

Emerging Technologies for the Circular Economy

Lecture 10: Ethereum and Smart Contracts

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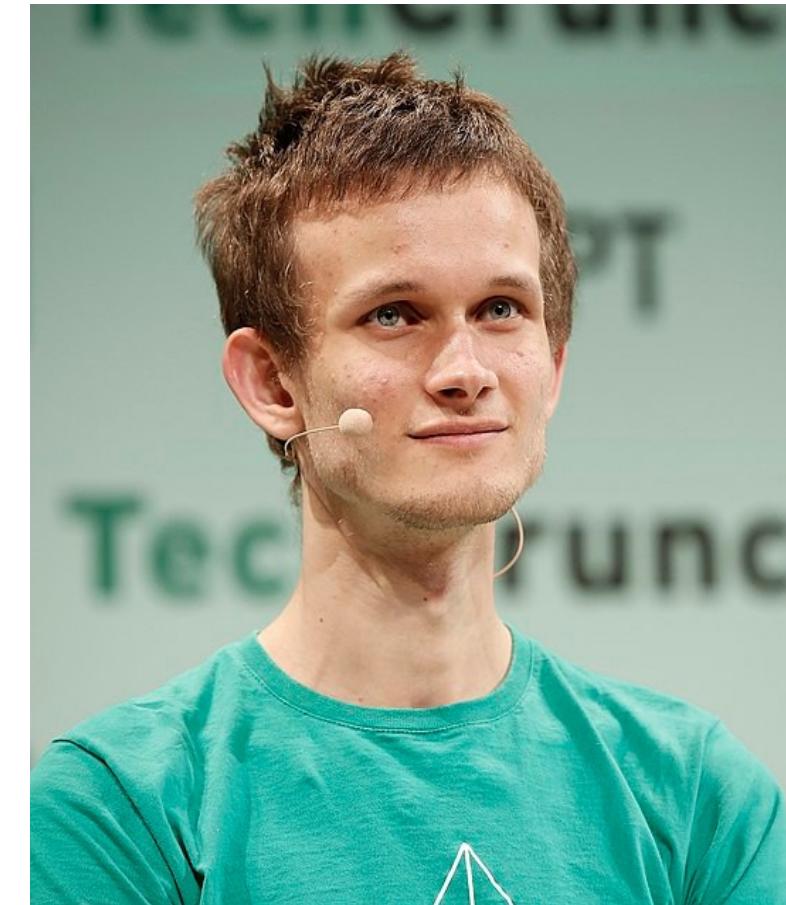
Disclaimer and Further Resources

- The lecture slides (Figures are often copied directly) are based on the course Blockchain-based Systems Engineering from TU Munich, which is distributed under a CC-BY-SA 4.0 license
- All their slides, exercises and further information are available online:
<https://github.com/sebischair/bbse>

INTRODUCTION TO ETHEREUM

History

- Publicly announced in January 2014 by Vitalik Buterin
- Public crowd sale in July 2014
 - 60 million Ether sold for 31,591 Bitcoin
 - Worth around 18.5 million USD at that time
 - Funds controlled by the Ethereum foundation



"Founder of Ethereum Vitalik Buterin during TechCrunch Disrupt London 2015 - Day 2 at Copper Box Arena on December 8, 2015 in London, England." by John philps is licensed under [CC BY 2.0](#).
History of Ethereum: <http://ethdocs.org/en/latest/introduction/history-of-ethereum.html>

Ethereum Foundation



*“The Ethereum Foundation’s **mission is to promote and support Ethereum platform and base layer research, development and education** to bring decentralized protocols and tools to the world that empower developers **to produce next generation decentralized applications** (dApps), and together build a more globally accessible, more free and more trustworthy Internet.”*

Ethereum Foundation

- Founded in June 2014 in Zug, Switzerland
- Non-profit organization
- Foundation council consists of Vitalik Buterin and Patrick Storchenegger (legal affairs)
- Owns (or owned) at least 31,591 Bitcoins funding capital from the initial crowd sale

Ethereum White Paper

- First draft was written by Vitalik Buterin himself (2013)
- Contains high-level descriptions of Ethereum's core functionalities
- Living document and regularly updated by Ethereum core developers
- Extensive summary of the Ethereum platform and technology
- Most current version is available via the public Git-repository: [Link](#)

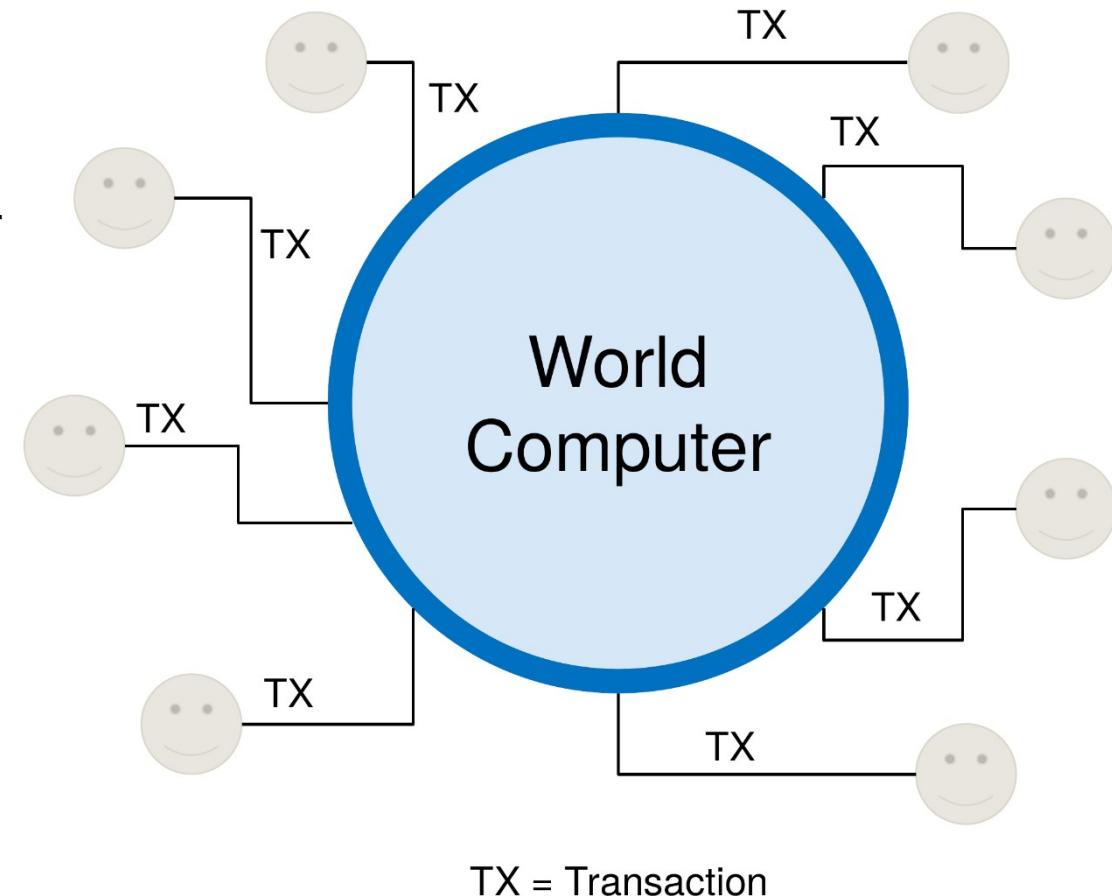
Ethereum Yellow Paper

- Published in April 2014 by Dr. Gavin Wood
- Dr. Gavin Wood is still listed as the only author
- Defines the technical specification of Ethereum
- Very detailed, contains mathematical function definitions and byte code mappings
- Required to implement a full node
- Only updated when errors are found or the specification changes
- [Yellow Paper](#)

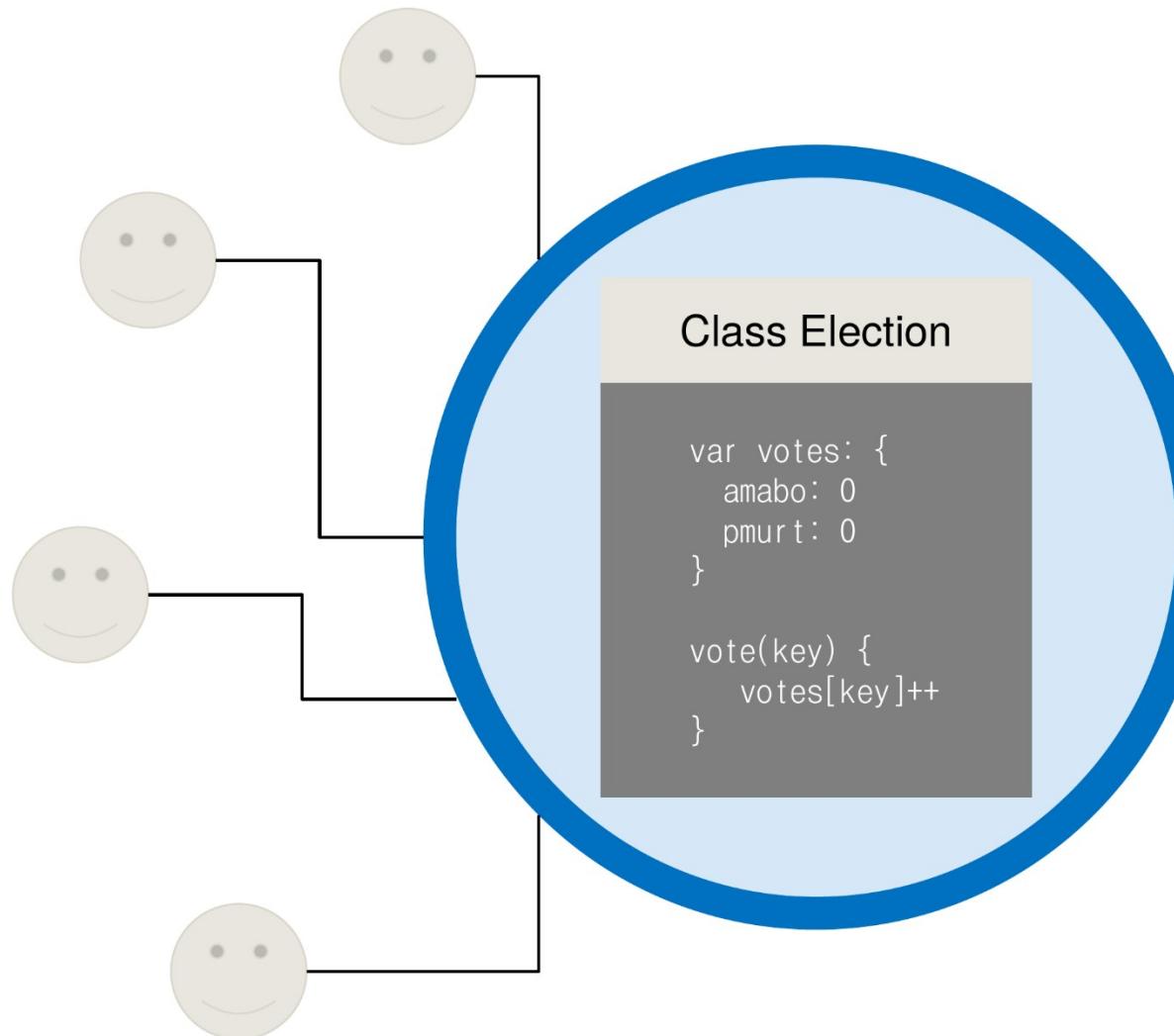
ETHEREUM SYSTEM ARCHITECTURE

The Concept of a World Computer

- All participants are using the same computer
- Users issue transactions to call programs on the computer
- Everyone shares the same resources and storage
- The computer has no explicit, single owner
- Using the computer's resources costs money



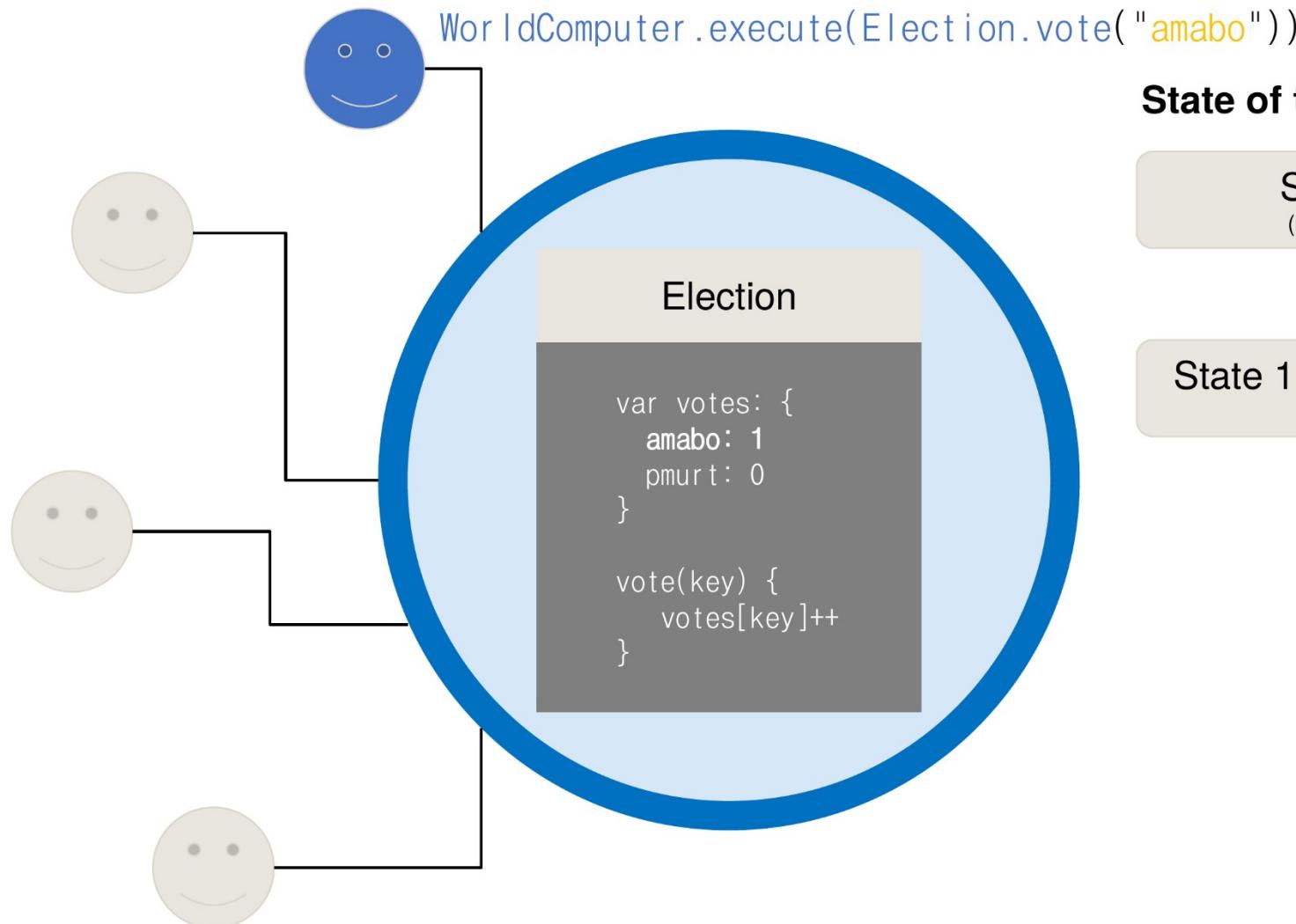
Elections using a World Computer



State of the world

State 0 (initial)
(nothing happened yet)

Elections using a World Computer

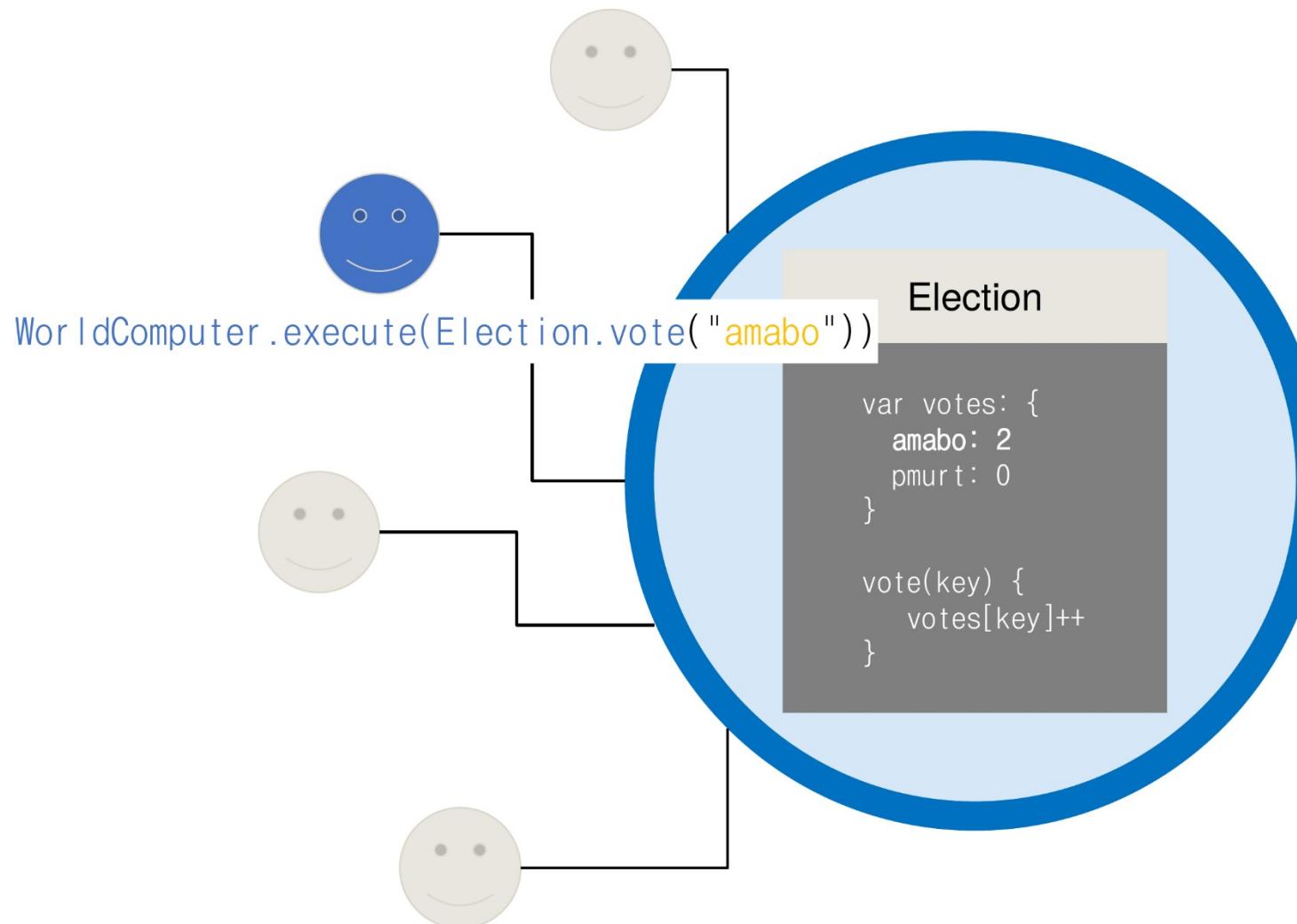


State of the world

State 0 (initial)
(nothing happened yet)

State 1 {amabo:1, pmurt:0}
(vote for amabo)

Elections using a World Computer



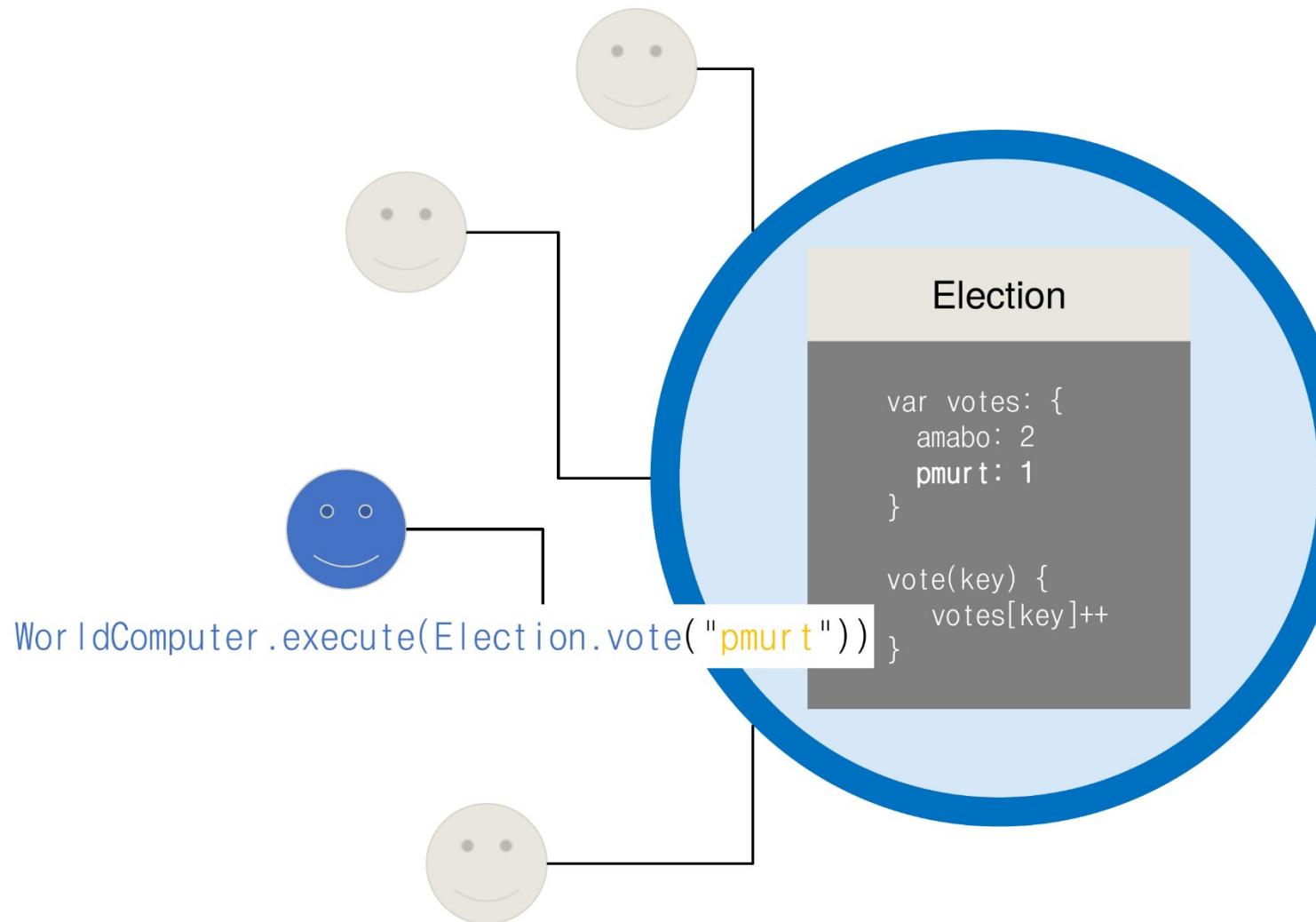
State of the world

State 0 (initial)
(nothing happened yet)

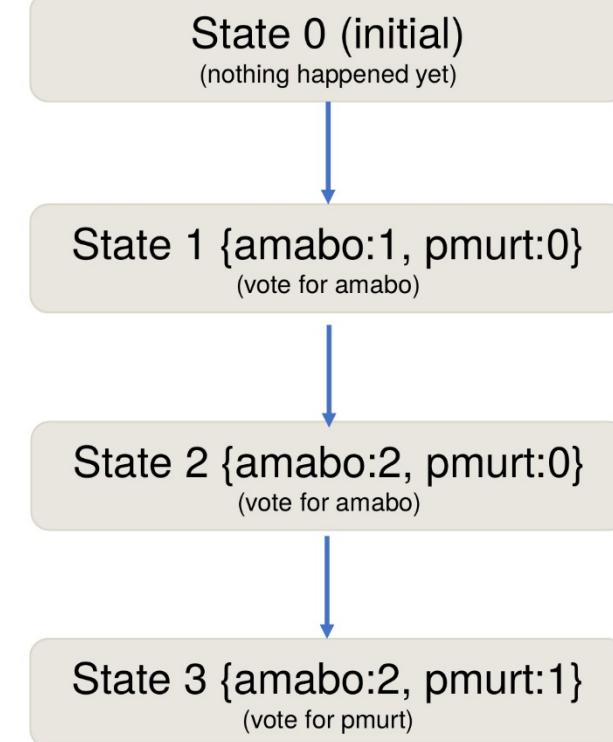
State 1 {amabo:1, pmurt:0}
(vote for amabo)

State 2 {amabo:2, pmurt:0}
(vote for amabo)

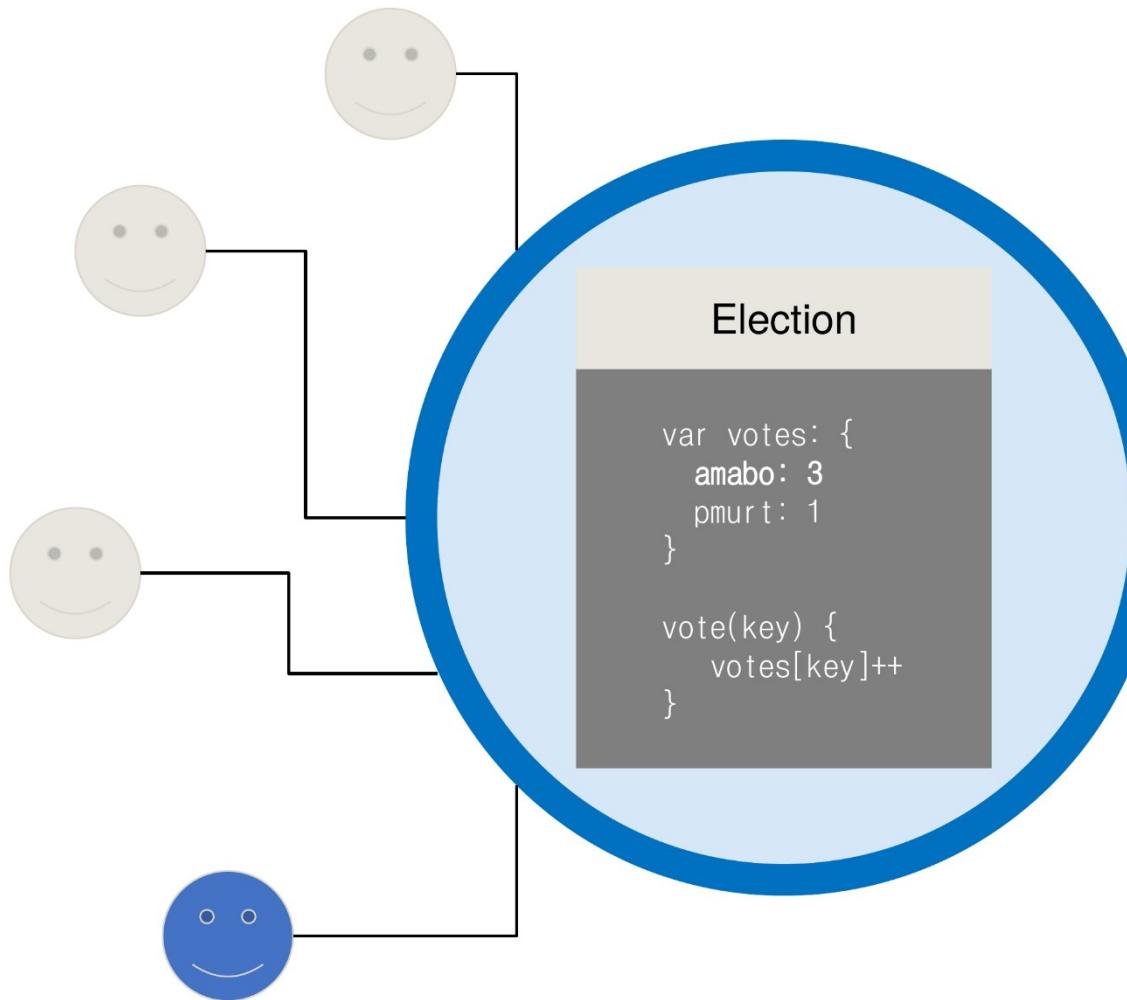
Elections using a World Computer



State of the world

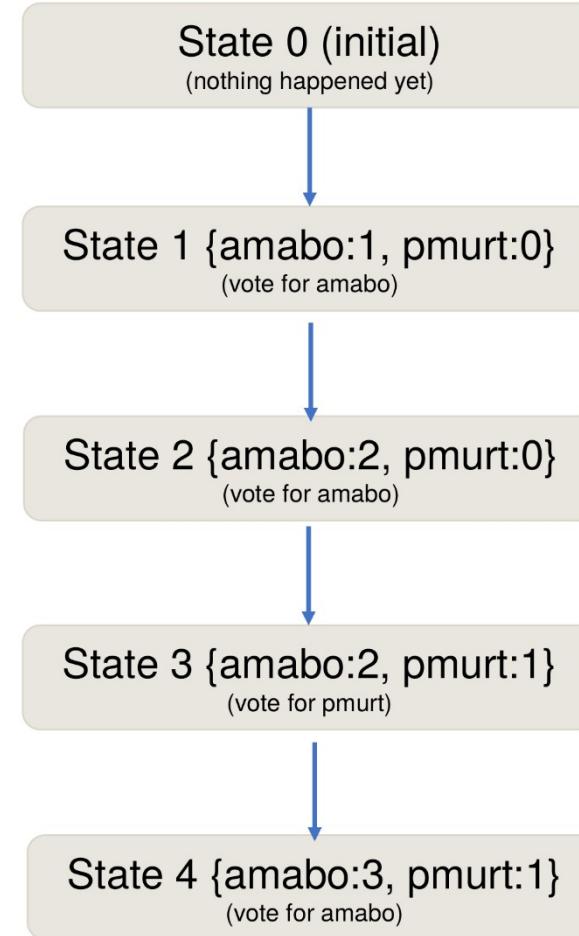


Elections using a World Computer



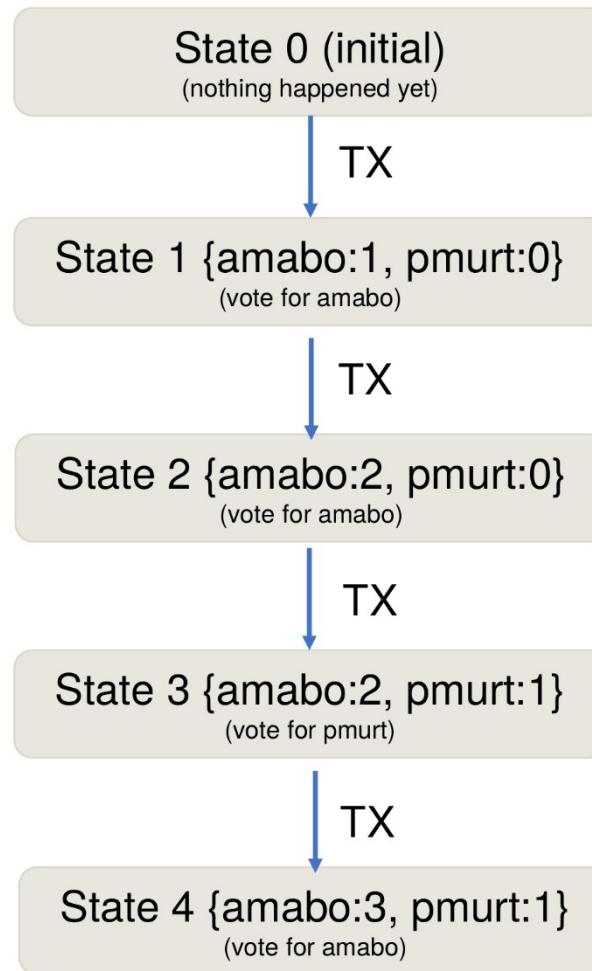
`WorldComputer.execute(Election.vote("amabo"))`

State of the world

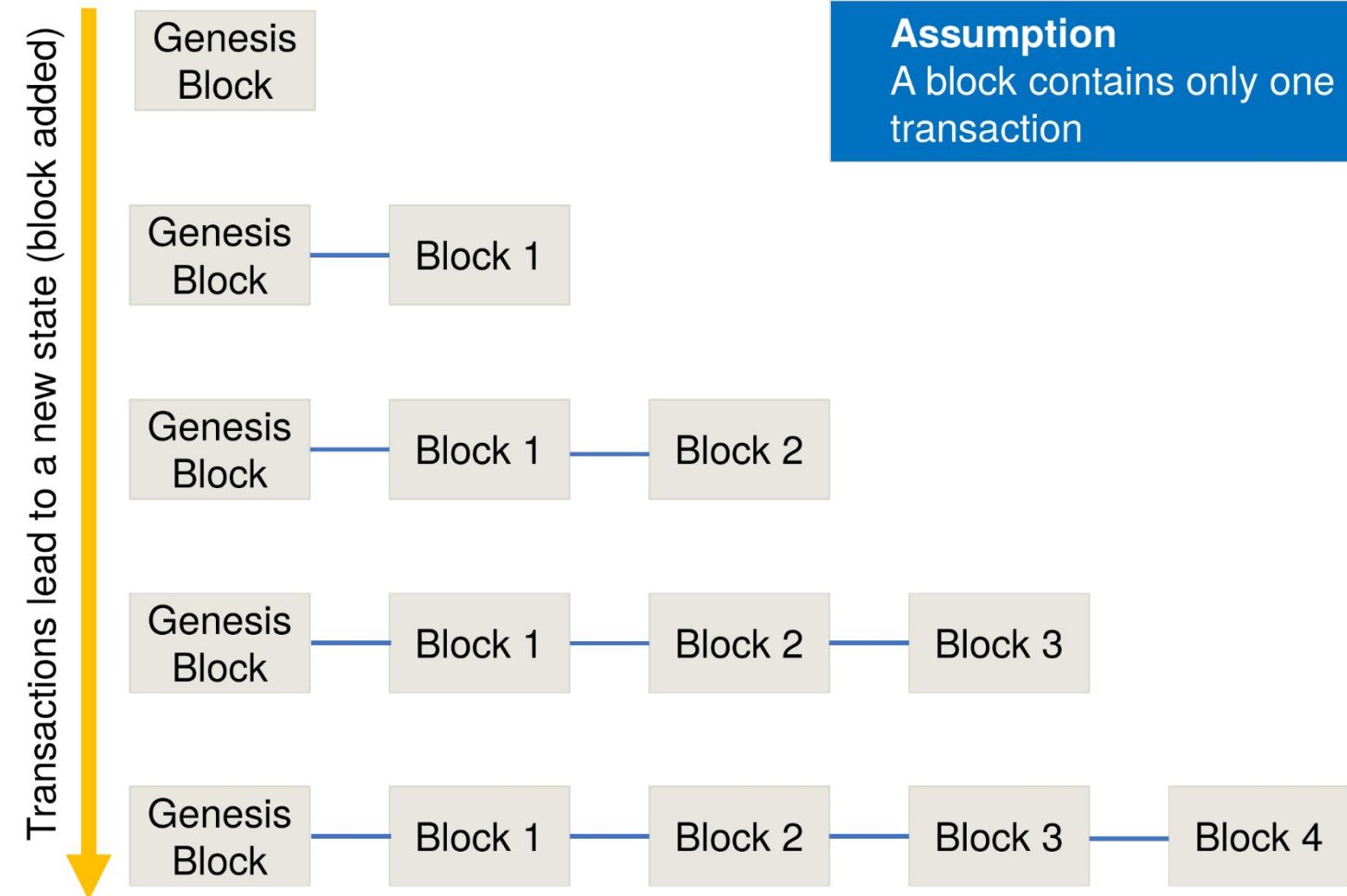


The Blockchain State Machine

State of the world

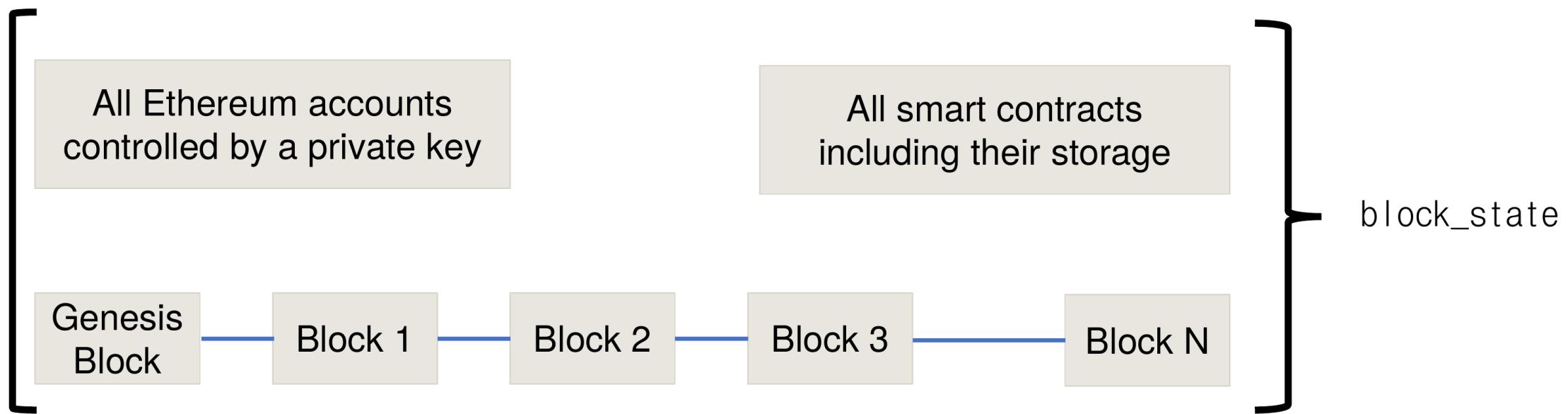


Blockchain



The Concept of a State Machine

- The EVM specifies an execution model for state changes of the blockchain
- Formally, the EVM can be specified by the following tuple: (block state, transaction, message, code, memory, stack, pc, gas)
- The block state represents the global state of the whole blockchain including all accounts, contracts and storage



Transaction

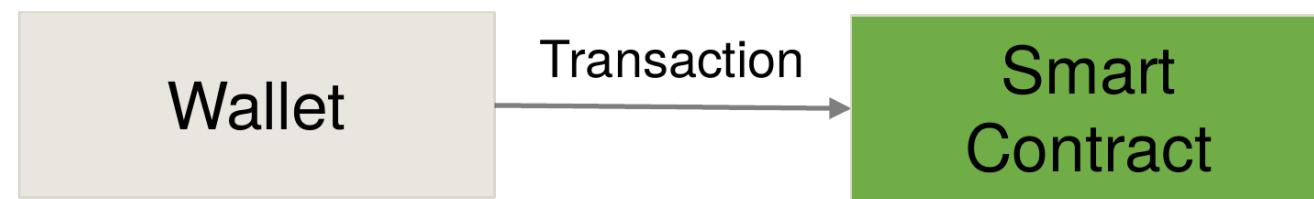
A transaction is a signed data package that is always sent by a wallet and contains the following data:

- Recipient
- Sender's signature
- Amount of ETH to transfer
- Optional data field
- A *STARTGAS* value, representing the maximum number of computational steps the transaction execution is allowed to take
- A *GASPRICE* value, representing the fee the sender pays per computational step

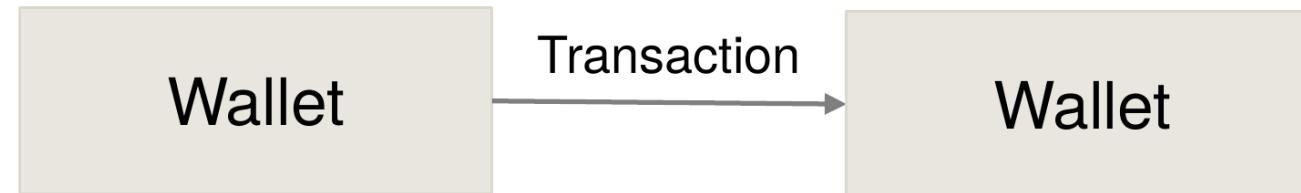
Transactions

- There are two types of transactions:

Type 1: Wallet to Smart Contract



Type 2: Wallet to Wallet



Messages

- Similar to a transaction, but only sent by contracts and exist only virtually, i.e. they are not mined into a block like transactions
- Message contains:
 - Sender of the message (implicit)
 - Recipient
 - Amount of ETH to be transferred
 - Optional data field
 - STARTGAS value

Messages

- Whenever a contract calls a method on another contract, a virtual message is sent.
- Whenever a wallet calls a method on a contract, a transaction is sent.



Code and Memory

■ Code:

- Bytecode representation of a smart contract.
EVM interprets smart contracts as a sequence
of opcodes similar to assembly code.

Example:

PUSH1 0x60

PUSH1 0x40

MSTORE

PUSH1 0x04

CALLDATASIZE

LT

PUSH2 0x00b6

JUMPI

PUSH4 0xffffffff

Code and Memory

- Code:
 - Bytecode representation of a smart contract.
EVM interprets smart contracts as a sequence of opcodes similar to assembly code.
- Memory:
 - An infinitely expandable byte array that is non-persistent and used as temporal storage during execution.

Example:

PUSH1 0x60
PUSH1 0x40
MSTORE
PUSH1 0x04
CALLDATASIZE
LT
PUSH2 0x00b6
JUMPI
PUSH4 0xffffffff

Stack and Program Counter

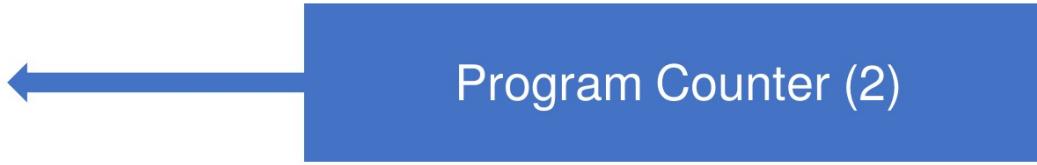
- Stack:
 - The stack is also used as a fast, non-persistent buffer to which 32 byte values can be pushed and popped during execution.

- PC:
 - Stands for “program counter”.
 - The program counter is always initialized with 0 and points to the position of the current opcode instruction.

Stack and Program Counter

Simple Opcode Execution Example:

0	<i>PUSH1 0x60</i>
1	<i>PUSH1 0x40</i>
2	<i>MSTORE</i>
3	<i>PUSH1 0x04</i>
4	<i>CALLDATASIZE</i>
5	<i>LT</i>
6	<i>PUSH2 0x00b6</i>
7	<i>JUMPI</i>
8	<i>PUSH4 0xffffffff</i>



Gas

- Executed opcode instruction use miner's computational resources → requires a fee (called gas)
- Each opcode uses a certain amount of gas which may depend on the arguments of the operation
- Opcode for self-destruct(address) uses negative gas because it frees up space from the blockchain
- Sender must specify maximum amount of gas that he/she/it is willing to pay for the transaction
- Sender can set an arbitrary amount of Ether to be spent → called gas price
- Final costs for transaction → $\text{gas} \times \text{gasprice}$
- If a transaction requires more gas as the maximum specified gas, the transaction fails
- If it takes less, the sender only pays the gas that was used

Account Types

Ethereum uses an account-based ledger → Each distinct address represents a separate, unique account.

1. Accounts controlled by private keys and owned externally
 - Can sign transactions, issue smart contract functions calls and send Ether from one account to another
 - Origin of any transaction is always an account controlled by a private key
2. Smart contract accounts controlled by their code
 - Smart Contracts are treated as account entities with their own, unique address
 - Can send messages to other accounts, both externally controlled and smart contracts
 - Can't issue a transaction themselves.
 - Have a persistent internal storage to write and read data from

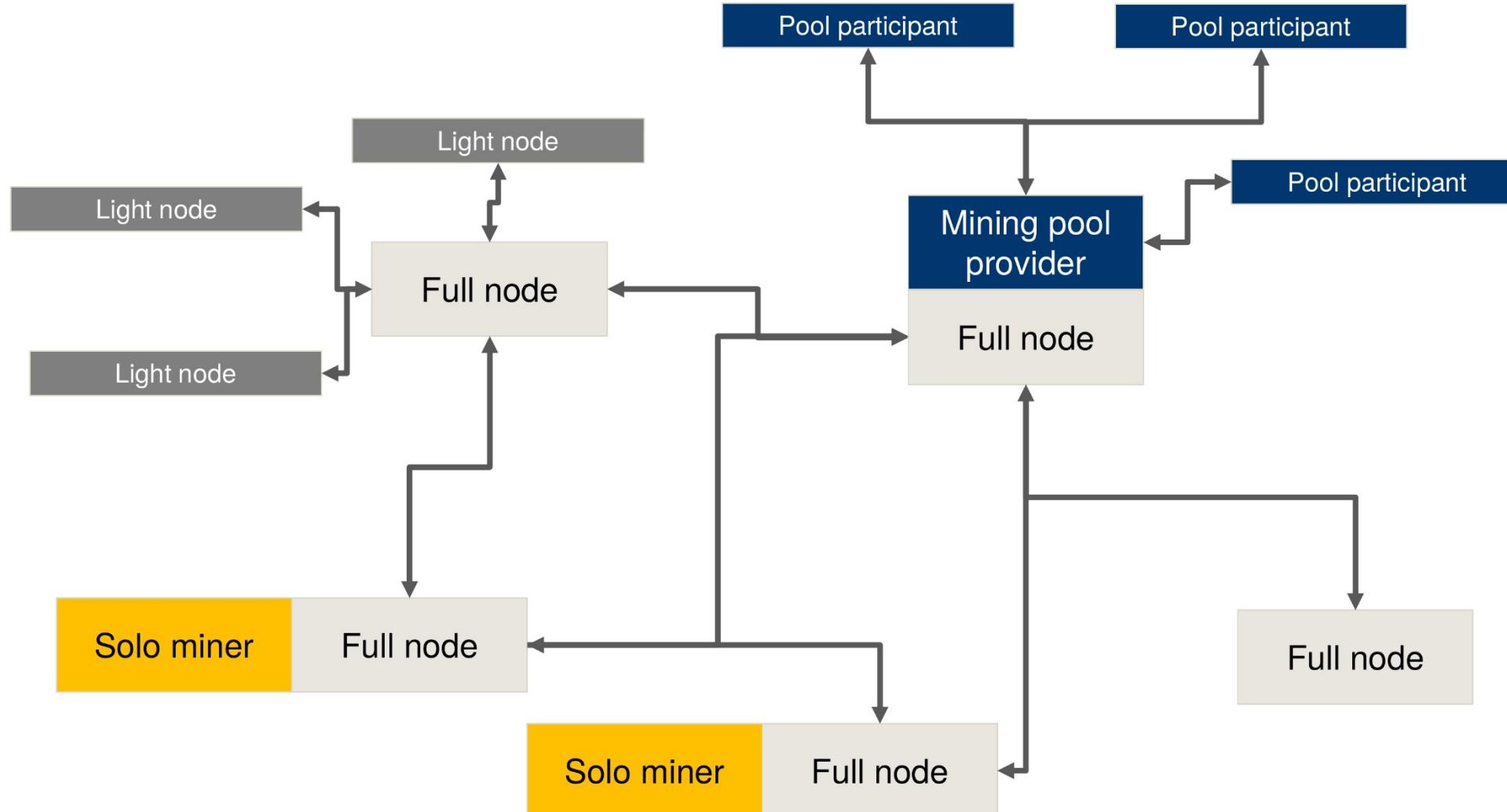
Account Properties

Ethereum account is a 4-tuple containing: (nonce, balance, contract code, storage)

- Nonce:
 - Increasing number that is attached to any transaction to prevent replay attacks and double spending.
- Balance:
 - Current account balance in ETH.
- Contract code:
 - Bytecode representation of the account. If no contract code is present, then the account is externally controlled.
- Storage:
 - Data storage used by the account - empty by default.
 - Only contract accounts can have their own storage.

ETHEREUM NETWORK ARCHITECTURE

Network Architecture Overview



Node Types

- Full nodes:
 - Holds complete copy of the entire blockchain
 - P2P synchronization with other full nodes
 - Transactions must be sent to a full node to join the transaction pool
- Light nodes:
 - Clients connected to full nodes → instead of downloading the full blockchain on its own
 - Most commonly used by private users
- Solo miner:
 - An entity that tries to mine a block on its own
- Staking/Mining pools:
 - Coalition of entities combining their hash power / staking power
 - Revenue/Reward is shared among participants

ETHEREUM SMART CONTRACTS

What is a *Smart Contract*?

- A contract is a legal document
 - that binds two or more parties
 - who agree to execute a transaction immediately or in the future
- Smart contracts are digitization of legal contracts
- In Ethereum,
 - smart contracts are deployed, stored and executed within the Ethereum Virtual machine (EVM)

What is a *Smart Contract*?

- Also known as self executing contract or digital contracts
- It is like a vending machine, i.e. the ledger → You put money/data and you expect a finite item (e.g. your license, ...)
- Vitalik Buterin's explanation:
 - An asset or currency is transferred into a program,
 - the program runs this code and at some point it automatically validates a condition
 - and it automatically determines whether the asset should go to one person or back to the other person,
 - or whether it should be immediately refunded to the person who sent it or some combination thereof.
 - In the meantime, the decentralized ledger also stores and replicates the document which gives it a certain security and immutability.

Smart Contract - Rent an Apartment

- You get a receipt which is held in our virtual contract;
- I give you the digital entry key which comes to you by a specified date
- If the key does not come on time, the blockchain releases a refund.
- If I send the key before the rental date, the function holds it releasing both the fee to me and key to you respectively when the date arrives.
- If I give you the key, I'm sure to be paid. If you send a certain amount in ETH, you receive the key.
- The document is automatically canceled after the time, and the code cannot be interfered with by either of us.

What is a *Smart Contract*?

- Smart contracts can also store data
- The data stored can be used to record
 - information, fact, associations, balances
 - or any other information needed to implement logic for real world contracts

What is a *Smart Contract*?

- Smart contracts can also store data
- The data stored can be used to record
 - information, fact, associations, balances
 - or any other information needed to implement logic for real world contracts
- Smart contracts are similar to Object-oriented classes
 - A smart contract can call another smart contract just like an Object-oriented object to create and use objects of another class.
 - Think of smart contract as a small program consisting of functions.
 - You can create an instance of the contract and invoke functions to view and update contract data along with execution of some logic

Smart Contracts in a Nutshell

- Is a set of functions that can be called by other users or contracts
- Used to execute functions, send ETH, or store data.
- Each smart contract is an account holding object, i.e. has its own address.
- Smart contracts have some peculiarities compared to traditional software.

Smart Contracts in a Nutshell

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- Smart contracts have some peculiarities compared to traditional software.

**All contracts deployed on the Ethereum blockchain
are publicly accessible and can't be patched.**

Ethereum Smart Contract Coding

- Solidity is a high-level language to write smart contracts for Ethereum
- Contracts can be defined as encapsulated units, similar to classes in traditional object-oriented programming languages like Java.
- A contract has its own, persistent state on the blockchain which is defined by state variables in the contract.
- Functions are used to change the state of the smart contract or to perform other computations.
- Solidity is compiled to bytecode which is persistent and immutable once deployed to the blockchain → Not patchable.

Brief Insight: Solidity

Solidity is a high-level language with a JavaScript-like syntax for writing Ethereum smart contracts.

- Language properties:

- Statically typed
- Object-oriented
- Supports inheritance
- Public & private methods
- Dynamic binding
- Compiles to EVM opcode instructions

```
pragma solidity ^0.4.24;
contract HelloWorld {

    constructor () {}

    function renderHelloWorld () returns (string) {
        return 'helloWorld';
    }
}
```

Solidity to Smart Contract

- Solidity code is stored in files with the special file extension .sol
- A good practice is to have one separate .sol file per contract
- The Solidity compiler takes a .sol file as input and generates the corresponding sequence of EVM opcode instructions
- The opcode instructions are then encoded as hex bytecode
- The contract is deployed via a special transaction containing the bytecode as payload
- Once the transaction is mined, a new contract account on the Ethereum network is created
- The contract is now usable



ETHEREUM DECENTRALIZED APPLICATIONS

Motivation

- Direct interaction with smart contracts is complicated
- Smart contracts do not provide a graphical user interface on their own
- Programming knowledge or special tools are required to make function calls

Interact with Contract or Deploy Contract

Contract Address

ABI / JSON Interface

```
[ { "constant": true, "inputs": [ { "name": "", "type": "address" } ], "name": "votings_", "outputs": [ { "name": "", "type": "uint256" } ], "payable": false, "stateMutability": "view", "type": "function" }, { "constant": true, "inputs": [], "name": "symbol", "outputs": [ { "name": "", "type": "string" } ], "payable": false, "stateMutability": "view", "type": "function" }, { "constant": true, "inputs": [ { "name": "_etherAmount", "type": "uint256" } ], "name": "calculateTokenAmountICO", "outputs": [ { "name": "", "type": "uint256" } ], "payable": false, "stateMutability": "view", "type": "function" }, { "constant": true, "inputs": [], "name": "raisedIcoValue", "outputs": [ { "name": "", "type": "uint256" } ], "payable": false, "stateMutability": "view", "type": "function" }, { "constant": true, "inputs": [], "name": "prizePool", "outputs": [ { "name": "", "type": "address" } ], "payable": false, "stateMutability": "view", "type": "function" } ]
```

Access

Select Existing Contract

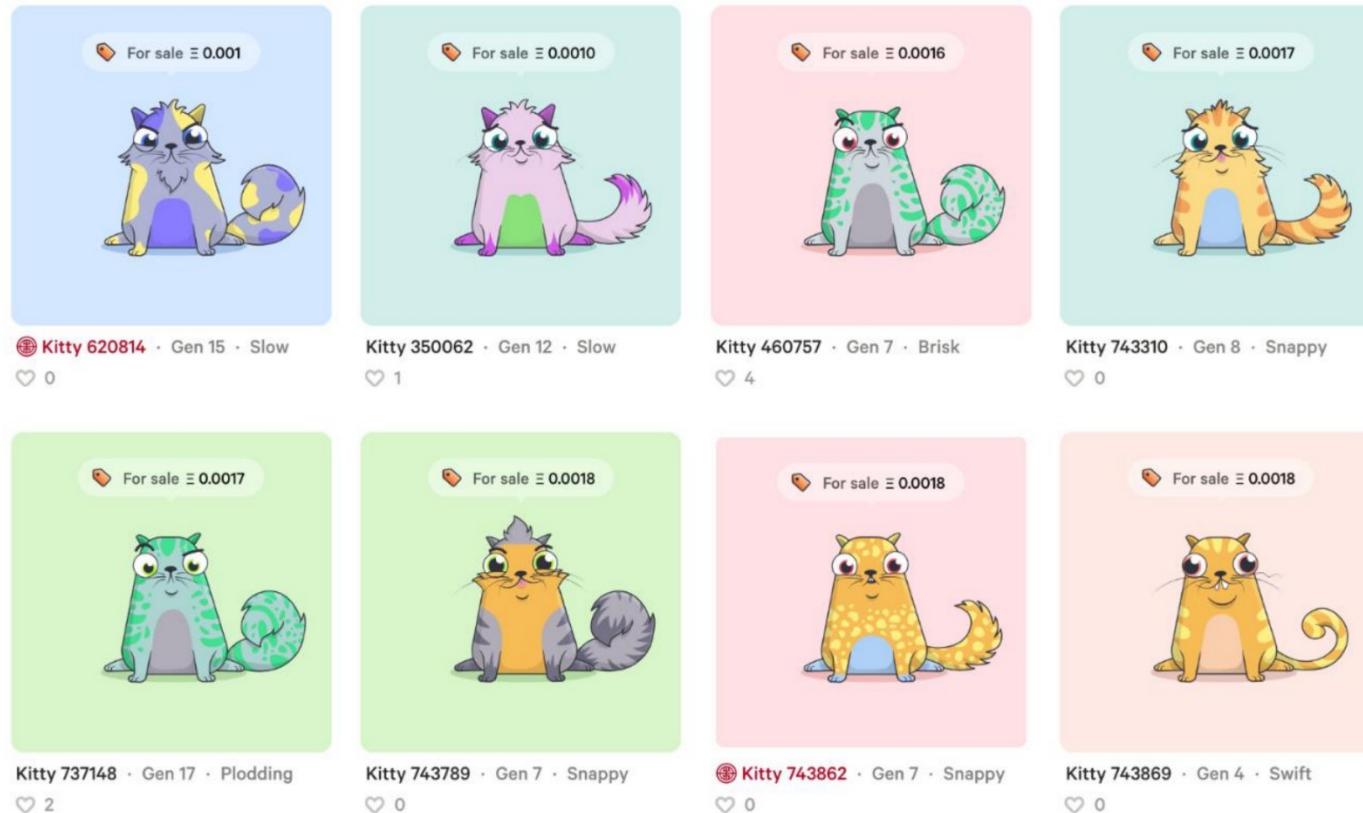


WhoHas 0xe933c0Cd9784414d5F278C114904F5A84b396919

Select a function ▾

Motivation

- Building UIs on top of smart contracts to make them accessible to average users
- The UI abstracts the complicated function calls and allows a user to interact with them just like with a regular (web) application



Definition

- In the community, multiple definitions for dApps exist
- In general, a dApp is not necessarily based on a Blockchain, e.g., BitTorrent is a decentralized P2P application without any blockchain involved
- In this lecture, we consider a dApp as a decentralized application (in the terms of blockchain) based on one or more smart contracts and accessible via a dedicated user interface
- In particular, the following properties must hold:
 - The core data records of the application must be stored on the blockchain
 - The functions that change the core data records must be executed on the blockchain, i.e. via a smart contract

Benefits

The meaningfulness of implementing a distributed application is dependent on the concrete use case and / or the problem that is being solved.

Some general properties of Ethereum-based dApps:

- **Trust**

- The source code of any verified smart contract can be checked by anyone.

- **Payment**

- Payment is implemented by default since anyone can send / receive Ether.

- **Accounts**

- dApps can be build on top of Ethereum's account system, so there is no need to implement an additional user account management system.

- **Storage**

- dApps can leverage the Blockchain as common (expensive) data storage.

Drawbacks

Decentralized applications have also some intrinsic disadvantages:

- **Costs**

- Any state change and computation costs money. For that reason, only mission-critical data and functionality should leverage the blockchain.

- **Time**

- The current block time of Ethereum is around 14 seconds, i.e., it takes at least 14 seconds from the function call to the definite result of it.

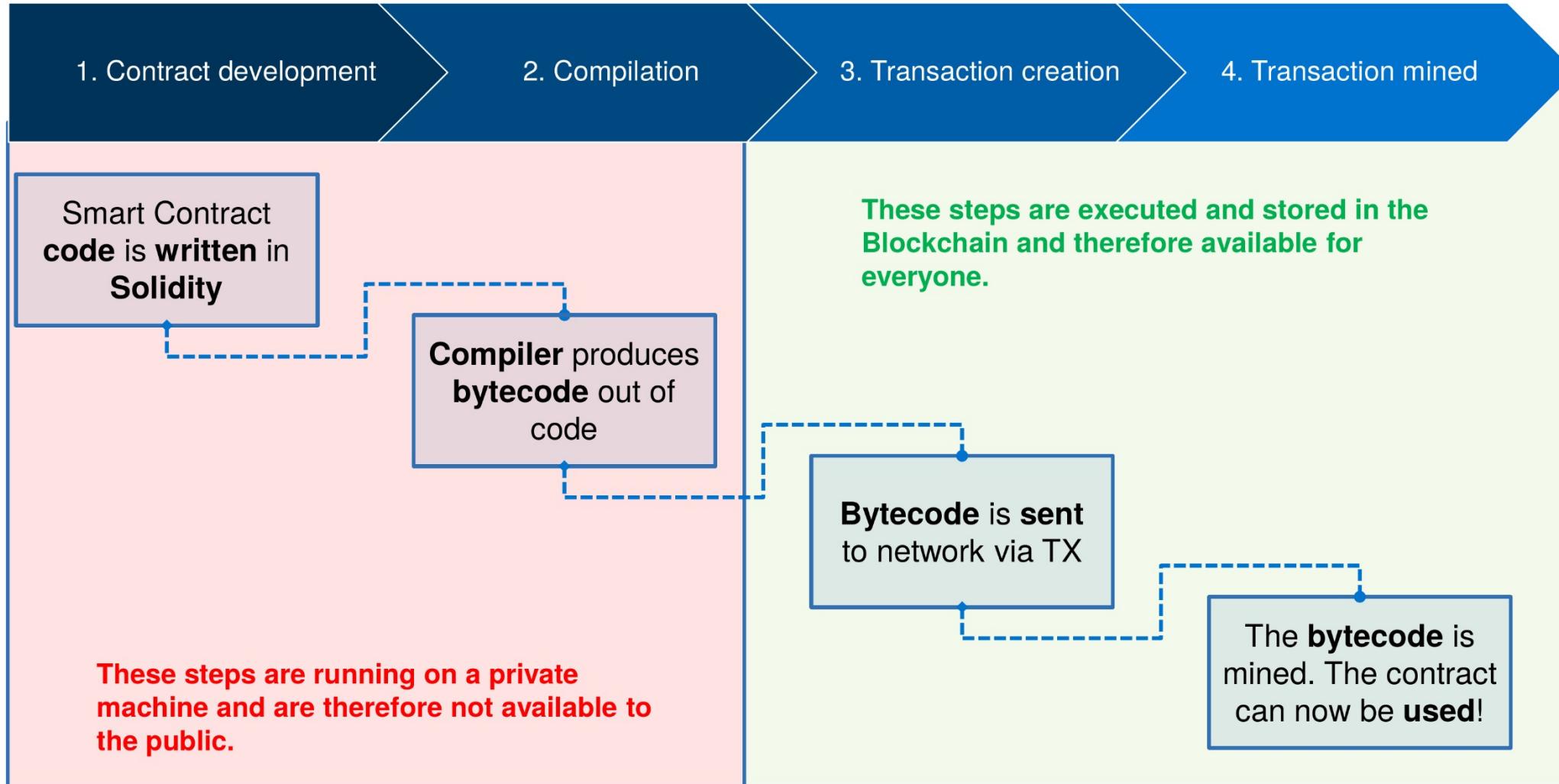
- **Availability**

- In theory, availability is one of the key advantages of dApps. However, in high transaction scenarios (e.g. the release of crypto kitties) it is possible that the network throttles and is not able to process function calls anymore.

- **Transparency**

- Without third party services, it is impossible to access and verify a Smart Contract source code.

Recap - Deploy Smart Contract on Chain



Bytecode Source Code on Chain

Publicly Available Source Code

Etherscan.io is a service which also verifies source codes and the respective byte code.

Contract Source Code Verified (Exact Match)

Contract Name:	SparkleCrowdsale	Optimization Enabled:	No
Compiler Text:	v0.4.25+commit.59dbf8f1	Runs (Optimiser):	200

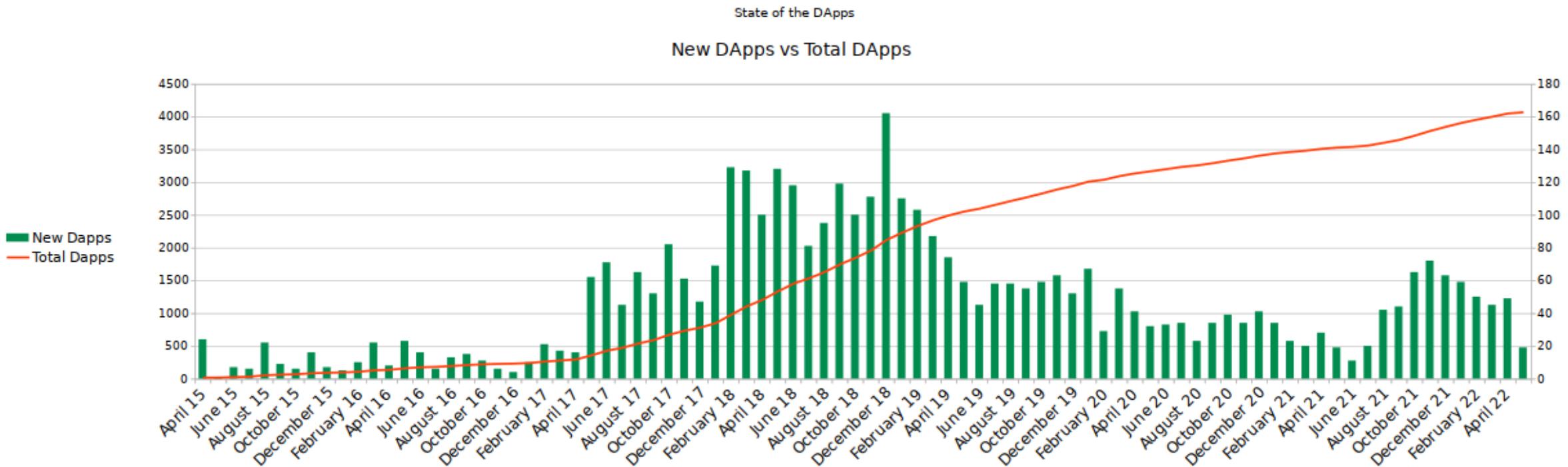
Contract Source Code </>

```
1 pragma solidity 0.4.25;
2
3 // File: openzeppelin-solidity/contracts/ownership/Ownable.sol
4
5 /**
6  * @title Ownable
7  * @dev The Ownable contract has an owner address, and provides basic authorization control
8  * functions, this simplifies the implementation of "user permissions".
9  */
10 contract Ownable {
11     address private _owner;
12
13     event OwnershipTransferred(
14         address indexed previousOwner,
15         address indexed newOwner
16     );
17
18 /**
19  * @dev The Ownable constructor sets the original `owner` of the contract to the sender
20  * account.
21  */
22 constructor() internal {
23     _owner = msg.sender;
24     emit OwnershipTransferred(address(0), _owner);
25 }
```

 Copy  Find Similar Contracts 

Web-based Ethereum dApps

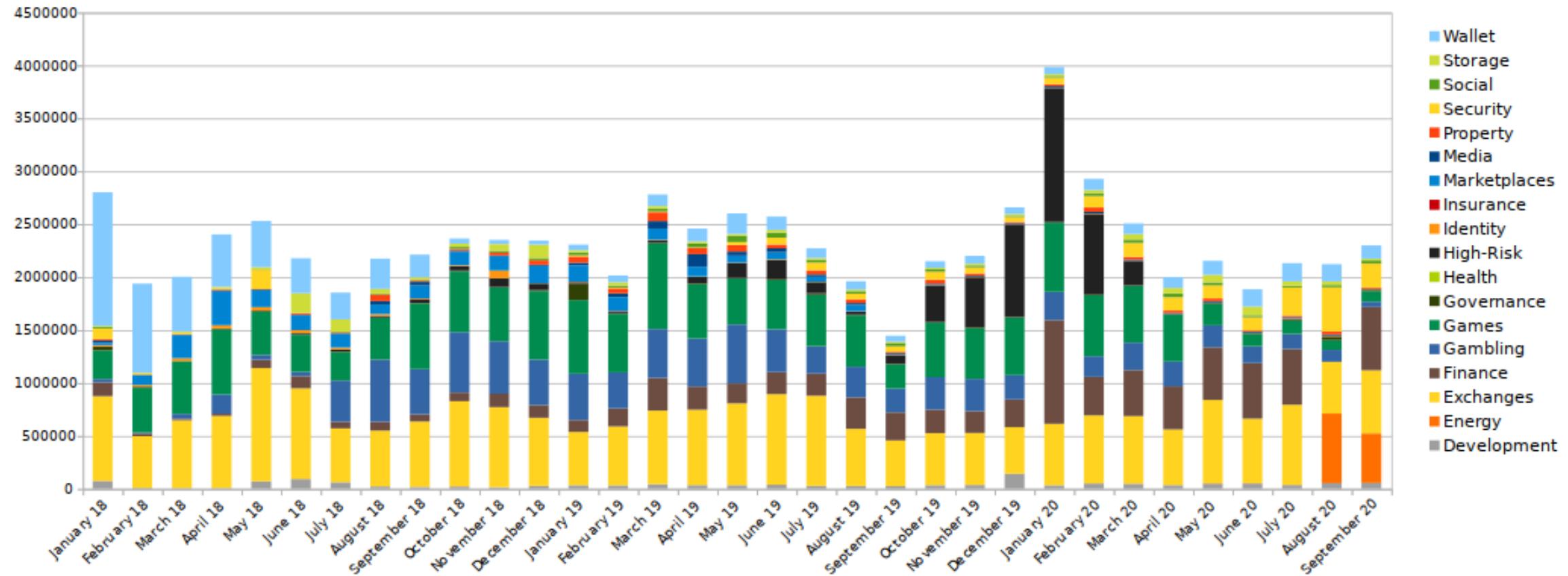
- State of the Dapps ([Link](#)) is a curated and community-driven directory of decentralized applications.
- As of May 2022, the directory lists 4073 DApps (2970 Ethereum DApps).



Graph recreated based on data from <https://www.stateofthedapps.com/stats>

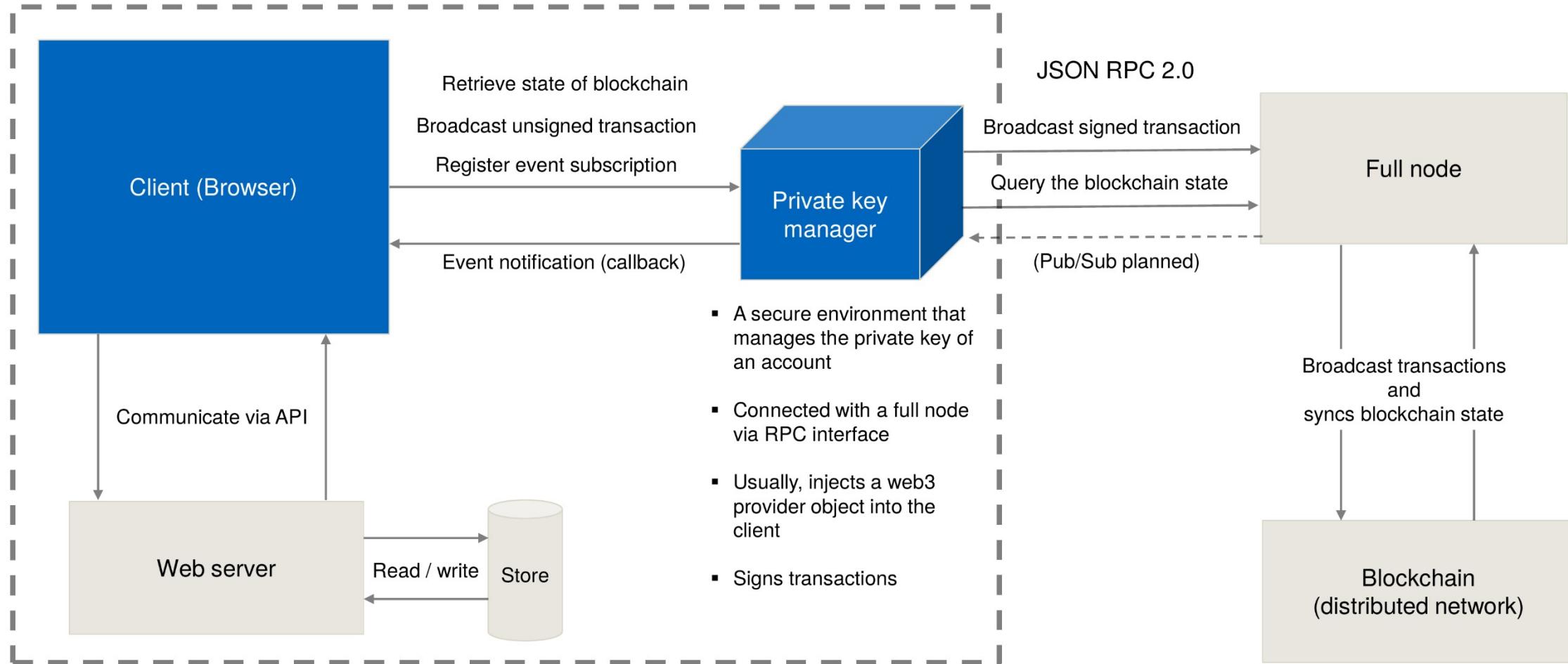
dApps Statistics - Transactions per dApp

State of the DApps
Ethereum DApp Activity by Category

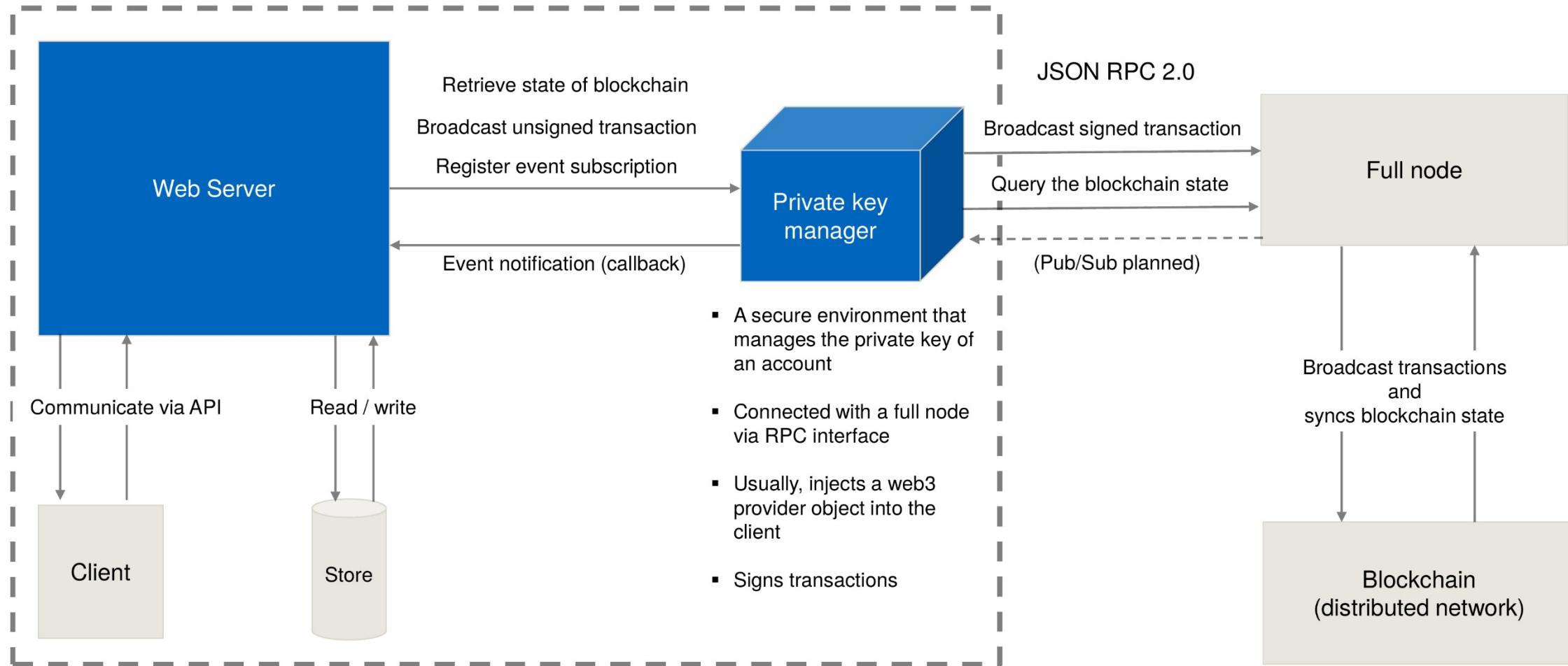


Graph recreated based on data from <https://www.stateofthedapps.com/stats>

Architecture of Web-based dApps

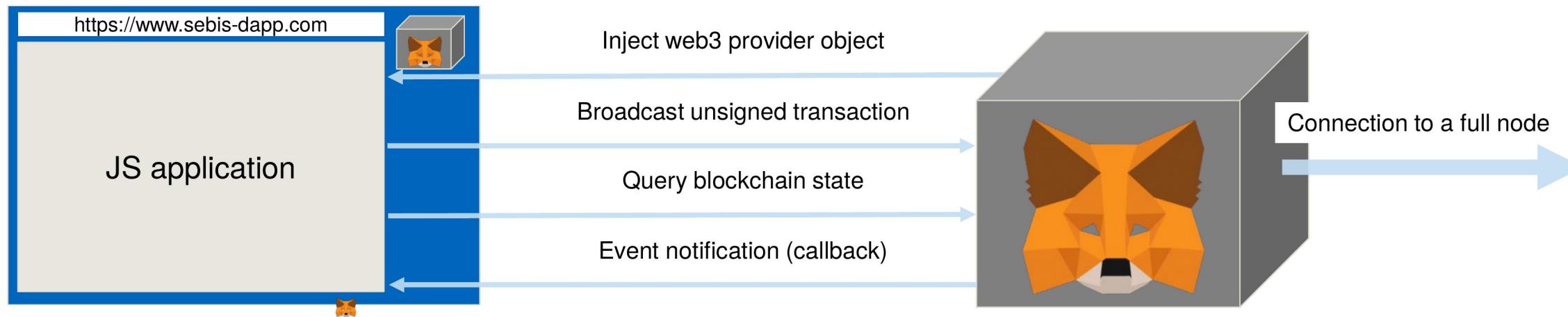


Architecture of Web-based dApps

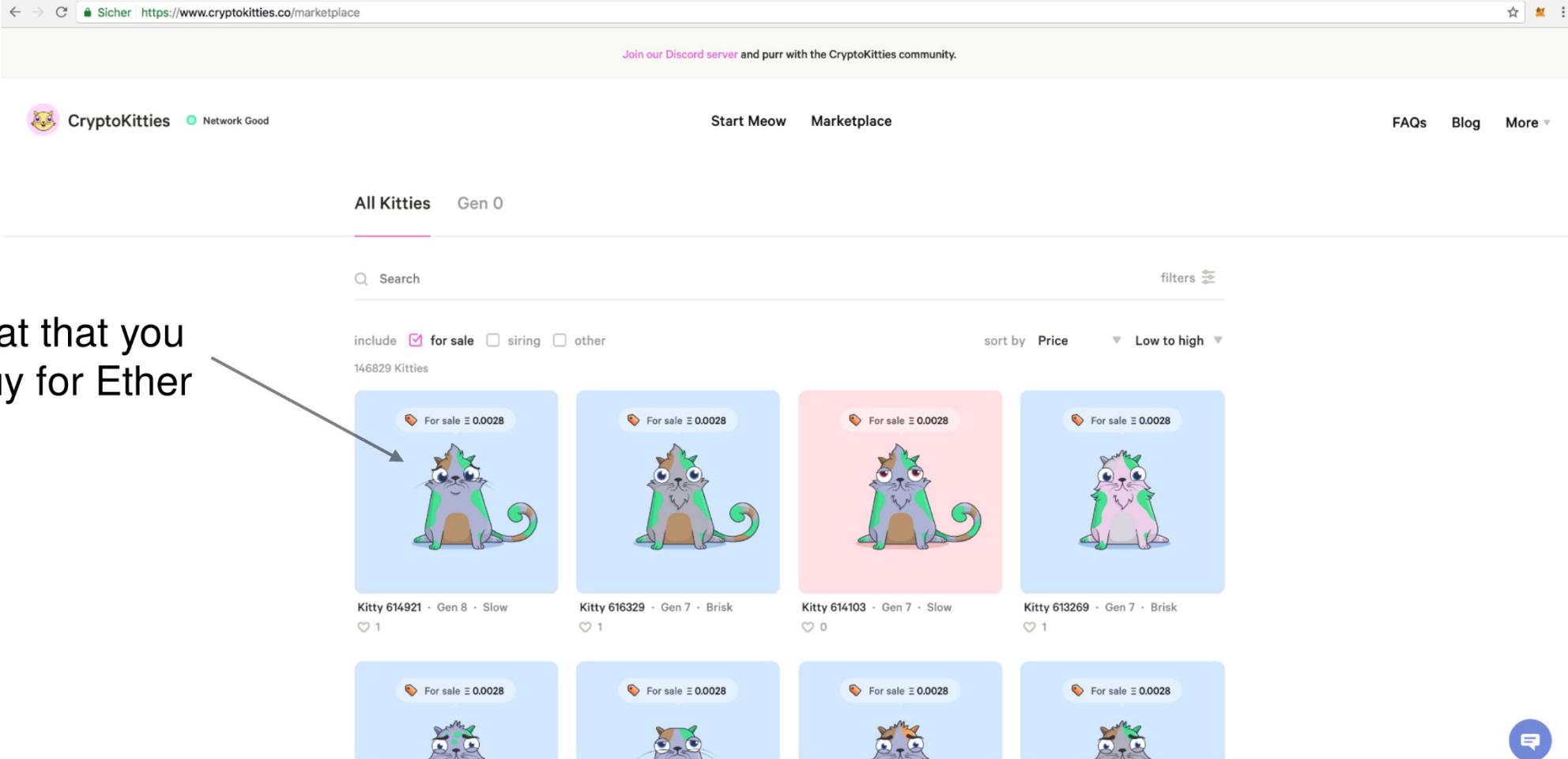


Metamask

Browser



Example: CryptoKitties

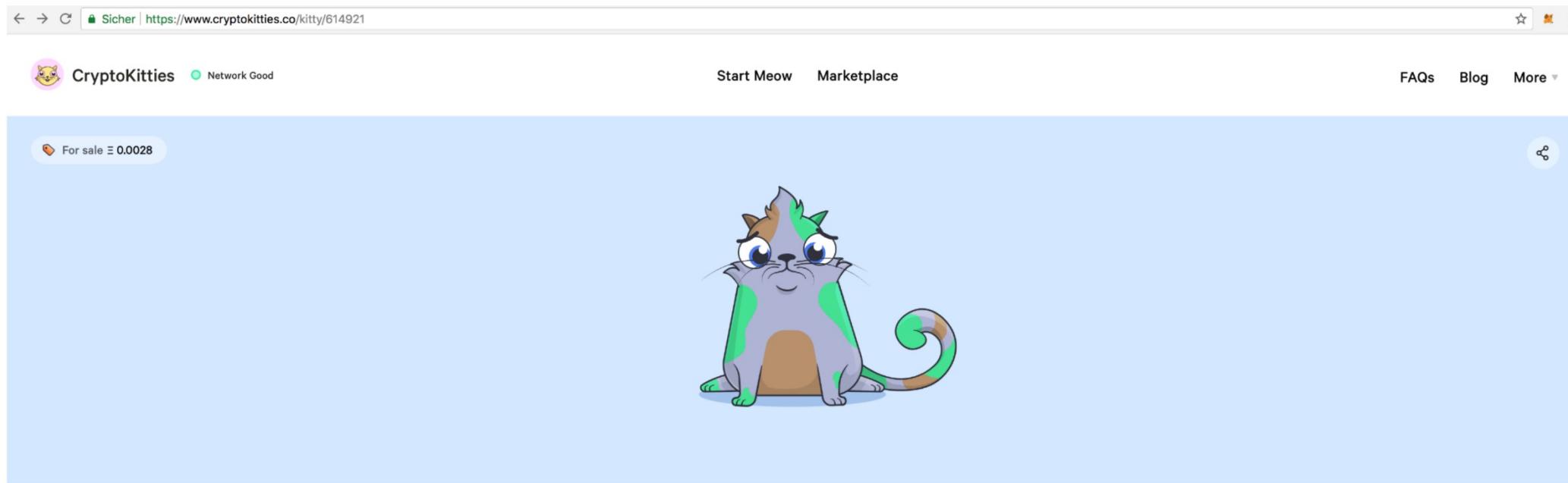


Select a cat that you want to buy for Ether

The screenshot shows the CryptoKitties marketplace interface. At the top, there's a navigation bar with links for 'CryptoKitties', 'Network Good', 'Start Meow', 'Marketplace', 'FAQs', 'Blog', and 'More'. Below the navigation is a search bar and filter options. The main area displays a grid of 146,829 kitties, with the first four shown in detail:

Kitty ID	Gen	Speed	Description
Kitty 614921	Gen 8	Slow	For sale ⚡ 0.0028
Kitty 616329	Gen 7	Brisk	For sale ⚡ 0.0028
Kitty 614103	Gen 7	Slow	For sale ⚡ 0.0028
Kitty 613269	Gen 7	Brisk	For sale ⚡ 0.0028

Example: CryptoKitties



G8 4.8/5 Add Beard

Kitty 614921 · Gen 8 · Slow Cooldown ⓘ

Like 1

Buy now price ⚡ 0.0028

Time left 1 day

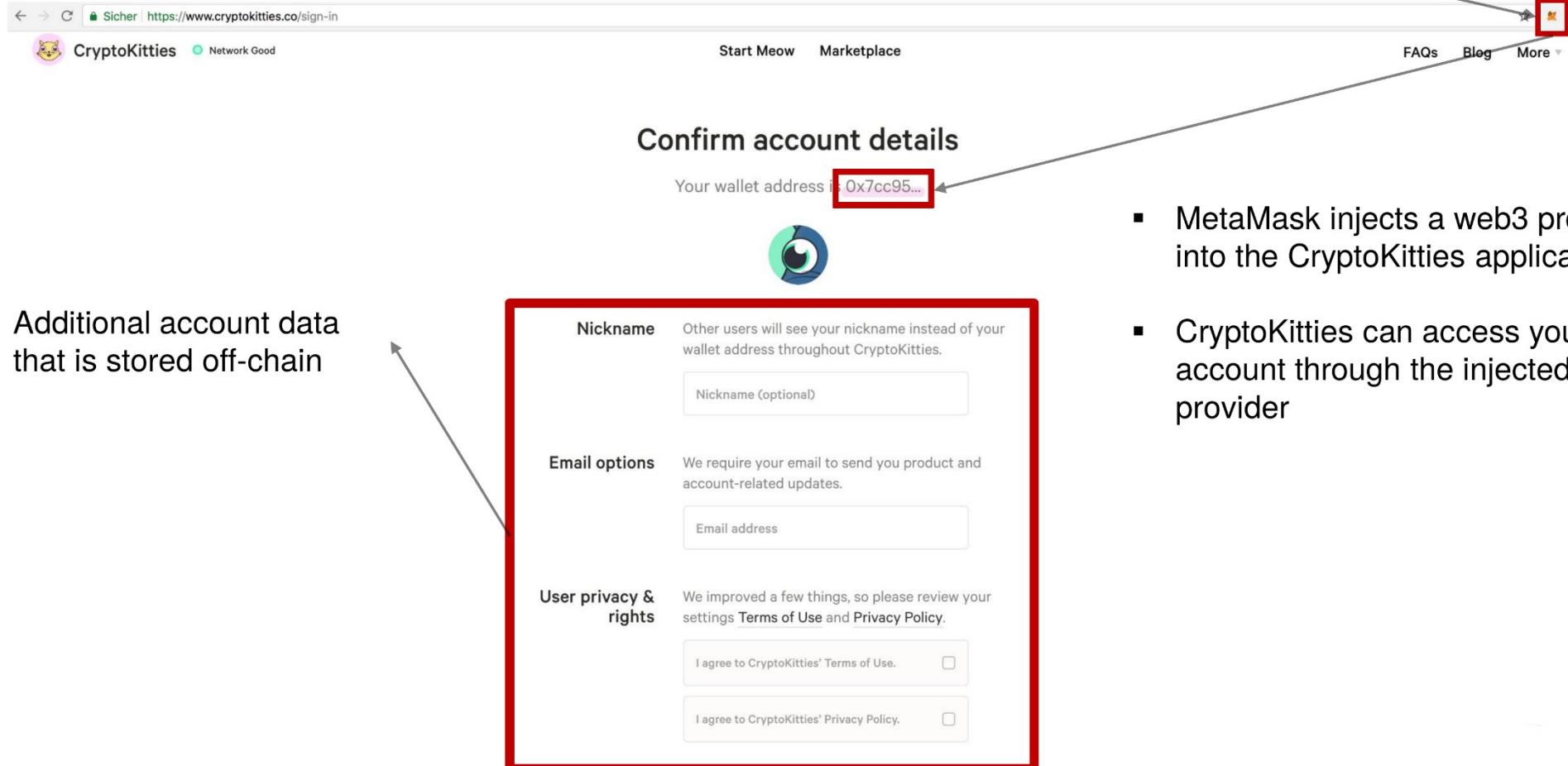
BlueBmtKitty@gmail.com Owner

Press the button to buy the cat

Buy now

Message icon

Example: CryptoKitties

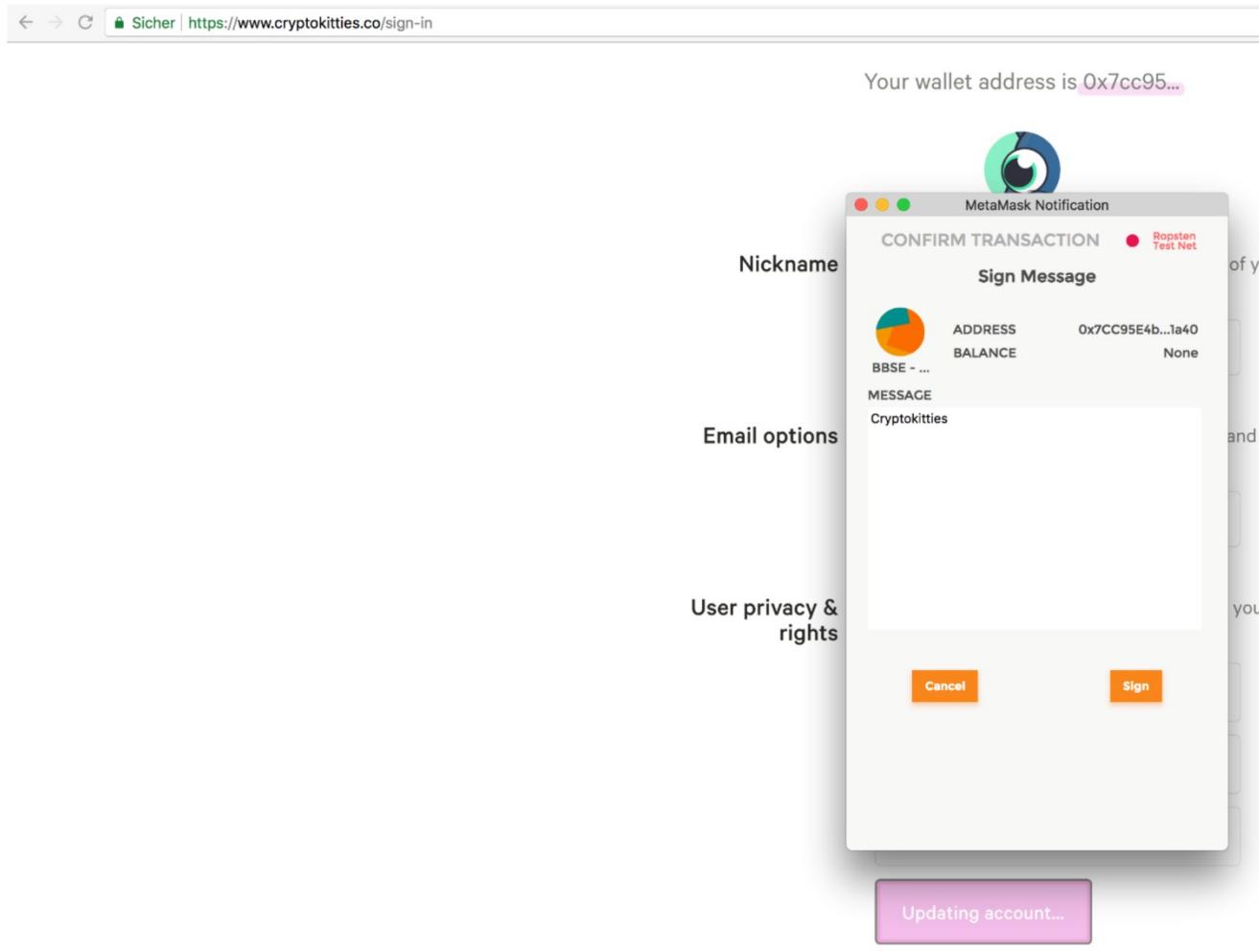


The screenshot shows the CryptoKitties sign-in page at <https://www.cryptokitties.co/sign-in>. At the top right, a MetaMask extension icon is highlighted with a red box. A callout arrow points from this icon to the text "MetaMask as private key manager". On the left, another callout arrow points from the "User privacy & rights" section of the sign-in form to the text "Additional account data that is stored off-chain". The sign-in form includes fields for Nickname, Email options, and User privacy & rights, along with two checkboxes for agreeing to terms and privacy policy.

MetaMask as private key manager

- Additional account data that is stored off-chain
- MetaMask injects a web3 provider into the CryptoKitties application
- CryptoKitties can access your account through the injected web3 provider

Example: CryptoKitties



The screenshot shows a web browser window for <https://www.cryptokitties.co/sign-in>. The address bar indicates the site is secure. A MetaMask notification dialog titled "CONFIRM TRANSACTION" is displayed over the page. The dialog shows the following details:

- Ropsten Test Net
- Sign Message
- BBSE - ... ADDRESS BALANCE 0x7CC95E4b...1a40 None
- MESSAGE Cryptokitties

At the bottom of the dialog are "Cancel" and "Sign" buttons. Below the dialog, a pink button says "Updating account...". On the left side of the page, there are three sections: "Nickname", "Email options", and "User privacy & rights".

- Once the “Sign up” button is pressed, the web application will create a transaction to the CryptoKitties smart contract that stores your account details on the blockchain.
- The unsigned transaction is sent to the private key manager (MetaMask).
- MetaMask asks the user if he/she wants to sign the transaction.
- By clicking “Sign” the transaction is signed and broadcasted to the network



Deployment Lifecycle

- Compilation of the Solidity source code
- Generate an **Application Binary Interface** (ABI) in JSON that can be used by other applications to interact with the contract

HelloWorld.sol

```
contract HelloWorld {  
    function greet() public returns(bytes32) {  
        return "Hello World!";  
    }  
}
```

Compile

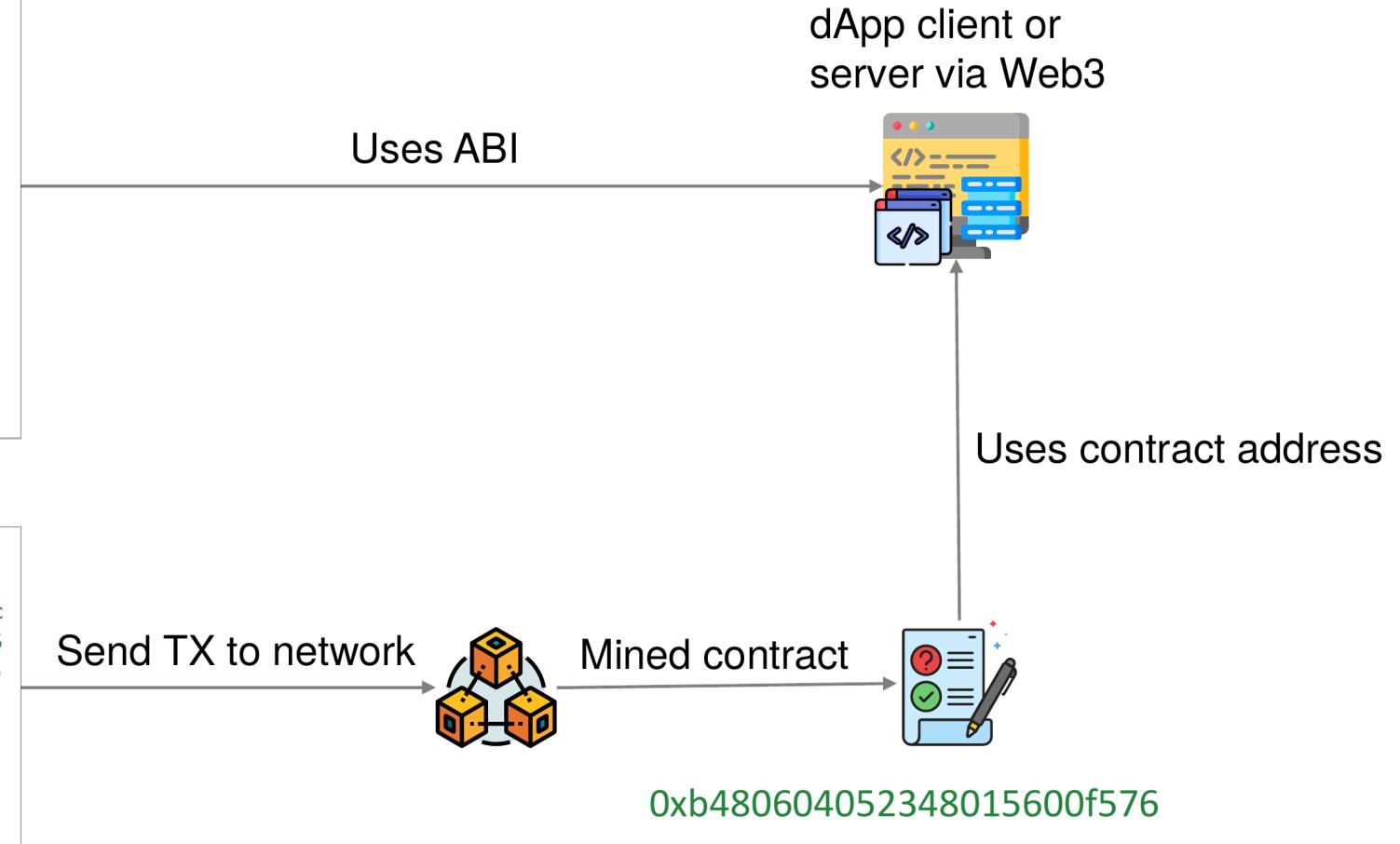
ABI
Bytecode

```
[  
 {  
     "constant": false,  
     "inputs": [],  
     "name": "greet",  
     "outputs": [  
         {  
             "name": "",  
             "type": "bytes32"  
         }  
     ],  
     "payable": false,  
     "stateMutability": "nonpayable",  
     "type": "function"  
 }]
```

```
6080604052348015600f57600080fd5b5060ba8061001e6000396  
000f3fe6080604052600436106039576000357c0100000000000000  
00000000000000000000000000000000000000000000000000000000000000  
00000000000000000000000000000000000000000000000000000000000000  
fae321714603e575b600080fd5b348015604957600080fd5b50605  
06066565b6040518082815260200191505060405180910390f35b  
60007f48656c6c6f20576f726c642100000000000000000000000000000000  
000000000000000090509056fea165627a7a72305820a4741ad95  
e951c73637b4a34111570c749d47ab815d9838dd50c29ed524020  
560029
```

Deployment Lifecycle

```
[  
 {  
   "constant": false,  
   "inputs": [],  
   "name": "greet",  
   "outputs": [  
     {  
       "name": "",  
       "type": "bytes32"  
     }  
   ],  
   "payable": false,  
   "stateMutability": "nonpayable",  
   "type": "function"  
 }  
 ]
```

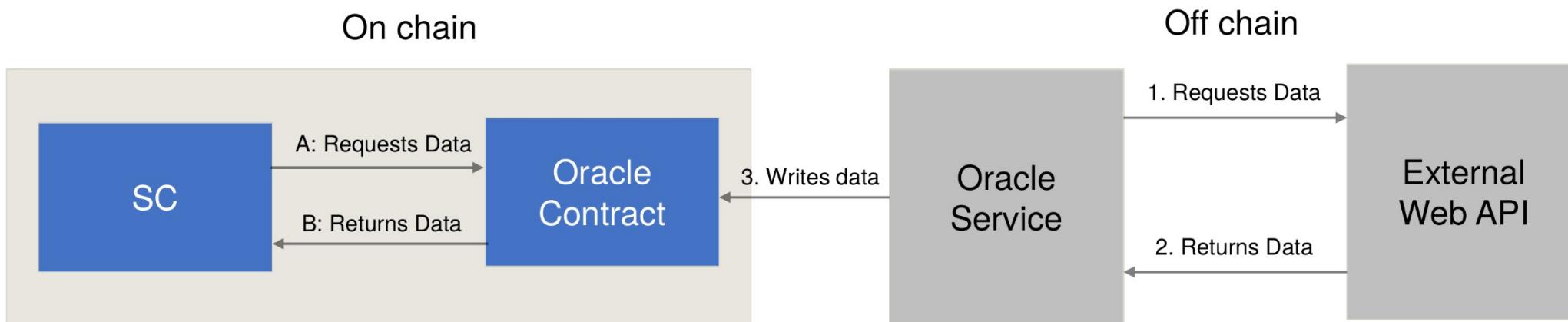


Oracles

- Smart contracts cannot access any data from outside the blockchain on their own → on purpose to prevent non-deterministic behavior
- Also no functions to generate random values

Oracles

- Smart contracts cannot access any data from outside the blockchain on their own → on purpose to prevent non-deterministic behavior
- Also no functions to generate random values
- Solution → Oracles
 - 3rd-party services that verify data from web services and write the data via a smart contract to the chain

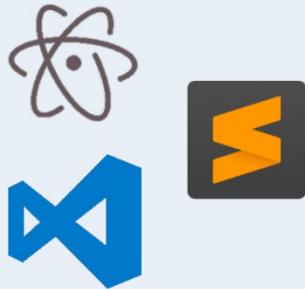


ETHEREUM DEVELOPMENT TOOLS

Development Tools

Local environment

IDE / Code editor



Artifacts

- Solidity source code files
- Test cases

Build management



Artifacts

- Compiled .sol files / Bytecode
- Contract ABI / JSON

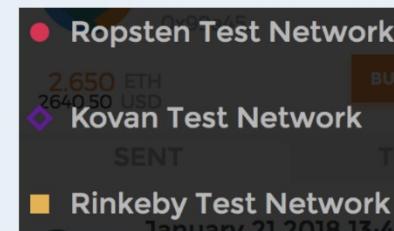
Network deployment

Local test network



Ganache

Public test network



Main network



Truffle - Development Framework for Smart Contracts



Truffle is a popular framework to facilitate the development of Ethereum smart contracts. It provides tools to compile, test and deploy Solidity contracts.

- Open source - [Github](#)
- Built-in network management that allows a developer to deploy a smart contract on various networks, e.g., live and test
- Web-pack like automated re-compilation on code change
- Provides project scaffolding



Ganache - Private Ethereum Test Network



Ganache is a local blockchain for Ethereum smart contract development. It can be used to deploy, simulate, and test smart contracts.

- Open source - [Github](#)
- Integrates a custom block explorer interface with additional debugging features.
- Uses workspaces to provide multiple Ethereum blockchains with different settings (blocktime etc.)
- Can be linked to Truffle projects to automate tests for smart contracts

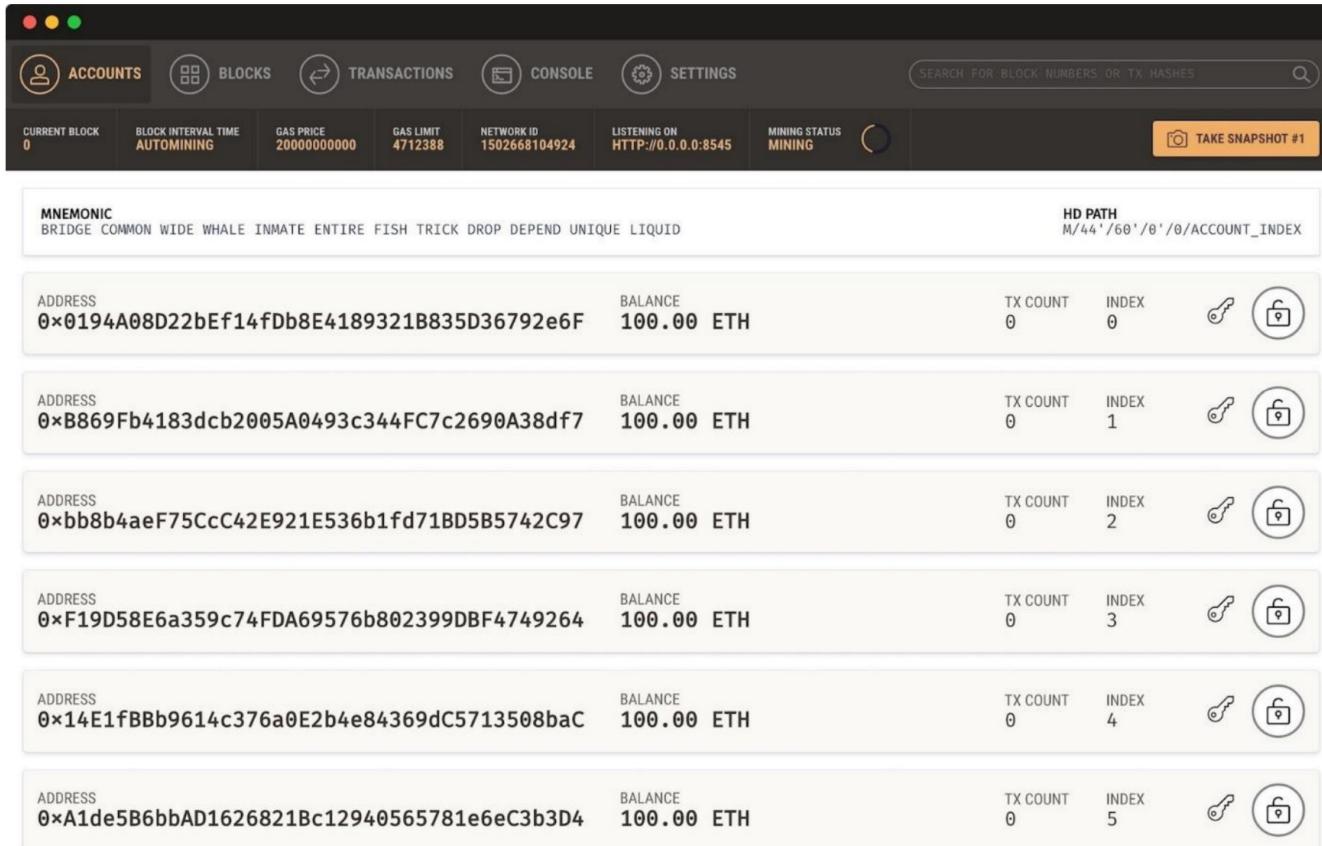


Ganache

Ganache - Private Ethereum Test Network



Ganache ships with a ready-made and developer friendly block explorer:



The screenshot shows the Ganache block explorer interface. At the top, there are tabs for ACCOUNTS, BLOCKS, TRANSACTIONS, CONSOLE, and SETTINGS. Below the tabs, there are several status indicators: CURRENT BLOCK (0), BLOCK INTERVAL TIME (AUTOMINING), GAS PRICE (20000000000), GAS LIMIT (471238), NETWORK ID (1502668104924), LISTENING ON (HTTP://0.0.0.0:8545), and MINING STATUS (MINING). A "TAKE SNAPSHOT #1" button is also present. The main area displays a table of accounts:

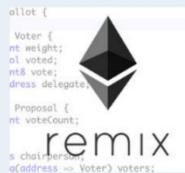
ADDRESS	BALANCE	TX COUNT	INDEX	
0x0194A08D22bEf14fDb8E4189321B835D36792e6F	100.00 ETH	0	0	 
0xB869Fb4183dc2005A0493c344FC7c2690A38df7	100.00 ETH	0	1	 
0xbb8b4aeF75CcC42E921E536b1fd71BD5B5742C97	100.00 ETH	0	2	 
0xF19D58E6a359c74FDA69576b802399DBF4749264	100.00 ETH	0	3	 
0x14E1fBBb9614c376a0E2b4e84369dC5713508baC	100.00 ETH	0	4	 
0xA1de5B6bbAD1626821Bc12940565781e6eC3b3D4	100.00 ETH	0	5	 

Development Tools



Cloud environment

IDE / Code editor + Build management



Artifacts

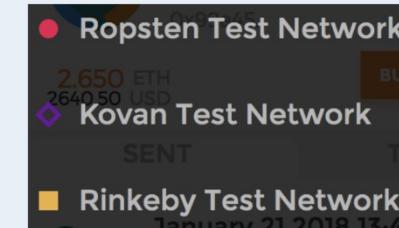
- Solidity source code files
- Compiled contracts bytecode
- Contract ABIs / JSON

Network deployment

Remix emulation



Public test network



Main network



Artifacts

- Transaction for creating the contract
- An address for the contract if the creation was successful

Test Networks - Ropsten



- Free to use
- Public
- Block time of ca. 30s
- Proof-of-Work consensus
- Geth and Parity compatibility
- Ether distribution via faucet - [Link](#)
- Anonymous

Test Networks - Rinkeby



- Free to use
- Public
- Block time of ca. 15s
- Proof-of-Authority consensus, i.e., one central instance decides what transaction will be mined.
- Geth only
- Ether distribution via faucet - [Link](#)
- Twitter or Facebook account required (Spam/DoS protection)

Test Networks - Kovan



- Free to use
- Public
- Block time of ca. 4s
- Proof-of-authority consensus, i.e., one central instance decides what transaction will be mined.
- Parity only
- Ether distribution via faucet - [Link](#)
- Github account required (Spam/DoS protection)

Questions?