Towards safer smart contract languages

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Datalogforeningen meeting, November 2, 2019

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!

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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
- Luu et al. *Making Smart Contracts Smarter*.
  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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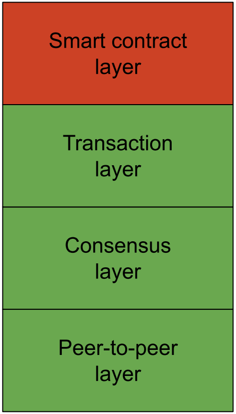
Safe languages should make shooting yourself in the foot if not impossible, but at least hard!

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!



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#, ...

Functional core, imperative shell

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:
  $\texttt{contract} : \texttt{state} * \texttt{parameters} \rightarrow \texttt{state} * \texttt{operation list}$

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Examples of languages with the functional "core".

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

Liquidity demo

DEMO

Oak[1]

- 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.

[1] Thanks Tom Davies for this and the next slide

Oak and Acorn

Oak — convenient, user-friendly	Acorn — internal, efficient
ML^F type system with type inference, user defined data types	Higher-rank polymorphism, explicit typing, no type inference
Intuitive string naming of types and terms	Compact de Bruijn indexing of types and terms
Syntactic sugar (binary operators, if-expressions, etc.)	Concise language with little/no redundancy
Expressive and convenient pattern matching	Predictable performance of pattern matching
Concrete syntax is a key feature	Concrete syntax is a convenience
User friendly tooling and errors	API, virtual machine

Towards formal verification

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.

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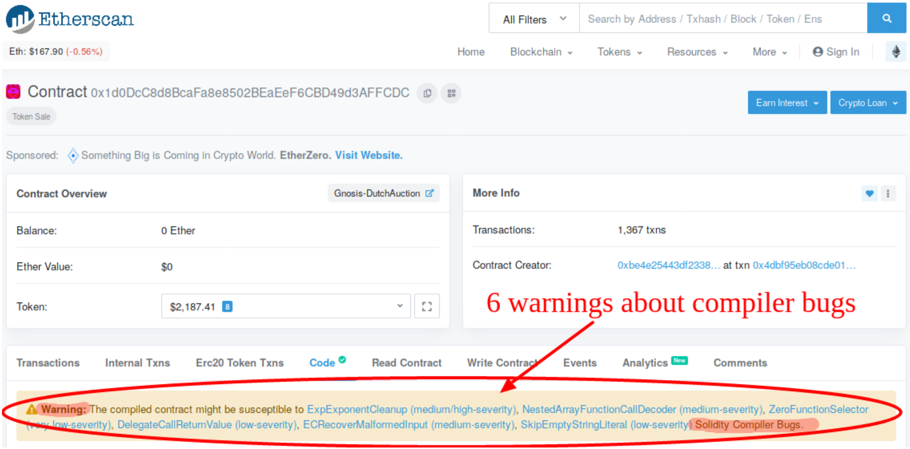
In particular:

- 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



Proof assistants

Proof assistants like Coq, Isabelle/HOL have been successfully applied in large-scale projects

- CompCert — verified C compiler.
- CakeML — verified implemtation 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.

ConCert: a smart contract verification framework in Coq

At the Concordium Blockchain Reserach Center, we develop **ConCert** (jww. Bas Spitters and Jakob Botsch Nielsen):

- Verification of *functional* smart contract landuages.
- 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.
```

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