LLMs as verification oracles for Solidity

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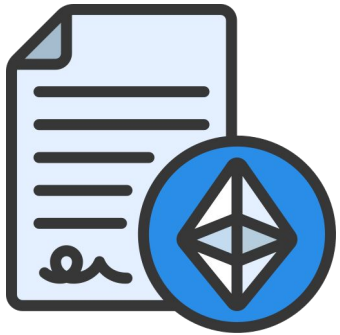
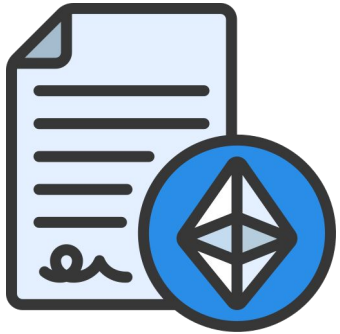


> $100 billion



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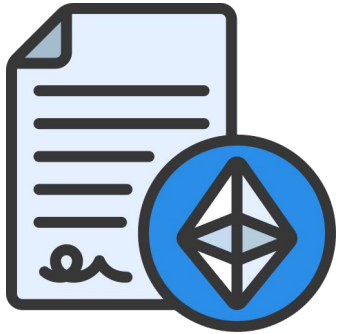

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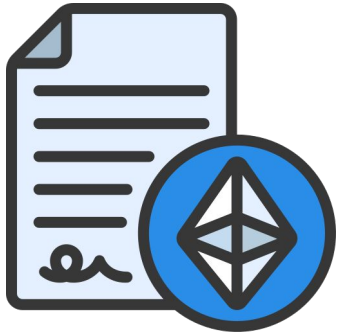

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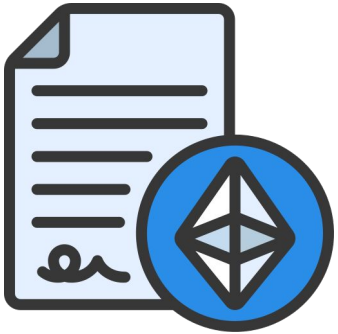

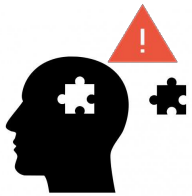

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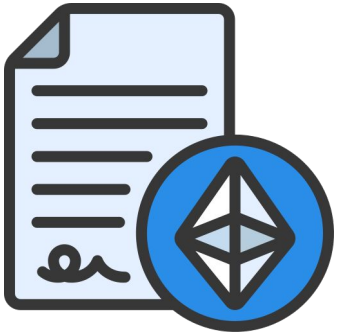
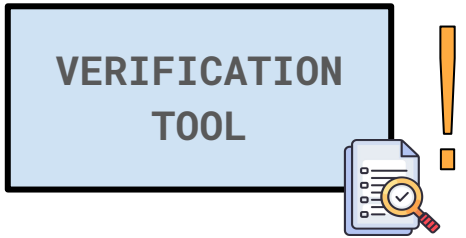
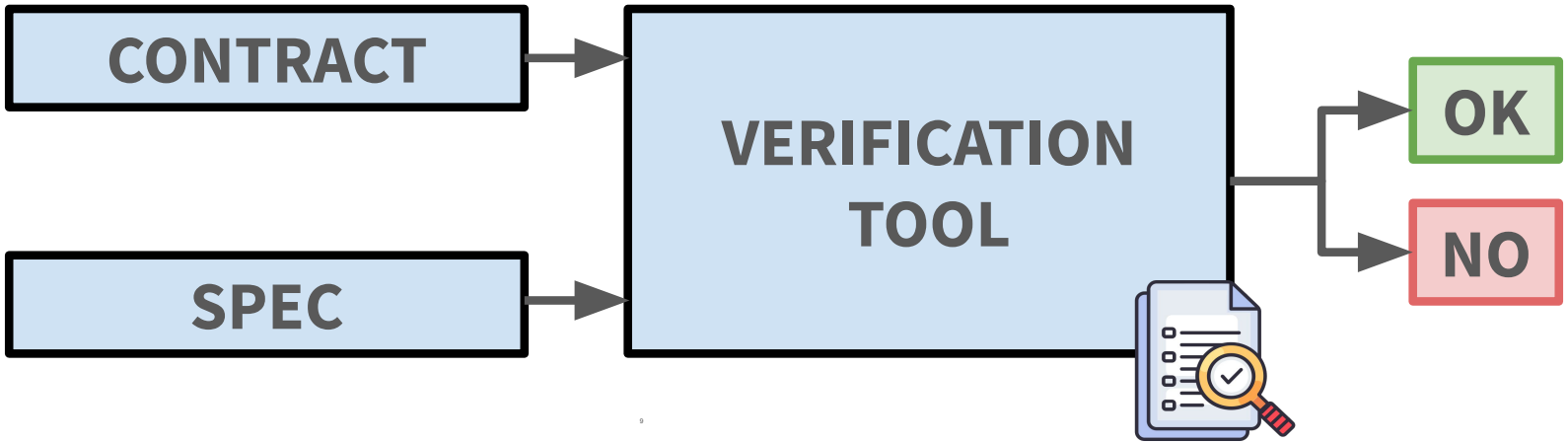
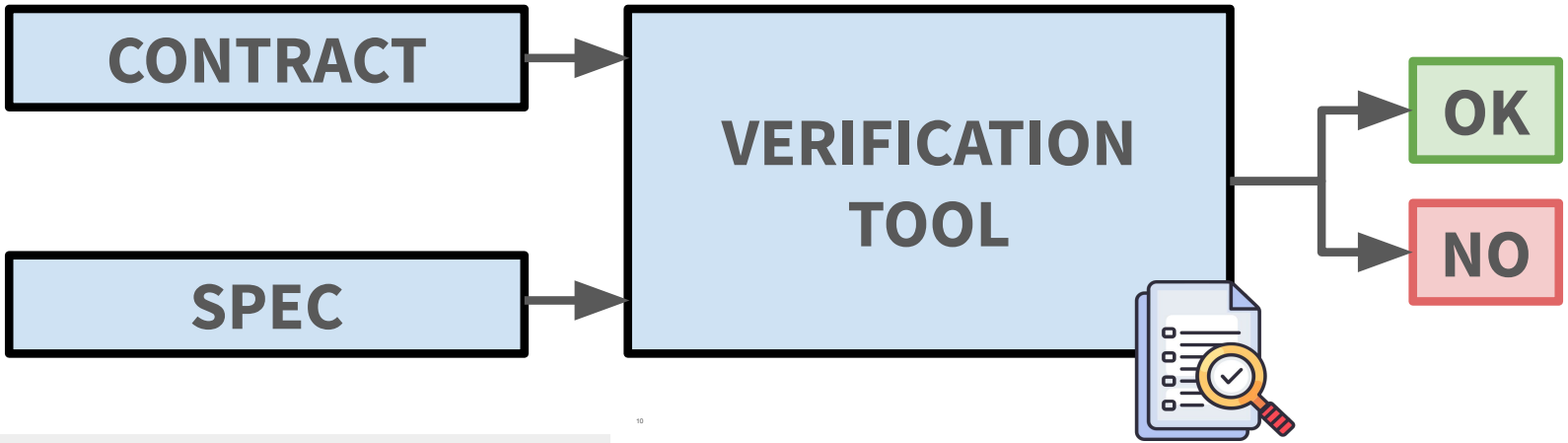





CONTRACT
SPEC
VERIFICATION TOOL
OK
NO

```
contract Bank {
    mapping (address user => uint credit) credits;

    function deposit() public payable {
        credits[msg.sender] += msg.value;
    }
```



"after a non-reverting deposit(), the credits of msg.sender are increased by msg.value"

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contract Bank {
    mapping (address user => uint credit) credits;

    function deposit() public payable {
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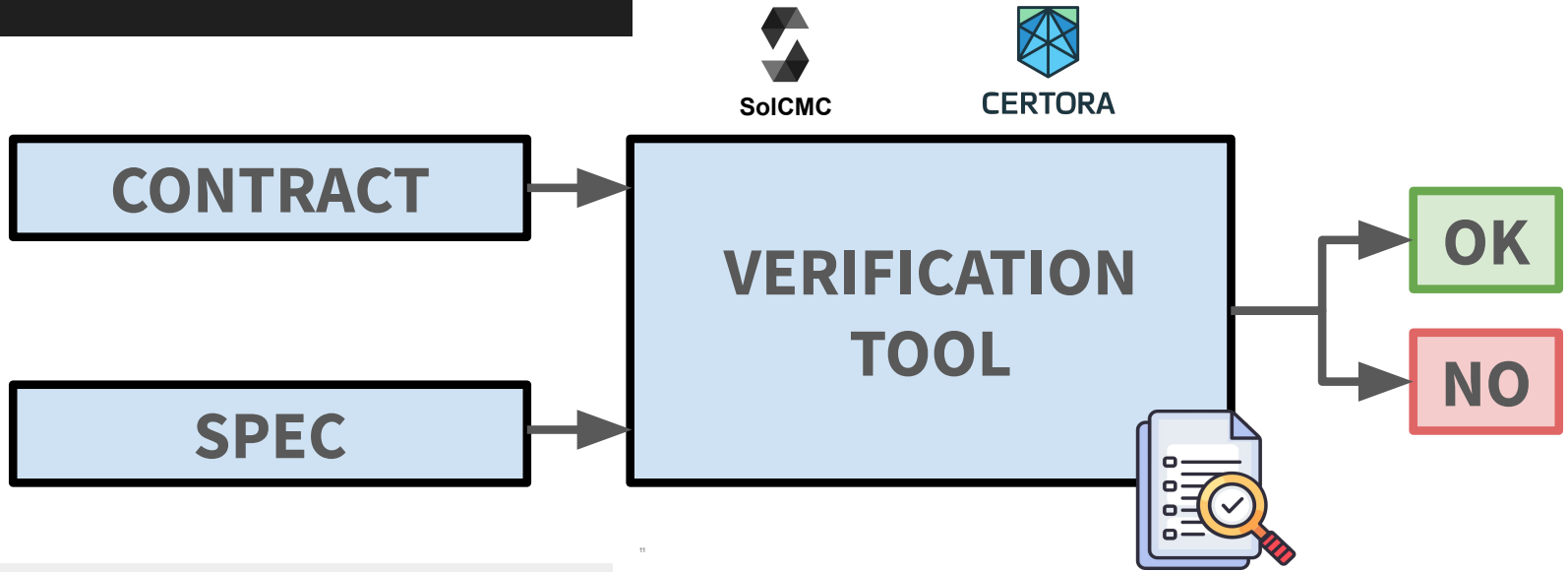

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Formal Verification

issues

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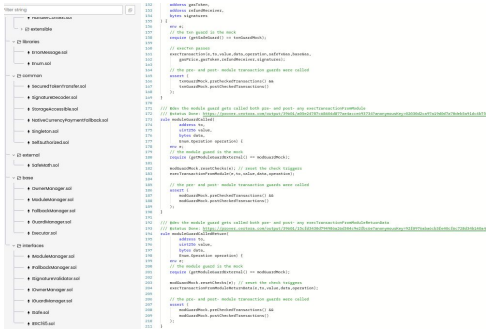
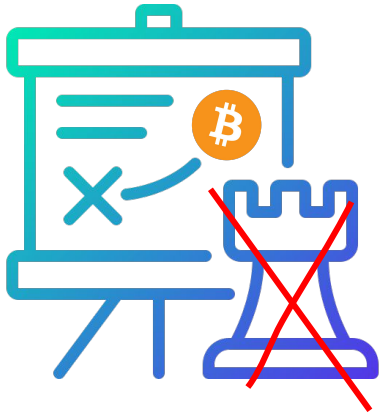
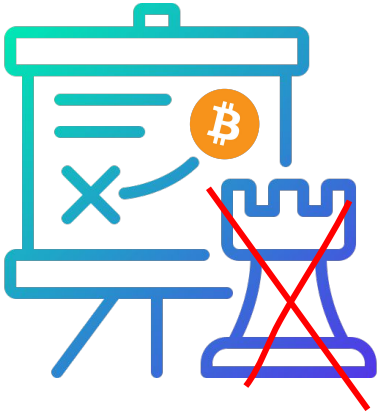
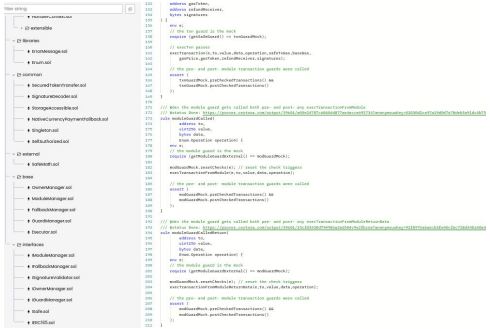


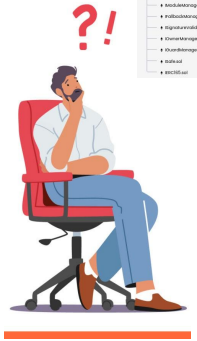


Formal Verification

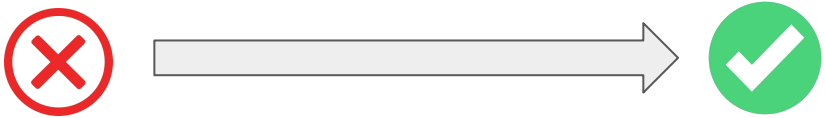
issues





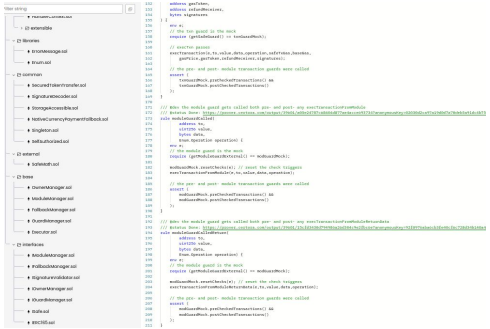


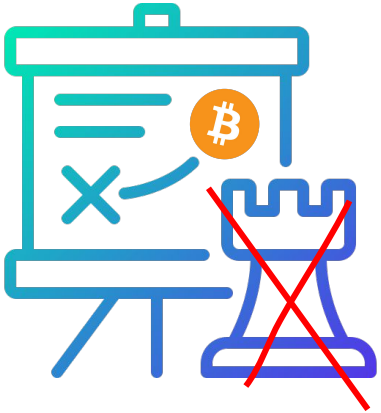
Semantics abstraction

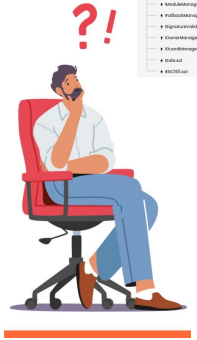


Formal Verification

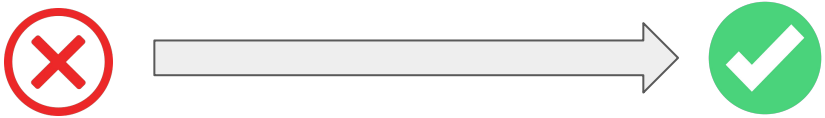
issues







Semantics abstraction

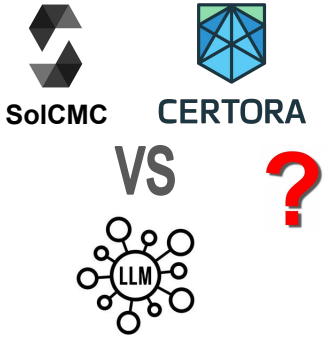


VERIFICATION TOOL

RQ1

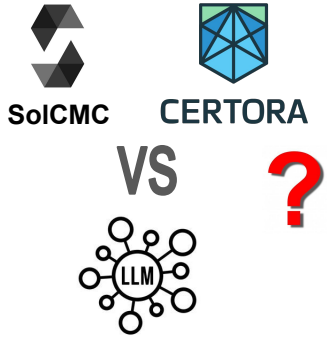
RQ1

RQ2



RQ1

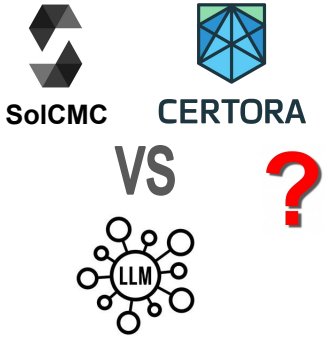
RQ2



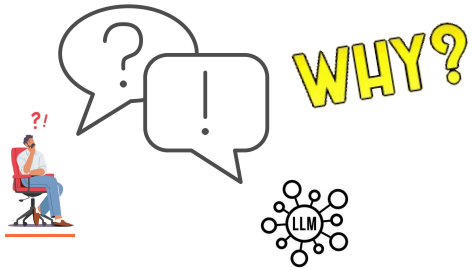
RQ3

RQ1

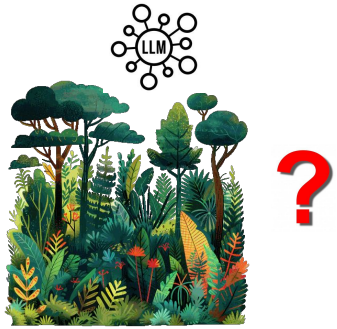
RQ2

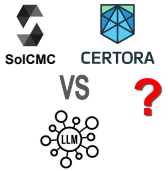


RQ3



RQ4





RQ1 RQ2 RQ3 RQ4

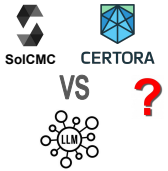
Controlled dataset

bitbart / **contracts-verification-benchmark**

- 5 use cases (→LP)
- 63 mutations
- 159 properties in natural language
- 2034 verification tasks
- specs for SolCMC / Certora

Certora Reports

- Safe (smart account wallet)
- InfiniFi (yield-bearing deposits)
- 75 properties (written in CVL + NL)

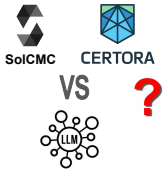


RQ1

RQ2

Dataset	Tool	F1 score
specs expressible in Certora		
$DS_{\|CVL}$	Certora	77%
$DS_{\|CVL}$	GPT-5	92%
$DS_{\|CVL}$	GPT-4	68%
specs expressible in SolCMC		
$DS_{\|SolCMC}$	SolCMC	79%
$DS_{\|SolCMC}$	GPT-5	90%
$DS_{\|SolCMC}$	GPT-4	66%

RQ1



RQ2

specs expressible in Certora

specs expressible in SolCMC

Dataset	Tool	F1 score
$DS_{\mid CVL}$	Certora	77%
$DS_{\mid CVL}$	GPT-5	92%
$DS_{\mid CVL}$	GPT-4	68%
$DS_{\mid SolCMC}$	SolCMC	79%
$DS_{\mid SolCMC}$	GPT-5	90%
$DS_{\mid SolCMC}$	GPT-4	66%

specs *not* expressible in Certora

$DS_{\mid \neg CVL}$	GPT-5	91%

specs *not* expressible in SolCMC

$DS_{\mid \neg SolCMC}$	GPT-5	93%

RQ3

PoC generated by GPT-5

- Deploy with payees [Owner O, Alice A], shares [1, 2] (totalShares = 3).
- Send 3 wei to the contract.
- Call release(O): pays 1 wei to O.
- Call release(A): pays 2 wei to A. Now totalReleased = 3, balance = 0, released[O]=1, released[A]=2, totalReceived = 3.
- Send 2 wei to the contract (balance = 2, totalReleased = 3, totalReceived = 5).
- Call release(A): payment = floor(5*2/3) - 2 = 1; pays 1 wei; totalReleased = 4; balance = 1; released[A] = 3; totalReceived remains 5.
- Call release(O): payment = floor(5*1/3) - 1 = 0; else-branch executes and transfers 1 wei to owner; totalReleased stays 4; balance becomes 0; totalReceived becomes 4.
- Now for A: RHS = floor(4*2/3) = 2, but released[A] = 3 and releasable(A) = floor(4*2/3) - 3 = -1 (underflow → revert).

Hence the property “released[A] + releasable(A) == (totalReceived * shares[A]) / totalShares” is violated (releasable(A) cannot be computed).

RQ3

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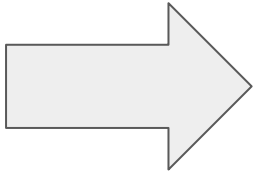
Manual validation in Forge



```
contract PaymentSplitterTest is Test {

    PaymentSplitter public ps;
      bart, last month • test/fair-split-eq_v9.t.sol
    function setUp() public {
    }

    function test_fair_split_eq() public {

        address o = address(0x1);
        address b = address(0x2);
        address c = address(0x3);

        address[] memory payees = new address[](2);
        payees[0] = address(o);
        payees[1] = address(b);

        uint256[] memory shares = new uint256[](2);
        shares[0] = 1;
        shares[1] = 1;

        vm.prank(o);
        ps = new PaymentSplitter(payees, shares);

        // C sends 100 wei to the contract
        vm.deal(address(c), 2);
        vm.prank(c);
        (bool success,) = address(ps).call{value:2}("");
        assert(success);

        ps.release(payable(b));
        ps.release(payable(c));

        // rhs = (totalReceived * shares[b]) / totalShares
        uint totalReceived = address(ps).balance + ps.getTotalReleased();
        uint rhs = (totalReceived * ps.getShares(b)) / ps.getTotalShares();
        assertEq(rhs, 0);

        // lhs = released[b] + releasable(b)
        vm.expectRevert();
        uint releasable_b = ps.releasable(b);

        // violation: lhs (reverted) != rhs
    }
}
```

RQ3

Correctness	92%
Completeness	89%
Coherence	95%

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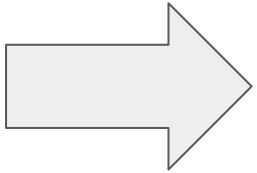

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        ps = new PaymentSplitter(payees, shares);

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        vm.deal(address(c), 2);
        vm.prank(c);
        (bool success,) = address(ps).call{value:2}("");
        assert(success);

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        ps.release(payable(c));

        // rhs = (totalReceived * shares[b]) / totalShares
        uint totalReceived = address(ps).balance + ps.getTotalReleased();
        uint rhs = (totalReceived * ps.getShares(b)) / ps.getTotalShares();
        assertEq(rhs, 0);

        // lhs = released[b] + releasable(b)
        vm.expectRevert();
        uint releasable_b = ps.releasable(b);

        // violation: lhs (reverted) != rhs
    }
}
```

```
contract Bank {
    mapping (address user => uint credit) credits;

    function deposit() public payable {
        credits[msg.sender] += msg.value;
    }
```

*"after a non-reverting **deposit()**,*
the credits of msg.sender
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[M. Bartoletti & E. Lipparini, VERIFAI 2026]

```
abstract contracts[] cs;

contract BankTest is Test {
  Bank immutable bank;

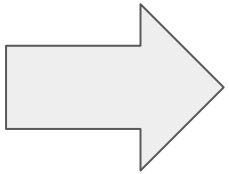
  constructor() {
    abstract address bank_deployer;
    vm.prank(bank_deployer);
    bank = new Bank();
  }

  function test_withdraw_assets_credit_others_violation()
    abstract transaction[] txs;
    abstract address user;
    uint256 user_creditsBefore = bank.credits(user);

    abstract uint256 amount;
    abstract address sender;
    vm.prank(sender);
    bank.withdraw(amount); // should not revert

    uint256 user_creditsAfter = bank.credits(user);

    assertNotEq(sender, user, "user equal to sender");
    assertNotEq(user_creditsBefore, user_creditsAfter, "cr
  }
}
```



```
contract Attacker {
 Bank public bank;
 User public user;

 constructor(Bank _bank) {
  bank = _bank;
 }

 function setUser(User _user) external {
  user = _user;
 }

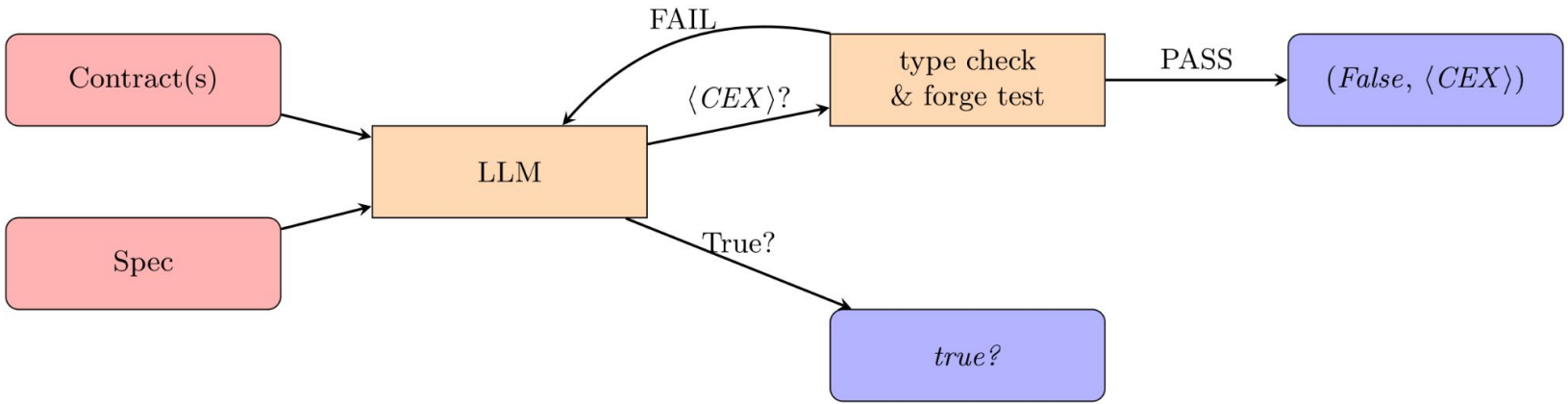
 // When receiving ETH from Bank.withdraw, forward it to User,
 // which deposits into Bank, crediting the User.
 receive() external payable {
  user.doDeposit{value: msg.value}(bank);
 }
}

contract BankTest is Test {
 constructor() {
  address bank_deployer = address(0xBEEF);
  [...]  // deployment of bank
 }

 function test_withdraw_assets_credit_others_violation() public {
  User u = new User();
  Attacker a = new Attacker(bank);
  a.setUser(u);
  vm.deal(address(a), 1 ether);
  vm.prank(address(a));
  bank.deposit{value: 1 ether}();

  address user = address(u);
  [...] // def. of user_creditsBefore
  uint256 amount = 1 ether;
  address sender = address(a);
  [...] // call to bank.withdraw and asserts
 }
```

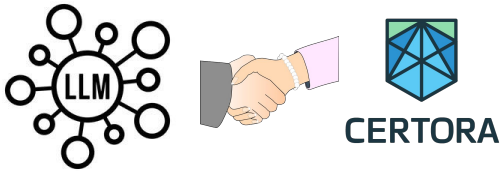
[M. Bartoletti & E. Lipparini, VERIFAI 2026]



results / # iter.	Total	(TRUE, *true?*)	(FALSE, *true?*)	(FALSE, *False*)
Total	109	57	4	48
0	90	46	4	40
1	15	10	0	5
2	4	1	0	3
3	0	0	0	0

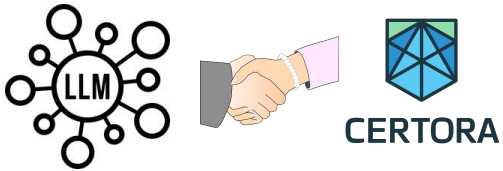
In the wild (RQ4)

In the wild (RQ4)



In the wild (RQ4)

Spotting inconsistencies between NL property - formal spec



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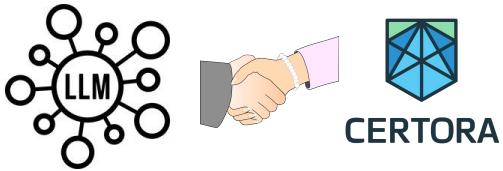
Spotting inconsistencies between NL property - formal spec

Completing trace violation



In the wild (RQ4)

Spotting inconsistencies between NL property - formal spec

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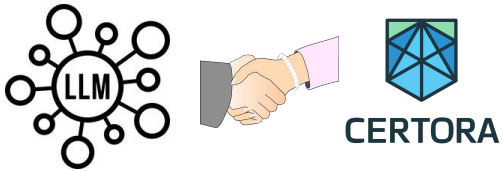
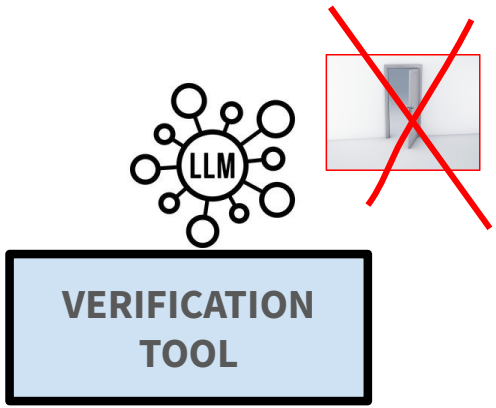
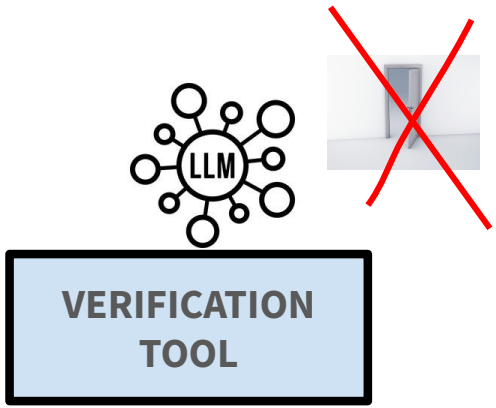


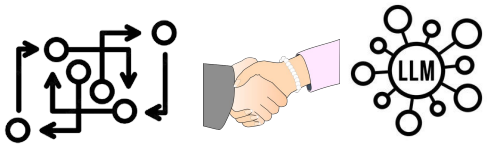
Flattened learning curve

Takeaway message

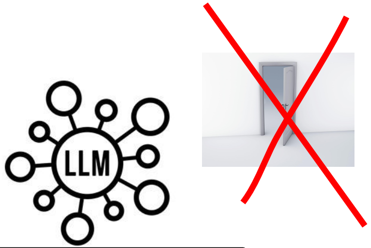


Takeaway message

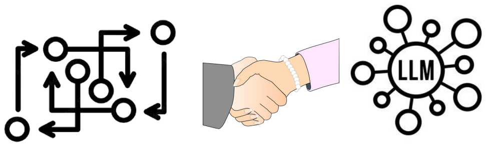


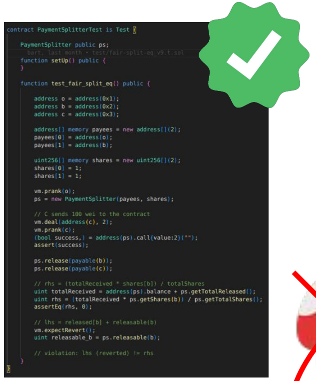


Takeaway message



VERIFICATION TOOL





```
contract PaymentSplitterTest is Test {

    PaymentSplitter public ps;
      bart, last month • test/fair-split-eq_v9.t.sol
    function setUp() public {
    }

    function test_fair_split_eq() public {

        address o = address(0x1);
        address b = address(0x2);
        address c = address(0x3);

        address[] memory payees = new address[](2);
        payees[0] = address(o);
        payees[1] = address(b);

        uint256[] memory shares = new uint256[](2);
        shares[0] = 1;
        shares[1] = 1;

        vm.prank(o);
        ps = new PaymentSplitter(payees, shares);

        // C sends 100 wei to the contract
        vm.deal(address(c), 2);
        vm.prank(c);
        (bool success,) = address(ps).call{value:2}("");
        assert(success);

        ps.release(payable(b));
        ps.release(payable(c));

        // rhs = (totalReceived * shares[b]) / totalShares
        uint totalReceived = address(ps).balance + ps.getTotalReleased();
        uint rhs = (totalReceived * ps.getShares(b)) / ps.getTotalShares();
        assertEq(rhs, 0);

        // lhs = released[b] + releasable(b)
        vm.expectRevert();
        uint releasable_b = ps.releasable(b);

        // violation: lhs (reverted) != rhs
    }
}
```

~~hallucinations~~