SAILFISH

Vetting Smart Contract State-Inconsistency Bugs in Seconds

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Smart contracts are popular

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- They process high value money transactions

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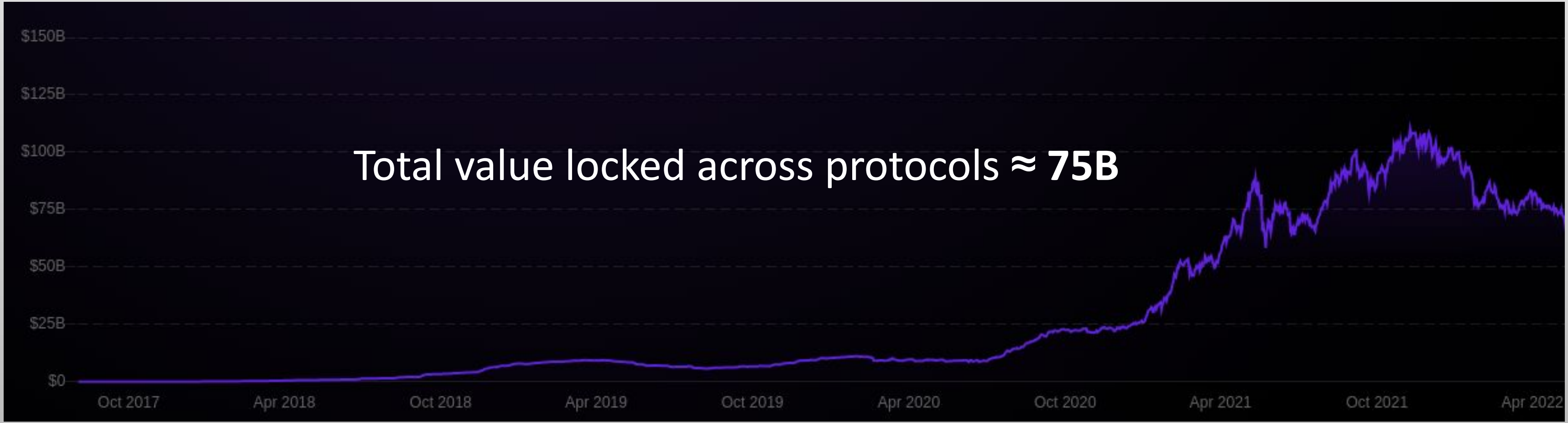

Smart contract attacks

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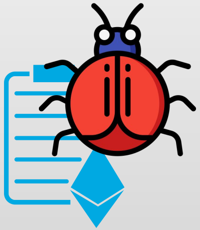
Vulnerabilities in smart contracts result in a loss of millions …



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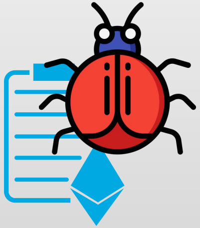

DAO	2016	$70M

Smart contract attacks

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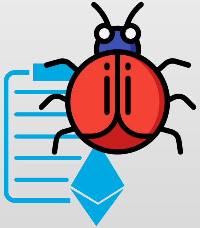

DAO	2016	$70M
BurgerSwap	2021	$7.2M
Cream Finance	2021	$17M
Fei Protocol	2022	$80M

Many more …

Existing techniques

Static analysis

Securify [Tsankov et. al., CCS 18]
Vandal [Brent et. al]
Slither [Feist et. al., WEBSTEB 19]
SmartCheck [Tikhomirov et. al., WEBSEB 18]

Symbolic execution

Oyente [Luu et. al., CCS 16]
Manticore [Trail of bits]
Mytril [Consensys]

Runtime analysis

Sereum [Rodler et. el., NDSS 19]
ECFChecker [Grossman et. al., POPL 18]

Verification

ZEUS [Kalra et. al, NDSS 18],
SeRIF [Cecchetti et. al, S&P 21]

Existing techniques

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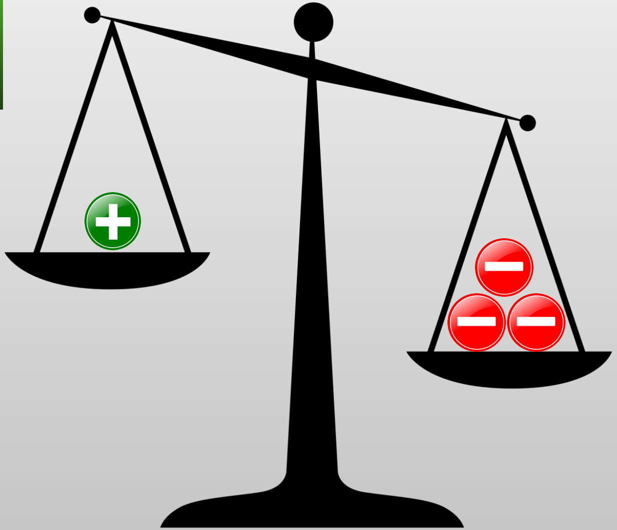
Variety of techniques to detect reentrancy and TOD



Symbolic techniques not scalable for large contracts

Static techniques incurs false positives

Relies on some bug signatures, misses others

Contributions

- A general technique to detect reentrancy and transaction order dependence (TOD)
- Scales well for large contracts and achieves precision

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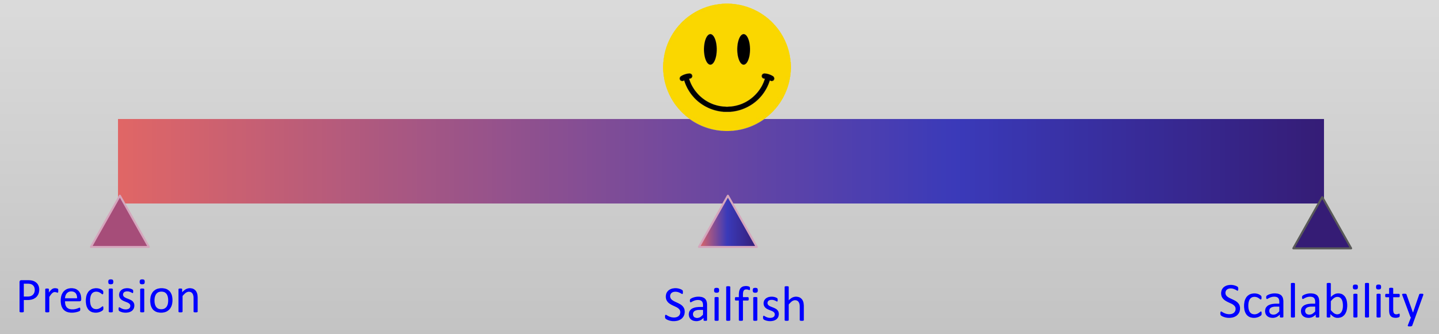

Sailfish

Introduces *State Inconsistency* (SI), a general definition of reentrancy and transaction order dependence (TOD)

Defines read-write dependencies of a storage variables as Hazardous access, a root cause of SI

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✓ Detects reentrancy and TOD including the ones missed by prior tools

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Combines static analysis and symbolic execution

Summarizes the contract storage variable using scalable value-summary analysis

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Detects reentrancy and TOD including the ones missed by prior tools

Combines static analysis and symbolic execution

Summarizes the contract storage variables using scalable value-summary analysis

Achieves scalability and precision.

State Inconsistency (SI)

Smart contract: C

Methods: $(f_1, f_2, \ldots, f_n)$

Schedule: H contains ordered external/public function invocations of C

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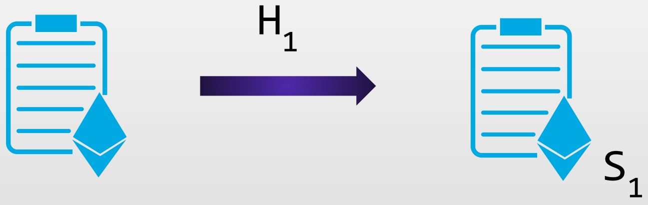
Schedule: H contains ordered external/public function invocations of C

Initial state: S_0



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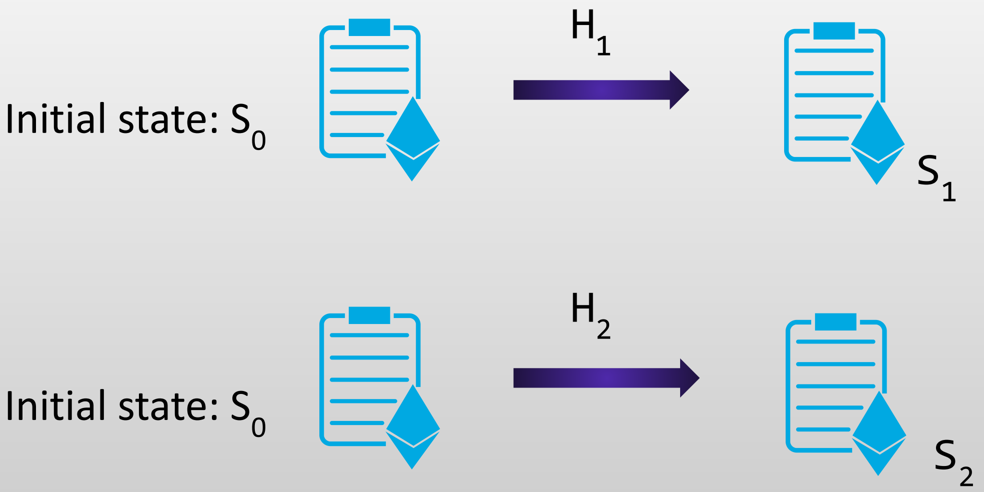

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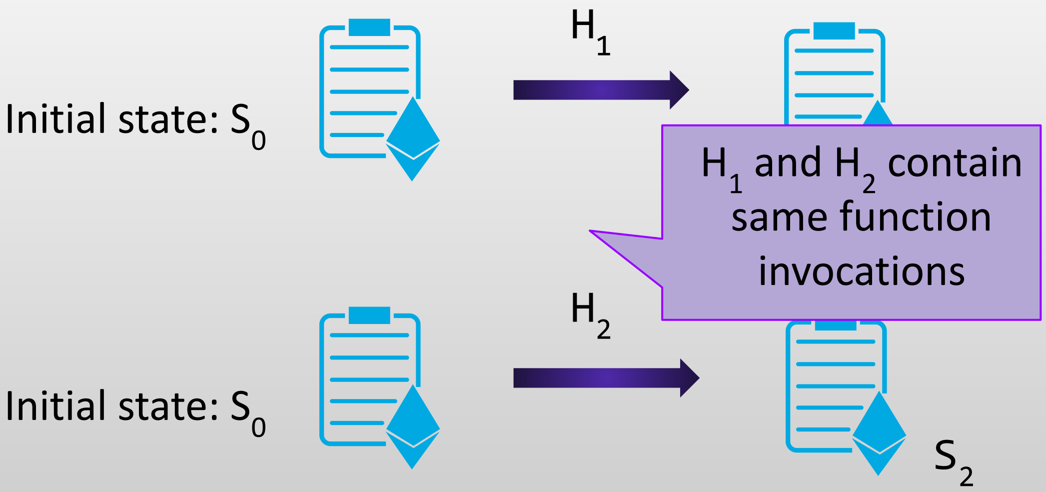

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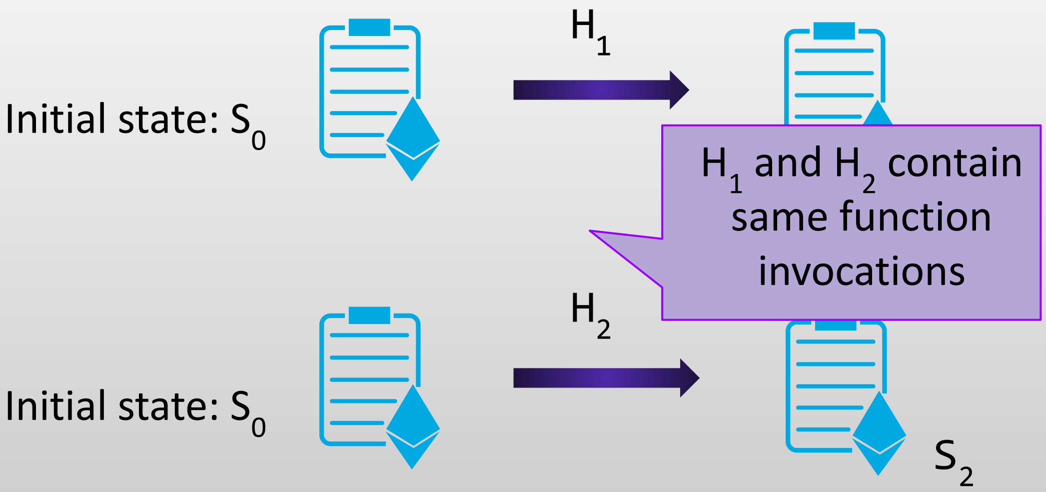
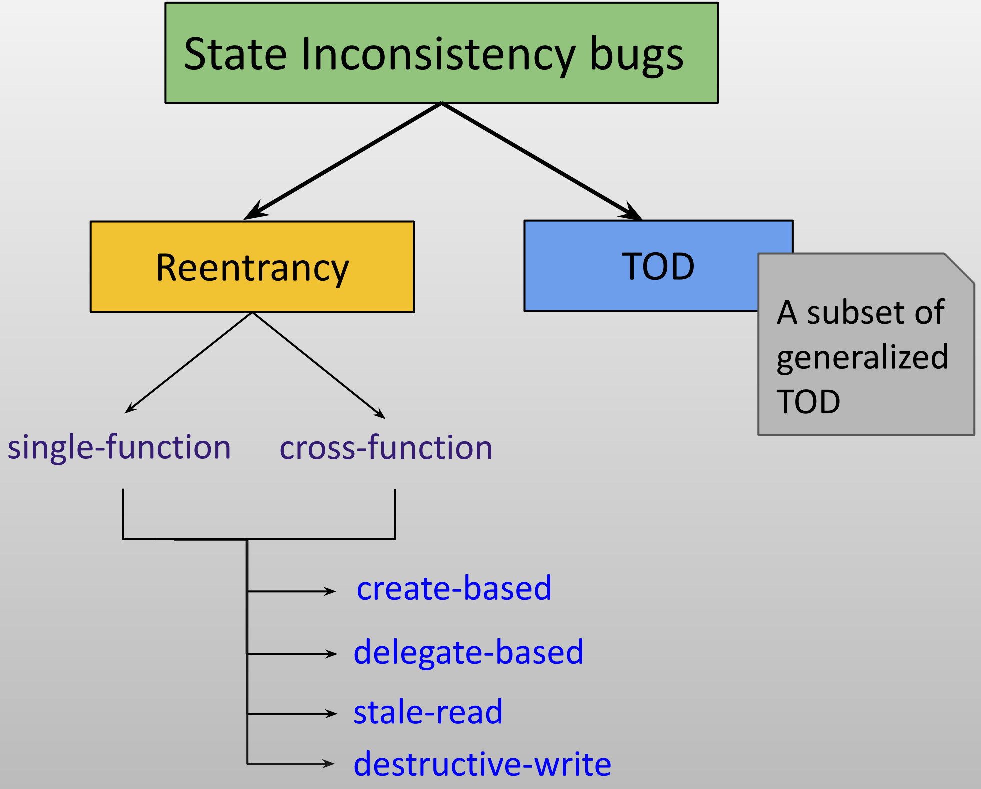


If $H_1 \neq H_2$ and $S_1 \neq S_2$, contract C is said to have a **State Inconsistency** bug

State Inconsistency bugs



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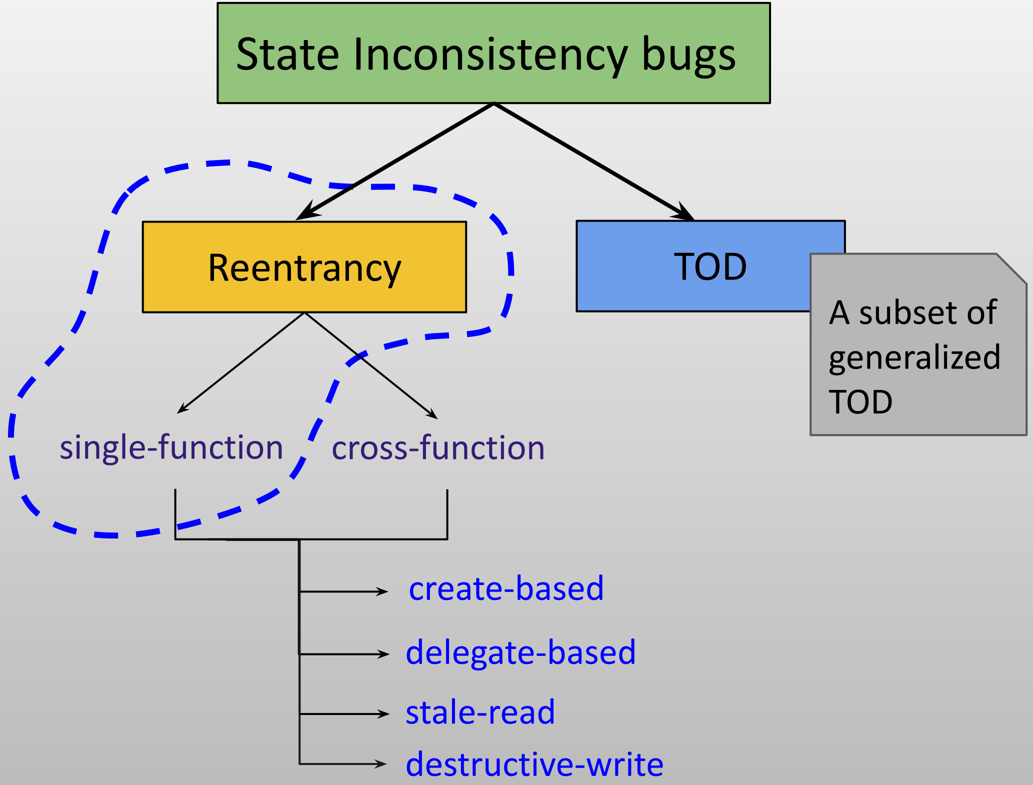
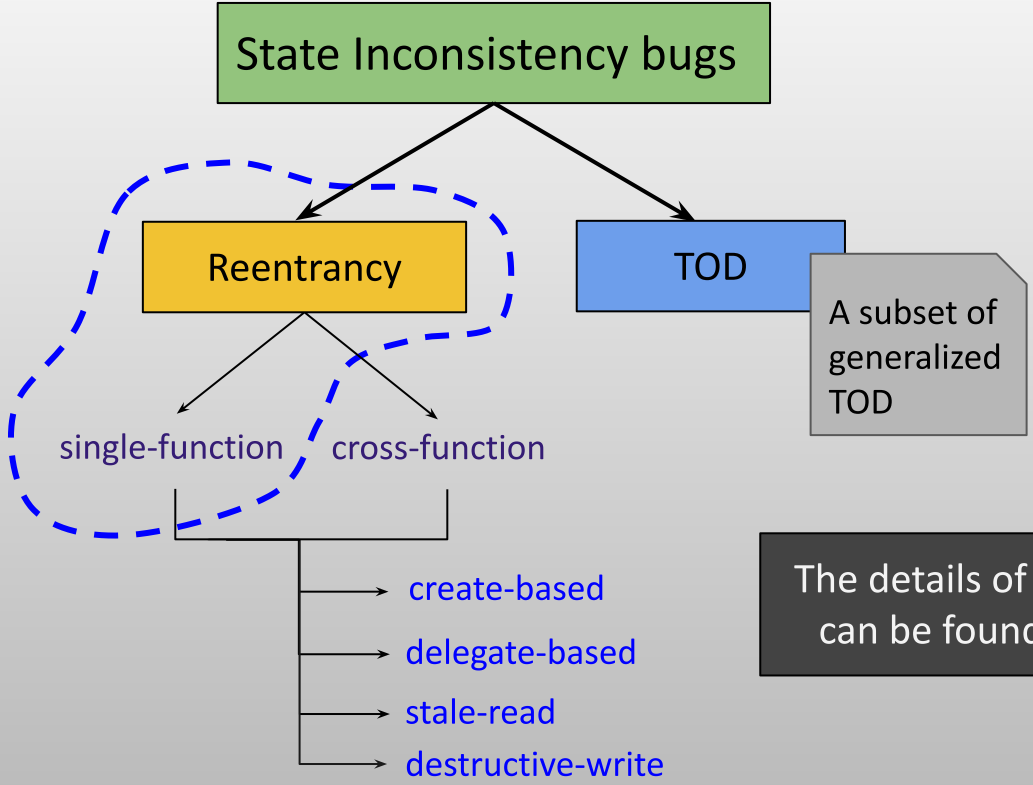


State Inconsistency bugs



The details of the other bugs can be found in our paper

The Reentrancy problem

User state

User’s balance: 0

User

```
bank.withdraw(100)
```

Bank

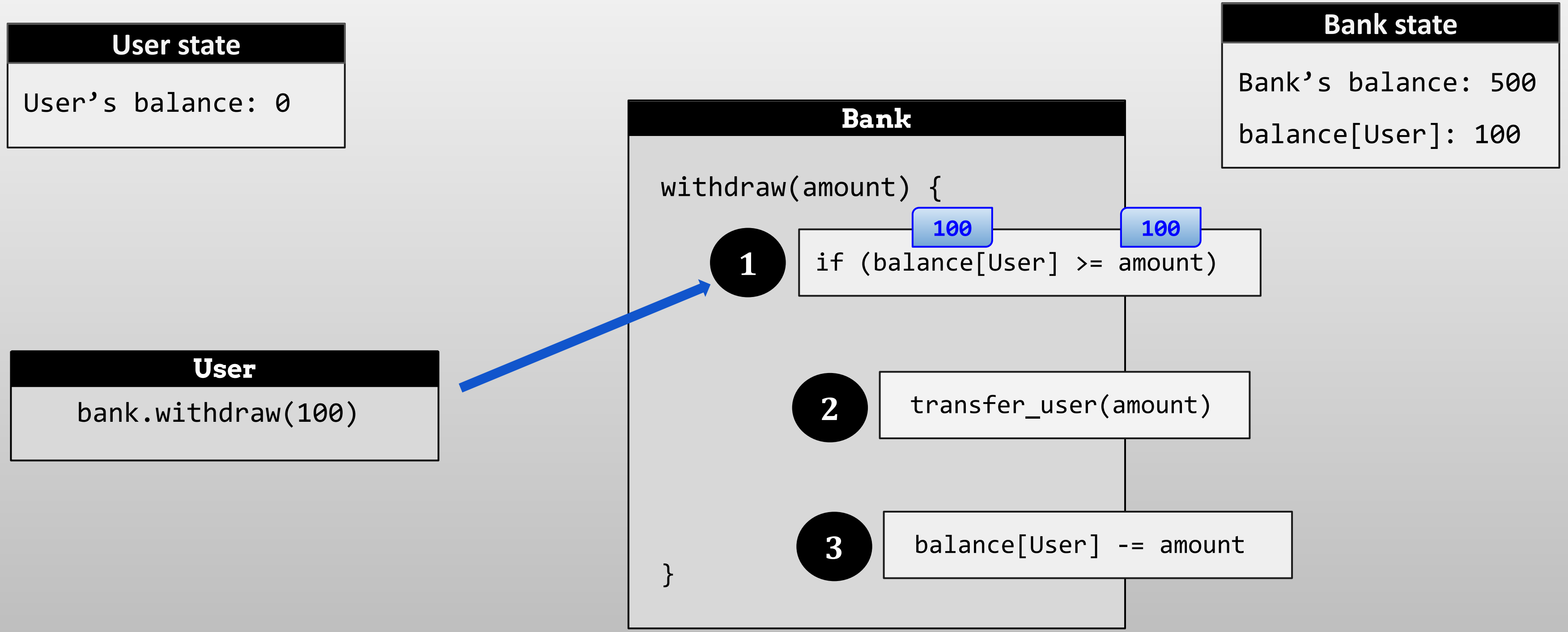
```
withdraw(amount) {
    1  if (balance[User] >= amount)
    2  transfer_user(amount)
    3  balance[User] -= amount
}
```

Bank state

Bank’s balance: 500

balance[User]: 100

The Reentrancy problem



The Reentrancy problem

User state

User's balance: 0

User

```
bank.withdraw(100)
```

Bank

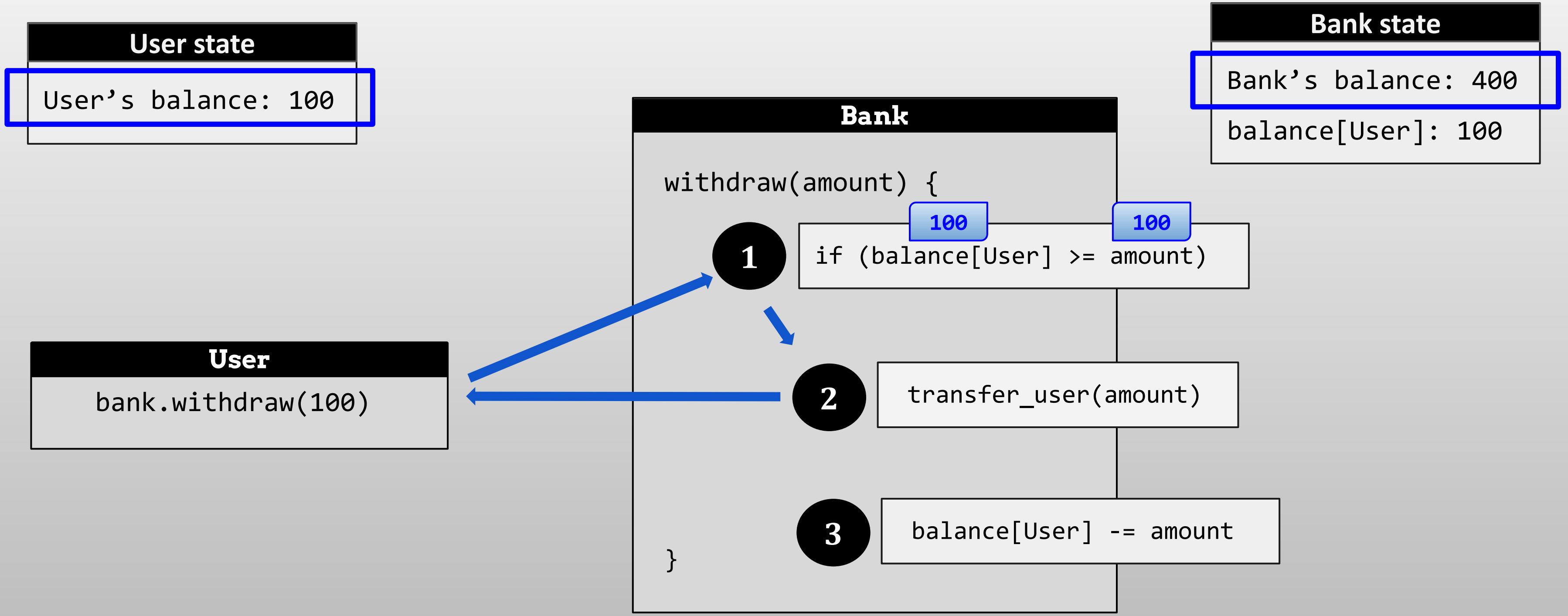
```
withdraw(amount) {
   1  if (balance[User] >= amount)      [balance[User] = 100, amount = 100]
   2  transfer_user(amount)
   3  balance[User] -= amount
}
```

Bank state

Bank's balance: 500

balance[User]: 100

The Reentrancy problem



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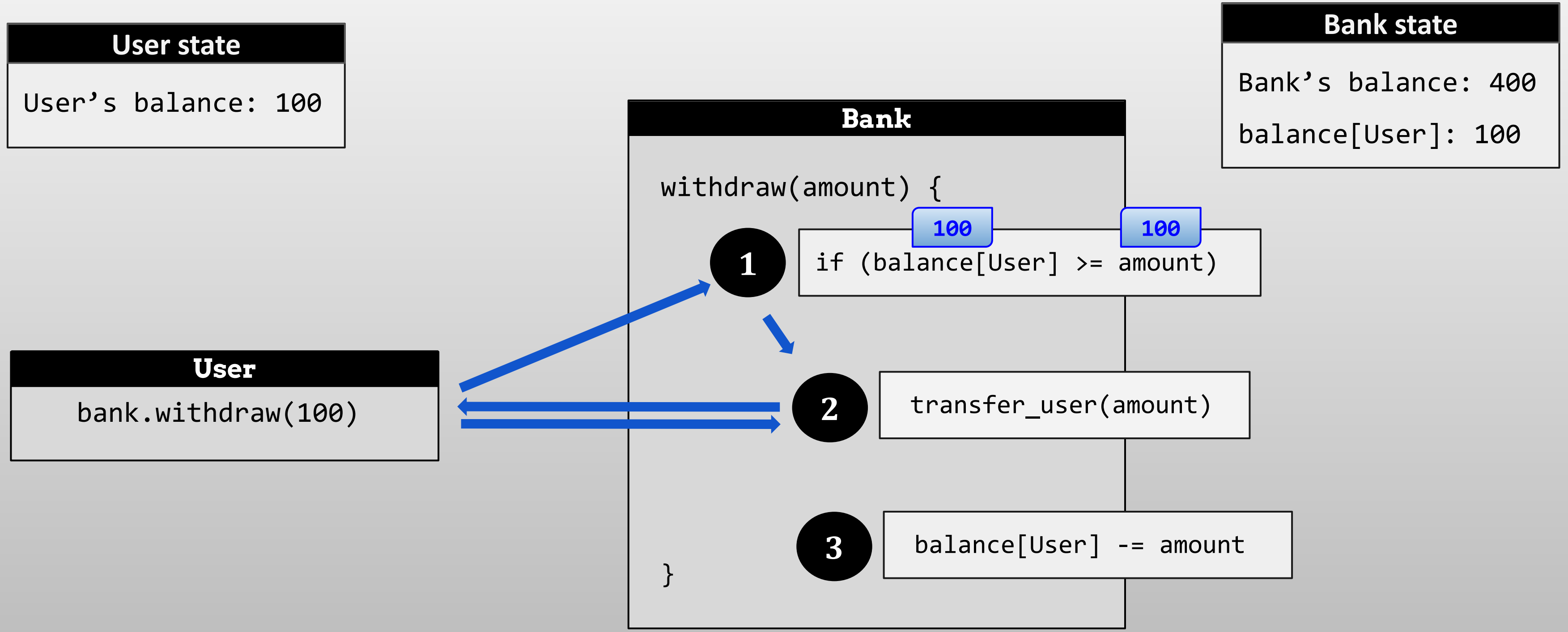

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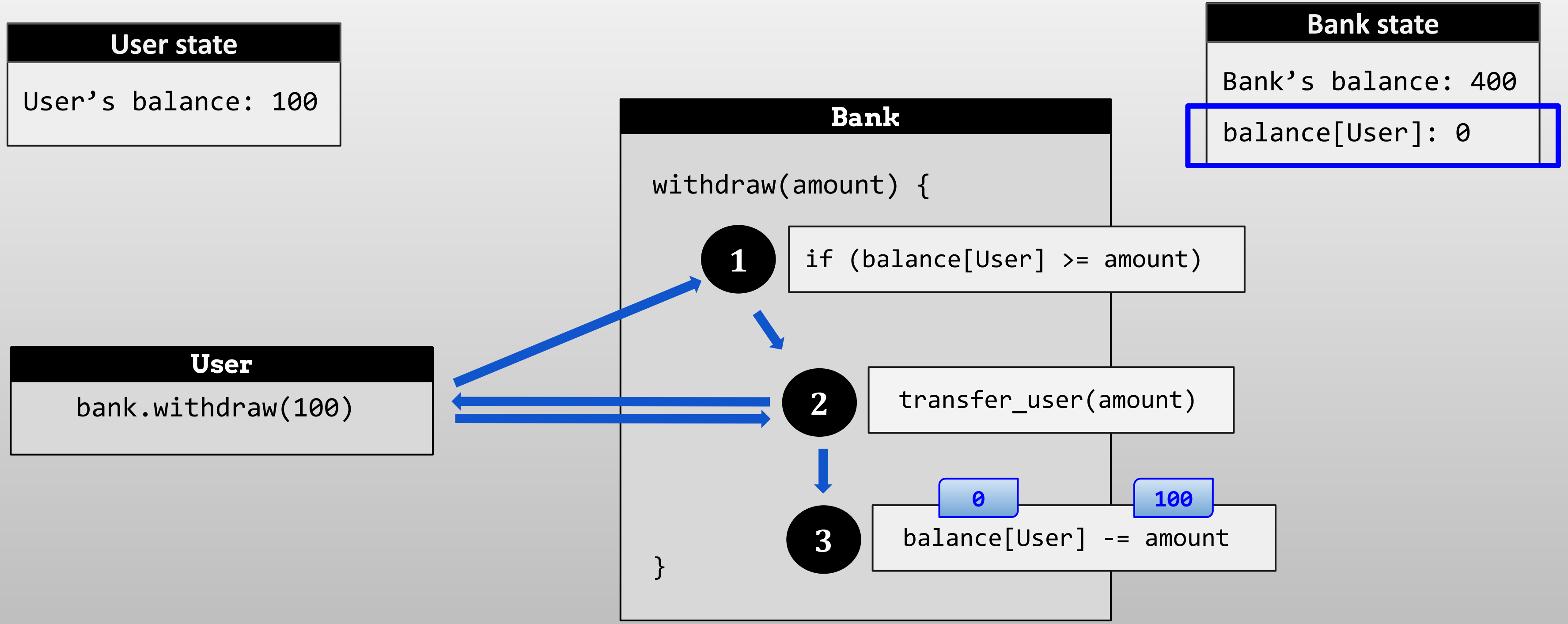

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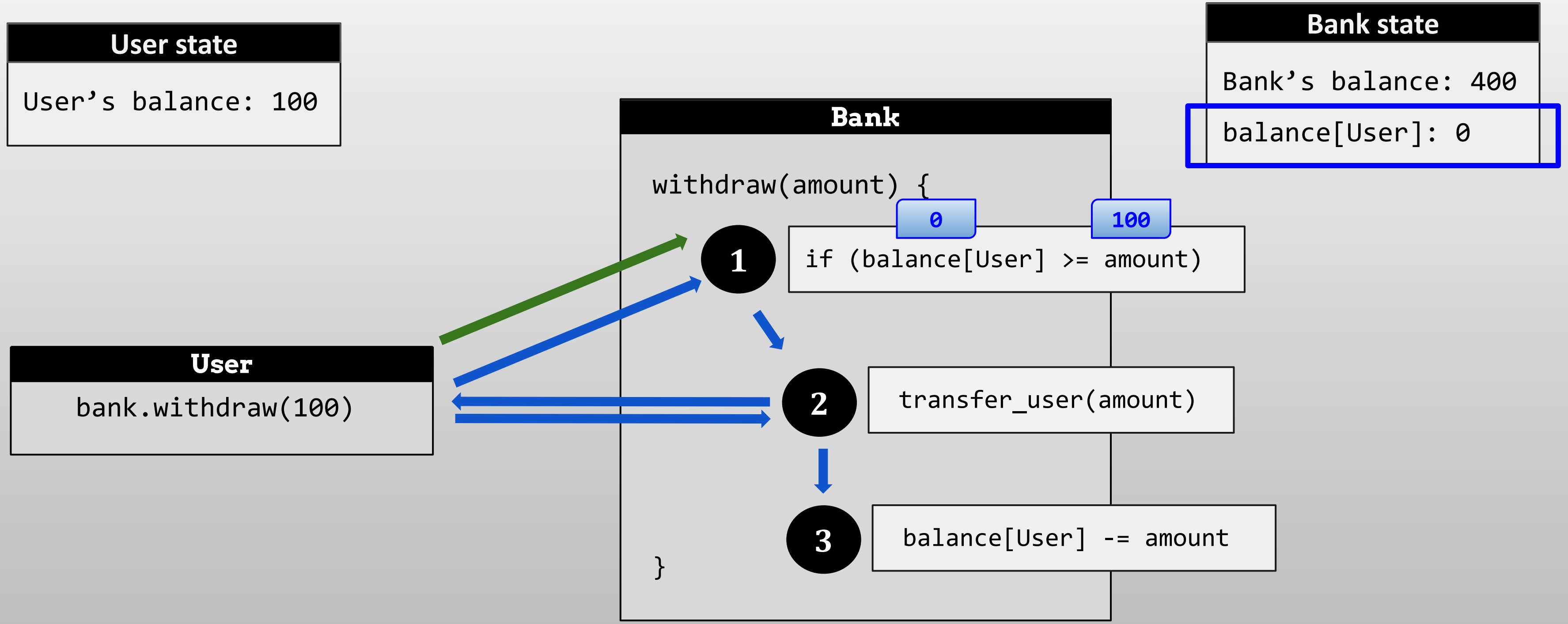

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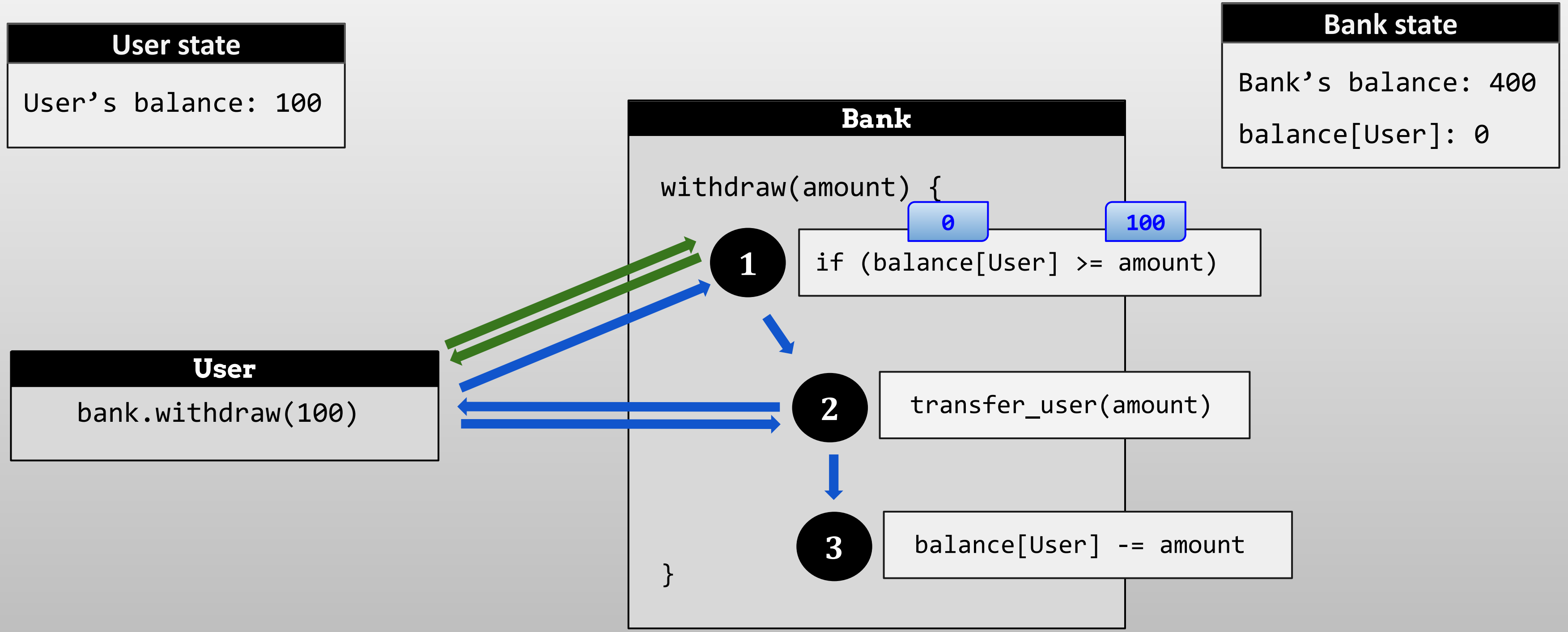

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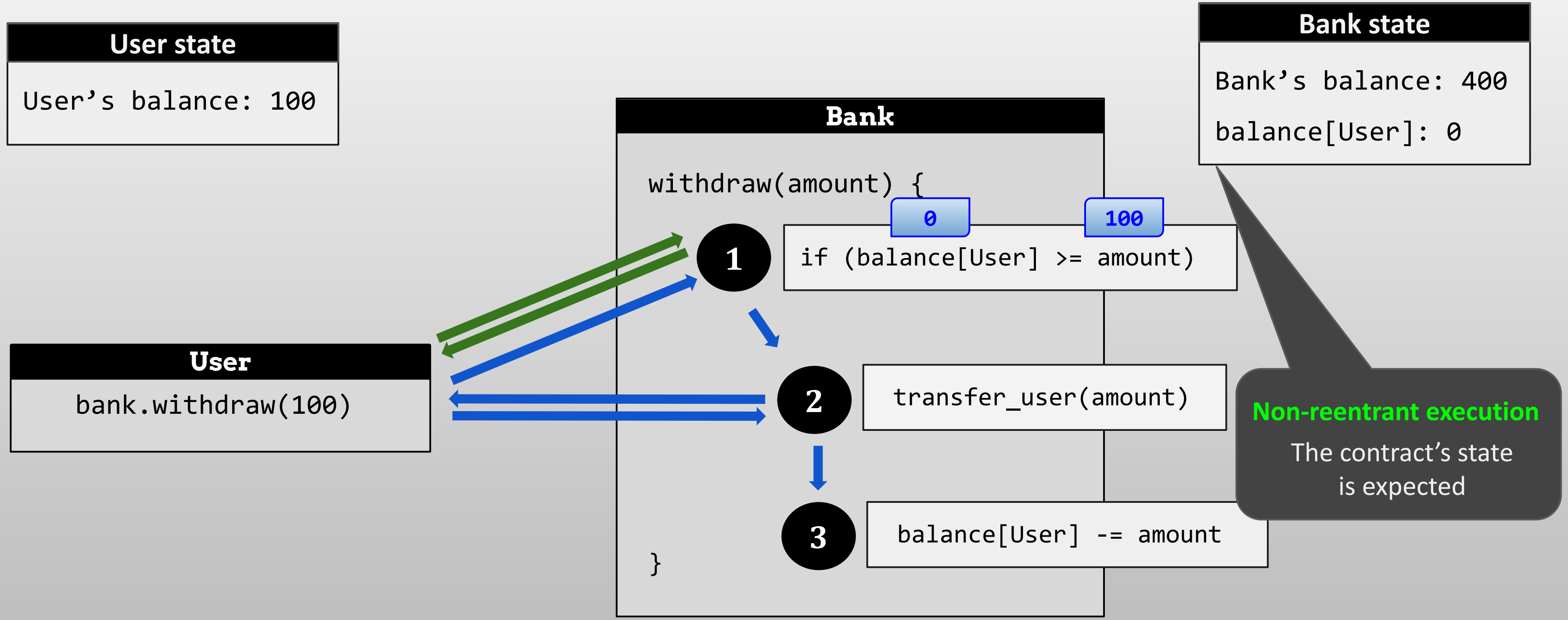


The Reentrancy problem

User state

User's balance: 100

Bank state

Bank's balance: 400

balance[User]: 100

Attacker

```
bank.withdraw(100)
```

Bank

```
withdraw(amount) {
  1  if (balance[User] >= amount)
  2  transfer_user(amount)
  3  balance[User] -= amount
}
```

100 100

The Reentrancy problem

User state

User's balance: 100

Bank state

Bank's balance: 400

balance[User]: 100

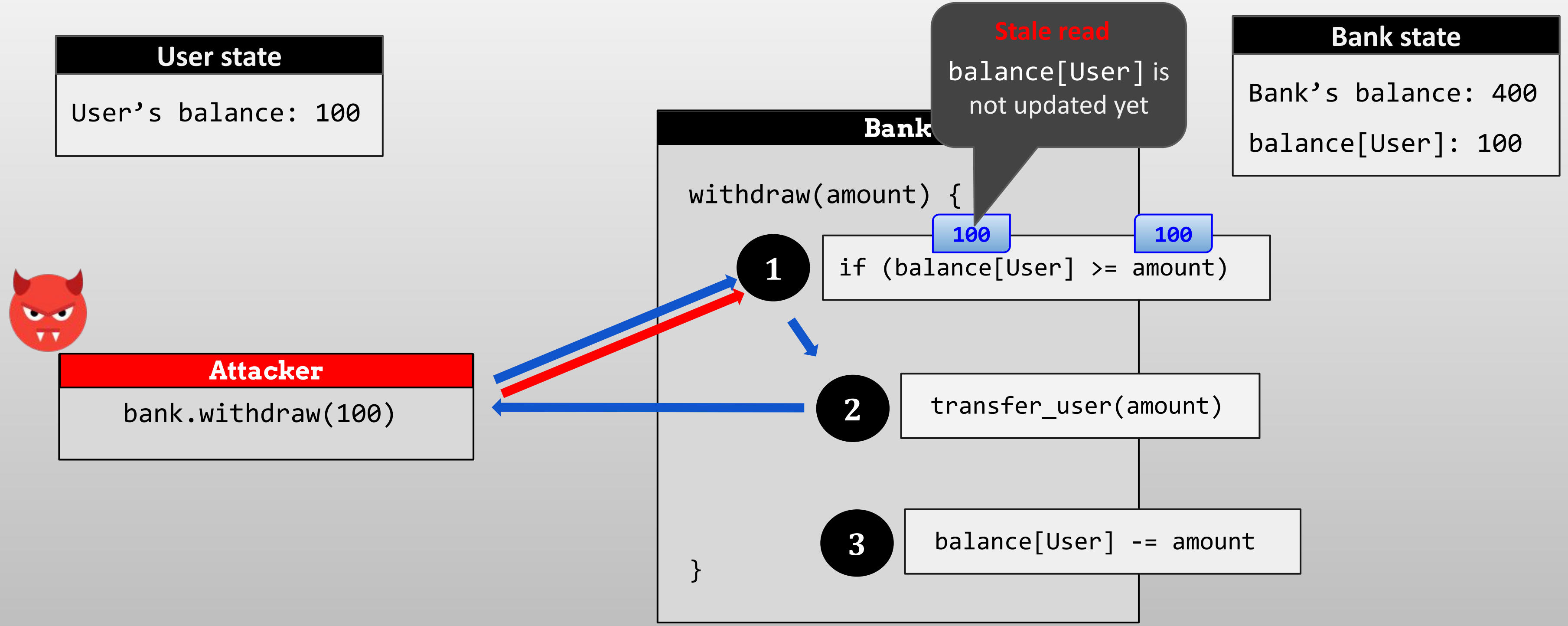
Attacker

```
bank.withdraw(100)
```

Bank

```
withdraw(amount) {
  1  if (balance[User] >= amount)      [100]  [100]
  2  transfer_user(amount)
  3  balance[User] -= amount
}
```

The Reentrancy problem



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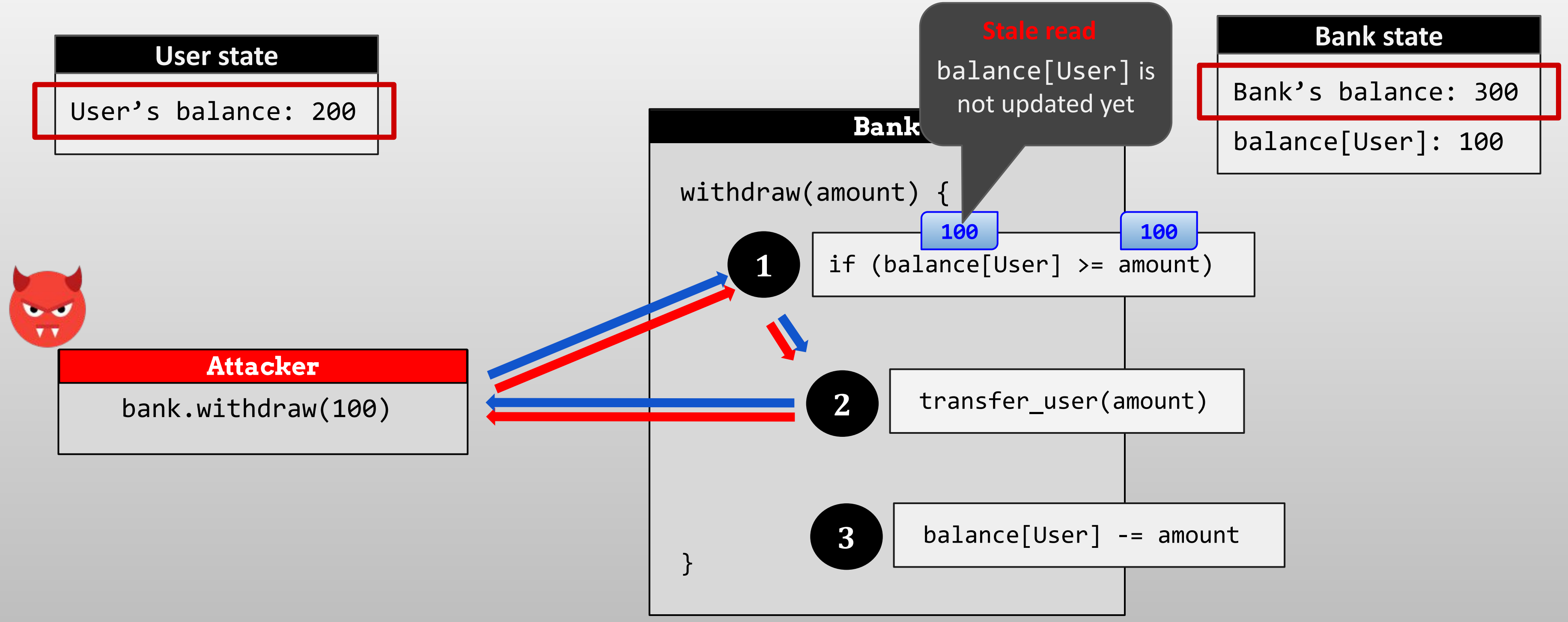

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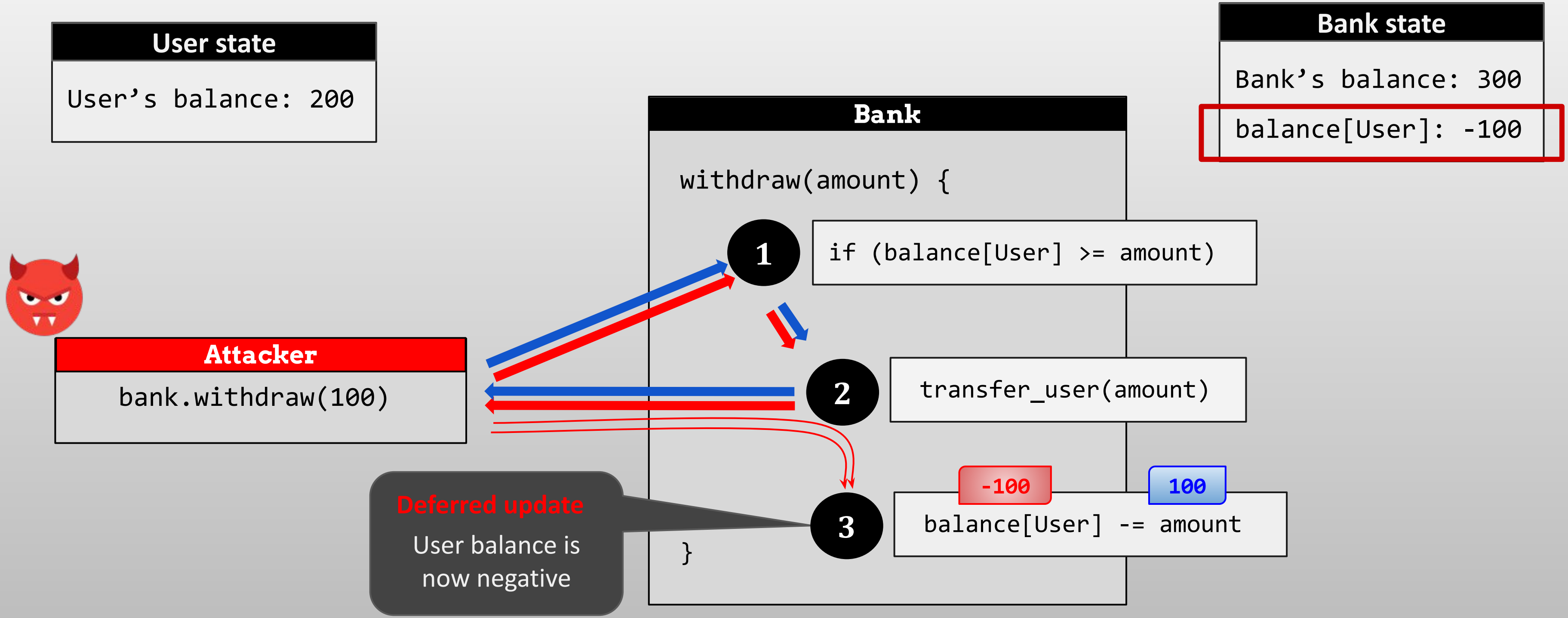

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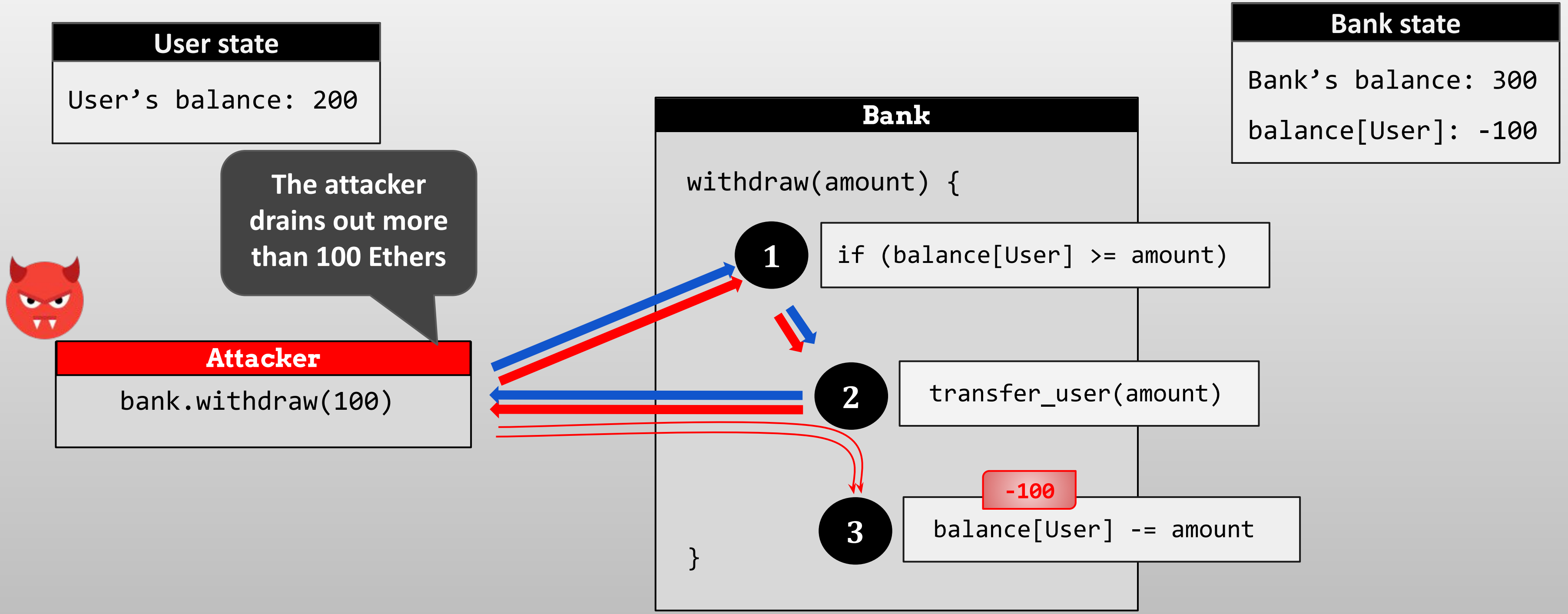

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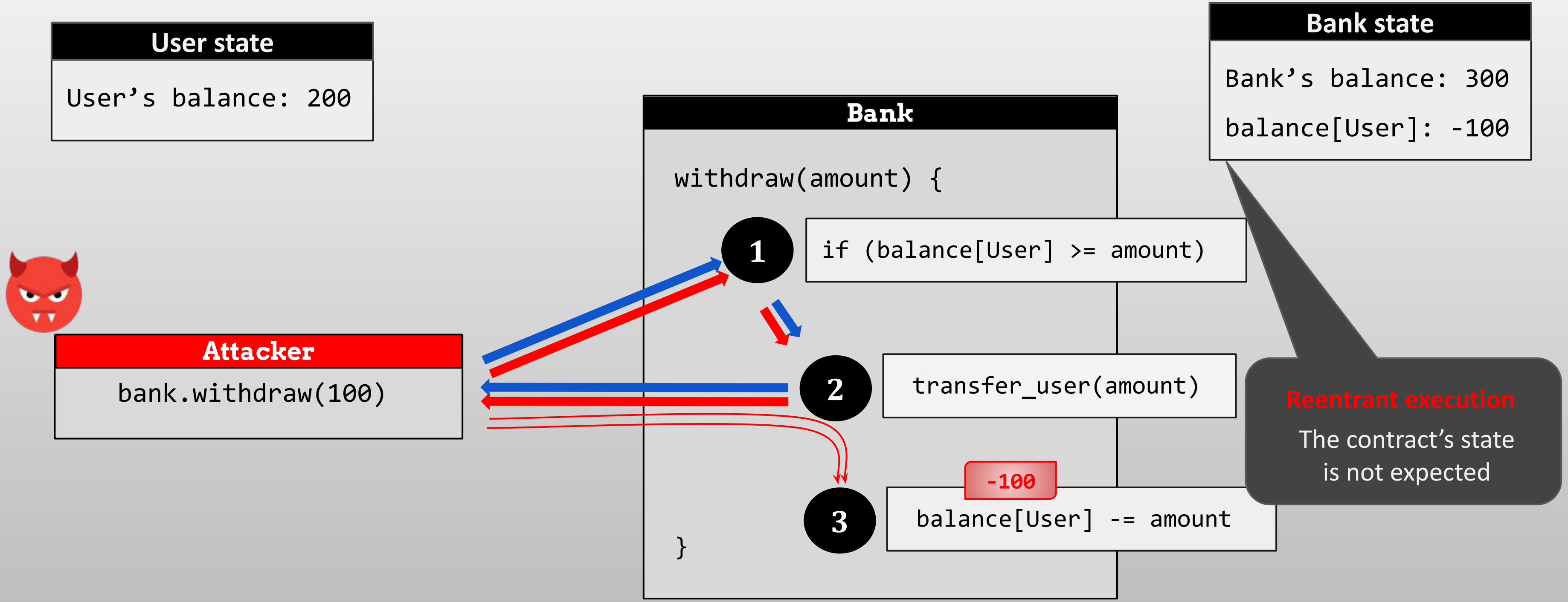
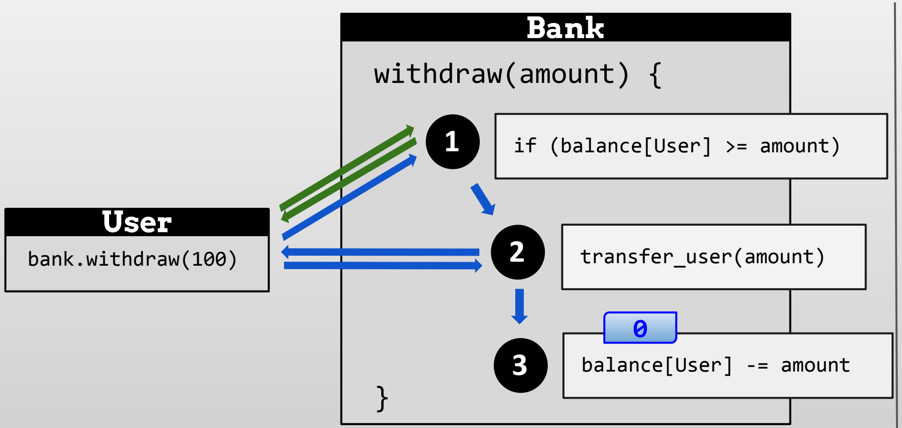
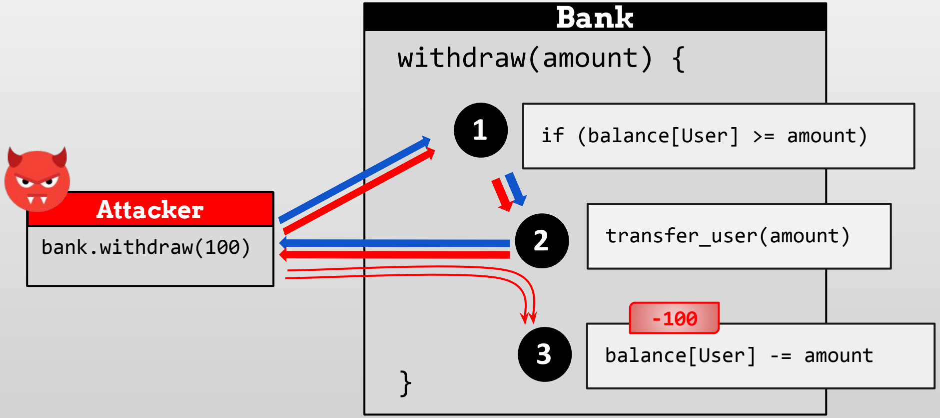


SI and Reentrancy

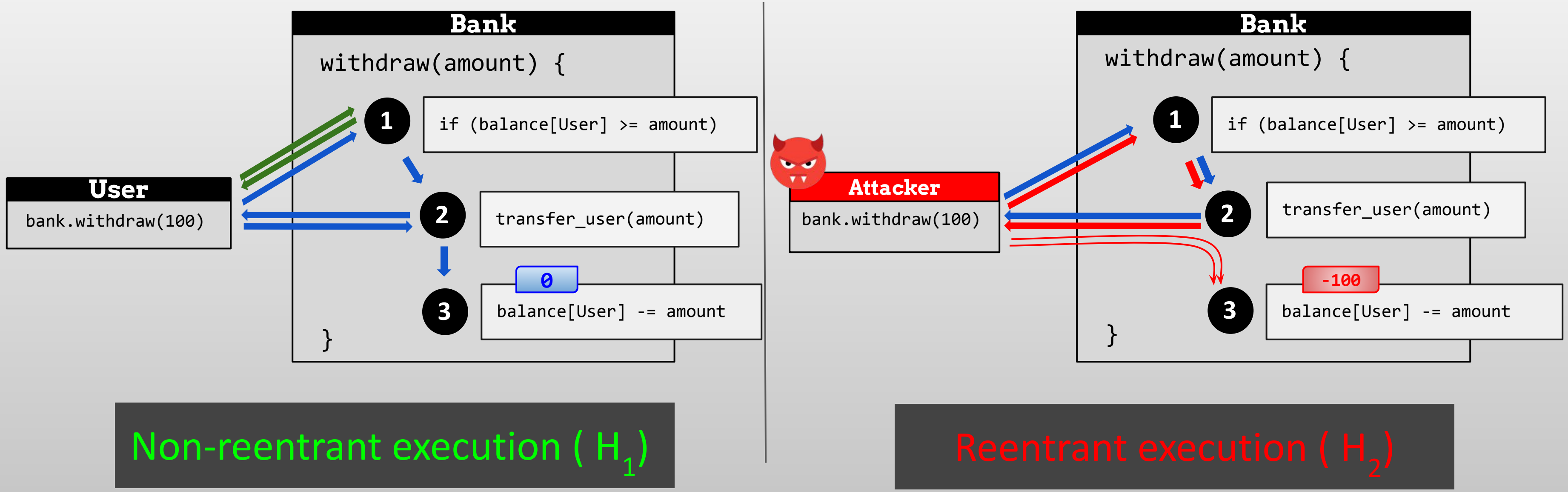


Non-reentrant execution (H_1)



Reentrant execution (H_2)

SI and Reentrancy



$H_1 \neq H_2$ and Final state@$H_1 \neq$ Final state@H_2

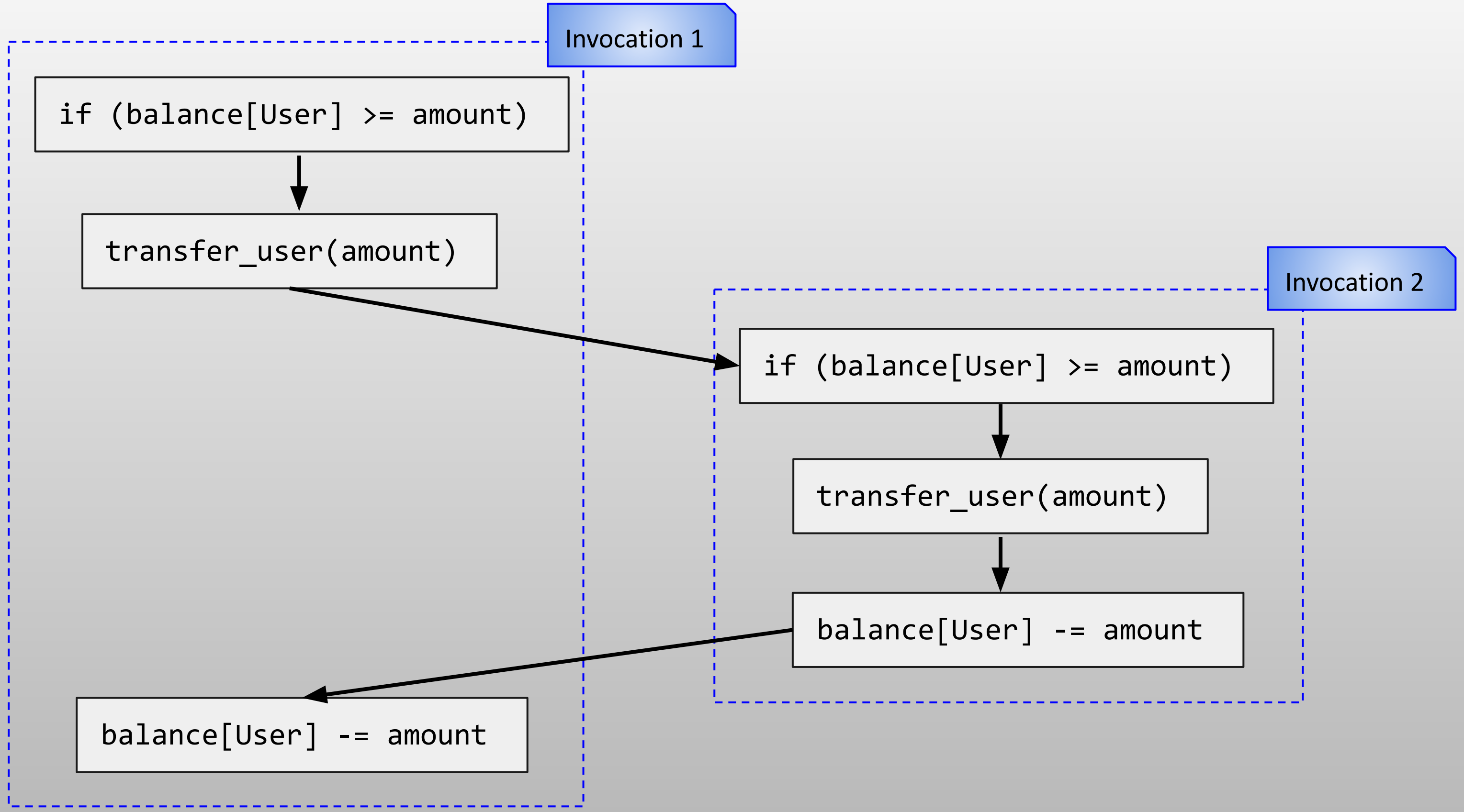
SI bugs: Intuition

- SI bugs occur because different schedules result in different final state, i.e., different values of storage variables.

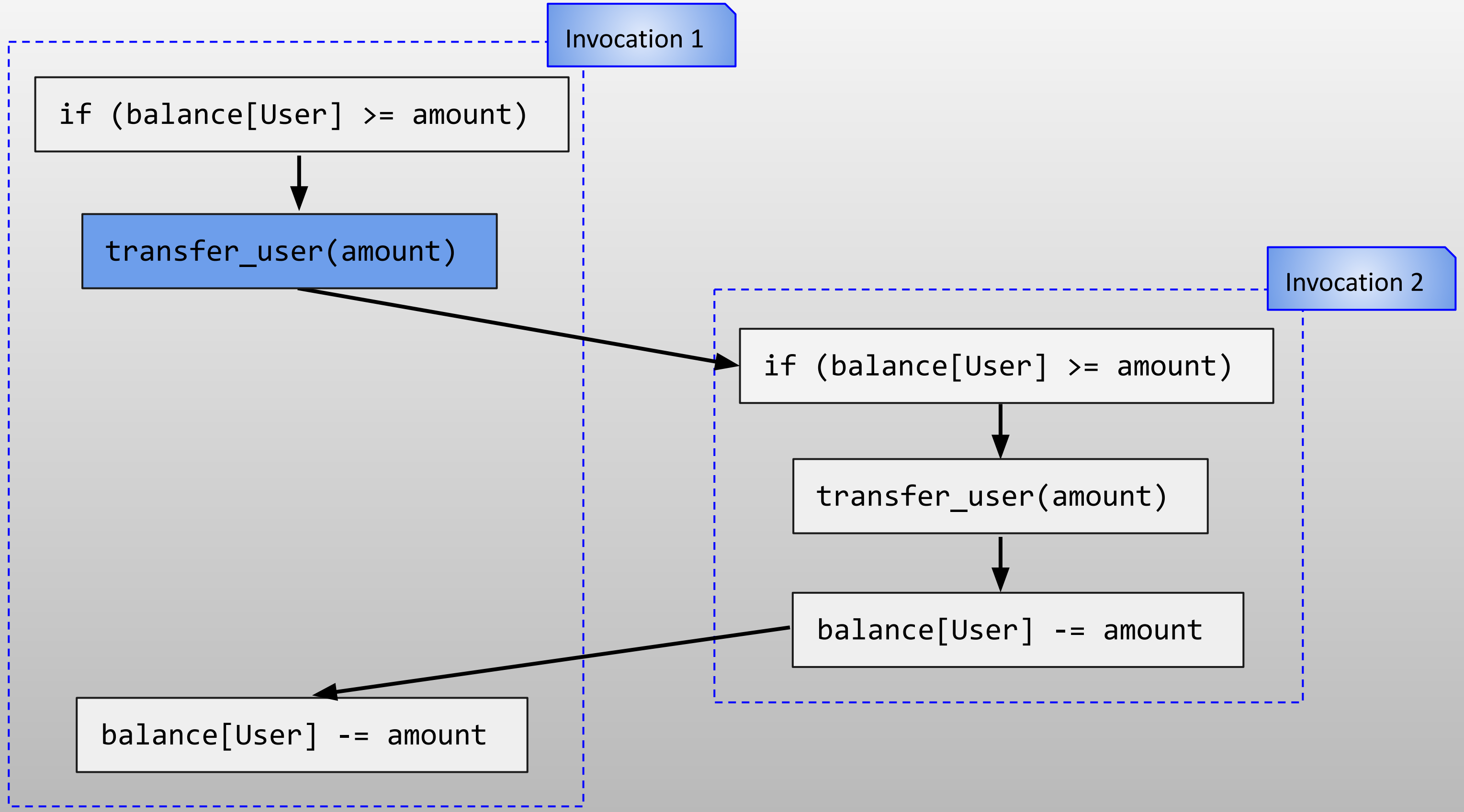
- Two such schedules can result in different contract states if:
  - There exist two operations, at least one is a write access, on a common storage variable
  - The relative order of such operations differ in these two schedules.

We define such a read-write hazard as ***Hazardous access***

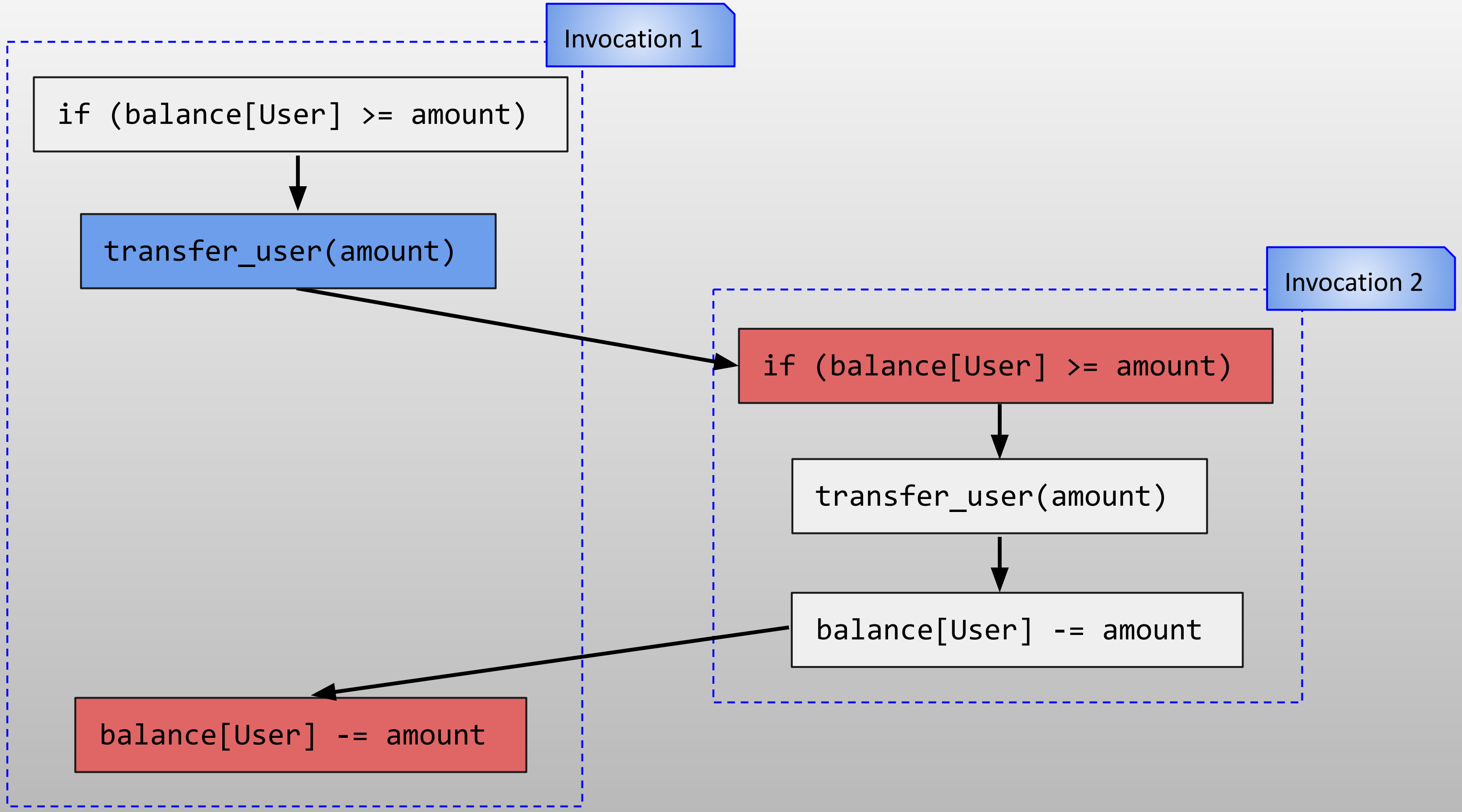
Hazardous access



Hazardous access



Hazardous access



Explorer: Hazardous access detection

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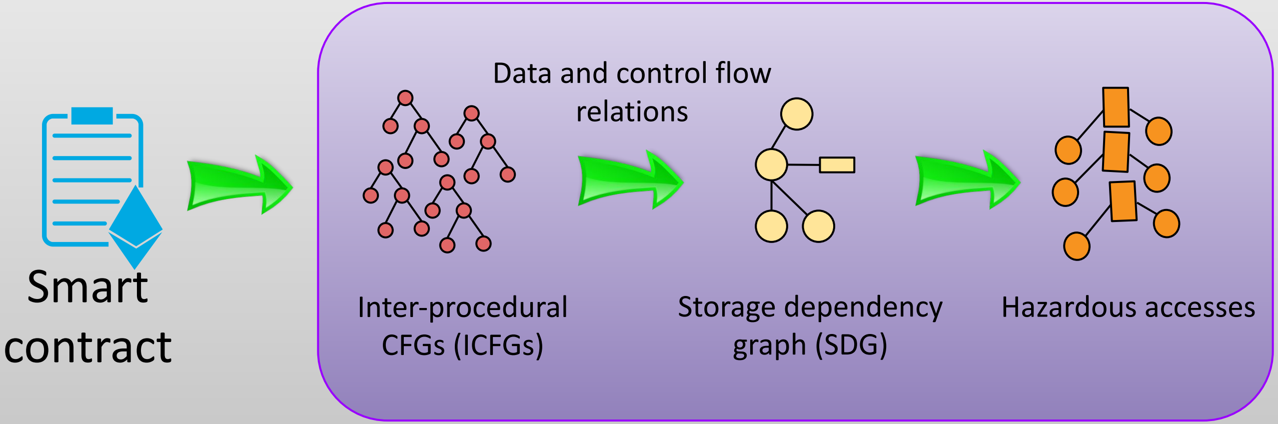
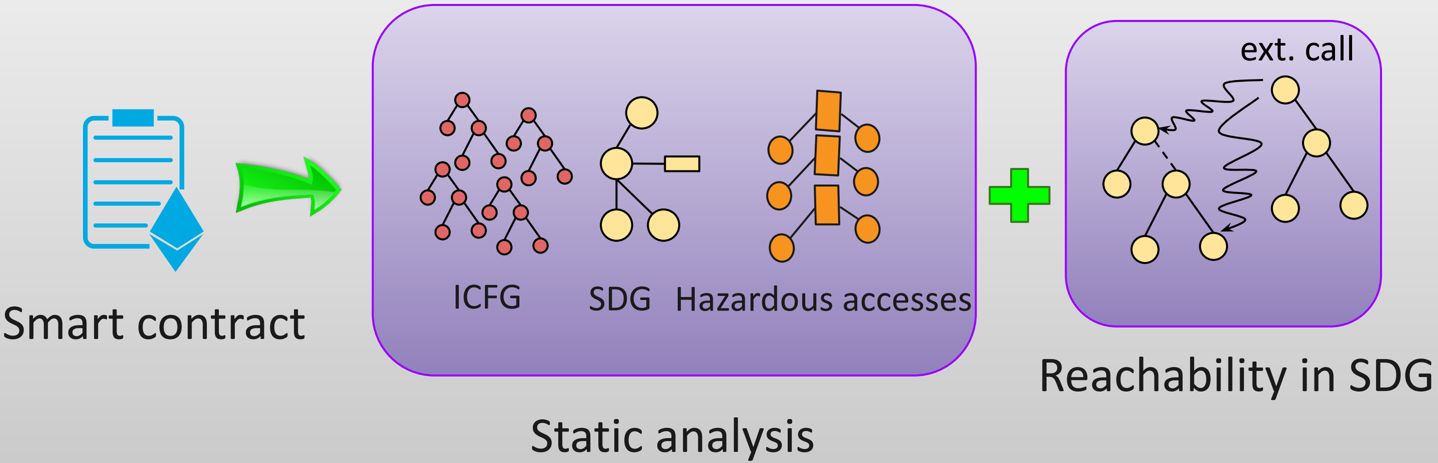


Static analysis

Explorer: Reachability in SDG



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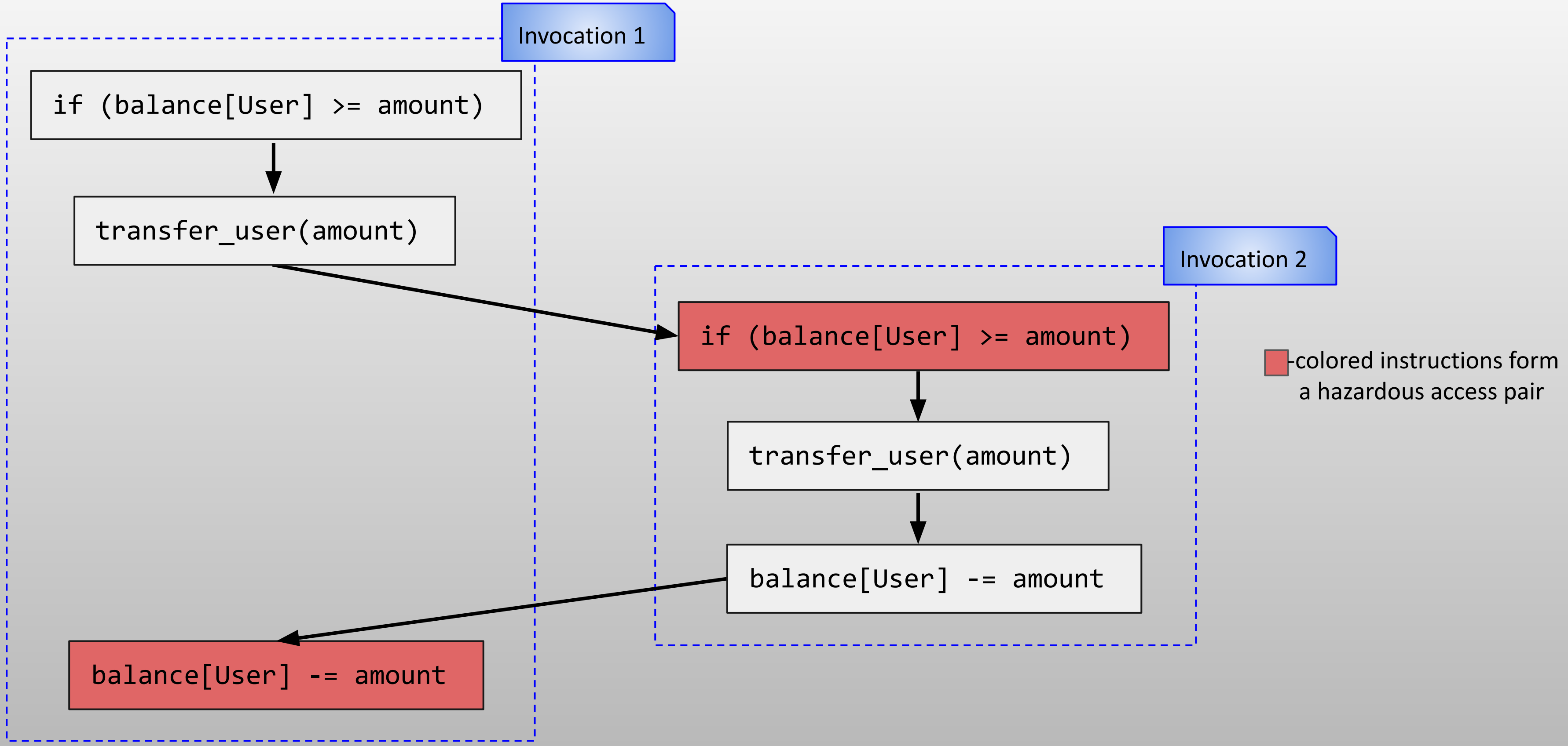

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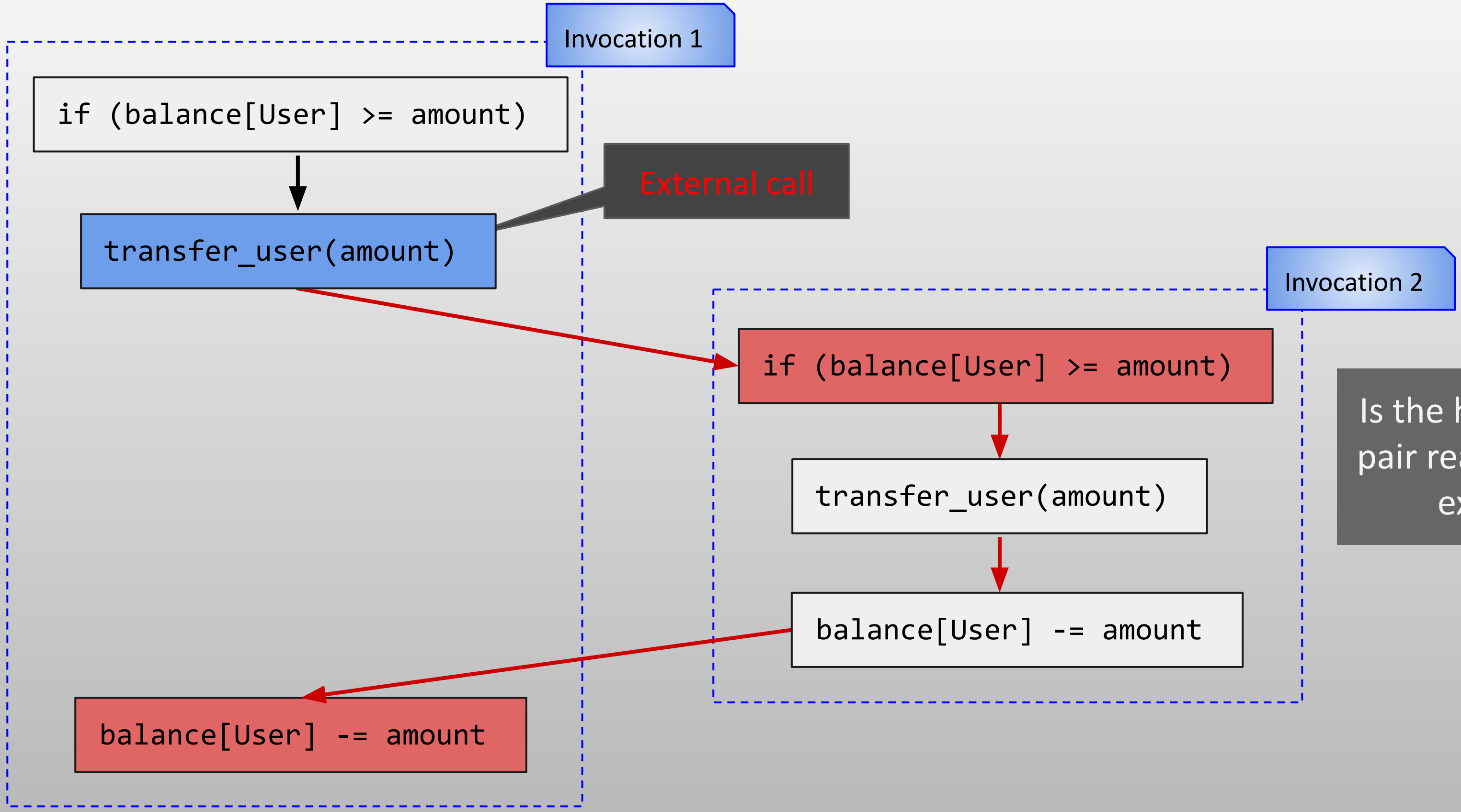
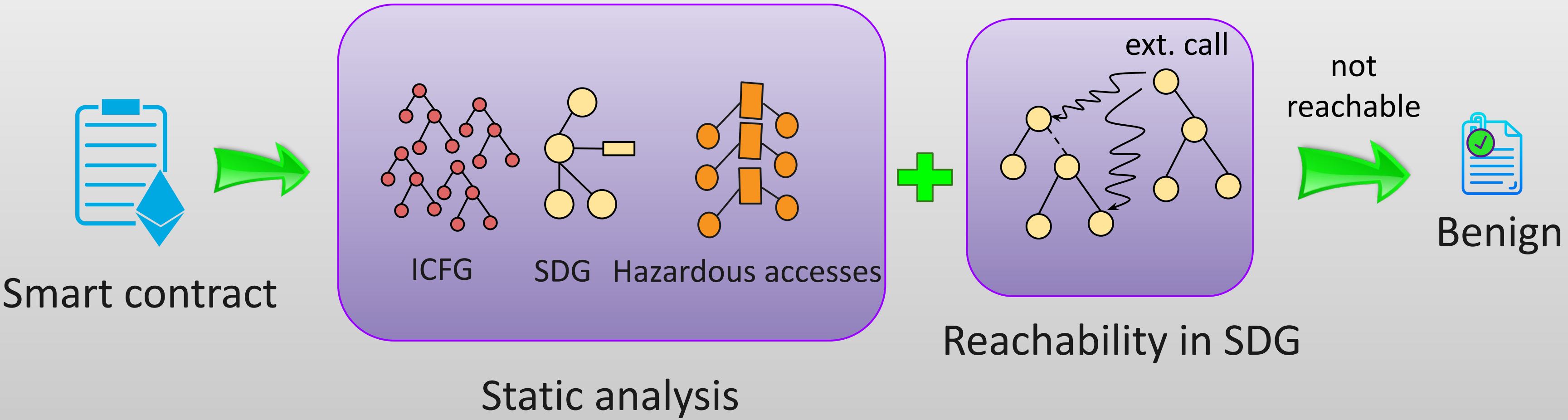


Is the hazardous access pair reachable from the external call?

Explorer: Reachability in SDG



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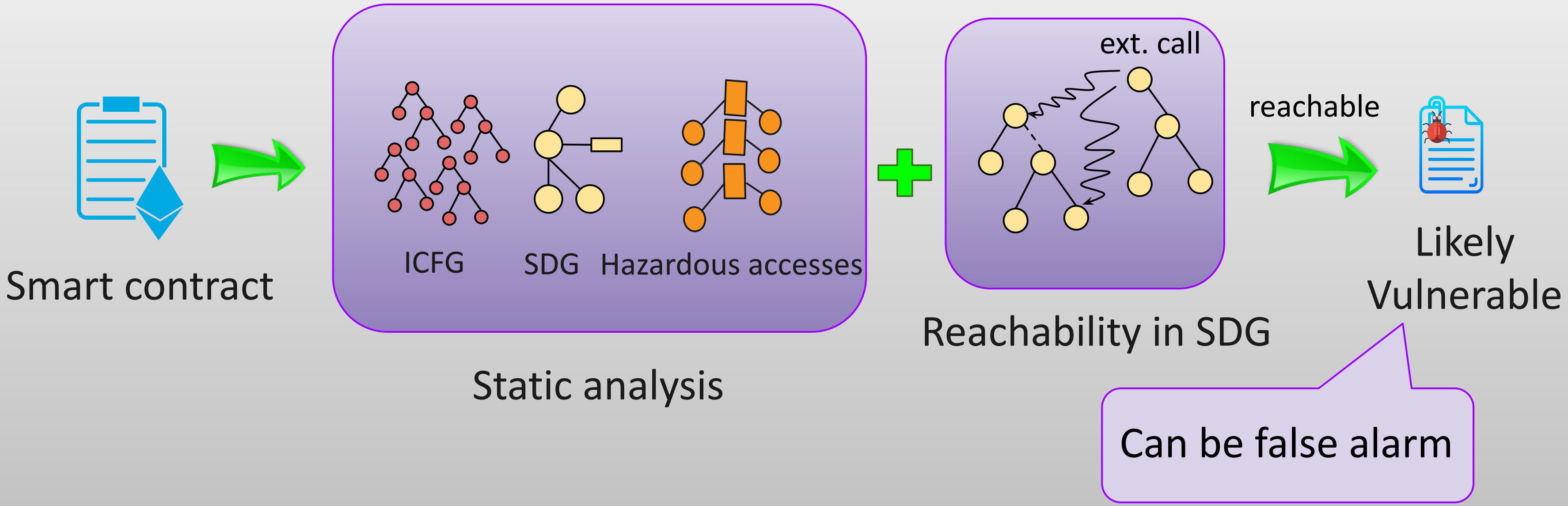
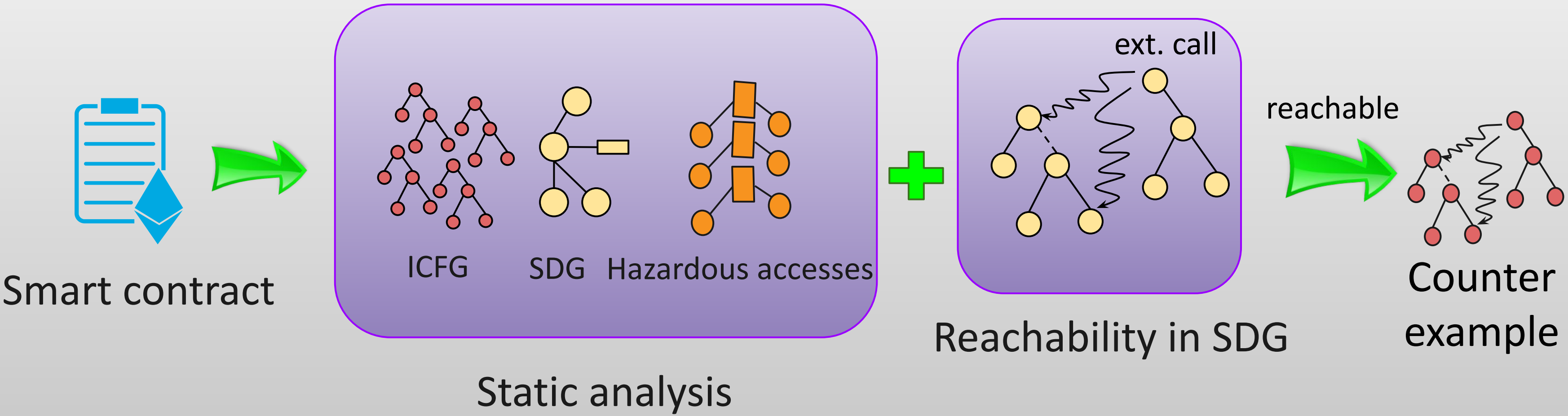


Explorer: Counter-example generation



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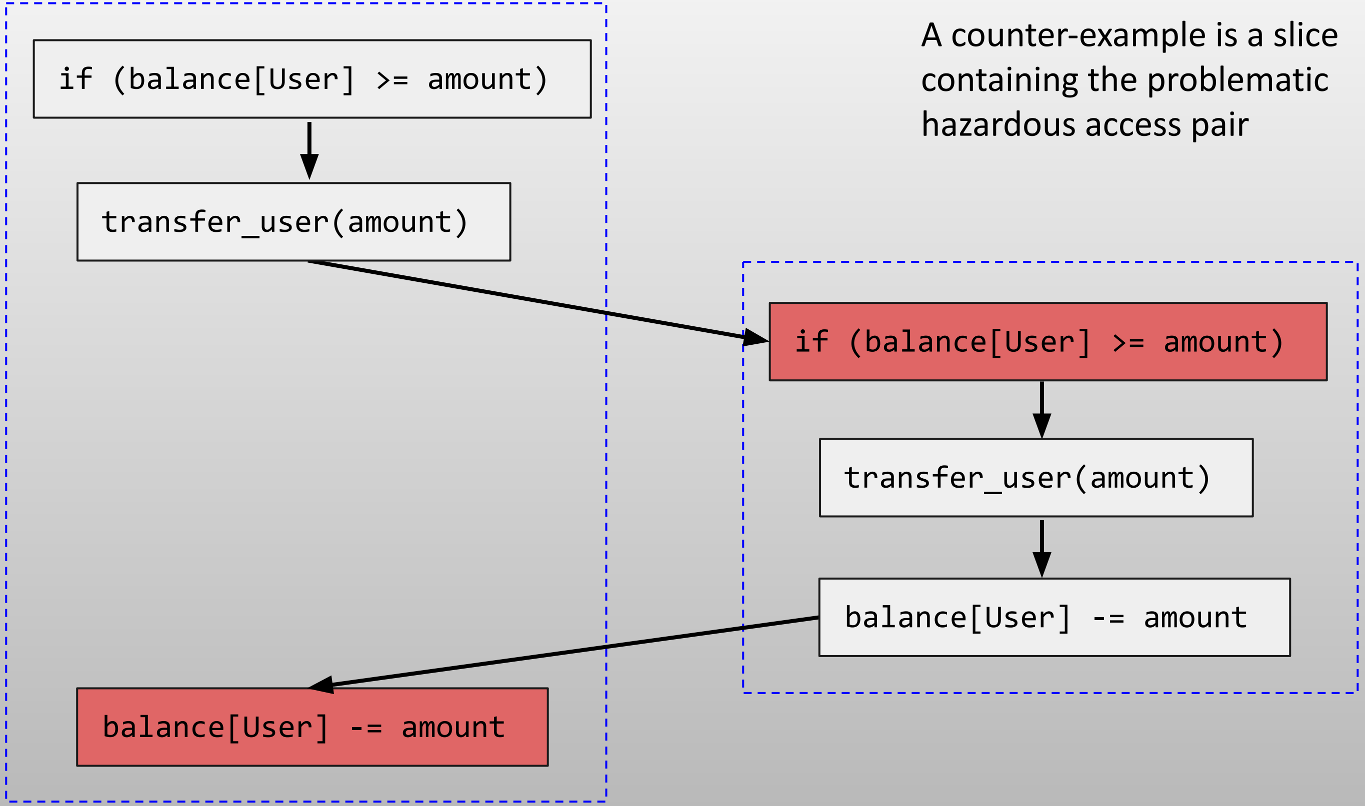

A counter-example is a slice containing the problematic hazardous access pair

Refiner: Value-summary analysis + Symbolic execution

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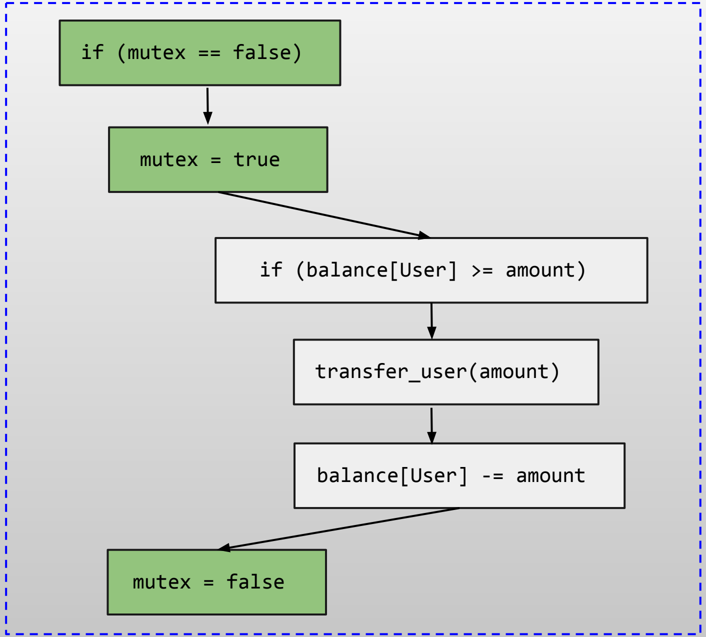
- Value-summary analysis (VSA) outputs the potential symbolic values of each storage variable under different constraints

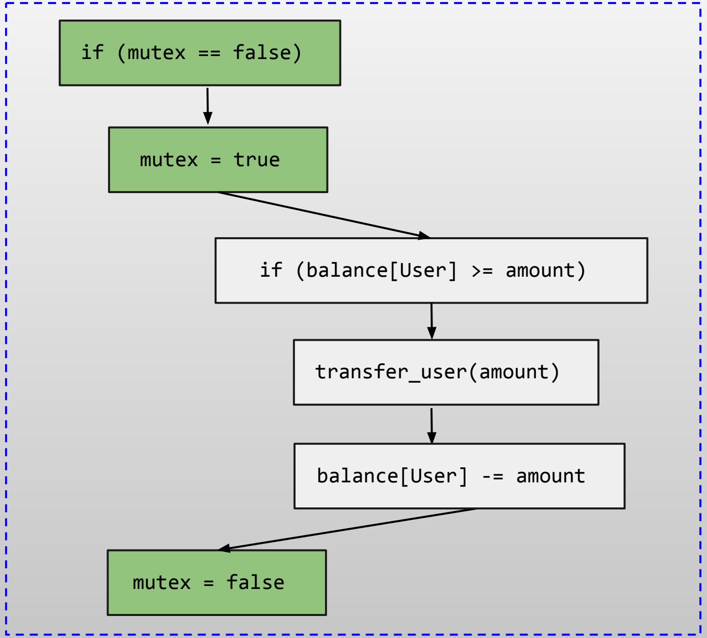
- This will be used as the precondition of the symbolic evaluation

Refiner: Value-summary analysis + Symbolic execution



withdraw

Refiner: Value-summary analysis + Symbolic execution



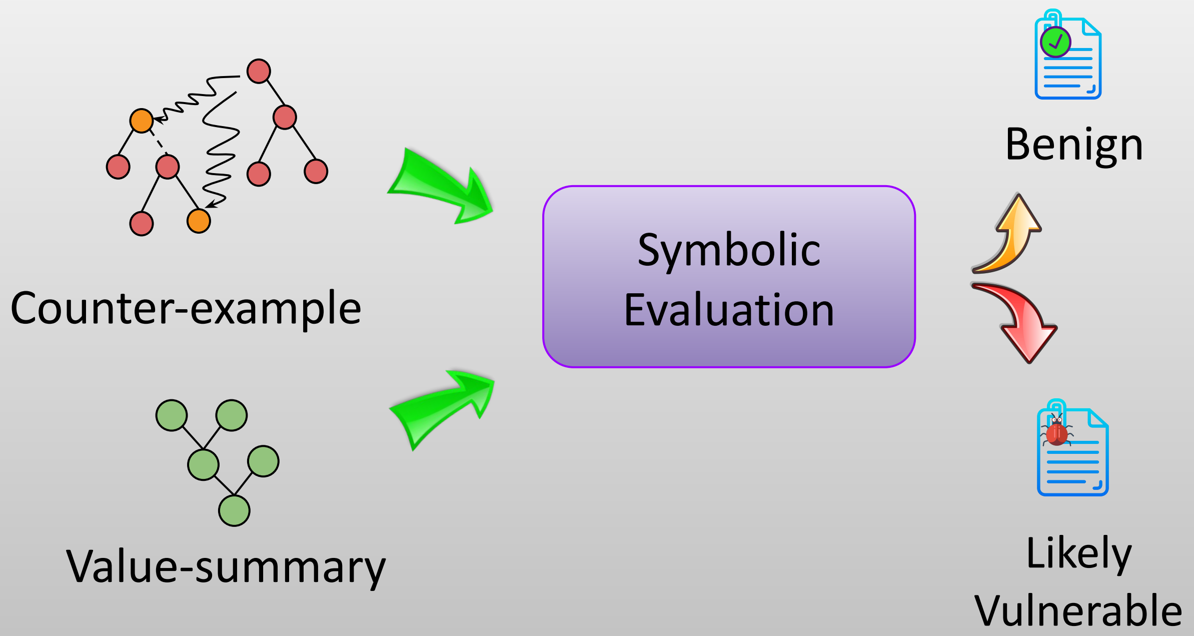
withdraw

Value-summary analysis outputs the following for `mutex`:

```
mutex: {<mutex=false, false>,
        <mutex=false, true>}
```

pre-condition   value

Refiner: Value-summary analysis + Symbolic execution



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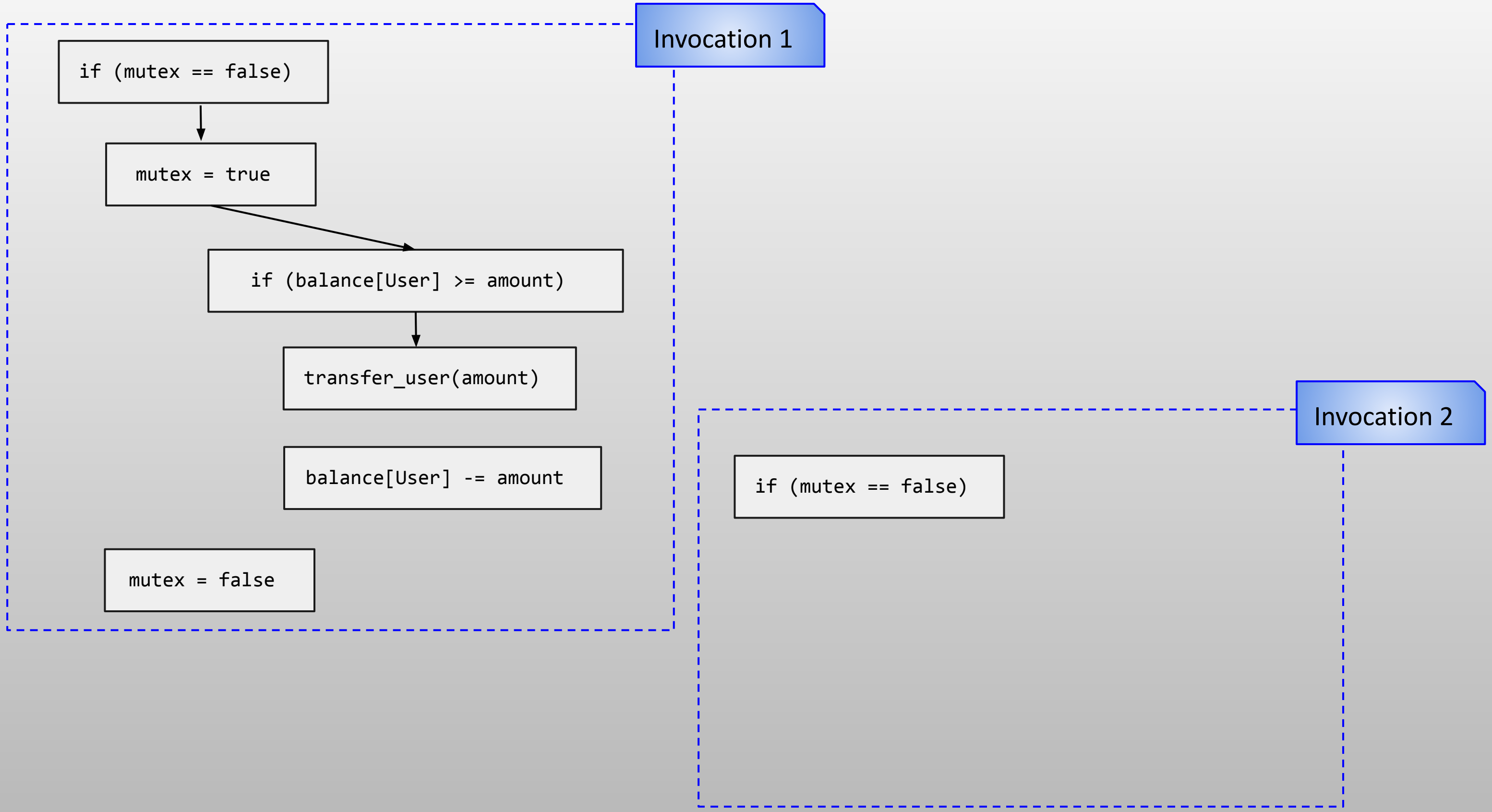

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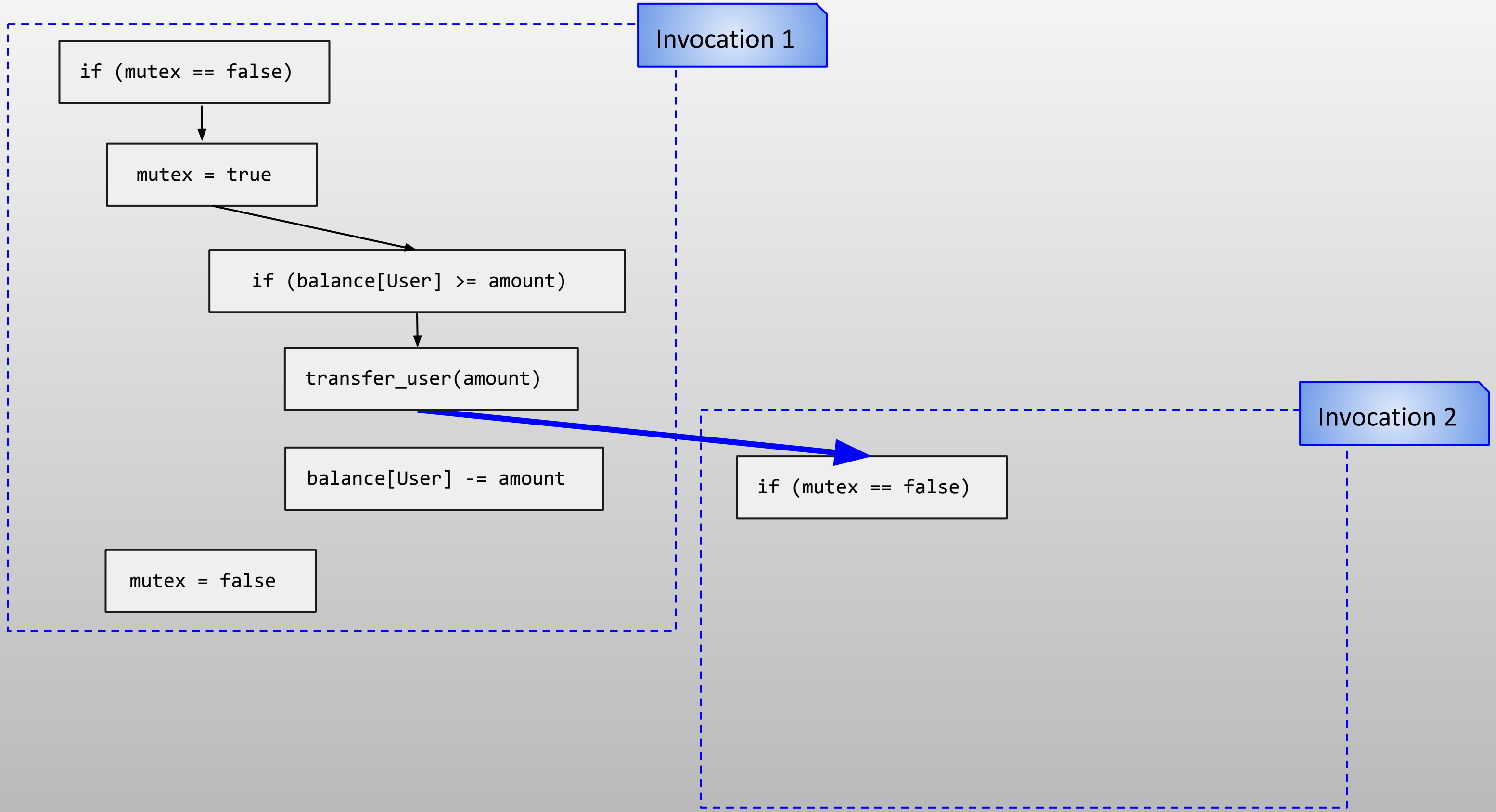

Refiner: Value-summary analysis + Symbolic execution

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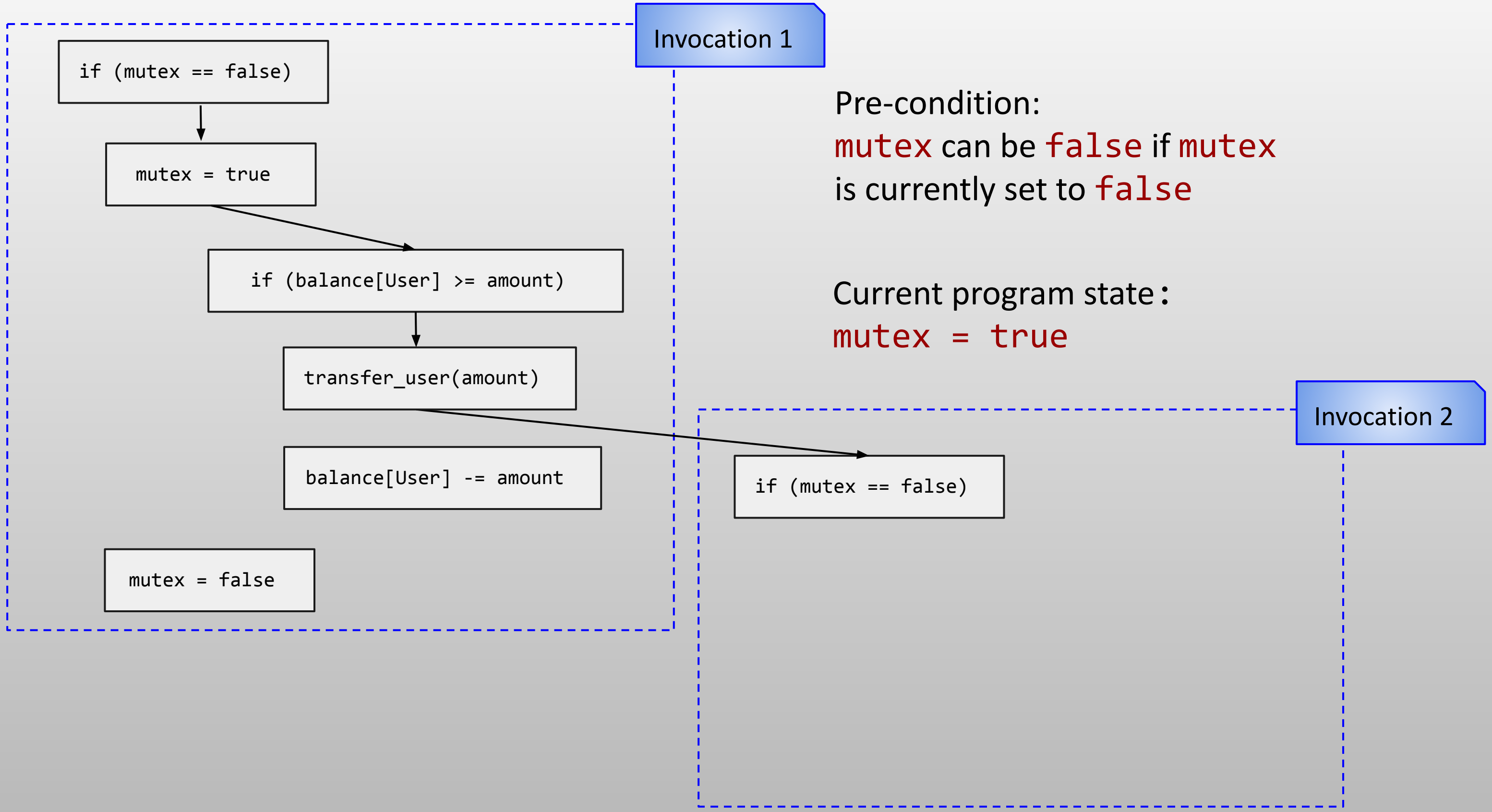
Pre-condition:
`mutex` can be `false` if `mutex` is currently set to `false`

Current program state:
`mutex = true`



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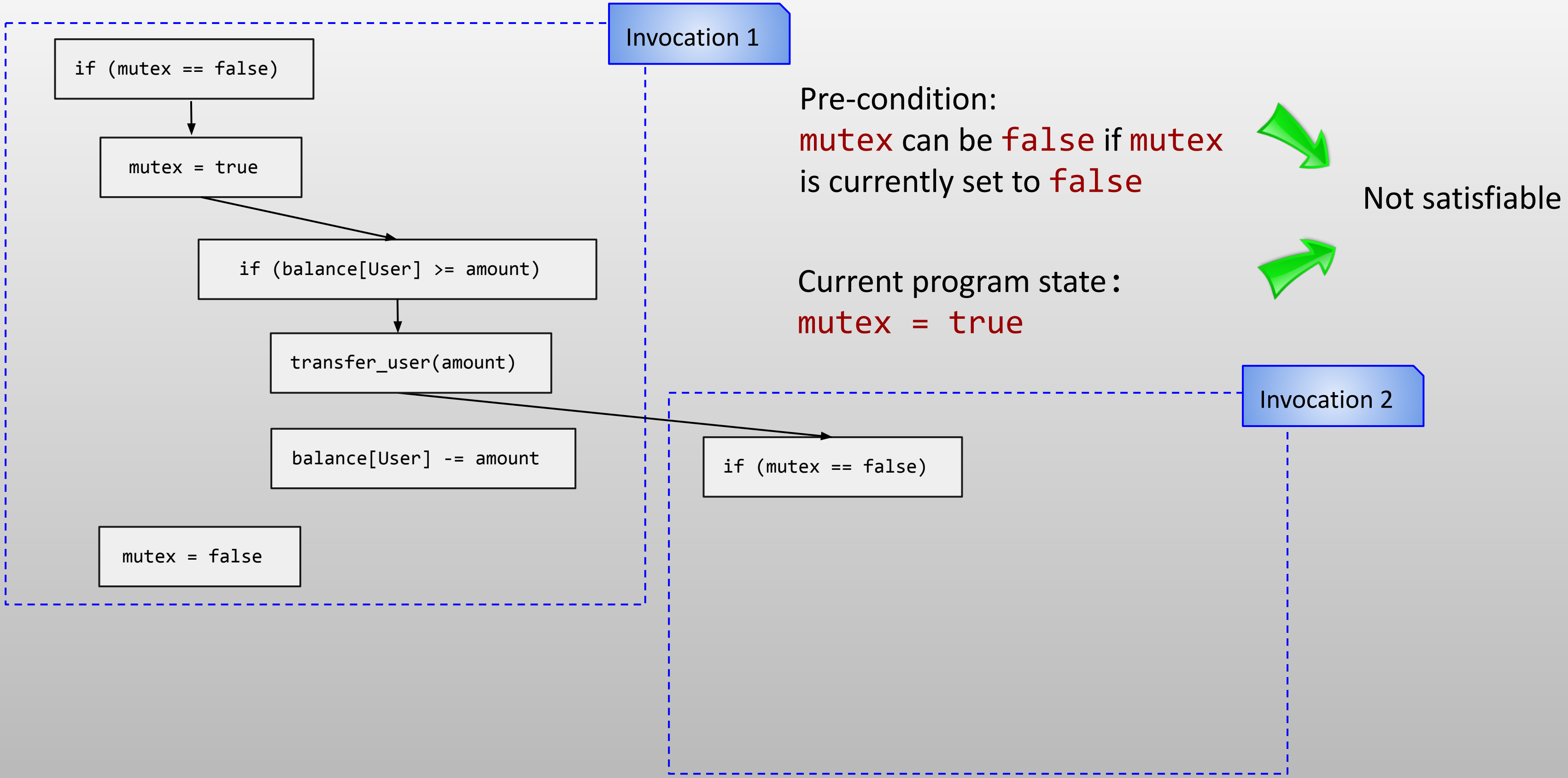

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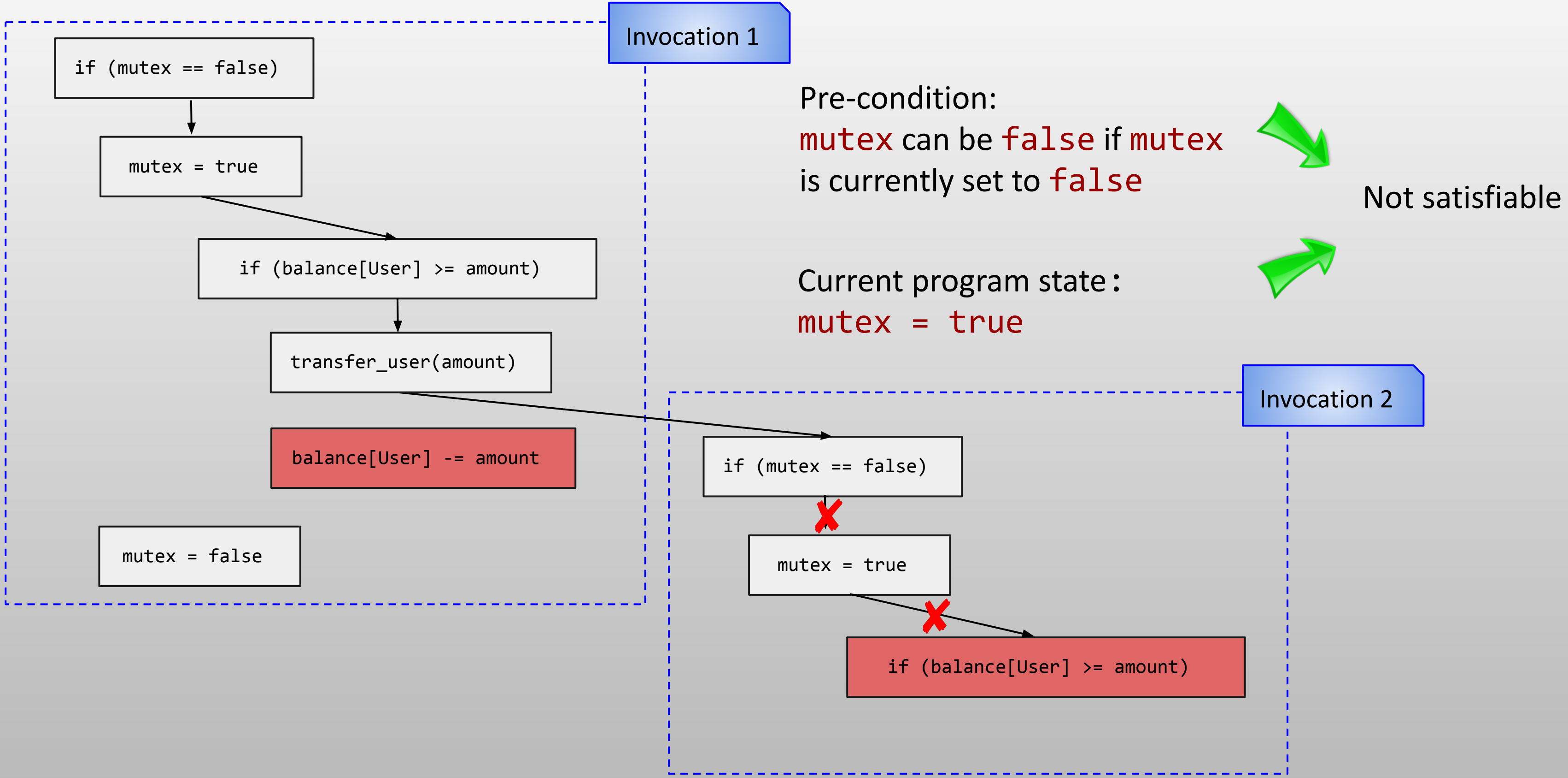

Results

Sailfish is evaluated against **Securify, Vandal, Oyente, Mythril**

+

The dataset consists of **89,853** Solidity open-sourced smart contracts

- ➔ Crawled from Etherscan
- ➔ All contracts till October, 2020
- ➔ Deduplicated

➔

(i) Vulnerability detection

(ii) Performance

Vulnerability detection

Tool	Reentrancy	TOD
Securify	6,321	19,031
Vandal	45,971	-
Mythril	3,708	-
Oyente	269	3,472
Sailfish	2,076	7,555

Vulnerability detection

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Mythril timed out for more than 50% of the contracts

Oyente errored out for around 60% of the contracts

Vulnerability detection

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Manually verified randomly-chosen 750 contracts from the our dataset

- ➔ [0, 3000] lines of code
- ➔ No tool errored out/timed out
- ➔ Found 26 reentrancy bugs

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Reentrancy

Tool	True positive	False positive	False negative
Securify	9 (35%)	163 (22%)	17 (65%)
Vandal	26 (100%)	626 (86%)	0 (0%)
Mythril	7 (27%)	334 (46%)	19 (73%)
Oyente	8 (31%)	16 (2%)	18 (69%)
Sailfish	26 (100%)	11 (1.5%)	0 (0%)

Vulnerability detection

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Vandal	26 (100%)	626 (86%)	0 (0%)
Mythril	7 (27%)	334 (46%)	19 (73%)
Oyente	8 (31%)	16 (2%)	18 (69%)
Sailfish	26 (100%)	11 (1.5%)	0 (0%)

Vulnerability detection

SECLAB

Tool	Reentrancy	TOD
Securify	6,321	19,031
Vandal	45,971	-
Mythril	3,708	-
Oyente	269	3,472
Sailfish	2,076	7,555

Manually verified randomly-chosen 750 contracts from the our dataset

- ➔ [0, 3000] lines of code
- ➔ No tool errored out/timed out
- ➔ Found 26 reentrancy bugs

Reentrancy

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- ➢ Least false positives
- ➢ No false negatives
- ➢ Finds all true bugs

Vulnerability detection

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Securify	6,321	19,031
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- Sailfish found **47** bugs not found by any other tool

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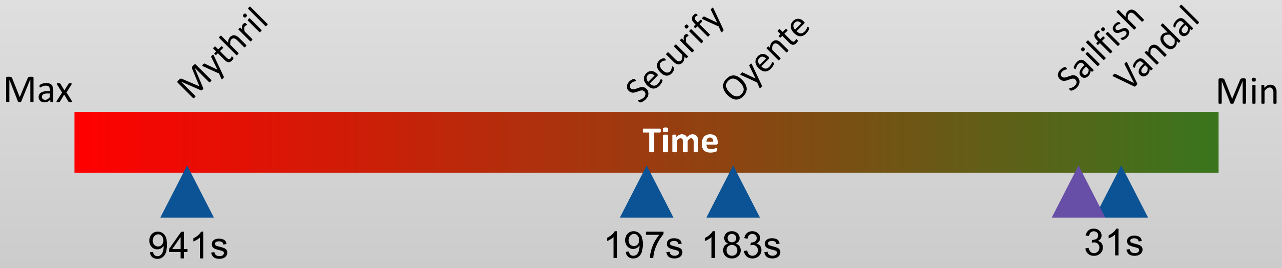
Performance



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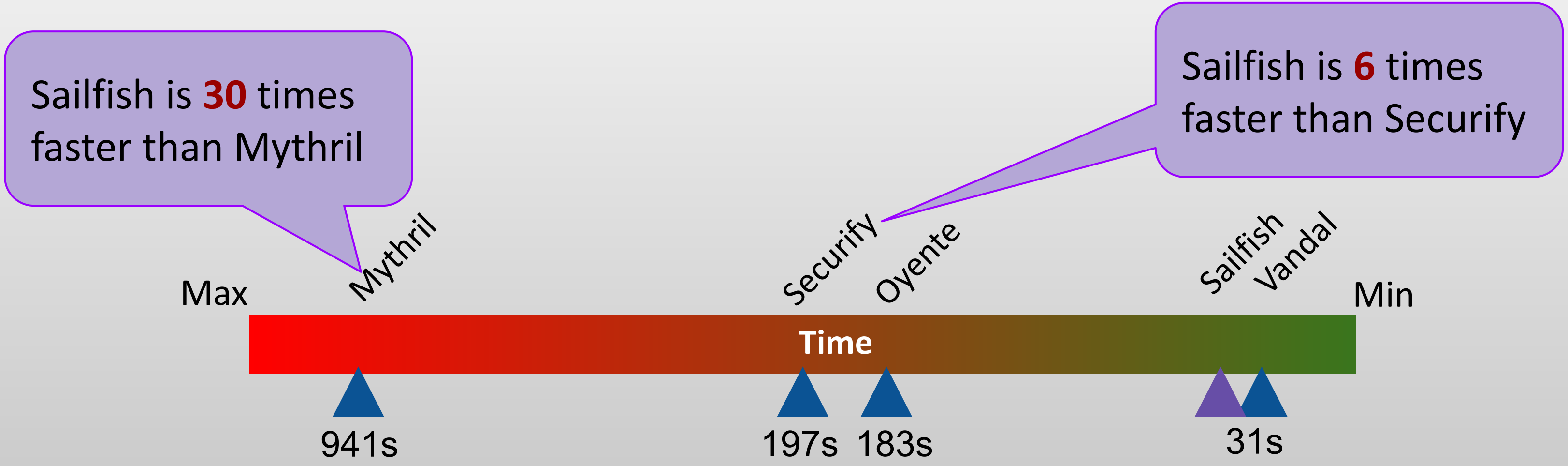

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SECLAB

- We presented Sailfish, a bug finding tool for reentrancy and TOD
- Sailfish generalized reentrancy and TOD in terms of State Inconsistency
- Sailfish combines static analysis and VSA-enabled symbolic execution to achieve both precision and scalability
- Sailfish outperforms state-of-the-art techniques in both performance and bug finding ability

THANKS!

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https://github.com/ucsb-seclab/sailfish