CS251 Fall 2020

(cs251.stanford.edu)

Ethereum: mechanics

Dan Boneh

Note: HW#2 is posted on the course web site. Due Oct. 12.

Limitations of Bitcoin

Recall: UTXO contains (hash of) ScriptPK

- simple script: indicates conditions when UTXO can be spent

Limitations:

- Difficult to maintain state in multi-stage contracts
- Difficult to enforce global rules on assets

A simple example: rate limiting. My wallet manages 100 UTXOs.

- Desired policy: can only transfer 2BTC per day out of my wallet

An example: NameCoin

Domain name system on the blockchain: [google.com → IP addr]

Need support for three operations:

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

Note: also need to ensure no front-running on **Name.new**()

A broken implementation

Name.new() and Name.upate() create a UTXO with ScriptPK:

DUP HASH256 <OwnerAddr> **EQVERIFY CHECKSIG**
VERIFY <NameCoin> <DomainName> <IPaddr> <1>

only owner can "spend" this UTXO to update domain data

Contract: (should be enforced by miners)

> if domain google.com is registered,
> no one else can register that domain

Problem: this contract cannot be enforced using Bitcoin script

What to do?

NameCoin: fork of Bitcoin that implements this contract

(see also the handshake project)

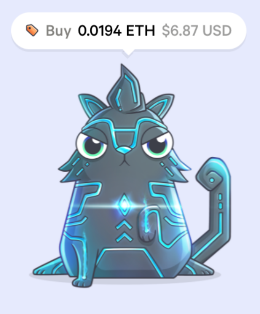
Can we build a blockchain that natively supports generic contracts like this?

$\Rightarrow$ Ethereum

Ethereum: enables many applications

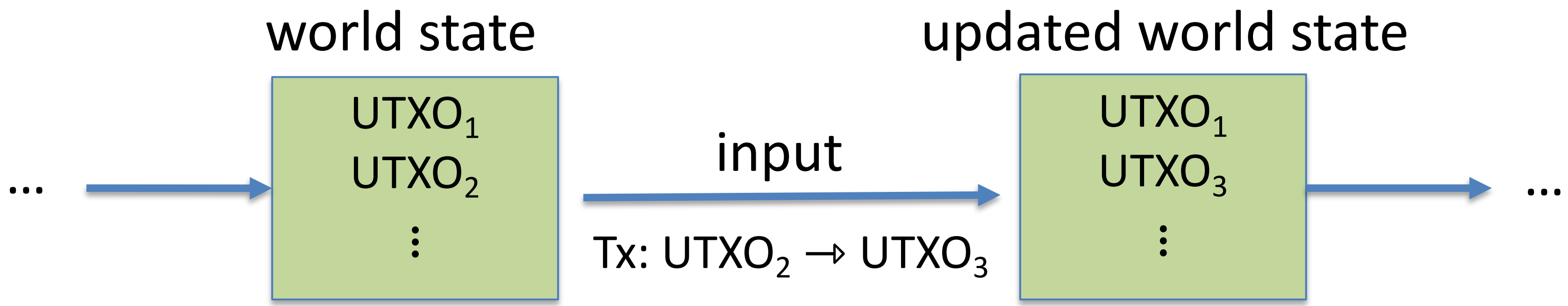
About 3000 Ethereum Decentralized Apps (DAPPs)

- New coins: ERC-20 interface to DAPP
- DeFi: exchanges, lending, stablecoins, derivatives, etc.
- Insurance
- Games: assets managed on chain (e.g. CryptoKitties)
- Managing distinguished assets (ERC-821)



stateofthedapps.com, dapp.review

Bitcoin as a state transition system



Bitcoin rules: $\boxed{F_{bitcoin} : S \times I \to S}$

S: set of all possible world states, $s_0 \in S$ genesis state

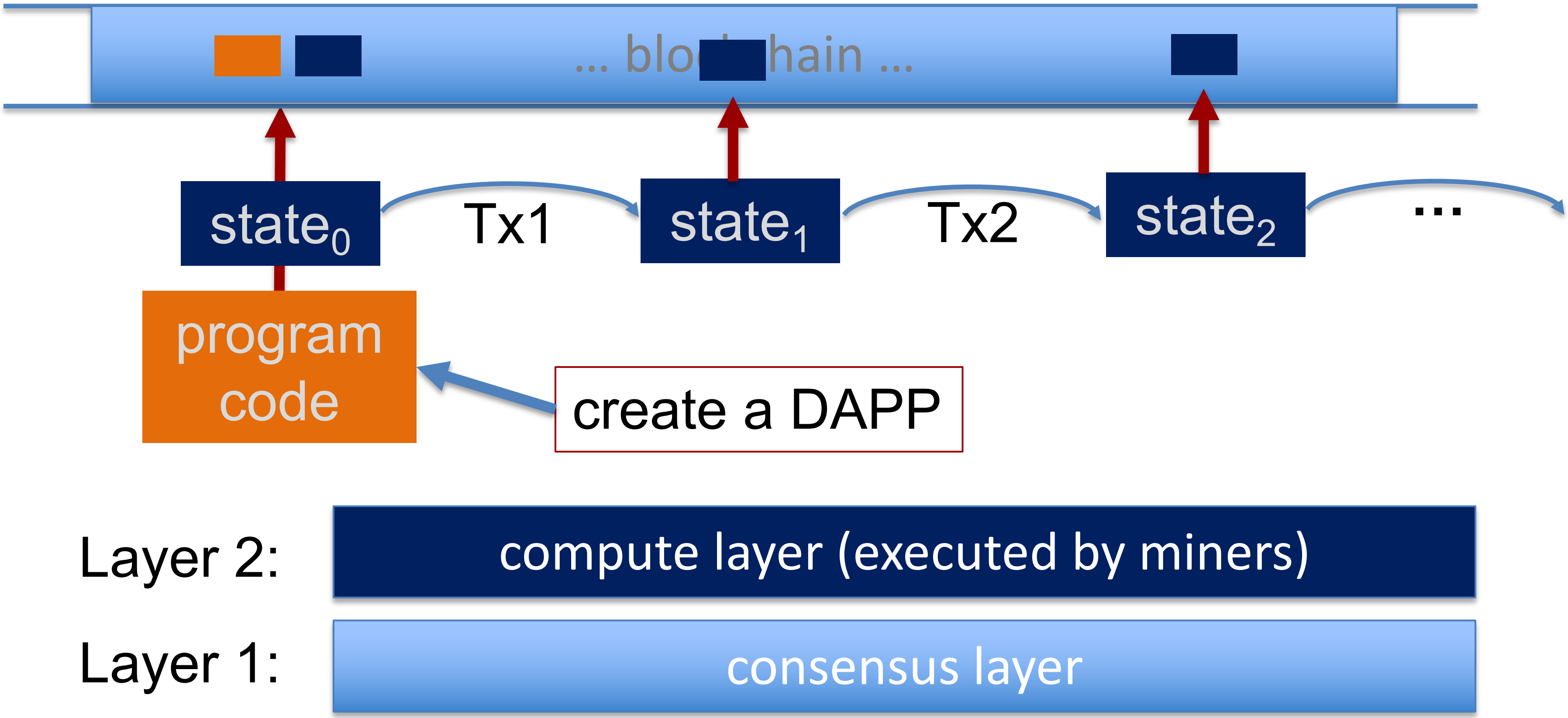
I: set of all possible inputs

Ethereum as a state transition system

Much richer state transition functions

⇒ one transition executes an entire program

Running a program on a blockchain (DAPP)



The Ethereum system

Layer 1: PoW consensus. Block reward = 2 ETH + Tx fees (gas)

Latest Blocks

Bk	10991728 43 secs ago	Miner BTC.com Pool 168 txns in 18 secs
Bk	10991727 1 min ago	Miner zhizhu.top 152 txns in 30 secs
Bk	10991726 1 min ago	Miner Spark Pool 203 txns in 14 secs
Bk	10991725 1 min ago	Miner F2Pool 131 txns in 6 secs
Bk	10991724 1 min ago	Miner 0x6ebaf477f83e05558… 119 txns in 0 secs
Bk	10991723 2 mins ago	Miner Ethermine 131 txns in 48 secs

avg. block rate = 15 seconds.

(variant of Nakamoto)

about 150 Tx per block.

Ethereum Layer 1.5: compute layer

World state: set of accounts identified by 160-bit address.

Two types of accounts:

(1) owned accounts: controlled by ECDSA signing key pair (PK,SK).

SK known only to account owner

(2) **contracts**: controlled by code.

code set at account creation time, does not change

Data associated with an account

Account data	Owned	Contracts
address (computed):	H(PK)	H(CreatorAddr, CreatorNonce)
code:	$\perp$	CodeHash
storage root (state):	$\perp$	StorageRoot
balance (in Wei):	balance	balance $(10^{18}$ Wei = 1 ETH)
nonce:	nonce	nonce

(#Tx sent) + (#accounts created): anti-replay mechanism

Account state: persistent storage

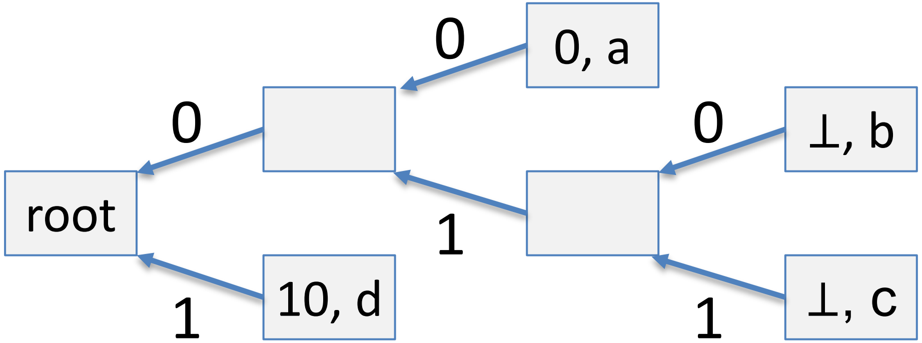
Every contract has an associated **storage array S**[]:

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

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

- Cannot compute full Merkle tree hash: 2^{256} leaves

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



time to compute root hash:
$\leq 2 \times |S|$

|S| = # non-zero cells

State transitions: Tx and messages

Transactions: signed data by initiator

- **To:** 32-byte address of target (0 → create new account)
- **From**, **Signature**: initiator address and signature on Tx
- **Value**: # Wei being sent with Tx
- **gasPrice, gasLimit**: Tx fees (later)
- if To = 0: create new contract **code = (init, body)**
- if To ≠ 0: **data** (what function to call & arguments)
- **nonce**: must match current nonce of sender (prevents Tx replay)

State transitions: Tx and messages

Transaction types:

owned $\rightarrow$ owned: transfer ETH between users

owned $\rightarrow$ contract: call contract with ETH & data

Example (block #10993504)

From		To	msg.value	Tx fee (ETH)
0xa4ec1125ce9428ae5…	→	0x2cebe81fe0dcd220e…	0 Ether	0.00404405
0xba272f30459a119b2…	→	Uniswap V2: Router 2	0.14 Ether	0.00644563
0x4299d864bbda0fe32…	→	Uniswap V2: Router 2	89.839104111882671 Ether	0.00716578
0x4d1317a2a98cfea41…	→	0xc59f33af5f4a7c8647…	14.501 Ether	0.001239
0x29ecaa773f052d14e…	→	CryptoKitties: Core	0 Ether	0.00775543
0x63bb46461696416fa…	→	Uniswap V2: Router 2	0.203036474328481 Ether	0.00766728
0xde70238aef7a35abd…	→	Balancer: ETH/DOUGH…	0 Ether	0.00261582
0x69aca10fe1394d535f…	→	0x837d03aa7fc09b8be…	0 Ether	0.00259936
0xe2f5d180626d29e75…	→	Uniswap V2: Router 2	0 Ether	0.00665809

Messages: virtual Tx initiated by a contract

Same as Tx, but no signature (contract has no signing key)

contract → owned: contract sends funds to user

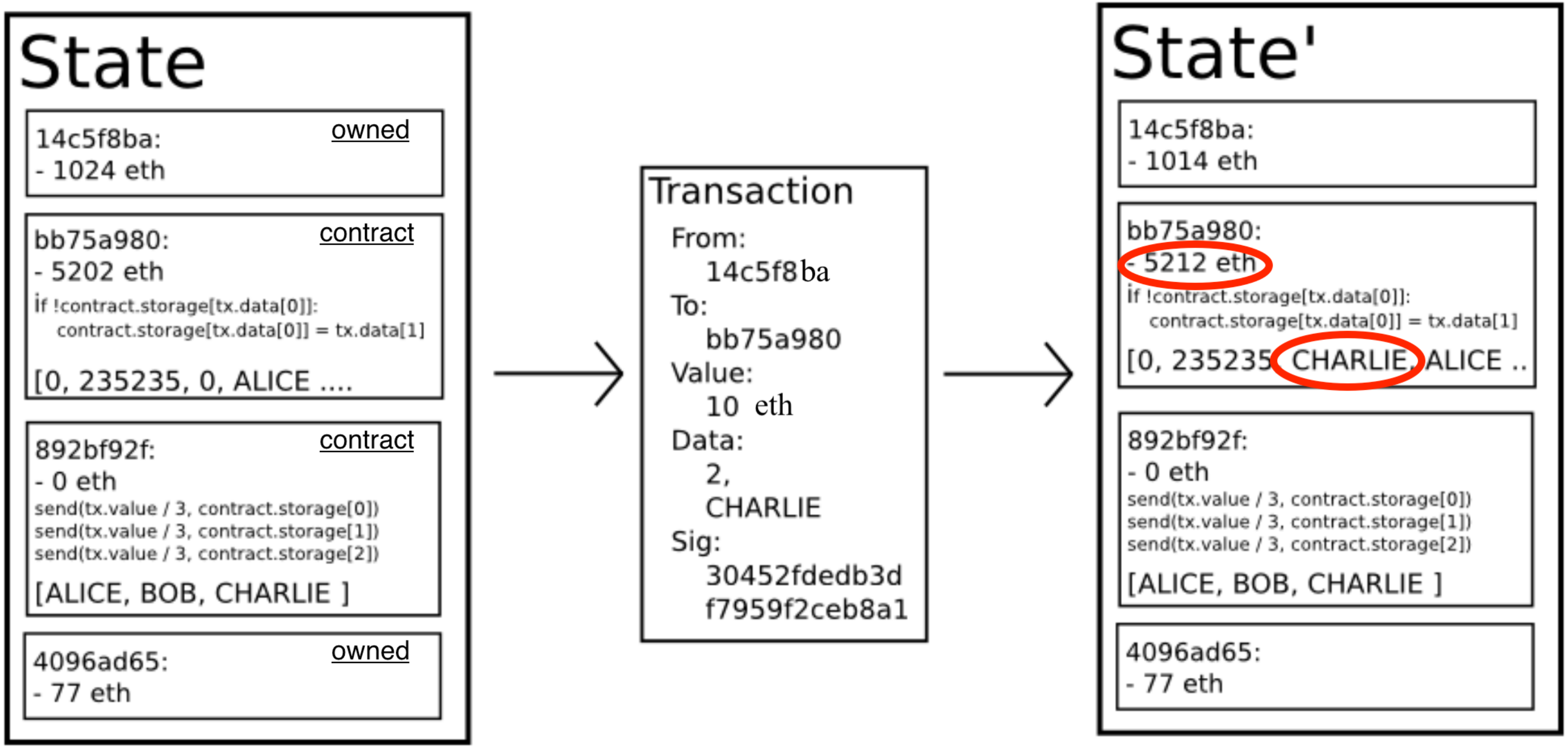
contract → contract: one program calls another (and sends funds)

One Tx from user: can lead to many Tx processed. Composability!

Tx from owned addr → contract → another contract

another contract → different owned

Example Tx



world state (four accounts)

An Ethereum Block

Miners collect Txs from users $\Rightarrow$ leader creates a block of n Tx

- Miner does:
  - for i=1,…,n: execute state change of Tx_i

    (can change state of >n accounts)
  - record updated world state in block

Other miners re-execute all Tx to verify block

- Miners should only build on a valid block
- Miners are not paid for verifying block (note: verifier’s dilemma)

Block header data (simplified)

(1) consensus data: parent hash, difficulty, PoW solution, etc.

(2) address of gas beneficiary: where Tx fees will go

(3) world state root: updated world state

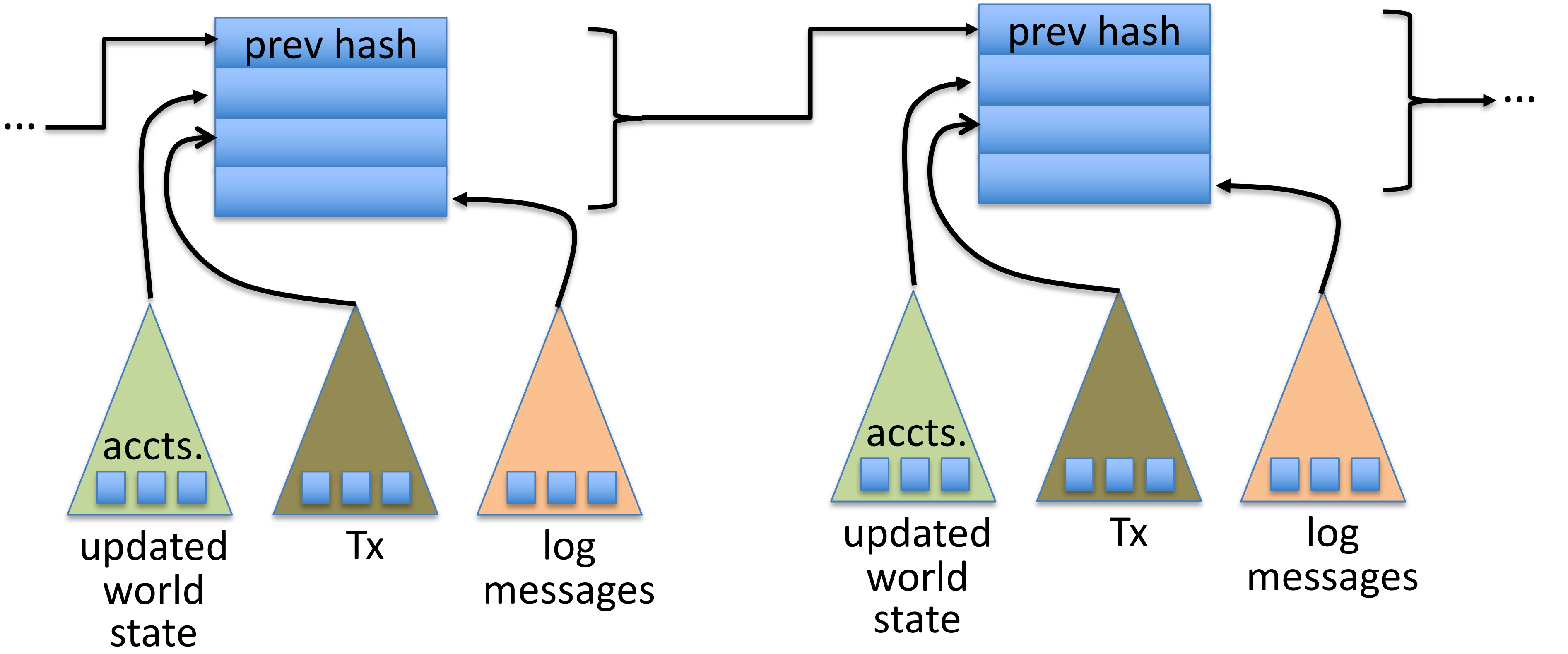
Merkle Patricia Tree hash of <u>all</u> accounts in the system

(4) **Tx root**: Merkle hash of all Tx processed in block

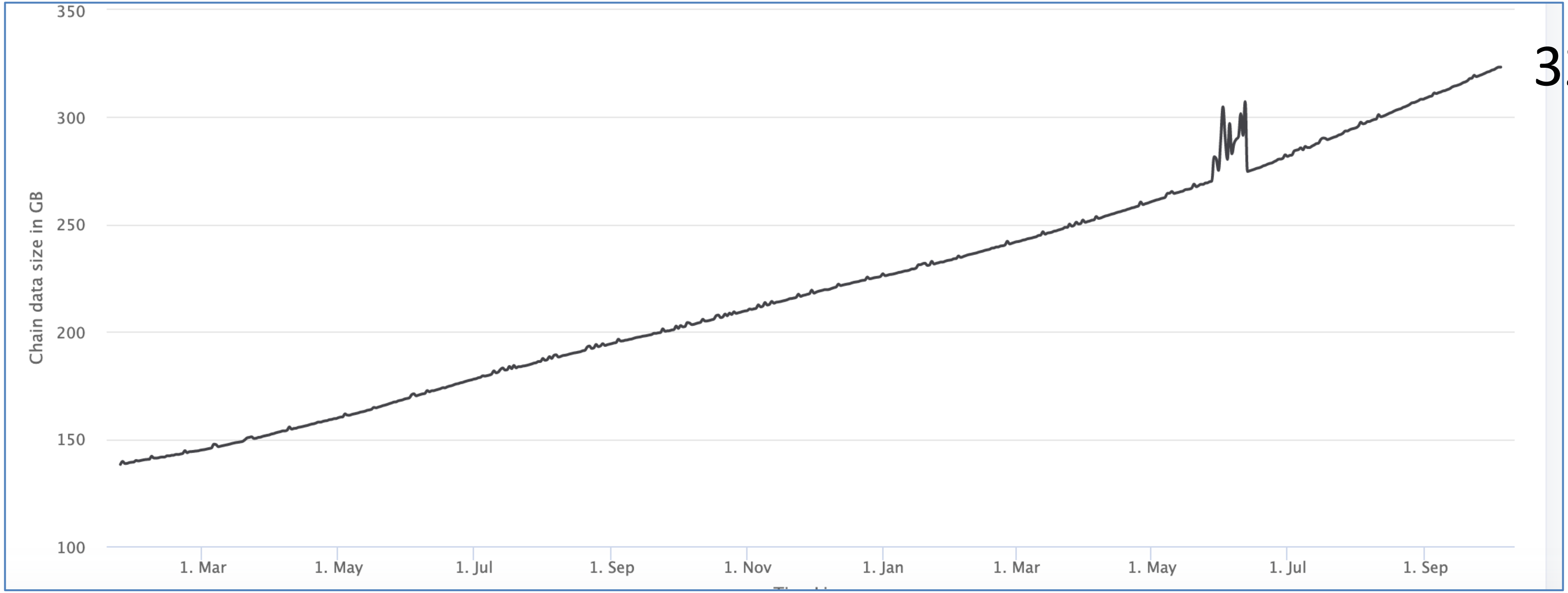
(5) **Tx receipt root**: Merkle hash of log messages generated in block

(5) Gas used: tells verifier how much work to verify block

The Ethereum blockchain: abstractly



Amount of memory to run a node (in GB)



323GB

ETH total blockchain size: 5.2 TB (Oct. 2020)

An example contract: NameCoin

```
contract nameCoin {        // Solidity code   (next lecture)

    struct nameEntry {
        address owner;     // address of domain owner
        bytes32 value;     // IP address
    }

    // array of all registered domains
    mapping (bytes32 => nameEntry)  data;
```

An example contract: NameCoin

```
function nameNew(bytes32 name) {

    // registration costs is 100 Wei

    if (data[name] == 0   &&   msg.value >= 100) {
        data[name].owner = msg.sender    // record domain owner
        emit Register(msg.sender, name)   // log event
}}
```

Code ensures that no one can take over a registered name

An example contract: NameCoin

```
function nameUpdate(
        bytes32 name, bytes32 newValue, address newOwner) {

  // check if message is from domain owner,
  //          and update cost of 10 Wei is paid

  if (data[name].owner == msg.sender   &&   msg.value >= 10) {

      data[name].value = newValue;        // record new value

      data[name].owner = newOwner;        // record new owner
}}}
```

An example contract: NameCoin

```
    function nameLookup(bytes32 name) {
        return data[name];
    }

} // end of contract
```

EVM mechanics: execution environment

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

⇒ compile to EVM bytecode

(recent projects use WASM or BPF bytecode)

⇒ miners use the EVM to execute contract bytecode
in response to a Tx

The EVM

Stack machine (like Bitcoin) but with JUMP

- max stack depth = 1024
- program aborts if stack size exceeded; miner keeps gas
- contract can create or call another contract

In addition: two types of zero initialized memory

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

Gas prices: examples

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

- zero → non-zero: 20,000 gas
- non-zero → non-zero: 5,000 gas
- non-zero → zero: 15,000 gas refund

SUICIDE: kill current contract. 24,000 gas refund

Refund is given for reducing size of blockchain state

Gas calculation

Tx fees (gas) prevents submitting Tx that runs for many steps

Every EVM instruction costs gas:

- Tx specifies **gasPrice**: conversion: gas → Wei

  gasLimit: max gas for Tx

Gas calculation

Tx specifies **gasPrice**: conversion gas → Wei

gasLimit: max gas for Tx

(1) if **gasLimit** × **gasPrice** > msg.sender.balance: abort

(2) deduct **gasLimit** × **gasPrice** from msg.sender.balance

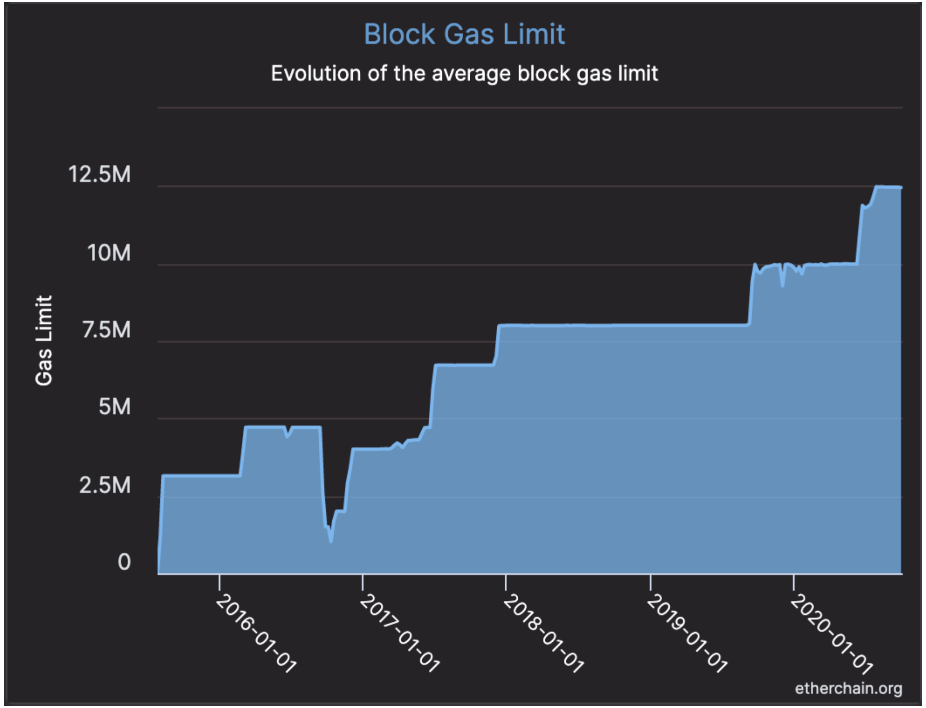
(3) set Gas = gasLimit

(4) execute Rx: deduct gas from Gas for each instruction

if (Gas < 0): abort, miner keeps **gasLimit** × **gasPrice**

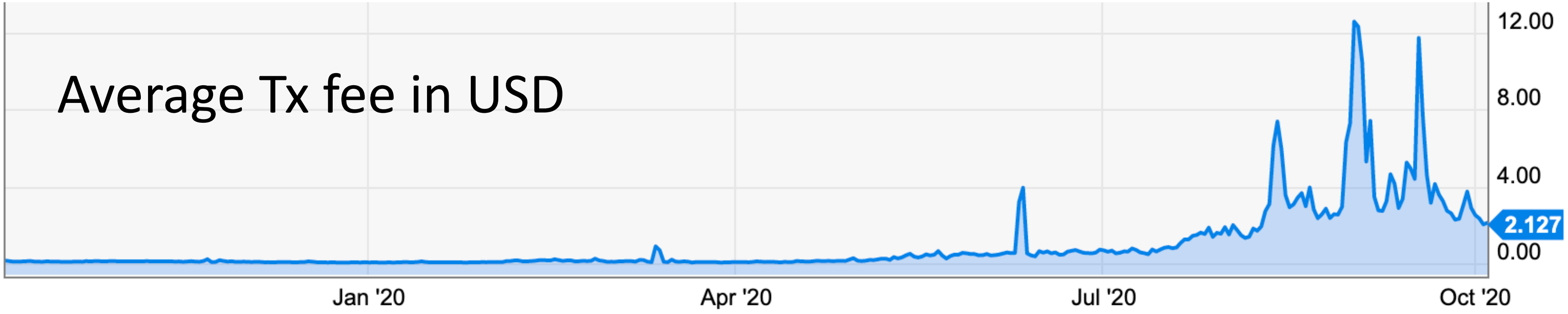
(5) Refund **Gas** × **gasPrice** to msg.sender.balance

Transactions are becoming more complex



GasLimit is increasing over time ⇒ each Tx takes more instructions to execute

Gas prices: spike during congestion



END OF LECTURE

Next lecture: writing Solidity contracts