

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 → root determines whole tree
- Can prove value of leaf with log-sized evidence
- Application: document timestamping (commitment) service

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## 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  $a_2, \dots$ , put  $y_1$  in  $a'_1, y_2$  in  $a'_2, \dots$ 
  - 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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## 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

## Wednesday presentations

1:00 - 1:13 JS API checking (Q)  
1:14 - 1:25 Password models (LMS)  
1:26 - 1:39 Reading CAPTCHAs (NORR)  
1:40 - 1:45 announcements  
1:46 - 1:59 Evil-twin WiFi (CNQT)  
2:00 - 2:13 Password managers (DEK)

## December dates

- Final project progress reports due tonight
- Exercise set 5 due Tuesday 12/12
- Project final reports due Wednesday 12/13

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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 497,498 blocks, ~154GB
- 16.7M BTC minted (many presumed lost)
- Theoretical value at market exchange rate > \$184 billion
- Millions of addresses, probably many fewer users
- Mining power: 11 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 a lot

## 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
  - Several changes that would effectively increase it still being discussed
- 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

## Next time

- Group project presentations