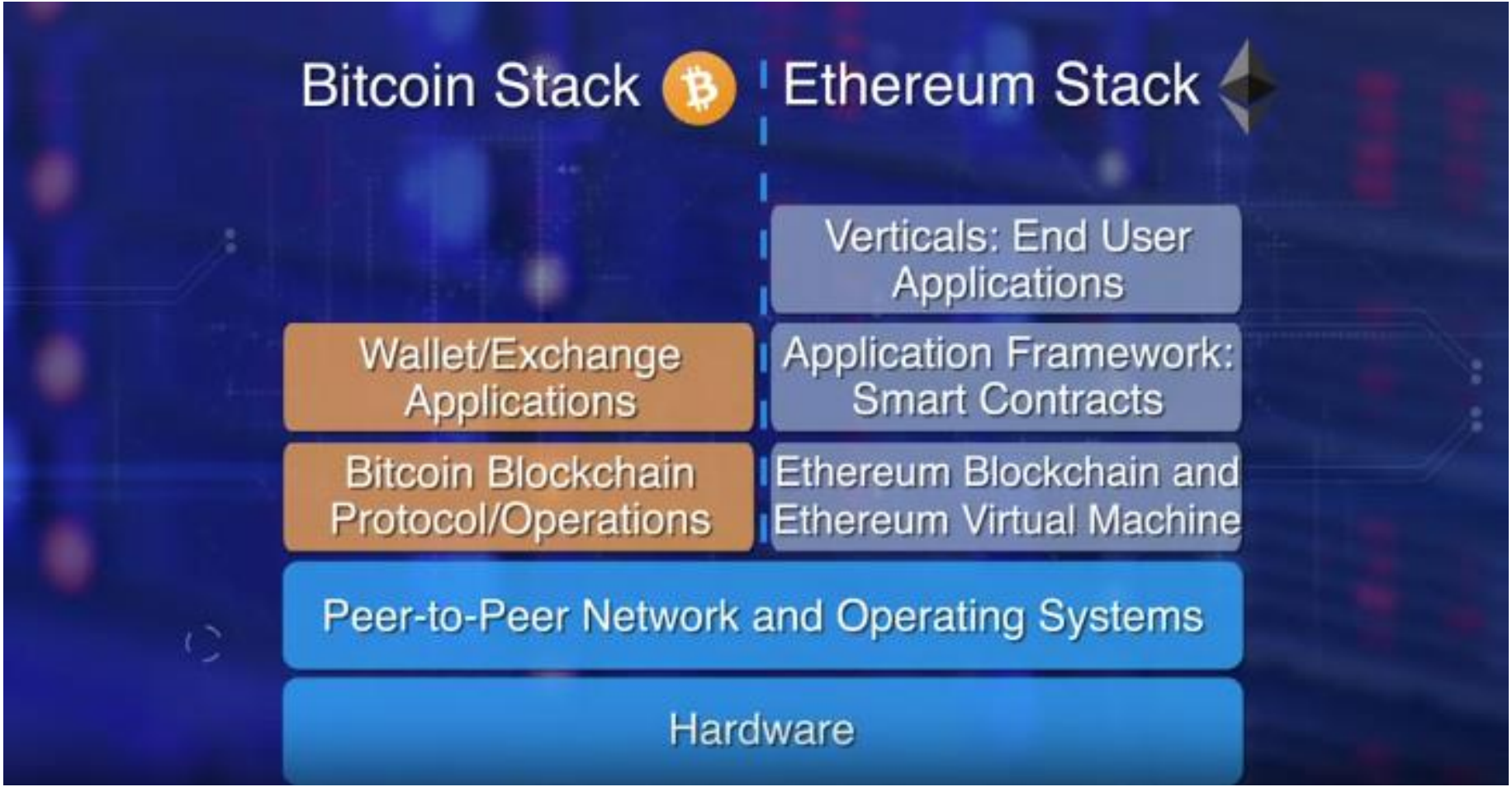
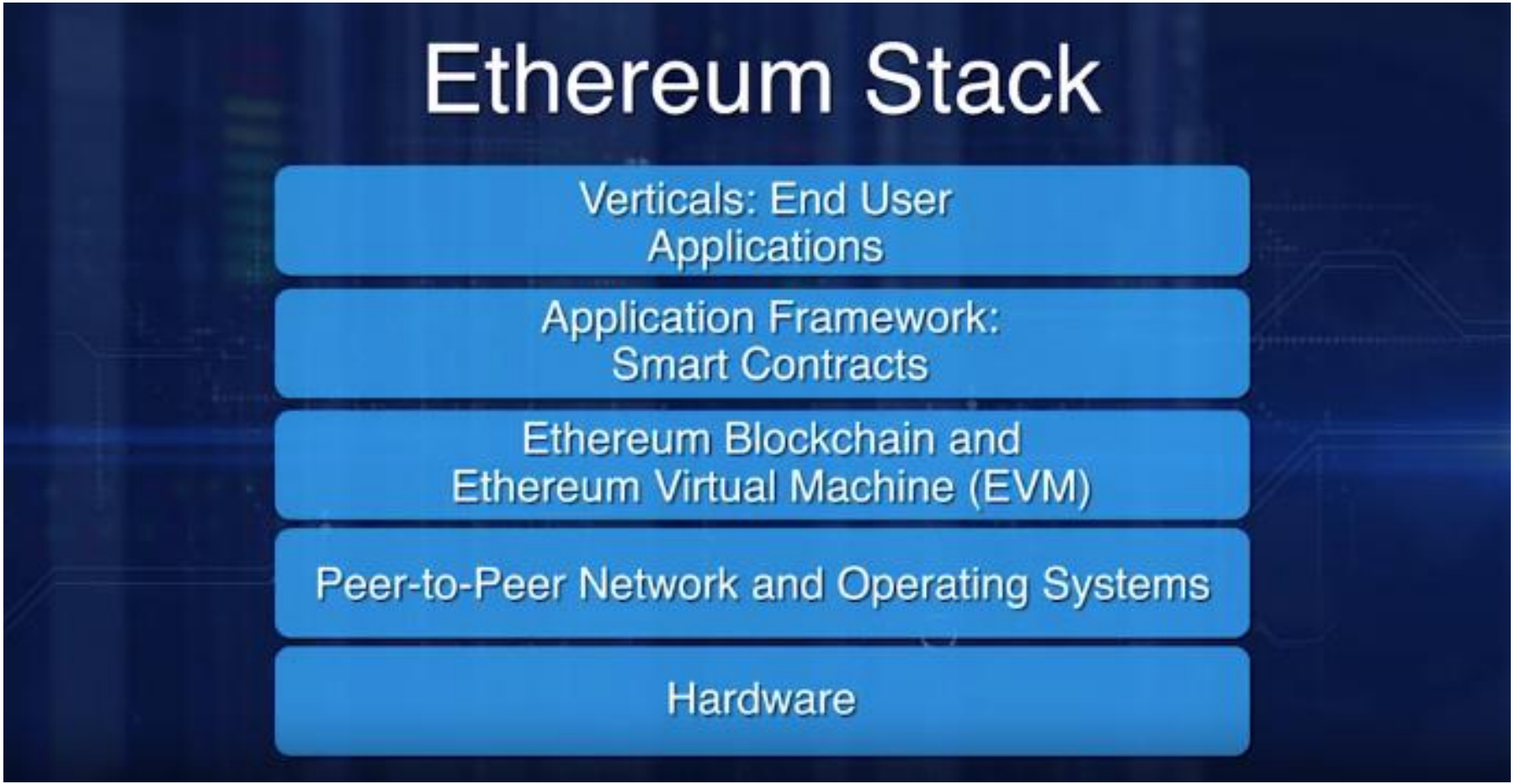
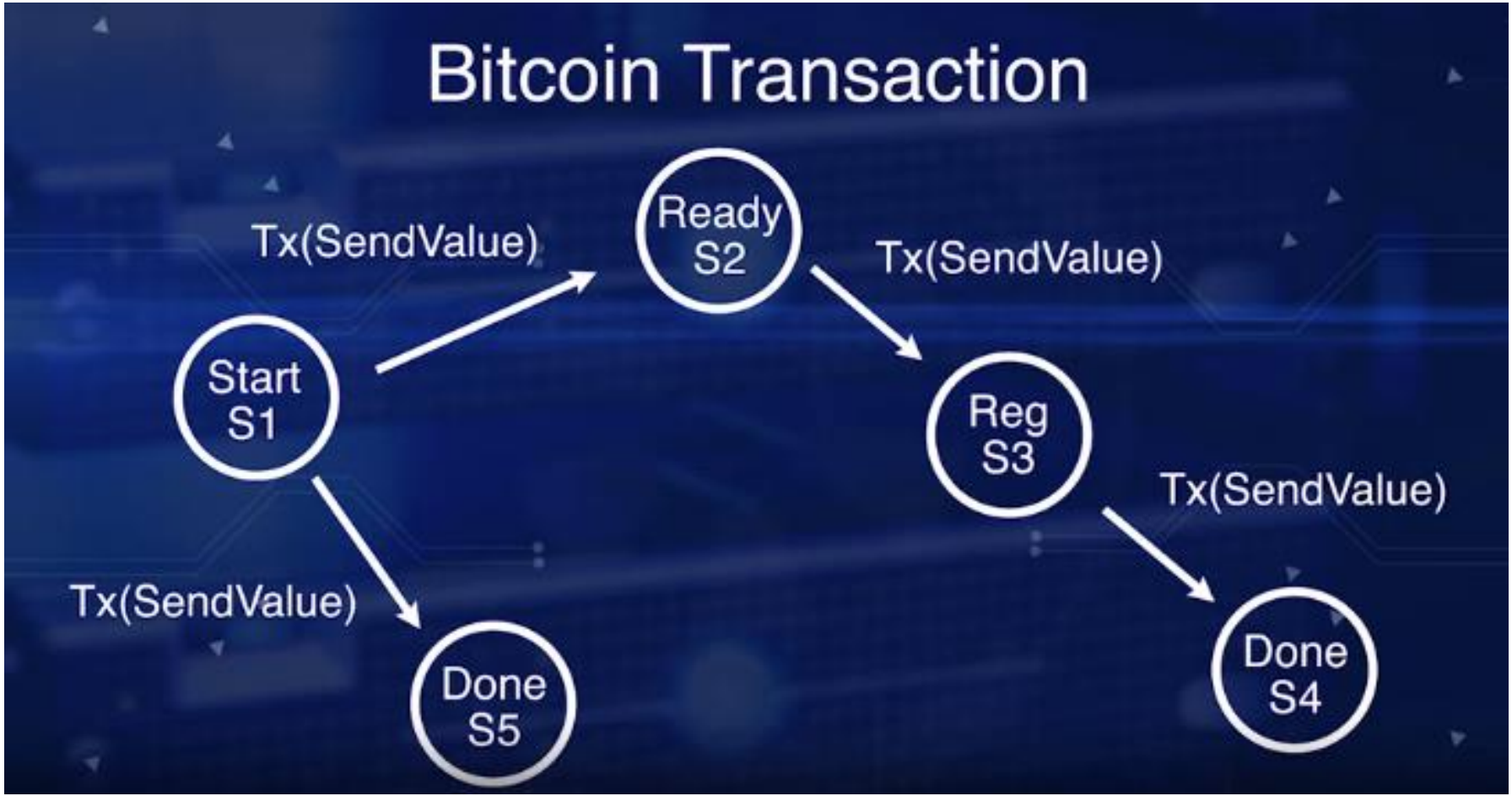
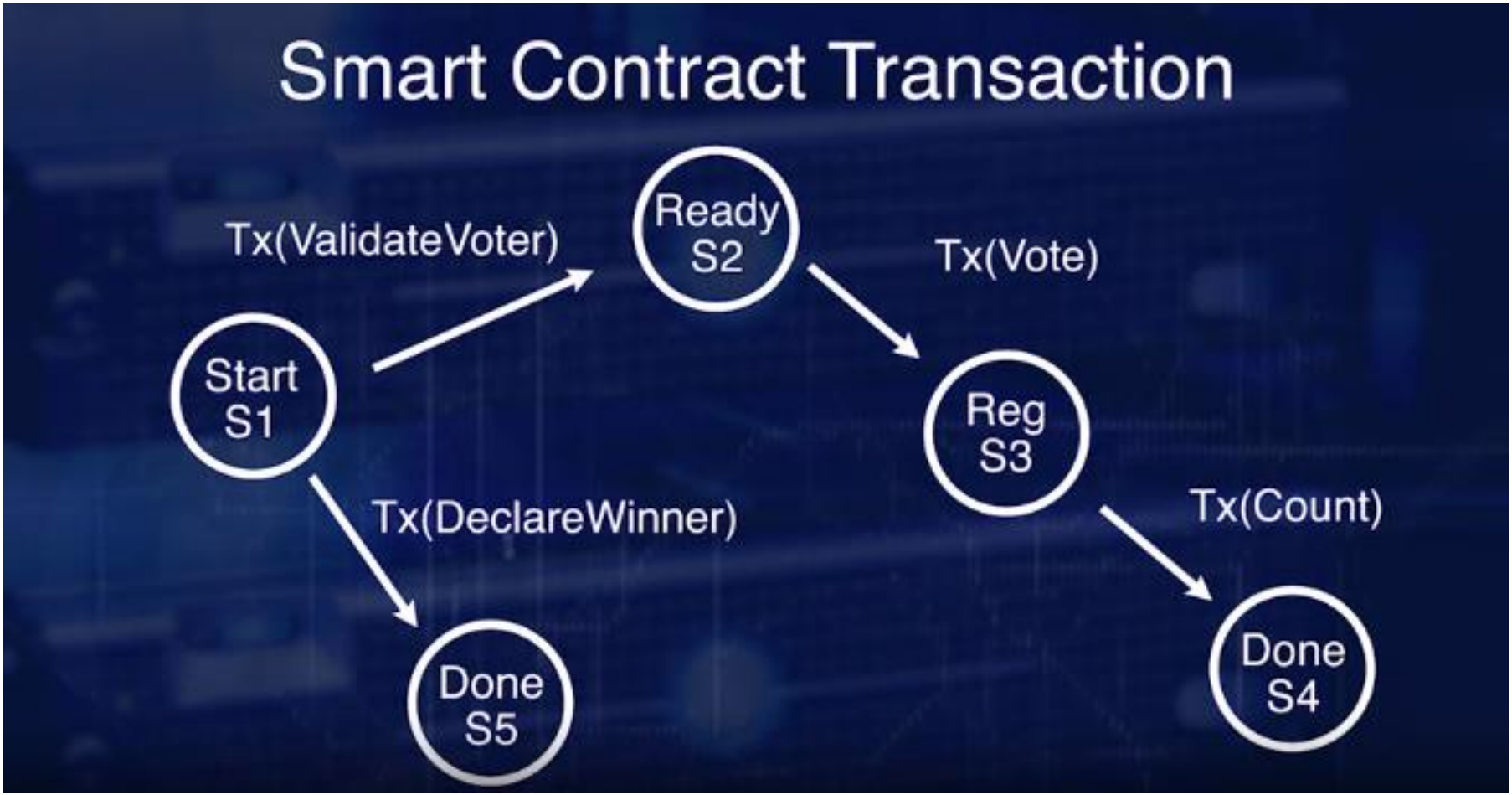
Ethereum


Bitcoin Stack
Ethereum Stack
Verticals: End User Applications
Wallet/Exchange Applications
Application Framework: Smart Contracts
Bitcoin Blockchain Protocol/Operations
Ethereum Blockchain and Ethereum Virtual Machine
Peer-to-Peer Network and Operating Systems
Hardware


Ethereum Stack
Verticals: End User Applications
Application Framework: Smart Contracts
Ethereum Blockchain and Ethereum Virtual Machine (EVM)
Peer-to-Peer Network and Operating Systems
Hardware


Bitcoin Transaction
Tx(SendValue)
Ready
S2
Tx(SendValue)
Start
S1
Reg
S3
Tx(SendValue)
Tx(SendValue)
Done
S5
Done
S4

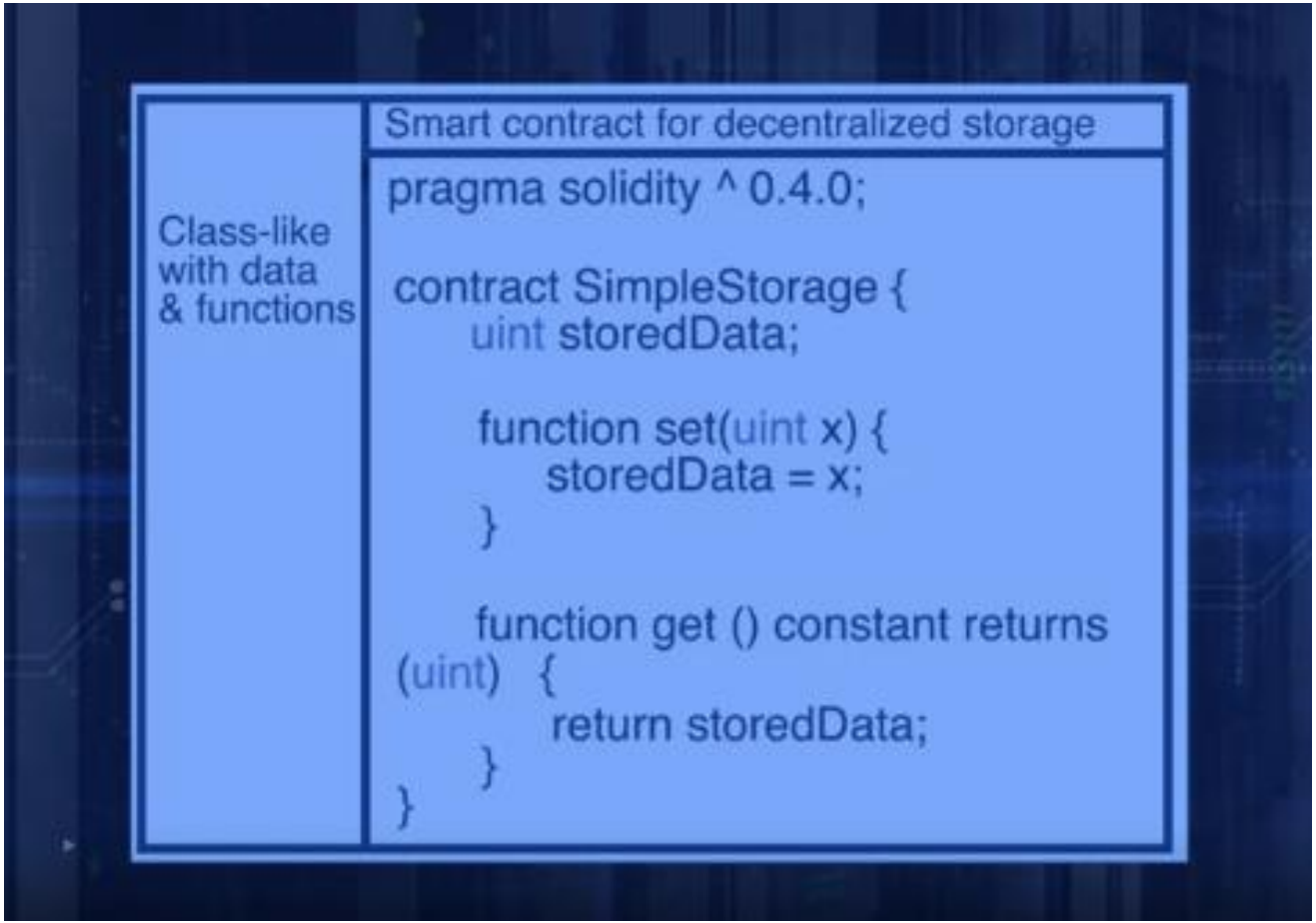

Smart Contract Transaction
Ready
S2
Tx(ValidateVoter)
Tx(Vote)
Start
S1
Reg
S3
Tx(DeclareWinner)
Tx(Count)
Done
S5
Done
S4


Currency Transfer
Service
Product
Utility

00101

11001

Transaction


Class-like with data & functions
Smart contract for decentralized storage
pragma solidity ^ 0.4.0;
contract SimpleStorage {
uint storedData;
function set(uint x) {
storedData = x;
}
function get () constant returns (uint) {
return storedData;
}
}

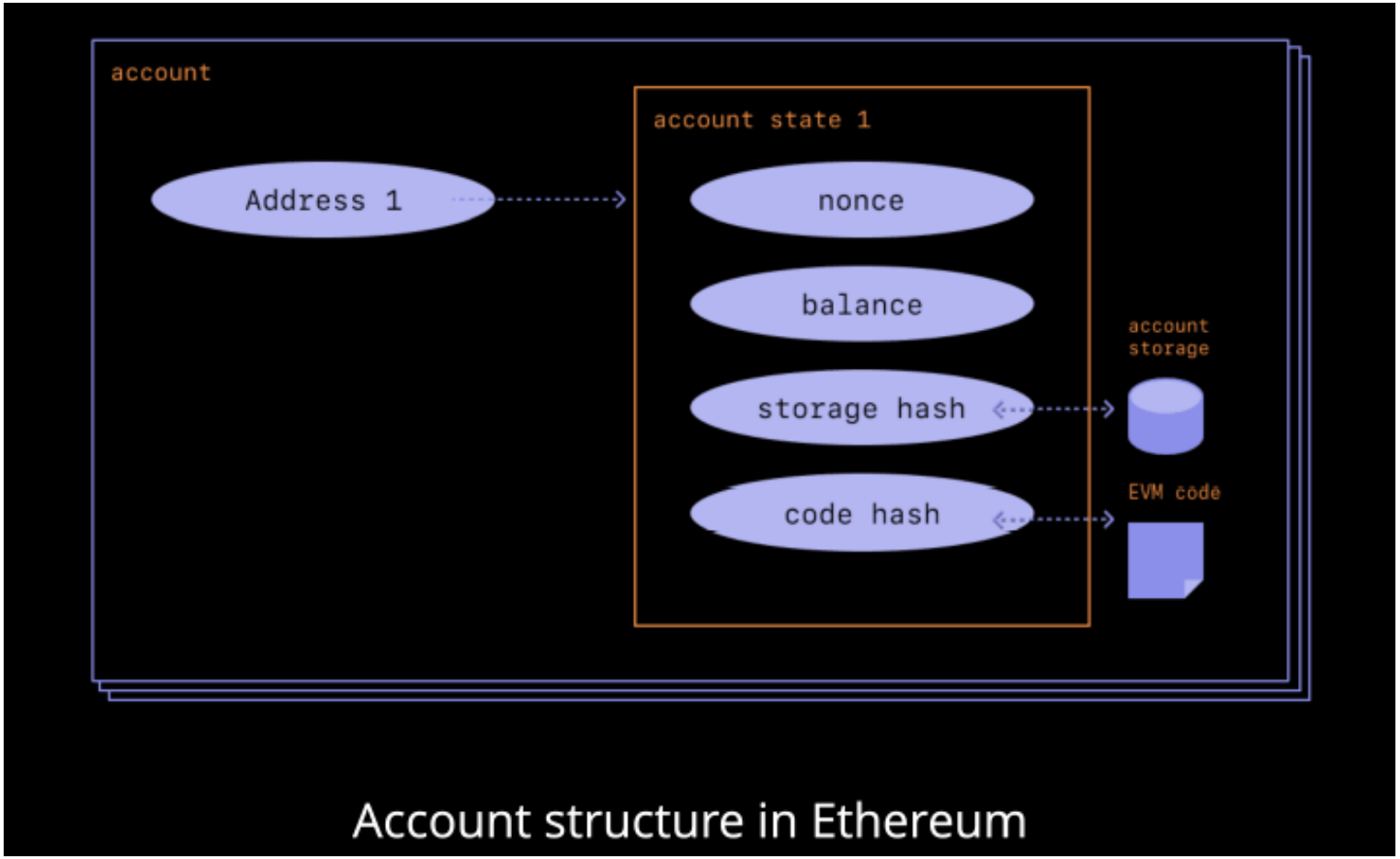

Accounts
Externally Owned Accounts
Contract Accounts
0x3ebF
EOA
CA
0xcDe

Ethereum... who art thou?

- A programmable public blockchain unlike Bitcoin
- Open source and can be forked to create your own blockchain.
- In the universe of Ethereum there is a single canonical computer called EVM or Ethereum Virtual Machine whose state everyone on the Ethereum network agrees on.
- Any participant or node can send request to run code on EVM which will then be verified, validated and executed.
- Ether is the currency unit of Ethereum.

Accounts

- There are two kinds of accounts in ethereum network: one is externally owned, which are owned and controlled by anyone having a wallet i.e. private key.
- The other kind of account is owned by a smart contract i.e. this is the kind of account which is controlled by code.
- The key difference between the two kinds of accounts is that creating a contract account costs you because you are using storage of the network.
- Transaction done from an external account to a contract account allows you to trigger the code.



Account structure in Ethereum

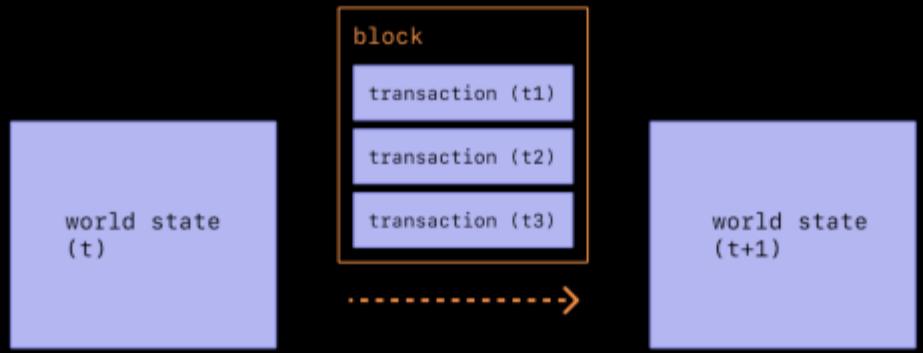
Transactions

- Transactions are cryptographically signed instructions from accounts.
- An ethereum transaction is only one which is initated by an externally owned account i.e. an account owned by human.
- When a transaction is done the state is changed and this state must be broadcasted throughout the entire network. The miner will take responsilbilty for confirming the transaction and for this each transaction costs extra fees.


```
{
  from: "0xEA674fdDe714fd979de3EdF0F56AA9716B898ec8",
  to: "0xac03bb73b6a9e108530aff4df5077c2b3d481e5a",
  gasLimit: "21000",
  gasPrice: "200",
  nonce: "0",
  value: "10000000000",
}
```

Blocks

- Dozens or hundreds of transactions are bundled together to form a block.
- The state of blockchain is linked to the blocks.
- Each block has a gas limit which is currently set to 15,000,000.



Contents of Block

- Timestamp
- Block number
- Difficulty
- mixHash
- A parent hash
- Transactions list
- State root
- Nonce

EVM

- Realistically, you cannot describe EVM as a cloud machine or a physical machine.
- It exists as a single entity in the sense that it's state is shared by all the nodes in the network thereby creating the unity.
- It's the environment on which all the accounts live and smart contracts run.
- EVM defines rules for creating new state from block to block.
- To give an analogy, think of EVM like a JVM which is Java Virtual Machine.

Gas

- Gas is perhaps the most intriguing part about the ethereum platform.
- To understand gas is very simple yet complex. Think of gas like a fuel for vehicle. Gas is very crucial for the ethereum network as a whole to operate.
- Gas in short refers to a fee that is required for a transaction to take place.
- The way gas is calculated is Gas Units (Limit) * Gas Price per unit which will give us the total gas in Gwei. 1 Gwei is equal to 10^-9 ETH.
- The extra fee or gas amount is paid to the miner for his work as a reward.

Smart Contracts

- Simply said, a smart contract is a piece of program which runs on the Blockchain.
- The program is collection of both code and data which resides on a specific address with in the blockchain.
- It is also a type of account with balance of its own.
- Since, deploying the smart contract is also a transaction you need to pay gas fees to deploy the code.
- The fees is proportional to how complex your code is.
- Smart Contracts are built using Solidity which is an EVM compliant language meaning all EVM supported blockchains can run smart contracts written in Solidity.

TestNet

- 1 ETH is around $2200 which would make it expensive for beginners or even enterprises to test their code directly on main net.
- Hence, there are different public test ethereum networks where you can run your code without actually paying real money.
- Virtually, your code would run the same way it would in ethereum main network.
- The most popular test networks are Rinkeby and Ropstein test networks.

MetaMask

- Your wallet is a container to hold your currency.
- Metamask is a web wallet which allows you to create accounts on various ethereum networks including your own private ethereum network.
- Web based wallet makes it easy for users and developers to access public blockchains easily.

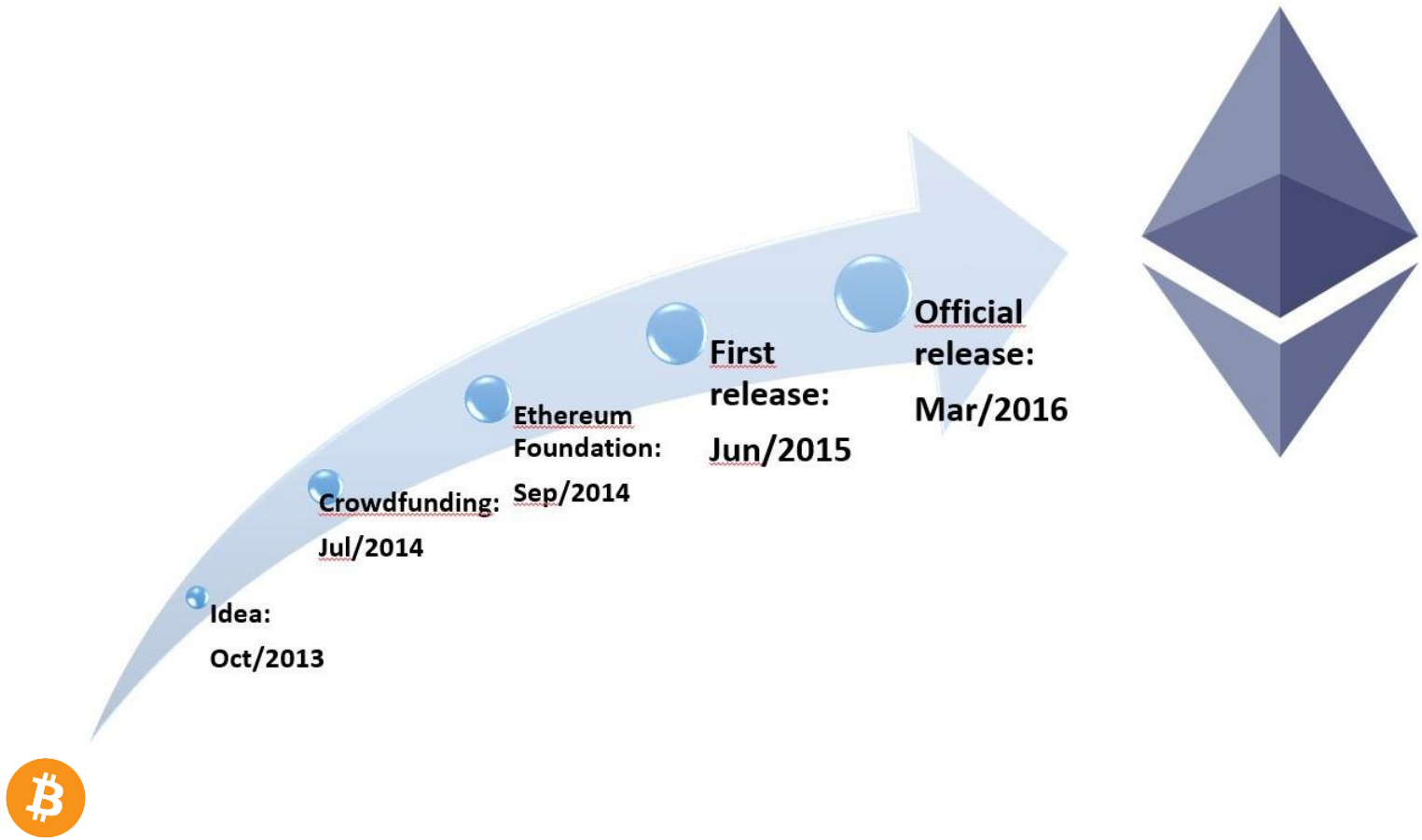
Geth

- Go Ethereum is one of the three original implementations (along with C++ and Python) of the Ethereum protocol. It is written in Go, fully open source and licensed under the GNU LGPL v3.
- Geth can be used to create your own forks of blockchain based out of ethereum. It's also a tool using which you can test your smart contracts without actually spending any real money.

History of Ethereum

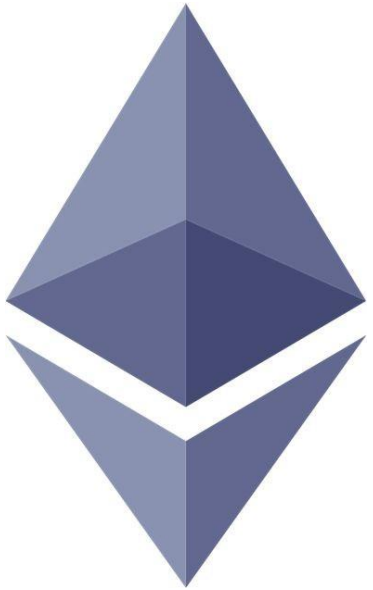
- Vitalik Buterin
- Russian-Canadian programmer
- Co-founded Ethereum when he was 19 years old

History of Ethereum - Timeline



Important Concepts

- Cryptography (similar to Bitcoin)
- Blockchain
  - Accounts (Two types) and Wallets
  - Transactions
- Smart Contracts
  - Solidity
    - Language Used for Smart Contract Development



Cryptography

- Hash functions
- Symmetric Cryptography
- Asymmetric Cryptography
- Signatures

Hash Functions

- BTC uses SHA-256
- Ethereum uses Keccak-256
  - Similar to SHA-3 (variant)
  - Won contest for security in 2007
  - Used for all hashing in Ethereum
  - Derived differently than standard block-cipher based hashes or previous SHA functions

Digital Signatures (Digital Proof)

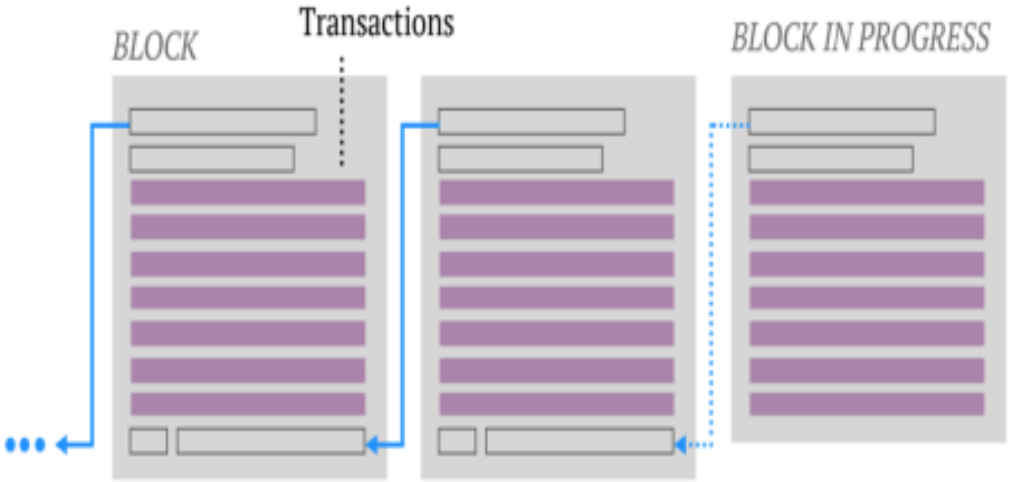
- Same use-case/cryptographic method (ECDSA) as BTC
- Signer uses private key to generate a signed message
- Signed message can be verified using the signer's public key
- Hashes are signed in Ethereum, not the data itself

Blockchain

Fully Distributed Database like BTC

<u>Advantages</u>:

- Highly Secure
- Transparent
- Immutable



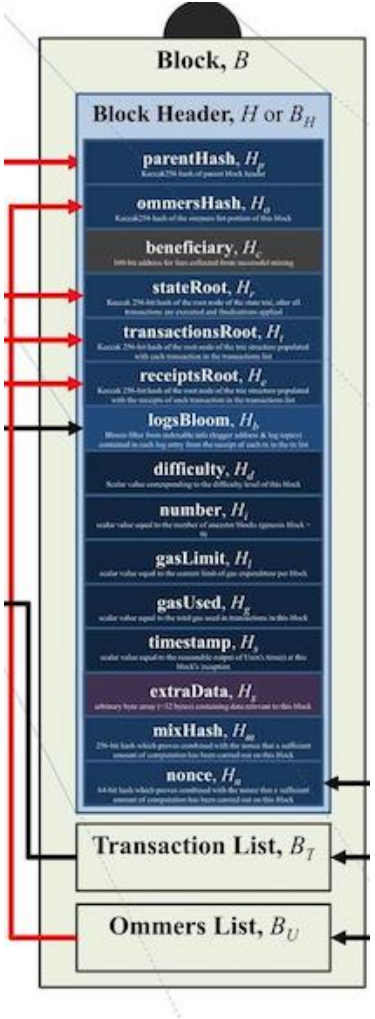
<u>Disadvantages</u>:

- Scaling
- Performance

Ethereum Blockchain

Blocks consist of 3 elements

- Transaction List
  - List of all transactions included in a block
- Block Header
  - Group of 15 elements
- Ommer List
  - List of all Uncle blocks included (described later)



Ethereum Blockchain

Uncles/Ommers

- Sometimes valid block solutions don't make main chain
  - Any broadcast block (up to 6 previous blocks back) with valid PoW and difficulty can be included as an uncle
  - Maximum of two can be included per block
- Uncle block transactions are not included – just header
- Aimed to decrease centralization and reward work

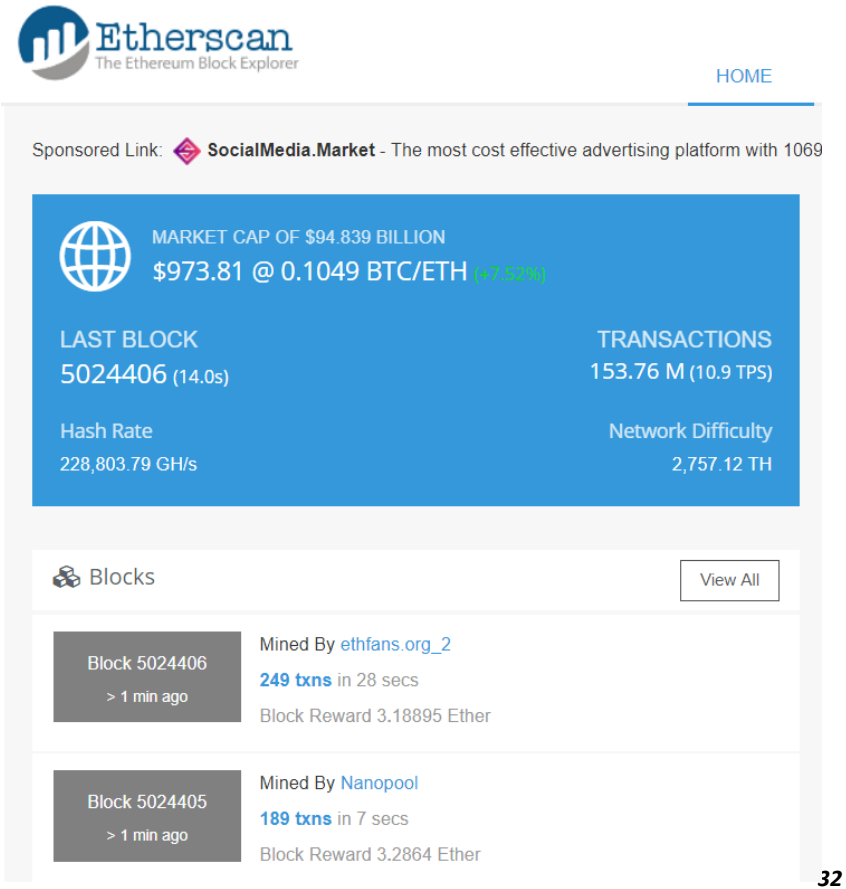
Ethereum Blockchain

Uncles/Ommers Rewards:

- Uncle headers can be included in main block for 1/32 of the main block miner's reward given to said miner
- Miners of uncle blocks receive percent of main reward according to:
  - $(U_n + (8 - B_n)) * 5 / 8$, where U_n and B_n are uncle and block numbers respectively.
  - Example $(1333 + 8 - 1335) * \frac{5}{8} = 3.75$ ETH

Ethereum Blockchain

- All blocks visible like BTC
- However, blocks have a different structure than BTC



https://etherscan.io/

Ethereum Blockchain

Blocks faster than BTC and reward is different

- Every 12 seconds
- 5 ETH main reward
- Miners can make a bit more by including uncle blocks (1/32 of an ETH each) up to maximum of two

Ethereum Blockchain

Blocks faster than BTC and reward is different

- Uses EthHash mining algorithm (different than Bitcoin)
  - Helps mitigate ASIC and GPU advantages
  - Involves smart contract execution
- Difficulty is adjusted every block (not every two weeks)
  – this is an important identifier for the Uncle blocks

Ethereum Blockchain

Key differences

- Blocks keep track of balances – not “unspent transaction outputs” like BTC
- Merkle-Patricia tries used (they have three branches compared to the Merkle tree’s two)
- Will transition from Proof of Work to Proof of Stake with Casper protocol
- See appendix for more details

Ethereum Nodes

- Validate all transactions and new blocks
- Operate in a P2P fashion
- Each contains a copy of the entire Blockchain
- Light clients - store only block headers
  - Provide easy verification through tree data structure
  - Don’t execute transactions, used primarily for balance validation
- Implemented in a variety of languages (Go, Rust, etc.)

Accounts and Wallets

Accounts:

- Two Kinds:
  - External Owned Accounts - (EOA, most common account)
  - Contract Accounts
- Consist of a public/private keypair
- Allow for interaction with the blockchain

Wallets:

- A set of one or more external accounts
- Used to store/transfer ether

Accounts and Wallets

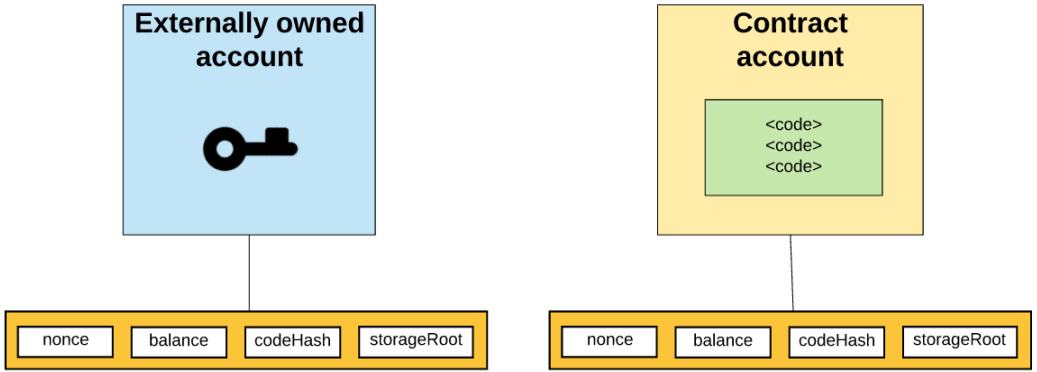
External Account (EOA, Valid Ethereum Address)

- Has an associated nonce (amount of transactions sent from the account) and a balance
- codeHash - Hash of associated account code, i.e. a computer program for a smart contract (hash of an empty string for external accounts, EOAs)
- Storage Root is root hash of Merkle-Patricia trie of associated account data

Accounts and Wallets

Contract Account

- Ethereum accounts can store and execute code
  - Has an associated nonce and balance
  - codeHash - hash of associated account code storageRoot contains Merkle tree of associated storage data



Example Account

Private Key:

0x2dcef1bfb03d6a950f91c573616cdd778d9581690db1cc43141f7cca06fd08ee

- Ethereum Private keys are 66 character strings (with 0x appended). Case is irrelevant. Same derivation through ECDSA as BTC.

Address:

0xA6fA5e50da698F6E4128994a4c1ED345E98Df50

- Ethereum Private keys map to addresses directly. Simply the last 40 characters of the Keccak-256 hash of the public key. Address is 42 characters total (append 0x to front).

Transactions

- A request to modify the state of the blockchain
  - Can run code (contracts) which change global state
    - Contrasts only balance updates in BTC
- Signed by originating account
- Types:
  - Send value from one account to another account
  - Create smart contract
  - Execute smart contract code

Ether Denominations

- Wei - lowest denomination
  - Named after Wei Dai - author of b-money paper (1998), many core concepts used in BTC implementation
  - 1/1,000,000,000,000,000,000 (quintillion)
- Szabo - next denomination
  - Named after Nick Szabo
    - author of Bit-Gold
- Finney – 2nd highest denomination
  - Named after Hal Finney
    - received first Tx from Nakamoto

Multiplier	Name
10^0	Wei
10^{12}	Szabo
10^{15}	Finney
10^{18}	Ether

http://www.weidai.com/bmoney.txt

Smart Contracts

- Executable code
- Turing Complete
- Function like an external account
  - Hold funds
  - Can interact with other accounts and smart contracts
  - Contain code
- Can be called through transactions

Code Execution

- Every node contains a virtual machine (similar to Java)
  - Called the Ethereum Virtual Machine (EVM)
  - **Compiles** code from high-level language to bytecode
  - Executes smart contract code and broadcasts state
- ***Every full-node on the blockchain processes every transaction and stores the entire state***

Gas

- Halting problem (infinite loop) – reason for Gas
  - Problem: Cannot tell whether or not a program will run infinitely from compiled code
  - Solution: charge fee per computational step to limit infinite loops and stop flawed code from executing
- Every transaction needs to specify an estimate of the amount of gas it will spend
- Essentially a measure of how much one is willing to spend on a transaction, even if buggy

Gas Cost

- Gas Price: current market price of a unit of Gas (in Wei)
  - Check gas price here: https://ethgasstation.info/
  - Is always set before a transaction by user
- Gas Limit: maximum amount of Gas user is willing to spend
- Helps to regulate load on network
- Gas Cost (used when sending transactions) is calculated by gasLimit*gasPrice.
  - All blocks have a Gas Limit (maximum Gas each block can use)

PoW vs. PoS

Ethereum in the process of moving to Proof of Stake

- This approach does not require large expenditures on computing and energy
- Miners are now “validators” and post a deposit in an escrow account
- The more escrow you post, the higher the probability you will be chosen to nominate the next block
- If you nominate a block with invalid transactions, you lose your escrow

PoW vs. PoS

Ethereum in the process of moving to Proof of Stake

- One issue with this approach is that those that have the most ethereum will be able to get even more
- This leads to centralization eventually
- On the other hand, it reduces the chance of a 51% attack and allows for near instant transaction approvals
- The protocol is called Casper and this will be a hard fork

https://blockonomi.com/ethereum-casper/

Other approaches to conensus

There are many other types of consensus

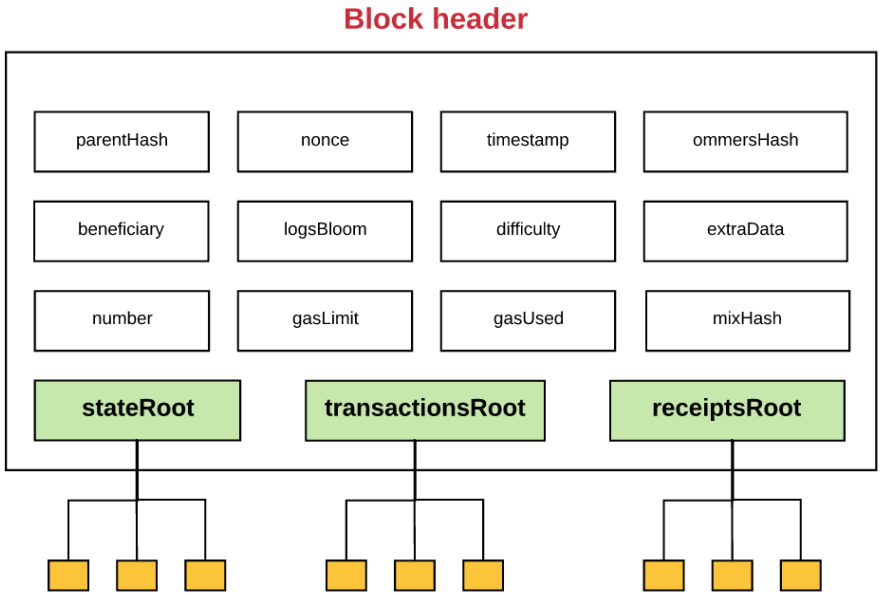
- (PoW) Proof of Work (Bitcoin, Ethereum, …)
- (PoS) Proof of Stake (Ethereum in future)
- (PoI) Proof of Importance (used in NEM)
- (PBFT) Practical Byzantine Fault Tolerance (Hyperledger Fabric)
- (FBFT) Federated Byzantine Fault Tolerance (Ripple, Stellar)
- (DPoS) Delegated Proof of Stake
- (PoET) Proof of Elapsed Time (Hyperledger Sawtooth)

https://medium.com/@chrshmmmr/consensus-in-blockchain-systems-in-short-691fc7d1fefe

Appendix materials

A. Ethereum Blockchain Header

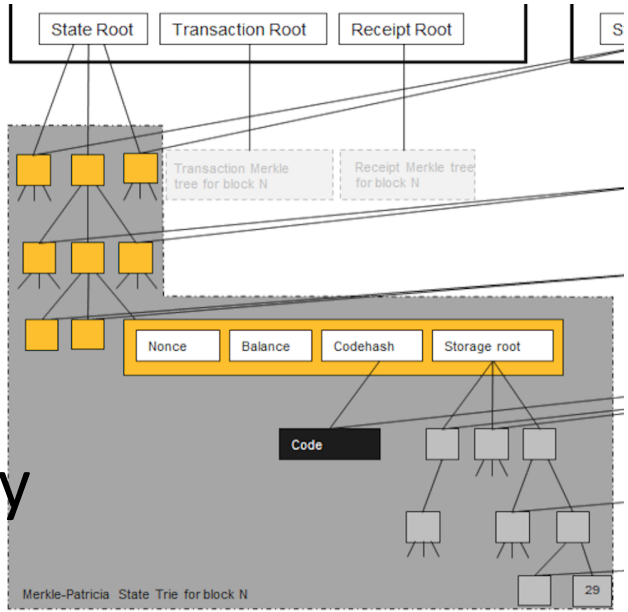
- Hash of included ommer's stored in block header
- State root is the hash of a merkle trie that holds all account information
- Similar storage structure for transactions and receipts



A. Ethereum Blockchain State

StateRoot, TransactionRoot, and ReciptsRoot

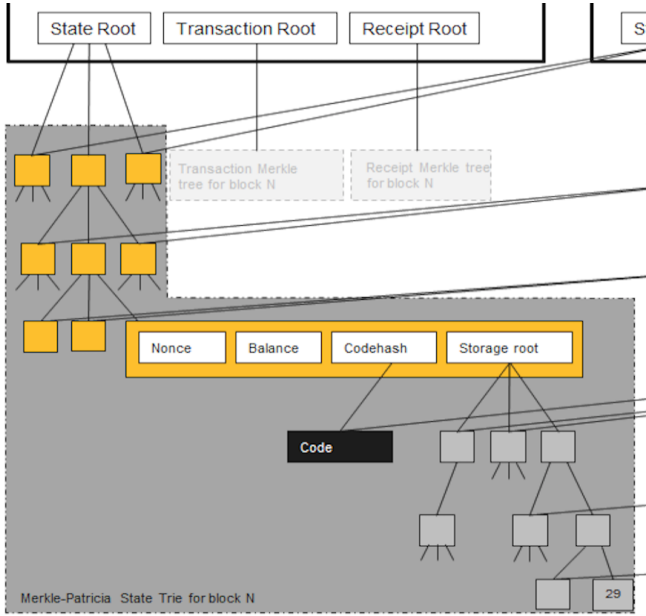
- Stored in data structure known as a Merkle-Patricia trie
- Similar to the Merkle trie used in BTC, but with three leaves per node
- Trie is cryptographically secure as any alteration of a leaf or intermediary node results in a different root hash



A. Ethereum Blockchain State

StateRoot

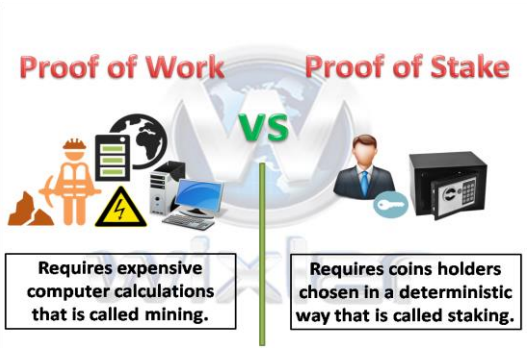
- Each node in the stateRoot trie represents an Ethereum address
- Each address has 4 components
  - Nonce - list of number of Tx's from address
  - CodeHash - hash of associated code
  - StorageRoot - Merkle-Patricia tree root of account storage contents
  - Balance - balance of account

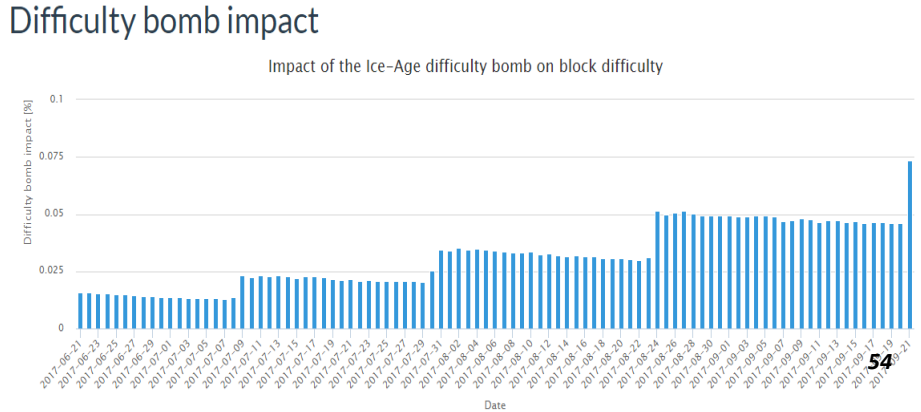


A. Ethereum Blockchain

Ethereum “difficulty bomb”

- Spike (increase) in mining difficulty
- Introduced to attempt to reduce number of miners
  - Aimed to pre-date shift of algorithm from PoW to Proof-of-Stake (PoS)





B. Smart Contract Programming

- Solidity (javascript based), most popular
  - Not yet as functional as other, more mature, programming languages
- Serpent (python based)
- LLL (lisp based)

B. Smart Contract Programming

Solidity

Solidity is a language similar to JavaScript which allows you to develop contracts and compile to EVM bytecode. It is currently the flagship language of Ethereum and the most popular.

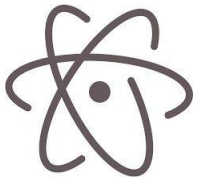
- Solidity Documentation - Solidity is the flagship Ethereum high level language that is used to write contracts.
- Solidity online realtime compiler

Serpent

Serpent is a language similar to Python which can be used to develop contracts and compile to EVM bytecode. It is intended to be maximally clean and simple, combining many of the efficiency benefits of a low-level language with ease-of-use in programming style, and at the same time adding special domain-specific features for contract programming. Serpent is compiled using LLL.

- Serpent on the ethereum wiki
- Serpent EVM compiler

B. Smart Contract Programming



Atom Ethereum interface - Plugin for the Atom editor that features syntax highlighting, compilation and a runtime environment (requires backend node).

Atom Solidity Linter - Plugin for the Atom editor that provides Solidity linting.

Vim Solidity - Plugin for the Vim editor providing syntax highlighting.

Vim Syntastic - Plugin for the Vim editor providing compile checking.

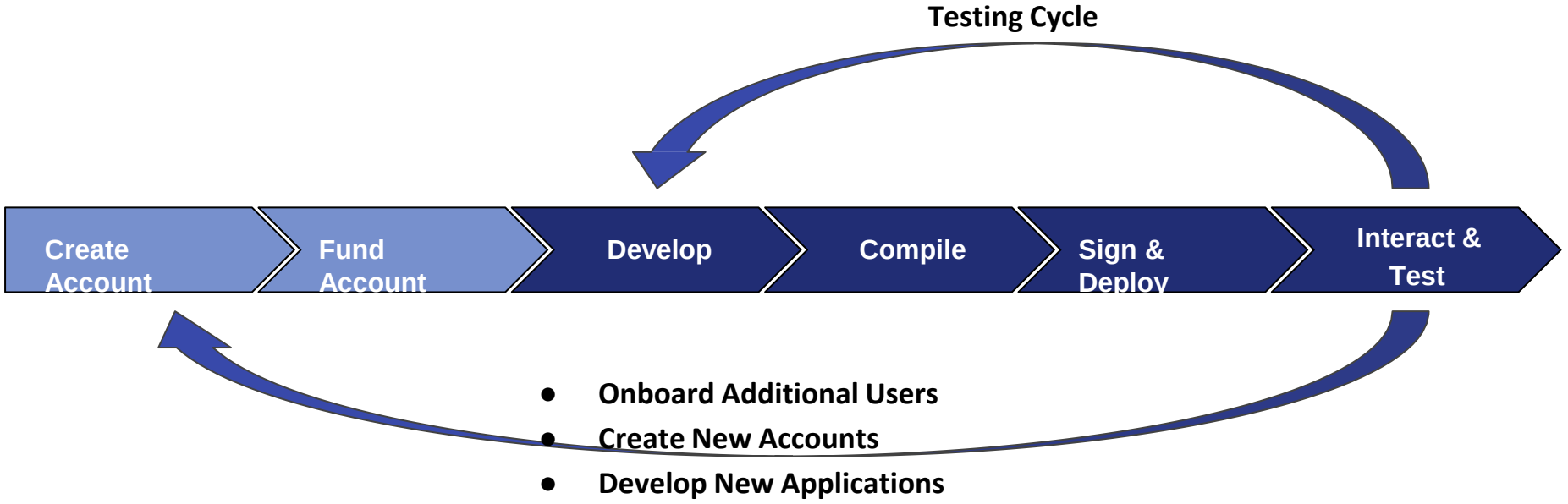
B. Smart Contract Programming: Solidity

```
contract Example {

   uint value;

   function setValue(uint pValue) {
      value = pValue;
   }

   function getValue() returns (uint) {
      return value;
   }

}
```

B. Smart Contract Programming: Solidity

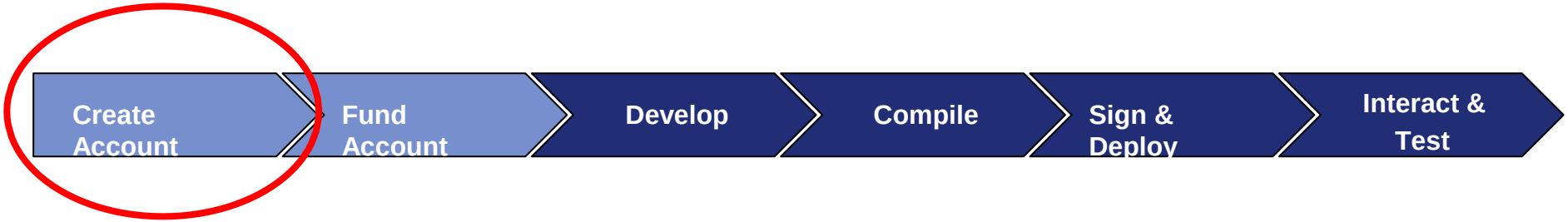
```
var logIncrement =
   OtherExample.LogIncrement({sender: userAddress,
uint value});

logIncrement.watch(function(err, result) {
  // do something with result
})
```

C. Development Workflow



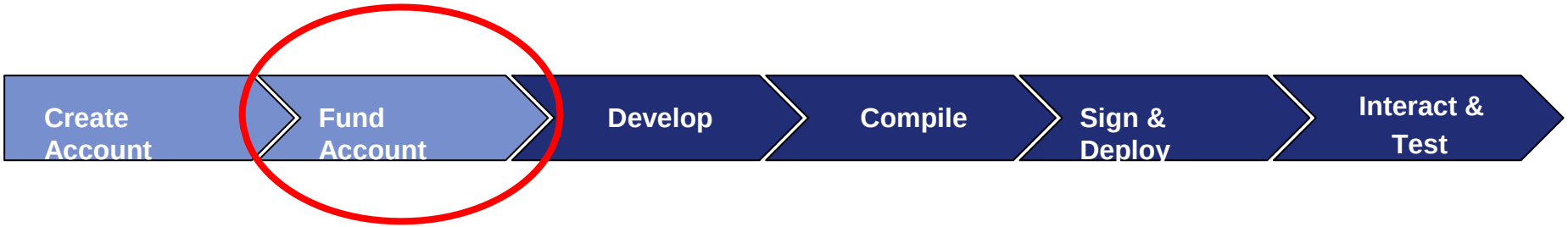
- Onboard Additional Users
- Create New Accounts
- Develop New Applications

C. Development Workflow: Create Account



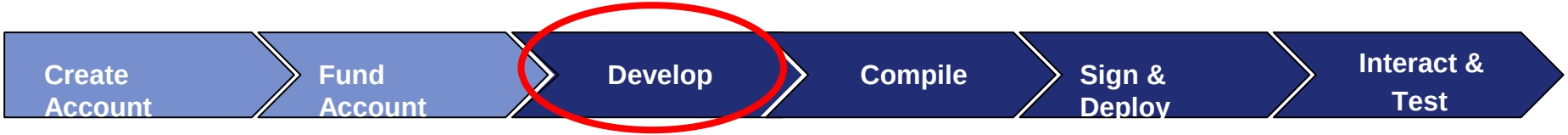
- Programmatically: Go, Python, C++, JavaScript, Haskell
- Tools
  - MyEtherWallet.com
  - MetaMask
  - TestRPC
  - Many other websites

C. Development Workflow: Fund Account



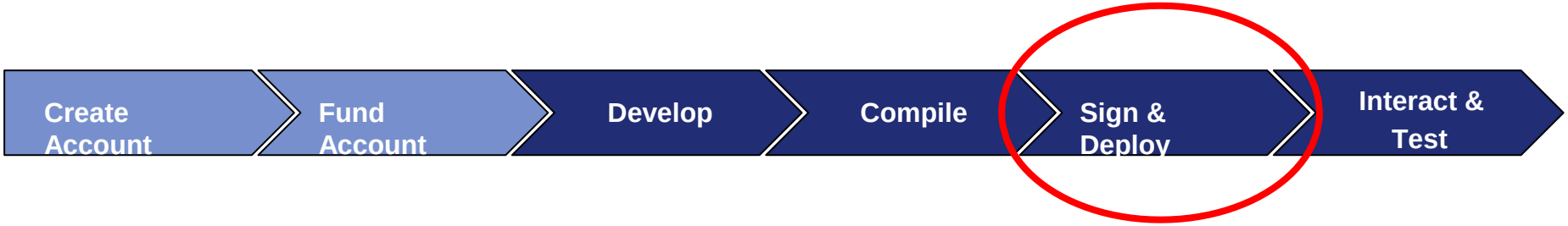
- From friends
- Faucet
- Exchanges (for public blockchain)

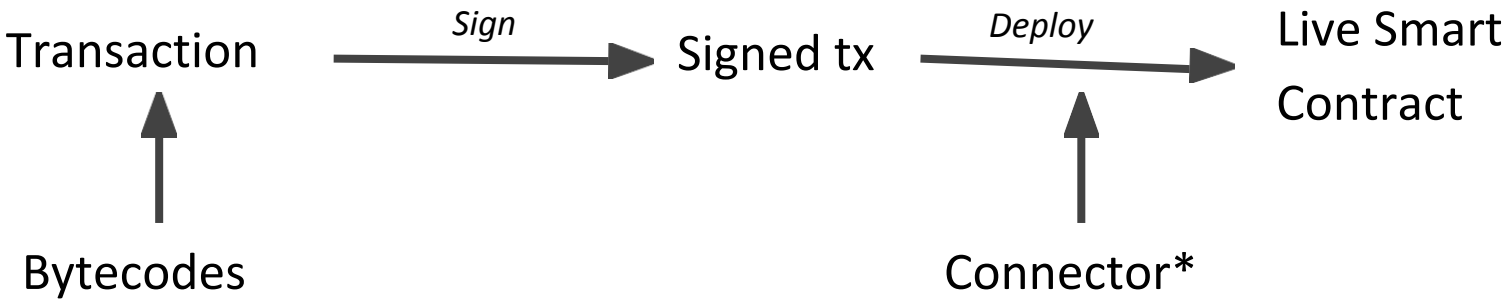
C. Development Workflow: Develop



- **Ethereum Application Components:**
  - **Base application**: can be developed in **any** language
  - **Smart contract**: developed in Solidity or one of the other contract compatible languages
  - **Connector library**: facilitates communication between base application and smart contracts (Metamask)

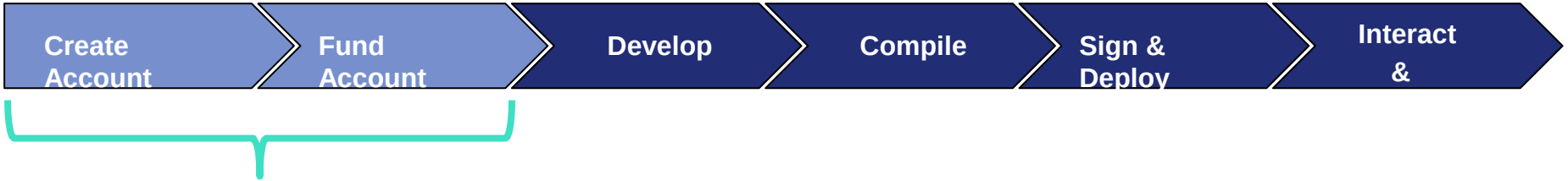
C. Development Workflow: Sign and Deploy





*Library that facilitates communication and connection with Blockchain; Connects your code to a running node.

C. Development Workflow: TestRPC



TestRPC/TestChain

- Local development or Test Blockchain
- https://github.com/ethereumjs/testrpc

C. Development Workflow: TestRPC

- EthereumJS TestRPC: https://github.com/ethereumjs/testrpc is suited for development and testing
- It's a complete blockchain-in-memory that runs only on your development machine
- It processes transactions instantly instead of waiting for the default block time – so you can test that your code works quickly – and it tells you immediately when your smart contracts run into errors
- It also makes a great client for automated testing
- Truffle knows how to use its special features to speed up test runtime by almost 90%.

References / Sources:

- Coursera Course ‘Smart Contracts’
- Innovation and Cryptoventures - Ethereum lecture slides by Campbell R. Harvey* Duke University and NBER, Ashwin Ramacha[illegible] Brent Xu ConsenSys

- https://preethikasireddy.medium.com/how-does-ethereum-work-anyway-22d1df506369