Towards safer smart contract languages

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Smart contracts

- A concept proposed by Nick Szabo in 90s.
- (Wikipedia) A smart contract is a computer protocol intended to digitally facilitate, verify, or enforce the negotiation or performance of a contract.
- Usually thought as self-enforcing, self-executing entities.
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This is not what “smart contracts” on blockchains are!
At least, currently:

**Smart contracts are programs in a general purpose language running “on a blockchain”**.
Smart contracts are neither

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**Smart contracts are programs in a general purpose language running “on a blockchain”.**

Why neither smart nor contracts?
- Connection to the legal contracts is not clear.
- Smart contracts mix together specification and execution.
- Can go terribly wrong.

*Fritz Henglein. Smart contracts are neither.*
Cyber Security, Privacy and Blockchain High Tech Summit, DTU, 2017
Smart Contracts: The Evolution

- First generation: Bitcoin script.
- Second generation: Ethereum EVM and Solidity.
- Third generation: functional languages + limited inter-contract communication patterns.
Ethereum and Solidity

- Solidity is a high level java/javascript-like imperative language.
- One of the most widely used smart contract languages.
- Compiles to EVM byte-code.
- **Each contract has state, which can be modified during the execution of any of contract’s methods.**
- **Contracts can interact** with other contracts **by calling their methods and sending money.**
- **Calls can happen in any point of the program execution (causes reentrancy issues).**
Is Solidity really solid?

Plenty of vulnerabilities have been found:

- Adrian Manning. *Solidity Security: Comprehensive list of known attack vectors and common anti-patterns*
  
  **16 Solidity Hacks/Vulnerabilities**

  
  **19366 contracts analysed, 8833 of them have vulnerabilities.**

- Ilya Sergey, Aquinas Hobor. *A Concurrent Perspective on Smart Contracts.*
  
  **Multiple issues related to (non-obvious) concurrent behaviour**
Towards safer smart contract languages

Why designing safe smart contract languages is crucially important? At least, because:

- Many smart contract developers with different backgrounds ("coding" is becoming a mass culture).
- Once deployed, contract code cannot be changed.
- Contract execution is irreversible ("Code is Law").
- Flaws in a smart contract may result in huge financial losses (infamous DAO smart contract on Ethereum).
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Safe languages should make shooting yourself in the foot if not impossible, but at least hard!
The smart contract layer

- Imagine, we have verified all other layers.
- We put some badly designed language on top.
- It’s like having your pension depend on a javascript program.
- And any bug is law!

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Towards safer smart contract languages
A functional perspective on smart contracts

How we can address the issues? Functional languages to the rescue!

- Based on variants of typed λ-calculi.
- Well-studied **formal semantics**.
- Well-suited for reasoning.
- Proof assistants are based on typed λ-calculi as well!
Semantics matters

Why do we care about formal semantics?

- Meta-theory of a language:
  - type soundness “well-typed programs can’t go wrong”;
  - termination;
  - compiler correctness;

- Program correctness.

Meta-theory of polymorphic λ-calculus (a.k.a System F) is well developed.

Theoretical foundation of: Haskell, OCaml, Standard ML, Elm, F#, ...
It’s all is good, **but**

- We cannot get rid of stateful computations completely — blockchains are inherently stateful.
- However, we can limit ways of modifying the state.
- Contracts are pure functions transforming the state:
  
  \[
  \text{contract : state } \times \text{parameters } \rightarrow \text{state } \times \text{operation list}
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Examples of languages with the functional “core”.

- Simplicity
- Plutus
- **Liquidity**
- Scilla
- **Oak**
DEMO
Oak

- A language for defining smart contracts for the Concordium blockchain.
- The means for developers to interface with the Concordium infrastructure.
- A fork of Elm, a purely functional programming language for web development.
- Prioritises good error messages.
- Static typing.

1Thanks Tom Davies for this and the next slide
## Oak and Acorn

<table>
<thead>
<tr>
<th>Oak — convenient, user-friendly</th>
<th>Acorn — internal, efficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{ML}^F$ type system with type inference, user defined data types</td>
<td>Higher-rank polymorphism, explicit typing, no type inference</td>
</tr>
<tr>
<td>Intuitive string naming of types and terms</td>
<td>Compact de Bruijn indexing of types and terms</td>
</tr>
<tr>
<td>Syntactic sugar (binary operators, if-expressions, etc.)</td>
<td>Concise language with little/no redundancy</td>
</tr>
<tr>
<td>Expressive and convenient pattern matching</td>
<td>Predictable performance of pattern matching</td>
</tr>
<tr>
<td>Concrete syntax is a key feature</td>
<td>Concrete syntax is a convenience</td>
</tr>
<tr>
<td>User friendly tooling and errors</td>
<td>API, virtual machine</td>
</tr>
</tbody>
</table>
Proof assistants — special software for developing machine-checkable proofs.

- Allows for developing proofs for mathematics and computer science.
- Proofs are developed by interacting with users.
- Proof automation: tactics, decision procedures, SAT/SMT integration.

Towards safer smart contract languages
Towards formal verification

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In particular:

- Formalisation of the programming language’s meta-theory.
- Proving correctness of compilers, interpreters, type checking/type inference, etc.
- “Extraction” of bug-free implementation.
Compiler correctness matters

6 warnings about compiler bugs
Proof assistants like Coq, Isabelle/HOL have been successfully applied in large-scale projects

- CompCert — verified C compiler.
- CakeML — verified implementation of Standard ML.
- seL4 — formal verification of an OS kernel.

Smart contracts formalisation

- Simplicity language — simple language formalised in Coq.
- Ongoing project at Concordium Research Center: formalisation of a more expressive smart contract language: the Oak language.
At the Concordium Blockchain Research Center, we develop ConCert (jww. Bas Spitters and Jakob Botsch Nielsen):

- Verification of functional smart contract languages.
- Particularly, verification of smart contracts in Oak/Acorn.
- Can be used to verify both properties of a smart contract language and properties of concrete smart contracts.
- Allows for verifying properties of interacting smart contracts.
What we can verify?

Crowdfunding: a smart contract allowing arbitrary users to donate money within a deadline.

- Will the users get their money back if the campaign is not funded (goal is not reached)?
- Can the owner withdraw money if goal is reached and deadline have passed?
- Are all contributions recorded correctly in the contract?
- Does contact have enough money at the account to cover all contributions?
- ...
Example: a counter

**Acorn**

data CState = CState [Int64, {address}]

definition owner (s :: CState) =
  case s of
    CState _ d → d

definition balance (s :: CState) =
  case s of
    CState x _ → x

definition count (s :: CState) (msg :: Msg) =
  case msg of
    Inc a →
      CState (Prim.plusInt64 (balance s) a)
        (owner s)
    Dec a →
      CState (Prim.minusInt64 (balance s) a)
        (owner s)

**Coq**

Inductive CState :=
  CState_coq : Z → string → CState.

Definition owner : CState →
string := fun x ⇒
  match x with
  | CState_coq _ x1 ⇒ x1
end.

Definition balance : CState →
Z := fun x ⇒
  match x with
  | CState_coq x0 _ ⇒ x0
end.

Definition count :
  CState → Msg → CState := fun x x0 ⇒
match x0 with
  | Inc_coq x1 ⇒
    CState_coq (plusInt64 (balance x) x1)
      (owner x)
  | Dec_coq x1 ⇒
    CState_coq (minusInt64 (balance x) x1)
      (owner x)
end.

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Properties of the counter

Sending the “increment” message updates the counter correctly:

**Lemma** inc_correct init_state n i final_state :
(* precondition *)
balance init_state = n →

(* sending "increment" *)
count init_state (Inc_coq i) = final_state →

(* result *)
balance final_state = n + i.

**Proof.**
intros Hinit Hrun. subst. reflexivity.
Qed.
Programming languages semanticists should be the obstetricians of programming languages, not their coroners.

— John C. Reynolds