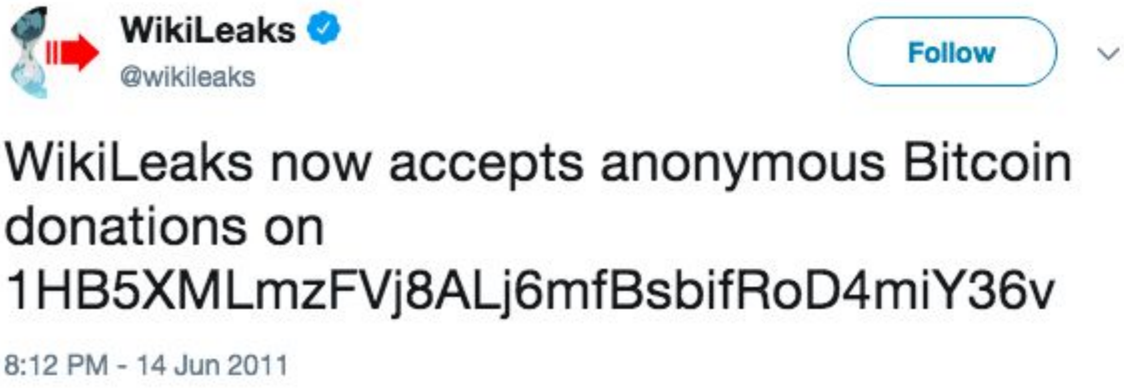
How much privacy is enough?

Evaluating tradeoffs in privacy and scalability

Ian Miers
@secparam
Cornell Tech/ Zcash Foundation



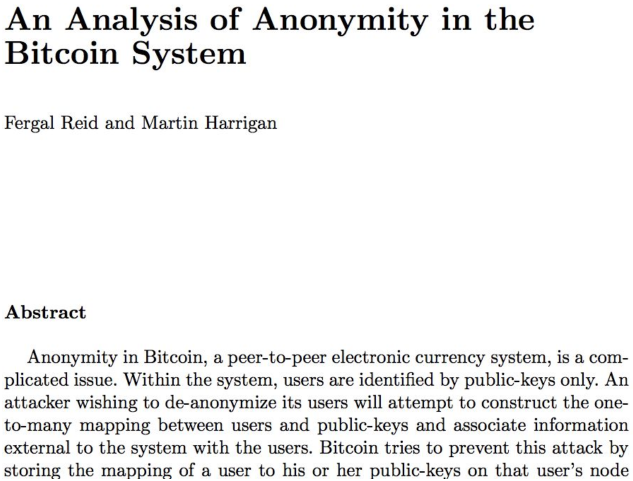
WikiLeaks
@wikileaks

WikiLeaks now accepts anonymous Bitcoin donations on 1HB5XMLmzFVj8ALj6mfBsbifRoD4miY36v

8:12 PM - 14 Jun 2011

ELLIPTIC

CHAINALYSIS

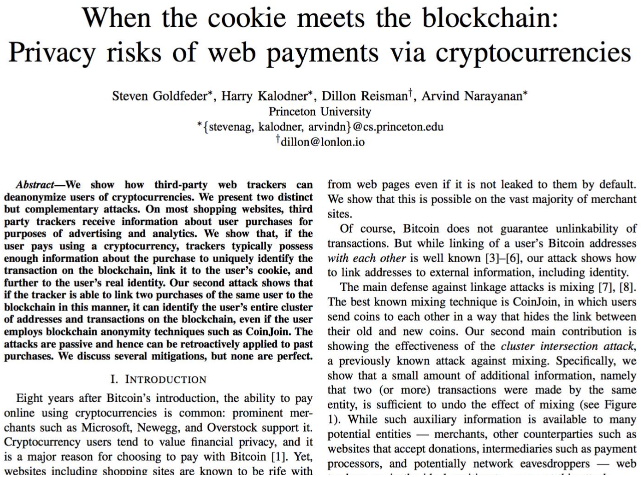


An Analysis of Anonymity in the Bitcoin System

Fergal Reid and Martin Harrigan

Abstract

Anonymity in Bitcoin, a peer-to-peer electronic currency system, is a complicated issue. Within the system, users are identified by public-keys only. An attacker wishing to de-anonymize its users will attempt to construct the one-to-many mapping between users and public-keys and associate information external to the system with the users. Bitcoin tries to prevent this attack by storing the mapping of a user to his or her public-keys on that user's node



When the cookie meets the blockchain: Privacy risks of web payments via cryptocurrencies

Steven Goldfeder*, Harry Kalodner*, Dillon Reisman†, Arvind Narayanan*
Princeton University
*{stevenag, kalodner, arvindn}@cs.princeton.edu
†dillon@lonlon.io

***Abstract*—We show how third-party web trackers can deanonymize users of cryptocurrencies. We present two distinct but complementary attacks. On most shopping websites, third party trackers receive information about user purchases for purposes of advertising and analytics. We show that, if the user pays using a cryptocurrency, trackers typically possess enough information about the purchase to uniquely identify the transaction on the blockchain, link it to the user's cookie, and further to the user's real identity. Our second attack shows that if the tracker is able to link two purchases of the same user to the blockchain in this manner, it can identify the user's entire cluster of addresses and transactions on the blockchain, even if the user employs blockchain anonymity techniques such as CoinJoin. The attacks are passive and hence can be retroactively applied to past purchases. We discuss several mitigations, but none are perfect.**

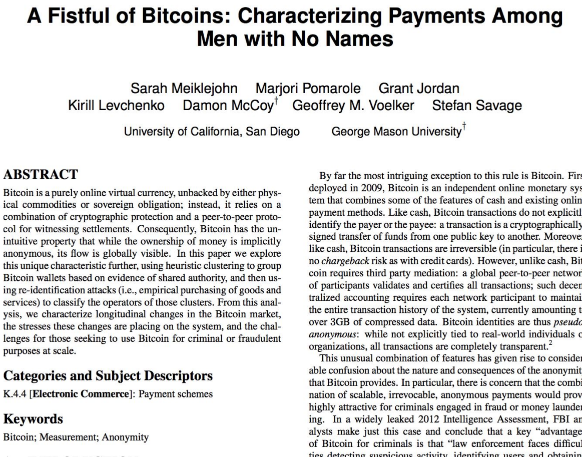
I. Introduction

Eight years after Bitcoin's introduction, the ability to pay online using cryptocurrencies is common: prominent merchants such as Microsoft, Newegg, and Overstock support it. Cryptocurrency users tend to value financial privacy, and it is a major reason for choosing to pay with Bitcoin [1]. Yet, websites including shopping sites are known to be rife with

from web pages even if it is not leaked to them by default. We show that this is possible on the vast majority of merchant sites.

Of course, Bitcoin does not guarantee unlinkability of transactions. But while linking of a user's Bitcoin addresses *with each other* is well known [3]–[6], our attack shows how to link addresses to external information, including identity.

The main defense against linkage attacks is mixing [7], [8]. The best known mixing technique is CoinJoin, in which users send coins to each other in a way that hides the link between their old and new coins. Our second main contribution is showing the effectiveness of the *cluster intersection attack*, a previously known attack against mixing. Specifically, we show that a small amount of additional information, namely that two (or more) transactions were made by the same entity, is sufficient to undo the effect of mixing (see Figure 1). While such auxiliary information is available to many potential entities — merchants, other counterparties such as websites that accept donations, intermediaries such as payment processors, and potentially network eavesdroppers — web



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

Sarah Meiklejohn Marjori Pomarole Grant Jordan
Kirill Levchenko Damon McCoy† Geoffrey M. Voelker Stefan Savage
University of California, San Diego George Mason University†

ABSTRACT

Bitcoin is a purely online virtual currency, unbacked by either physical commodities or sovereign obligation; instead, it relies on a combination of cryptographic protection and a peer-to-peer protocol for witnessing settlements. Consequently, Bitcoin has the unintuitive property that while the ownership of money is implicitly anonymous, its flow is globally visible. In this paper we explore this unique characteristic further, using heuristic clustering to group Bitcoin wallets based on evidence of shared authority, and then using re-identification attacks (i.e., empirical purchasing of goods and services) to classify the operators of those clusters. From this analysis, we characterize longitudinal changes in the Bitcoin market, the stresses these changes are placing on the system, and the challenges for those seeking to use Bitcoin for criminal or fraudulent purposes at scale.

Categories and Subject Descriptors

K.4.4 [**Electronic Commerce**]: Payment schemes

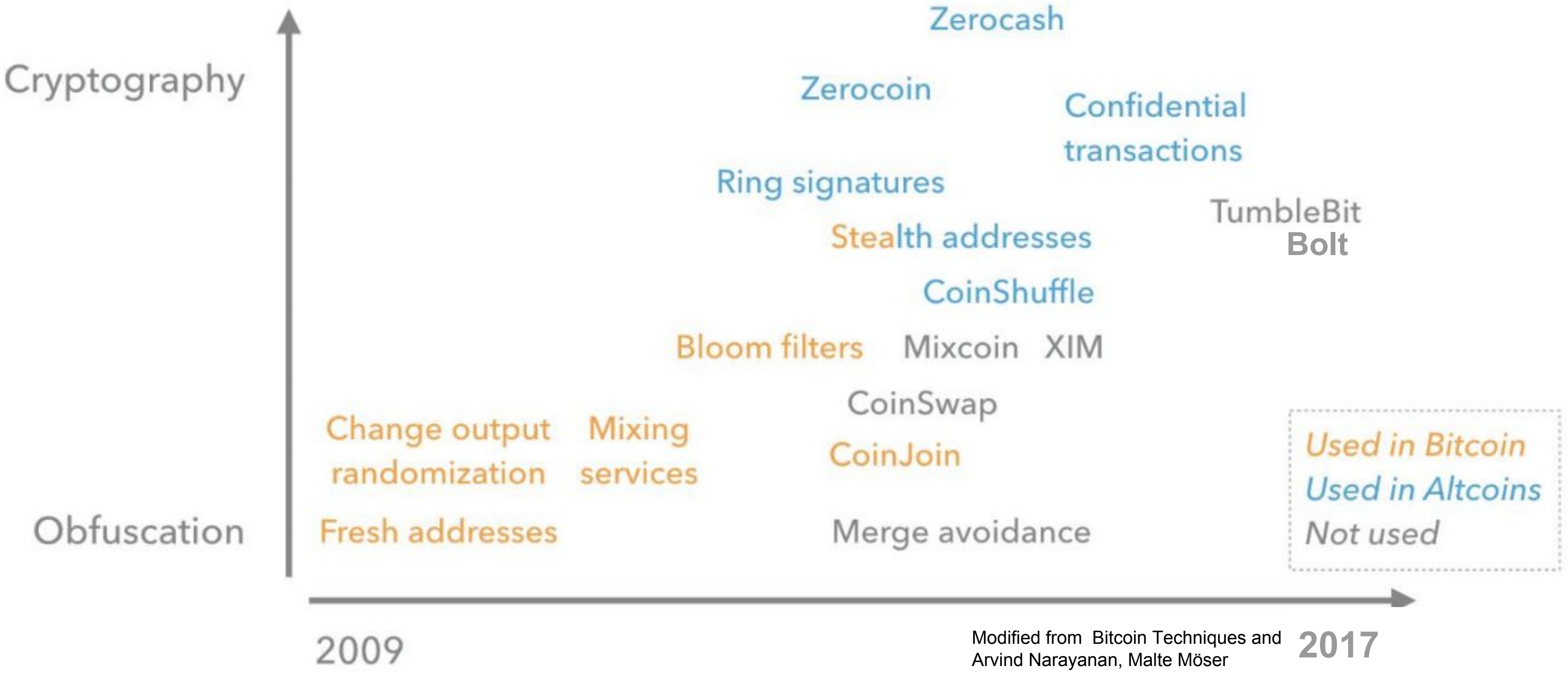
Keywords

Bitcoin; Measurement; Anonymity

By far the most intriguing exception to this rule is Bitcoin. Firs deployed in 2009, Bitcoin is an independent online monetary sys tem that combines some of the features of cash and existing onlin payment methods. Like cash, Bitcoin transactions do not explicitl identify the payer or the payee: a transaction is a cryptographically signed transfer of funds from one public key to another. Moreove like cash, Bitcoin transactions are irreversible (in particular, there i no *chargeback* risk as with credit cards). However, unlike cash, Bit coin requires third party mediation: a global peer-to-peer networ of participants validates and certifies all transactions; such decen tralized accounting requires each network participant to maintai the entire transaction history of the system, currently amounting t over 3GB of compressed data. Bitcoin identities are thus *pseudo anonymous*: while not explicitly tied to real-world individuals o organizations, all transactions are completely transparent.[2]

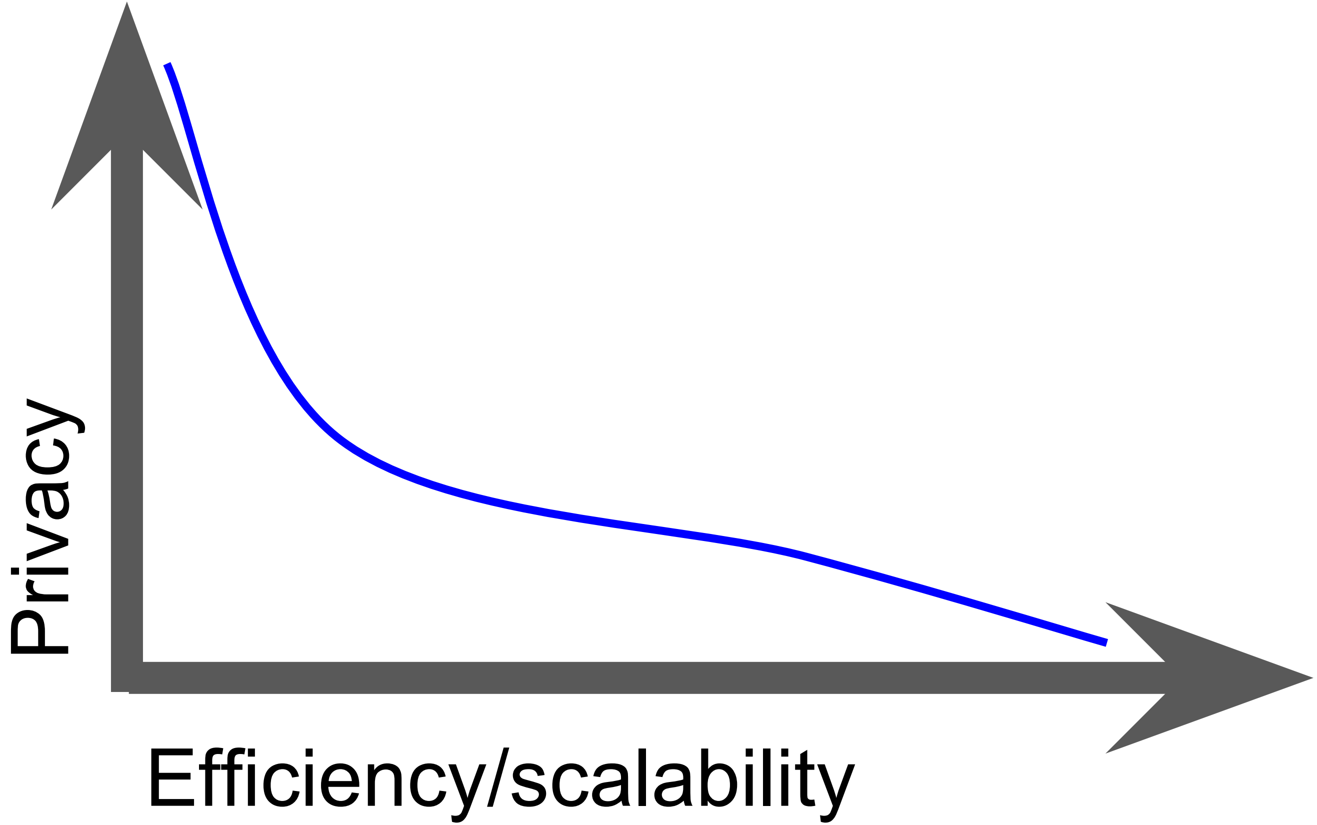
This unusual combination of features has given rise to consider able confusion about the nature and consequences of the anonymit that Bitcoin provides. In particular, there is concern that the combi nation of scalable, irrevocable, anonymous payments would prov highly attractive for criminals engaged in fraud or money launder ing. In a widely leaked 2012 Intelligence Assessment, FBI an alysts make just this case and conclude that a key "advantage of Bitcoin for criminals is that "law enforcement faces difficul ties detecting suspicious activity, identifying users and obtainin

Privacy enhancements: so many choices?



Modified from Bitcoin Techniques and Arvind Narayanan, Malte Möser

Where does a given technique fall?

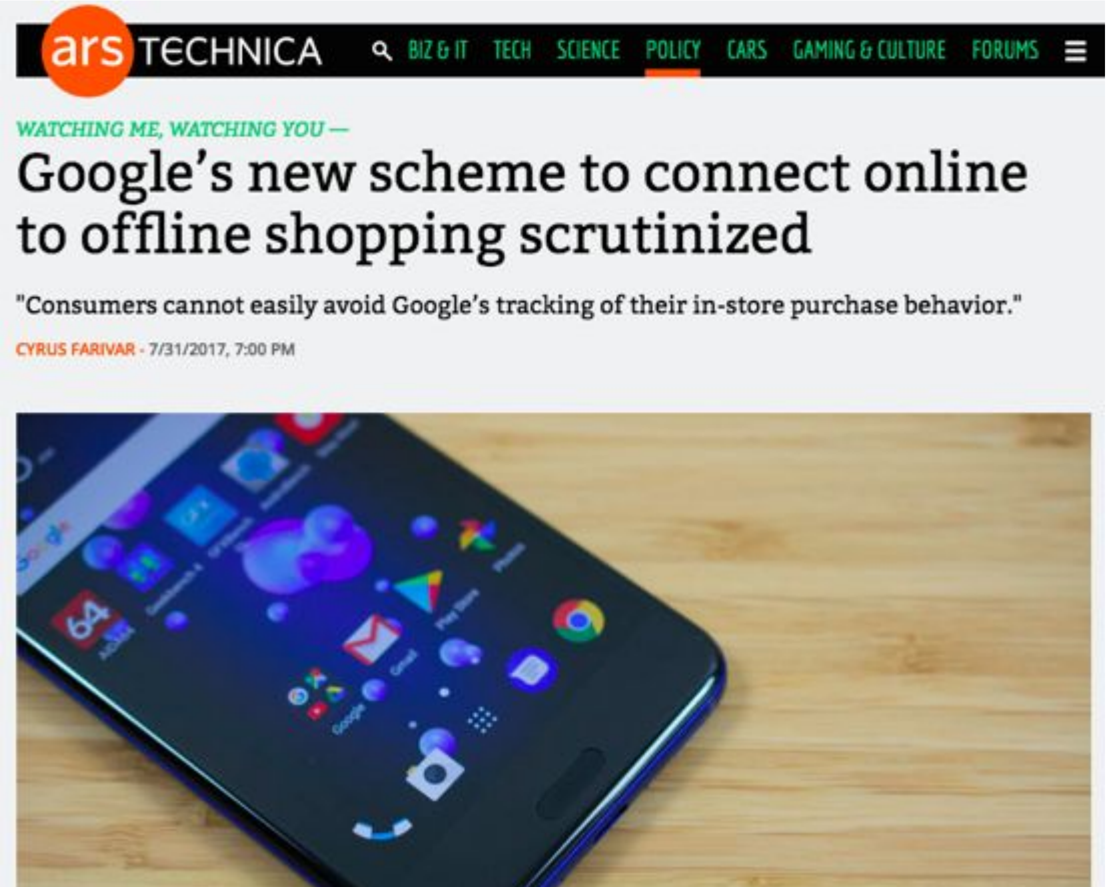


Evaluating privacy?

- Akin to evaluating privacy issues on the Internet in 1992
- Cannot measure with empirical attacks
  - Almost all transactions are speculative
  - Limited usage in daily lives
  - Researchers have data, cost, and ethics limitations
- Need to use thought experiments
- To do so, we must understand realistic threats

Some Real World Privacy Threats

This is your threat model:

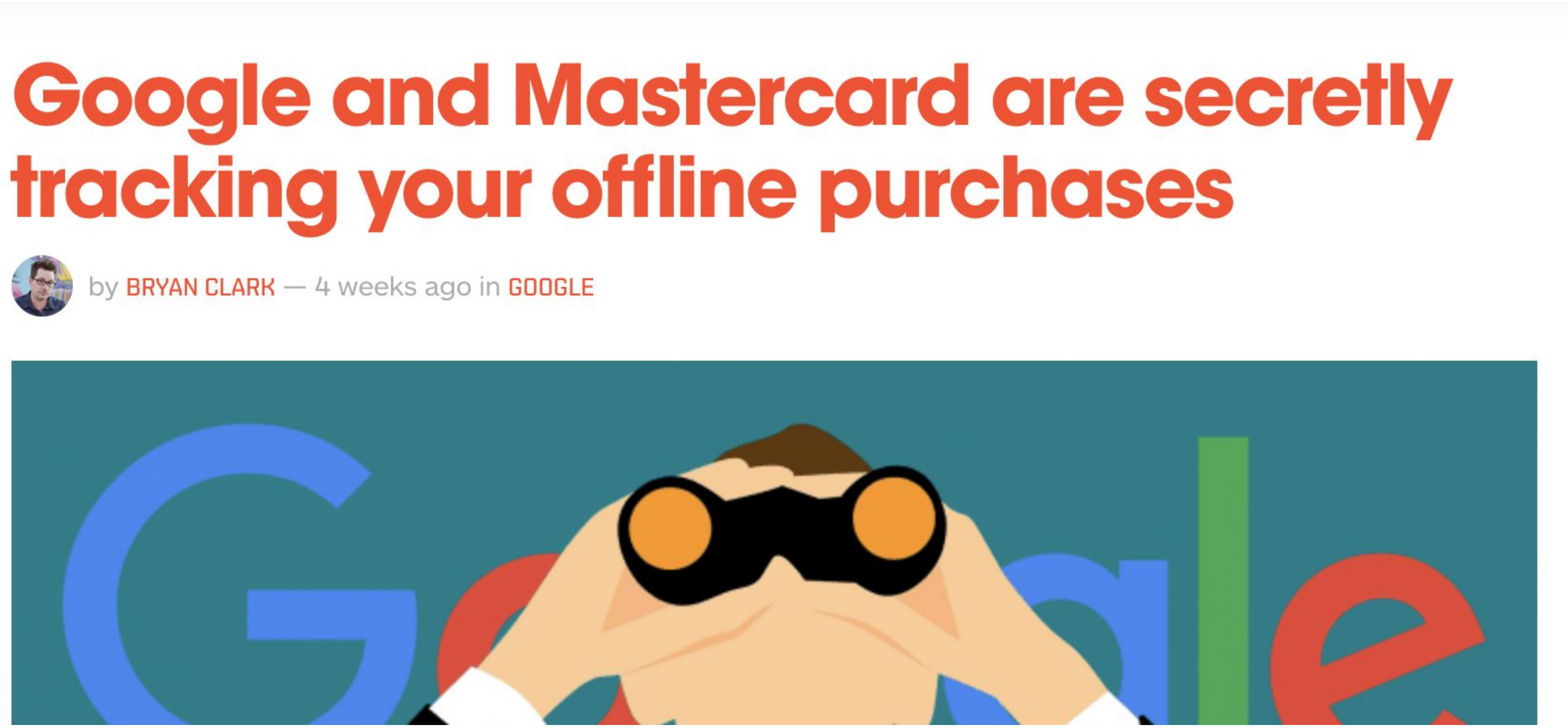


WATCHING ME, WATCHING YOU —

Google’s new scheme to connect online to offline shopping scrutinized

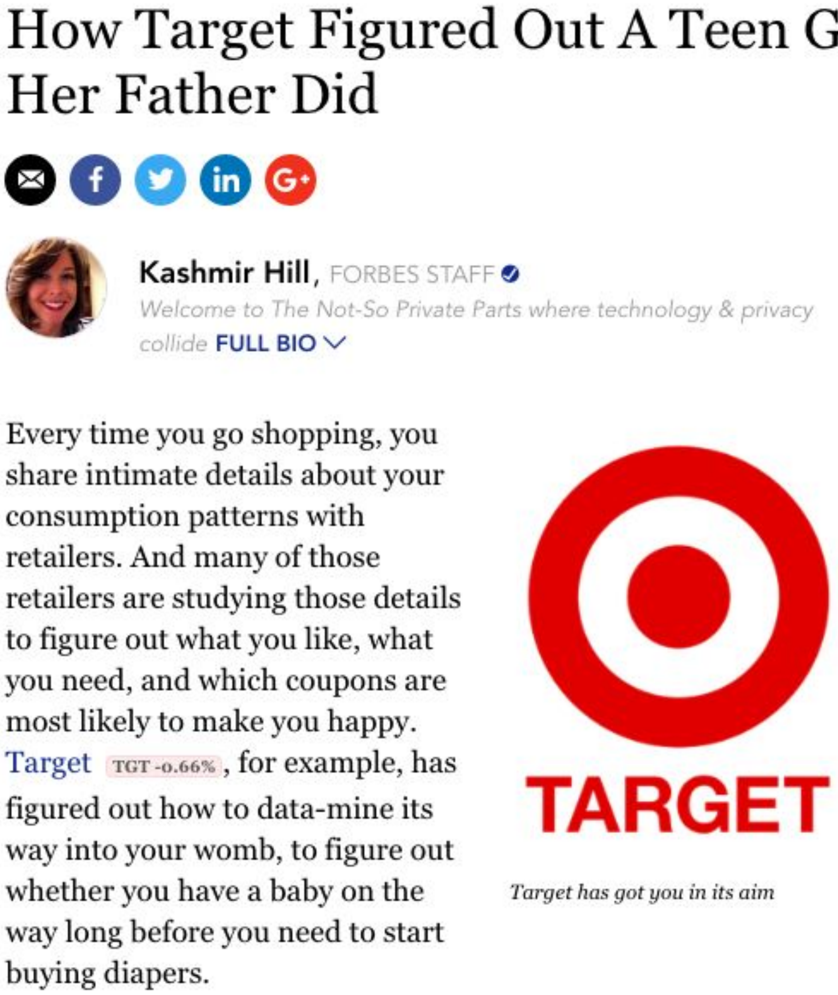
"Consumers cannot easily avoid Google’s tracking of their in-store purchase behavior."

CYRUS FARIVAR - 7/31/2017, 7:00 PM



Google and Mastercard are secretly tracking your offline purchases

by BRYAN CLARK — 4 weeks ago in GOOGLE



How Target Figured Out A Teen Girl Was Pregnant Before Her Father Did

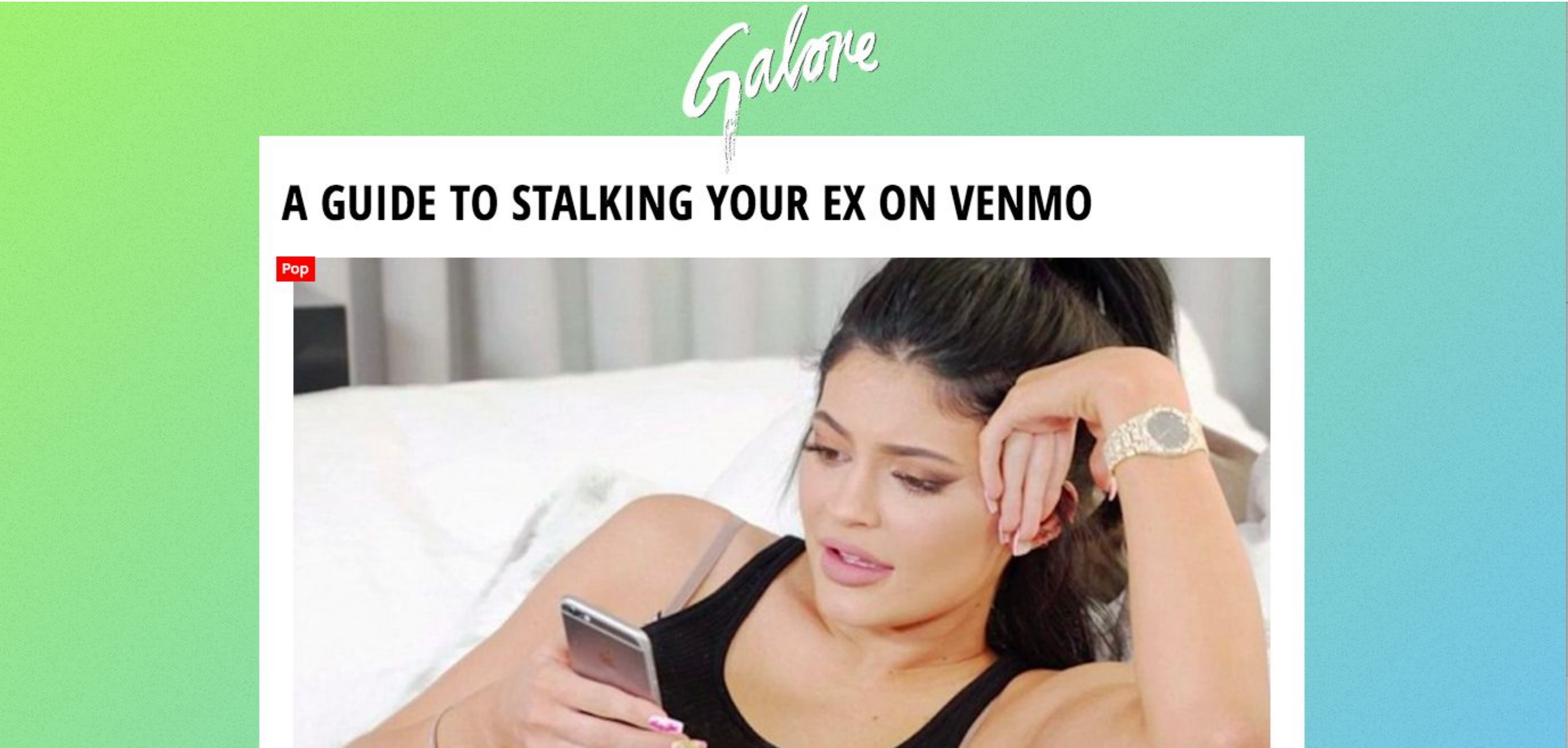
Kashmir Hill, FORBES STAFF

Welcome to The Not-So Private Parts where technology & privacy collide **FULL BIO**

Every time you go shopping, you share intimate details about your consumption patterns with retailers. And many of those retailers are studying those details to figure out what you like, what you need, and which coupons are most likely to make you happy. Target TGT -0.66%, for example, has figured out how to data-mine its way into your womb, to figure out whether you have a baby on the way long before you need to start buying diapers.

Target has got you in its aim

And this



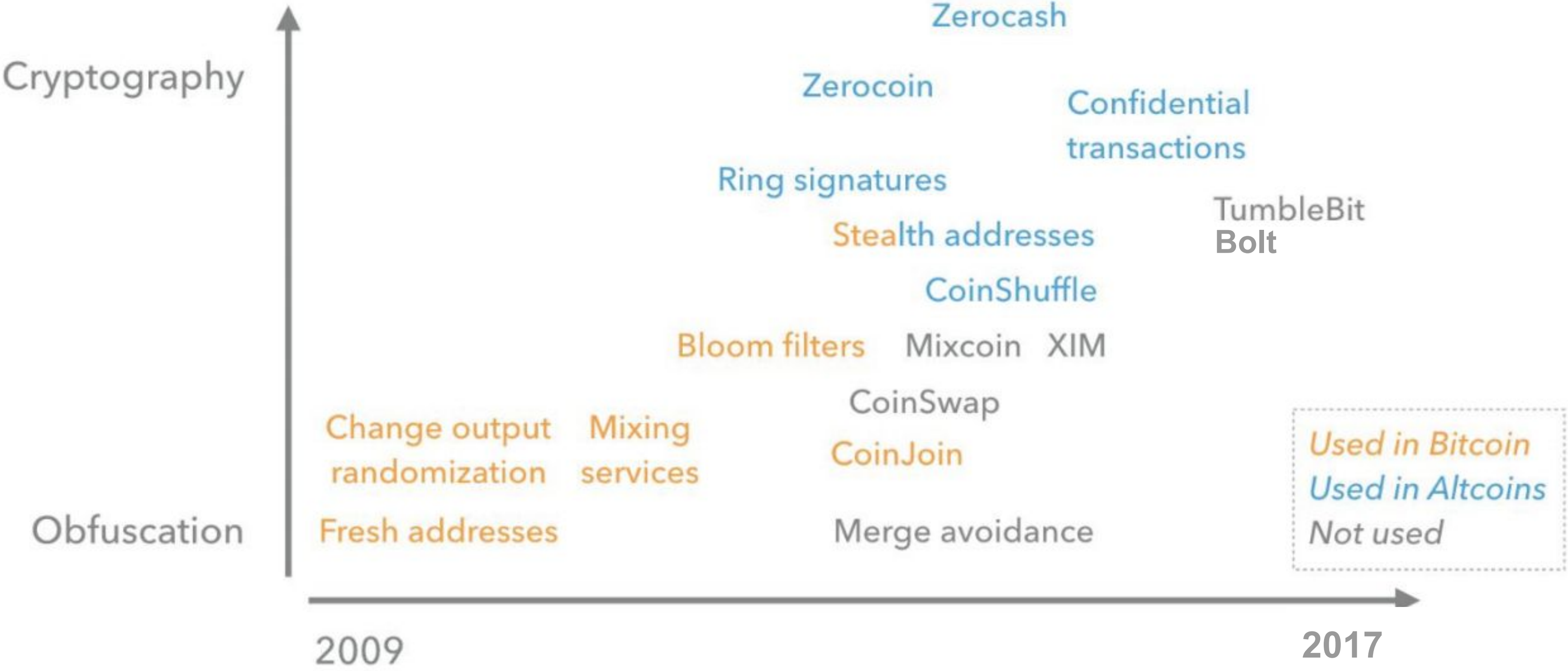
A GUIDE TO STALKING YOUR EX ON VENMO

Fungibility:

- Freshly mined coins sell for a premium
- Exchanges blocking customers based on transaction history
- Exchanges are not mere third party observers:
    - Know more than just the transaction graph
    - Make transactions on user’s behalf
- Akin to being private on the internet while using Google/Gmail/Maps/Android

What are the defenses?

In a world of AI/ML and targeted ads, ***plausible deniability*** is not a **plausible defense**.



Cryptography

Obfuscation

Zerocash

Zerocoin

Confidential transactions

Ring signatures

TumbleBit

Bolt

Stealth addresses

CoinShuffle

Bloom filters

Mixcoin

XIM

CoinSwap

Change output randomization

Mixing services

CoinJoin

Fresh addresses

Merge avoidance

Used in Bitcoin

Used in Altcoins

Not used

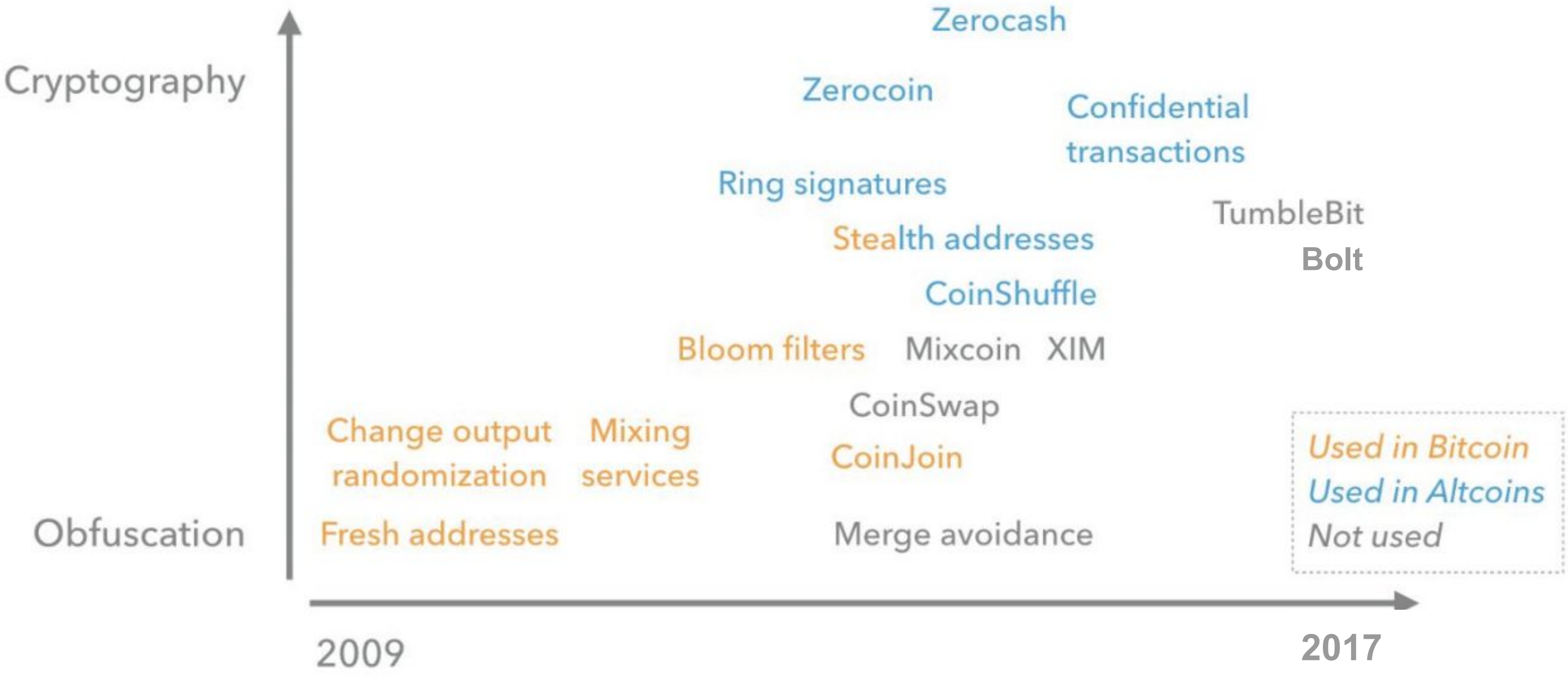
2009

2017

Modified from Bitcoin Techniques and Politics
Arvind Narayanan, Malte Möser

Blockchain privacy is not intuitive.

- Only threat is NOT a third party passive observer
- Must consider ***active*** attackers who:
  - Receives payments from targeted users
  - Sends payments to targeted users
  - Interact with third parties
- Consider obvious attacks:
  - Merchants who try and track customers
  - Users who try and identify a recipients real identity
  - Exchanges who ban customers for certain transaction types

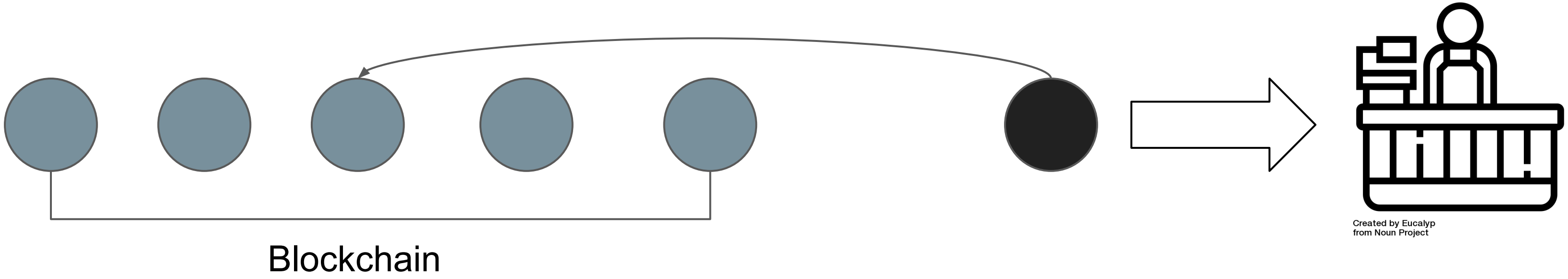


Modified from Bitcoin Techniques and Politics
Arvind Narayanan, Malte Möser

Privacy approaches

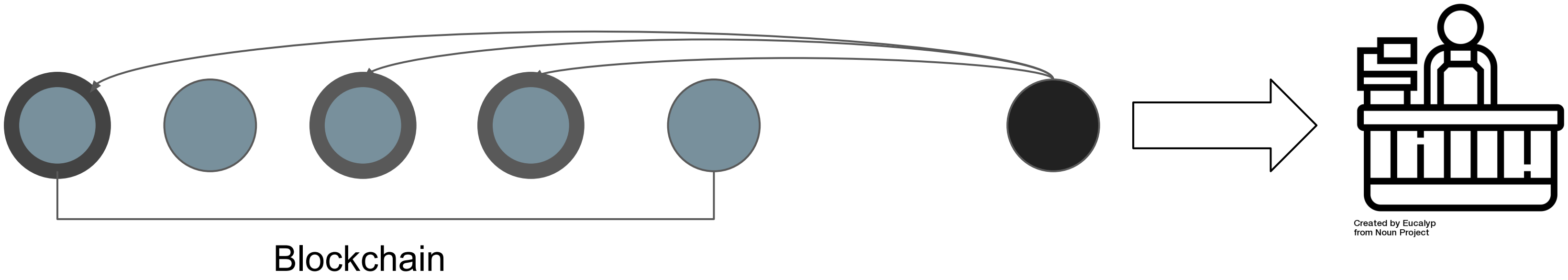
- Bitcoin (vanilla): explicitly identify origin of payment
- Decoy transaction based systems:
  - Pick e.g. 5 decoy source transactions to hide real origin
    - Coinjoin, Mimblewimble, etc. (decoys sampled from current transactions)
    - Cryptonote/RingCT(e.g Monero, etc) (decoys sampled from all of history)
- Zerocoin and Zerocash like (e.g. Zcash, etc)
  - Private transactions have no identified origin.

Payments in Bitcoin:



Created by Eucalyp
from Noun Project

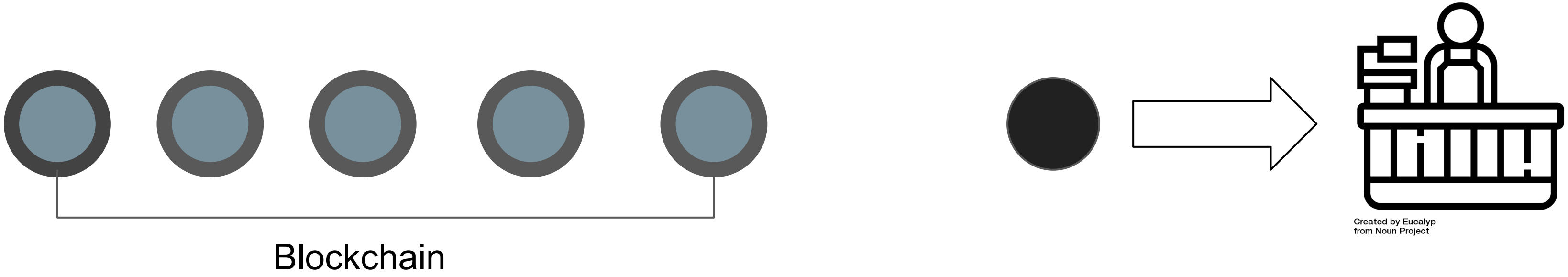
Payments in Decoy Systems (coinjoin/monero/etc)



- Coinjoin, etc : decoy set sampled from current transactions
- Cryptonote/RingCT(e.g Monero): decoy sampled from all of history)

Decoy transactions

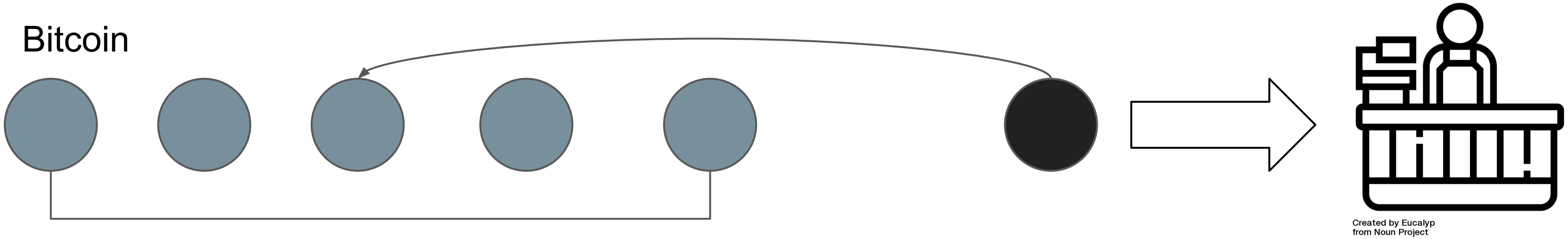
Payments in Zerocash



Blockchain

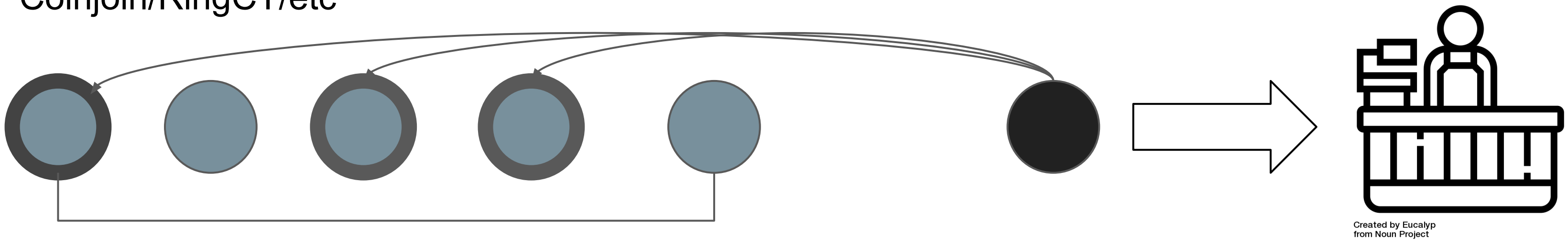
Created by Eucalyp
from Noun Project

Bitcoin



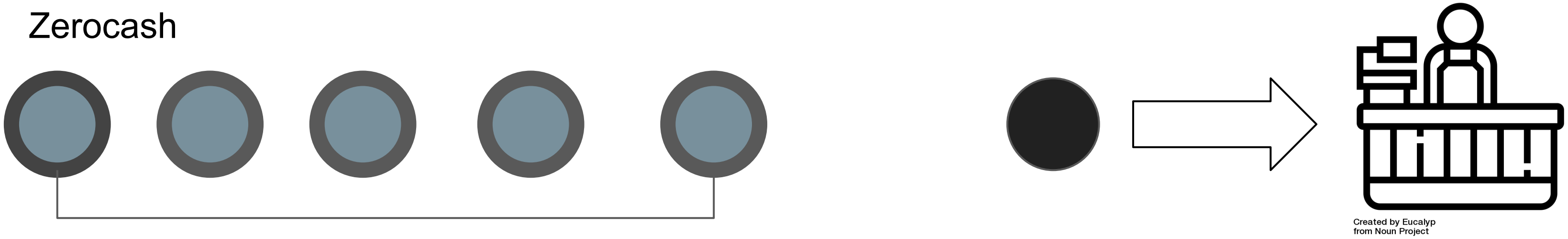
Created by Eucalyp
from Noun Project

Coinjoin/RingCT/etc



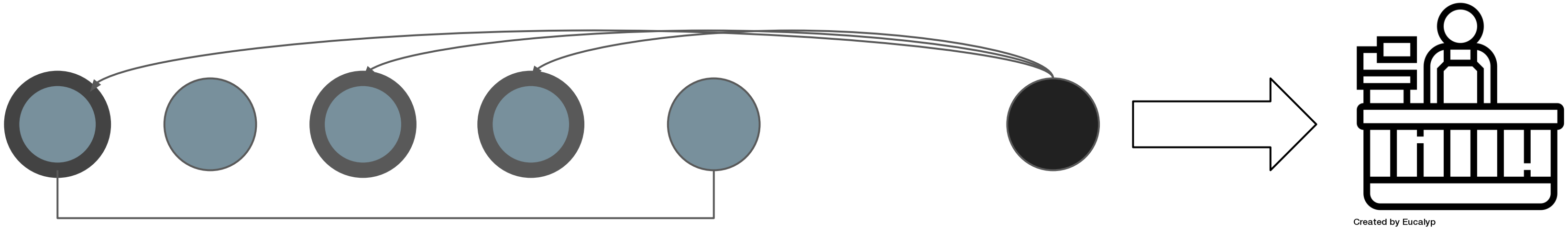
Created by Eucalyp
from Noun Project

Zerocash



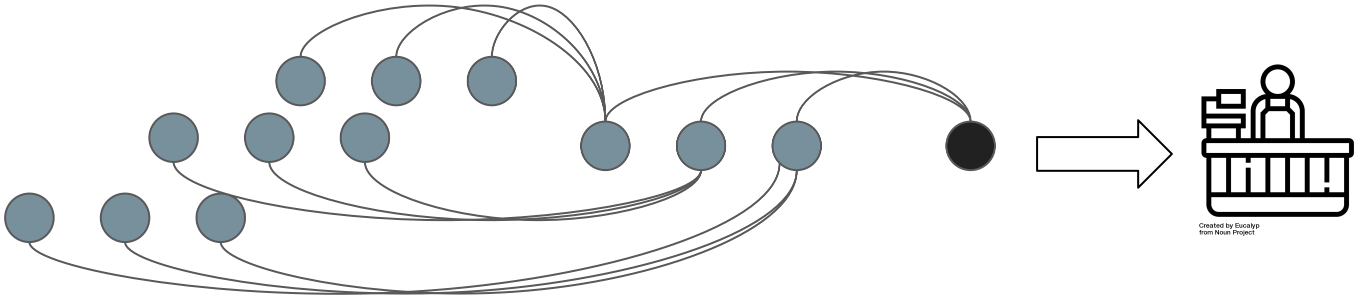
Created by Eucalyp
from Noun Project

Are decoy systems private?



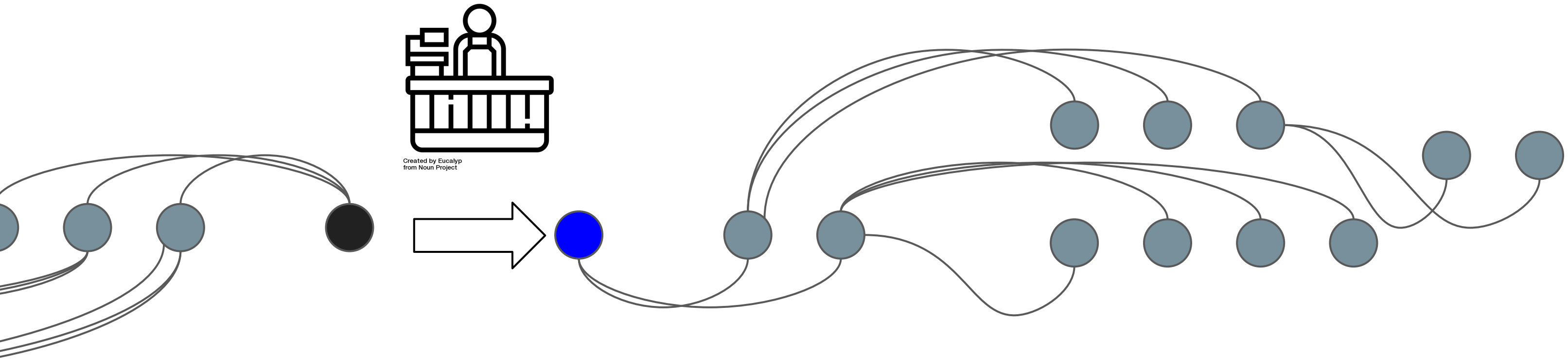
Created by Eucalyp
from Noun Project

Taint tree: possible ancestor payments



Created by Eucalyp
from Noun Project

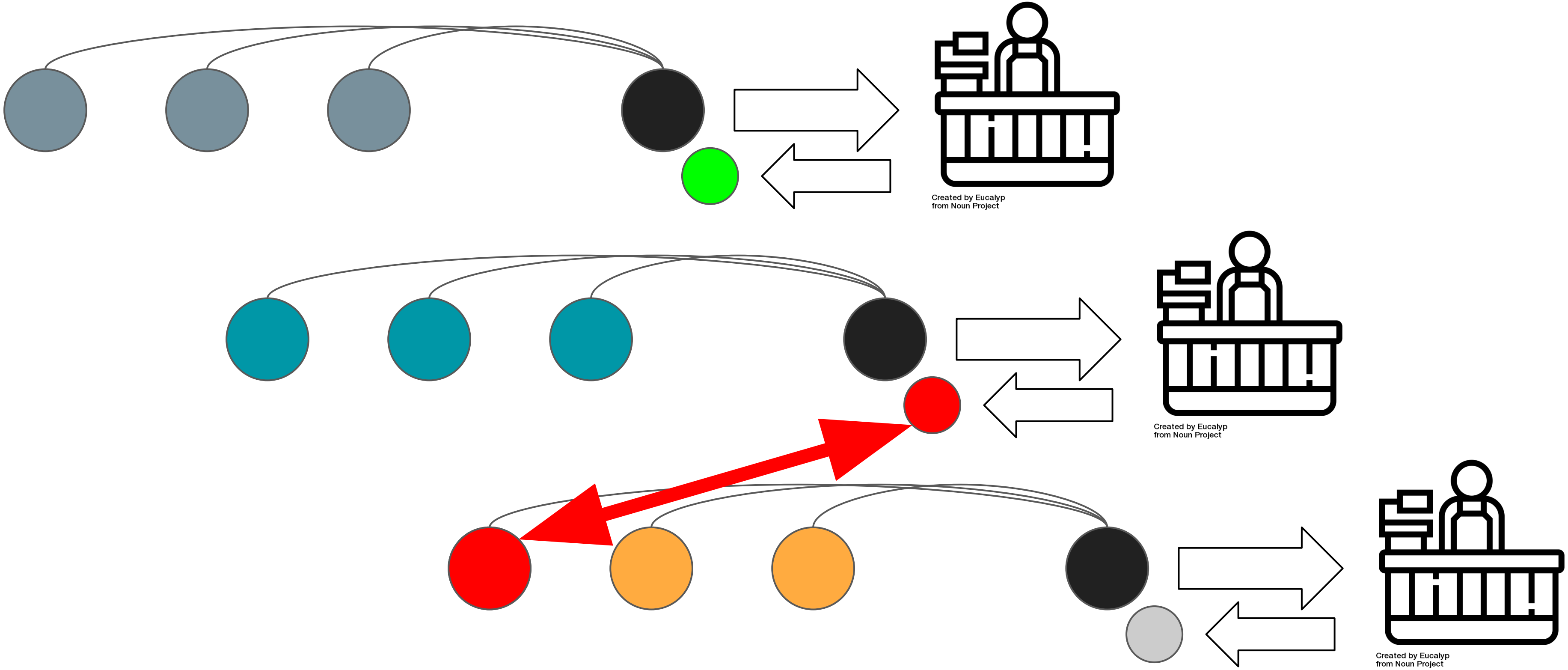
Taint free: following your money



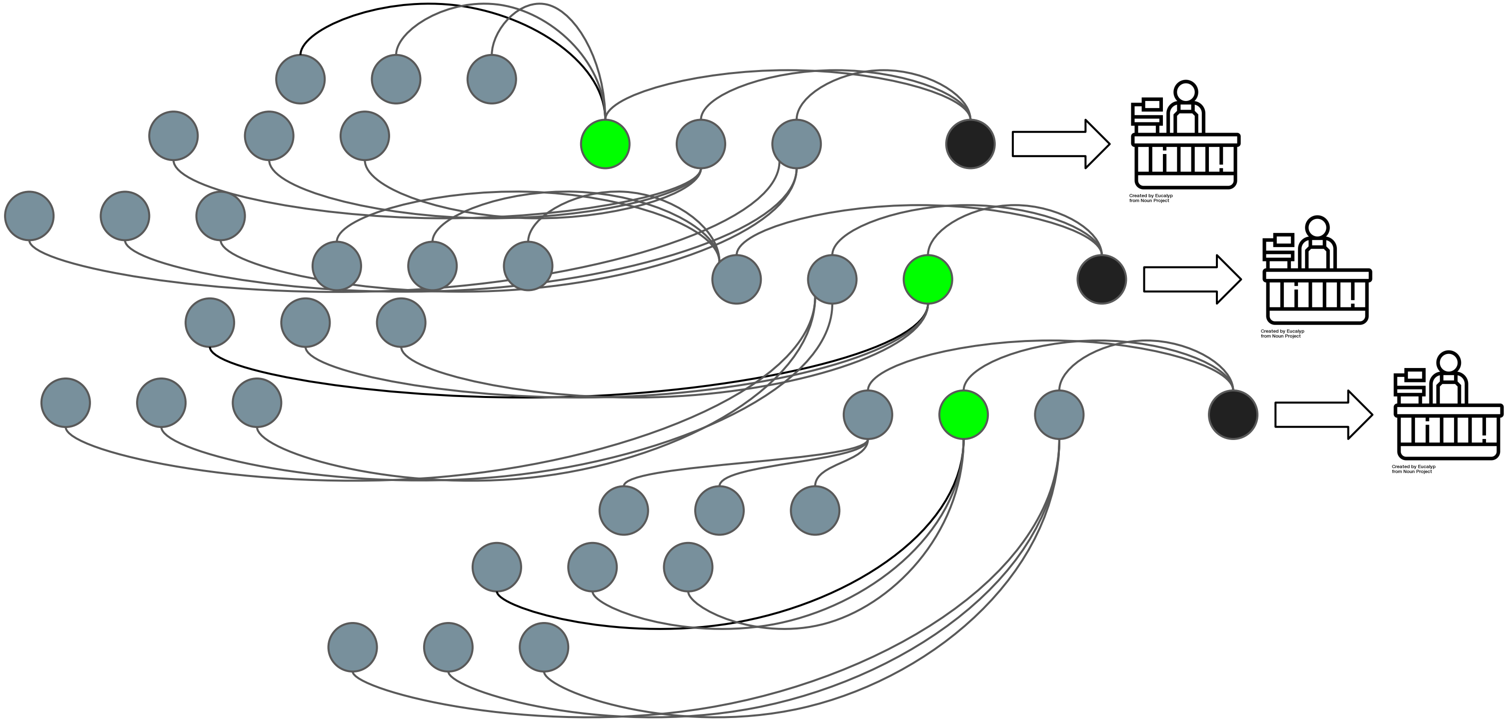
Created by Eucalyp
from Noun Project

Attacks

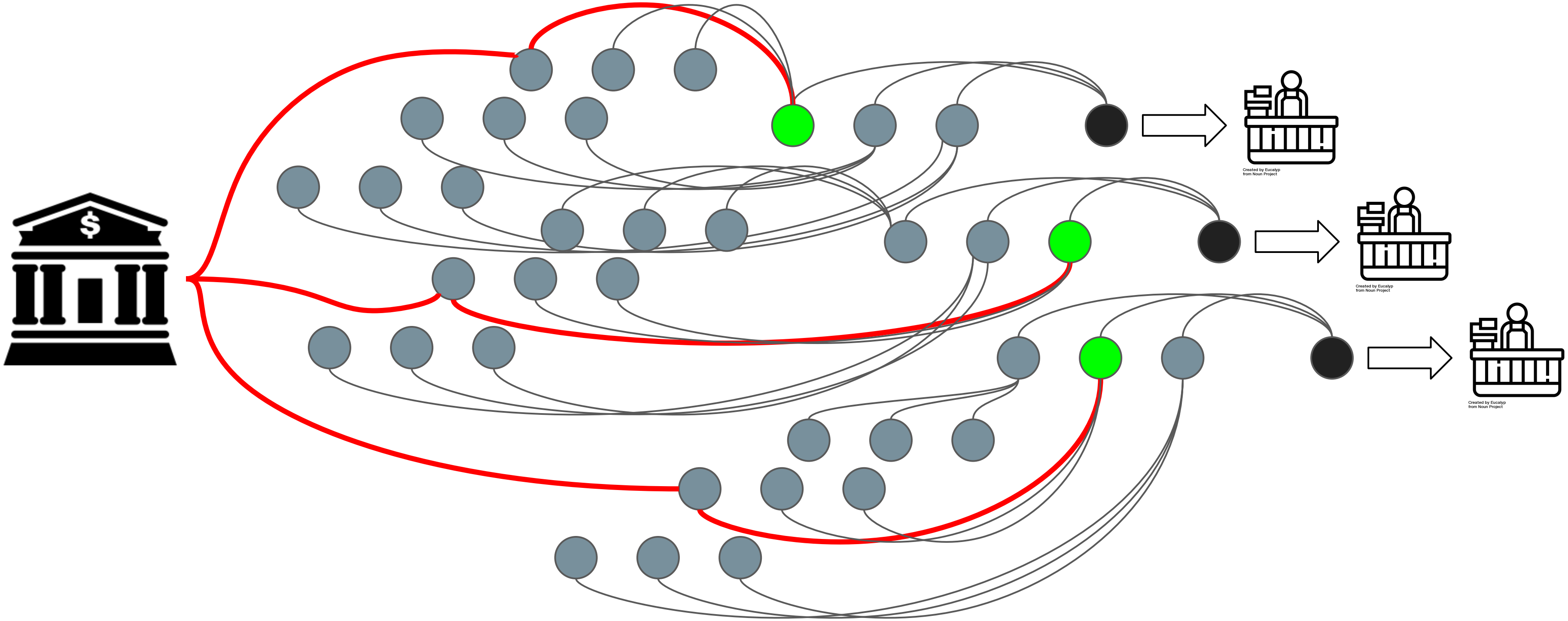
Tracking customers



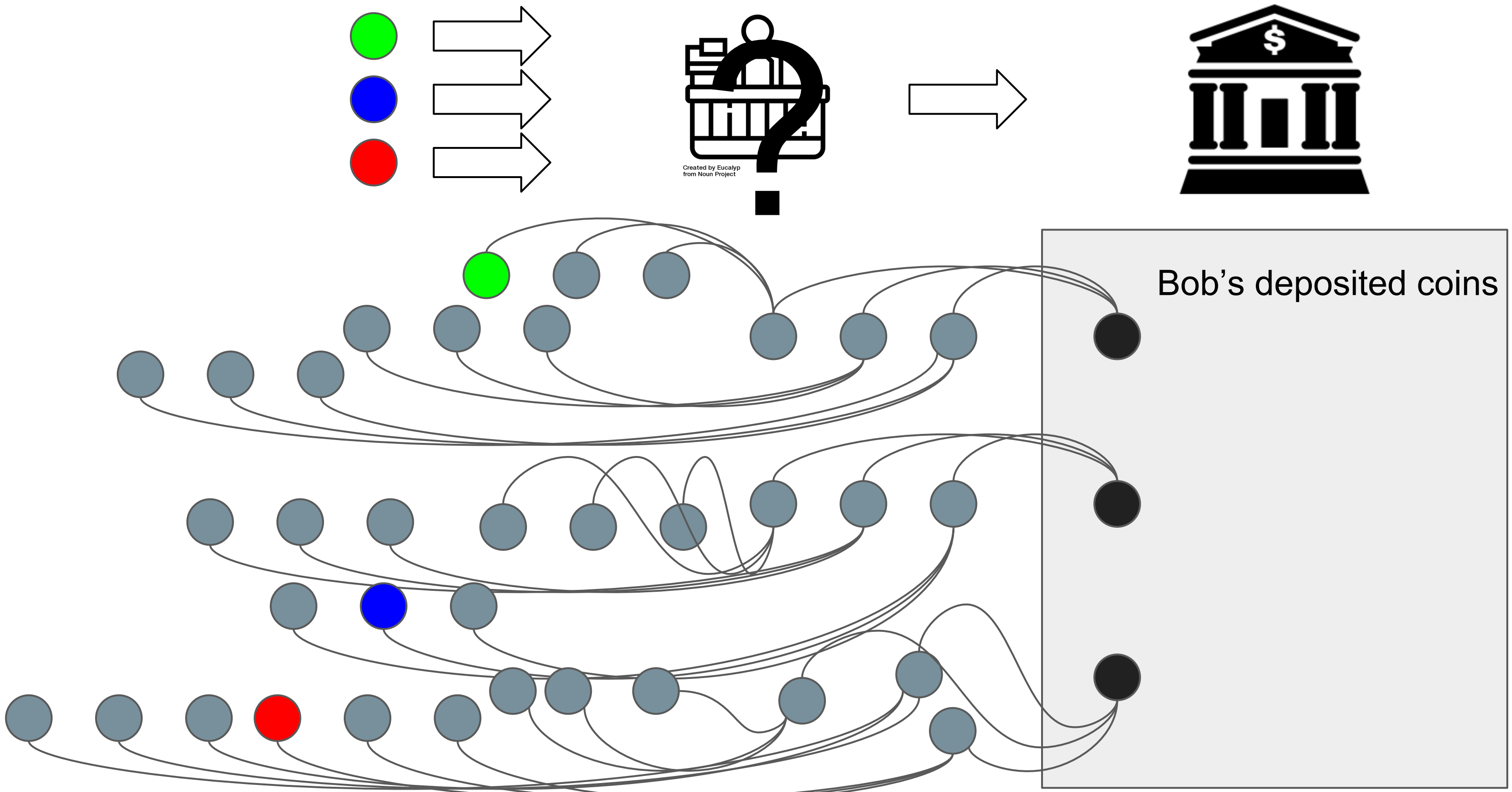
Tracking customers



Tracking customers


Created by Eucalyp from Noun Project
Created by Eucalyp from Noun Project
Created by Eucalyp from Noun Project

Identifying anonymous merchants

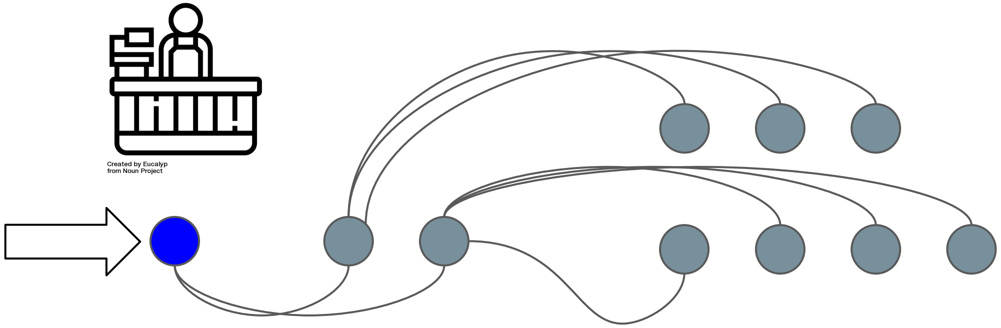


Created by Eucalyp
from Noun Project

Bob’s deposited coins

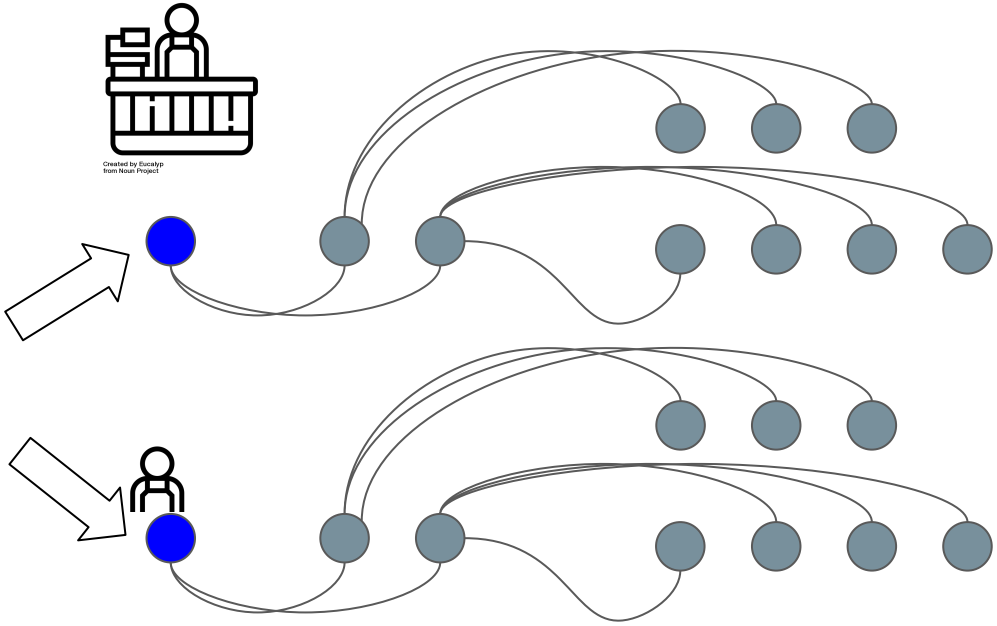
Repeated interactions with a malicious sender/recipient are dangerous

Taint tree: following your money

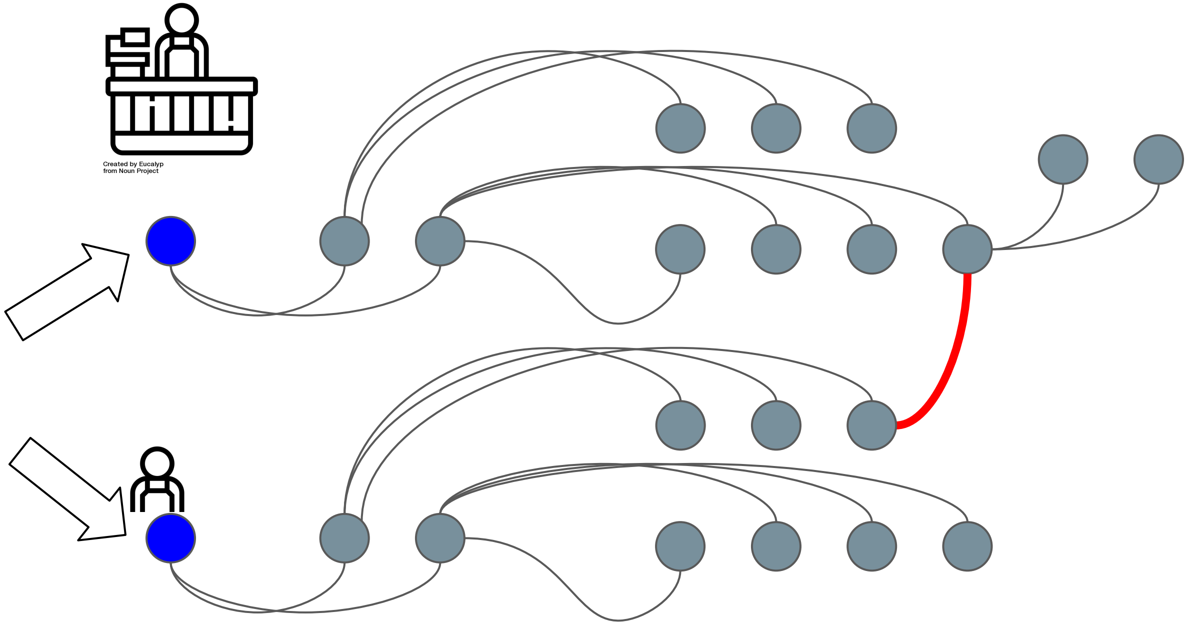


Created by Eucalyp
from Noun Project

Dust attack: confirming where money is spent

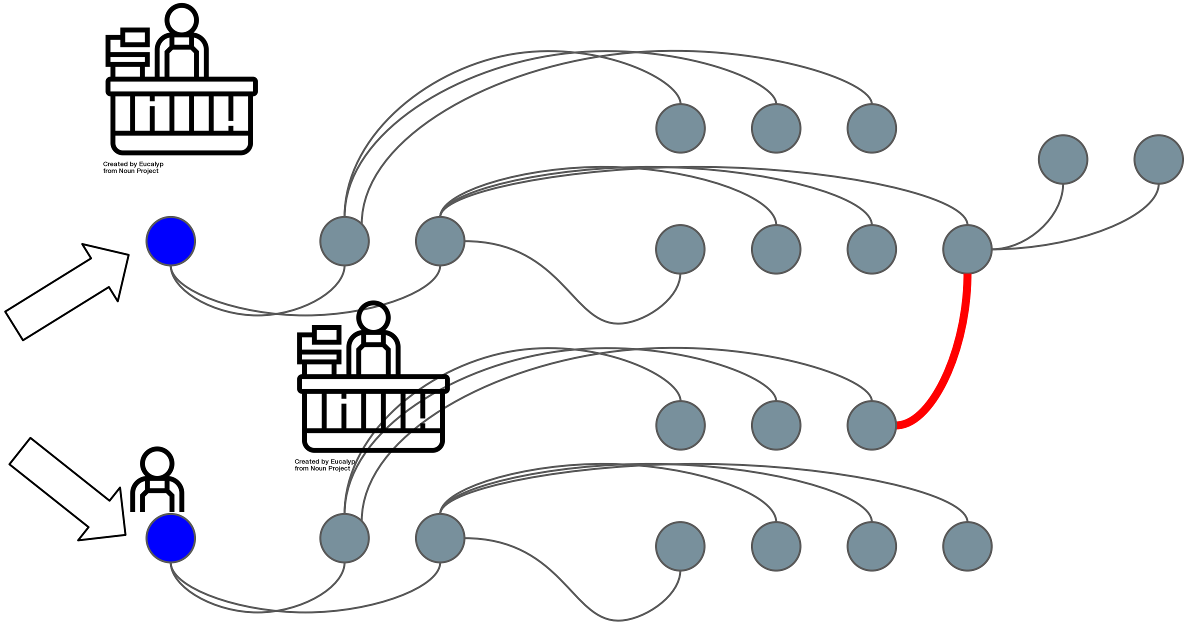


Dust attack: confirming where money is spent



Created by Eucalyp
from Noun Project

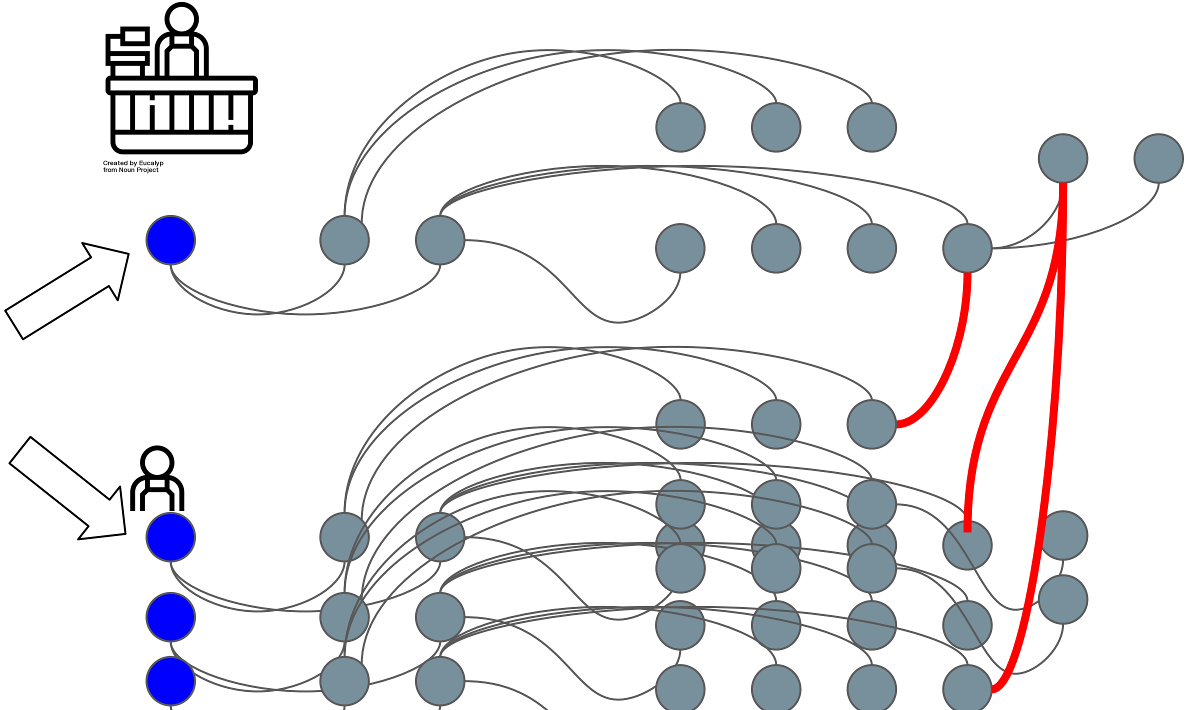
Dust attack: confirming where money is spent



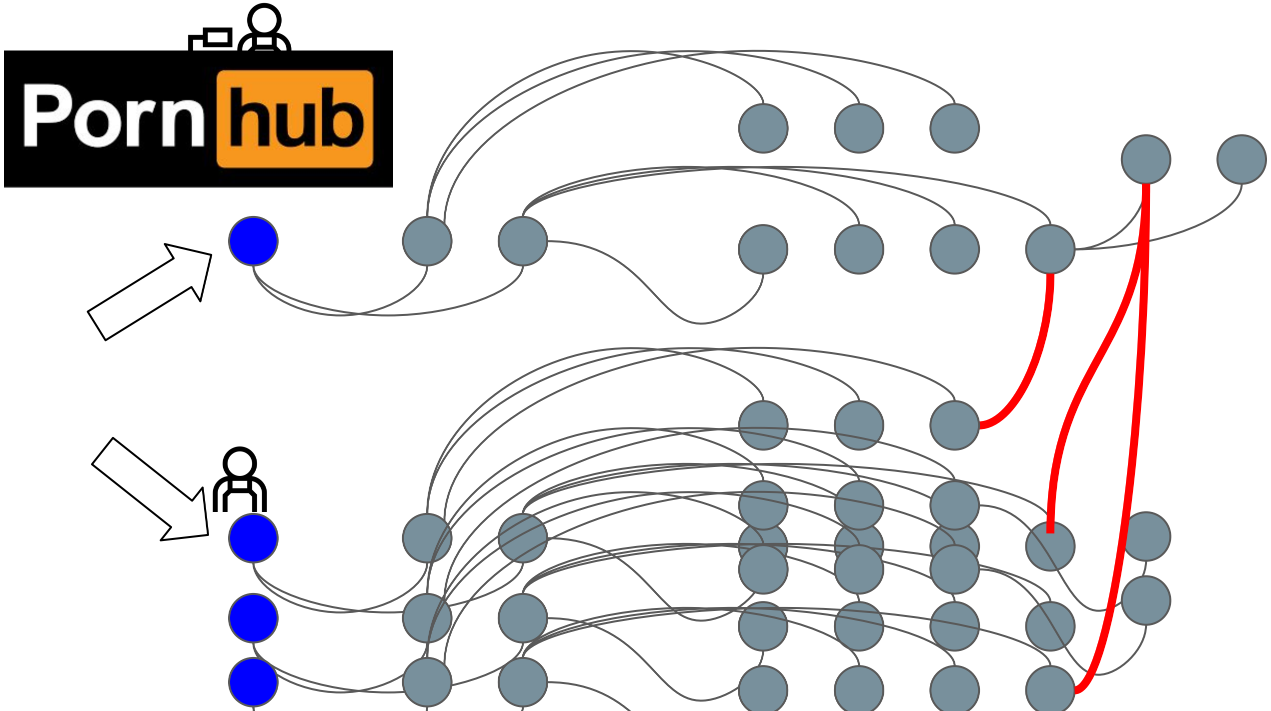
Created by Eucalyp
from Noun Project

Created by Eucalyp
from Noun Project

Dust attack: confirming where your money is spent



Dust attack: confirming where your money is spent



Limitations of decoy approaches:

- Customers can be tracked
  - Use of change transactions
  - Common origins in taint tree
- Anonymous Merchants can be identified
- Third parties can see where your money goes

Privacy approaches: perception

- Bitcoin (vanilla): explicitly identify origin of payment

NOT PRIVATE

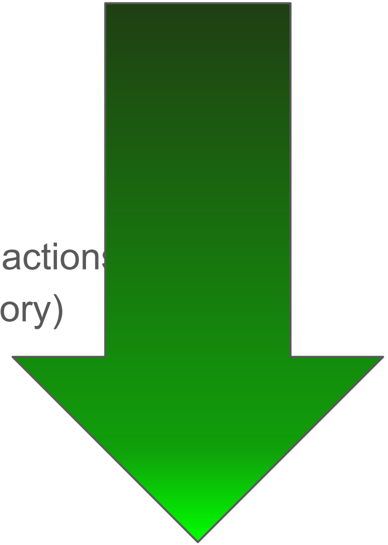
- Decoy transaction based systems:
  - Pick e.g. 5 decoy source transactions to hide real origin
    - Coinjoin, Mimblewimble, etc. (decoys sampled from current transactions)
    - Cryptonote/RingCT(e.g Monero) (decoys sampled from all of history)
- Zerocoin and Zerocash like (e.g. Zcash, etc)
  - Private transactions have no identified origin.

PRIVATE

Privacy approaches: reality

- Bitcoin (vanilla): explicitly identify origin of payment
- Decoy transaction based systems:
  - Pick e.g. 5 decoy source transactions to hide real origin
    - Coinjoin, Mimblewimble, etc. (decoys sampled from current transactions
    - Cryptonote/RingCT(e.g Monero) (decoys sampled from all of history)
- Zerocoin and Zerocash like (e.g. Zcash, etc)
  - Private transactions have no identified origin.

NOT PRIVATE



PRIVATE

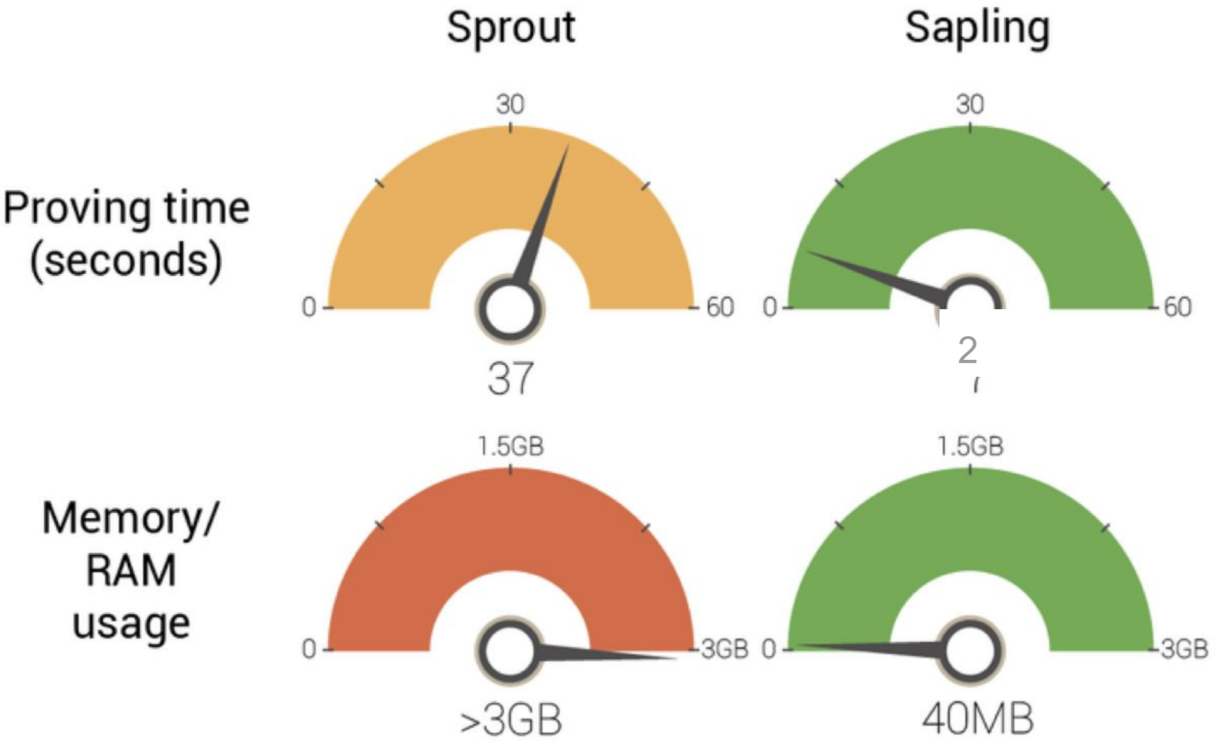
If you do use decoy schemes

- Decoy systems might work if
  - If your decoy set is very large (i.e. 5,000,000 instead of 5)
  - **Decoy sets substantially overlap across all recent transactions**
  - Decoys are sampled really carefully
- But:
  - We need much more rigorous analysis
  - A careful understanding of when things fail
  - Acknowledge limitations

Scalable decoy schemes

- Cannot have O(decoy set size) sized transactions
- Need logarithmic scaling for size/ transaction generation
- Use a Zerocash style system:
    - Transactions outputs are commitments to (value, recipient address)
    - Merkle Tree over some fraction of UTXO set
    - Zk-proof that origin exists in the UTXO merkle tree.
- Pick a zk-proof technology you like (zkSNARKs, bullet proofs, STARKs, MPC in head,etc)
- Pick a merkle tree depth **d** that the zk circuit is efficient
- Your decoy set is now 2^**d**
- **Somehow sample decoys securely**

Strongly private protocols are getting faster



Think critically about scalability vs privacy

- Cryptocurrencies need some privacy solution:
    - Maybe on chain
    - Maybe in layer two
- By all means prioritize scaling over privacy, but understand the limitations of what you have:
    - Your threat model isn’t just passive observers
    - Adding some privacy doesn’t make a protocol private
    - Attacks only get better
- Privacy problems don’t magically go away with small tweaks

Questions?

Ian Miers

@secparam

Cornell Tech/ Zcash foundation