# Ethereum Mechanics

Ronghui Gu

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Columbia University

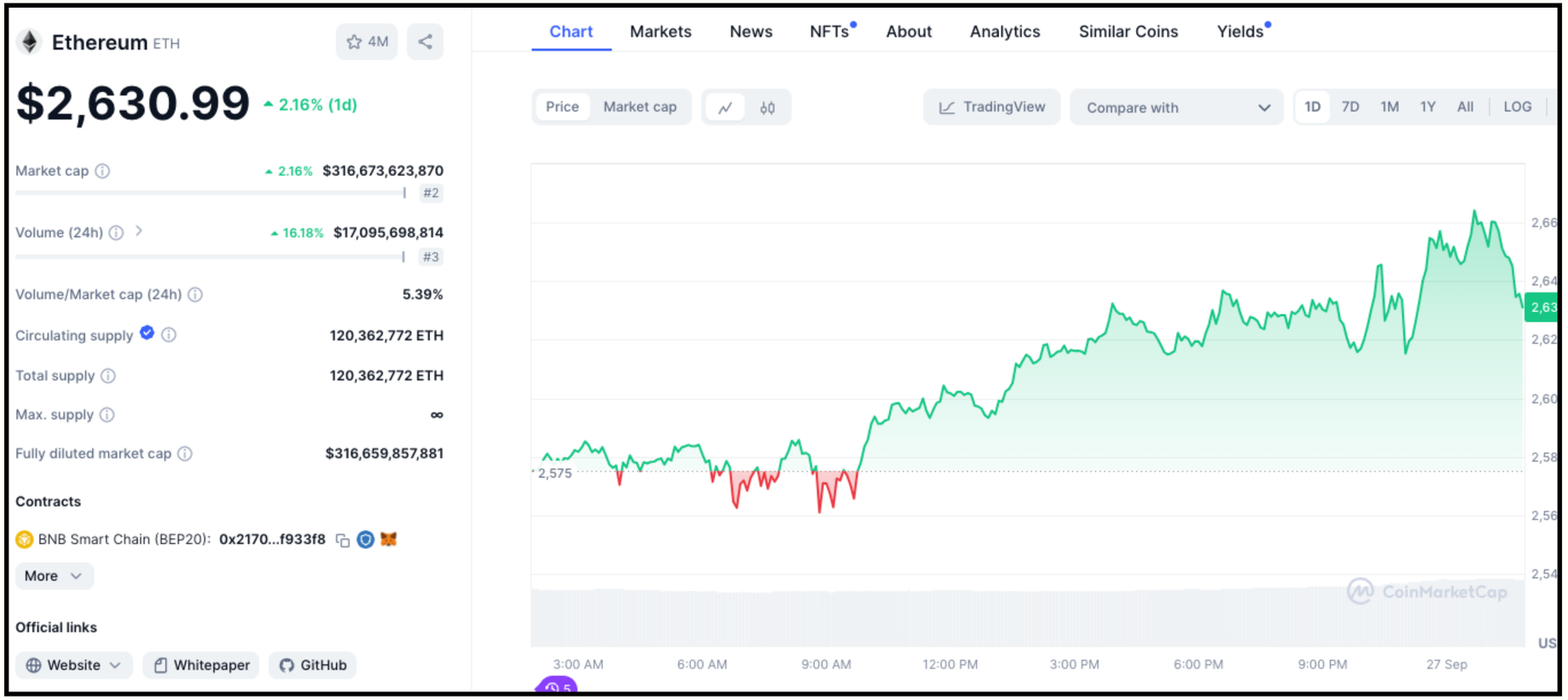
Course website: https://verigu.github.io/6998Fall2024/

# Ethereum

**Ethereum: A Next-Generation Smart Contract and Decentralized Application Platform.**
**By Vitalik Buterin (2014).**

When Satoshi Nakamoto first set the Bitcoin blockchain into motion in January 2009, he was simultaneously introducing two radical and untested concepts. The first is the "bitcoin", a decentralized peer-to-peer online currency that maintains a value without any backing, intrinsic value or central issuer. So far, the "bitcoin" as a currency unit has taken up the bulk of the public attention, both in terms of the political aspects of a currency without a central bank and its extreme upward and downward volatility in price. However, there is also another, equally important, part to Satoshi's grand experiment: the concept of a proof of work-based blockchain to allow for public agreement on the order of transactions. Bitcoin as an application can be described as a first-to-file system: if one entity has 50 BTC, and simultaneously sends the same 50 BTC to A and to B, only the transaction that gets confirmed first will process. There is no intrinsic way of determining

# ETH MarketCap



# 1 Limitations of Bitcoin

# Review of Bitcoin Script: P2PKH (Pay to Public Key Hash)

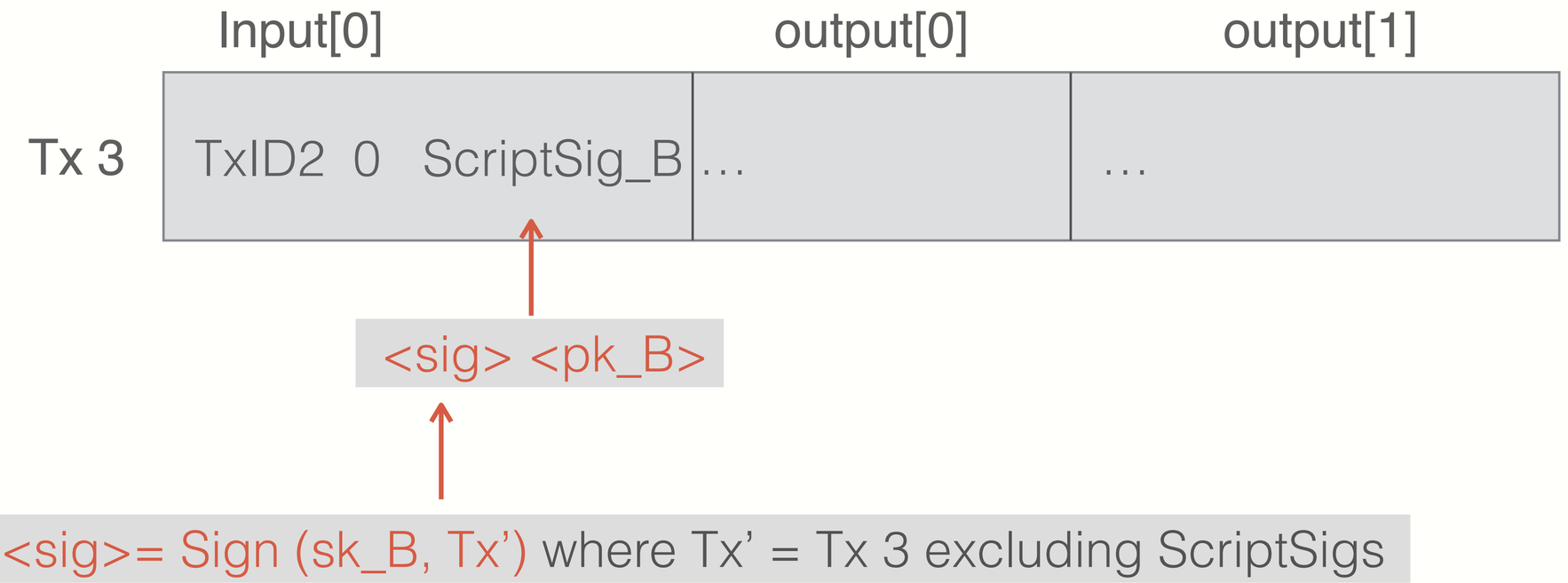
Alice want to pay Bob 5 BTC

- **Step1**: Bob generates key pair (pk_B, sk_B)
- **Step2**: Bob computes his BTC address as addr_B <— H(pk_B)
- **Step3**: Bob sends addr_b to Alice
- **Step4**: Alice broadcasts TX:


ScriptPK_B = **DUP HASH256** < addr_B > **EQVERIFY CHECKSIG**

# Review of Bitcoin Script: P2PKH (Pay to Public Key Hash)

Later, when Bob wants to spend his UTXO, he creates **Tx 3**



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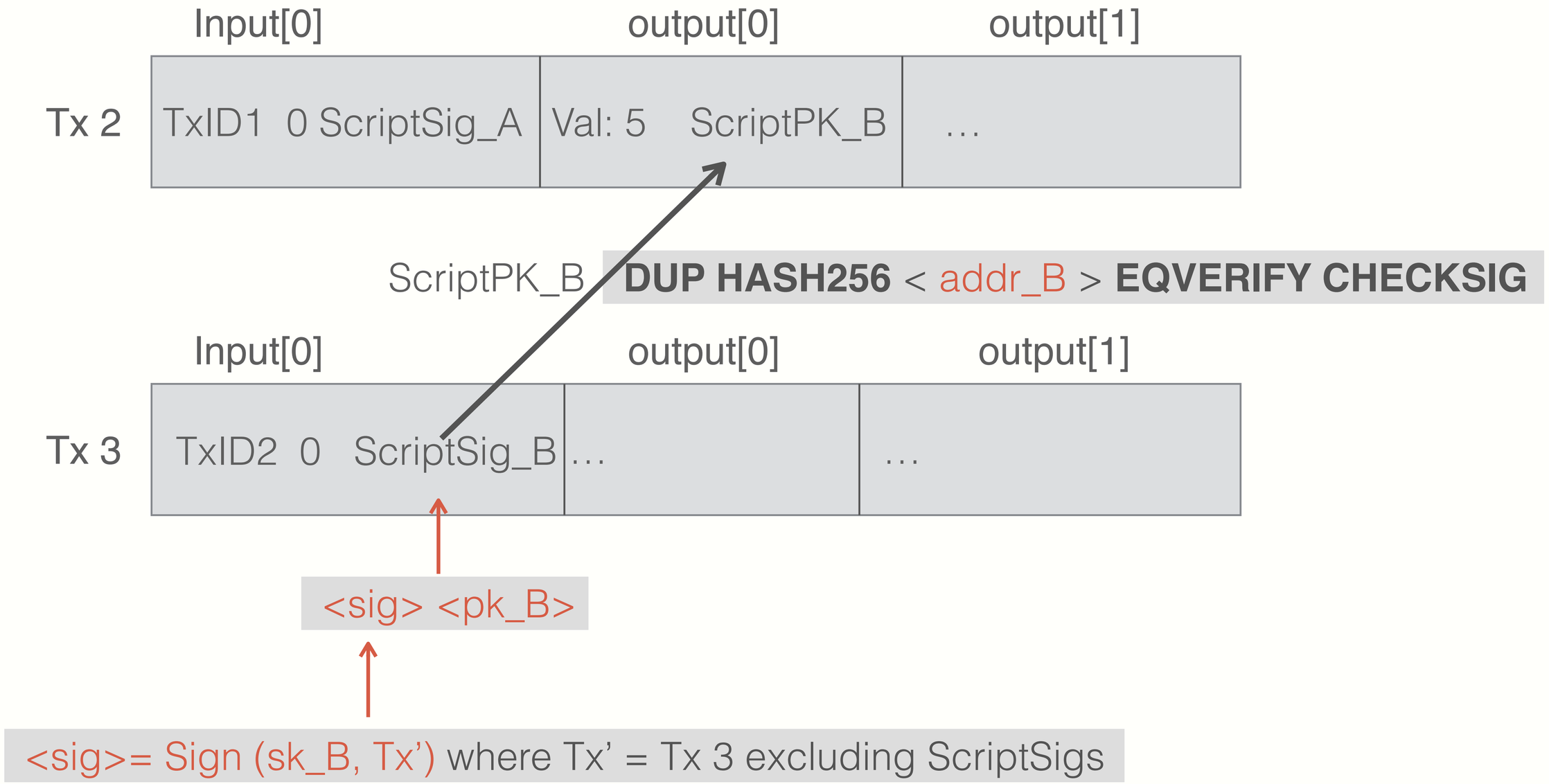


# Review of Bitcoin Script: P2PKH (Pay to Public Key Hash)

<sig> <pk_B> **DUP HASH256** <addr_B> **EQVERIFY CHECKSIG**

| **Stack** | |
|---|---|
| [ ] | Init |
| [ <sig> <pk_B> ] | Push values |
| [ <sig> <pk_B> <pk_B> ] | **DUP** |
| [ <sig> <pk_B> <addr_B> ] | **HASH256** addr_B <— H(pk_B) |
| [ <sig> <pk_B> <addr_B> <addr_B>] | Push values |
| [ <sig> <pk_B> ] | **EQVERIFY** |
| [ 1 ] | **CHECKSIG** <sig>= Sign (sk_B, Tx') |

# Limitations of Bitcoin

**UTXO contains (hash of) ScriptPK**

- Simple script: indicates conditions when UTXO can be spent
- UTXO matches outputs and inputs, but does not track states explicitly

**Limitations**

- Difficult to maintain state in multi-stage contracts
- Difficult to enforce global rules on assets
- Example: rate limiting
  - Desired policy: can only transfer 2BTC per day out of my wallet

# An Example: NameCoin

**Domain name system on the blockchain: [certik.com —> IP Addr]**

**Need support for three operations:**

- Name.new(OwnerAddr, DomainName): intent to register
- Name.update(DomainName, newVal, newOwner, OwnerSig)
- Name.lookup(DomainName)

# An Example: NameCoin

Name.new and Name.update create a UTXO with **ScriptPK**:

**DUP HASH256** <OwnerAddr> **EQVERIFY CHECKSIG VERIFY**
<NAMECOIN><DomainName> <IPAddr> <1>

only owner can spend this UTXO to update domain data:

**Contract**: if certik.com is registered, no on else can register the domain

**Problem**: this contract cannot be enforced just using Bitcoin script

# An Example: NameCoin

**Namecoin**: fork of Bitcoin that implements this contract

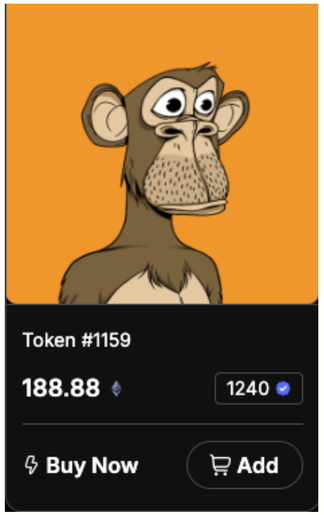
Can we build a blockchain that is programmable to support generic contracts?

ethereum

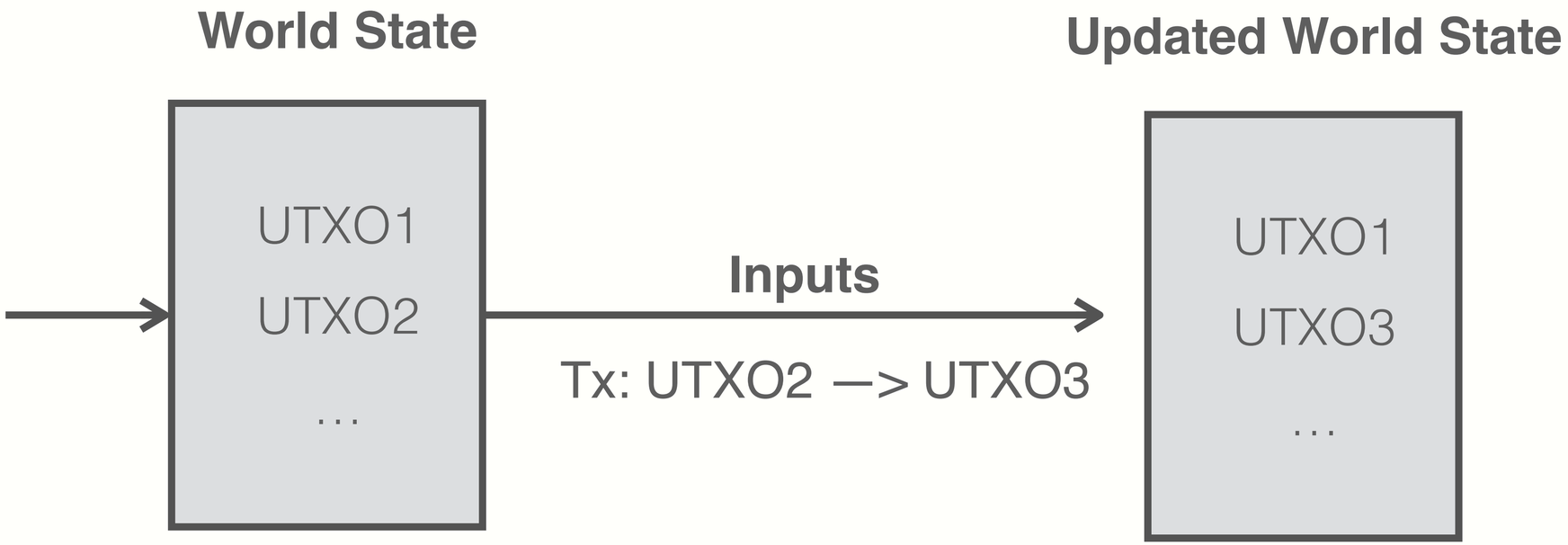
# 2 Ethereum

# Ethereum: Enables a World of  DApps

- New coins: ERC-20 Interface to DApps.
- DeFi: exchanges, lending, stablecoins, etc.
- NFTs: ERC-721 Interface to manage distinguished assets
- Games: assets managed on chain



# Bitcoin as a State Transition System



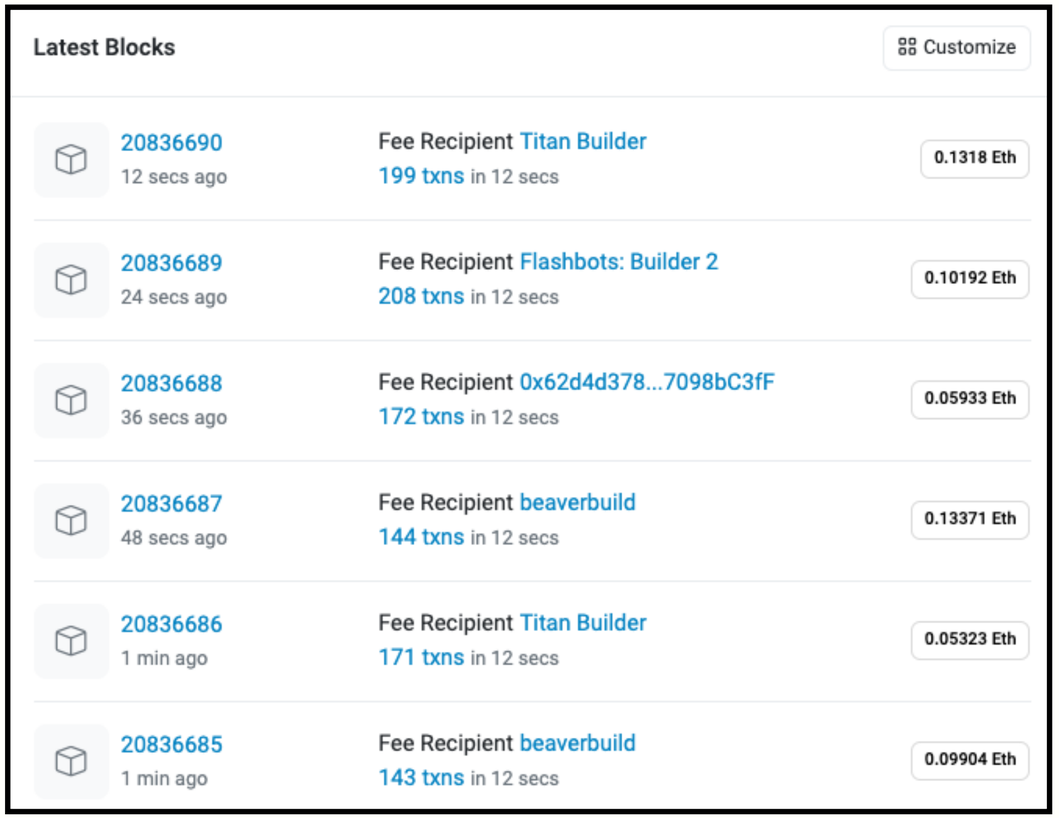
# Ethereum System

## Layer1 (ETHv1)

- PoW consensus
- Block reward = 2 ETH + Tx fees (gas)
- Avg block rate = 15s
- ~ 150 Tx per block

## ETHv2:

- PoS (Proof of Stake) consensus
- Sept 15, 2022



# Ethereum Compute Layer: the EVM

**World State:** set of accounts identified by 32-byte address

**Two types of accounts:**

- Owned accounts: controlled by signing key pair (PK, SK)
- Contracts: controlled by code
    - Code set at account creation time
    - Does not change

# Ethereum Compute Layer: the EVM

| Data | Owned | Contracts |
|---|---|---|
| **Address** | H(PK) | H(CreatorAddr, CreatorNonce) |
| **Code** | — | CodeHash |
| **State** | — | Storage Root |
| **Balance** | Balance | Balance |
| **Nonce** | Nonce | Nonce |

= #Tx sent + #accounts created

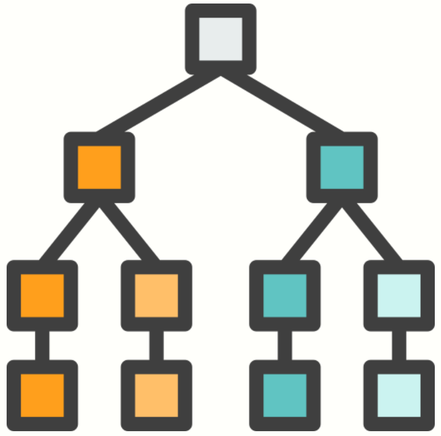
# Account State: Persistent Storage

Every contract has an associated **storage array S[]**:

- S[0], S[1], …, S[2^256 -1]: each cell holds 32 bytes, init to 0.

Account storage root: Merkle Patricia Tree hash of S[]:

- Why not directly using Merkel Tree hash?



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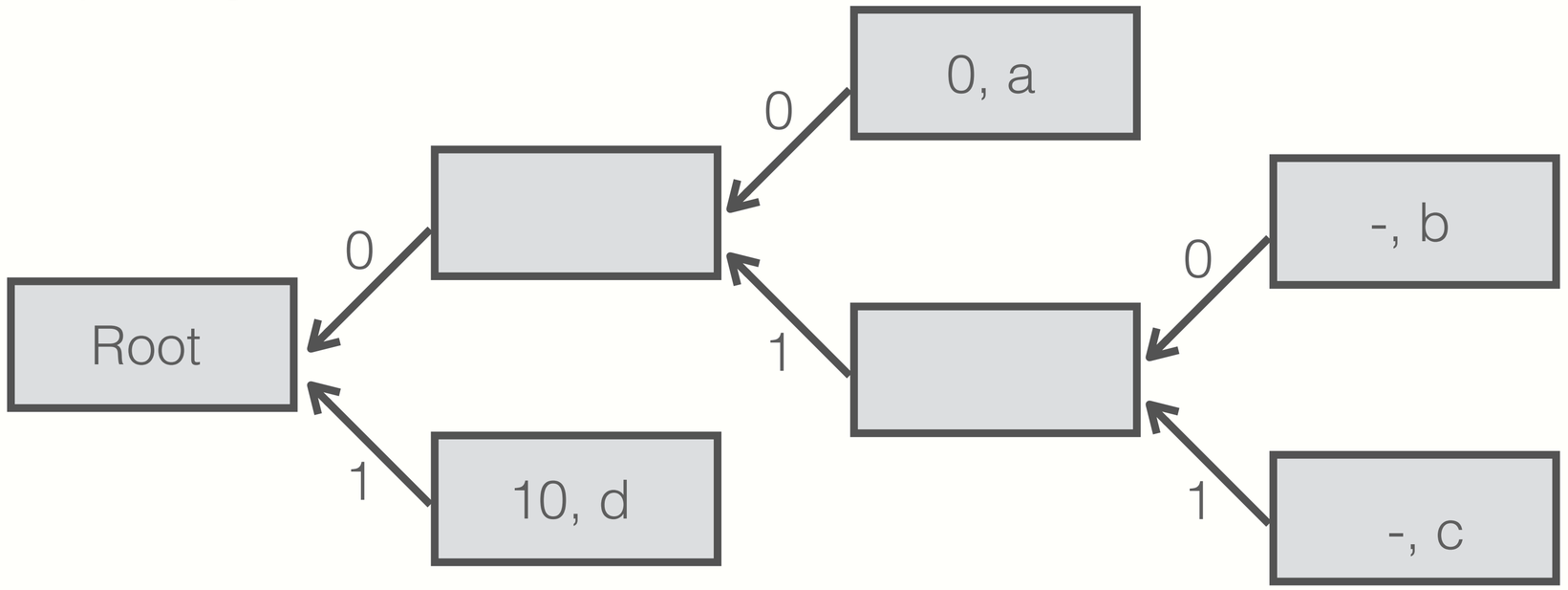
S[000] = a
S[010] = b
S[011] = c
S[110] = d



# State Transitions: Tx and Messages

**Transactions**: signed data by initiator

- **To**: 32-byte address of target (0 means creating new contract)
- **From, [Sig]**: initiator address and [signature on Tx if owned accounts]
- **Value**: #Wei being sent with Tx
- **Tx fees** (EIP 1559): gasLimit, maxFee, maxPriorityFee
- **Code** (If To = 0): (init, body)
- **Data** (If To != 0): what function to call and args
- **Nonce**: must match current nonce of sender
  - Preventing Tx replay

# State Transitions: Tx and Messages

## Transaction Types

- Owned -> Owned: transfer ETH between users
- Owned -> Contract: call contract with ETH and data

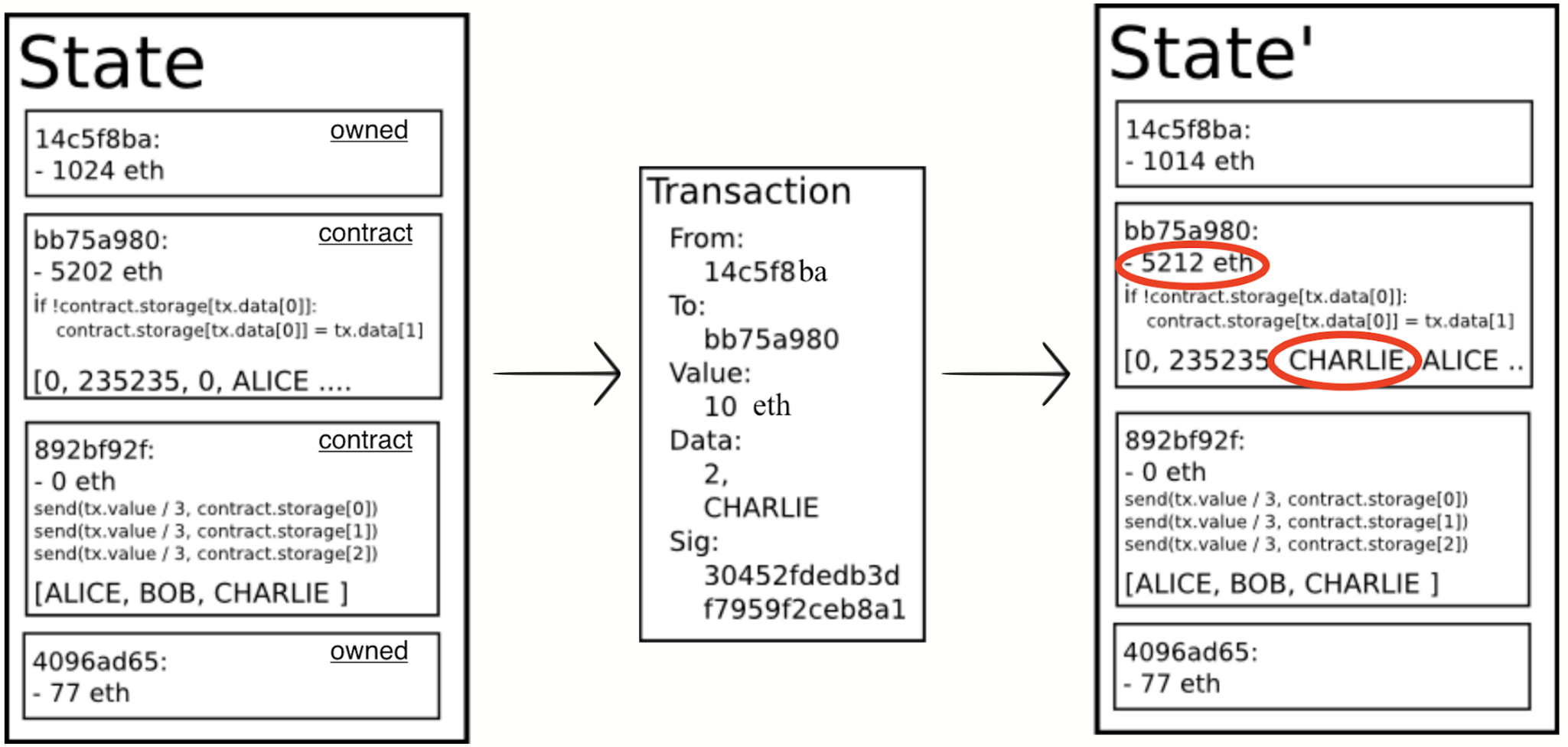
**Messages:** same as Tx, but no signature

- Contract -> Owned: contracts sends funds users
- Contract -> Contract: one program calls another (and sends funds)

**One Tx from user:** can lead to many Tx and messages

- Tx from Owned -> Contract -> another Contract -> Different Owned

# State Transitions: Tx and Messages



# An Ethereum Block

**Miners:** collect Txs from users

- For each Tx, execute state change sequentially
- Record updated world state in block

**Leader:** creates a block

**Other miners**: re-execute all Txs to verify the block

- Miners should only build on a valid block
- Miners are not paid for verifying block

# Block Header Data (Simplified)

**Consensus data:** Prev hash, difficulty, PoW solution, etc

**Address of gas beneficiary:** where Tx fees will go

**World state root**: updated world state

- Merkle Patricia Tree has of all accounts in the system

**Tx root**: Merkel hash of all Tx in the block

**Tx receipt root**: Merkel hash of log messages generated in the block

**Gas used**: tells verifier how much work to verify block

# 3 Ethereum Contracts

# An Example Contract: NameCoin

```
contract nameCoin {    // Solidity code

    struct nameEntry {

        address owner; // address of domain owner
        bytes32 value;  // IP address

    }

    // array of all registered domains

    mapping (bytes32 => nameEntry) data;
```

# An Example Contract: NameCoin

```
function nameNew (bytes32 name)  {
    // registration costs is 100 Wei
    if (data[name] == 0 && msg.value >= 100) {
        data[name].owner = msg.sender;   // record domain owner
        emit Register(msg.sender, name);  // log event
    }
}
```

# An Example Contract: NameCoin

```
function nameUpdate (
                    bytes32 name,  bytes32 newValue, address newOnwer)  {
    // check if message is from domain owner, and update if 10Wei is paid
    if (data[name].owner == msg.sender && msg.value >= 10) {
        data[name].value = newValue;      // record new value
        data[name].owner = newOwner;   // record new owner
    }
}
```

# An Example Contract: NameCoin

```
    function nameLookup (bytes32 name)  {

        return data[name];

    }

} // end of contract
```

# EVM Mechanics: Execution

Write code in **Solidity** (or another front-end language)

=> Compile to EVM bytecode

=> Miners use the EVM to execute contract bytecode

# The EVM

## Stack machine with JUMP

- Max stack depth = 1024
- Program aborts if stack size exceeds; miner keeps gas
- Contract can create or call another contract

## Two types of zero initialized memory

- Persistent storage (on blockchain): SLOAD, SSTORE (expensive)
- Volatile memory (for single Tx): MLOAD, MSTORE (cheap)
- LOG0(data): write data to log

# Every Instruction Costs Gas

**SSTORE addr** (32bytes)**, value** (32bytes)

- Zero -> Non-Zero: 20,000 gas
- Non-Zero -> Non-Zero: 5,000 gas (for a cold slot)
- Non-Zero -> Zero: 15,000 gas refund

**Refund:** is given for reducing size of blockchain state

# Every Instruction Costs Gas

**SELFDESTRUCT addr** (32bytes)

- Kill current contract
- In the past, 24,000 gas refund

**CREATE**

- 32,000 + 200 * (code size) gas

# Gas Calculation

**Why charge gas?**

- Prevents submitting Tx that runs for many steps
- During high load: miners choose Tx from the mempool with high gas

**Old EVM (prior to EIP 1559)**

- Every Tx contains a gasPrice “bid” (gas -> Wei conversion price)
- Miners choose Tx with highest gasPrice
  - First price auction
  - Not efficient

# Gas Calculation (EIP 1559)

**Every block has a “baseFee”:**

- The minimum gasPrice for all Tx in the block

**baseFee is computed from total gas in earlier blocks:**

- If earlier blocks as “target size” (15M gas) => baseFee does not change
- If earlier blocks at gas limit (30M gas) => baseFee goes up 12.5%
- If earlier blocks empty => baseFee decreases by 12.5%

# Gas Calculation (EIP 1559)

**EIP1559 Tx specifies three parameters:**

- **gasLimit**: max total gas allowed for Tx
- **maxFee**: max allowed gasPrice
- **maxPriorityFee:** additional “tip” to be paid to miner
- gasPrice = min (maxFee, baseFee + maxPriorityFee)

# Let’s Look at a Transition

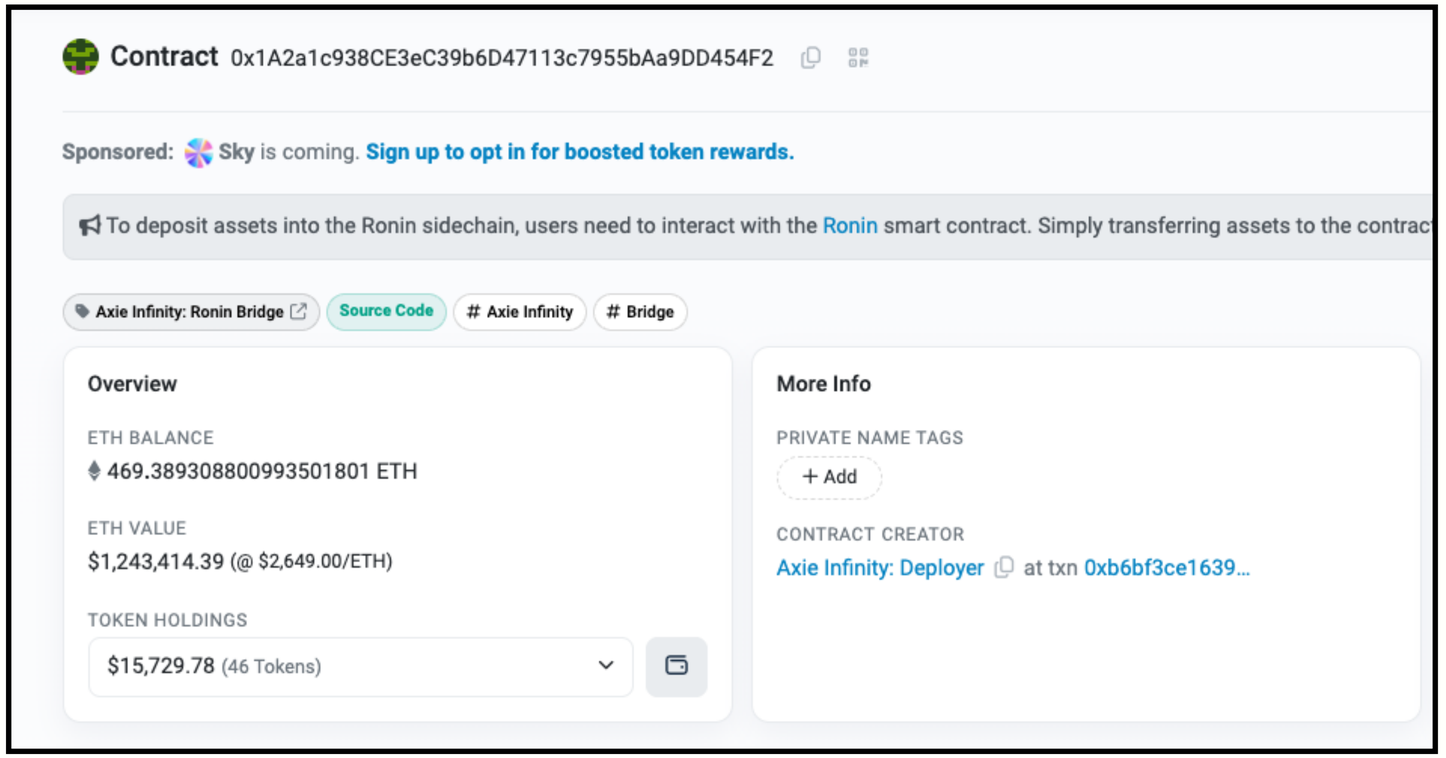
**Transaction ID:** 0xe3b0c810424edca4d07a00a84…

- **From**: 0x628ebe4e3fe7386da04a6f9a37ccb5e980c22ffc
- **To**: Contract 0x1a2a1c938ce3ec39b6d47113c7955baa9dd454f2
  - (Axie Infinity: Ronin Bridge)
- **Value:** 0.167 Ether
- **Data:** Function: depositEthFor [0]: d256119bb3ca86c7c9fcda4daba95bd233150e6

# Let’s Look at a Transition

**Contract:** 0x1a2a1c938ce3ec39b6d47113c7955baa9dd454f2

- (Axie Infinity: Ronin Bridge)



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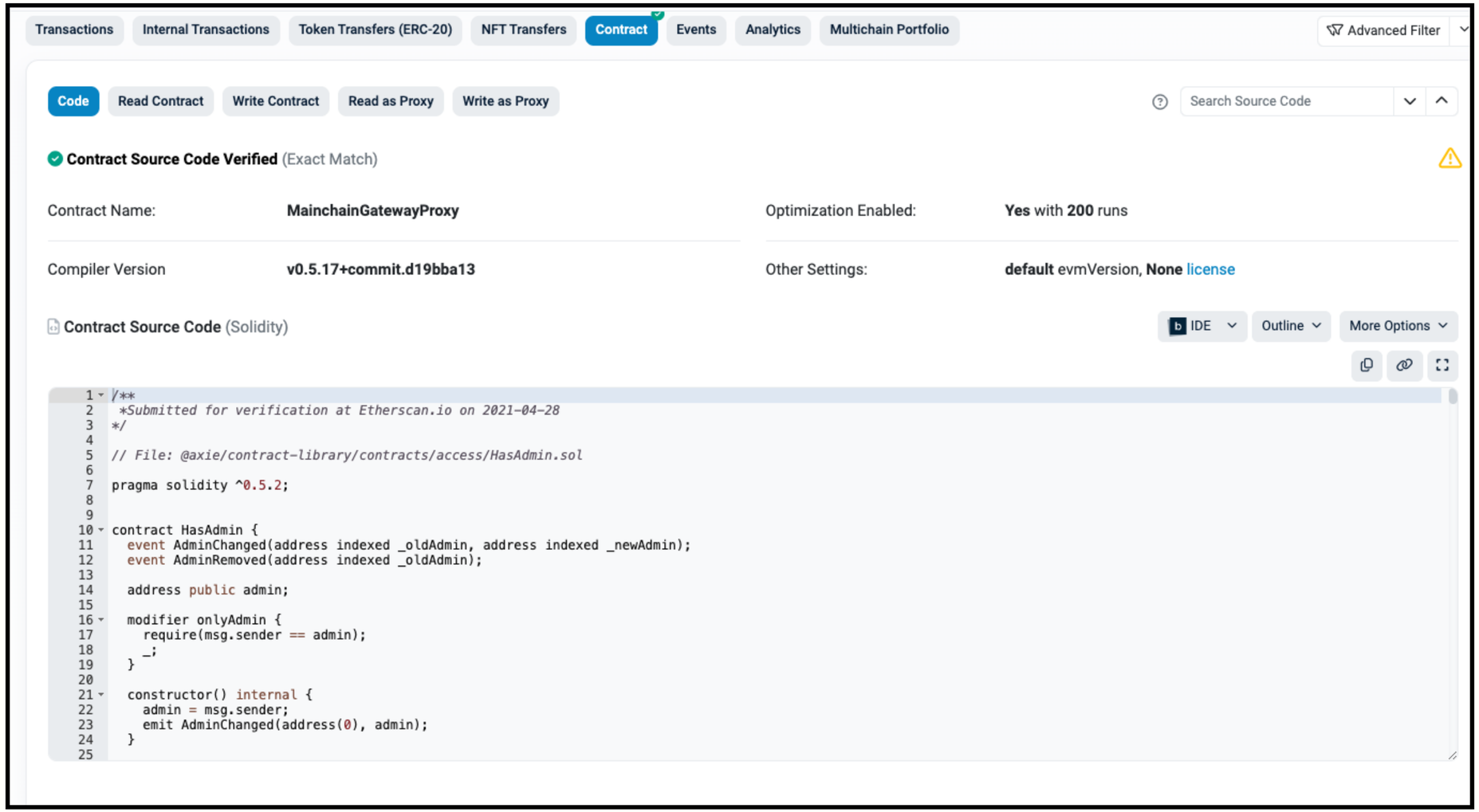

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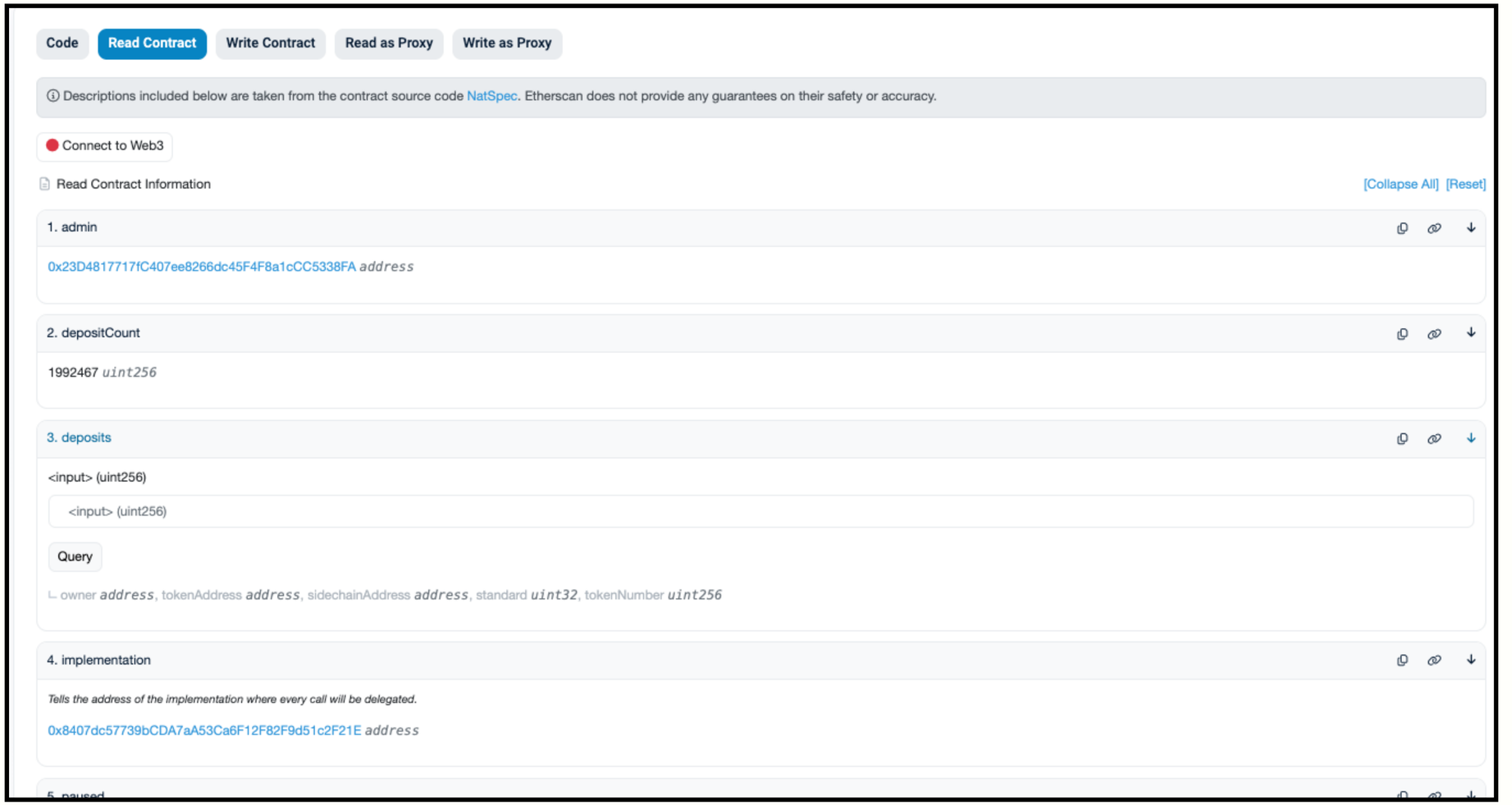

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## Discussion Session

How to raise funds?