CAS Module 1: Days 1+2, Zürich, Fridays, September 4 and 11, 2020

Blockchains

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With many thanks addressed to M. Franco, G. Parangi, S. Rafati, E. Scheid, and Dr. E. Schiller – all @ CSG[1]

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CSG
Communication Systems Group

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Outline Day 2 – Blockchain Platforms and Architectures

Part V: Ethereum

11. Bascis
12. Mechanism and Protocol
13. Smart Contracts

Part VI: The Blockchain World

14. Other Blockchains
15. Blockchain Interoperability

Lunch Break

Part VII: Practical Exercises

16. Ethereum Wallet
17. Smart Contract

Part VIII: Blockchain Evaluations (Technical View, mainly)

18. To Blockchain or not to Blockchain
19. Comparisons and Assessment
20. Challenges and Risks
21. Expected Impacts and Conclusions

Day 2: Blockchain Platforms and Architectures

Ethereum Basics

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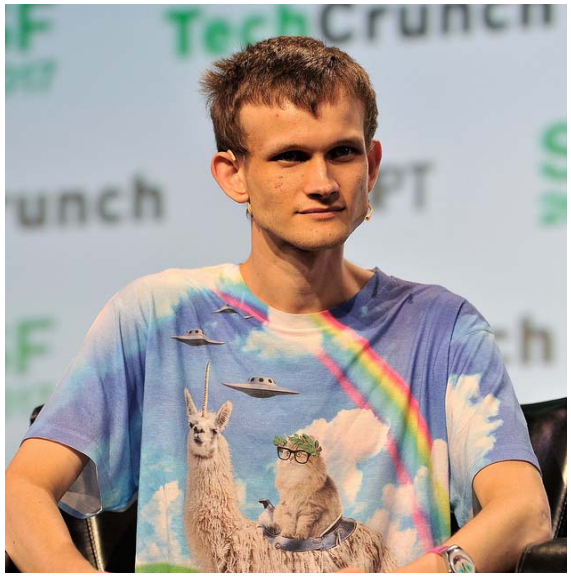
Bitcoin / Ethereum

- “Issues” with Bitcoin
  - Bitcoin Script limited
    - But: many use-cases possible: Lightning network, escrow
  - Slow development, implementing new features difficult
    - E.g., when running into block limits: improve protocol vs. increase block size - SegWit
    - SegWit vs. BTU (segregated witness vs. increasing block size voting)
    - If you don’t agree: fork
- Ethereum (1 ETH ~470$)
  - «General-purpose» blockchain (loops, arithemitcs, etc.)
  - White paper released in December 2013
  - Protocols designed from scratch (not like Bitcoin forks)
  - Ethereum foundation located in Zug (initiators known) - non-profit foundation
  - Mining reward ~ block every ~14s – ~2 ETH (“always”, unlike Bitcoin’s ~21m BTC limit)



Vitaly Buterin

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Ethereum History

- Olympic (past) – released 09.05.2015
  - Last Ethereum Proof-of-Concept series
  - “Olympic will feature a total prize fund of up to 25,000 ether” (now 11.7m USD)
- Frontier (past) - released 30.07.2015
  - Main public network, “Beta”/use at your own risk
- Muir Glacier (now) - released 01.01.2020
  - Delay difficulty bomb
  - St. Petersburg: change from 3 ETH to 2 ETH reward
- Ethereum 2.0
  - Proof-of-stake (energy), sharding (storage space)

Frontier	2015-07-30	0
Ice Age	2015-09-08	200’000
Homestead	2016-03-15	1’150’000
DAO Fork	2016-07-20	1’920’000
Tangerine Whistle	2016-10-18	2’463’000
Spurious Dragon	2016-11-28	2’675’000
Byzantium	2017-10-16	4’370’000
Constantinople / St. Petersburg	2019-02-28	7’280’000
Istanbul	2019-12-08	9’069’000
Muir Glacier	2020-01-01	9’200’000
Berlin	?	?

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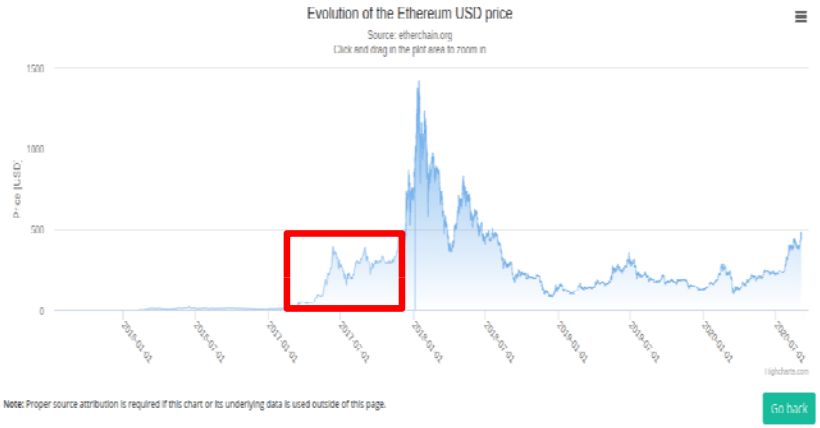
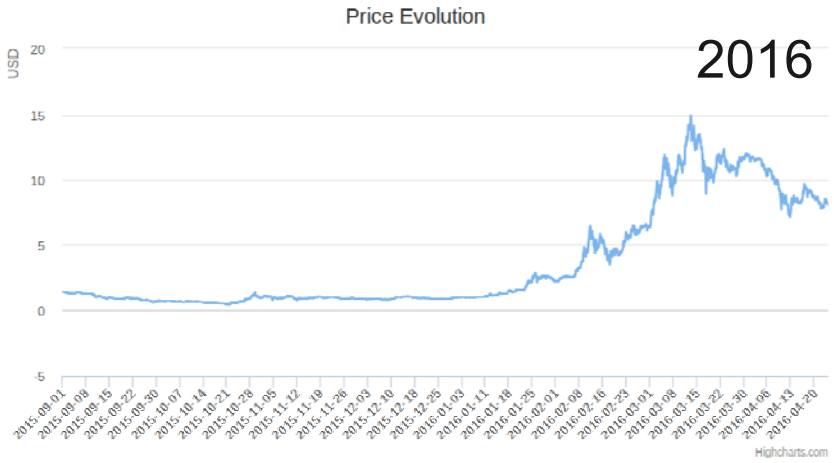
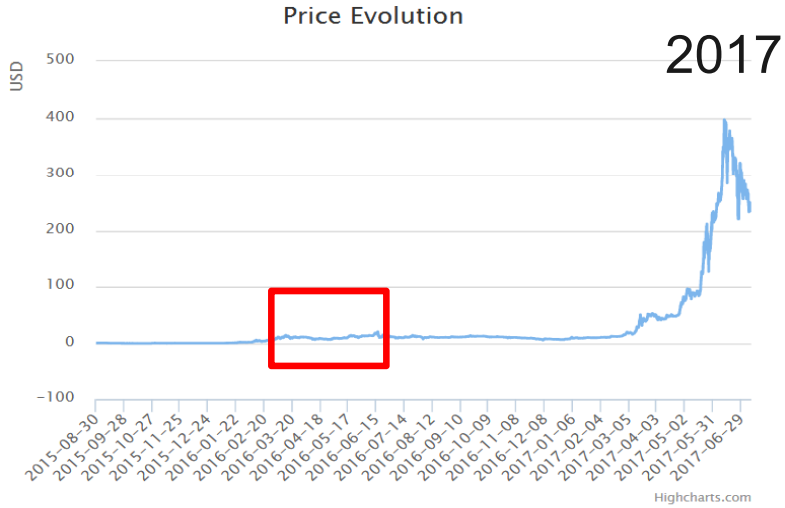
Ethereum Stats

- Basic Stats
  - 2nd in market cap ~ 50b USD
  - 112mio ETH supply (stats)
  - Transactions (highest ~15.5 TPS) now ~1mio per day
  - Node count (~9'000 nodes)
  - Blocksize ~40KB
  - Accounts (113mio)







Mining Mechanisms

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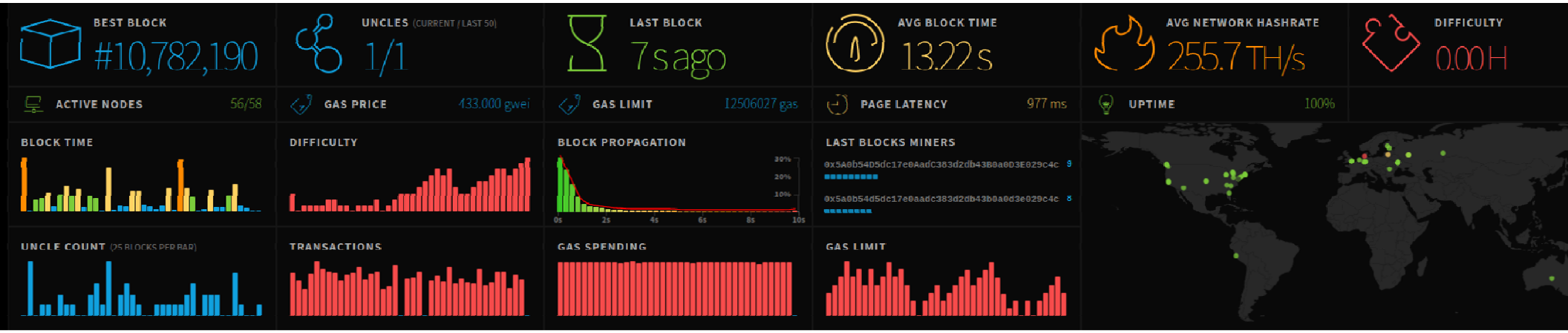
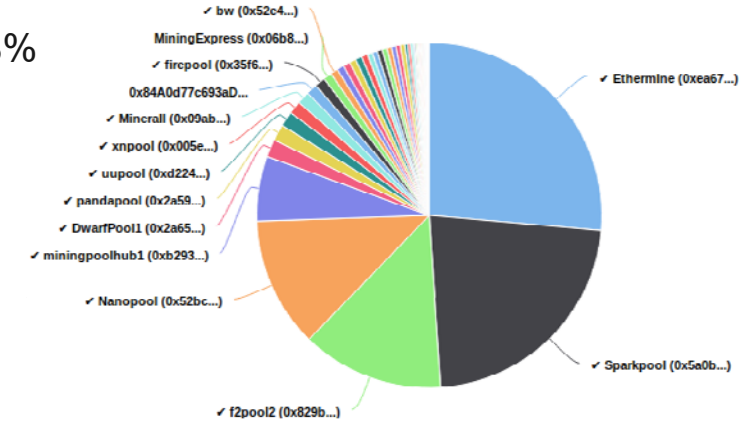
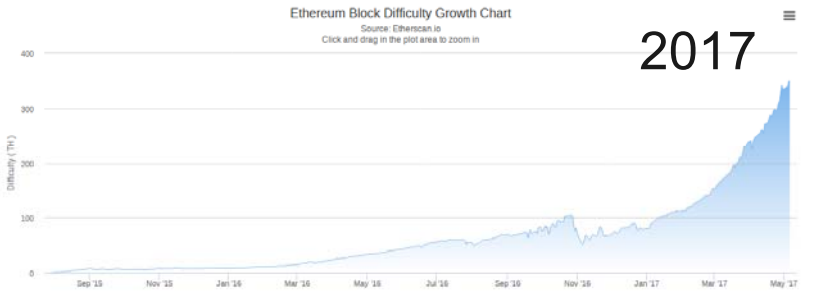
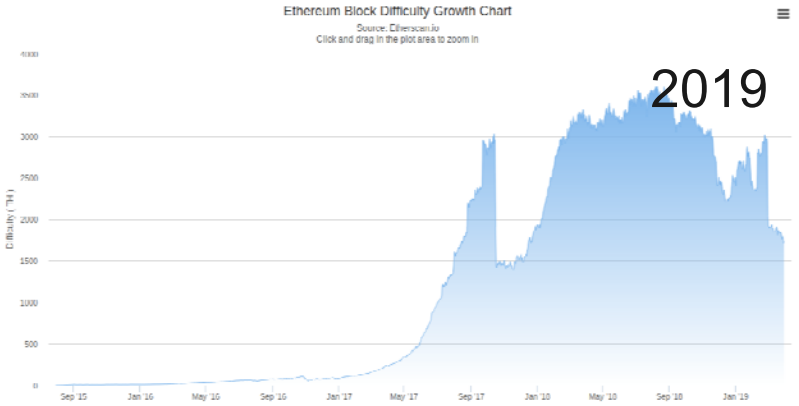


- Proof-of-work - Increasing difficulty
  - Mining in pools
  - Ethermine + Sparkpool 48.8%
  - Farms







51% Attack in Ethereum / Bitcoin

- “If a majority of CPU power is controlled by honest nodes, the honest chain will grow the fastest and outpace any competing chains.”
  - https://bitcoin.org/bitcoin.pdf
- PoW: majority of hashing power
- How expensive is a 51% attack?
  - Buy an attack?
  - “Ethereum Classic Labs singled out crypto-mining marketplace NiceHash for allegedly facilitating multiple attacks against the network”

- 01.08.2020: Ethereum Classic suffered a 3,693-blockchain reorganization early Saturday morning, an event first thought to be a possible 51% attack, after a miner used old software after having been offline, according to Terry Culver, CEO of Ethereum Classic Labs.
- 06.08.2020: Ethereum Classic has suffered its second 51% attack in a week after more than 4,000 blocks were reorganized Thursday morning.
- 17.08.2020: OKEx has confirmed a loss of approximately $5.6 million in Ethereum Classic (ETC) from two recent 51% attacks and is considering removing ETC from its exchanges.
- 01.09.2020: Ethereum Classic (ETC) Suffers Yet Another 51% Attack, Major Changes Needed to Improve Blockchain Platform’s Security

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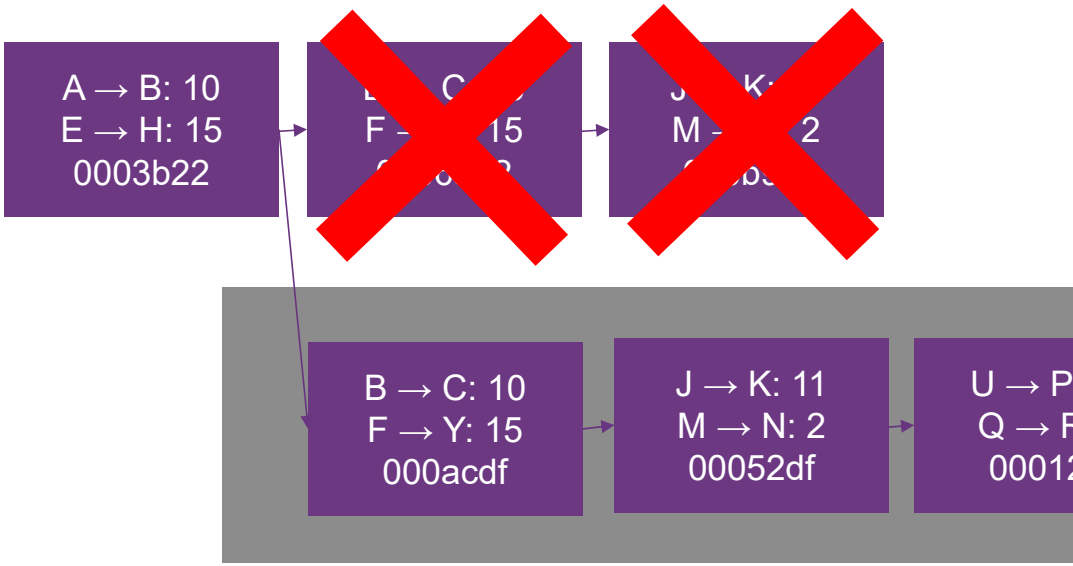
51% Attack in Ethereum / Bitcoin

- Longest chain survives (same as Bitcoin)
- Double spend: rollback transactions
  - X is an exchange address
  - Mine secretly, Y is attacker address
  - X arrived – miner does payout USD (wait 2 block conf.)
  - You mine faster as you have 51%, broadcast secret chain
  - Tx F→X: 15 never happened, goes to Y, but attacker already got the USD
    - Attacker can spend the 15 coins again (double spend)



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Transaction Time and Costs

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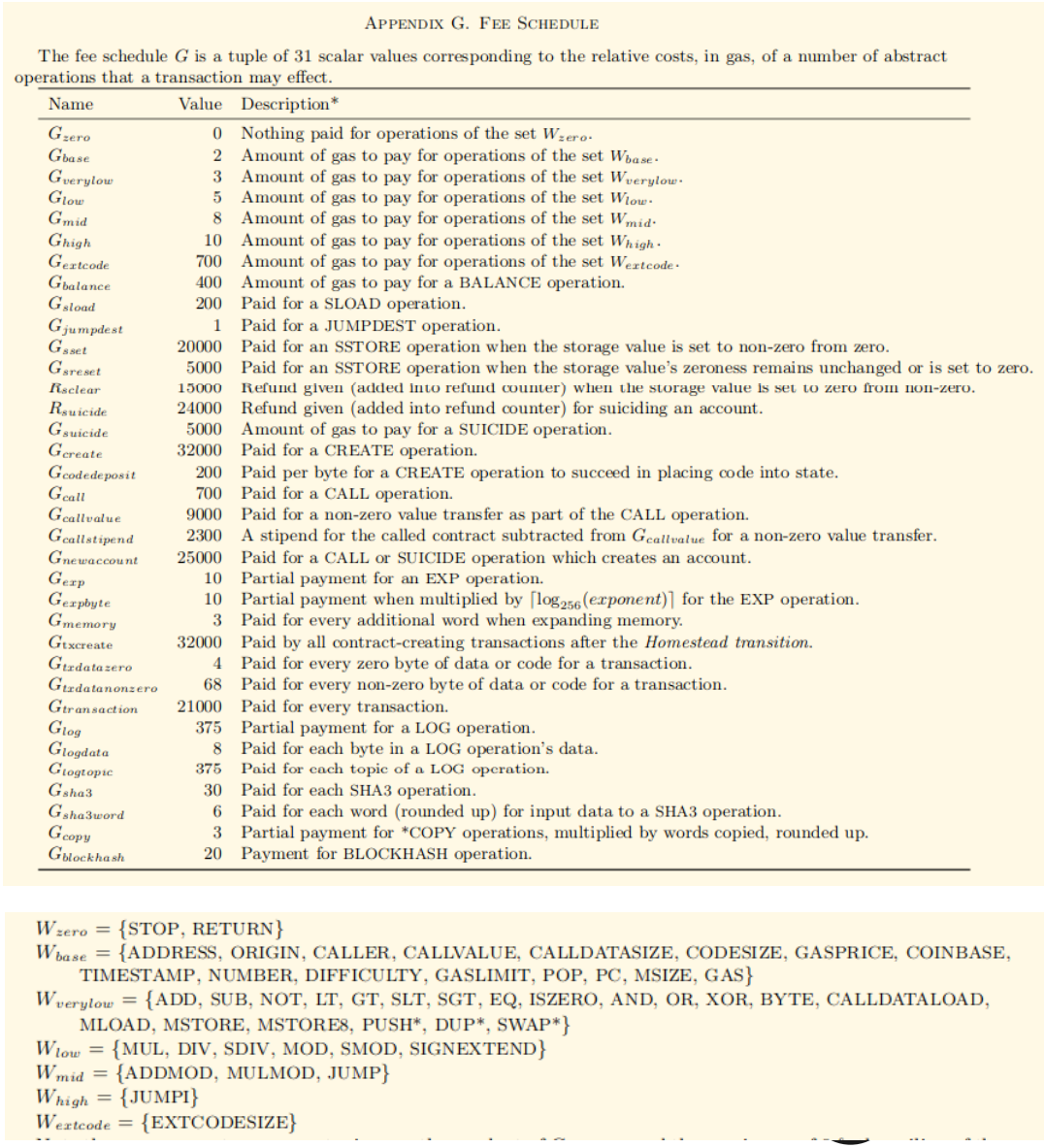
Gas

- Recap: Ethereum is needs a lot of energy – proof-of-work – Miners are rewarded with 2 ETH – 900USD
  - Miner also gets TX fee
    - Bitcoin (simple TX)~ 3USD
    - Ethereum (simple TX) ~ 2USD
- How much do I need to pay?
  - Bitcoin easy, proportional to size: 300 bytes = 0.0003BTC, 600b = 0.0006BTC
  - Ethereum can have loops, so 300 bytes script may run forever
    - Solution: pay per instruction → gas



APPENDIX G. FEE SCHEDULE

The fee schedule G is a tuple of 31 scalar values corresponding to the relative costs, in gas, of a number of abstract operations that a transaction may effect.

Name	Value	Description*
G_{zero}	0	Nothing paid for operations of the set W_{zero}.
G_{base}	2	Amount of gas to pay for operations of the set W_{base}.
$G_{verylow}$	3	Amount of gas to pay for operations of the set $W_{verylow}$.
G_{low}	5	Amount of gas to pay for operations of the set W_{low}.
G_{mid}	8	Amount of gas to pay for operations of the set W_{mid}.
G_{high}	10	Amount of gas to pay for operations of the set W_{high}.
$G_{extcode}$	700	Amount of gas to pay for operations of the set $W_{extcode}$.
$G_{balance}$	400	Amount of gas to pay for a BALANCE operation.
G_{sload}	200	Paid for a SLOAD operation.
$G_{jumpdest}$	1	Paid for a JUMPDEST operation.
G_{sset}	20000	Paid for an SSTORE operation when the storage value is set to non-zero from zero.
G_{sreset}	5000	Paid for an SSTORE operation when the storage value's zeroness remains unchanged or is set to zero.
R_{sclear}	15000	Refund given (added into refund counter) when the storage value is set to zero from non-zero.
$R_{suicide}$	24000	Refund given (added into refund counter) for suiciding an account.
$G_{suicide}$	5000	Amount of gas to pay for a SUICIDE operation.
G_{create}	32000	Paid for a CREATE operation.
$G_{codedeposit}$	200	Paid per byte for a CREATE operation to succeed in placing code into state.
G_{call}	700	Paid for a CALL operation.
$G_{callvalue}$	9000	Paid for a non-zero value transfer as part of the CALL operation.
$G_{callstipend}$	2300	A stipend for the called contract subtracted from $G_{callvalue}$ for a non-zero value transfer.
$G_{newaccount}$	25000	Paid for a CALL or SUICIDE operation which creates an account.
G_{exp}	10	Partial payment for an EXP operation.
$G_{expbyte}$	10	Partial payment when multiplied by $\lceil \log_{256}(exponent) \rceil$ for the EXP operation.
G_{memory}	3	Paid for every additional word when expanding memory.
G_{txcreate}	32000	Paid by all contract-creating transactions after the *Homestead transition*.
$G_{txdatazero}$	4	Paid for every zero byte of data or code for a transaction.
$G_{txdatanonzero}$	68	Paid for every non-zero byte of data or code for a transaction.
$G_{transaction}$	21000	Paid for every transaction.
G_{log}	375	Partial payment for a LOG operation.
$G_{logdata}$	8	Paid for each byte in a LOG operation's data.
$G_{logtopic}$	375	Paid for each topic of a LOG operation.
G_{sha3}	30	Paid for each SHA3 operation.
$G_{sha3word}$	6	Paid for each word (rounded up) for input data to a SHA3 operation.
G_{copy}	3	Partial payment for *COPY operations, multiplied by words copied, rounded up.
$G_{blockhash}$	20	Payment for BLOCKHASH operation.

$W_{zero} = \{\text{STOP, RETURN}\}$
$W_{base} = \{\text{ADDRESS, ORIGIN, CALLER, CALLVALUE, CALLDATASIZE, CODESIZE, GASPRICE, COINBASE, TIMESTAMP, NUMBER, DIFFICULTY, GASLIMIT, POP, PC, MSIZE, GAS}\}$
$W_{verylow} = \{\text{ADD, SUB, NOT, LT, GT, SLT, SGT, EQ, ISZERO, AND, OR, XOR, BYTE, CALLDATALOAD, MLOAD, MSTORE, MSTORE8, PUSH*, DUP*, SWAP*}\}$
$W_{low} = \{\text{MUL, DIV, SDIV, MOD, SMOD, SIGNEXTEND}\}$
$W_{mid} = \{\text{ADDMOD, MULMOD, JUMP}\}$
$W_{high} = \{\text{JUMPI}\}$
$W_{extcode} = \{\text{EXTCODESIZE}\}$

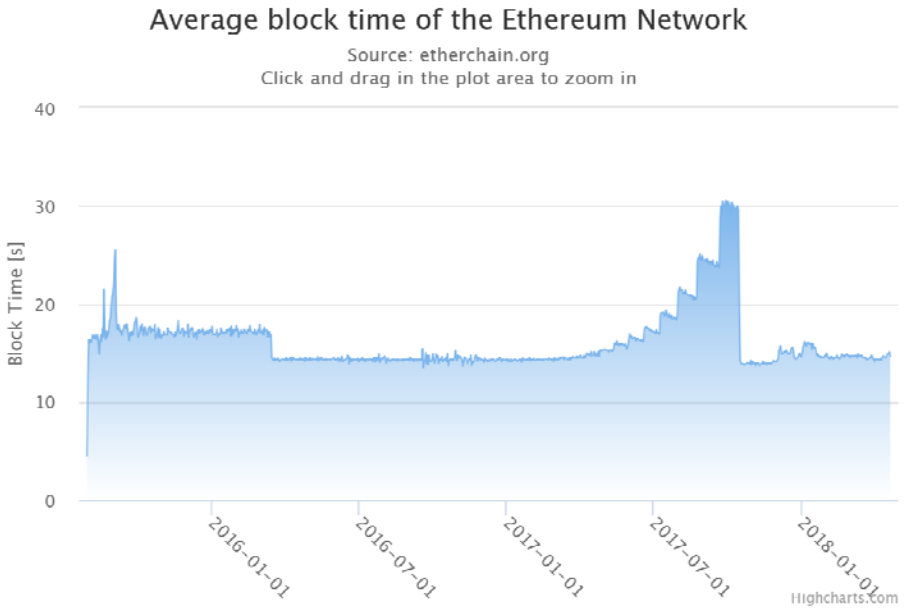
Blocktime and Gas

Gas

- Every instruction is paid for (example)
  - Total gas amount: dry-run contract
- Issue transaction: specify how much gas you want to use (max) and gas price
  - If you run out of gas, state is reverted, ETH gone
- Gas Price also set by Miner
  - Gas price ~375 gwei
  - Market for TX
    - Gas price too low, longer waiting time until TX will be included

Blocktime

- Block time: ~14-15s
  - But: Ice age



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Smart Contracts

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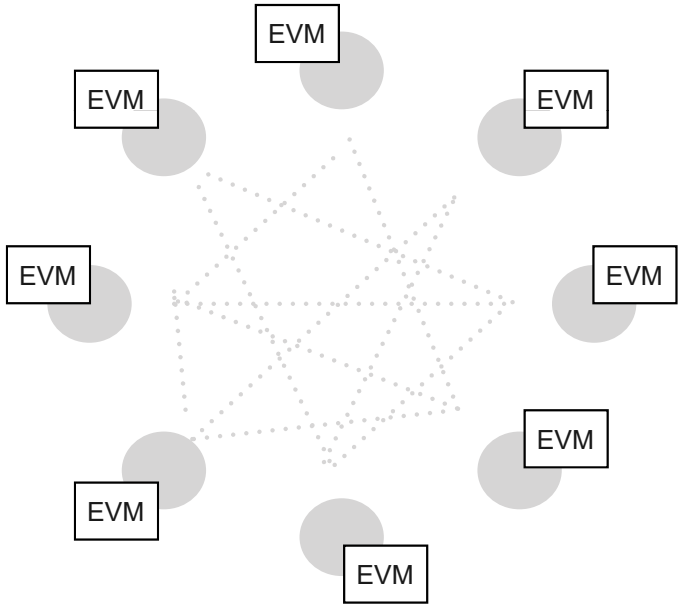
Ethereum smart contract

- Ethereum Virtual Machine runs instructions (slide 11)
- Computation on EVM is "very expensive“: every contract is run on every full Ethereum node
  - Global computer, always running, always correct
  - Result on every node is the same
- Coin flip?
  - Not easy - no random number generator in Ethereum



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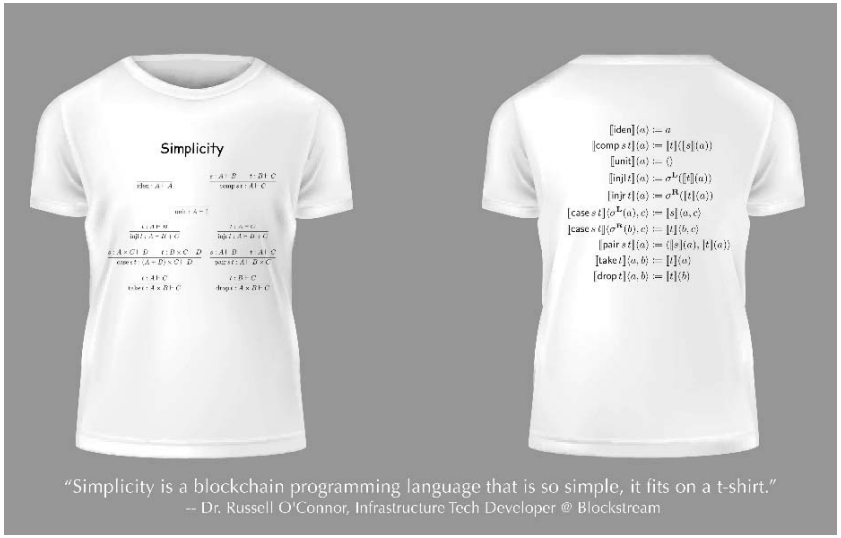
Scripts / Opcodes / Smart Contracts

- Ivy - a non Turing complete higher-level language that compiles to Bitcoin Script
  - Experimental
- Rootstock
  - Rootstock (RSK) is a smart-contract platform with a Turing Complete VM for Bitcoin.
  - Bitcoin Sidechain, 2-way pegging
  - Backward compatible with Ethereum VM
- Simplicity - a typed, combinator-based, functional language without
  - By Blockstream
  - Definition fits on a t-shirt
- Miniscript: language for writing Bitcoin scripts in a structured way



Solidity Language https://solidity.readthedocs.io

- JavaScript-like language
  - Statically-typed that compiles to EVM bytecode
- Comments

```
// This is a single-line comment.
/*
This is a
multi-line comment.
*/
```

- Contract with State Variables (expensive!)

```
pragma solidity ^0.7.1;
//minimal contract
contract Example1 {
    uint256 counter;
}
```

https://learnxinyminutes.com/docs/solidity/
https://solidity.readthedocs.io/en/v0.7.1/

Details in Part VII

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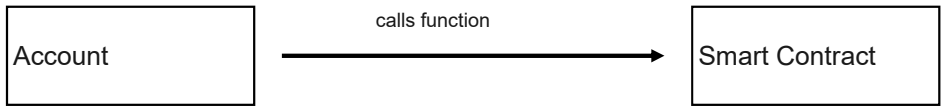
Solidity: Constructor / Function Calls

- The constructor is run only once, i.e., when the contract is created!
- Smart contract function can call another smart contract function
- Initiator **always** needs to be an external account (smart contract can have account)
  - But smart contract can never initiate a transaction on its own



OR

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Solidity: Version, Mapping

```
/* Specifies what versions of Solidity a
 * source file can work on
 */
pragma solidity ^0.7.1;

contract Notary {
    …
}
```

- Ensures that the source code is only meant for compiler versions that are not older than 0.5.0 and will also not work on a compiler starting from version 0.6.0.
- Mapping of address, of mapping of hash, and timestamp

```
contract Notary {

  mapping (address => mapping (bytes32 => uint256)) stamps;
    …
}
```

Address	Hash	Timestamp
0xD6df5935cD03a768b7B9E92637A01b25e24cb709	ed52f3833d5d2c920fd43a0972add3555ad149f0201bbd134907498a851a5ec3	2009-06-24 12:39:54 +0900
0xD6df5935cD03a768b7B9E92637A01b25e24cb709	0c911c1d3bde4be991e3d39c2f7e97c621617feaf8f7070e2384c602430ee382	2015-04-14 10:34:24 +0800
0x1530df3e1C69501d4Ecb7E58eB045b90DE158873	0c911c1d3bde4be991e3d39c2f7e97c621617feaf8f7070e2384c602430ee382	2020-09-11 14:33:24 +0900
…	…	…

Example Solidity Contract

- Notary Contract
  - Simple Contract, 2 functions
  - No constructor

```
pragma solidity ^0.7.1;

contract Notary {

    mapping (address => mapping (bytes32 => uint256)) stamps;

    function store(bytes32 hash) public {
        stamps[msg.sender][hash] = block.timestamp;
    }

    function verify(address recipient, bytes32 hash)
                  public view returns (uint256) {
        return stamps[recipient][hash];
    }
}
```


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Architecture Overview

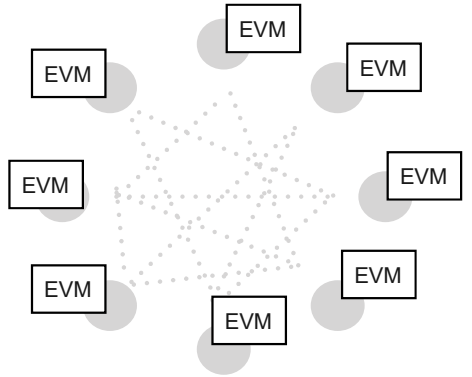
```
pragma solidity ^0.7.1;

contract Notary {
    …
}
```

Compiler

Remix IDE

METAMASK



ethereum

EVM

Local Ethereum Node

```
$ solc --version
solc, the solidity compiler commandline interface
Version: 0.6.0+commit.26b70077.Linux.g++
```

```
0000 PUSH1 60
0002 PUSH1 40
0004 MSTORE
0005 PUSH1 04
0007 CALLDATASIZE
0008 LT
0009 PUSH2 0133
0012 JUMPI
```

Instructions

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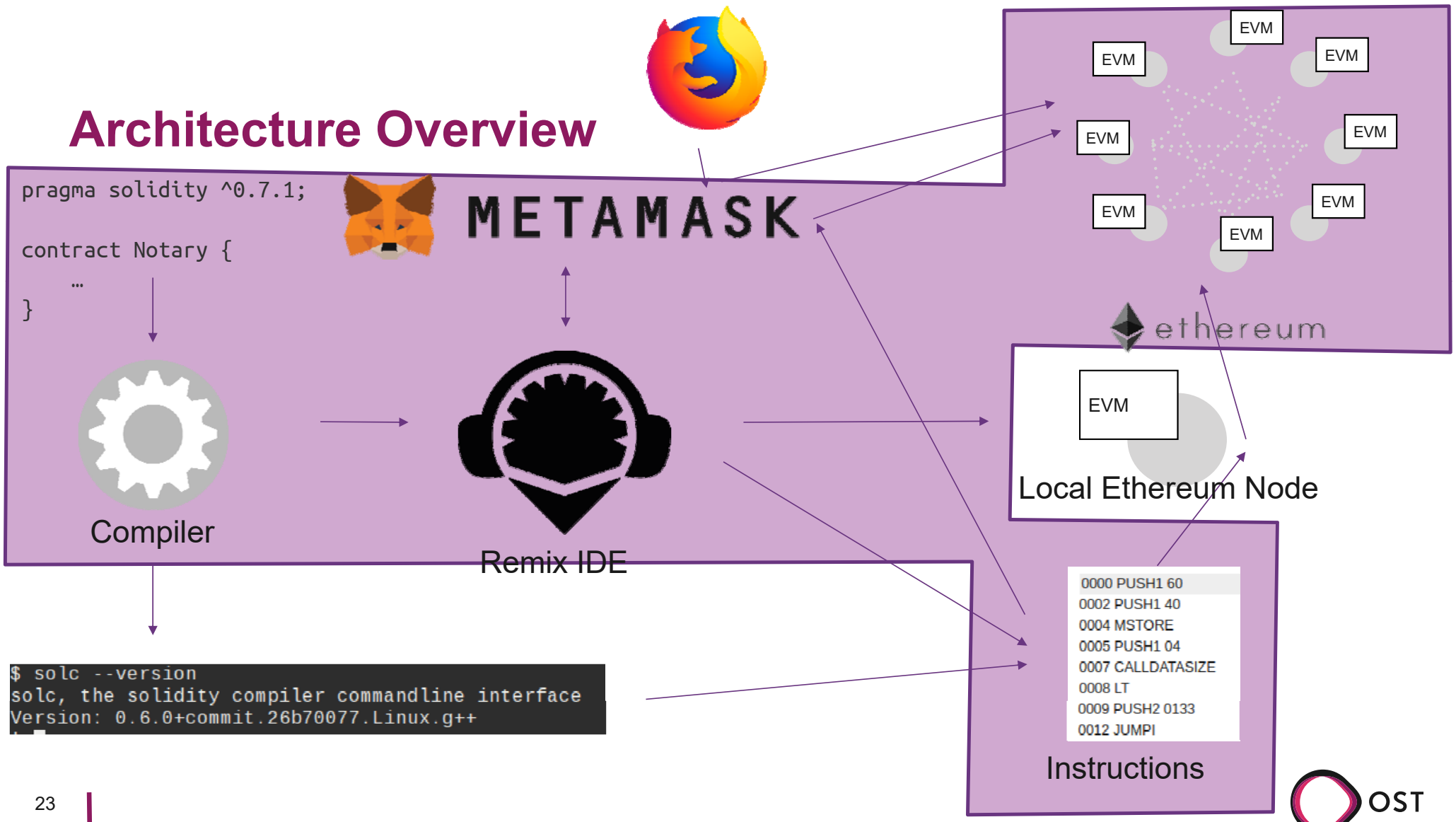
Architecture Overview



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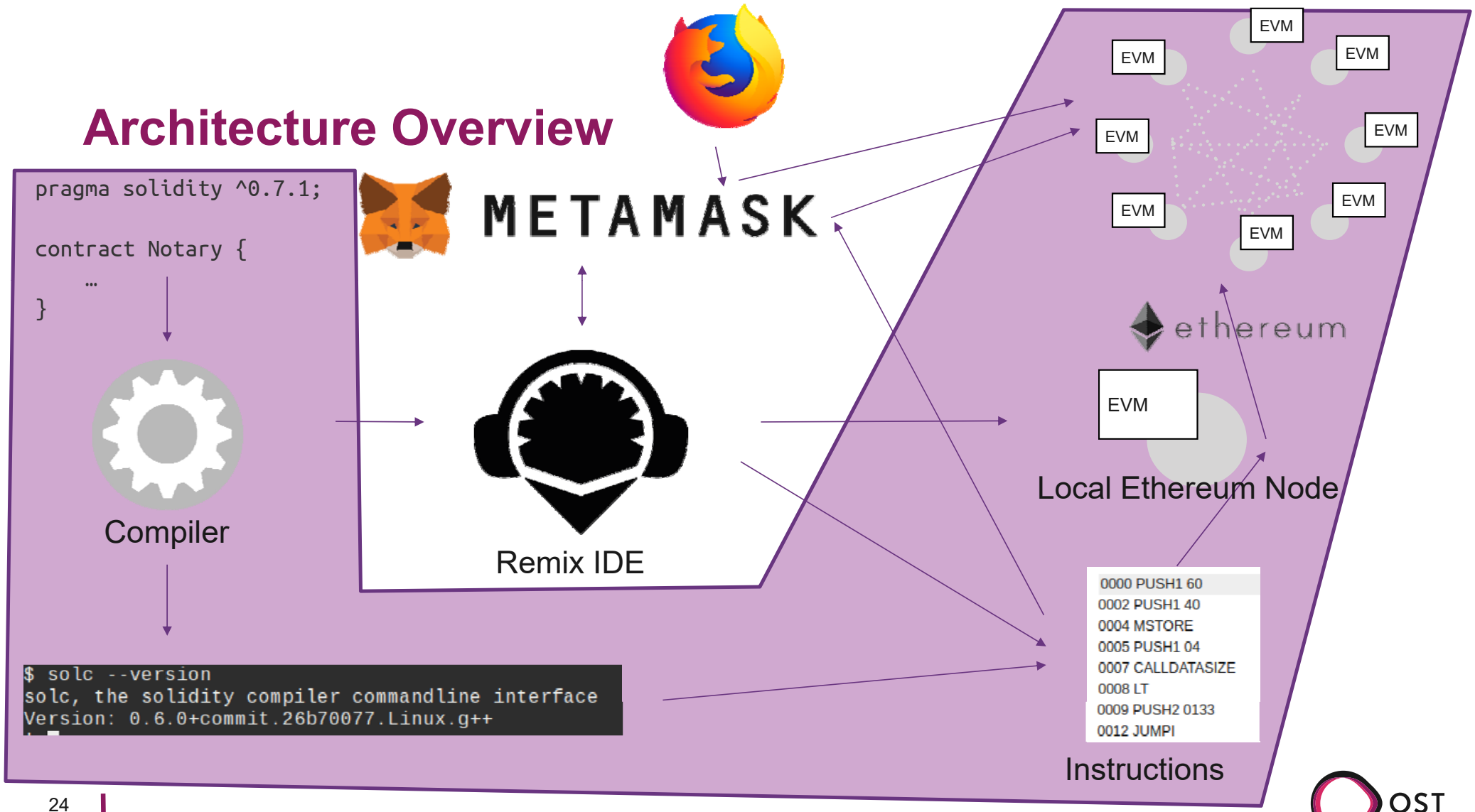
Architecture Overview



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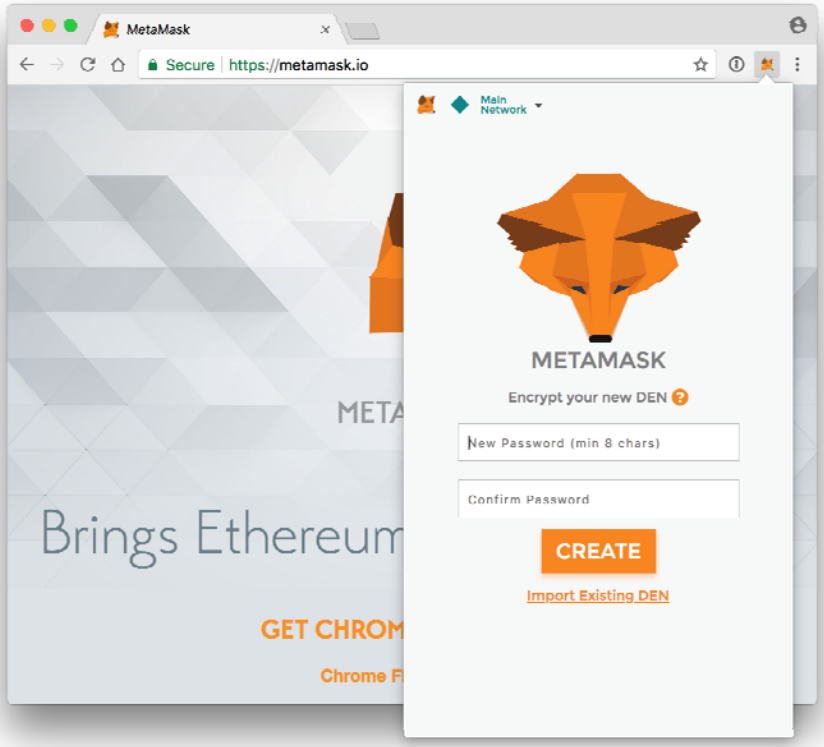
MetaMask

- Browser plugin to ease Ethereum transactions in browsers
  - Manage your key pairs and sign blockchain transactions
  - MetaMask injects javascript library - web3.js
  - Uses infura

- Remix IDE: https://remix.ethereum.org
  - Use Notary.sol from https://github.com/tbocek/VSS-WEB3/blob/master/Notary.sol
  - Alternatively, use IntelliJ solidity plugin and deploy via geth, parity, or a local test blockchain



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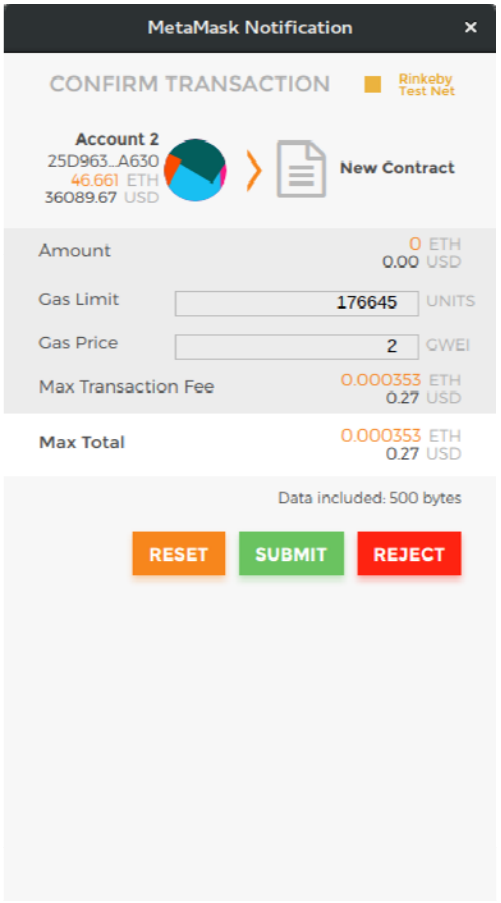
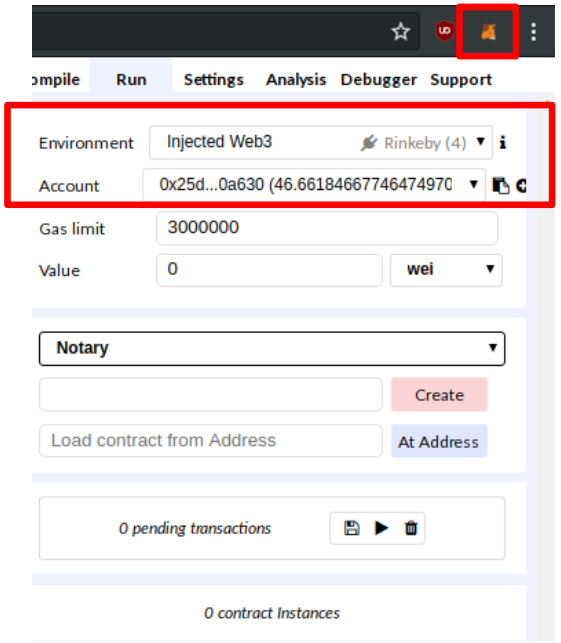
Create Contract

- Connect to MetaMask
  - Injected Web3
  - If you see your accounts, good!
- Create contract!
  - Add address to the code (manually)
- Store value
  - 0x654cf88c**4cff3e62696f7cbb55fbba922b2a7589 7a010347e371e9398b658c4affa611aa**
  - Hash is: 0x4cff3e62696f7cbb55fbba922b2a75897a010347 e371e9398b658c4affa611aa
- First four bytes of the Keccak (SHA-3) hash of the signature of the function.
  - Keccak(store(bytes32))





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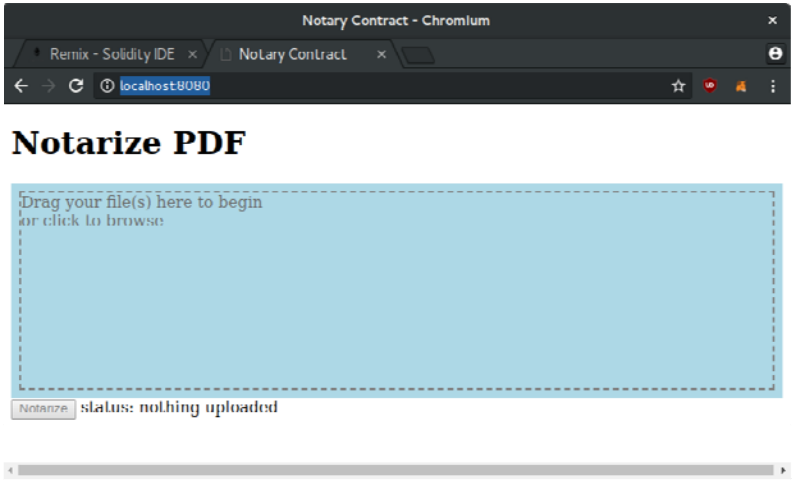
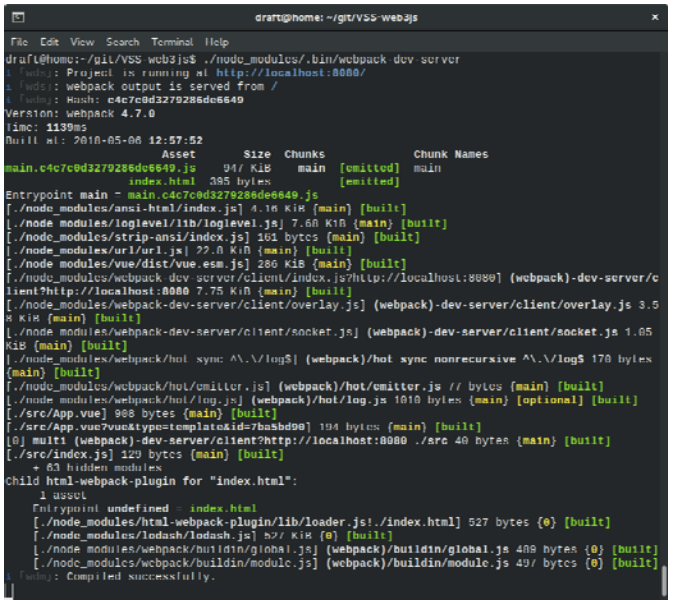
Run it!

- Installation
  - yarn install
  - ./node_modules/.bin/webpack-dev-server
- Open Browser: http://localhost:8080/



- Frontend
  - Vue.js, dependencies:
    - crypto-js, vue, web3
- App.vue, main file
  - Template
  - Create web3 instance
  - Events
    - fileChange()
    - store()



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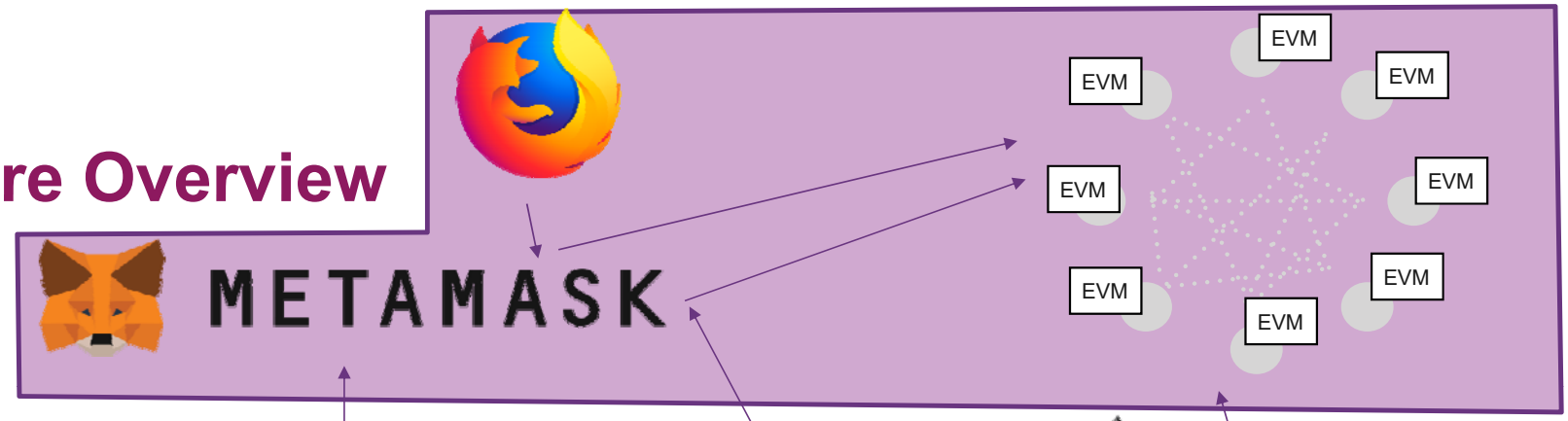

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0005 PUSH1 04
0007 CALLDATASIZE
0008 LT
0009 PUSH2 0133
0012 JUMPI
```

Instructions

OST

ERC20

- ERC20 is a technical standard for smart contracts on the Ethereum blockchain for implementing tokens
  - proposed on November 19, 2015
  - Sep 2020: ~290'000 ERC20 token contracts: EOS, Tether, DCHF
- ERC20 Token (Simplified)
  - No allowance / approval / transferFrom, also no Approval event
  - Creator gets 1000 coins
  - Using SafeMath (always use it)

```
contract SimpleERC20 {
    function totalSupply() public view returns (uint256);
    function balanceOf(address who) public view returns (uint256);
    function transfer(address to, uint256 value) public returns (bool);
    event Transfer(address indexed from, address indexed to, uint256 value);
}

string public constant name = "CAS-UZH-TOKEN";
string public constant symbol = "CUT";
uint8 public constant decimals = 18;

using SafeMath for uint256;
mapping(address => uint256) balances;
uint256 totalSupply_;

constructor() public {
    totalSupply_ = 1000 * (10**18);
    balances[msg.sender] = totalSupply_;
}
…
```


OST

Security Considerations

Security Considerations

- List of the top smart contract vulnerabilities
  1. Reentrancy (DAO 3.5M)
  2. Access Control (Parity 150K)
  3. Arithmetic Issues (DAO)

```
function withdraw(uint _amount) {
      require(balances[msg.sender] >= _amount);
      msg.sender.call.value(_amount)();
      balances[msg.sender] -= _amount;
}


Contract AA {
function attack() {
      A a = A(addressOfA);
      a.withdraw(100);
}
function () payable {
      A a = A(addressOfA);
      a.withdraw(100);
}
}
 function initContract() public {
       owner = msg.sender;
 }

 function withdraw(uint _amount) {
       require(balances[msg.sender] - _amount > 0);
       msg.sender.transfer(_amount);
       balances[msg.sender] -= _amount;
 }
```

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Security Considerations

- List of the top smart contract vulnerabilities
  1. Reentrancy (DAO 3.5M)
  2. Access Control (Parity 150K)
  3. Arithmetic Issues (DAO)
  4. Unchecked Return Values For Low Level Calls
  5. Denial of Service (Parity 500K)
  6. Bad Randomness (400K)
     - Future blockhash as random source, but miner can influence it.

```
function withdraw(uint256 _amount) public {
      require(balances[msg.sender] >= _amount);
      balances[msg.sender] -= _amount;
      etherLeft -= _amount;
      msg.sender.send(_amount);
}

function getEtherBalanceIndex(address _address) internal
returns (uint256) {
       for (uint256 i = 0; i < investors.length; i++) {
           if (investors[i] == _address) {
               return i;
           }
       }
       return investors.length;
   }

function play() public payable {
     require(msg.value >= 1 ether);
     if (block.blockhash(blockNumber) % 2 == 0) {
          msg.sender.transfer(this.balance);
     }
}
```


OST

Random Numbers

- Every EVM needs to come to the same result
- Random Numbers from Oracle
- Commitment schemes
  - Commit to a hashed random number, reveal later, punish if not revealed
- Or: use future blockhash
  - Only up to 256 blockhashes from the past can be accessed.
  - Deduct / add tokens/ETH from the past address
  - Miner can influence the random value – e.g., don't publish block if random value not in favor
    - Value needs to be low (miner gets 2 ETH)

```
function transfer(address _to, uint256 _value) public returns (bool) {
    …
        //since this is a lucky coin, the value
        //transferred is not what you expect
        luckyTransfer();
        previousTransferBlockNr = block.number;
        previousTransferAddress = msg.sender;
        …
        uint256 val = _value.sub(potIncrease);
        pot = pot.add(potIncrease);
}

function luckyTransfer() private {
        if(block.number != previousTransferBlockNr &&
          (block.number - previousTransferBlockNr) < 256 ) {
            uint256 rnd = uint256(keccak256(
                          block.blockhash(previousTransferBlockNr)));
            if(rnd % 200 == 0) { //.5%
                balances[previousTransferAddress] =
                         balances[previousTransferAddress].add(pot);
                Transfer(this, previousTransferAddress, pot);
                //tokens are from pot, thus no tokens are created from thin ai
                pot = 0;
                previousTransferBlockNr = 0;
                previousTransferAddress = 0;
            }
        }
}
```


OST

Security Considerations

- List of the top smart contract vulnerabilities
    1. Reentrancy (DAO 3.5M)
    2. Access Control (Parity 150K)
    3. Arithmetic Issues (DAO)
    4. Unchecked Return Values For Low Level Calls
    5. Denial of Service (Parity 500K)
    6. Bad Randomness (400K)
    7. Front-Running
    8. Time Manipulation - A malicious miner sets own timestamp ~ 900s

1. A smart contract publishes an RSA number (N = prime1 x prime2).
2. A call to its submitSolution() public function with the right prime1 and prime2 rewards the caller.
3. Alice successfully factors the RSA number and submits a solution.
4. Someone on the network sees Alice's transaction (containing the solution) waiting to be mined and submits it with a higher gas price.
5. The second transaction gets picked up first by miners due to the higher paid fee. The attacker wins the prize.

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Security Considerations

- Multiple Exchanges Suspend ERC20 Token Trading Due To Potential BatchOverflow Bug
  - Integer overflows in multiple contracts
  - Poloniex suspended all ERC20 token deposits and withdrawals,
  - OKEX's decision to halt ERC20 deposits

```
255   function batchTransfer(address[] _receivers, uint256 _value) public whenNotPaused returns (bool) {
256     uint cnt = _receivers.length;
257     uint256 amount = uint256(cnt) * _value;
258     require(cnt > 0 && cnt <= 20);
259     require(_value > 0 && balances[msg.sender] >= amount);
260
261     balances[msg.sender] = balances[msg.sender].sub(amount);
262     for (uint i = 0; i < cnt; i++) {
263         balances[_receivers[i]] = balances[_receivers[i]].add(_value);
264         Transfer(msg.sender, _receivers[i], _value);
265     }
266     return true;
267   }
268 }
```


OST

Part VI: The Blockchain World

14. Other Blockchains

Blockchains, Cryptocurrencies, Tokens

- App. 6500 different ones are listed at https://coinmarketcap.com/
- A classification wrt application domain had been presented already earlier
- A mapping on a set of selected BCs to these eras here is used to dive into further details:
  - Done and to come

Era 1.0	Era 2.0	Era 3.0	Era 4.0
BinanceCoin	Algorand	Tetha	Aelf
Bitcoin	Bazo		Polkadot
Bitcoin Cash	Chainlink		
Bitcoin Gold	Corda		
Dasch	Elements		
Dodgecoin	EOS		
Libra	Ethereum		
Litecoin	Hyperledger		
Monero	IOTA		
Paxos	MultiChain		
Ripple	NEO		
Stellar	OpenChain		
Tether	Tezos		
ZCash			

Era 1.0

Libra

- URL: https://libra.org
- BC type: Permissioned
  - Node types: Participant and Validators
- Token type: Currency
- Account model: Account-based
- Consensus mechanism: LibraBFT
  - Variation of the HotStuff protocol
    - Leader-based Byzantine fault-tolerant replication protocol for the partially synchronous model
      - Works at the pace of actual (vs. maximum) network delay ⇨ Property “responsiveness”
  - About 100 founding members as Validators

Libra Characteristics

- Major characteristics
  - Mining scheme used: Dedicated protocol based on trusted Validators
  - Block size: There is no concept of a block of transactions
  - Transaction size: 5 KByte
  - Transaction rate: 1,000 tx/s
  - Security features: Proof of authority, cryptographically authenticated database, memory-safe using Rust
  - Smart Contract
    - Language: “Move” Programming Language
    - Key details: Implemented using modules containing code values and resources containing data values.

Libra Economics

- Cryptocurrency: Yes, Libra Coins
  - Details: New coins are minted and excess is burnt
    - Value of the coin will be tightly bound to the global economy
  - Exchange rates to fiat: Stable (planned for)
  - Transaction fees: Low fees, variable according to gas price
- Wallet
  - Not available yet
- Listed on crypto exchange(s)
  - Not listed yet
- Market capitalization (as of July 31, 2019)
  - The stablecoin will be released only in 2020

Libra Organization

- Developer community: Libra Association
  - Country of origin: Switzerland
  - SDKs: Not available yet
  - Blockchain explorer: Yes, http://libra-explorer.net (testnet)
  - Full or light client: Testnet only, https://developers.libra.org
- Known vulnerabilities and attacks: Double spending attack avoided by using the LibraBFT
- Major application domain(s)
  - Financial services, payments, e-commerce

Libra Overall Evaluation

- Scalability
  - Initial set-up at 1,000 tx/s for a set of 100 validator nodes
  - Plans to become permisionless as technology matures
- Centralization degree
  - 50%, partial decentralization
- Energy efficiency
  - Projected to use energy more like current data centers
- Security level
  - Designed to deal with most-common attacks (*e.g.*, double spending) and tolerate faults within the Validator network,
  - Not storing any personal data of users (plan)

Era 1.0

Monero

- URL: https://getmonero.org
- BC type: Public

- Token type: Currency
- Account model: UTXO
- Consensus mechanism: Proof-of-Work (PoW)
  - Block size changes based on the transaction volume
- Additional mechanisms:
  - Pruning, ASIC-resistance PoW

Monero Characteristics

- Major characteristics
  - Mining scheme used: Proof-of-Work
  - Block size: Variable
    - Defined according the previous 100 blocks
    - Storage efficiency: 1,883,942 (block height)
      - ~ 72 GB (full node)
  - Transaction size: ~ 14 KByte
  - Transaction rate: ~ 7 tx/s (1,700 tx/s estimated)
  - Security features: ring signatures, ring confidential transactions (RingCT), and stealth addresses
    - All transactions on the network are private by mandate
    - Pseudo-anonymous

Monero Economics

- Cryptocurrency: Yes, XMR
  - Exchange rates to fiat: Unstable
  - Transaction fees: Variable
    - Based on transaction priority, $0.021 USD (average)
- Wallet
  - Reference implementation in Javascript, https://mymonero.com
  - API: JSON RPC Interface
- Listed on crypto exchange(s)
  - https://localmonero.co, https://anycoindirect.eu
- Market capitalization (as of July 31, 2019)
  - $1,388,479,350 USD

Monero Organization

- Developer community: Monero Team
  - Country of origin: N/A
  - SDKs: Daemon RPC, Wallet RPC
  - Blockchain explorer: https://moneroblocks.info
  - Full or light client: Both, https://getmonero.org/downloads
- Known vulnerabilities and attacks:
  - Zero-amount miner TX, DDoS risk, Traceable transactions
  - Incident Response Team and community of developers work on reported bugs/vulnerabilities
- Major application domain(s)
  - Cryptocurrency with a focus on private and censorship-resistant transactions

Monero Overall Evaluation

- Scalability
  - Large size of the blockchain, poorly scalable
- Centralization degree
  - 100%, fully decentralized
- Energy efficiency
  - 645.62 GWh of eletricity (higher than a country like Haiti)
- Security level
  - 100% privacy-driven project

Era 2.0

EOS

- URL: https://eos.io/
- BC type: dApp Ecosystem
  - Node types: block producers, backup block producers, api nodes, seed nodes, validators
- Token type: Utility
- Account model: Account (name in a human readable format)
- Consensus mechanism: BFT-dPoS
  - 21 allowed block producers → centralization
  - EOS holders vote for block producers, EOS tokens for votes
- Additional mechanisms:
  - Free of charge for users
  - Contracts mutable, freezing accounts possible

EOS Coin

- Major characteristics
  - Mining scheme used: BFT-dPoS
  - Block size: limited by network capacity
    - Storage efficiency: 4 TB after 8 months of operation
  - Transaction size: N/A, max 30 ms for execution
  - Transaction rate: max 3,996 tx/s
  - Security features: SHA 256 is used to generate the digest and ECDSA to sign the block
  - Smart Contract
    - Supported binaries Web Assembly (WASM/ABI files), Turing-complete
    - Supported Languages: C++
    - Other languages that produce WASM code: RUST, Python, Solidity

EOS Economics

- Cryptocurrency: No
  - Utility token to acquire EOS CPU/RAM to run dApps
  - Exchange rates to fiat: floating, “rather” stable
  - Transaction fees: free of charge for users, accounts with dApps need to stake EOS tokens against EOS CPU and trade EOS tokens against EOS RAM
- Wallet
  - Reference implementation C++, Cleos, Nodeos, Keosd https://github.com/EOSIO/eos and API in C++
- Listed on crypto exchange(s)
  - Bitfinex, Binance, Kraken, HitBTC, Liqui, Gate.io, EtherDelta, Kucoin, Mercatox, Exrates, Livecoin, IDEX, COSS, TIDEX
- Market capitalization (as of August 15, 2019)
  - $3,780,703,585 USD

EOS Organization

- Developer community: 188 developers (GitHub)
  - Country of origin: Cayman Islands
    - Deployment needs: depending on the role, *i.e.*, block producers, backup block producers, api nodes, seed nodes
  - SDK: Jeos (Java), Eospy (Python)
  - Blockchain explorer: Yes, https://bloks.io
  - Full or light client: Full https://github.com/EOSIO/eos
- Known vulnerabilities and attacks:
  - Against dApps: Numerical Overflows, Authorization Checks, Apply Checks, Transfer Error Prompt, Random Number Practice, Rollback Attack
- Major application domain(s)
  - SC-based distributed Applications (dApps)

EOS Overall Evaluation

- Scalability
  - High: both horizontal and vertical scaling
- Centralization degree
  - Centralized among block producers
- Energy efficiency
  - High
- Security level
  - Pseudo anonymous, Smart Contract mutability, account freezing, account code change

Era 2.0

HyperLedger

- No currency
- Private distributed ledger

HYPERLEDGER

- Umbrella Project
  - Fabric: Platform for building blockchain-based products
  - Composer: tools to build, test, and operate a blockchain
  - Cello: allows Blockchain-as-a-Service (BaaS)
  - Explorer: dashboard for blockchain monitoring
  - Burrow: Ethereum Smart Contracts execution
  - Sawtooth: modular enterprise-level blockchain
  - Caliper: blockchain benchmarking tool

Active Hyperledger Projects

- Open source effort created to advance cross-industry Distributed Ledger Technologies (DLT) hosted by “The Linux Foundation”
  - https://www.hyperledger.org
- Active HL projects include
  - HL Fabric a general-purpose, permissioned DL
  - HL Indy a special-purpose, permissioned DL
    - Focusing on decentralized identity management
  - HL Iroha is a permissioned DL
    - Tailored for digital asset management
  - HL Sawtooth a general-purpose, permissioned or permissionless DL

Hyperledger Fabric

- Hyperledger Fabric (HLF) initialized by IBM
- HLF implemented in Golang
  - Smart contracts in Go, JavaScript, or Java
  - SDKs exist in Node.js, Java, Go, REST and Python
- Network roles and components of HLF
  - Channels for complete data isolation b/w a set of participants
  - Private data collections enable transactions between participants on the same ledger, but keep data private to a subset of transactors
    - Private data is shared peer-to-peer, with only hashes stored on the shared ledger as
  - Identity Mixer for anonymity of transaction submitters

Hyperledger Indy

- Hyperledger Indy focused on identity management
  - DIDs (Decentralized Identifiers) without requiring central resolution authorities.

    - Verifiable claims are an interoperable format for the exchange of digital identity attributes and relationships
      - Currently in the W3C standardization pipeline
    - Zero Knowledge Proofs enable that some or all of the data in a set of claims is true without leaking any additional information, including the identity of the prover
- HL Indy is independent, but commonly associated with "The Sovrin Foundation", which offers a public utility for identity, built on top of Indy's codebase

Hyperledger Iroha

- Hyperledger Iroha is written in C++, initially developed by a group of Japanese developers, who built their own BC for mobile use cases

- BFT Consensus algorithm called YetAnotherConsensus (YAC)
  - Iroha offers ready-to-use set of commands and queries, as well as multi-signature transactions
- Digital asset management capabilities
  - *E.g.,* create digital assets, register accounts, and transfer assets between accounts.
  - Robust permission system, allowing permissions to be set for all commands, queries, and joining of the network

Hyperledger Sawtooth

- Hyperledger Sawtooth initialized by Intel
- Permissioned and permissionless deployment possible

- Proof-of-Elapsed-Time (PoET) consensus algorithm
  - Dependent on Intel's Software Guard Extensions (SGX) to elect leaders to cut blocks based on random wait times.
  - Peers have access to all transaction data, unlike in Fabric, where "private" channels can be established
- Smart contract capabilities
  - SDK for Python, Javascript, Go, and Rust
  - Ethereum contract compatibility is provided with Seth, enabling the deployment of Sawtooth contracts to Ethereum

Era 2.0

NEO

- URL: https://neo.org
- BC type: Public
  - Node types: Participants, Validators, Speakers
- Token type: Currency, Utility
- Account model: UTXO
- Consensus mechanism: dBFT 2.0
  - Decision on consensus nodes for next round by voting
  - Users only need to wait for one confirmation (15 s)
- Additional mechanisms:
  - Digital Identity based on KYC (Know Your Customer)
    - "Roll back the chain" with consensus

NEO Characteristics

- Major characteristics
  - Mining scheme used: dBFT 2.0
  - Block size: ~ 5 KB (average)
    - Storage efficiency: 4,038,763 (block index)
  - Transaction size: ~ 200 Byte
  - Transaction rate: 1,000 tx/s (10,000 tx/s theoretically)
  - Security features: Anti-quantum cryptography mechanism (NeoQS), digital certificate
  - Smart Contract
    - Language: .Net, Java, C, C#, Go, Python, Kotilin, Javascript
    - Key details: Turing-complete, support concurrent operation, sharding, and unlimited scalability, when running in NeoVM
      - All operations have GAS costs, but, the first 10 GAS are for free

NEO Economics

- Cryptocurrency: Yes
  - Details: 100 millions NEO created in the Genesis Block
  - Exchange rates to fiat: Unstable
  - Transaction fees: Variable based on operations (GAS)
- Wallet
  - Reference implementation in Javascript
    https://docs.neo.org/docs/en-us/node/gui/wallet.html
  - API: RPC, Smart Contract Framework
- Listed on crypto exchange(s)
  - https://coinall.com, https://etoro.com
- Market capitalization (as of July 31, 2019)
  - $807,485,181 USD

NEO Organization

- Developer community: NEO Contributors
  - Country of origin: China
  - SDKs: NEO SDK (current version: 2.9.0)
  - Blockchain explorer: https://neotracker.io
  - Full or light client: both, https://neo.org/client
- Known vulnerabilities and attacks:
  - NEO Vulnerability Bounty Program paid up to $10,000 USD per vulnerability reported
- Major application domains:
  - Smart economy, digital assets, digital identity

NEO Overall Evaluation

- Scalability
  - Theoretically, NEO achieves infinite scalability with NEOVM
- Centralization degree
  - 50%, centralization of control
- Energy efficiency
  - Lower electricity costs and attendant carbon footprints
- Security level
  - Uses digital identity to link accounts to real life identity, traceable, assets protection
- Other dimensions of importance
  - Peer-to-peer networking, cross-chain interoperability

Era 3.0

THETA

- URL: https://www.thetatoken.org/
- BC type: Public
  - Node types: Validators, Guardian, Normal

- Token type: Currency and Utility
- Account model: Account/Balance
- Consensus mechanism: PoS/BFT
  - 10-20 validators
  - Guardian nodes finalize blocks
- Additional mechanisms
  - Blockchain pruning, off-chain payments

THETA Characteristics

- Major characteristics
  - Mining scheme used: Multi-Level BFT
  - Block size: up to 8,192 tx per block
    - Storage efficiency: N/A
  - Transaction size: N/A
  - Transaction rate: > 1,000 tx/s
  - Security features: Pseudo-anonymous addresses
  - Smart Contract
    - Language: Solidity
    - Key details: Ethereum-based Smart Contracts, Turing-complete, Ethereum Virtual Machine

THETA Economics

- Cryptocurrency: Yes
  - Details: THETA and TFuel (related to gas in Ethereum)
  - Exchange rates to fiat: unstable
  - Transaction fees: variable on transaction size (gas)
- Wallet
  - Reference implementation in Go, https://github.com/thetatoken/theta-protocol-ledger
  - API: Web, Command-line only
- Listed on crypto exchange(s)
  - Binance, https://www.binance.com
- Market capitalization (as of July 24, 2019)
  - 101,154,392 USD

THETA Organization

- Developer community: 10 (Theta Developer Team)
  - Country of origin: United States of America (U.S.A.)
  - Deployment needs: Theta Ledger Node
  - SDKs: Android SDK, REMIX
  - Blockchain explorer: https://explorer.thetatoken.org/
  - Full or light client: Full https://github.com/thetatoken/theta-protocol-ledger
- Known vulnerabilities and attacks:
  - 51% Attacks (Expensive, but doable)
- Major application domain(s)
  - Video Streaming, Live TV

THETA Overall Evaluation

- Scalability
  - High
- Centralization degree
  - 10-20 Validators (small number)
  - Limited number of Guardian nodes
- Energy efficiency
  - Energy-efficient (BFT-based)
- Security level
  - Standard BC-security
- Other dimensions of importance
  - Plans to reduce dependency from Content Delivery Networks

Era 4.0

Aelf

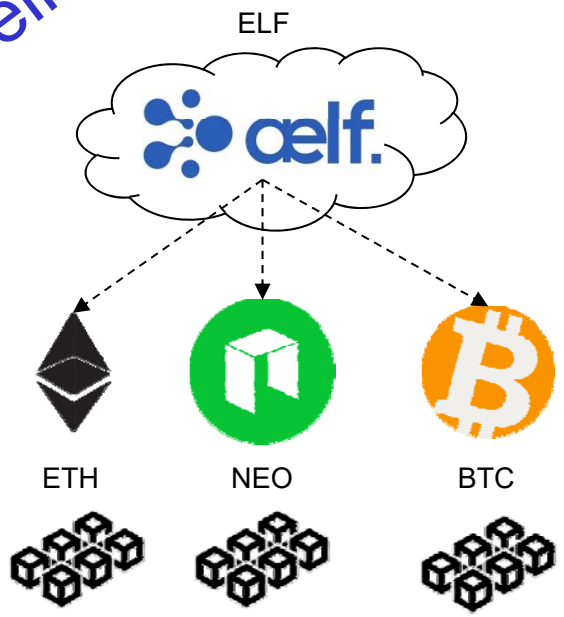
- URL: https://aelf.io/
- BC type: multi-purpose chain
  - Node types: Participant and Miner (stake)

- Token type: Currency
- Account model: Account-based
- Consensus mechanism:
  - Delegated Proof-of-Stake (dPoS)
  - Token holders cast votes to elect nodes that produce blocks
- Additional mechanisms:
  - Cross-chain communication

Aelf Characteristics

- Major characteristics
  - Mining scheme used: DPoS
  - Block size: making use of side-chains
    - Storage efficiency: N/A
  - Transaction size: variable
  - Transaction rate: 14,968 tx/s*
  - Security features: N/A
  - Smart Contract
    - Language: N/A

Aelf relies on side-chain



*Data from Aelf test scenario

Aelf Economics

- Cryptocurrency: Yes (ELF)
  - Details: multi-chain (and multi-purpose) blockchain
  - Exchange rates to fiat: unstable
  - Transaction fees: variable based on the market perception
- Wallet
  - Reference implementation: Coinomi
  - Also available on Android, iOS, Windows, Linux and MacOS
- Listed on crypto exchange(s)
  - Binance, BitMex, Poloniex
- Market capitalization (as of July 31, 2019)
  - $60,977,204 USD

Aelf Organization

- Developer community: 34 contributors on GitHub
  - Country of origin: China
  - Deployment needs: Wallet
  - SDKs: Docker, Java, C#, JavaScript, Lua
  - Blockchain explorer: https://explorer.bitcoin.com/bch
  - Full or light client: full
  - Known vulnerabilities and attacks:
    - Heavy centralization due to DPoS
    - 51% Attack, i.e., single organization holds 51% of the mining capacity and may censor transactions
- Major application domain(s)
  - General purpose applications

Aelf Overall Evaluation

- Scalability
  - High
- Centralization degree
  - Partially Decentralized
- Energy efficiency
  - High
- Security level
  - Immutable, transparent
- Other dimensions of importance
  - Enable cross-chain communications

Era 4.0

Polkadot

- URL: https://polkadot.network
- BC type: interoperability platform
  - Network roles: Validators, Collators and Nominators
  - Network structure: Parachains, Relay chains and Bridge chains
- Token type: Utility (DOT) tokens
- Consensus mechanism: Hybrid GRANDPA/BABE
  - **G**HOST-based **R**ecursive **A**ncestor **D**eriving **P**refix **A**greement/**B**lind **A**ssignment for **B**lockchain **E**xtension
  - Hybrid and variant of Proof-of-Stake consensus

Polkadot Characteristics

- Major characteristics
  - Heterogeneous multichain with scalable security and an interoperability protocol
  - Central chain of Polkadot termed relay-chain
    - On which all validators are staked on with DOT tokens.
  - Polkadot network based on parachains
    - Parallelizable blockchains comprising the Polkadot network
    - Each parachain can have a unique architecture
    - All parachains are connected and secured by the relay chain
  - Hybrid consensus mechanism
    - Splits up the finality gadget (GRANDPA) from the block production (BABE) mechanism of the relay-chain
    - BABE runs b/w validator nodes and determines authors of new blocks

Polkadot Economics

- Cryptocurrency: Yes
  - Details: Native DOT tokens are used for 4 purposes
    - Used for governance of the network
    - Staked for operation of the network
    - Bonded to connect a chain to Polkadot as a parachain
    - Enabling interoperability between blockchains
- Multiple wallets in active development
- Not yet listed on crypto exchanges
  - First ICO raked in $144 million
  - Second ICO may be launched
- Market valuation
  - ~1$ billion USD (as of August 15, 2019)

Polkadot Organization

- Polkadot is a project of the Web3 Foundation
  - Sponsoring community development and software services
    - Web3 Foundation is based in Switzerland, Zug
  - SDKs: Substrate framework
  - Blockchain explorer available: https://telemetry.polkadot.io/

- Major application domain
  - Easy deployment of public or private parachains
  - Enabling interoperability between those parachains
  - Using “Bridges” to interact with other Blockchains
    - Such as Ethereum or Bitcoin

Era 1.0-4.0

Bazo

- Bazo is a permissionless blockchain for research
  - Its not an ICO, not looking for funding, but for ideas
  - Testing of new ideas, new mechanisms, new algorithms
- Blockchain from scratch at CSG and now HSR
  - Started with simple PoW, a solid, well-tested mechanism
  - Gradually extended with new ideas and concepts
  - Now with unique feature proposals/ideas
    - Self-contained proofs
    - Sharding
    - Pruning
    - Smart Contracts with only big-ints
  - https://github.com/bazo-blockchain

Bazo Functionality (as of March 2020)

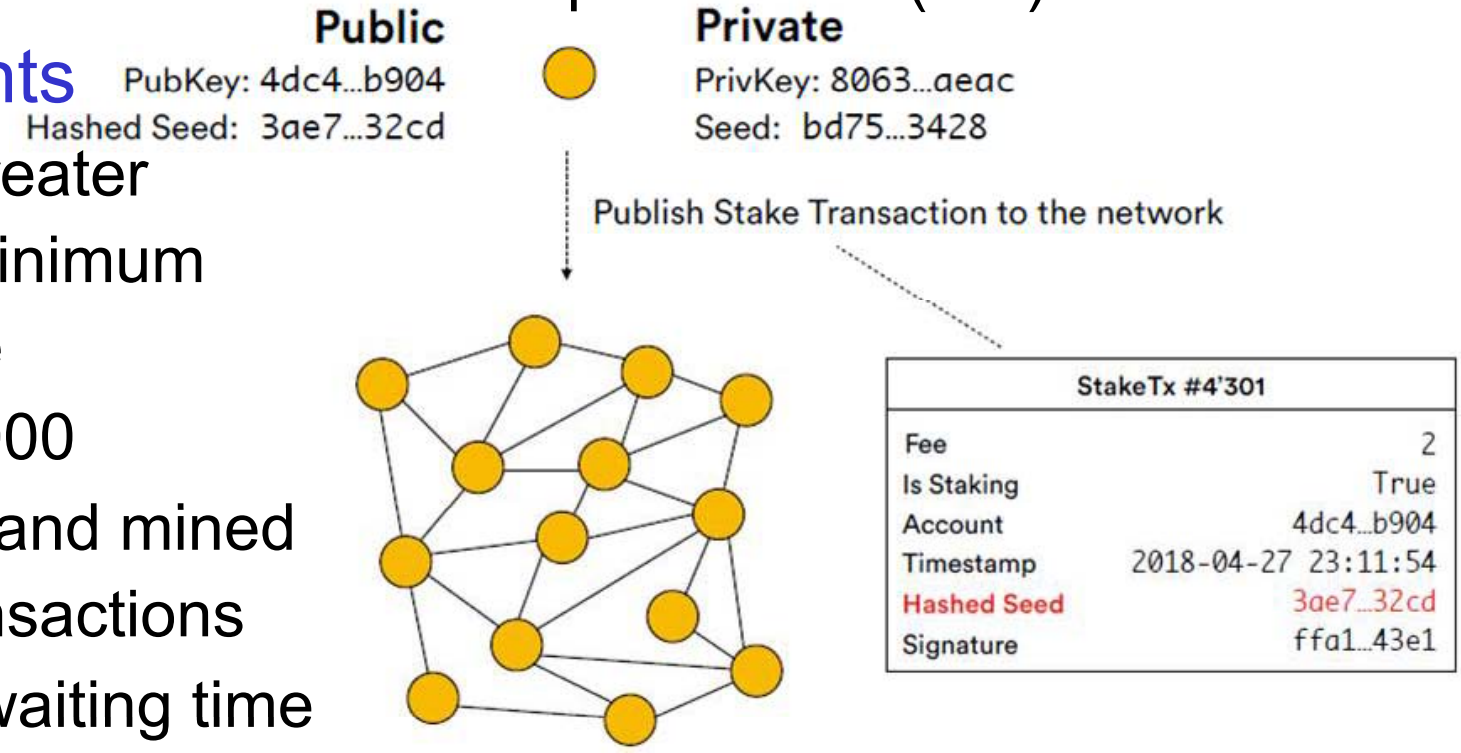
- PoW consensus mechanism initially
- PoS consensus mechanism later + cryptographic proof
- Progressive Web App (PWA)-based Mobile Wallet for Bazo
- Blockchain Explorer for Bazo
- Mobile Light Client for Bazo
- Pruning in Bazo and self-contained proofs
- Bazo Smart Contracts
- Sharding (in progress)

- Application
  - Oysy (Aduno) BC-based loyalty system

Credits go to T. Bocek (now HSR), S. Rafati, B. Stiller, and MA/BA students with CSG: L. Sgier, J. van der Assen, L. Boillat, S. Bachmann, M.-A. Chételat, A. Kürsat and HSR students R. Blum, S. Fontana, E. Meier, M. Steiner

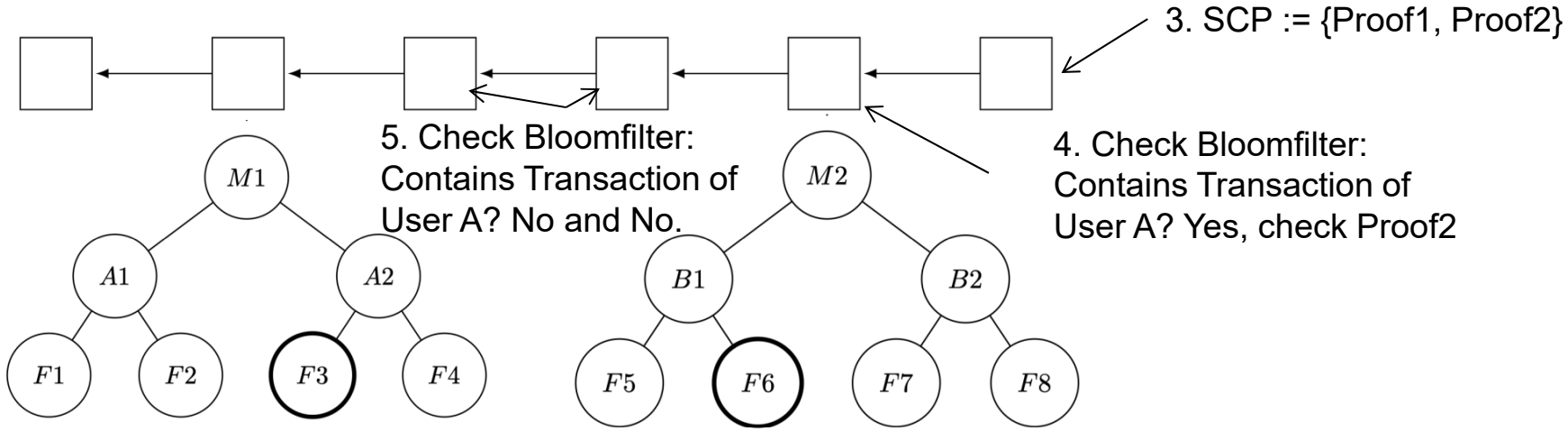
Bazo's PoS

- Miner ("**validator**") **of a block chosen depending on his** wealth, also defined as "stake"
  - Validators restricted to 1 hash per second (H/s)
- Requirements
  - Balance greater or equal minimum staking fee
  - Default: 1000
  - Published and mined Stake Transactions
  - Minimum waiting time elapsed (default: 0)



Bazo's Self-contained Proofs (SCP)

- Traditionally, miners require the full blockchain to validate a transaction of a user
- With SCPs a user has to provide all required proofs in the transaction in order for validators to verify a transaction independent of the blockchain



1. F3: Transaction User A
Proof1 :={F3, F4, A1}

2. F6: Transaction User A
Proof2 :={F5, F6, B2}

Bazo's Sharding

- Inspired by the applicability in database research

- Current approach
  - Partition the Blockchain state into shards (communities)
    - Enables parallel validation of transactions
  - Build up several shard-chains concurrently
    - Each shard has own set of transactions
- Next steps (possibly)
  - Entity management in shards according to the SCP concept
  - Save state in the newest block of a shardchain
    - Merkle Patricia Trees

15. Blockchain Interoperability

Need for Interoperability

- Each blockchain (6500+) has its pros and cons
  - Transparency vs. privacy
  - Transaction fees, speed of transaction confirmation
- Interoperable chains enable several opportunities
  - Move assets between different platforms
  - Access information from one chain inside other chain
  - Different payment schemes
  - Allowing to choose the best alternative BC possible

- V. Buterin: "In the longer term, building interoperable applications is something that should be done on a basis of responding to actual need; while the underlying technology can certainly be developed in the abstract, it would likely to be a waste of resources to try to build applications that connect chains without a clear understanding on the reasons driving the use case."

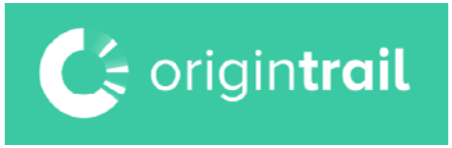
Types of Interoperable Chains

- Notary schemes
  - One or more trusted parties validate events on another chain
  - Ease of implementation: medium
- Sidechains/relays
  - The chain validate events on external chains as part of validating local events
  - Ease of implementation: hard
- Hash-locking
  - Events on different chains are unlocked using a secret value
  - Ease of implementation: easy

V. Buterin, Chain Interoperability, September 2016

State-of-the-art

- Projects that use or provide a platform for interoperable chains include:



BC4CC
Interoperability API

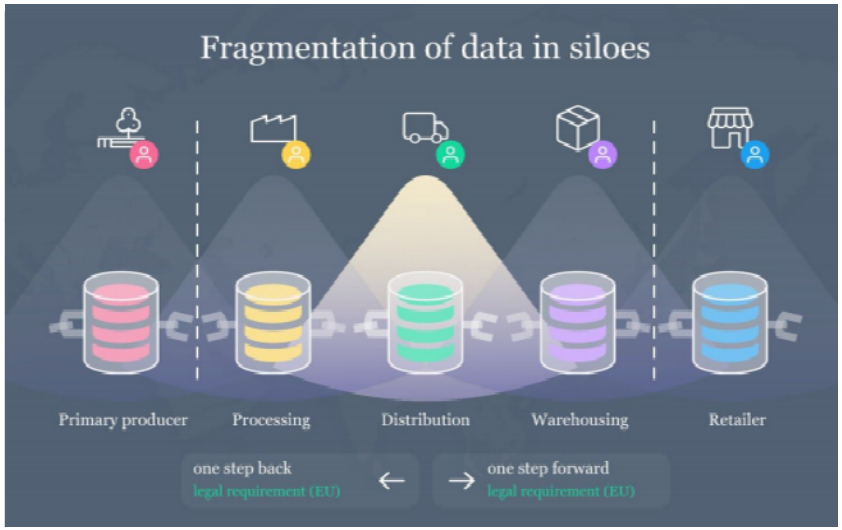
...

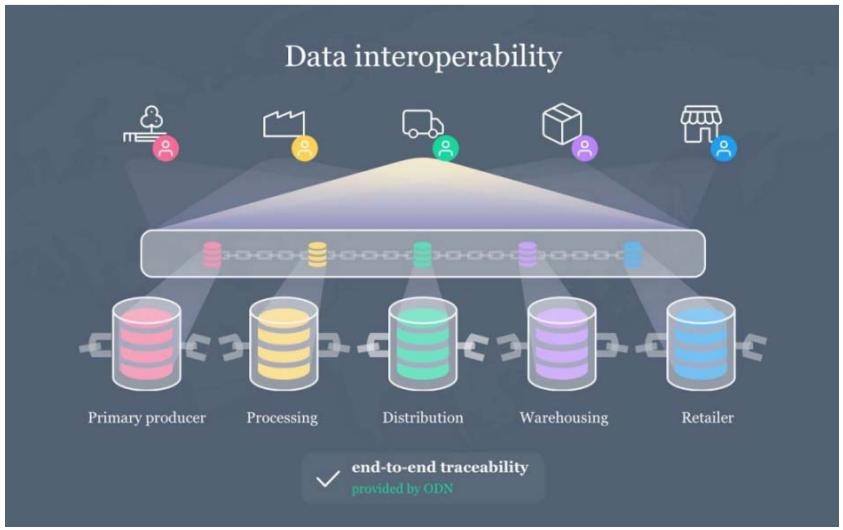
Origintrail.io

- Origintrail.io
  - Type: Sidechain/Relay
  - Description:

In order to provide the optimal solution we implement the OriginTrail protocol that runs on an off-chain decentralized peer to peer network, called the OriginTrail Decentralised Network (ODN). It enables peers on the network to negotiate services, transfer, process and retrieve data, verify it's integrity and availability and reimburse the provider nodes. This solution minimizes the amount of data stored on the blockchain in order to reduce cost and inefficiency.

    - Blockchain-agnostic protocol for asset tracking in supply-chain
    - Provide a cost-effective solution to store sensitive data in a secure manner through a blockchain-agnostic approach



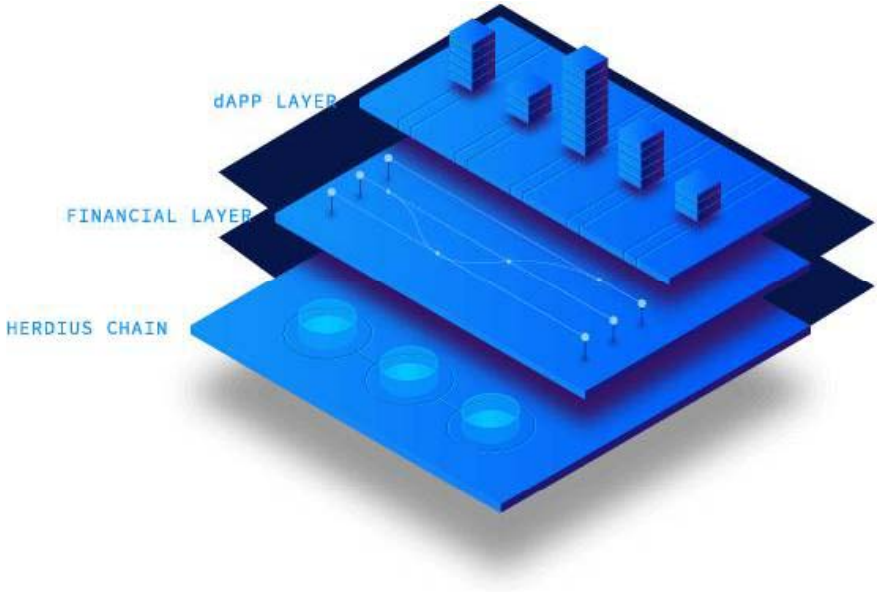


Herdius

- Herdius
  - Type: Notary-scheme
  - Description:
    - Build a highly performant decentralized financial platform enabling users to transact assets between different chains

verification: *Supervisors* will have two minutes to inspect child blocks for traces of misconduct from validators and, if necessary, to invalidate those transactions. If validators create invalid transactions, supervisors are responsible for reporting it.

HERDIUS



ifi

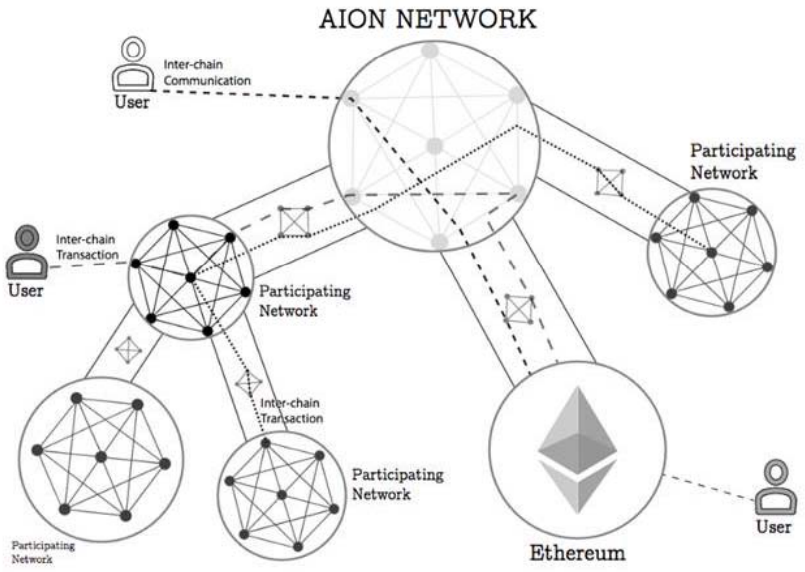
Aion

- Aion
  - Type: Hash-locking
  - Description:

The Third Generation Blockchain Network

Interchain transactions are initially created on a source blockchain and then processed and forwarded by bridges and connecting networks before finally reaching the target blockchain. As stated previously, the creator of an interchain transaction must pay a transaction fee for the communication cost using AION tokens, thereby incentivizing all the participants in each junction of the route.

    - A multi-tier blockchain system designed to address unsolved questions of scalability, privacy, and interoperability in blockchain networks.



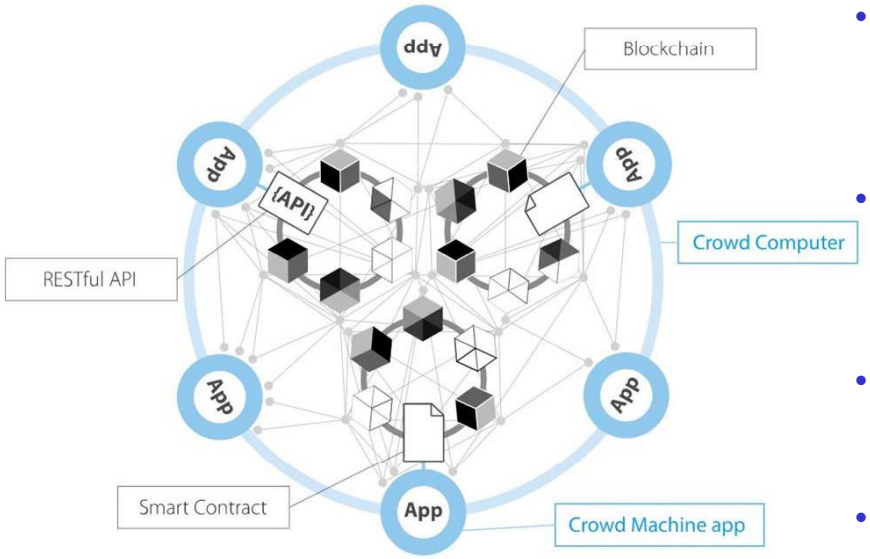
- Connecting networks: facilitate interchain communication and interchain transactions between multiple private or public blockchain networks
- Inter-chain transaction: is a trust-free message between blockchains, which allows any connected blockchain to exchange information
  - Defined format, routing, states
- Bridges: communication protocol or API responsible for registering connected chains
- Participating networks: any AION-compliant network, can be purpose-specific blockchains, private networks, or consortium blockchains representing collections of entities

Crowdmachine

- Crowdmachine
  - Type: Sidechain/Relay
  - Goals:

1. Enable any mobile device or computer owner to allow the spare capacity of their device to function as a member of a global network to run apps, and be rewarded for the use of their device; and
2. Allow developers and non-developers to create apps, without writing a line of code, that run on that global network and be rewarded every time the app is used.

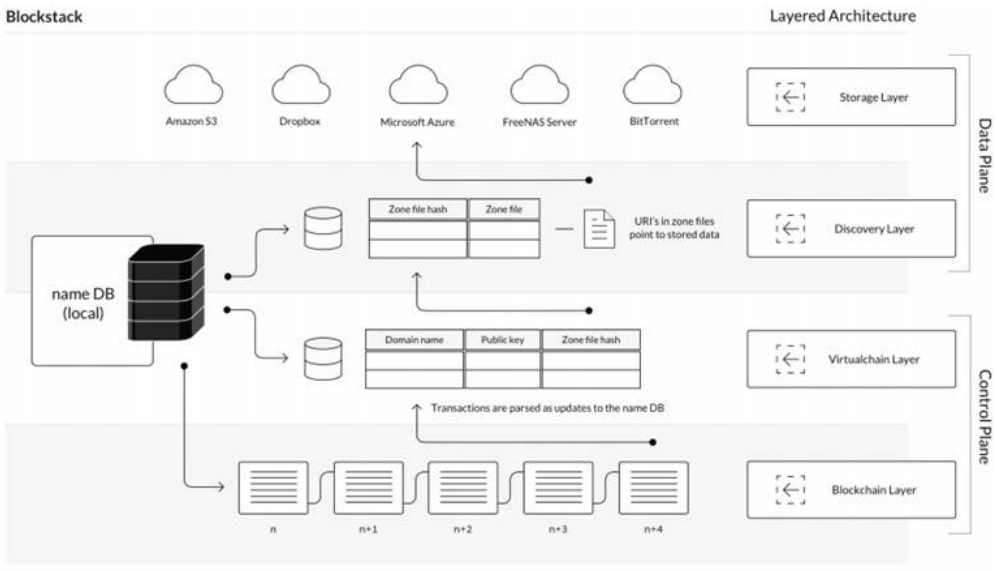
Confusing description! Distributed Cloud Computing?



- Crowd Machine: consists of the Crowd Computer, Crowd App Studio and Crowd Share, being designed to execute blockchain smart contracts and decentralized apps that meet any requirement.
- Crowd Computer: consists of a peer-to-peer network of Crowd Virtual Machines ("CVM") that run on the peer devices. Device owners are compensated for the use of their surplus processing power to run the CVM.
- Crowd App Studio: allows App feature and function to be drawn as logic diagrams, making it faster and easier to create apps than current development approaches.
- Crowd Share: a GitHub-like source repository enabling the commercialization of source code by the developer community

Blockstack

- Blockstack
  - Type: Side-chain/Relay
  - Description:
    - Digital Identity service. Instead of relying on remote, third party servers for access to data and the Internet, Blockstack aims to remove those trust points and give them back to the users via blockchains.



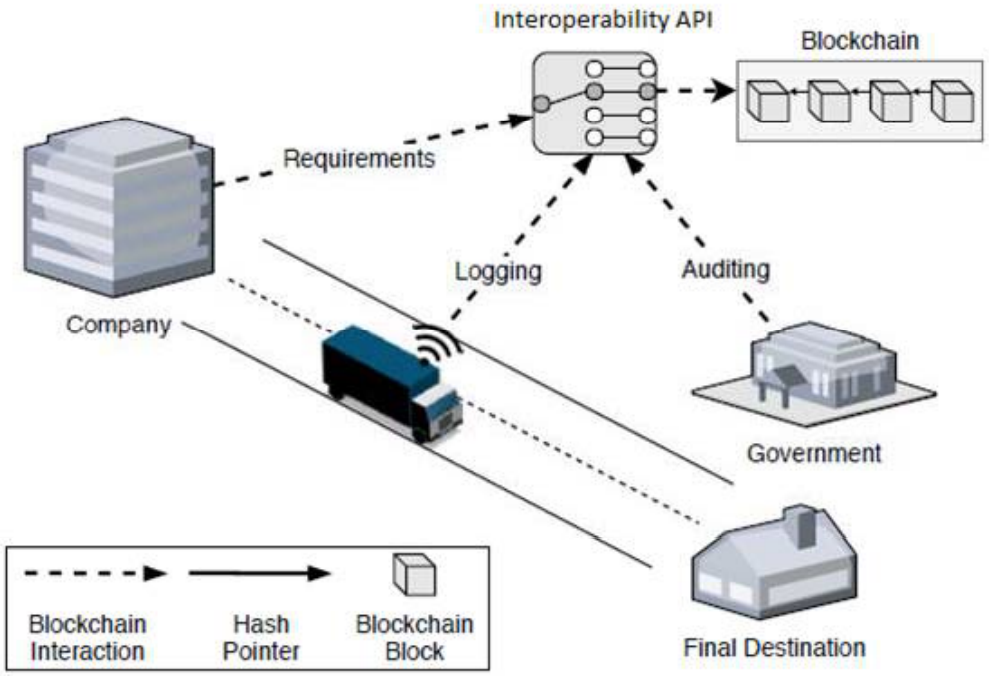
- Storage layer: includes the actual data values and represents a part of the data plane.
- Discovery layer: Blockstack uses zone files to store routing information. The format of zone files resembles that of DNS zone files.
- Virtualchain layer: designates new operations without having to modify the underlying blockchain, which are not aware of the virtual layer
- Blockchain layer: provides the medium for storage of operations and it also provides consensus regarding the order of writing of operations

BC4CC Interoperability API

- Enable the interaction with multiple blockchains
  - Supporting different logistic chains
- Provide a blockchain interoperability
  - Relying in a Notary Scheme
  - Central solution managing transactions
- Allow transparent blockchain interaction
  - Technical details hidden from users
- Requirement: storage of arbitrary data
  - *E.g.*, character strings

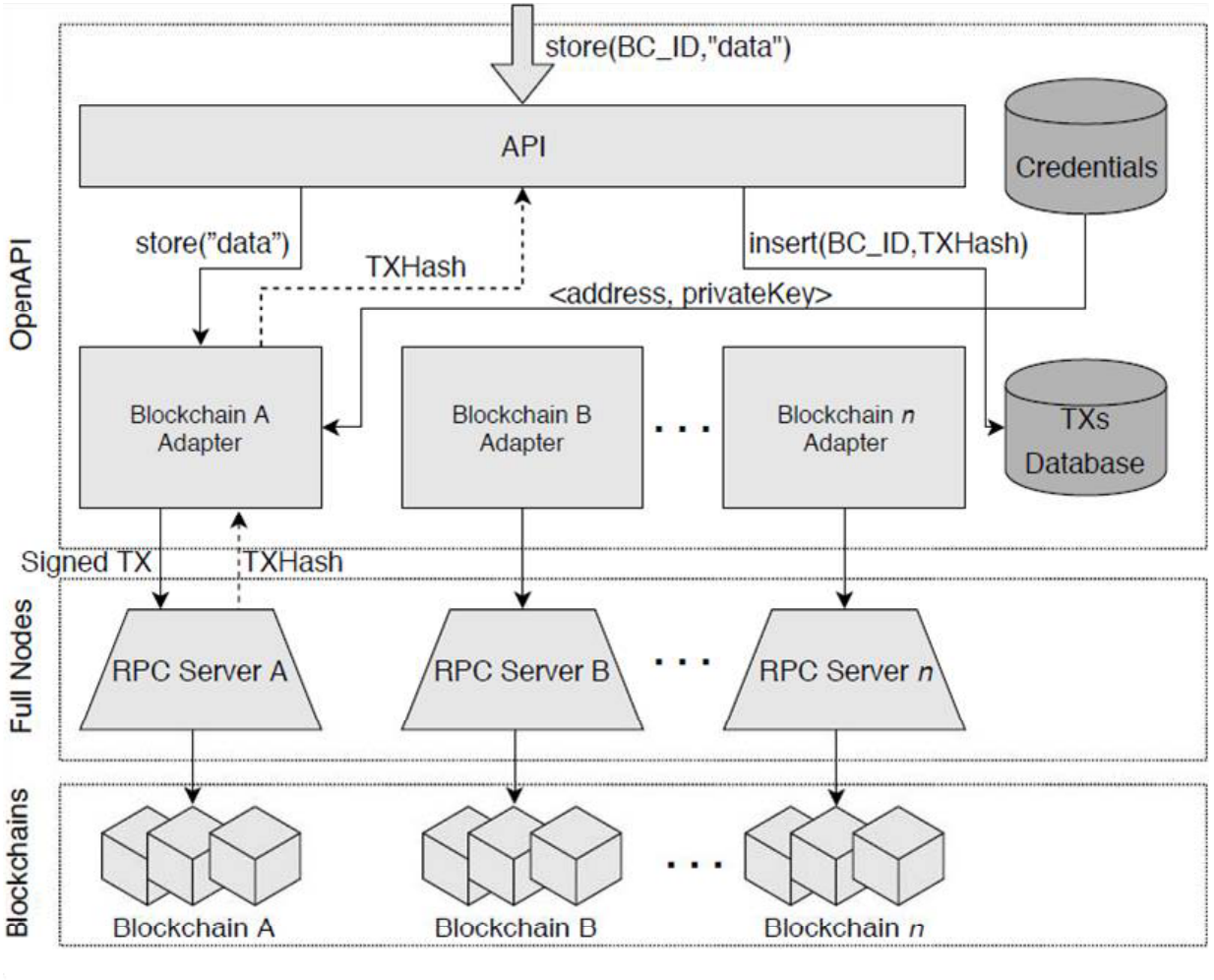
HYPERLEDGER

Applicability Scenario – Coldchain



- Medical drug companies
  - Standards compliance
  - *Store*: drug quality
- Transportation service
  - Temperature monitoring
  - *Store*: sensor readings
- Final destination and authorities
  - Standards verification
  - Data auditing
  - *Retrieve*: quality and temperature readings

Interoperability API – Workflow



- API Entry Point
  - No technical details
  - Implementation hidden
- Credentials DB
  - Pub/Private key
- Transactions DB
  - Hash
  - Timestamp
  - Blockchain ID
- Specialized Adapters
  - BC-specific functions

API Implementation

- User Entry-Point Example
- Interfaces implemented in the API
  - Store data interface

```
def store(text, blockchain):
    adapter = Adapter[blockchain]
    tx_hash = adapter.store(text)
    return tx_hash
```

```
tx = create_transaction("data")
signed_tx = sign_transaction(tx)
transaction_hash = send_raw_transaction(signed_tx)
add_transaction_to_database(tx_hash)
return tx_hash
```

  - Retrieve data interface

```
def retrieve(transaction_hash):
    blockchain = database.find_blockchain(tx_hash)
    adapter = Adapter[blockchain]
    text = adapter.retrieve(tx_hash)
    return text
```

```
tx = get_transaction(tx_hash)
data = extract_data(tx)
return to_text(data)
```

- Functions implemented in each blockchain adapter

Impact of Blockchain Heterogeneity

- UTXO and Account-based blockchains
  - Bitcoin Transactions != Ethereum Transactions
  - Each BTC transactions must have an input transaction to verify if the address has funds or not (unspent)
  - Whereas, Ethereum is Account-based, *i.e.,* an account holds the funds, and is updated on sending/receiving of coins
- Many other technical differences
  - Address generation mechanisms, fees, data structure…
  - RPC IP, port number, communication protocol, authentication…
- Need for specialized blockchain adapters!

Blockchain Adapters

- Specialized adapters must implement
  - Transaction creation function
  - Transaction signing function
  - Communication with RPC function
- Currently implemented

Blockchain	Python Library Name
Bitcoin	python-bitcoinrpc
Ethereum	web3.py
Stellar	py-stellar-base
IOTA	PyOTA
EOS	eosjs_python
Hyperledger	sawtooth_sdk
Multichain	python-bitcoinrpc

Specialized Adapter Implementation (1)

Bitcoin Adapter – Transaction Creation [1]

```
def create_transaction(cls, text):
    input_transaction_hash = database.find_latest_transaction(Blockchain.BITCOIN)
    inputs = [{'txid': input_transaction_hash, 'vout': 0}]
    data_hex = cls.to_hex(text)
    output = cls.create_transaction_output(data_hex, input_transaction_hash)
    # Necessary so that the address is the first output of the TX
    output = collections.OrderedDict(sorted(output.items()))
    transaction_hex = cls.client.createrawtransaction(inputs, output)
    return transaction_hex
```

- Input transaction
- Unspent input
- Data encoded in hexa
- Fee estimation and change

Transaction Signing

```
def sign_transaction(cls, transaction_hex):
    parent_outputs = []
    signed = cls.client.signrawtransactionwithkey(
        transaction_hex,
        [cls.key]
    )
    assert signed['complete']
    return signed['hex']
```

- Recently created transaction
- Private key from address
- Verify if signing was completed

https://gitlab.ifi.uzh.ch/scheid/bc4cc/

Specialized Adapter Implementation (2)

Ethereum Adapter – Transaction Creation [1]

```
def create_transaction(cls, text):
    transaction = {
        'from': cls.address,
        'to': cls.address,
        'gasPrice': cls.client.gasPrice,
        'value': 0,
        'data': bytes(text, 'utf-8'),
        'nonce': cls.get_transaction_count()
    }
    transaction['gas'] = cls.estimate_gas(transaction)
    return transaction
```

- 'from' / 'to': Equal
- 'value': 0 → No funds transfer
- 'data': bytes(text, 'utf-8') → Data encoded in bytes
- transaction['gas'] = cls.estimate_gas(transaction) → Transaction fee estimation

Transaction Signing

```
def sign_transaction(cls, transaction):
    signed = cls.client.account.signTransaction(transaction, cls.key)
    return signed.rawTransaction
```

- cls.key → Private key from address
- transaction → Recently created transaction

https://gitlab.ifi.uzh.ch/scheid/bc4cc/

Transaction Confirmation

- Transactions (tx) might not be processed
  - Refused by the network due to low fees
  - May remain in the tx pool for unknown duration
- Tx finality
  - Number of blocks that a tx is considered immutable
  - I.e., the probability of a 51% attack is close to zero
- Solution
  - Wait for X amount of time before confirming tx
    - Value of X depends on the blockchain in use
      - E.g., Bitcoin requires 6 blocks to ensure finality (3,600 s)
  - Replace tx with increased tx fees
    - Tx re-broadcast to increase the system's robustness

[1] I. Weber *et al.*, "On Availability for Blockchain-Based Systems," *IEEE 36th Symposium on Reliable Distributed Systems (SRDS 2017)*, September 2017, Hong Kong, China, pp. 64-73.

Data Size

- Blockchains not designed as a database!
  - Data size is limited (*i.e.*, non-transaction related data)
  - Possible solution: rely on off-chain storage, *e.g.*, IPFS

Blockchain	Maximum String Size
Bitcoin	80 Byte
Ethereum	46 kByte
Stellar	28 Byte
EOS	256 Byte
IOTA	1300 Byte
HyperLedger	20 Byte
Multichain	80 Byte

Cannot store a **SHA256** hash (**32 Byte**)

Private Keys

- Blockchains based on public/private key cryptography

- Private key required to sign a transaction
  - Different address for each BC → several private keys
- Private key never leaves the server
  - RPC node receives a signed raw transaction

- However,
  - If private key stored as plain text in the DB → no encryption
  - Incentivization of invasions
    - *E.g.*, steal/ransom address funds

Basic Comparison

Blockchain	Area	Interoperability Type
Origintrail.io	Supply-chain	Sidechain/Relay
Ælf (ELF)	General purpose	Sidechain/Relay
Wanchain	Finance	Hash-locking
Herdius	Finance	Notary-scheme
Cosmos	General purpose	Sidechain/Relay
Aion	General purpose	Hash-locking
Polkadot	General purpose	Sidechain/Relay
Ark.io	General purpose	Sidechain/Relay
Crowdmachine	Cloud-computing	Sidechain/Relay
Blockstack	Identity	Sidechain/Relay
BC4CC	Supply-chain	Notary-scheme

Discussed above

Part VII: Practical Exercise

16. Ethereum Wallet

Exercise Goals

1. Differentiate between blockchain nodes
2. Create an address and send a transaction
3. Send funds and verify account balance
4. Verify a transaction sent using a blockchain explorer

Set-up Overview

- Focus on Ethereum blockchain
  - Ethereum Basics and Geth Commands here
  - Connecting to your Node
  - Connecting to a Blockchain Network

- Practical Exercises
  1. Create an account, check balance, and receive Ethers
  2. Transfer Ethers
  3. Interact with a Smart Contract

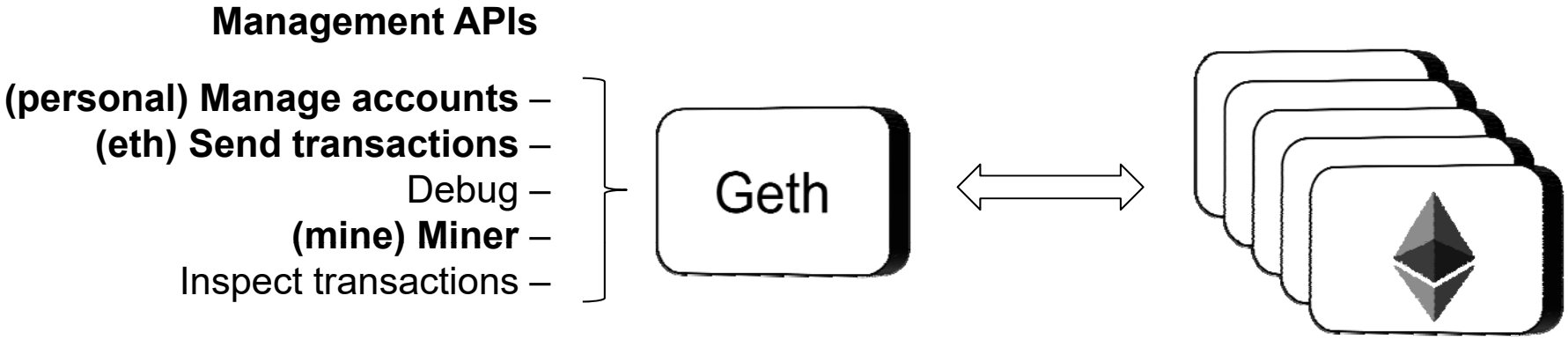
Ethereum Basics – Recalled

- Ethereum is a general purpose blockchain
  - Support the execution of complex Smart Contracts (SC)
  - Empowered the blockchain beyond financial applications

- An Ethereum Virtual Machine (EVM) processes and executes smart contracts.
  - Abstraction layer: the EVM connects requests (transactions) to and from the network
  - SC operations requires Gas
    - Mathematical operations, write data
    - Table of EVM OP costs

Geth Client

- Go implementation of the Ethereum Protocol
  - CLI (Command Line Interface) client
  - Entry point to the main, test and private networks



Management APIs

- Personal API:
  - `personal.newAccount()` // create a new acc.
- Eth API:
  - `eth.accounts[0]` //returns the first created acc.
  - `eth.sendTransaction({from:acc, to:acc, value:ethers})` //send transaction to acc.
- Miner API:
  - `miner.setEtherBase(account)` // define which account to receive ethers

Geth Commands

```
$ geth account <command> [options...] [arguments...]
```

Description	Command
Print summary of existing accounts	*$ list*
Create a new account	*$ new*
Update an existing account	*$ update*
Import a private key into a new account	*$ import*
Info about **subcommands**	*$ [command] --help*

Geth Options (1)

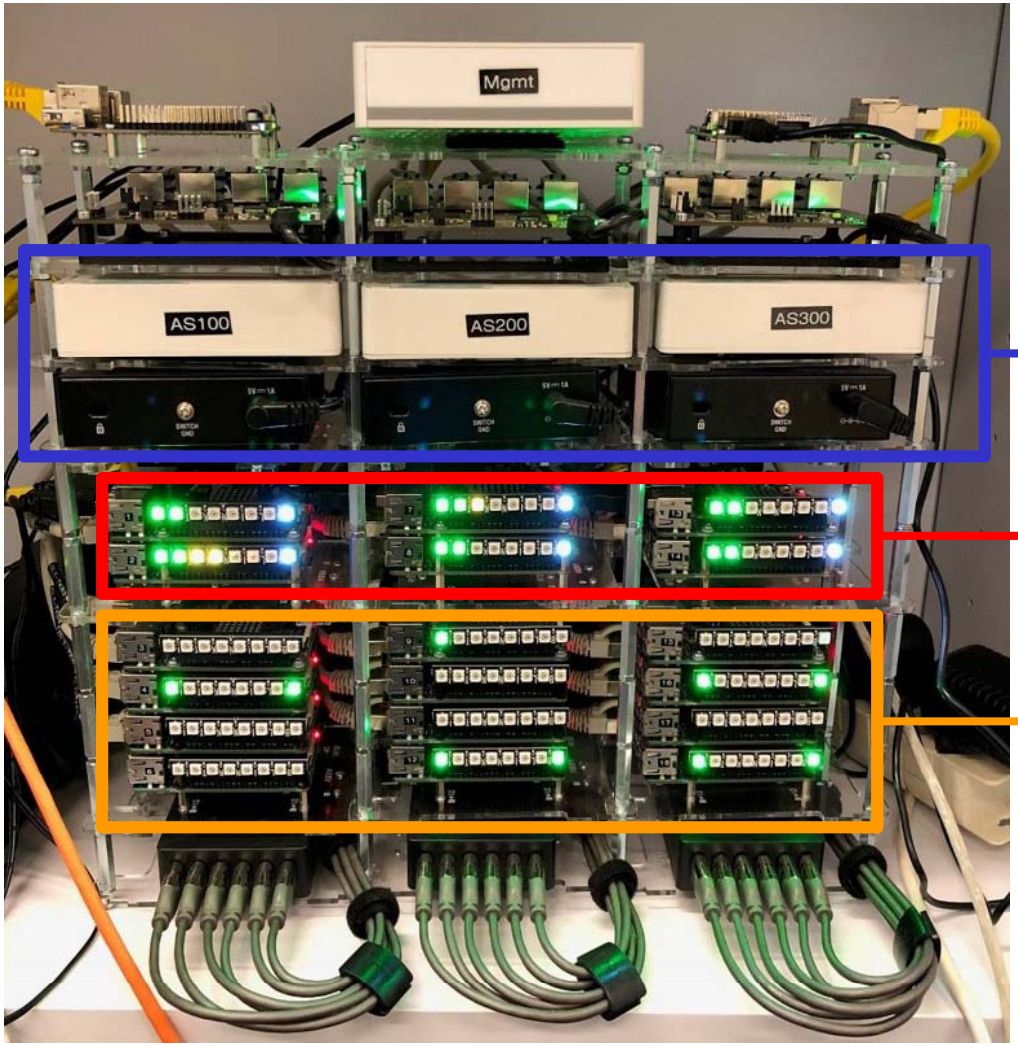
```
$ geth [options] command [command options] [arguments...]
```

Description	Command
Data directory for the databases and key-store	*$ --datadir "path"*
Directory for the keystore (default = inside the datadir)	*$ --keystore*
Network identifier (integer, 1=Frontier, 2=Morden (disused), 3=Ropsten, 4=Rinkeby) (default: 1)	*$ --networkid value*
Ropsten network: pre-configured proof-of-work test network	*$ --testnet*
Rinkeby network: pre-configured proof-of-authority test network	*$ --rinkeby*

Geth Options (2)

blockchain sync mode ("fast", "full", or "light")	*$ --syncmode "fast"*
Enable the HTTP-RPC server	*$ --rpc*
Change, respectively, the address and port of the HTTP server endpoint	*$ --rpcaddr value* *$ --rpcport value*
Ropsten network: pre-configured proof-of-work test network	*$ --testnet*
Rinkeby network: pre-configured proof-of-authority test network	*$ --rinkeby*
blockchain sync mode ("fast", "full", or "light")	*$ --syncmode "fast"*

Blockchain Testbed Overview



Network Components

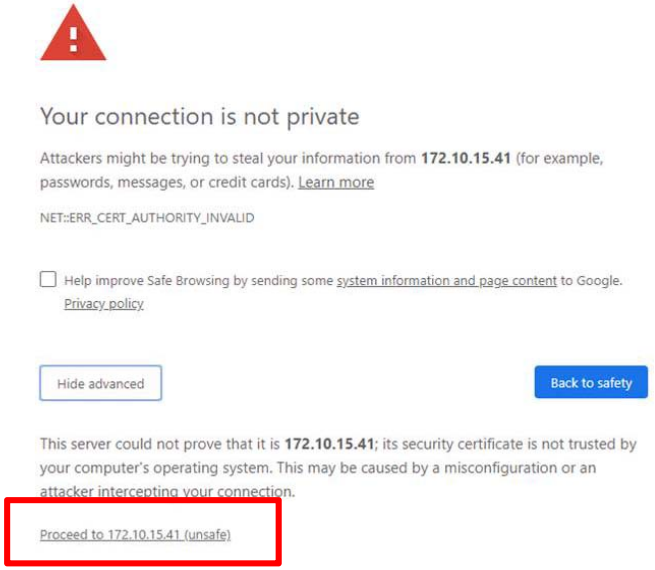
Blockchain Miners Nodes

Blockchain Client Nodes
(You will be accessing these)


YOUR
TURN !

Connecting to Your Node

- Nodes host a **web-based** shell:
  - https://blockchain.csg.uzh.ch/student1...12
- Access the **Summer School Etherpad** in your browser
  - https://blockchain.csg.uzh.ch/etherpad/p/bcsummerschool
- User: `student`
- Password: `123456`



Blockchain Initialization

Step 1: Type: `sh init-blockchain.sh`

```
student@node401:~$ sh init-blockchain.sh
rm: cannot remove 'history': No such file or directory
INFO [05-04|15:29:12] Maximum peer count                       ETH=25 LES=0 total=25
INFO [05-04|15:29:12] Allocated cache and file handles         database=/home/student/geth/chaindata
INFO [05-04|15:29:12] Writing custom genesis block
INFO [05-04|15:29:12] Persisted trie from memory database      nodes=356 size=65.35kB time=10.523177m
INFO [05-04|15:29:12] Successfully wrote genesis state         database=chaindata
INFO [05-04|15:29:12] Allocated cache and file handles         database=/home/student/geth/lightchain
INFO [05-04|15:29:12] Writing custom genesis block
INFO [05-04|15:29:12] Persisted trie from memory database      nodes=356 size=65.35kB time=6.780313ms
INFO [05-04|15:29:12] Successfully wrote genesis state         database=lightchaindata
```

Step 2: Type: `sh start-blockchain.sh`

```
student@node401:~$ sh start-blockchain.sh
INFO [05-04|15:30:02] Maximum peer count                       ETH=25 LES=0 total=25
INFO [05-04|15:30:03] Starting peer-to-peer node               instance=Geth/v1.8.2-stable-b8b9f7f4/linux-arm/go1.9.4
INFO [05-04|15:30:03] Allocated cache and file handles         database=/home/student/geth/chaindata cache=768 handles=512
WARN [05-04|15:30:04] Upgrading database to use lookup entries
INFO [05-04|15:30:04] Initialised chain configuration          config="{ChainID: 2019 Homestead: 1 DAO: <nil> DAOSupport: false EIP150: 2 EIP155: 3
INFO [05-04|15:30:04] Initialising Ethereum protocol           versions="[63 62]" network=2019
INFO [05-04|15:30:04] Loaded most recent local header          number=0 hash=7ae695…90bfb4 td=1
INFO [05-04|15:30:04] Loaded most recent local full block      number=0 hash=7ae695…90bfb4 td=1
INFO [05-04|15:30:04] Loaded most recent local fast block      number=0 hash=7ae695…90bfb4 td=1
INFO [05-04|15:30:04] Database deduplication successful        deduped=0
INFO [05-04|15:30:04] Regenerated local transaction journal    transactions=0 accounts=0
INFO [05-04|15:30:04] Starting P2P networking
INFO [05-04|15:30:06] UDP listener up                          self=enode://26cae4bd6a1dd523861b0f3cf821f40c212744eb1eca54e3963824689f2cd14a84f2f9ce
0:30303
INFO [05-04|15:30:06] RLPx listener up                         self=enode://26cae4bd6a1dd523861b0f3cf821f40c212744eb1eca54e3963824689f2cd14a84f2f9ce
0:30303
INFO [05-04|15:30:06] IPC endpoint opened                      url=/home/student/geth.ipc
```

Blockchain Syncing

- If the blockchain is syncing you will see this type of information:

```
> INFO [05-04|15:30:15] Block synchronisation started
INFO [05-04|15:30:16] Imported new chain segment           blocks=137 txs=0 mgas=0.000 elapsed=383.255ms mgasps=0.000 number=137 hash=7a970e
INFO [05-04|15:30:18] Imported new chain segment           blocks=823 txs=8 mgas=2.107 elapsed=2.307s    mgasps=0.913 number=960 hash=9ef2d3
WARN [05-04|15:30:20] Synchronisation failed, dropping peer peer=c50eee4954f2902f err="retrieved hash chain is invalid"
INFO [05-04|15:30:24] Imported new chain segment           blocks=1   txs=0 mgas=0.000 elapsed=8.955ms   mgasps=0.000 number=1379 hash=7d733
INFO [05-04|15:30:29] Imported new chain segment           blocks=1   txs=0 mgas=0.000 elapsed=7.700ms   mgasps=0.000 number=1380 hash=7ae35
INFO [05-04|15:30:34] Imported new chain segment           blocks=1   txs=0 mgas=0.000 elapsed=7.680ms   mgasps=0.000 number=1381 hash=3698c
INFO [05-04|15:30:39] Imported new chain segment           blocks=1   txs=0 mgas=0.000 elapsed=15.529ms  mgasps=0.000 number=1382 hash=ca556
INFO [05-04|15:30:44] Imported new chain segment           blocks=1   txs=0 mgas=0.000 elapsed=10.861ms  mgasps=0.000 number=1383 hash=43356
WARN [05-04|15:30:45] Synchronisation failed, dropping peer peer=c50eee4954f2902f err="retrieved hash chain is invalid"
INFO [05-04|15:30:49] Imported new chain segment           blocks=1   txs=0 mgas=0.000 elapsed=12.175ms  mgasps=0.000 number=1384 hash=262bb
INFO [05-04|15:30:54] Imported new chain segment           blocks=1   txs=0 mgas=0.000 elapsed=11.500ms  mgasps=0.000 number=1385 hash=c859c
INFO [05-04|15:30:59] Imported new chain segment           blocks=1   txs=0 mgas=0.000 elapsed=13.292ms  mgasps=0.000 number=1386 hash=b96c7
INFO [05-04|15:31:04] Imported new chain segment           blocks=1   txs=0 mgas=0.000 elapsed=11.004ms  mgasps=0.000 number=1387 hash=03eaa
INFO [05-04|15:31:09] Imported new chain segment           blocks=1   txs=0 mgas=0.000 elapsed=11.047ms  mgasps=0.000 number=1388 hash=19cf8
INFO [05-04|15:31:14] Imported new chain segment           blocks=1   txs=0 mgas=0.000 elapsed=11.896ms  mgasps=0.000 number=1389 hash=fdeee
WARN [05-04|15:31:16] Synchronisation failed, dropping peer peer=c50eee4954f2902f err="retrieved hash chain is invalid"
INFO [05-04|15:31:24] Imported new chain segment           blocks=1   txs=0 mgas=0.000 elapsed=8.481ms   mgasps=0.000 number=1391 hash=fa510
INFO [05-04|15:31:29] Imported new chain segment           blocks=1   txs=0 mgas=0.000 elapsed=7.796ms   mgasps=0.000 number=1392 hash=ef345
```

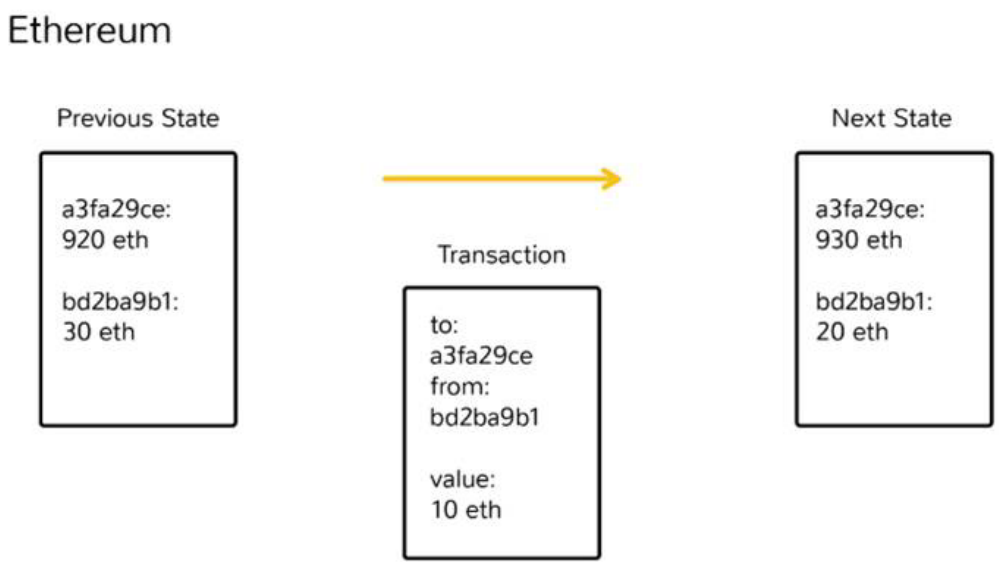
- You can also see the blocks being appended
- Blockchain Explorer: **http://172.10.15.22:8000**

Practical Steps

1. Create account, check balance, receive Ethers
2. Send/transfer Ethers
3. Interaction with a Smart Contract (SC)

1. First Exercise

- Create an account, check your balance, and receive Ethers



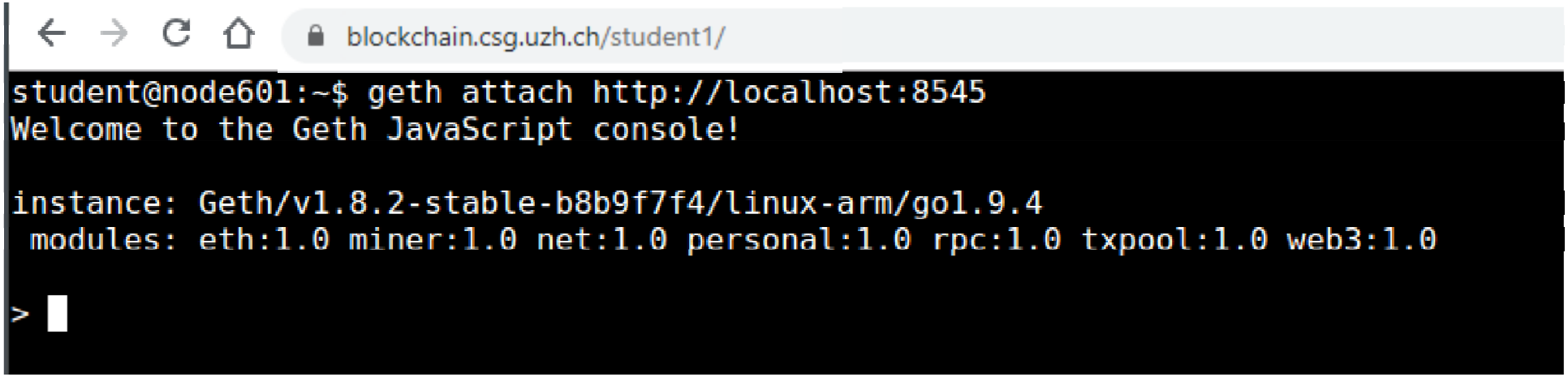
https://www.coindesk.com/information/how-ethereum-works

Wei	1000000000000000000
Kwei, Ada, Femtoether	1000000000000000
Mwei, Babbage, Picoether	1000000000000
Gwei, Shannon, Nanoether, Nano	1000000000
Szabo, Microether,Micro	1000000
Finney, Milliether,Milli	1000
Ether	1
Kether, Grand,Einstein	0.001
Mether	0.000001
Gether	0.000000001
Tether	0.000000000001

https://etherconverter.online/

Interacting with the Blockchain (1)

- Open a **new shell** to **your node** in **a new tab**:



- Create a **new account** (do not forget your password):

```
> personal.newAccount()
Passphrase:
Repeat passphrase:
"0x01b93652d702a967f9eb88de3cafa770858ece34"
>
```

Interacting with the Blockchain (2)

- Set the new account as your geth main account:

```
> eth.accounts[0]
"0x01b93652d702a967f9eb88de3cafa770858ece34"
> miner.setEtherbase(eth.accounts[0])
true
>
```

- Unlock your account to send Ethers:

```
>
> personal.unlockAccount(eth.accounts[0],"typeYourPassword",999999)
```

Check your Balance

- Set the new account as your geth main account:
- Type:
  - `eth.getBalance(eth.accounts[0])`
    - Should return 0
    - Value returned in “wei”, which is the smallest unit in Ethereum

- If you want to see your balance in Ether:
- Type:
  - `balance = eth.getBalance(eth.accounts[0])`
  - `web3.fromWei(balance, "ether")`

Receive Ethers

- Access the CAS Etherpad in your browser
  - https://blockchain.csg.uzh.ch/etherpad/p/cas

- Inform your account to receive Ethers

```
30 Write down your name and account below:
31
32 ----------------------------------------------------------------------------------------------------
33 NAME - ACCOUNT
34
35 Eder - 0x444076e9eeafe57aa8fb63e88f942ddd1986e171
36 Bruno - 0x9d29cf9313cea1f801f2725a0e2bc82100f71616
37
38
```

- Check your balance again

2. Second Exercise

- Transfer Ethers to another account
- On geth console type:
  - `sender = eth.accounts[0]`
  - `receiver = "<account from colleague>"`
  - `valueEth = web3.toWei(0.5, "ether")`
  - `eth.sendTransaction({from: sender , to: receiver, value: valueEth, gas:21000})`
- Check your balance

17. Smart Contracts

3. Third Exercise

- Interacting with a Smart Contract (SC)

```
1   pragma solidity ^0.5.1;
2
3   //CAS BC 2019 Smart Contract Example
4   contract Accountbook {
5
6       address owner;
7       mapping  (uint => string) accounts;
8       uint accountCount = 0;
9
10      constructor() public {
11          owner = msg.sender;
12      }
13
14      function register(string memory end) public returns (uint) {
15          accounts[accountCount] = end;
16          accountCount++;
17          return accountCount-1;
18      }
19      function getAccountCount() public view returns (uint) {
20          return accountCount;
21      }
22
23      function getAccount(uint n) public view returns (string memory) {
24          return accounts[n];
25      }
26  }
```

Each account has an unique ID

First ID is 0

New registered account receives an ID

Returns the account associated with the ID

SC Storage

- What data does the SC stores?
  - List of IDs and Account (Example)

ID	Account
0	0xC0A565abfa50349c59a4D0647834Bb6763b8fFC9
1	0xe3c01b34bBcfeDf5D5Cf090226D50767c8DBC029
2	0xd41aA1F353CdcdC3d3bd22D2EcD2e4fF490f2847
3	0x5e694ceCb56d4C24a79547468B80c5ffD186B06F
4	0xAF418BAe762962dEdb6aC027A0706972260F910d
5	0xeB23D0a558482D6D706C51234F4210aef0797F5F
6	0xAB38C7C0e9FA8f30bFF71c25781e1207E6BCfb06

  - Number of Accounts: 7
  - New Account will have ID 7

3. Third Exercise

- Interacting with a Smart Contract (SC)
- On geth console type
  - `loadScript('initContract.js')`
  - `example.getAccount(0)`
- Send 0.1 Ethers to the returned account
- Check your balance

Part VIII: Blockchain Evaluations (Technical View, Mainly ...)

18. To Blockchain or not to Blockchain?

Choosing a Blockchain (1)

Posted November 22, 2015 by Gideon Greenspan in Private blockchains.

Avoiding the pointless blockchain project

How to determine if you've found a real blockchain use case

Do you need a Blockchain?

Karl Wüst
Department of Computer Science
ETH Zurich
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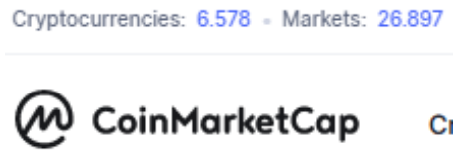
Arthur Gervais
Department of Computing
Imperial College London
a.gervais@imperial.ac.uk

The Use of Blockchains: Application-Driven Analysis of Applicability

Bruno Rodrigues, Thomas Bocek, Burkhard Stiller
Communication Systems Group (CSG), Department of Informatics (IfI), Universität Zürich (UZH), Zürich, Switzerland

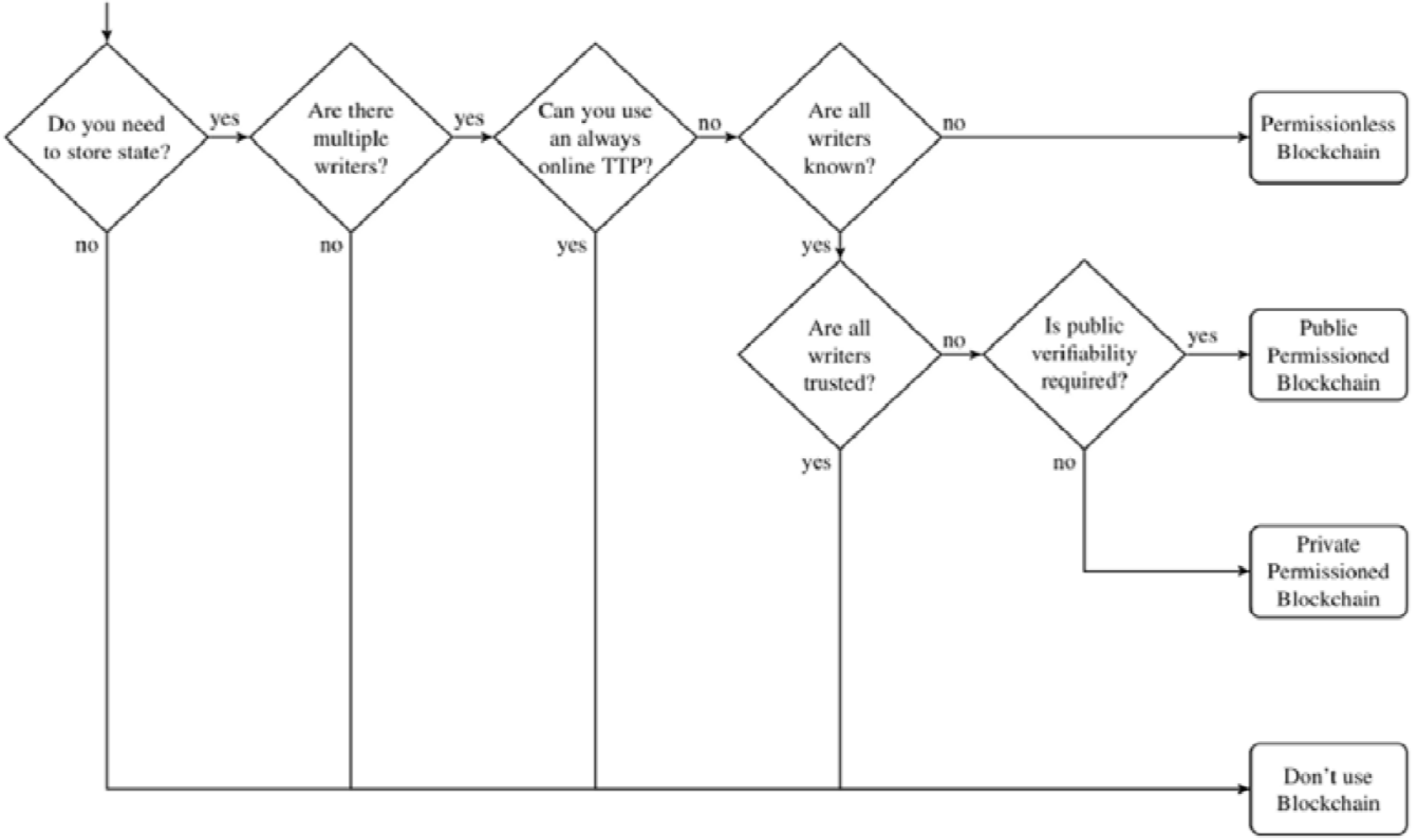
Choosing a Blockchain (2)

- Not a trivial question to answer
  - … besides these 6500+ BCs available
- Myriad of facets/parameters
  - Marketcap
    - Value to buy all shares at today's market value
  - Community involvement
    - Telegram chats, discussion channels
  - Full Node/Miners Geolocation
    - Politics, possibility of centralization
  - Technical concerns
    - Transactions per second, implementation language, design choices
  - Security
    - Hashing algorithm, possible attack vectors



[1] https://coinmarketcap.com/

Blockchain Demand “Checker”



K. Wüst, A. Gervais, 2017

Related Impact Analysis

- Performance and scalability requirements impact alternative BC solutions and data bases in comparison

	Permissionless Blockchain	Permissioned Blockchain	Central Database
Throughput	Low	High	Very High
Latency	Slow	Medium	Fast
Number of readers	High	High	High
Number of writers	High	Low	High
Number of untrusted writers	High	Low	0
Consensus mechanism	Mainly PoW, some PoS	BFT protocols (e.g. PBFT [6])	None
Centrally managed	No	Yes	Yes

BFT: Byzantine Fault Tolerance
PBFT: Practical Byzantine Fault Tolerance

K. Wüst, A. Gervais, 2017+2018

19. Comparisons and Assessment (Neither Good* nor Bad*, Only “as is”!)

* “Good” or “bad” qualifications can be determined from results of evaluations, which depend heavily on models and assumptions!

Blockchain Benefits (1)

- Trust derived from network's protocol transparency and the assurance of immutable blocks protected by cryptographic mechanisms
  - Trust included into every single transaction
  - All parties have access to a "single" shared copy
- Personal, persistent, digital, ID ownership-enabled, which supports licensing of owned "information"
  - Higher security, better cost efficiency, optimized reconciliation process
- Cost reductions expected due to SCs automated execution on the BC (no intermediaries needed)

Blockchain Benefits (2)

- Application domains “not” limited as such
  - But, digital assets used determine a major application advantage
- FinTech
  - Reduction of transaction costs for financial transactions, such as within e-payment systems
  - Potential participation of many participants in financial economy
- Rights Protection
  - Immutable blocks (world-wide distributed) complicates fraud on digital data, such as stealing or misuse of land titles, Intellectual Property
- Supply Chain
  - Persisting of production, transport, and delivery characteristics

Probabilities and Blockchains (1)

- Public-private key pairs:
  - Two public-private keys may be the same
    - Probability of that “astronomically low” (not zero), technically irrelevant
    - Primality tests: Sieve of Eratosthenes, probabilistic Miller–Rabin tests
      - Composite number at 75% chance of being detected per round
      - After 64 rounds of testing, the probability that composite number is undetected is at probability of 2^{-128}
- Mining:
  - Probability of winning “block race” proportional to computational power of participants
    - Time restriction on block mining; Bitcoin set to the block time: 10 min
    - Computational, hashing power increase ⇨ chance of discovering a new block under 10 min increases ⇨ increase target value

Probabilities and Blockchains (2)

- Centralized mining with unfairness and 51% attack
  - Incentives to “combine” miner into pools
  - Chances to take over a BC from a country with “many” miners
    - Mining power of above 51% at one country

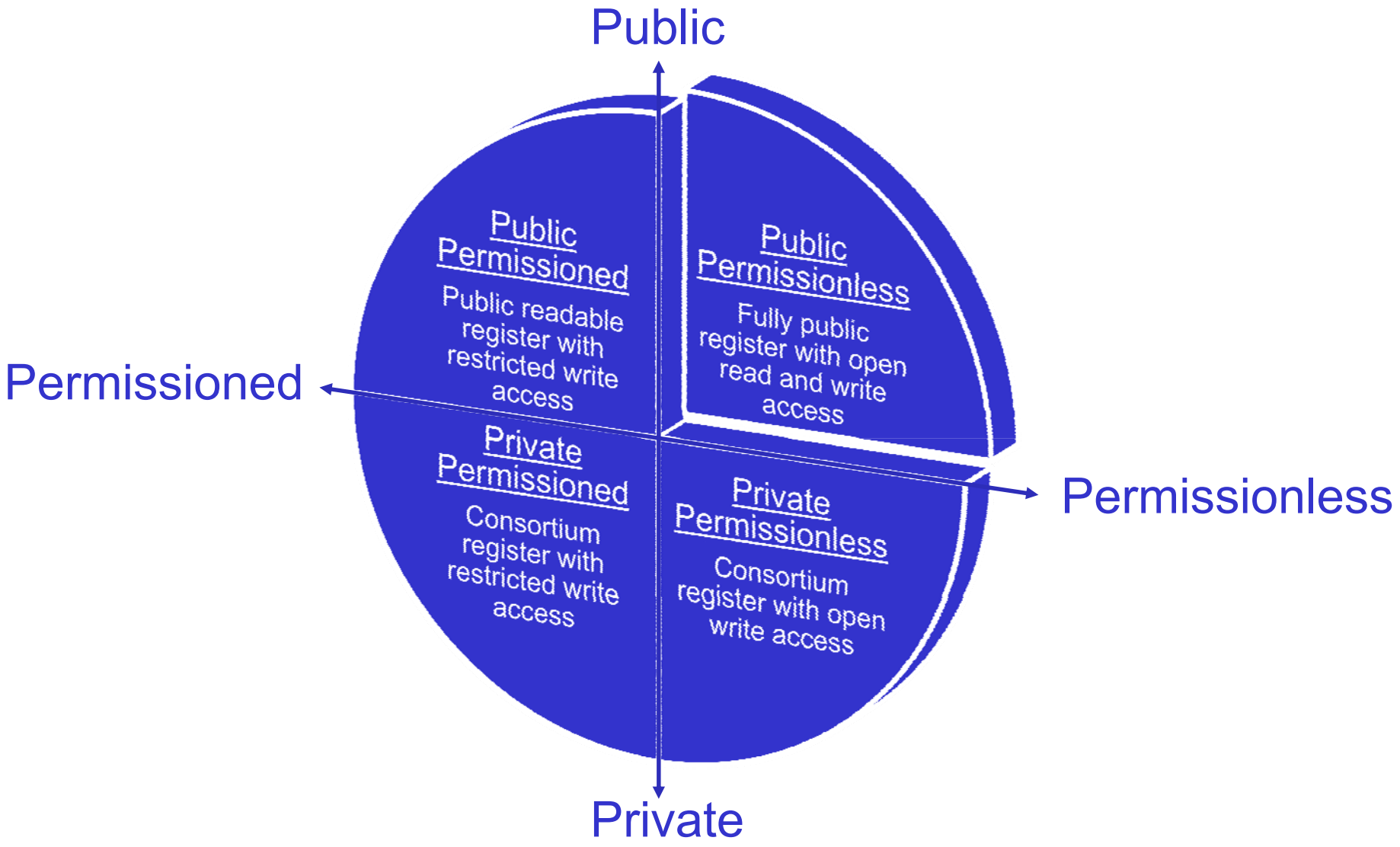
M. Saad et al.: Exploring the Attack Surface of Blockchain: A Systematic Overview, 2019

- Consensus mechanisms (distributed)
  - Randomness for multiple parties trying to come to agreement
    - Constraints as upper bounds on (a) number of messages sent within a block time (throughput) and (b) time it takes for message to be sent (latency) ⇨ BC (public) make it hard to “consent” an agreement via messages needed ⇨ solved by PoW and messages needed!
    - PoS: selection of subcommittee ⇨ unbiasable? Not possible!
- Stakeholders (maliciously behaving trusted nodes)
  - Probabilities of an “internal” attacker within a given private BC

Key BC Characteristics

- Permissions (write/read)
  - Fully: everyone in the world can participate (W/R)
  - Partially: selected public can participate (W/R)
- Transparency
  - Fully: all members access the history of transactions
  - Partially: some members access the history of transactions
    - Better than a traditional DB
- Permanent storage, *i.e.*, immutability
  - Transactions cannot be removed
- Level of decentralization
  - Fully: consensus with elected leader
  - Partially: consensus with selected leader(s)

Deployment Models



Mapping Tradeoffs vs. Blockchain Types

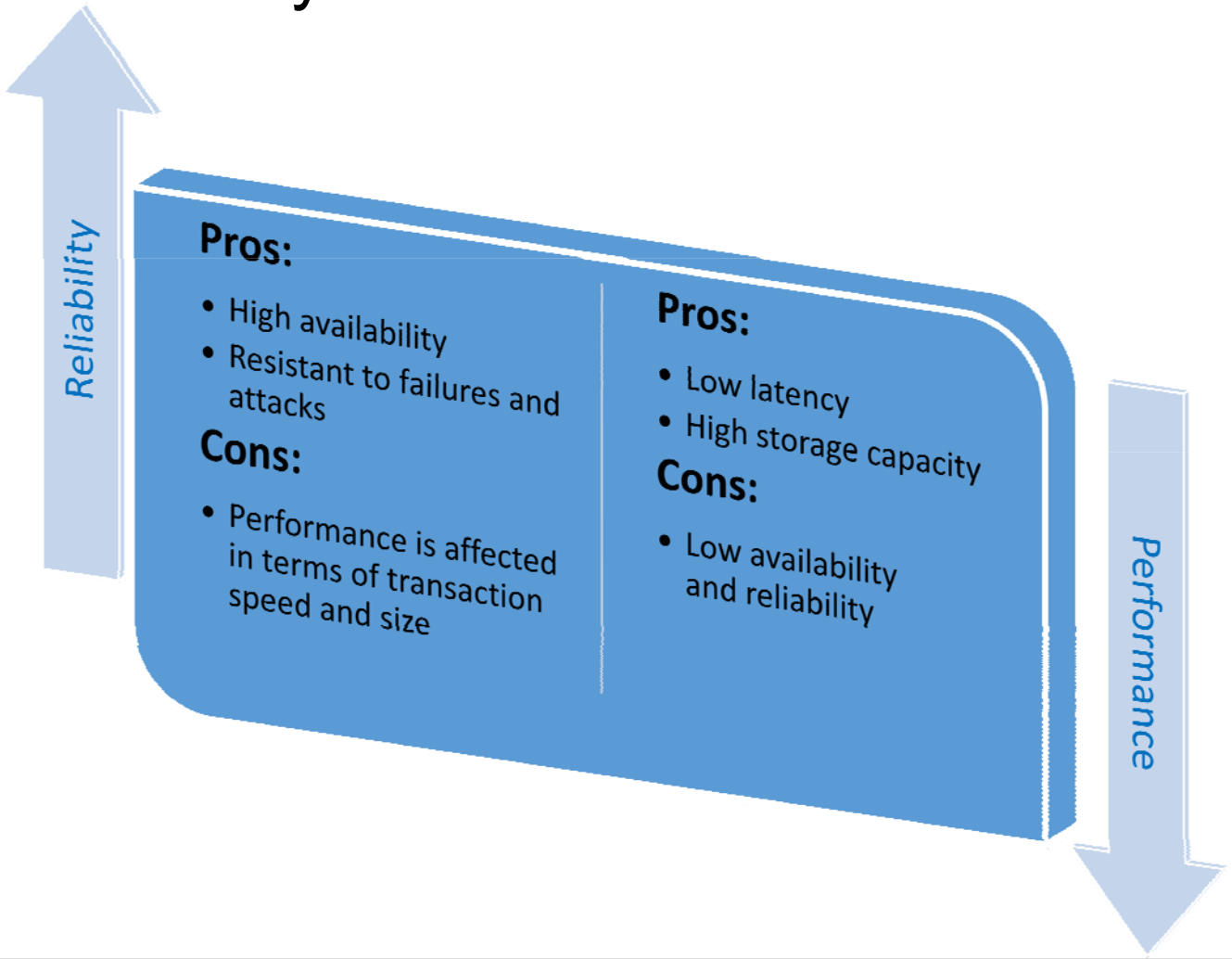
	Public Permissionless	Public Permissioned	Private Permissionless	Private Permissioned
Transparency	World visibility	World visibility	Community visibility	Role-based visibility
Control	Distributed due to the **election process**	Distributed but validators are defined in a **selection process**	Distributed but validators are defined in a **selection process**	Centralized based on **trusted nodes**
Reliability	**Full replication** (light nodes always rely on full nodes)	**Full or partial replication** (possible to define super nodes)	**Full or partial replication** (possible to define super nodes)	**Full or partial replication** (master-slave)
Performance	**Slow** due the consensus and replication models	**Intermediate** depending on consensus and replication models	**Intermediate** depending on consensus and replication models	**Fast** because its mostly centrally managed

Blockchain Comparison (Selected Examples)

Blockchain	Type	Consensus	Blocktime (s)
Bitcoin	Public	PoW	600
Ethereum	Public	PoW	15
Stellar	Public	SCP	5
EOS	Public	dPoS	0.5
IOTA	Public	IOTA	60
HyperLedger	Private	PoET	20
Multichain	Private	PoA	15
Bazo	Public	PoS	N/A

Reliability vs. Performance

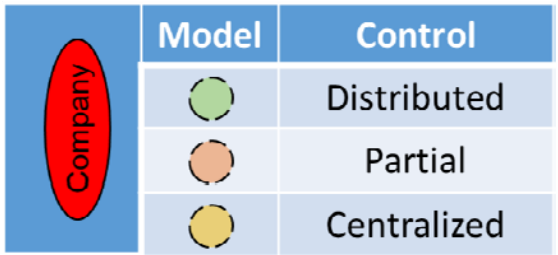
- Analysis case-by-case

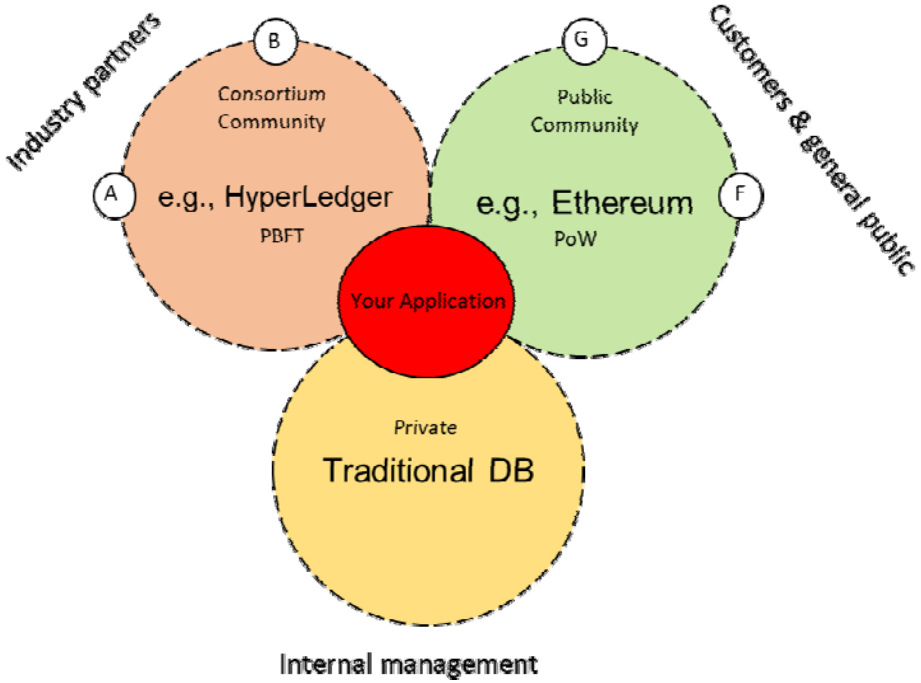


Distributed vs. Centralized Control

- Distributed control based on elected leader (*e.g.*, PoW)
- Partially based on selected leaders (*e.g.*, PoA, PBFT)
- Centralized Control based on trust (*e.g.*, traditional databases)

- Multiple possibilities
  - At the same time...





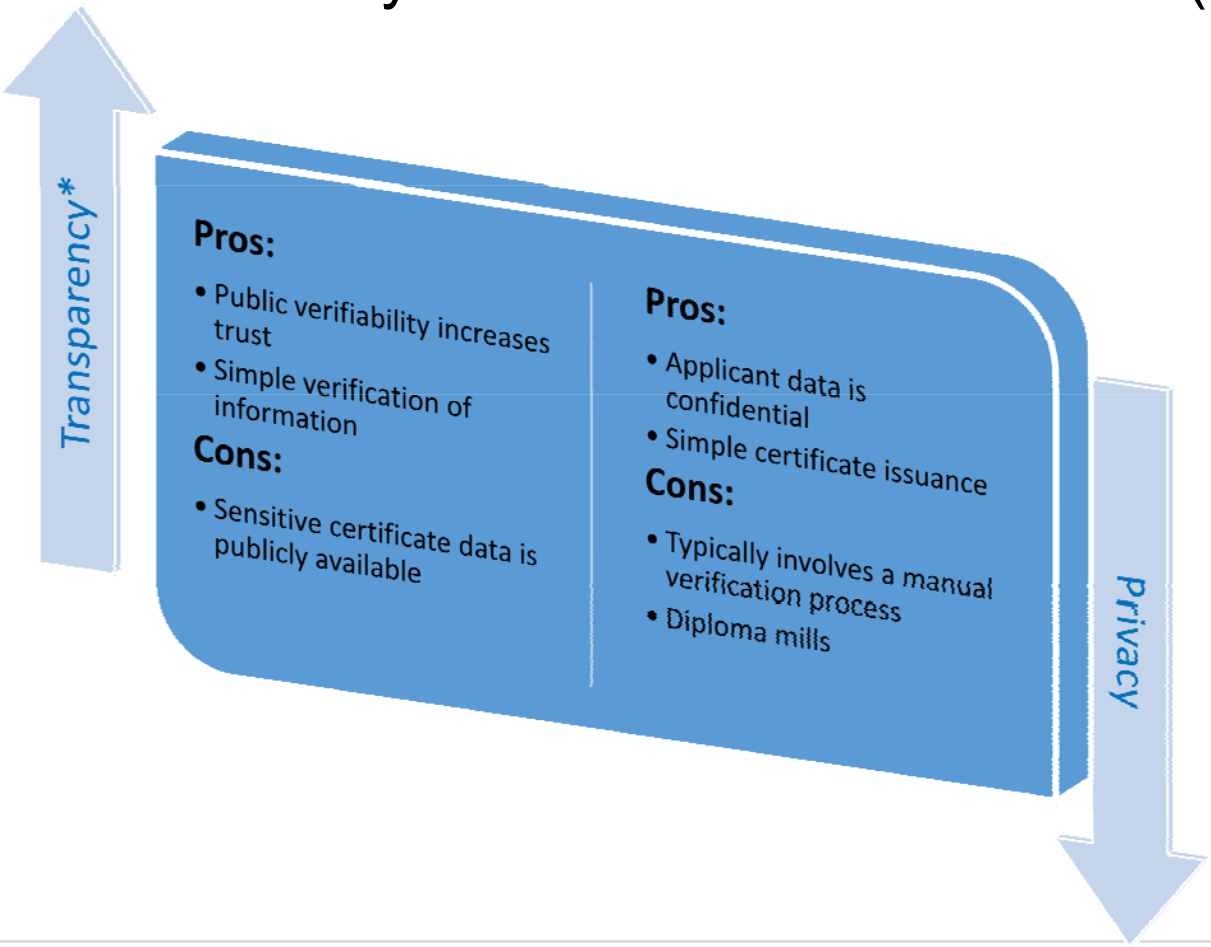
Comparison of Consensus Mechanisms

Incomplete!

Mecha-nism	Security Level	Depending on	Scalability	Remarks
BFT	“Reasonable” Leader pre-elected 51% failure	-	Medium	Trust in pre-election
dBFT	“Reasonable” Set of leaders pre-elected	-	Medium	Trust in set of leaders
PoW	High 51% attack	Hashes	Controversial	Energy consumption high, needed to ensure high security level (by design)
PoS	Unknown “Nothing-at-Stake”	PoW-based “stake”	Under discussion	“Costless” forking, thus, measurable assets needed
PoA	Identity-based	PoS, PoW	Under discussion	Authorities required
Shards	Unknown	Any PoX	Unknown	Communities, interoperability

Transparency vs. Privacy

- Analysis case-by-case
  - Possible to store only checksums of information (integrity)



Blockchain to Database Comparison

		Blockchains (BC)	Databases (DB)
Operations	Operations	Insert, read	Insert, read, delete, update
	Replication	Full replication	*E.g.*, master-slave model
	Consensus	Majority of nodes agree on outcome of transactions	Distributed transactions
	Invariants	Any node can validate transactions	DB manager in charge of validation
Characteristics	Disintermediation	Fully reached for public BCs Partially reached private BCs	Central management (logical view), while physical distribution possible
	Performance	Still limited for public BCs "Increasing" for private BCs	All scales reachable
	Storage size	*n* copies	1 database, optional replicas
	Reliability	As distributed systems can be	Based on failover and redundancy
	Integrity	Dependent on consensus protocol	Typically based on ACID principle
	Confidentiality and Privacy	Partially reachable for public BCs Fully reachable for private BCs	Dependent on access control regime and storage regulations of DB
	Trust	Unknown, typically non-trusted	Database (operator) trusted
	History	Fully achieved since start	Only partially, DB archiving function

Blockchain Interoperability

- Projects using or providing a platform for interoperable chains

Blockchain	Area	Interoperability Type
Origintrail.io	Supply-chain	Sidechain/Relay
Ælf (ELF)	General purpose	Sidechain/Relay
Wanchain	Finance	Hash-locking
Herdius	Finance	Notary-scheme
Cosmos	General purpose	Sidechain/Relay
Aion	General purpose	Hash-locking
Polkadot	General purpose	Sidechain/Relay
Ark.io	General purpose	Sidechain/Relay
Crowdmachine	Cloud-computing	Sidechain/Relay
Blockstack	Identity	Sidechain/Relay

Cryptocurrency Comparison

Blockchain ≠ Bitcoin

Bitcoin	Ethereum
A maximum of 21 million bitcoins supply, halving newly generated supply every 4 years	Unlimited ethers supply
10 minutes block creation time	14 seconds block creating time
Crypto puzzle via partial SHA256 hash collision, requiring CPU time and minimal RAM; dedicated hardware, application-specific integrated circuit (ASIC) used	Crypto puzzle is variation of Dagger-Hashimoto which requires besides CPU time also RAM; GPU cards currently used
Limited scripting language, not Turing complete	General-purpose scripting language, Turing complete
Started in 2009, creator unknown (pseudonym used: Satoshi Nakamoto)	Started in 2015, initiator Vitalik Buterin
Balance based on unspent transaction outputs	Balance is account-based
Transaction costs driven by transaction size	Transaction costs driven by operations in the smart contract
Max throughput: 3-7 transactions per second	Max throughput: 23 - 25 transaction per second
Transactions created by users	Transactions created by users or smart contracts
Market capitalization: 9.9 billion USD	Market capitalization: 1 billion USD
Bitcoin created: 15.8 million BTC (2016)	Ethers created: 83 million ETH

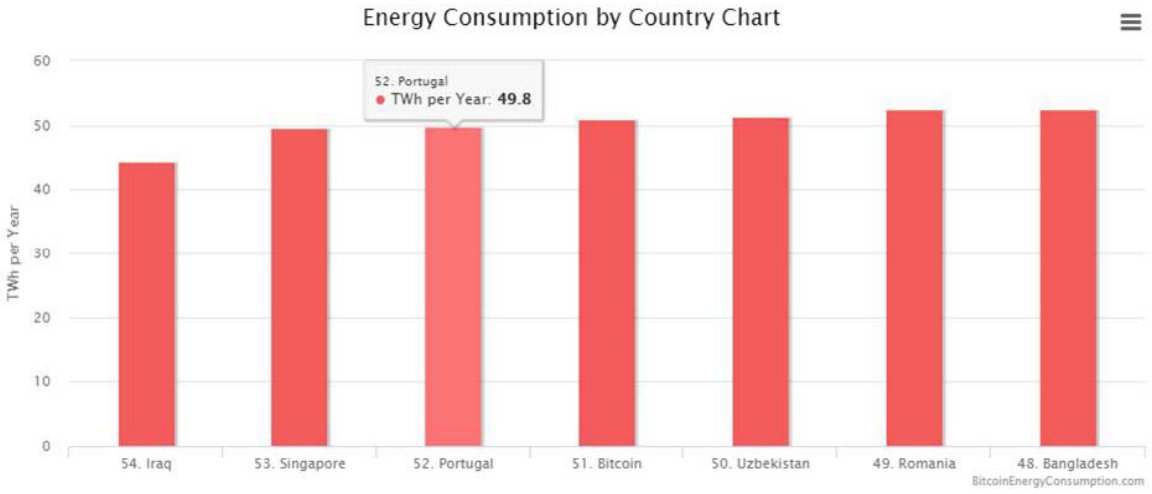
However, Bitcoin's and Ethereum's BC can be used and applied elsewhere.

Assessment of BC Operations

- Trust (depends on consensus mechanism, cryptography)
  - "No" power to change or delete previously persisted block
    - Auditability, traceability for data of a transaction
- Decentralization (full autonomy)
  - No-one "owns", no single instance controls the BC
    - Immutability, no single-point-of-failure
- Integrity (one important facet of security)
  - State of a transaction cryptographically secured (signed)
    - Privacy depends on handling of the blocks/transactions content
- Sustainability
  - Depending on the consensus mechanism

Example: Sustainability

- Sustainability: Energy efficiency of consensus mechanisms
  - Energy consumption for Bitcoin BC in 2018 ≈ The Netherland's production, projected for 2019 ≈ Portugal's production
- Proof-of-Work (PoW) does not produce socially "beneficial" output, but it highly secures transactions!
- Possible Solution
  - Alternative consensus mechanisms
    - Proof-of-Useful-Work



https://digiconomist.net/bitcoin-energy-consumption

Assessment of Transaction Durations

- Bitcoin Cash: 615 s
- Bitcoin: 504 s
- Litecoin: 135 s
- Ethereum: 15 s
- Ripple (XRP): 4 s
- EOS: 1.5 s

Tx Durations termed “Block Time”, too

Sample effect of BCs very visible by the user!

Bitcoin report, March 2018, http://www.bitcoin.report.de

EOS “provides accounts, authentication, databases, asynchronous communication, and the scheduling of applications across many of CPU cores or clusters. The resulting technology is a blockchain architecture that ***may ultimately scale*** *to millions of transactions per second, eliminates user fees, and allows for quick and easy deployment and maintenance of decentralized applications, in the context of a* ***governed*** *blockchain”, thus a private BC.*

https://globalcoinreport.com/eos-strides-towards-recovering-its-record-against-bitcoin/

Assessment of Data Storage

- Data within a transaction is limited

Blokchain	Maximum String Size in tx
Bitcoin	80 Byte
Ethereum	46 kByte
Stellar	28 Byte
EOS	256 Byte
IOTA	1300 Byte
HyperLedger	20 Byte
Multichain	80 Byte

- Possible Solution
  - Off-chain storage, *e.g.*, IPFS (Inter-planetary File System)
  - Hashing of data, *e.g.*, SHA 256
  - Smart Contracts (still limited and costly)

SC's Assessment

- Trust (depends on consensus mechanism, cryptography)
  - "No" power to change or delete previously persisted SC
    - Auditability, traceability for the processing of data of a transaction
- Decentralization (full autonomy)
  - No single instance controls the processing of a SC
    - Immutability, no single-point-of-failure
- Integrity (one important facet of security)
  - State of SC and processing results cryptographically secured
- Costs
  - Depend on the SC (code and run-time information)
- Legal relevance of "coded", more general contracts?

The Seven Comparative Dimensions (1)

	Public Permissionless	Public Permissioned	Private Permissionless	Private Permissioned
Scalability	Public usage → **size growth hard to be controlled**	Only selected nodes create blocks → **more control over size**	Blockchain designed for specific use case → **controlled size**	Blockchain designed for specific use case → **controlled size**
Data Storage	Not designed as DB → **High fees, size is limited**	Know writers → **No fees, no size limit**	Know participants → **Low fees, partial size limit**	Know writers → **No fees, no size limit**
Sustainability	PoW → **computational power has no "social benefit"**	PoA → **Sustainable, no significant computations**	PoS → **Sustainable, no significant computations**	PoA → **Sustainable, no significant computations**
Identity Management	Pseudo-anonymity, data visible → **Hard to link to physical user, data encryption**	Data is supposed to be visible → **Ensuring integrity**	Know participants → **Trusted environment**	Know participants → **Trusted environment**

The Seven Comparative Dimensions (2)

	Public Permissionless	Public Permissioned	Private Permissionless	Private Permissioned
Standardization	No standard → **Complex Interoperability**	No standard → **Complex Interoperability**	No standard → **Complex Interoperability**	No standard → **Complex Interoperability**
Trust	Data in the BC → **Trusted** Input data → **Untrusted**	Know writers → **Trusted**	Know participants → **Trusted Environment**	Know participants → **Trusted Environment**
Economics and Regulations	No clear regulations → **"Gray area"**	No clear regulations → **"Gray area"**	Regulated by participants → **Defined rules**	Regulated by participants → **Defined rules**

BC Advantages and Drawbacks

Selection only!

Characteristics	Advantages	Drawbacks	Remarks
Distributed	No central control, no “master” needed	No central control, no “master” exists	Censorship vs. conflict resolution!
Unknown stakeholders	Everyone can participate	Lacking control of participants’ “writes”	Application-specific needs
Open, transparent	No hiding possible	Stakeholders’ activities publicly viewable	Application-specific needs
Immutable	Once persisted, persisted forever	Wrongly deployed SC(s) not retractable	Realistic for “useful” SCs? GDPR?
Append-only	No deletions	Growing in size	GDPR compliance?
Traceable	Proof of actions	No hiding of actions	Error handling?
Technical aspect	Effective	Efficiency, energy dem.	Sustainability?
Economic aspect	Cryptocurrency (fully elect., decen.)	Impacts on economic stability, currencies, …	Survivability of too many “tokens” or “coins”?
Legal aspect	Contracts without intermediary	“Unknown” conflict resolution instance(s)	No jurisdictional borders, enforceability?

20. Challenges and Risks

Public Blockchain Challenges!

Selection only!
Solutions seem possible

- How to handle reliably tangible (non-digital) assets in BC?
  - A token is represented in bits vs. property/real estate as physical items
- Sustainability: Energy efficiency of consensus mechanisms?
  - Energy consumption Bitcoin BC only in 2018 ≈ The Netherland‘s production
- Scalability: BC throughput as a number of transactions per second, volume of data persisted in Mega (?) bytes, costs?
  - *E.g.*, BC sizes grow faster than the density of HDDs/SSDs
  - BC (always) better than a (distributed) data base? Exorbitant costs?
- Identity management (users, objects) and anonymity
- Standardized APIs for switching BCs for BC-based dApps
  - *E.g.*, in contrast, databases from different vendors offer “similar” APIs
- Many economic effects of BC-based cryptocurrencies unknown
  - Role of national “e”-currency, interrelationships of about 2100+ cryptocurr.
- Legal/regulative compliance, societal/governmental acceptance

Public Blockchain Risks!

Selection only!
Fundamental concerns

- BCs' "true semantics" depend on the input received!
- BCs' security, privacy, and reliability
  - Unknown attack vectors (& 51% attack), Programming errors in SCs
  - Alternative consensus mechanisms beyond PoW? Security at stake?
  - The breaking of currently used security algorithms
    - Long-term storage? Quantum Computing impacts?
  - Privacy: persisted data at stake? GDPR?
    - The right to forget vs. immutability
    - Transparency (public knowledge of BC) vs. privacy (private data)

GDPR: General Data Protection Regulation

- Networking infrastructure's reliability (critical infrastructures)
  - Lacking Internet connectivity for a "longer" period of time?
- Economic/legal risks (cryptocurrency/tokens/coins, BC)
  - Fraudulent profitability projections, volatility, dispute resolutions, no central entity or simply a central Customer Relationship Management

Private Blockchain Risks? Challenges?

Selection only!
Real needs?

- How to handle reliably tangible (non-digital) assets in BC?
  - A token is represented in bits vs. property/real estate as physical items
- Sustainability: Energy efficiency of consensus mechanisms!
  - Known stakeholders' tx persisting based on round-robin schemes
- Scalability: BC throughput as a number of transactions per second, volume of data persisted in "any" volume
  - *E.g.*, BC sizes grow faster than the density of HDDs/SSDs
  - BC (always) better than a (distributed) data base?
- Service offered: trusted third party time stamping service
  - Cryptographically sealing electronic data with a tamperproof digital signature and BC timing information (well known from the past)
- BCs' security, privacy, and reliability
  - Depending on known stakeholders' agreements (like within today's IT)
  - With a very different trust model as compared to public BCs

Broader Challenges? Risks?

- Discontinuation of “cash” and replacement with a cryptocurrency – loss of any anonymity?
- Cryptocurrencies only – failure of energy supply? Sustainability? Payments made with empty battery?
  - On-the-spot payments? Input channels are “delicates”
- Decentralization of token handling – full control of the individual? No central “CRM” for sure

  CRM: Customer Relation Management
  - Full decentralization today impossible, thus, “central” players
- Reliability of IT systems – here “billions” of handhelds are part of the game? BYOD?

  BYOD: Bring Your Own Device
  IF: Interfaces
  - Different OSes? Different HW? Hundreds of applications? IF?

21. Expected Impacts and Conclusions

Application Trade-offs

- Trade-offs based on technical BC characteristics
  - Distributed vs. centralized control
    - No central authority (PoW) or trusted nodes (PBFT)
  - Performance vs. reliability
    - BC offers slow throughput but more robustness than traditional DBs
  - Privacy vs. transparency
    - More transparency (trust) and less confidentiality
- Limited storage
- “Unknown” regulations
  - Different countries, different regulations
- Lack of standards
  - Blockchain 4.0 target

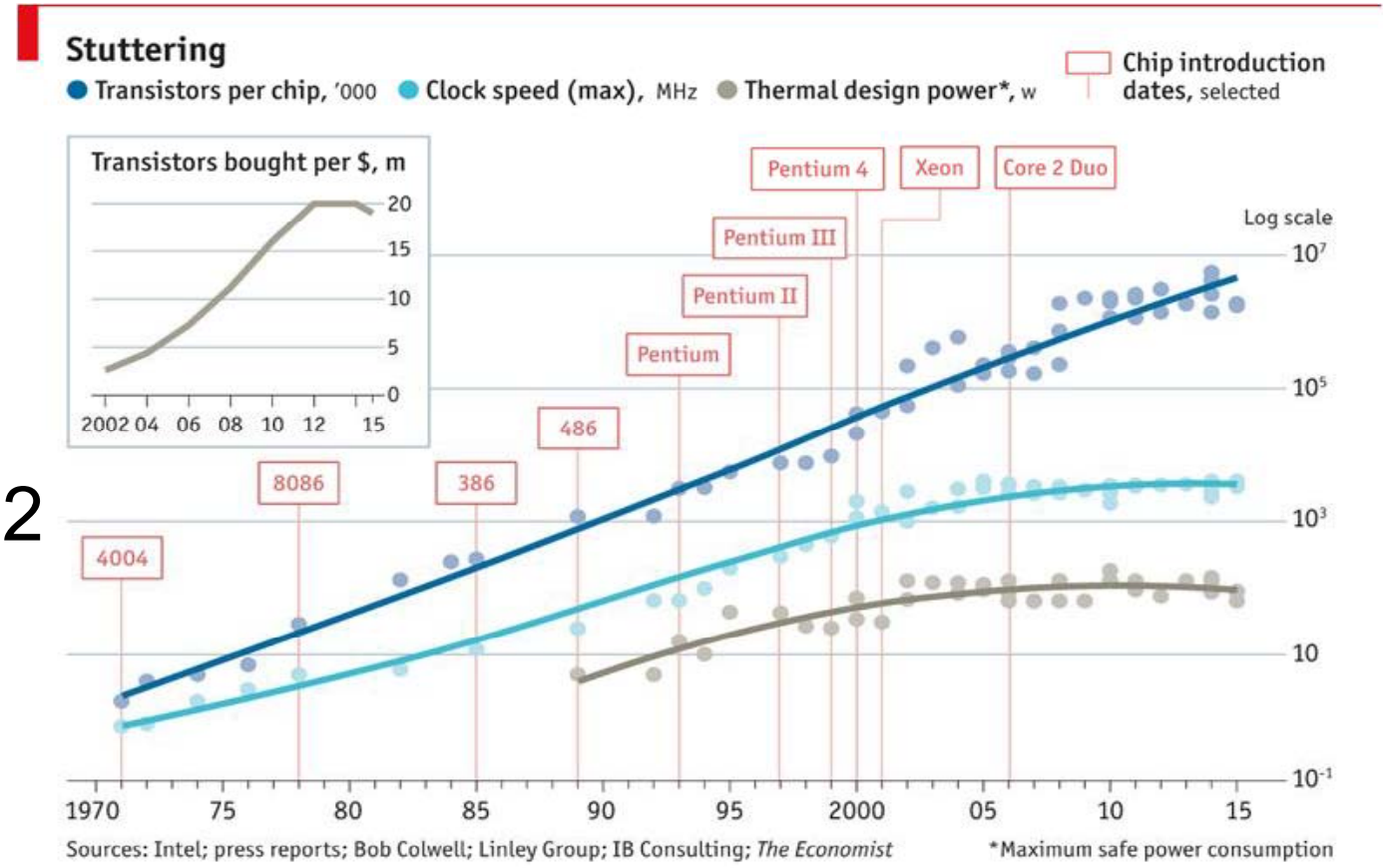
B. Rodrigues, T. Bocek, B. Stiller: The Use of Blockchains: Application-Driven Analysis of Applicability; in: P. Raj, G. Deka (Edt.), "Blockchain Technology: Platforms, Tools and Use Cases, Volume 111 (Advances in Computers)", Springer, Waltham, MA, U.S.A, No. 111, September 2018, pp 163–198

General Technology Trends (1)

- Moore's Law: The number of transistors doubles every 18 month

- Hard to maintain, likely to end in 2021/22

- Processing, hashing limited?

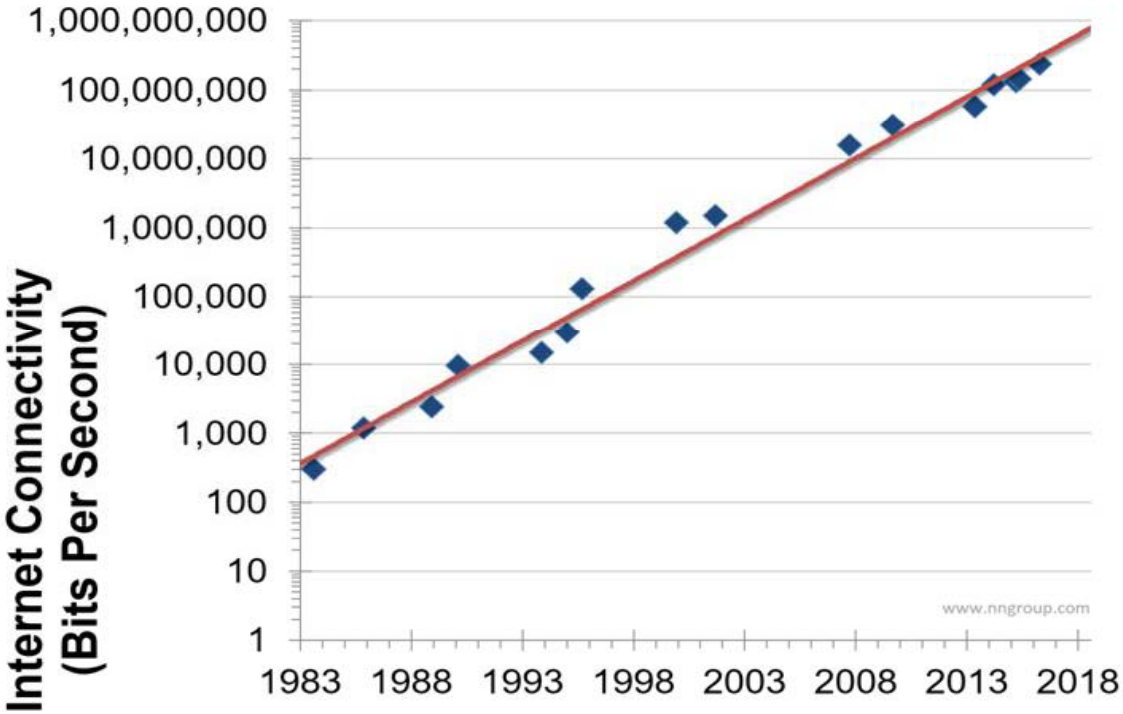


https://www.techrepublic.com/article/moores-law-dead-in-2021-heres-what-the-next-revolution-will-mean/

General Technology Trends (2)

- Nielsen's Law: A high-end user's connection speed grows by 50% per year

- However, bandwidth grows slower than compute power
  - Zmap completes scan of IPv4 address space in under 5 min



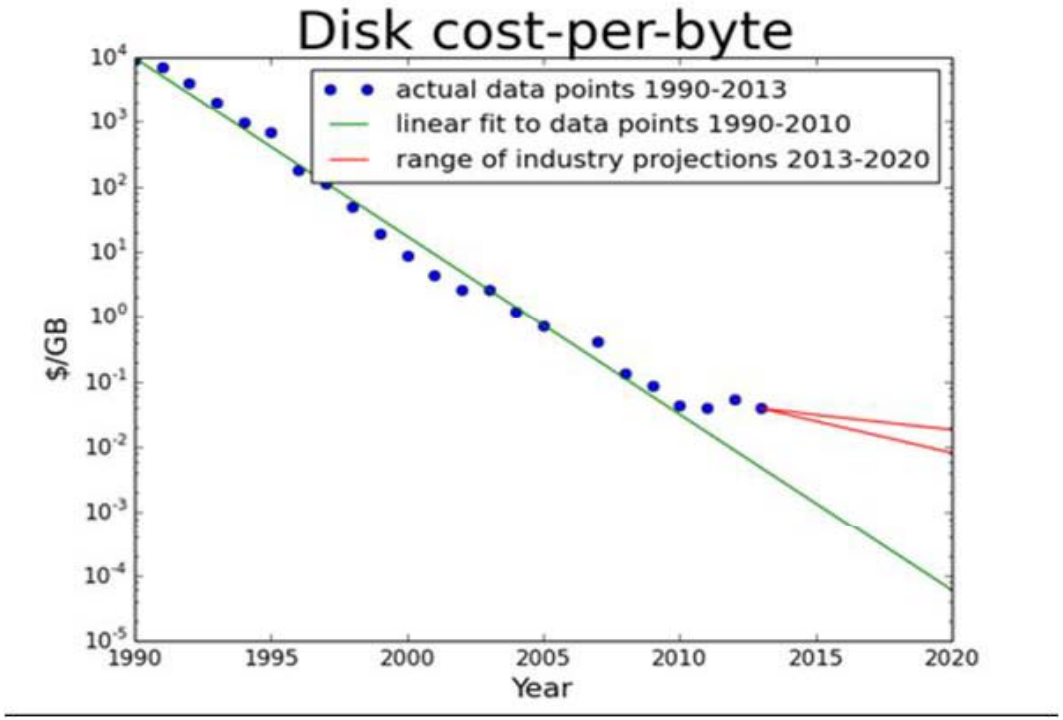
https://zmap.io/

https://www.nngroup.com/articles/law-of-bandwidth/

General Technology Trends (3)

- Kryder's Law: Disk density doubles every 13 month
- «Soon hard drives will migrate into phones, still cameras, PDAs, cars and everyday appliances»

https://www.scientificamerican.com/article/kryders-law/, August 2005



http://blog.dshr.org/2016/05/the-future-of-storage.html

- User behavior changes
  - SSD, speed is important
  - Clouds: *e.g.*, Dropbox
  - Streaming: *e.g.*, Spotify

Development Trends (2019/2020)

- Libraries and developers
  - Redundant development efforts led the push toward libraries
    - Libp2p: Modular P2P networking stack (used by IPFS and others)
    - Matrix.org: Open standard for secure, interoperable, decentralized real-time E2E encrypted communications
    - OpenZeppelin: Establishing Ethereum SC security best-practizes via open-source, modular, security-focused Ethereum SCs and SDKs
- Programming languages
  - Shift from Go to Rust: Open-source Systems Programming Language initialized by Mozilla
    - Designed toward reliability and efficiency (memory usage, ownership)
  - WebAssembly (Wasm) as compilation target (W3C)
    - Low-level binary instruction format for stack-based Virtual Machines

General Observations

- Distributed apps show a larger coordination effort

- Blockchain's cost/benefit perspective (incentives)
  - Costs: "known" in advance (*e.g.*, HW, VM, network, setup, or fees)
  - Benefits: less central infrastructure plus "unknown" soft factors

- Once risks are mitigated and legal/regulatory constrains are known, applications may benefit from blockchains
  - Addressing value destruction problems
  - ICO vs. traditional emission rules
  - Country-specific rules and handling will become obstacles

- Dedicated applications maintaining inherently digital assets do show a much larger (disruption) potential
  - Solving the "media break" may increase this potential

Conclusions (1)

1. Blockchains ***do*** show a logical evolution of linked lists, however, public BCs "exaggerate" processing demands
   - By design: Proof-of-Work (PoW), but this ensures immutability

2. Blockchains ***do not*** have a relevant impact on general networking, however, "unreliable" networks do have an impact on the BC
   - Especially in case of longer outages

Modulo "measurable" effects, but at no impact

3. Blockchains ***do not*** have a relevant impact on Distributed Systems, however, the full decentralization is (very) costly (PoW) or still not secure (other Po"X")
   - Especially (in case of PoW) BC-related energy demands

Conclusions (2)

4. Blockchains ***do not*** solve the media break, thus, leading to a lack of trust for tangible assets, key: trust in "sensor"
   - Major trust model differences for public vs. private blockchains

5. The technical future of blockchains is still based on ***security ingredients*** of today's technology, however, long-term security management is key
   - "Unknown" impact of quantum computing (certainly on all IT!)

6. Blockchains show ***no revolution***, but a typical Computer Science (Abstract Data Type) **evolution** of linked lists
   - But "distribution" of consensus ***does not always*** make sense
     - Any system as of the past has ***not*** been replaced fully by a BC

Selected References (1)

- A. Antonopoulos: *Mastering Bitcoin – Unlocking Digital Cryptocurrencies;* O'Reilly, Sebastopol, California, U.S.A., 2015
- T. Bocek, B. Rodrigues, T. Strasser, B. Stiller: *Blockchains Everywhere - A Use-case of Blockchains in the Pharma Supply Chain;* IFIP/IEEE International Symposium on Integrated Network Management (IM 2017), Lisbon, Portugal, May 2017
- T. Bocek, B. Stiller: *Smart Contracts - Blockchains in the Wings;* in: Claudia Linnhoff-Popien, Ralf Schneider, Michael Zaddach (Edts.) "Digital Markets Unleashed", Springer, Germany, 2016
- C. Chinchilla (Edts.): *A Next-Generation Smart Contract and Decentralized Application Platform;* Ethereum White Paper, June 2019, https://github.com/ethereum/wiki/wiki/White-Paper
- M. Herlihy: *Blockchains from a Distributed Computing Perspective;* ACM CCR, Vol. 62, No. 2, February 2019
- S. Nakamoto: *Bitcoin: A Peer-to-Peer Electronic Cash System;* https://bitcoin.org/bitcoin.pdf, 2009
- A. Narayanan, J. Bonneau, E.W. Felten, A. Miller, S. Goldfeder, J. Clark: *Bitcoin and Cryptocurrency Technologies;* Princeton University Press, July 19, 2016, http://bitcoinbook.cs.princeton.edu/
- M.E. Peck: *Do You Need a Blockchain?* IEEE Spectrum, September 29, 2017, https://spectrum.ieee.org/computing/networks/do-you-need-a-blockchain

Selected References (2)

- S. Rafati, L. Pelloni, S. Wullschleger, A. Schaufelbühl, T. Bocek, B. Stiller, L. Rajendran: *A Blockchain-based Scientific Publishing Platform*; IEEE International Conference on Blockchains and Cryptocurrencies (ICBC 2019), Seoul, South Korea, May 2019
- B. Rodrigues, B. Stiller: *Cooperative Signaling of DDoS Attacks in a Blockchain-based Network*; ACM SIGCOMM 2019, Demo, Beijing, China, August 2019
- E. Scheid, T. Hegnauer, B. Rodrigues, B. Stiller: *Bifröst: a Modular Blockchain Interoperability API*; 44th Conference on Local Computer Networks (LCN 2019), Osnabrück, Germany, October 2019
- N. Szabo: *Smart Contracts: Building Blocks for Digital Markets;* http://www.fon.hum.uva.nl/rob/Courses/InformationInSpeech/CDROM/Literature/LOTwinterschool2006/szabo.best.vwh.net/smart_contracts_2.html,1996
- D. Tapscott, A. Tapscott: *Blockchain Revolution;* Portfolio/Penguin, 2016
- B. Rodrigues, T. Bocek, B. Stiller: *The Use of Blockchains: Application-Driven Analysis of Applicability*; in: Pethuru Raj, Ganesh Deka (Edts.), "Blockchain Technology: Platforms, Tools and Use Cases", Volume 111 (Advances in Computers), Springer, Waltham, MA, U.S.A, No. 111, September 2018
- T. Spies: *Blockchain Mechanics;* http://slideplayer.com/slide/11374043/
- A. Welfare: *Commercializing Blockchains – Strategic Applications in the Real World,* John Wiley & Sons Ltd., Chichester, West Sussex, U.K., 2019
- K. Wüst, A. Gervais: *Do you need a Blockchain?* Crypto Valley Conference on Blockchain Technology (CVCBT 2018), Zug, Switzerland, June 2018

Thank you for your attention!
Good luck at the test(s).

End of Day 2:
Blockchain Platforms and Architectures