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Towards the Automated Verification of (Ethereum) Smart Contracts

Chiara Braghin, Elvinia Riccobene and Simone Valentini

chiara.braghin@unimi.it

Why smart contract verification?

- Smart contracts can hold *significant financial assets*
- They are *immutable* after deployment
- Source code is *publicly available*
- *Anyone* can submit a transaction to a contract

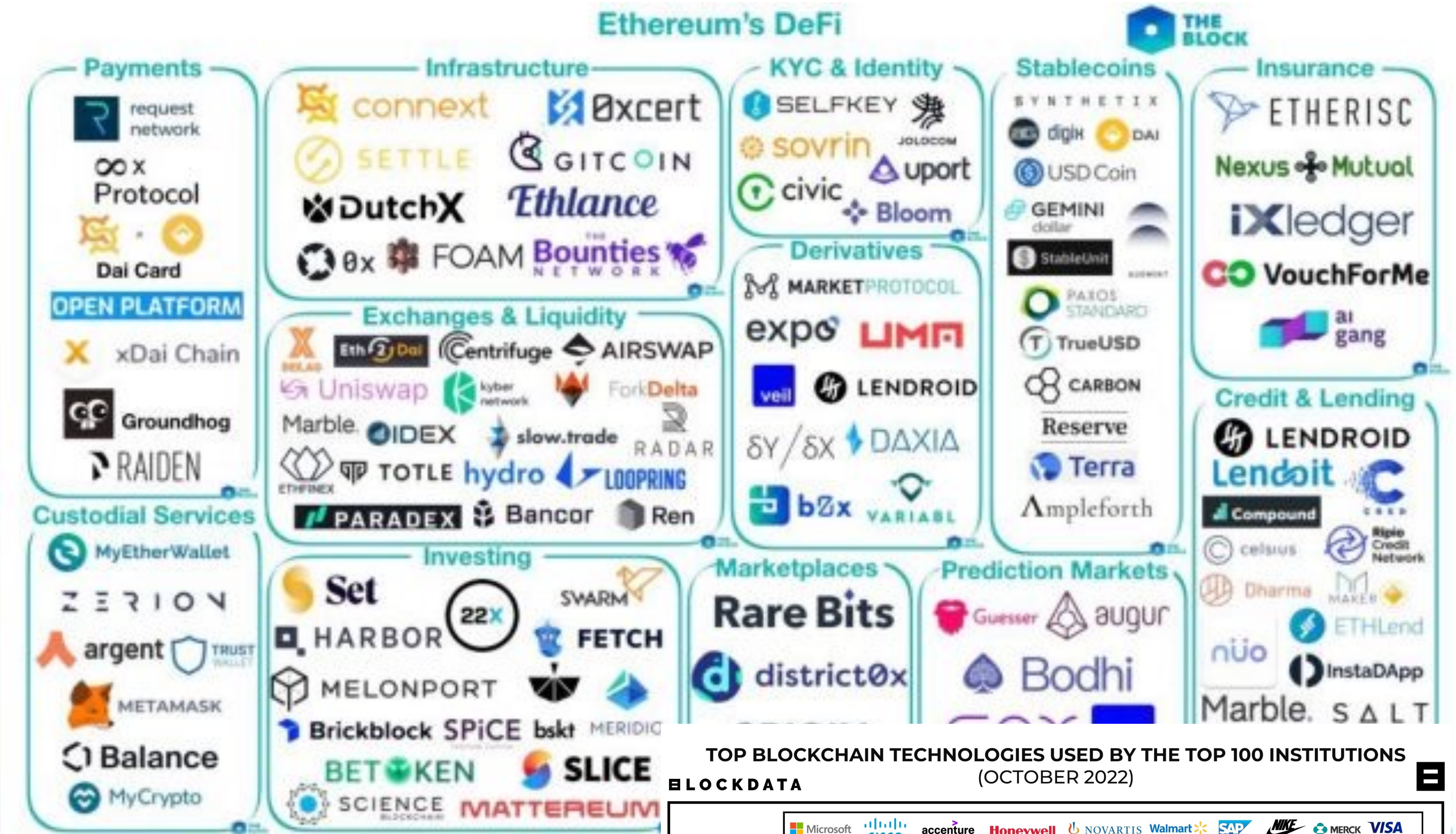
And...

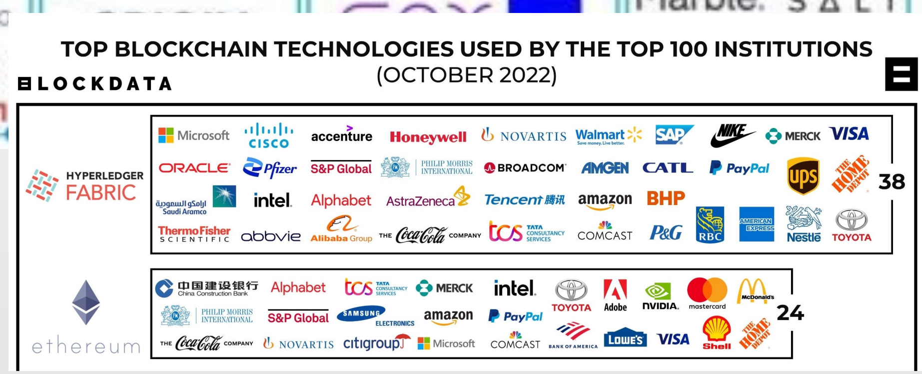
- Writing code correctly is hard
- Often the semantics of a SC language is not fully understood by programmers

Why smart contract verification?

- DAO Hack on June 17, 2016: worth 3.6 million ETH, about $70 million
- Veritaseum attack on April 2018: worth $8.4 million
- "Double" bZx DeFi Hack:
  - (1) on February 14, 2020 worth $6 million
  - (2) on February 18, 2020, additional $350,000
- Grim Finance on Dec 2021: worth $30 million
- ...

Why Ethereum?





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State of Art (1) – Common Vulnerabilities

- Integer Overflow and Underflow
- Default Visibilities

- Race Conditions (Reentrancy, Cross-function race conditions)

- Timestamp Dependence
- DoS with Block Gas Limit
- Forcibly Sending Ether to a Contract

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State of Art (2) - Which verification technique?

- Formal verification (of bytecode or Solidity code)
  - Oyente (CCS 2016) – symbolic execution
  - VeriSol (Microsoft 2019) – Boogie intermediate language
  - Solc-Verify (VSSTTE 2019, ESOP 2020)
  - Securify 2.0 (2020) - context-sensitive static analysis in Datalog
  - ....

- Common features of existing formal techniques:
  - Not fully automated
  - Difficult formal languages, translation task might be error prone
  - Not user friendly
  - Not maintained, code not available
  - Focused only on some types of errors/attacks

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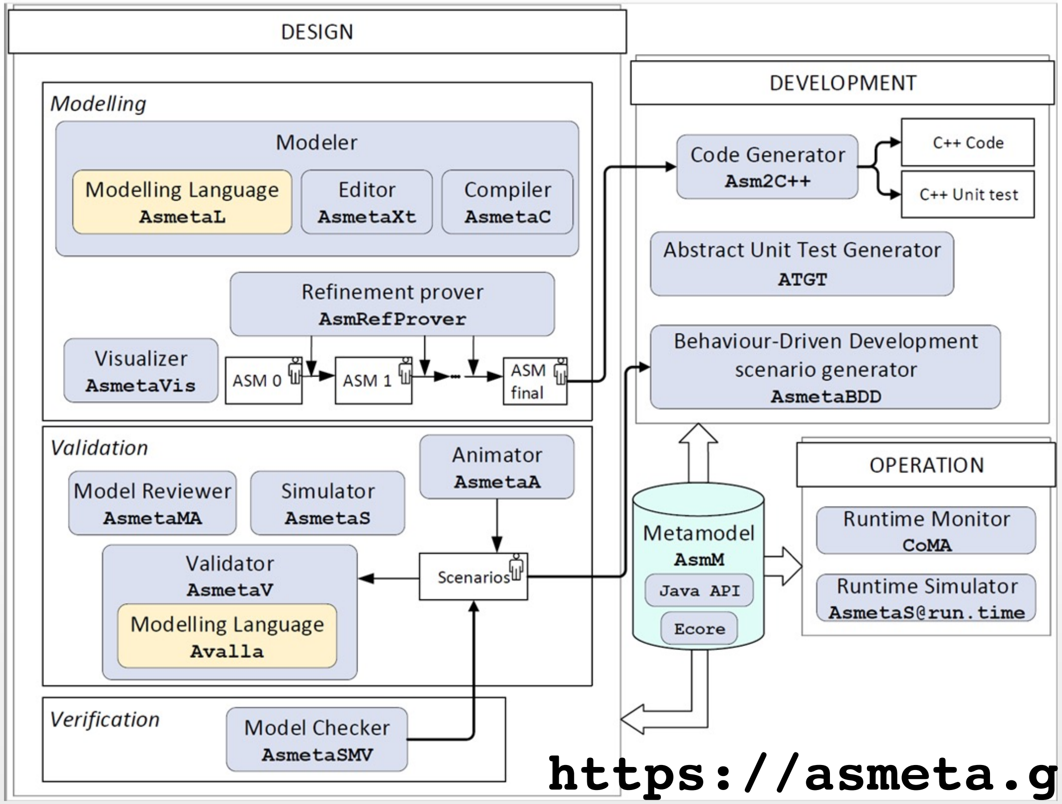
Our approach: using ASM and ASMETA

- Abstract State Machine (ASM) [1,2]
  - an extension of Finite State Machines, replacing unstructured FSM control states with *algebraic structures*
  - state transitions are performed by firing *transition rules*
  - different *computational paradigms*: single agent and multi-agent
  - ASM model predefined structure: a *signature* with declarations of domains and functions; a block of *definitions* of static domains and functions, transition rules, state invariants and properties to verify; a *main rule*; a set of *initial states*, one of which is elected as default.

[1] Börger, E. and Raschke, A. (2018). Modeling Companion for Software Practitioners. Springer Verlag.
[2] Börger, E. and Stärk, R. (2003). Abstract State Machines: A Method for High-Level System Design and Analysis. Springer Verlag.

Our approach: using ASM and ASMETA

- ASM mETAmodeling: a toolset supporting ASM formal method for model editing, validation and verification [3]



https://asmeta.github.io/

[3] Arcaini, P., Gargantini, A., Riccobene, E., and Scandurra, P. (2011). A model-driven process for engineering a toolset for a formal method. Software: Practice and Experience, 41(2):155–166.

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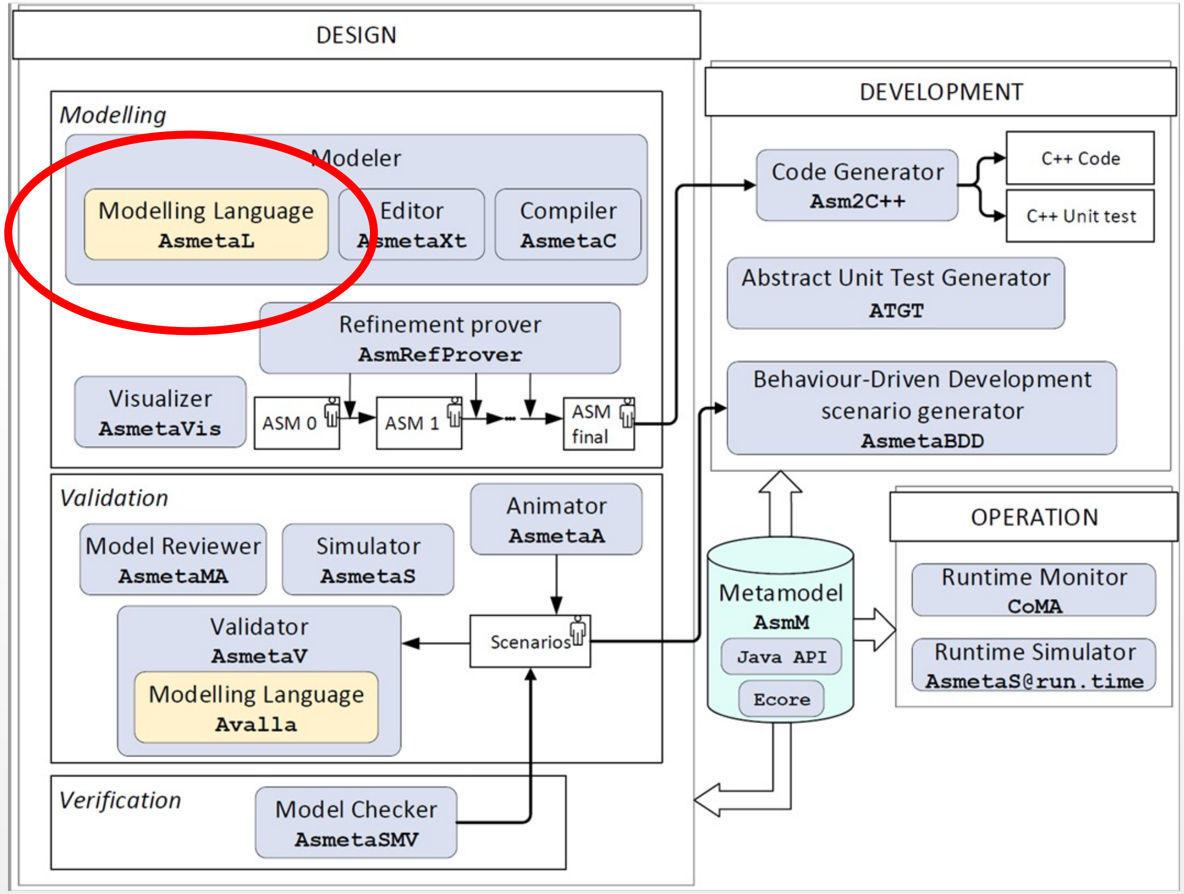
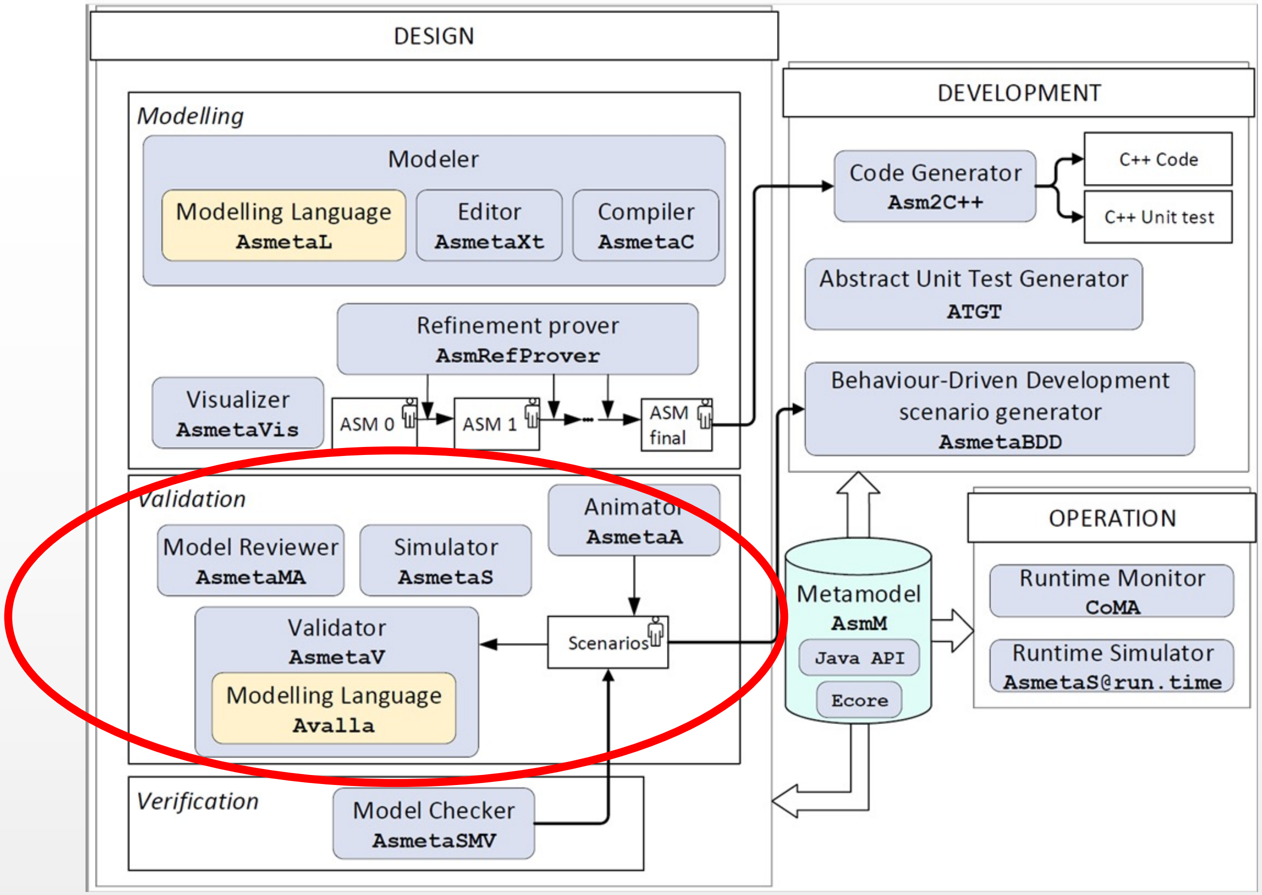
Our approach: using ASM and ASMETA



Our approach: using ASM and ASMETA



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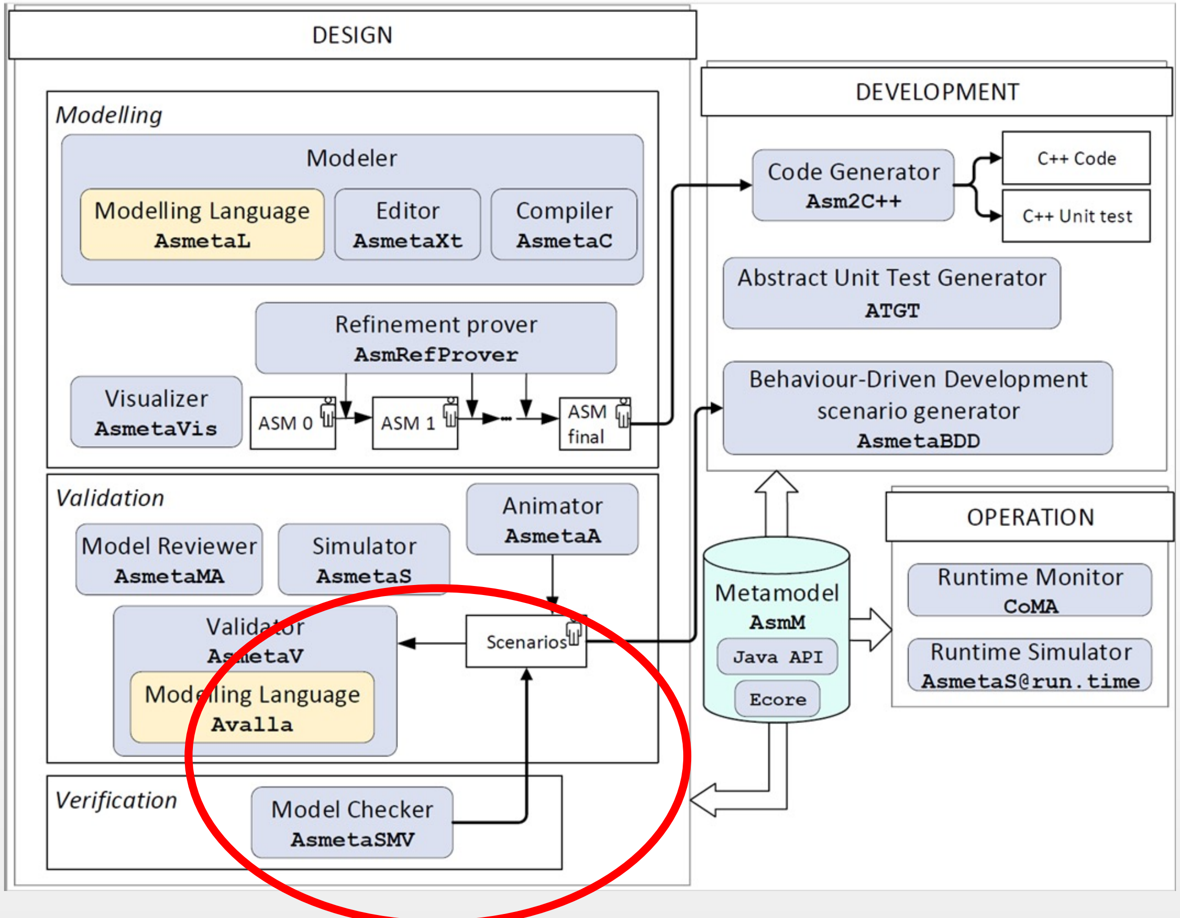
Our approach: using ASM and ASMETA



Advantages

- Easy pseudo-code format
- Executable models for different light forms of analysis
- Mantained

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ASM by example (1)

```
contract DAO {
 mapping (address => uint) balances;
   function Deposit() {
    balances[msg.sender] += msg.value;
   }
   function Withdraw(uint amount) {
    if (balances[msg.sender] >= amount) {
      msg.sender.call.value(amount);
      balances[msg.sender] -= amount;
    }
   }
}
```

balances is updated only **after** ether transfer

ASM by example (1)

```
contract DAO {
 mapping (address => uint) balances;
   function Deposit() {
    balances[msg.sender] += msg.value;
   }
   function Withdraw(uint amount) {
    if (balances[msg.sender] >= amount) {
      msg.sender.call.value(amount);
      balances[msg.sender] -= amount;
    }
   }
}
```

balances is updated only **after** ether transfer

```
contract Attacker {
 ...
   function moveBalance() {
     dao.Withdraw();
   }
   function () payable {
     dao.Withdraw();
}
```

ASM by example (2)

Set-up

```
signature:

    /* --------------------------------------------LIBRARY SIGNATURE-------------------------------------------- */

    enum domain ExecutingFunction = {DEPOSIT, WITHDRAW, CALLBACK, NONE}
    enum domain User = {USER, DAO, ATTACKER}
    enum domain Contract = {CONTRACTDAO, CONTRACTATTACKER}
    domain MoneyAmount subsetof Integer
    domain StackLayer subsetof Integer
    domain InstructionPointer subsetof Integer
    domain GeneralInteger subsetof Integer

    /* USER ATTRIBUTES */
    dynamic controlled balance : User -> MoneyAmount
    derived user_contract : User -> Contract
    derived is_contract : User -> Boolean

    /* FUNCTIONS THAT ALLOW TRANSACTIONS */
    controlled sender : StackLayer -> User
    dynamic controlled amount : StackLayer -> MoneyAmount

    /* STACK MANAGEMENT */
    dynamic controlled current_layer : StackLayer

    /* ALLOW FUNCTION EXECUTIONS */
    /* State Functions */
    dynamic controlled executing_function : StackLayer -> ExecutingFunction
    dynamic controlled instruction_pointer : StackLayer -> InstructionPointer
    dynamic controlled executing_contract : StackLayer -> Contract



    /* --------------------------------------------END LIBRARY SIGNATURE-------------------------------------------- */




    /* CONTRACT ATTRIBUTES, PARAMETERS AND RETURN VALUES */
    /* CONTRACT ATTRIBUTES */
    dynamic controlled costumer_balance : User -> MoneyAmount
    dynamic controlled counter : GeneralInteger

    /* FUNCTIONS PARAMETERS */
    controlled value_deposit : StackLayer -> MoneyAmount // amount of coin to deposit calling
    controlled value_withdraw : StackLayer -> MoneyAmount // amount of coin to withdraw calling






definitions:

    /* --------------------------------------------LIBRARY-------------------------------------------- */
```

ASM by example (2)

```


/*
 * TRANSACTION RULE
 */
rule r_Transaction($s in User, $r in User, $n in MoneyAmount, $f in ExecutingFunction) =
    if balance($s) >= $n and $n >= 0 then
        let ($ucr = user_contract($r), $cl = current_layer) in
            par
                balance($s) := balance($s) - $n // subtracts the amount from the sender user balance
                balance($r) := balance($r) + $n // adds the amount to the dest user balance
                if is_contract($r) then
                    par
                        sender($cl + 1) := $s // set the transition attribute to the sender user
                        amount($cl + 1) := $n // set the transaction attribute to the amount of coin to transfer
                        current_layer := $cl + 1
                        executing_contract($cl + 1) := $ucr
                        executing_function($cl + 1) := $f
                        instruction_pointer($cl + 1) := 0
                        instruction_pointer($cl) := instruction_pointer($cl) + 1
                    endpar
                endif
            endpar
        endlet
    endif


/*
 * RETURN RULE
 */
rule r_Ret =
    current_layer := current_layer - 1

```

Set-up

ASM by example (2)

```
function Deposit() {
  balances[msg.sender] += msg.value;
}
```

```
/*
 * DEPOSIT FUNCTION RULE
 */

rule r_Deposit_bank1 =
    let ($cl = current_layer) in
        let ($scl = sender($cl)) in
            if executing_function($cl) = DEPOSIT then
                switch instruction_pointer($cl)
                    case 0 :
                        par
                            value_deposit($cl) := amount($cl)
                            instruction_pointer($cl) := instruction_pointer($cl) + 1
                        endpar
                    case 1 :
                        par
                            costumer_balance($scl) := costumer_balance($scl) + value_deposit($cl)
                            r_Ret[]
                        endpar
                endswitch
            endif
        endlet
    endlet


/*
 * WITHDARW FUNCTION RULE
 */

rule r_Withdraw_bank1 =
    let ($cl = current_layer) in
        let ($scl = sender($cl)) in
            if executing_function($cl) = WITHDRAW then
                switch instruction_pointer($cl)
                    case 0 :
                        par
                            value_withdraw($cl) := 1
                            instruction_pointer($cl) := instruction_pointer($cl) + 1
                        endpar
                    case 1 :
                        if costumer_balance($scl) >= value_withdraw($cl) then
                            r_Transaction[DAO, $scl, value_withdraw($cl), CALLBACK]
                        else
                            r_Ret[]
                        endif
                    case 2 :
                        par
                            costumer_balance($scl) := costumer_balance($scl) - value_withdraw($cl)
                            r_Ret[]
                        endpar
                endswitch
            endif
        endlet
    endlet
```

```
function Withdraw(uint amount) {
  if (balances[msg.sender] >= amount) {
    msg.sender.call.value(amount);
    balances[msg.sender] -= amount;
  }
}
```

ASM by example (2)

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EclipseWorkspace - ThesisProject/ThesisProject/DAO Attack/mybank2_4_noAgent.asm - Eclipse IDE

mybank2_4_noAgent.asm

```
        endlet



    /*
     * CALLBACK FUNCTION RULE
     */

    rule r_Callback_bank1 =
        let ($cl = current_layer) in
            if executing_function($cl) != DEPOSIT and  executing_function($cl) != WITHDRAW then
                switch instruction_pointer($cl)
                    case 0 :
                         r_Ret[]
                endswitch
            endif
        endlet








    /* -------------------------------------------ATTACKER CONTRACT IMPLEMENTATION------------------------------------------- */

    /*
     * CALLBACK FUNCTION RULE
     */
    rule r_Callback_bank2 =
        let ($cl = current_layer) in
            switch instruction_pointer($cl)
                case 0 :
                    if counter < 2 then
                        par
                            r_Transaction[ATTACKER, DAO, 1, WITHDRAW]
                            counter := counter + 1
                        endpar
                    else
                        r_Transaction[ATTACKER, DAO, 1, CALLBACK]
                    endif
                case 1 :
                    r_Ret[]
            endswitch
        endlet






    /* -------------------------------------------MAINS AND INVARIANTS------------------------------------------- */
```

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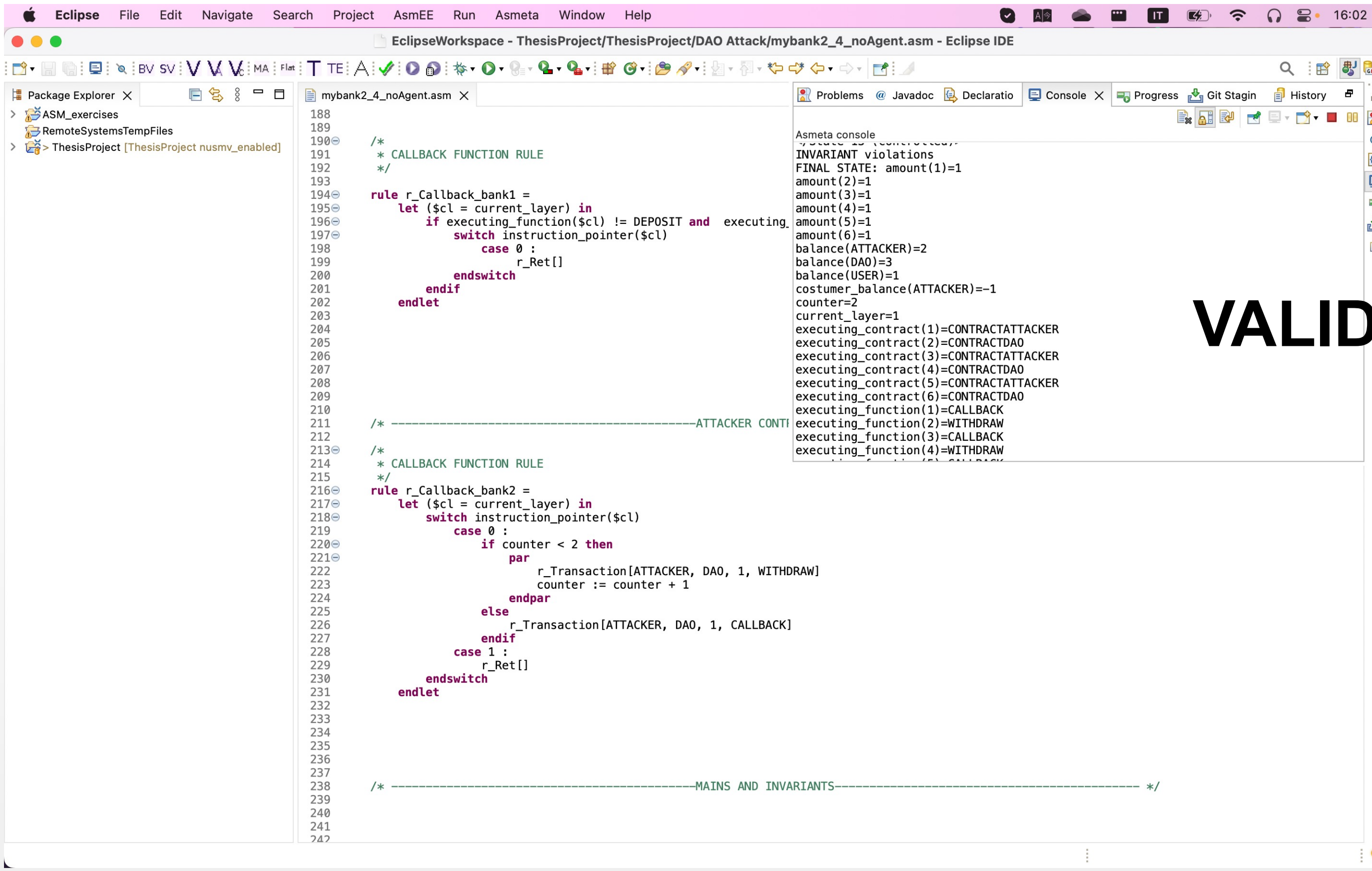
ASM by example (3)

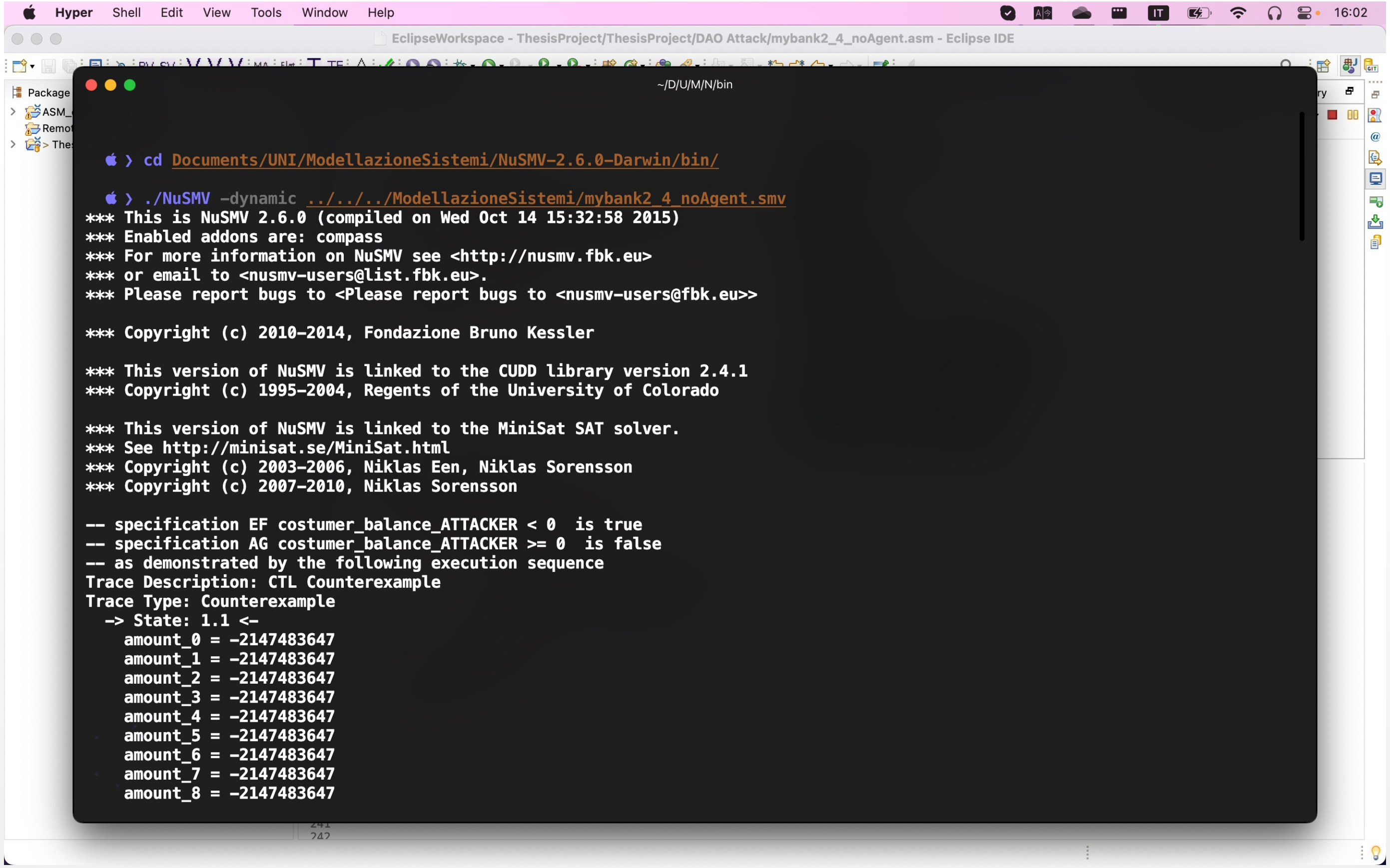


VALIDATION

```
/*
 * INVARIANT
 */
invariant over costumer_balance : costumer_balance(ATTACKER) >= 0


/*
 * CTLSPEC
 */
CTLSPEC ef(costumer_balance(ATTACKER) < 0)
```

ASM by example (3)




```
❯ cd Documents/UNI/ModellazioneSistemi/NuSMV-2.6.0-Darwin/bin/

❯ ./NuSMV -dynamic ../../../ModellazioneSistemi/mybank2_4_noAgent.smv
*** This is NuSMV 2.6.0 (compiled on Wed Oct 14 15:32:58 2015)
*** Enabled addons are: compass
*** For more information on NuSMV see <http://nusmv.fbk.eu>
*** or email to <nusmv-users@list.fbk.eu>.
*** Please report bugs to <Please report bugs to <nusmv-users@fbk.eu>>

*** Copyright (c) 2010-2014, Fondazione Bruno Kessler

*** This version of NuSMV is linked to the CUDD library version 2.4.1
*** Copyright (c) 1995-2004, Regents of the University of Colorado

*** This version of NuSMV is linked to the MiniSat SAT solver.
*** See http://minisat.se/MiniSat.html
*** Copyright (c) 2003-2006, Niklas Een, Niklas Sorensson
*** Copyright (c) 2007-2010, Niklas Sorensson

-- specification EF costumer_balance_ATTACKER < 0  is true
-- specification AG costumer_balance_ATTACKER >= 0  is false
-- as demonstrated by the following execution sequence
Trace Description: CTL Counterexample
Trace Type: Counterexample
  -> State: 1.1 <-
    amount_0 = -2147483647
    amount_1 = -2147483647
    amount_2 = -2147483647
    amount_3 = -2147483647
    amount_4 = -2147483647
    amount_5 = -2147483647
    amount_6 = -2147483647
    amount_7 = -2147483647
    amount_8 = -2147483647
```

VERIFICATION

```
/*
 * INVARIANT
 */

 invariant over costumer_balance : costumer_balance(ATTACKER) >= 0


/*
 * CTLSPEC
 */
CTLSPEC ef(costumer_balance(ATTACKER) < 0)
```

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Future Works

- Generalizie the approach
  - Model the full semantics of SC
  - Identify common patterns in the structure of the contract to build an ASM library
  - Build a catalog of common vulnerabilities and express it in terms of properties to check
  - A GUI for specification of verified smart contracts?
  - What about other blockchains?