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Formal Specification and Verification of Solidity Contracts with Events

Ákos Hajdu[1], Dejan Jovanović[2], Gabriela Ciocarlie[2]

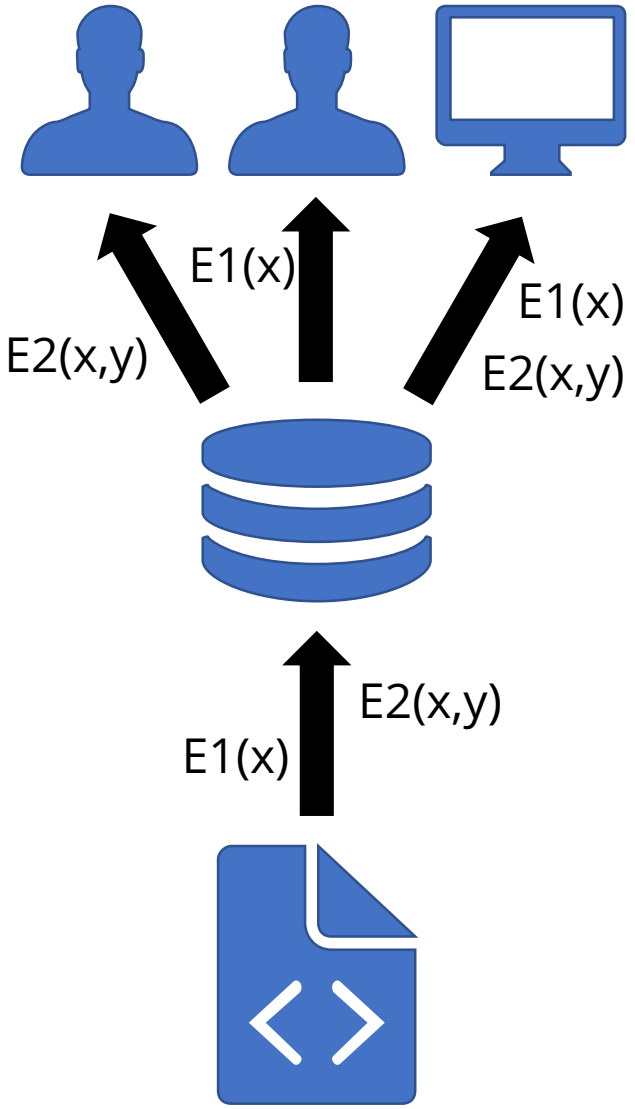
[1]*Budapest University of Technology and Economics*
[2]*SRI International*

Solidity Smart Contracts and Events

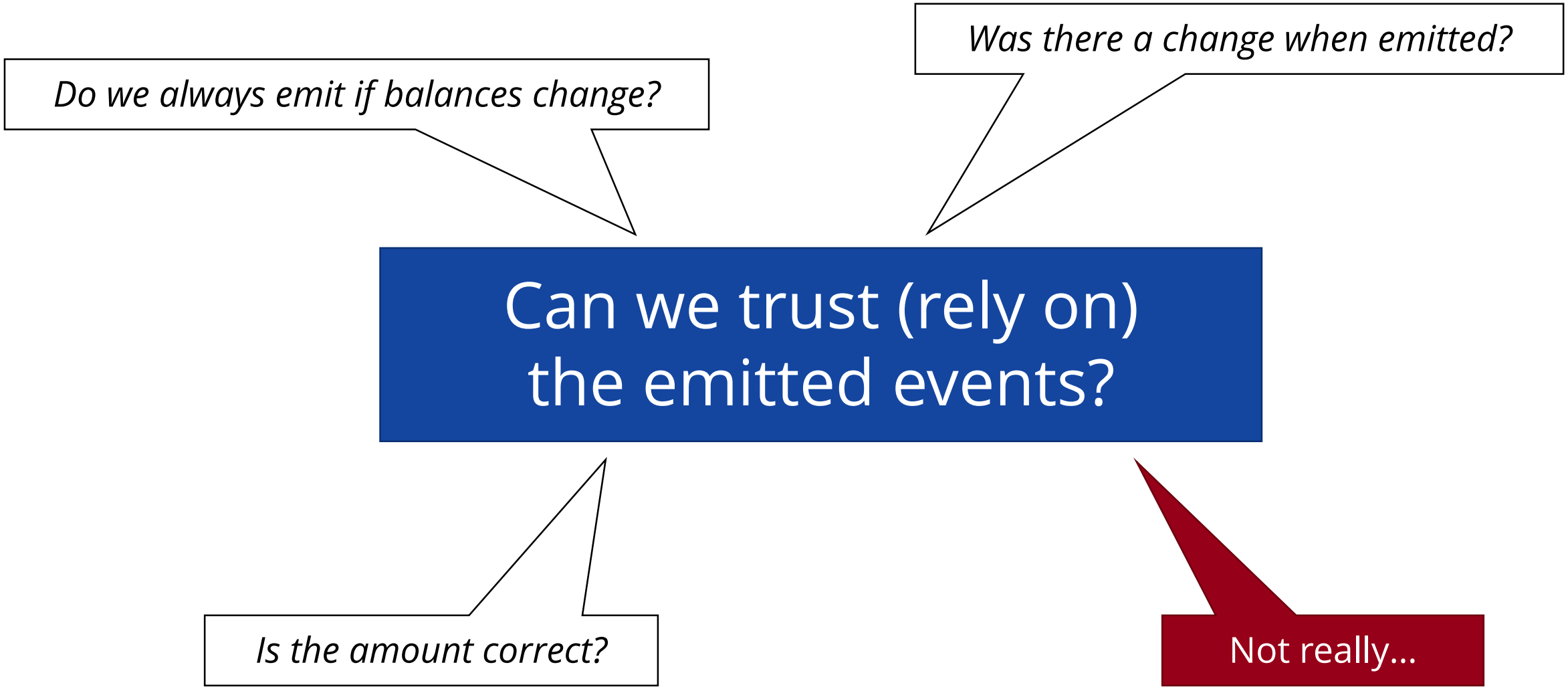
```
contract Token {
  mapping(address=>uint) balances;
  uint total;

  event initialized(address from, uint amount);
  event transferred(address from, address to, uint amount);

  constructor(uint _total) public {
    balances[msg.sender] = total = _total;
    emit initialized(msg.sender, total);
  }

  function transfer(address to, uint amount) public {
    require(balances[msg.sender] >= amount && msg.sender != to);
    balances[msg.sender] -= amount;
    balances[to] += amount;
    emit transferred(msg.sender, to, amount);
  }
}
```

Solidity Events

- Stored in blockchain logs
- Contract communicates with user
  - Important state changes
- Abstract view of execution
  - Relevant aspect to each user



Motivation


Was there a change when emitted?
Do we always emit if balances change?
Can we trust (rely on) the emitted events?
Is the amount correct?
Not really...

Formal Specification of Events

- What state variable(s) do events track?
  - Emit event *iff* there was a change

```
contract Token {
  mapping(address=>uint) balances;
  uint total;

  /// @notice tracks-changes-in balances
  /// @notice tracks-changes-in total
  event initialized(address from, uint amount);

  /// @notice tracks-changes-in balances
  event transferred(address from, address to, uint amount);
}
```

Formal Specification of Events

- What events *can* functions emit?
  - Similar to Java *throws*

```
contract Token {

  /// @notice emits initialized
  constructor(uint _total) public {
    ...
  }

  /// @notice emits transferred
  function transfer(address to, uint amount) public {
    ...
  }
}
```

Formal Specification of Events

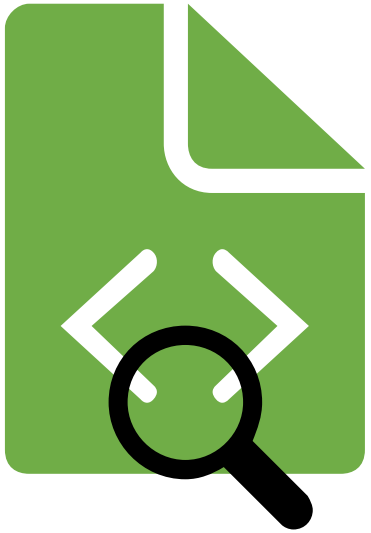
- What are the conditions *before* and *at* the emit?

```
contract Token {
  /// @notice precondition balances[from] == 0
  /// @notice postcondition balances[from] == amount
  /// @notice postcondition total == amount
  event initialized(address from, uint amount);

  /// @notice precondition balances[from] >= amount
  /// @notice postcondition balances[from] == before(balances[from]) - amount
  /// @notice postcondition balances[to] == before(balances[to]) + amount
  event transferred(address from, address to, uint amount);
}
```

DEMO

Formal Verification

- Where to check if an event has been emitted?
  - Cannot check immediately (modification in multiple steps)
- Where to check preconditions?
  - What does “before the change” exactly mean?



Checkpoints

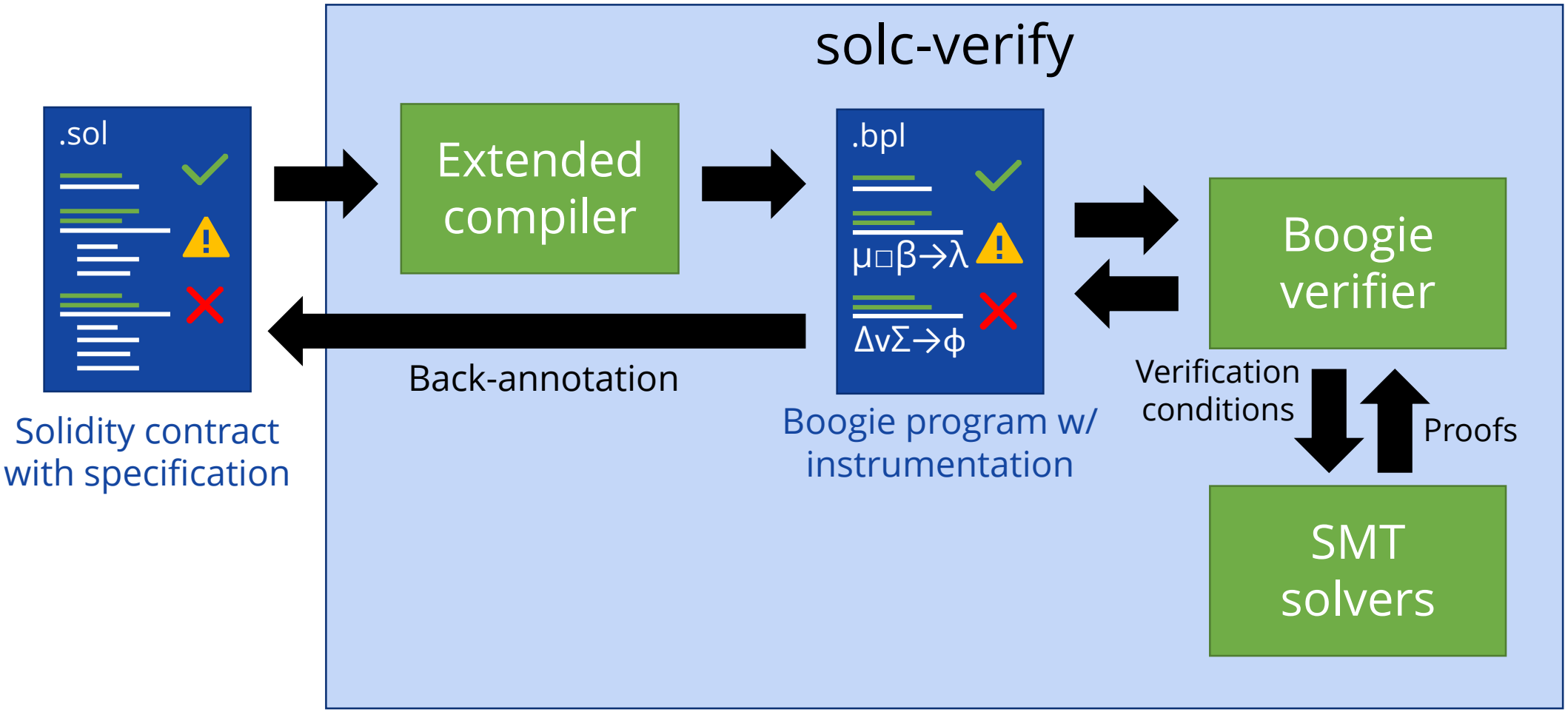
```
function transfer(address to, uint amount) public {
  require(balances[msg.sender] >= amount && msg.sender != to);
  ...
  balances[msg.sender] -= amount;
  balances[to] += amount;
  ...
  emit transferred(msg.sender, to, amount);
  ...
}
```

Before checkpoint
- First time variable changes
- Save state (for precondition)

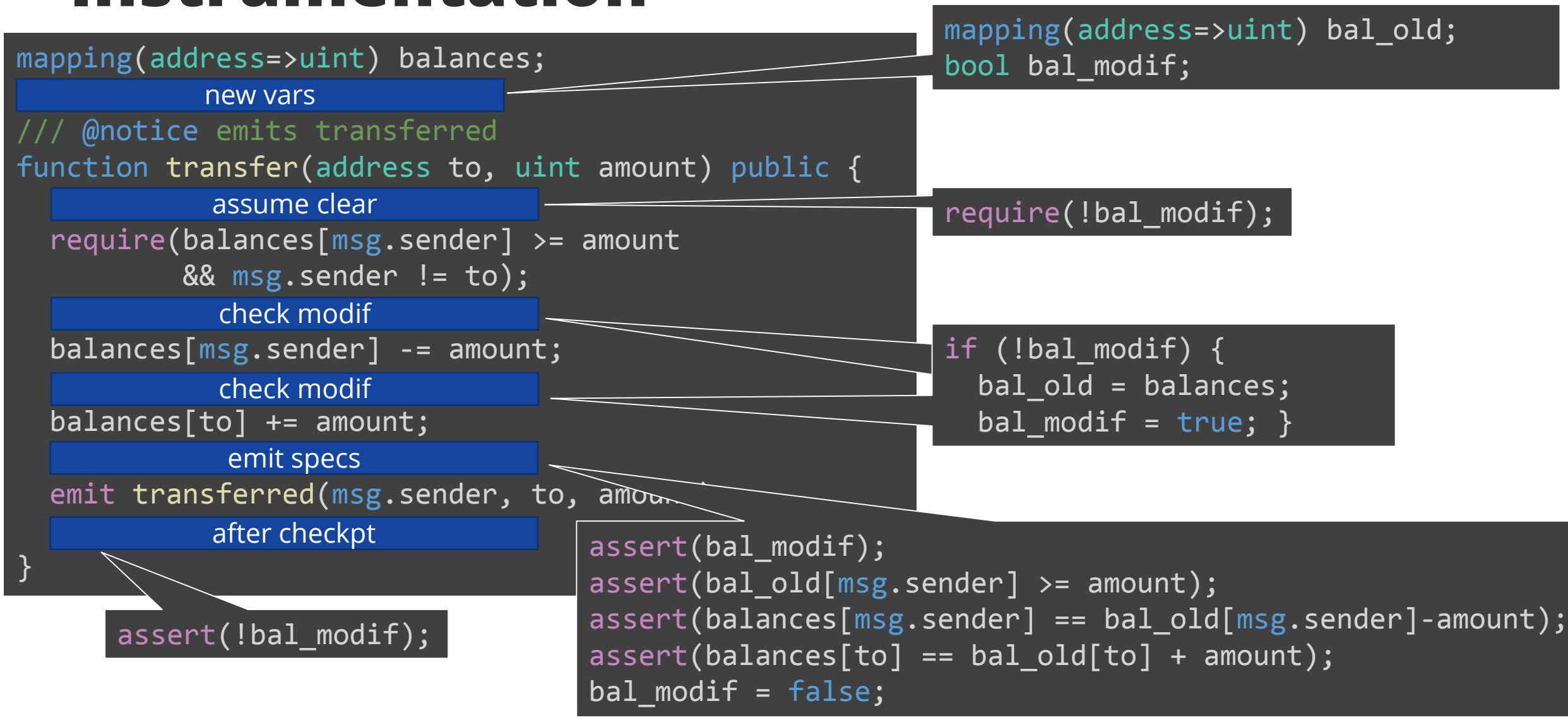
Emit
- Check pre/post
- Clear before/after checkpoint

After checkpoint
- Static barrier
- Latest point to emit
- E.g., function end

Overview


solc-verify
.sol
Extended compiler
.bpl
μ□β→λ
ΔvΣ→ϕ
Boogie verifier
Back-annotation
Verification conditions
Proofs
Solidity contract with specification
Boogie program w/ instrumentation
SMT solvers

Instrumentation



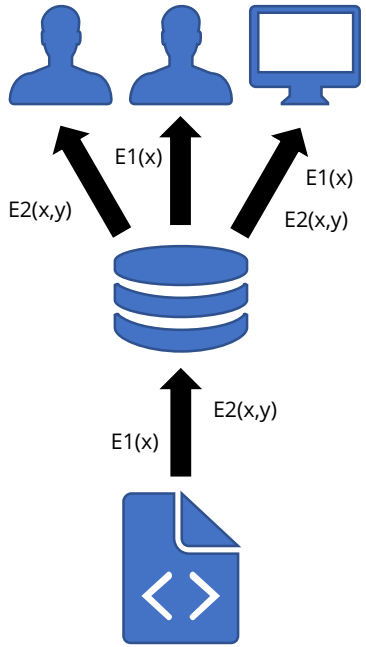
Discussion

- We used solc-verify
  - Modular verifier based on Boogie and SMT
  - Can work with other verifiers (supporting assertions)

- After checkpoints
  - Depend on verification approach
  - Modular verification: loop boundaries as well

Conclusions

- Solidity events provide abstract view
- Formal specification and verification
- In-code annotations
- Checkpoints
- Instrumentation



arxiv.org/abs/2005.10382

github.com/SRI-CSL/solidity

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  mapping(address=>uint) balances;
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