Kinds of Internet payments

- Credit/debit cards: most popular
  - Wide adoption among consumers, little consumer fraud liability
  - Restrictive merchant procedures
- PayPal
  - Easier to accept payments
  - Centrally managed to deal with fraud

One ideal: electronic cash

- Direct transactions without third party
- No transaction fees
- Potentially anonymous
- Non-revocable: buyer bears fraud risk

Micropayments

- Claim: what the web needs is small payments to support content
  - Too small for existing mechanisms
- One idea (Peppercoin): simulate small payment with small probability of larger payment
- Actual market for micropayments has been small
  - Most buyers and sellers prefer free + other revenue

Blinded signatures

- Sign something without knowing its value
  - Often used together with randomized auditing
  - For RSA, multiply message by \( r^e \), \( r \) random
- Allows a bank to “mint” coins that can still be anonymous
**Challenge: double spending**

- Any purely electronic data can be duplicated, including electronic money
- Can’t allow two copies to both be spent
- Shows ideal no-third-party e-cash can’t be possible

**Puzzles / proof-of-work**

- Computational problem you solve to show you spent some effort
- Common: choose \( s \) so that \( h(m || s) \) starts with many 0 bits
- For instance, required solved puzzles can be a countermeasure against DoS

**Hashcash and spam**

- Idea: use proof of work to solve email spam problem
- Puzzle based on date and recipient
- Legitimate users send only a few messages
  - Problem 1: mailing lists
  - Problem 2: spam botnets
- Never caught on

**Hash trees and timestamp services**

- Merkle tree: parent node includes hash of children
- Good hash function → root determines whole tree
- Can prove value of leaf with log-sized evidence
- Application: document timestamping (commitment) service

**Outline**

- Previous e-cash and techniques
- Bitcoin design
- Announcements
- Bitcoin experience

**Bitcoin addresses**

- Address is basically a public/private signing key pair
  - Randomized naming, collision unlikely
- At any moment, balance is a perhaps fractional number of bitcoins (BTC)
- Anyone one can send to an address, private key needed to spend
Global transaction log

Basic transaction: Take $x_1$ from $a_1$, $x_2$ from $a_2$, ..., put $y_1$ in $a'_1$, $y_2$ in $a'_2$, ...

- Of course require $\sum_1 x_i = \sum_1 y_i$
- Keep one big list of all transactions ever
- Check all balances in addresses taken from are sufficient

Bitcoin network

- Use peer-to-peer network to distribute transaction log
- Roughly similar to BitTorrent, etc. for old data
- Once a node is in sync, only updates need to be sent
- New transactions sent broadcast

Consistency and double-spending

- If all nodes always saw the same log, double-spending would be impossible
- But how to ensure consistency, if multiple clients update at once?
- Symmetric situation: me and “me” in Australia both try to spend the same $100 at the same time

Bitcoin blocks

- Group ~10 minutes of latest transactions into one “block”
- Use a proof of work so creating a block is very hard
- All nodes race, winning block propagates

Bitcoin blockchains

- Each block contains a pointer to the previous one
- Nodes prefer the longest chain they know
- E.g., inconsistency usually resolved by next block

Regulating difficulty

- Difficulty of the proof-of-work is adjusted to target the 10 minute block frequency
- Recomputed over two-week (2016 block) average
- Network adjusts to amount of computing power available
**Bitcoin mining**

- Where do bitcoins come from originally?
- Fixed number created per block, assigned by the node that made it
- Incentive to compete in the block generation race
- Called *mining* by analogy with gold

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**Group project presentations**

- Start next week, run three lectures
- Plan 15 minute presentation plus up to 5 minutes Q&A
- One student per group presents
- Slides, BYO laptop recommended

**December dates**

- Final project progress reports due Friday 12/4
- Malware analysis guest lecture Wednesday 12/9
- Exercise set 5 due Thursday 12/10
- Project final reports due Wednesday 12/16

**TCP congestion control**

- Congestion control is a voluntary mechanism
- Forge reset packets to misbehaving hosts?
  - Used in reality for other sorts of misbehavior
- Blacklist misbehaving addresses
  - Can be misused by a dishonest adversary
  - Note: MAC spoofing is local-net only

**Seeding a PRNG**

- Entropy required for unpredictability
- Black-box attacks easy, reverse engineering also possible
- Bad ideas:
  - `time()`
  - Process ID
  - Time XOR PID
- How to do better?
Outline

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Where Bitcoin came from

- Paper and early implementation by Satoshi Nakamoto
  - Generally presumed to be a pseudonym
- "Genesis block" created January 2009
  - Containing headline from The Times (of London) about a bank bailout

Current statistics

- Block chain 386,300 blocks, ~55GB
- 14.9M BTC minted (many presumed lost)
- Theoretical value at market exchange rate > $5 billion
- Millions of addresses, probably many fewer users
- Mining power: 560 petahash/sec

What can you buy with Bitcoin?

- Random stuff from many small online retailers
- Novelty/trials of some in-person purchases
- Donations to like-minded non-profits
- Illegal drugs (Silk Road successors)
- Murder for hire: currently probably a fraud

Bitcoin as a currency

- Can be exchanged for dollars, etc.
  - Currently pretty cumbersome
- In some ways more like gold than fiat currencies
  - No central authority
  - Price changes driven more by demand than supply
- Exchange rate trend: volatile, recently modestly up

Deflation and speculation

- Some people want bitcoins to spend on purchases
  - Demand based on "velocity"
  - Supply does not keep up with interest
  - So, value of 1 BTC has to go up
- Others want bitcoins because they think the price will go up in the future
  - Self-fulfilling prophecy
  - But vulnerable to steep drops if expectations change
Bitcoin mining trends
- Exponentially increasing rates
- CPU → GPU → FPGA → ASIC
- Specialized hardware has eclipsed general purpose
  - Including malware and botnets
- Recent price trends suggest continuing investment

Enforcing consistency
- Structure of network very resistant to protocol change
  - Inertia of everybody else’s code
- Changes unpopular among miners will not stick
- Minor crisis March 2013: details of database lock allocation cause half of network to reject large block

Scaling Bitcoin
- Current most pressing limitation: 1MB block size
  - Limits volume of transactions
  - A proposed increase ("BIP 101") is currently under discussion
- Size of block chain
  - Compare growth to external storage cost/GB
  - Fewer and fewer users keep the whole chain anyway

Speed of confirmation
- When is it safe to know you have received money?
  - Safe answer: wait for several blocks
  - Too slow for, say, in-person transactions
  - Much faster: wait for transaction to propagate
    - Basic rule: precedence by order seen

Stealing bitcoins
- Bitcoins are a very tempting target for malware
  - Private keys stored directly on client machines
  - Theft is non-reversible
  - Much easier than PayPal or identity theft
- Standard recommendation is to keep keys mostly offline

Bitcoin (non-)anonymity
- Bitcoin addresses are not directly tied to any other identity
- But the block chain is public, so there’s lots of information
  - E.g., list of largest balances easily collectable
- Real unlinkability is a research topic
Next time

Group project presentations