Blockchains & Cryptocurrencies

Introduction

Instructor: Abhishek Jain
Johns Hopkins University - Spring 2021

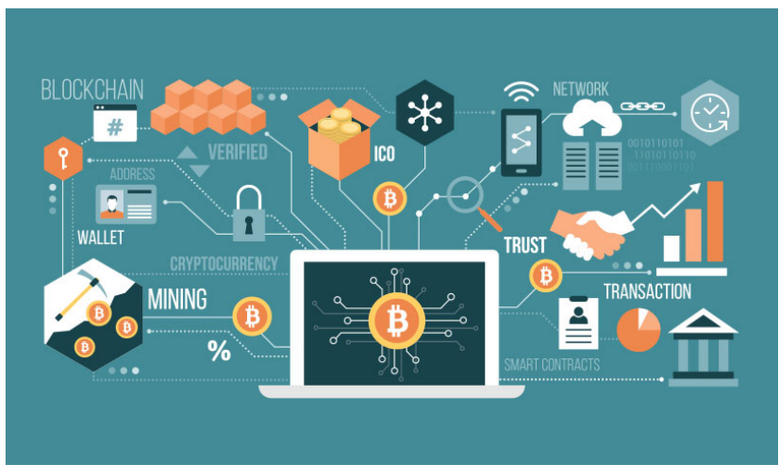
My background

- I work in cryptography
  (mostly, on problems related to computing on private data)

- I'm interested in blockchains because of their potential capabilities

What is a blockchain?

- A specific type of distributed ledger or database ("DLT")
- Used for building decentralized cryptocurrencies such as Bitcoin
- Several other applications such as distributed Domain Name system (DNS), Public-Key Infrastructure (PKI), stock trade database, etc.



Course objectives

- Understanding the mechanics of blockchains and distributed consensus
- Understanding the necessary cryptographic background
- Exploring applications of blockchains to cryptocurrencies and beyond
- Understanding limitations of current blockchains

Course objectives (contd.)

- Introduction to recent exciting research
- **Main course goal: Extend this research**
  - Entrepreneurial or research projects by student teams
  - These can be major projects, or even small applications

Disclaimer

This is not a finance course on cryptocurrencies.
You should not expect to be taught how to
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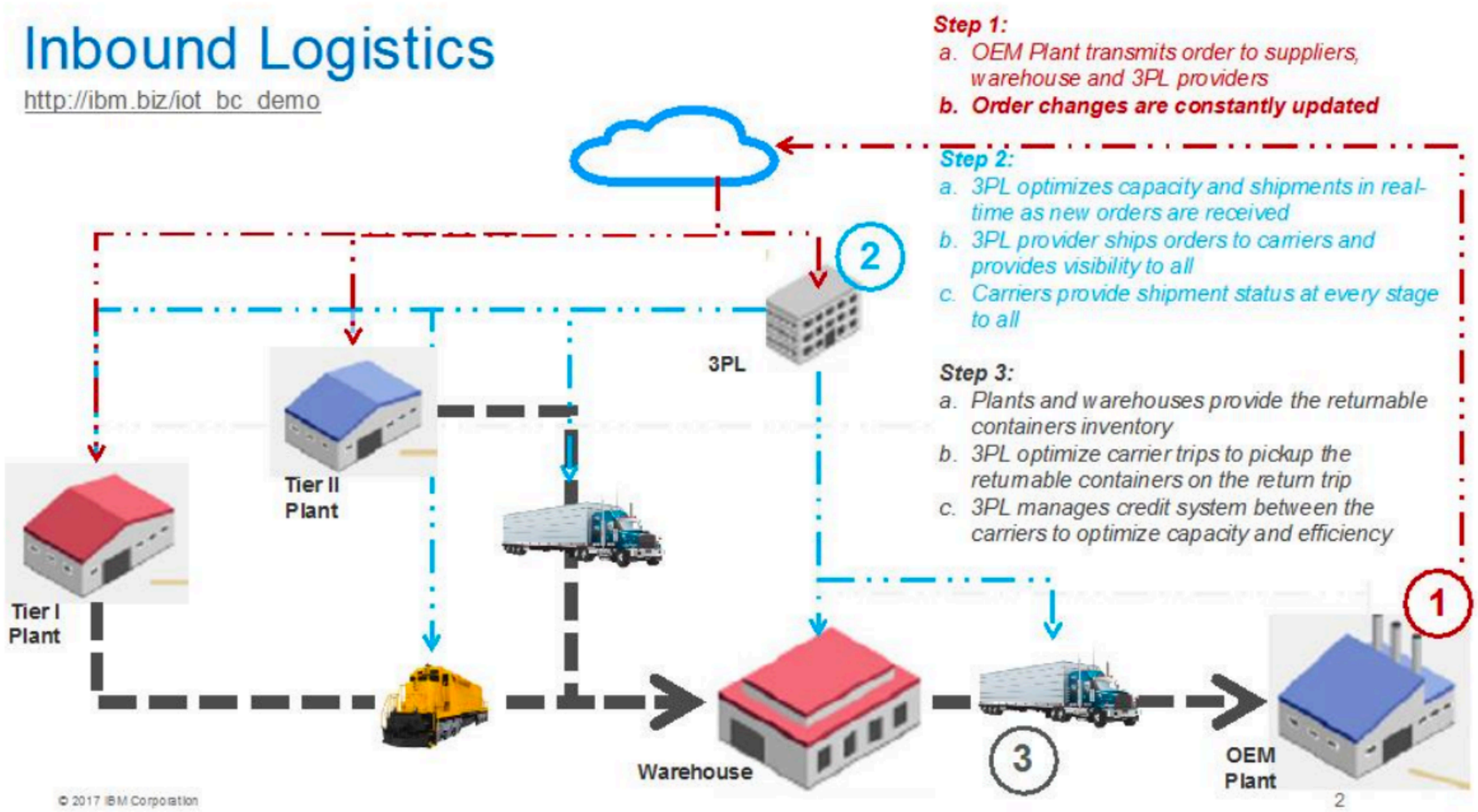
(Unless you're already a billionaire — then we can
certainly help you become a millionaire.)

Pre-requisites

- No background in cryptography is necessary. However, the following are expected:
  - Basic mathematical maturity
  - Comfort with basic probability
  - Basic familiarity with asymptotic (Big-O) notation
  - Programming capability (in Python/Java, etc.)

Boring course logistics



Source: https://www.ibm.com/blogs/internet-of-things/blockchain-automotive-supply-chain/

Resources

- **Course website & syllabus:**

  https://github.com/PratyushRT/blockchainsS21/

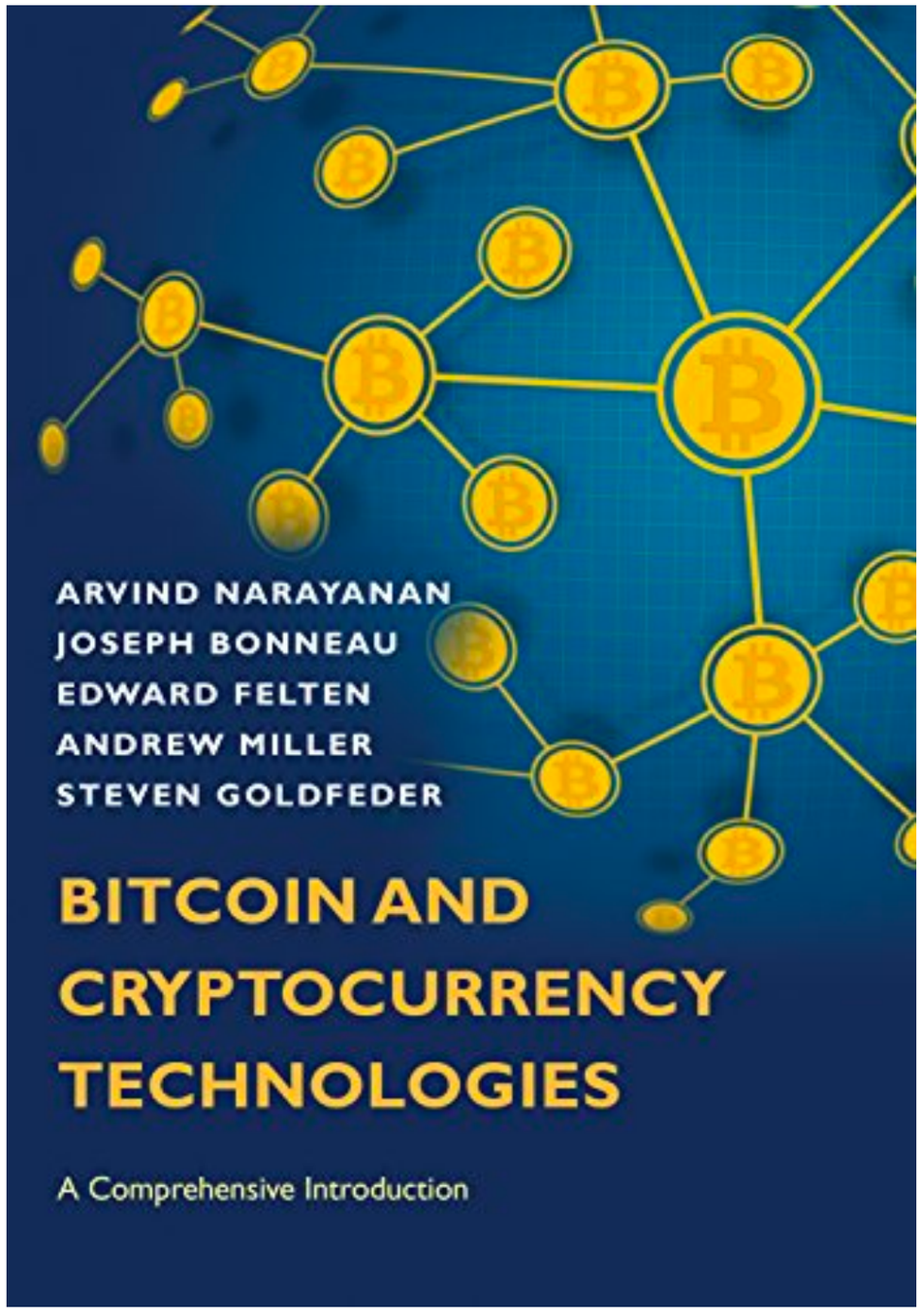
  (Or visit Piazza)

- **Piazza:** piazza.com/jhu/spring2021/601641441

  (Or search for 601.441/641, course title)

Texts/Readings

- **Text:** NBFMG (right)
- However, many readings will be drawn from online papers and resources
- Readings on syllabus are <u>assigned</u> the day they are listed, will be <u>discussed</u> during the following lecture



TA & Office Hours

- **TA:** Pratyush Ranjan Tiwari (ptiwari4@jhu.edu)

TA Office hours: Wed 9:30-10:30am EST

Instructor Office hours:
Tuesday 9:30–10:30am EST

Grading & Exams

- **Grading:**

  10% class participation, 45% assignments,
  45% project

- **Assignments:**

  Written & Programming; submit
  via Gradescope (Entry Code: **BPKGR2**).

Course project

- This is a research-quality project, conducted by groups of 1-3 students. You must have instructor approval for your project topic.

- The project ideas page on the course website will be updated in coming days with a list of themes and topics. If you want to pursue other themes, ask for approval.

- Deliverables: high-quality written report, new software, detailed presentation (choose 2)

- 1-page proposal due 2/28 (Tentative)

Honor Code

- Except where explicitly marked, assignments and exams are individual work. You're expected to do your own work on these. Don't give or receive exam-specific assistance on these.
- See the JHU academic integrity code.
- Exceptions for general-purpose programming advice, etc.
- We hope never to discuss this again.

Honor Code ++, Cryptocurrency edition

- Many legal aspects are unsettled in the blockchain/cryptocurrency space
- E.g., what happens if you discover and exploit a vulnerability in an experimental blockchain project?
- In this course we practice responsible disclosure. If this comes up e.g., in your course project, **see the TA or instructors.**

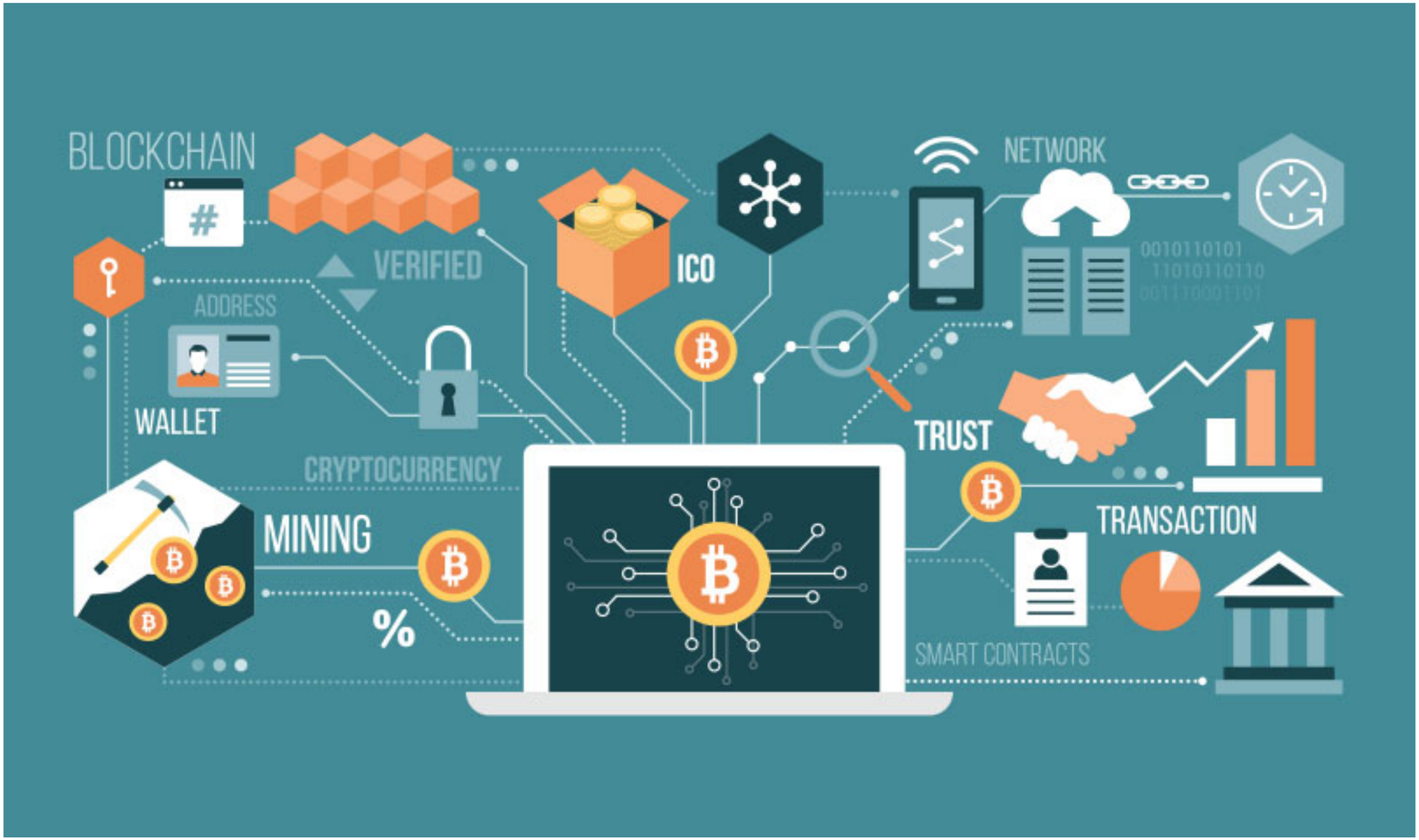
News

- RTFN!
- CoinDesk, CoinTelegraph, etc.
- Twitter: maybe @VitalikButerin, @pwuille, @IOHK_Charles, @iam_preethi, @officialmcafee (for entertainment), @ethereumJoseph, @starkness, @adam3us, etc.
- Lots of currency-specific forum sites, Discords, etc.

Any other questions?

- Ask during class, or send an email to abhishek@cs.jhu.edu or ptiwari4@jhu.edu

Towards blockchains



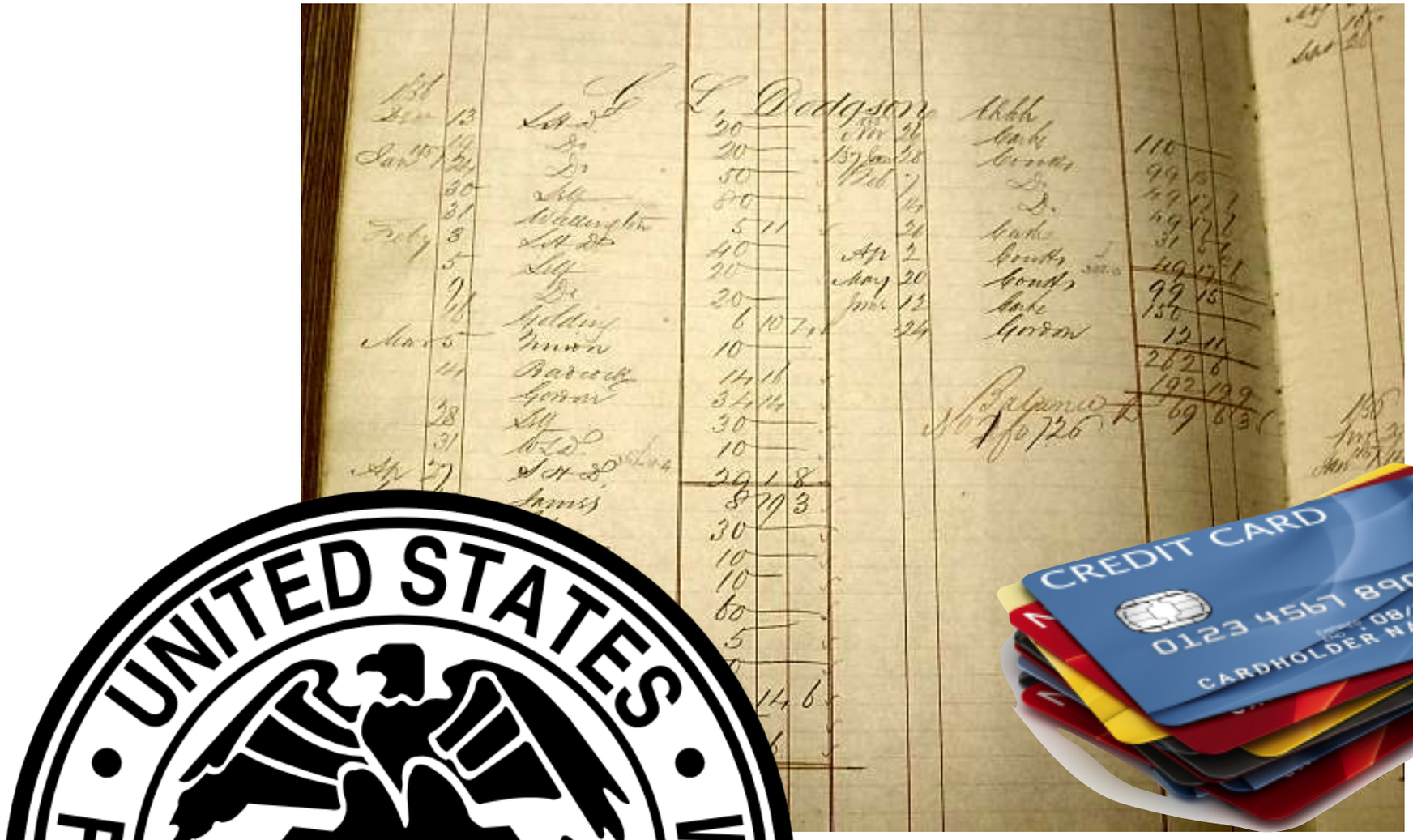
Source: https://www.intheblack.com/articles/2018/03/22/blockchain-future-record-keeping

Cryptocurrencies Aren't 'Crypto'

As the price of Bitcoin and Ethereum skyrocket, and more and more people who are unfamiliar with technology join in the craze, words start to lose their original and correct meaning.

- **Whether you love it or hate it…**
  - Cryptocurrencies are exerting a massive influence on our field
  - Most people's first major exposure to cryptography
  - That's both a good thing and a bad thing
    - The good: we get to deploy some really exciting new cryptography
    - The bad: if you stare into the abyss…

Before blockchains: 1980s-2007




Harrah's Council Bluffs
1 Harrah's Blvd. Council Bluffs, IA 51501
CASHOUT TICKET
VALIDATION 51-3601-7245-2982-3145
07/31/2010 18:13:16 TICKET # 7680
ZERO DOLLARS AND SEVENTEEN CENTS
$0.17
Ticket Void after 90 days ASSET# 1724

1980s: Retail Payments

- **Goal: Digital payment system that**
  - Allows payments between customers and merchants (c2m)
  - Or between individual customers (c2c)
- **Strong cryptographic security**
- **Privacy**

1980s: Retail Payments

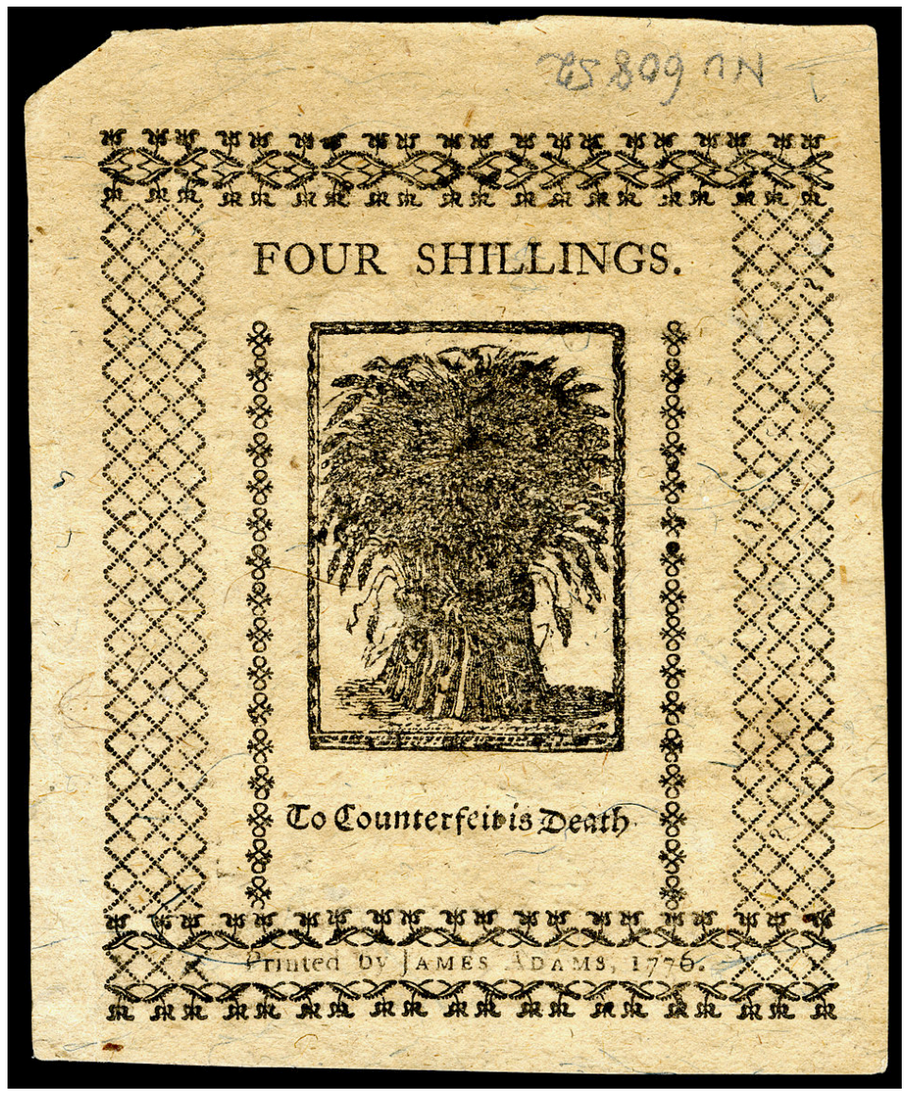
- **Some of the earliest ideas:**
  - Let's make digital cash!
  - Let's make digital checks!

“Digital cash”

- **Some of the earliest ideas:**
  - What’s the problem with the idea of (offline) digital cash?

"Digital cash"

- **Some of the earliest ideas:**
  - What's the problem with the idea of (offline) digital cash?
  - Idea: hardware tokens?

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Experts Videos

$1.5M Robbery of Bellagio Casino Foiled Thanks to RFID Chips

By **Aaron Saenz** - Feb 12, 2011

51,689

If you're thinking of robbing a Las Vegas casino, and you're not George Clooney, I have a word of advice: give up now. As Anthony Carleo recently found out, even if you leave the casino in one piece, the chips you stole are going to be worthless long before you make your get away. The 29 year old suspect is accused of robbing the Bellagio on December 14th of 2010, stealing chips whose face value totaled around $1.5 million dollars. Their real value, however, was zero. Thanks to RFID tags embedded inside them, the chips with denominations of $100 to $25,000 could be immediately deactivated rendering them unredeemable for cash value. Watch CCTV footage from the December 14th robbery in the video clip below, followed by the recent press conference from the Las Vegas Police concerning Carleo's arrest. Stealing worthless chips and then getting caught trying to sell them to undercover officers? Danny Ocean this guy is not.

“Digital cash”

- **Some of the earliest ideas:**
  - BankAmericard (?) ATMs: record debit balance on magstripe
    - Problem?
  - Use offline smartcards to store balances

Source: https://www.elprocus.com/working-of-smart-card/

"Digital checks"

- **Some of the earliest ideas:**
  - Ideas to use smart cards with digital signatures to write IOUs to merchants, who could later redeem them
  - Problem: **double spending**
    - Can spend my whole bank balance at fifty different merchants
    - When they each go to claim the funds, I'm long gone

Summary of problems

- **Double spending**
  - To capture double spending you need an online (networked) party that must be trusted
  - They can attack the system or simply fail
- **Privacy**
  - In many naive systems, the bank sees every transaction you make
- **Origin**
  - How is new currency created?

Centralized electronic $

- Use a centralized bank database ("ledger") to record account balances
  - Require merchants/ATMs to contact the bank for approval
  - Ledger can be "account-based" or "transaction-based"
- Typically it's both, and the two are reconciled

Private e-Cash

- Devised by Chaum, Chaum/Fiat/Naor, Brands, etc.
  - Move to a "cash" model, with added privacy
  - Individuals would carry redeemable tokens
- Reduces the problem to detecting double spending and user privacy

DIGICASH

POWER UP • LOGIN • GAME ON

Chaum (CRYPTO '83)

Payer

σ

(Blind) signature

Bank

sk

pk

Merchant

Redeem/
verify not previously
spent

CHL (Eurocrypt '05)

Payer

$$\sigma K$$

(Blind) signature

sk

Bank

pk

$$SN = PRF(K, i)$$

$$NIZK\ \Pi$$

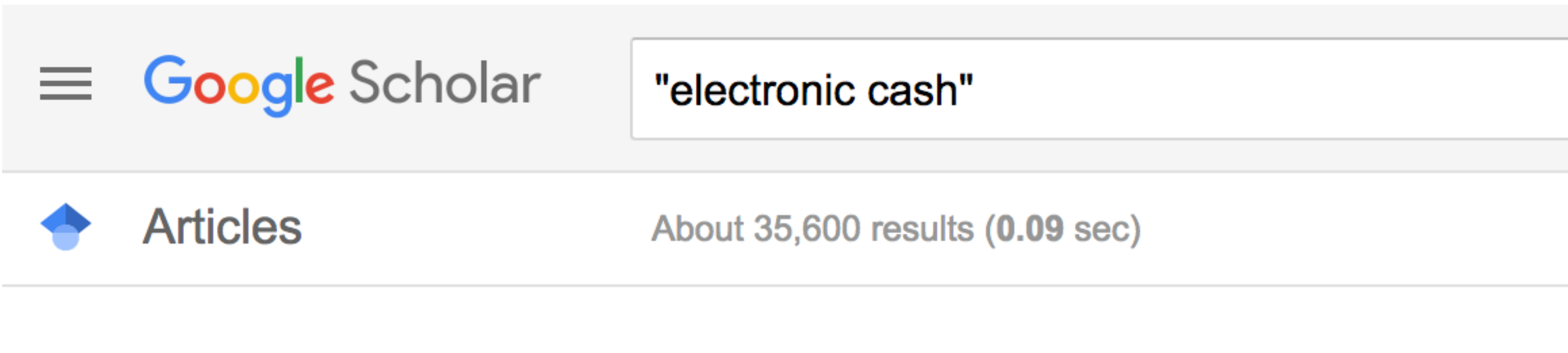
For I = 1 to N

Merchant

Redeem/
verify not previously
spent

e-Cash

- Huge number of academic works / practical improvements
  - Online schemes / offline schemes
    - (Offline required using tamper-resistant storage)
    - Main research problem continued to be privacy



Why did centralized e-Cash fail?

- Deploying e-Cash systems required a centralized bank
  - Required a trusted server with money issuing powers
  - In 1994, EU regulations made this more challenging
- 9/11 and beyond saw closures of *anonymous* currencies (e-Gold and Liberty Reserve)

Why did e-Cash fail? (2)

- Were these technical or policy failures? Maybe both.
- The e-Cash model was centralized and relied on a vulnerable interface with the banking system
- Privacy was (eventually) off the table for regulators
- Any solution would have to work around those (manufactured) technical problems

Conclusions (1980s-2007)

- Most cryptographic solutions too complex, or had "undesirable" features (privacy)
- Commercial solutions (existing credit cards, SET) failed to support the case of person->person transfers
- Web browsers didn't support fancy crypto anyway.
- **We got PayPal**

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  su
- W
  an
- **W**

You can no longer use PayPal

At PayPal, we value a safer community in which our customers can do business. Some of your recent transactions violated our User Agreement and Acceptable Use Policy.

Any bank account or card linked to your PayPal account cannot be removed or used to create a new account. You can still log in and see your account information but you can't send or receive payments. Any money in your balance will be held for 180 days, at which point we'll email you instructions about withdrawing your money.

Reference # PP-005-921-770-133

Continue

The decentralized era (2008 onwards…)

Nakamoto, 2008

- Replace the server with a **distributed** ledger (blockchain)
- Use a new consensus technique to construct the ledger

Nakamoto, 2008

- Replace the server with a distributed ledger (blockchain)
- Use a new consensus technique to construct the ledger
- Use puzzles to handle consensus & generate funds
  [Credit to Dai, (B-Cash) Back (HashCash) etc.]

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Nakamoto, 2008

- Replace the server with a distributed ledger (blockchain)
- Use a new consensus technique to construct the ledger
- Use puzzles to handle consensus & generate funds
- Eliminate the need for explicit key/identity bindings
- Everything else is straightforward crypto and excellent engineering

Lessons of Bitcoin

- Getting the consensus algorithm right makes all the difference

Lessons of Bitcoin

[B]lockchain-style consensus indeed achieves certain robustness properties in the presence of sporadic participation and node churn that none of the classical style protocols can attain.

- Pass, Shi 2018 (also '16, '17, Daian, Pass, Shi '16)

Lessons of Bitcoin

- Using the right consensus algorithm really makes a difference
- **Eliminating the need for key/identity mapping significantly simplifies the currency problem**

Lessons of Bitcoin

- Using the right consensus algorithm really makes a difference
- Eliminating the need for key/identity mapping significantly simplifies the currency problem
- **Human beings are weird**

Lessons of Bitcoin

- U… …nce
- I…
  s…
- I…

This is simultaneously trivial and the most unexpected lesson of the entire cryptocurrency experiment:

People will assign significant value to **meaningless electronic tokens** — *if* you convince them that the tokens are **secure** and have a **predictable supply.**

Limitations of Bitcoin

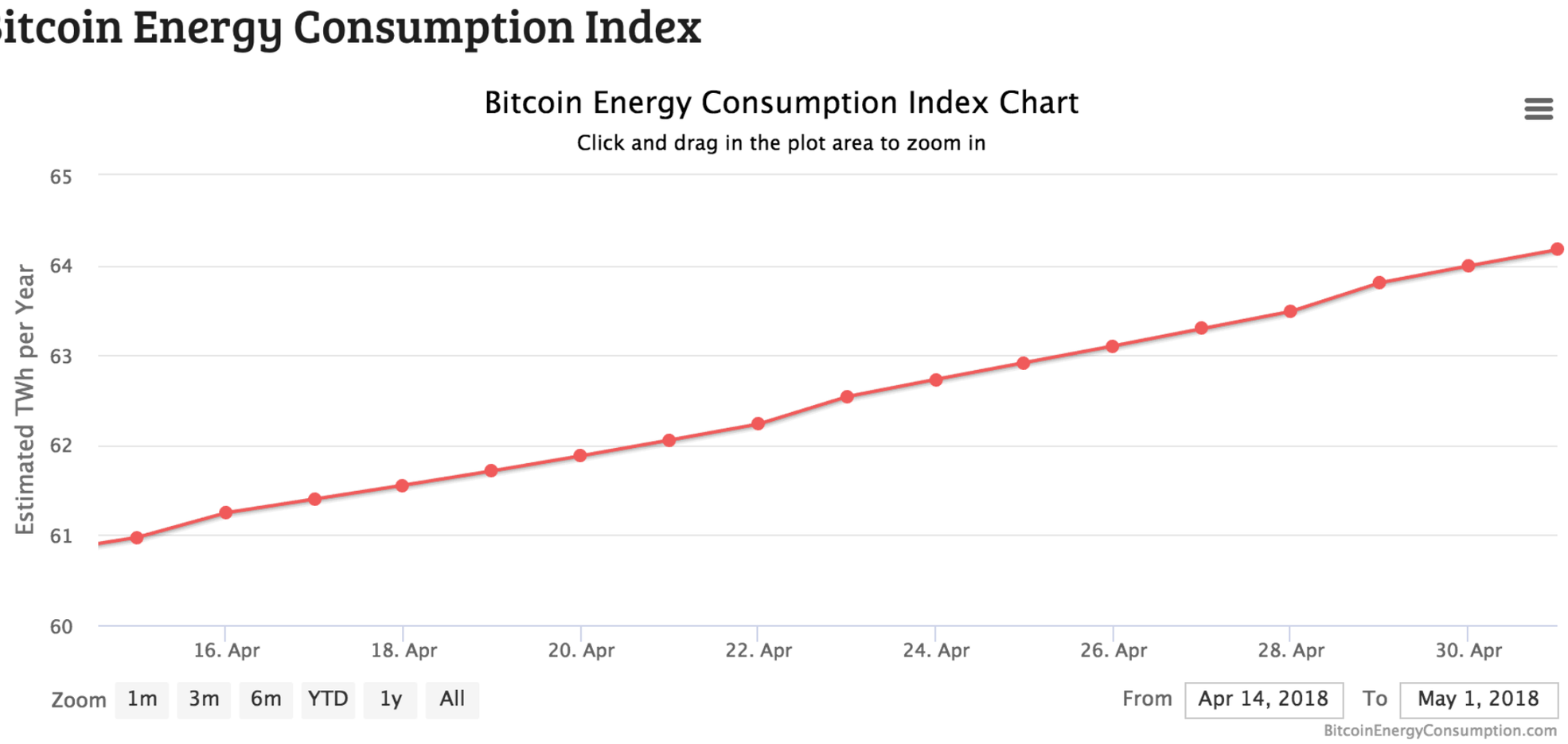
- Functionality limitations
- Sustainability limitations
- Scalability limitations
- Privacy limitations

Overcoming Functionality Limitations: From payments to state

- Of course once you have a ledger…
  - Each Bitcoin transaction can be considered a function f() consuming some previous state and producing a state update
  - Obviously this generalizes nicely to more complex programs and stored data

Improving Sustainability

- Bitcoin network power consumption higher than some nation states



Improving Sustainability

- Main Culprit: Proof-of-Work puzzles
- Replacing with "Proof-of-Stake" and "Proof-of-Space" puzzles
- Already many proposals (Algorand, Cardano, Chia, …)

Improving Scalability

- Current Bitcoin/Ethereum transaction rate is ~7TX/s
- Compare with Visa at 10,000-40,000+ TX.s globally
- This gets worse as transaction complexity increases
- Problems are storage/throughput/validation bandwidth

Improving Scalability (counted…)

- Reducing "main-chain" overhead:
  - Via payment channels (e.g., Lightning Network)
    - ZK Rollup
- Optimistic Consensus mechanisms (e.g., Thunderella)
- Sharding

L2 (Channels)

1

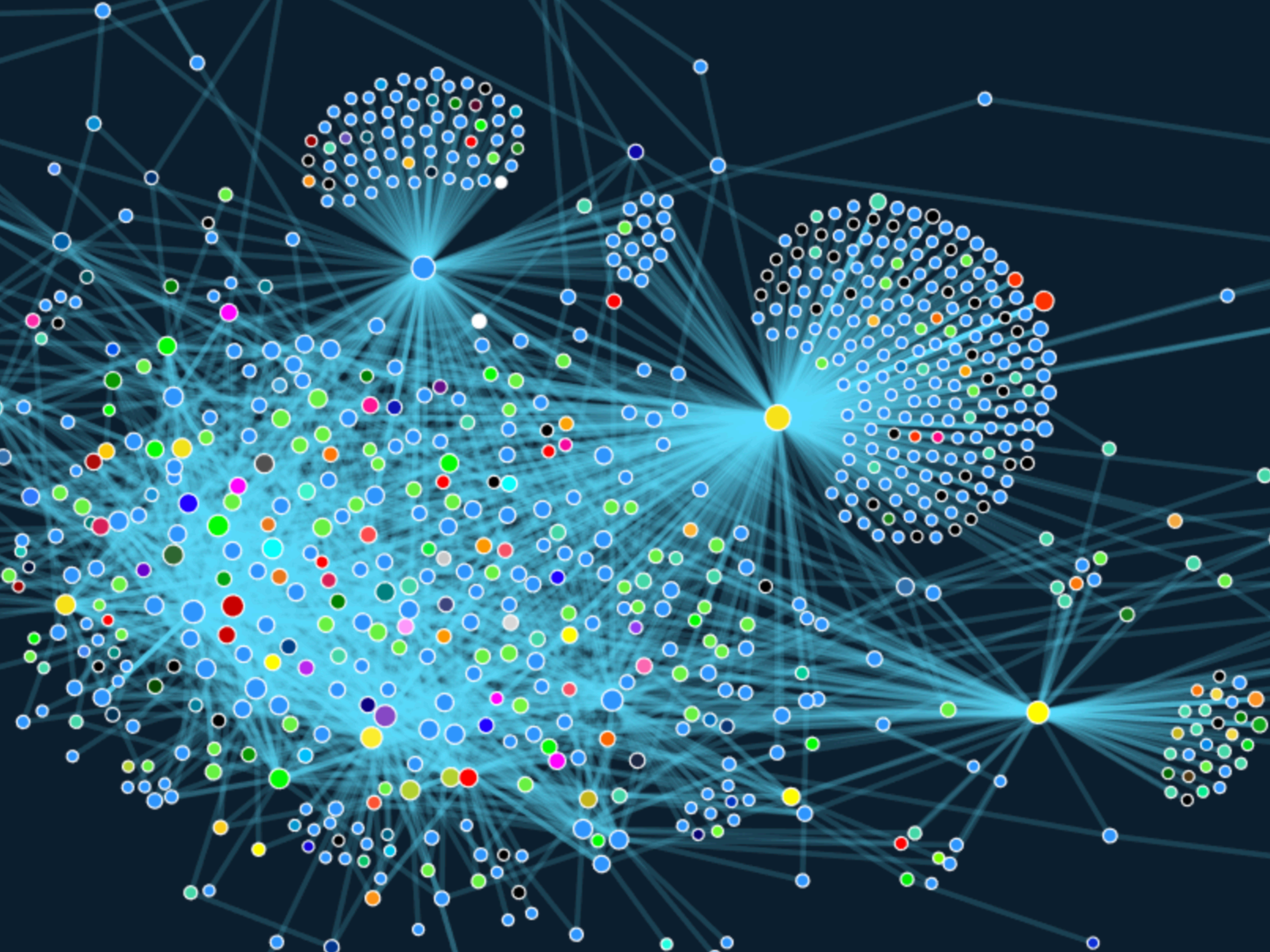
0

Open

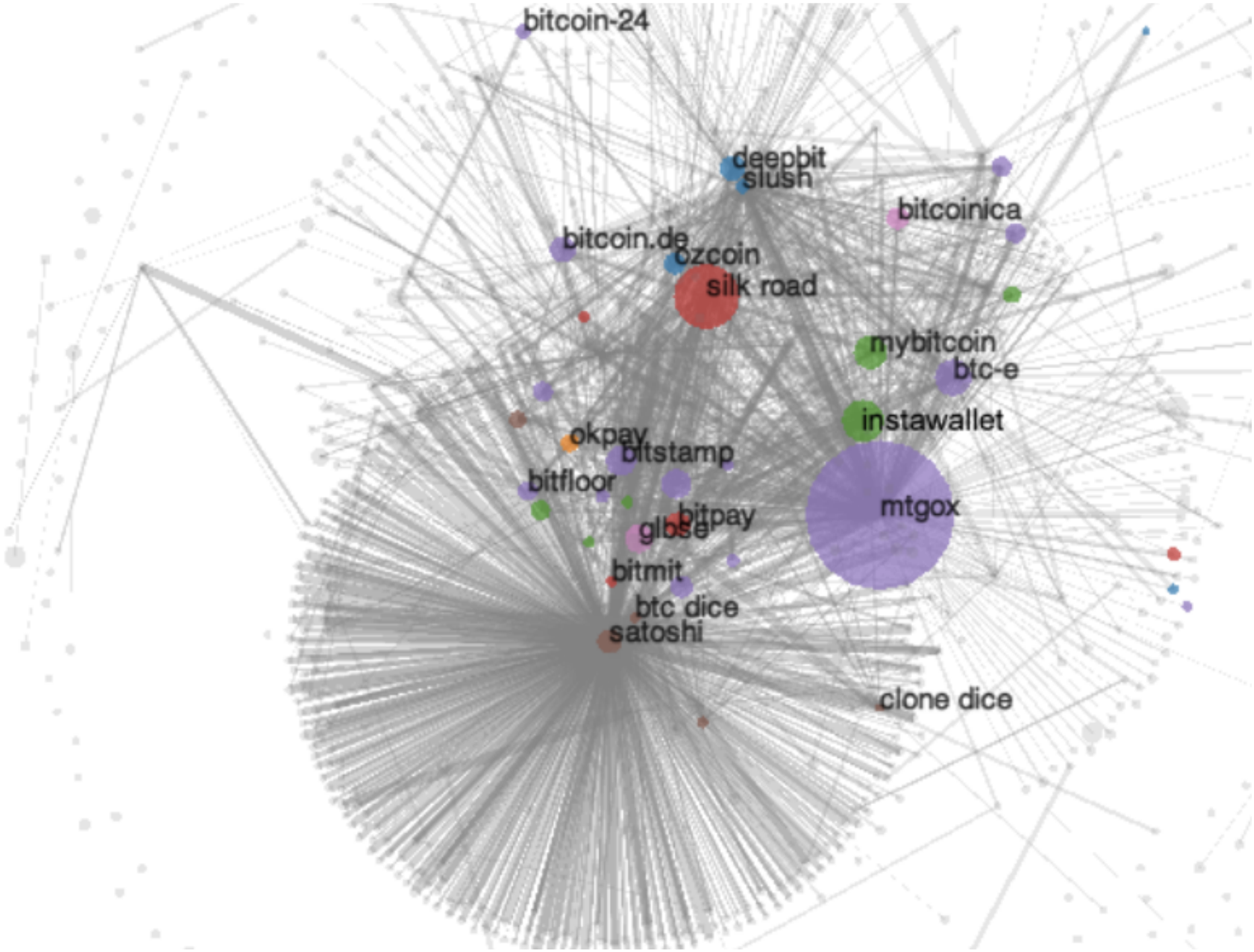
0.9 Update 0.1

0.8 Update 0.2

… Close result on blockchain …



Bitcoin & Privacy



Source: MPJLMVS13

Anonymity and Privacy via Advanced Cryptography

- New Blockchains (examples below):
  - ZeroCoin, ZCash (use of Zero-Knowledge proofs)
  - Monero (use of Ring Signatures)
- Private off-blockchain payment methods
  - Bolt
  - Tumblebit

Moving forward

- Next Lecture: Crypto background
- Do the reading
- Start thinking about projects