DAFL:
Directed Grey-box Fuzzing Guided by Data Dependency

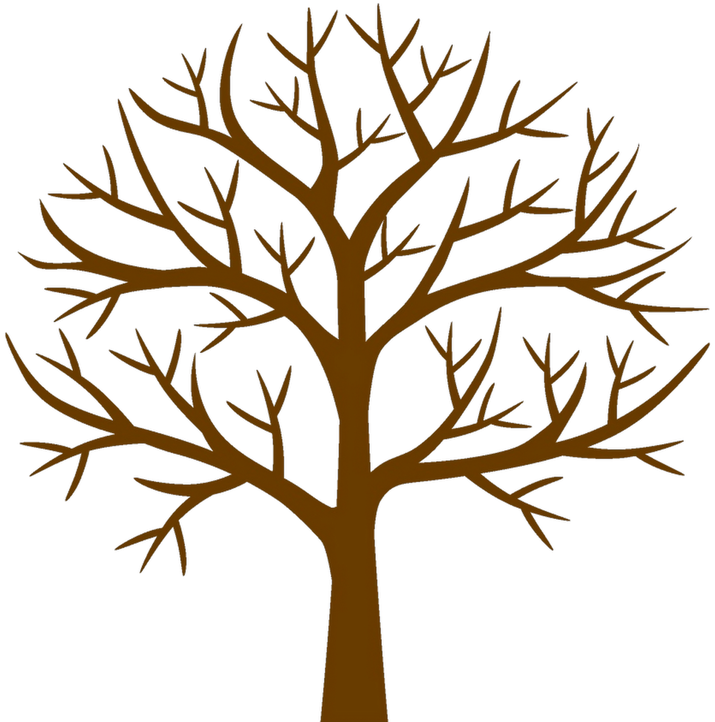
Tae Eun Kim, Jaeseung Choi, Kihong Heo, Sang Kil Cha

KAIST SOGANG UNIVERSITY

Background

Fuzzing

- Testing a program with randomly generated inputs
- Successful achievements
  - e.g., AFL, Google’s OSS Fuzz project



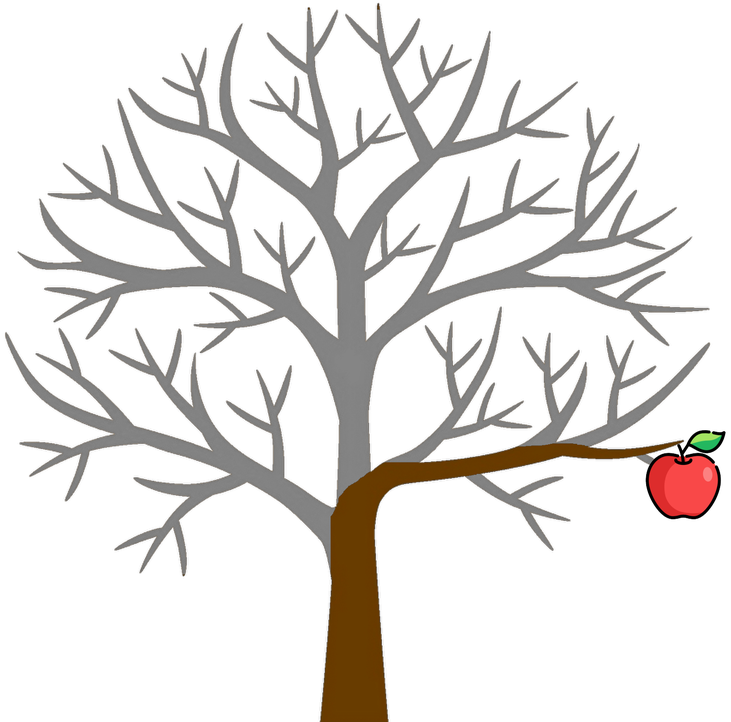
Background

Fuzzing

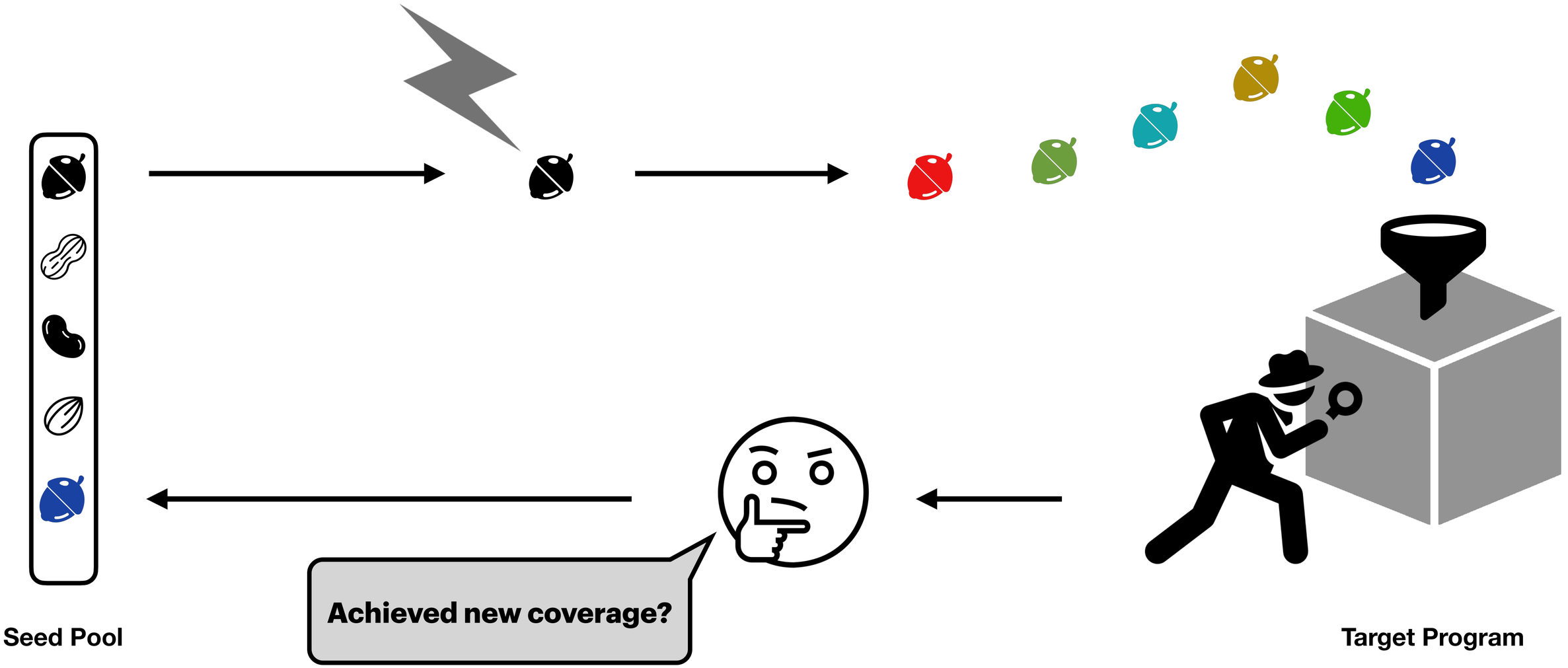
- Testing a program with randomly generated inputs
- Successful achievements
  - e.g., AFL, Google's OSS Fuzz project

Directed Fuzzing

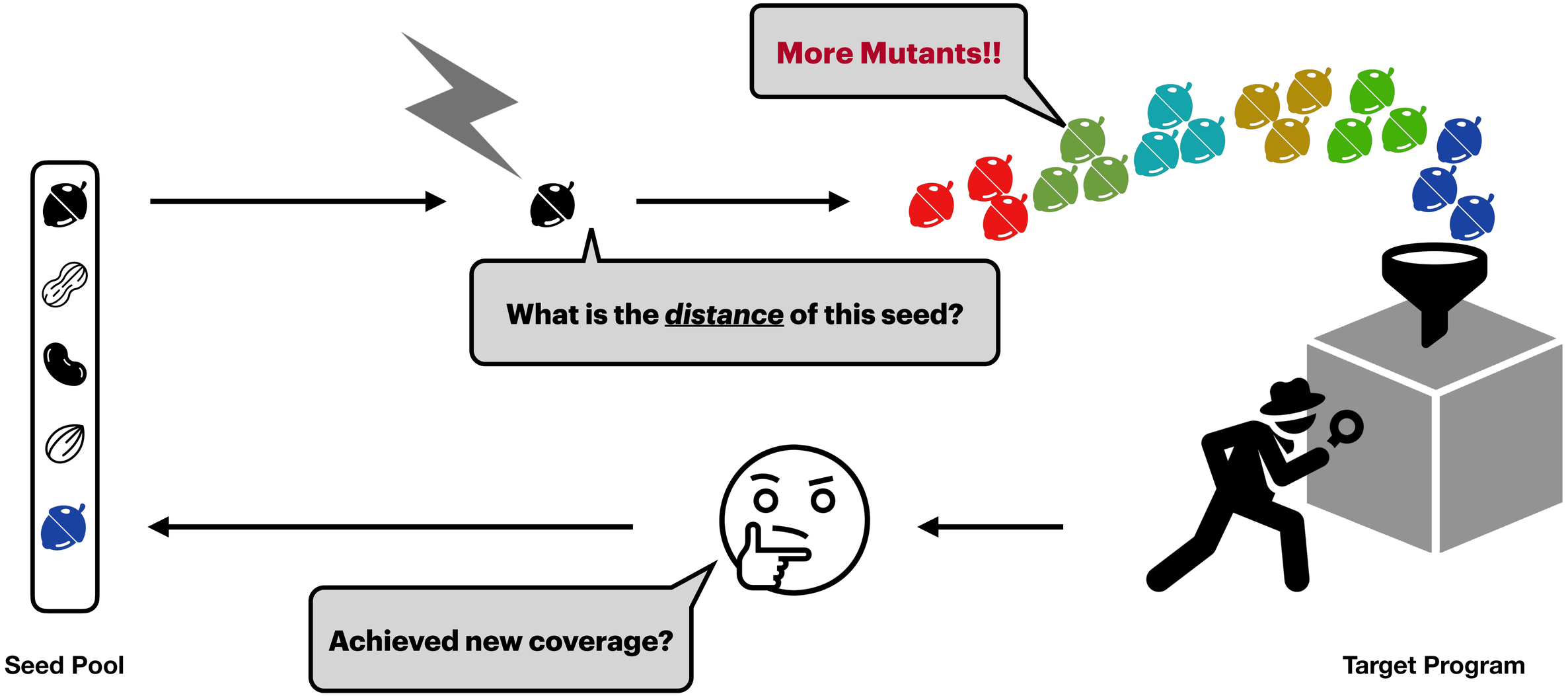
- Aims to reach the given target location(s)
  - Generate crashing inputs from bug reports (e.g., static analysis alarms)



Directed Grey-box Fuzzing (DGF)



Directed Grey-box Fuzzing (DGF)

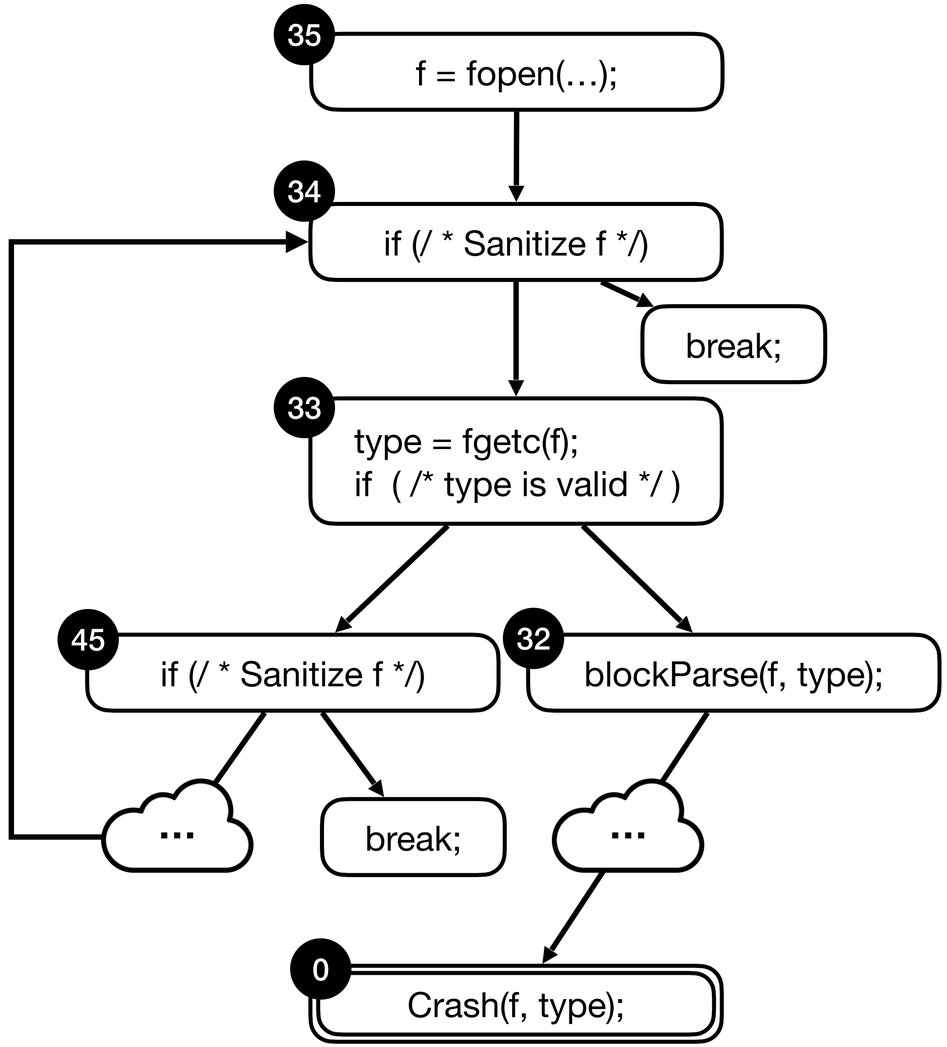


Limitations of DGF

1. **Noisy** seed distance based on Control Flow Graph (CFG)
   - Complex control structures (e.g., loops) introduce noise in the seed distance

Limitations of DGF

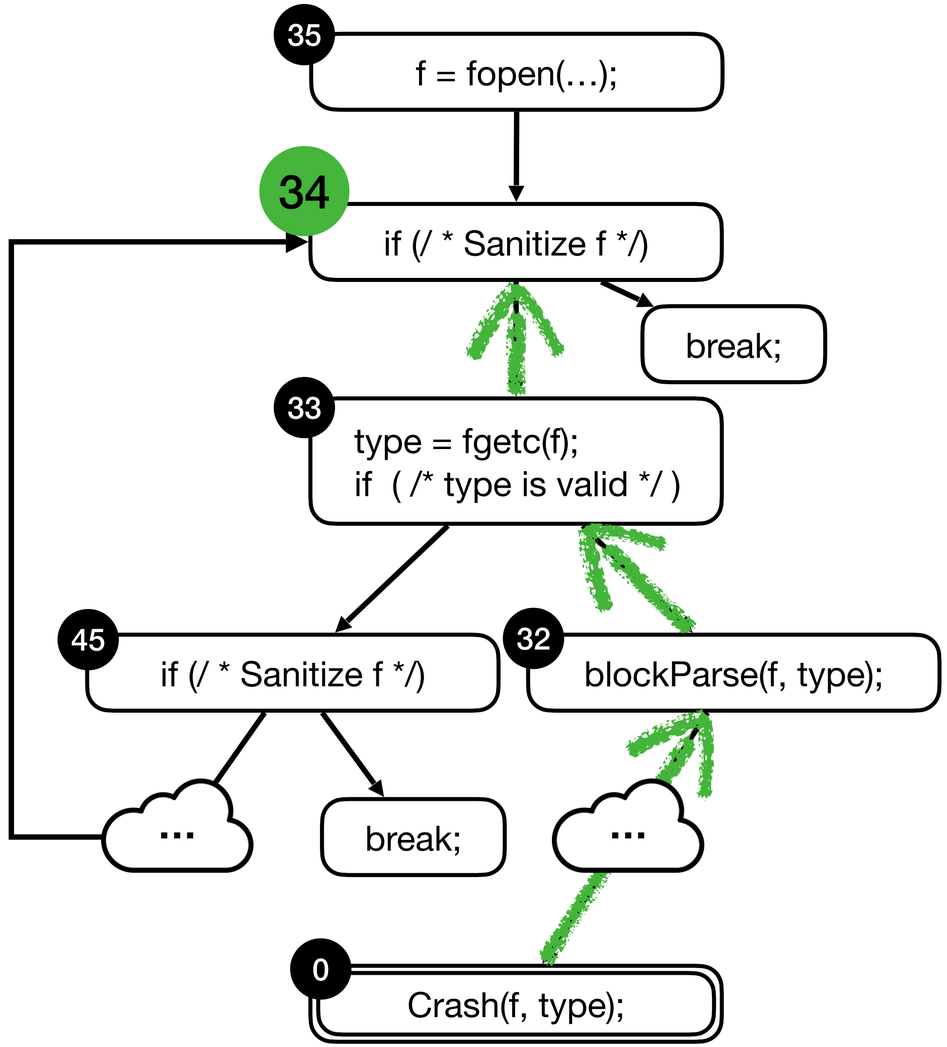
Noisy CFG-based Seed distance



*CVE-2017-7578 in swftophp

Limitations of DGF

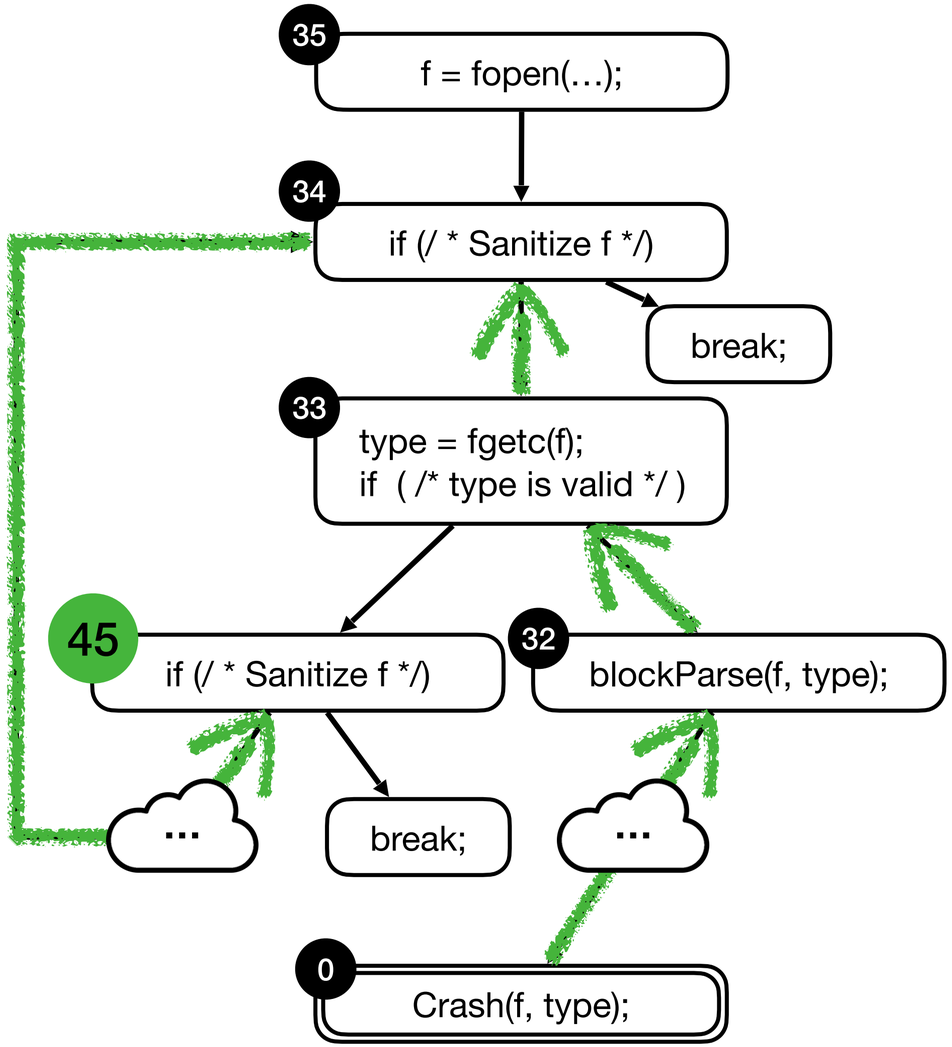
Noisy CFG-based Seed distance



*CVE-2017-7578 in swftophp

Limitations of DGF

Noisy CFG-based Seed distance



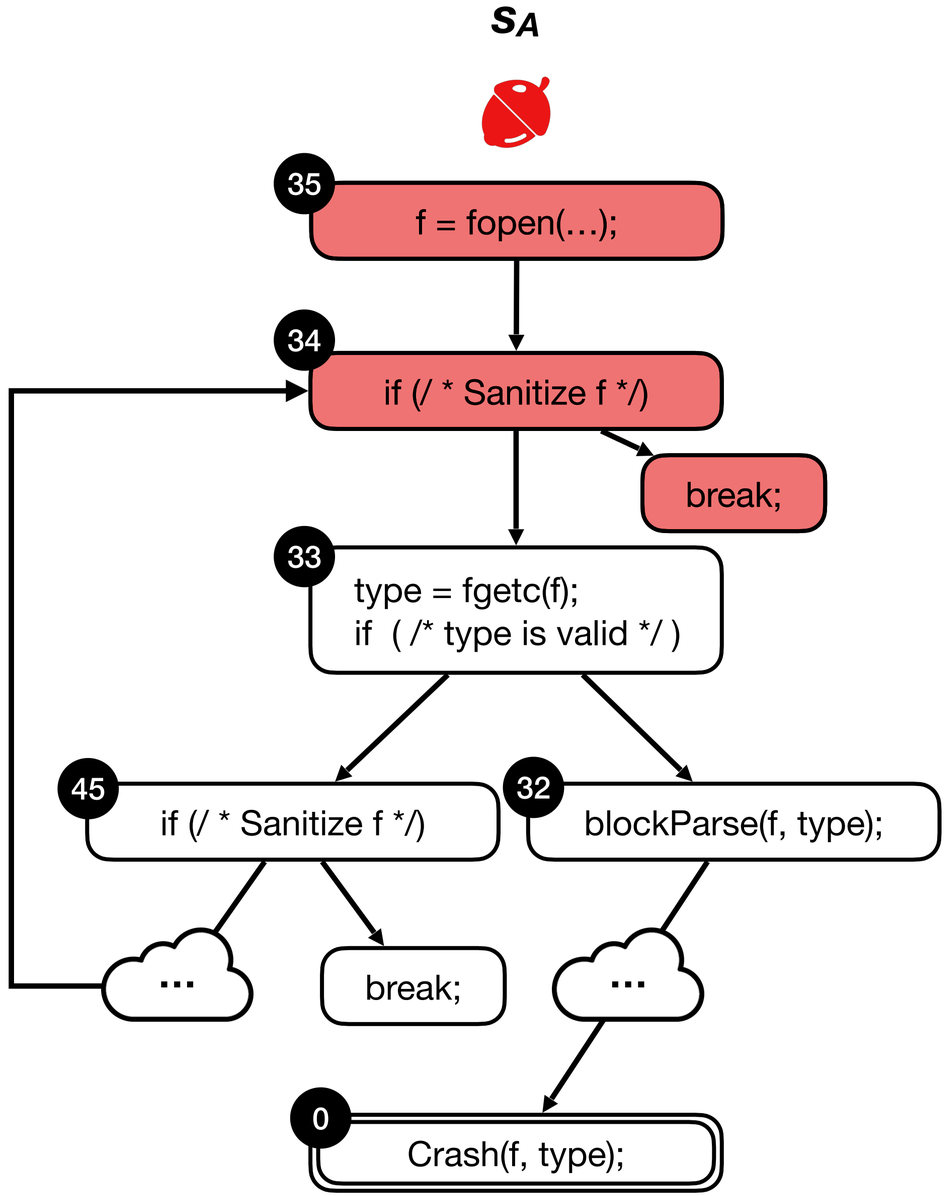
*CVE-2017-7578 in swftophp

Limitations of DGF

Noisy CFG-based Seed distance

AFLGo: Distance based on all nodes in CFG (Lower is Better)

34.5 Averge(34, 35)



*CVE-2017-7578 in swftophp

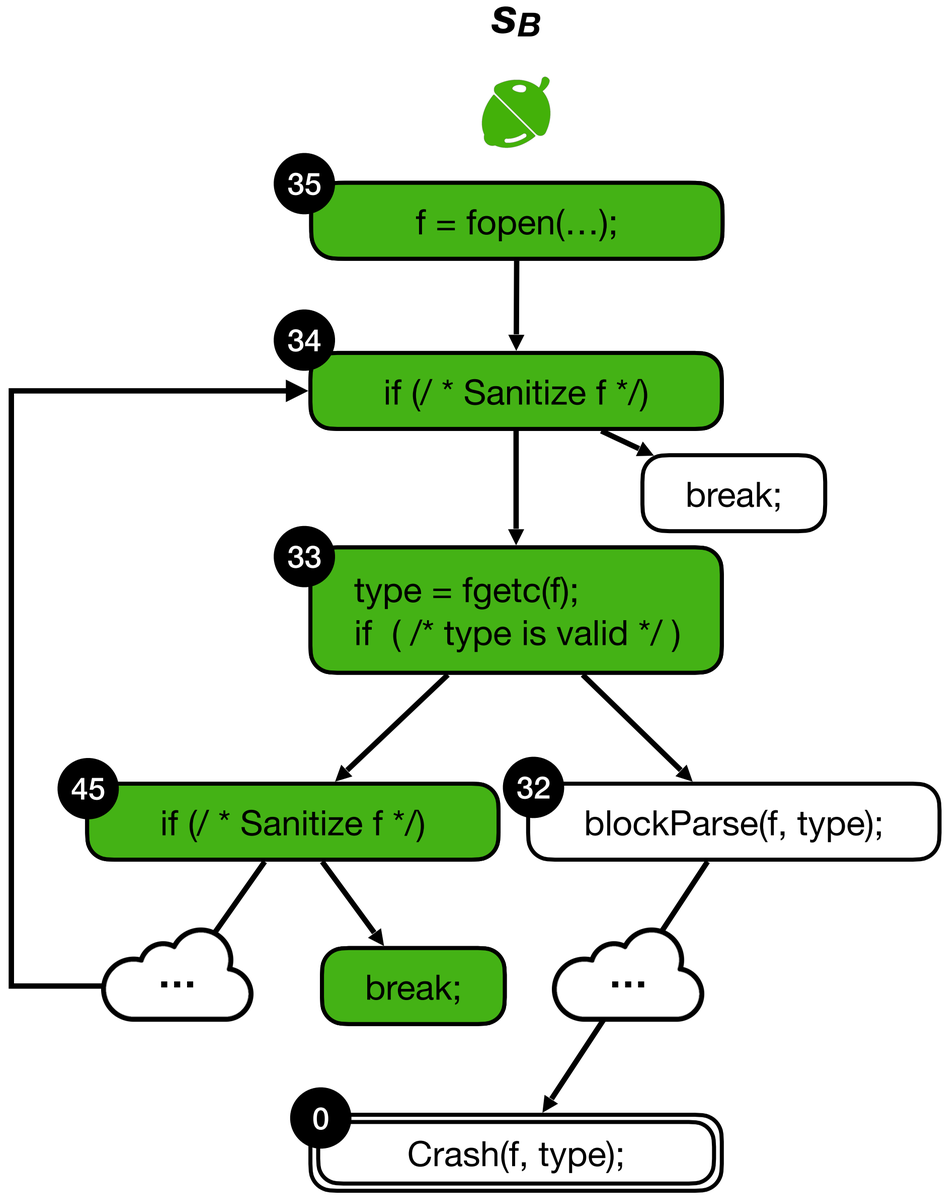
Limitations of DGF

Noisy CFG-based Seed distance

AFLGo: Distance based on all nodes in CFG (Lower is Better)

34.5 Averge(34, 35)

37.5 Averge(34, 35, 36, 45)



*CVE-2017-7578 in swftophp

Limitations of DGF

Noisy CFG-based Seed distance

AFLGo: Distance based on all nodes in CFG (Lower is Better)

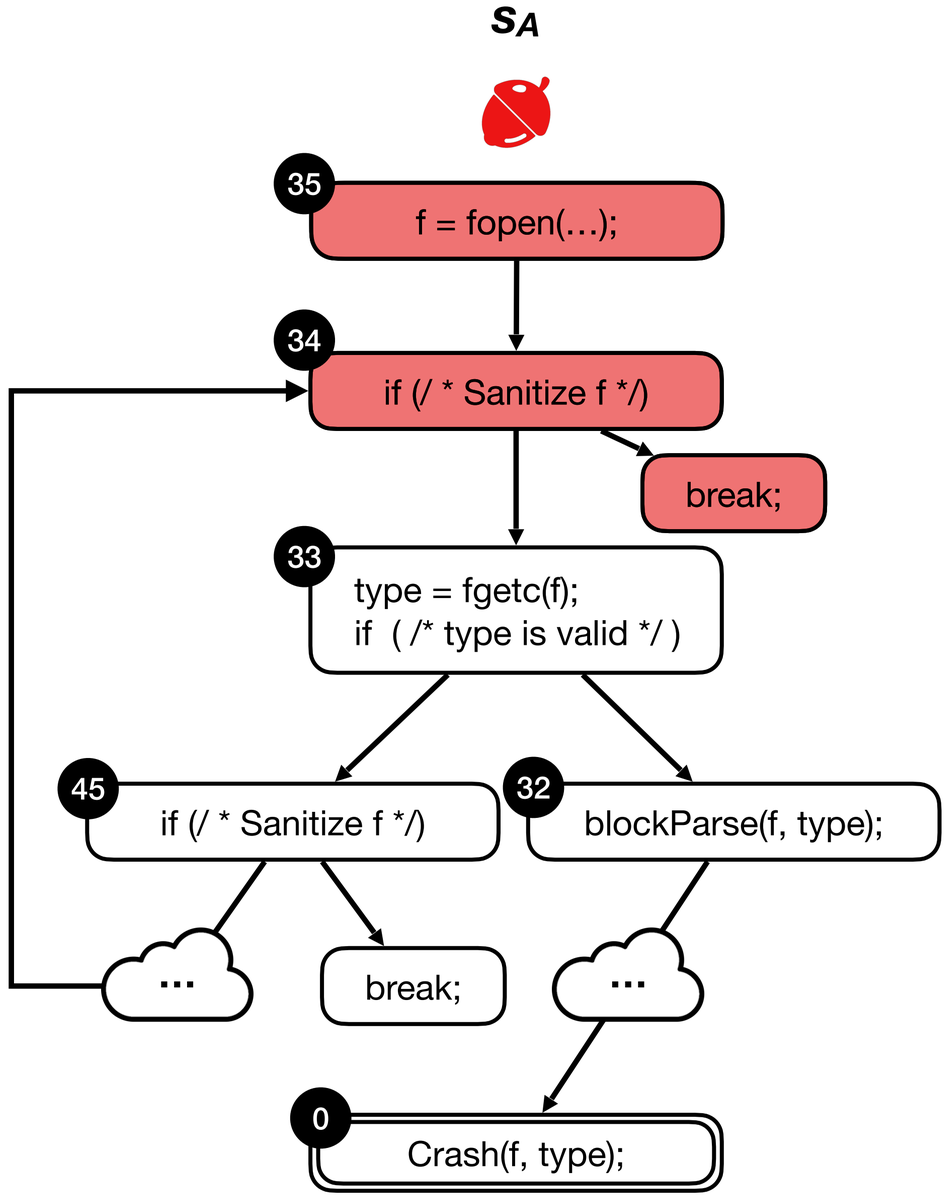
34.5

37.5

WindRanger: Distance based on Diverging nodes in CFG

(Lower is Better)

34



*CVE-2017-7578 in swftophp

Limitations of DGF

Noisy CFG-based Seed distance

AFLGo: Distance based on all nodes in CFG (Lower is Better)

34.5

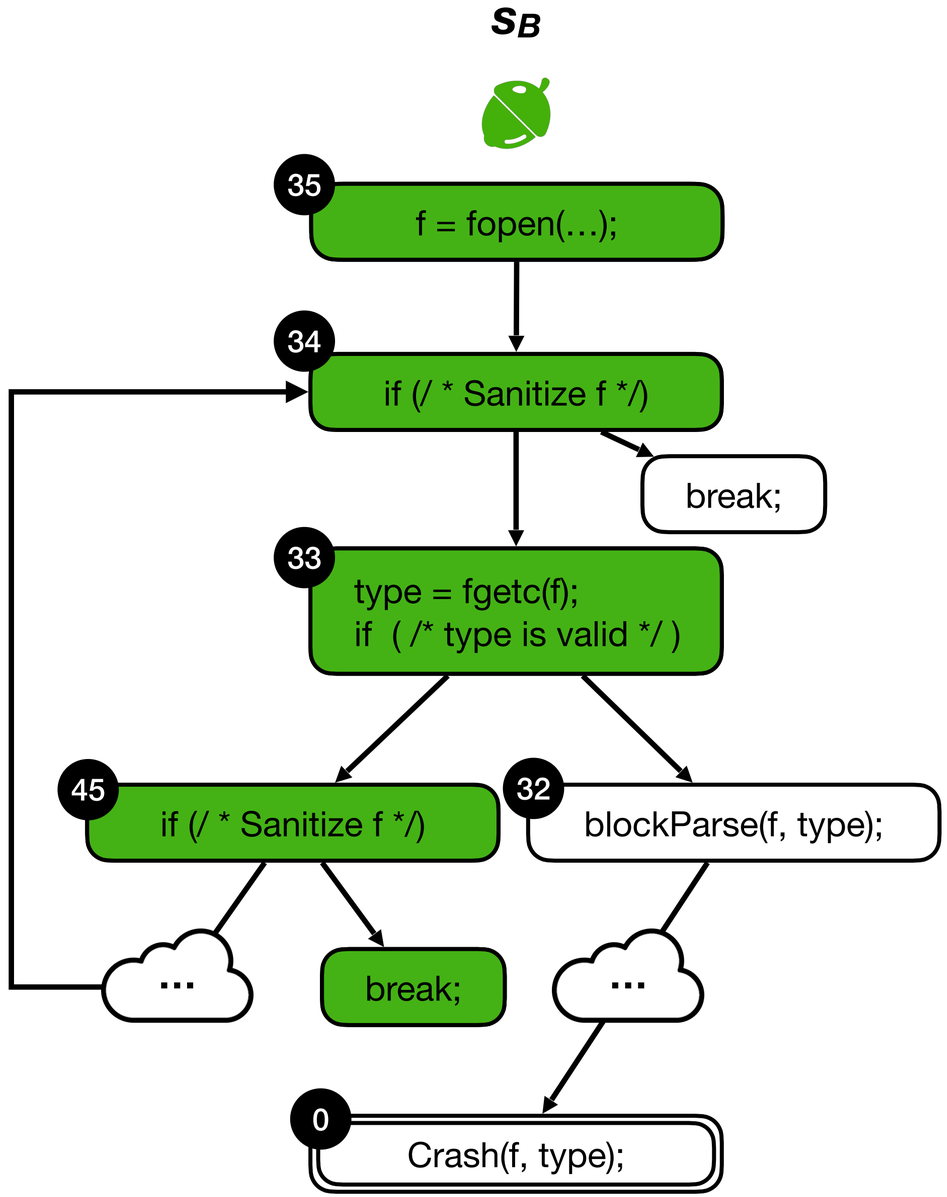
37.5

WindRanger: Distance based on Diverging nodes in CFG

(Lower is Better)

34

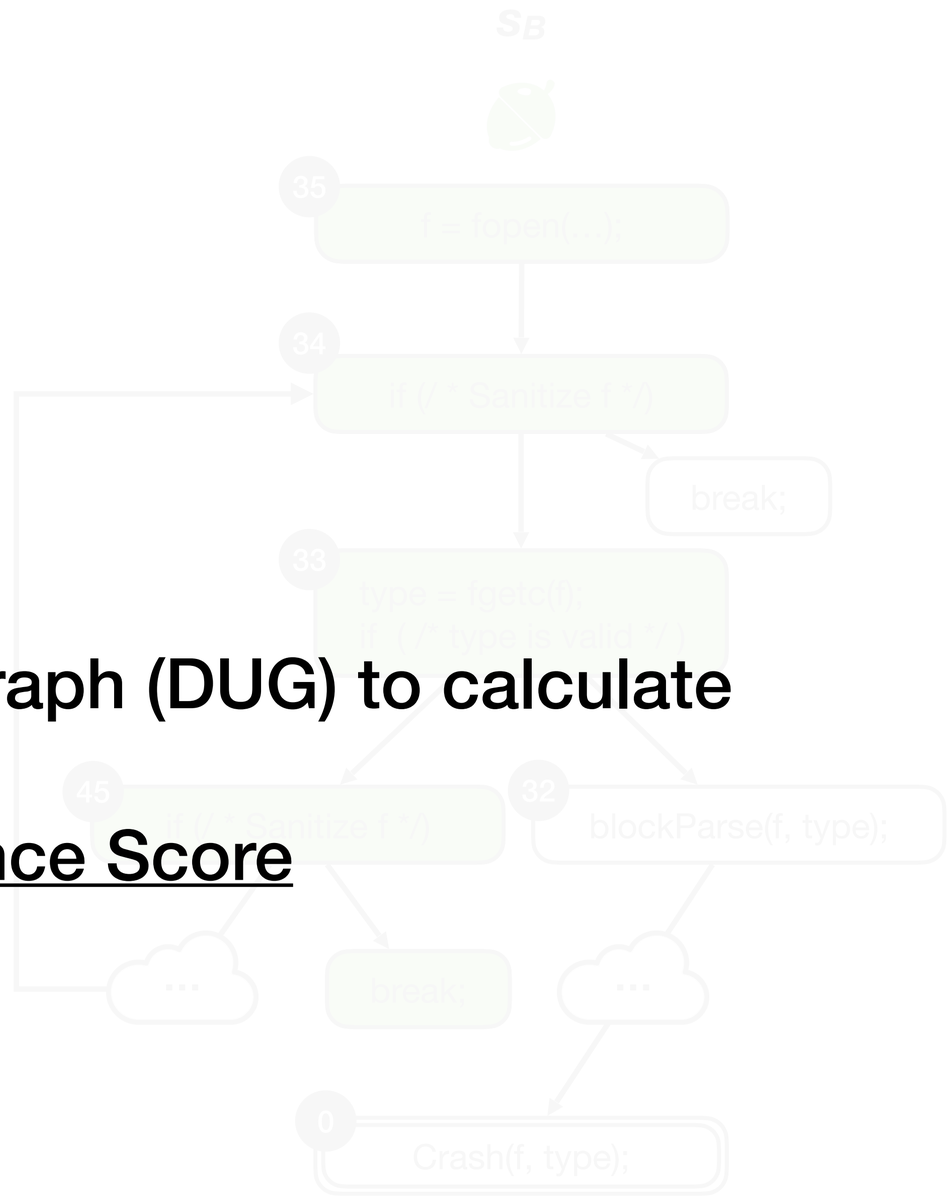
45



*CVE-2017-7578 in swftophp

DAFL's Solution

DUG-based Semantic Relevance Score



AFLGo: Distance based on all nodes in CFG

34.5 Averge(34, 35)

37.5 Averge(34, 35, 36, 45)

WindRanger: Distance based on Diverging nodes in CFG

34

45

DAFL utilizes Definition-Use Graph (DUG) to calculate

Semantic Relevance Score

*CVE-2017-7578 in swftophp

DAFL's Solution

DUG-based Semantic Relevance Score

AFLGo: Distance based on all nodes in CFG (Lower is Better)

34.5

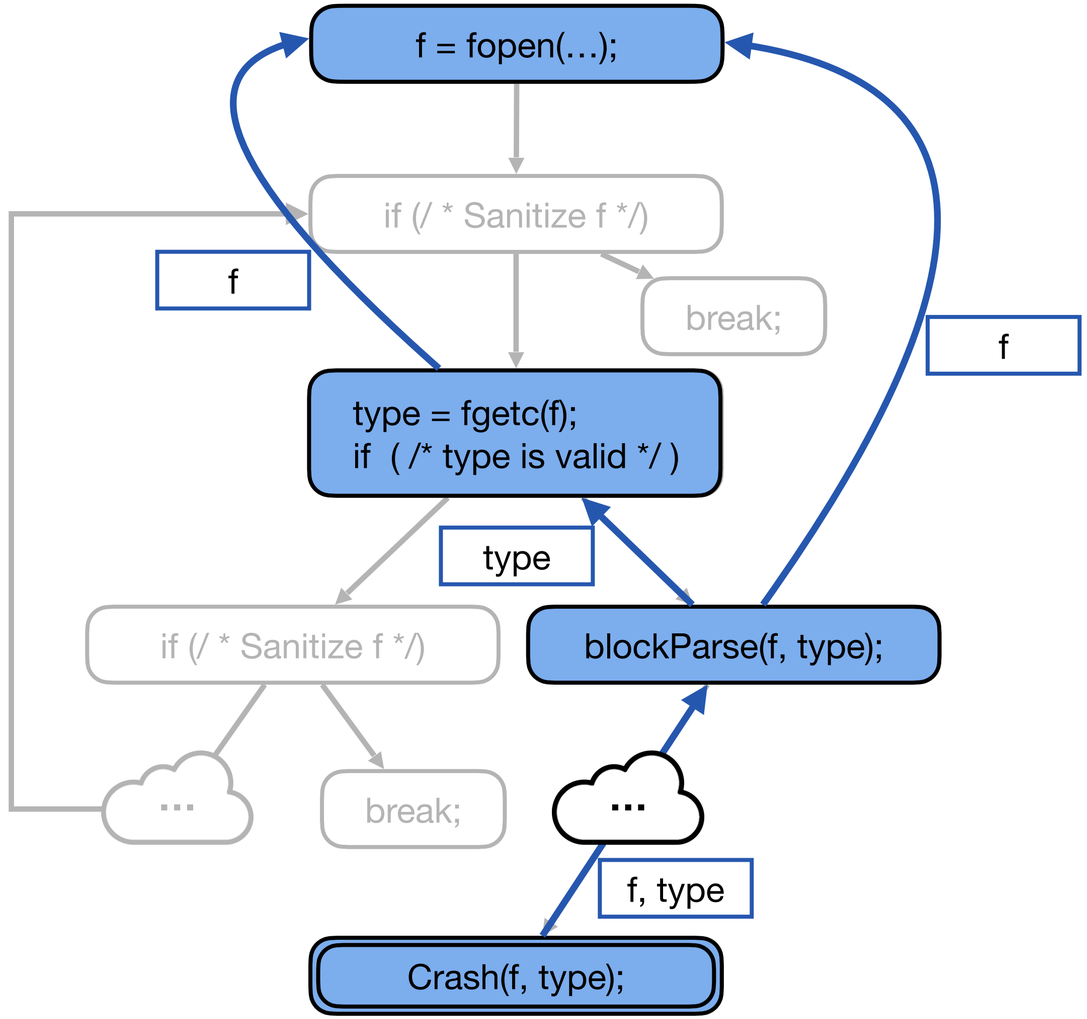
37.5

WindRanger: Distance based on Diverging nodes in CFG

(Lower is Better)

34

45



*CVE-2017-7578 in swftophp

DAFL's Solution

DUG-based Semantic Relevance Score

AFLGo: Distance based on all nodes in CFG (Lower is Better)

34.5

37.5

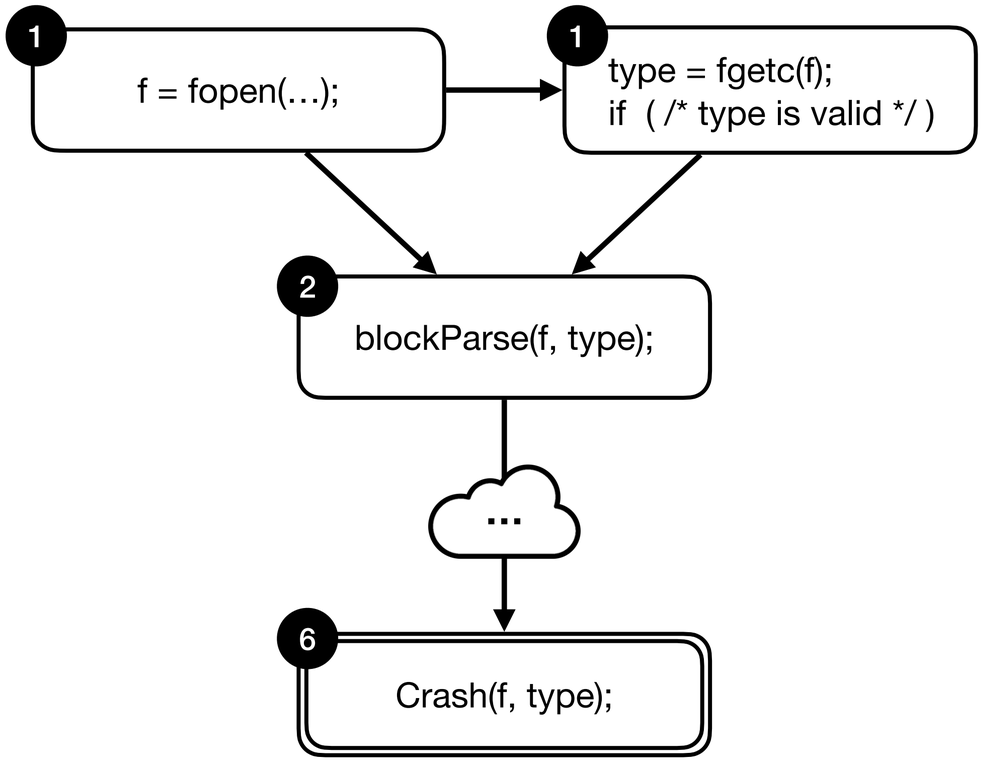
WindRanger: Distance based on Diverging nodes in CFG

(Lower is Better)

34

45

DAFL: Semantic Relevance Score based on DUG (Higher is Better)



*CVE-2017-7578 in swftophp

DAFL's Solution

DUG-based Semantic Relevance Score

AFLGo: Distance based on all nodes in CFG (Lower is Better)

34.5

37.5

WindRanger: Distance based on Diverging nodes in CFG

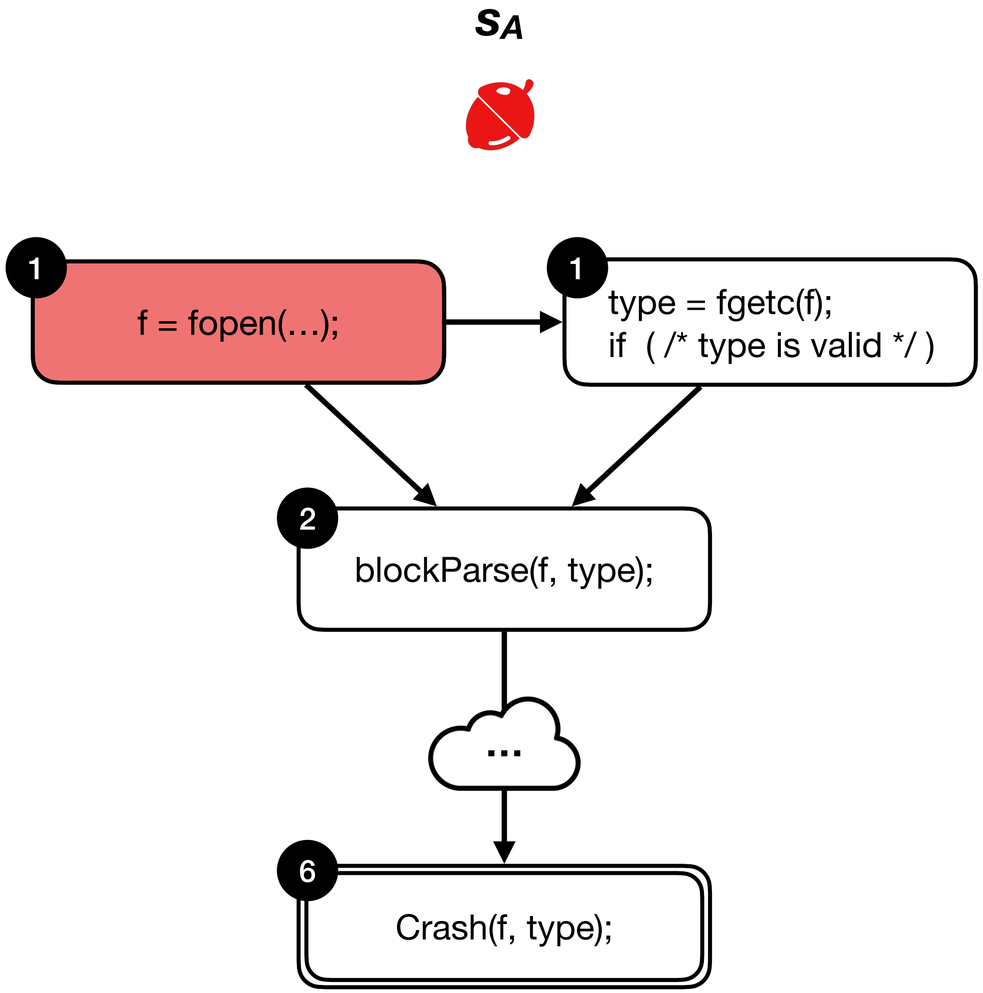
(Lower is Better)

34

45

DAFL: Semantic Relevance Score based on DUG (Higher is Better)

1 Sum(1)



*CVE-2017-7578 in swftophp

DAFL's Solution

DUG-based Semantic Relevance Score

AFLGo: Distance based on all nodes in CFG (Lower is Better)

34.5

37.5

WindRanger: Distance based on Diverging nodes in CFG

(Lower is Better)

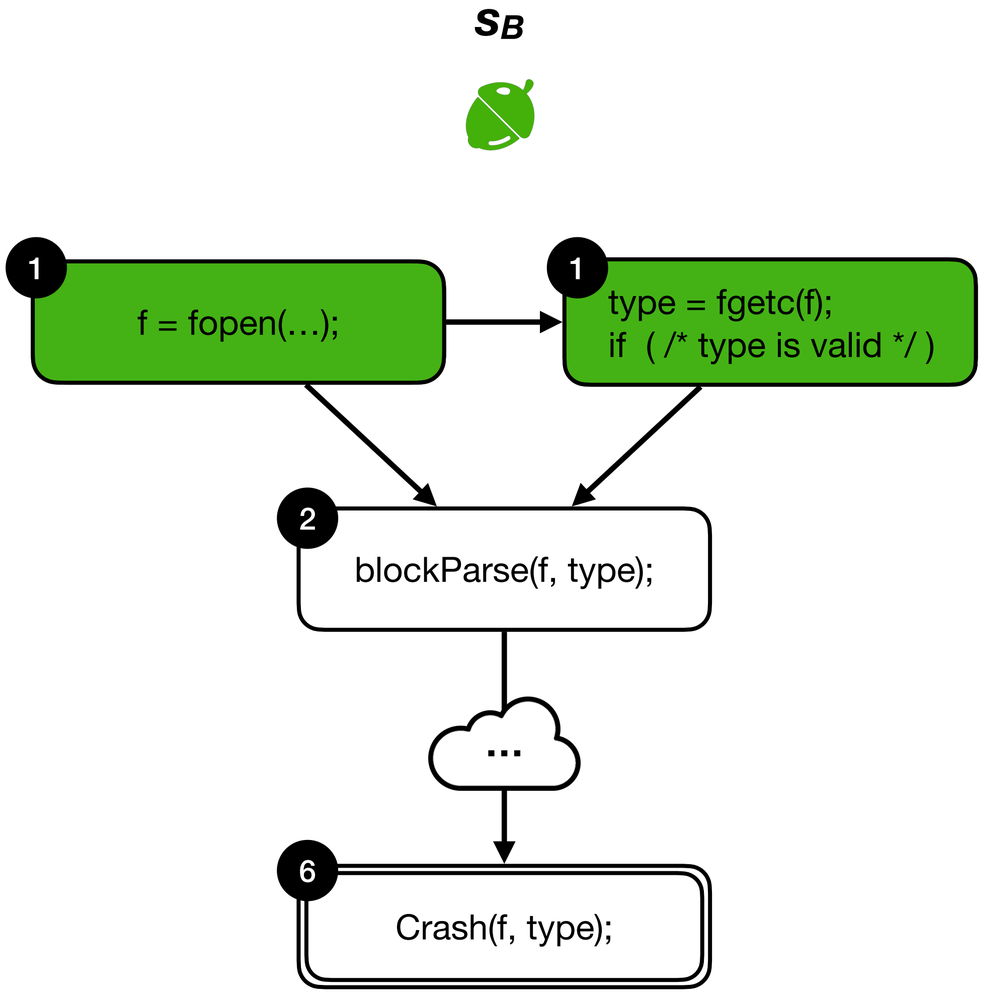
34

45

DAFL: Semantic Relevance Score based on DUG (Higher is Better)

1 Sum(1)

2 Sum(1, 1)



*CVE-2017-7578 in swftophp

Limitations of DGF

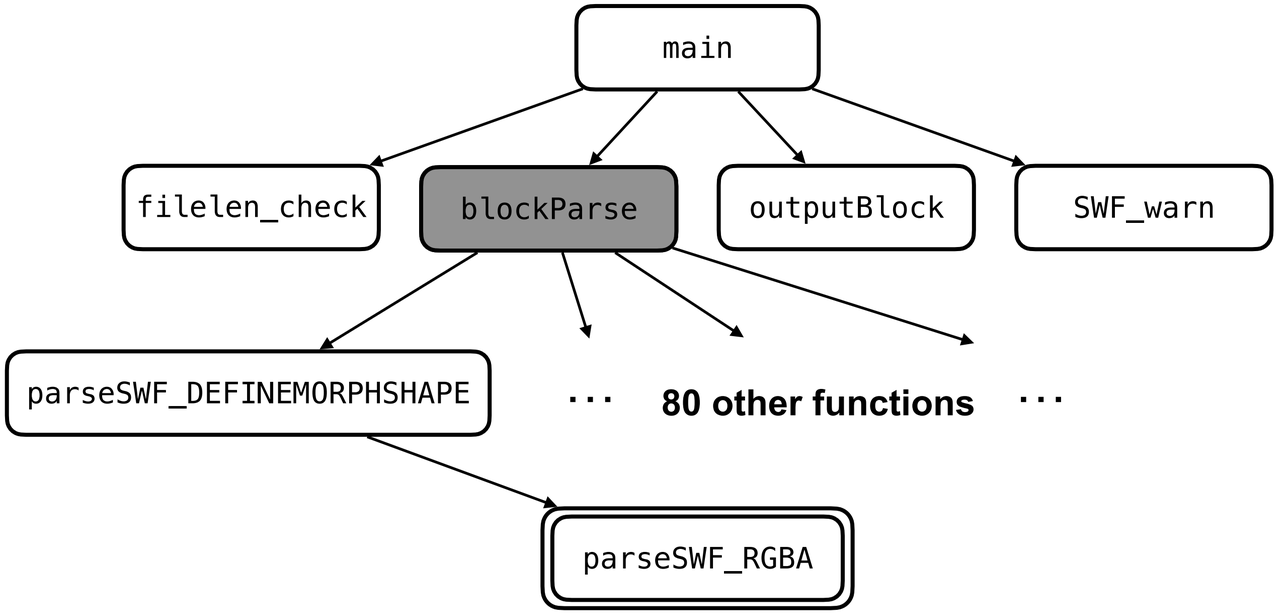
1. **Noisy** seed distance based on Control Flow Graph (CFG)
   - Complex control structures introduce noise in the seed distance

2. **Negative** Coverage Feedback
   - Generate seeds that cover irrelevant program locations

Limitations of DGF

Negative coverage feedback

- Case: CVE-2017-7578 in swftophp

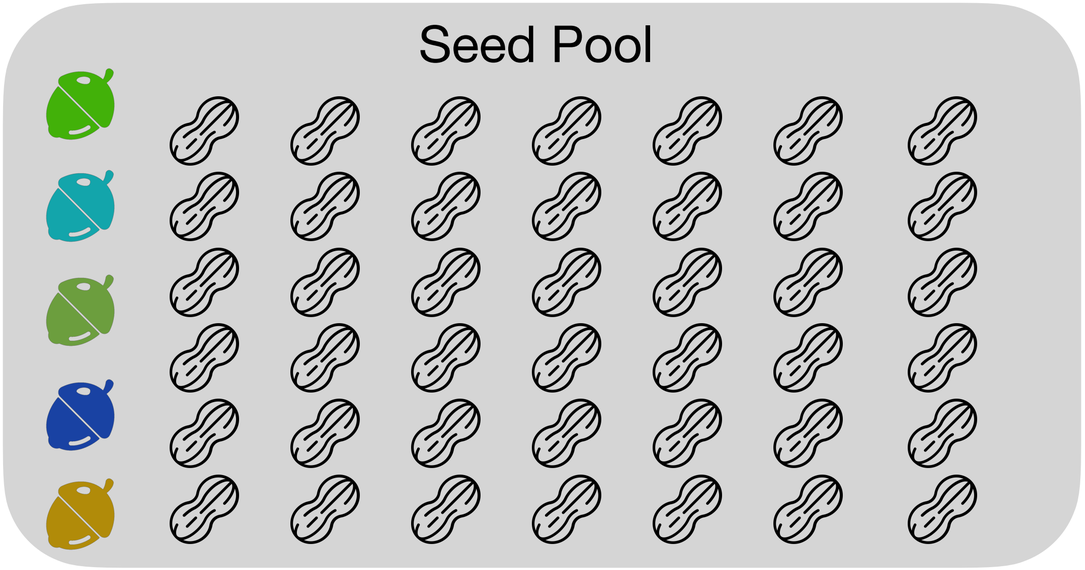


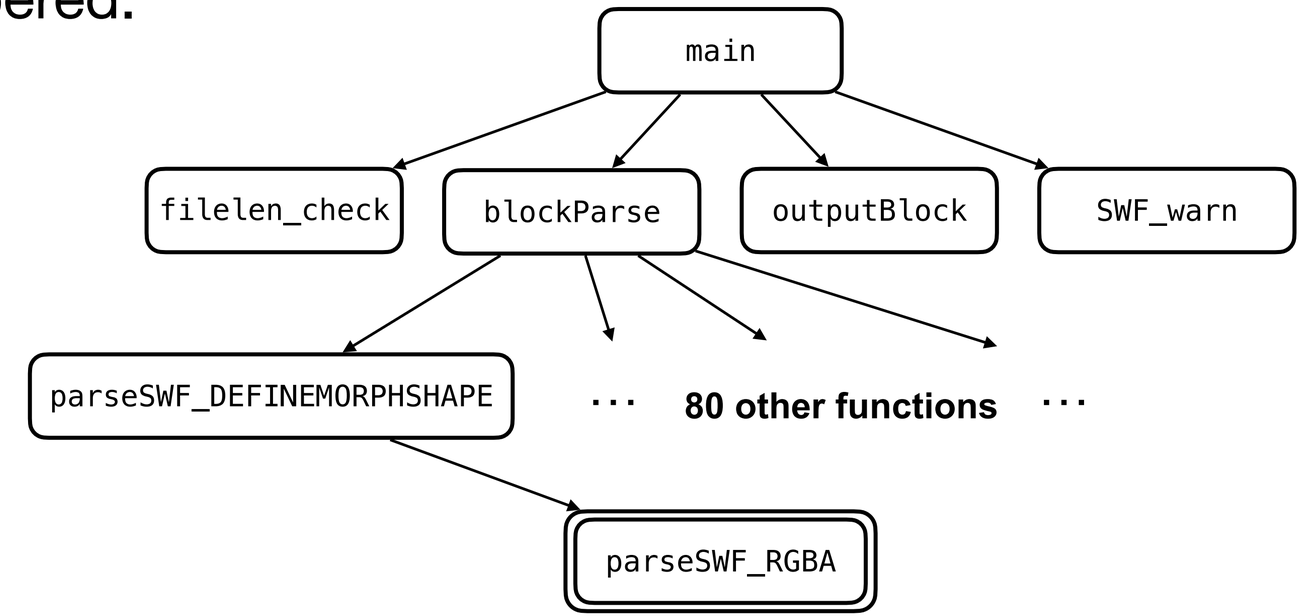
*CVE-2017-7578 in swftophp

Limitations of DGF

Negative coverage feedback

- Case: CVE-2017-7578 in swftophp
- The promising seed is easily outnumbered.





*CVE-2017-7578 in swftophp

DAFL’s Solution

Selective Coverage Instrumentation

- Case: CVE-2017-7578 in swftophp
- The promising seed is easily outnumbered.

DAFL selectively receives coverage feedback by

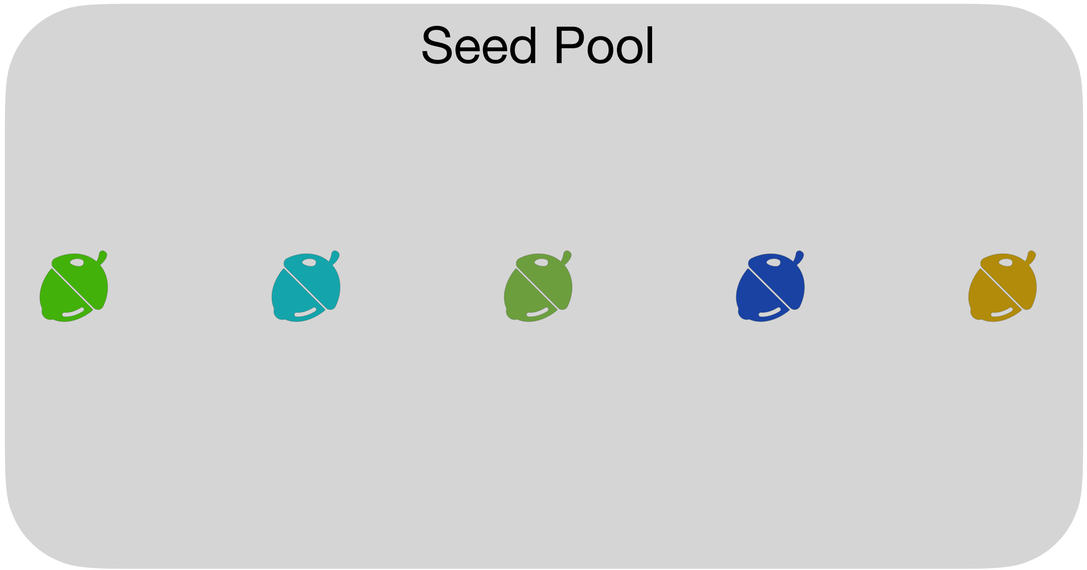
<u>Selective Coverage Instrumentation</u>

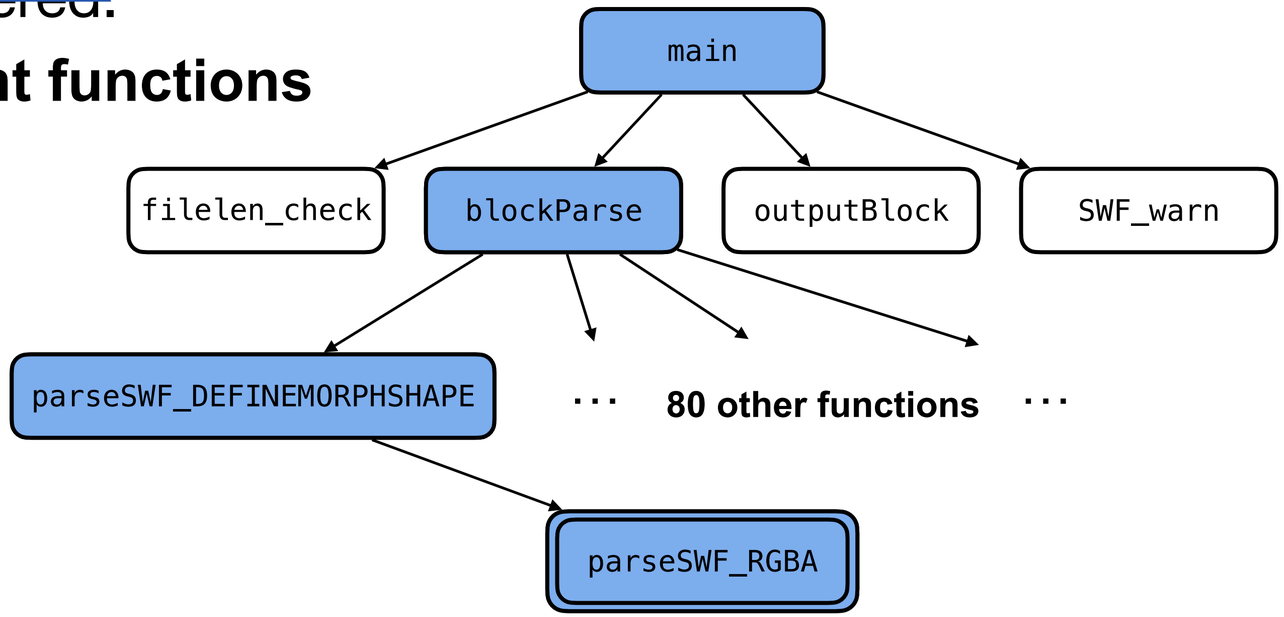
DAFL's Solution

Selective Coverage Instrumentation

- Case: CVE-2017-7578 in swftophp
- ~~The promising seed is easily outnumbered.~~

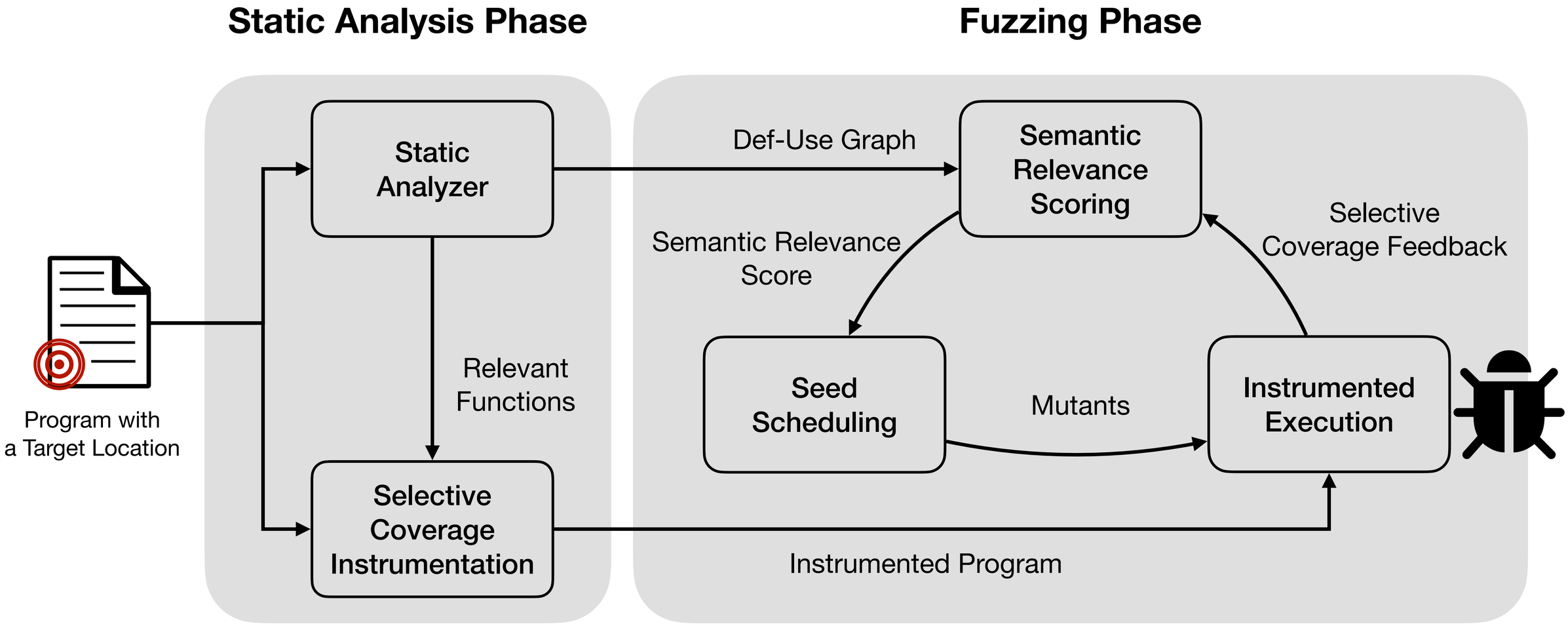
No seeds are generated from irrelevant functions



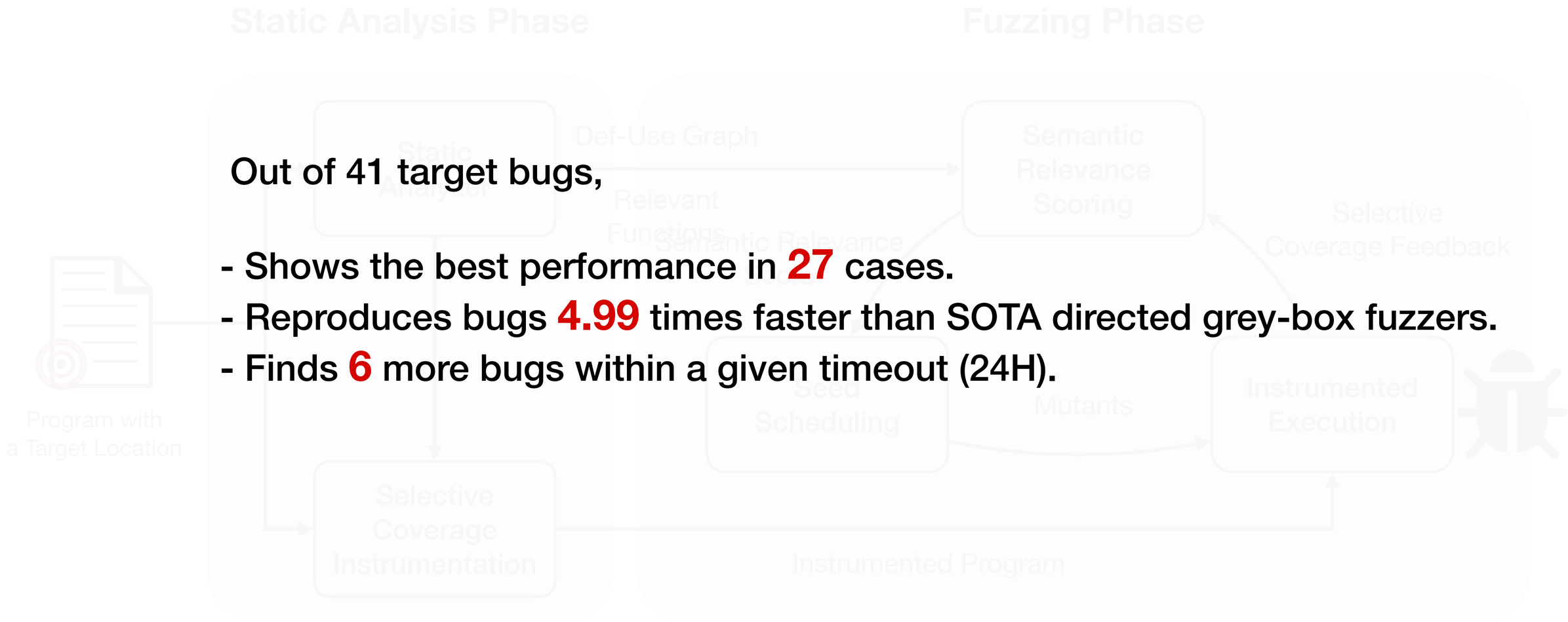


*CVE-2017-7578 in swftophp

DAFL Overview



DAFL Overview



Out of 41 target bugs,

- Shows the best performance in **27** cases.
- Reproduces bugs **4.99** times faster than SOTA directed grey-box fuzzers.
- Finds **6** more bugs within a given timeout (24H).

Evaluation

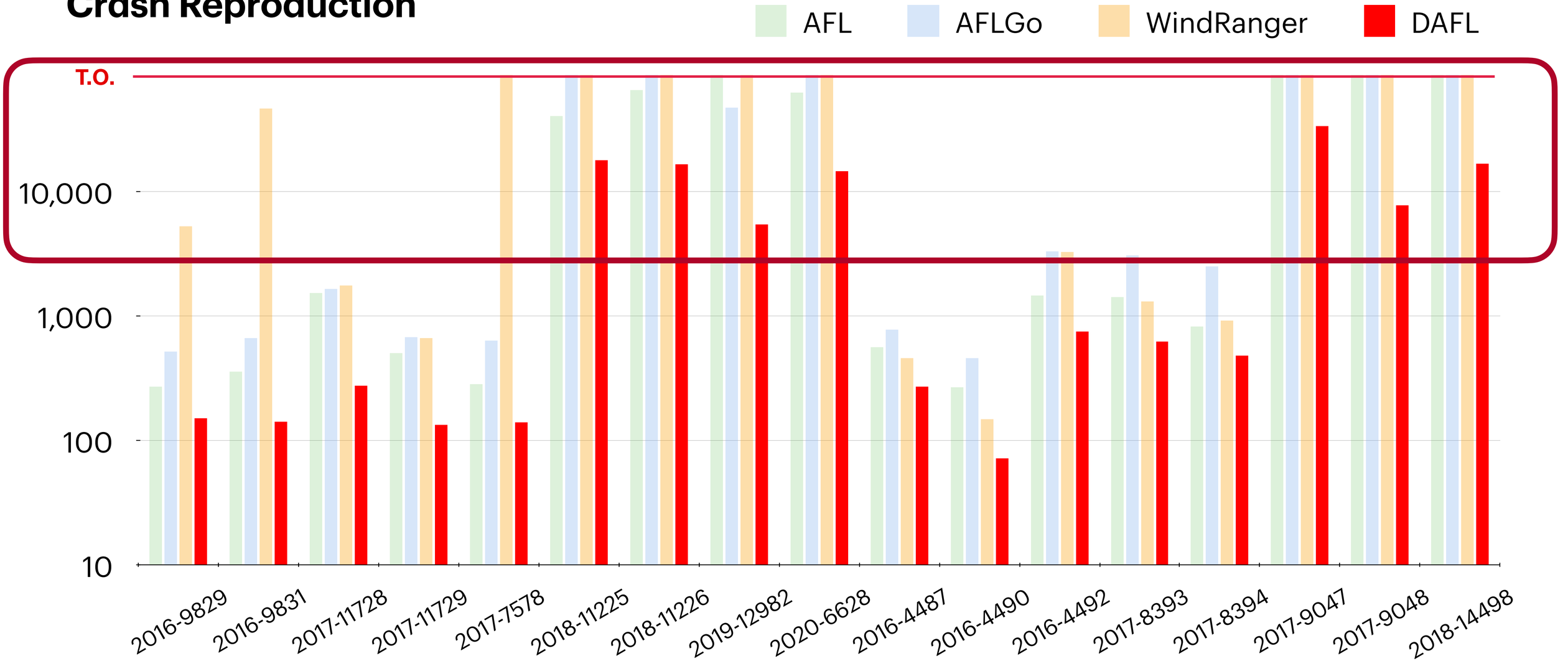
Crash Reproduction

- Benchmark
  - 41 CVEs from 10 programs
- Baselines
  - 1 Undirected Fuzzer
    - AFL
  - 3 Directed Fuzzers
    - AFLGo
    - WindRanger
    - Beacon
- Criteria
  - Median time of 40 iterations to reproduce the target bug

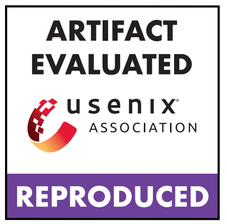
Evaluation

Best performance in **27** cases.
4.99 times faster than the baseline DGF
Finds **6** more bugs within a given timeout (24H).

Crash Reproduction



Summary



- **Directed Grey-box Fuzzing**
  - Limitations
    - Noisy Seed Distance
    - Negative Coverage Feedback

- **Solution: DAFL**
  - Directed Grey-box Fuzzing Guided by Data Dependency

- **Key Concepts of DAFL**
  - Semantic Relevance Scoring
  - Selective Coverage Instrumentation

  → Achieves 4.99 times performance boost against the SOTA Directed Grey-box Fuzzers

Link to our artifact!!