Threat Modeling for Cryptocurrency-based Systems

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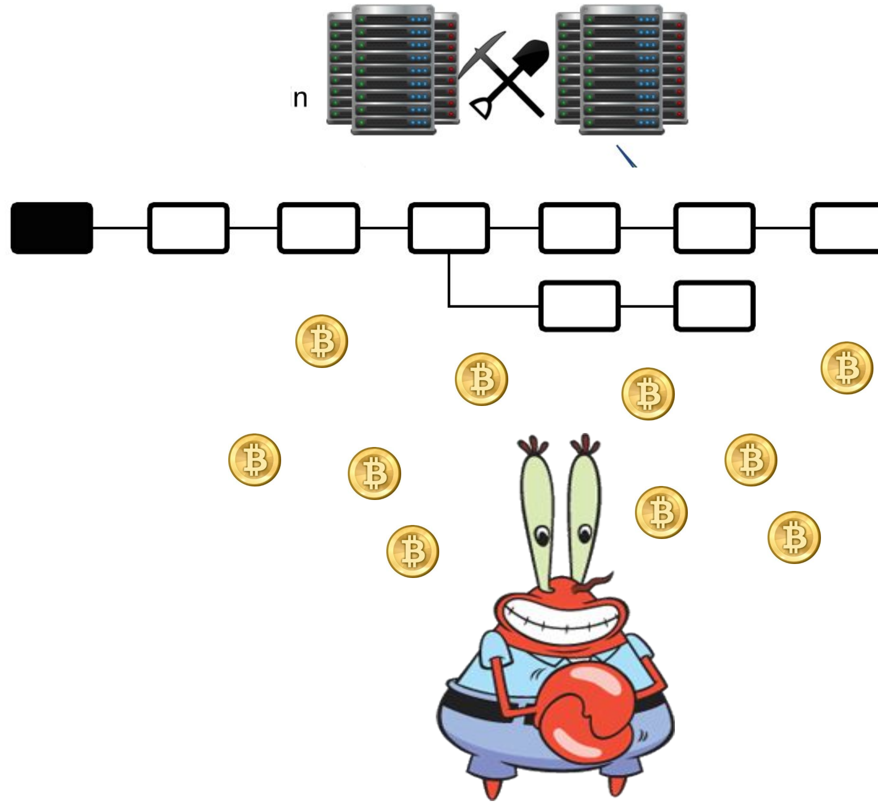
Outline

- Motivation.
- Overview of cryptocurrencies.
- Cryptocurrency and distributed services.
- ABC: a cryptocurrency-focused threat modeling framework.
- Conclusions.

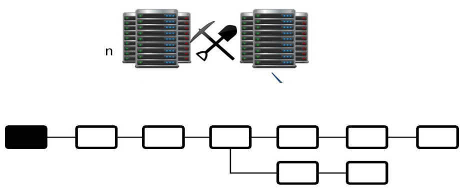
Once Upon A Time

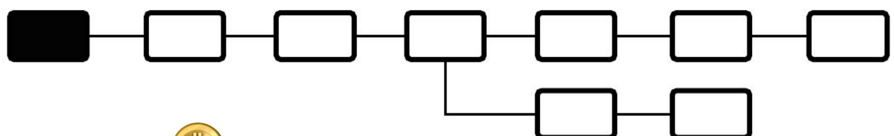
Centralized Currency

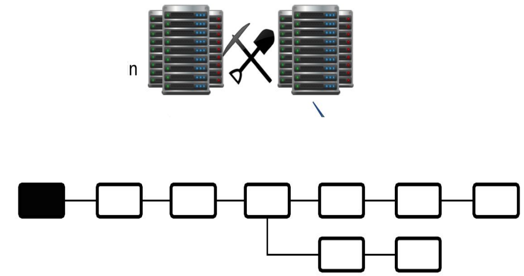
Decentralized Currency

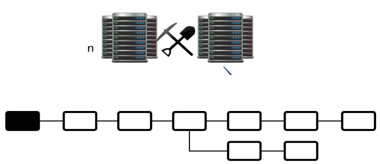


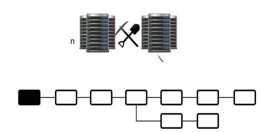
But, is it secure?











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Bitcoin History

- A whitepaper posted online in 2008: "Bitcoin: A Peer-to-Peer Electronic Cash System".
    - By Satoshi Nakamoto.
    - Described a distributed cryptocurrency system not regulated by any government.
- The system went live in January 2009.
- Now "Satoshi Nakamoto" is only associated with certain public keys on Bitcoin blockchain.
    - She/He/They was/were active on forums/emails till 2010.
- Currently there are ***2000+ cryptocurrencies*** (https://coinmarketcap.com/).

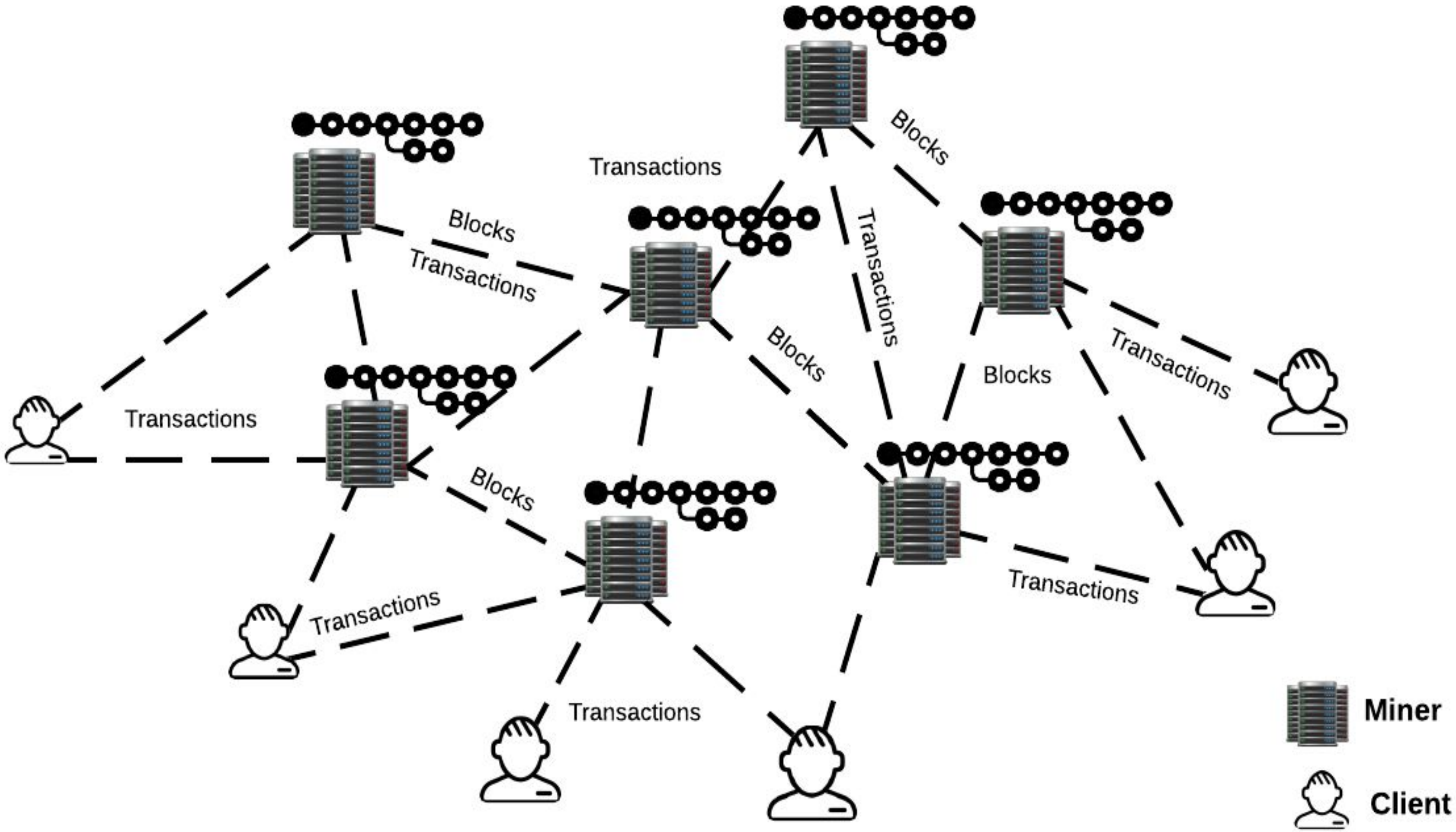
Bitcoin in a Nutshell I

- A distributed currency exchange medium open to anyone to join.
- Utilize basic cryptographic primitives to control the money flow in the system.
- Main components:
  - **Participants:** miners and clients.
  - **Transactions:** virtual currency tokens that move funds around.
  - **Blockchain:** an append only log.
  - **Mining:** extending the blockchain.
  - **Consensus:** agreeing on the current state of the Blockchain.

Bitcoin in a Nutshell II

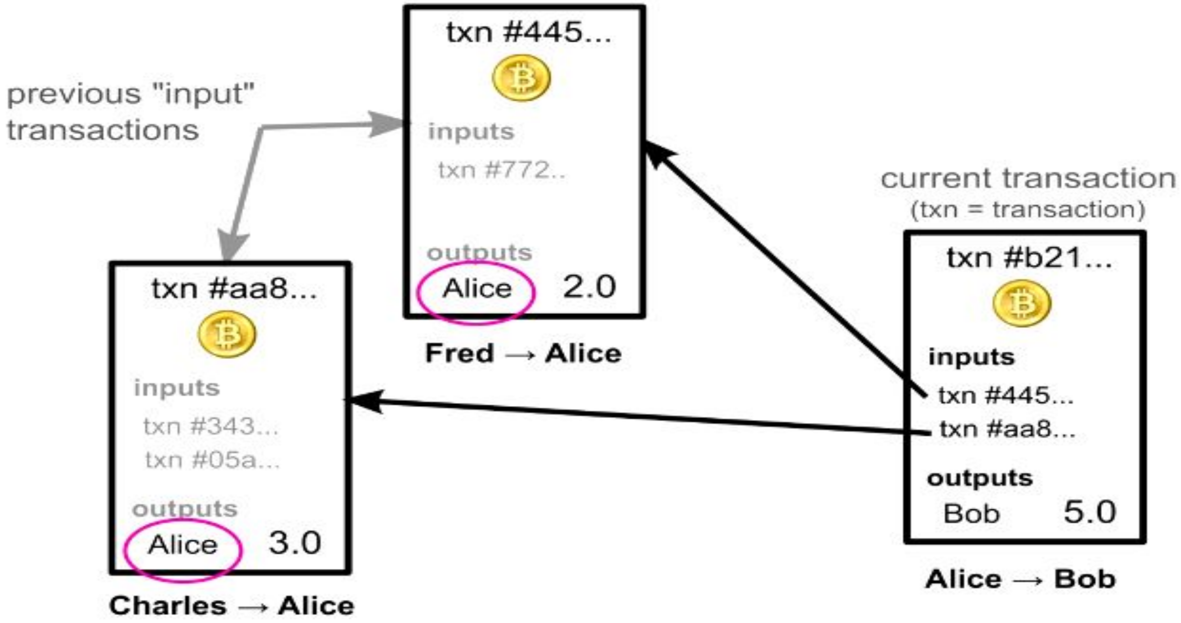
- No real identities are required, just a key pair.
  - Usually the hash of the public key is the participant’s address.
- Losing the private key of a specific address means losing the coins associated to this address forever.
  - Wallets take care of tracking coins, issuing transactions, etc.
- Clients, or simple payment verification (SPV) nodes, are concerned with their transactions only.
  - Do not mine or hold full copies of the blockchain.
- Miners, or fully validating nodes, track everything.
  - Hold full copies of the blockchain.
  - Mine and run the consensus protocol.

Bitcoin Pictorially



Virtual Coins

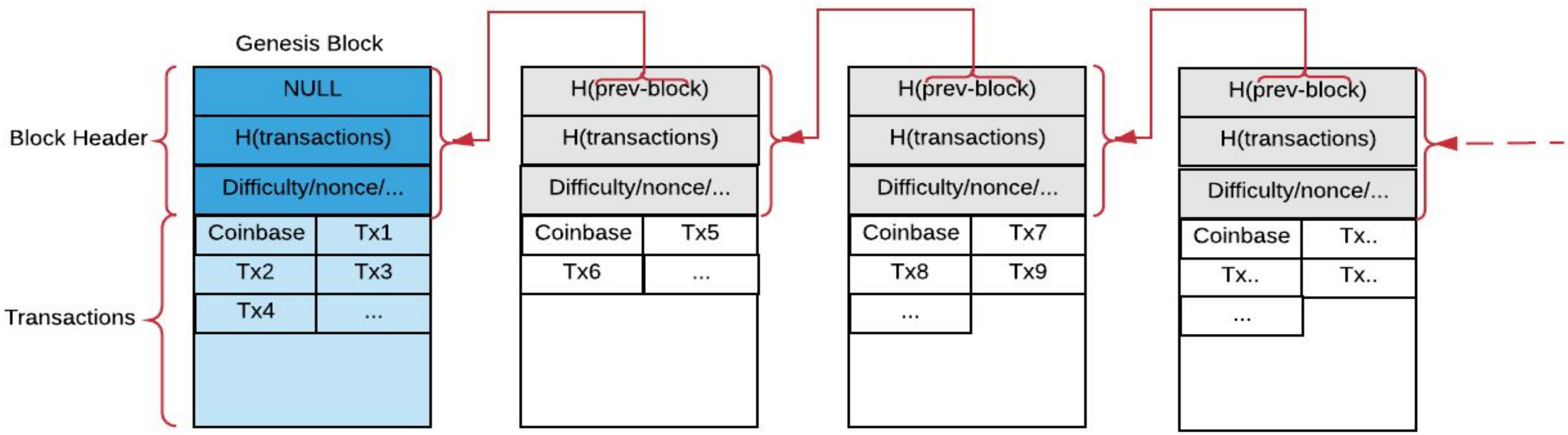
- Digital tokens, or transactions, that can be spent by providing signatures.
- No notion of accounts, track chains of transactions.
    - Other cryptocurrencies do it differently, e.g., Ethereum have accounts for users.



Source: http://www.imponderablethings.com/2013/07/how-bitcoin-works-under-hood.html

The Blockchain

- It is an append only log containing a full record of all transactions.
    - Full history is needed to handle double spending.



Mining

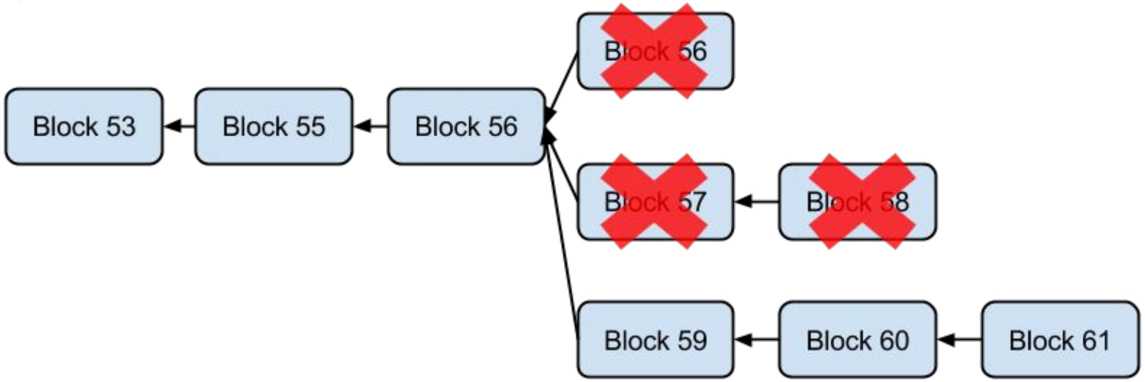
- Miners extend the blockchain by mining new blocks.
  - Proof-of-work in Bitcoin.
- Miners solve a hash puzzle,

SHA-256(SHA-256 (new block header)) < Difficulty Target

- Difficulty is adjusted periodically.
- This is needed to prevent Sybil attacks.
- Miners collect rewards: mining rewards + transaction fees.
- Total Bitcoin to mine is capped by 21 million BTC.
  - Currently there are around 17.4 million coins in circulation.

Consensus

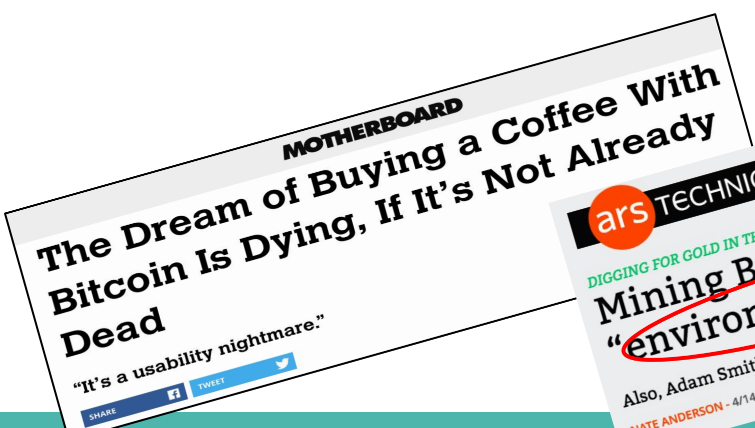
- Miners hold , hopefully, consistent copies of the blockchain.
  - Only differ in the recent unconfirmed blocks.
- A miner votes for a block implicitly by building on top of it.
- Forking the blockchain means that miners work on different branches
  - Caused by network propagation delays, adversarial actions, etc.
  - Resolved by adopting the longest branch.
- Security is subject to the assumption that at least 50% of the mining power is honest.

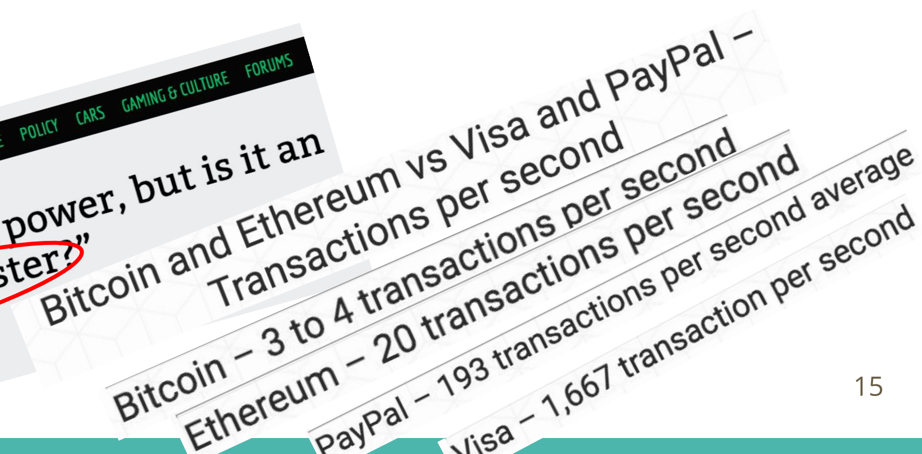


Source: http://www.ybrikman.com/writing/2014/04/24/bitcoin-by-analogy/

Bitcoin Sisters

- Bitcoin has several limitations related to:
    - Supported functionality, anonymity, transaction fees, mining and consensus, scalability, etc.
- This motivated the community to develop new cryptocurrencies, to name few:
    - Ethereum, Litecoin, Zcash, IOTA, Storj, Golem, etc.
- Will focus more on systems that provide distributed services on top of the currency exchange medium.





Cryptocurrency and Distributed Services

System Types

- Two types of cryptocurrency integration with distributed services:
  - **Resource-backed cryptocurrencies.**
    - Provides a distributed services(s) on top of the currency exchange medium, e.g., file storage, video transcoding, etc.
    - Mining itself could be tied to the service put in the system, e.g., Filecoin.
  - **Monetary-incentivised distributed systems.**
    - Reward users for participation in the system.
    - Use a cryptocurrency as a decentralized payment service instead of centralized ones.
    - Not concerned with the details of the cryptocurrency system.

Goals

- Achieve decentralization.
- An advancing step toward useful proof-of-work mining algorithms.
    - Provide a public good.
    - Reduce energy consumption,.
    - Achieve decentralized mining (think about mining pools).

Threat Modeling and Cryptocurrencies

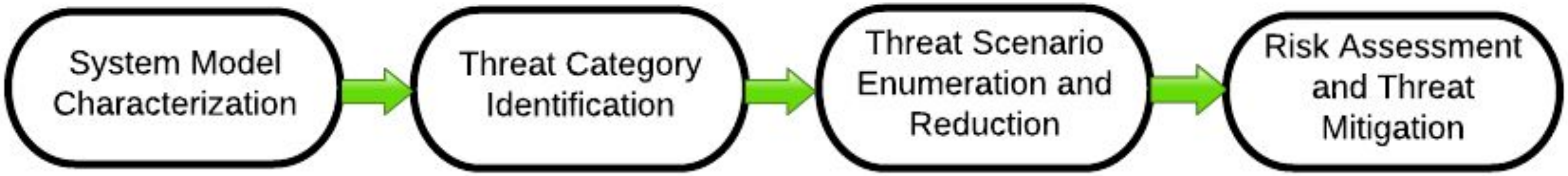
- Threat modeling is an essential step in secure systems design.
    - Explore the threat space to a system and identify the potential attack scenarios.
    - Helps in both guiding the system design, and evaluating the security of developed systems.
- Cryptocurrency/blockchain-based space experienced a huge number of attacks.
    - Financial incentives lead to more motivated attackers.
    - Security is more challenging in resource-backed cryptocurrency.

ABC: Asset-Based Cryptocurrency-focused Threat Modeling Framework

What is ABC?

- A systematic threat modeling framework geared toward cryptocurrency-based systems.
  - Its tools are useful for any distributed system.
- Helps designers to focus on:
  - Financial motivation of attackers.
  - New asset types in cryptocurrencies.
  - Deriving system-specific threat categories.
  - Spotting collusion and managing the complexity of the threat space.
    - using a new tool called a collusion matrix.
- Integrates with other steps of a system design; risk management and threat mitigation.

ABC Steps



Running Example: ***CompuCoin***

- A cryptocurrency that provides a distributed computation outsourcing service.
- Parties with excessive CPU power may join as servers to perform computations for others in exchange for CompuCoin tokens.
- The mining process is tied to the amount of service these servers provide.

Step 1: System Model Characterization

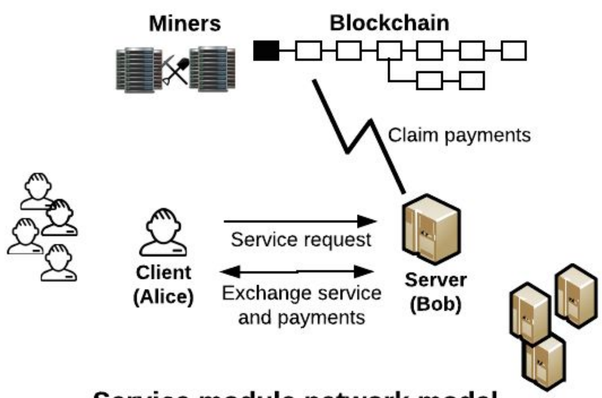
- Identify the following:
    - Activities in the system.
    - Participant roles.
    - Assets.
    - Any external dependencies on other services.
    - System assumptions.
- Draw a network diagram(s) of the system modules.

Functionality description. Outlined in CompuCoin description introduced earlier.

Participants. Clients and servers.

Dependencies. May rely on a verifiable computation outsourcing protocol.

Assets. Computation service, service rewards (or payments), blockchain, currency, transactions, and the communication network.



Service module network model

Step 2: Threat Category Identification

- Define broad threat classes that must be investigated.
- ABC defines these classes around the assets.
- For each asset, do the following:
  - Define what constitute a secure behaviour for the asset.
  - Use that knowledge to derive the asset security requirements.
  - Define threat classes as violations of these requirements.

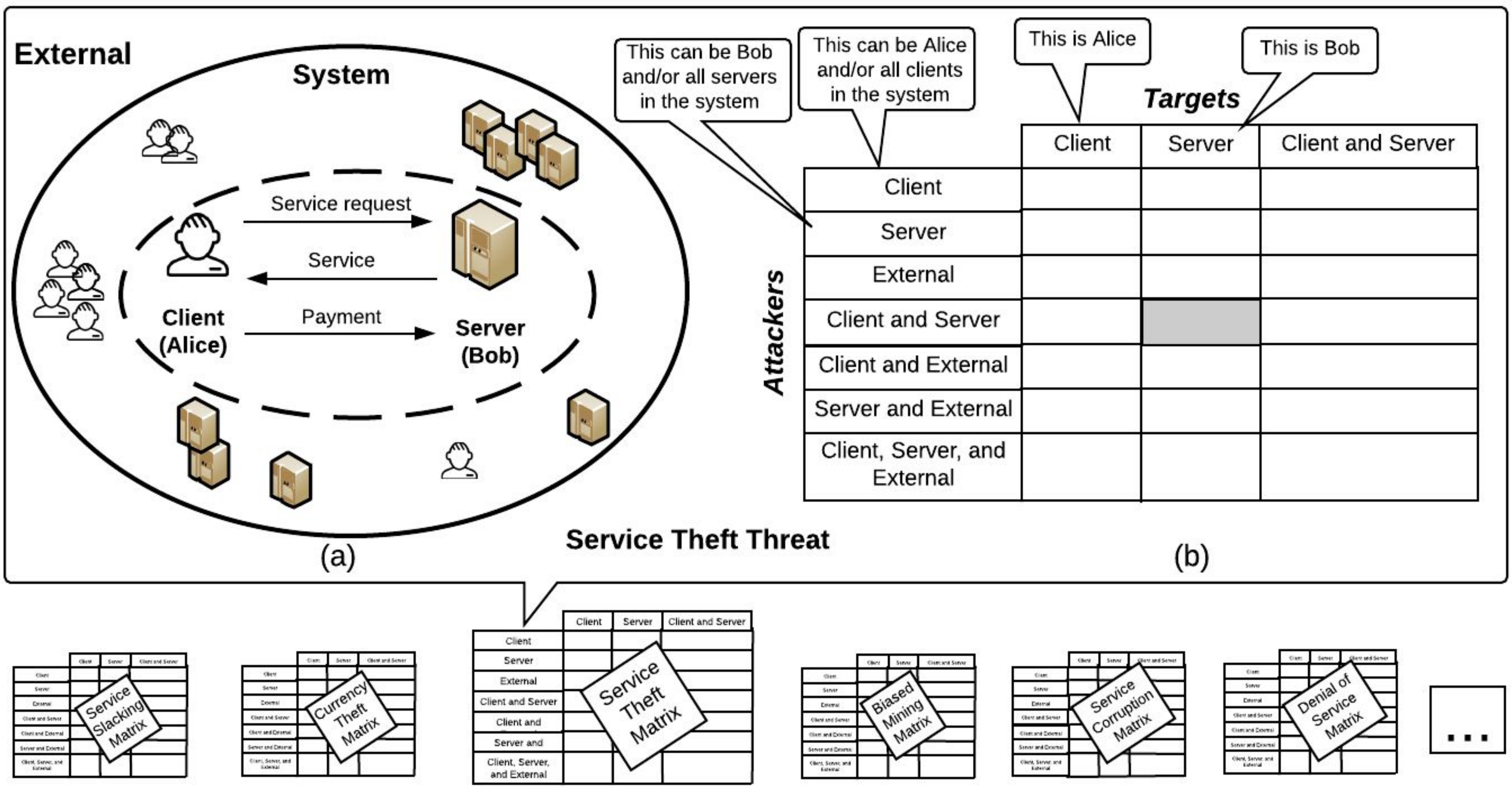
Step 2: Running Example Application

Asset	Security Threat Category
Service	Service corruption (provide corrupted service for clients).
	Denial of service (make the service unavailable to legitimate users).
	Information disclosure (service content/related data are public).
	Repudiation (the server can deny a service it delivered).
Service payments	Service slacking (a server collects payments without performing all the promised work).
	Service theft (a client obtains correct service for a lower payment than the agreed upon amount).
Blockchain	Inconsistency (honest miners hold copies of the blockchain that may differ beyond the unconfirmed blocks).
	Invalid blocks adoption (the blockchain contains invalid blocks that does not follow the system specifications).
	Biased mining (a miner pretends to expend the needed resources for mining to be elected to extend the blockchain).
Transactions	Repudiation (an attacker denies issuing transactions).
	Tampering (an attacker manipulates the transactions in the system).
	Deanonymization (an attacker exploits transaction linkability and violates users' anonymity).
Currency	Currency theft (an attacker steals currency from others in the system).
Communication network	Denial of service (interrupt the operation of the underlying network).

Step 3: Threat Scenario Enumeration and Reduction

- For each threat, define scenarios that attackers may follow to pursue their goals.
  - Be comprehensive, consider collusion and financial motivation.
- ABC devises collusion matrices to help with this step.
- Analyzing a collusion matrix involves:
  - Enumerating all possible attack scenarios.
  - Crossing out irrelevant cases and merge together those that have the same effect.
  - Documenting all distilled threat scenarios.

Collusion Matrix



Step 2: Running Example Application

Service Theft Threat Collusion Matrix

<table>
<tr><th>Target
Attacker</th><th>Client</th><th>Server</th><th>Client and Server</th></tr>
<tr><td>External</td><td rowspan="7">Clients cannot be targets because they do not serve others.</td><td rowspan="3">Servers and external cannot attack because they do not ask/pay for service.</td><td rowspan="7">Reduced to the case of attacking servers only, clients do not serve others (cannot be targets).</td></tr>
<tr><td>Server</td></tr>
<tr><td>Server and External</td></tr>
<tr><td>Client</td><td>(1) Refuse to pay after receiving the service.
(2) Issue invalid payments.</td></tr>
<tr><td>Client and External</td><td rowspan="3">Reduced to the case of an attacker client. A client does not become stronger when colluding with other servers or external entities.</td></tr>
<tr><td>Server and Client</td></tr>
<tr><td>Client, Server, and External</td></tr>
</table>

Step 4: Risk Management and Threat Mitigation

- An independent task of threat modeling.
- However, financial incentives affect prioritizing threats and their mitigation techniques.
  - Use game theory-based analysis to quantify the pay-off an attacker may obtain.
  - Use detect-and-punish techniques to address certain threat types.
- For example, in CompuCoin:
  - Locking payments in an escrow neutralizes threat 1.
  - Having a penalty deposit that is fortified upon cheating addresses threat 2.
  - Both require careful design and economic analysis.

Last Stop

Conclusions

- Cryptocurrencies provide a disruptive work model.
  - But also exhibit complicated relations between, financially motivated, untrusted parties.
- Great potential and huge arena of applications.
  - However, deeper thinking is needed to assess when/where to apply.
  - Threat modeling is a critical step to enhance their security.
- Are they just a hype that will fade away?!
  - Still provide an elegant proof of concept.

Questions?

aNd ThANk yOU :)