Decentralized Anonymous Credentials

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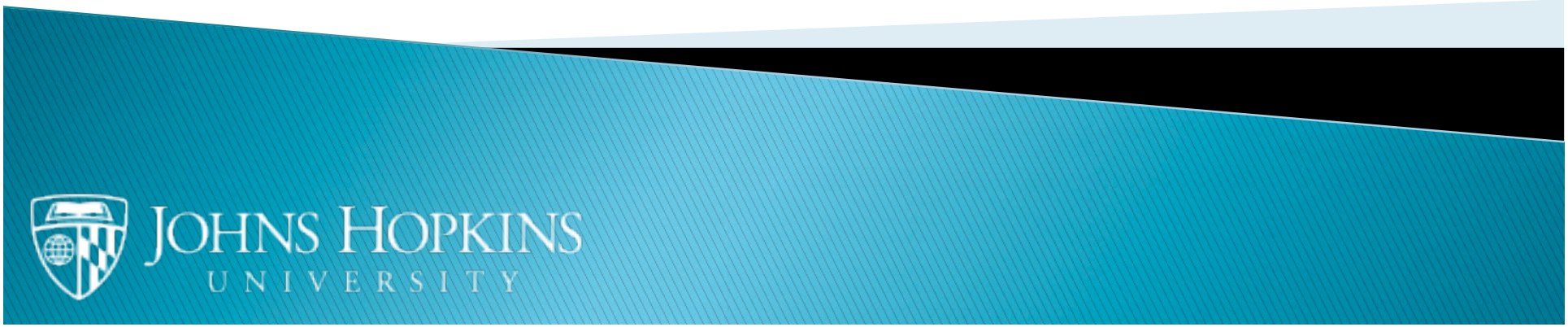
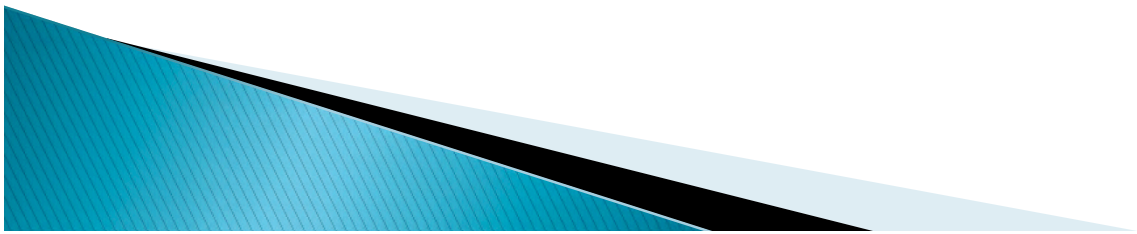


Privacy and Identity on the Internet

- Cannot make statements of identity privately
- But what about identity attributes?



Privacy and Identity on the Internet

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"Welcome to the club!"

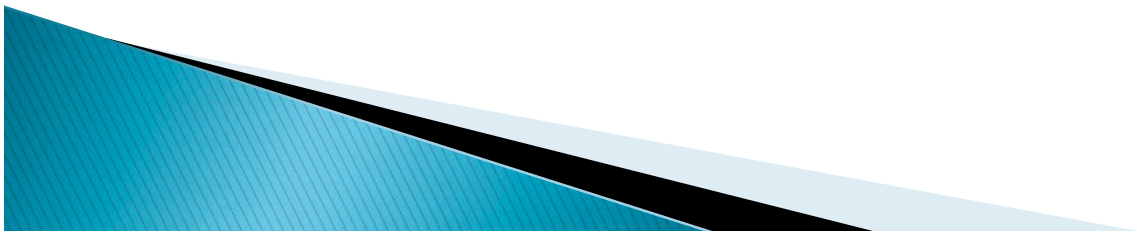
Privacy and Identity on the Internet

"Welcome to the club!"

Privacy and Identity on the Internet

Anonymous Credentials

- Introduced by Chaum [Chaum85] and extended in [Brands00, CL01, CL02, CL03, BCKL08,…]
- Prove that you have a credential issued by some organization without revealing anything other than that you have the credential
- Standard techniques use a specialized digital signature



Example of Anonymous Credentials

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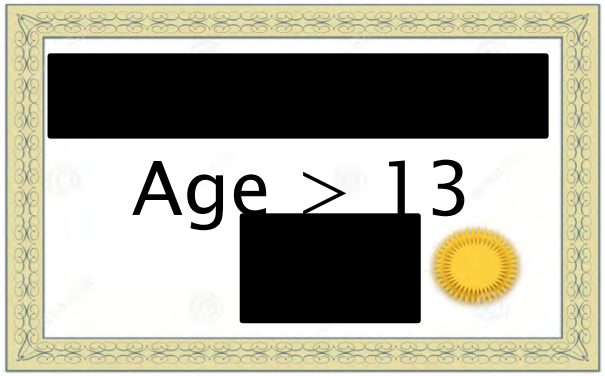


Example of Anonymous Credentials

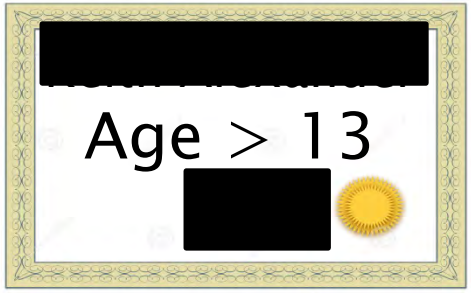
Keith
Age = 62
Signature

[redacted]
Age > 13
[redacted]

Problems?

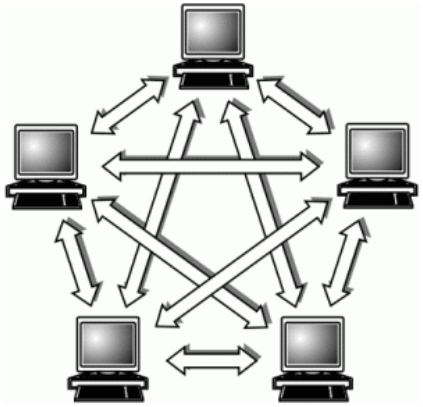

Birth Certificate


Keith
Age = 62
Signature


[redacted]
Age > 13
[redacted]


JUSTIN BIEBER
FAN CLUB

Solution?

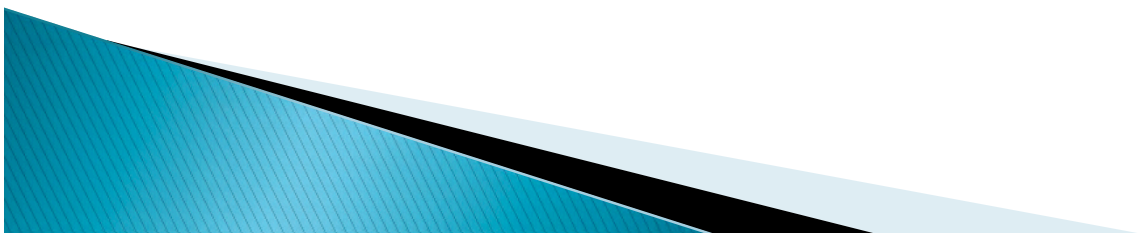


Keith
Age = 62
Signature

[redacted]
Age > 13
[redacted]

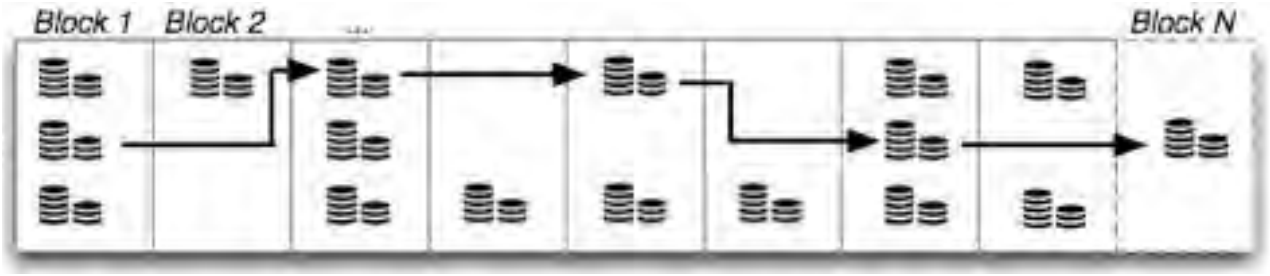
Our Contribution: Decentralized Anonymous Credentials

- Related to our electronic cash proposal [MGGR13]
  - Zerocoin (decentralized e-cash)
- **Decentralized** anonymous credentials
  - Decentralized credential issuance
  - Decentralized identity certification
  - Requires:
    - Public append-only ledger
    - Publicly verifiable identity claims



Public Append-Only Ledger

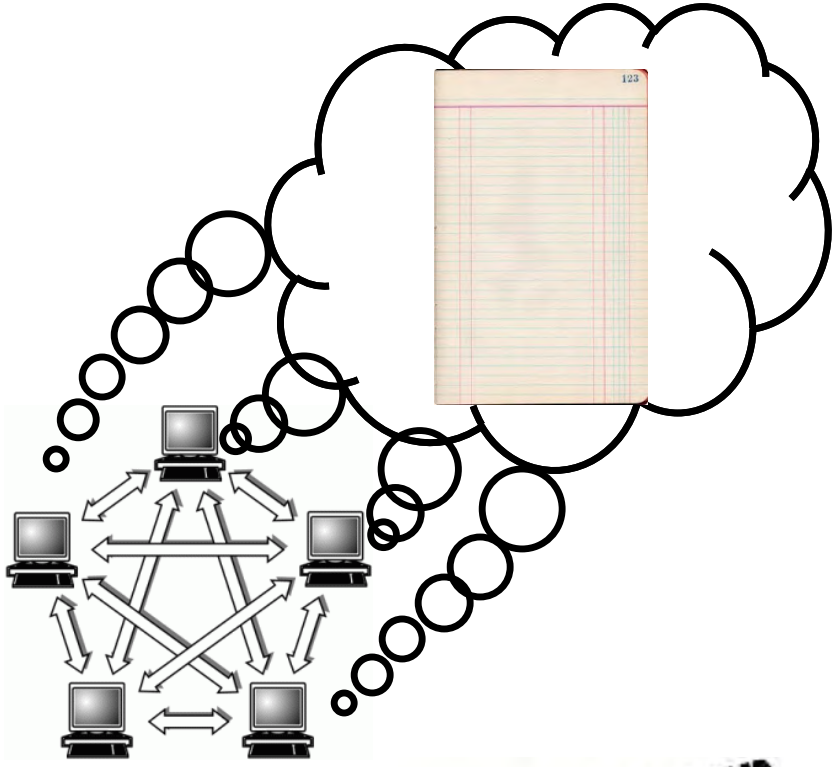
- Central ledger (audited by users)
- Broadcast networks
- Distributed consensus network
  - Bitcoin block chain



Publicly Verifiable Identity Claims

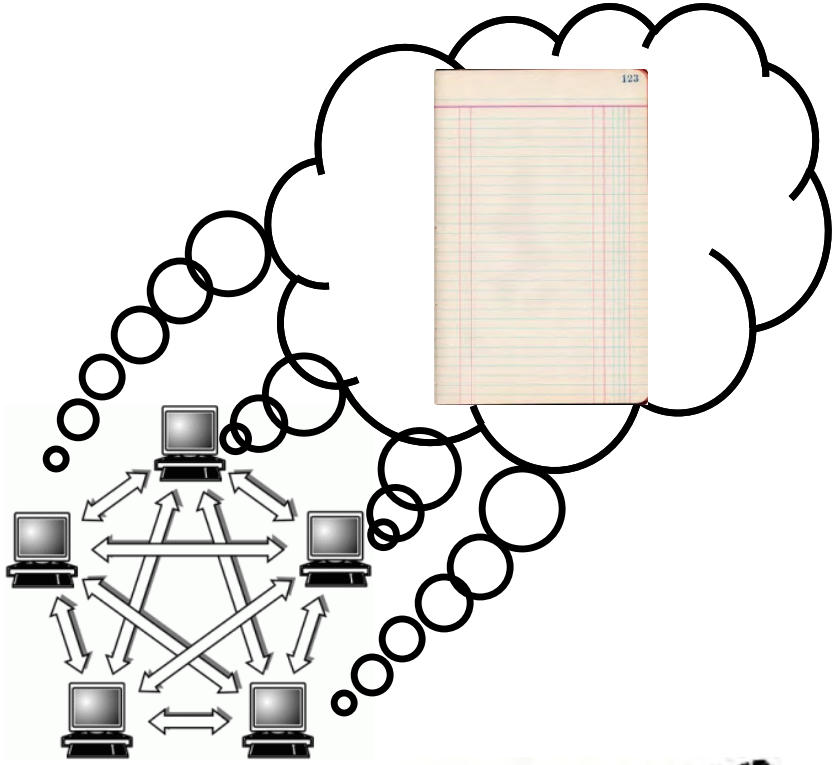
- Identity assertions are frequently publicly verifiable
- So why bother with (decentralized) anonymous credentials?
- Just because an identity assertion is publicly verifiable does not mean we want to link all of the information to every interaction!

Overview



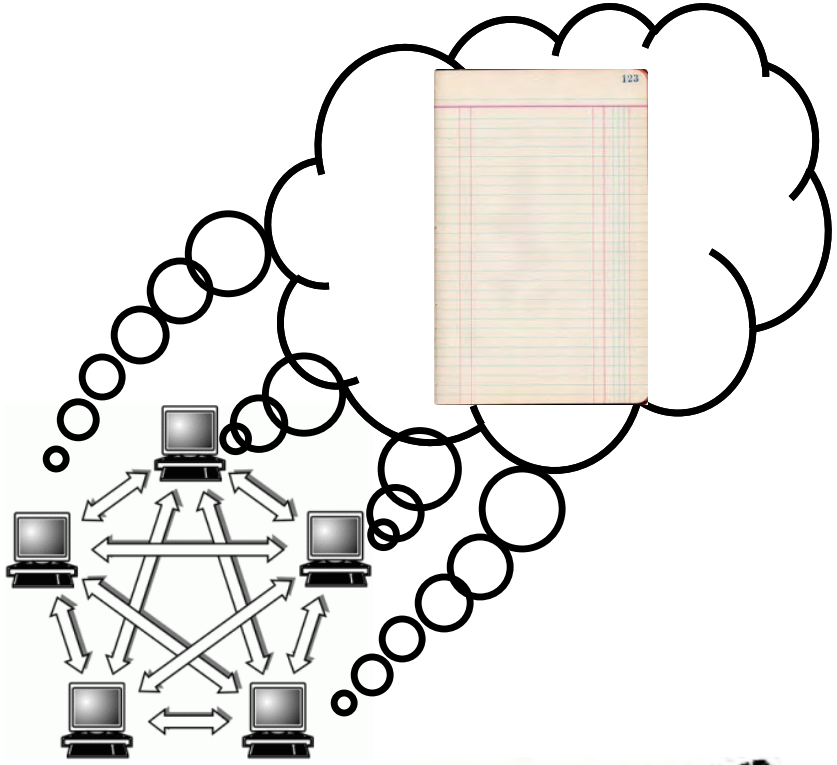
Overview

$cred$



Overview

$cred$



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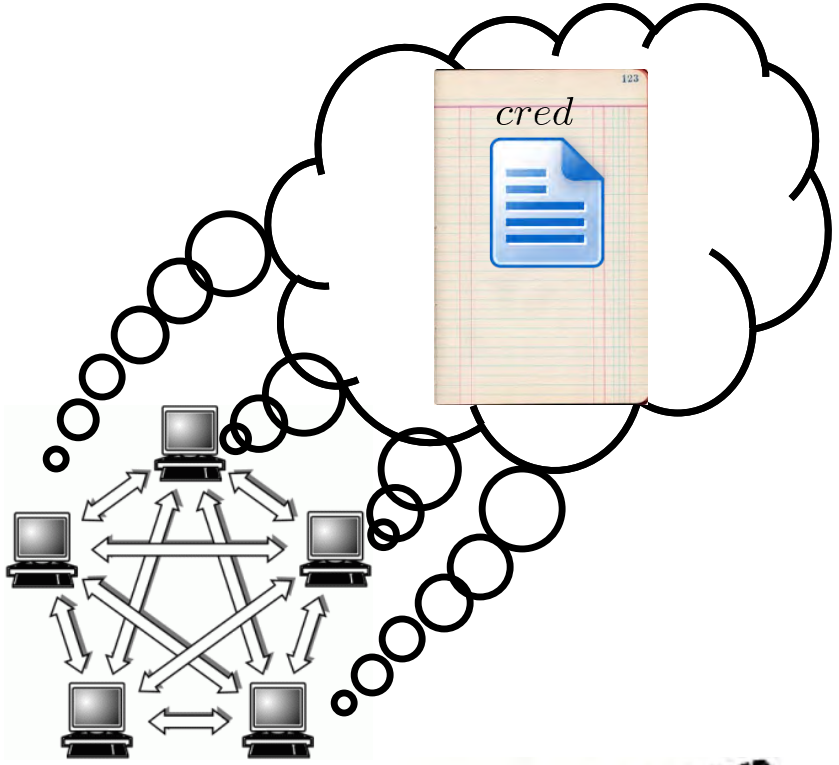
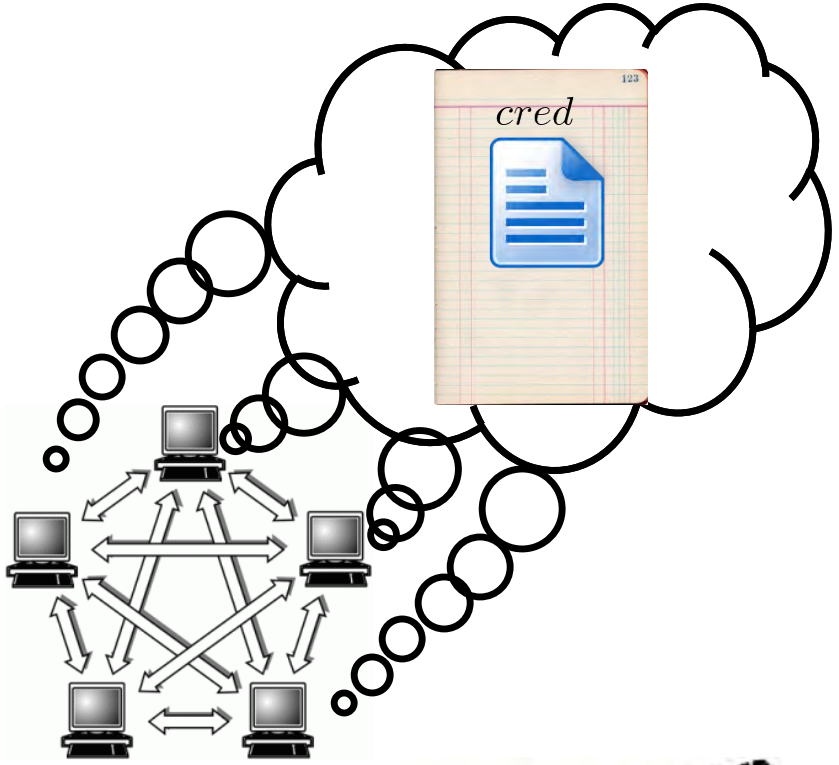
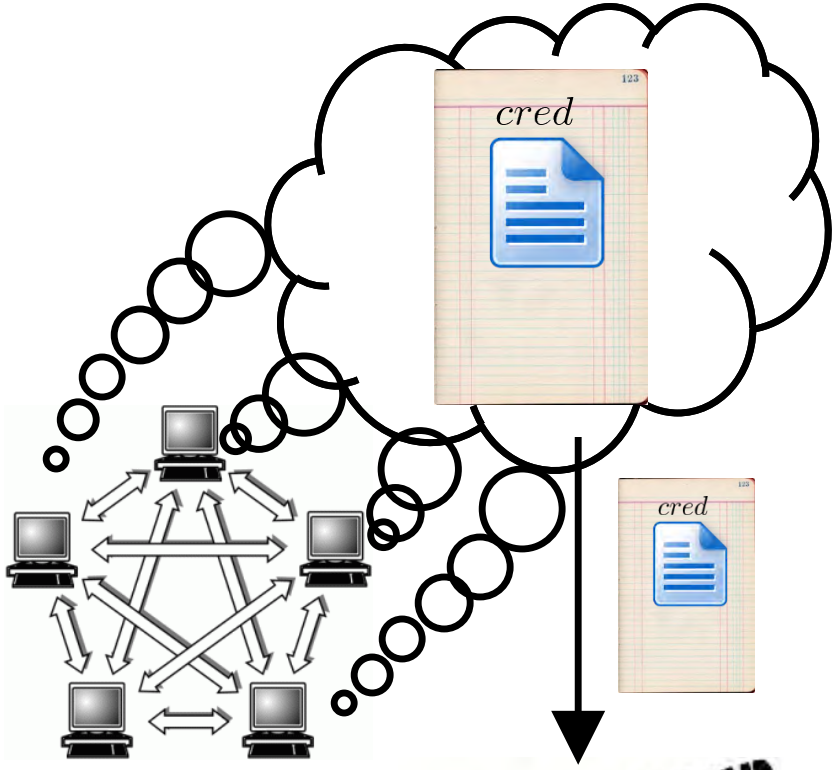


Overview



"A credential on the ledger says age > 13."

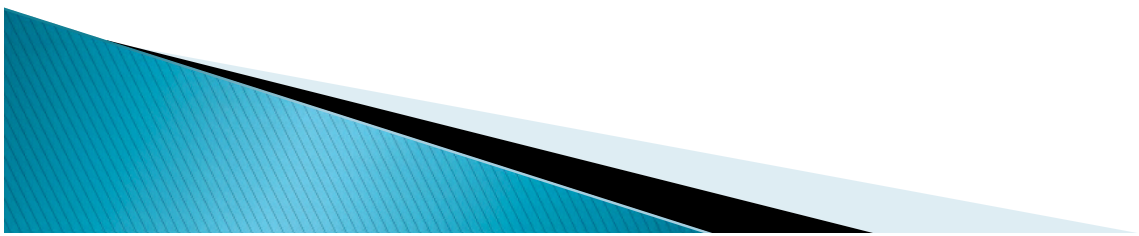
Overview



"A credential on the ledger says age > 13."

Cryptographic Building Blocks

- Commitments
- Zero-knowledge proofs
- Accumulators



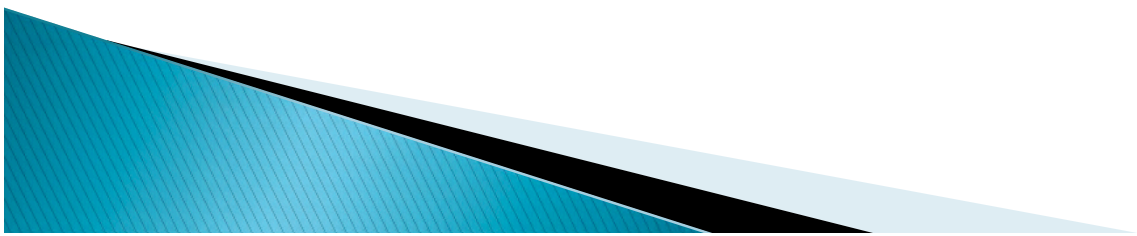
Commitments

- Allow you to commit to and later reveal a value
- Binding: value cannot be tampered with
- Hiding: value cannot be read until revealed
- We use Pedersen commitments

$$C = g^x h^r \bmod q$$

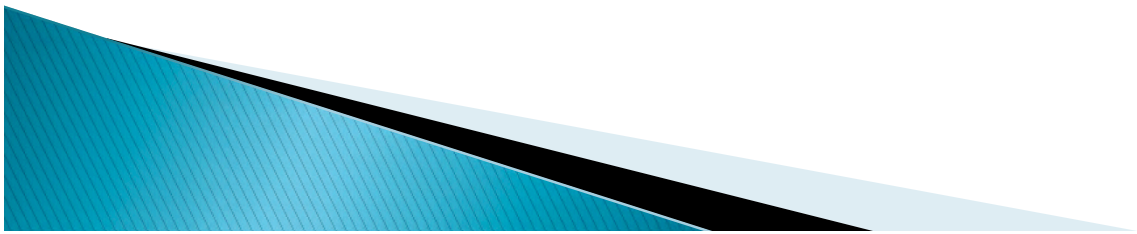
Zero-knowledge Proofs

- Zero-knowledge [Goldwasser, Micali 1980s, and beyond]
- Prove a statement without revealing <u>any other information</u>
- Specific variant: non-interactive proof of knowledge
- Here we prove we know:
  1. The opening for a credential
  2. That the credential is in the ledger



An inefficient approach…

- Inefficient proof
  - Identify all valid credentials in the ledger (call them $C{\downarrow}1$,..., $C{\downarrow}N$)
  - Prove that you know the opening of a credential C and $C = C{\downarrow}1 \vee C = C{\downarrow}2 \vee \ldots \vee C = C{\downarrow}N$
  - This “OR” proof is O(N)



Cryptographic Accumulators

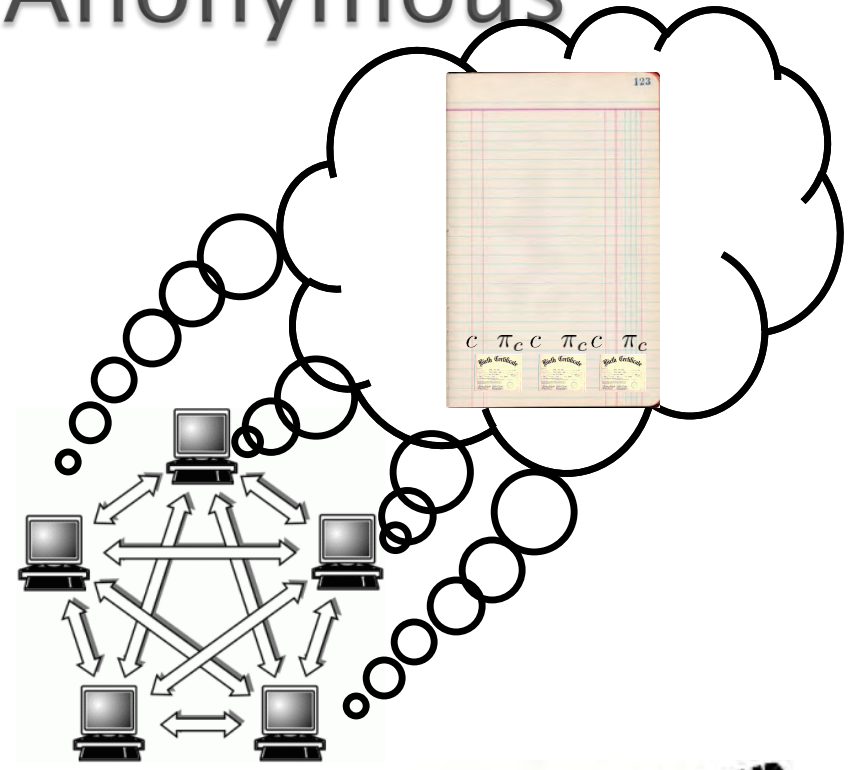
- Allow constant size set membership proofs
- Strong RSA accumulator originally due to Benaloh and de Mare
- Efficient proof for accumulation of primes proposed by Camenisch and Lysyanskaya '01

$$N = p \cdot q, u \in QR_N (u \neq 1)$$

$$A = u^{C_1 \cdot C_2 \cdot \ldots \cdot C_n} \bmod N$$

$$w_i = u^{C_1 \cdot C_2 \cdot \ldots \cdot C_{i-1} \cdot C_{i+1} \cdot \ldots \cdot C_n} \bmod N$$

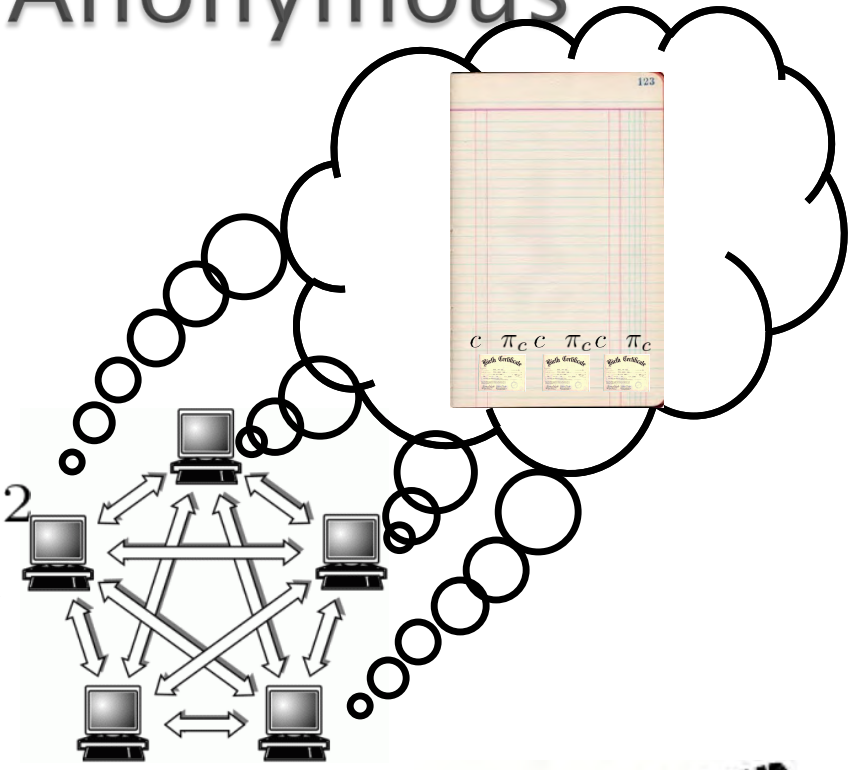
Basic Decentralized Anonymous Credentials



Basic Decentralized Anonymous Credentials

$$c = g_0^r g_1^{sk} g_2^{\text{age}=62}$$

π_c



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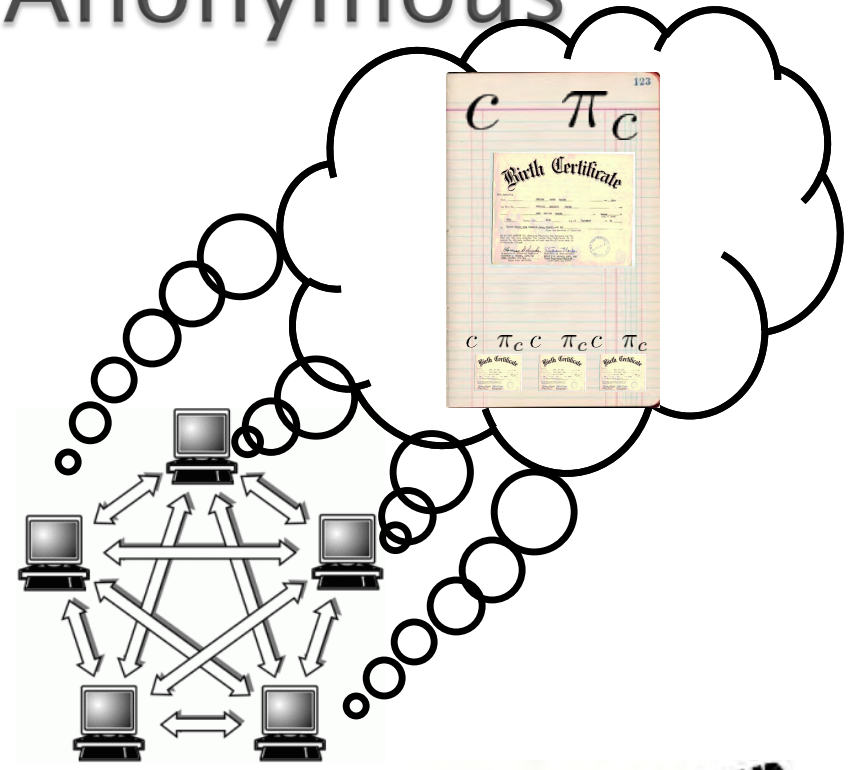
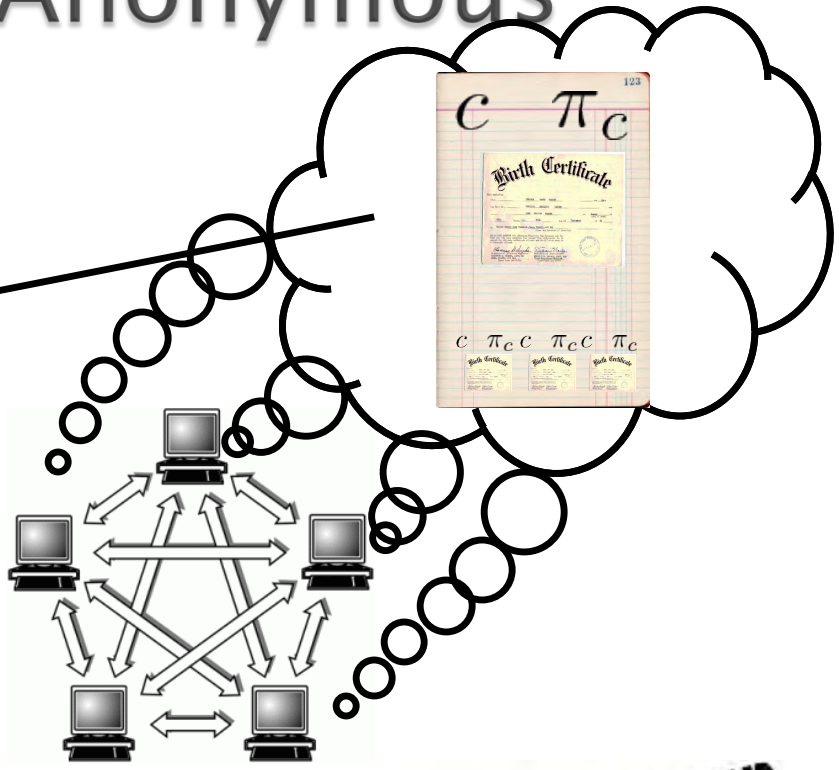


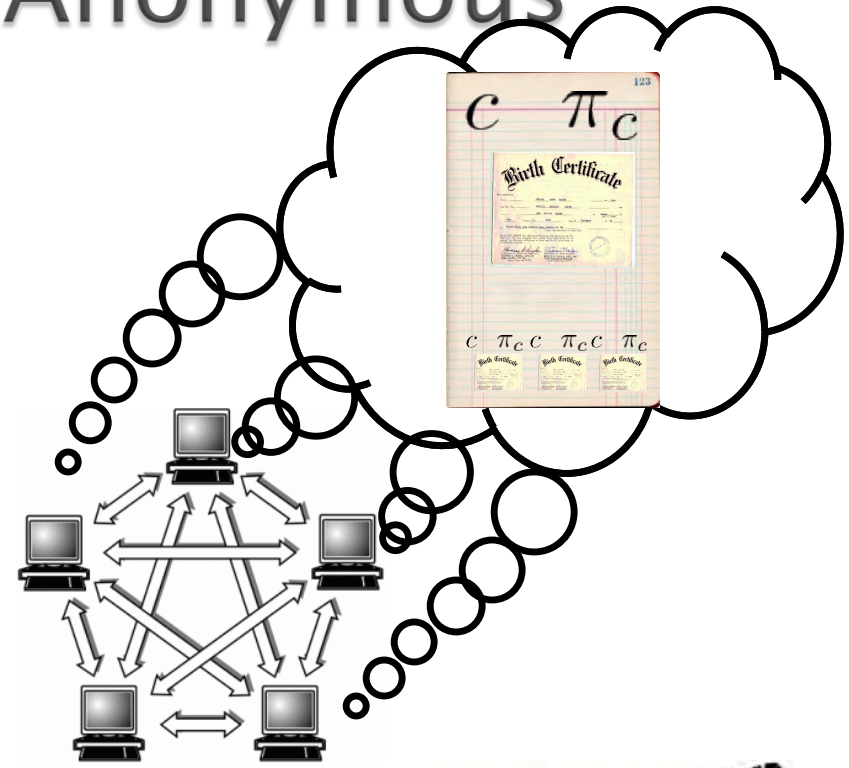
Basic Decentralized Anonymous Credentials

$c_1, c_2, \ldots, c_n$



Basic Decentralized Anonymous Credentials

$$A = u^{c_1 \cdot c_2 \cdot \ldots \cdot c_n} \bmod N$$



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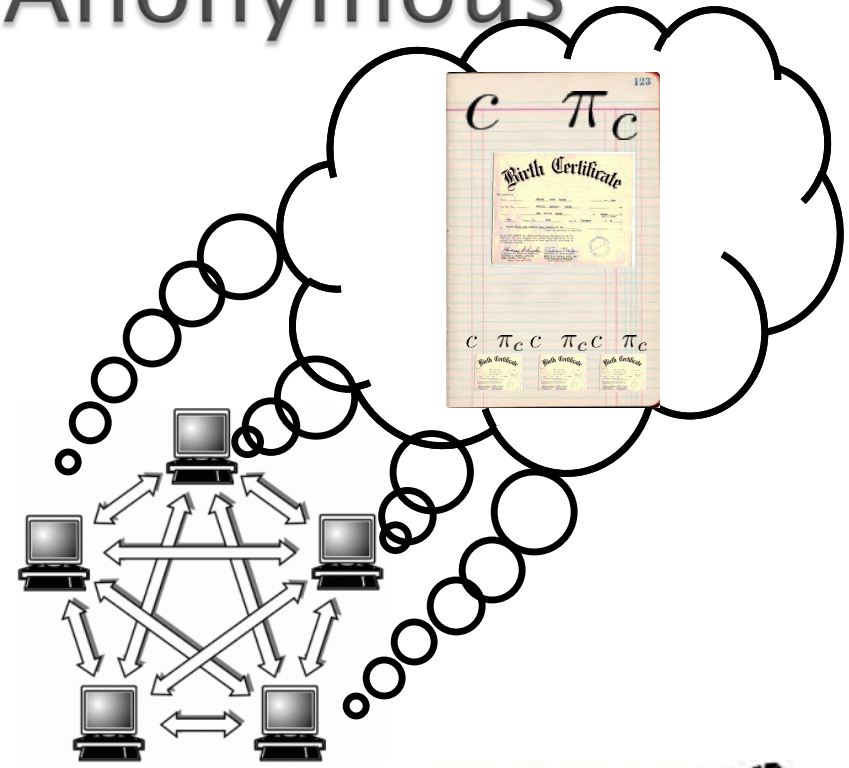

π_s

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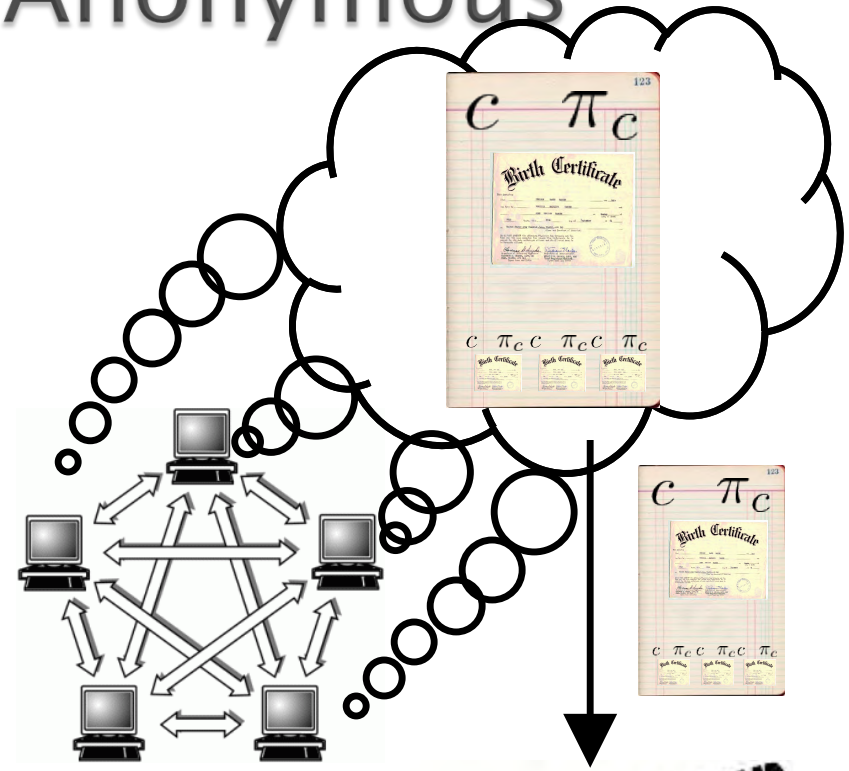
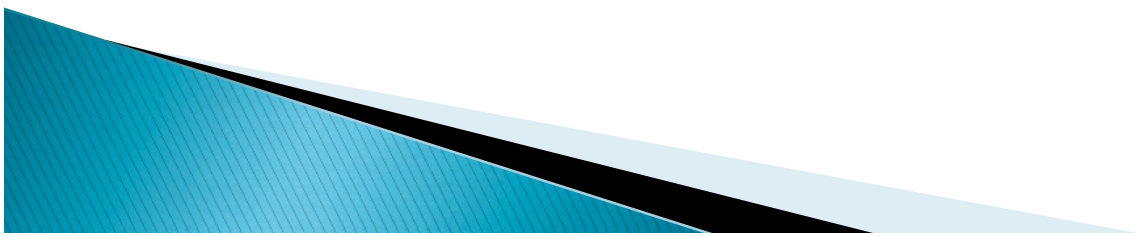


π_s

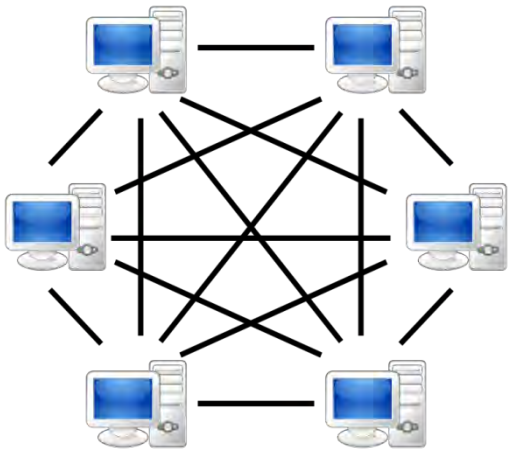
Applications

- Anonymous resource management in ad hoc networks
- Decentralized Direct Anonymous Attestation
- Auditable credentials
- Mitigating Sybil attacks in ad hoc networks



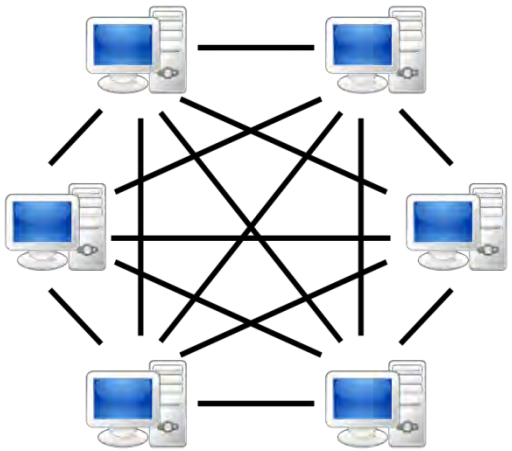
Protecting Against Sybil Attacks

VeriSign®



Protecting Against Sybil Attacks

"I am John Smith", $
$



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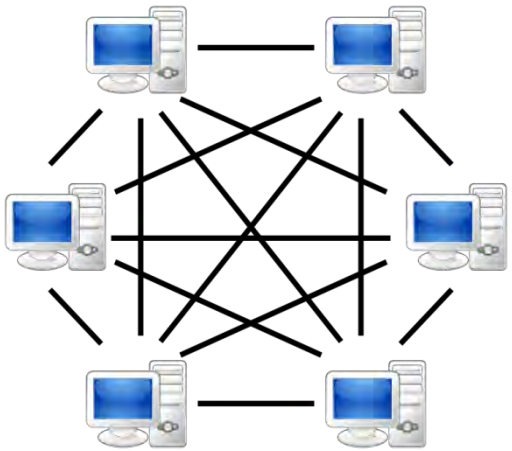

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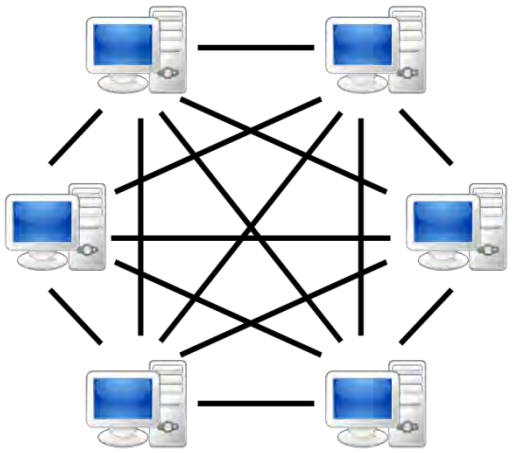

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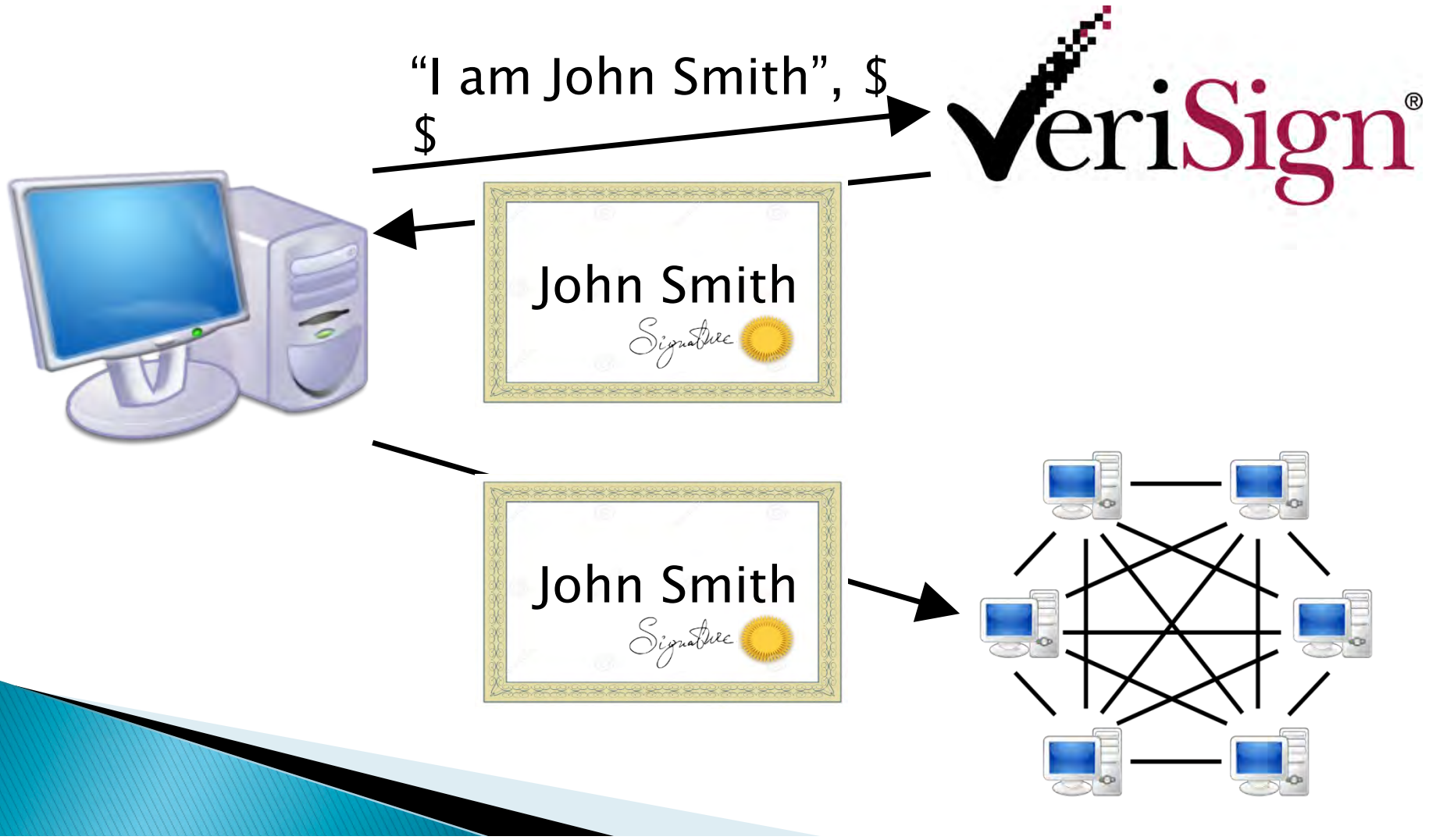

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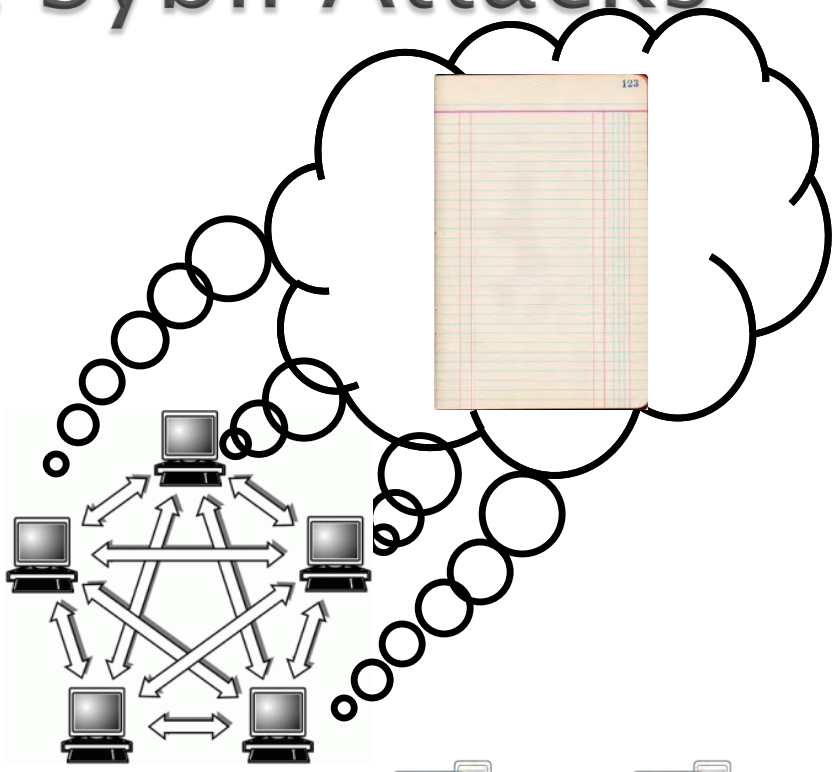
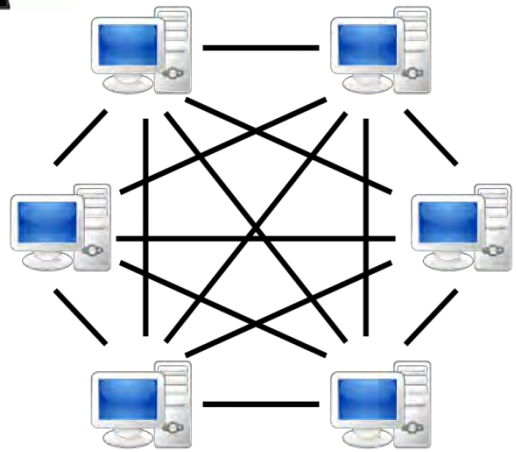
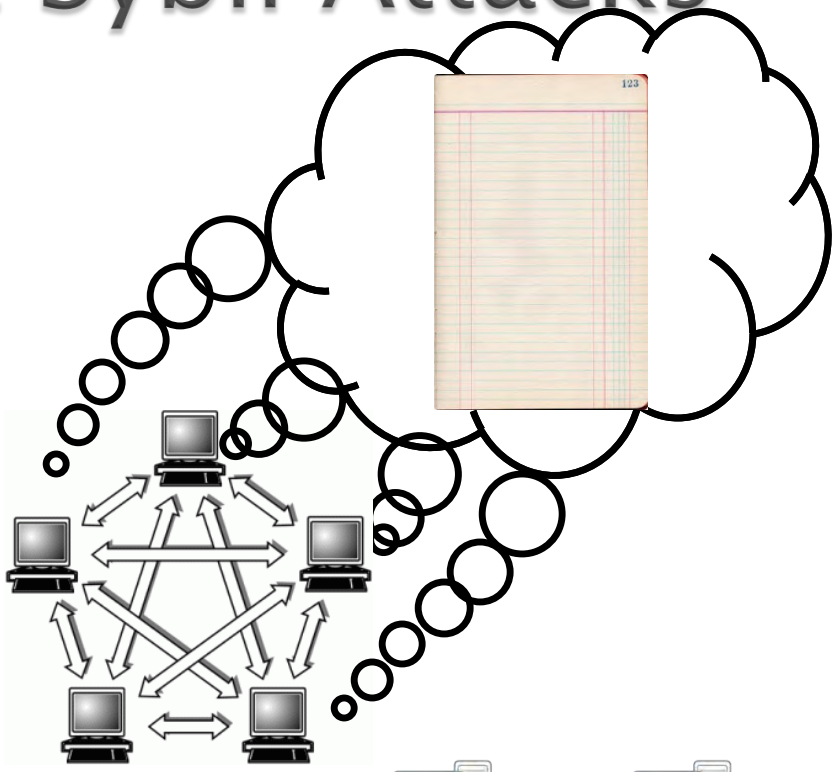


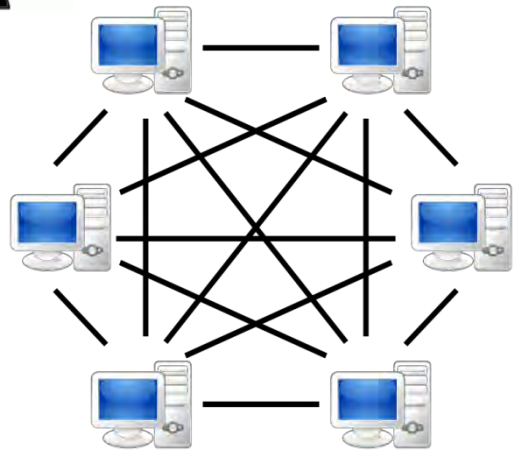


Protecting Against Sybil Attacks

$cred$

"I have paid
1 BTC"





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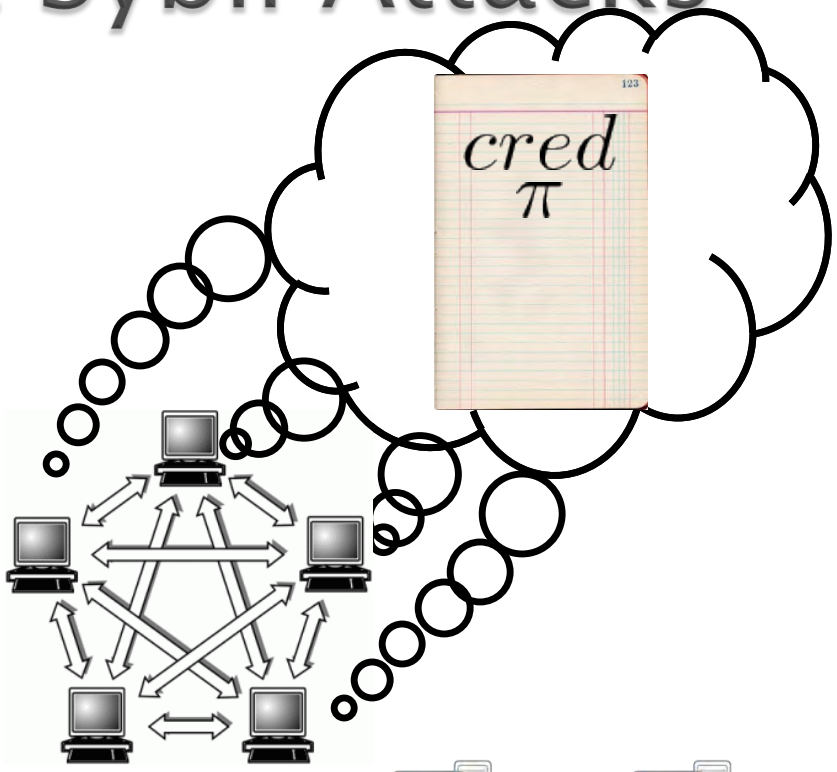

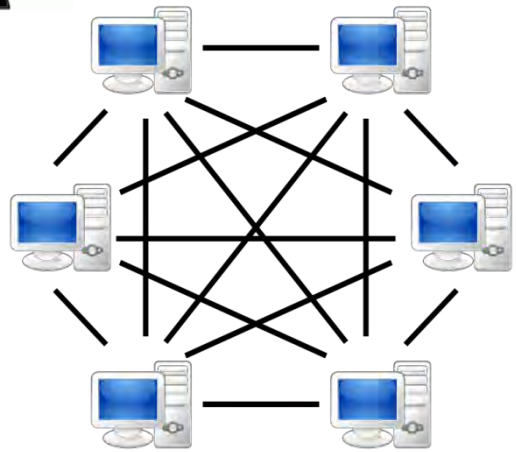

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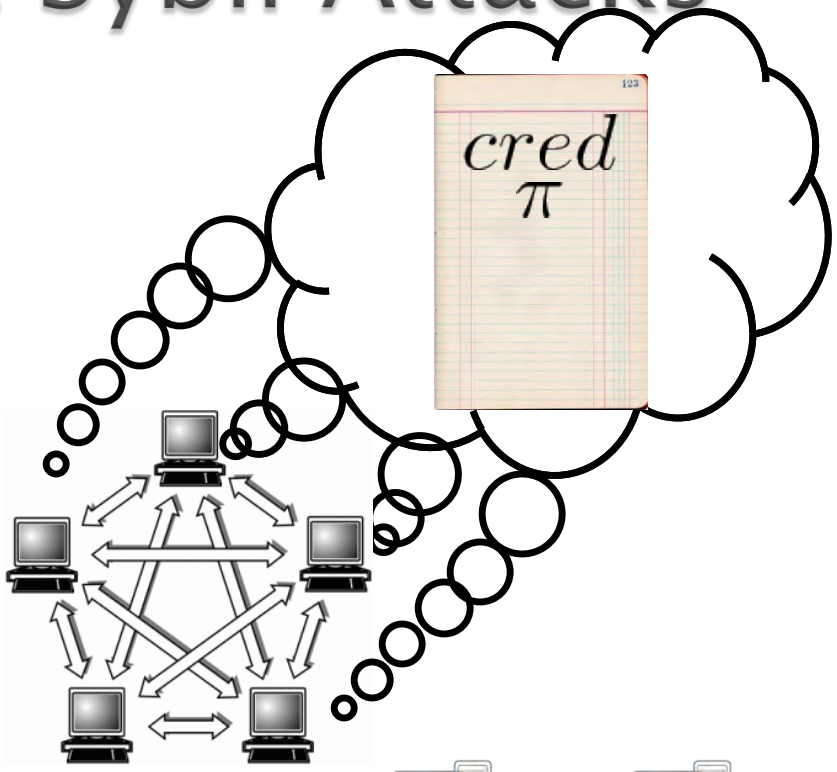
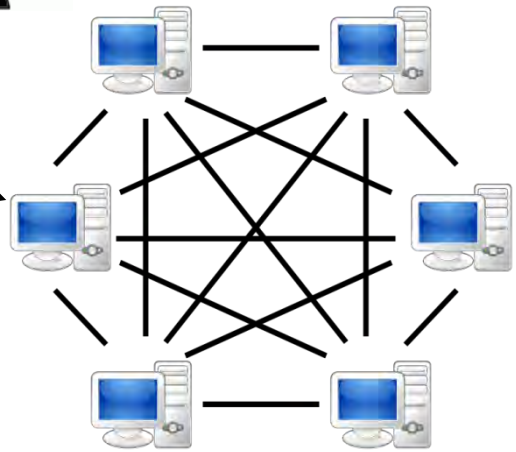


"I am not
a Sybil"



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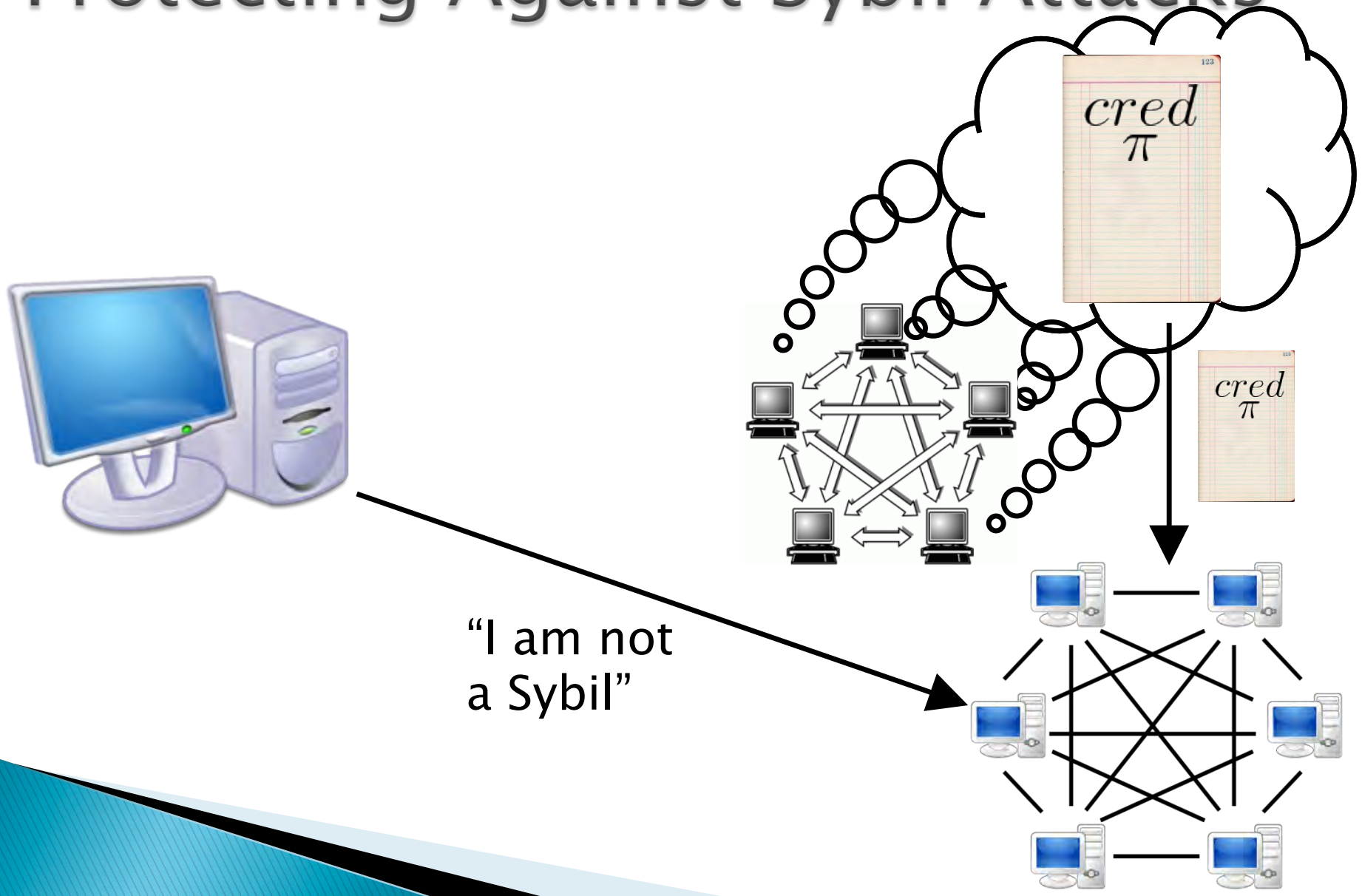
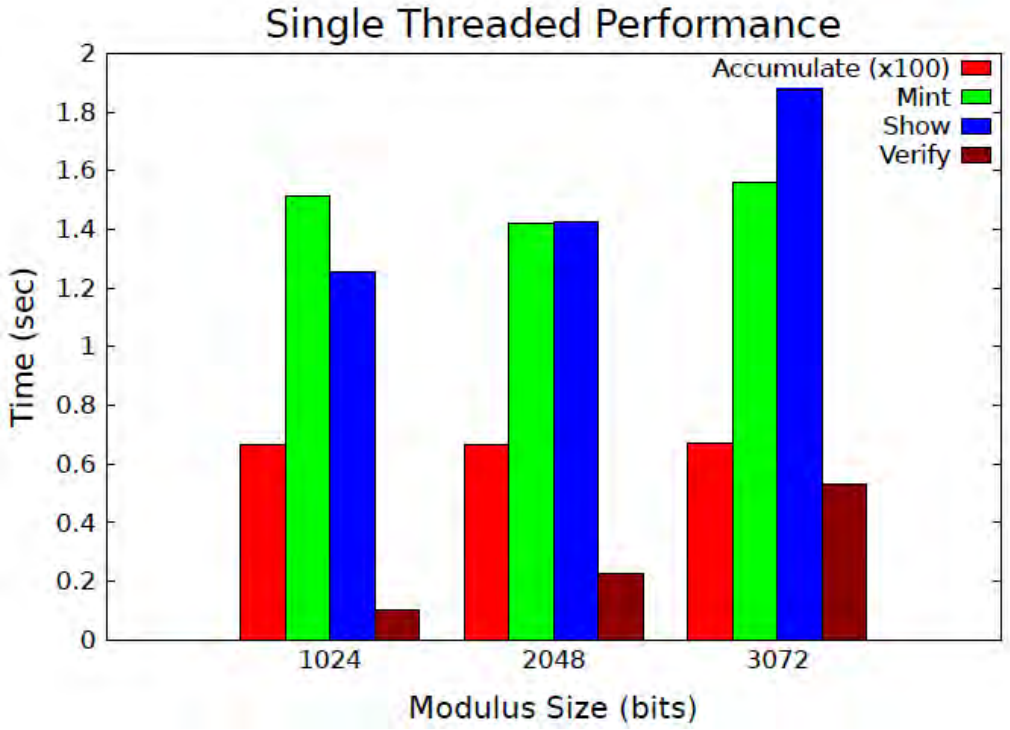


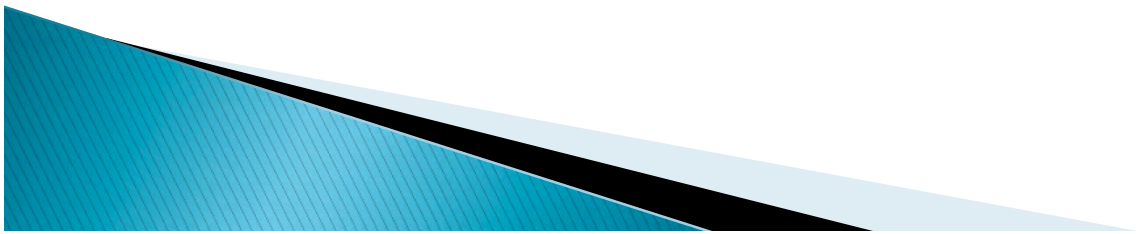
Performance



- Basic scheme implemented as stand-alone library
  - Proofs 50 KB

Future Work

- Better, smaller "proofs" of knowledge:
- **S**uccinct **N**on-Interactive **AR**guments of Knowledge (zkSNARKs) [PHGR13, BCGTV13]
  - 288 byte proof for arbitrary-sized arithmetic circuits
  - 8 ms verification time
- Additional applications?



Questions?

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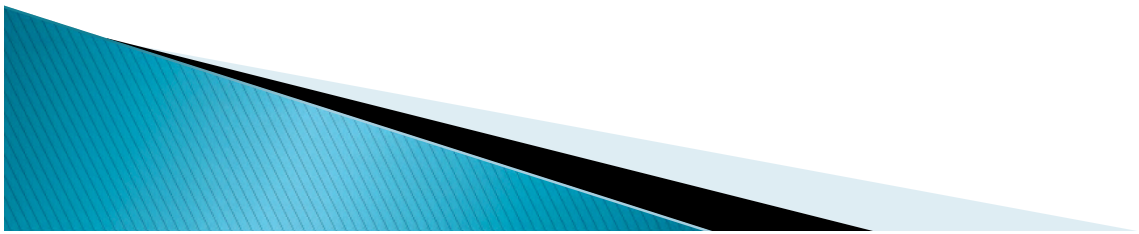
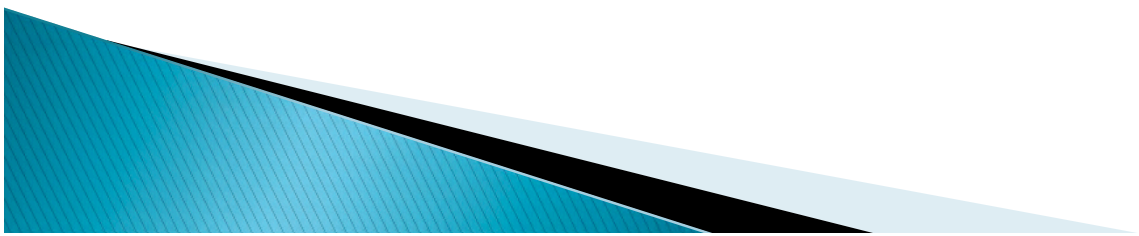
Potential Alternatives

- Threshold cryptography
  - High setup cost for large number of parties
  - Difficult for parties to come and go
- Ring signatures [RST01]
  - Grow linearly with the number of participating signers
  - Expensive to generate



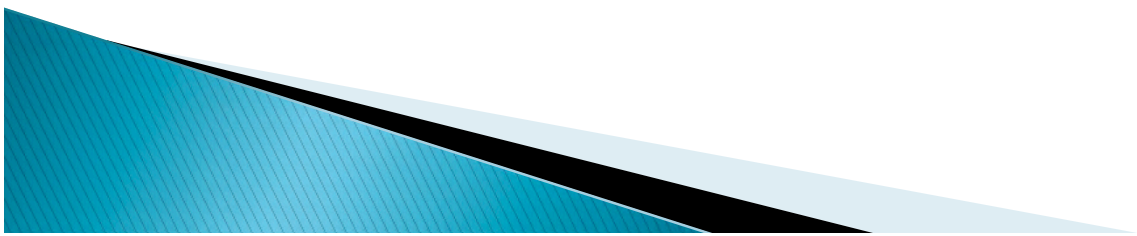
Non Publicly Verifiable Credentials

- Credential transform service
- Allows user to transform a credential to an anonymous credential without additional trust assumption
- Works for any statement that an authority can certify



Proof of Work for Sybil Attacks

- Proof of resource expenditure instead of payment
- Cannot reuse proof of work with different peers
  - Not anonymous
  - Clonable
- Do not want to have to do a proof of work with each peer in the system
- Instead do one proof of work per k interactions



Resource Management

- Publicly verifiable proofs of resources
- File storage, bandwidth, etc.
- Do not want to link resources provided to resources consumed
  - Files uploaded vs. files downloaded