ACSAC 2021
December 6-10, 2021 • Online

WESTWORLD: Fuzzing-Assisted Remote Dynamic Symbolic Execution of Smart Apps on IoT Cloud Platforms

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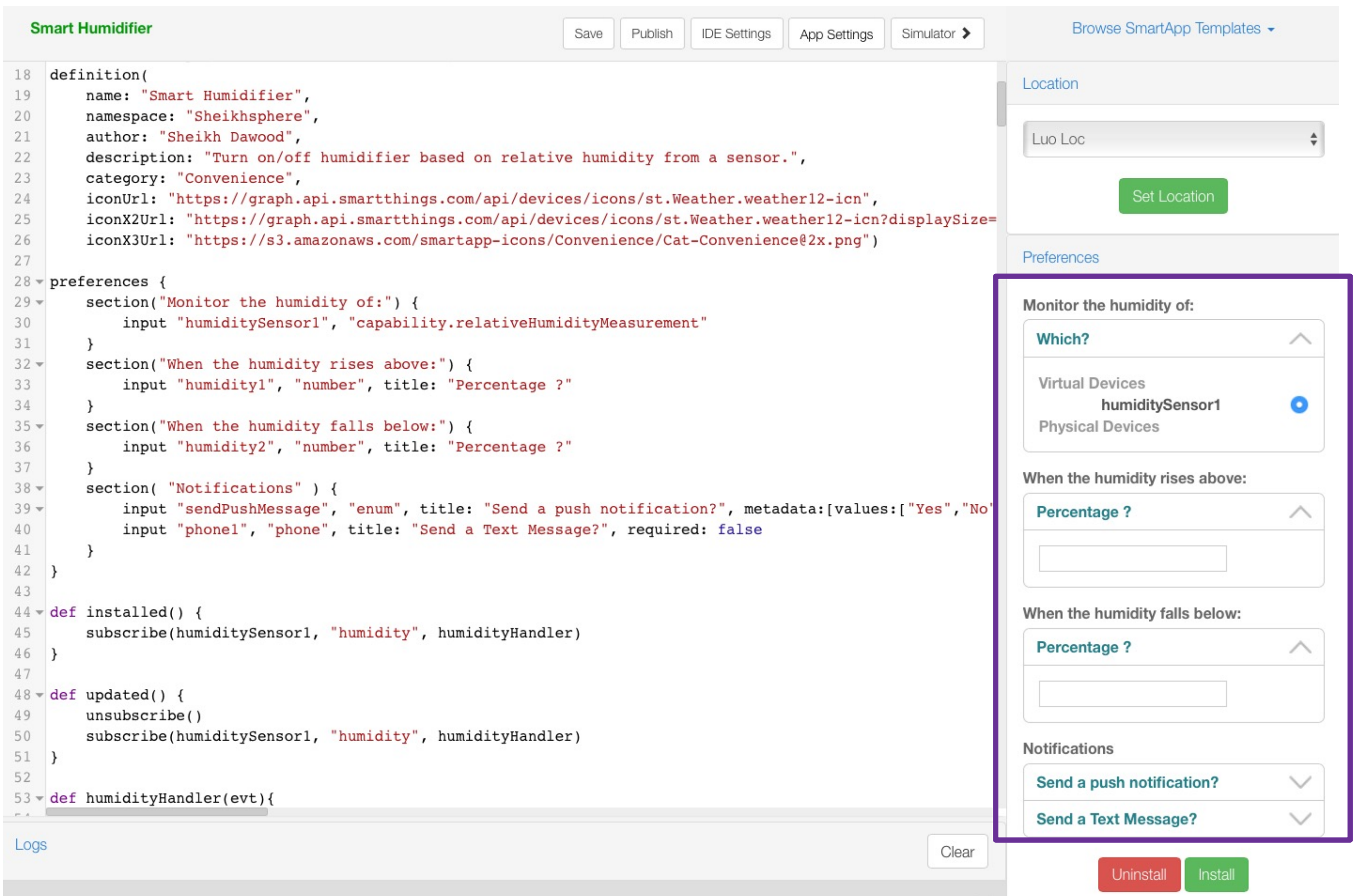
SmartThings
Smart home monitor
State
Everything OK
ARM (AWAY)
ARM (STAY)
DISARM
Routines
Good Morning!
Good Night!
Good Bye!
I'm Back!
Things
Refrigerator
Door open

Motivation

- On platforms such as SmartThings, *official* smart apps are manually reviewed.
- Many community members enjoy writing *custom* smart apps and share them in the SmartThings community forum so that others can use them, which however does not enforce code review.
- Smart apps tend to have bugs.
- Automated testing of smart apps for bug discovery is critical needed.

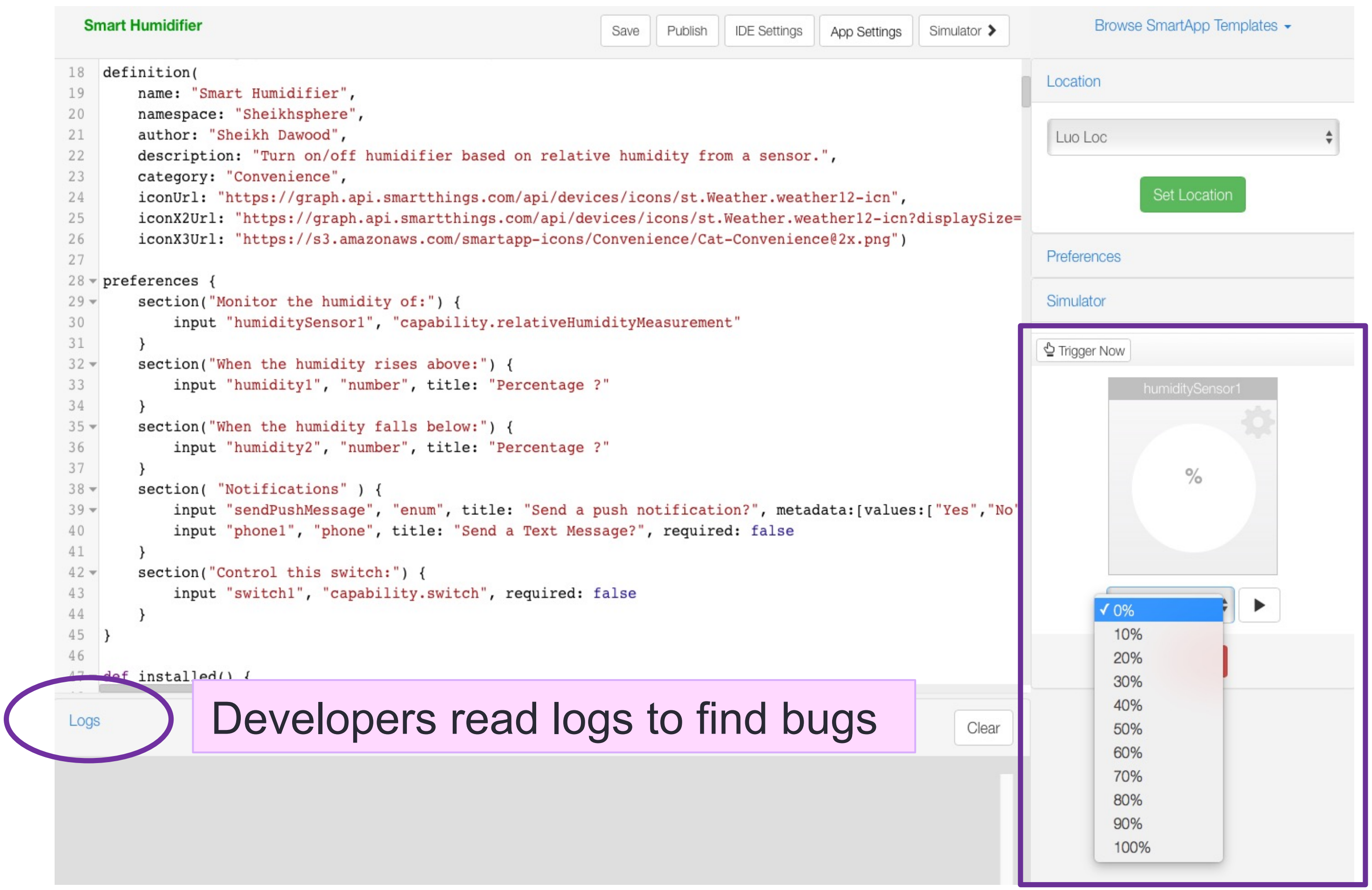
Current Method of Testing Smart Apps

- Step 1: fill app configurations (user inputs)



Current Method of Testing Smart Apps

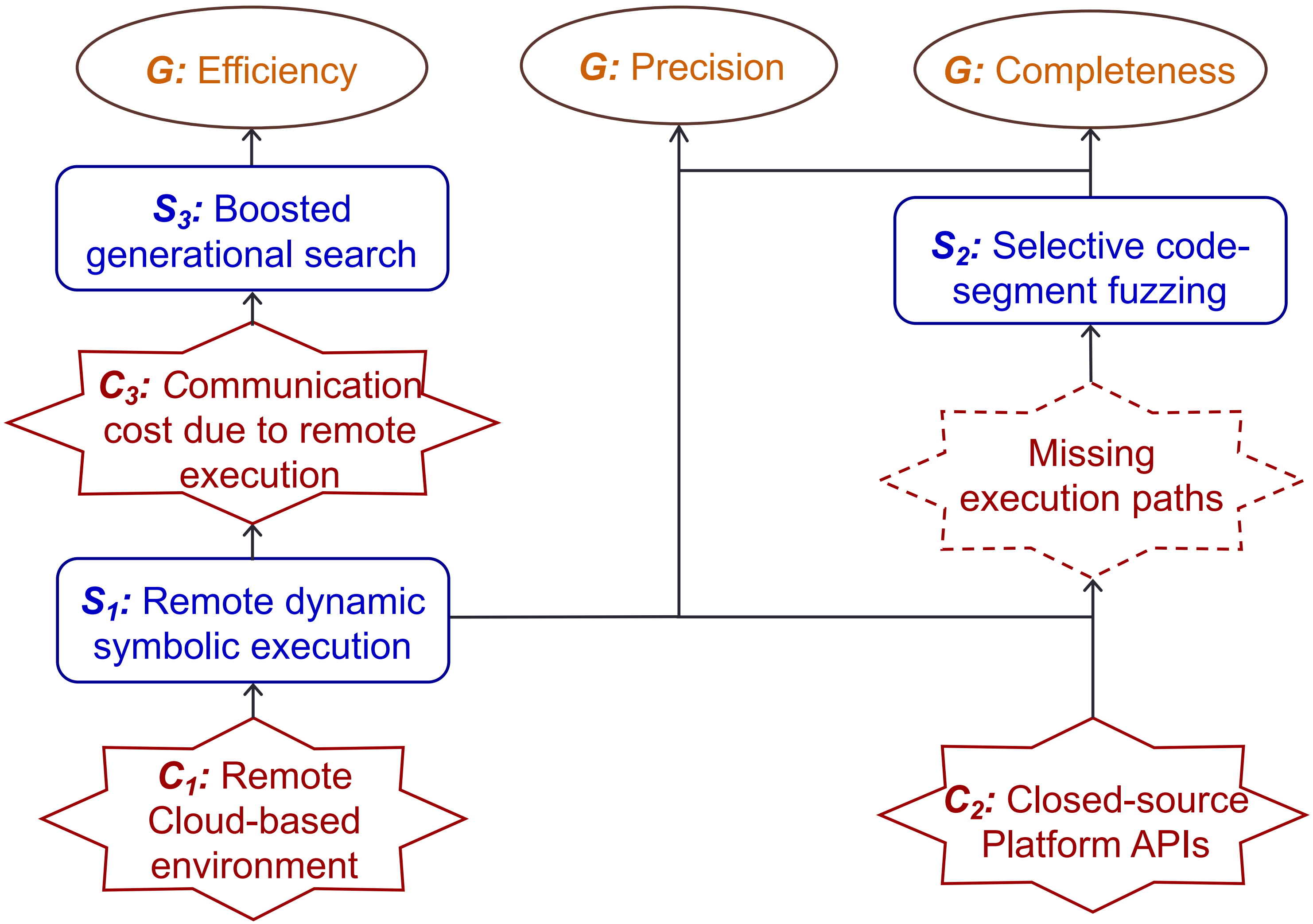
- Step 2: select environment inputs



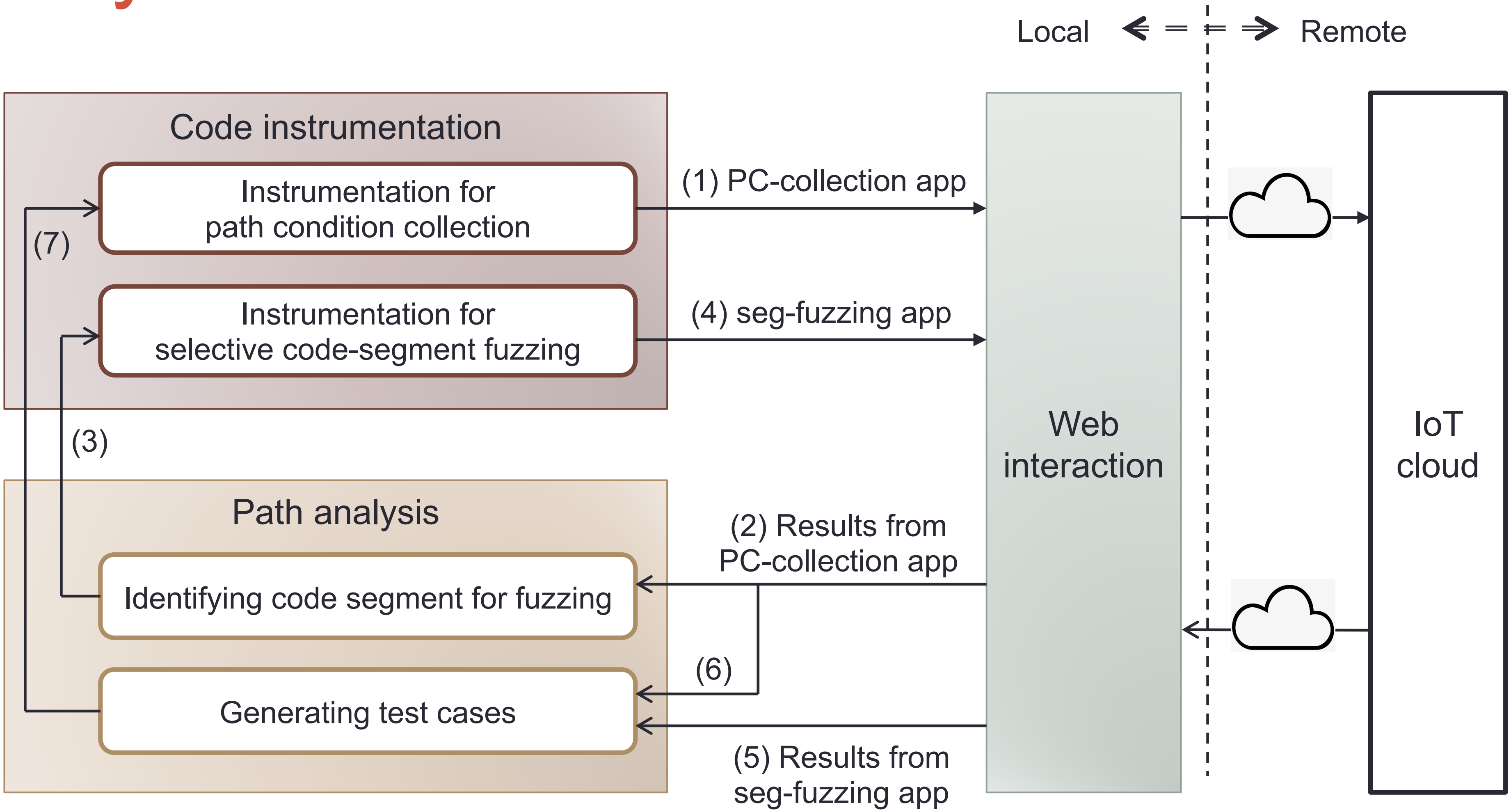
Symbolic Execution

- Symbolic execution is a promising automatic testing technique for finding bugs.
- While many symbolic executors have been proposed for analyzing Windows programs, Linux programs and Java programs, none support the analysis of IoT apps.
- Due to unique characteristics of IoT platforms, multiple challenges exist for symbolically executing IoT apps.

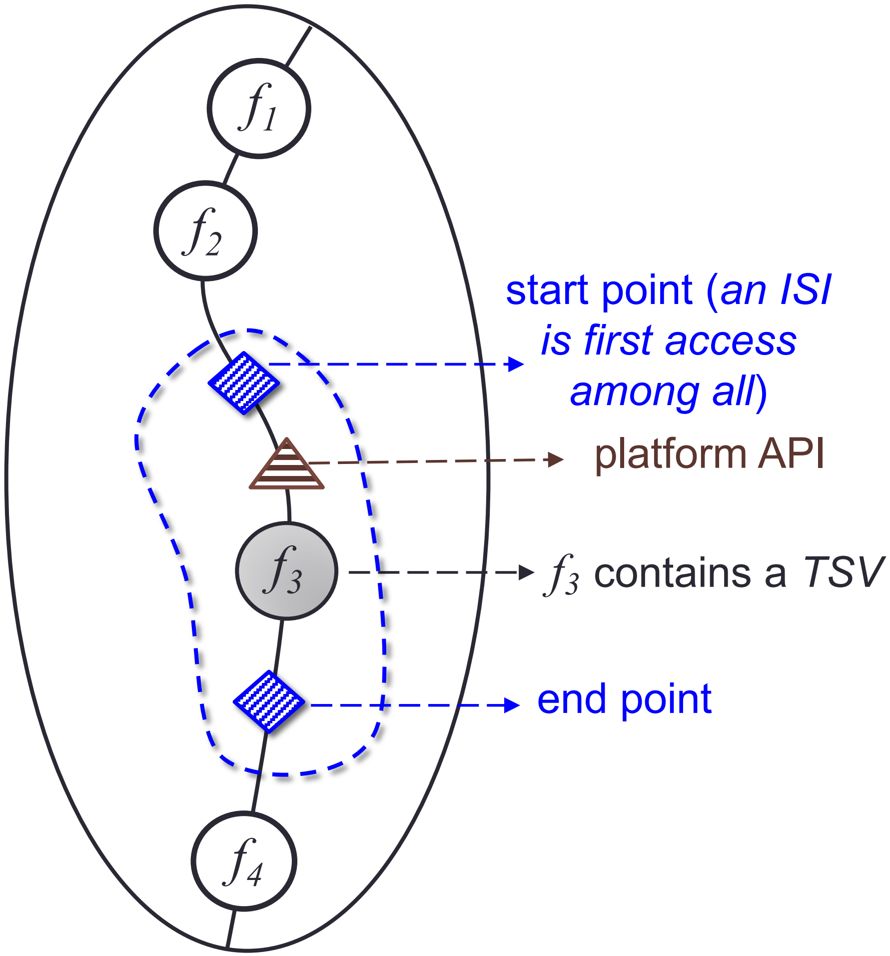
Challenges, Solutions, and Goals



System Architecture



An Example



- Return value of a platform API is assigned as a temporary symbolic variable (TSV)
- *Selective code-segment fuzzing:* find out the relation between a TSV and symbolic inputs that it relies on, called *influential symbolic inputs* (ISI)
- ***Our insight***: most symbolic inputs usually have a small to moderate number of possible values. E.g., “humidity” has 101 integer values between 0 and 100.
- A for-loop is inserted to iterate over values of ISIs and learn the relation between the TSV and ISIs.
- The relation is combined with symbolic path condition to generate test cases

Comparison with Driller

- Westworld: symbolic execution-centric
- Driller: fuzzing-centric

- **Reason of our design choice**: The communication cost between the remote cloud and local analyzer cannot be omitted. Each testing request is expensive.
  - E.g., given a path like (temp<75 && temp>68), Driller cannot avoid generating a lot of testing requests that repetitively take the same path, while symbolic execution is good at this.

Evaluation

- We evaluate Westworld in five aspects: feasibility, completeness, precision, efficiency, and effectiveness in bug finding.

- Three Datasets.
  - *Dataset-I* includes 136 official (84) and third-party (52) apps randomly collected from the SmartThings GitHub repo.
  - *Dataset-II* includes 64 hand-crafted apps with more paths and more complex conditional statements.
  - *Dataset-III* has 8 apps with different types of bugs inserted by us.

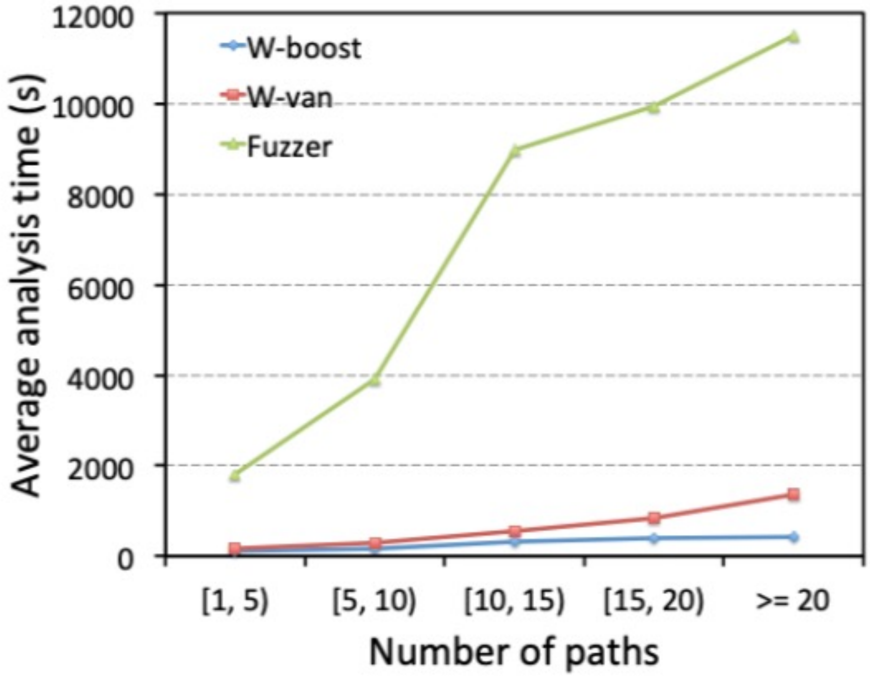
Completeness

Table 2: Completeness result (%) (full path coverage is attained by WESTWORLD after a minor implementation change).

# of paths in apps	WESTWORLD						Fuzzer						Concolic executor					
	Dataset-I			*Dataset-II*			*Dataset-I*			*Dataset-II*			*Dataset-I*			*Dataset-II*		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
≥ 20	100	100	100	100	100	100	69.6	22.4	43.3	46.8	14.3	20.0	72.4	28.3	45.7	44.6	12.8	22.3
[15, 20)	100	100	100	100	100	100	68.4	28.6	46.7	58.3	22.6	42.7	73.5	30.6	50.8	50.2	24.1	38.8
[10, 15)	100	100	100	100	100	100	70.4	27.3	43.3	67.2	36.4	51.0	76.4	32.3	48.3	65.5	33.2	40.3
[5, 10)	100	100	100	100	100	100	82.4	30.5	69.3	78.8	31.5	43.4	100	35.5	64.3	67.2	25.5	38.2
[2, 5)	100	100	100	100	100	100	100	37.2	74.9	86.4	42.4	62.5	100	56.2	80.2	73.2	32.0	56.4

- **Grey-box fuzzer** adopts the coverage-guided input generation technique used in American Fuzzy Lop (AFL).
- **Concolic executor** considers user inputs and environment variables as symbolic inputs (the same as Westworld), but does not apply selective code-segment fuzzing to improve path coverage.

Efficiency



(a) Our tools *vs.* fuzzer

- W-vanila executes each test case through one testing request.
- W-boost executes all test cases of one generation via one testing request.

Bug Finding

- We apply Westworld to four types of bugs: (1) division by zero, (2) array out of bound, (3) null-pointer dereference, and (4) dead code.

- In Dataset-I, we found 4 apps with null-pointer dereference bugs

- Dataset-III contains 8 apps with different bugs. Westworld can successfully find all the bugs.
  - (1) two apps contain division by zero bugs, (2) four are inserted with dead code, (3) one contains an array out of bound bug, and (4) one contains a null-pointer dereference bug.

Summary

- We have presented the first system that enables dynamic symbolic execution (DSE) of smart apps.
- Exploiting the uniqueness of environment inputs, selective code-segment fuzzing was proposed to assist DSE.
- We implemented Westworld, which performs fuzzing-assisted DSE-centric analysis of smart apps.
- The evaluation shows that Westworld is effective and efficient in path exploration and bug finding.


THANK YOU
VERY MUCH