SoK: Decentralized Finance (DeFi)

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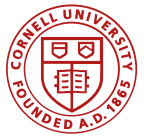

Cornell University

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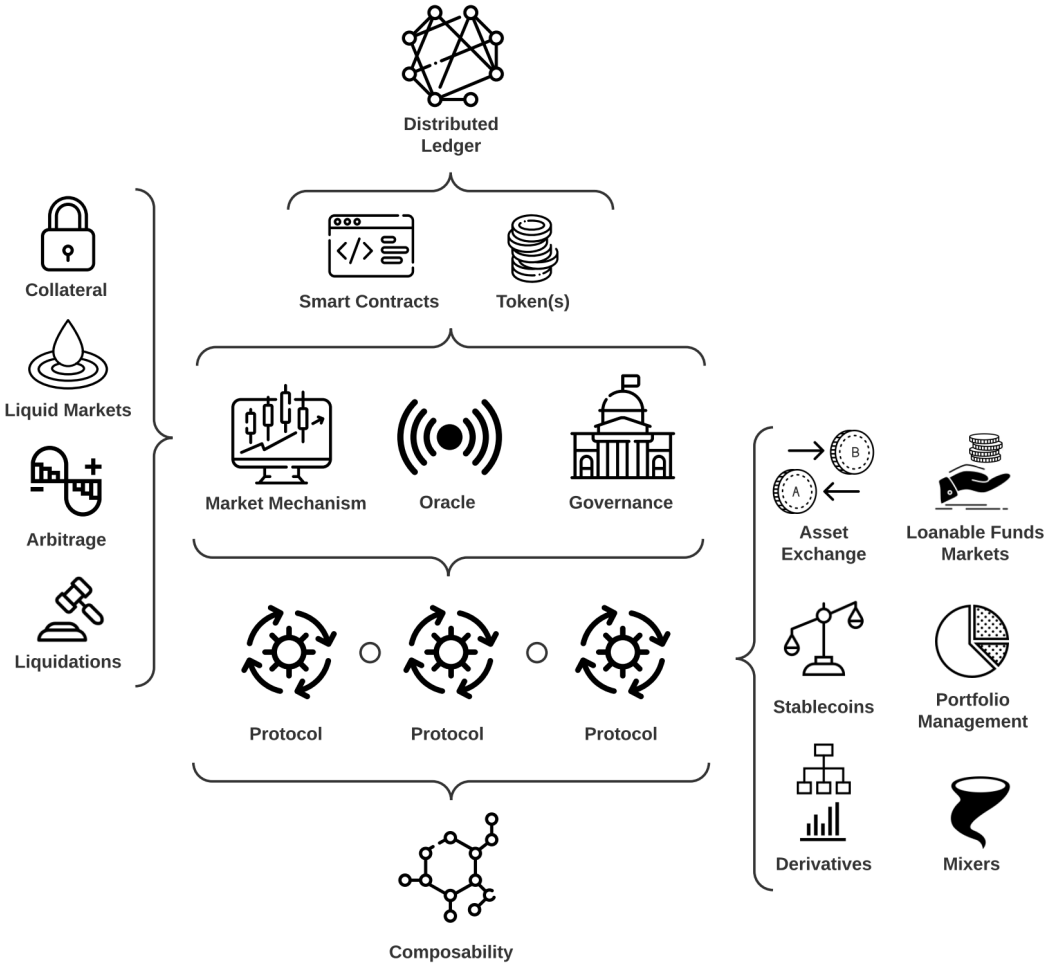
Outline

- Introduction
- Primitives
- Protocols

- Security
  - Technical Security
  - Economic Security
- Open challenges for research



What is DeFi?

“Decentralized Finance (DeFi) is a peer-to-peer powered financial system”

The properties of idealized DeFi: I

Non-custodial:
Participants have full control over their funds at any point in time

The properties of idealized DeFi: II

Permissionless:

Anyone can interface with financial services without being censored or blocked by a third party

The properties of idealized DeFi: III

Openly auditable:
Anyone can audit the state of the system

The properties of idealized DeFi: IV

Composable:

The financial services can be arbitrarily composed such that new financial products and services can be created

Views on DeFi

We can consider two views on DeFi: **DeFi Optimist** vs **DeFi Pessimist**

Views on DeFi

“DeFi amounts to a breakthrough technological advance, offering a new financial architecture that is non-custodial, permissionless, openly auditable, pseudo(anonymous), and with potentially new capital efficiencies.”

-- DeFi Optimist

Views on DeFi

Why Argentines Are Turning From Dollars to Stablecoins Like DAI

A cocktail of high inflation, devaluation and lack of access to U.S. dollars has led Argentines to find in the decentralized stablecoin a way to protect their battered incomes.

Celsius, 3AC demonstrated why more financial activity needs to be on-chain

Instead of operating in darkness, more players in the financial industry should move their transactions to the blockchain, where every move is public.

Views on DeFi

"The unregulated, hack-prone DeFi ecosystem serves to facilitate unfettered and novel forms of financial crime. Pseudo-anonymity permits cryptocurrency attackers, scammers, and money launderers to move, clean, and earn interest on capital."

-- DeFi Pessimist

Views on DeFi

Crypto Hacks Soar as North Korea Targets DeFi

- Around $1.9 billion in crypto stolen in hacks: Chainalysis
- DeFi protocols continue to be the sector's weak point

Treasury Dept. Sanctions North Korean Hackers' Favorite Crypto "Mixer"

This SoK

- Many valid issues to tackle
- For DeFi to fulfil vision of DeFi Optimist, it must be *secure*
- We focus on delineating DeFi's security challenges in terms of
  - Technical security
  - Economic security

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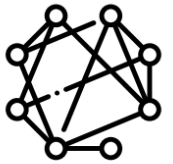
Primitives: the basic assumption



DeFi protocols build on a distributed ledger (blockchain)

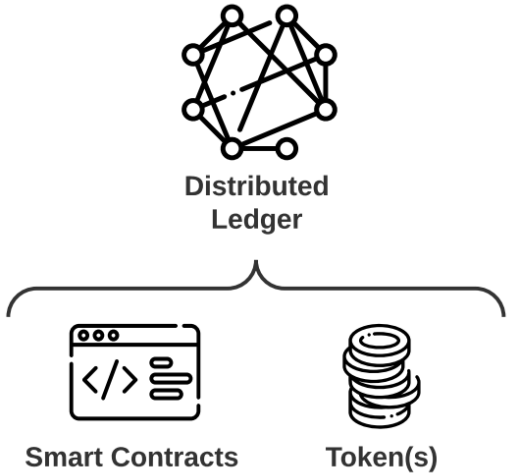
- Allows mistrusting agents to cooperate w/o trusted third parties

Assumed security properties: consistency, integrity and availability

Primitives

Blockchain primitives:

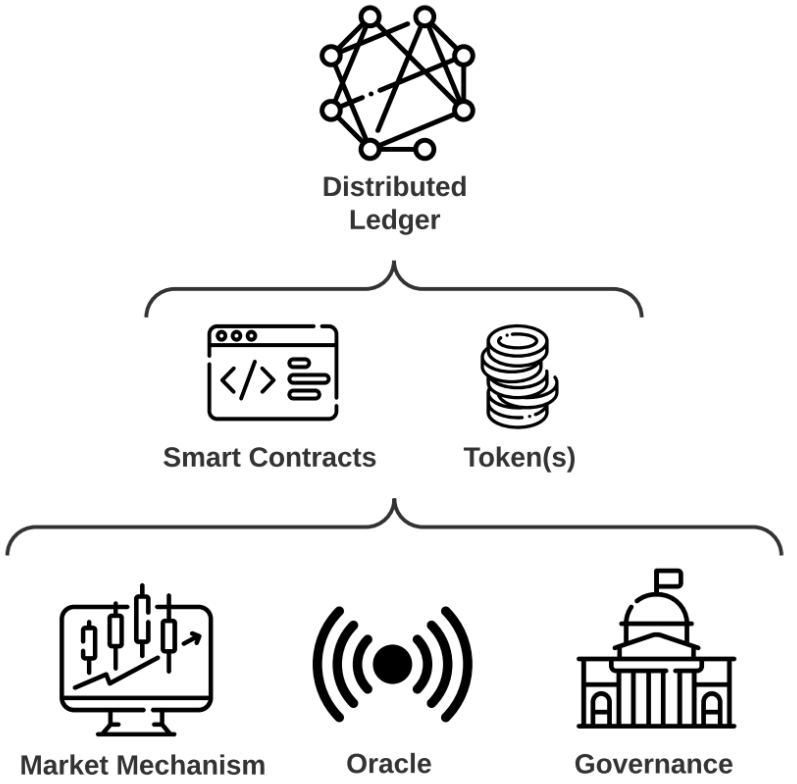
- **Transactions** (txs)
- **Atomicity**: a tx either succeeds fully (state updated) or fails entirely (state remains unaltered)
- **Smart contracts**: programs that run on the blockchain computer
  - E.g., tokens and functionality behind tokens



Primitives

DeFi primitives:

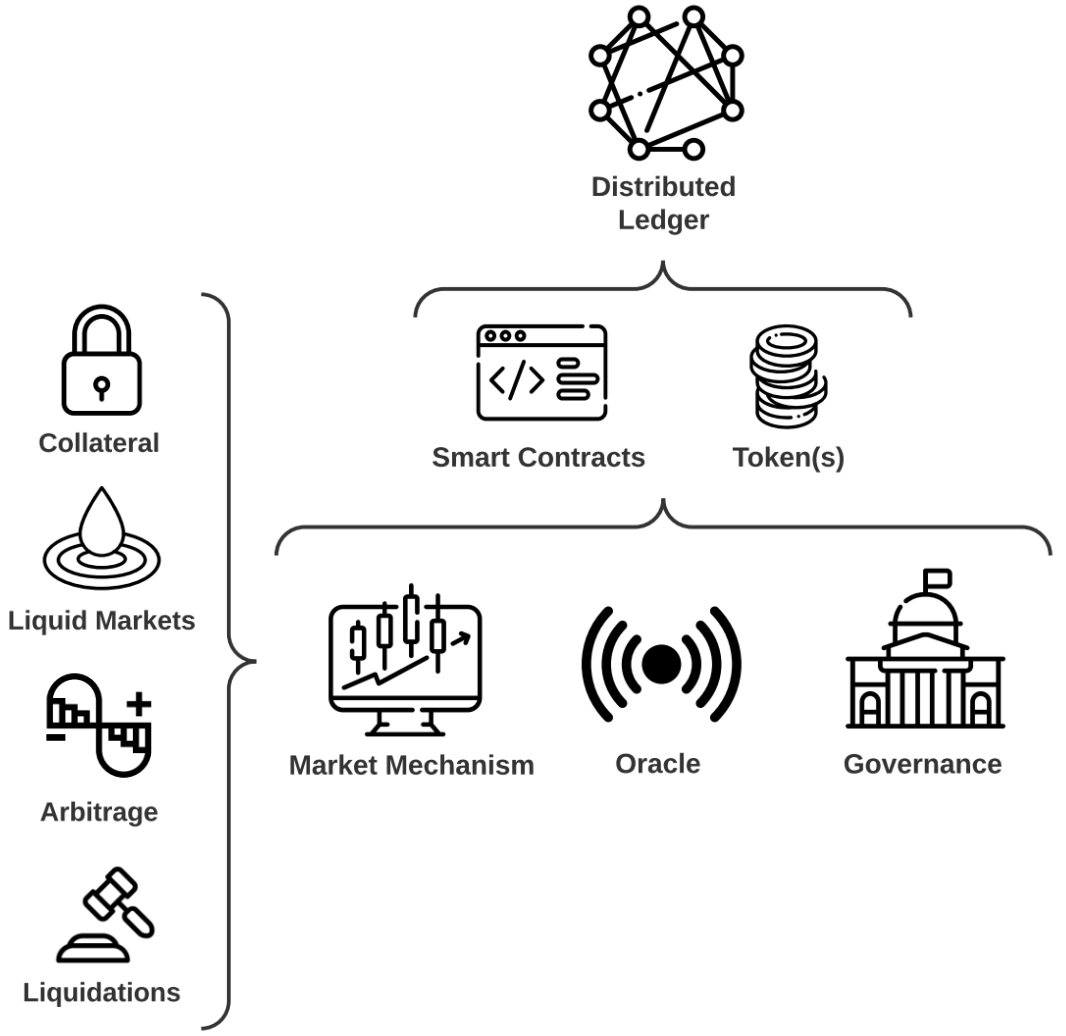
- Oracles = price feeds
- Governance = upgradeability
- Keepers = incentive to trigger state updates
- Market mechanisms



Primitives

DeFi primitives:

- Oracles
- Governance
- Keepers
- Market mechanisms



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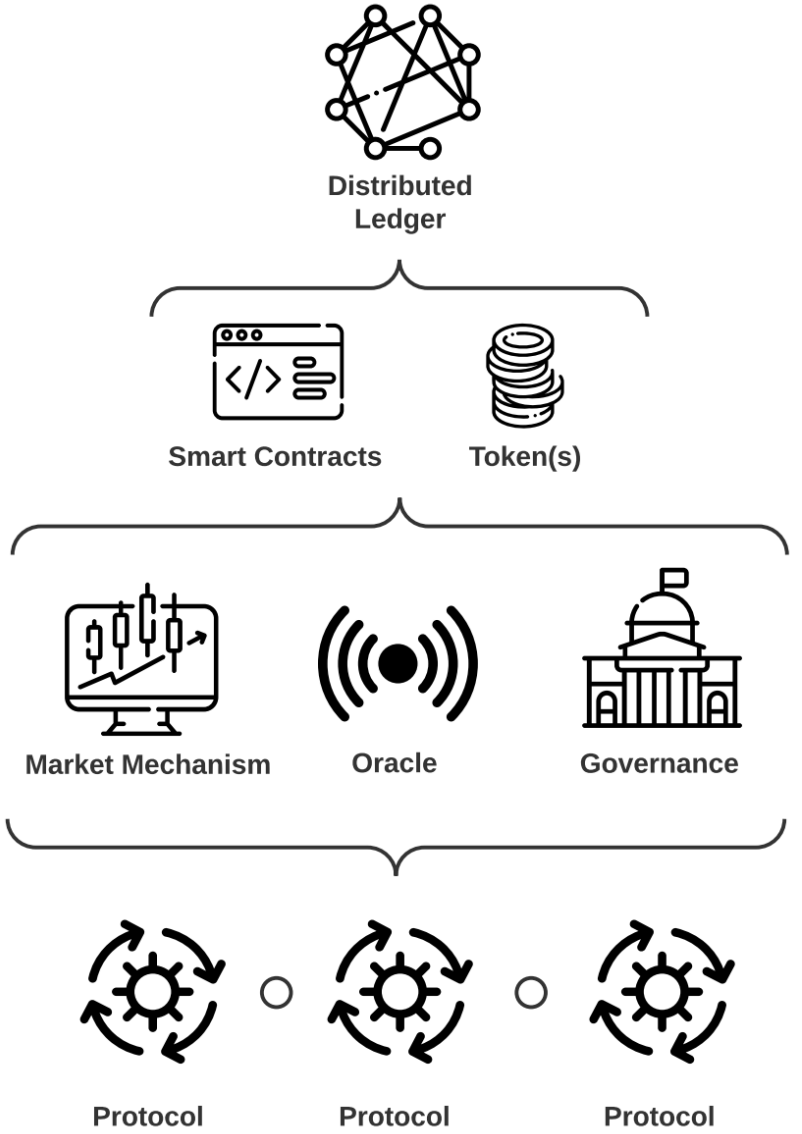
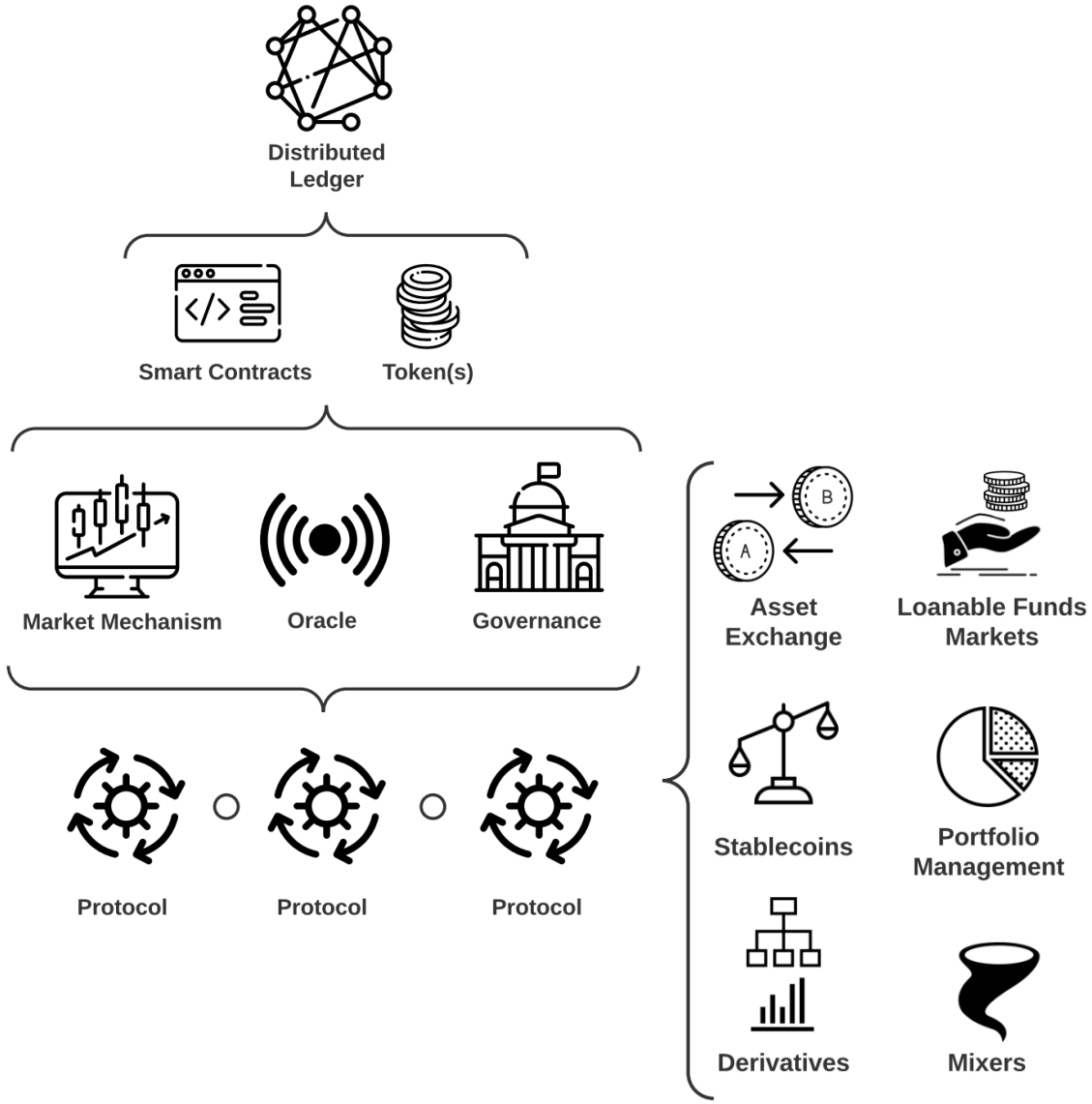


What types of DeFi protocols exist?



Decentralized Exchanges (DEXs)

Facilitate non-custodial exchange of digital assets

- **Order book DEXs**:
  - Open orders as presigned transactions
  - Orders matched manually or algorithmically
  - On-chain order books are expensive (computation and storage)
- **Automated market makers (AMMs)**:
  - Liquidity provided algorithmically through on-chain pricing rule
  - Providing liquidity ~ commit to a portfolio rule (rebalanced by arbitrageurs)
  - Anyone can trade through the pool → generate fees for the pool
  - AMMs are profitable when they are 'volatility harvesting', but face strategy risk and adverse selection

Protocols for Loanable Funds (PLFs)

On-chain markets for lending and borrowing assets

- Deposits pooled together in a smart contract
- Agents borrow (overcollateralized) against reserves
- Algorithmic interest rate balances market (~ no duration risk)
- Borrower collateral can be liquidated based on health rules
- Flash loans: uncollateralized loans for duration of a single transaction

Non-custodial Stablecoins

Aim to be price stabilized (e.g., pegged to USD) and seek to achieve this via additional economic mechanisms

- **Collateral** as store of primary value
- **Agents:** stablecoin holders and to absorb risk/speculate
- **Governance** mechanism to tune parameters (monetary policy)
- **Issuance** mechanism of minting and redeeming stablecoins
- **Oracles** to import external data onto the blockchain (e.g. price feeds)

Portfolio Management

Smart contracts manage automated investment strategies in other protocols

- Range from simple rebalancing to yield maximization
- Yield mechanisms: interest, fees and token rewards/rebates
- Smart contracts encode rules restricting how funds can be invested (less trust assumptions vs custodial management)

Derivatives

Derivatives derive value from the performance of an underlying asset

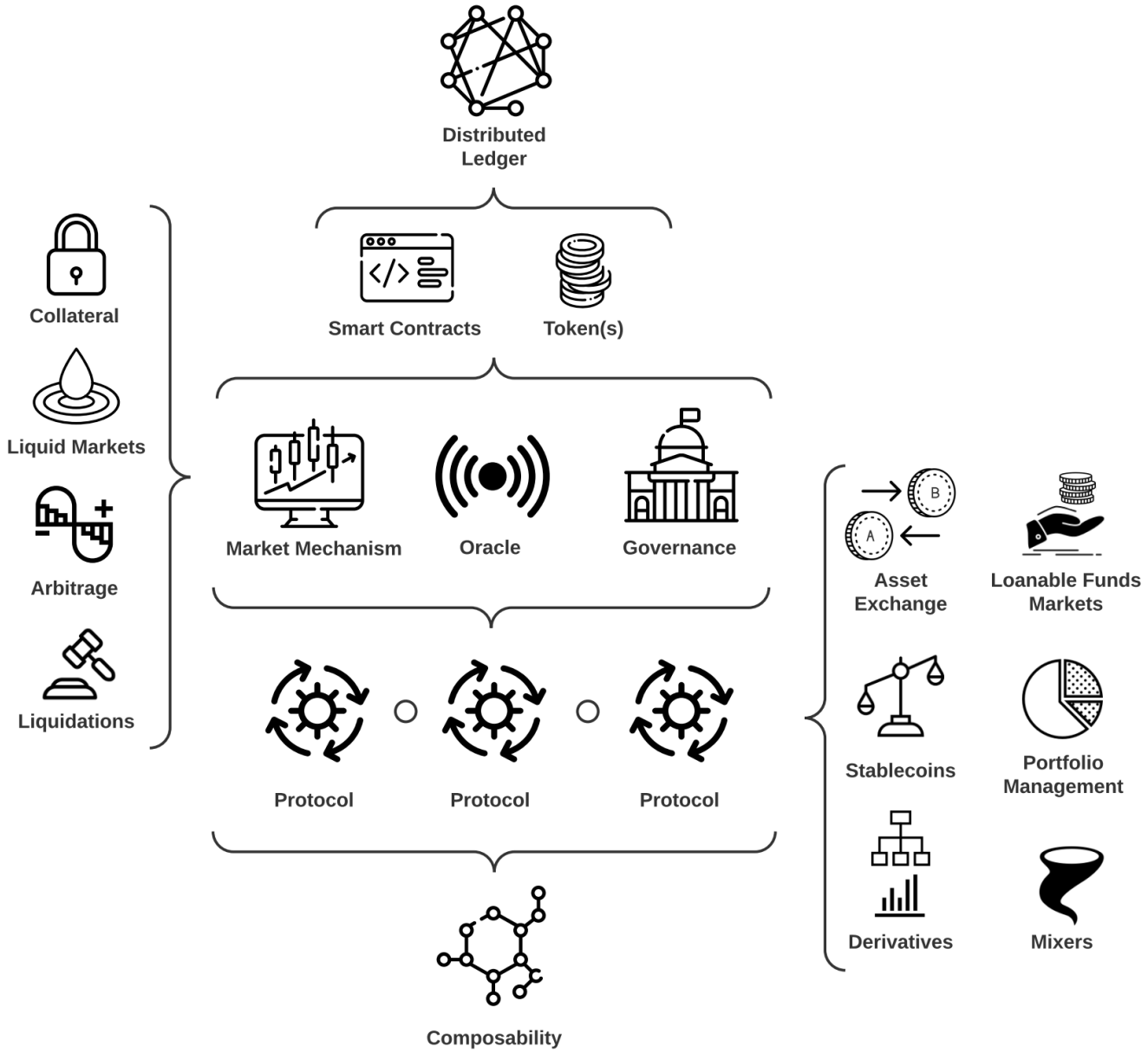
- **Synthetic assets** typically replicate off-chain assets on-chain
- **Perpetual swaps** (popularized in crypto markets)
  - Allow users to take short and long positions on cryptoassets without expiry
  - Positions are collateralized, can be liquidated and balanced by a funding rate
  - Capital efficient b/c positions can be highly leveraged (vs directly shorting)
- **Futures** have seen little adoption in DeFi (for now)
- Market for **options** in DeFi is nascent (basic call and put options)

Privacy-preserving Mixers

Prevent tracing of cryptocurrency txs using cryptographic protocols

- Important to preserve user privacy but also contentious
- Construct shielded pool of assets, difficult to trace back before entering
  - Mix funds from many sources so that individual deposits look the same
  - Directly shield contents of txs using zero knowledge proofs of tx validity
- Some create a ‘market for privacy’ where fees accrue to users who keep assets in the shielded pool

Protocols can compose with one another



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Technical Security

Informal Definition

Technical security = secure from an attacker who is limited to atomic actions (e.g., not possible to steal assets)

- Technical security is ~ about whether an on-chain system can be exploited within a **single tx** or a **bundle of txs** in a block
- Technical attacks are **risk-free** b/c outcomes are binary for attacker
  - Either attack is successful = profit $$
  - Or it reverts = only pay gas fee
- Examples: atomic MEV, sandwich attacks, reentrancy, logic bugs
  - Now well studied!
- Best addressed: program analysis, formal models to specify protocols

Smart Contract Vulnerabilities

Reentrancy

- Delegate control to an untrusted contract, by calling it with a large enough gas limit, while its state is partially modified

Integer Manipulation

- Over- and –underflow
- Unit error during integer manipulation

Logic Bugs

- Simple programming errors in smart contracts

Single Transaction Attacks

Single Transaction Sandwich Attacks

- Attacker manipulates an instantaneous AMM Price in order to exploit a smart contract that uses that as an oracle

Governance Attacks

- Attacker may obtain an amount of governance tokens sufficient to propose and execute malicious contract code and steal funds

Transaction Ordering Attacks

Displacement Attacks

- Attacker front-runs a target tx to displace/ ‘snipe’ it

Multi-transaction Sandwich Attacks

- Attacker alters AMM price before and after a target tx so that the target tx executes at a bad price that the attacker can arbitrage

Economic Security

Informal Definition

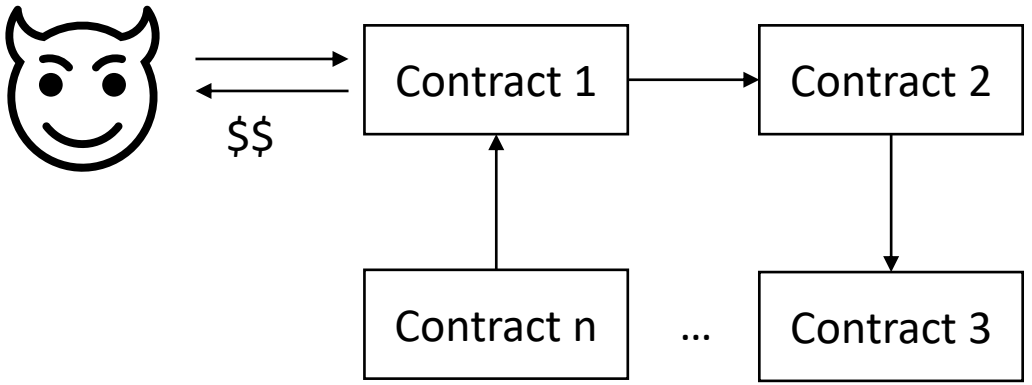
Economic security = not profitable for an attacker who can perform non-atomic actions to manipulate the protocol into unintended states

- Economic security is about an exploiting agent who tries to manipulate the incentive structure of the protocol to profit (e.g., by stealing assets)
- Economic exploits are non-atomic
- They have upfront tangible costs and are **not risk-free**
  - The attack may fail depending what else happens in the time period
  - The attacker may mis-estimate the market response
- To address: needs economic models of how these systems and agents work

Technical vs Economic – what's different?

Technical exploit: attacker finds sequence of contract calls that leads to a profit

- Single tx or bundle of txs



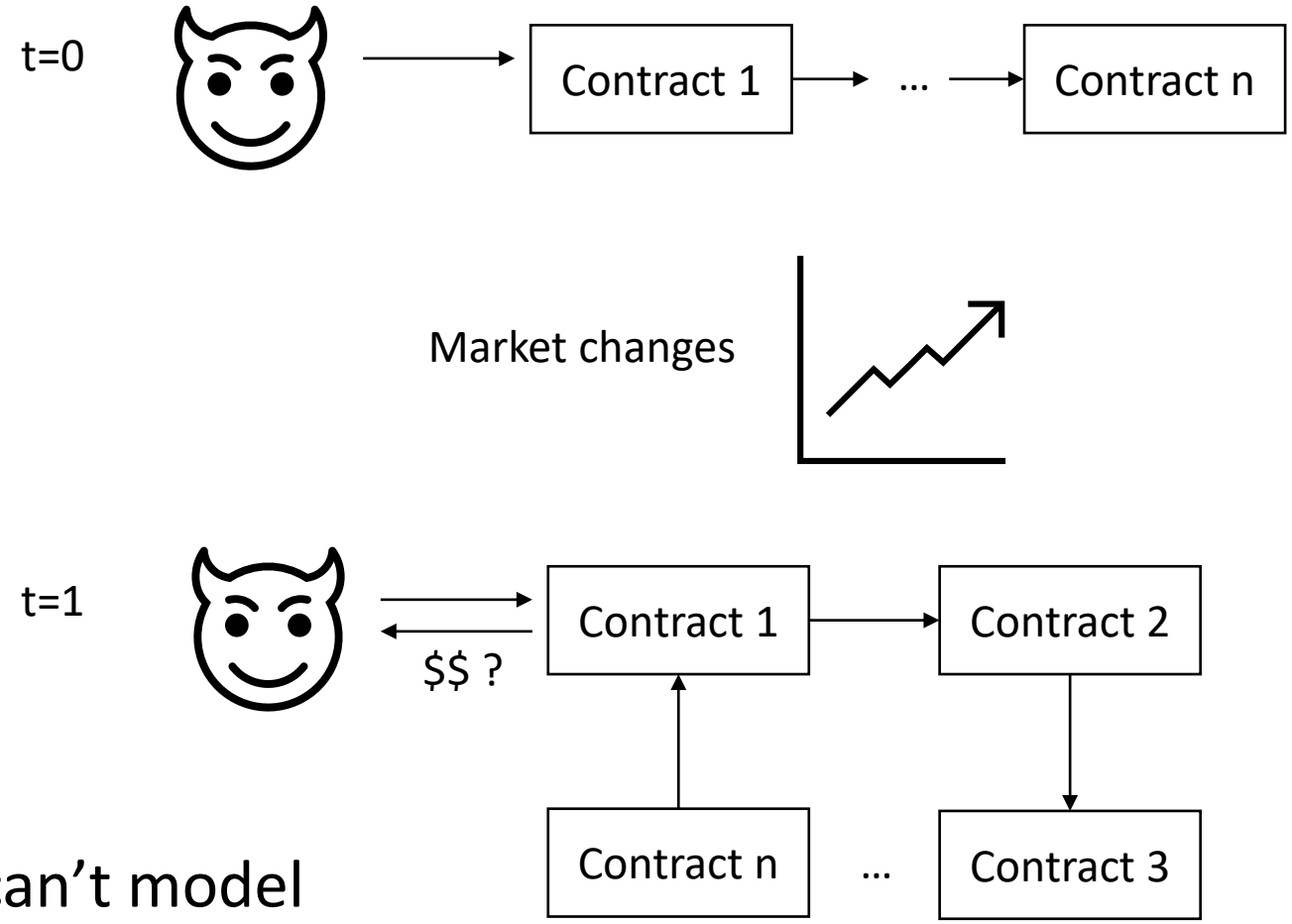
Formal model of contracts is 'enough'

- Can be hard CS problem to work out optimal attack

Technical vs Economic – what's different?

Economic exploit:

- Attacker performs multiple actions at different 'times'
- But doesn't control what happens between the actions
- No guarantee final action is profitable



Need models of markets, which we can't model exactly vs. formally verifying contract code

Technical vs Economic – a simple example

A technical exploit: a protocol uses the instantaneous AMM price as an oracle, and an attacker performs a (atomic) sandwich attack to steal assets

An economic exploit: a protocol uses a time-weighted average AMM price as an oracle. An attacker manipulates this price over time and may be able to steal assets

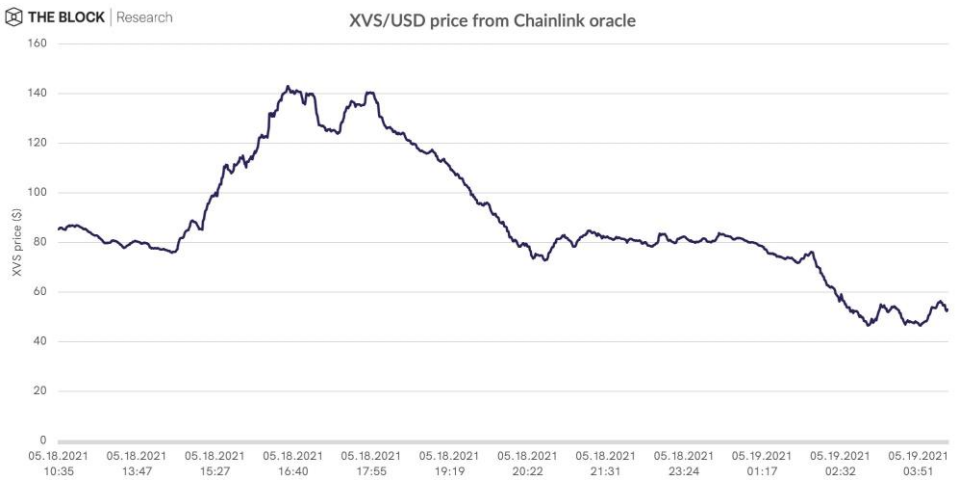
Example Economic Exploit

Illustration (not clear exploit): Nov 2020

DAI price increase led to a massive $88 million worth of liquidations at DeFi protocol Compound

May 2021: a clear exploit

Venus, BSC's largest lending platform, once again experienced problems. By manipulating the price of XVS, someone borrowed 4100BTC and 9600ETH, generated more than $100m in bad debts. Venus had similar loopholes before, and was loaned 3000 Bitcoins and 7000 ETH.



Overcollateralization as Security

Collateralization is a primary device to ensure economic security

- Overcollateralization is not without risks
- Persistent negative shocks to collateral prices can result in thin, illiquid markets, in which loans may become undercollateralized
- Unprofitable for liquidators to initiate liquidations
- Stablecoins can have deleveraging feedback effects that contribute to volatility (e.g., Dai on ‘Black Thursday’)

Miner Extractable Value

The value a miner can extract by deciding tx order and inclusion

- DeFi applications give rise to many new sources of MEV
  - DEXs present atomic arbitrage opportunities
  - Liquidation mechanisms (e.g., in stablecoins, PLFs) = arbitrage opportunities
  - MEV can arise when miners are incentivized to re-order or exclude transactions based on cross-chain payments
- Consensus layer risks if MEV > block reward
  - Can lead to undercutting and time bandit attacks

Governance Risks

Protocol governance introduces means upgrade systems

- Governance may not be incentive compatible, may not act in interest of protocol users
- If value of ‘honest’ gov cash flows crashes, region of incentive compatibility shrinks, may be more profitable for a coalition to attack the protocol
- Costs to attack can sometimes be low in DeFi: tokens can be borrowed and agents can be pseudo-anonymous

Market and Oracle Manipulation

We need to distinguish between (1) a market price that is manipulated yet correctly supplied by an oracle and (2) an oracle itself being manipulated

- Market Manipulation
  - An adversary may manipulate the market price (on-chain or off-chain) of an asset over a certain time period if a profit can be realized as a consequence of the price manipulation
  - Market manipulation problems persist even if the oracle is not an instantaneous AMM price
  - If there is high cost of market manipulation makes this risky
- Oracle manipulation
  - Centralized oracle as a single point of failure
  - On-chain AMM-based oracles can be manipulated
  - Decentralized oracle solutions are imperfect b/c can't 'verify' their correctness

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Open Challenges

1. Composability risks remain mostly unquantified
   - Program analysis: Tools do not embrace composable nature of smart contracts
2. Governance: Model incentive compatibility of governance in various systems with ‘governance extractable value’
   - Needs economic models, e.g., borrowing from corporate governance models
3. Oracles: How to structure oracle incentives to maintain incentive compatibility to report correct prices (vs attack protocols)
4. MEV: Quantify the full extent of MEV + quantify negative externalities (e.g., wasted gas, upward gas price pressure)
   - Hardness of intra-block (atomic) MEV: resemble knapsack but where set of items changes depending on current selection
   - Inter-block MEV (and cross-chain MEV): intertemporal version of this selection problem + market models/risk
5. Anonymity and privacy: understudied how to make private financial protocols

Conclusion

- DeFi has innovations and risks
- To fulfil vision of DeFi Optimist, DeFi needs to be *secure*
- Delineate security challenges
  - Technical Security
  - Economic Security
- Key distinctions: atomicity and type of models required