Extending SolCMC to Verify Temporal Logic Specifications

From Solidity assertions to temporal specifications for SolCMC model checker

Luigi Bellomarini, Marco Favorito

Applied Research Team @ Bank of Italy
https://bankit.art/

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Why contract analysis?

high financial stakes
(∼billions of $)

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(...and public bugs)

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(...and public bugs)

permissionless
(also for bad actors)

immutable
(hard to patch)

smart contract security analysis

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vulnerability detectors

detect bad patterns

reentrancy | overflows | access control

fast & scalable

limited to known patterns

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formal verification

prove correctness against a spec

proof · counterexample

strong guarantees ✨

sometimes automatable (model checking) ✨

often slow

needs specifications

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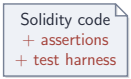
strong guarantees ✨
sometimes automatable (model checking) ✨
often slow
needs specifications

Example: SolCMC (Solidity model checker)

SolCMC workflow [1] [2]



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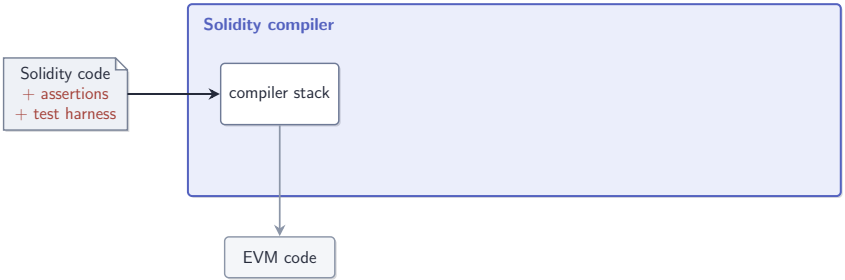

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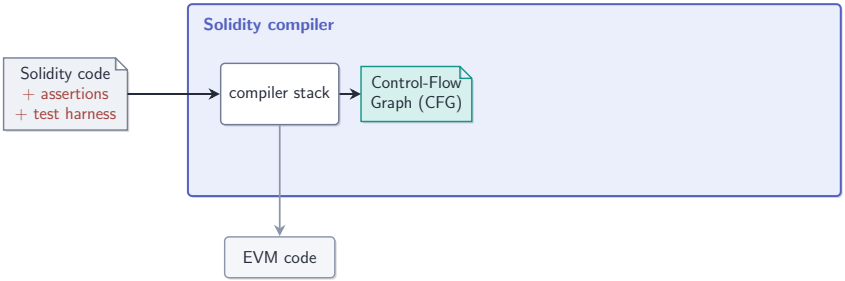

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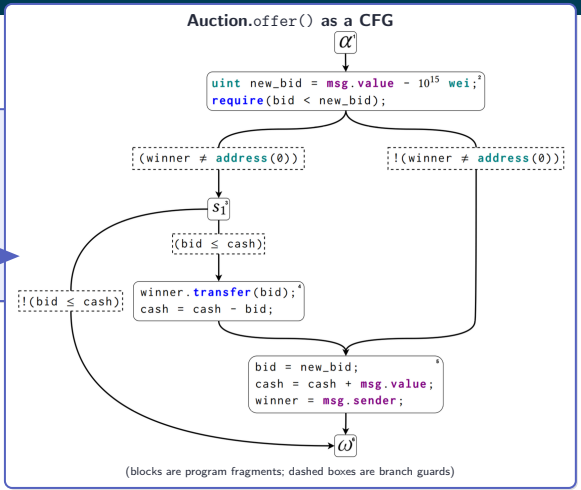
SolCMC workflow [1] [2]

Auction contract

```
1  contract Auction {
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);
12             cash = cash − bid;
13         }
14         bid = new_bid;
15         cash = cash + msg.value;
16         winner = msg.sender;
17     }
18 }
```



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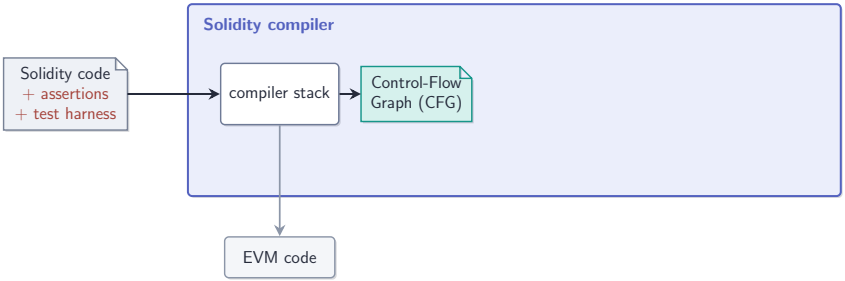

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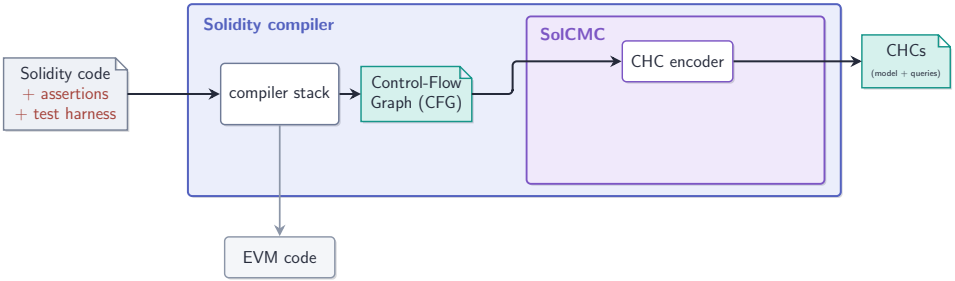

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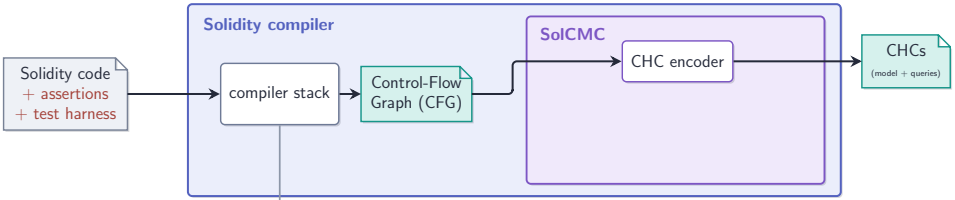

Constrained Horn Clauses (CHC)

$$\forall \mathcal{V}.\ \left(\underbrace{H(\mathbf{x})}_{\text{head}} \leftarrow \exists \mathbf{y}.\ \underbrace{P_1(\mathbf{y}) \wedge \cdots \wedge P_n(\mathbf{y}) \wedge \phi(\mathbf{x}, \mathbf{y})}_{\text{body}} \right)$$

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

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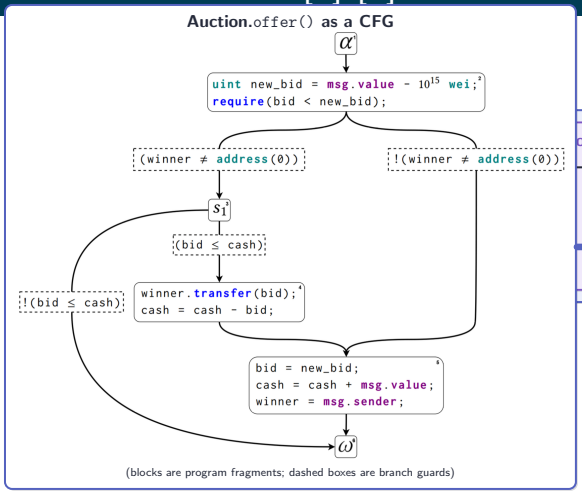

Encoding in CHC

$$C(b,c,w) \leftarrow b = 0 \wedge c = 0 \wedge w = 0$$
$$\mathcal{P}_o^2 \leftarrow \mathcal{P}_o^1$$
$$\mathcal{P}_o^3 \leftarrow \mathcal{P}_o^2 \wedge I_{nb} = I_v - 10^{15} \wedge I_b < I_{nb} \wedge I_w \neq 0$$
$$\mathcal{P}_o^5 \leftarrow \mathcal{P}_o^2 \wedge I_{nb} = I_v - 10^{15} \wedge I_b < I_{nb} \wedge \neg(I_w \neq 0)$$
$$\mathcal{P}_o^4 \leftarrow \mathcal{P}_o^3 \wedge I_b \leq I_c$$
$$\mathcal{P}_o^6 \leftarrow \mathcal{P}_o^3 \wedge \neg(I_b \leq I_c) \wedge I_{\tilde{r}} = 3$$
$$\mathcal{P}_o^5 \leftarrow \mathcal{P}_o^4 \wedge I'_c = I_c - I_b$$
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$$\cdots$$
$$C(s') \leftarrow C(s) \wedge S_o(s,a,s',\tilde{r}) \wedge \tilde{r} = 0$$
$$\bot \leftarrow C(s) \wedge S_o(s,a,s',\tilde{r}) \wedge \tilde{r} \neq 0$$

$$\mathcal{P}_o^n(\underbrace{b,c,w}_{state}, \underbrace{s,v}_{args}, \underbrace{\ell}_{localvars}), \quad n \in \{1..6\}$$

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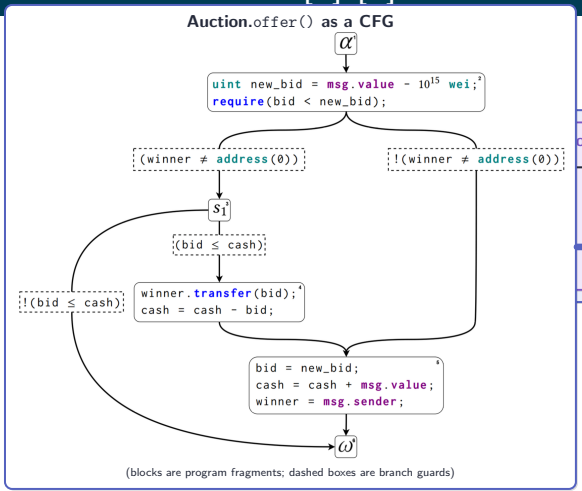

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C(s') &\leftarrow C(s) \wedge S_o(s,a,s',\tilde{r}) \wedge \tilde{r} = 0 \\
\bot &\leftarrow C(s) \wedge S_o(s,a,s',\tilde{r}) \wedge \tilde{r} \neq 0
\end{aligned}$$

$$\mathcal{P}^n_o(\underbrace{b,c,w}_{state}, \underbrace{s,v}_{args}, \underbrace{\ell}_{localvars}), \quad n \in \{1..6\}$$

Initialization rule:
$C(s) \leftarrow I(s)$

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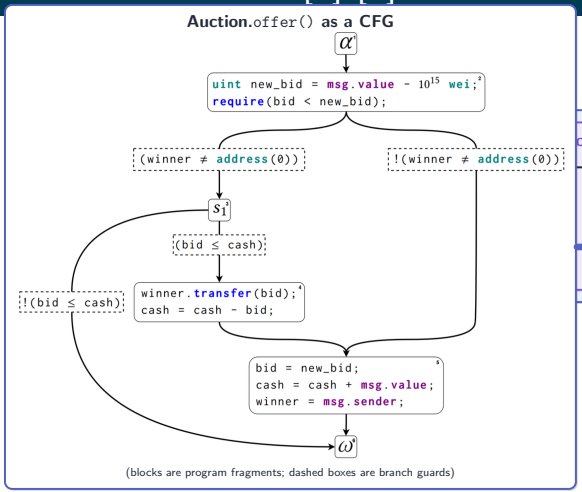

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$$C(s') \leftarrow C(s) \wedge S_o(s,a,s',\tilde{r}) \wedge \tilde{r} = 0$$

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$$\mathcal{P}^n_o(\underbrace{b,c,w}_{\text{state}}, \underbrace{s,v}_{\text{args}}, \underbrace{\ell}_{\text{localvars}}), \quad n \in \{1..6\}$$

Root transaction rule:

$$C(s') \leftarrow C(s) \wedge S_f(s,a,s',r) \wedge \tilde{r} = 0$$

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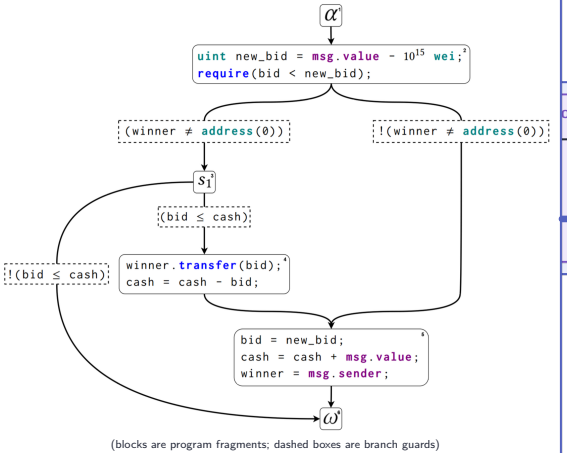
SolCMC workflow [1] [2]

Auction.offer() as a CFG



(blocks are program fragments; dashed boxes are branch guards)

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$$\mathcal{P}^n_o(\underbrace{b,c,w}_{\text{state}}, \underbrace{s,v}_{\text{args}}, \underbrace{\ell}_{\text{localvars}}), \quad n \in \{1..6\}$$

General safety rule:
$$\bot \leftarrow C(s) \wedge S_f(s,a,s',r) \wedge \tilde{r} \neq 0$$

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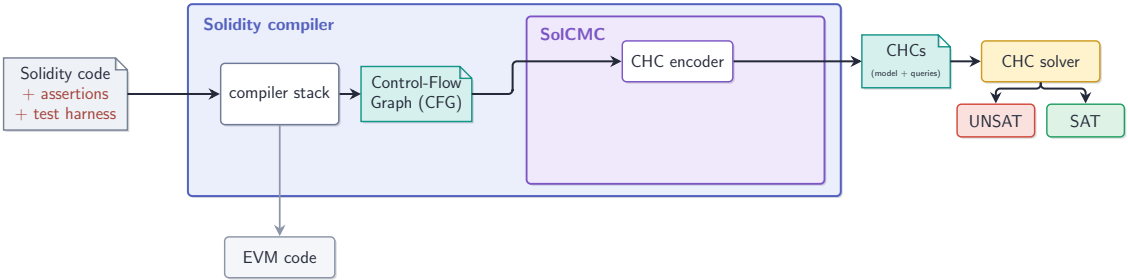

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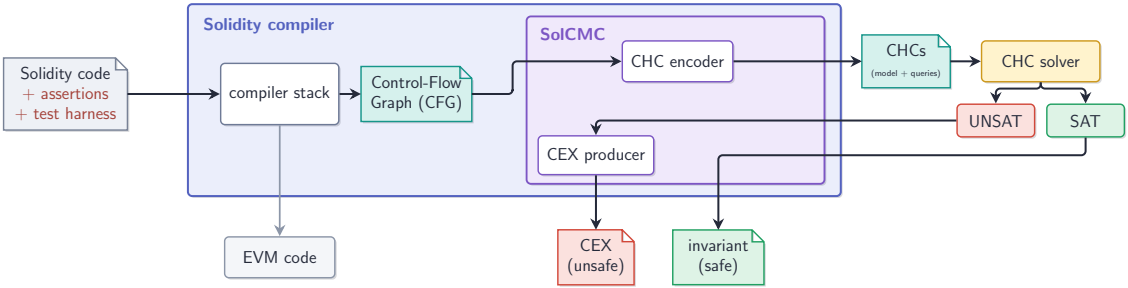

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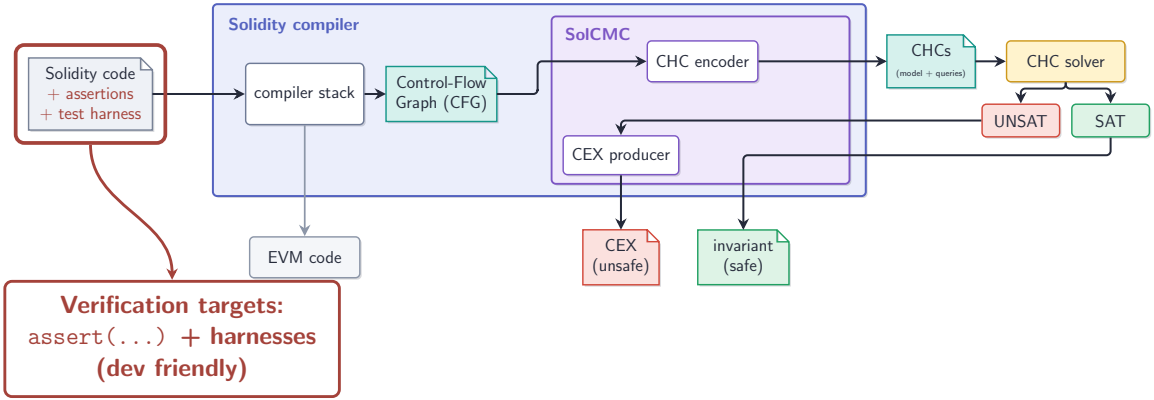

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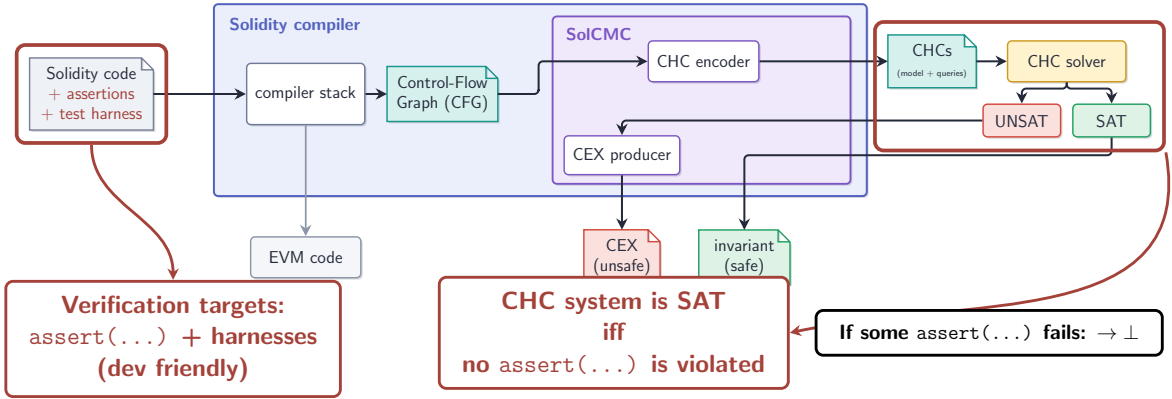

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SolCMC Limitations

Many requirements constrain the history of calls, but hard to encode them via assertions.

Example: no two (successful) `deposit()` calls in a row [3]

Encode it as a harness:

```
// "no two deposits in a row"
function harness() public {
  deposit();
  deposit();
  assert(false);  // unreachable => property holds
}
```

✗ both are internal self-calls: same `msg.sender`;
→ not a sound encoding! `msg.sender` might differ between calls

Make it sound with ghost variables:

```
function withdraw() public payable {
    // must be updated in every function != deposit()
    g_lastWasDeposit = false;
    ...
}

function deposit() public {
    assert(!g_lastWasDeposit);
    g_lastWasDeposit = true;
    ...
}
```

✓ *can* encode the specification correctly;
✗ intrusive → might change contract behaviour
✗ fragile → hard to mantain when spec/contract changes

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Root issue: mixing program with its spec

`assert(...)` is developer-friendly, but not sufficient for complex specifications.

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Goal

How can we equip SolCMC with a separate specification layer...
(with a more expressive specification language)

... while reusing SolCMC's "verification pipeline" as much as possible?

Why extend SolCMC?

- a "high-quality" model of Solidity contracts;
- a strong community behind the Solidity compiler codebase.

Observation: many interesting properties are temporal

Many interesting properties are about sequences of calls

- authorise before settle;
- wait before finalise;
- do not pay the same claim twice;
- close one phase before opening the next.

These are temporal properties, not just local assertions.

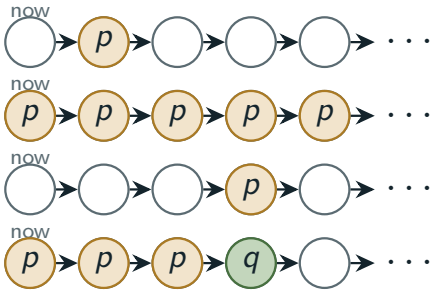
$\longrightarrow$ temporal logic as spec language

What are Temporal logics?

A family of formal languages to reason about properties through time.
Formulas are interpreted over traces (sequences of states)

Examples of temporal operators:

$\mathsf{X}p$	p holds at the **next** step
$\mathsf{G}p$	p must **always** hold
$\mathsf{F}p$	**eventually**, p holds
$p\ \mathsf{U}\ q$	p holds **until** q



Successful specification language for about 50 years since Pnueli's work on LTL [4].

[4] A. Pnueli. "The Temporal Logic of Programs". In: *FOCS*. IEEE Computer Society, 1977, pp. 46–57

The temporal logic LTL_f^{MT}

In this paper, we adopt Linear Temporal Logic on finite traces modulo theories (LTL_f^{MT}) [5] [6].

- interpreted over finite traces $\rightarrow$ semantics is "easier" to handle
- modulo theories $\rightarrow$ faithfully models Solidity data types and constraints

Examples

- **Global invariant:** a recorded balance never exceeds its cap, $\text{G}(\text{balance} \leq \text{cap})$.
- **Call sequencing:** no two successful deposits occur in a row: $\text{G}\,\neg(\text{deposit} \wedge \text{X}\,\text{deposit})$.
- **Conditioned call:** cannot settle before authorisation, $\neg\text{settle}\,\text{W}\,\text{authorise}$.
- **Reachability** there exists an execution where we get an empty balance: $\text{balance} = 0$).

Note: LTL_f^{MT} **model checking** can be reduced to **CHC satisfiability** [6].

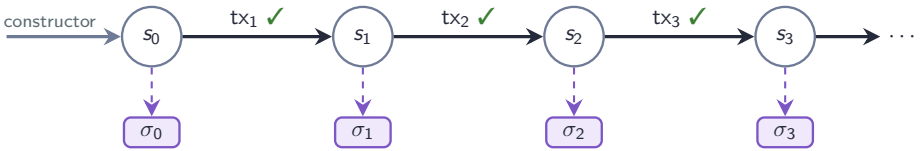
[5] L. Geatti et al. "Linear Temporal Logic Modulo Theories over Finite Traces". In: *IJCAI*. ijcai.org, 2022, pp. 2641–2647

[6] M. Faella and G. Parlato. "A Unified Automata-Theoretic Approach to LTL_f Modulo Theories". In: *ECAI*. 2024

A smart contract as a set of (data) traces

We see a contract C as the set of finite traces of states C can reach

- one step = one successful, top-level public call (a reverts or an internal sub-call add *no* step.)



finite data word $w = \sigma_0\sigma_1\sigma_2\sigma_3\cdots \in \mathrm{Obs}(C)$

- tuple σ_i contains contract state variables + auxiliary variables (e.g., last function called)

Contract satisfaction over traces

A contract C satisfies a specification φ iff all its traces w satisfy φ:

$$C \models \varphi \iff \forall\, w \in \mathrm{Obs}(C).\ w \models \varphi$$

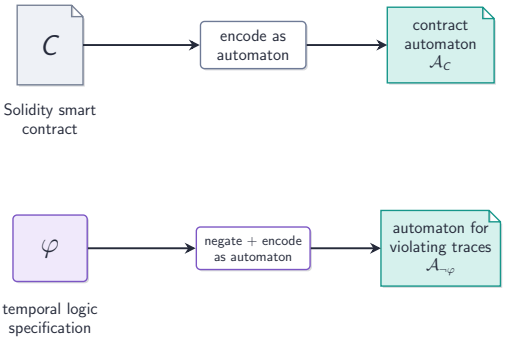
If we followed the classic approach to $\mathrm{LTL}_f^{\mathrm{MT}}$ model checking...

Solidity smart contract

temporal logic specification

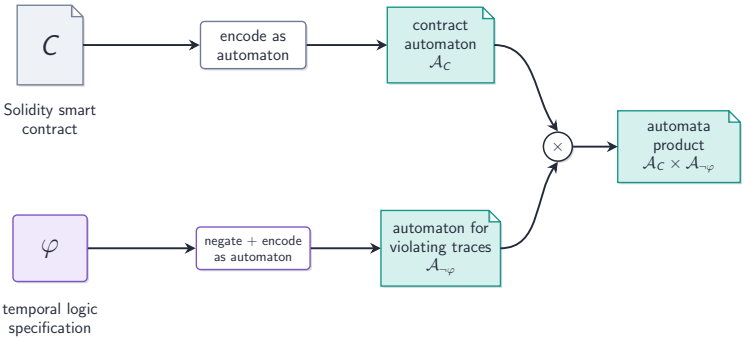
Start from the Solidity contract and the temporal specification.

If we followed the classic approach to $\mathrm{LTL}_f^{\mathrm{MT}}$ model checking...



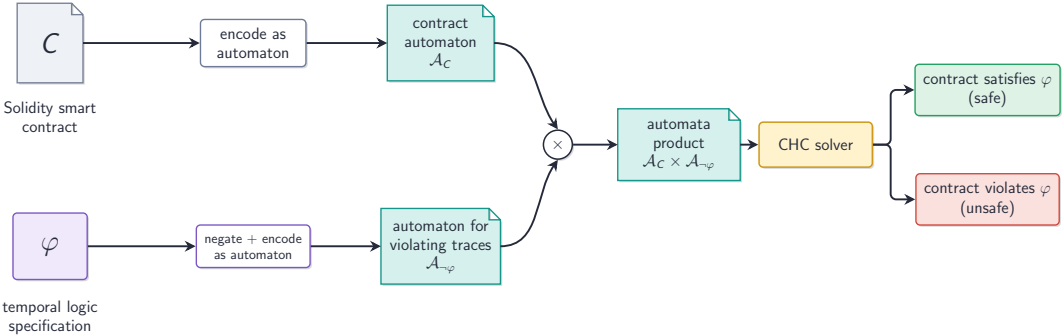
Classic LTL model checking turns both sides into automata.

If we followed the classic approach to LTL_f^{MT} model checking...



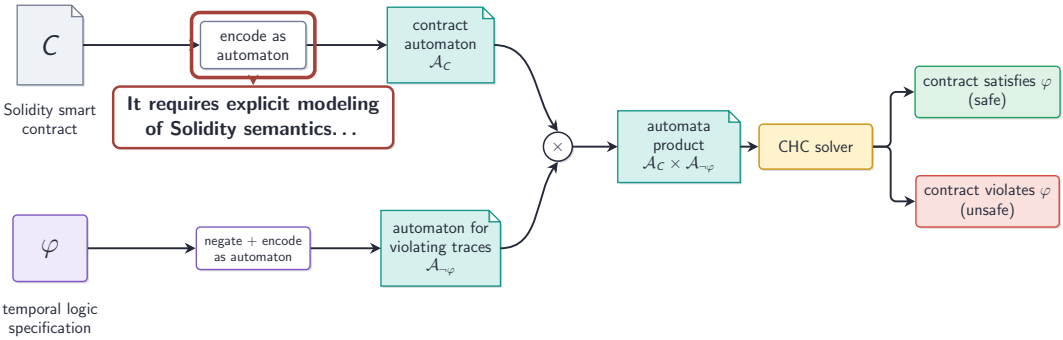
The product automaton $\mathcal{A}_C \times \mathcal{A}_{\neg\varphi}$ accepts all executions of C that satisfy $\neg\varphi$.

If we followed the classic approach to LTL_f^{MT} model checking...



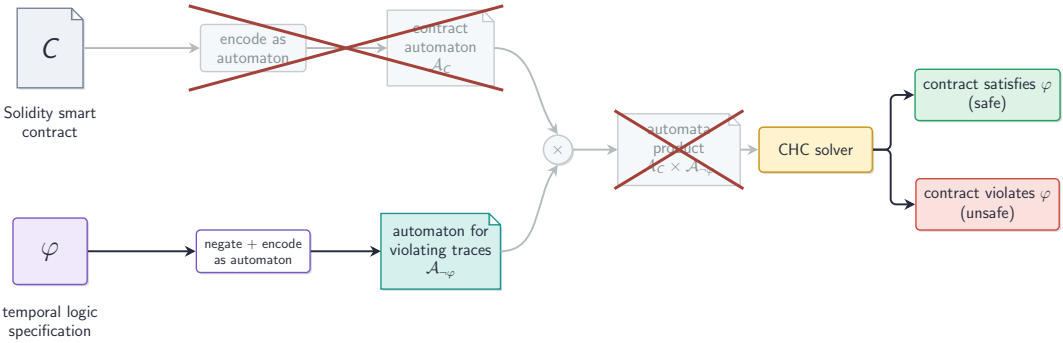
If $\mathcal{L}(\mathcal{A}_C \times \mathcal{A}_{\neg\varphi}) \neq \emptyset \rightarrow$ there exists a counterexample for φ;
Otherwise, φ always holds.

If we followed the classic approach to LTL_f^{MT} model checking...



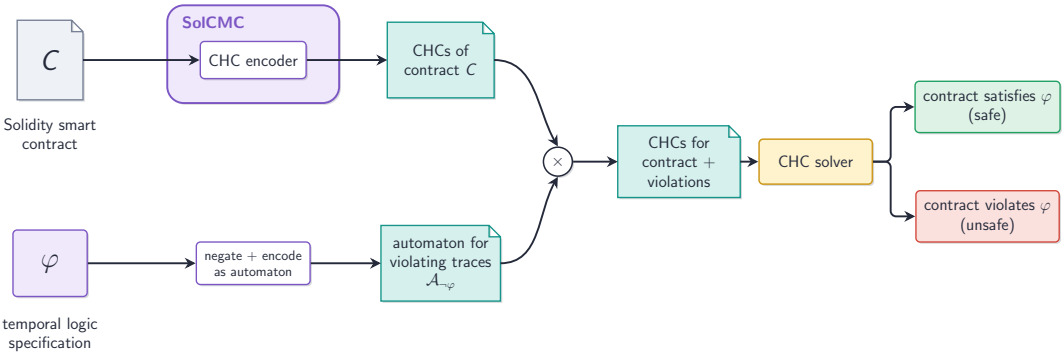
The costly part is the contract side: Solidity semantics must be modeled explicitly.

If we followed the classic approach to LTL_f^{MT} model checking...



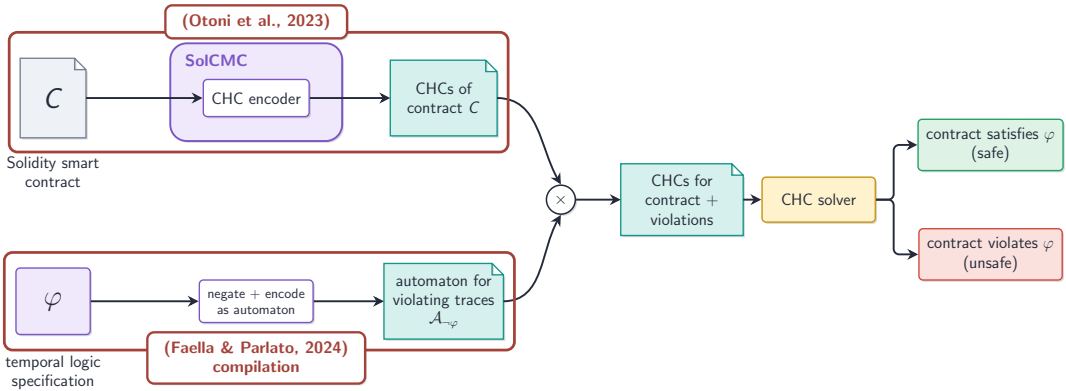
Let's reuse SolCMC's CHC encoding!

Our approach



Key idea: cross-product done at the CHC level, reusing SolCMC's contract model

Our approach



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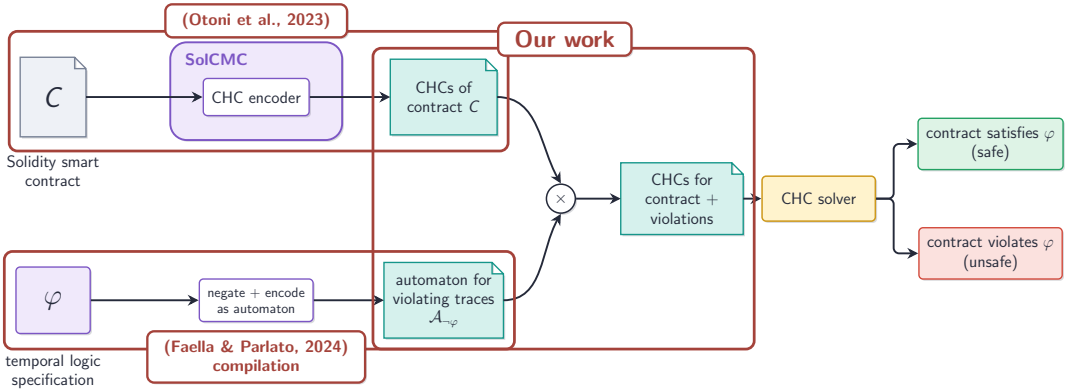

Key idea: cross-product done at the CHC level, reusing SolCMC's contract model

The CHC product construction

SolCMC CHC encoding Π_C

$$Init_C : C(s) \leftarrow I(s)$$
$$RootTx_{C,f} : C(s') \leftarrow C(s) \wedge S_f(s, a, s', r)$$

Internals of functions
external call rules
SolCMC helper predicates
...
} unchanged

SDWA $\mathcal{A}_{\neg\varphi}$

$$\mathcal{A}_{\neg\varphi} = (\Sigma_C, S^Q, \psi^0, \psi^\Delta, \psi^F)$$

- $\psi^0(q)$ **initial-state formula**
- $\psi^\Delta(q, \sigma, q')$ **transition formula**
- $\psi^F(q)$ **accepting-state formula**

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$\times$

Product CHC system $\Pi_C \otimes \mathcal{A}_{\neg\varphi}$

$$Init : C^\otimes(s, q) \leftarrow I(s) \wedge ObsInit(s, \sigma) \wedge \psi^0(q_0) \wedge \psi^\Delta(q_0, \sigma, q)$$
$$RootTx_f : C^\otimes(s', q') \leftarrow C^\otimes(s, q) \wedge S_f(s, a, s', r) \wedge Obs_f(s, a, s', r, \sigma) \wedge \psi^\Delta(q, \sigma, q')$$
$$Acc : \bot \leftarrow C^\otimes(s, q) \wedge \psi^F(q)$$

CFG-derived rules are reused unchanged.

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CFG-derived rules are reused unchanged.

Key intuition:

- $C(s)$ becomes $C^\otimes(s, q)$: contract state plus automaton state.
- Each committed call computes s' and advances $q \xrightarrow{\sigma} q'$;
- If we visit an accepting q, we get UNSAT $\Rightarrow$ we found a violation of φ

The CHC product construction

SolCMC CHC encoding Π_C

$Init_C : C(s) \leftarrow I(s)$

Product CHC system $\Pi_C \otimes \mathcal{A}_{\neg\varphi}$

Correctness (relative to SolCMC's model)

$$\Pi_C \otimes \mathcal{A}_{\neg\varphi} \text{ is SAT} \iff \forall\, w \in \mathrm{Obs}(C).\ w \models \varphi$$

(the product CHC query is satisfiable *iff* no trace of C accepted by $\mathcal{A}_{\neg\varphi}$ exists)

$\wedge\ \psi^F(q)$

CFG-derived rules are reused unchanged.

$$\mathcal{A}_{\neg\varphi} = (\Sigma_C, S^Q, \psi^0, \psi^\Delta, \psi^F)$$

- $\psi^0(q)$ **initial-state formula**
- $\psi^\Delta(q, \sigma, q')$ **transition formula**
- $\psi^F(q)$ **accepting-state formula**

Key intuition:

- $C(s)$ becomes $C^\otimes(s, q)$: contract state plus automaton state.
- Each committed call computes s' and advances $q \xrightarrow{\sigma} q'$;
- If we visit an accepting q, we get UNSAT $\Rightarrow$ we found a violation of φ

Example: Bank

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

  function deposit() public payable {
    balances[msg.sender] += msg.value;
  }
  function withdraw(uint amount) public {
    require(amount > 0);
    require(amount <= balances[msg.sender]);
    balances[msg.sender] -= amount;
    (bool ok,) = msg.sender.call{value: amount}("");
    require(ok);
  }
}
```

deposit-user-balance

for a fixed sender α: deposit increases its ledger by msgValue

$$\mathsf{G}(\mathsf{X}\,\mathrm{func} = \mathrm{deposit} \wedge \mathsf{X}\,\mathrm{msgSender} = \alpha \rightarrow \mathsf{X}\,\mathrm{balances}[\alpha] = \mathrm{balances}[\alpha] + \mathsf{X}\,\mathrm{msgValue})$$

deposit-contract-balance-lower-bound

contract ETH balance grows by at least msgValue; c = contractAddress

$$\mathsf{G}(\mathsf{X}\,\mathrm{func} = \mathrm{deposit} \rightarrow \mathsf{X}\,\mathrm{ethBalance}[c] \geq \mathrm{ethBalance}[c] + \mathsf{X}\,\mathrm{msgValue})$$

Example: Vault

```
contract Vault {          // two-step withdraw
  enum States { IDLE, REQ }
  address owner; uint wait_time;
  uint request_time; uint amount; address receiver;
  States state;
  function withdraw(address r, uint a) public {
    require(state == States.IDLE);
    require(msg.sender == owner);
    request_time = block.number;
    amount = a; receiver = r; state = States.REQ;
  }
  function finalize() public {
    require(state == States.REQ);
    require(block.number >= request_time + wait_time);
    state = States.IDLE;
    payable(receiver).transfer(amount);
  }
  // + cancel() -> IDLE (recovery key)
}
```

wd-twice

no two successful withdrawals in a row

$$\mathsf{G}\,\neg(\mathsf{func} = \mathsf{withdraw} \wedge \mathsf{X}\,\mathsf{func} = \mathsf{withdraw})$$

relates step i to $i{+}1$ — no single-assert form

finalize-after-wait

finalize only after the recorded waiting period

$$\mathsf{G}(\mathsf{X}\,\mathsf{func} = \mathsf{finalize} \rightarrow \mathsf{X}\,\mathsf{blockNumber} \geq \mathsf{request\_time} + \mathsf{wait\_time})$$

Example: ZeroTokenBet

```
contract ZeroTokenBet {        // a vs b
  address a; address b; address oracle;
  uint timeout_block;
  int balance, balance_a, balance_b;
  // init (balance,balance_a,balance_b) = (1,0,1)
  function deposit() public {          // b only
    require(msg.sender == b);
    require(balance >= 1 && balance_b >= 1);
    balance_b -= 1; balance += 1;
  }
  function win(address dst) public {   // oracle
    require(msg.sender == oracle);
    require(balance >= 2);
    if (dst==a) { balance_a += balance; }
    else        { balance_b += balance; }
    balance = 0;
  }
  function timeout() public {          // split pot
    require(balance >= 2);
    balance_a += 1; balance_b += 1; balance -= 2;
  }
}
```

balance-range

pooled balance remains between 0 and 2

$$G(0 \leq \text{balance} \leq 2)$$

balance-a-range

player A's ledger remains between 0 and 2

$$G(0 \leq \text{balance\_a} \leq 2)$$

balance-b-range

player B's ledger remains between 0 and 2

$$G(0 \leq \text{balance\_b} \leq 2)$$

timeout-balance-zero

some execution reaches a successful timeout with empty pool

$$F(\text{func} = \text{timeout} \wedge \text{balance} = 0)$$

a successful `deposit` by *b*, then `timeout`

Related work (Summary)

- **Certora** is another mature Solidity model checker, but uses procedural specifications and less flexible than LTL_f^{MT} specifications;
- many frameworks support temporal logic too (e.g., **SmartPulse** [7])), but rely on intermediate representation and custom modeling of Solidity semantics (e.g., Boogie/VeriSol)
- other connect smart contracts to mature model checking back ends (**NuSMV/nuXmv** [8, 9], **SPIN** [10], **BIP**, or **CPN tools** [11]).
  - the guarantee is relative to the fidelity of that model/translation to deployed Solidity/EVM behaviour.
- Strategic analyzers: **Solvent** [12]; **KindHML** [13]:
  - Their focus is branching-time properties and strategic reasoning on restricted Solidity fragments;
  - our focus is data-aware linear-time properties over finite execution traces, reusing SolCMC's compiler-generated CHC model.

Conclusion

Take-away

`solcmc-ltl` checks external, data-aware temporal specifications over smart-contract transaction traces by reusing SolCMC's compiler-generated CHC model.

Limitations:

- Ultimately, expressivity is bounded by the underlying SolCMC model: no reverts, no low-level features, untrusted external calls etc.
- no branching-time properties
- CHC solving might be undecidable.

Upside. Because the layer stays close to SolCMC, it can benefit from the Solidity/SolCMC and CHC solving communities.

Future work

- extensive experimental analysis on larger benchmark suites and real contracts;
- attempt-trace semantics for failed calls and revert-aware properties;
- strategic analysis, e.g., two-player games via CHCs;

Extending SolCMC to Verify Temporal Logic Specifications

From Solidity assertions to temporal specifications for SolCMC model checker

Luigi Bellomarini, Marco Favorito

Applied Research Team @ Bank of Italy
https://bankit.art/

8th DLT Workshop
June 4–6, 2026 — Pula, Italy

References I

[1] L. Alt et al. "SolCMC: Solidity Compiler's Model Checker". In: *CAV*. 2022.

[2] R. Otoni et al. "A Solicitous Approach to Smart Contract Verification". In: *ACM Trans. Priv. Secur.* 26.2 (2023), 15:1–15:28.

[3] M. Bartoletti et al. "Towards Benchmarking of Solidity Verification Tools". In: *FMBC@CAV*. 2024.

[4] A. Pnueli. "The Temporal Logic of Programs". In: *FOCS*. IEEE Computer Society, 1977, pp. 46–57.

[5] L. Geatti, A. Gianola, and N. Gigante. "Linear Temporal Logic Modulo Theories over Finite Traces". In: *IJCAI*. ijcai.org, 2022, pp. 2641–2647.

[6] M. Faella and G. Parlato. "A Unified Automata-Theoretic Approach to LTL_f Modulo Theories". In: *ECAI*. 2024.

[7] J. Stephens et al. "SmartPulse: Automated Checking of Temporal Properties in Smart Contracts". In: *SP*. IEEE, 2021, pp. 555–571.

[8] Z. Nehai, P. Piriou, and F. F. Daumas. "Model-Checking of Smart Contracts". In: *iThings/GreenCom/CPSCom/SmartData*. IEEE, 2018, pp. 980–987.

[9] A. Mavridou et al. "VeriSolid: Correct-by-Design Smart Contracts for Ethereum". In: *Financial Cryptography*. Vol. 11598. Lecture Notes in Computer Science. Springer, 2019, pp. 446–465.

[10] T. Osterland and T. Rose. "Model checking smart contracts for Ethereum". In: *Pervasive Mob. Comput.* 63 (2020), p. 101129.

[11] I. Garfatta et al. "A Solidity-to-CPN Approach Towards Formal Verification of Smart Contracts". In: *WETICE*. IEEE, 2021, pp. 69–74.

[12] M. Bartoletti et al. "Solvent: Liquidity Verification of Smart Contracts". In: *IFM*. Vol. 15234. LNCS. Springer, 2024, pp. 256–266.

[13] M. Bartoletti et al. "KindHML: formal verification of smart contracts based on Hennessy-Milner logic". In: *CoRR* abs/2604.14038 (2026).

[14] I. Garfatta et al. "Model checking of vulnerabilities in smart contracts: a solidity-to-CPN approach". In: *SAC '22: The 37th ACM/SIGAPP Symposium on Applied Computing, Virtual Event, April 25–29, 2022*. Ed. by J. Hong et al. ACM, 2022, pp. 316–325. DOI: 10.1145/3477314.3507309.

Related work I

- **Certora / CVL** [3]
  - Mature external spec language, supporting invariants and rule programs.
  - Their specifications are procedural, we use declarative specification
  - CVL rules describe fixed scenarios `require; call; assert/satisfy`; $\mathrm{LTL}_f^{\mathrm{MT}}$ formulas more flexible.
  - Certora has richer production features, but has its own Solidity model; we reuse SolCMC CHCs.
  - Certora is closed-source; SolCMC is open-source
- **SmartPulse** [7]
  - Stronger temporal language: SmartLTL supports liveness, fairness, and event predicates for `start`, `finish`, `revert`, and `send`.
  - Also data-aware at the surface: Solidity predicates, old values, and aggregate constructs.
  - SmartPulse instruments the program and propositionalizes temporal atoms; we keep $\mathrm{LTL}_f^{\mathrm{MT}}$ atoms as symbolic theory constraints in the SDWA/CHC product.
  - SmartPulse uses a Boogie/VeriSol + Ultimate Automizer pipeline; we reuse the more lightweight SolCMC's compiler-generated CHC system, and tool-agnostic (Spacer, Eldarica, etc.)
- **External model-checking infrastructures:** NuSMV-based modelling [8], VeriSolid [9], PROMELA/SPIN translations [10], Coloured Petri Nets [11, 14]
  - They connect smart contracts to mature model-checking back ends such as NuSMV/nuXmv, SPIN, BIP, or CPN tools.

Related work II

- They can exploit established temporal/property languages and state-space exploration techniques.
- The verified artifact is usually an external model, a generated transition system, a restricted Solidity fragment, or a Petri-net abstraction.
- Therefore, the guarantee is relative to the fidelity of that model/translation to deployed Solidity/EVM behaviour.
- We avoid introducing another contract semantics: the contract side remains SolCMC's compiler-generated CHC model, and only the temporal monitor is added.

- **Strategic analyzers: KindHML / Solvent** [13] [12]
  - Go beyond linear traces: branching-time logic and liquidity-style strategic reachability.
  - KindHML: first-order Hennessy–Milner logic, via Lustre/Kind 2.
  - Solvent: liquidity, i.e. $\forall$ reachable state, $\exists$ user/transaction sequence achieving an asset-transfer goal.
  - They capture $\forall\exists$-style reasoning that we currently do not support.
  - We instead target linear, data-aware $\mathrm{LTL}_f^{\mathrm{MT}}$ properties over finite successful-call traces, inside SolCMC's CHC pipeline.

Scope and limitations

The method is useful, but the guarantee is intentionally scoped:

1. **Relative to SolCMC's Chc semantics.** Any abstraction or unsoundness (external calls, native ETH, low-level features) is inherited unchanged.
2. **Successful-call finite traces only.** No revert-aware properties, no infinite-run liveness/fairness, no branching-time or strategic notions (liquidity). *Finite-prefix reading*: $\mathsf{G}(p \rightarrow \mathsf{F}q)$ fails on a prefix with p and no later q.
3. **Pointwise observers, incomplete solving.** Mappings / native balance via $m[k]$, balance$[a]$ with bounded lookahead; the CHC solver may return unknown or diverge.

These are not incidental bugs — they define the current semantic contract of the tool.