University of Luxembourg

Interdisciplinary Centre for Security, Reliability and Trust

ConFuzzius: A Data Dependency-Aware Hybrid Fuzzer for Smart Contracts

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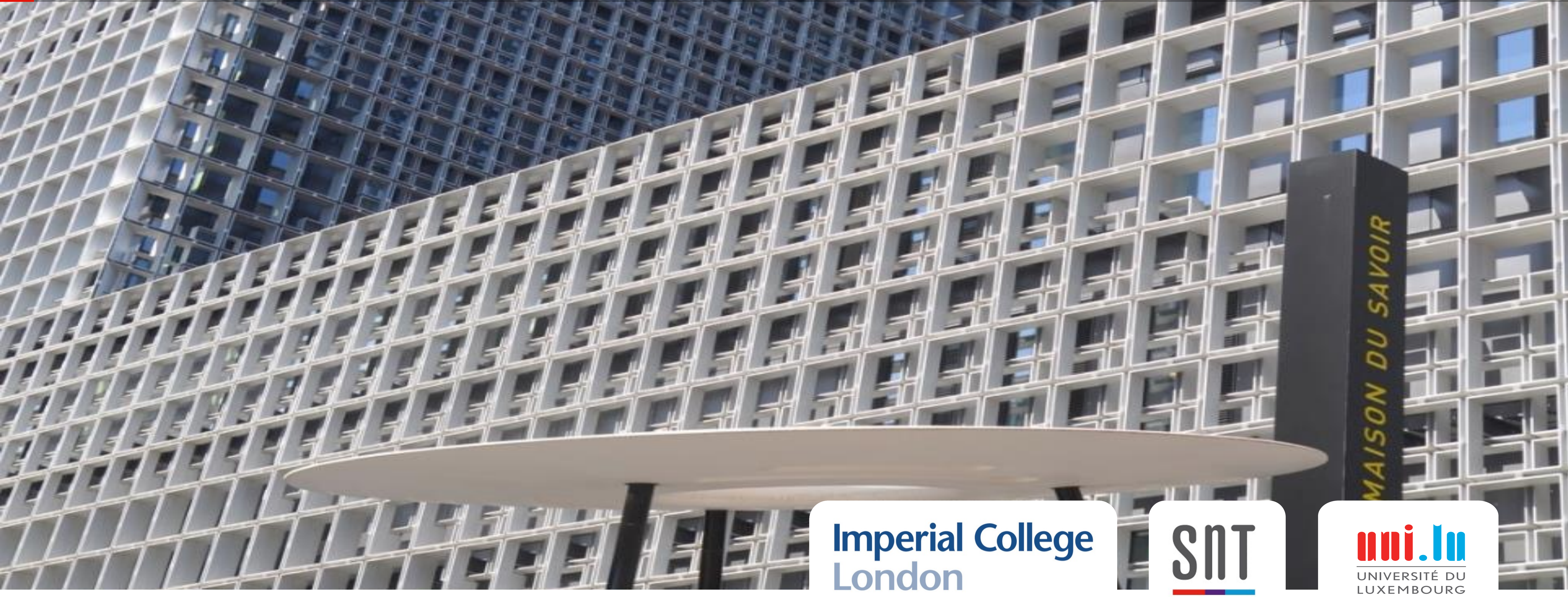

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Attacks on Smart Contracts

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A $50 MILLION HACK JUST SHOWED THAT THE DAO WAS ALL TOO HUMAN

20 JULY 2017 / #ETHEREUM #BLOCKCHAIN #SECURITY

A hacker stole $31M of Ether — how it happened, and what it means for Ethereum

SpankChain, a cryptocurrency project focused on the adult industry, has suffered a breach that saw almost $40,000 in ethereum (ETH) stolen.

Wallet bug freezes more than $150 million worth of Ethereum

A hackers' dream payday: Ledf.Me and Uniswap lose $25 million worth of cryptocurrency

by Alina Bizga on April 21, 2020

Smart Contract Security Challenges

```
contract TokenSale {
  uint256 start = now;
  uint256 end = now + 30 days;
  address wallet = 0xcafebabe...;
  Token token = Token(0x12345678...);

  address owner;
  bool sold;

  function Tokensale() public {
    owner = msg.sender;
  }

  function buy() public payable {
    require(now < end);
    require(msg.value == 42 ether + (now - start)
          / 60 / 60 / 24 * 1 ether);
    require(token.transferFrom(this, msg.sender,
        token.allowance(wallet, this)));
    sold = true;
  }

  function withdraw() public {
    require(msg.sender == owner);
    require(now >= end);
    require(sold);
    owner.transfer(address(this).balance);
  }
}
```

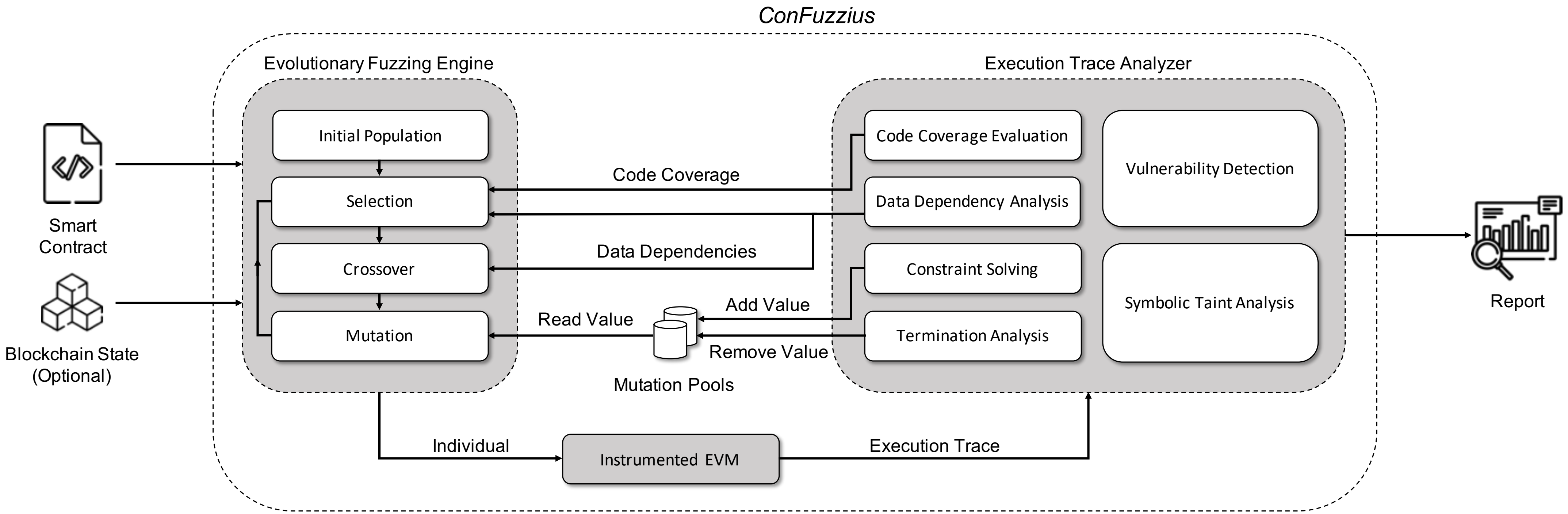
Stateful exploration
Solution: read-after-write data dependency

Input generation
Solution: Input generation via symbolic execution

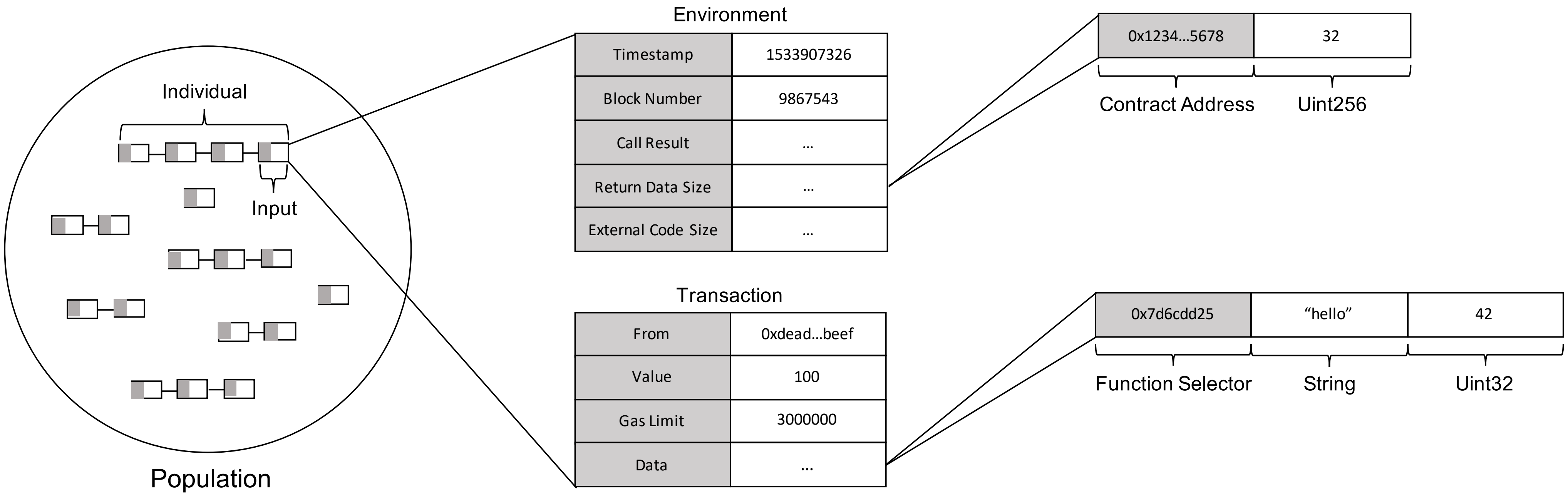
Environmental dependency
Solution: Model and fuzz environmental inputs

ConFuzzius

Architecture



Encoding Individuals



Data Dependency Analysis

- Access to state variables is retrieved dynamically via `SLOAD` and `SSTORE` instructions.
- Retrieve storage variable from storage location:
  - Statically-sized:
    - Includes: primitives, structs, and fixed arrays.
    - Pop first element from stack.
  - Dynamically-sized:
    - Mappings: Map result of `SHA3` instruction to memory contents and only extract the last 32 bytes (concatenation).
    - Dynamic Arrays: keep track of arithmetic additions of `SHA3` hashes.

Variable Type	**Declaration**	**Access**	**Storage Location**
Primitive	`T v`	`v`	s(v)
Struct	`struct v { T a }`	`v.a`	s(v) + s(a)
Fixed Array	`T[10] v`	`v[n]`	$s(v) + n \cdot \lvert T \rvert$
Dynamic Array	`T[] v`	`v[n]`	$h(s(v)) + n \cdot \lvert T \rvert$
		`v.length`	s(v)
Mapping	`mapping(`T_1` => `T_2`) v`	`v[k]`	$h(k \,\Vert\, s(v))$

Evaluation

Datasets, Baselines, and Experimental Setup

Datasets

1. Real-World dataset
   - **21,147** contracts with source code from Etherscan.
   - Clustered using k-means into a **large** cluster (**3,344** contracts) and **small** cluster (**17,803** contracts).
2. Curated dataset
   - Based on **SmartBugs** by Durieux et al. and extended with **5 additional types** from SWC registry.
   - **128 contracts** with **148 annotated vulnerabilities** across **10 different types**.

Baselines

Toolname	Type	Requires Source Code	Requires ABI	Vulnerability Detectors AF	IO	RE	TD	BD	UE	UD	LE	LO	US
OYENTE [28]	Symbolic	✗	✗	●	●	●	●	●	○	○	○	○	●
MYTHRIL [31]	Symbolic	✗	✗	●	●	●	●	●	●	●	●	○	●
M-PRO [31]	Symbolic	✓	✗	●	●	●	●	●	●	●	●	○	●
ILF [18]	Fuzzer	✓	✓	○	○	○	○	●	●	●	●	●	●
sFUZZ [32]	Fuzzer	✓	✓	○	●	●	○	●	●	●	○	●	○
CONFUZZIUS	**Hybrid**	✗	✓	●	●	●	●	●	●	●	●	●	●

Experimental Setup

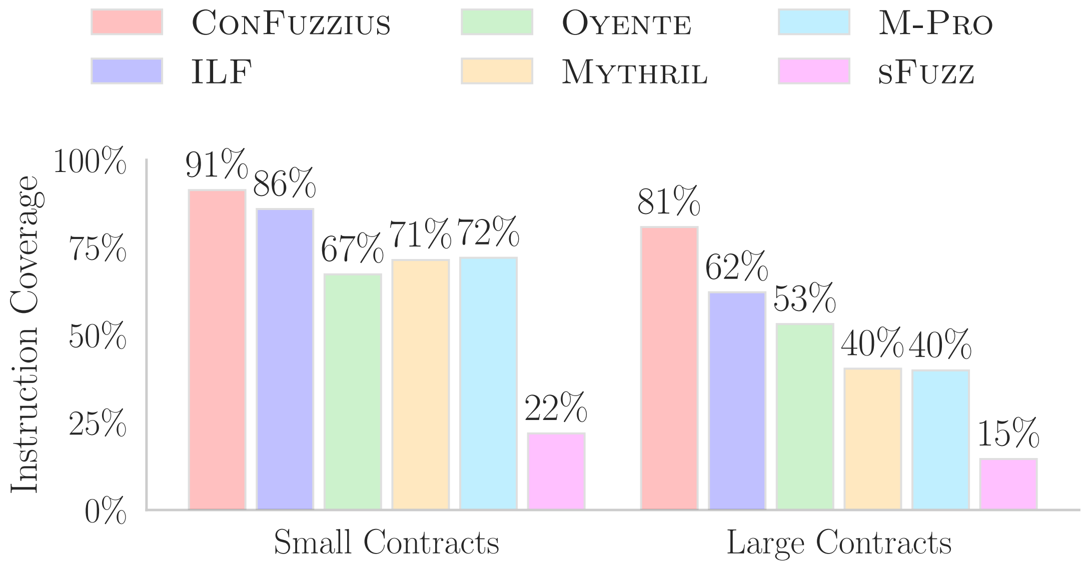
10 runs with **independent seeds** with **10 min for small** contracts and **1 hour for large** contracts.

1st Research Question

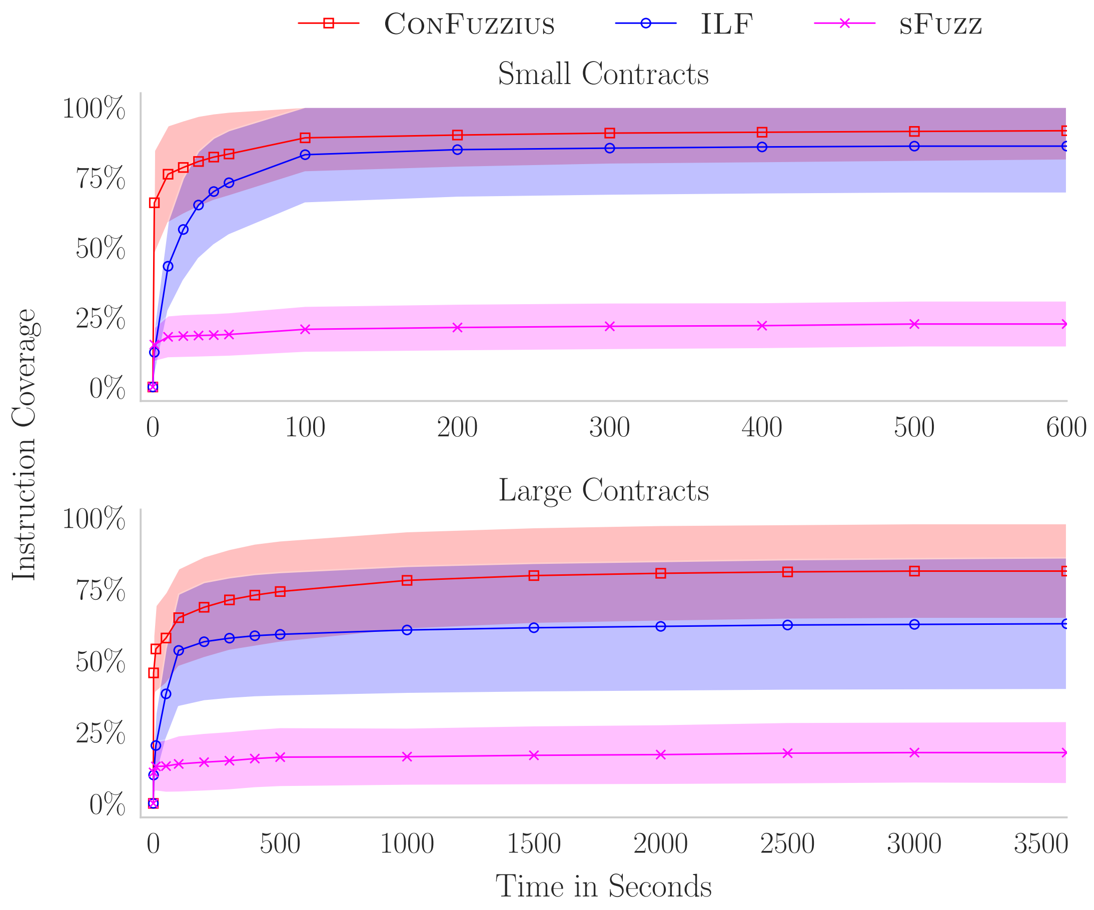
RQ1: Does ConFuzzius achieve higher code coverage than current state-of-the art symbolic execution and fuzzing tools for smart contracts?

Code Coverage

- ConFuzzius achieves highest code coverage:
  - **91% small** contracts and **81% large** contracts
  - Every tool **struggles with large** contracts
  - **10%** difference between small and large for ConFuzzius vs. **31%** difference for symbolic execution tools (Mythril)



Code Coverage Over Time



- ConFuzzius outperforms state-of-the art fuzzers:
  - **66% after 1 second** on **small** contracts vs. **12%** ILF and **15%** sFuzz
  - **46% after 1 second** on **large** contracts vs. **10%** ILF and **11%** sFuzz

2^{nd} Research Question

RQ2: Does ConFuzzius discover more vulnerabilities than current state-of-the art symbolic execution and fuzzing tools for smart contracts?

Vulnerability Detection

- ConFuzzius **detected most vulnerabilities** (106/148).
- All symbolic execution tools **reported false positives**, especially for integer overflows.
- ConFuzzius **does not report false positives**.
- ILF and sFuzz reported **false positives for unsafe delegatecalls** due to the imprecision of their detectors:

```
function setCallee(address newCallee)
  require(msg.sender == owner);
  callee = newCallee;
}
function forward(bytes _data) {
  require(callee.delegatecall(_data));
}
```

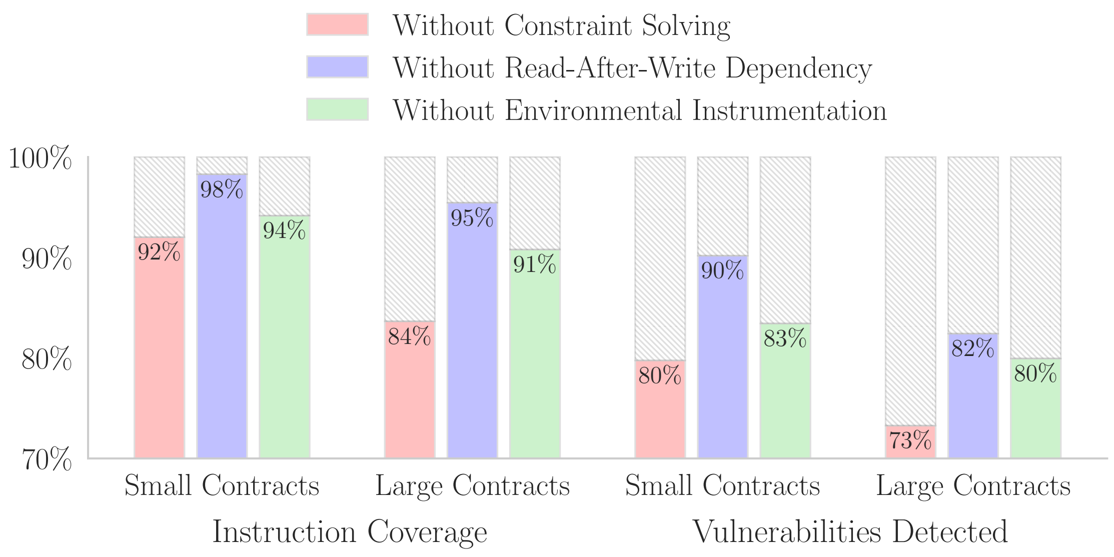
Toolname	Vulnerabilities										Total
	AF	IO	RE	TD	BD	UE	UD	LE	LO	US	
OYENTE	6/6	12/4	8/0	2/0	0/0	-	-	-	-	0/0	28
MYTHRIL	7/3	18/5	10/0	0/0	3/0	24/0	0/0	4/0	-	2/0	68
M-PRO	7/3	18/5	10/0	0/0	3/0	24/0	0/0	4/0	-	2/0	68
ILF	-	-	-	-	0/0	10/0	1/2	4/0	5/0	3/0	23
SFUZZ	-	12/0	7/0	-	1/0	21/0	1/2	-	0/0	-	42
CONFUZZIUS	**10/0**	**18/0**	**10/0**	**2/0**	**7/0**	**46/0**	**1/0**	**4/0**	**5/0**	**3/0**	**106**
Total Unique	14	19	11	4	7	75	1	9	5	3	148

3rd Research Question

RQ3: How relevant are ConFuzzius's individual components in terms of code coverage and vulnerability detection?

Component Evaluation

- We randomly selected 100 contracts from each cluster and disabled each component separately.
- Each component is an added value.
- Constraint solving plays an essential part in coverage and vulnerability detection.
- Environmental instrumentation is more relevant for detecting vulnerabilities.
- Data dependency analysis allows to find 10% and 18% more vulnerabilities in small and large contracts, respectively.



Conclusion

Conclusion

- We presented **ConFuzzius** – the first **data dependency-aware hybrid fuzzer for smart contracts** that tackles the following three challenges:
  - **Input generation**: evolutionary fuzzing + constraint solving.
  - **Stateful exploration**: read-after-write access patterns across state variables.
  - **Environmental dependencies**: modelling block and contract information as fuzzable inputs.
- We compared ConFuzzius against 2 fuzzers and 3 symbolic execution tools using a **curated dataset of 128 contracts** and a **dataset of 21K real-world contracts**.
- ConFuzzius detects **more bugs** (up to **23%**) and achieves **higher code coverage** (up to **69%**).
- Our data dependency analysis can **boost the detection of bugs** (up to **18%**).

Questions?

All **code** & **data** is available on GitHub:

https://github.com/christoftorres/ConFuzzius

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