

# Lecture 6

Bitcoin and anonymity

# Lecture 6.1:

## Anonymity basics

# Some say Bitcoin provides anonymity

“ Bitcoin is a secure and anonymous digital currency ”

— WikiLeaks donations page

# Others say it doesn't

“ Bitcoin won't hide you from the NSA's prying eyes”

— Wired UK

# What do we mean by anonymity?

Literally: anonymous = without a name

Bitcoin addresses are public key hashes rather than real identities

Computer scientists call this pseudonymity

# Anonymity in computer science

Anonymity = pseudonymity + unlinkability



Different interactions of the same user with the system should not be linkable to each other

# Pseudonymity vs anonymity in forums

Reditd: pick a long-term pseudonym

vs.

4Chan: make posts with no attribution at all

# Why is unlinkability needed?

1. Many Bitcoin services require real identity
1. Linked profiles can be deanonymized by a variety of side channels



# Defining unlinkability in Bitcoin

Hard to link different addresses of the same user

Hard to link different transactions of the same user

Hard to link sender of a payment to its recipient

# Quantifying anonymity

Complete unlinkability (among all addresses/transactions) is hard

Anonymity set: the crowd that one attempts to blend into

To calculate anonymity set:

- define adversary model
- reason carefully about: what the adversary knows, does not know, and cannot know

# Why anonymous cryptocurrencies?

Block chain based currencies are totally, publicly, and permanently traceable

Without anonymity, privacy is much worse than traditional banking!

# What about money laundering?

Legitimate worry

Bottleneck: moving large flows into and out of Bitcoin (“cashing out”)

# Can we keep only the good uses?

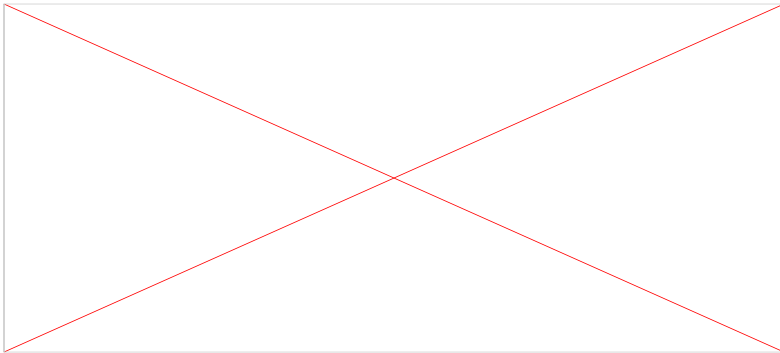
Common conundrum in computer security and privacy:

uses that are very different morally are pretty much the same technologically

# Similar dilemma: Tor

Anonymous communication network

Sender and receiver of message unlinkable



Used by:

- Normal people
- Journalists & activists
- Law enforcement
- Malware
- Child pornographers

Funded by (among others):  
U.S. State Department

# Anonymous e-cash: history

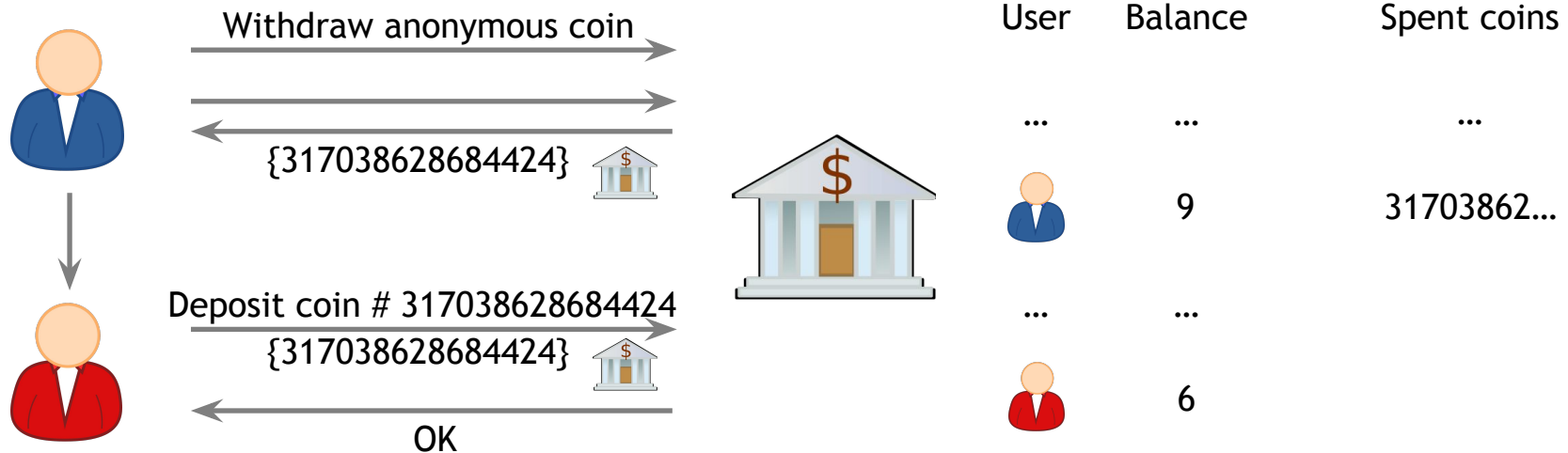
David Chaum, 1982



Blind signature:

two-party protocol to create digital signature  
without signer knowing the input

# Anonymous e-cash via blind signatures



Bank cannot link the two users



# Anonymity & decentralization: in conflict


- Interactive protocols with bank are hard to decentralize
- Decentralization often achieved via public traceability to enforce security

## Lecture 6.2:

# How to de-anonymize Bitcoin

# Bitcoin

**Bitcoin** is a secure and anonymous digital currency. Bitcoins cannot be easily tracked back to you, and are safer and faster alternative to other donation methods. You can send BTC to the following address:

13DFamCvSxG8EG16VyXzdpfqxyooifswYx 


Various sites offer a service to exchange other currency to/from Bitcoins. There are also services allowing trades of goods for Bitcoins. Bitcoins are not subject to central regulations and are still gaining value. To learn more about Bitcoins, visit the website (<http://bitcoin.org>) or read more on [Wikipedia](#).

To generate a new, private address for your donation, click the refresh button above.



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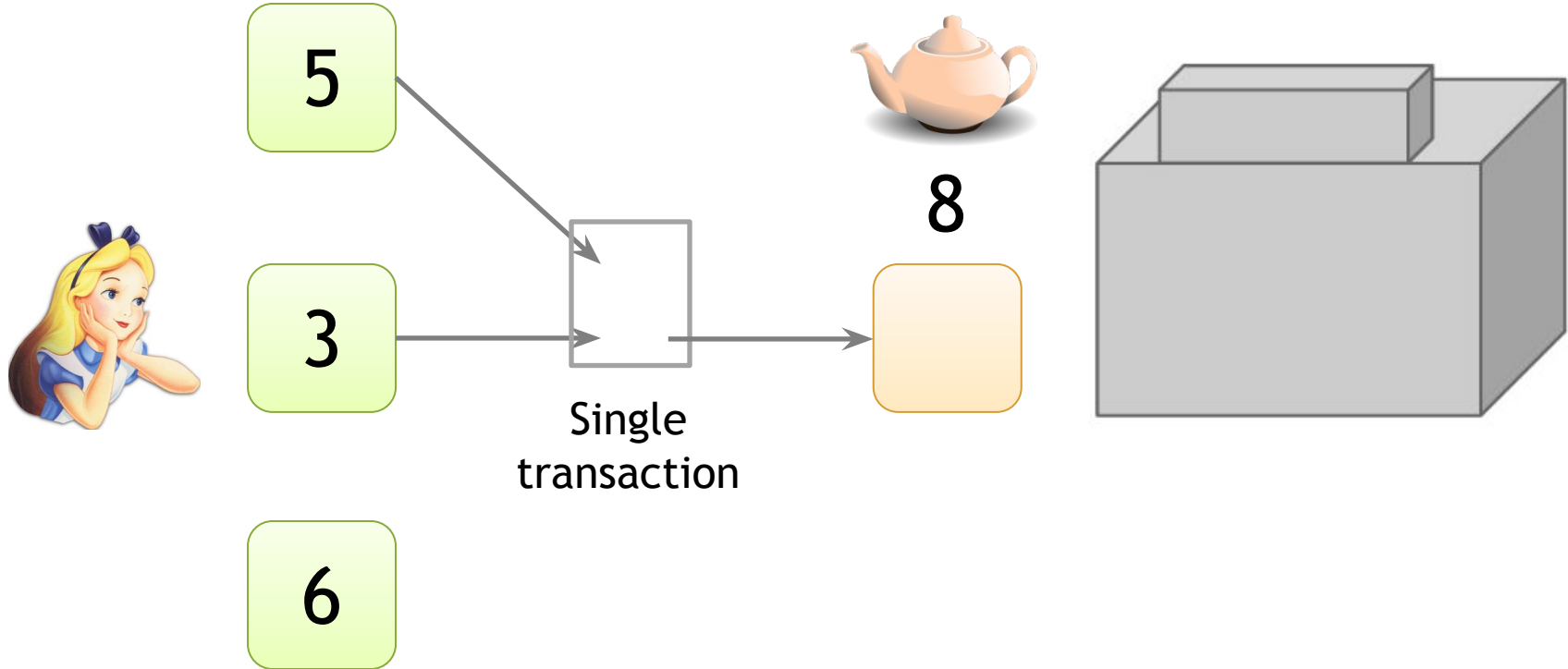


# Trivial to create new address

Best practice: always receive at fresh address

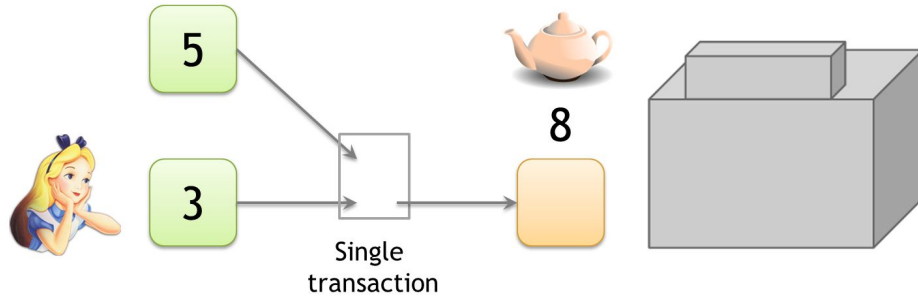
So, unlinkable?

# Alice buys a teapot at Big box store



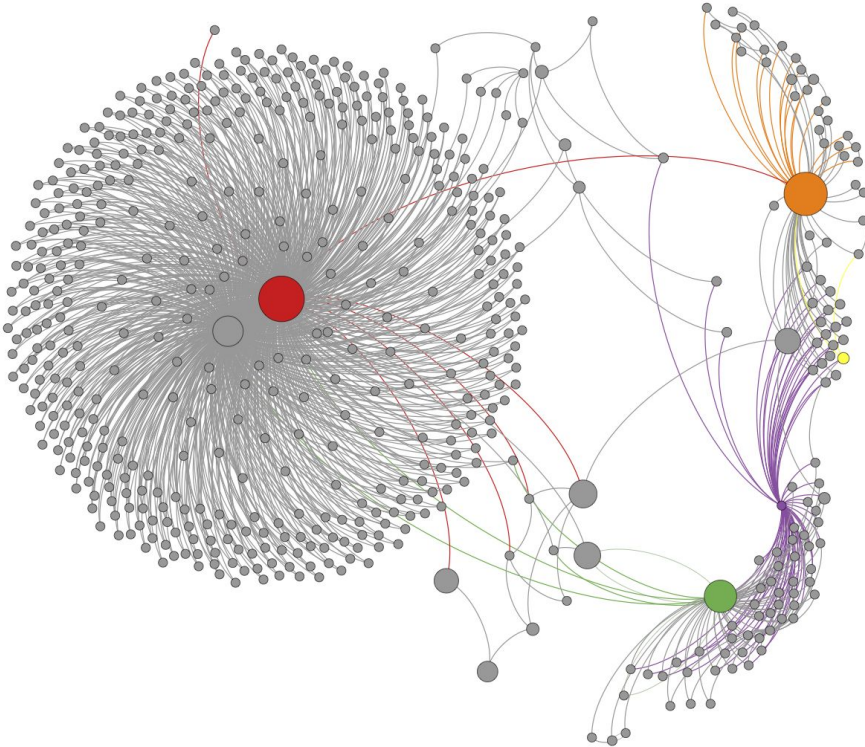
# Linking addresses

Shared spending is evidence of joint control



Addresses can be linked transitively

# Clustering of addresses

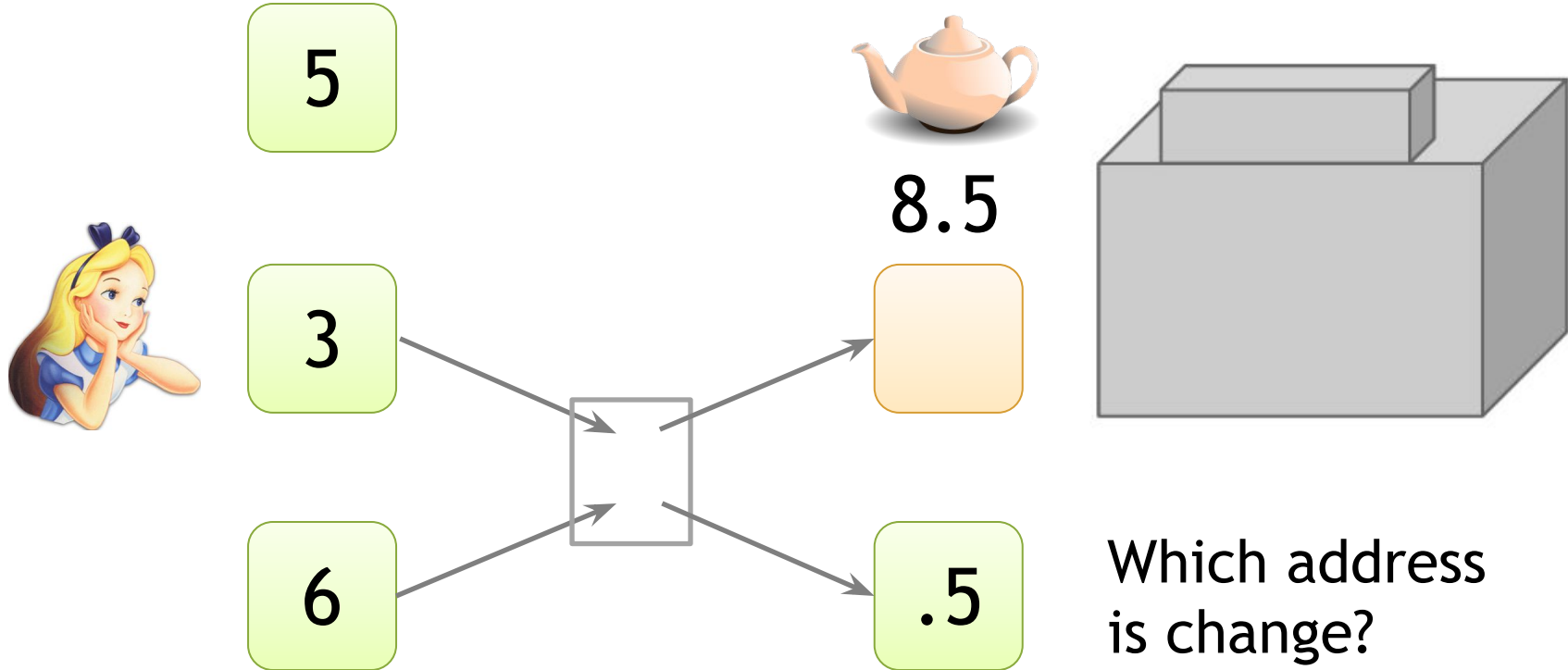


*An Analysis of Anonymity  
in the Bitcoin System*

F. Reid and M. Harrigan  
PASSAT 2011



# Change addresses



# **“Idioms of use”**

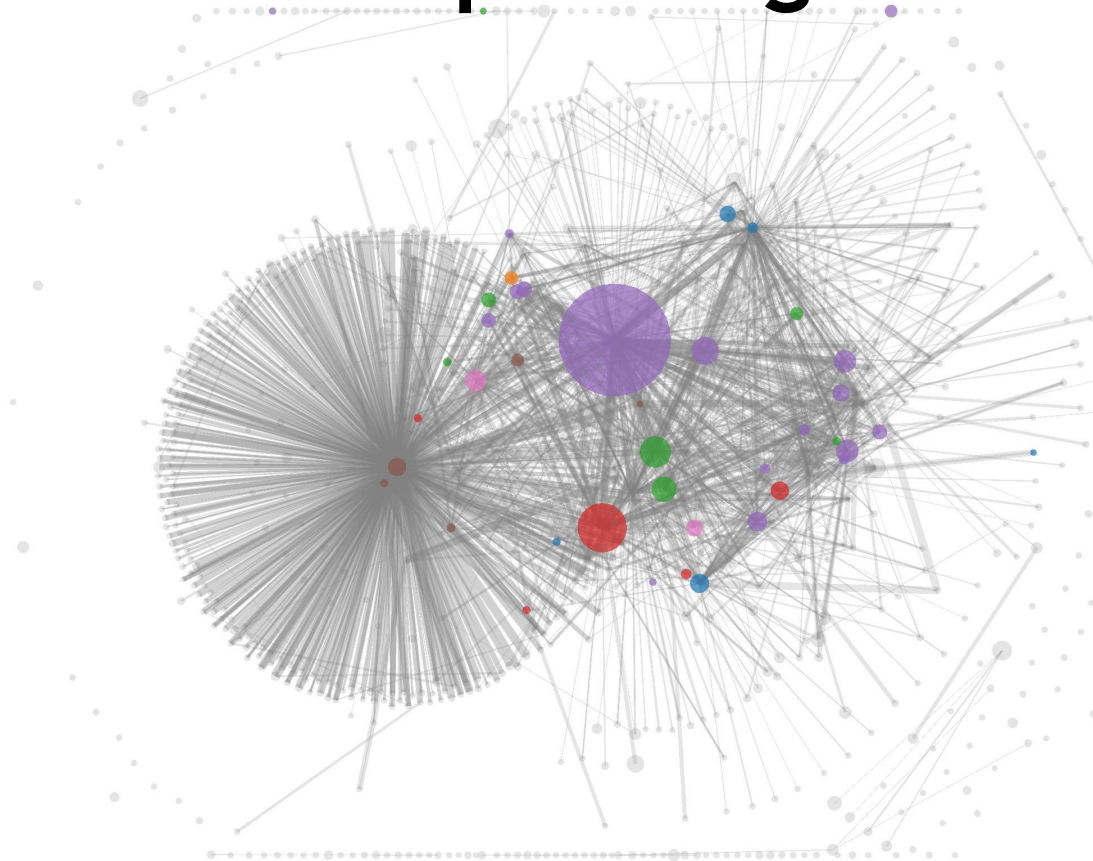
Idiosyncratic features of wallet software

e.g., each address used only once as change

# Shared spending + idioms of use

*A Fistful of Bitcoins:  
Characterizing Payments  
Among Men with No Names*

S. Meiklejohn et al.  
IMC 2013



# To tag service providers: transact!



# *A Fistful of Bitcoins: Characterizing Payments Among Men with No Names*

S. Meiklejohn et al.

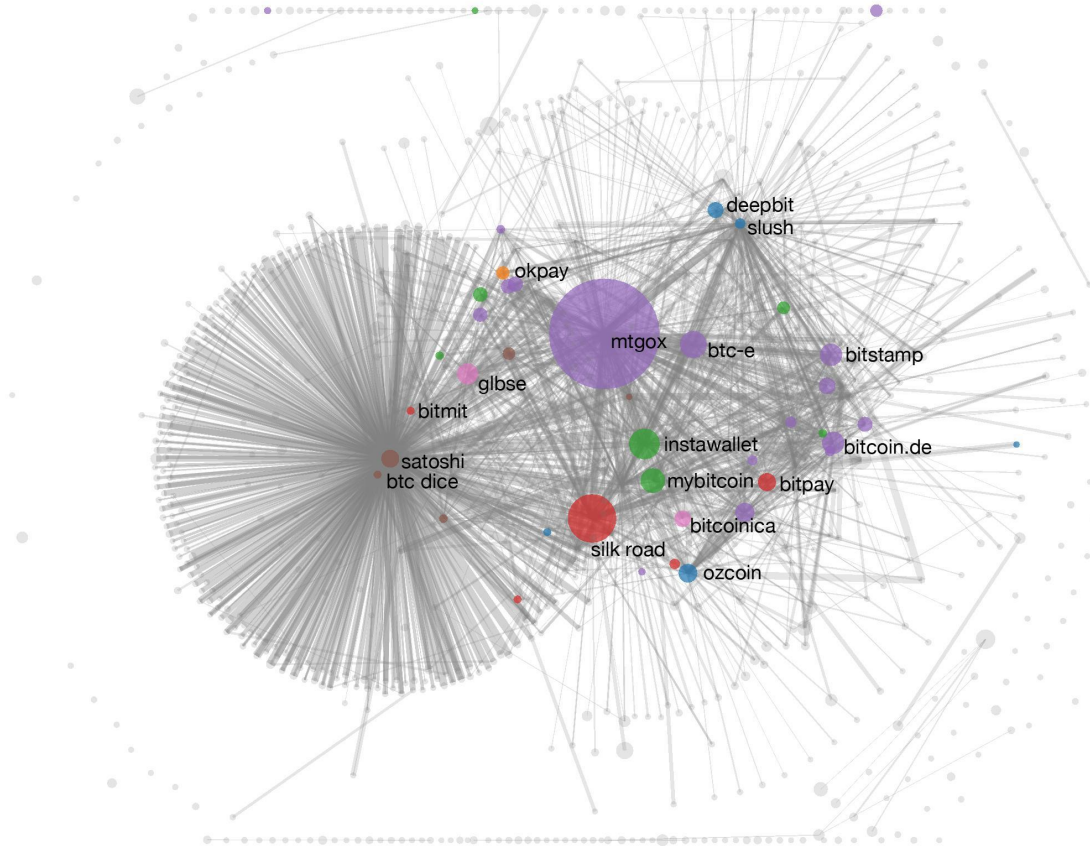
# 344 transactions

- Mining pools
- Wallet services
- Exchanges
- Vendors
- Gambling sites

# Shared spending + idioms of use

*A Fistful of Bitcoins:  
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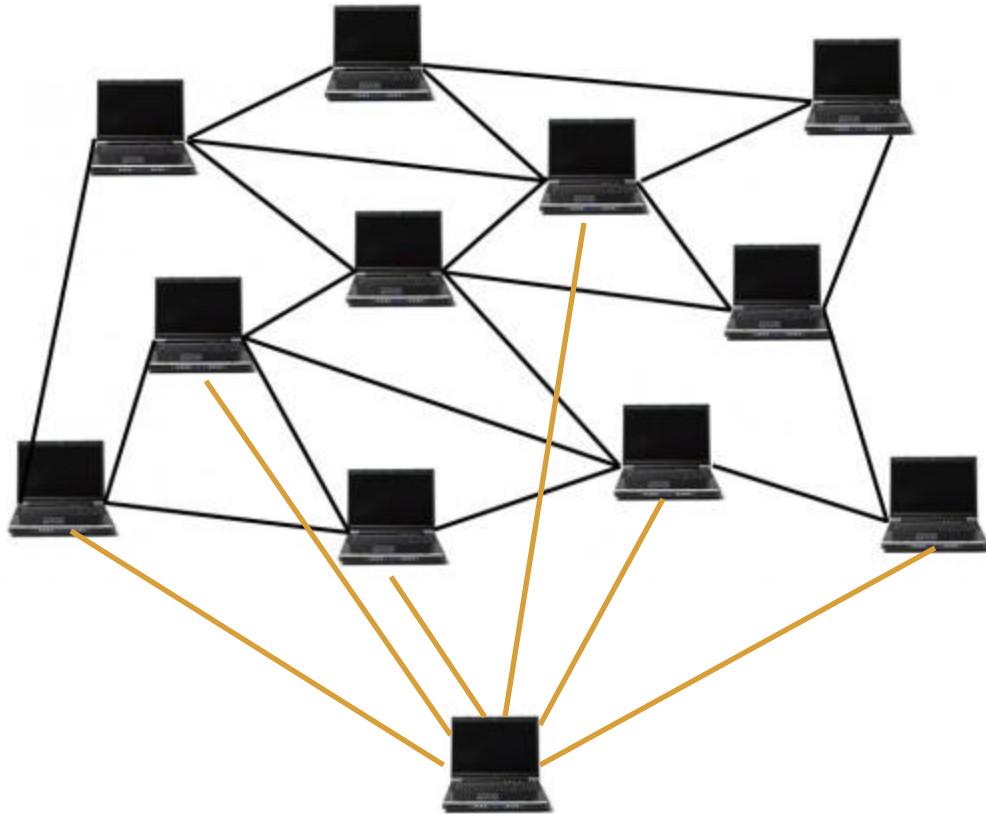
# From services to users

## 1. High centralization in service providers

Most flows pass through one of these — in a traceable way

## 2. Address — identity links in forums

# Network-layer de-anonymization



“The first node to inform you of a transaction is probably the source of it”

Dan Kaminsky  
Black Hat 2011 talk

# Solution: use Tor

Caveat: Tor is intended for low-latency activities such as web browsing

Mix nets might provide better anonymity

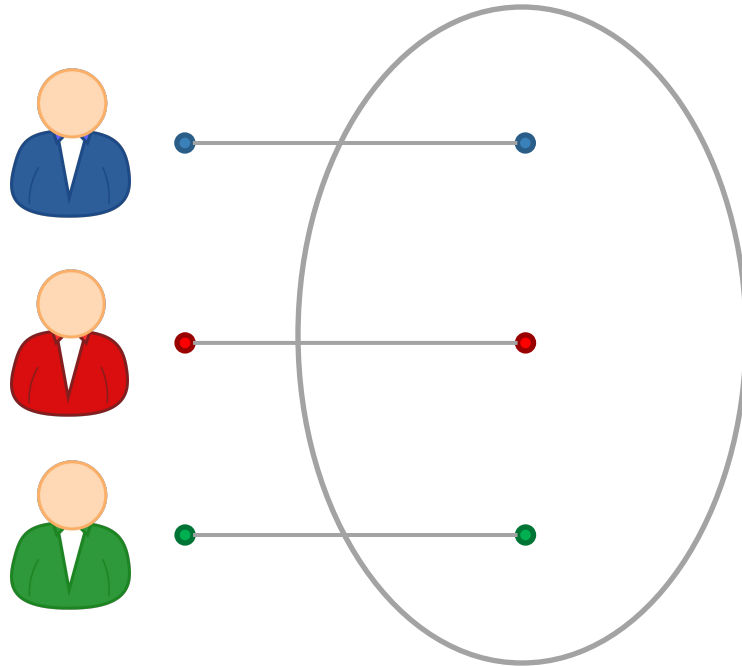
BUT Tor is what's deployed and works



# Lecture 6.3:

## Mixing

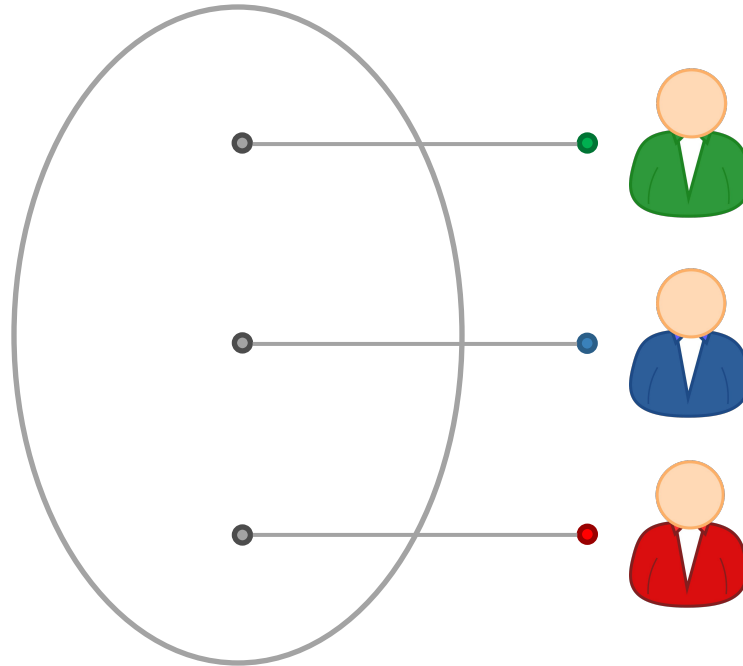
# To protect anonymity, use an intermediary



# To protect anonymity, use an intermediary

Online wallets  
do this

Do they provide  
anonymity?!





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## Study Suggests Link Between Dread Pirate Roberts and Satoshi Nakamoto

By **JOHN MARKOFF** NOVEMBER 23, 2013 6:13 PM  23 Comments



E-MAIL



FACEBOOK



TWITTER



SAVE

Two Israeli computer scientists say they may have uncovered a puzzling financial link between Ross William Ulbricht, the [recently arrested](#) operator of the Internet black market known as the Silk Road, and the secretive inventor of bitcoin, the anonymous online currency, used to make Silk Road purchases.



## Researchers Retract Report That Linked Bitcoin Creator and Silk Road

By **JOHN MARKOFF** NOVEMBER 27, 2013 12:45 PM [6 Comments](#)

 E-MAIL

 FACEBOOK

 TWITTER

 SAVE

 MORE

Two Israeli computer scientists who over the weekend published a paper describing a financial connection between the Bitcoin peer-to-peer transaction system and the operator of Silk Road, an Internet black market, have backed away from the claim after an independent security researcher took responsibility for the puzzling account that generated the transfer.

# Dedicated mixing services

- Promise not to keep records
- Don't ask for your identity

# Back to online wallets

Reputable, often regulated, businesses

- Typically require identity, keep records → no anonymity w.r.t. wallet service
- Users trust them with their bitcoins → keep them for longer → bigger anonymity set w.r.t. everyone else

Rest of this lecture:

assume a user for whom the trust requirements  
and anonymity properties of online wallets are  
unacceptable



# Mixing: terminology

Mix vs. mixer

Another term: laundry  
Won't use in this lecture

# Principles for mixing services

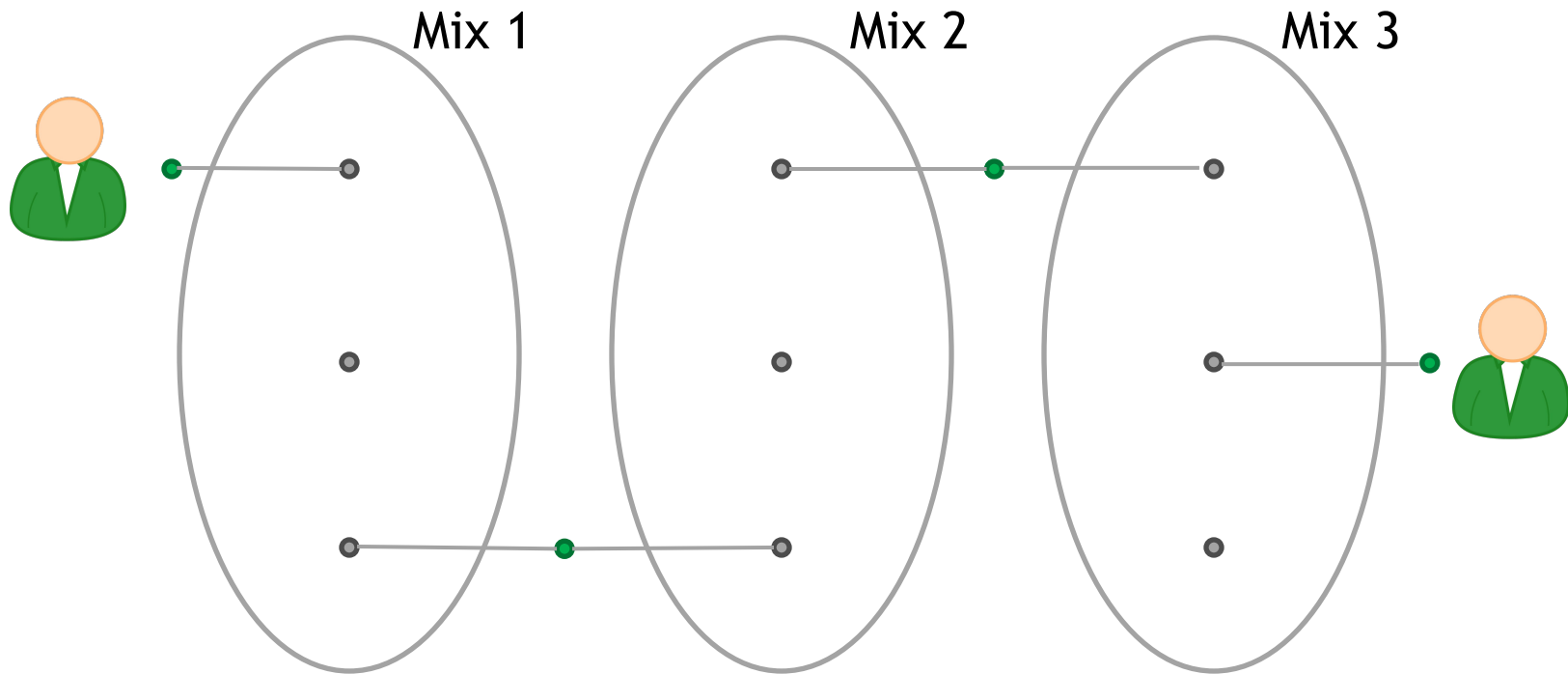
## 1. Use a series of mixes

Mixes should implement a standard API to make this easy

*Mixcoin: Anonymity for Bitcoin with accountable mixes*

J. Bonneau et al.  
Financial Cryptography  
2014

# Series of mixes



# Principles for mixing services

## 2. Uniform transactions

In particular: all mix transactions must have the same value!

*“Chunk size”*

*Mixcoin: Anonymity for Bitcoin with accountable mixes*

J. Bonneau et al.  
Financial Cryptography  
2014

# Principles for mixing services

3. Client side must be automated

Desktop wallet software

*Mixcoin: Anonymity for Bitcoin with accountable mixes*

J. Bonneau et al.  
Financial Cryptography  
2014

# Principles for mixing services

## 4. Fees must be all-or-nothing

Probabilistic fees:

0.1% mixing fee =  
mix will swallow chunk  
with 0.1% chance

*Mixcoin: Anonymity for  
Bitcoin with accountable  
mixes*

J. Bonneau et al.  
Financial Cryptography  
2014

Current mixes follow none of these principles

# Remaining problem: trusting mixes

- 1. Stay in business, build up reputation
- 1. Users can test for themselves
- 1. Cryptographic “warranties”

# Currently no reputable dedicated mix

Caution: Mixing services may themselves be operating with anonymity. As such, if the mixing output fails to be delivered or access to funds is denied there is no recourse. Use at your own discretion.

— Bitcoin Wiki



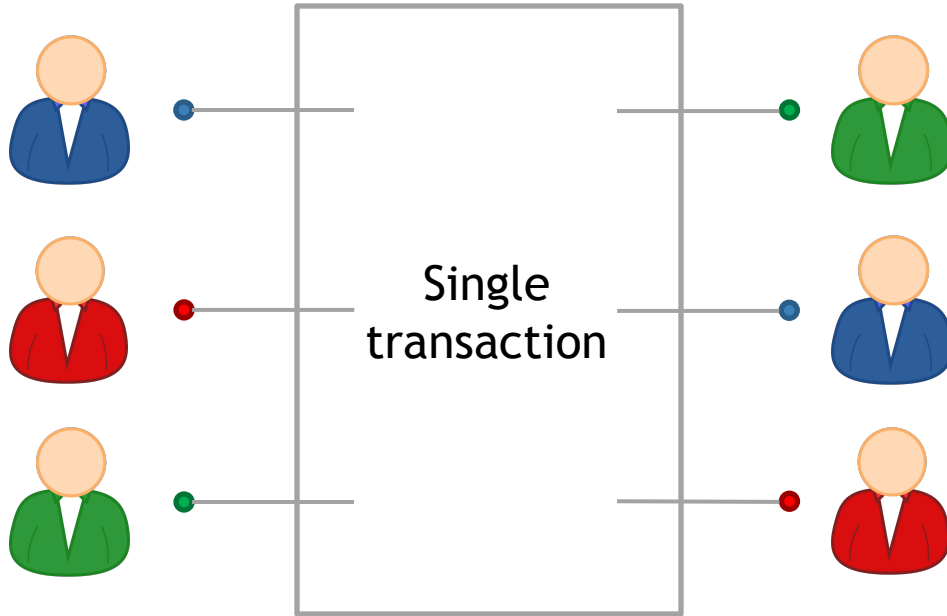
## Lecture 6.4:

# Decentralized mixing

# Why decentralized mixing?

- No bootstrapping problem
- Theft impossible
- Possibly better anonymity
- More philosophically aligned with Bitcoin

# Coinjoin



Each signature is entirely separate

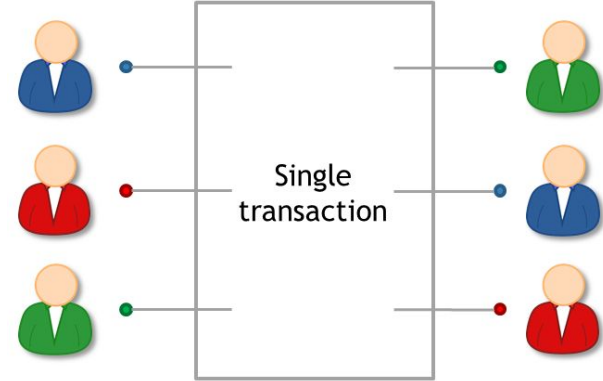
This is 1 mixing round

Mixing principles from before apply on top of basic protocol

Proposed by Greg Maxwell, Bitcoin core developer

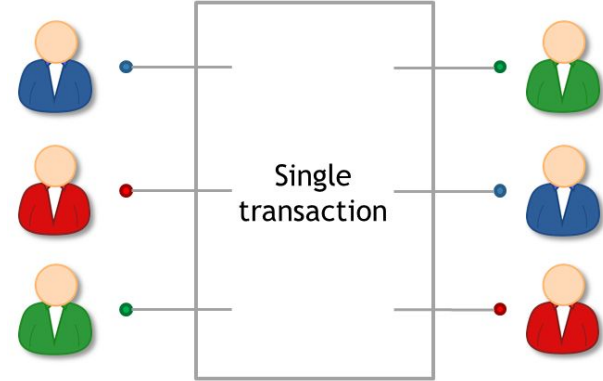
# Coinjoin algorithm

1. Find peers who want to mix
2. Exchange input/output addresses
3. Construct transaction
4. Send it around, collect signatures  
(Before signing, each peer checks if her output is present)
5. Broadcast the transaction



# Coinjoin: remaining problems

- How to find peers
- Peers know your input-output mapping  
(This is a worse problem than for centralized mixes)
- Denial of service



# Finding peers

Use an untrusted server

# Peer anonymity

Strawman solution:

1. exchange inputs
2. disconnect and reconnect over Tor
3. exchange outputs

Better solution:

special-purpose anonymous routing mechanism

# Denial of service

Proposed solutions:

- Proof of work
- Proof of burn
- Server kicks out malicious participant
- Cryptographic “blame” protocol  
(*CoinShuffle: Practical Decentralized Coin  
Mixing for Bitcoin*  
T. Ruffing et al., PETS 2014)



# High-level flows could be identifying

Example:

Alice receives 43.12312 BTC / week as income

Always immediately transfers 5% to retirement account

# Heuristic: merge avoidance

Instead of a single payment transaction

receiver provides multiple output addresses  
sender avoids combining different inputs

(Proposed by Mike Hearn)

## Lecture 6.5:

# Zerocoin and Zerocash

# Zerocoin: protocol-level mixing

Mixing capability baked  
into protocol

*Zerocoin: Anonymous  
Distributed E-Cash  
from Bitcoin*

Advantage: cryptographic  
guarantee of mixing

I. Miers et al.  
IEEE S&P 2013

Disadvantage: not currently  
compatible with Bitcoin

# Basecoin and Zerocoin

Basecoin: Bitcoin-like Altcoin

Zerocoin: Extension of Basecoin

Basecoins can be converted into zerocoins  
and back

Breaks link between original and new basecoin

# Zerocoins

A Zerocoin is a cryptographic proof that you owned a Basecoin and made it unspendable

Miners can verify these proofs

Gives you the right to redeem a new Basecoin  
(Somewhat like poker chips)

# Two challenges

How to construct these proofs?

How to make sure each proof can only be “spent” once?

# Zero-knowledge proofs

A way to prove a statement without revealing any other information



Crypto  
magic

Example:

- “I know an input that hashes to da39a3ee5e”
- “I know an input that hashes to some hash in the following set: ... ”



# Minting zerocoins

Zerocoins come in standard denominations  
(Let's assume 1 basecoin)

Anyone can make one!

They have value once put on the block chain  
That costs 1 basecoin

# Minting a zerocoin: “commitment”

Generate serial number  $S$   
(eventually made public)

and random secret  $r$   
(never public, ensures  
unlinkability)

Compute  $H(S, r)$

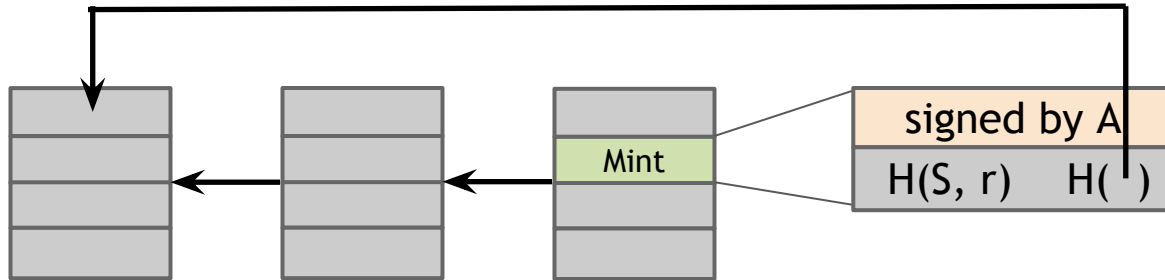
Simplification



# Minting a zerocoin

To put  $H(S, r)$  on block chain

Create Mint Tx with 1 basecoin as input



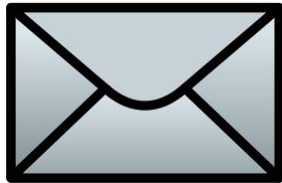
# To spend a zerocoin $S$ :

- Reveal  $S$   
(miners will verify  $S$  hasn't been spent before)
- Create zero-knowledge proof that:  
“I know a number  $r$  such that  $H(S, r)$  is one of the zerocoins in the block chain”
- Pick arbitrary zerocoin in block chain & use as input to your new transaction

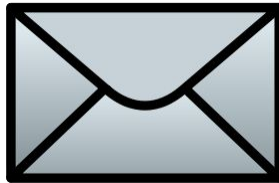
# Zerocoin is anonymous

Since  $r$  is secret, no one can figure out *which* zerocoin corresponds to serial number  $S$

$H(S, r)$

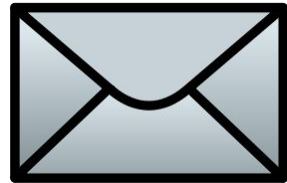


$h_1$



$h_2$

...



$h_N$

# Zerocoin is “efficient”

The proof is a giant  
disjunction over all  
zerocoins

Yet the proof is  
relatively small!

*I know  $r$  such that*

$$H(S, r) = h_1$$

*OR*

$$H(S, r) = h_2$$

*OR*

...

*OR*

$$H(S, r) = h_N$$

# ZeroCash: Zerocoin without Basecoin

Two differences

- Different crypto for proofs (More efficient)
- Proposal to run system without Basecoin

*ZeroCash:  
Decentralized  
Anonymous Payments  
from Bitcoin*

E. Ben-Sasson et al.  
Usenix Security 2014

# ZeroCash: untraceable e-cash

All transactions are zerocoins

Splitting and merging supported

Put transaction value inside the envelope

Ledger merely records existence of transactions



# Zerocash: the catch

Random, secret inputs are required to generate public parameters

These secret inputs must then be securely destroyed

No one can know them (anyone who does can break the system)

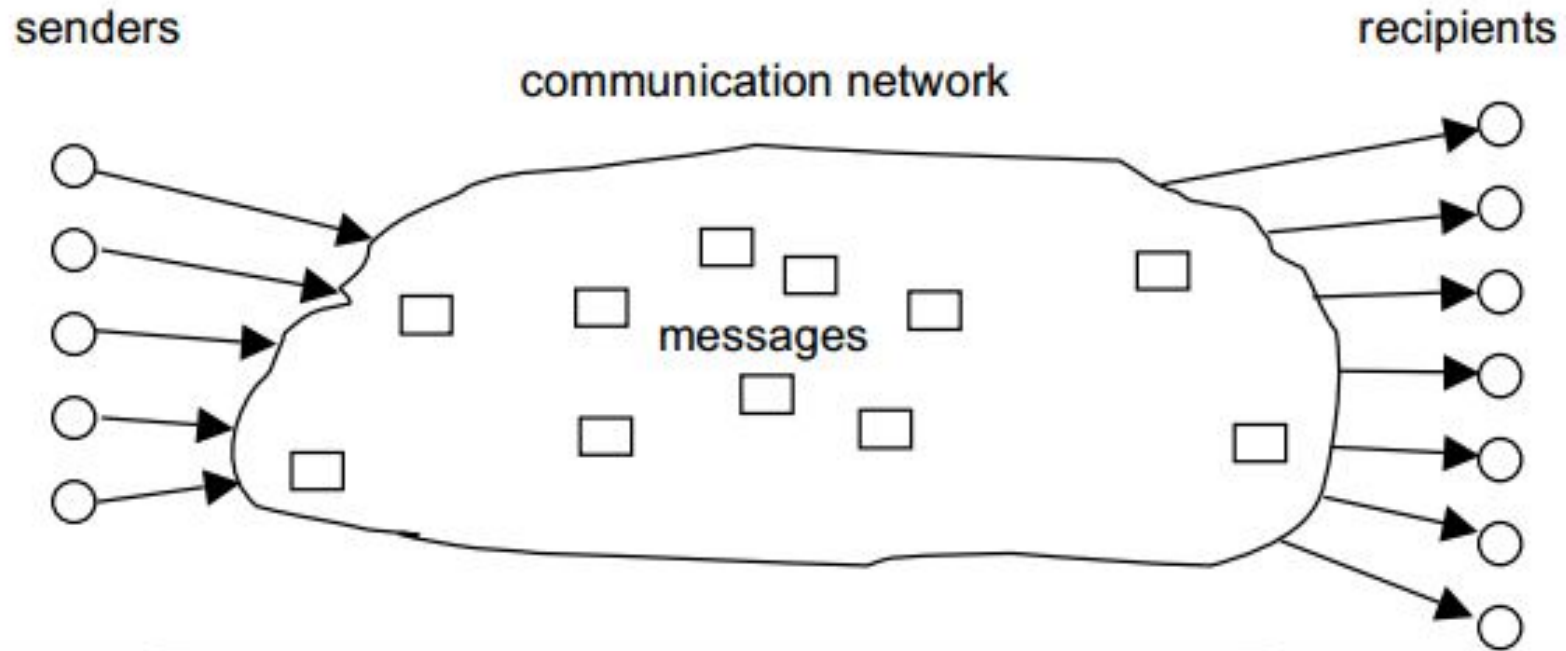
# 5 levels of anonymity

System	Type	Anonymity attacks	Deployability
Bitcoin	Pseudonymous	Tx graph analysis	Default
Single mix	Mix	Tx graph analysis, bad mix	Usable today
Mix chain	Mix	Side channels, bad mixes/peers	Bitcoin-compatible
Zerocoin	Cryptographic mix	Side channels (possibly)	Altcoin
Zerocash	Untraceable	None	Altcoin, tricky setup

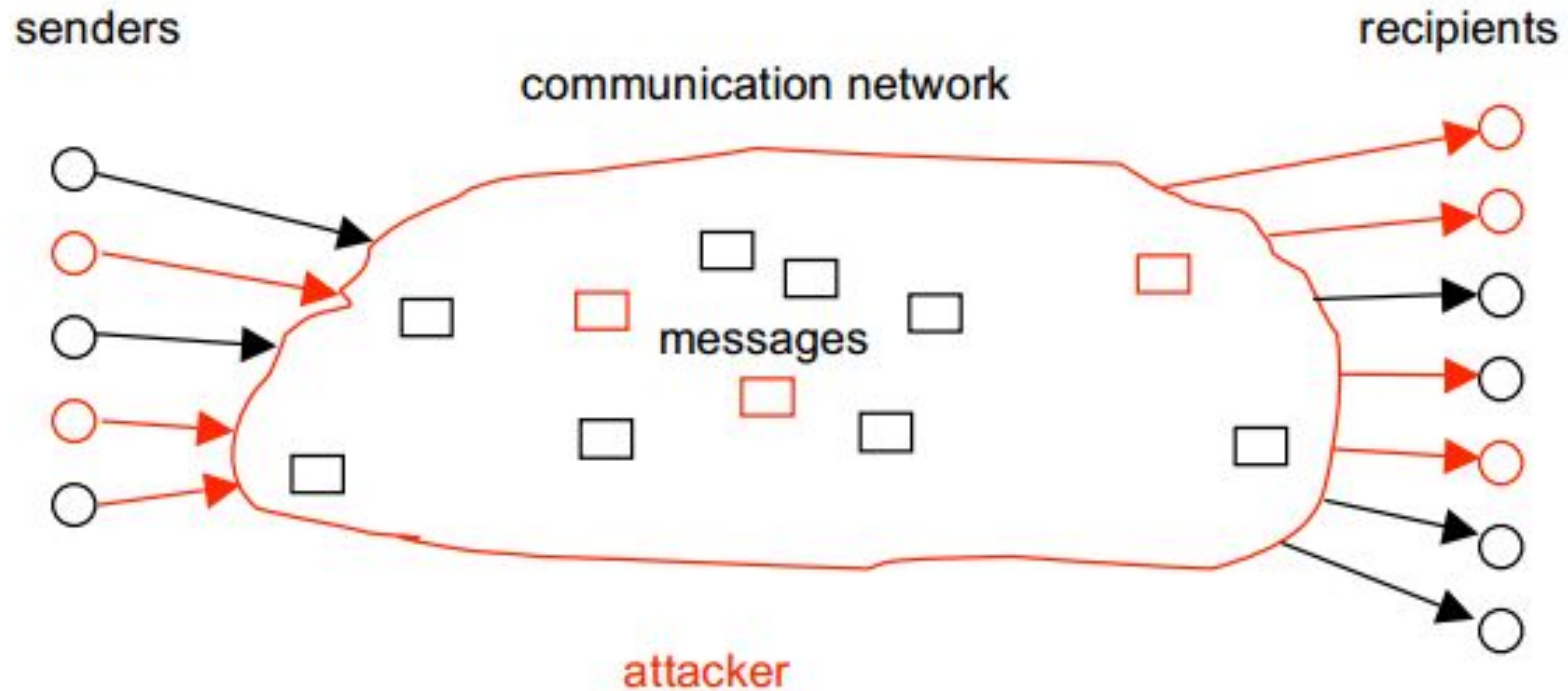
## Lecture 6.6:

### Tor and the Silk Road

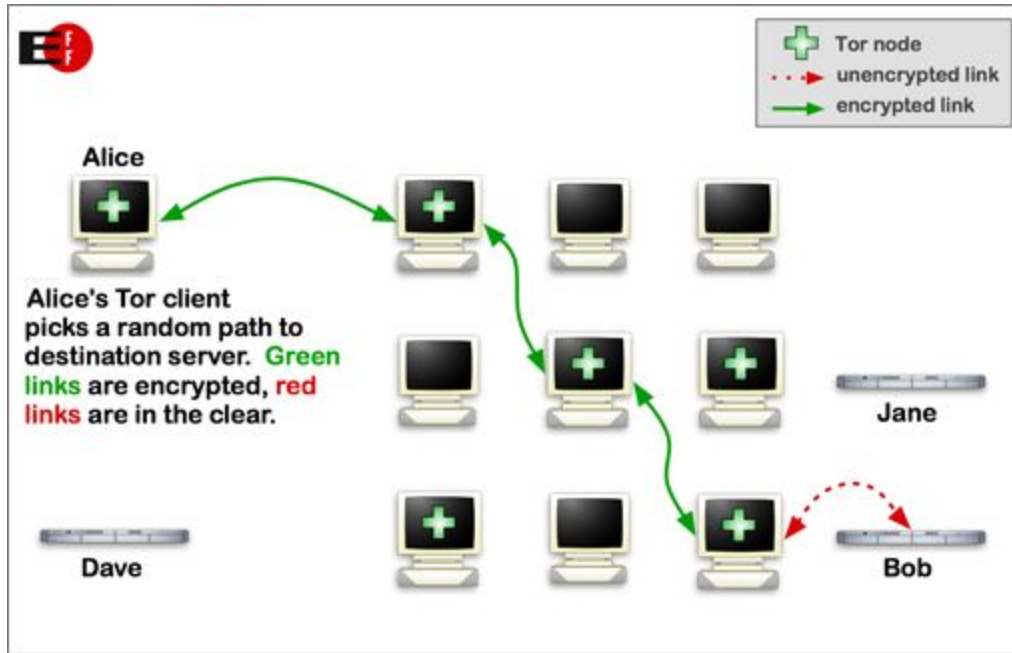
# Anonymous communication



# Threat model



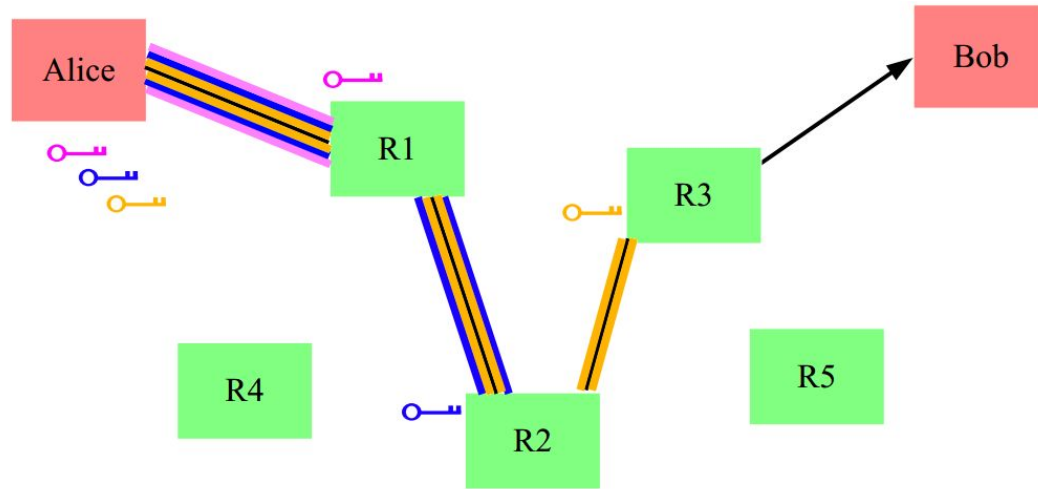
# How Tor works



Safe(ish) if at least one router honest

Key challenge: hiding routing information

# Solution: layered encryption



Side effect: contents encrypted from Alice to exit node

BUT: Unencrypted from exit node to Bob

# Hidden services

What if the server wants to hide its address?

Simplified:

1. Connect to “rendezvous point” through Tor
2. Publish name → rendezvous point mapping
3. Client connects to rendezvous point

Onion address looks like

**`http://3g2up14pq6kufc4m.onion/`**



# Silk Road

- Communication: Tor hidden service
- Payment: Bitcoin
- Security?
- Anonymous shipping?