CSci 5271
Introduction to Computer Security
Day 26: Electronic cash and Bitcoin

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Outline

Previous e-cash and techniques

Bitcoin design

Announcements

Bitcoin experience

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 $h(m \parallel s)$ 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 $\rightarrow$ root determines whole tree
- Can prove value of leaf with log-sized evidence
- Application: document timestamping (commitment) service

Outline

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 $\sum_i x_i = \sum_j y_j$
- 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
- An incentive to compete in the block generation race
- Called *mining* by analogy with gold

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Project progress report #3

- Due tonight
- Should also include sample of report formatting
  - Content can be draft or just progress material
  - Choice of MS Word or LaTeX
  - N.B., format is more dense than typical class report

Group project presentations

- Start next Wednesday, run three lectures
- Plan 10 minute presentation plus say 3 minutes Q&A
- One student per group presents
- Slides, BYO laptop recommended
  - Can send me backup slides (PDF, PPT) night before
  - Let me know if you'd prefer a remote Zoom presentation

Hands-on assignment status

- Current target for VM availability is late tonight
- PDF instructions updated with .4 monitoring interface
- VM-specific detailed instructions posted
- Many groups still haven't registered

Exercise set 4

- Also targeting late tonight for release
- Questions covering the last few course topics

Compensating for late releases

- Staggered due dates planned: 12/8 for Ex. 4, 12/13 for HA, 12/15 for project final report
- Prefer not to extend, lest all the due dates pile up
- Instead, reduce weighting:
  - For each day HA is late (2 already), 1% of HA weight (out of 15) replaced with automatic 100%
  - For each day Ex. 4 is late, 1% of Ex. weight (out of 10, max 4) replaced with automatic 100%

Outline

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

Example statistics (Dec. 2021)

- Block chain 712,038 blocks, ~438GB
- 18.9M BTC minted (many presumed lost)
- Theoretical value at market exchange rate $>$ $1,072 billion
- $>$ 30 million addresses, probably many fewer users
- Mining power: 150 etahash/sec

What can you buy with Bitcoin?

- Stuff from increasingly many online retailers
- In-person purchases, still mostly a novelty
- Ransomware ransoms
- 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 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 $\rightarrow$ GPU $\rightarrow$ FPGA $\rightarrow$ 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

- Most-discussed limitation: block size
  - Long limited to 1MB, currently more like 2MB
  - Limits volume of transactions
  - Trade-offs affect transaction fees and network size
- 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

Zero-knowledge for privacy

- Basic idea: prove this money came from a previous transaction
  - But without revealing which
- Made possible with recent crypto constructions
  - Downsides: still expensive, trusted setup
- Two rounds of academic papers lead to "Zcash"

Different proofs of work

- Desire: avoid centralizing mining in large farms
- Common approach is to make memory rather than computation the limiting factor in cost
  - Similar constructions also used for password hashing
- Some tricky trade-offs, including desire for cheap verification

Smart contracts

- Basically, computer programs that disburse money
  - Idea predates Bitcoin, but it's a natural match
- Bitcoin has a limited programming language
  - Other contenders, such as Ethereum, have a richer one

Smart contracts challenges

- Expensive to run contracts many times (e.g., during mining)
- Code visible, but bugs can't be fixed
  - Hack of high-profile Ethereum "DAO" application lead to a community fork