SymDefFix - Sound Automatic Repair Using Symbolic Execution

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Automatic repair of programs

- Developers spend ~90% of their time to manually understand and fix bugs

- Several approaches for automatically repairing programs, e.g., GenProg, SemFix, DirectFix, and ExtractFix

Drawbacks of existing approaches

- Many approaches, e.g., GenProg, SemFix, DirectFix, suffer from overfitting - they generate patches that pass the test suite

- Constraints based automatic repair, e.g. ExtractFix, addresses overfitting, but need a test case to trigger the bug and output the constraint(s) for generating the patch(es)

- Quality of the generated patch(es) is still questionable

Example of a patch generated by ExtractFix

Program:

```
size_t LOWFAT_GLOBAL_MS__heap_overflow__malloc_7;
char* _malloc(int size){
  char* buf = (char*)malloc((
    {LOWFAT_GLOBAL_MS__heap_overflow__malloc_7 = size;
     LOWFAT_GLOBAL_MS__heap_overflow__malloc_7;}
  ));
  return buf;
}

int main(int argc, char *argv[]){
  char *buffer = _malloc(5);
  // ......
  char* content = argv[1];
  int content_size = strlen(content);
  for (i; i<content_size; i++)
    buffer[i] = content[i];
  // ......
}
```

Input :
HelloWorld!

Crash Location & Generated Constraints:
i < LOWFAT_GLOBAL_MS__heap_overflow__malloc_7

Generated Patch:

```
- for (i; i<sizeof(content); i++)
---
+ for (i;(((i)<sizeof(content)) &&((i)<
(LOWFAT_GLOBAL_MS__heap_overflow__malloc_7)));i++)
```

Better Patch could be:

```
- char *buffer = _malloc(5);
  // ......
    char* content = argv[1];
    int content_size = strlen(content);
+ char *buffer = _malloc(content_size);
  for (i; i<content_size; i++)
    buffer[i] = content[i];
  // ......
```

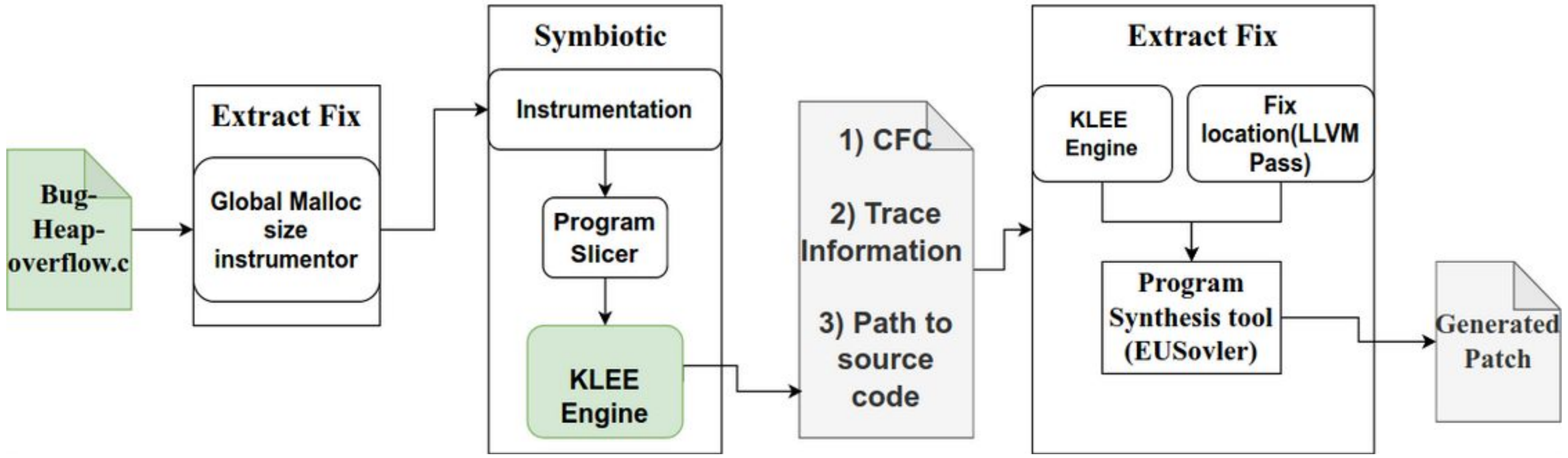
Goal of SymDefFix

- Create an automatic program repair tool that
  - detects bugs in the source code using static analysis
  - generates high quality patches
  - does not overfit a test suite

Research hypothesis of SymDefFix

- We can use symbolic execution to get more information about the bug
  - to determine the crash free constraint(s) and fix location(s)
  - to generate more accurate patches

SymDefFix approach



- Questions addressed in this work:
  - RQ1: How can we derive crash free constraints using KLEE symbolic execution engine?
  - RQ2: How can we derive the interprocedural calls using KLEE symbolic execution engine?

RQ1: Output the CFC using KLEE

Implemented it using the dump stack feature of KLEE

Example:

```
size_t GLOBAL_MS__heap_overflow__malloc_7;
char* _malloc(int size){
  char* buf = (char*)malloc((
    {GLOBAL_MS__heap_overflow__malloc_7 = size;
     GLOBAL_MS__heap_overflow__malloc_7;}
  ));
  return buf;
}

int main(int argc, char *argv[]){
  char *buffer = _malloc(5);
  // ......
  char* content[10];
  int content_size = strlen(content);
  for (i; i<content_size; i++)
    buffer[i] = content[i];
  // ......
}
```

Format of constraints:
filename.c:function_name:crash_line_number#constraints

CFC output from KLEE engine:

cfc.out information: heap_overflow.c:main:30#(i < GLOBAL_MS__heap_overflow__malloc_7)

RQ2: Output the inter-procedure calls using KLEE

Implemented it by utilizing the Executor class of KLEE

Example:

```
size_t GLOBAL_MS__heap_overflow__malloc_7;
char* _malloc(int size){
  char* buf = (char*)malloc((
    {GLOBAL_MS__heap_overflow__malloc_7 = size;
     GLOBAL_MS__heap_overflow__malloc_7;}
  ));
  return buf;
}

int main(int argc, char *argv[]){
  char *buffer = _malloc(5);
  // ......
  char* content[10];
  int content_size = strlen(content);
  for (i; i<content_size; i++)
    buffer[i] = content[i];
  // ......
}
```

Calls:

```
IN >>>> main :
: Success
IN >>>> _malloc
: Success
OUT >>>> _malloc
:Success
OUT >>>> main
: Success
```

Generated patch(es)

```
- for (i; i<sizeof(content); i++)
---
+ for (i;(((i)<sizeof(content)) &&((i)< (GLOBAL_MS__heap_overflow__malloc_7)));i++)
```

Conclusions

- Used KLEE symbolic execution to get more information about the bug to compute the crash free constraints and inter-procedural call trace
- Replaced the dynamic analysis part of ExtractFix with a static analysis approach
- SymDefFix obtained the same patch as output by ExtractFix
- Future Work
  - Consider all symbolically executed (error) paths
  - Improve the algorithm(s) to determine the fix locations
  - Improve the algorithm(s) to synthesize (generate) the patches
  - Consider other types of bugs, e.g., divide by zero, null pointer, pointer dereferencing issues etc.