Summaries of C String Loops for More Effective Symbolic Execution (and Refactoring)

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Joint work with
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Motivation

- Strings everywhere!
- Lots of work on building string constraint solvers from the SMT community
  - E.g., Z3, CVC4, HAMPI
- Let’s use them for symbolic execution!

Problem

- Developers often use custom loops instead of string functions

```
#define whitespace(c) (((c) == '␣') || ((c) == '\t'))
char *p;
for (p = line; p && *p && whitespace (*p); p++)
  ;
```

```
while (*s != '\n’)
    s++;
```

```
char *p = path + strlen (path);
for (; *p != '/' && p != path; p--)
  ;
```

```
while (('␣' == *pbeg) || ('\r' == *pbeg)
   || ('\n' == *pbeg) || ('\t' == *pbeg))
   pbeg++;
```

Objective

- Replace custom loops with sequence of primitive pointer operations and calls to standard string functions

```
#define whitespace(c) (((c) == ' ') || ((c) == '\t'))
char *p = line + strspn(line, " \t")
```

```
s = rawmemchr(s, '\n');
```

```
pbeg += strspn(pbeg, " \r\n\t");
```

```
p = strrchr(path, '/');
p = p == NULL ? path : p;
```

How?

- Counterexample-guided inductive synthesis (based on symex)
- Proof of bounded equivalence (up to a certain string length)
- Mathematical proof of unbounded equivalence

Scope: Memoryless Loops

- Loops conforming to an interface:
  - Argument: single pointer to a string
  - Returns: pointer to an offset in the string
- Only reads the character under current pointer

```
char* loopSummary(char*);
```

Vocabulary for summarizing string loops

string.h functions

- `strspn`
- `strcspn`
- `memchr`
- `strchr`
- `strrchr`
- `strpbrk`

pointer manipulation

- `increment`
- `set to start`
- `set to end`

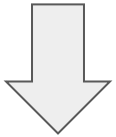
special

- `backward traverse`
- `return`

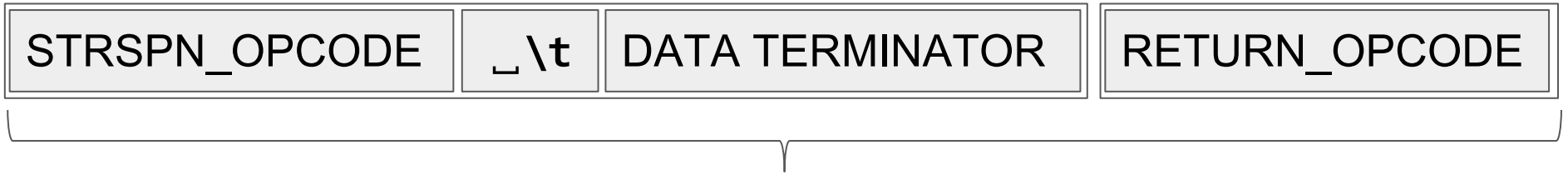
conditionals

- `is null`
- `is start`

```
char *p;
for (p = line; p && *p && whitespace (*p); p++)
  ;
```

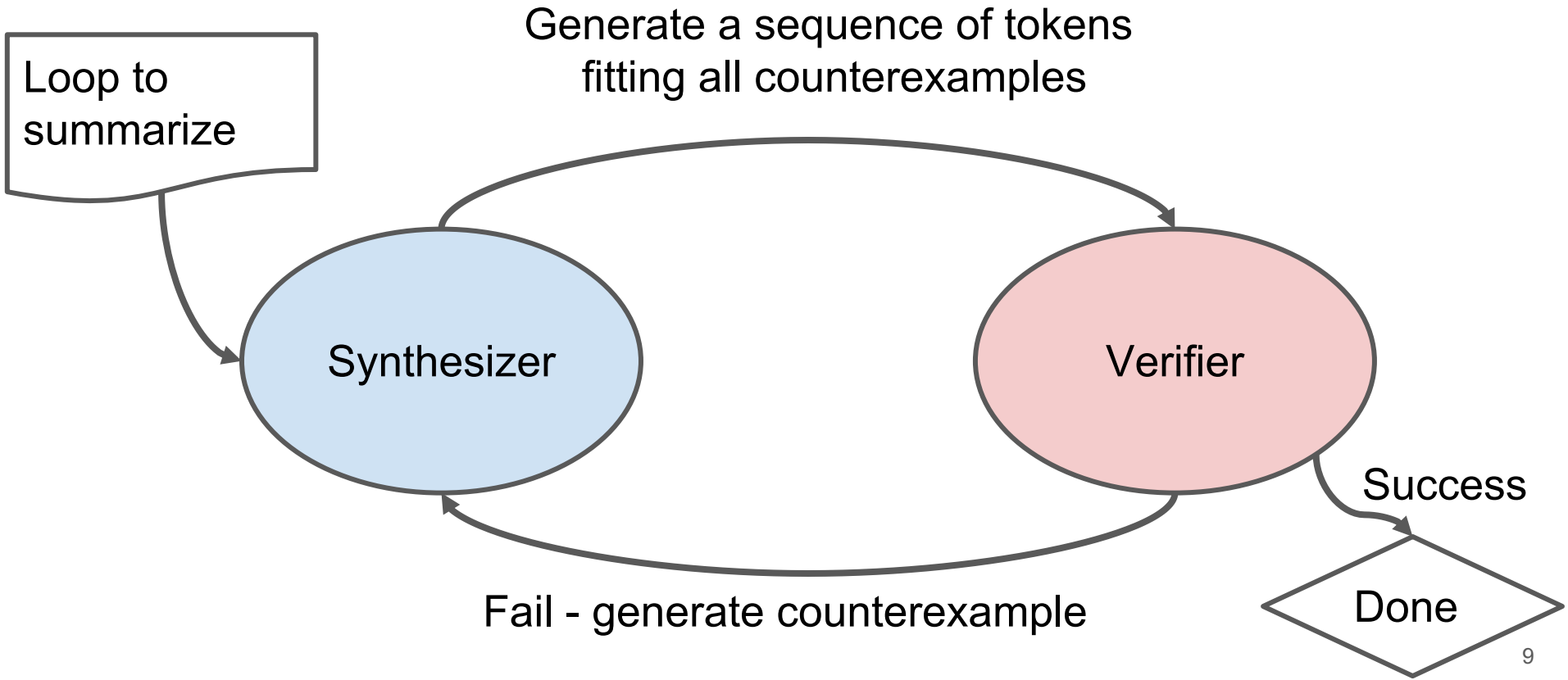


```
char *p = line + strspn(line, "␣\t")
```



Loop summary!

Counter-example guided synthesis



Synthesizer

- Symbolic execution
- Symbolic input: sequence of tokens
- Constrain it to be equivalent on current (counter)examples
- Ask an SMT solver for a solution

Verifier

- Symbolic execution
  - Bounded equivalence checking strings of length ≤ 3
- For memoryless loops:
  - checking lengths ≤ 3 sufficient to show equivalence for any length (proof in the paper)
  - Intuitively the proof depends on the fact that each iteration is independent from previous ones

Synthesis Evaluation

- 13 open source programs
- Extracted 115 memoryless loops
- 88/115 successfully synthesized within 2h*
- 81 within 5 minutes

*Gaussian process optimization to optimize the vocabulary

patch

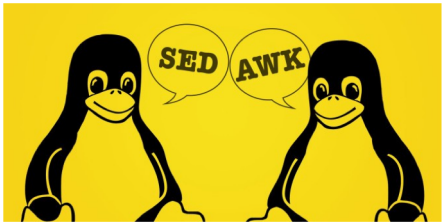
libosip

git

diff

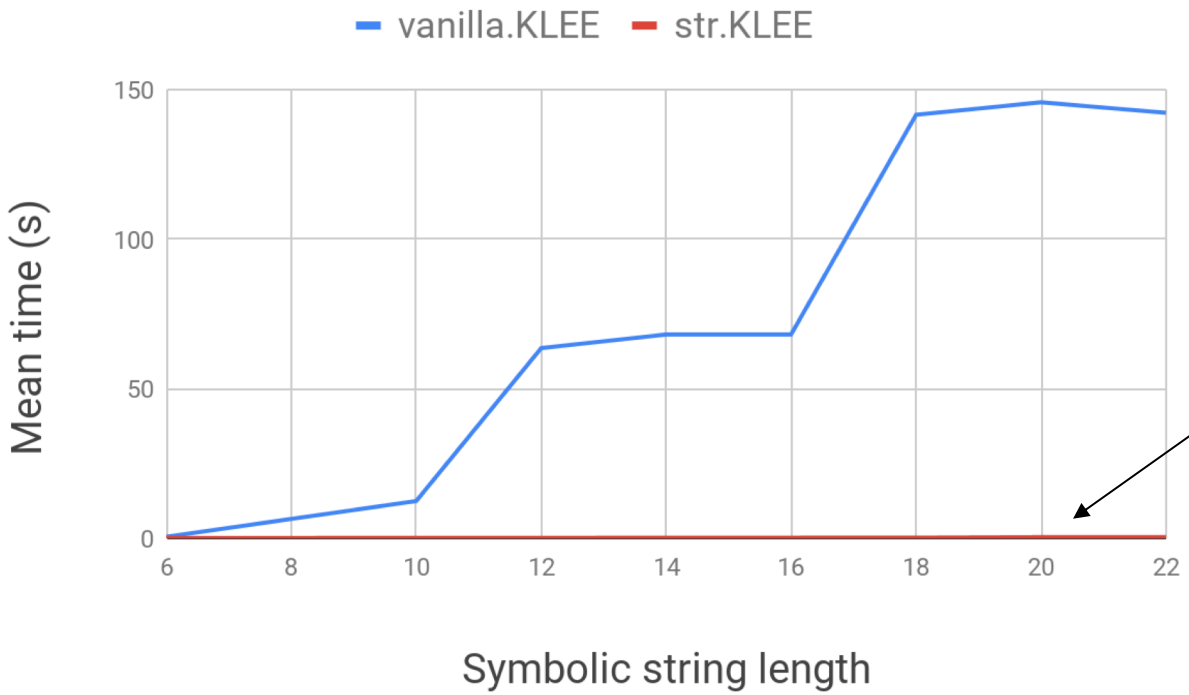
m4

make



Impact of string solvers (KLEE+Z3str) on Sym Ex

Average across loops, 2min timeout



Can reason about unbounded string lengths

Refactoring

- Used summaries to create patches and send them to developers
- Submitted patches to 5 applications
- Patches accepted in `libosip`, `patch` and `wget`

```
- for(; *tmp == ' ' || *tmp == '\t'; tmp++){
- }
- for(; *tmp == '\n' || *tmp == '\r'; tmp++){
- }                                  /* skip LWS */
+ tmp += strspn(tmp, " \t");
+ tmp += strspn(tmp, "\n\r");
```

Conclusion

- C developers often use custom loops to operate on strings
- Developed synthesis technique to transform such loops into sequences of primitive operations and calls to standard string library
- Potential to significantly speed up symbolic execution of string-intensive code
- Applications to refactoring and compiler optimisations