Accurate Smart Contract Verification through Direct Modelling

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Foreword

Industrial application of our work

- Component of the SMTChecker module of the Solidity compiler
  - SMTChecker's constrained Horn clauses model checking engine

Availability of our tool

- `github.com/ethereum/solidity`
- Add `pragma experimental SMTChecker;` to the source file

Formal Verification of Smart Contracts

Essential for safety

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Many works published

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- Symbolic execution, e.g.:
  - Oyente [Luu et al., CCS'16]
  - Maian [Nikolić et al., ACSAC'18]
  - Manticore [Mossberg et al., ASE'19]
  - VerX [Permenev et al., S&P'20]
- Model checking, e.g.:
  - Zeus [Kalra et al., NDSS'18]
  - SAFEVM [Albert et al., ISSTA'19]
  - VeriSol [Wang et al., VSTTE'20]
- Others, e.g.:
  - F* [Bhargavan et al., PLAS'16]
  - KEVM [Hildenbrandt et al., CSF'18]
  - Securify [Tsankov et al., CCS'18]
  - Why3 [Nehaï and Bobot, FM'19]
  - Solc-Verify [Hajdu and Jovanovic, VSTTE'19, ESOP'20]

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Limitations to be addressed

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Common Feature: Domain Translation

Translation for reuse

- Established off-the-shelf frameworks, e.g.:
  - Boogie
  - LLVM
- Programming languages ecosystems, e.g.:
  - C/C++
  - WhyML

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Translation layer drawbacks

- Error prone to develop
- Requires correctness proofs
- Adverse effect on precision and efficiency

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Our approach

- Direct modelling into the target formalism
  - Focus on Solidity contracts
  - Modelling in constrained Horn clauses (CHCs)

Smart Contracts Verification through Direct Modelling

- Rule-based encoding for assertion checking

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- Rule-based encoding for assertion checking, starting with the contracts' control-flow graphs

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CHC rule format

$$\forall \mathcal{V}. (\underbrace{H(\boldsymbol{x})}_{\textit{head}} \leftarrow \underbrace{\exists \boldsymbol{y}. P_1(\boldsymbol{y}) \wedge \ldots \wedge P_n(\boldsymbol{y}) \wedge \phi(\boldsymbol{x}, \boldsymbol{y})}_{\textit{body}})$$

with $\mathcal{V}$ a set of variables over a background theory $\mathcal{T}$, $\boldsymbol{x} \cup \boldsymbol{y} \subseteq \mathcal{V}$, $n \geq 0$

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Example: an Auction in Solidity

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2      uint bid = 0;
3      uint cash = 0;
4      address payable winner = address(0);
5
6      function offer() public payable {
7          uint new_bid = msg.value − 10^15 wei;
8          require(bid < new_bid);
9          if (winner ≠ address(0)) {
10             //assert(bid ≤ cash);
11             winner.transfer(bid);
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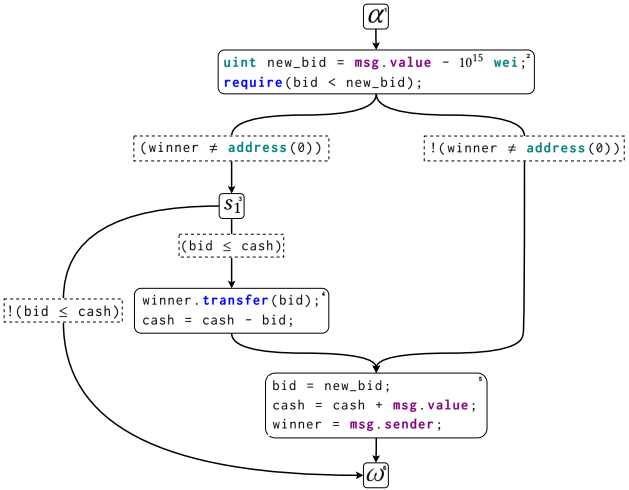

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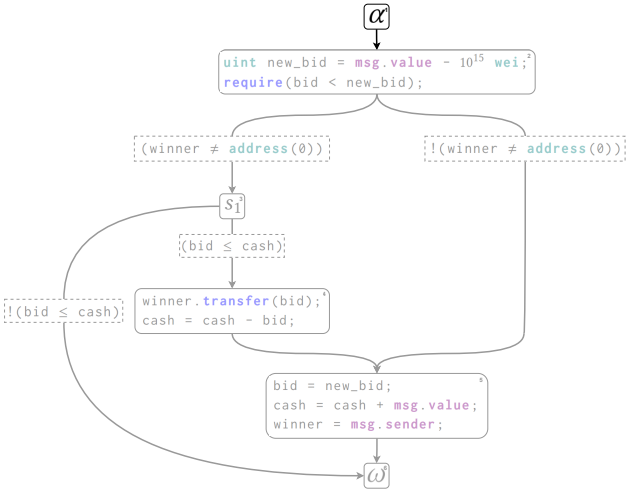

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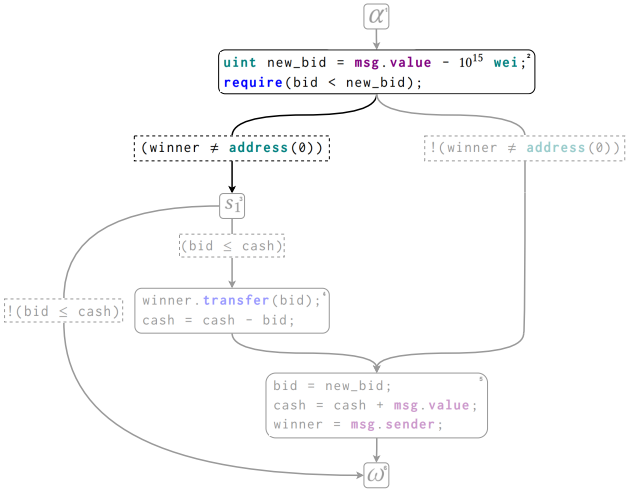

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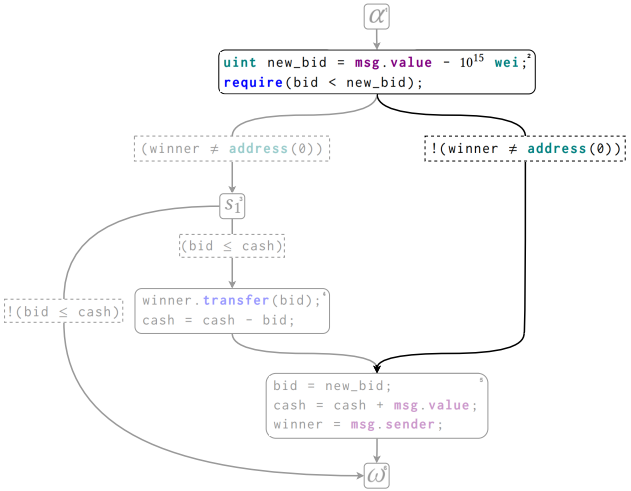

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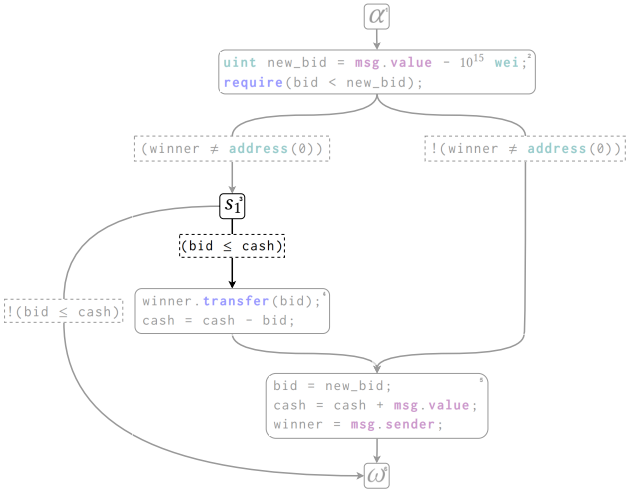

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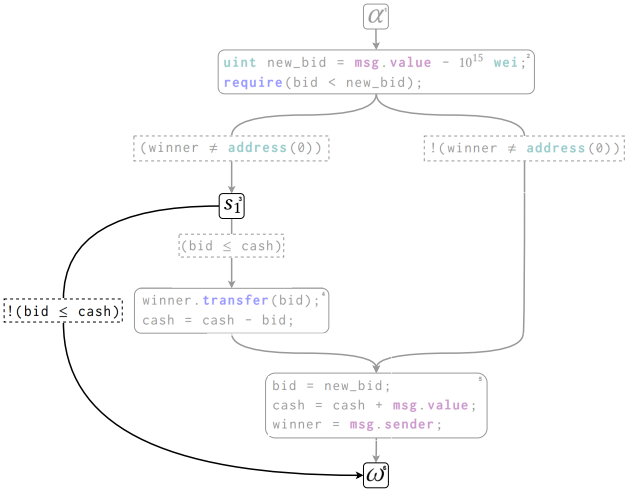

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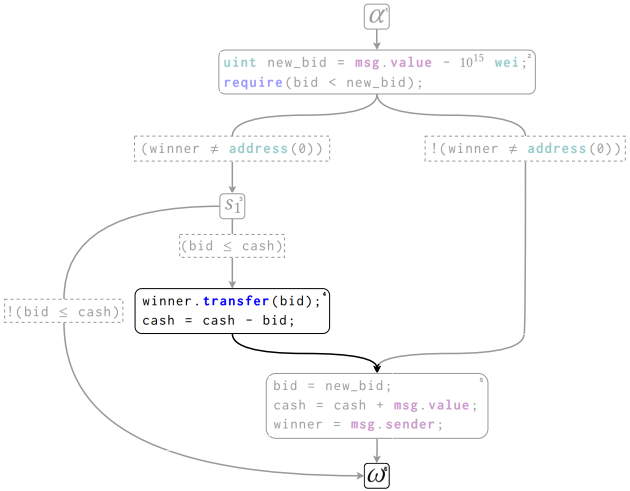

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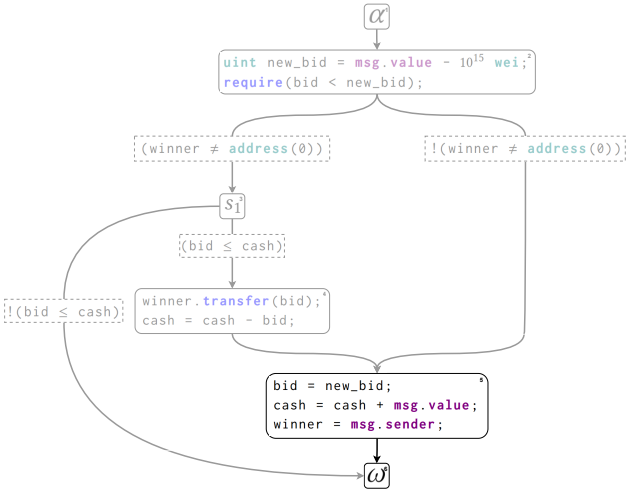

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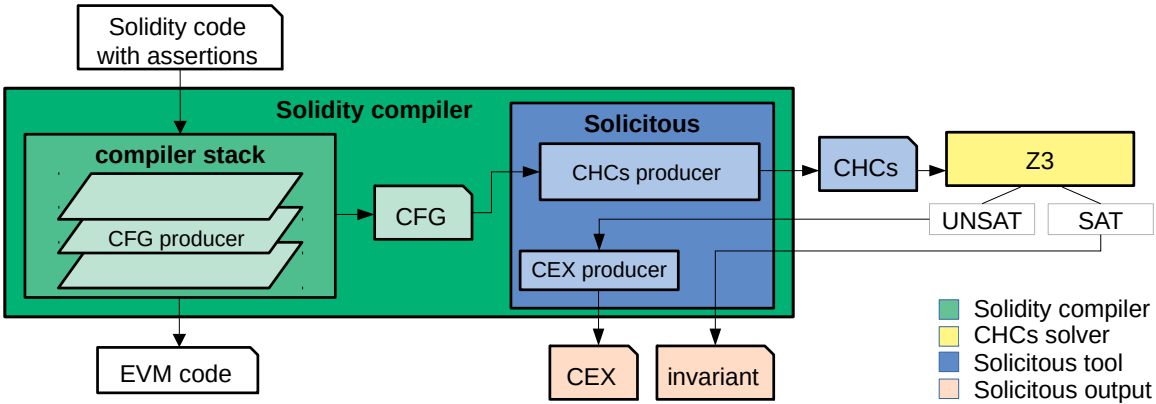

Solicitous (Solidity Contract verification using constrained Horn clauses)

- Assertion failures lead to reverts, which are modelled as error predicates
- Queries are made to the solver for the reachability of error predicates

Evaluation

- Evaluation with 22446 real-world contracts
  - Solidity versions 0.5 to 0.8

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