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!

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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 methods and sending money.
- Calls can happen in any point of the program execution.

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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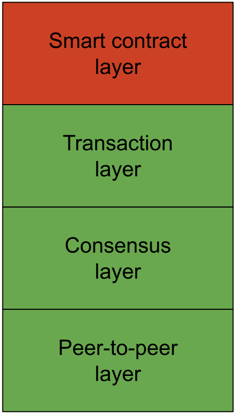
Safe languages should make shooting yourself in the foot if not impossible, but at least hard!

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, 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:

```
contract : state * parameters -> state * operation list
```

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Examples of languages with the functional "core".

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

DEMO

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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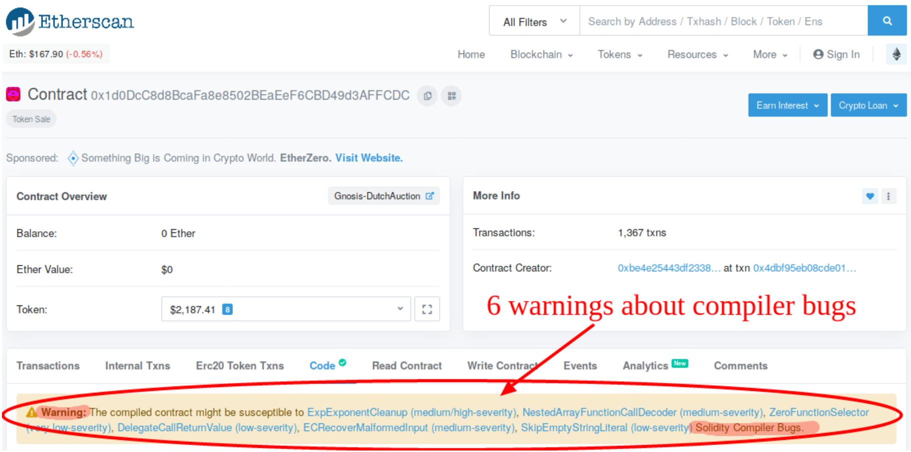
In particular:

- 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.

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But formal verification still remains challenging.
Careful design of smart contract languages is a key factor.

> Programming languages semanticists should be the obstetricians of programming languages, not their coroners.
>
> — John C. Reynolds