

Admin:

- Project proposal deadline (Friday) is only nominal.
(not enforced - get it in when you can)
- Recitation? - online / in-person / cancelled (vote)
- Classes - not held next week
 - online after Spring Break (Quiz? project presentations?)
 - follow announcements for details
- Today - lecture videotaped & posted (as Monday)
in password-protected section (student / yak20bug)
- Let us know if we can help...

Today:

E-cash & bitcoin

Representing value: bits vs. atoms

Gold atoms: unforgeable & scarce

"ownable"

transferable (multiple times
one after another)

decentralized

divisible & combinable

anonymous

Bits: Easy to generate bits (dig. sigs?)

Easy to copy

⇒ double spending!!

Need "accounts" to prevent/detect
double-spending

accounts may be centralized
or decentralized (bit coin)

transferable (≠ checks)

divisible & combinable

not as anonymous (PK=identity)

Electronic Checks

With TTP (trusted-third party = bank):

Bank has PK_B, SK_B

User has PK_u, SK_u

certificate on PK_u (signed by B)

Check = cert on PK_u signed by B

↖ ("Pay PK_v \$100, date, serial #)
↙ signed by U

Bank processes check once (ser # prevents replay = double spending)

Usual problem: overdraft

Privacy: Bank & Merchant know exact details

Bank maintains transaction history & accts

Coins vs Checks

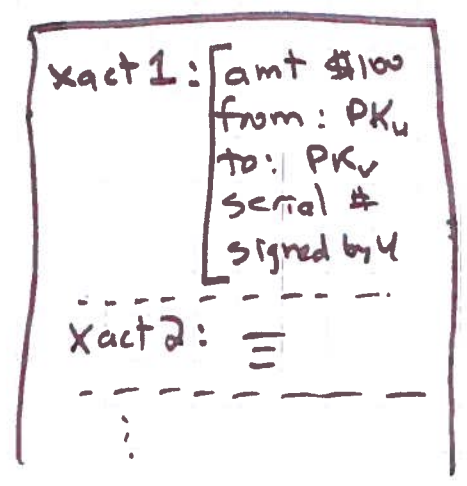
Coin: bit string signed by bank \equiv coin
"blindly"

bank can recognize coin when deposited

Checks: Replace bank B by "public ledger"
(append-only log of xacts)

IDs are just PKs, not more
(\rightarrow anonymous, pseudonymous)

Ledger =



ledger = entire state of system!

where do accts get value?

Anyone can check that xact is valid

Public Ledger:

Centralized or decentralized?

Who can read?
write? (create xact
add to ledger)

[Decentralized public ledger is key
Bitcoin contribution

Bitcoin (Nakamoto 2009)

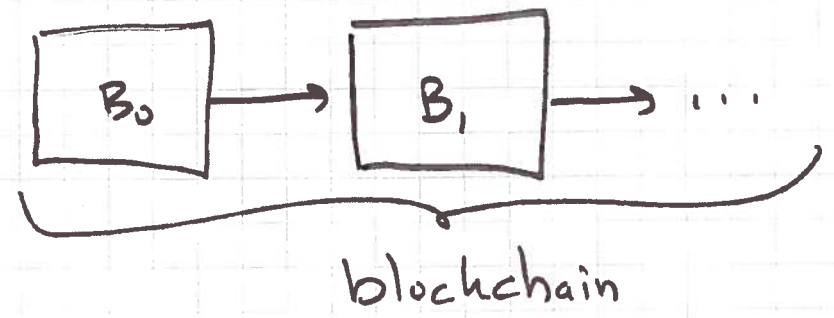
Public ledger records all transactions

Decentralized maintenance of ledger

based on POW to validate blocks

put on the "block chain" (ledger)

Uses bitcoin to incentivize maintenance



Block chain

6

Each block contains:

- hash of previous block (to "chain")
- PK of creator (x "miner") (really $H(pk)$)
- nonce (for puzzle - see later)
- Transactions:

① coinbase = fee to creator = 12.5 ₿

② Merkle tree of transactions

Each transaction has

inputs: block & output #
where created (or coinbase)
with sigs

outputs: PKs (actually hashes)
of recipients,
with amounts

Value (inputs) \geq Value (outputs)

Inputs not previously spent

Input sigs valid

Change \Rightarrow miner as xact fee

Communications Network

- Anyone (with bitcoins) can propose a transaction for inclusion in public ledger.
- Transaction is only valid if it is on ledger.
- Blocks distributed to other nodes via a "gossip" protocol.
- New blocks posted about 1 / ten-minutes.
- If network partitioned, can be lack of consensus as to what is current state of blockchain.
- Even if no partition, several nodes may propose what should be "next" block on blockchain.
Bitcoin provides a distributed consensus protocol
(perhaps its biggest contribution)

Consensus Protocol

Consensus via race to solve block puzzle first

"nonce" is solution to puzzle if

$$H(\text{block}) \leq 2^{256-d}$$

↑ includes block header, nonce,

$H(\text{PK}(\text{miner}))$, Merkle root of txs

$d \approx 74.5$ now (e.g. start with 74 "0" bits)

Takes about 2^d tries to find a good nonce.

d adjusted so soln found about every 10 minutes

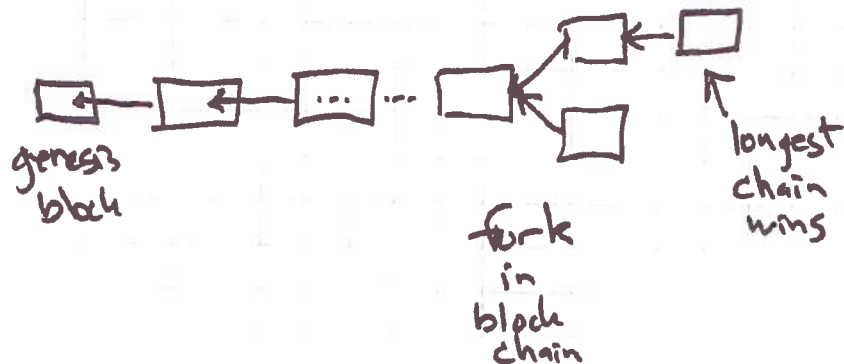
"POW" = proof of work

Prob (good guys find soln first)

= % of hash power owned by good guys

Once a solution is found, it is broadcast.

All other nodes work to extend longest blockchain



Hash power & 51% attack

Let p = prob honest node finds next block

q = "malicious" " " " "

g_z = " " miner will overtake main chain if it starts z nodes behind

$$= \begin{cases} 1 & \text{if } q \geq p \\ \left(\frac{q}{p}\right)^z & \text{if } q < p \end{cases}$$

e.g. $\left(\frac{0.49}{0.51}\right)^{144} = 0.003148$

"wait 6 blocks" (one hour) to "confirm payment received"

Mining Pools

Many miners combine forces to even out variance in payments.

Make "pay to" for coinbase = mining pool operator
Can show "POW" for "almost solns" to pool operator

Reward split among pool miners according to work done

Bitcoin (In)efficiency

- Ledger getting big (197GB)
- Electricity use 500 kWh/transaction
total \approx Bangladesh
0.25% of all electricity
- Time to "settle"
one hour?
more? (Latency)
- Throughput
VISA 5000/sec
Bitcoin 5/sec

Variations & Extensions

"Side chains"

"smart contracts"

"anonymity & Zcash"

algorand (Micali) - not POW

"Proof of stake" (more generally)

Probabilistic payments?

memory-hard POW