #define BLOCK_SIZE 128
 7.
 8.  void foo (){ ...
16.
17.  int main ()
18.  {
19.    n = BLOCK_SIZE;
20.    a = malloc (n * sizeof(*a));
21.    b = malloc (n * sizeof(*b));
22.    *b++ = 0;
```

Phase 1: identify and track variables

Input: Abstract Syntax Tree (AST)

Output: Variables Tracking (Map)

Analyzing the program scope

```
foreach node IN the AST do
    if type(node) == FuncDef then
        compound_func = get the sub tree from node
        foreach subNo FROM compound_func == Decl do getDataFromVar(subNo, 0) ;
    end
    else if type(node) == Decl then getDataFromVar(node, 1) ;
end
Function getDataFromVar(node, enableGlobalSearch)
```

Step 4: Memory tracking

```
 3.  int *a, *b;
 4.  int n;
 5.
 6.  #define BLOCK_SIZE 128
 7.
 8.  void foo (){ ... }
16.
17.  int main ()
18.  {
19.    n = BLOCK_SIZE;
20.    a = malloc (n * sizeof(*a));
21.    b = malloc (n * sizeof(*b));
22.    *b++ = 0;
23.    foo ();
24.    if (b[-1])
25.    { /* invalid free (b was iterated) */
26.    free(a); free(b); }
27.    else
28.    { free(a); free(b); } /* ditto */
29.
30.    return 0;
31.  }
```

Tracking of the variables

Pointer variable assignments

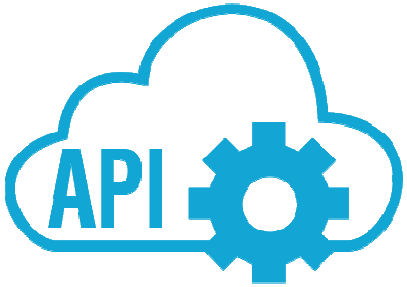
Step 5: Code instrumentation with assertions

```
16.  ...
17.
18.  int main ()
19.  {
20.    n = BLOCK_SIZE;
21.    a = malloc (n * sizeof(*a));
22.    b = malloc (n * sizeof(*b));
23.    *b++ = 0;
24.    foo ();
25.    if (b[-1])
26.    {
27.      ...
28.    }
29.    else
30.    {
31.      ASSERT(INVALID_FREE(LIST_LOG, (void *)(intptr_t)(a), 28));
32.      free(a);
33.  ASSERT(INVALID_FREE(LIST_LOG, (void *)(intptr_t)(b), 28));
34.  free(b);
35.    }
36.    return 0;
37.  }
```

Step 6: Implementation of the tests

Model using C assertions

debugging



#include <map2check.h>

Model for CUnit

options/statements for unit testing

Unit Testing Framework

Step 7: Execution of the tests

```
3.  int *a, *b;
4.  int n;
5.
6.  #define BLOCK_SIZE 128
7.
8.  void foo () {
16.
17. int
18. {
19.   n
20.   a
21.   b
22.   *
23.   f
24.   if (
25.   {
26.   f
27.   else
28.   { free(a); free(b); } /* ditto */
29.
30.   return 0;
31. }
```

Invalid free

Tracking memory execution

Line	Address	Points to	Escope	Is Dynamic	Is Free
28	0x601050	0xb44034	global	0	1
28	0x601060	0xb44010	global	0	1
...	...	...	...	...	...
10	0x7fff39f18a2c	(nil)	foo	0	0
22	0x601050	0xb44034	global	0	0
21	0x601050	0xb44030	global	1	0
...	...	...	...	...	...

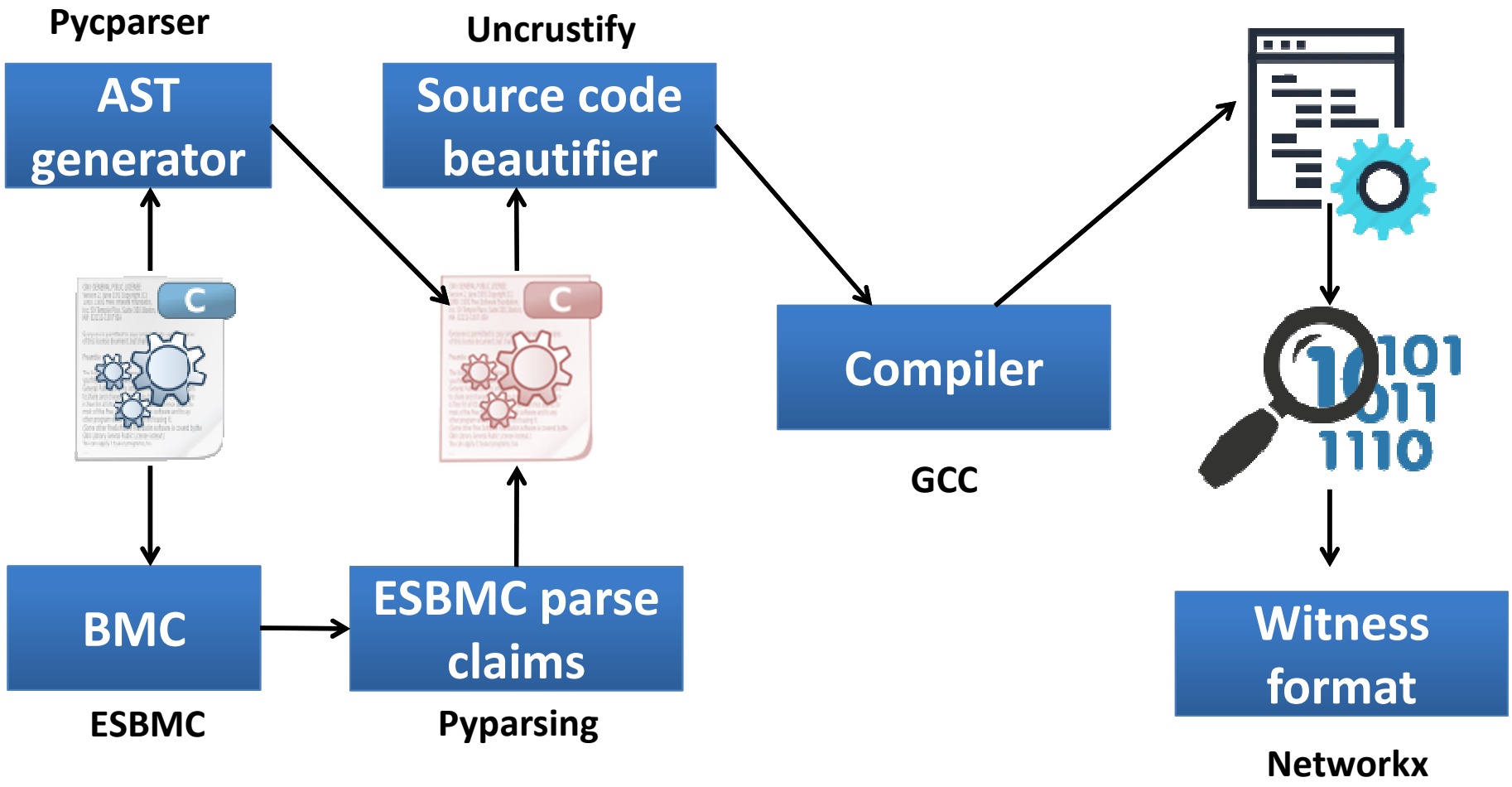
variable b was iterated

Strengths and Weaknesses - Map2Check

- ✓ Map2Check participates in the Heap Data Structures category only.
- ✓ The strength of the **tool lies in the precision** of its answers based on the **concrete execution of the analyzed program** over the VCs generated by ESBMC
- ✓ In preliminary experiments, Map2Check outperforms ESBMC due to timeouts or memory model limitations.
- ✓ The strategy based on **random data to unwind loops** and their respective loop exit condition do **not allow the correct execution of the program.**

Architecture, Implementation and Availability

source-to-source transformation



Map2Check tool is available at https://github.com/hbgit/Map2Check

Thank you for your attention!

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