

Network Layer and Information Propagation



Sergi Delgado Segura

ToDos:

- Decide where to split the lecture (1h + 1h)
- Finish network topology part



What are we going to cover

balboa

Before we start

We will use Bitcoin as example when explaining how certain parts of the network work. However, the same mechanisms apply to most of the existing cryptocurrencies with slight modifications (some times even without any).

Also keep in mind that for most of things within cryptocurrencies there is no formal specification but the live code. Therefore some details may change in the near future.



Introduction

Client-Server paradigm (1/2)

- Classic paradigm
- Actors are split in two types:
 - Servers:
 - serve specific resources upon request
 - can also provide different types of services

Client-Server paradigm (2/2)

- Clients:
 - resource/service requesters
 - do not share resources nor provide any service
- Clients initiate the communication and need to know the server endpoint
- Classical examples: WWW, DNS, Email, etc

Peer-to-peer (P2P) paradigm

- All actors (**peers**) are equal and have both client and server capabilities
- Services / resources can be shared between several peers or found in a single location
- Each peer can choose what to serve/request
- Quite usual paradigm for distributed file sharing (e.g: BitTorrent)
- **Usual problems:** Bootstrapping and file searching

P2P bootstrapping

P2P bootstrapping

- How do you find peers when you run a new node in the network?

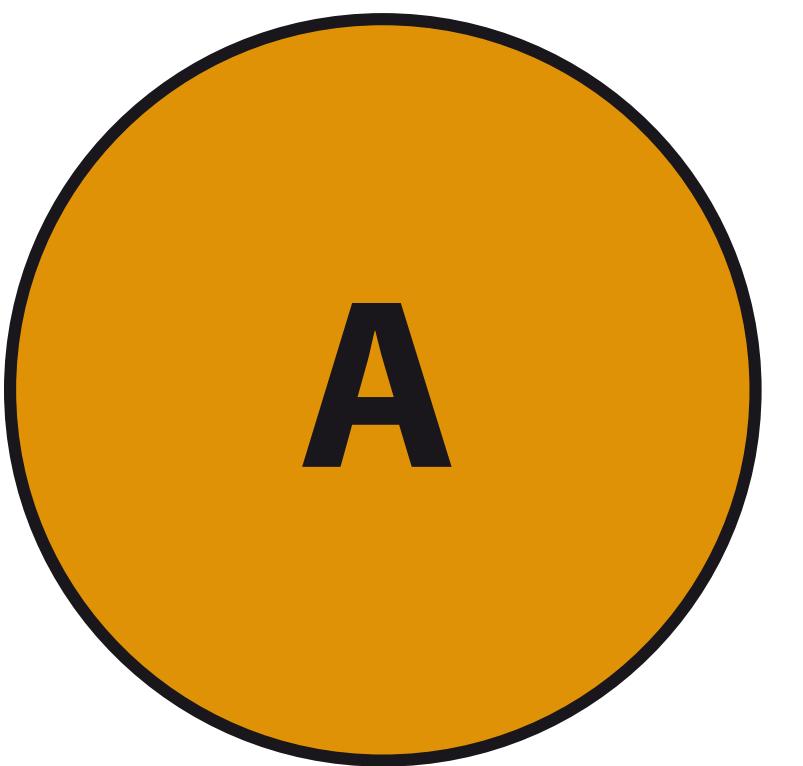
P2P bootstrapping

- How do you find peers when you run a new node in the network?
- How peers announce its presence in the network?



Peer discovery?

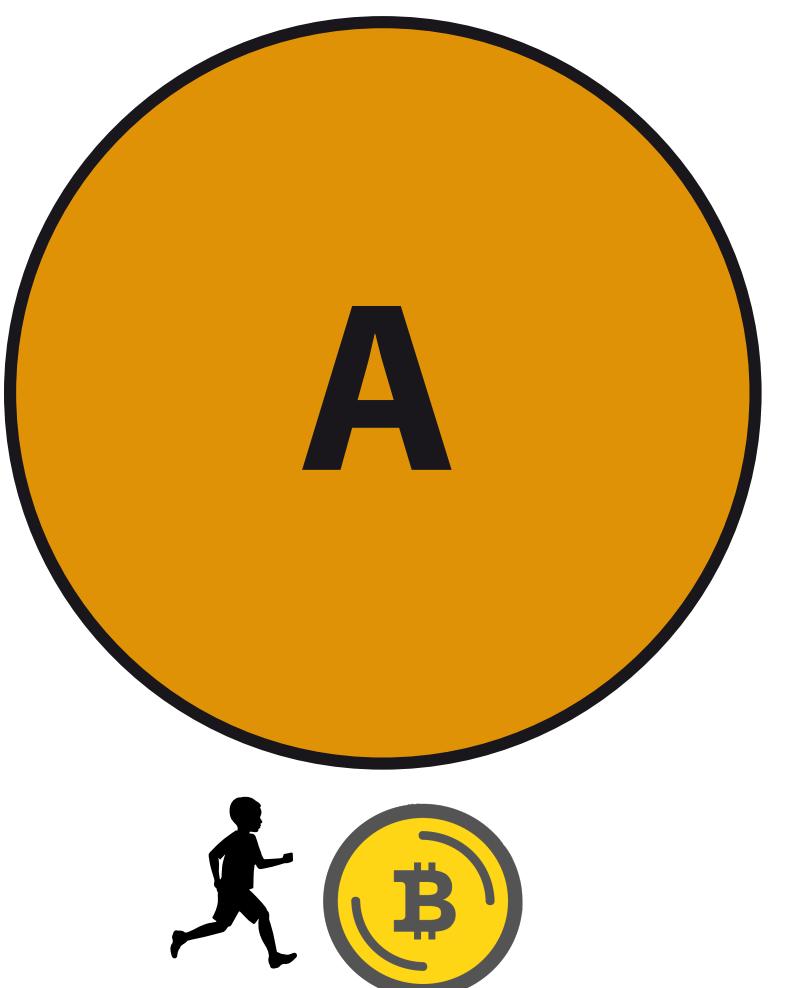
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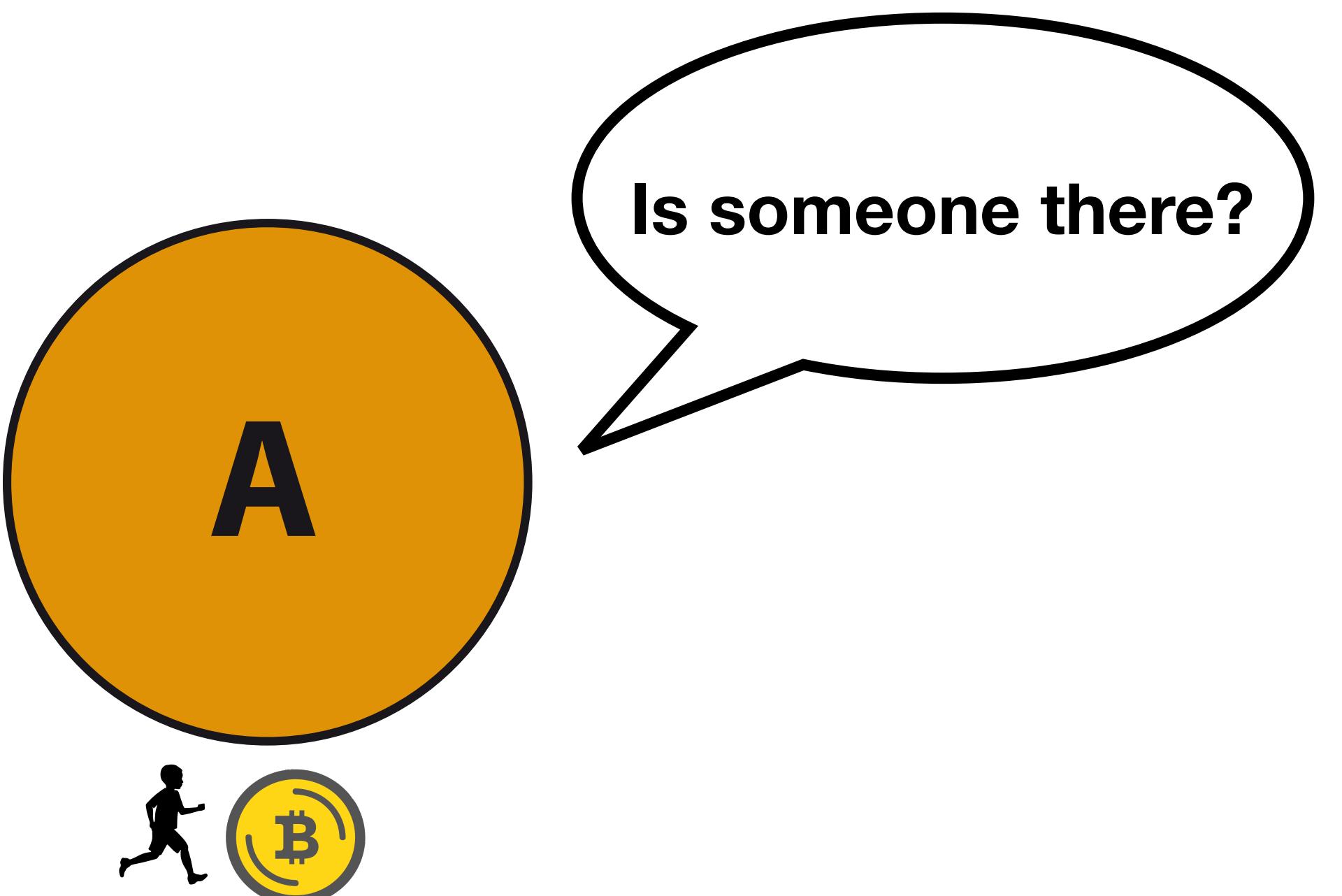
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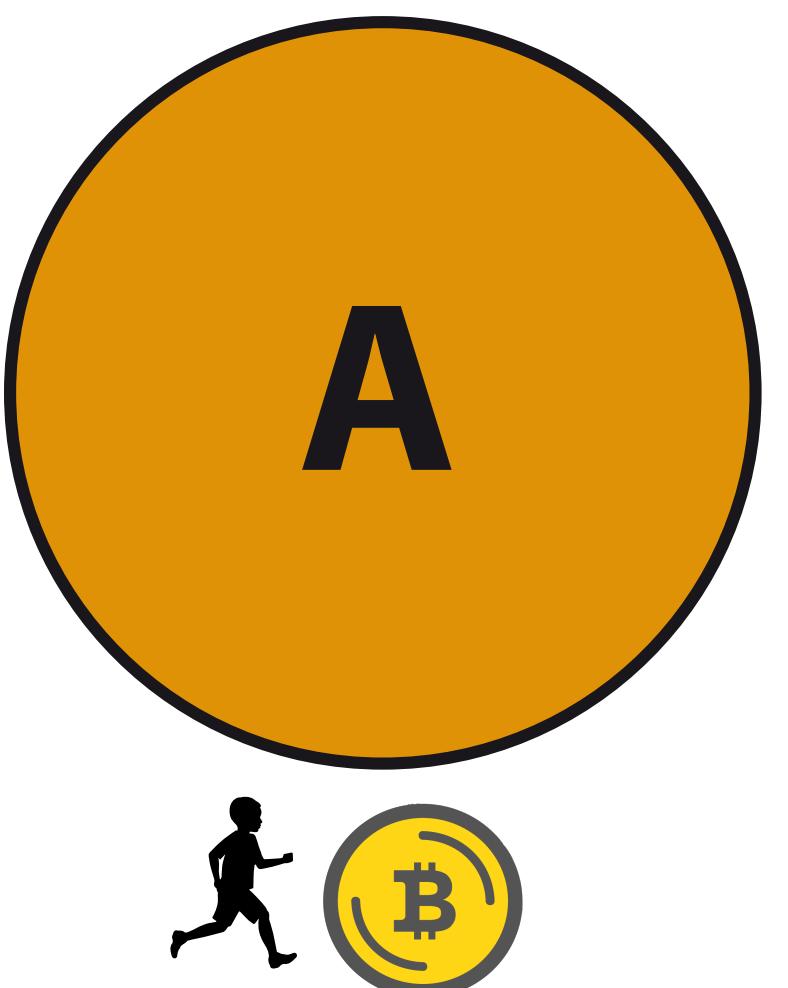
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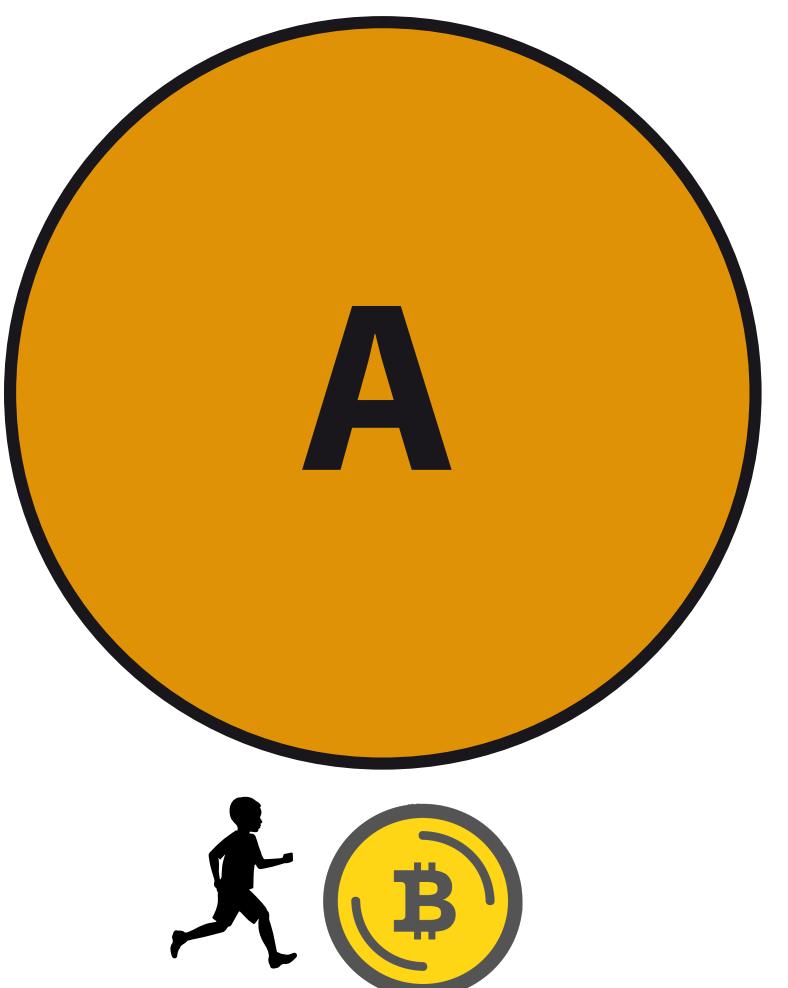
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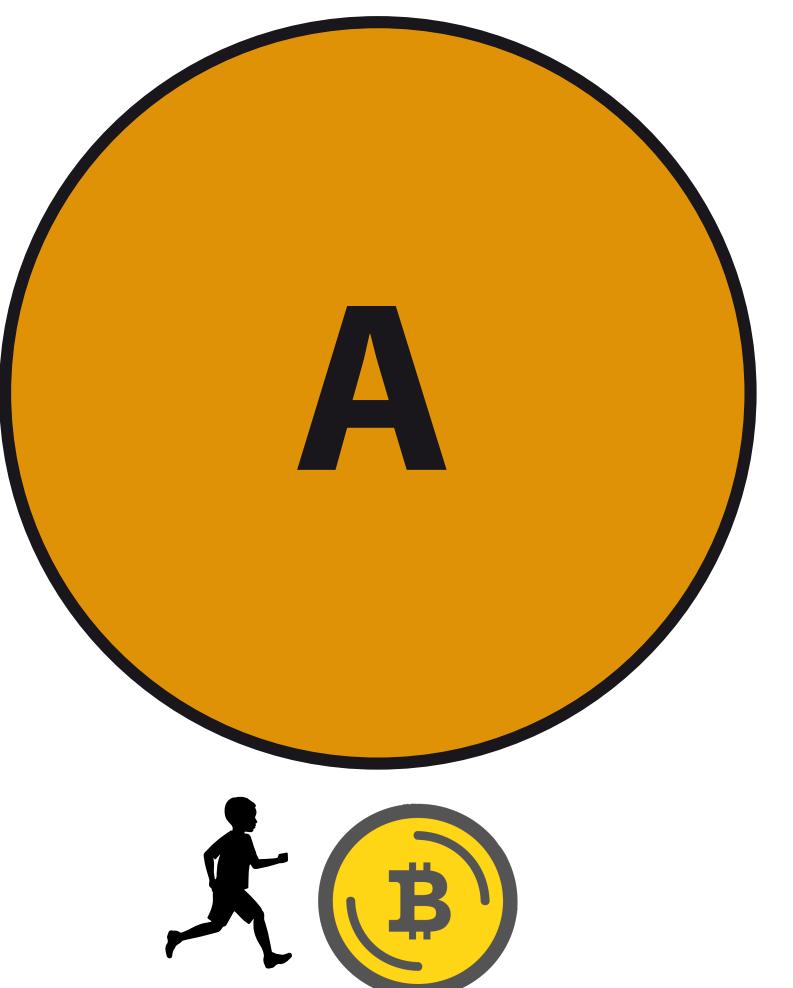
Peer discovery?



****tumbleweed****

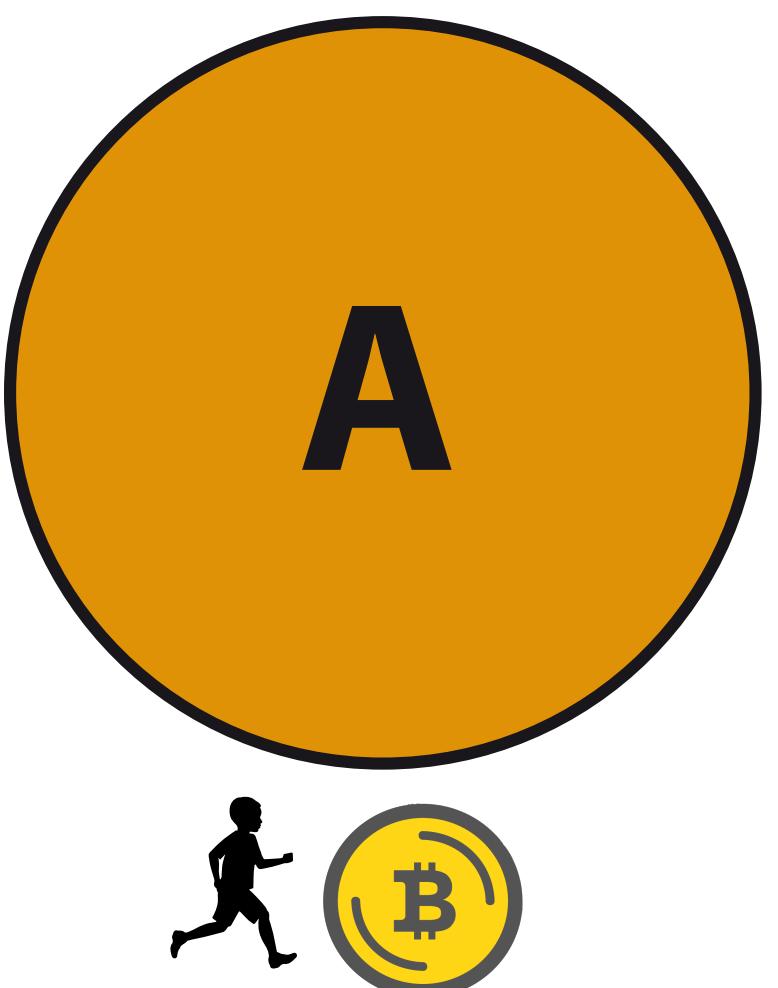


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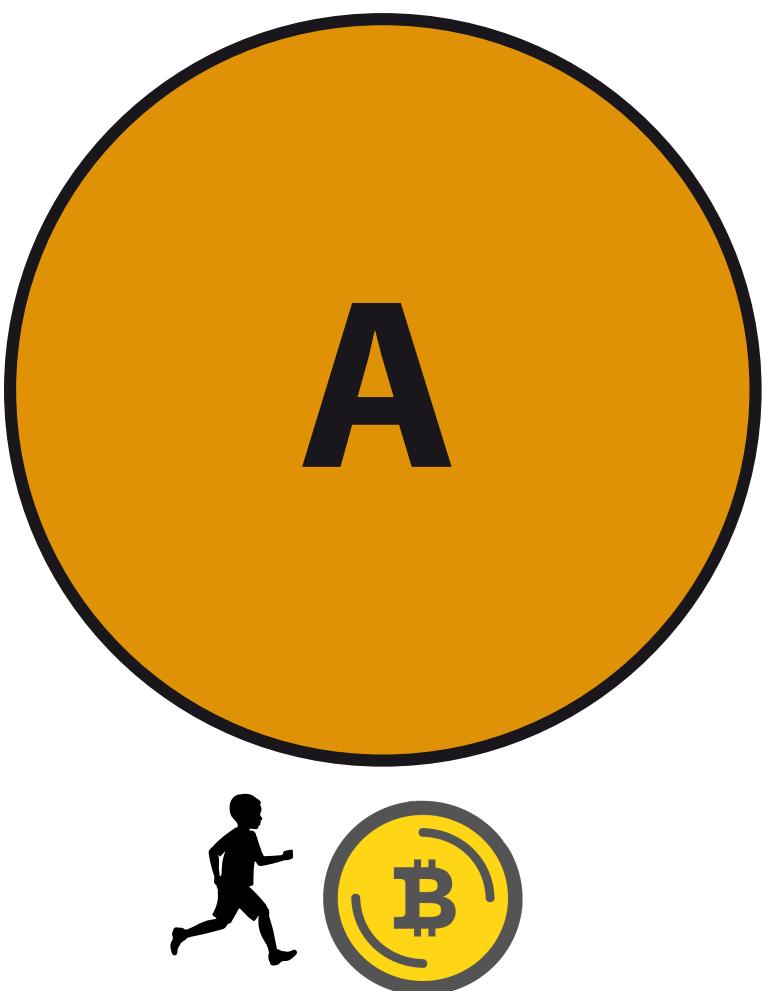
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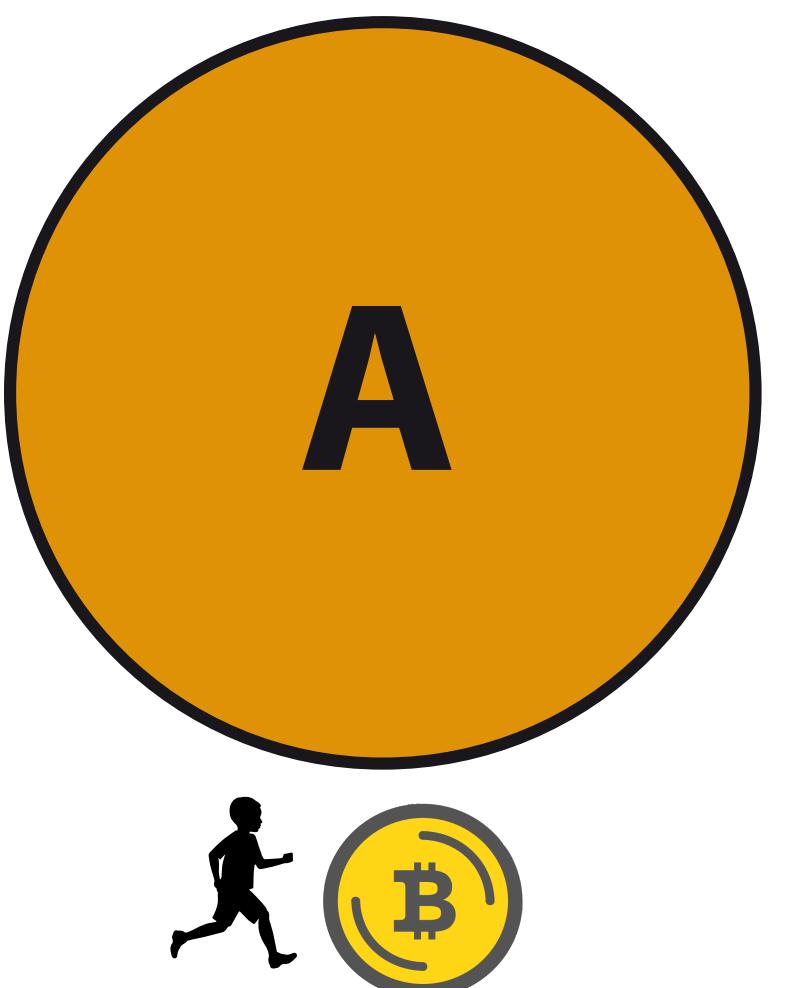
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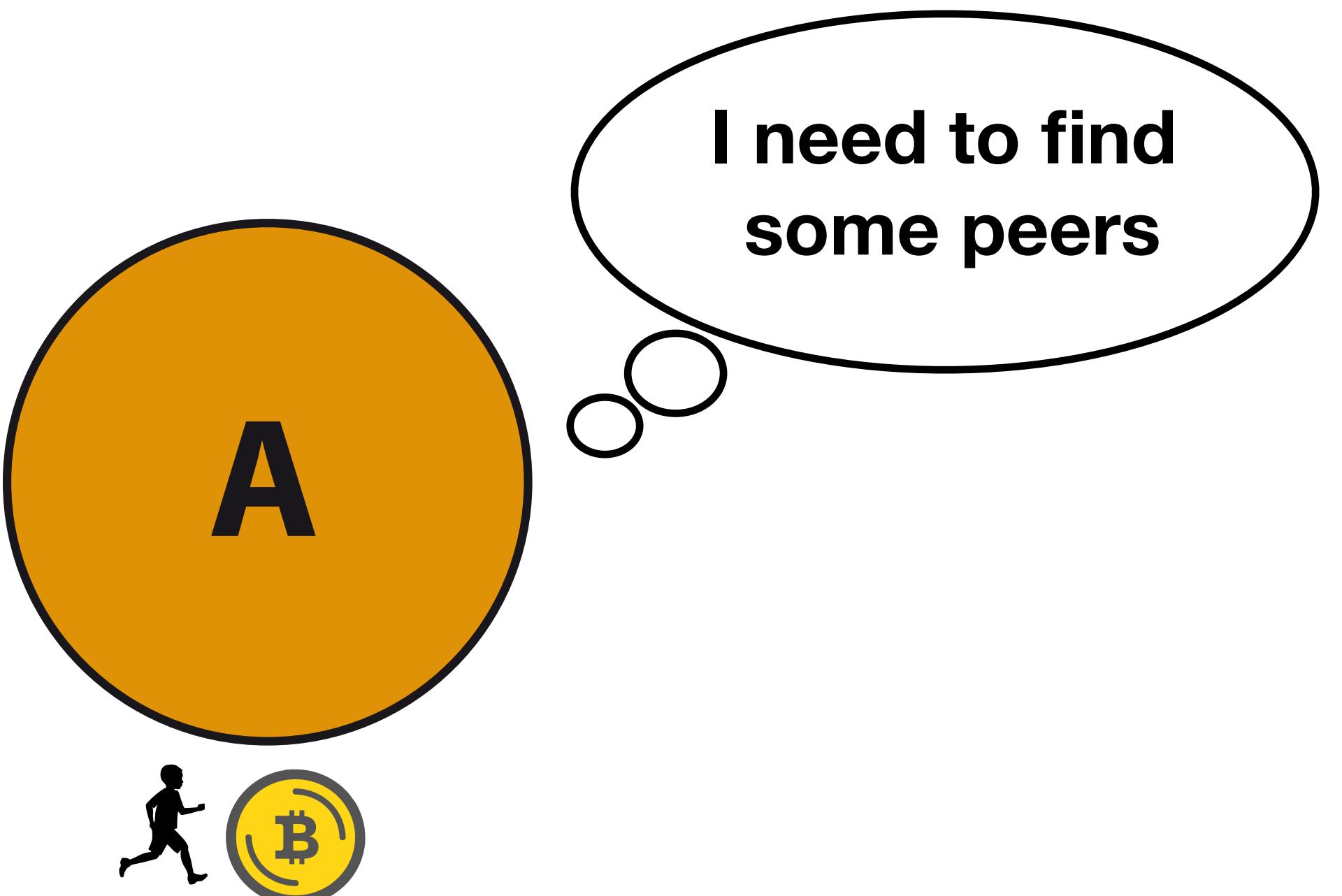


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P2P bootstrapping

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P2P bootstrapping

- How do you find peers when you run a new node in the network?
- How peers announce its presence in the network?
- **Hardcoded trusted addresses / IRC bootstrapping / Trusted DNS seeds / etc**

P2P file sharing (1/2)

- How can you find files in a network when each peer can have different files?
- How files are announced?

P2P file sharing (1/2)

- How can you find files in a network when each peer can have different files?
- How files are announced?
- **Announce / Request**

P2P file sharing (2/2)

- **Request paradigm:** Files are requested by peers, so the network needs a lookup protocol to identify who knows what
- **Announce paradigm:** Files are announced to peers, which will decide whether they would like a copy or not. No lookup protocol is required

P2P file sharing (2/2)

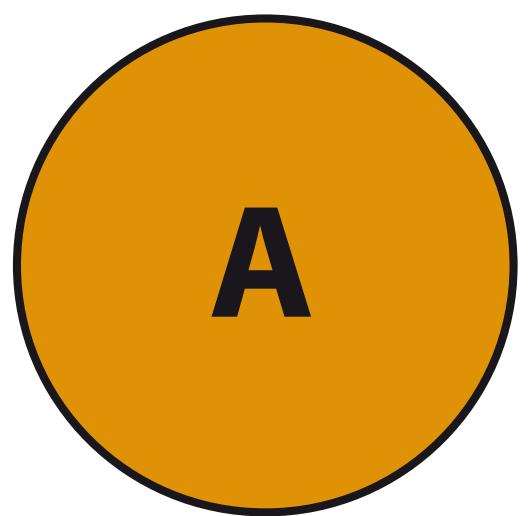
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- **What paradigm do cryptocurrencies follow?**

P2P file sharing (2/2)

- **Request paradigm:** Files are requested by peers, so the network needs a lookup protocol to identify who knows what
- **Announce paradigm:** Files are announced to peers, which will decide whether they would like a copy or not. No lookup protocol is required
- **What paradigm do cryptocurrency networks follow? Announce**

P2P file sharing: Request paradigm (BitTorrent)

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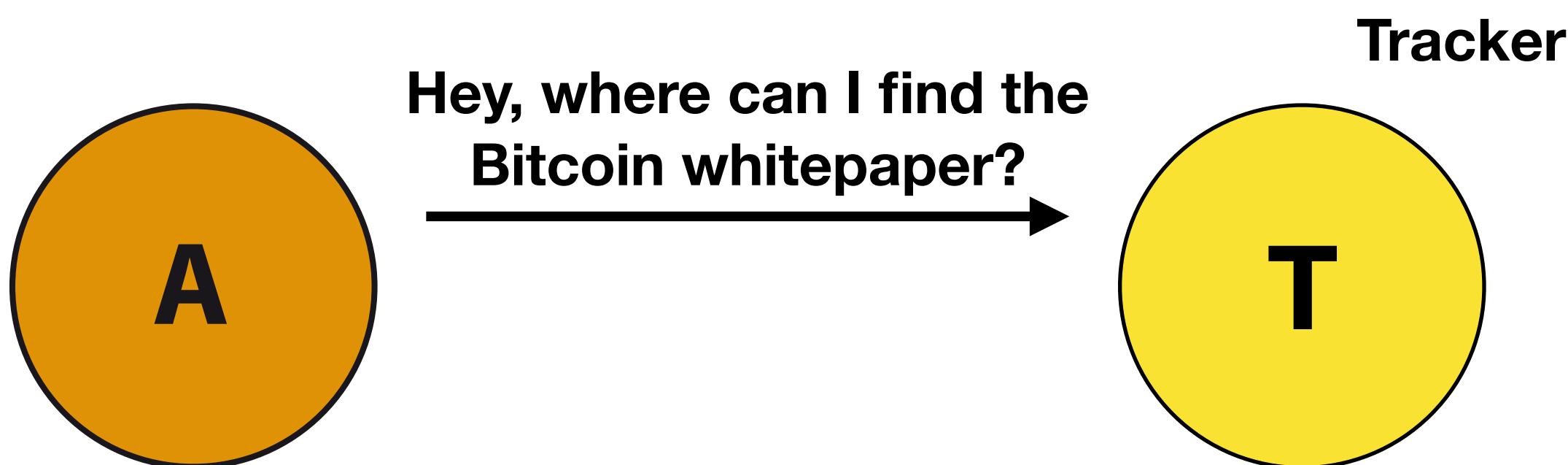


P2P file sharing: Request paradigm (BitTorrent)



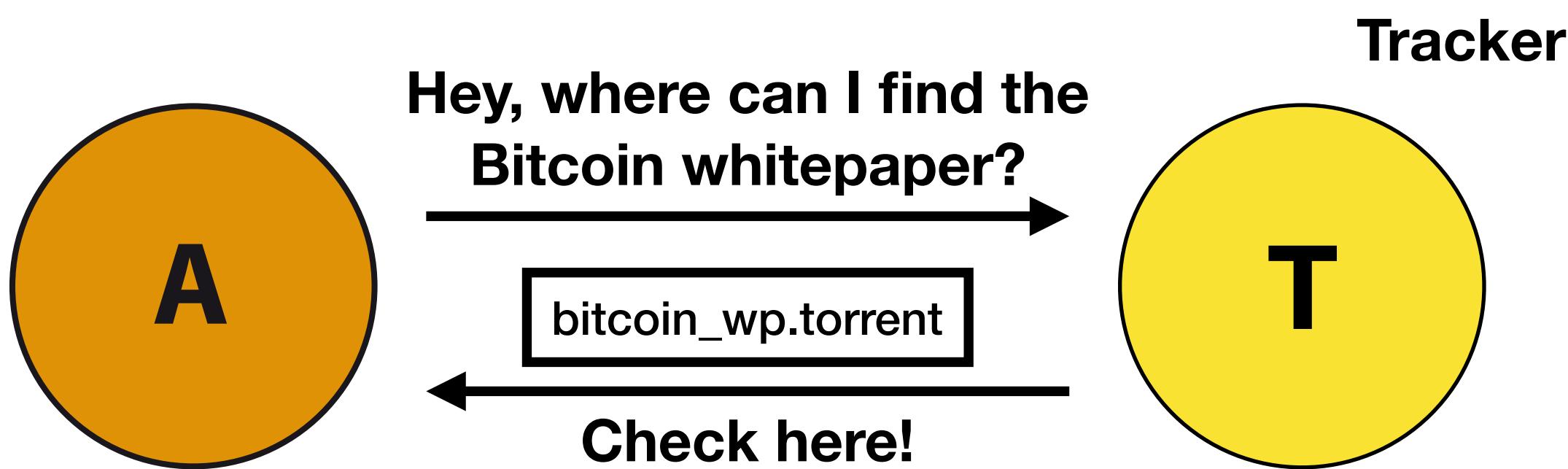
P2P file sharing: Request paradigm (BitTorrent)

- Get file information from a tracker



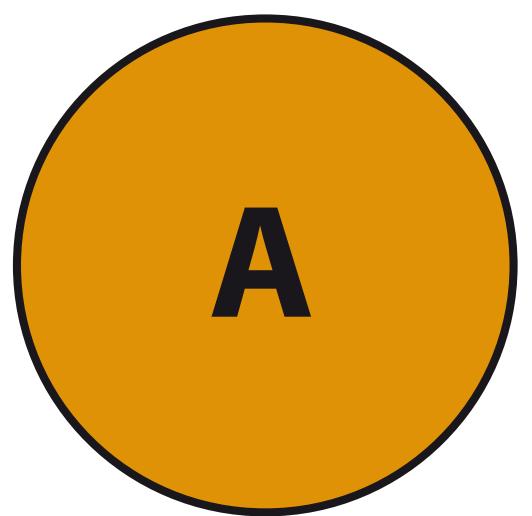
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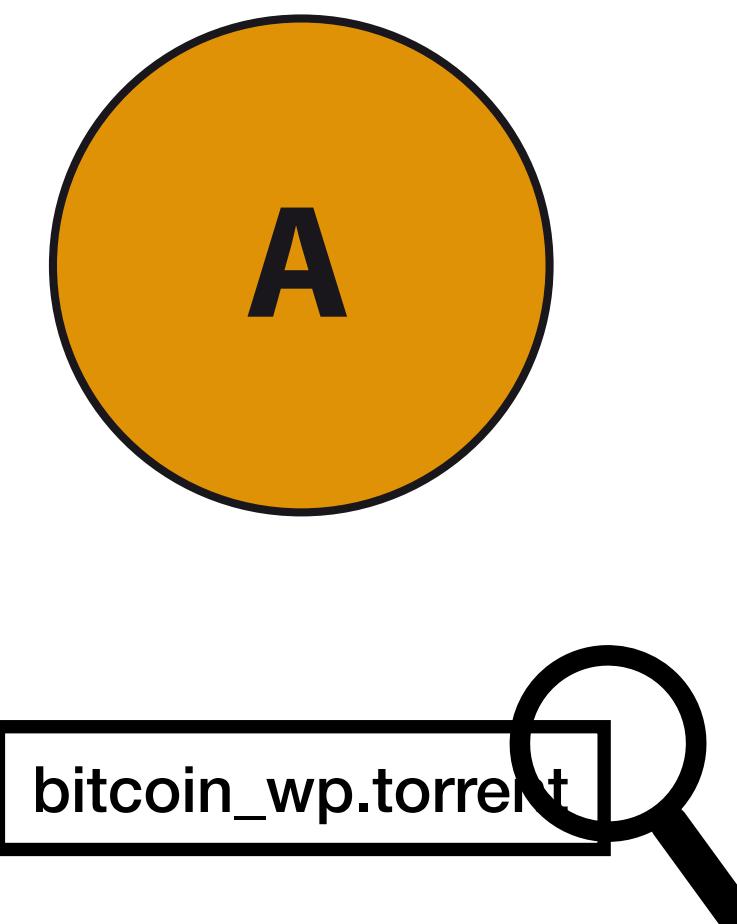
- Get file information from a tracker



bitcoin_wp.torrent

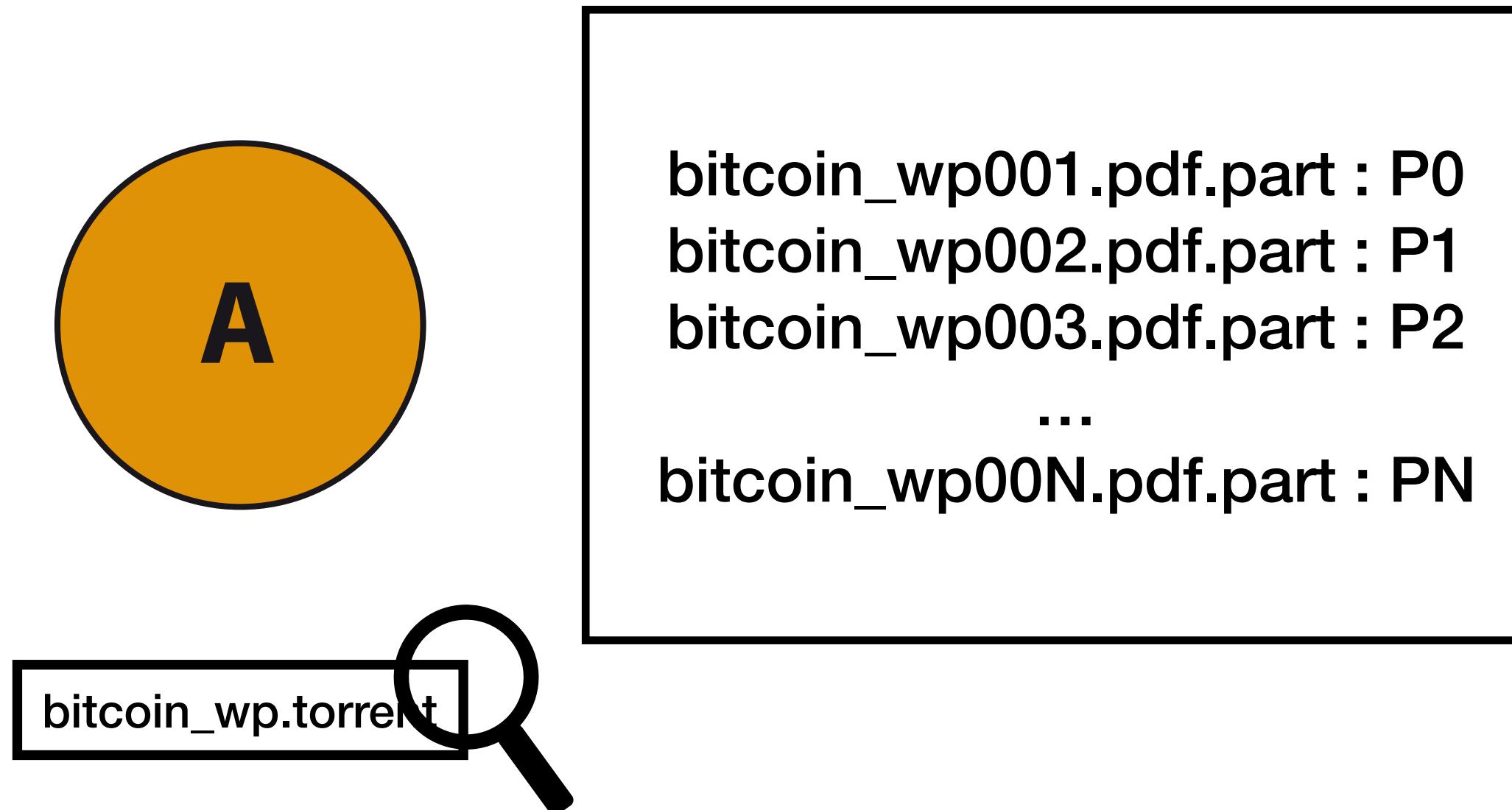
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- Check the .torrent file

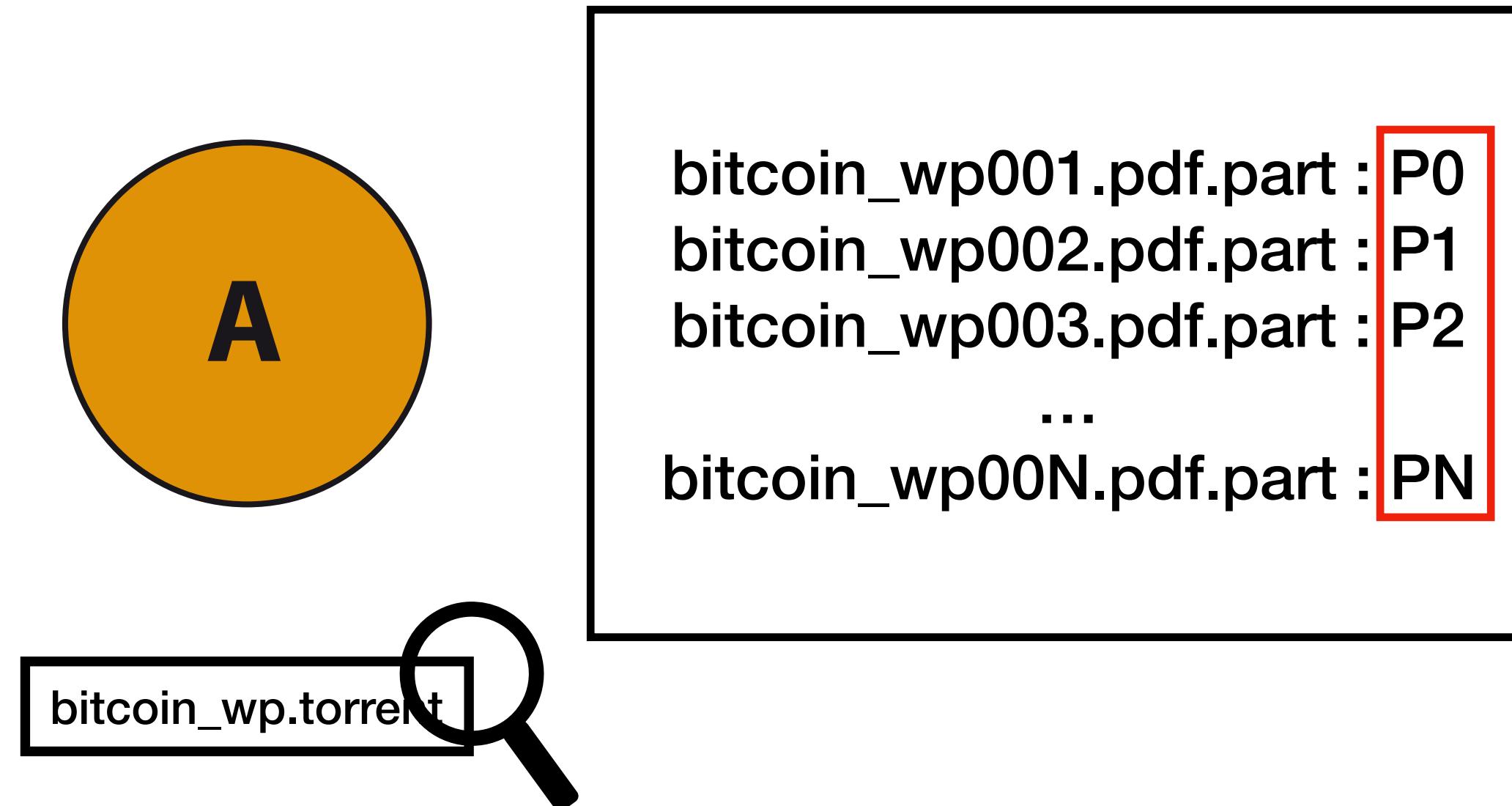


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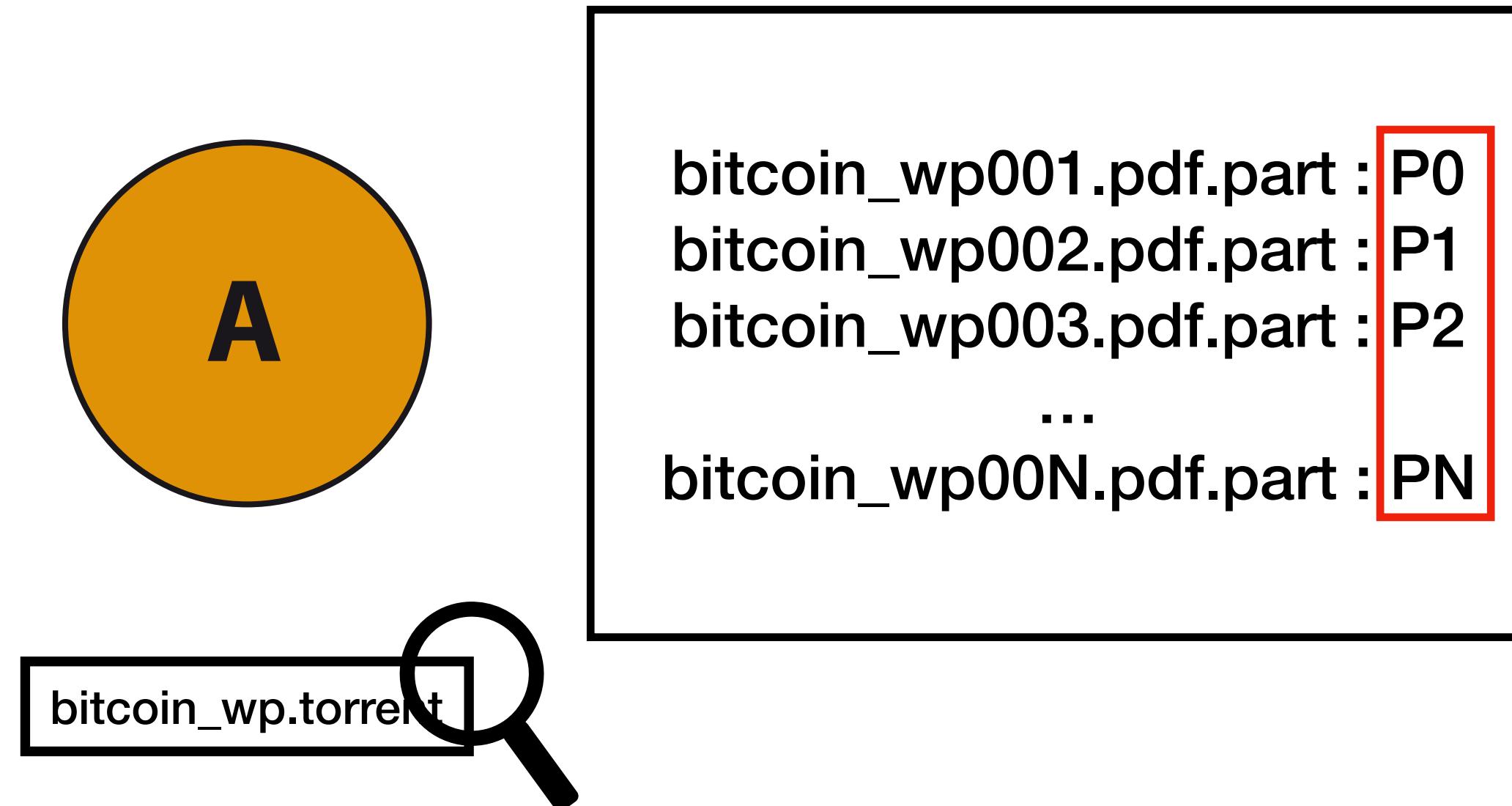


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- Connect to peers and retrieve the file parts

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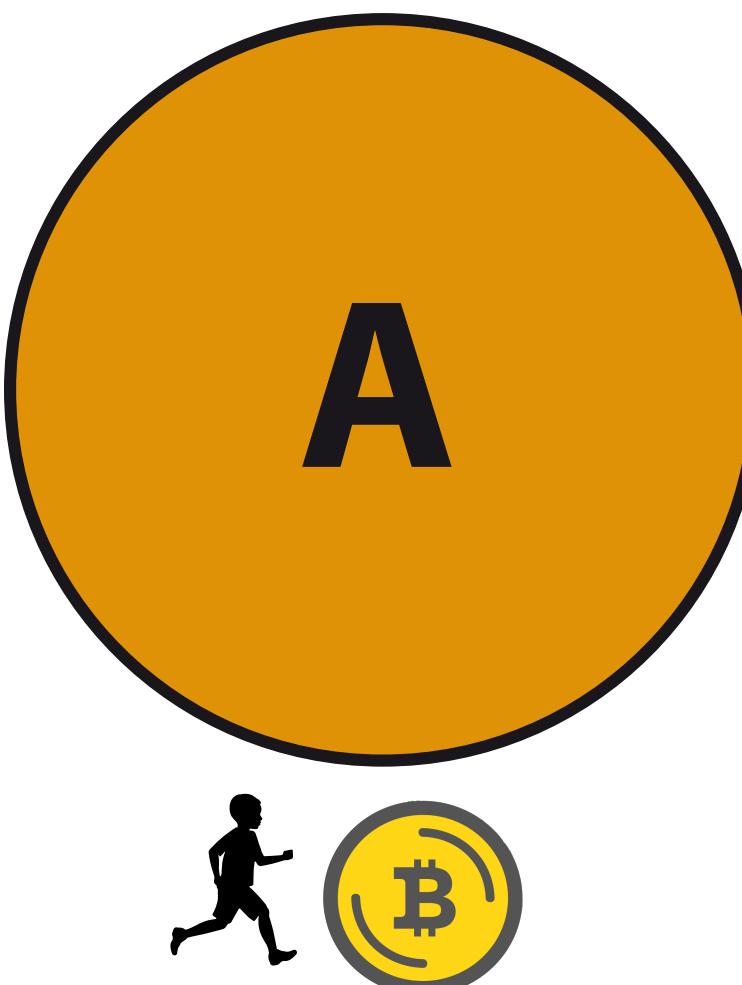


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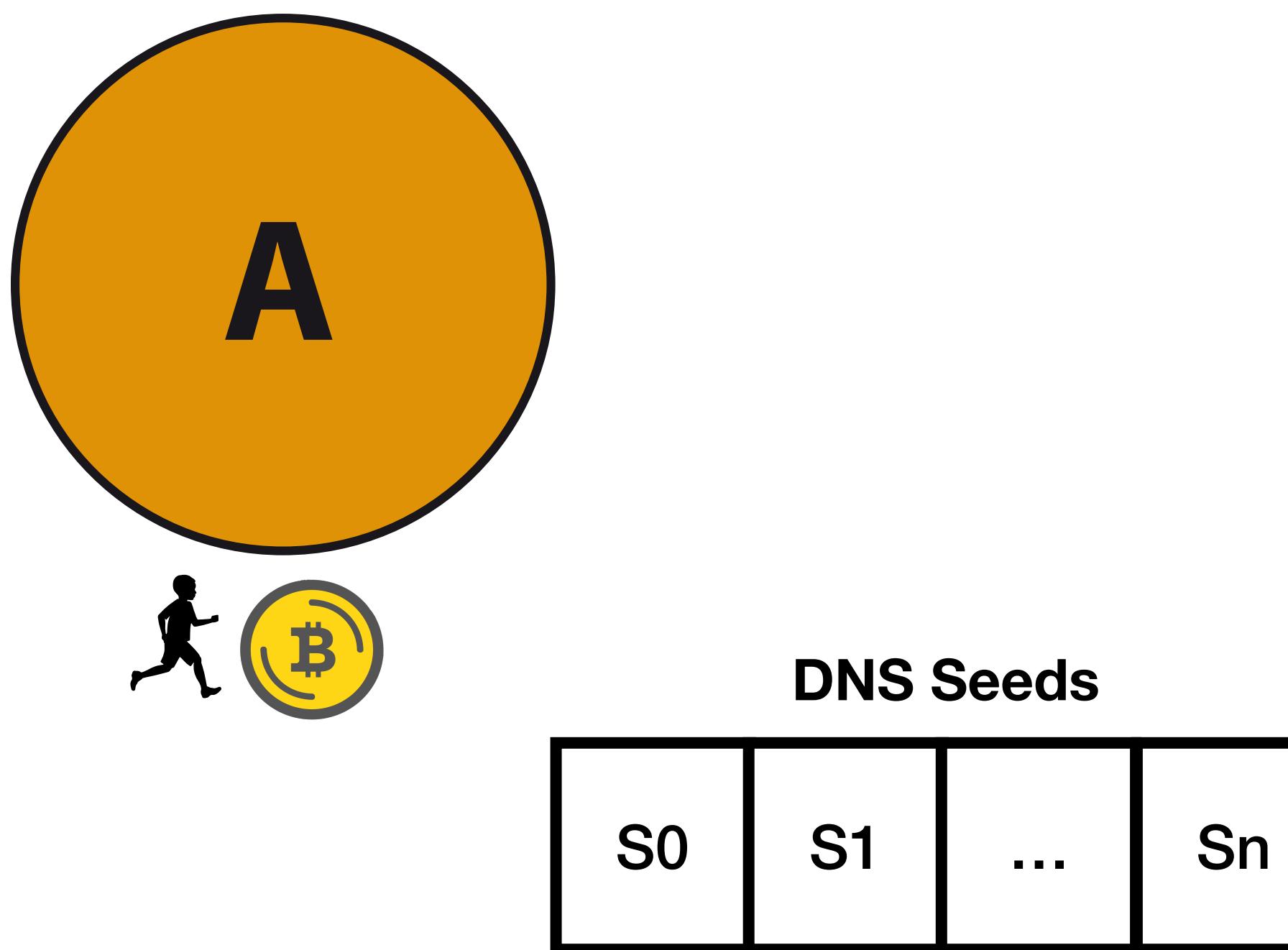
We will cover the announce paradigm later on!

Node bootstrapping and peer discovery

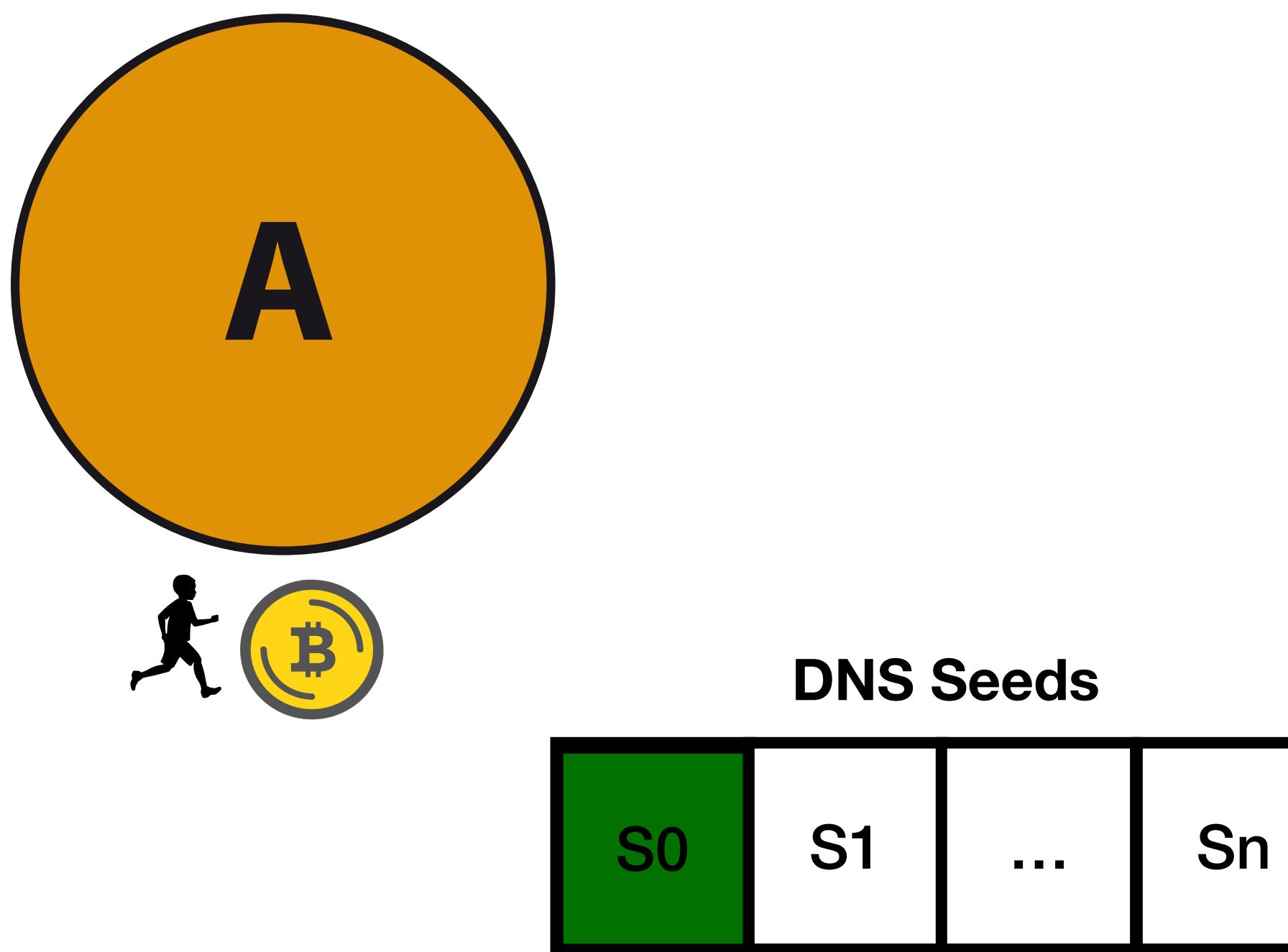
Bitcoin P2P bootstrapping (peer discovery)



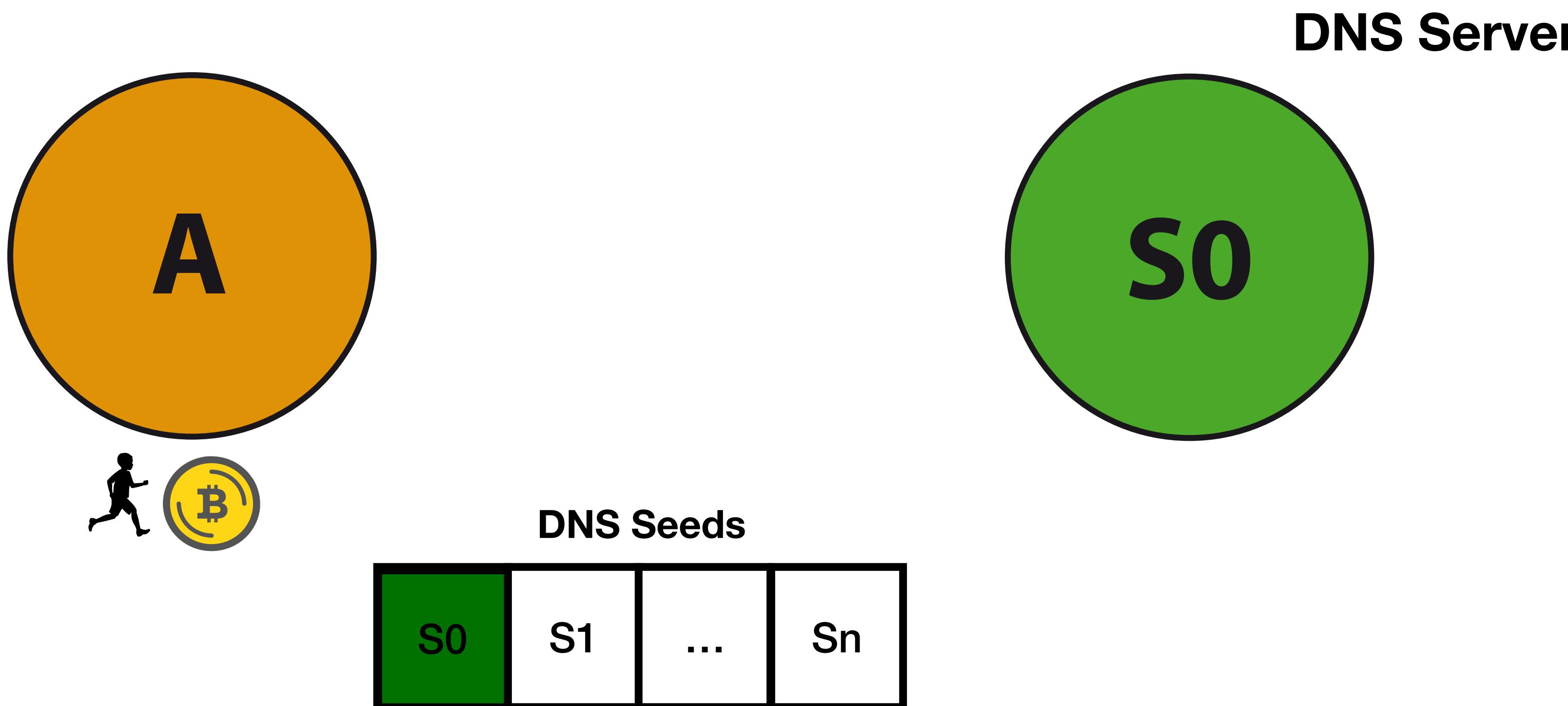
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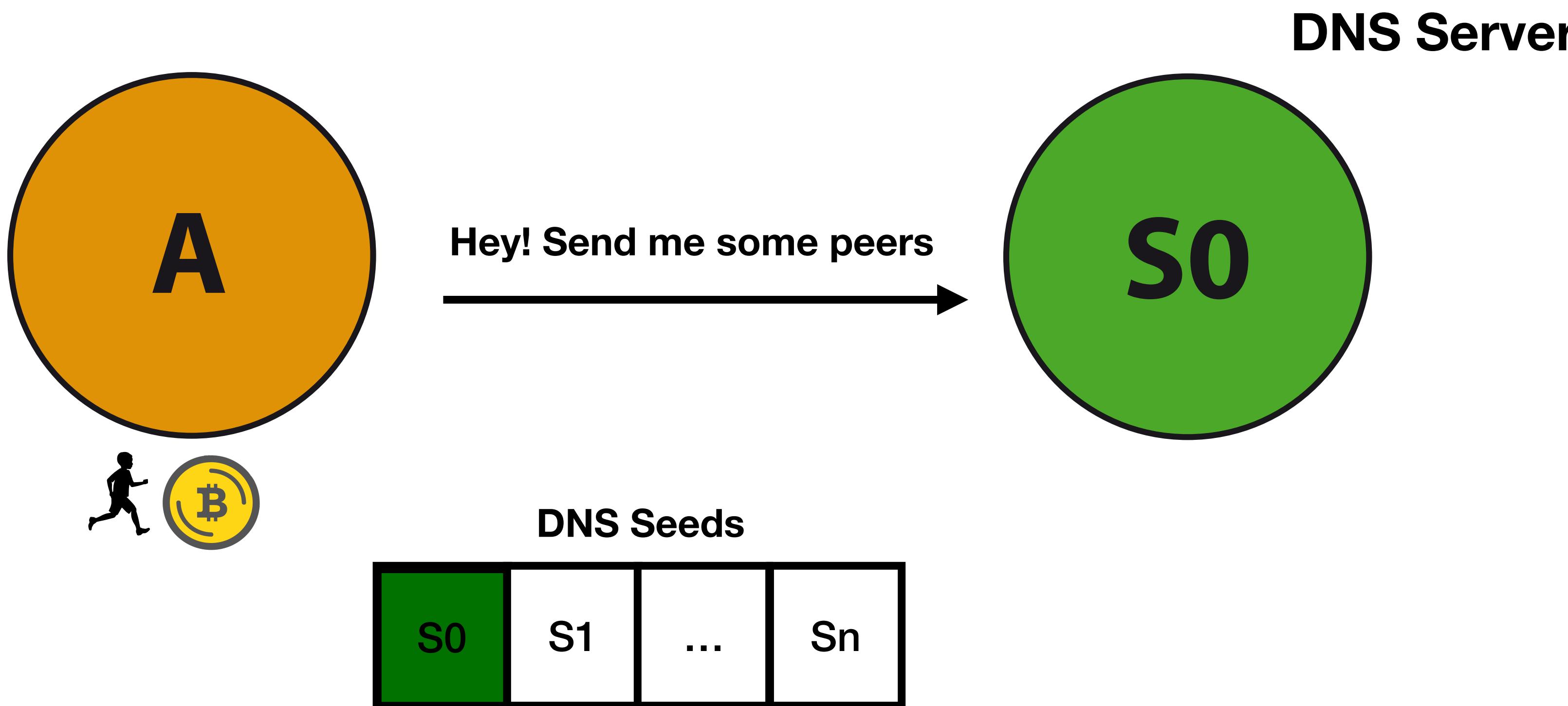
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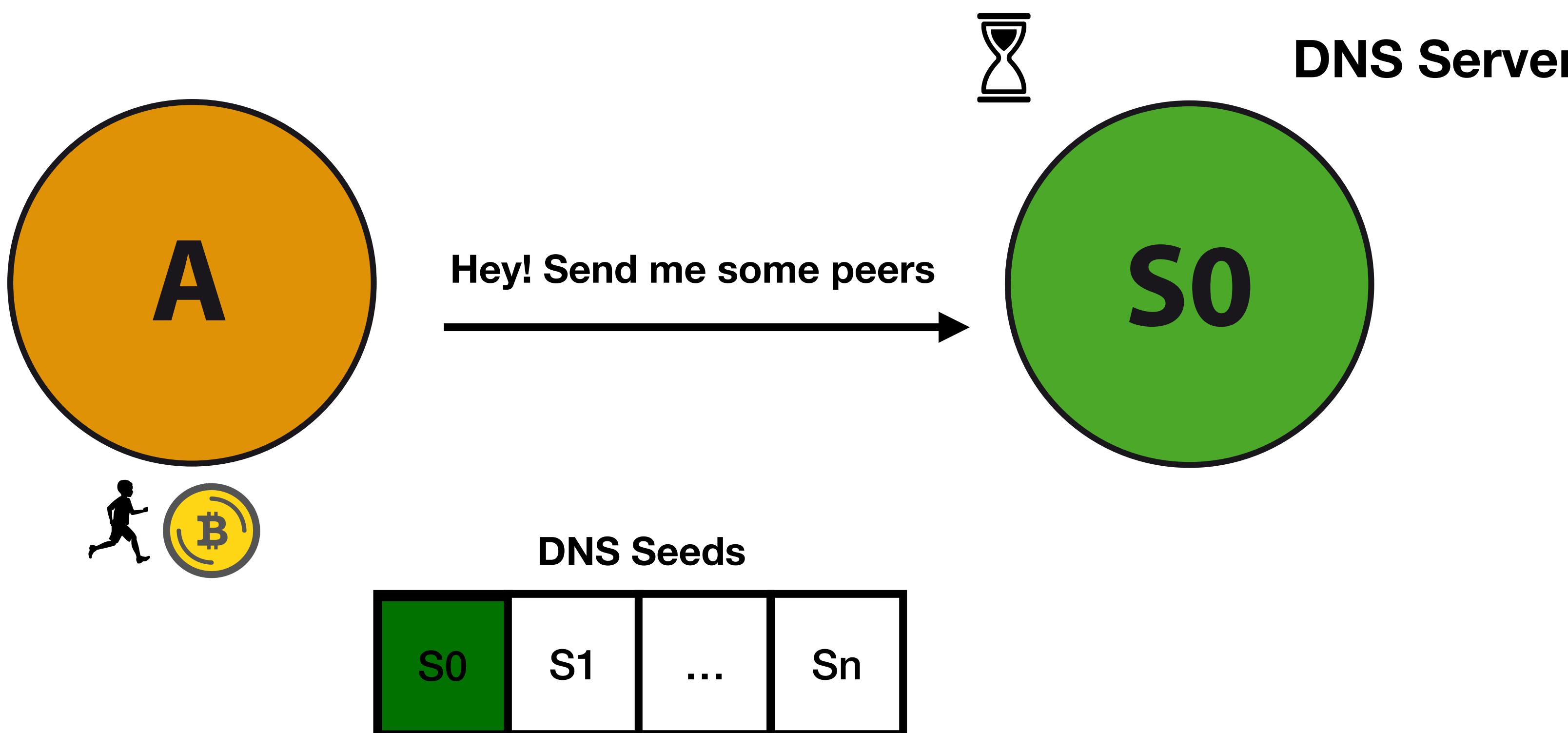
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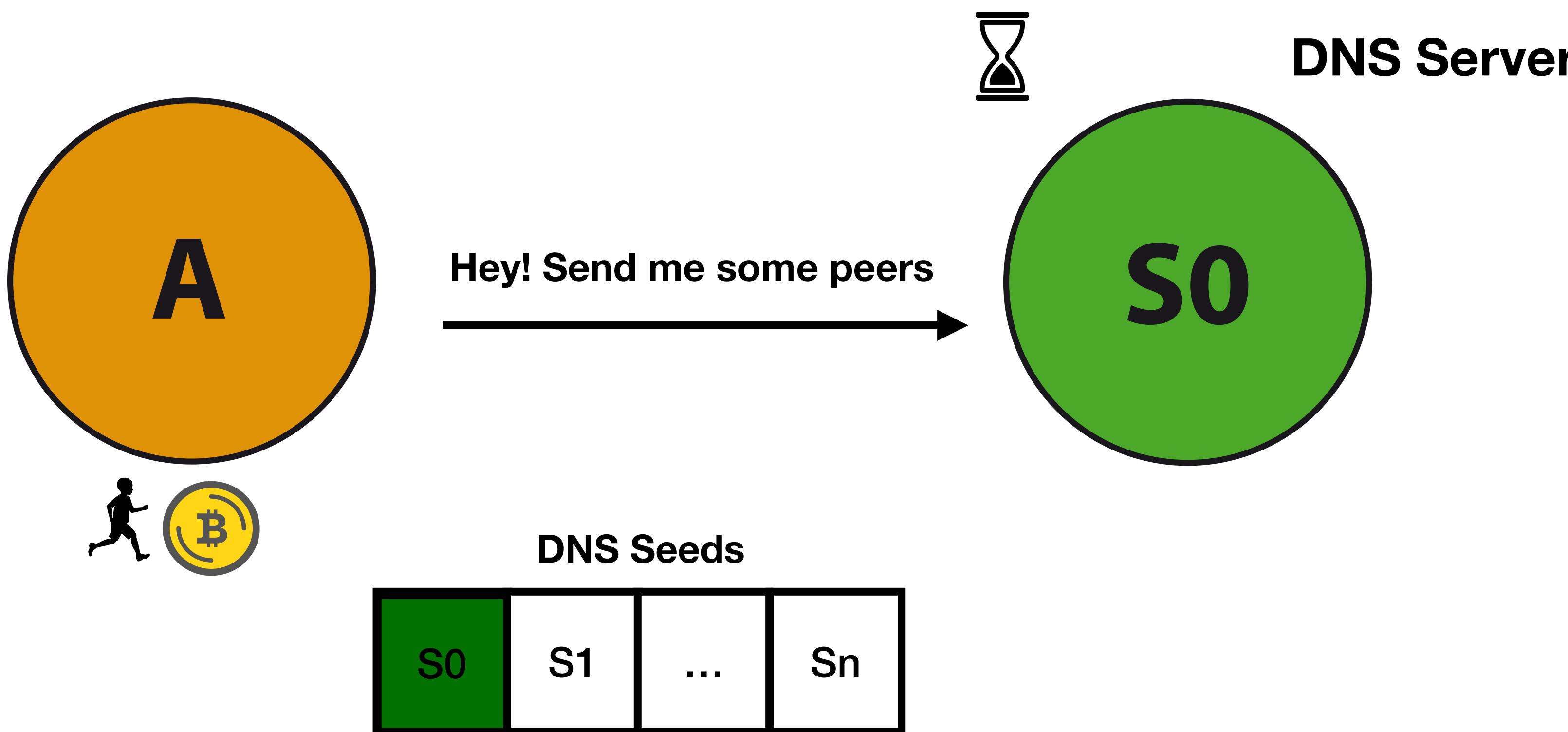
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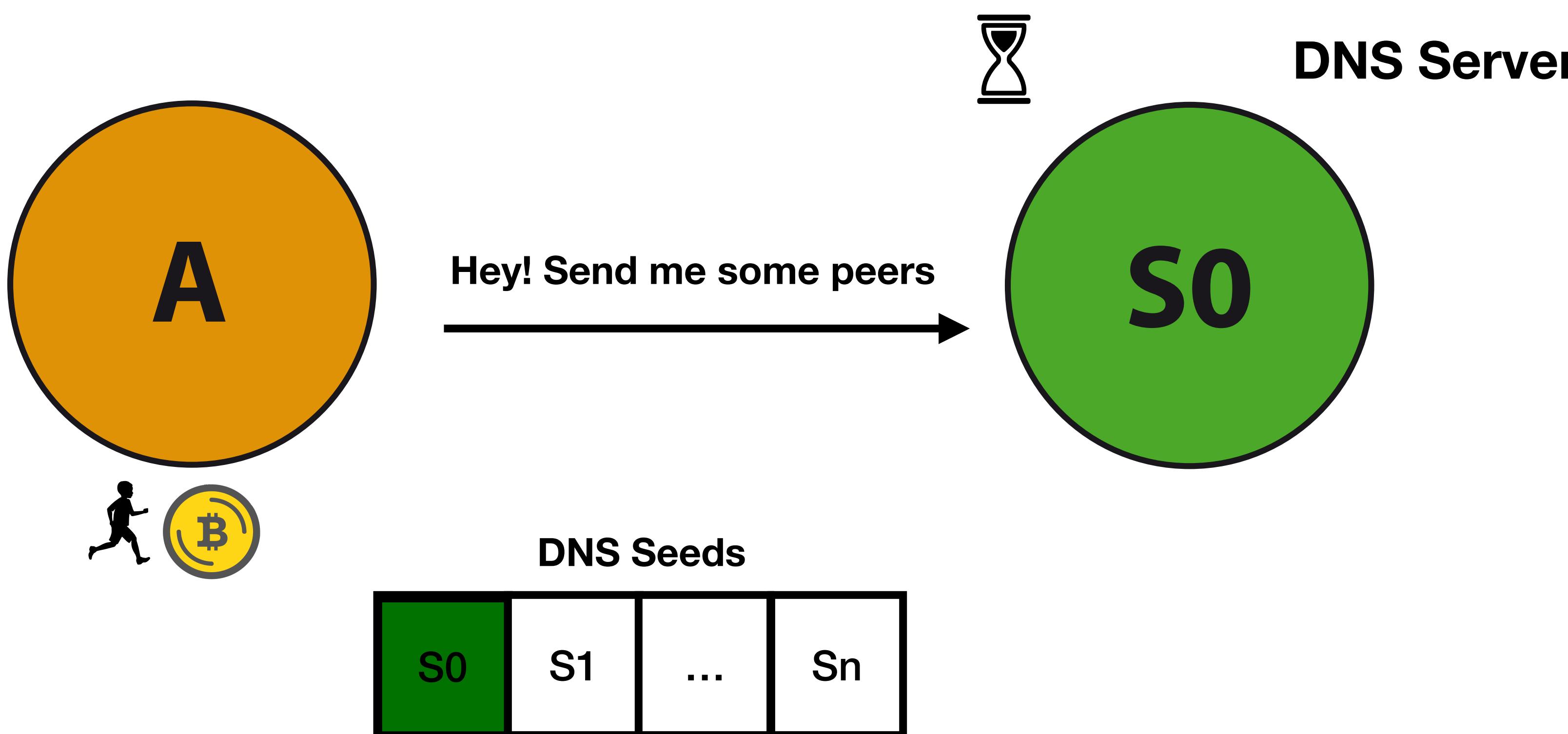
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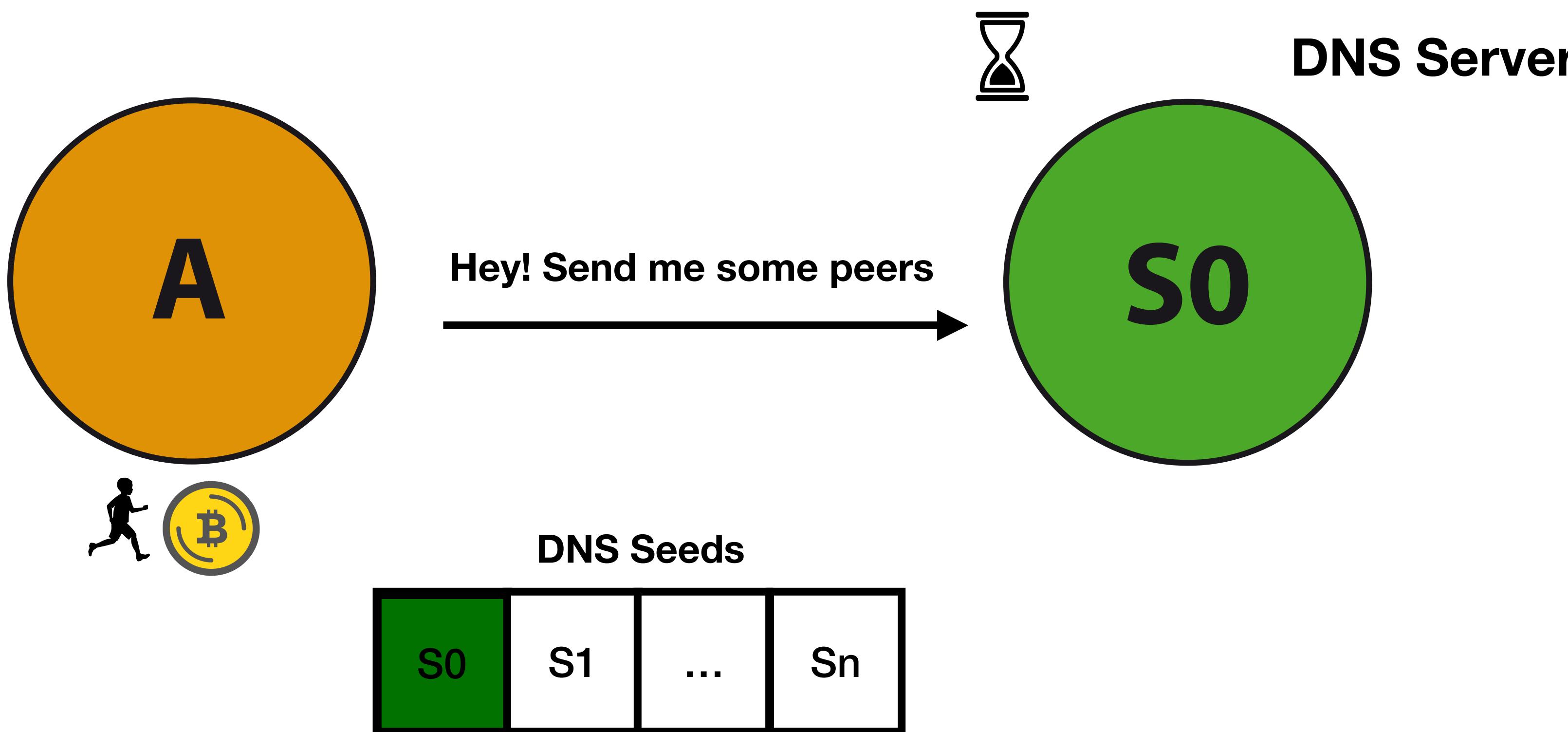
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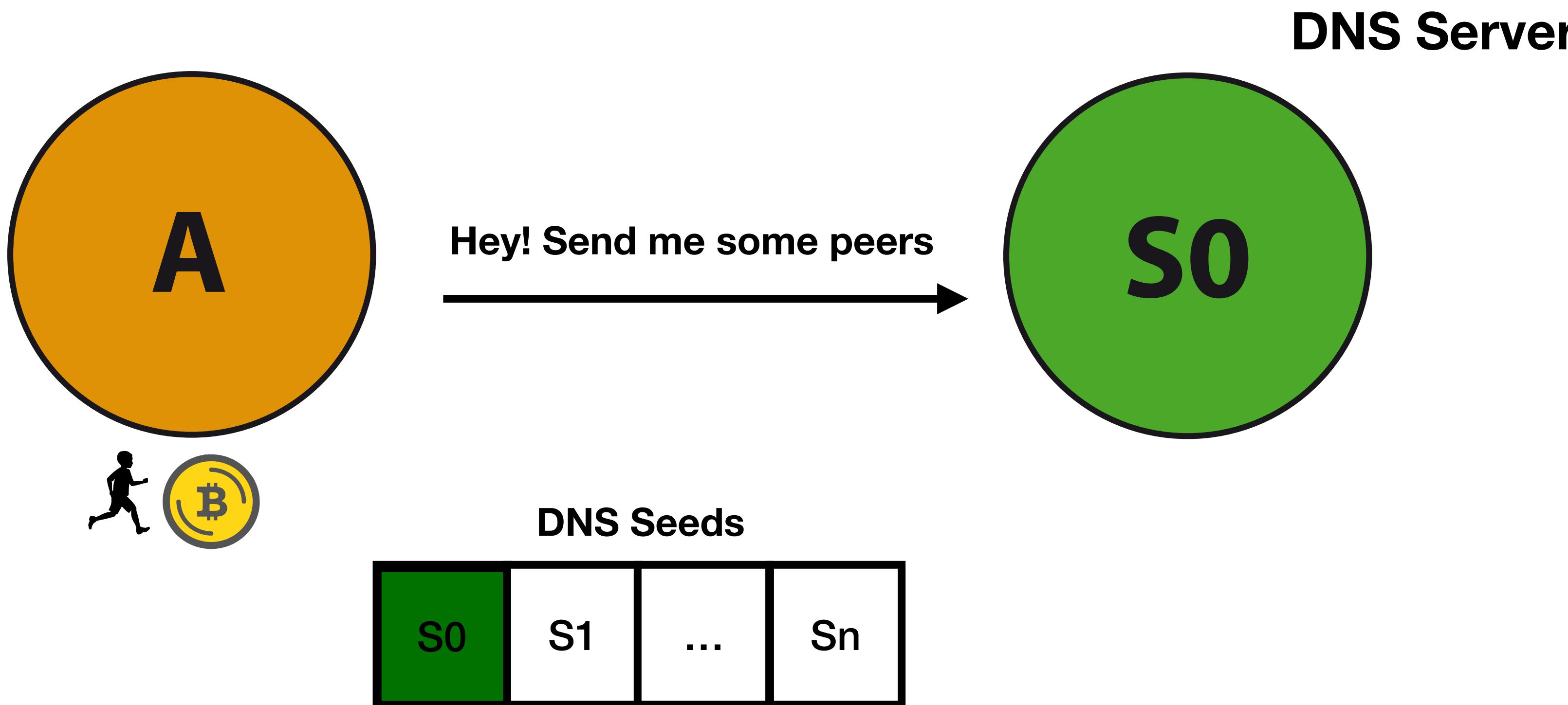
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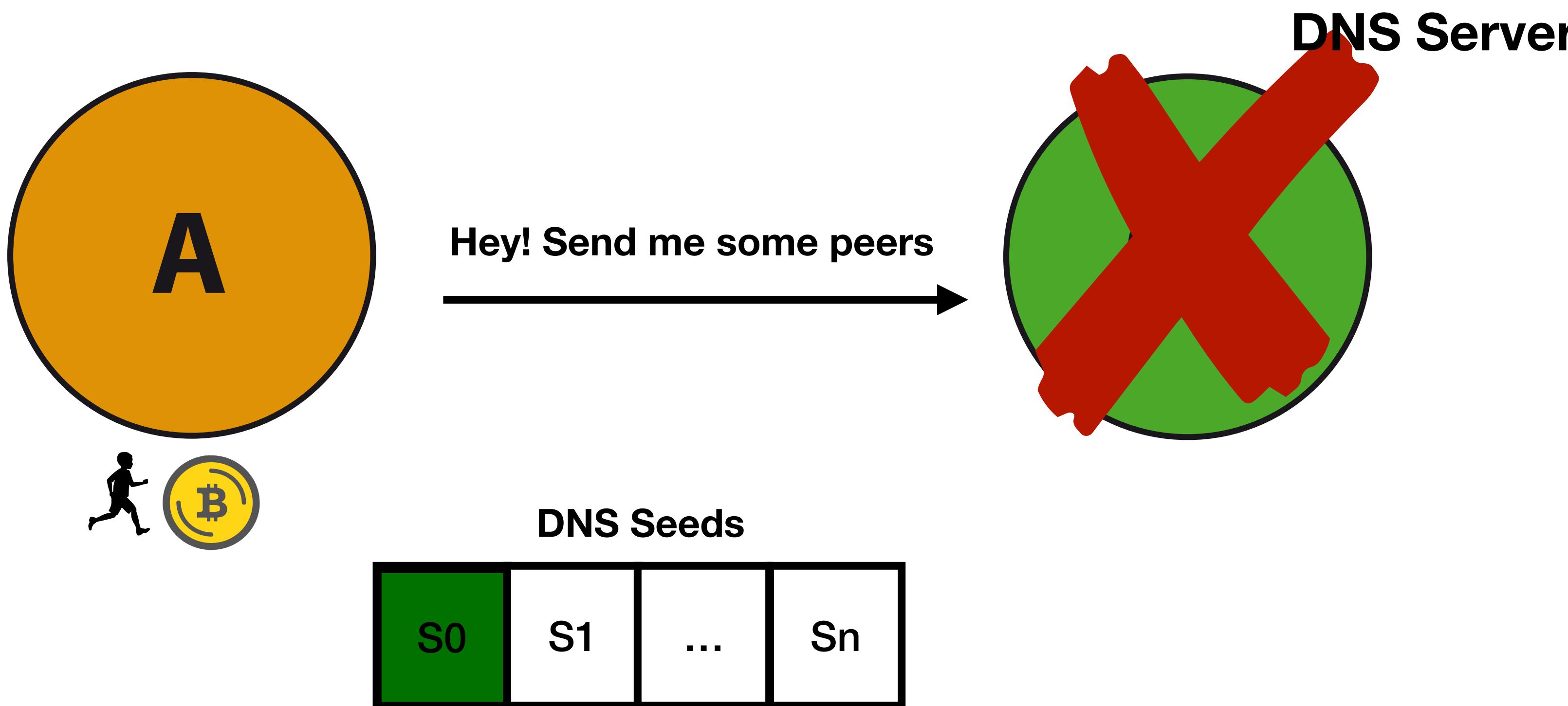
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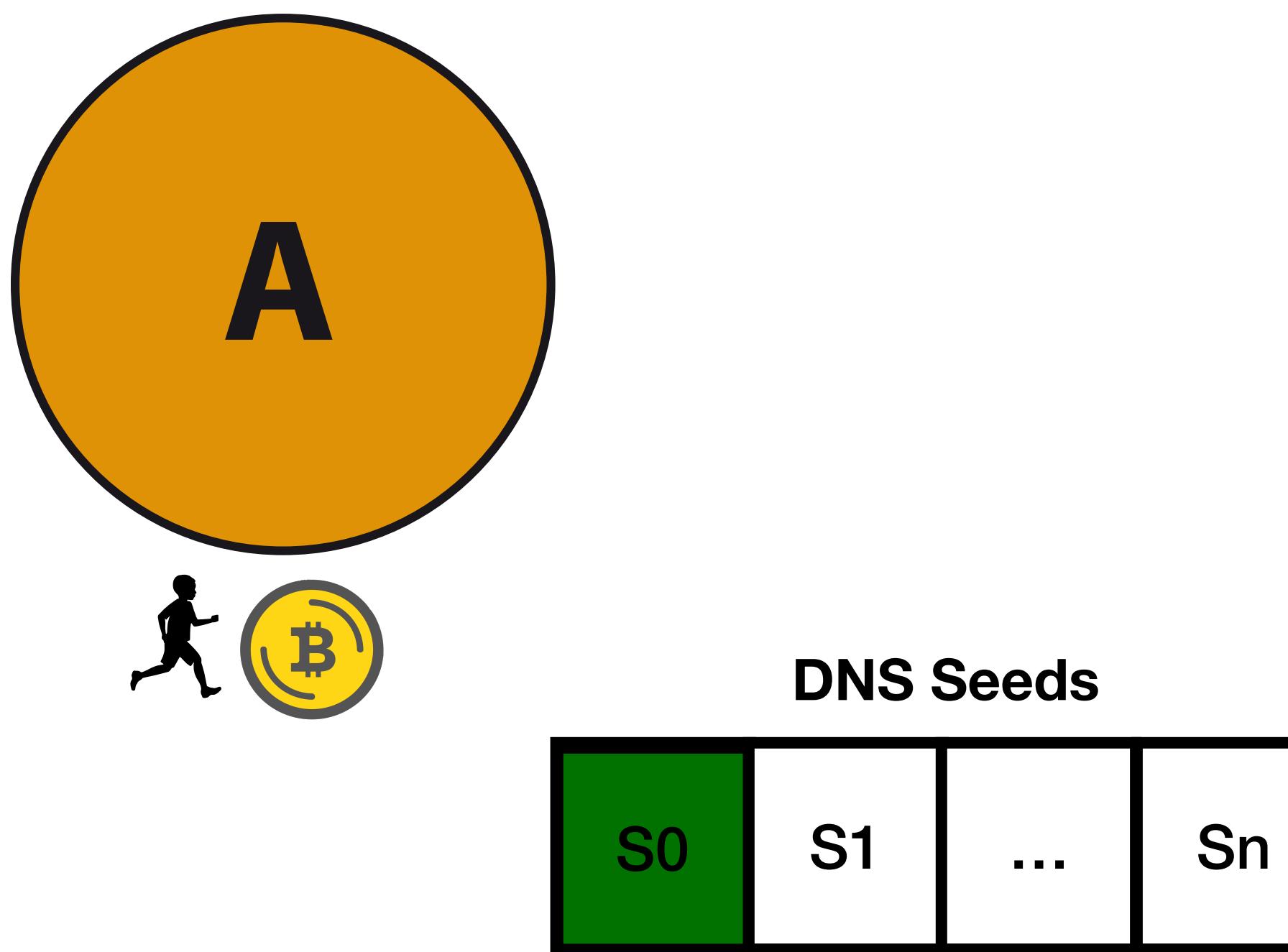
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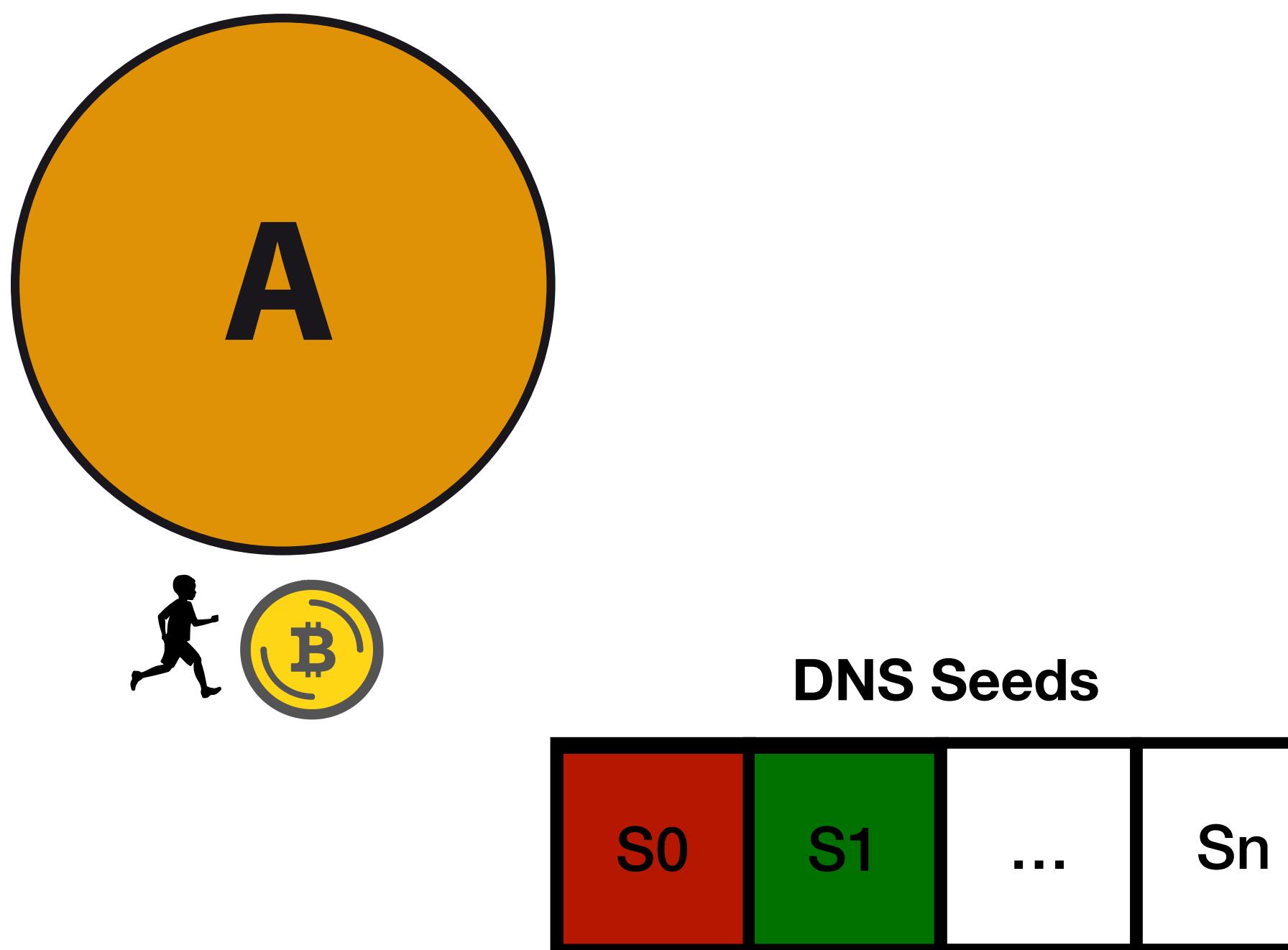
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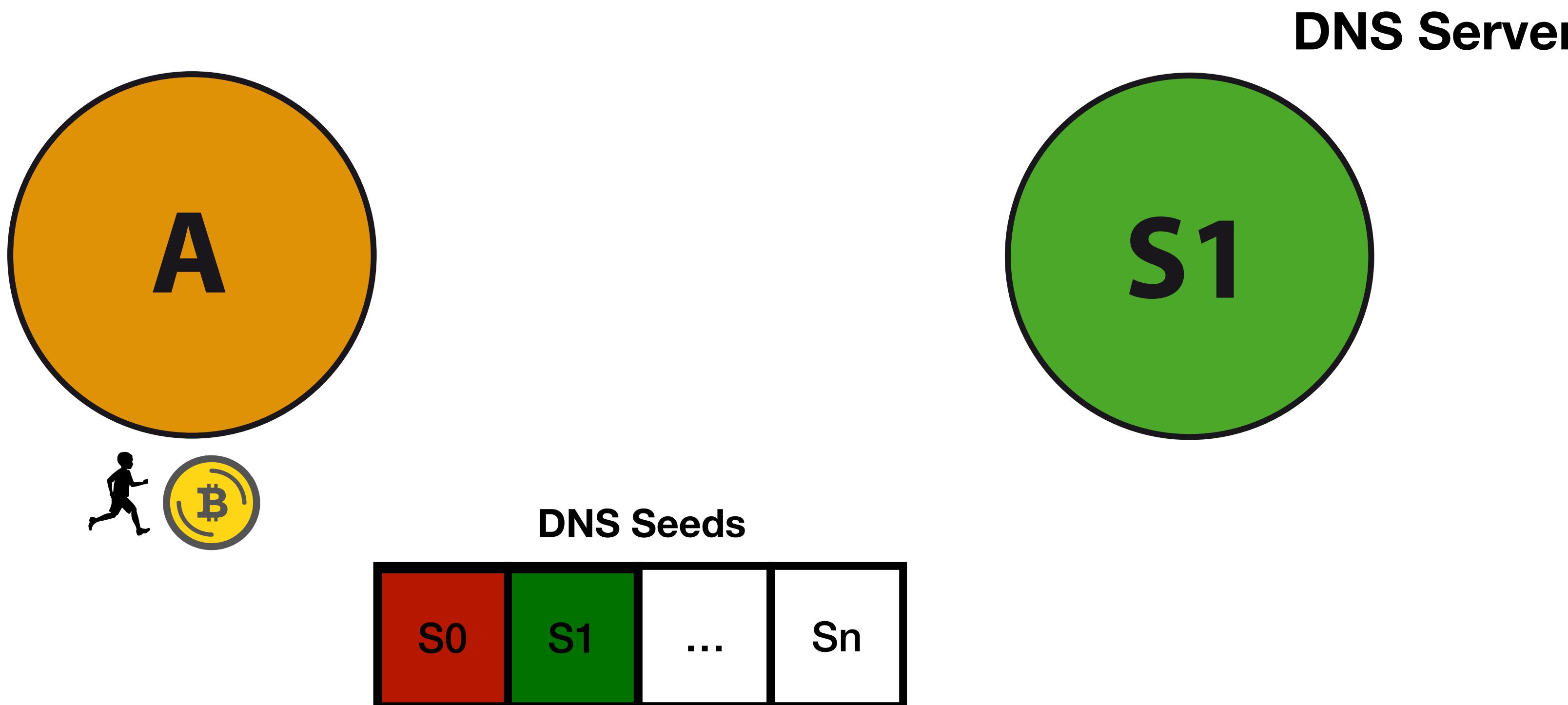


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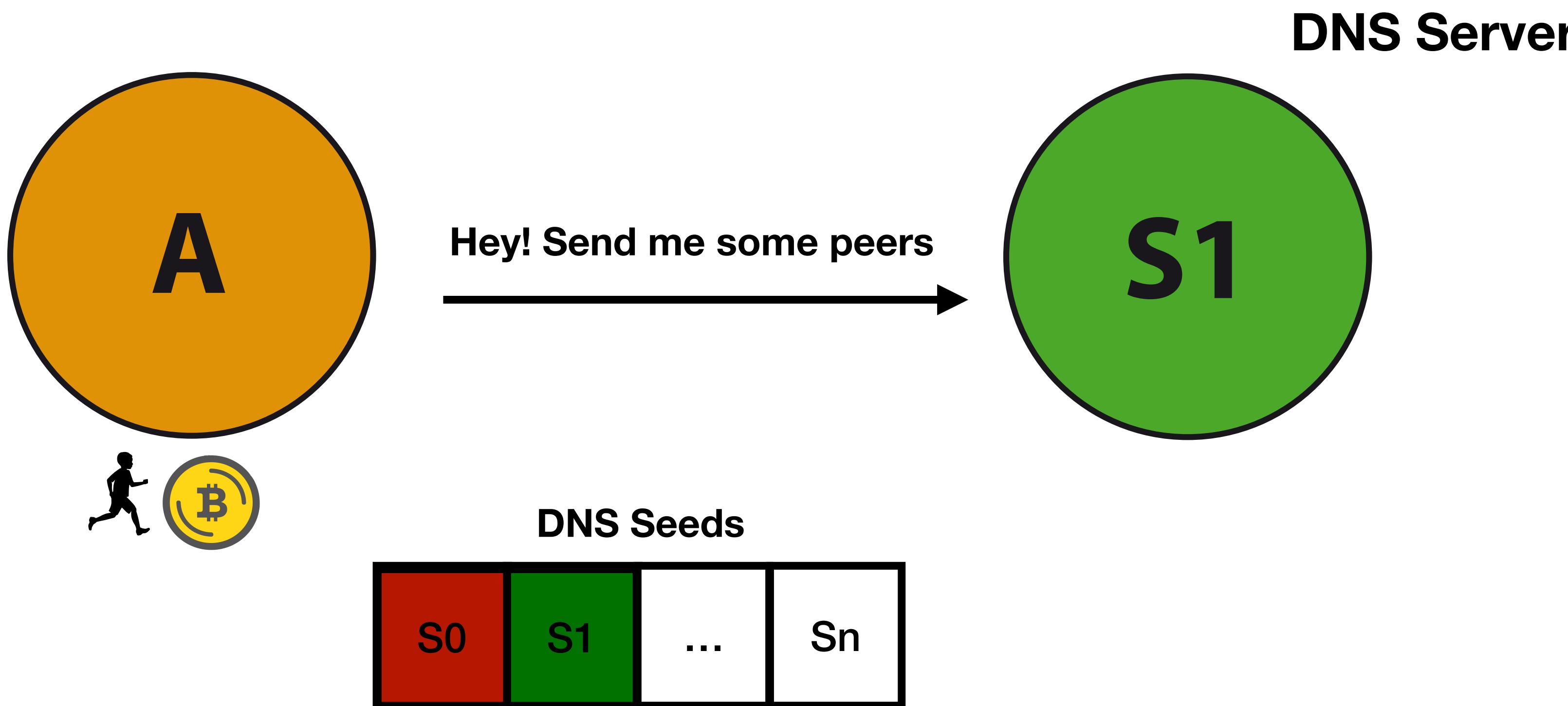


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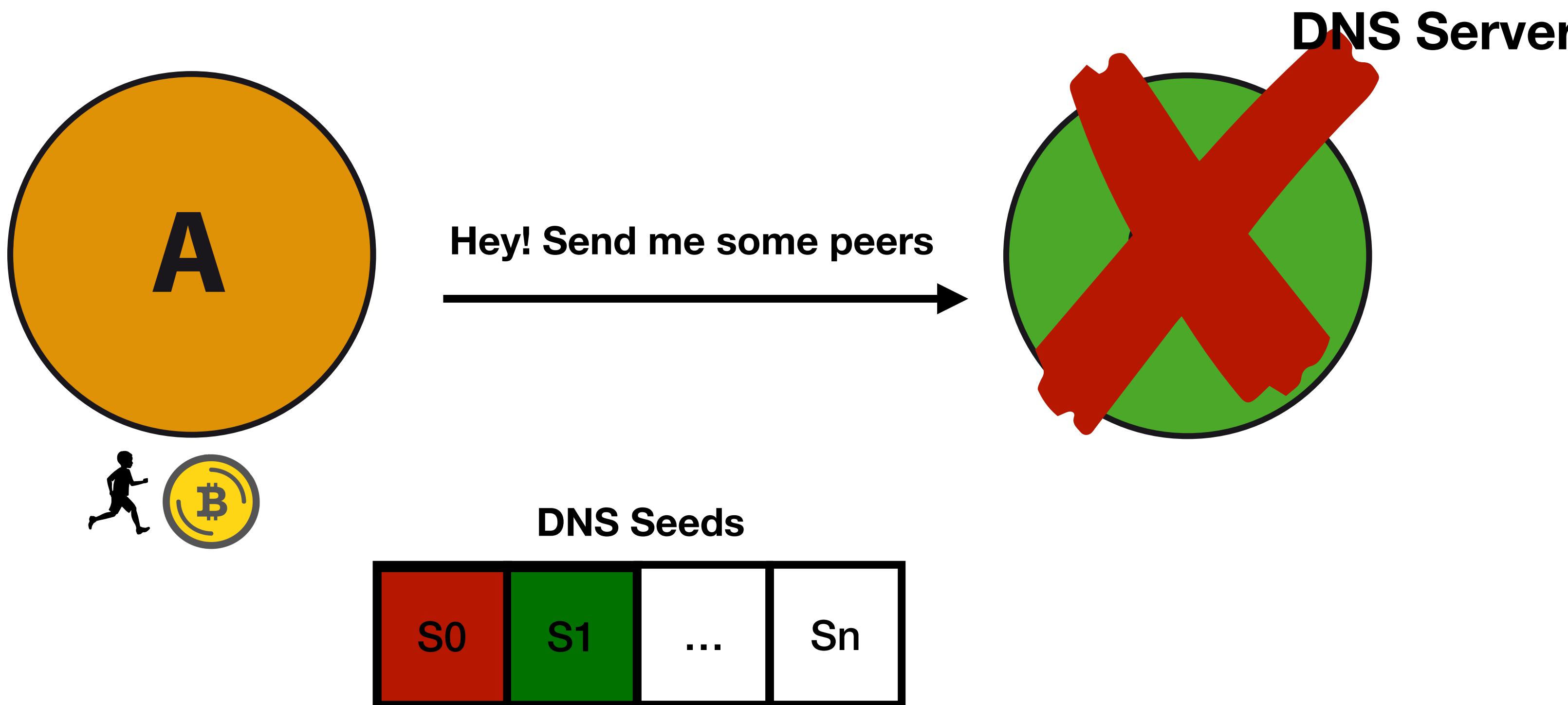
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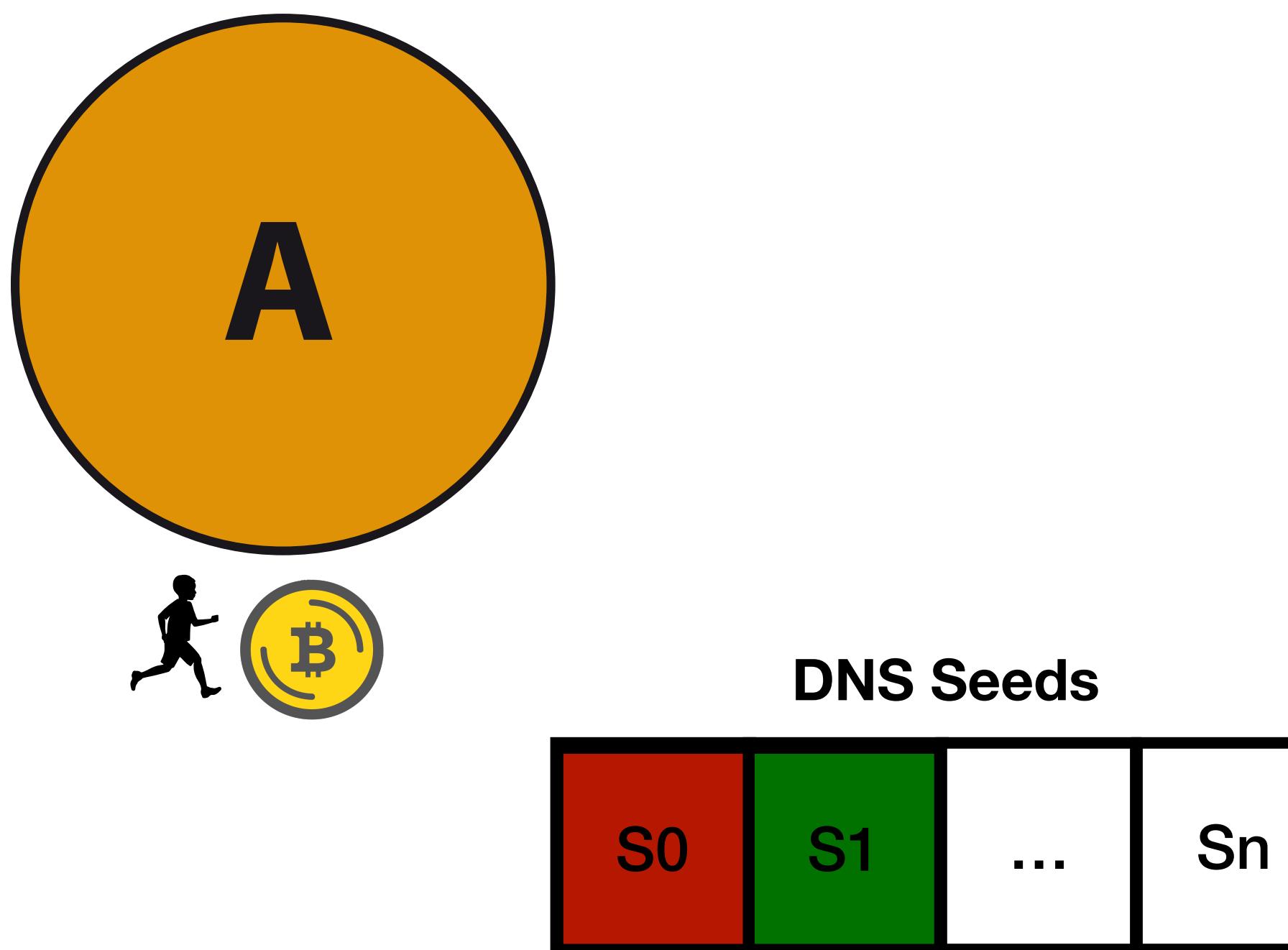
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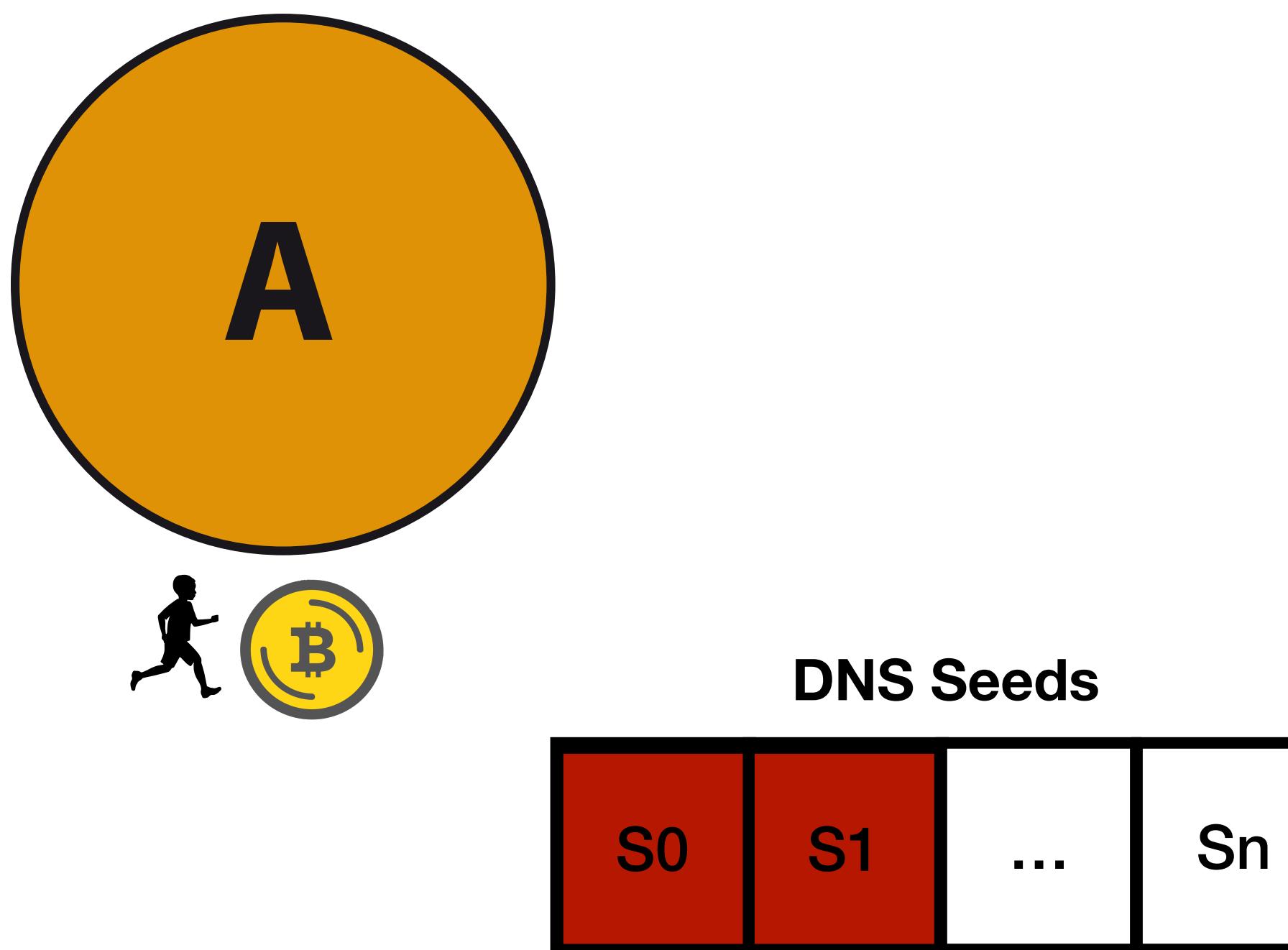
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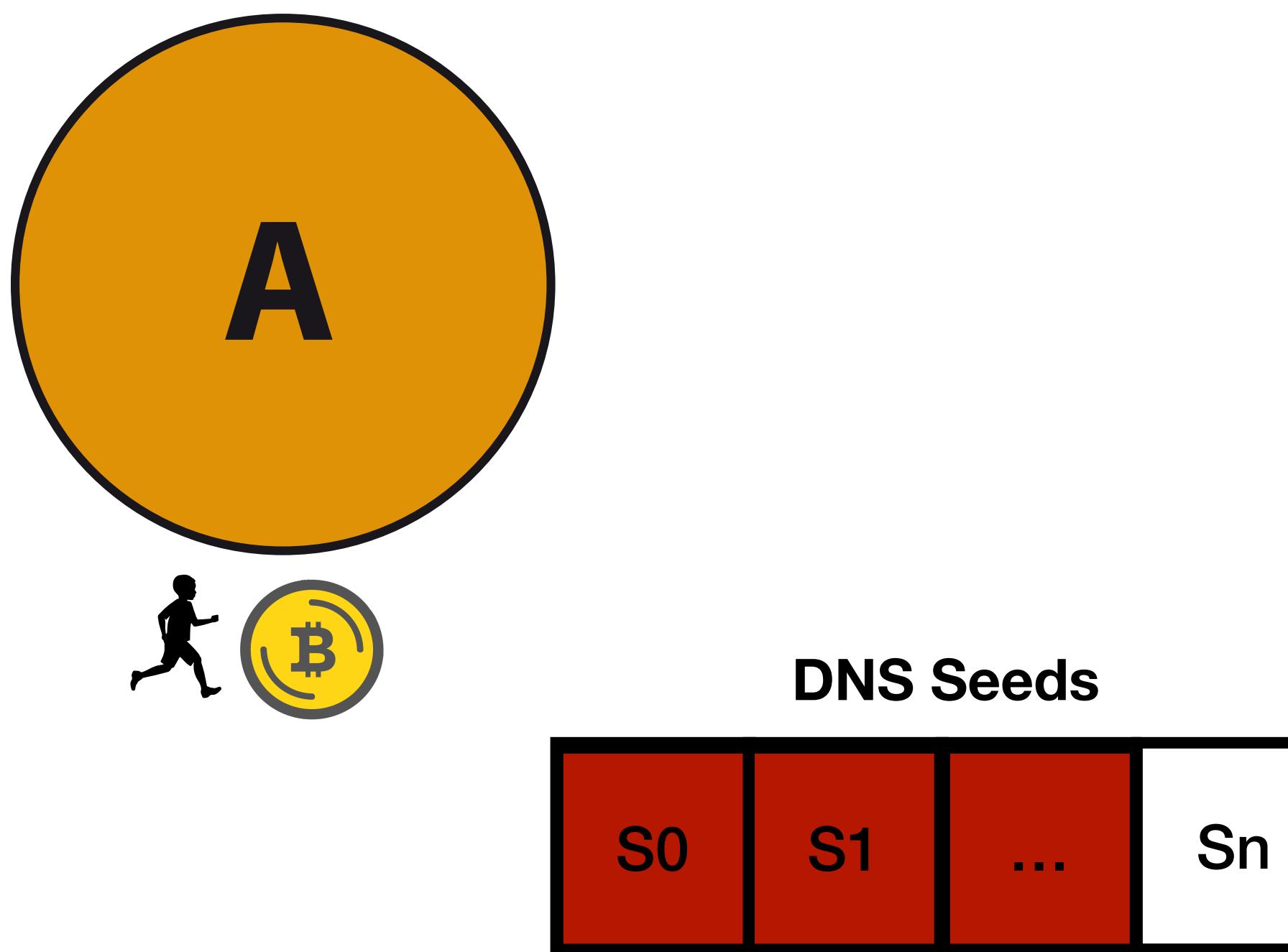
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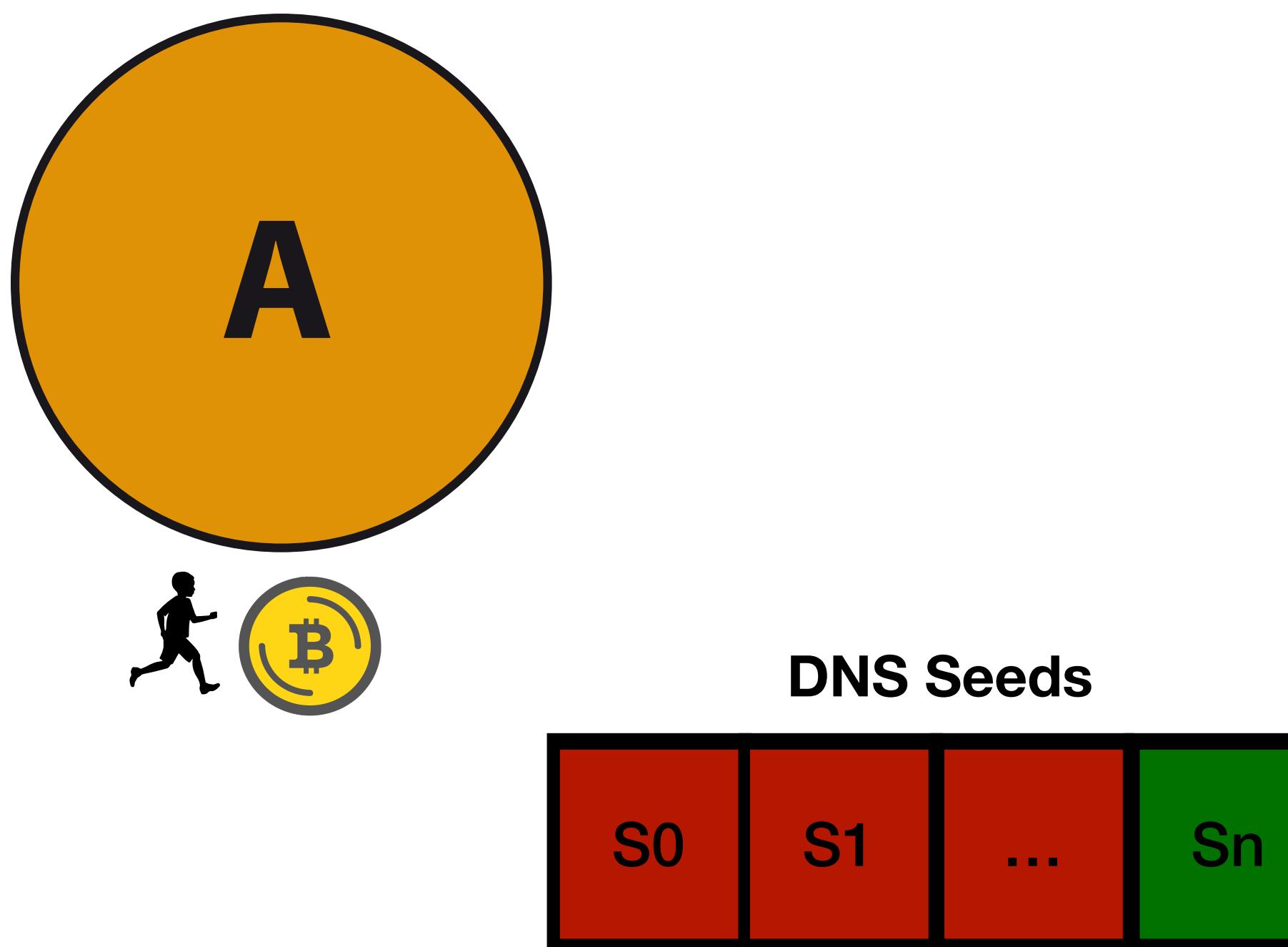
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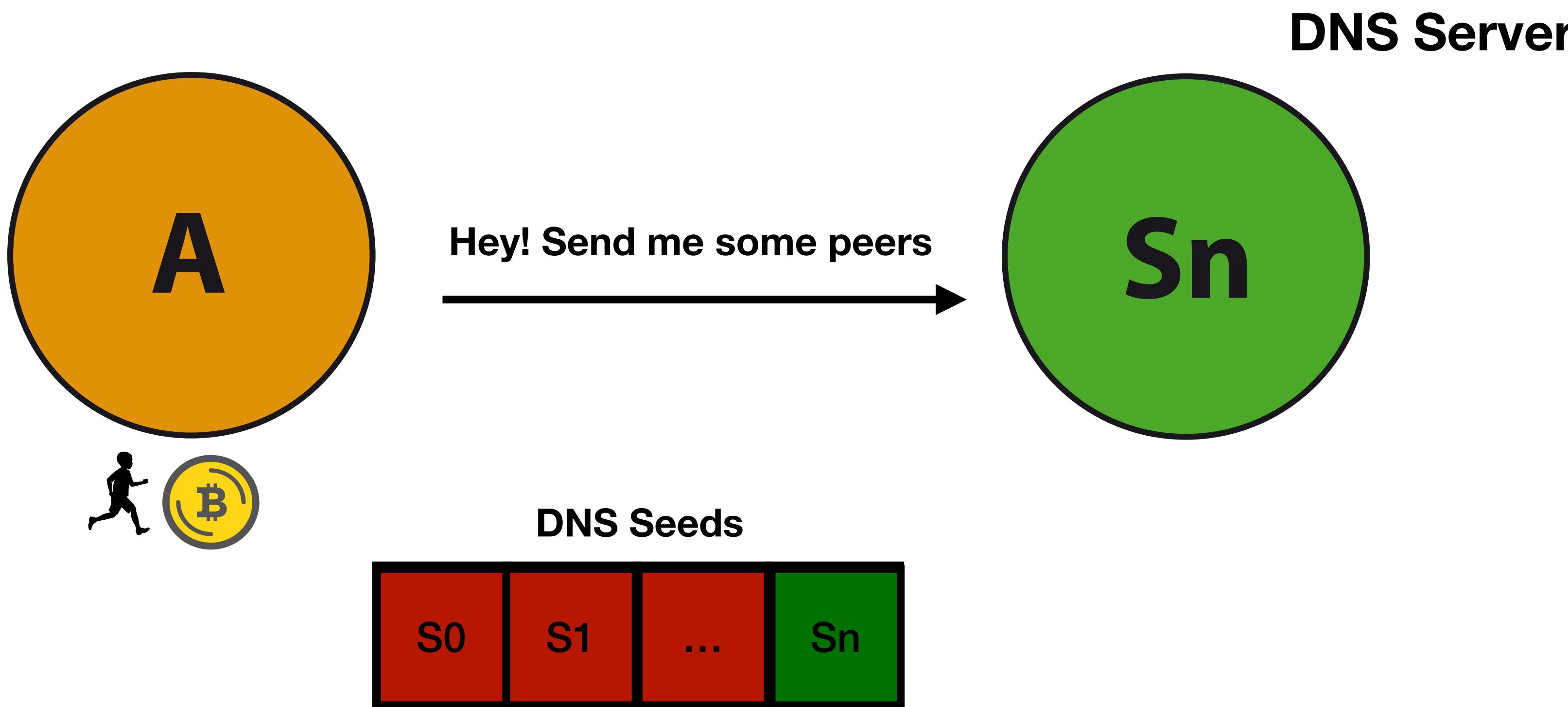
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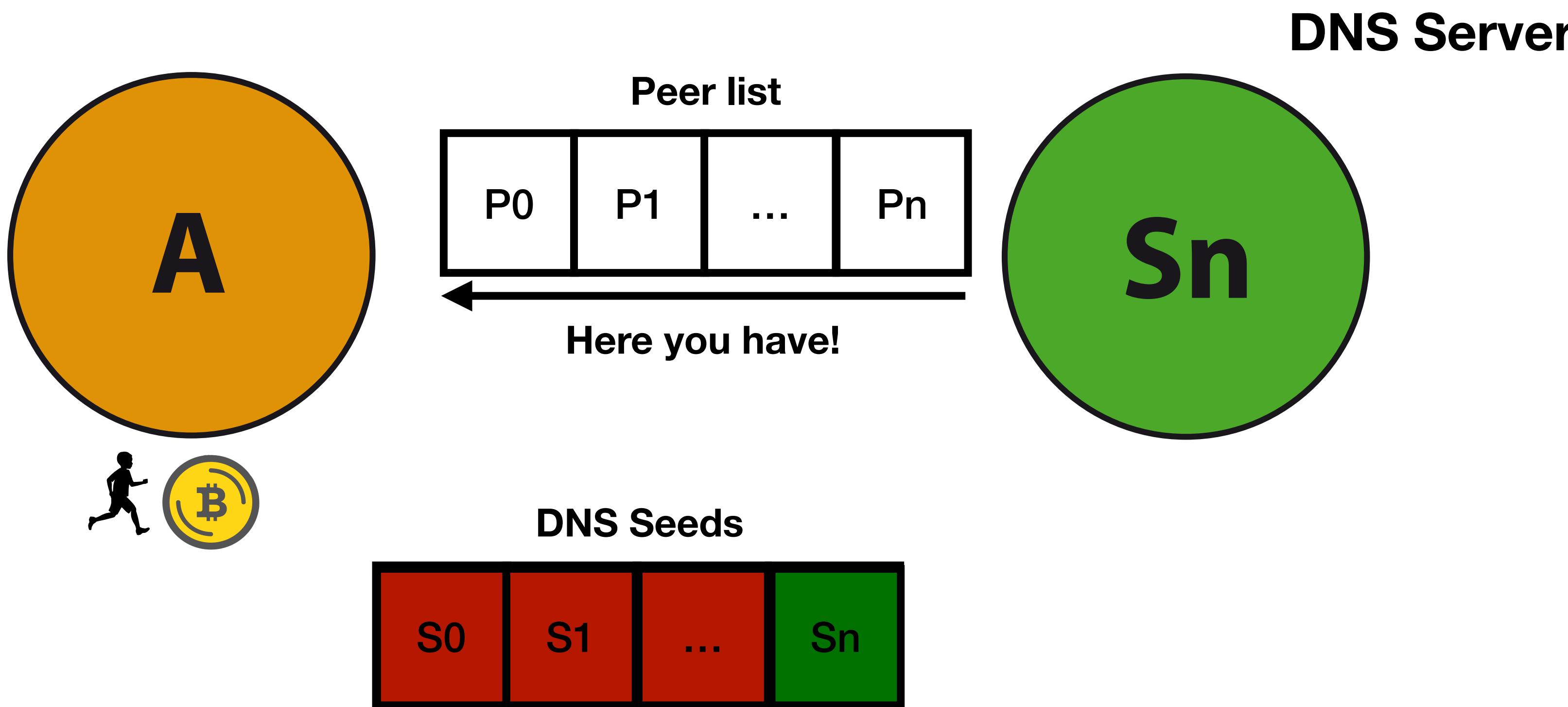


Bitcoin P2P bootstrapping (peer discovery)



Node bootstrapping and peer discovery

Bitcoin P2P bootstrapping (peer discovery)



Bitcoin P2P bootstrapping (DNS server hosts)

```
vSeeds.emplace_back("seed.bitcoin.sipa.be"); // Pieter Wuille  
vSeeds.emplace_back("dnsseed.bluematt.me"); // Matt Corallo  
vSeeds.emplace_back("dnsseed.bitcoin.dashjr.org"); // Luke Dashjr  
vSeeds.emplace_back("seed.bitcoinstats.com"); // Christian Decker  
vSeeds.emplace_back("seed.bitcoin.jonasschnelli.ch"); // Jonas Schnelli  
vSeeds.emplace_back("seed.btc.petertodd.org"); // Peter Todd  
vSeeds.emplace_back("seed.bitcoin.sprovoost.nl"); // Sjors Provoost
```

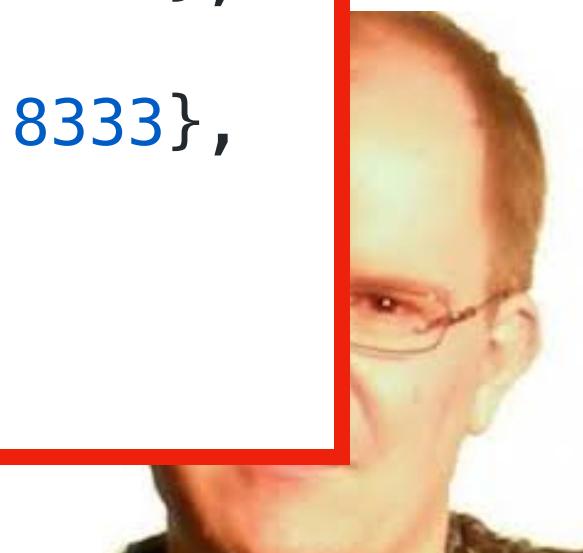
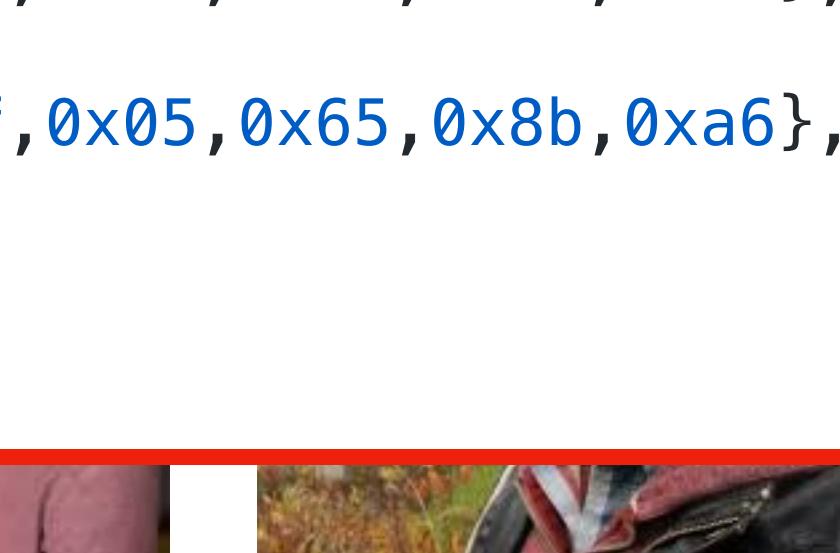
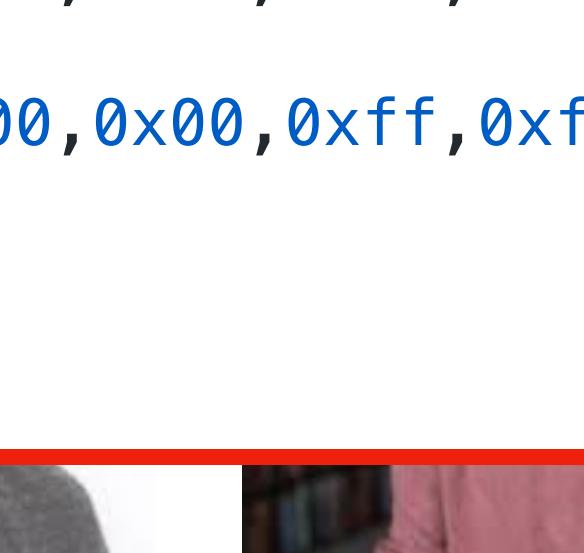
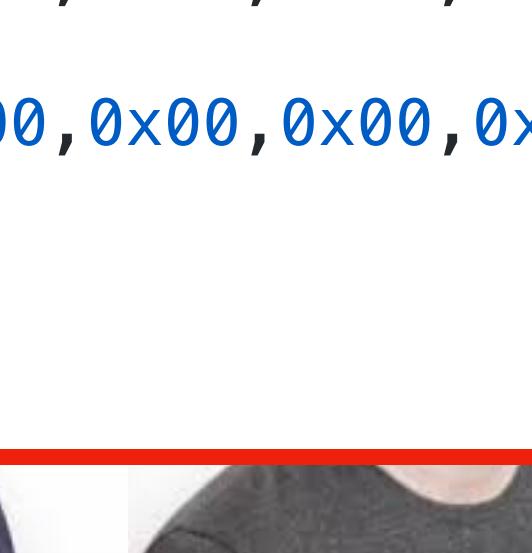
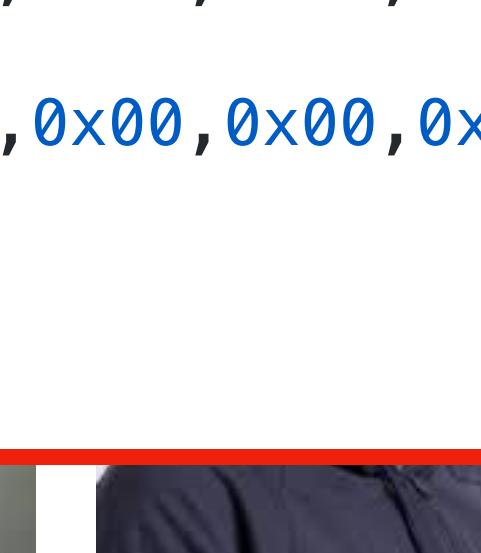
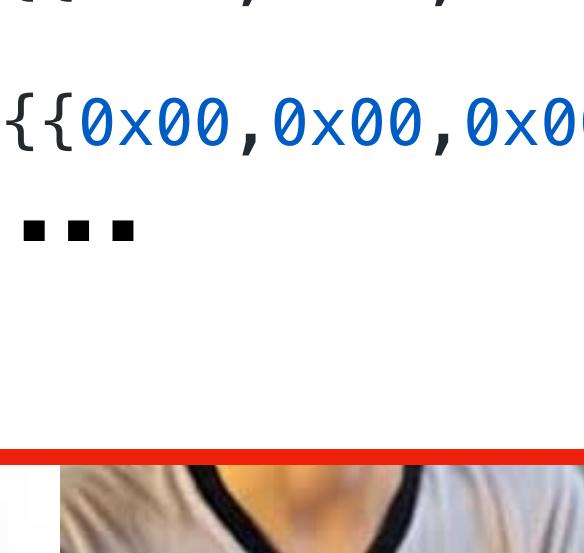


Bitcoin P2P bootstrapping (DNS server hosts)

If DNS seeds do not work,
a node will try to connect
to a hardcoded list of
nodes (fixed seed)

```
vSeeds.emplace_back("seed.bitcoin.sipa.be"); // Pieter Wuille
```

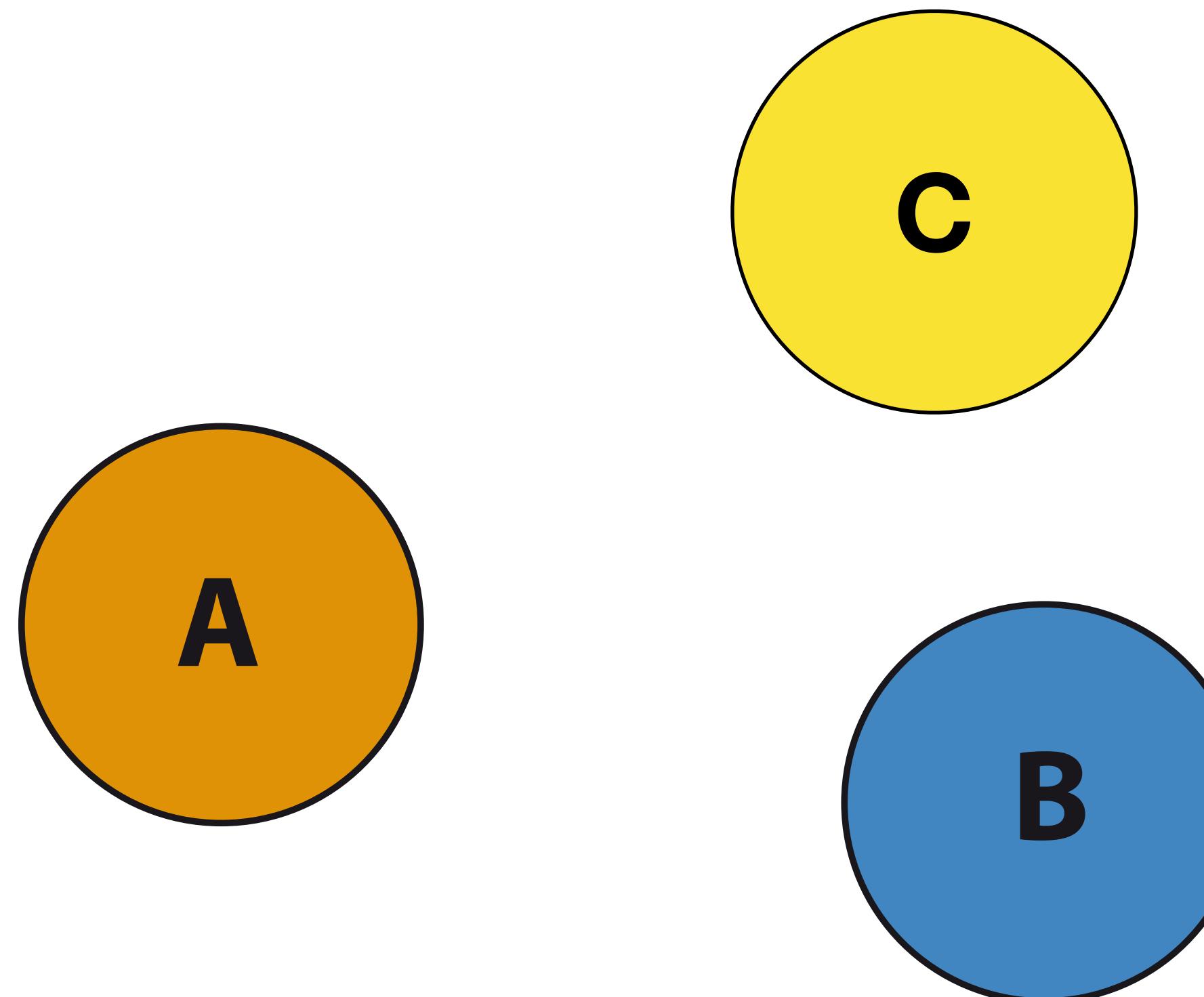
```
vSeed
vSeed
vSeed
vSeed
vSeed
vSeed
vSeed
static SeedSpec6 pnSeed6_main[] = {
    {{0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0xff,0xff,0x02,0x84,0x64,0x2f}, 8333},
    {{0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0xff,0xff,0x05,0x01,0x61,0x04}, 8333}, i
    {{0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0xff,0xff,0x05,0x27,0xae,0x74}, 8333},
    {{0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0xff,0xff,0x05,0x2d,0x4f,0xe}, 8333},
    {{0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0xff,0xff,0x05,0x35,0x10,0x85}, 8333},
    {{0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0xff,0xff,0x05,0x65,0x8b,0xa6}, 8333},
    ...
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```



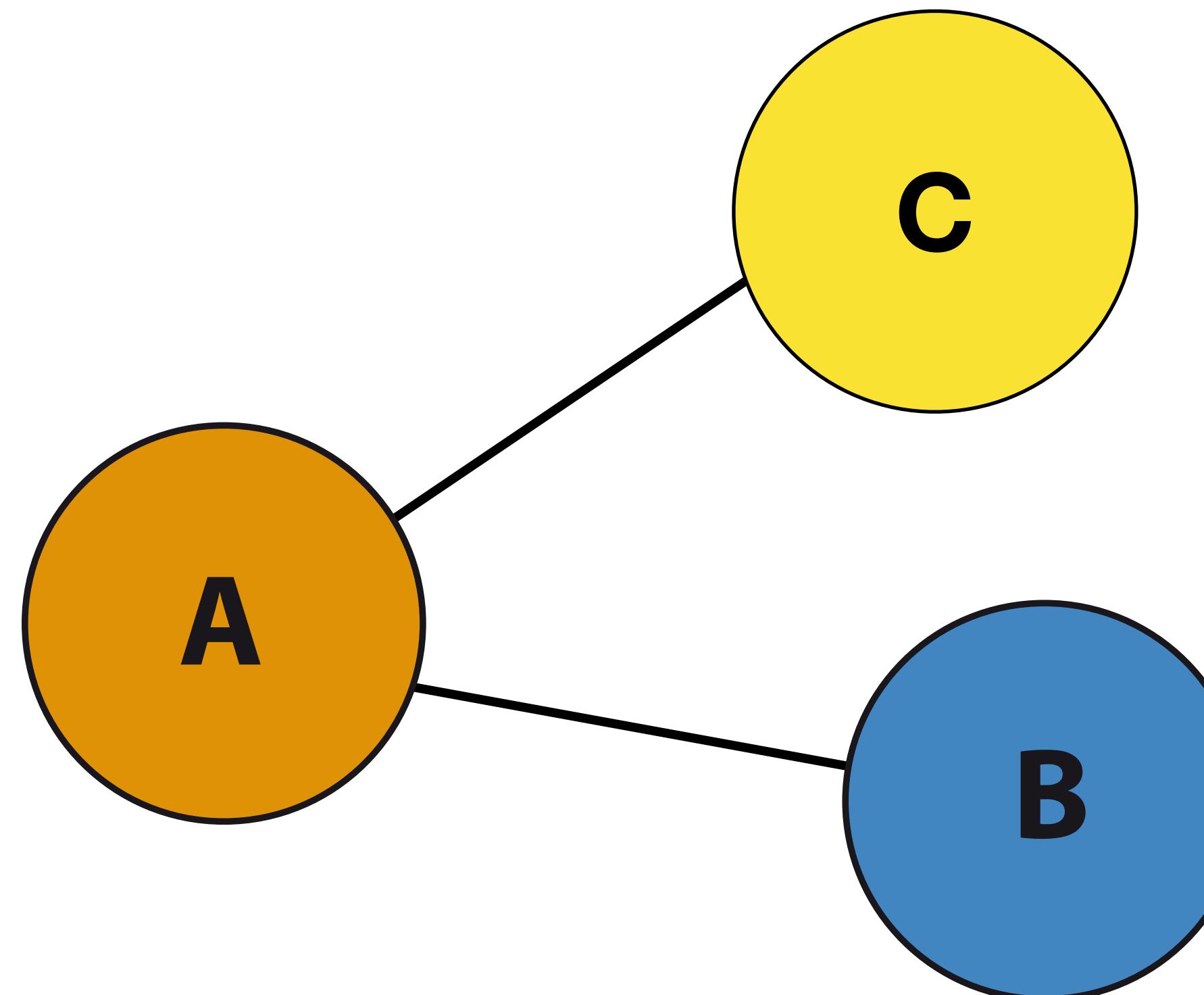
Bitcoin P2P bootstrapping (recap)

- A node bootstraps with no known peers
- First it tries to query a list of well known DNS seeds
- As **last resource** it uses a hardcoded seed

Populating the peers database (addrman)

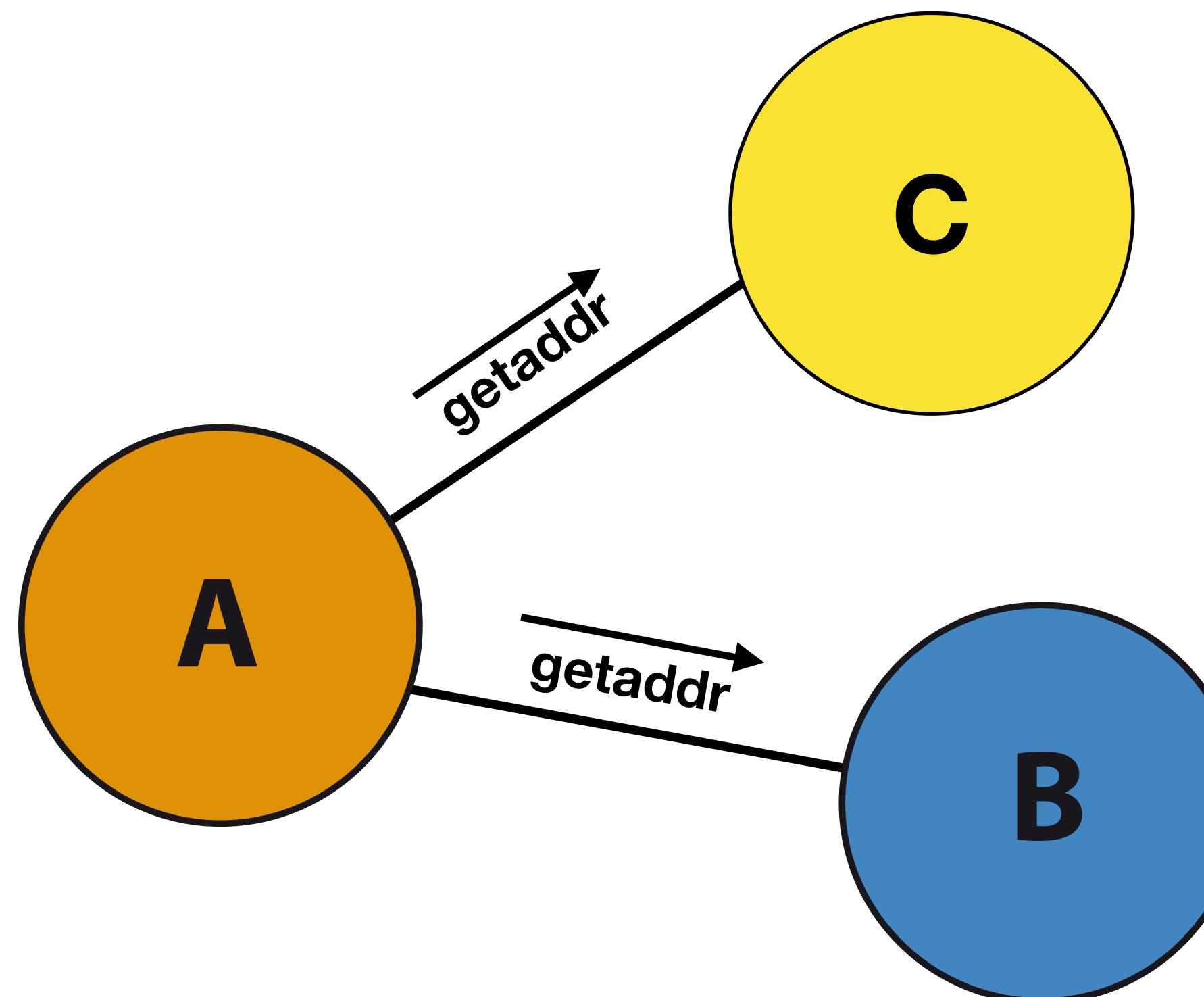


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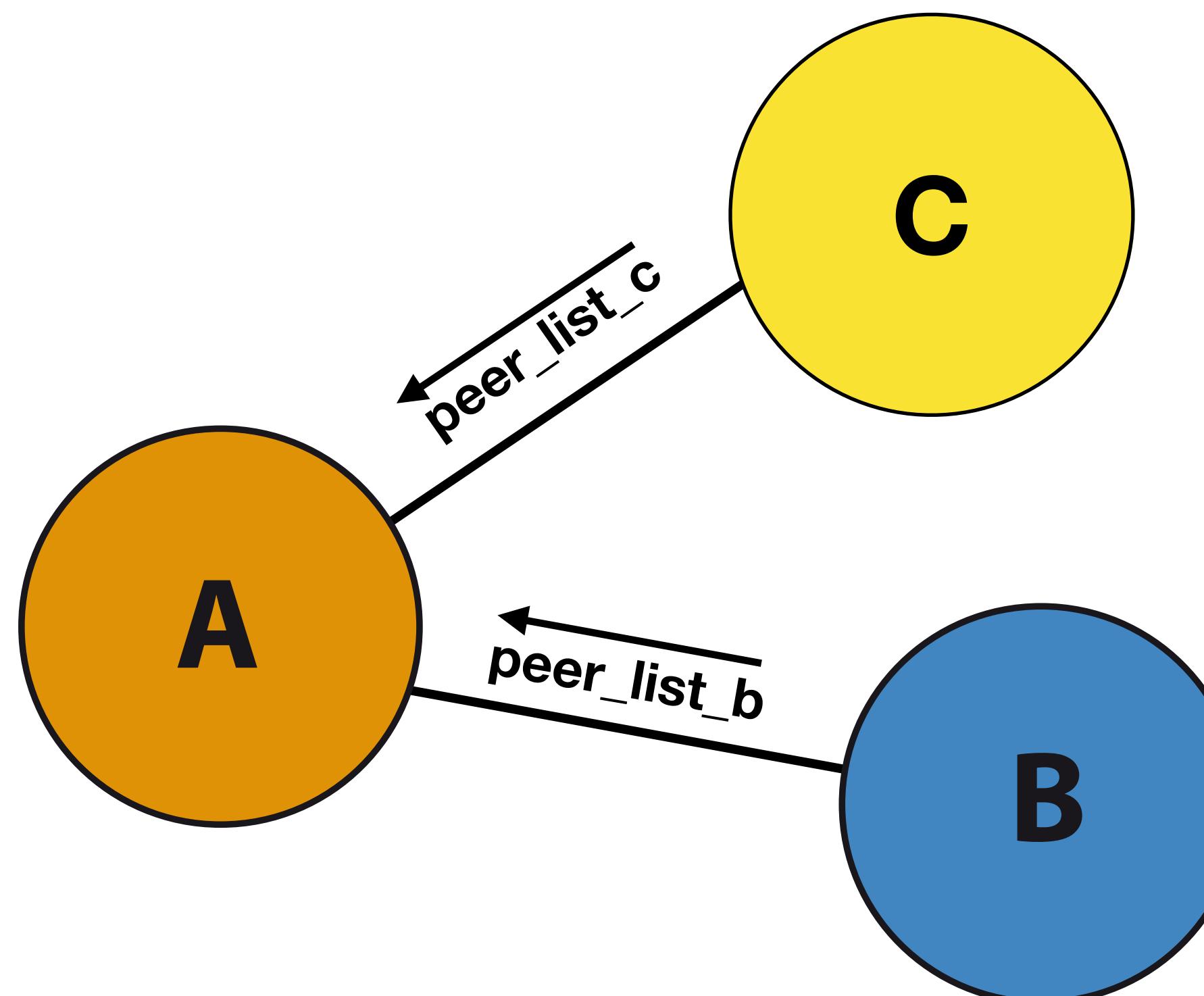
- A connects a subset of peers from the ones learned from the DNS seeds

Populating the peers database (addrman)



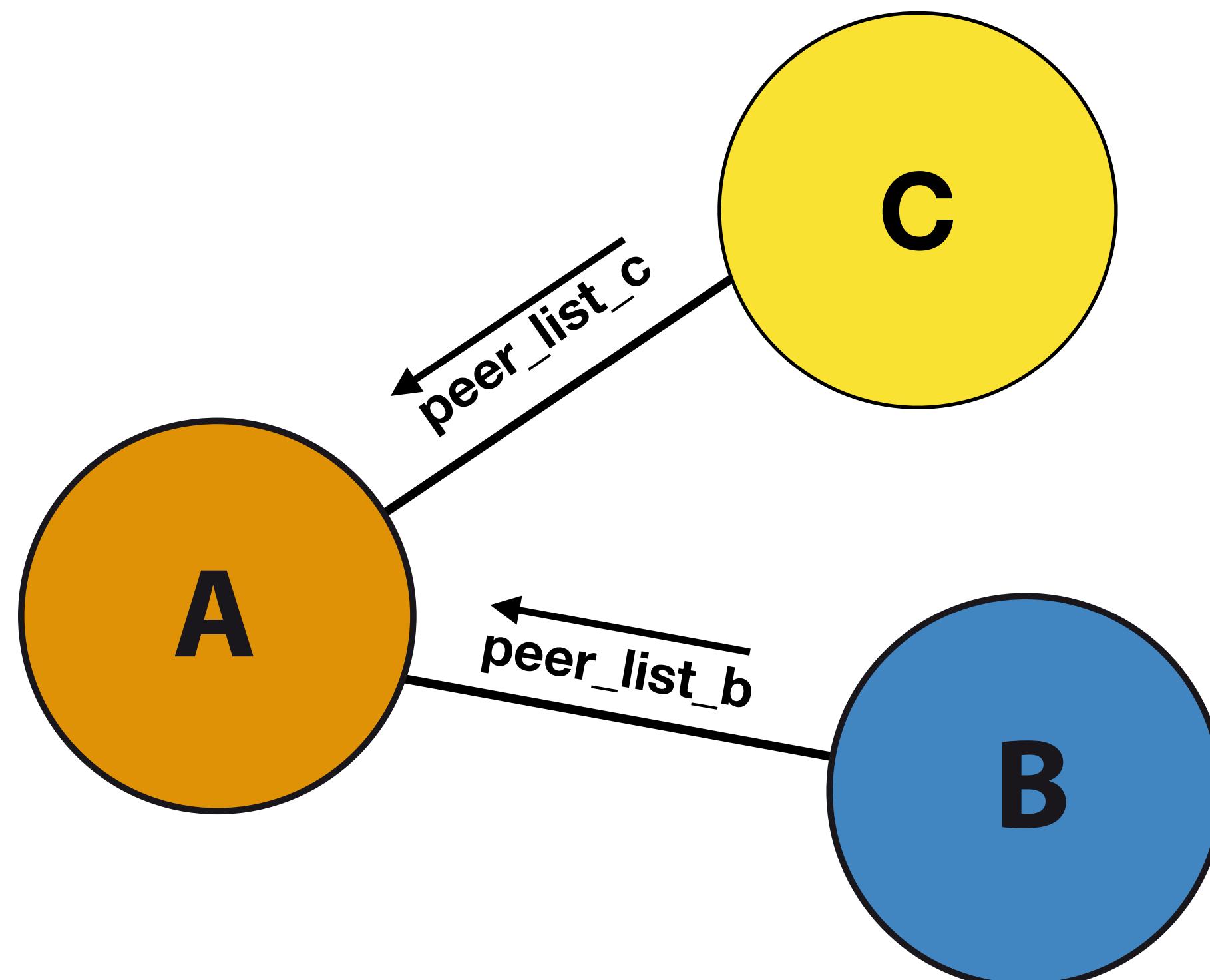
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Populating the peers database (addrman)



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- Peers reply with some addresses they know about (**addr**, up to 1000 addresses)

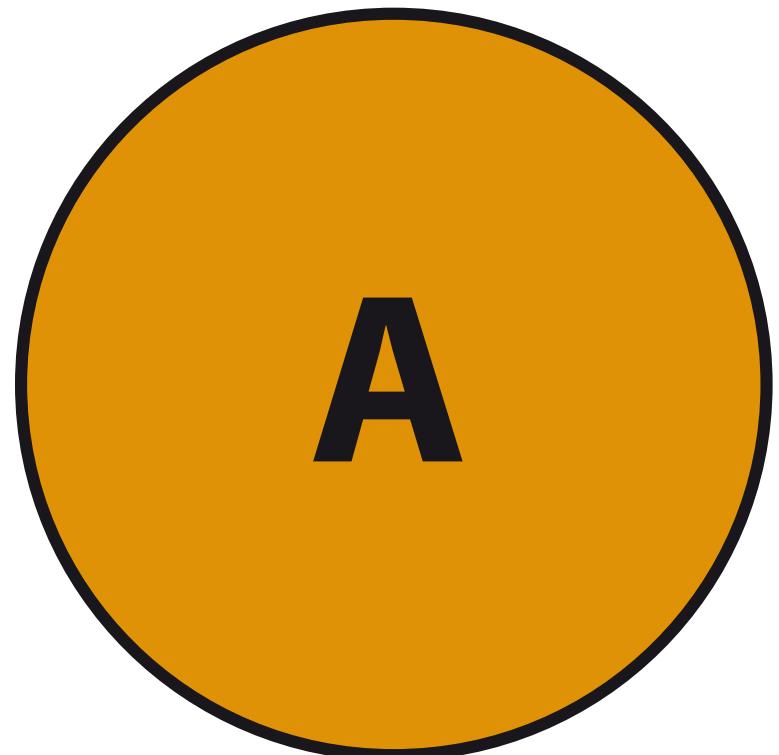
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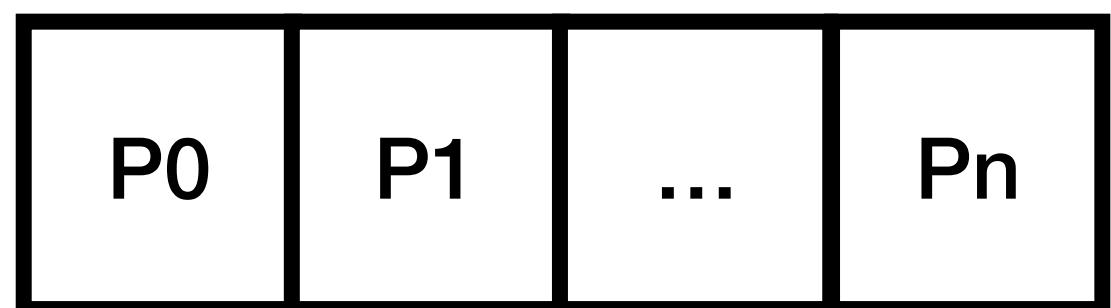
- A connects a subset of peers from the ones learned from the DNS seeds
- A requests more peers to his neighbors (**getaddr**)
- Peers reply with some addresses they know about (**addr, up to 1000 addresses**)
- A adds the new addresses to its peers database (or update the existing ones)

A's addrman = A's addrman U peer_list_c U peer_list_b

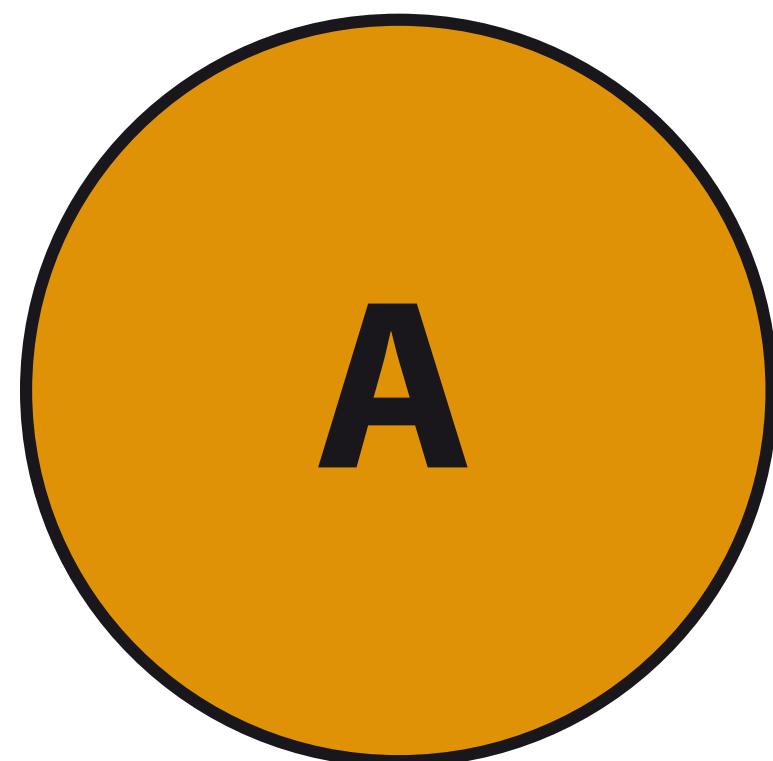
Incoming / outgoing connections



Peer database (addrman)



Incoming / outgoing connections

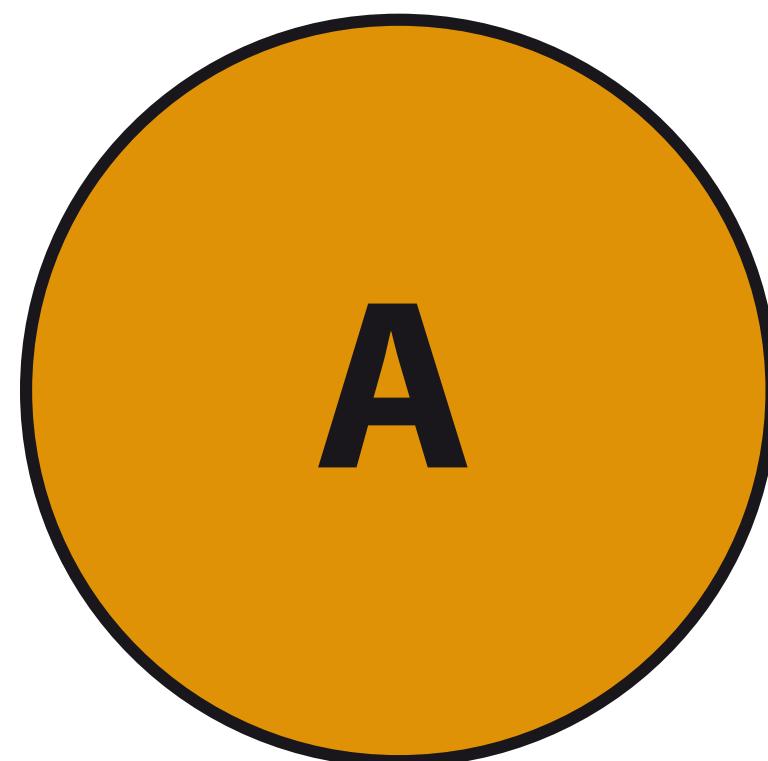


- During bootstrap, a node will start some **outgoing connections** with peers it has learned about (**8 by default**) and try to maintain them

Peer database (addrman)

P0	P1	...	Pn
----	----	-----	----

Incoming / outgoing connections



- During bootstrap, a node will start some **outgoing connections** with peers it has learned about (**8 by default**) and try to maintain them
- A node will also accept **some incoming connections** (**117 by default**)

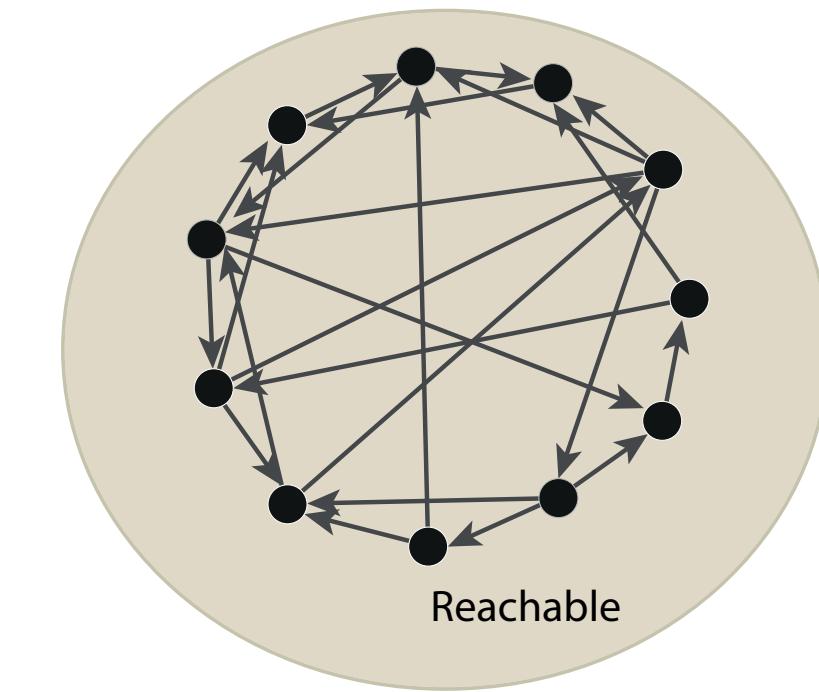
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Cryptocurrency networks taxonomy

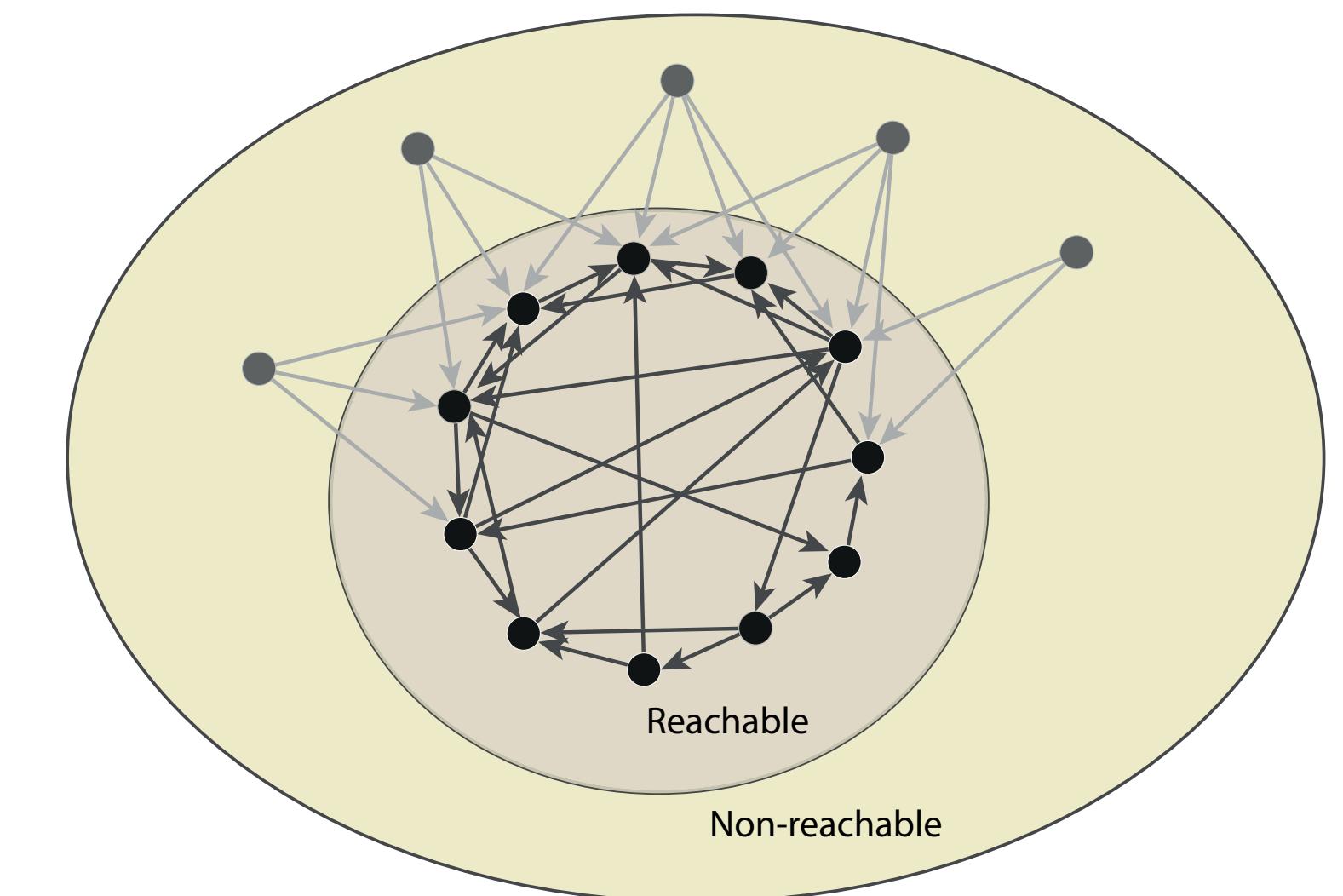
Cryptocurrency networks taxonomy

- Reachable network: all nodes accept incoming / outgoing connections



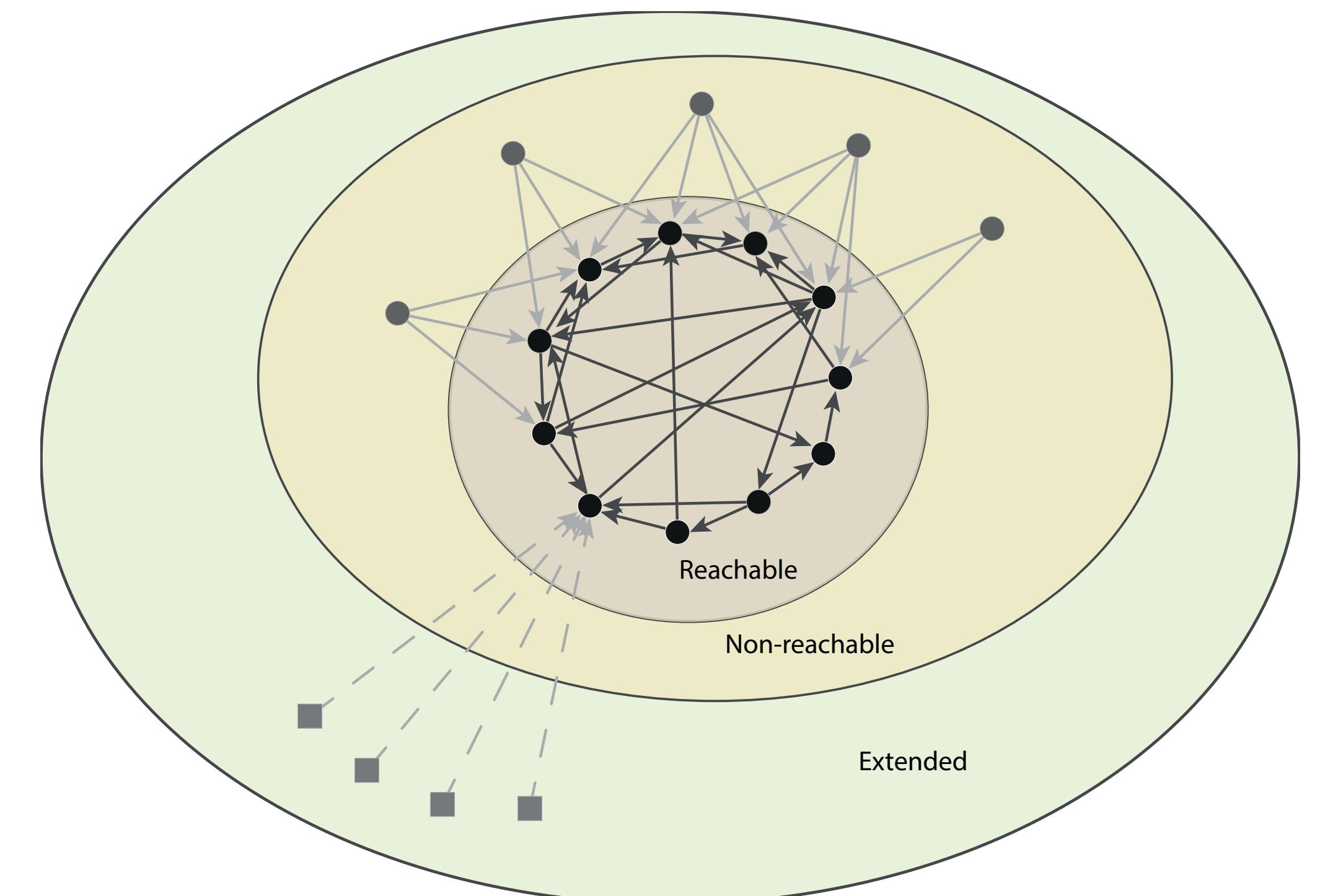
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Cryptocurrency networks taxonomy

- Reachable network: all nodes accept incoming / outgoing connections
- Non-reachable: nodes do not accept incoming connections / cannot be reached (NAT/firewalls/...)
- Extended network: nodes use different protocol to communicate (not always P2P)

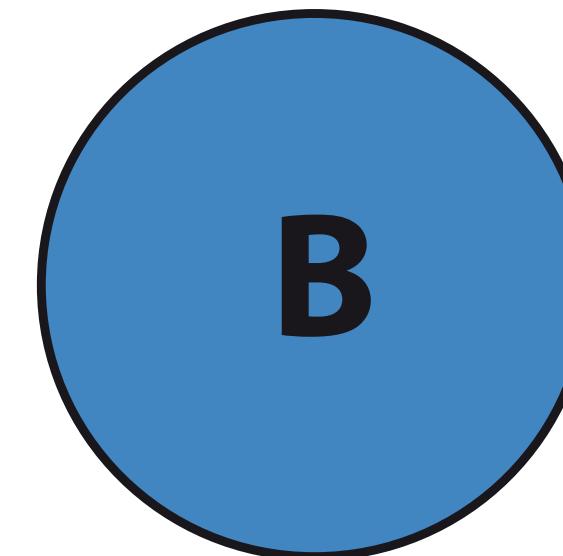
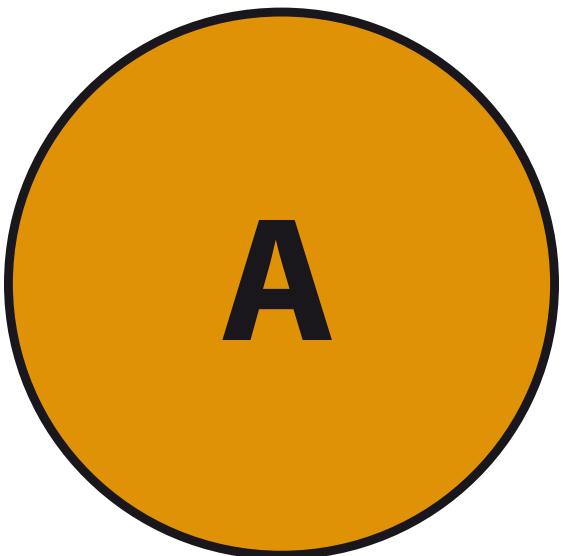


Hello world!

- How does a node announce his presence to the rest of the network?

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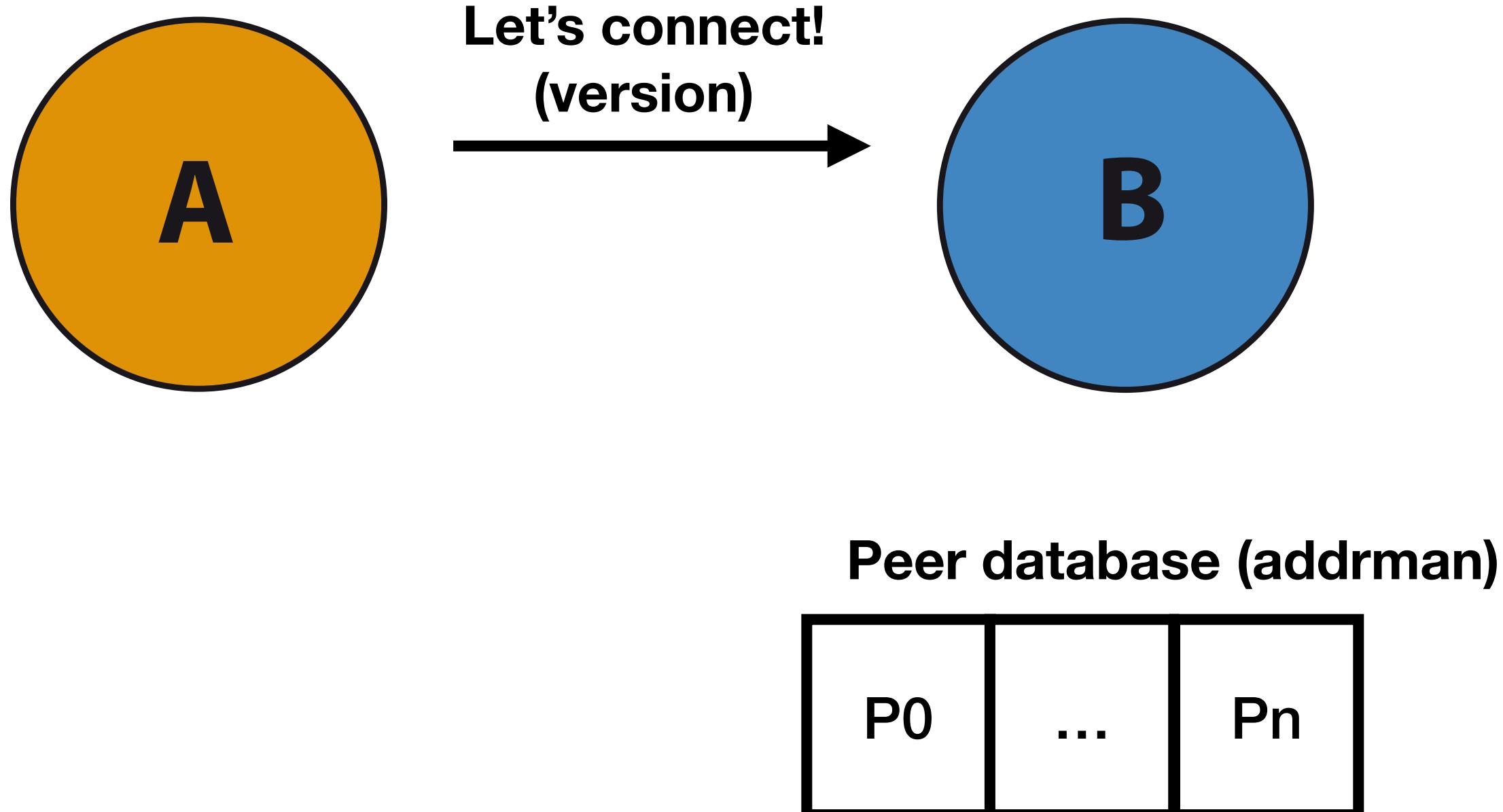
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P0	...	Pn
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Node bootstrapping and peer discovery

Hello world!

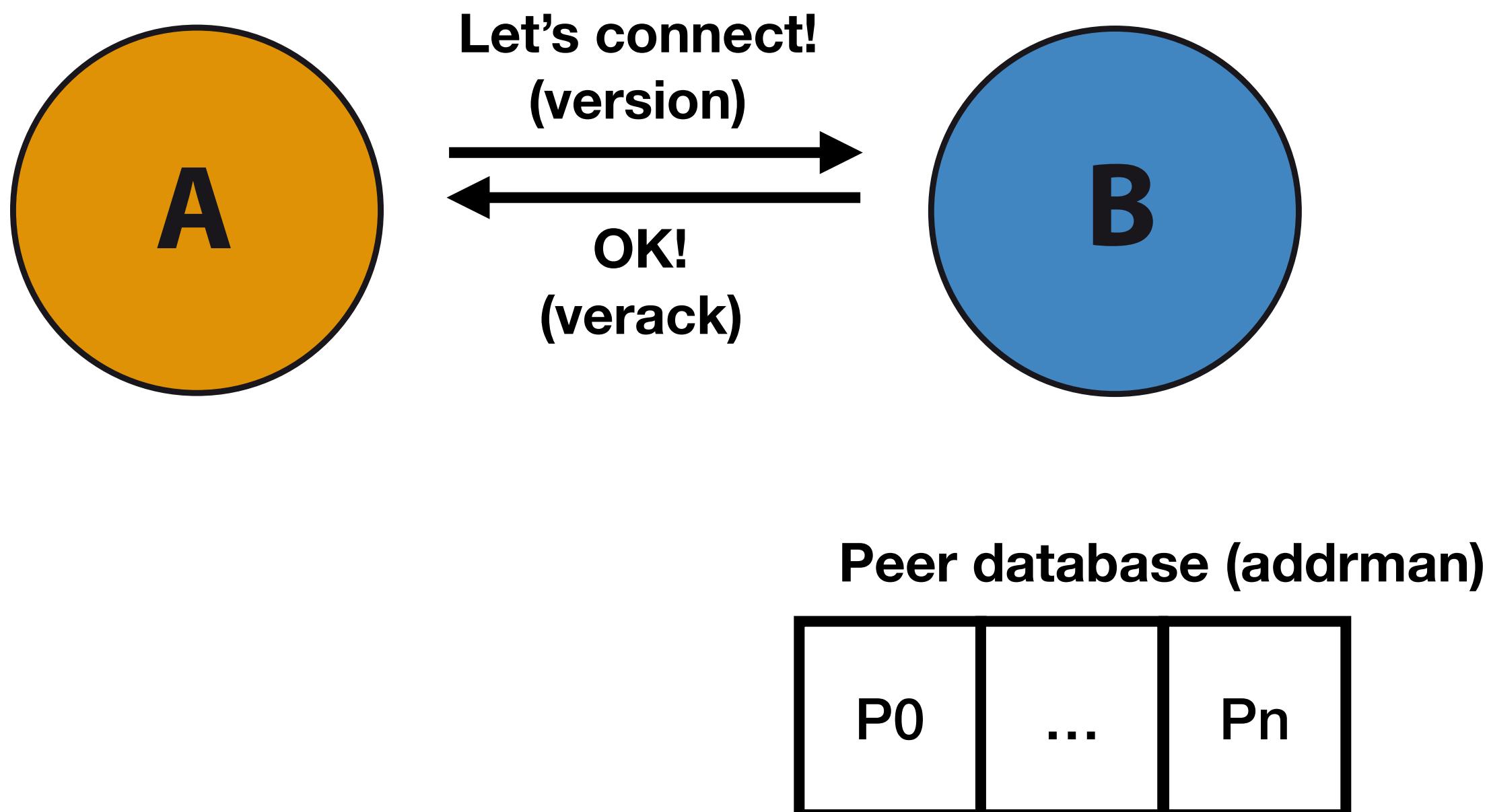
- How does a node announce his presence to the rest of the network?



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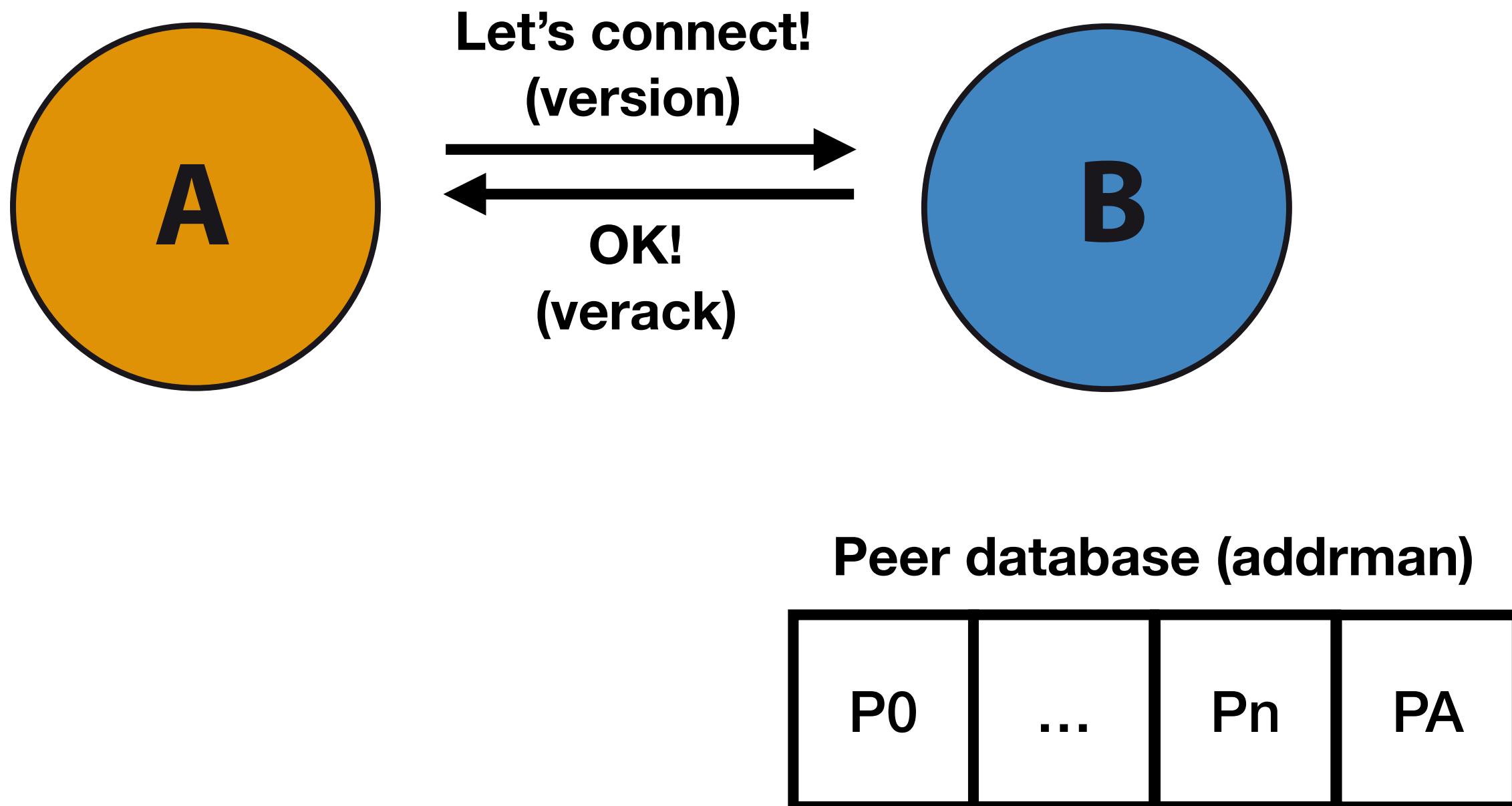
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Node bootstrapping and peer discovery

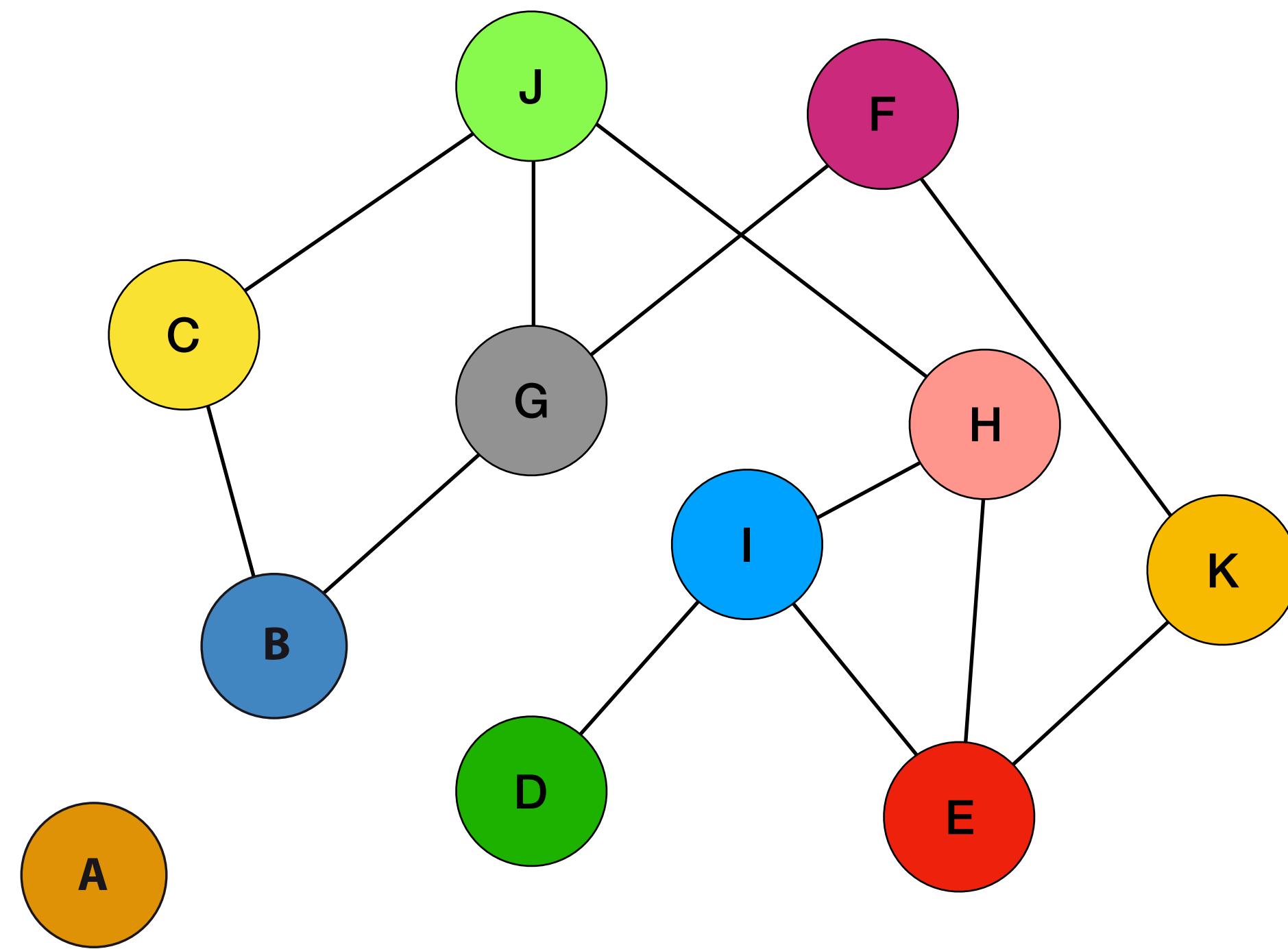
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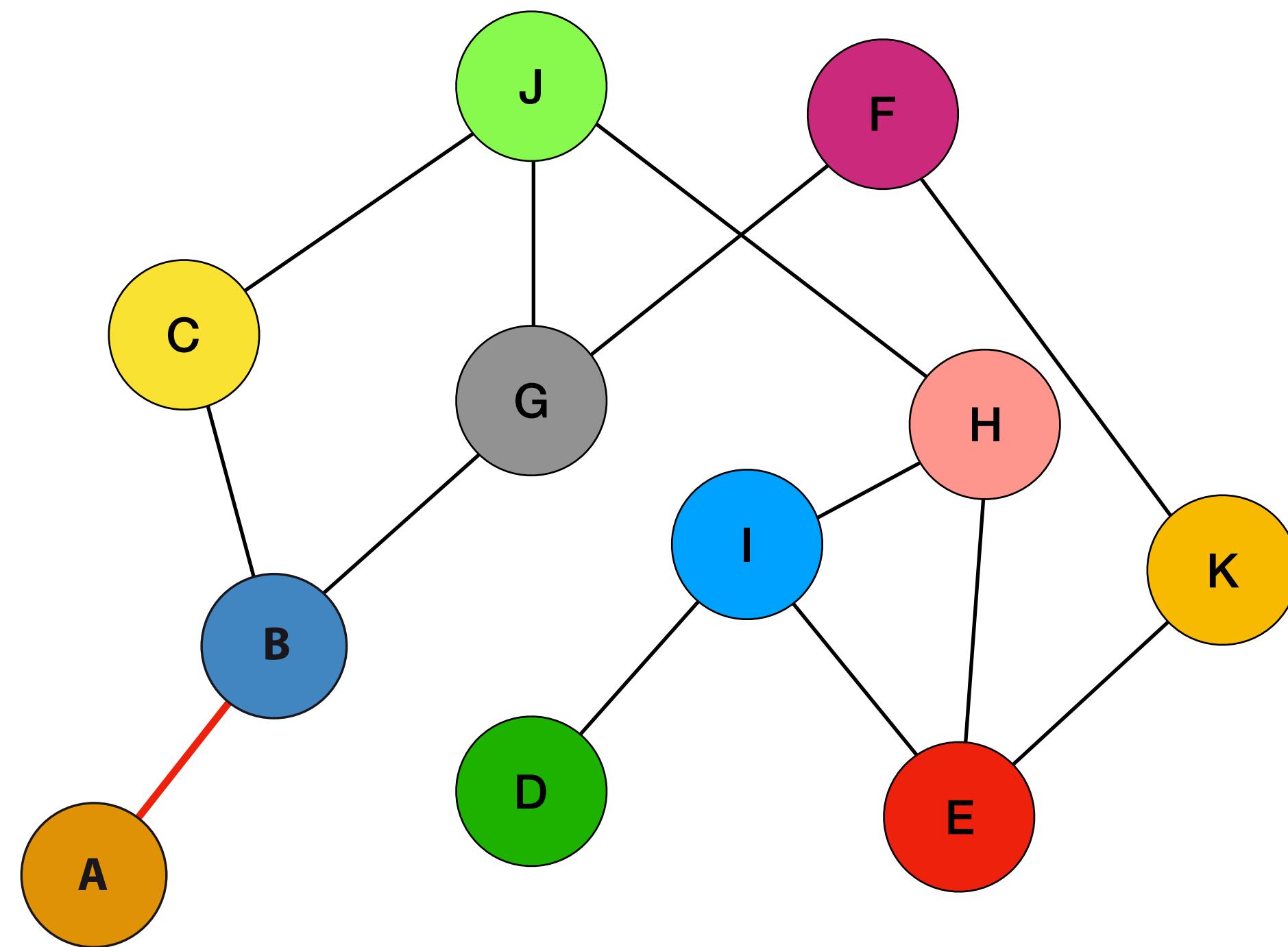
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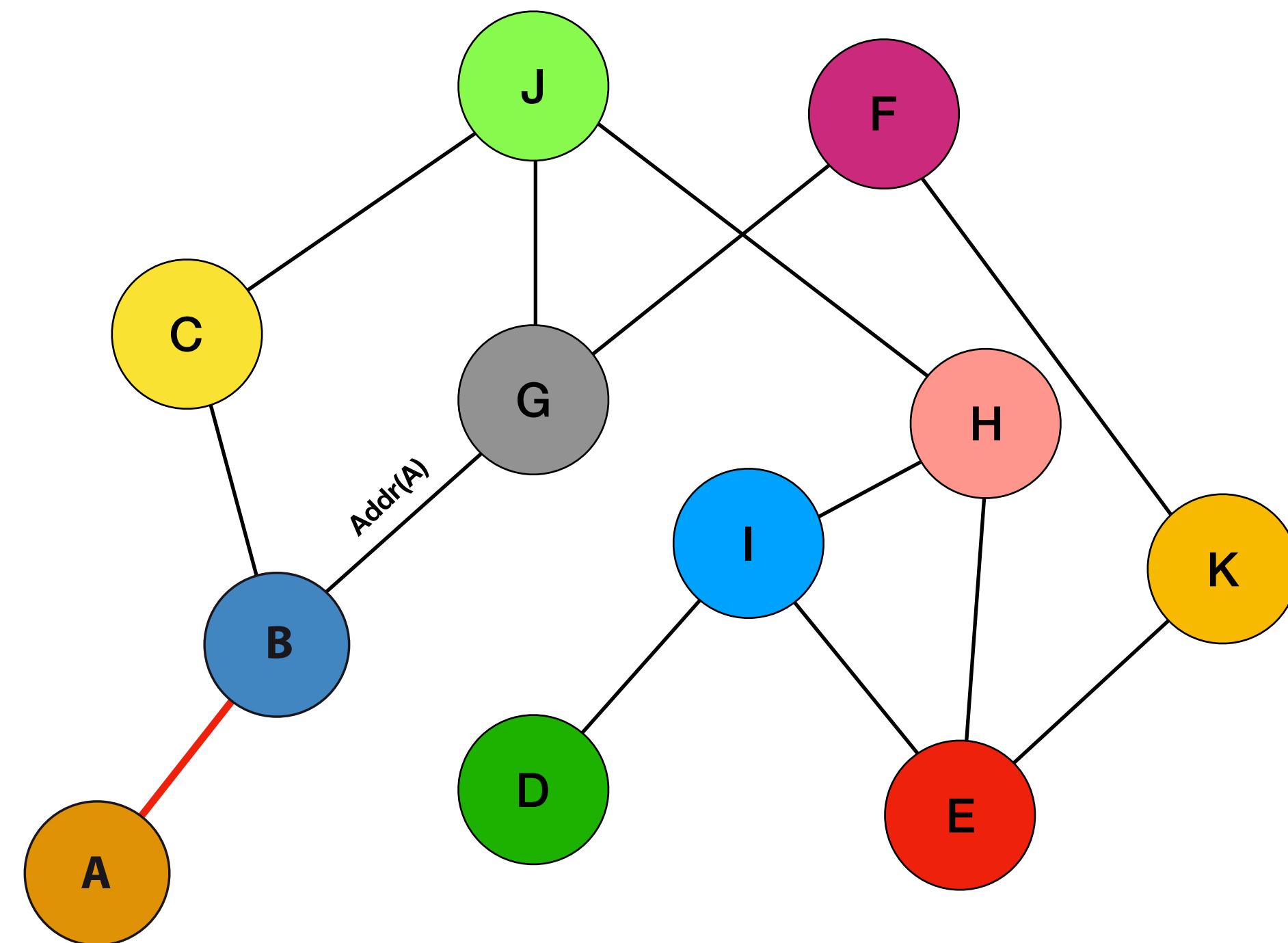
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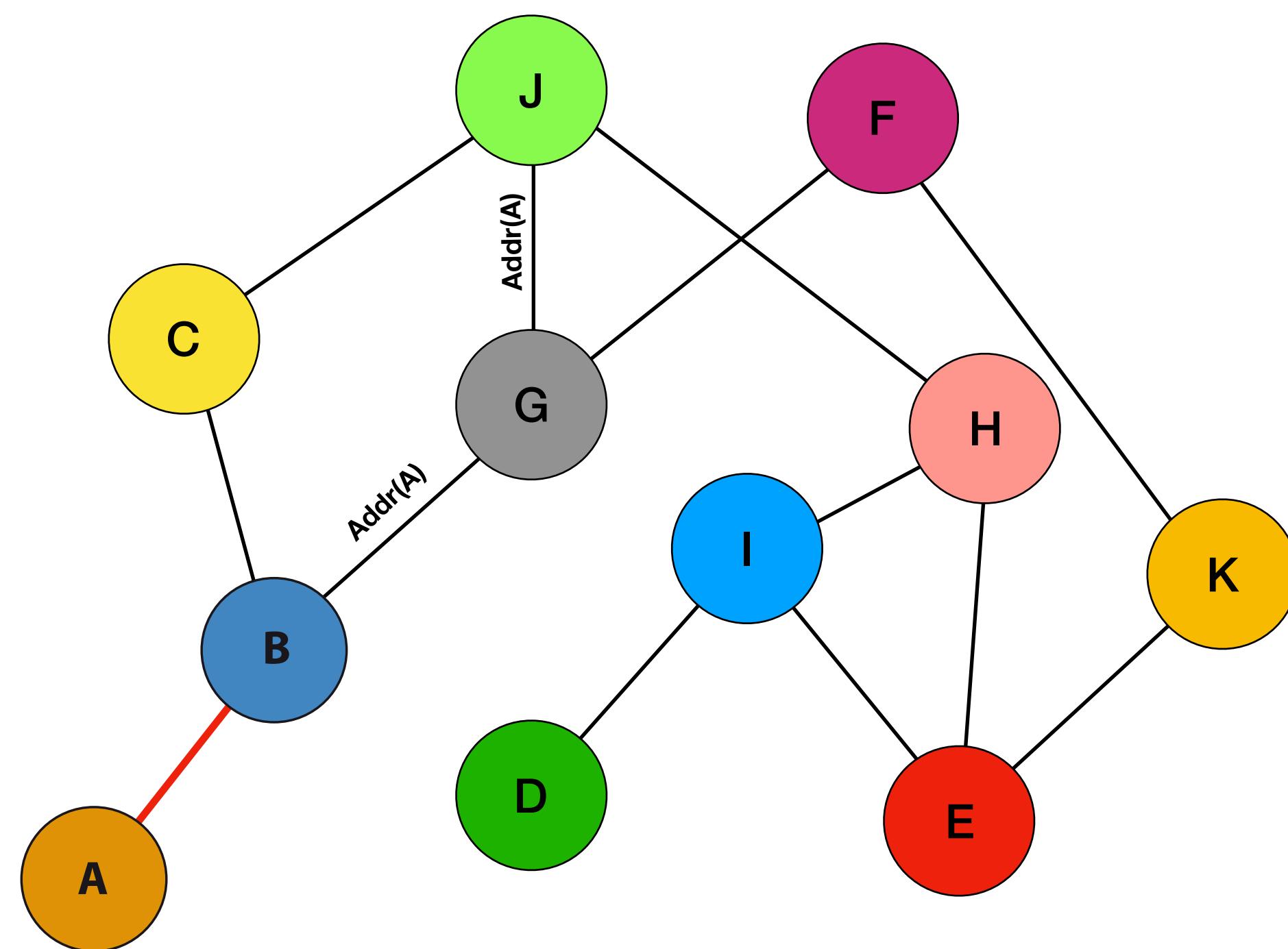
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- B picks a random subset of its neighbors and relays A's address

Hello world!

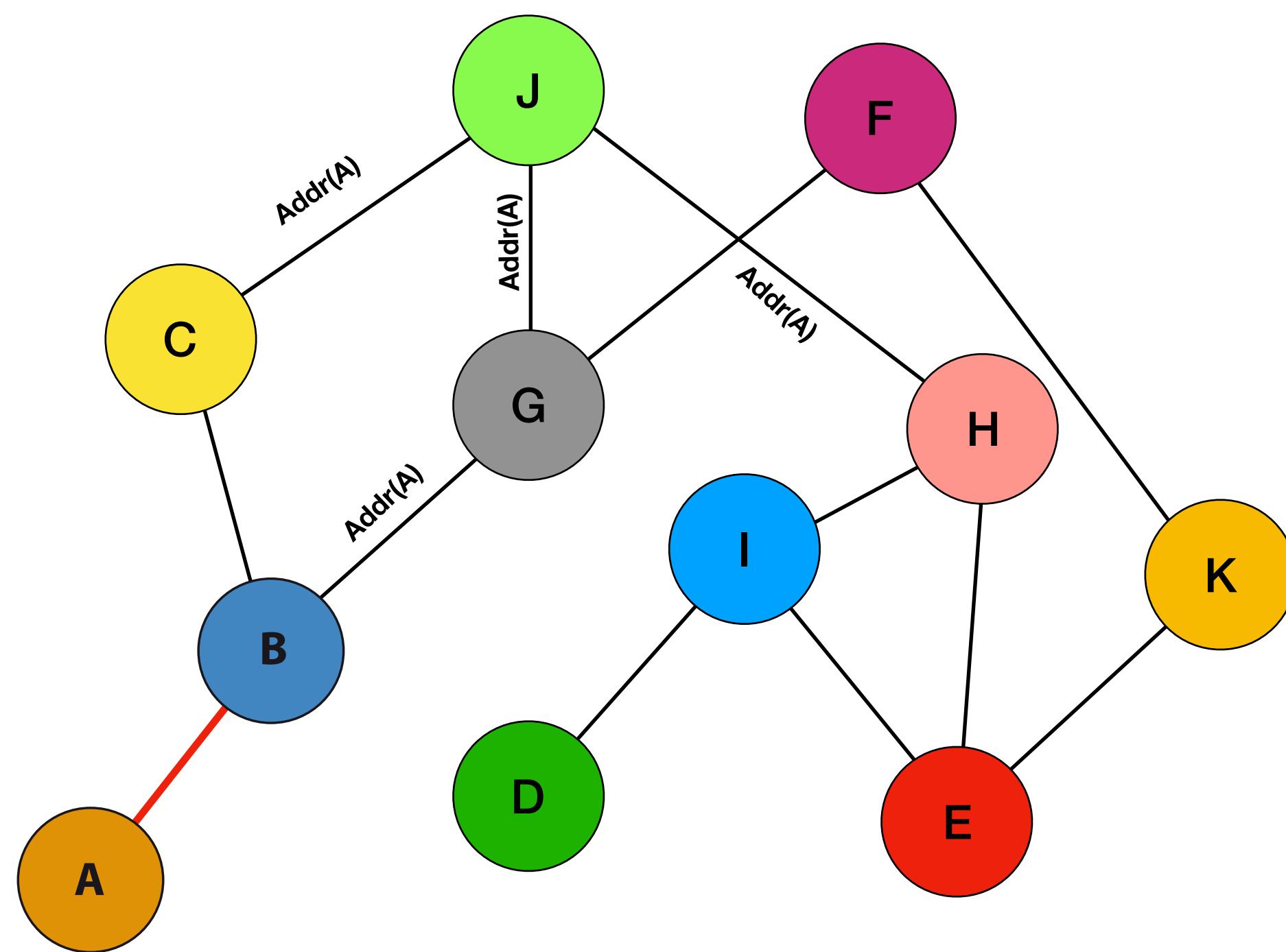
- How does a node announce his presence to the rest of the network?



- B picks a random subset of its neighbors and relays A's address
- The nodes picked by B pick a random subset of their neighbors and relay A's address

Hello world!

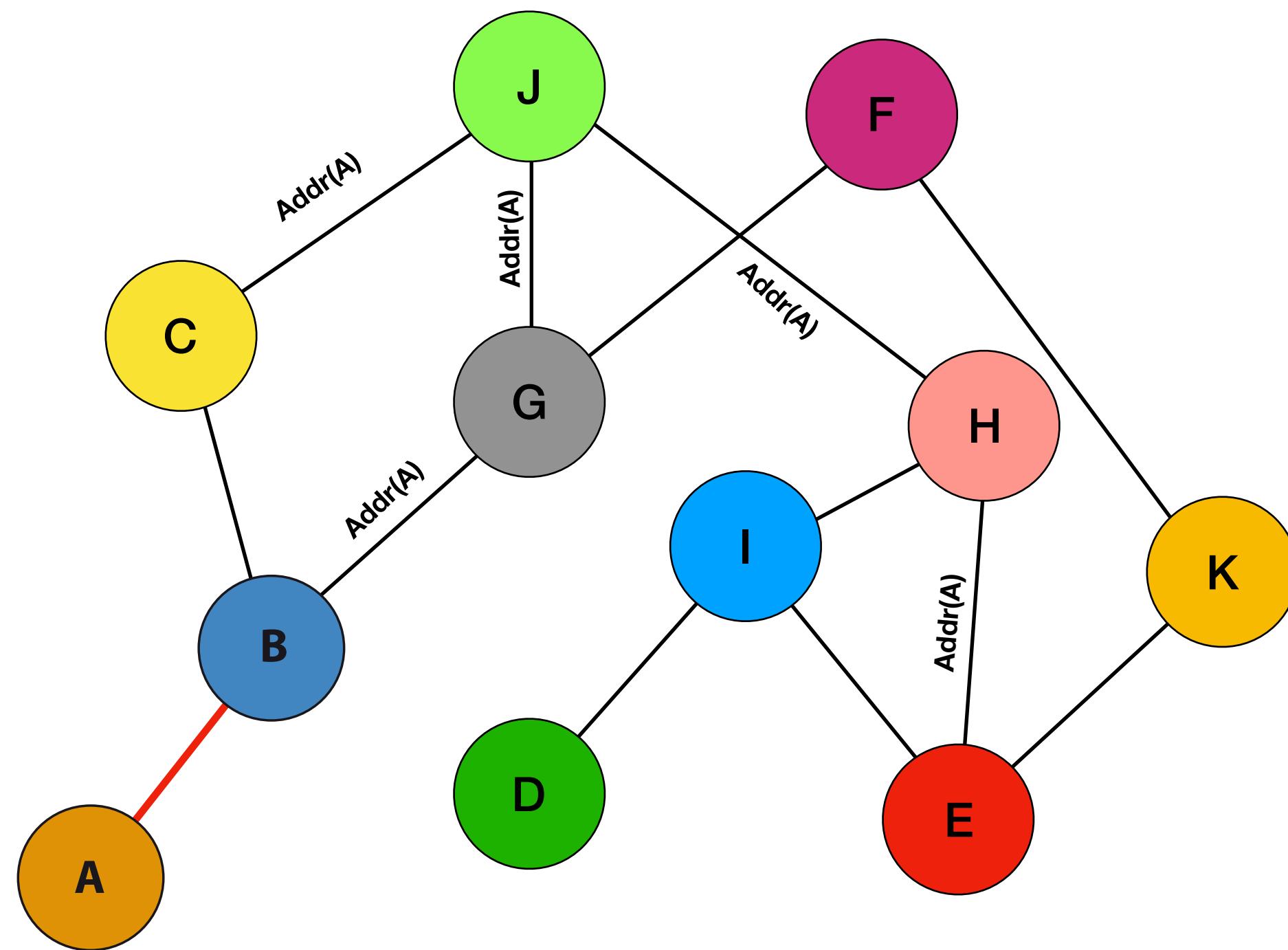
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- And so on and so forth...

Hello world!

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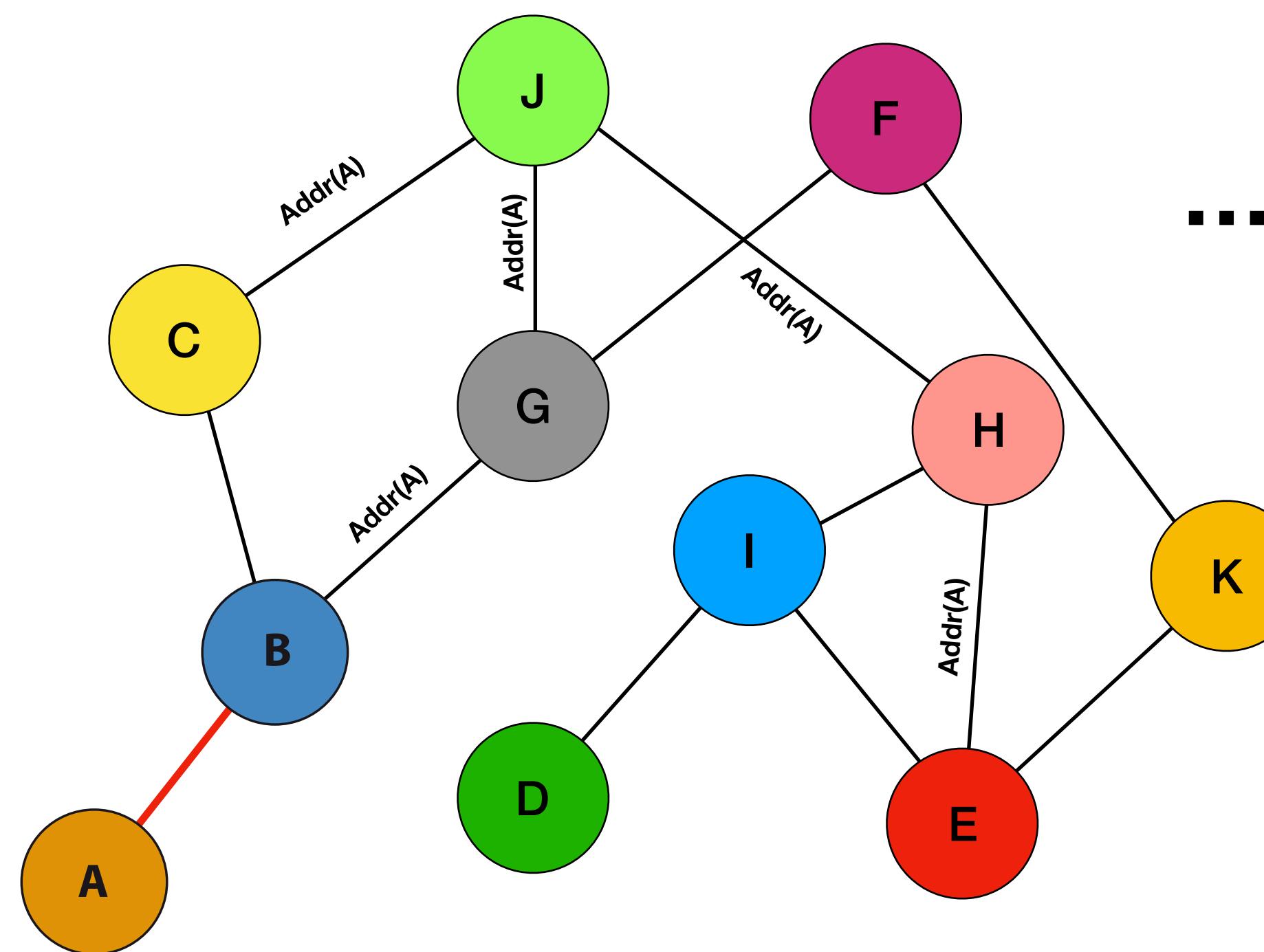


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Node bootstrapping and peer discovery

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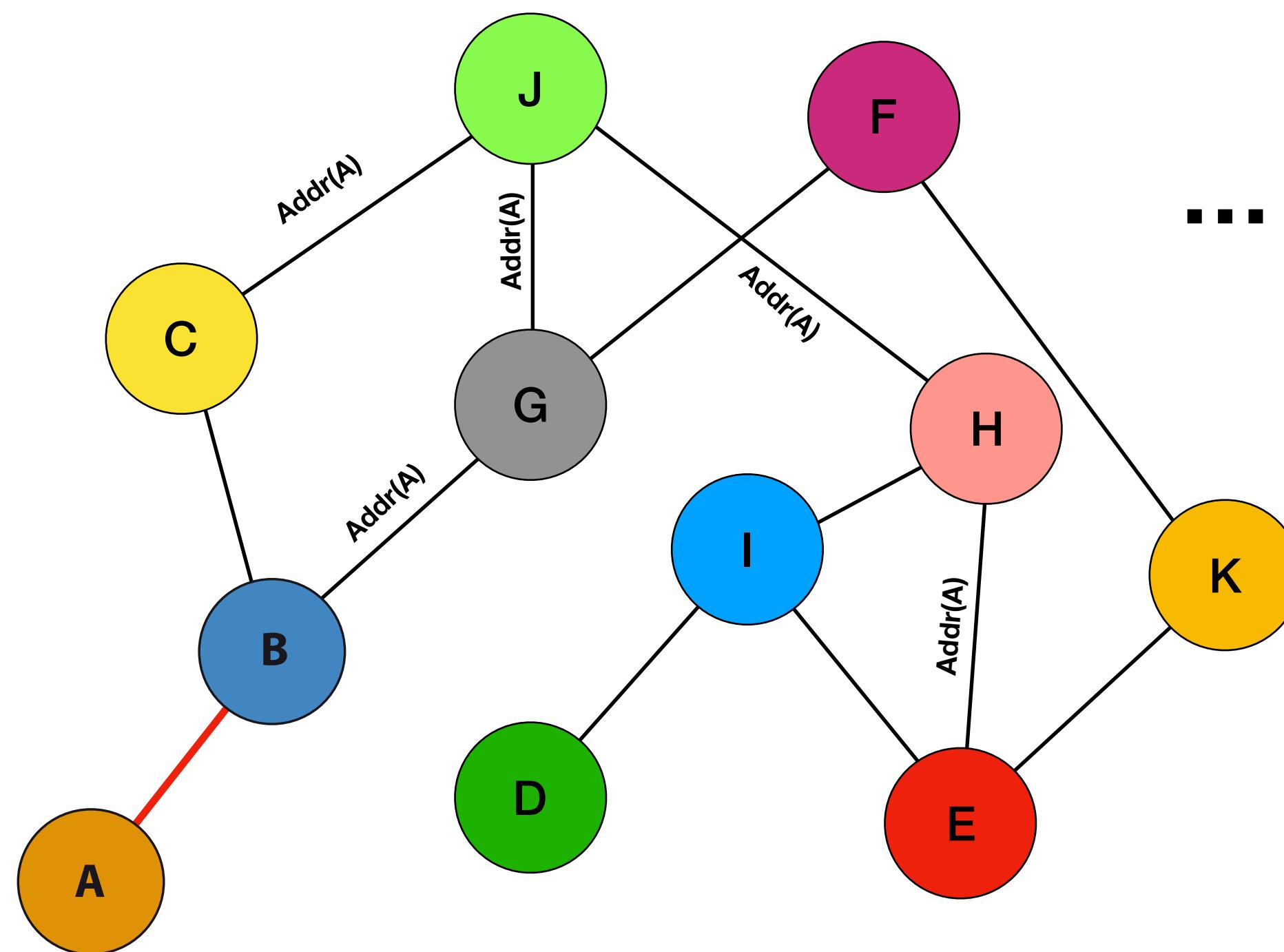
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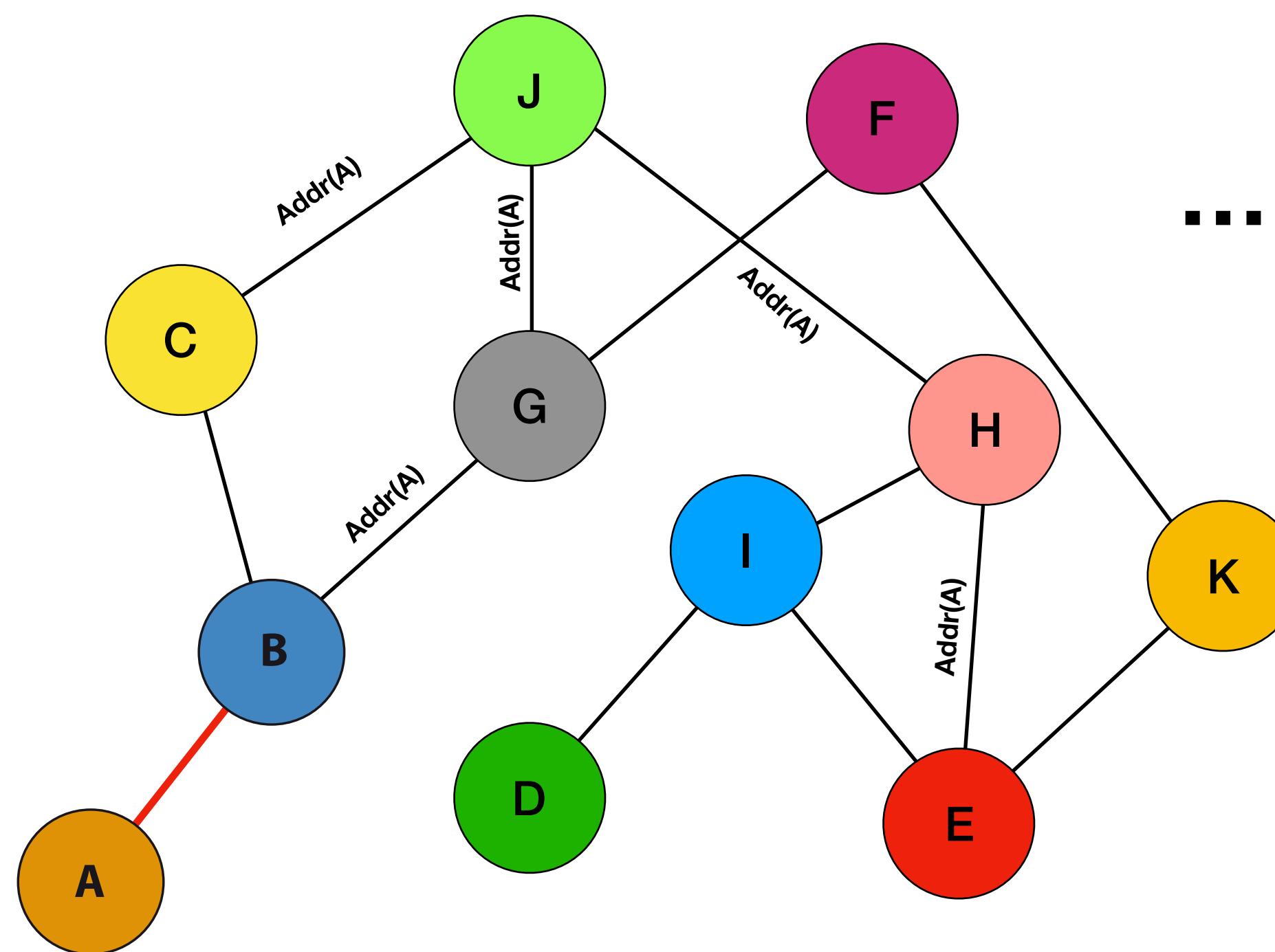
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Hello world!

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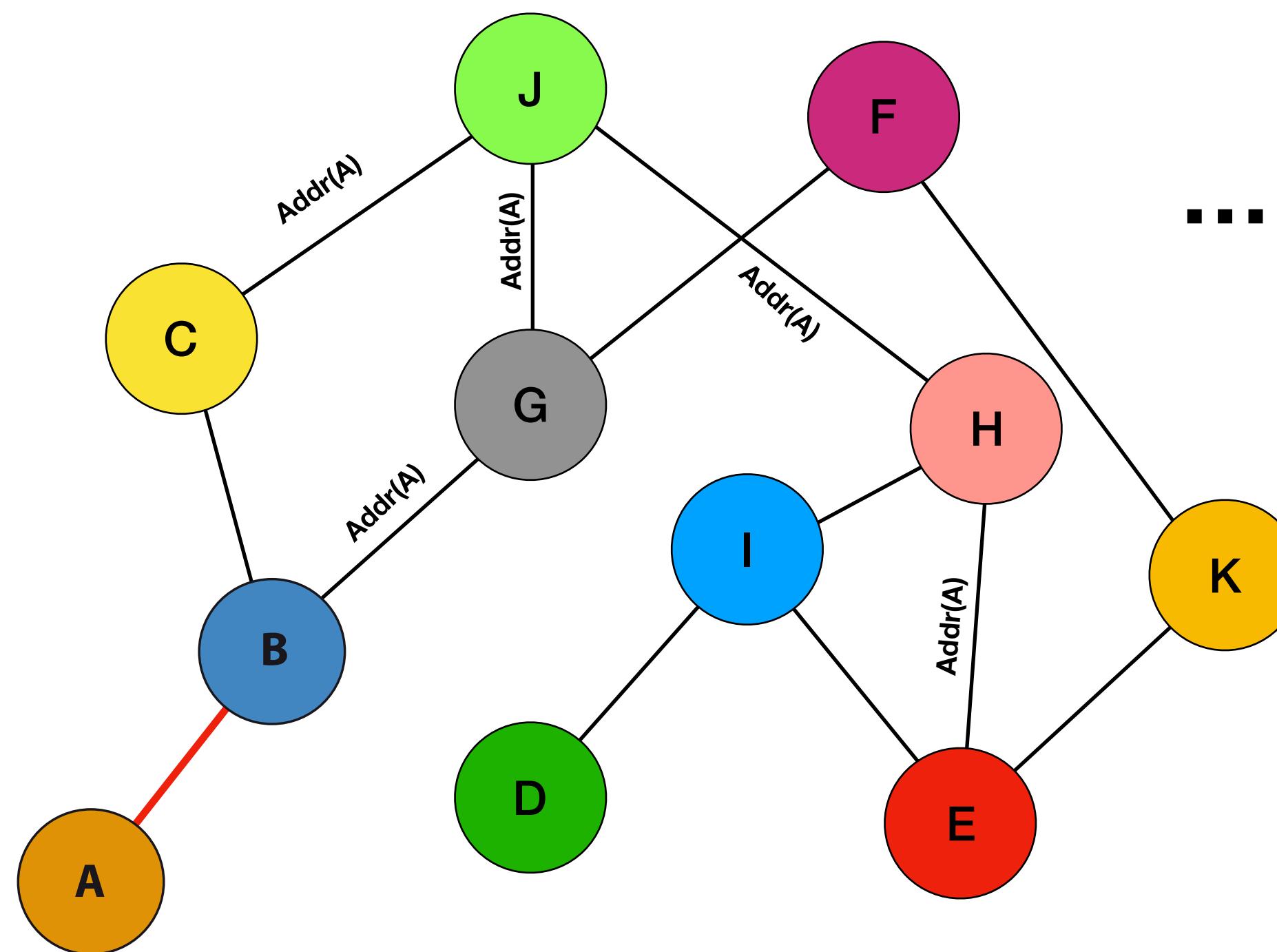


- The address will eventually be spread throughout the network

Node bootstrapping and peer discovery

Hello world!

- How does a node announce his presence to the rest of the network?



- The address will eventually be spread throughout the network
- Nodes learning about the new peer will add it to their peers database

Connections (recap)

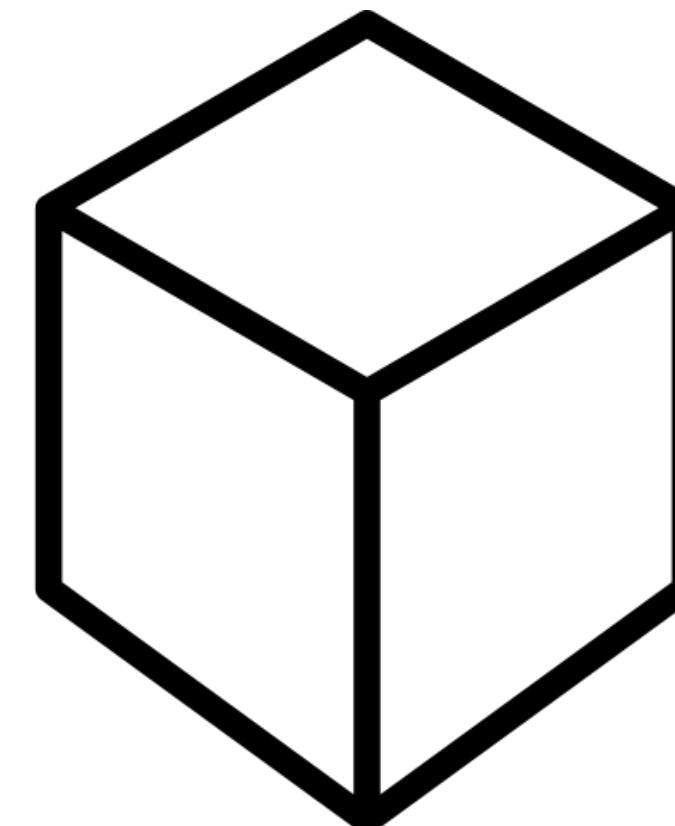
- A node learns about the peers in the network by asking other peers (after an initial bootstrap)
- A node maintains a database of all the peers he has heard of and keeps populating it / updating it
- A node initiates (and maintain) some outgoing connects and also accept some incoming ones
- The address of a new node is propagated thought the network so all peers can know about it

Actors and purpose (what, who, why, and how)

The data (what?)

- There are two main items that peers share in a cryptocurrency P2P network: **transactions** and **blocks**

From: Ford	To: Arthur	42
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The actors (who?) (1/2)

The actors (who?) (1/2)

- There are two main roles followed by nodes:
peers and **miners**

The actors (who?) (1/2)

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- (Normal) Peers:

The actors (who?) (1/2)

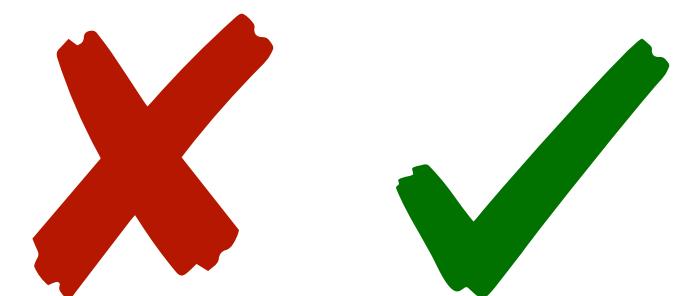
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 - Can **create transactions** that spend some of their bitcoins

From: Alice	To: Bob	5
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The actors (who?) (1/2)

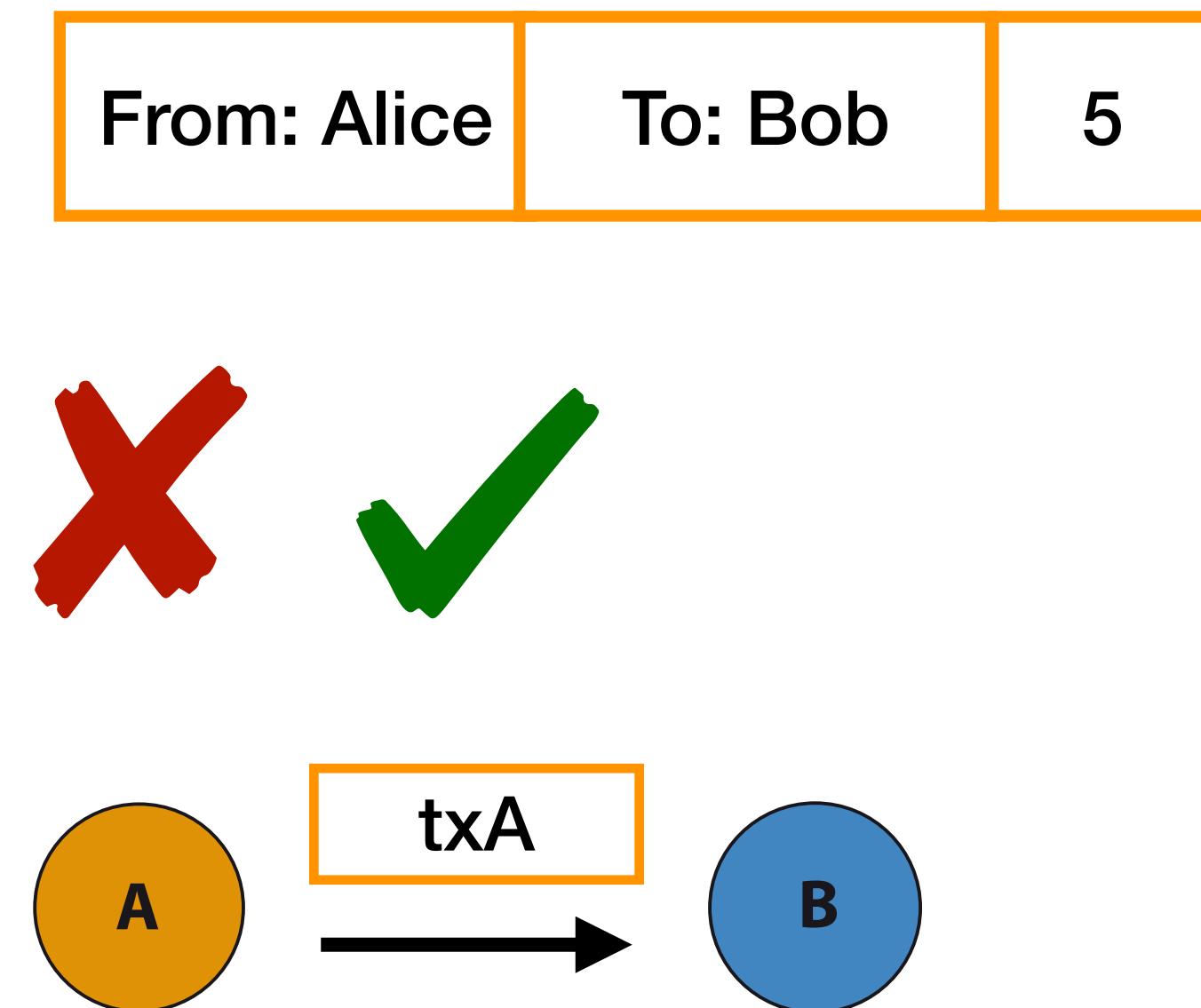
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From: Alice	To: Bob	5
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The actors (who?) (1/2)

- There are two main roles followed by nodes:
peers and **miners**
- (Normal) Peers:
 - Can **create transactions** that spend some of their bitcoins
 - Do **verify** the correctness of received **transactions** and **blocks** (from other peers)
 - Do **relay** valid **transactions** and **blocks** (created by them or obtained from other peers)



The actors (who?) (2/2)



The actors (who?) (2/2)

- Miners:



The actors (who?) (2/2)

- **Miners:**
 - Can do all what a **peer** could do*

The actors (who?) (2/2)

- Miners:
 - Can do all what a **peer** could do*
 - Can **generate blocks** through a process known as mining



The actors (who?) (2/2)

- Miners:
 - Can do all what a **peer** could do*
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* There are specific purpose miners (ASICs) that only perform mining

The purpose (why?)

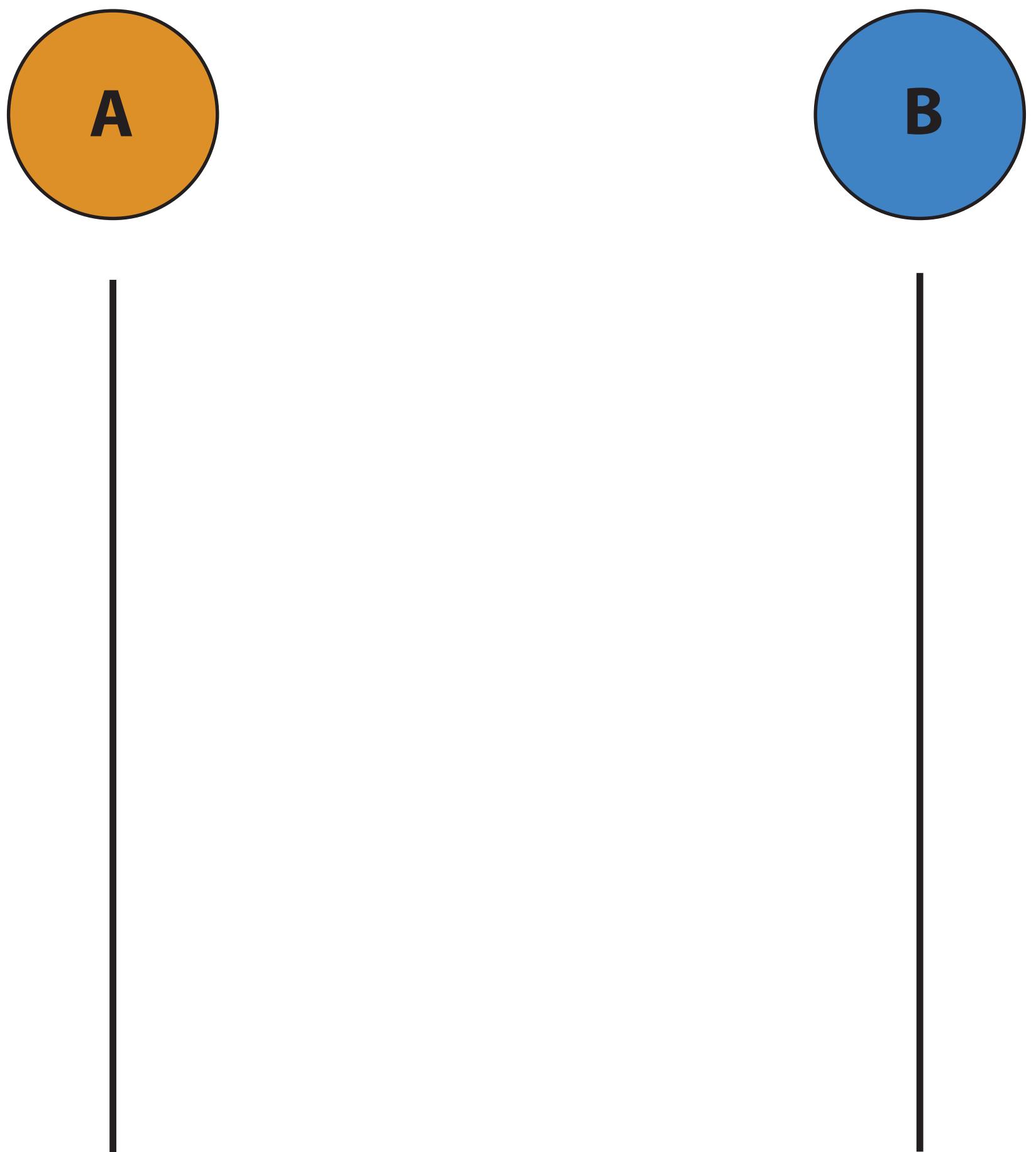
- Peers relay transactions in order to reach miners, which will include such transactions in future blocks
- Miners generate blocks to obtain its reward (and also the transactions fees)
- Blocks are relayed to ultimately achieve a consistent view of the blockchain
- Peers validate transactions and blocks (and relay only the valid ones) in order to avoid cheating (e.g: double-spending, coin forgery, etc)

The gossip protocol (how?)

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- Items (transactions and blocks) are shared between peers in a push manner

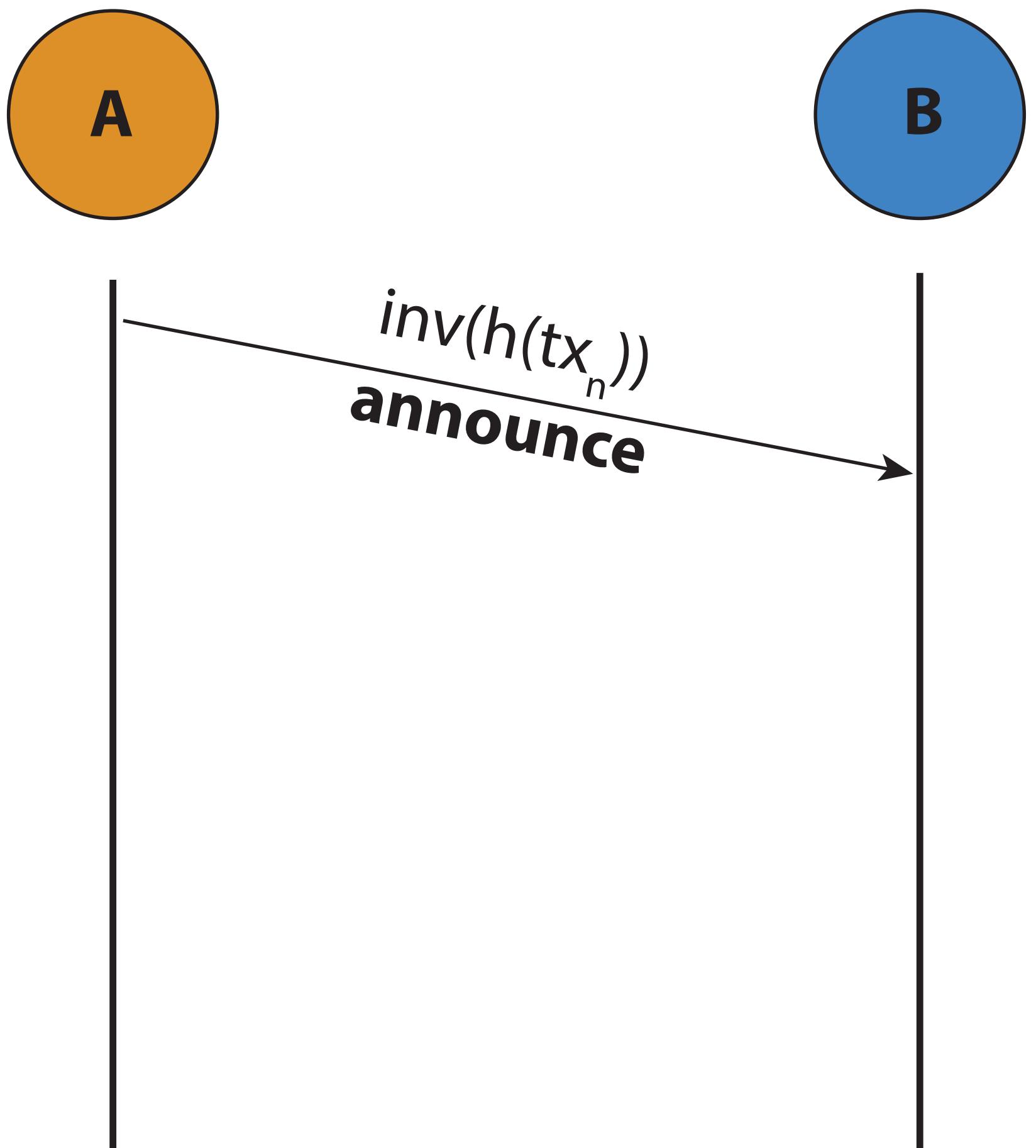
Announce paradigm



The gossip protocol (how?)

- Items (transactions and blocks) are shared between peers in a push manner
- When a peer receives / generates a new item he announce it to his neighbors (**announce**)

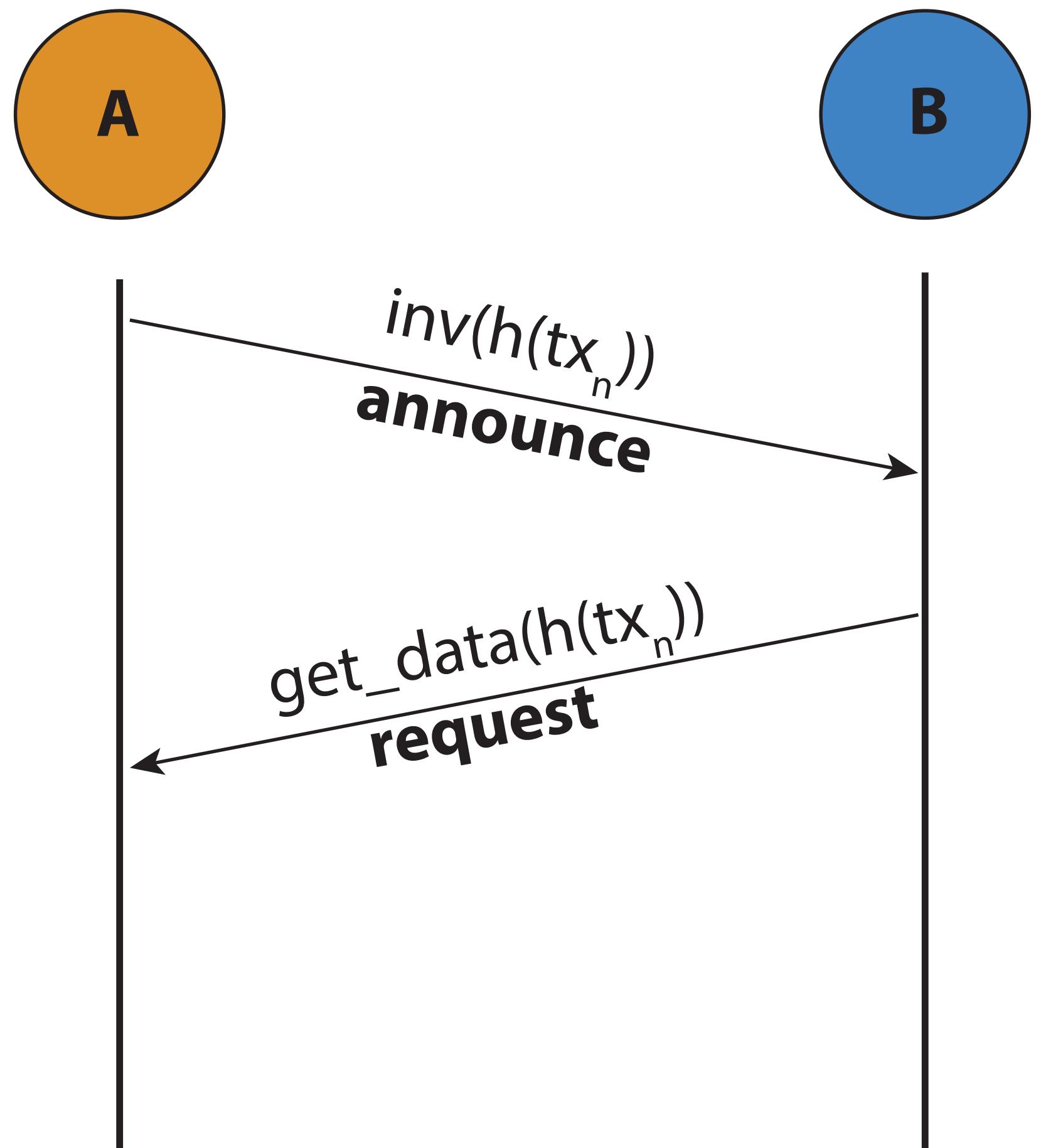
Announce paradigm



The gossip protocol (how?)

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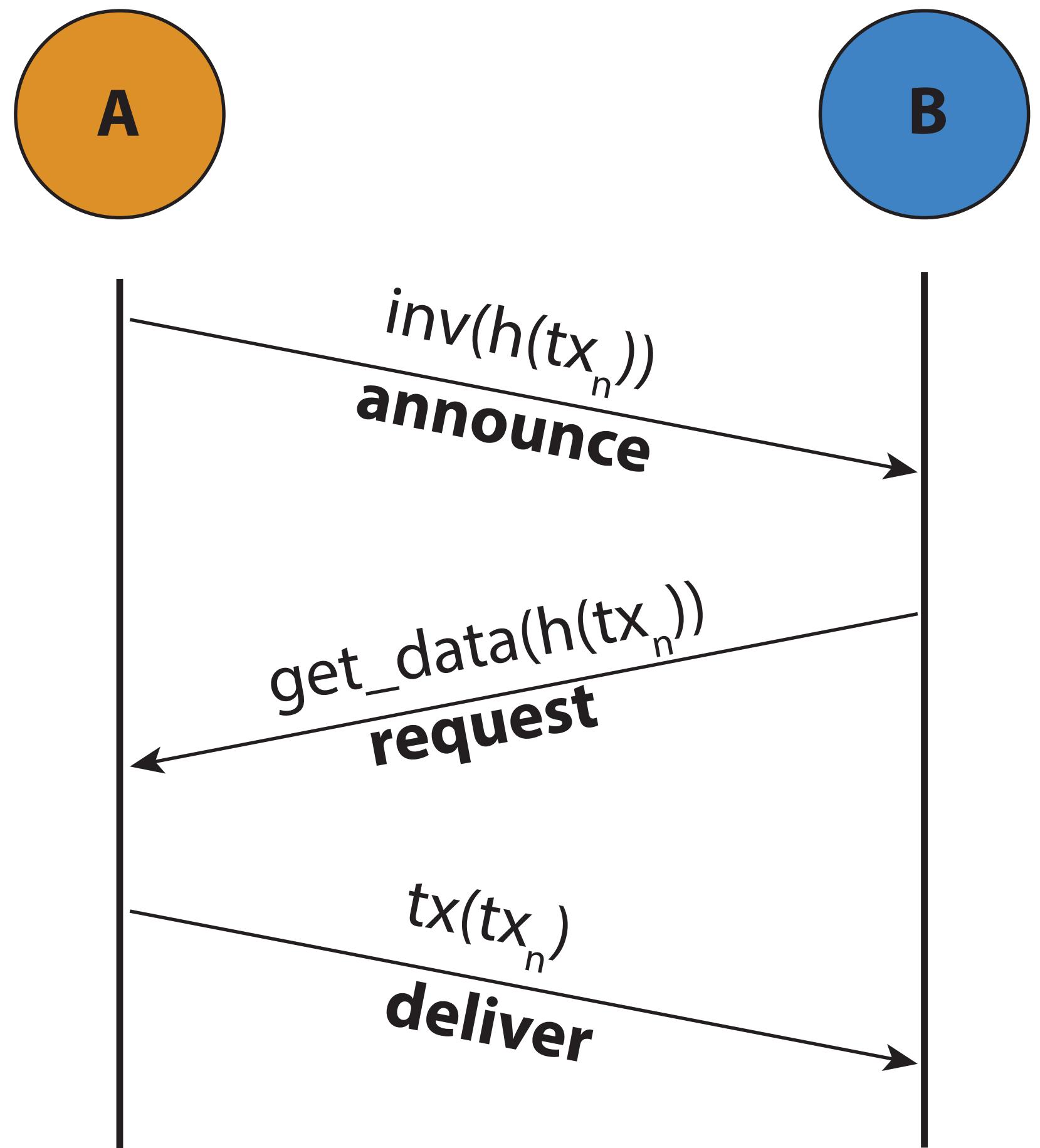
Announce paradigm



The gossip protocol (how?)

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- When a peer receives / generates a new item he announce it to his neighbors (**announce**)
- Upon receiving an announce of an item, a node that does not know about it will request such item back to the announcer (**request**)
- Upon receiving a request of a known item, a node will reply back with it (**deliver**)

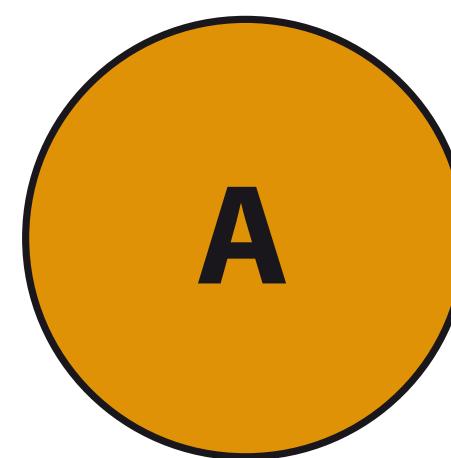
Announce paradigm



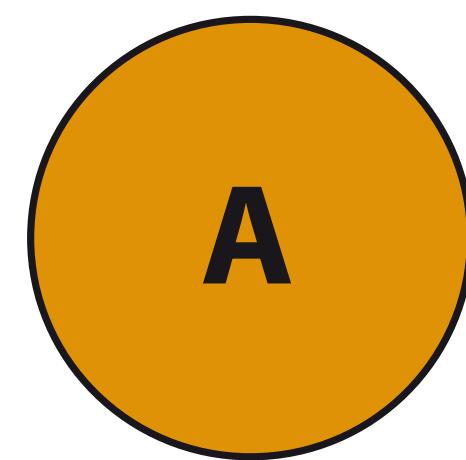
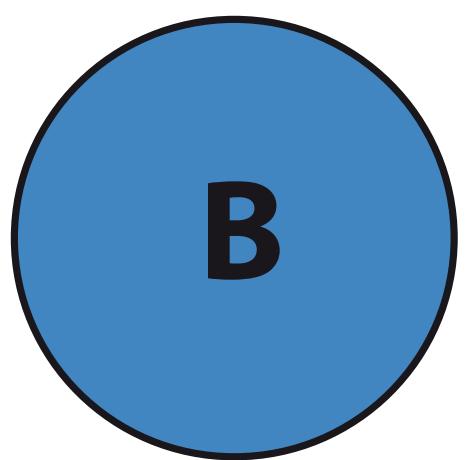
Information propagation

Information propagation (1/2)

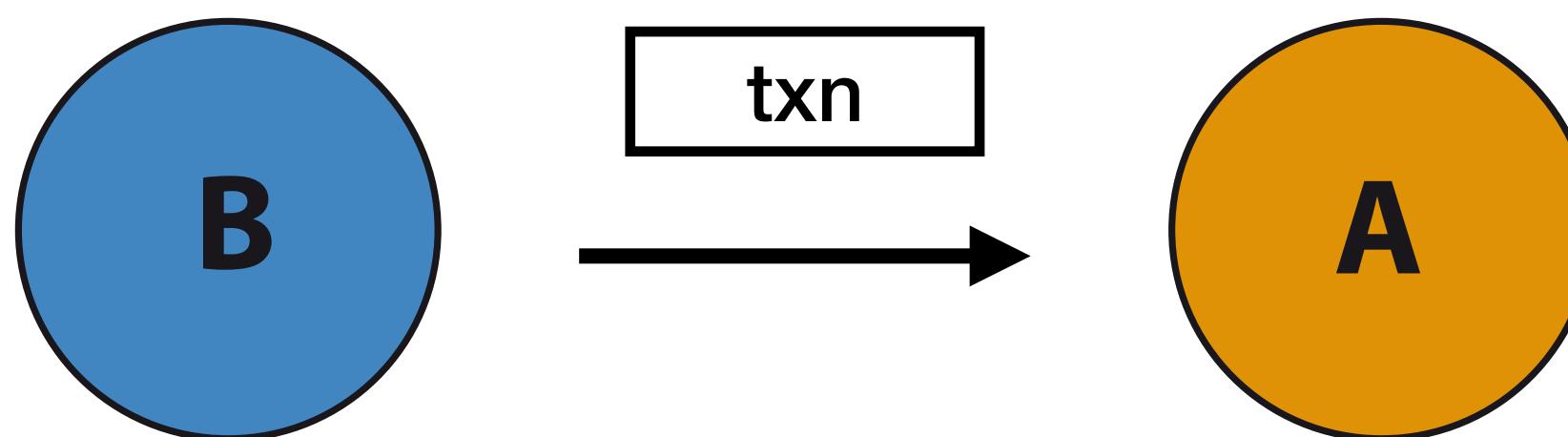
Information propagation (1/2)



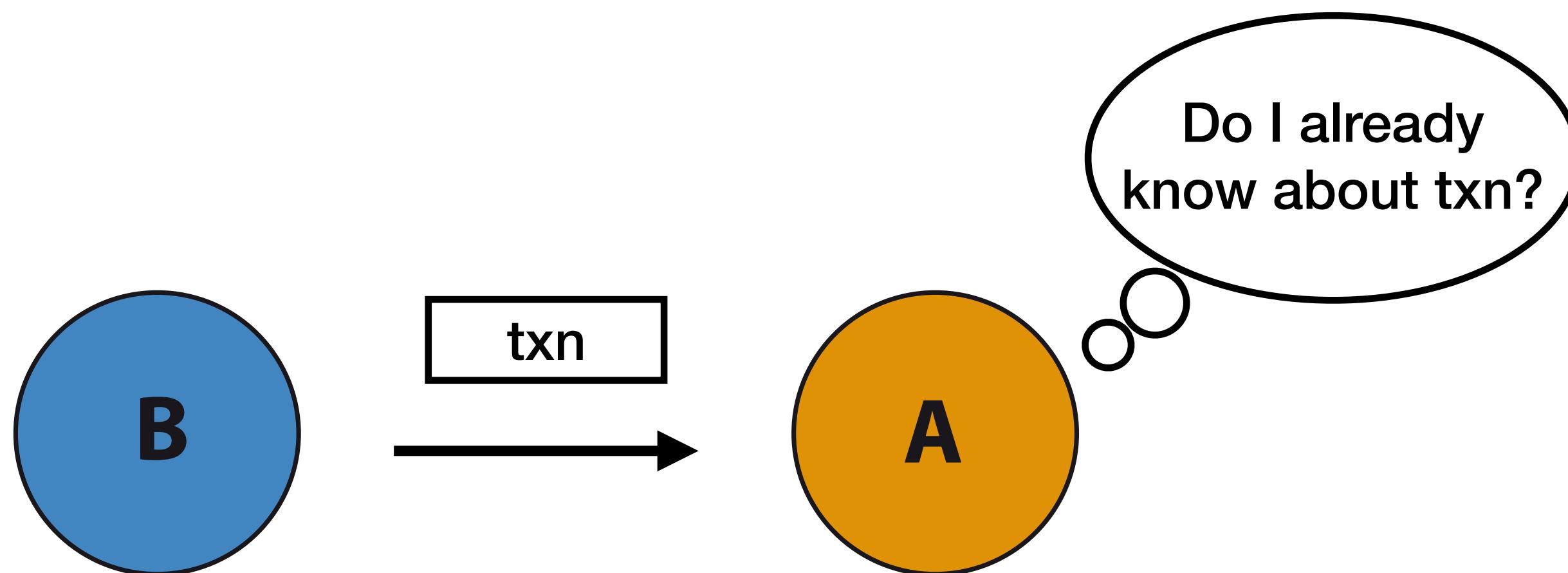
Information propagation (1/2)



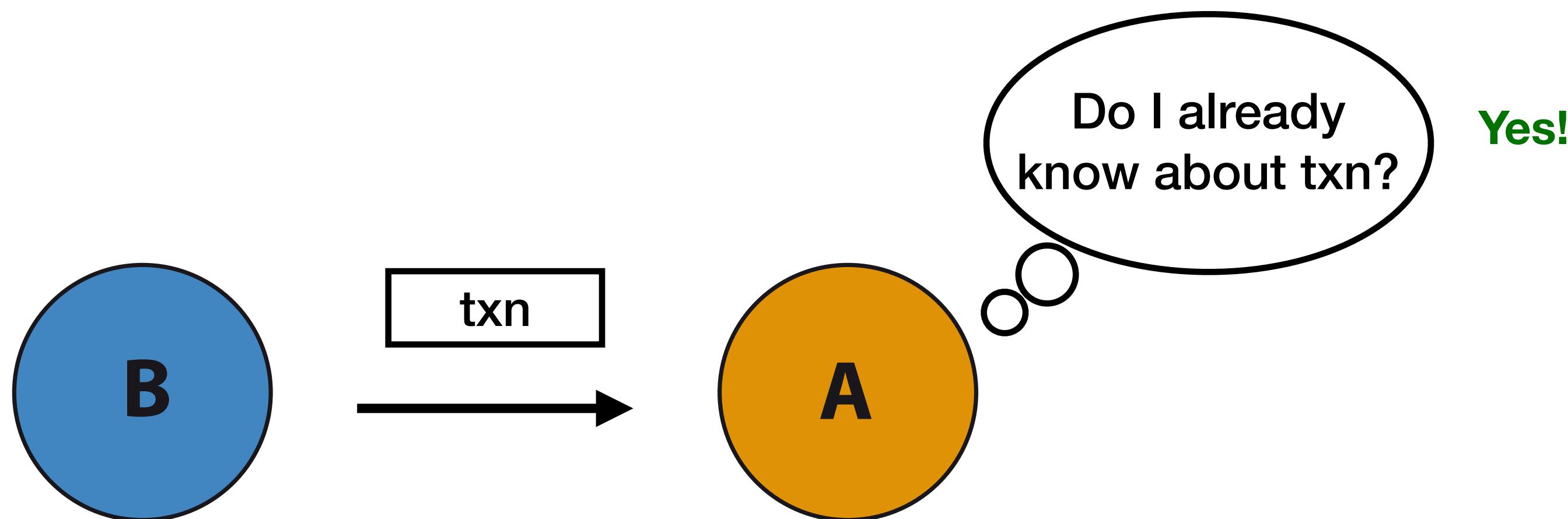
Information propagation (1/2)



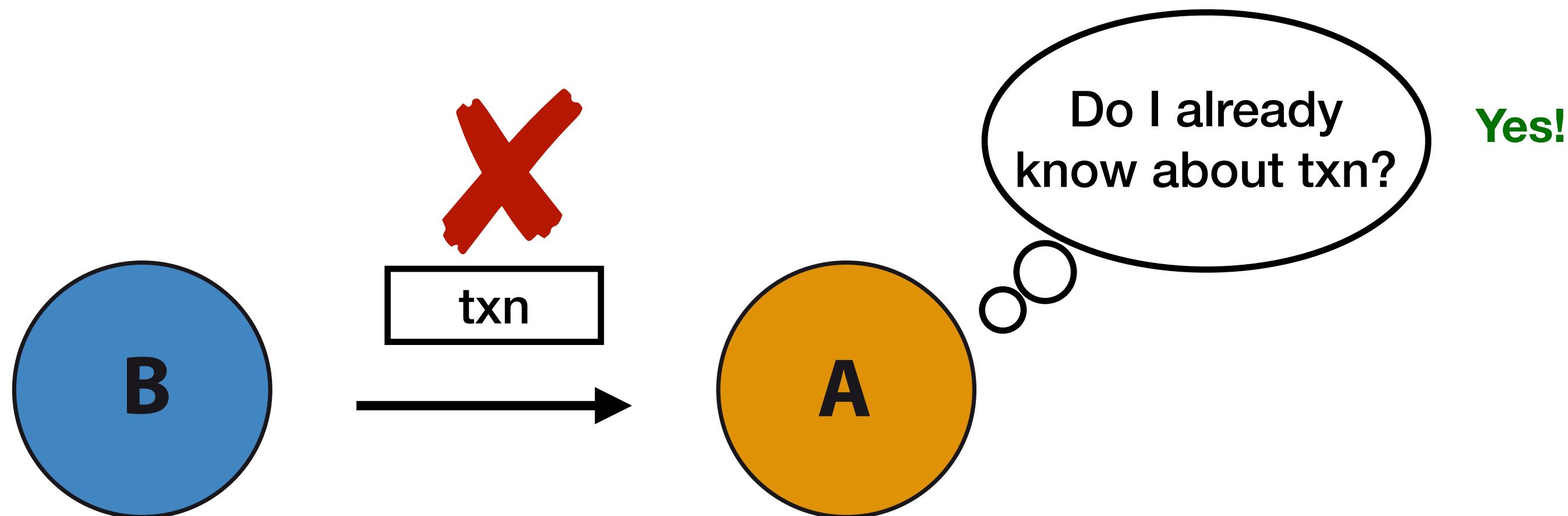
Information propagation (1/2)



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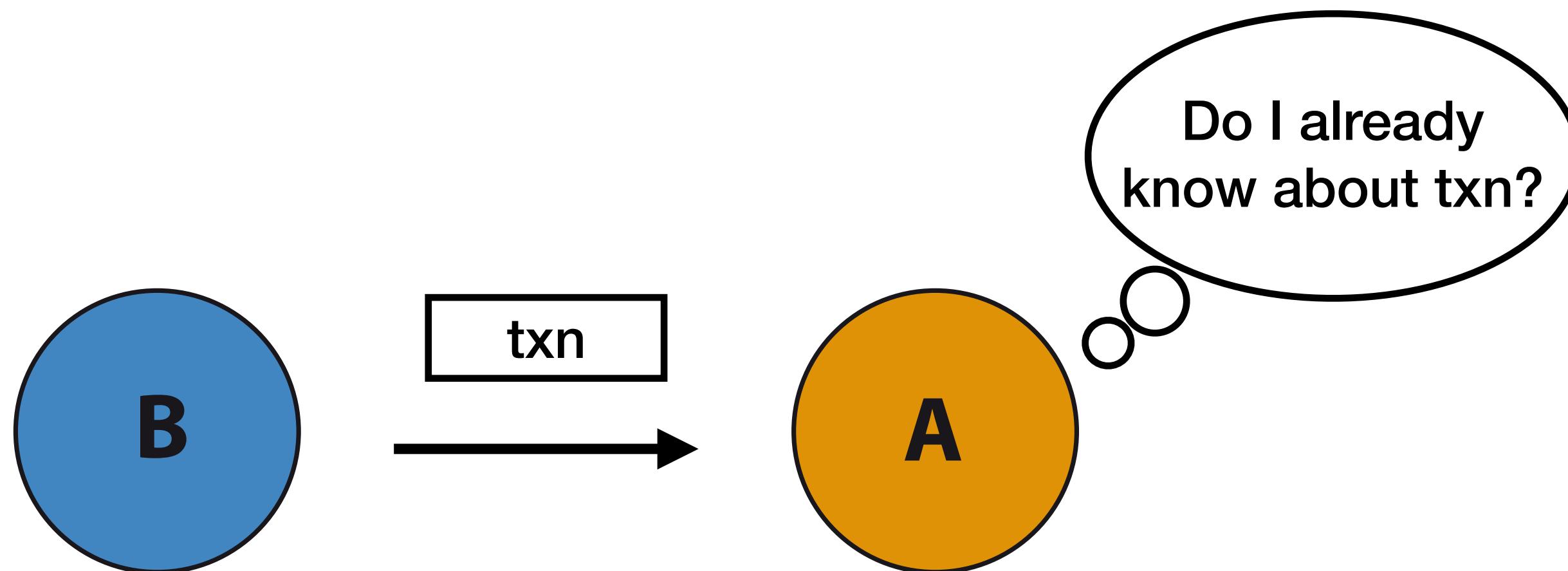


Information propagation (1/2)



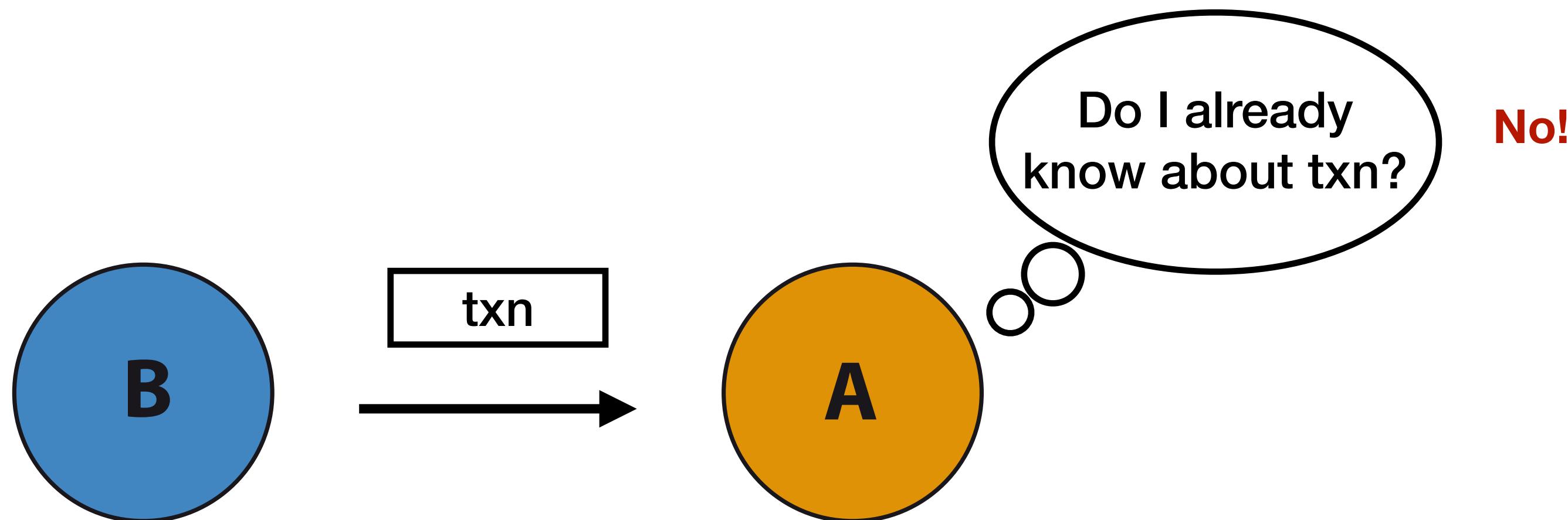
- Known transaction will be rejected

Information propagation (1/2)



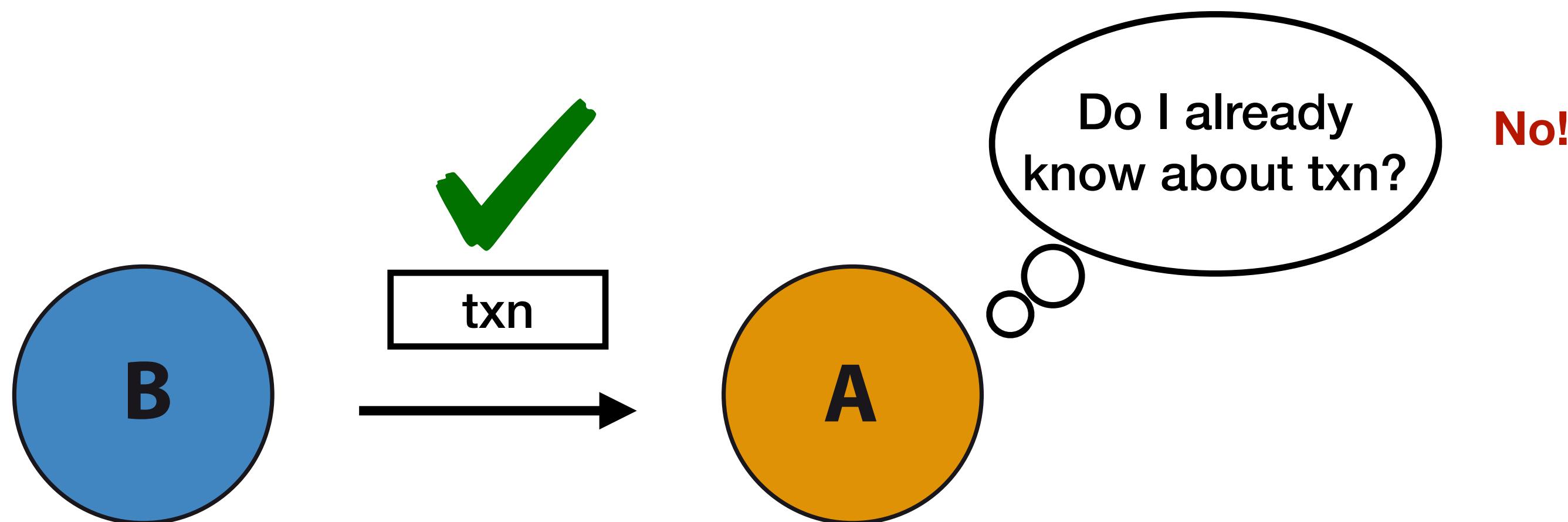
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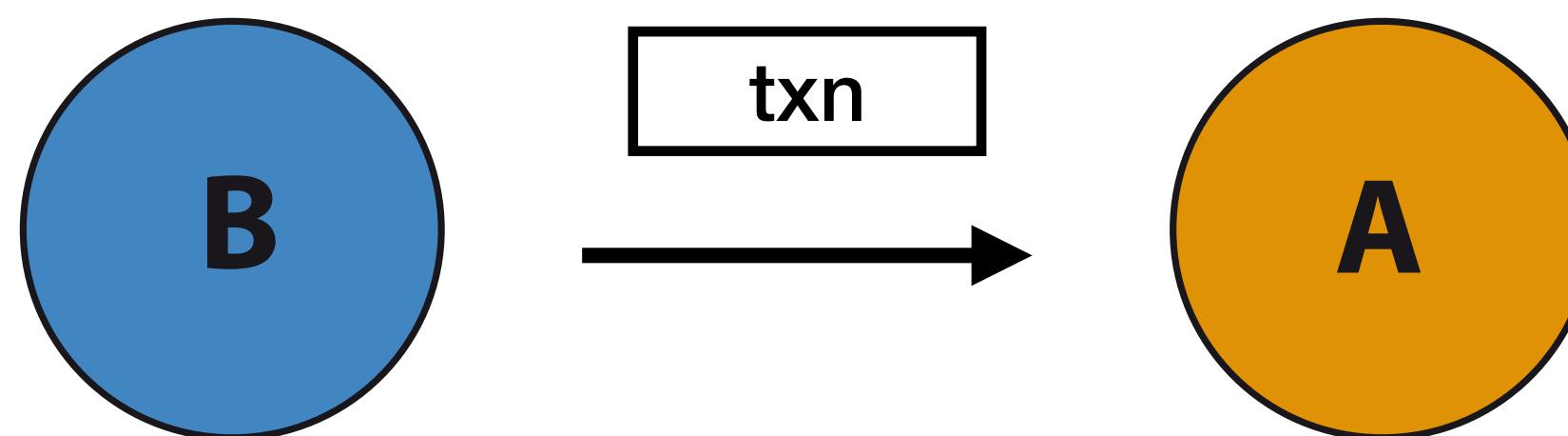
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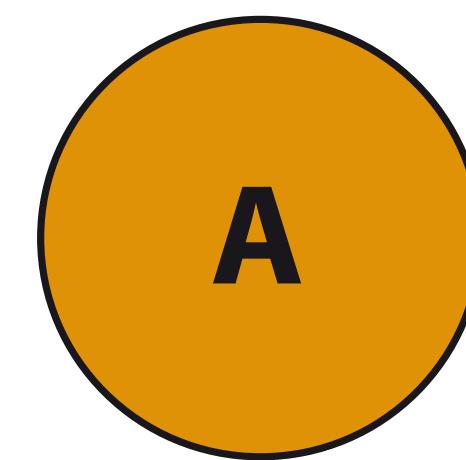
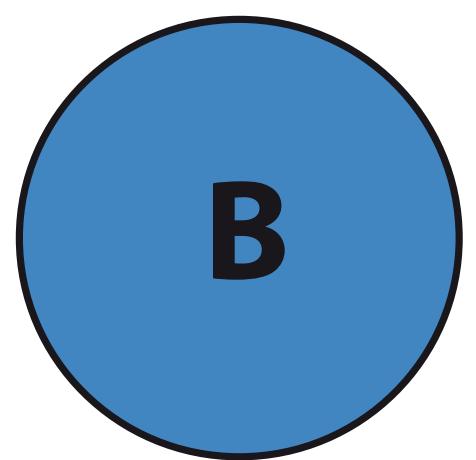
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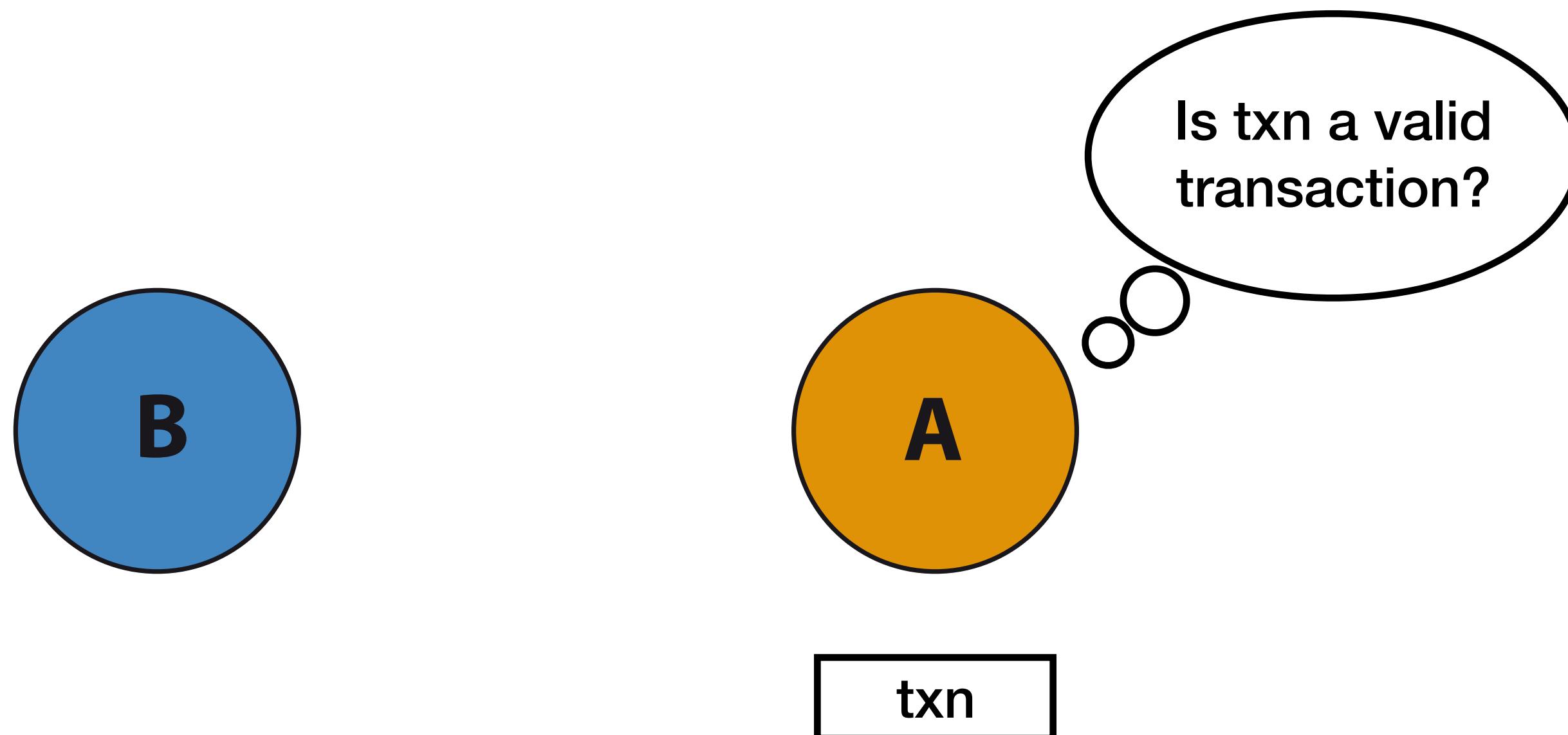


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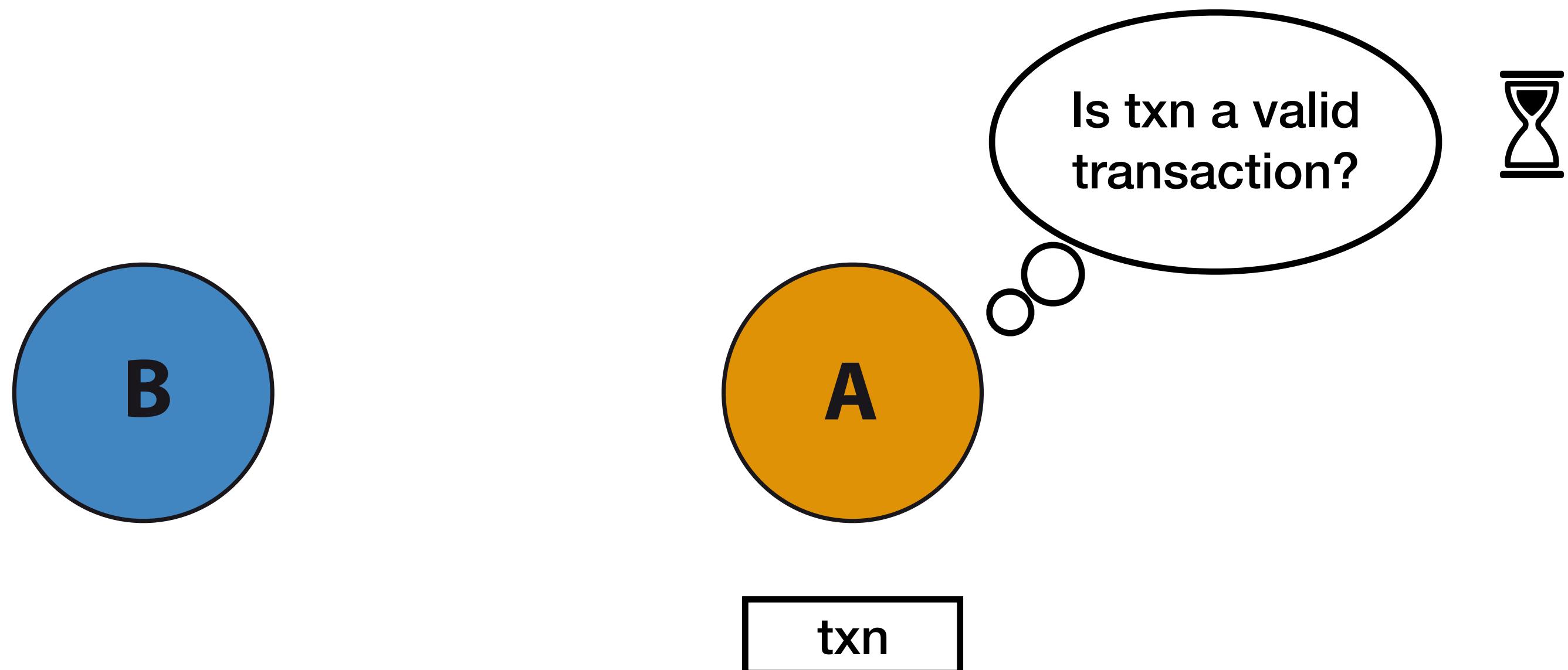


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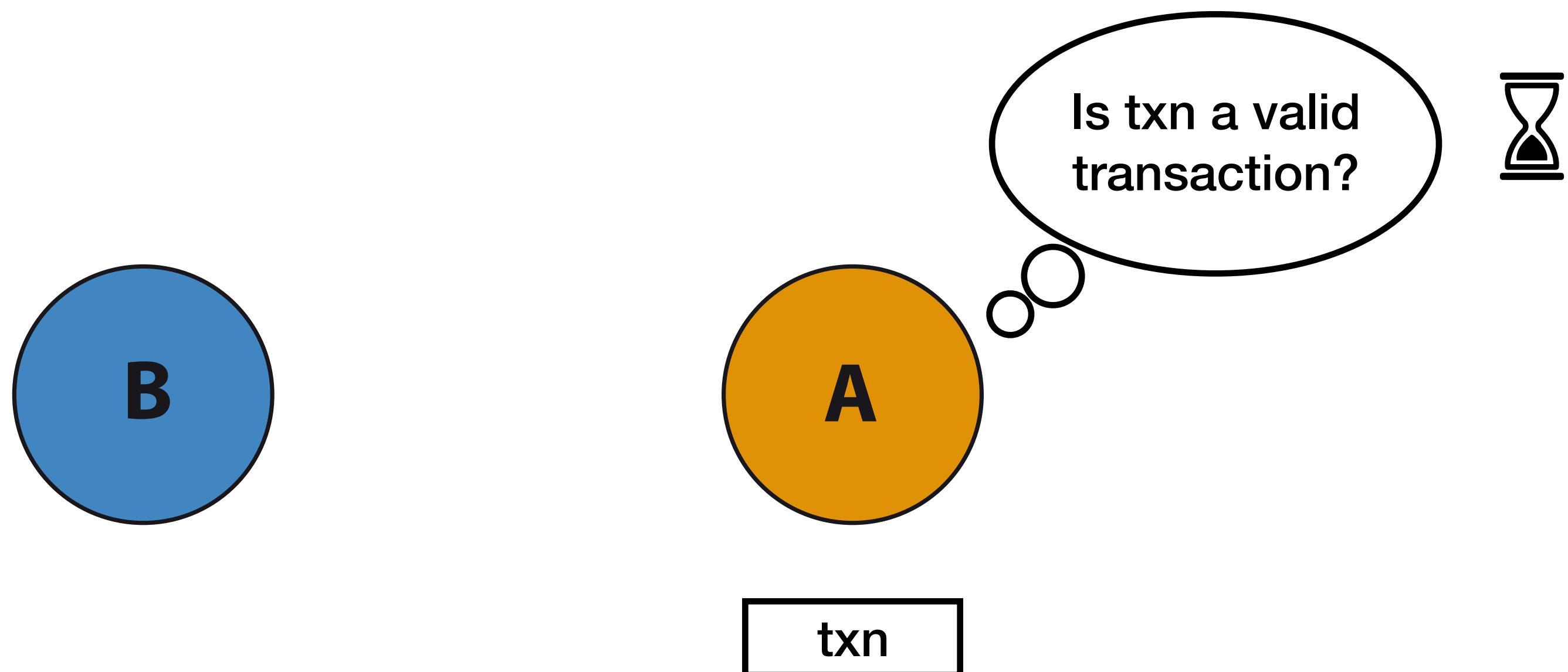
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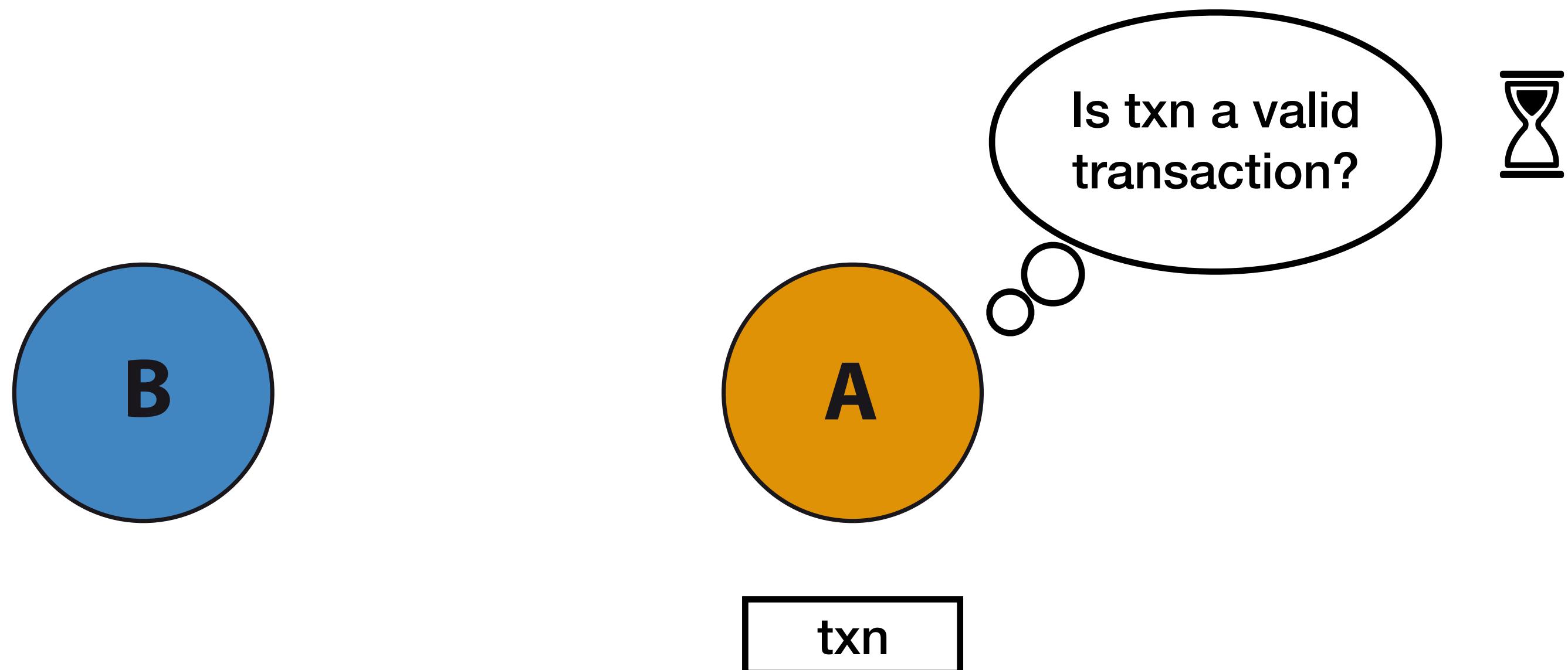
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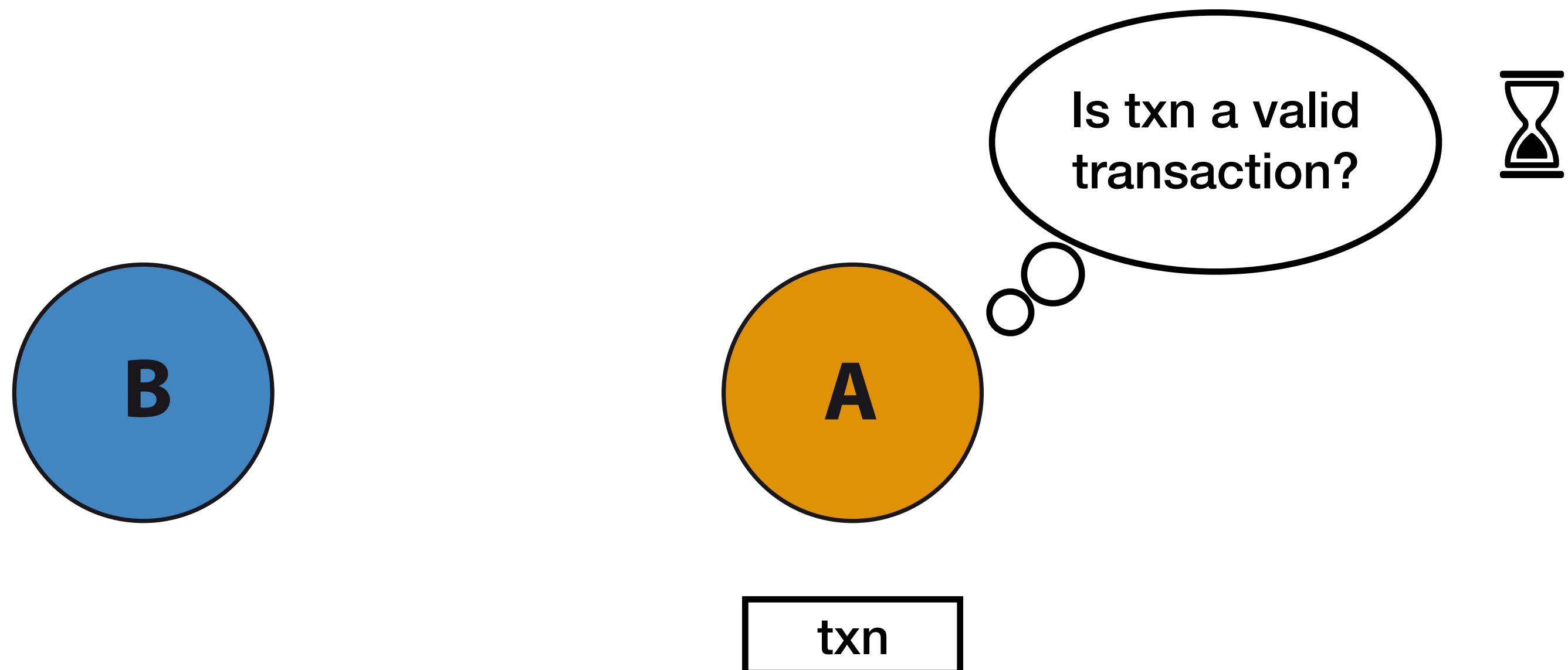
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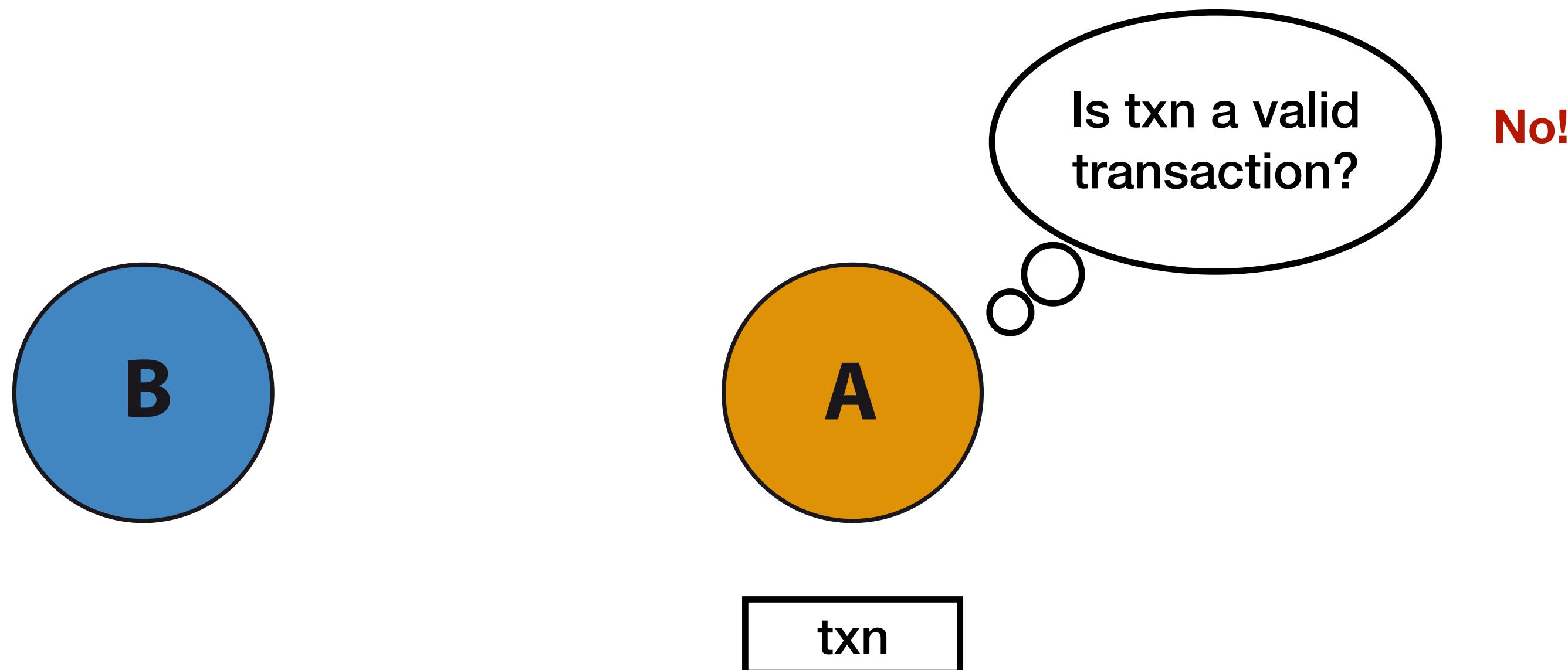
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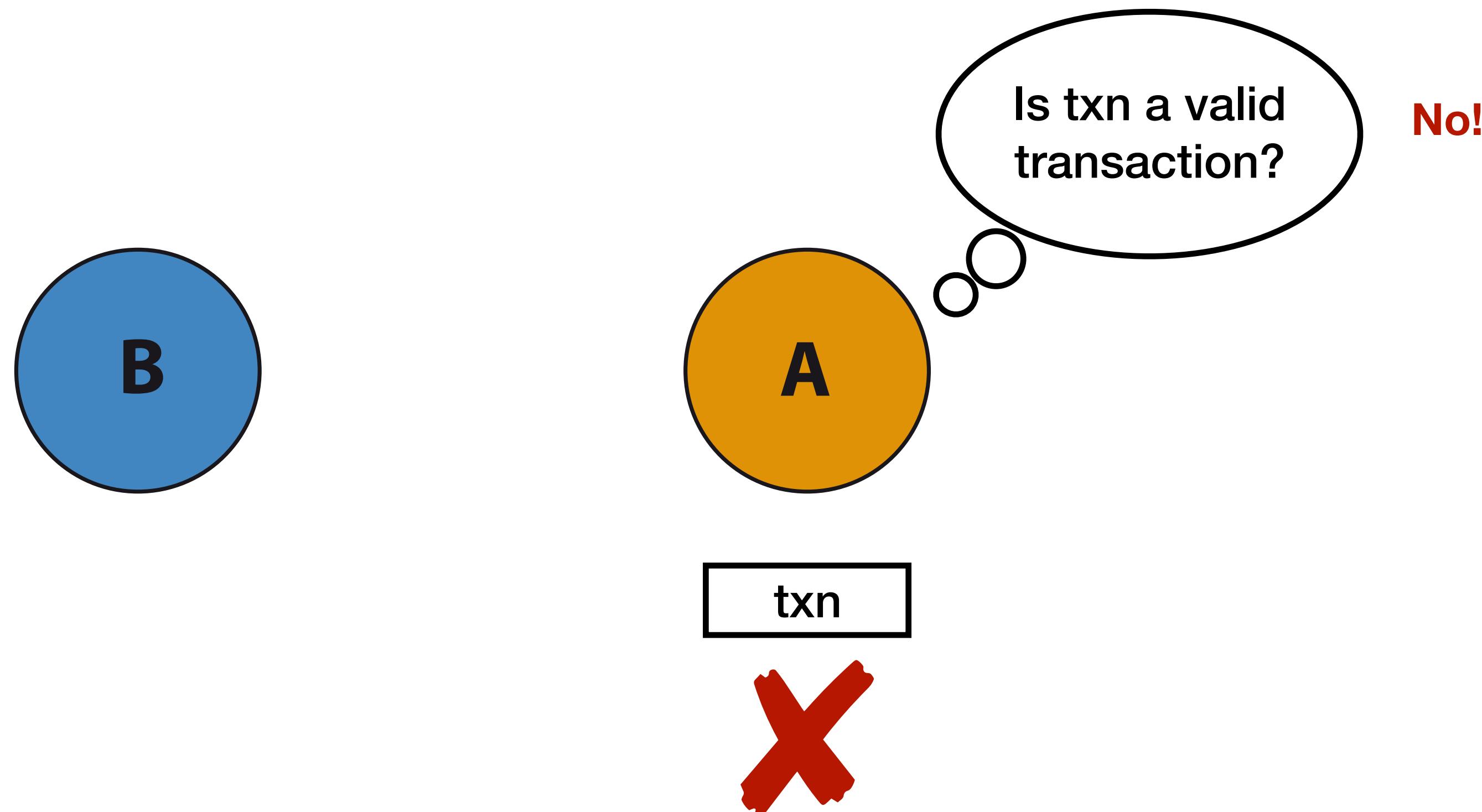
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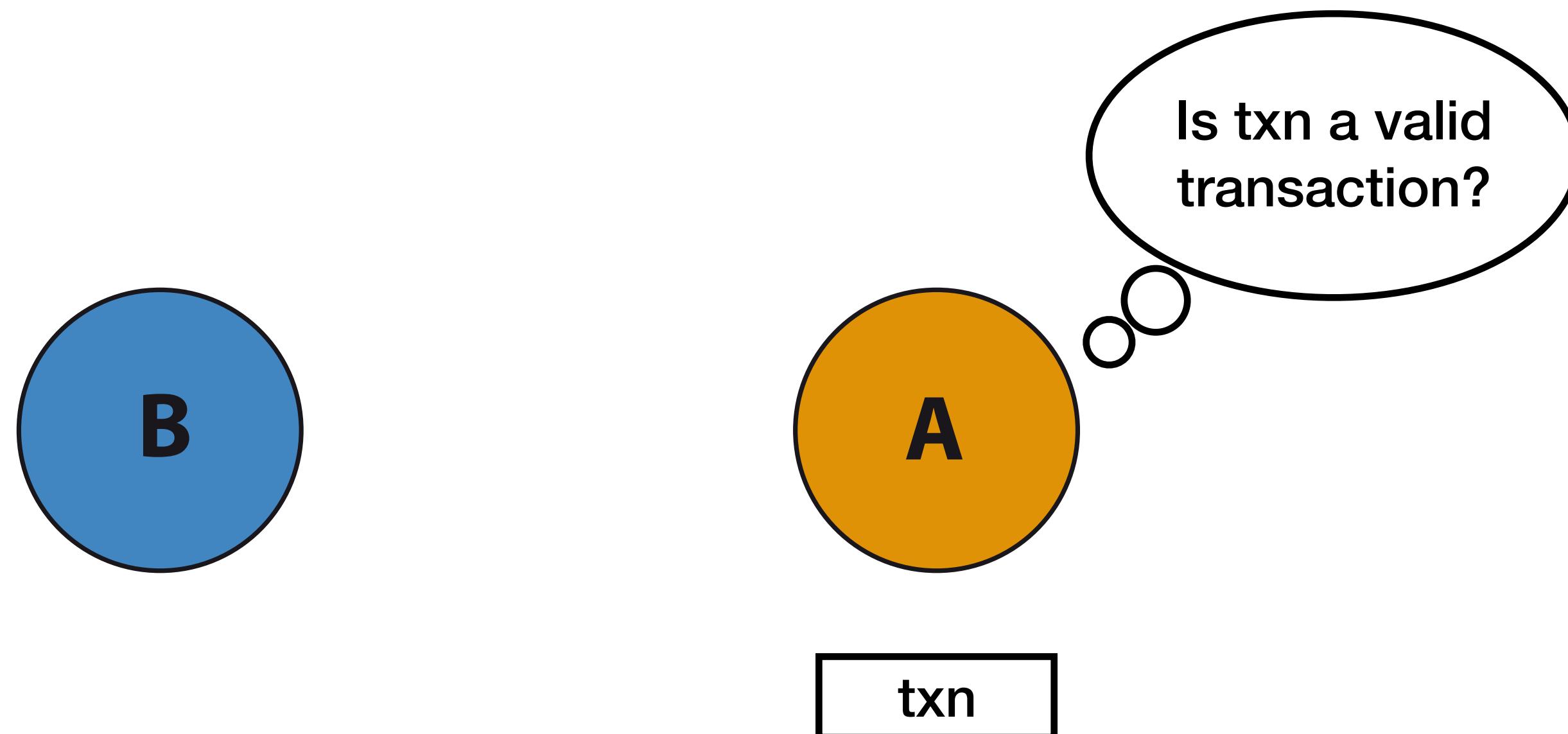
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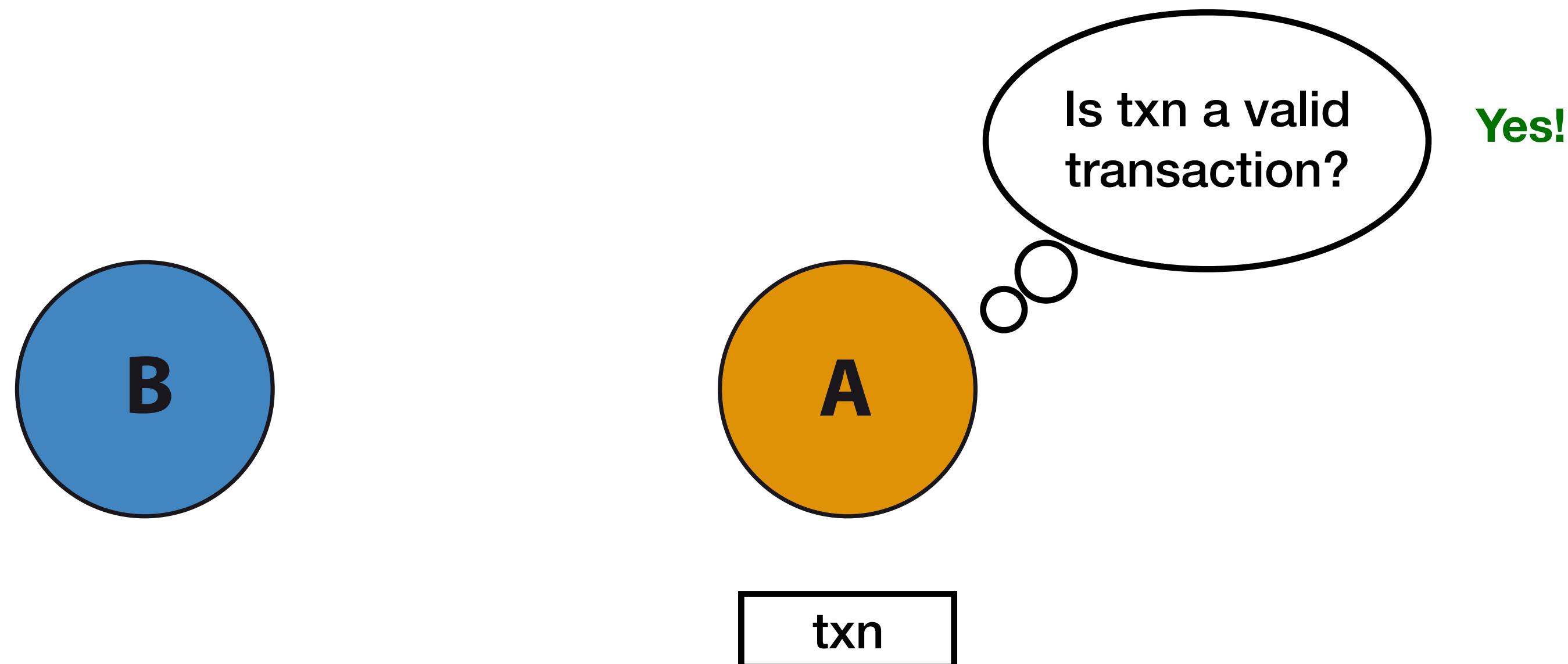
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Information propagation (1/2)



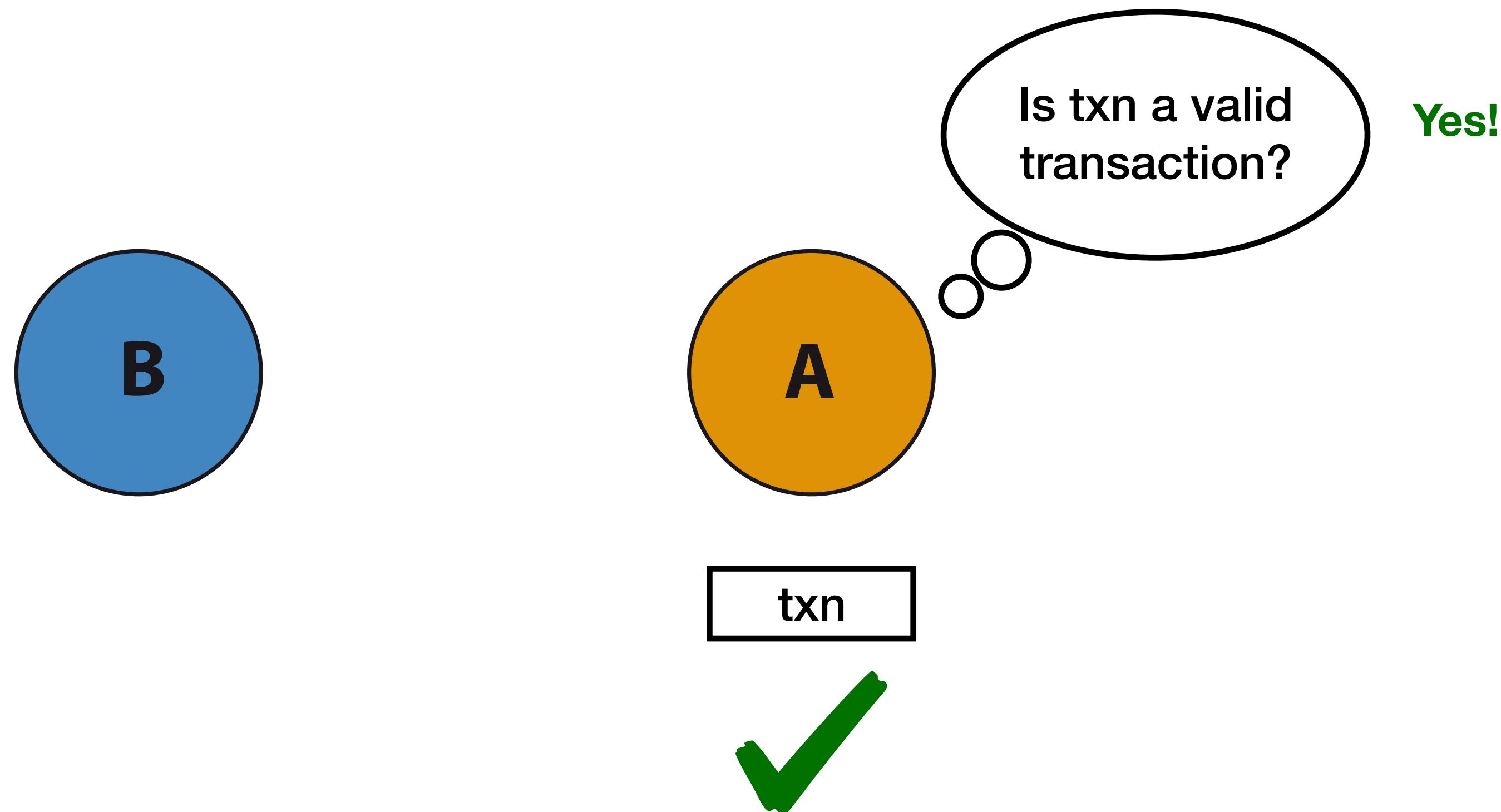
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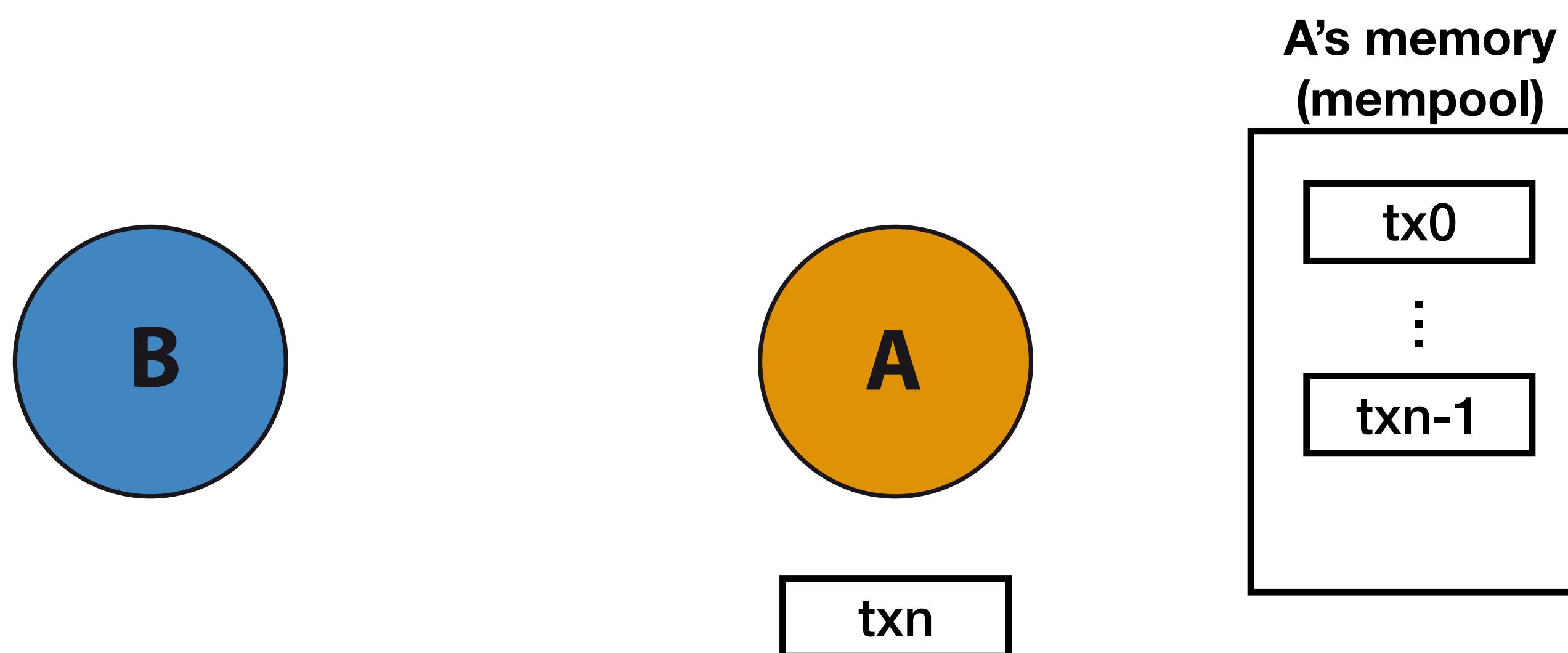
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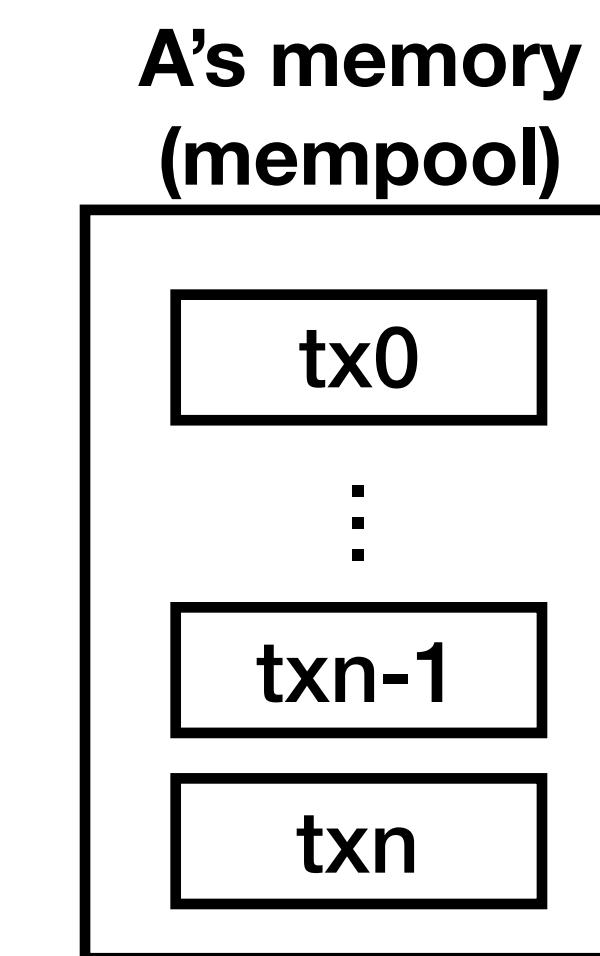
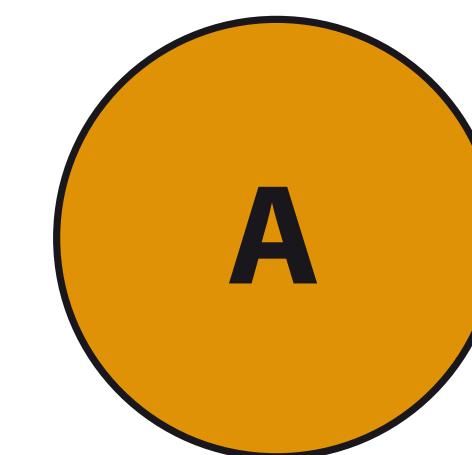
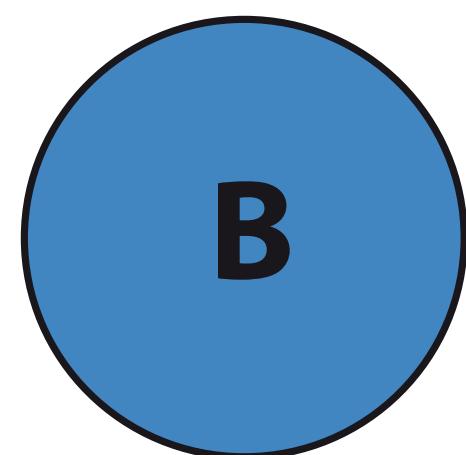
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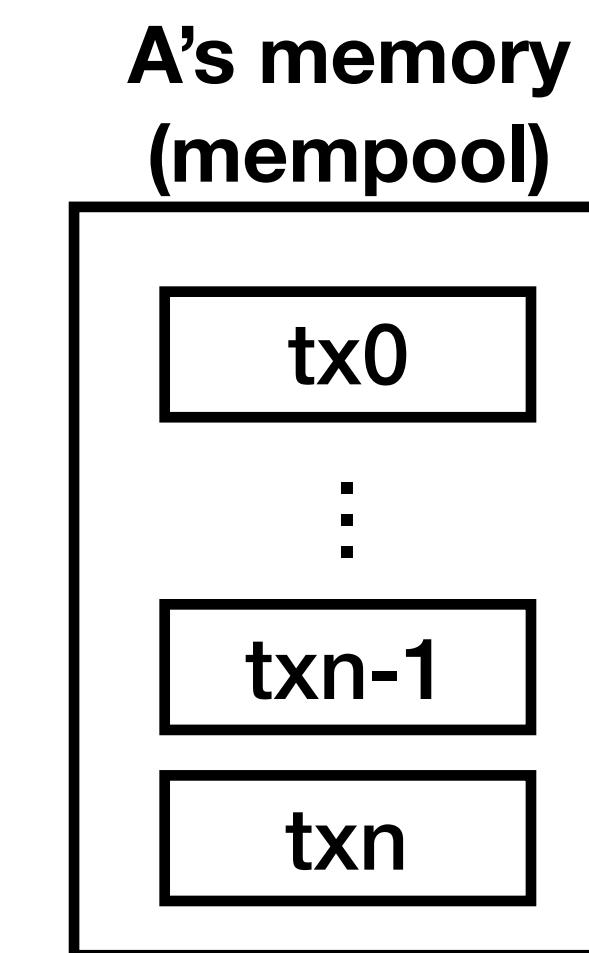
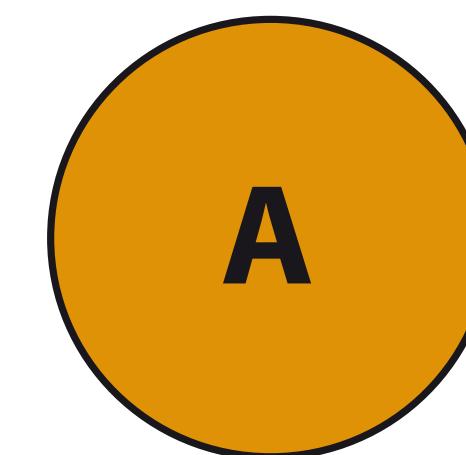
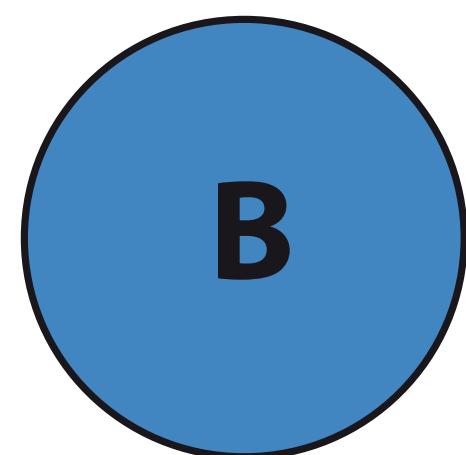
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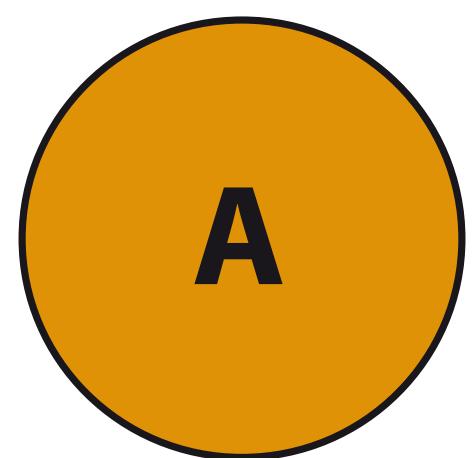
Information propagation (1/2)



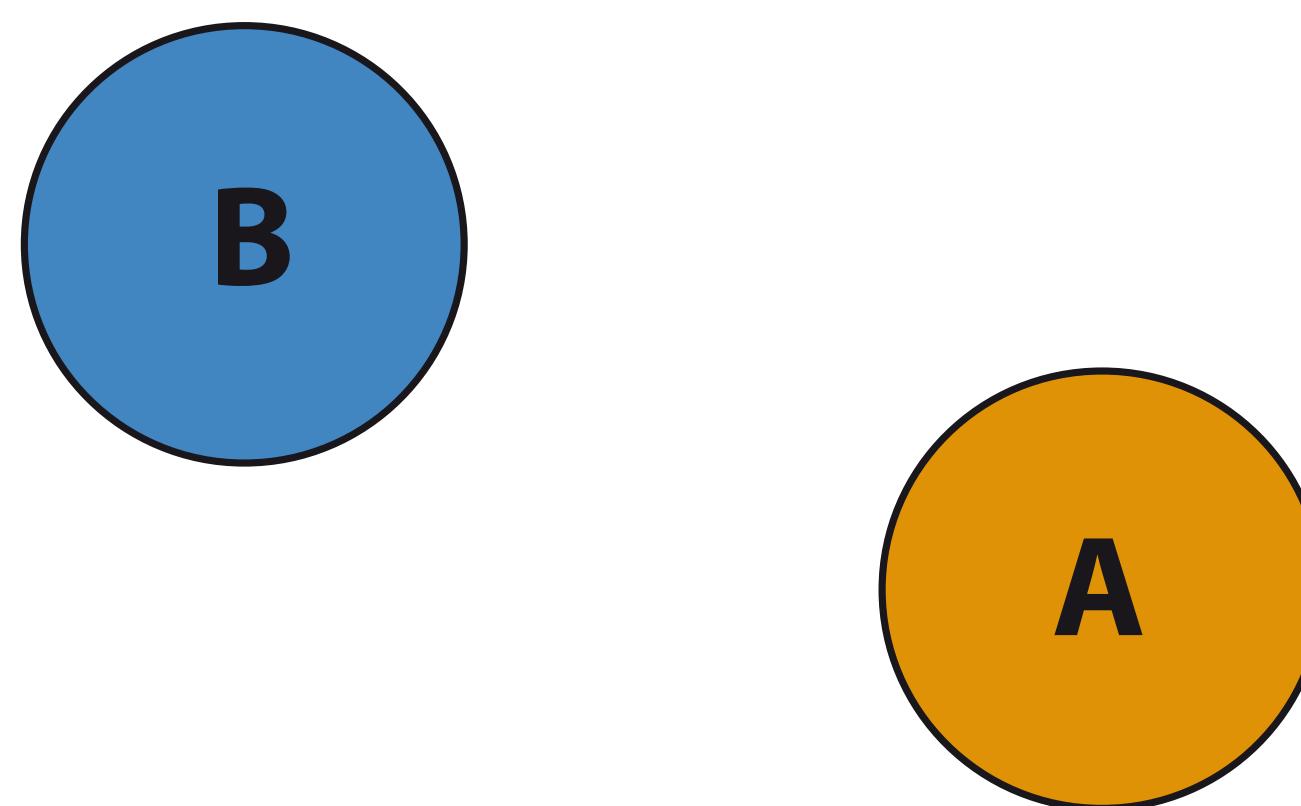
- Known transaction will be rejected
- Invalid transaction will also be rejected
- Valid (new) transactions will be kept in memory (mempool)

Information propagation (2/2)

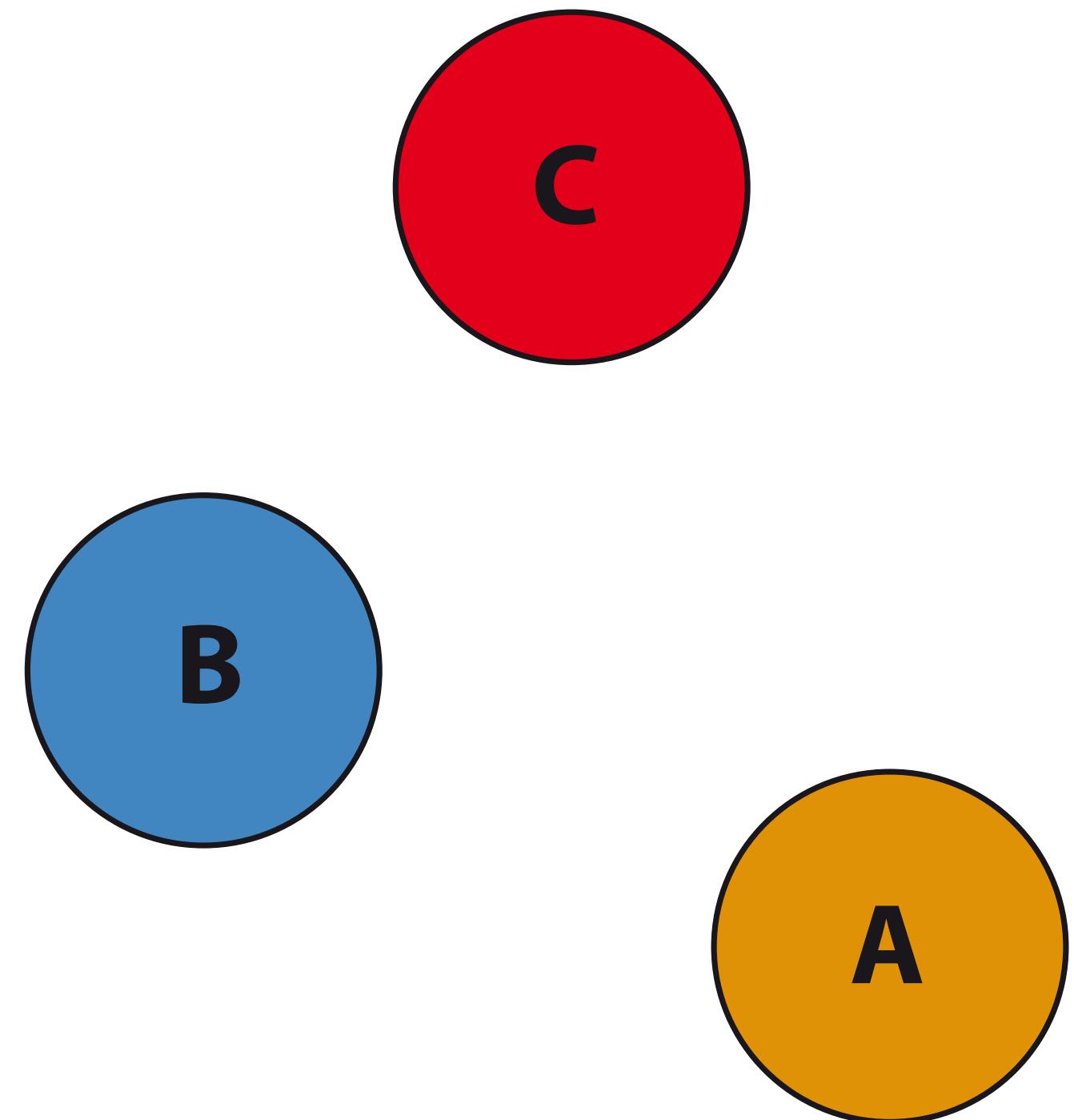
Information propagation (2/2)



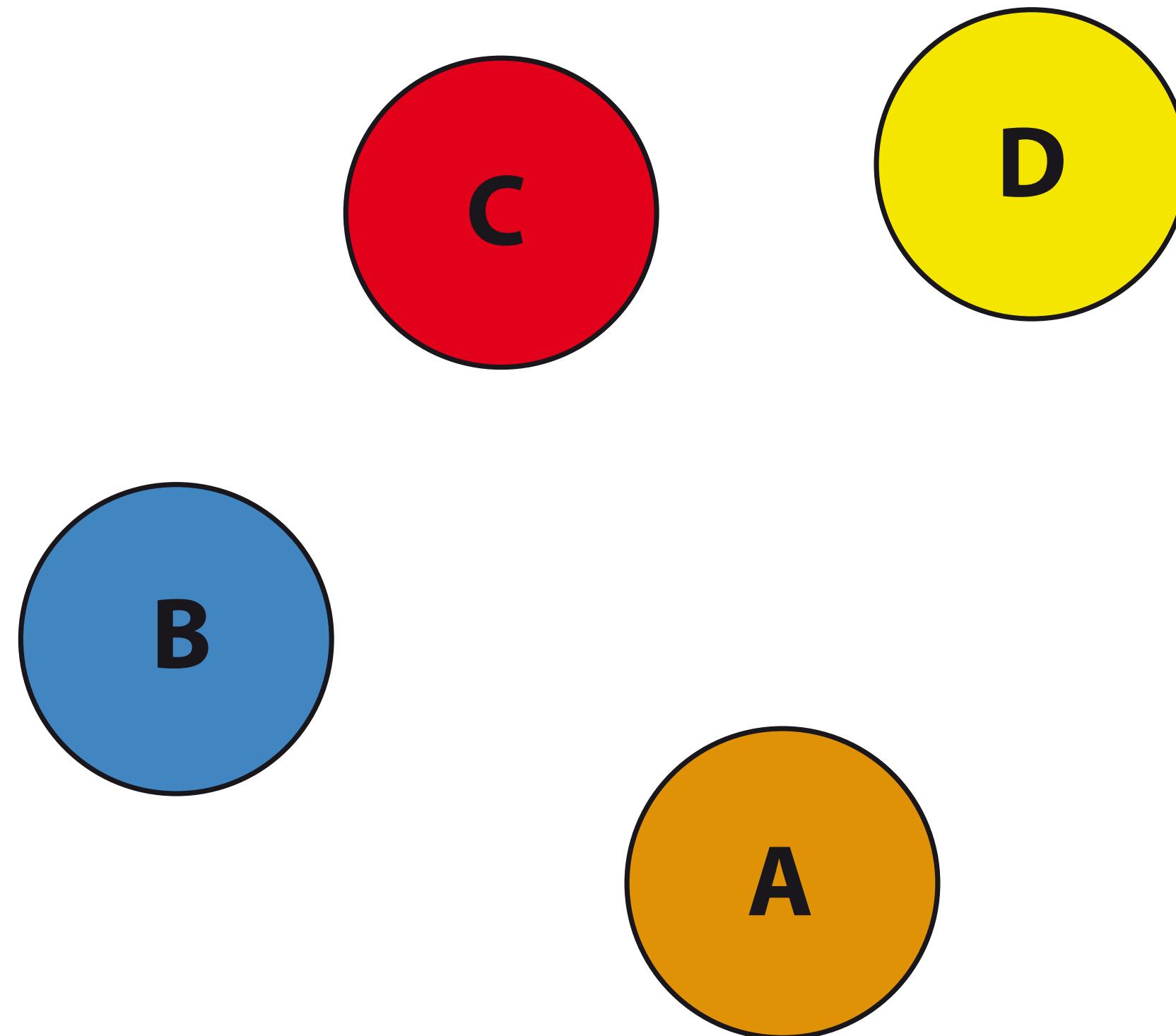
Information propagation (2/2)



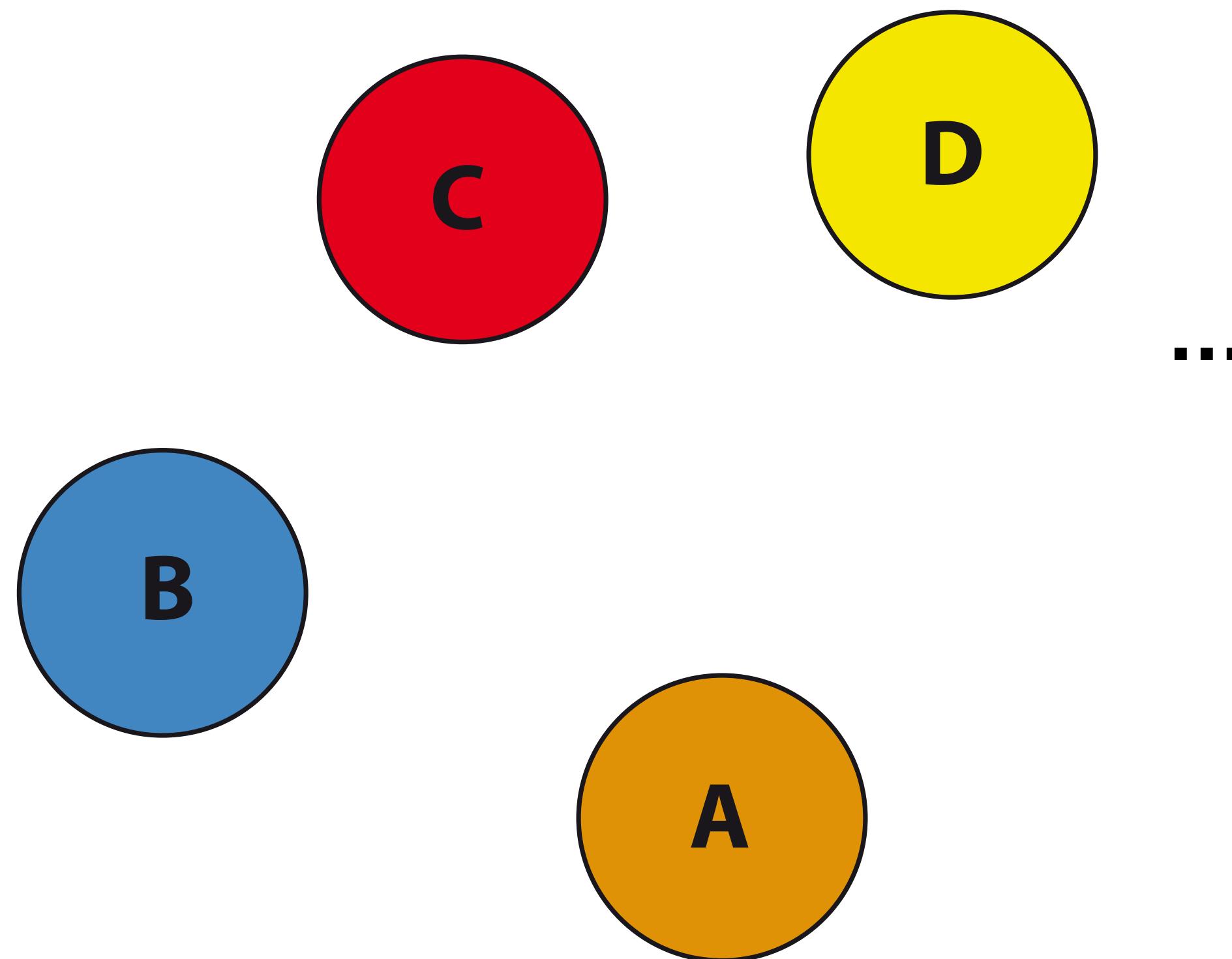
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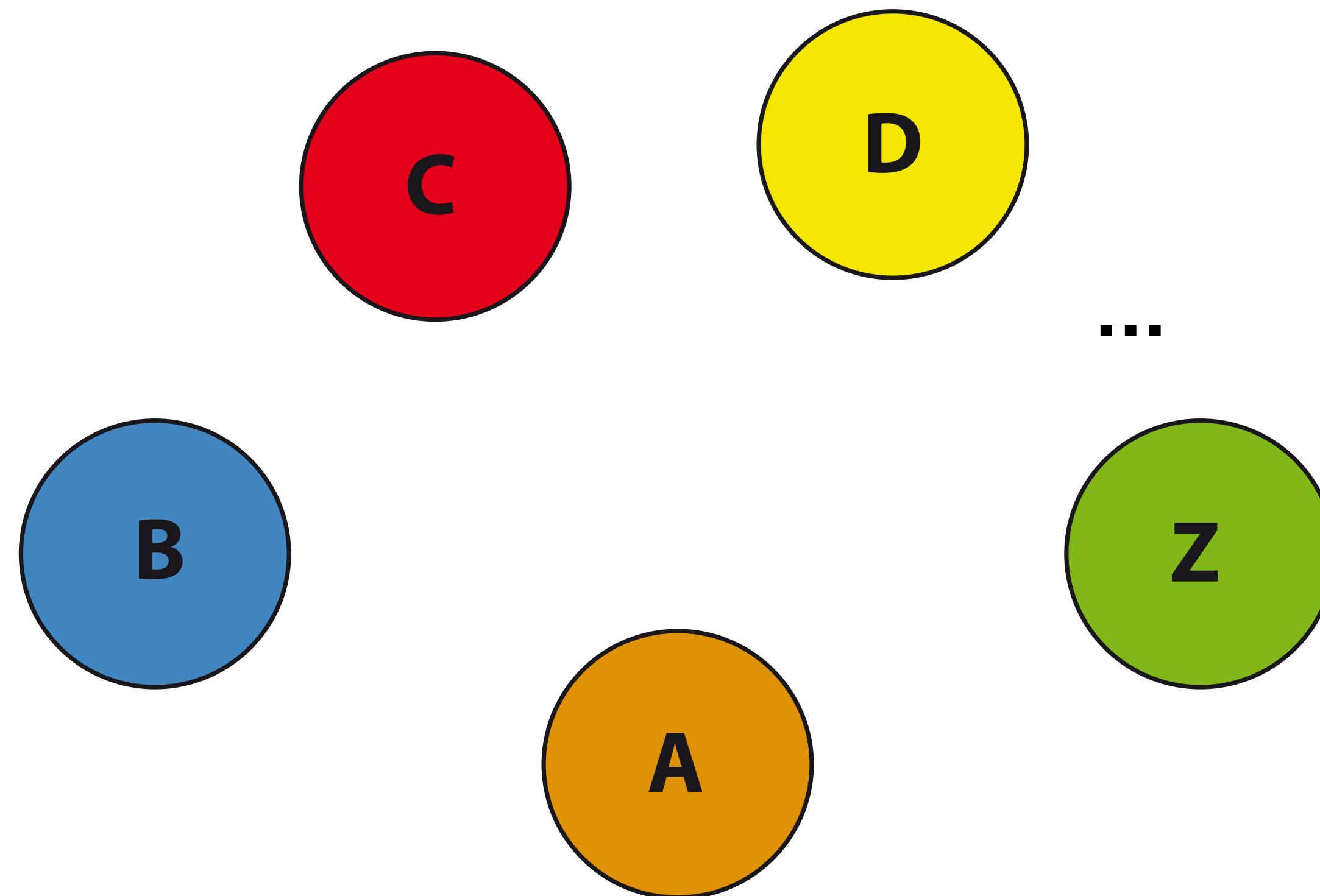
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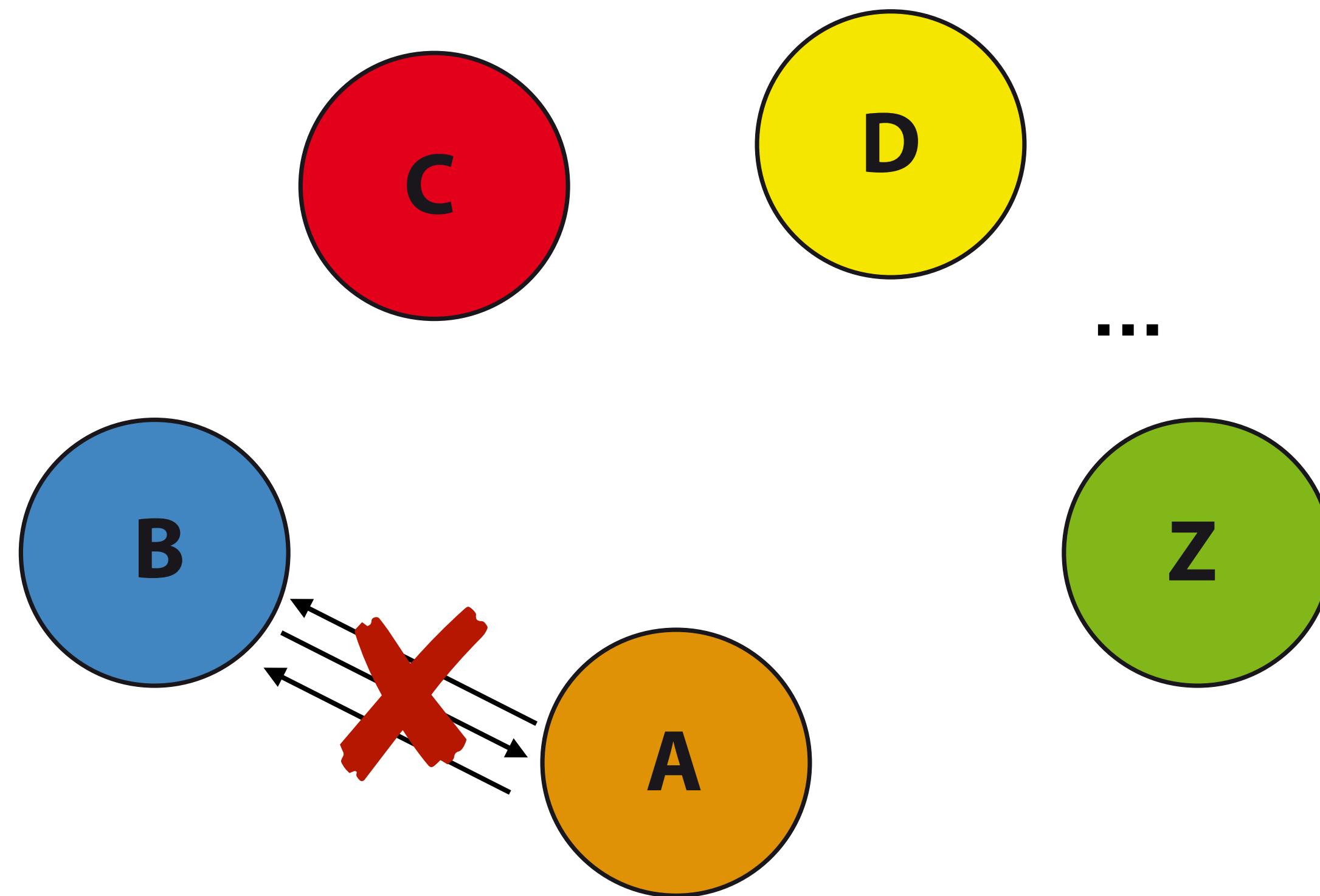
Information propagation (2/2)



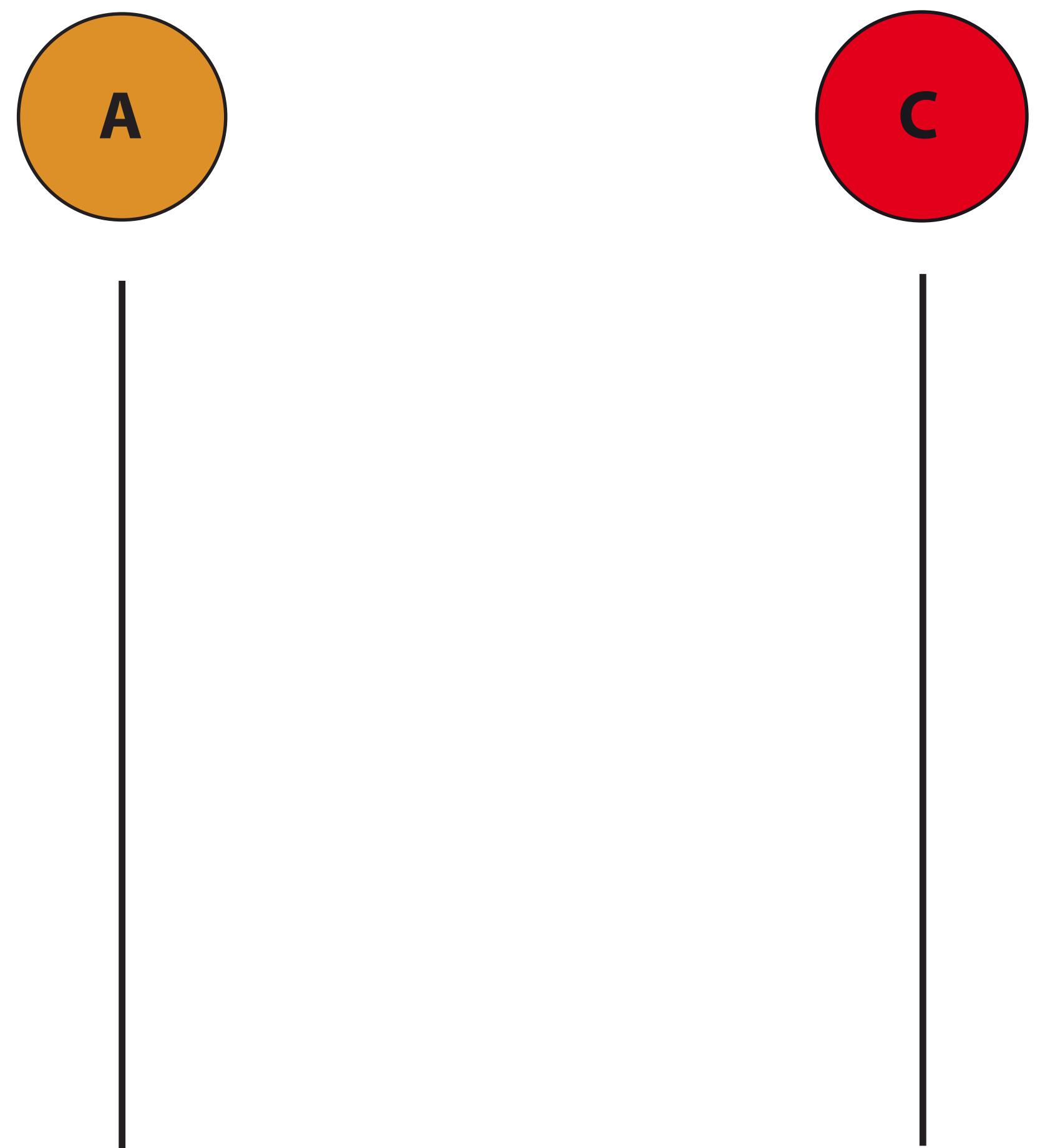
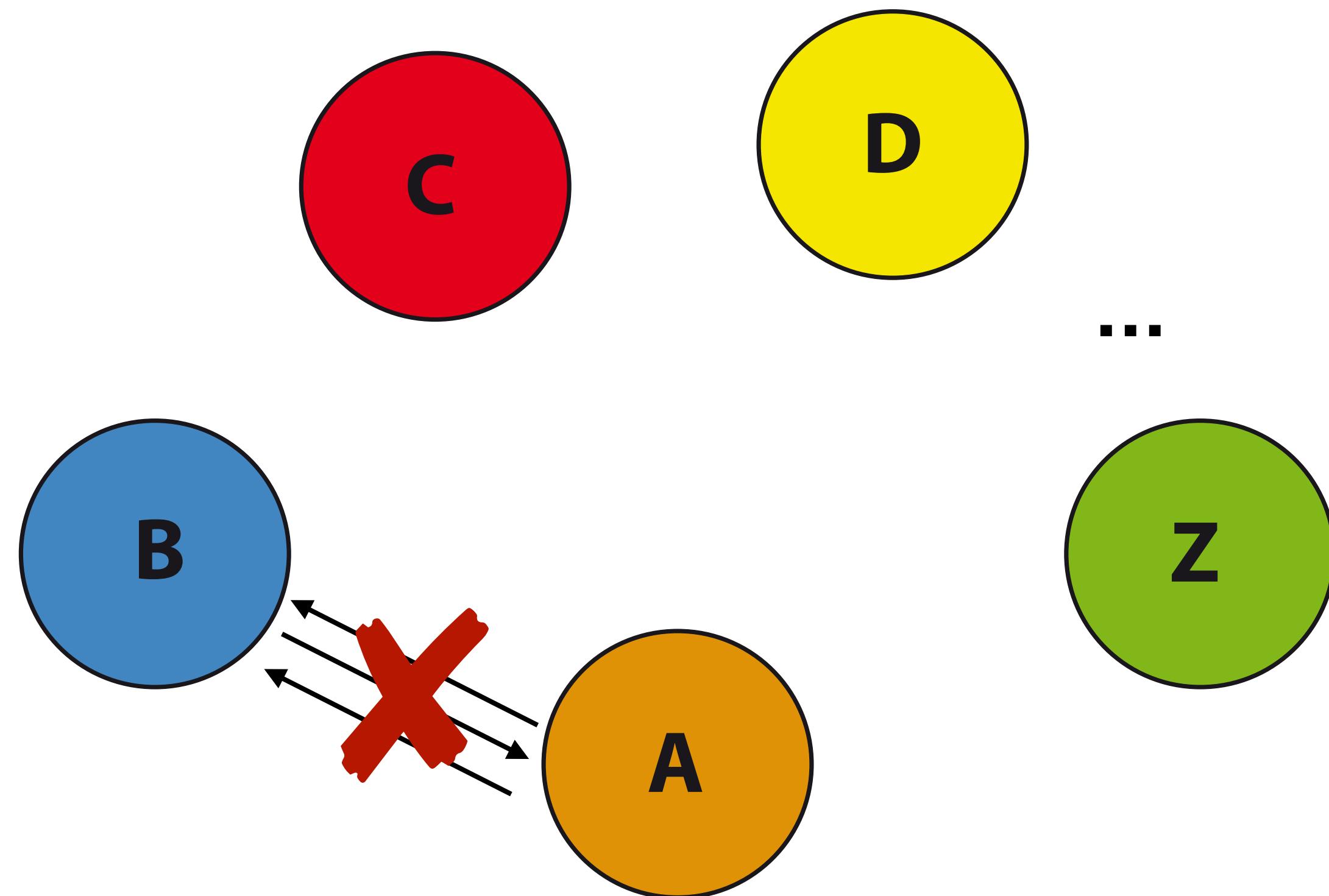
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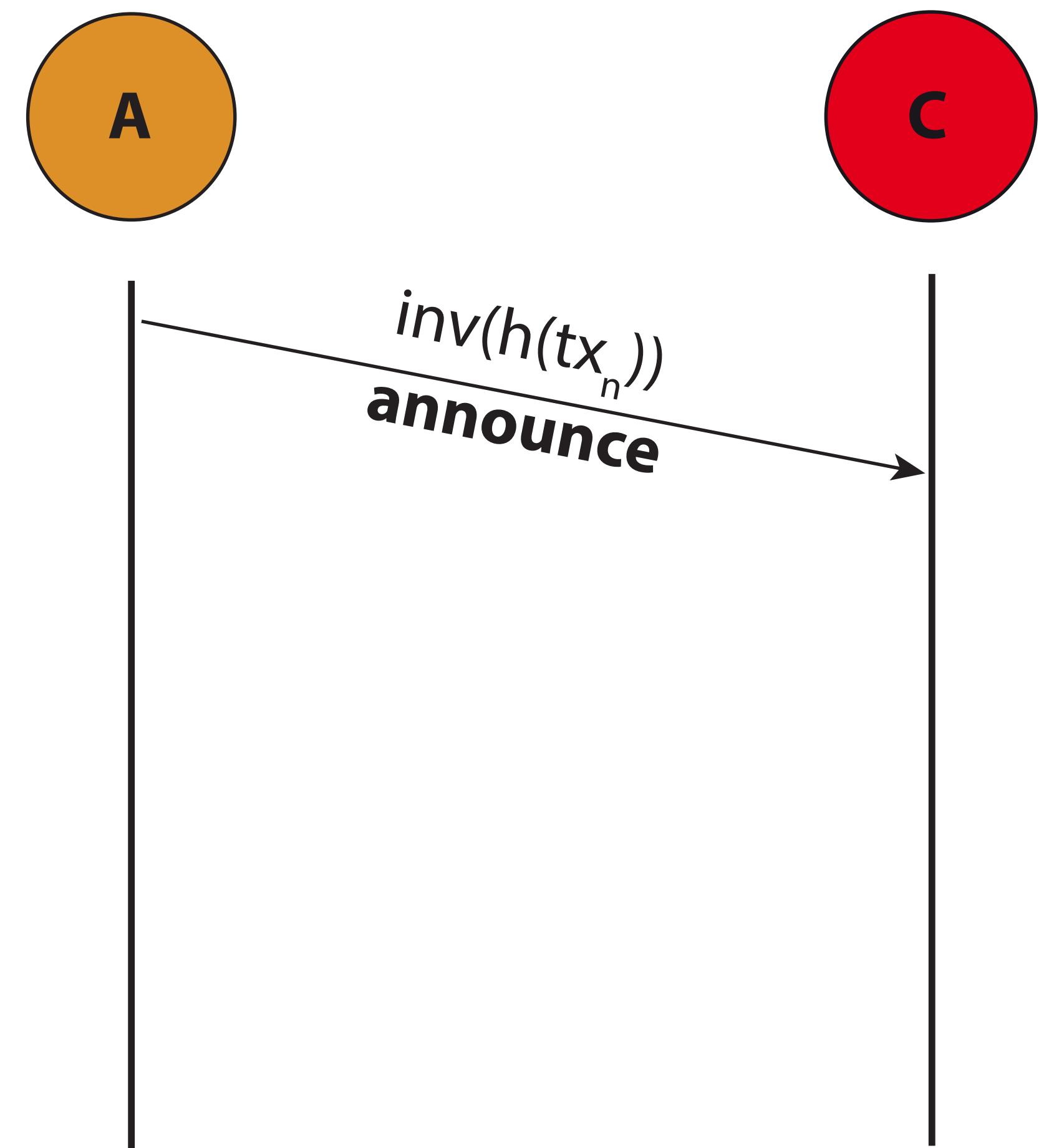
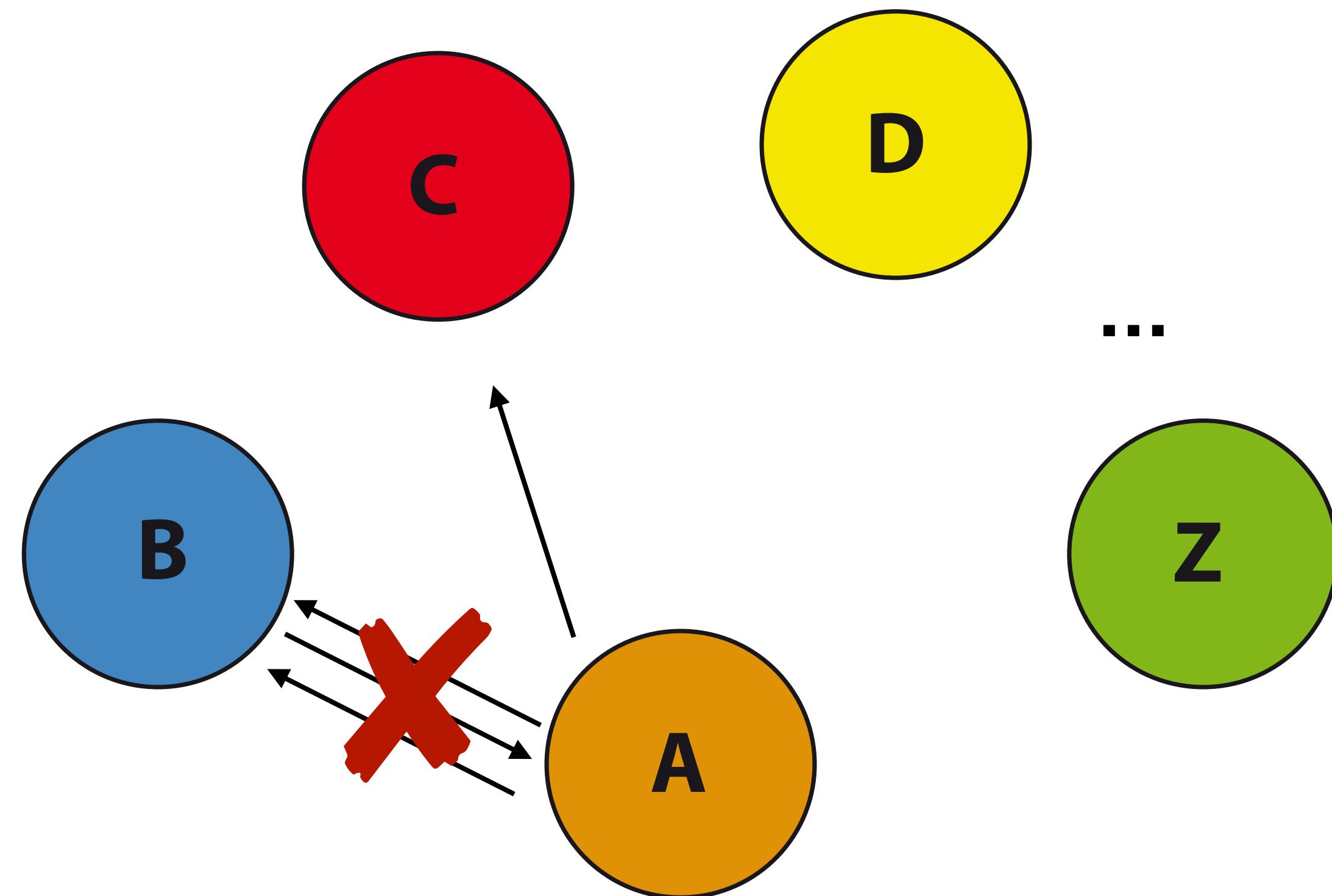
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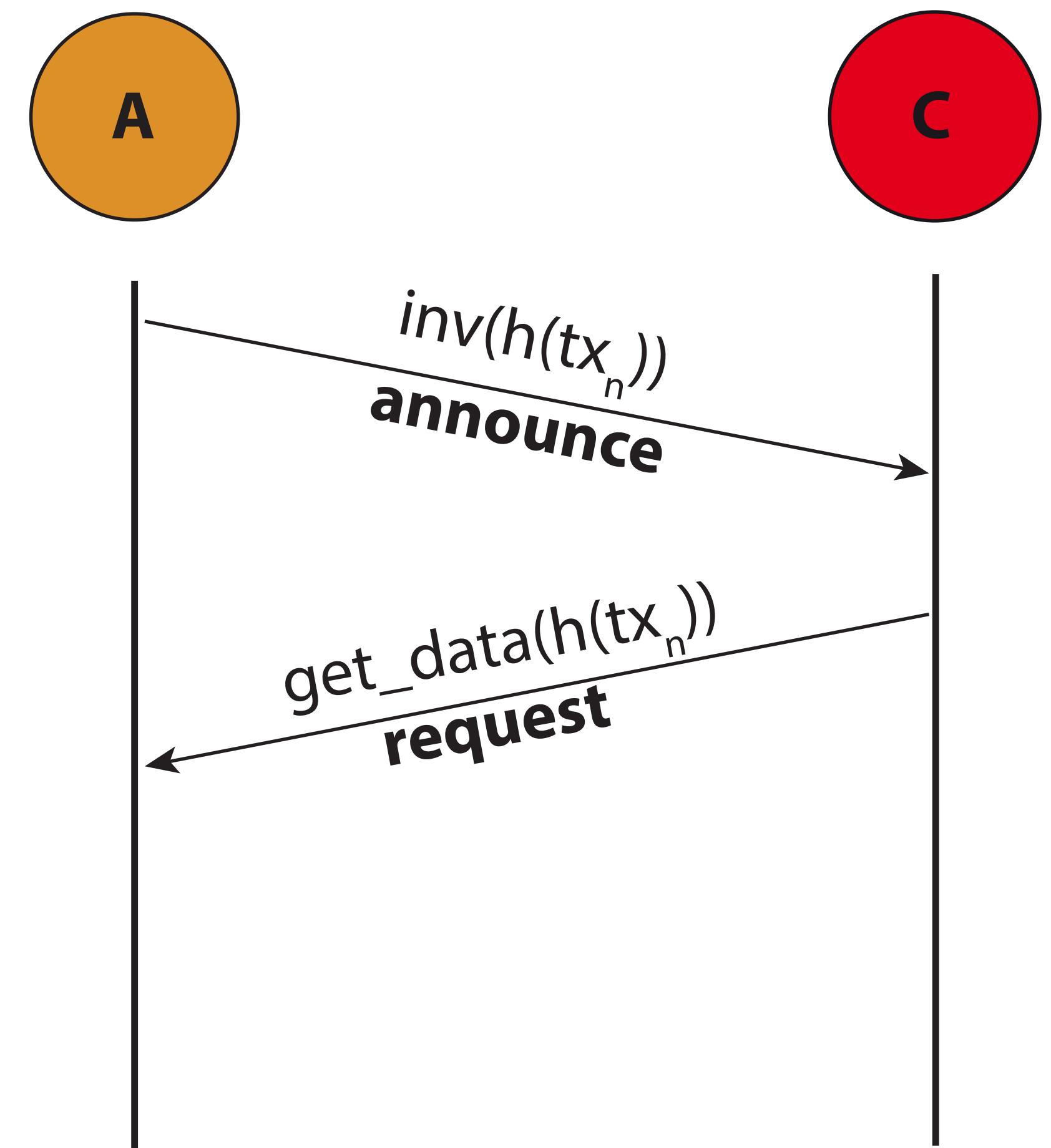
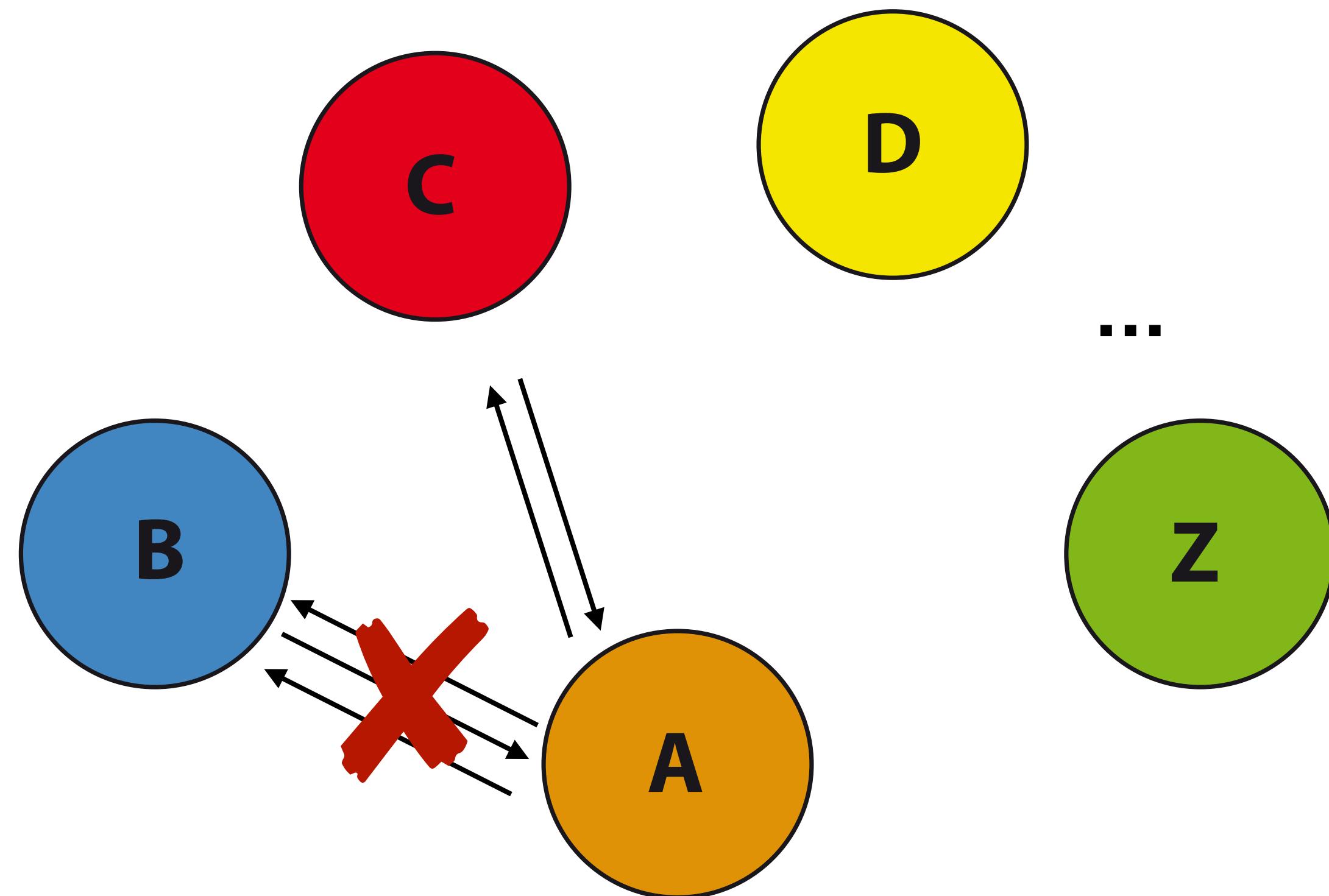
Information propagation (2/2)



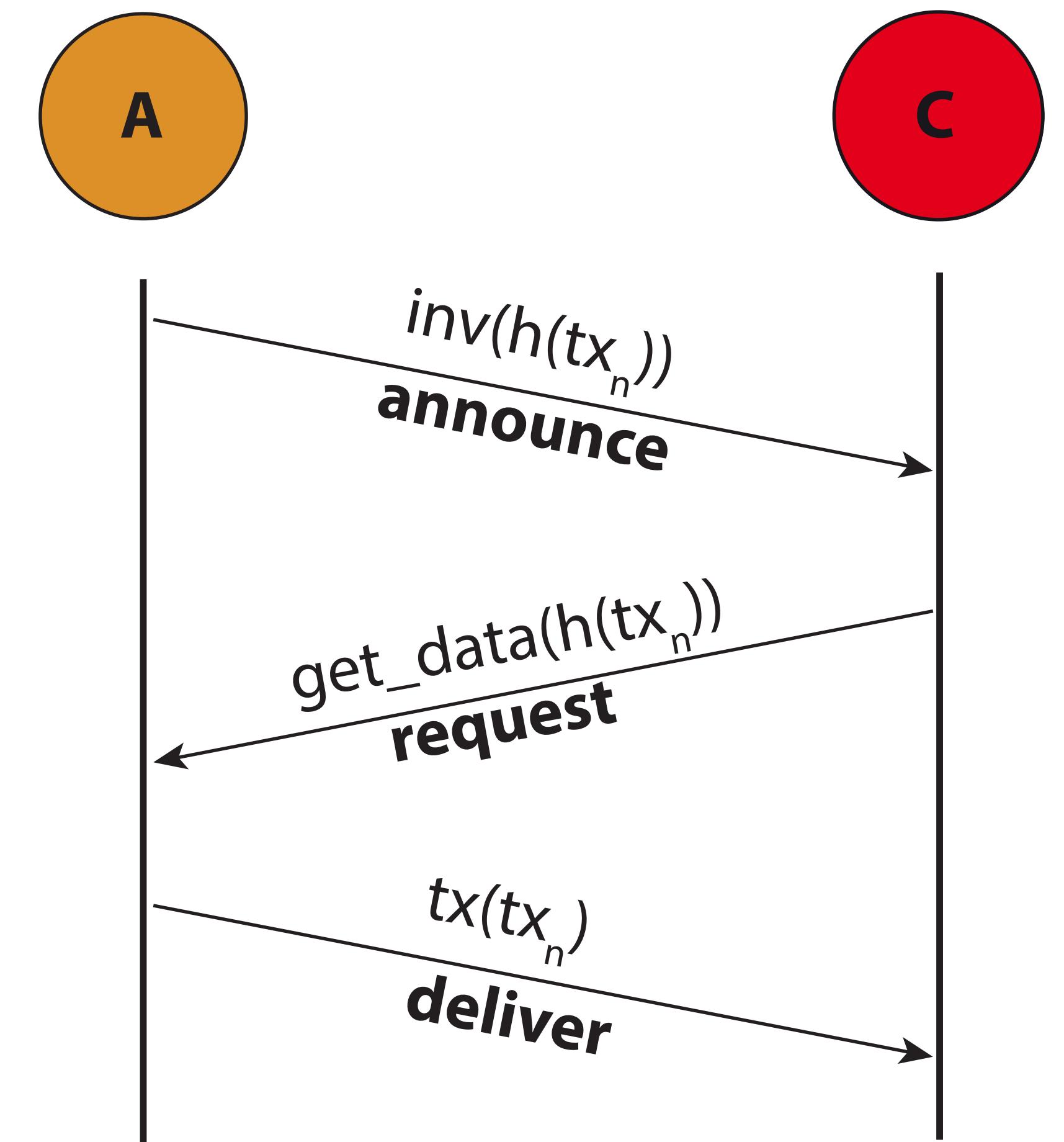
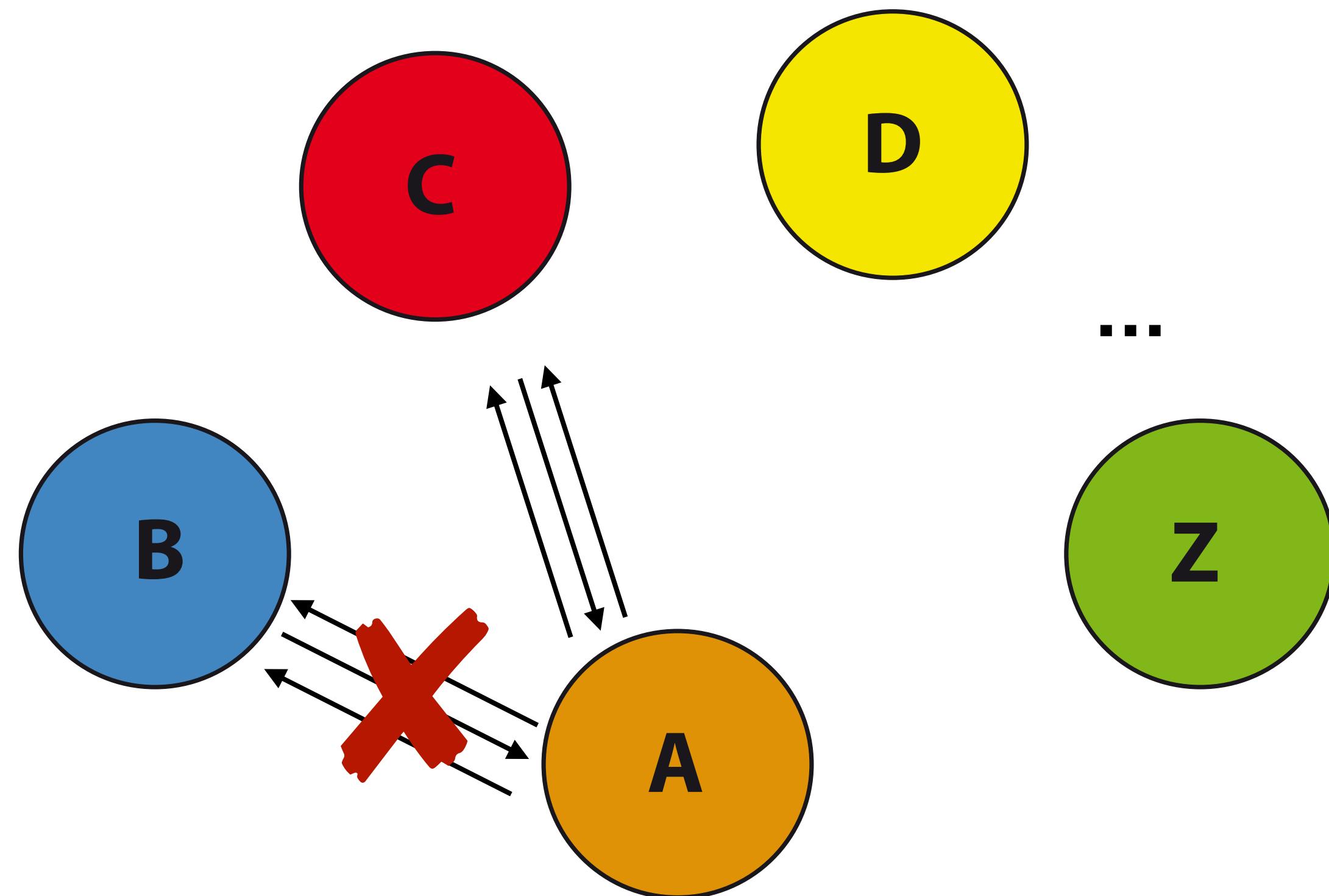
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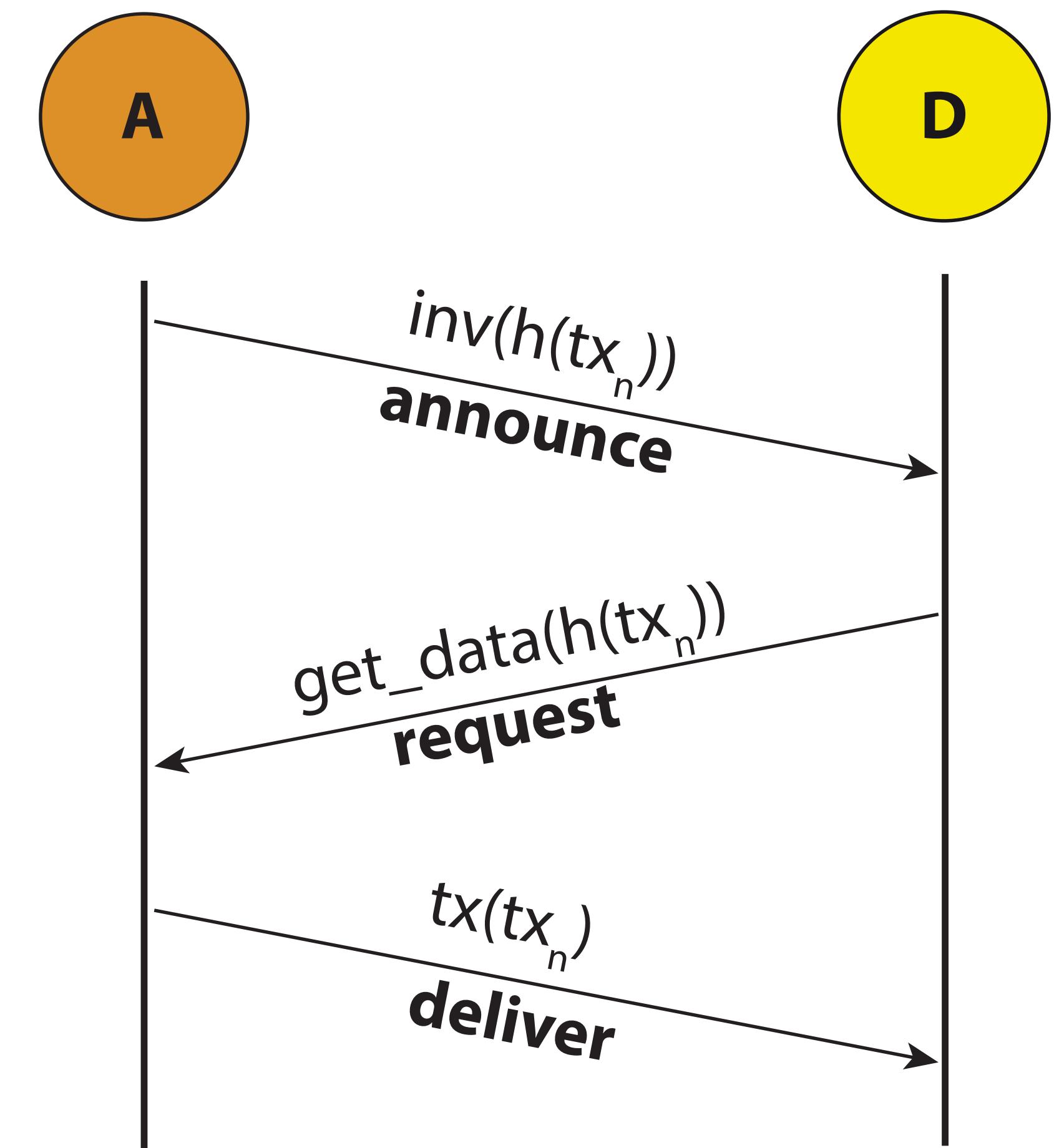
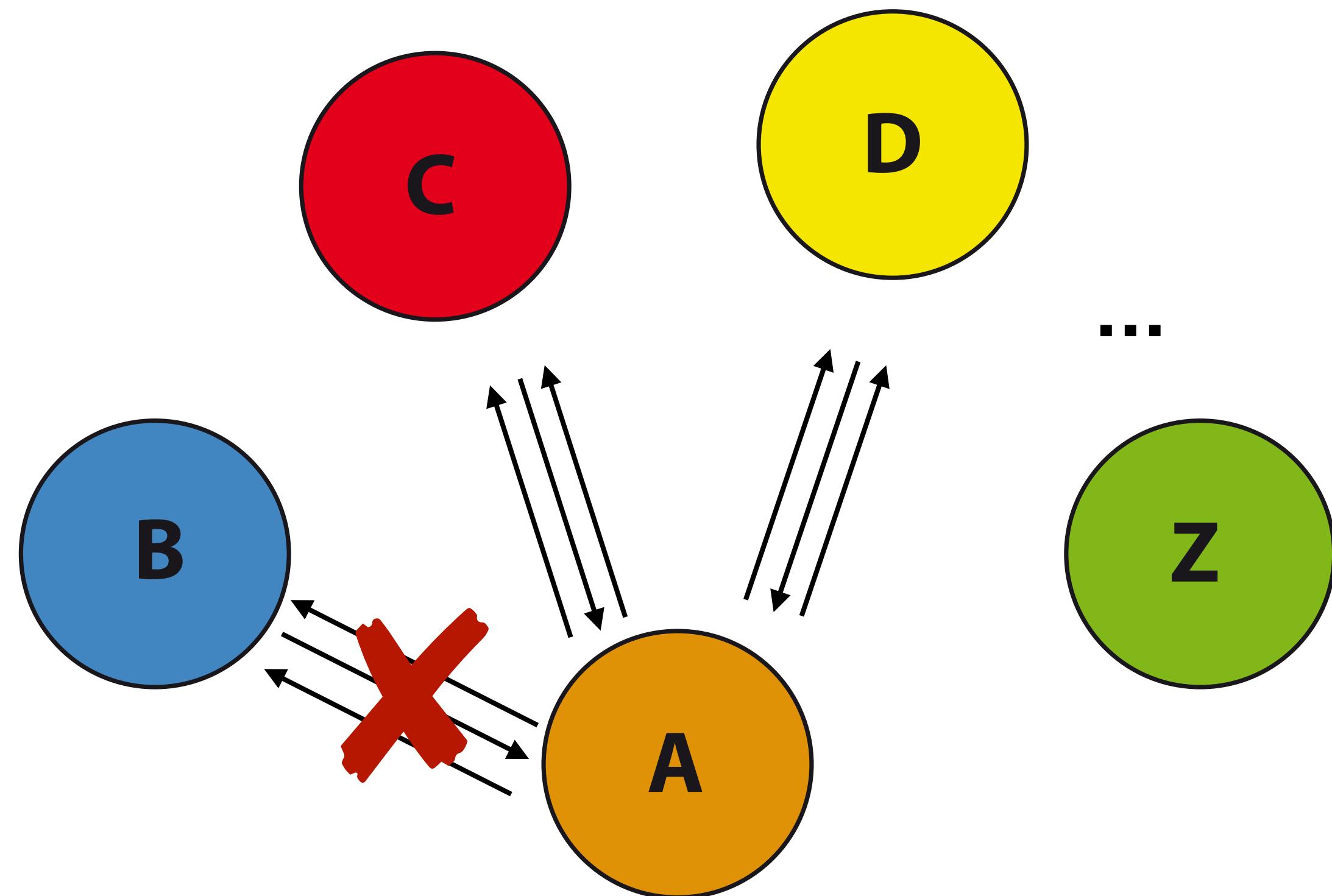
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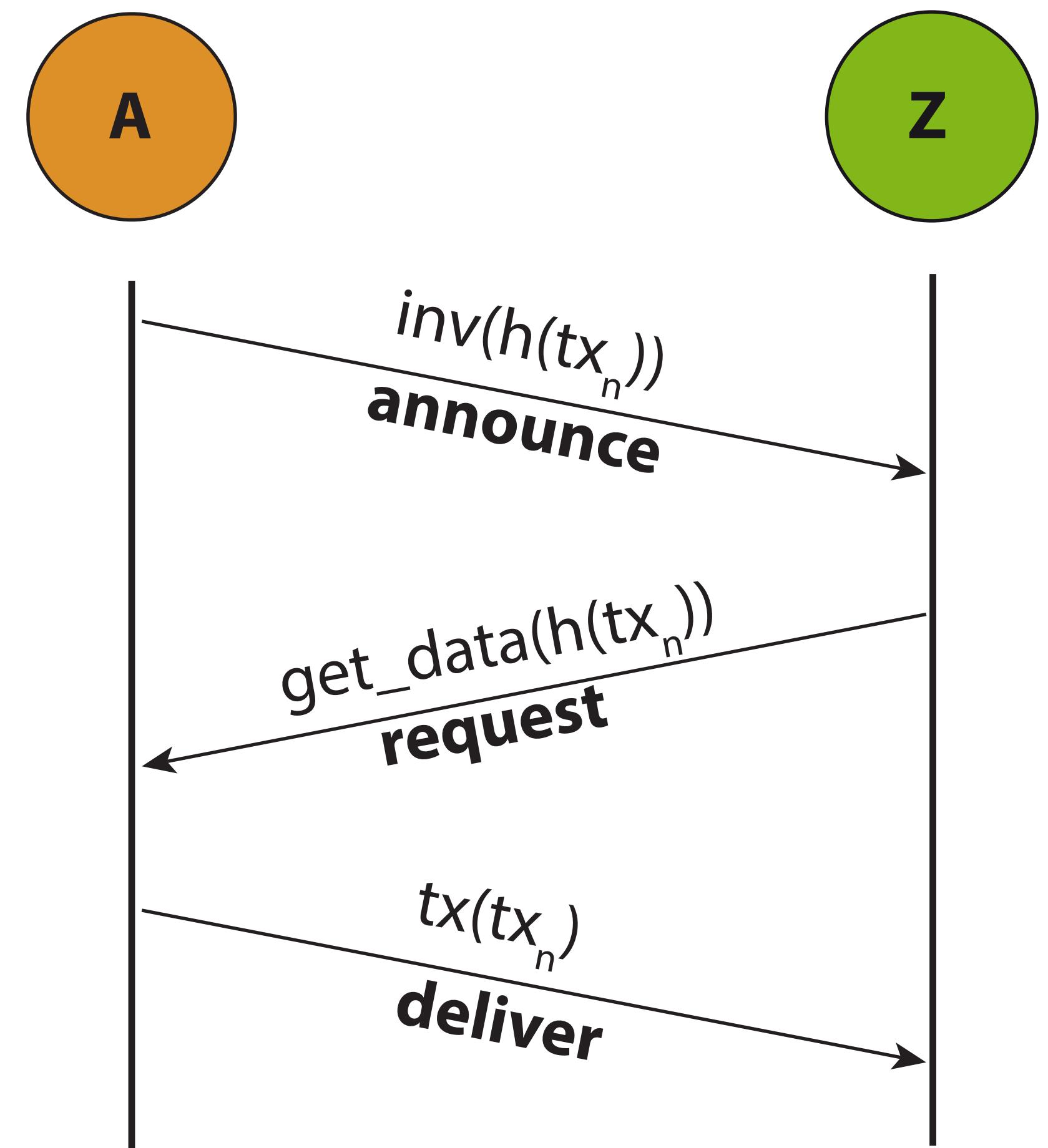
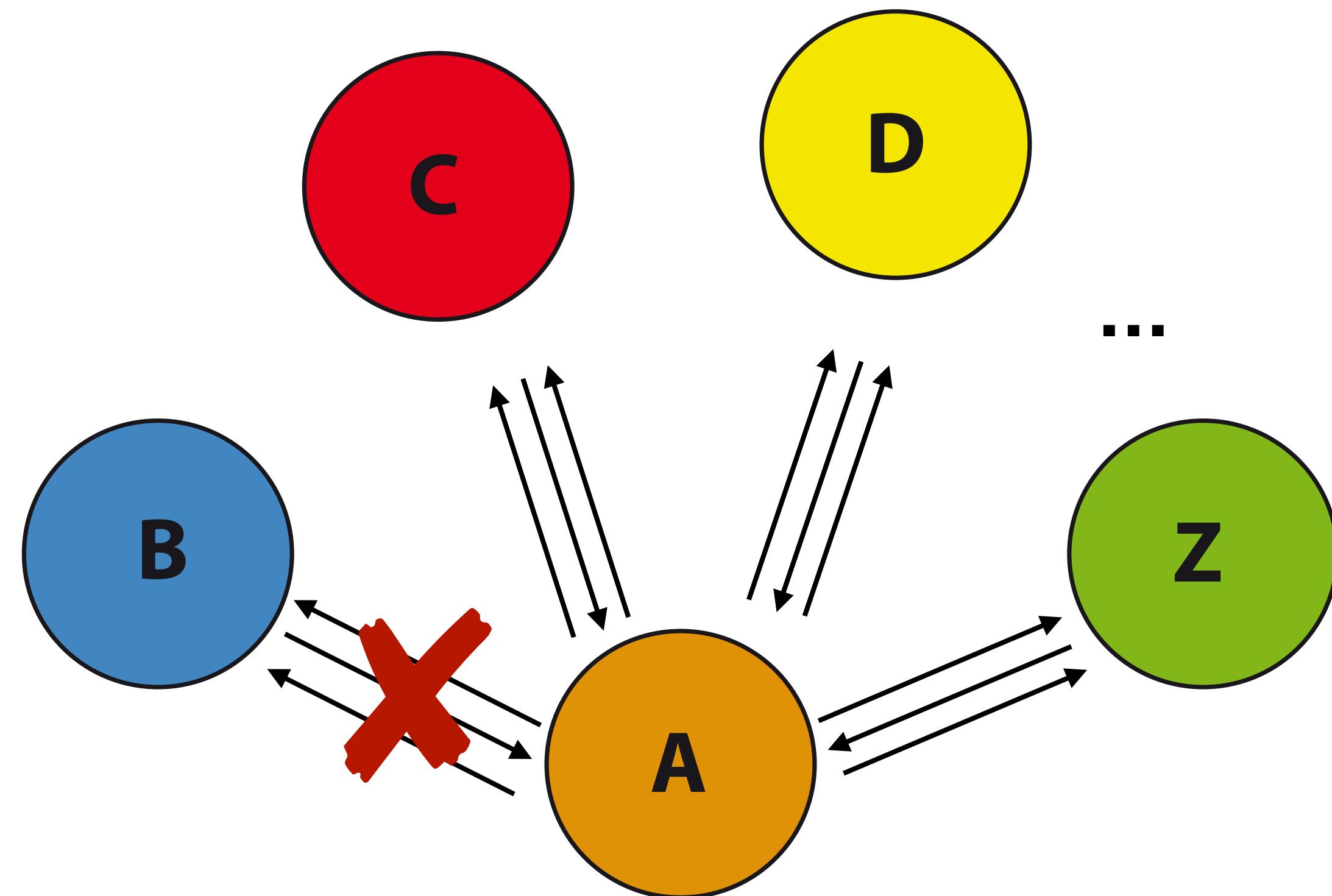
Information propagation (2/2)



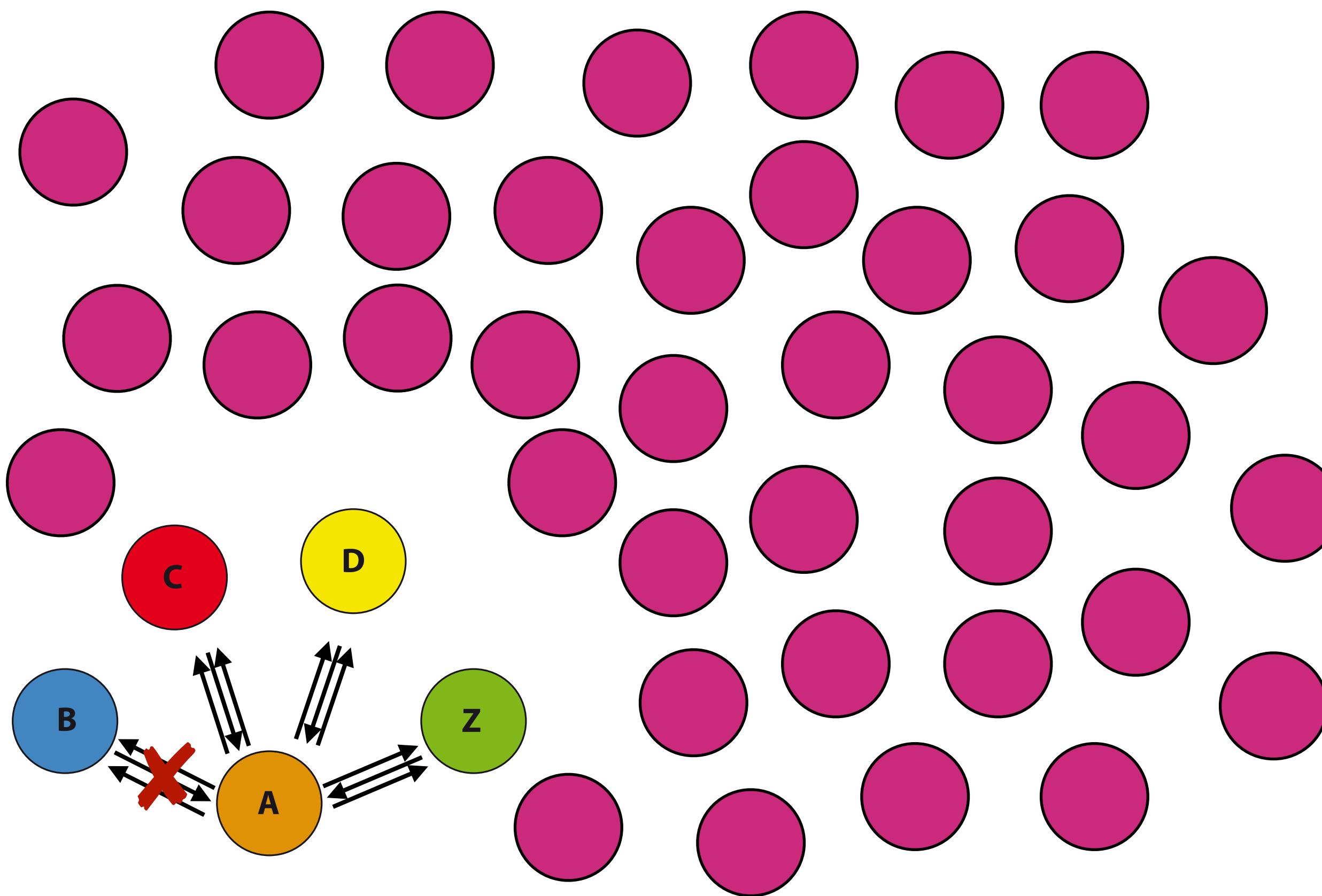
Information propagation (2/2)



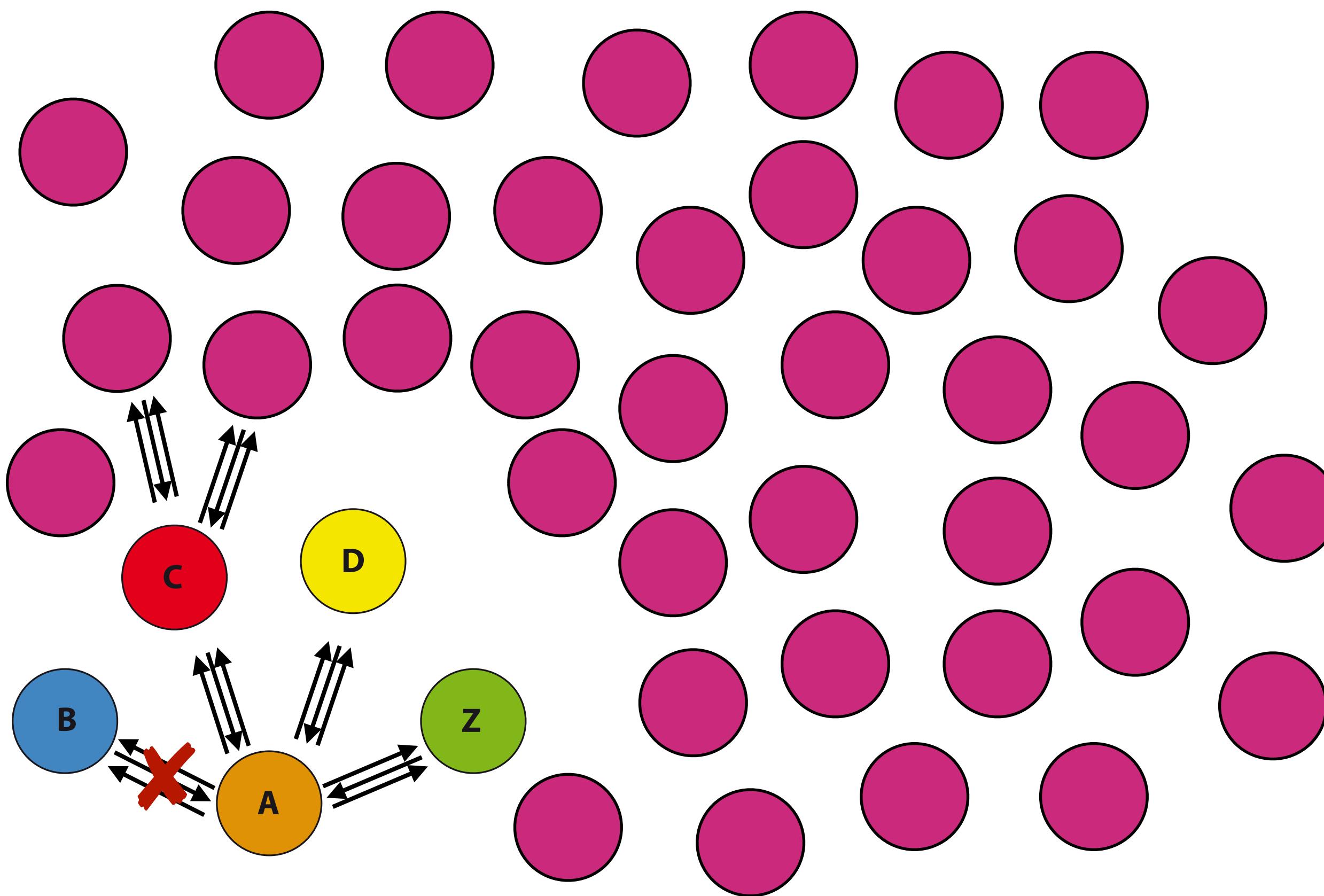
Information propagation (2/2)



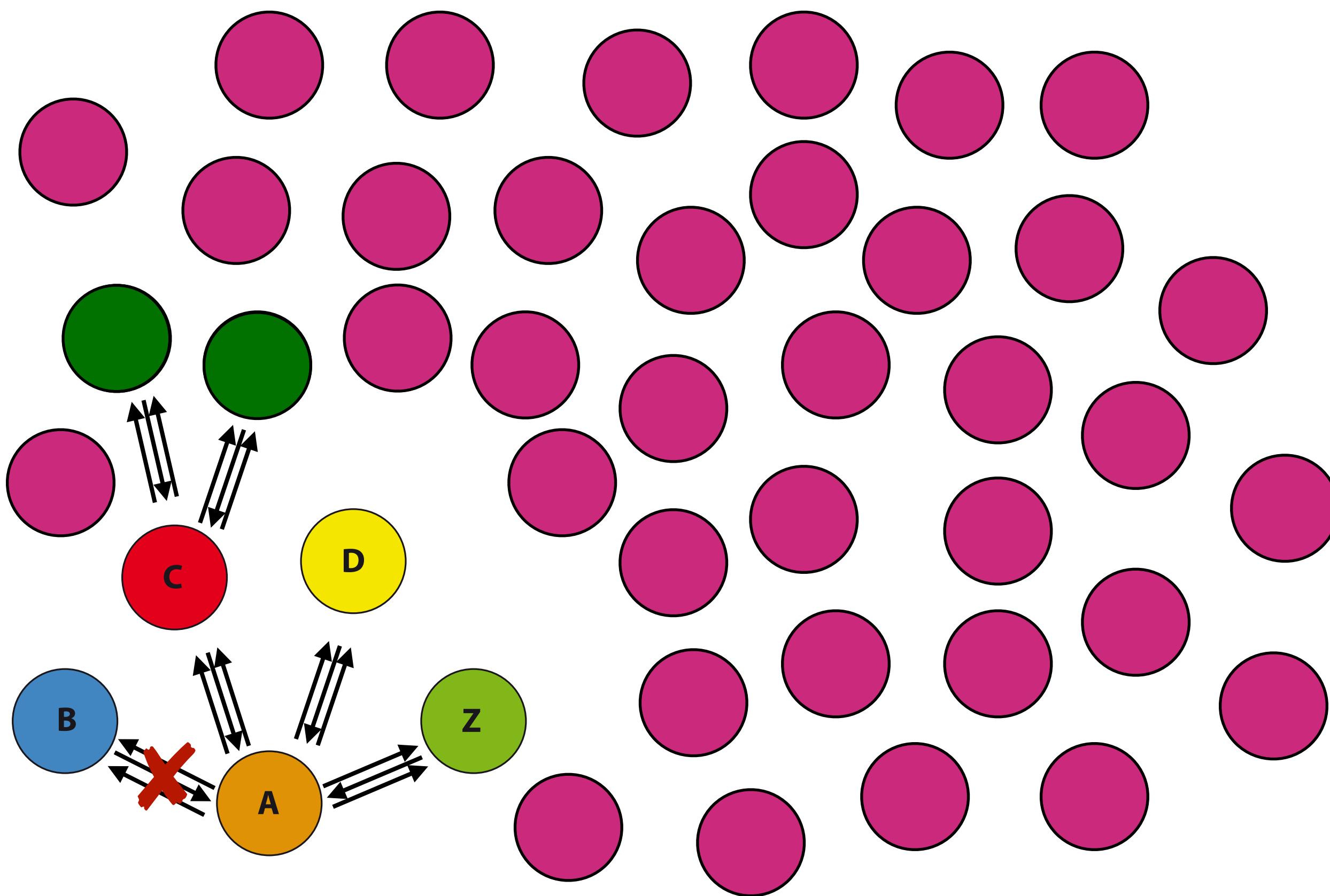
Information propagation (2/2)



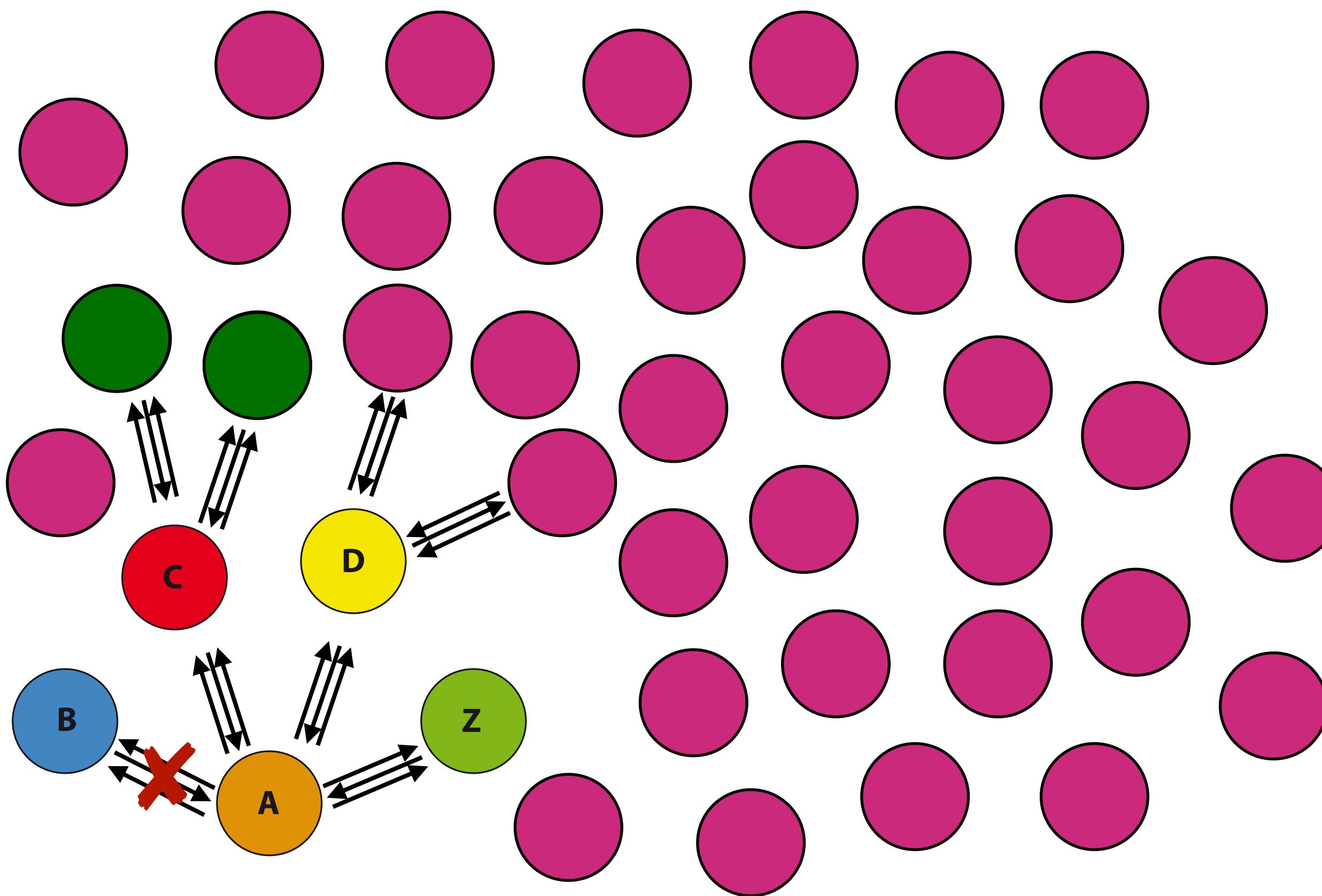
Information propagation (2/2)



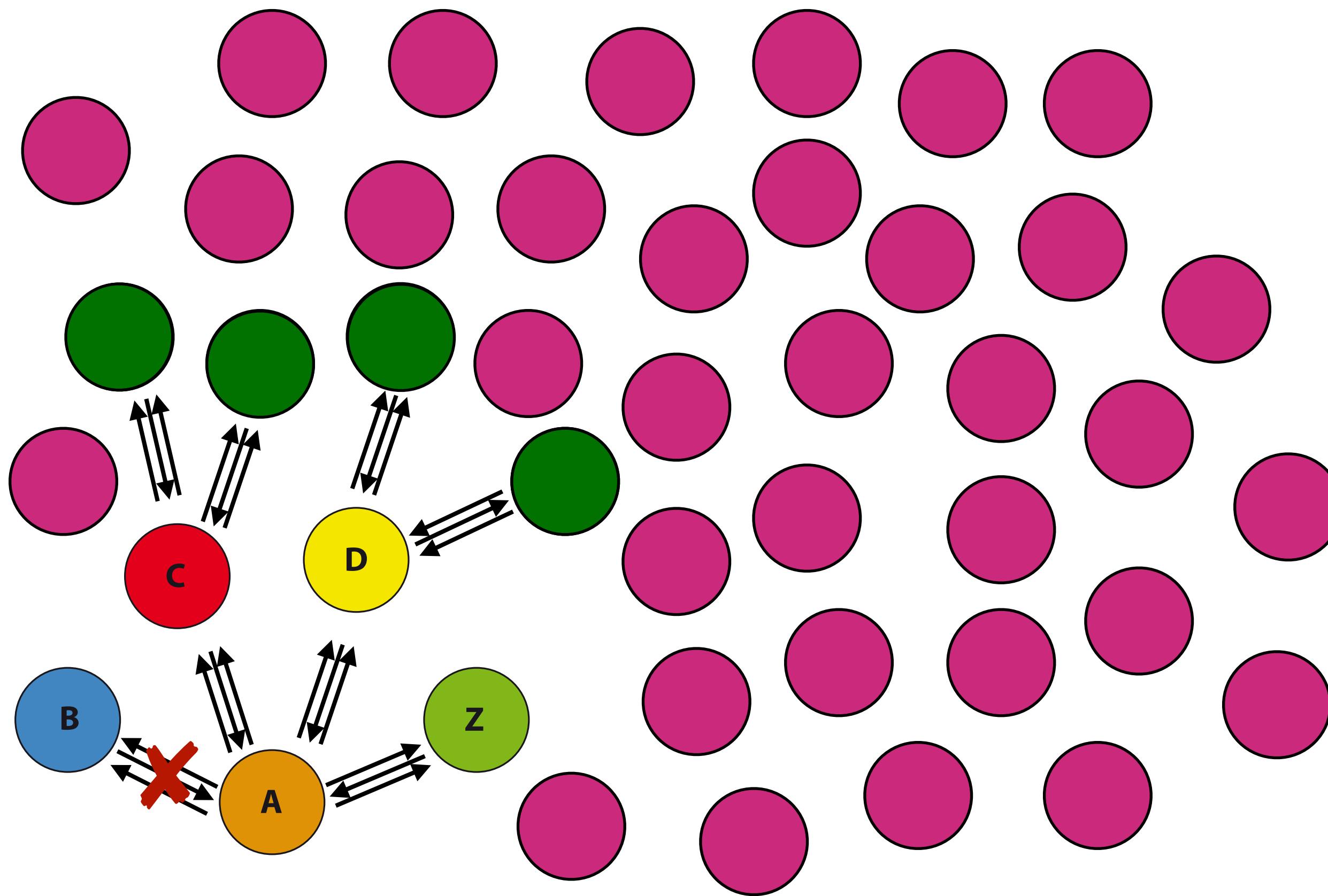
Information propagation (2/2)



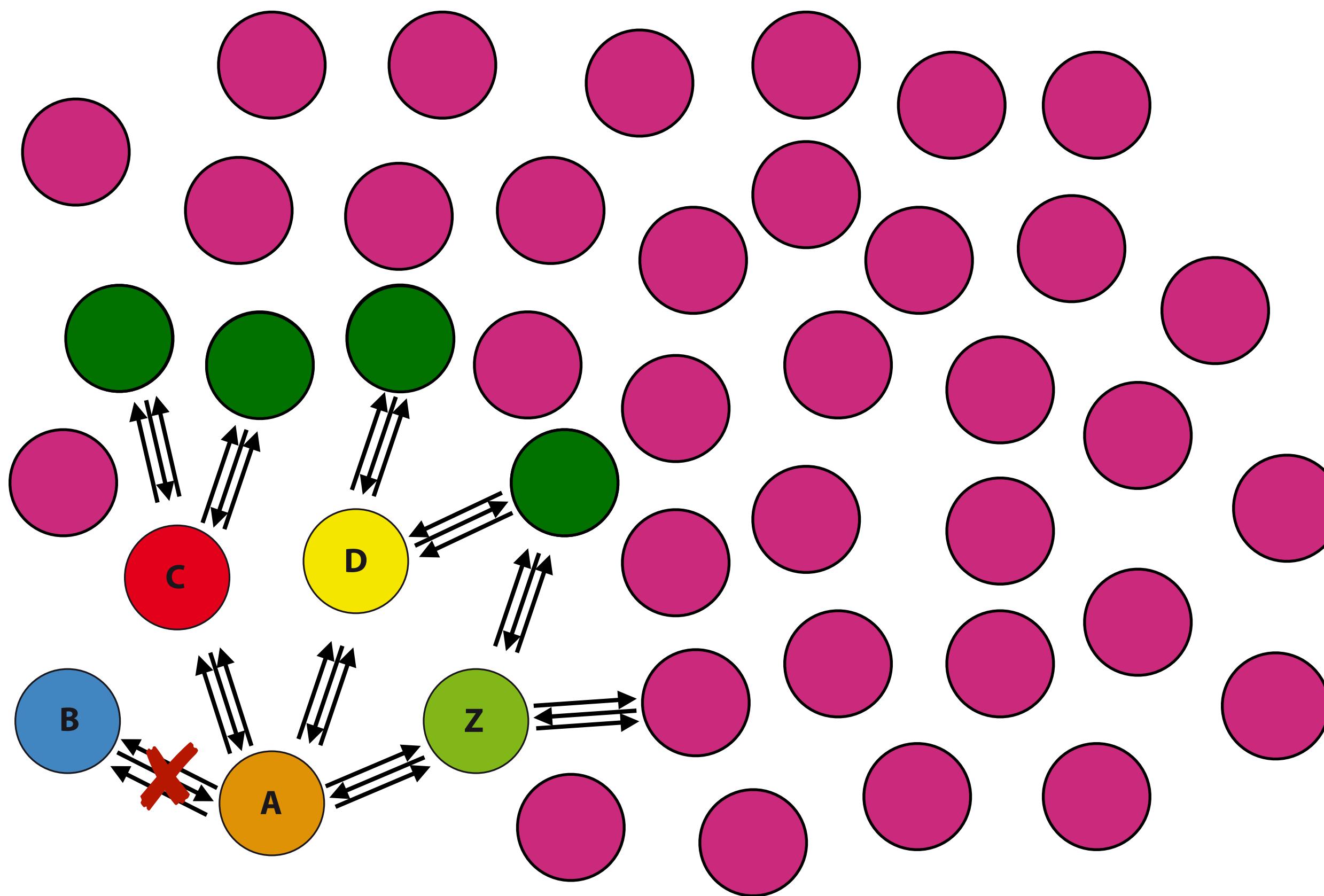
Information propagation (2/2)



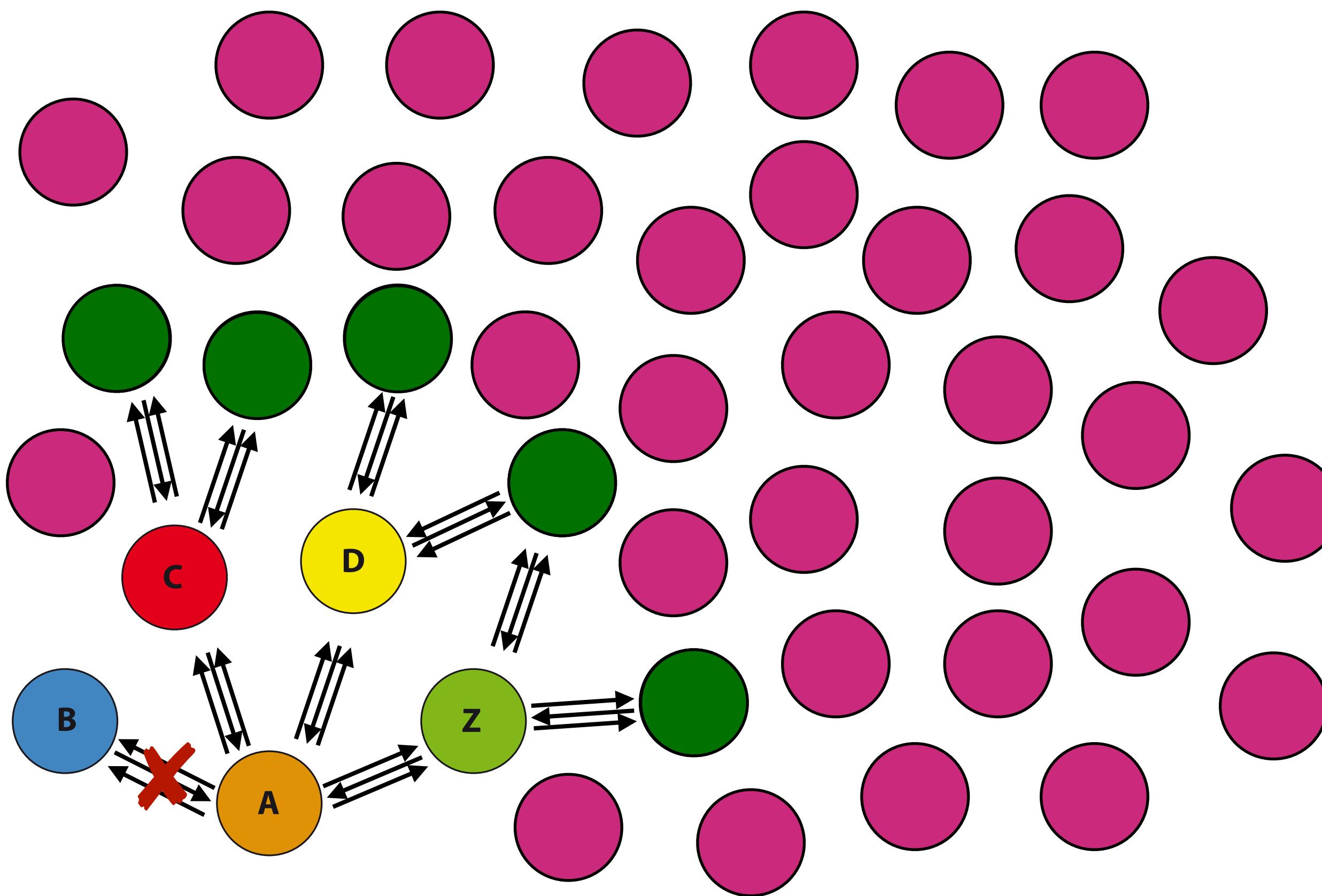
Information propagation (2/2)



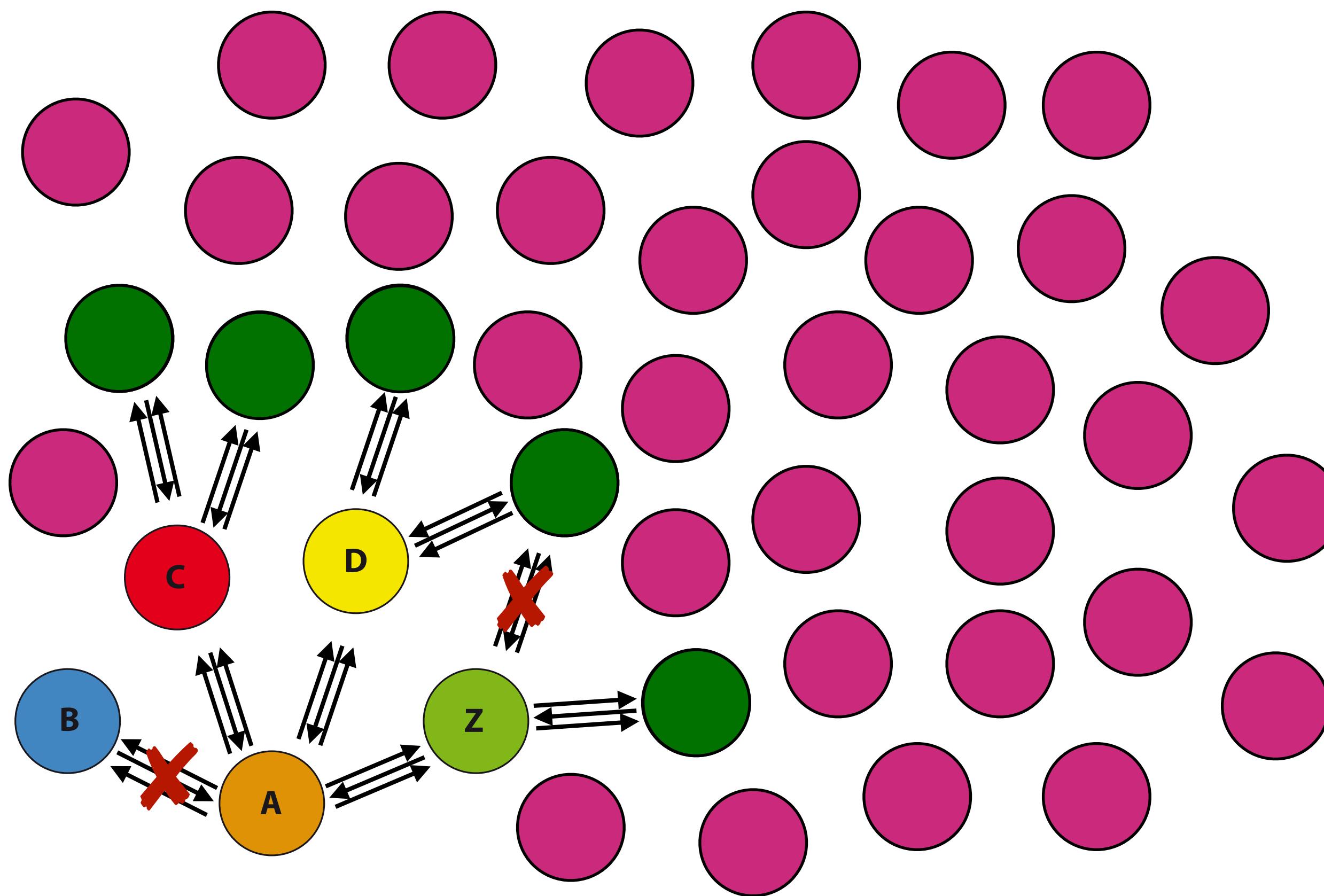
Information propagation (2/2)



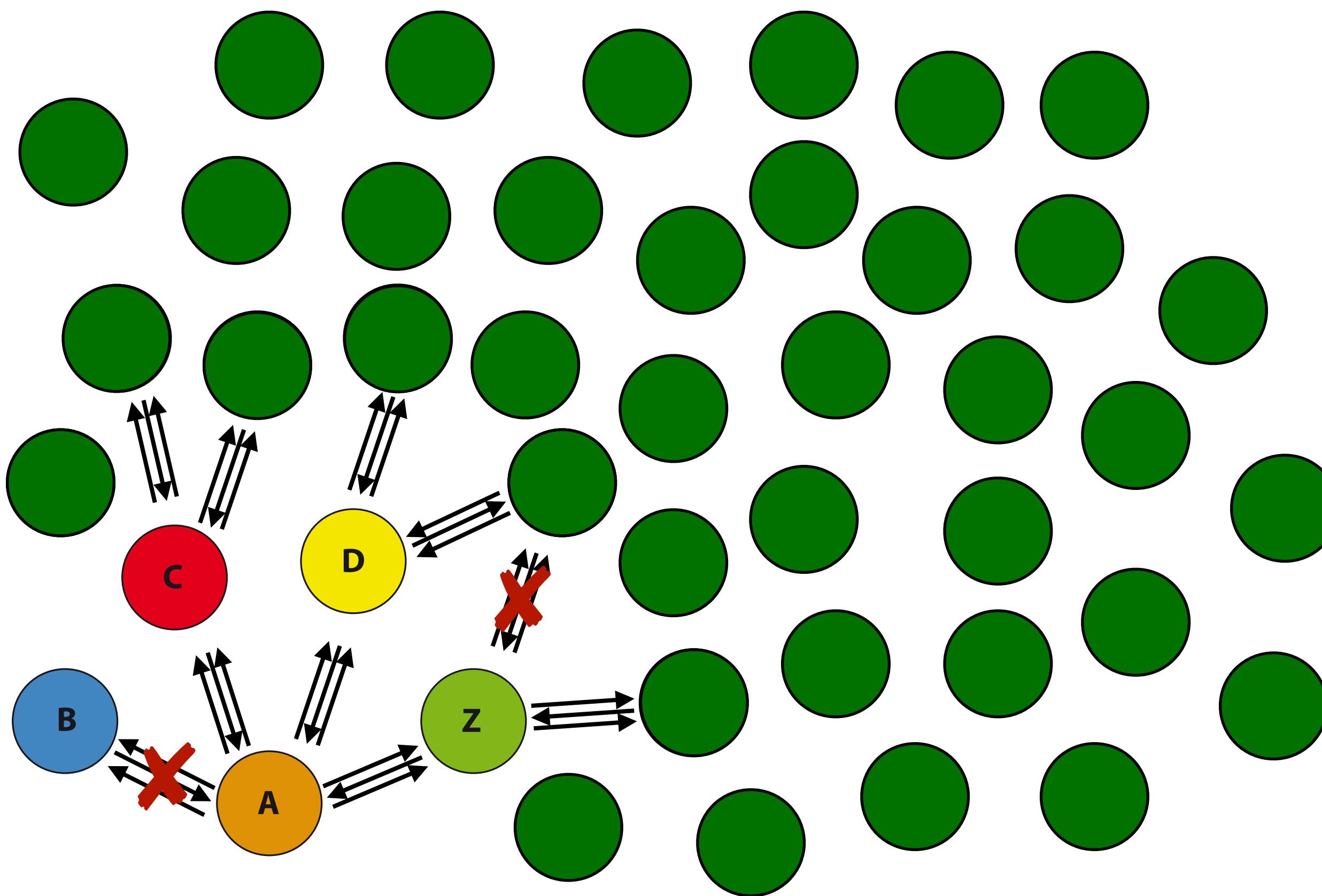
Information propagation (2/2)



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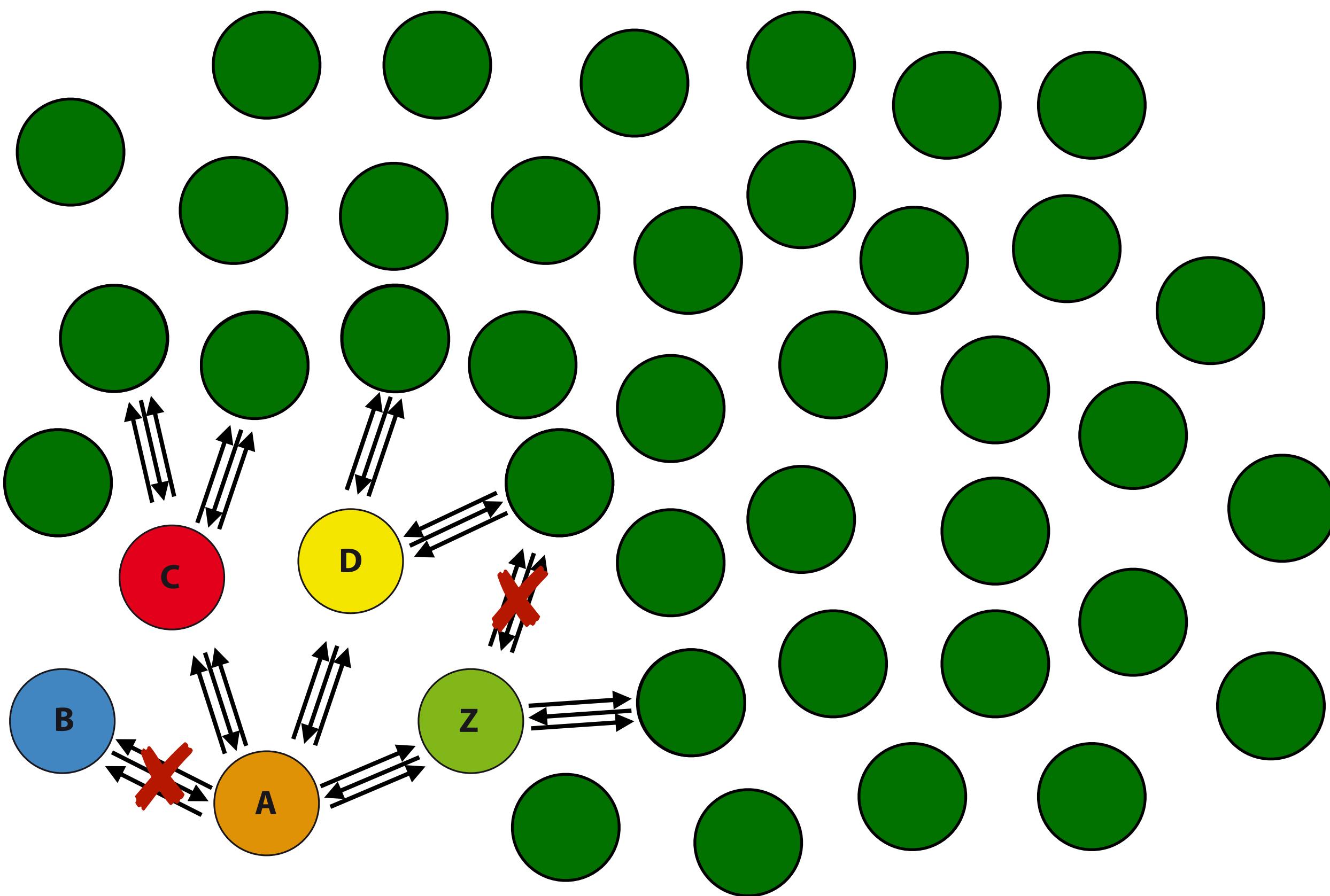


Information propagation (2/2)

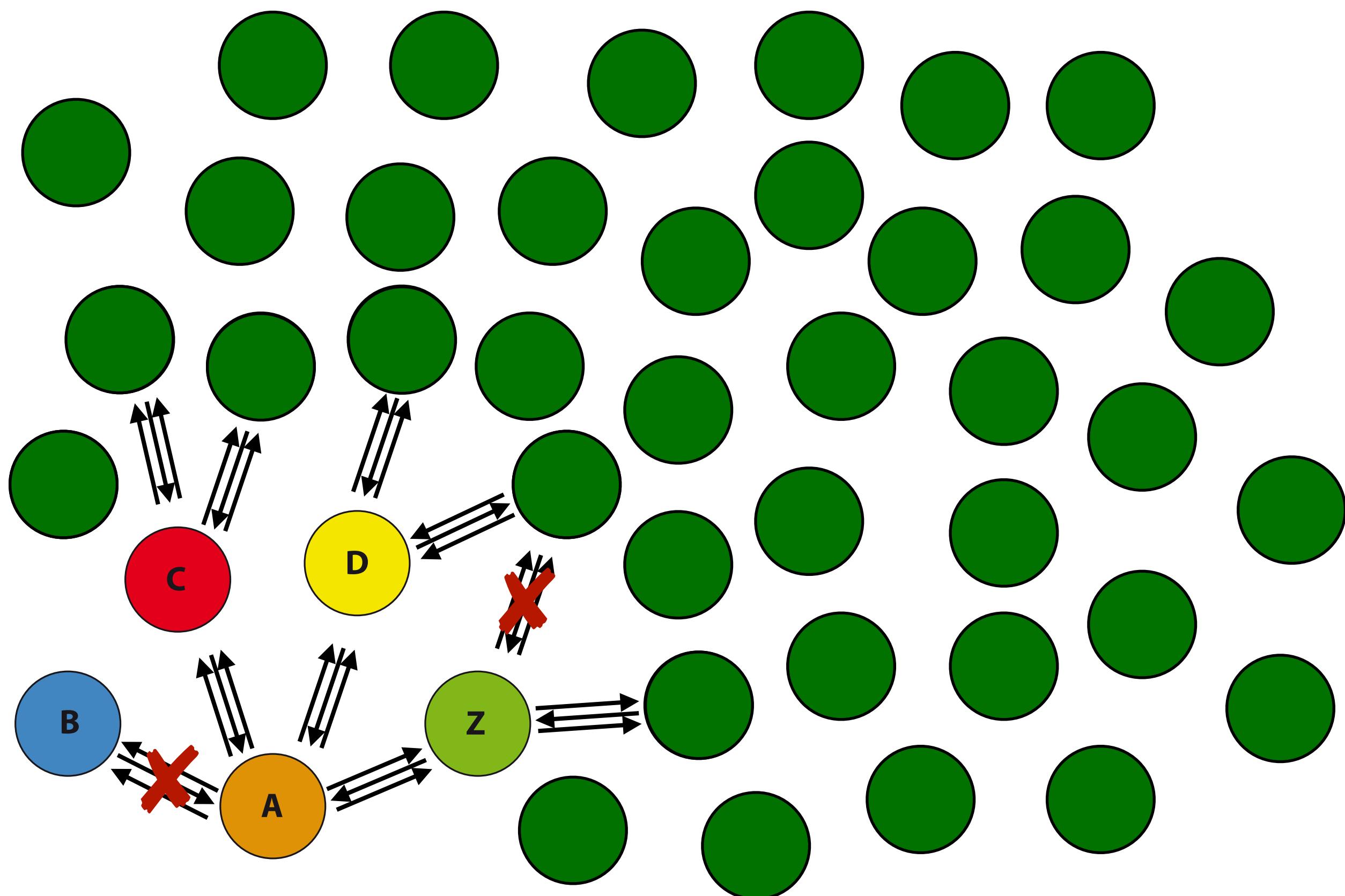


Information propagation (2/2)

- And so on and so forth until all the nodes are reached

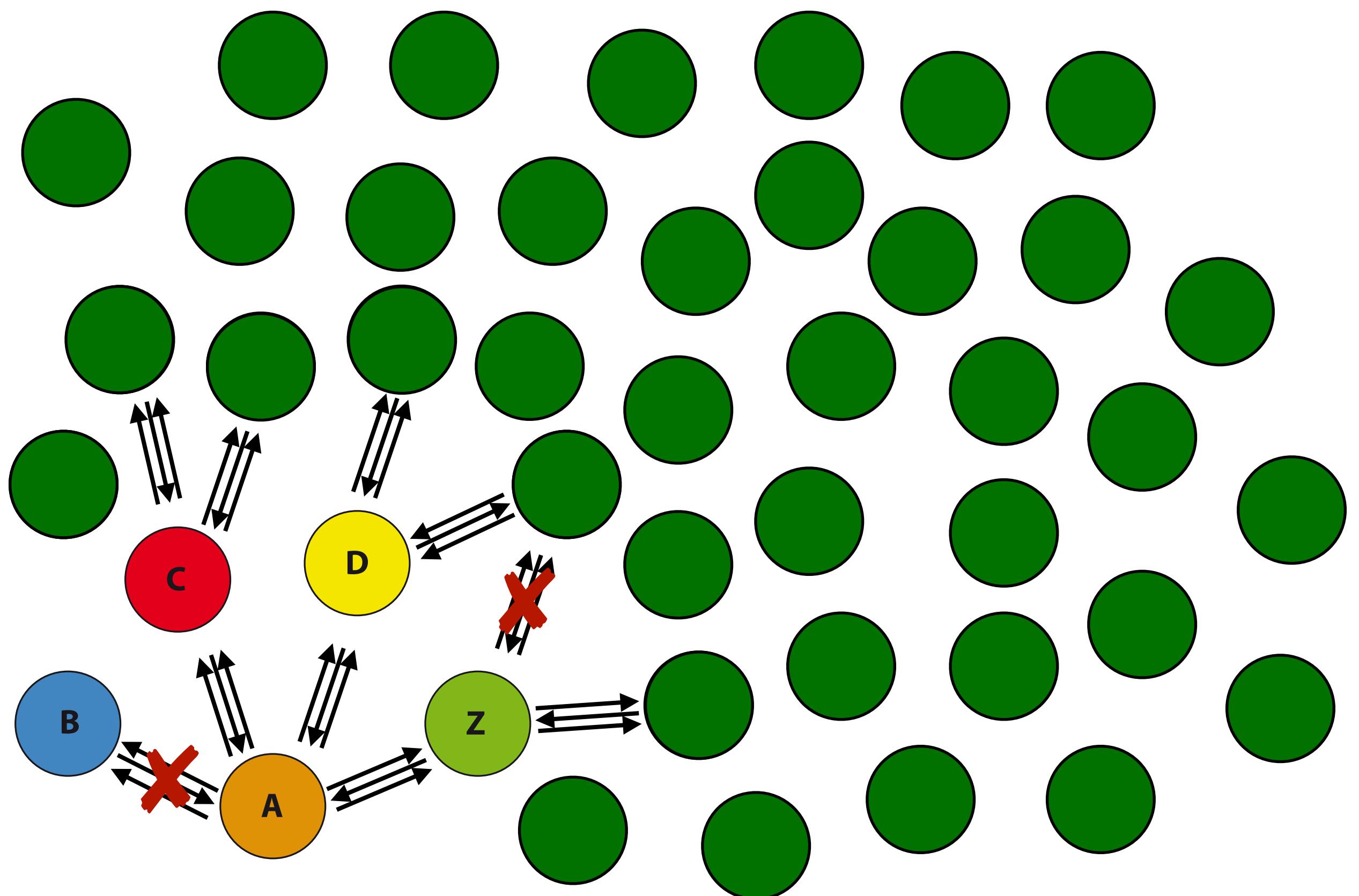


Information propagation (2/2)



- And so on and so forth until all the nodes are reached
- Recall that a node will reject a transaction if it has already learnt about it from any of its neighbors

Information propagation (2/2)



- And so on and so forth until all the nodes are reached
- Recall that a node will reject a transaction if it has already learnt about it from any of its neighbors
- The same procedure applies for blocks



Implications

- The bigger the network the more it takes for an item to propagate (**this can be counterintuitive**)
- The bigger an item, the more it takes to validate and propagate
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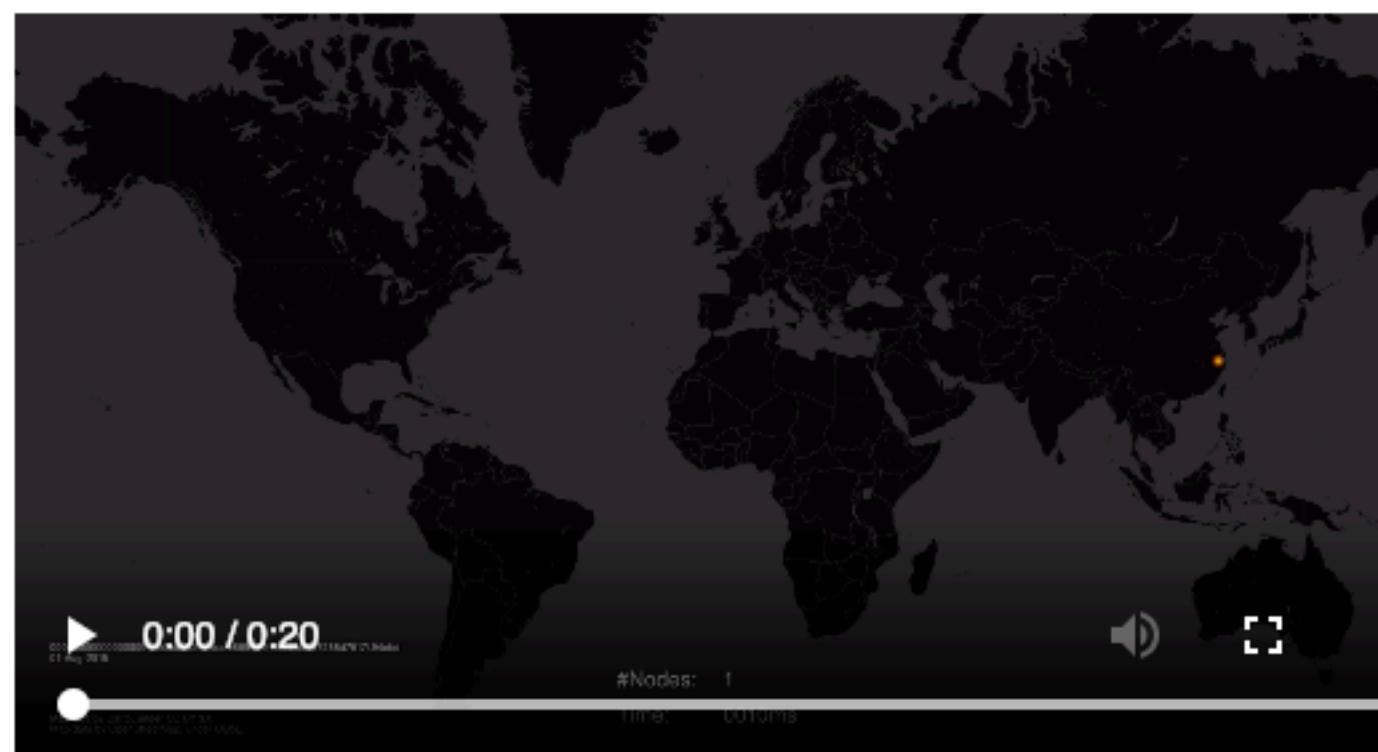
Bitcoin testnet data propagation times



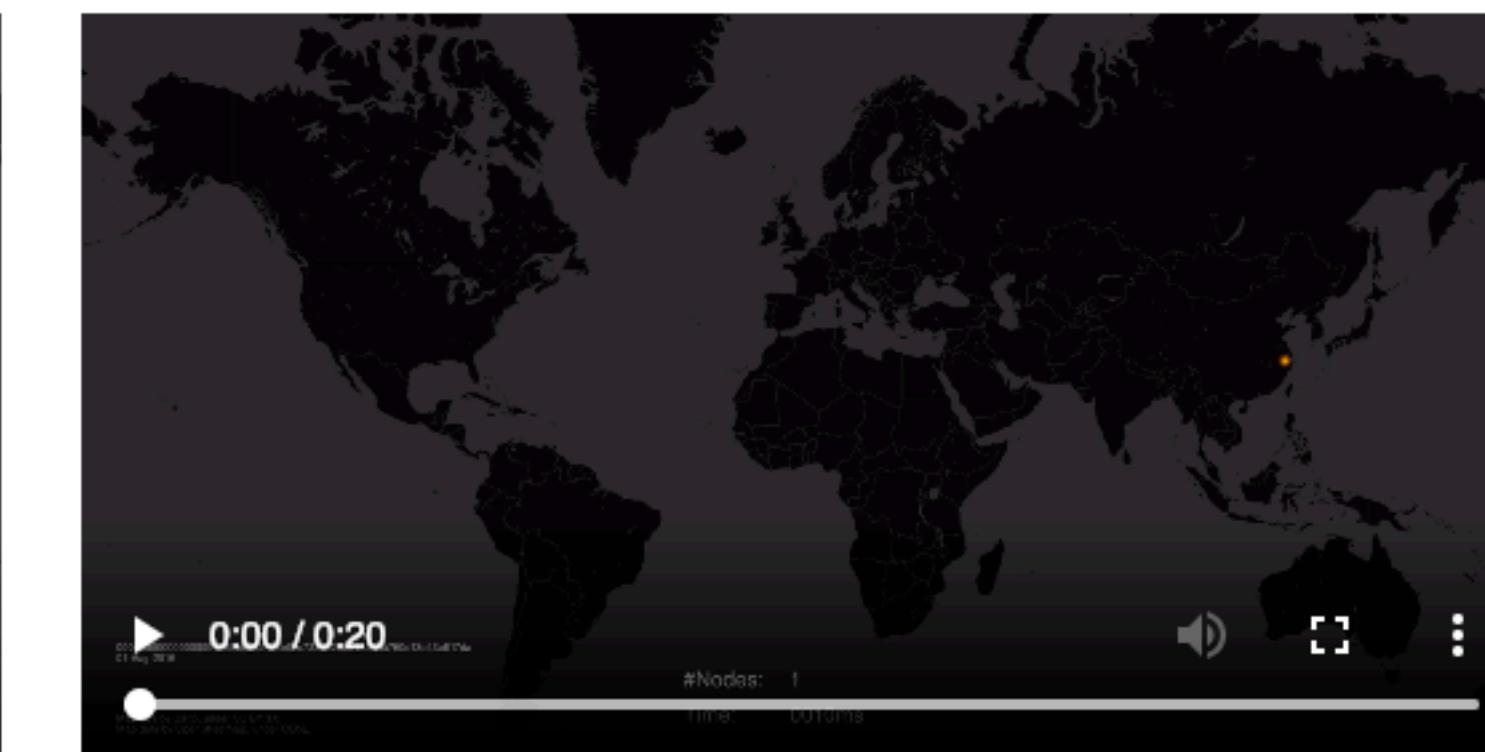
source: charts.satoshi.uab.cat

Information propagation

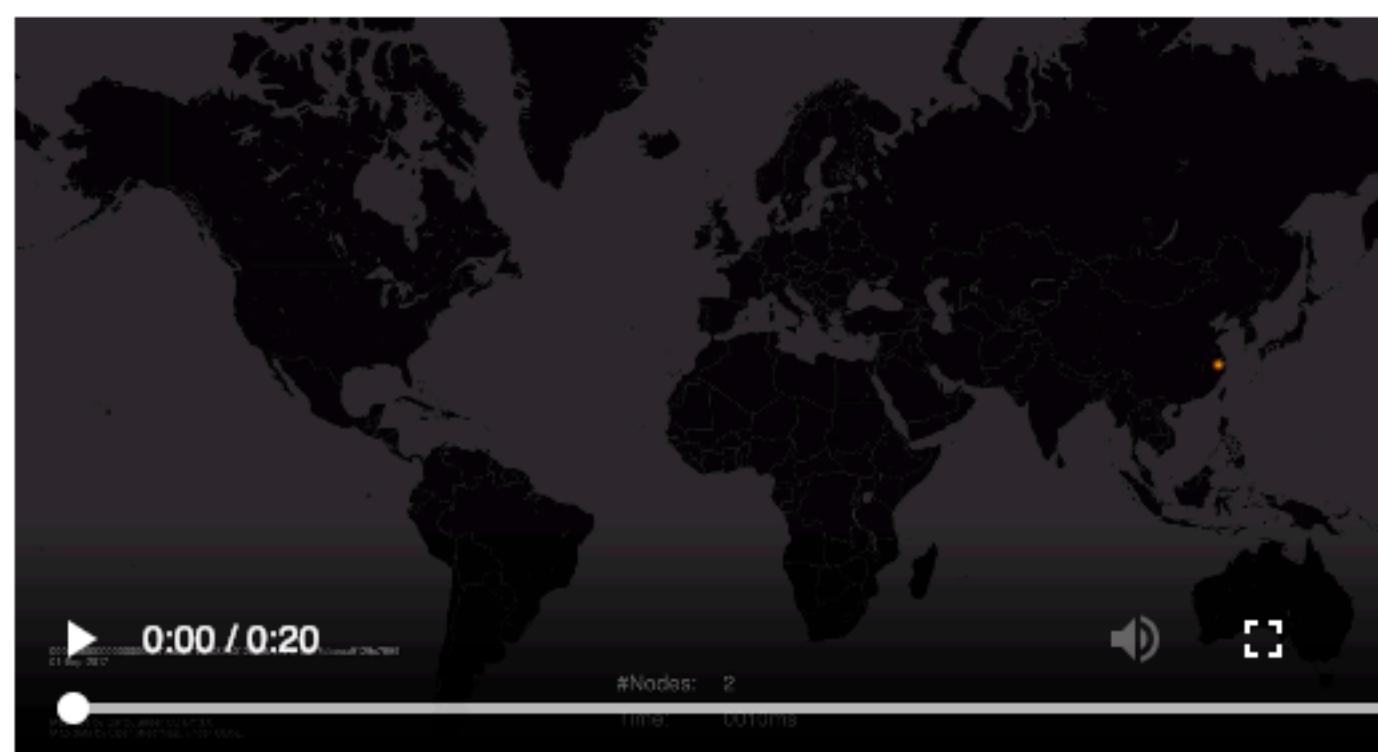
More about propagation times



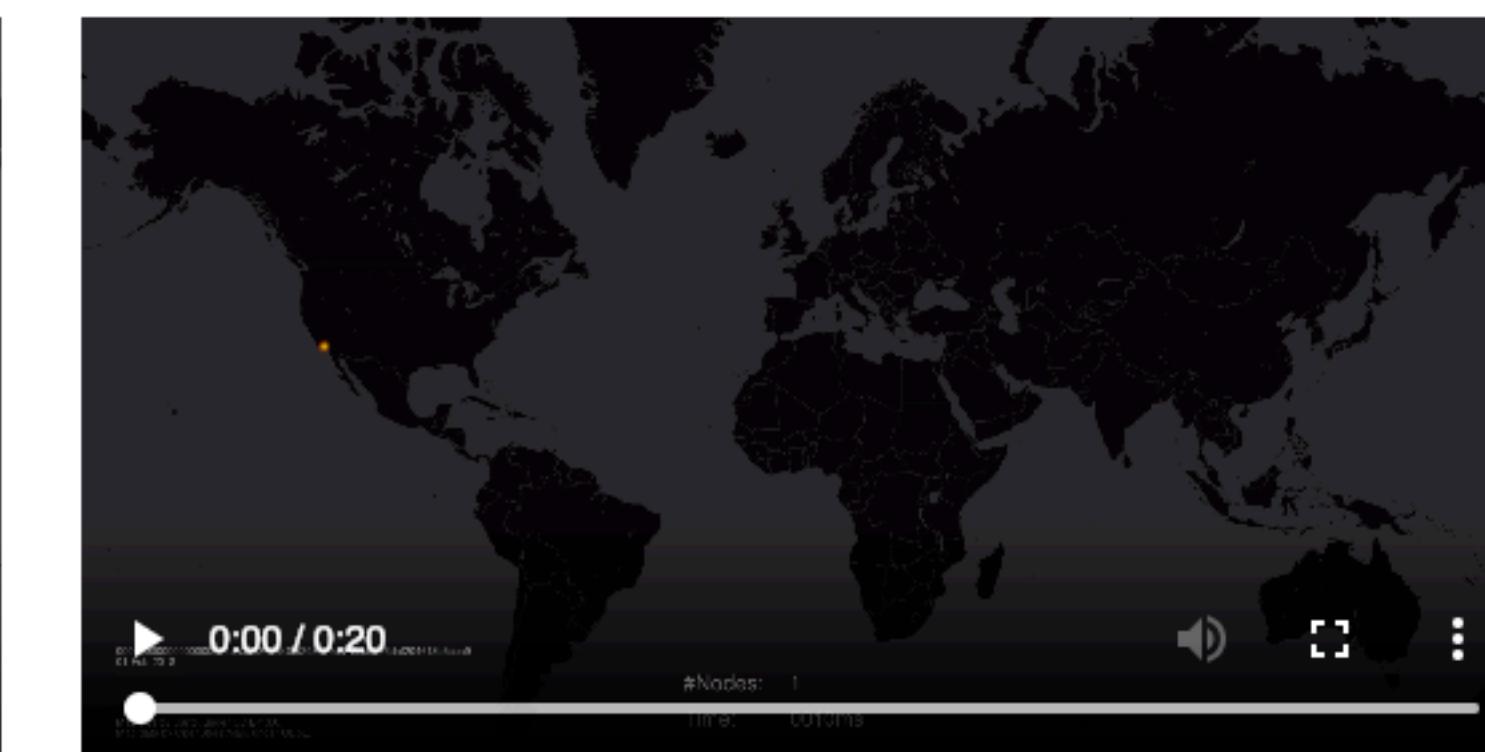
Block propagation | 01.08.2015



Block propagation | 01.08.2016



Block propagation | 01.09.2017



Block propagation | 01.02.2018

source: <https://dsn.tm.kit.edu/bitcoin/videos.html>

Propagation delays (1/2)

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Propagation delays (1/2)

- How can blocks propagate faster than transactions if the former are bigger than the later?
- Transactions are accumulated in buffers and forwarded in batches to break the link between first relayer and origin of a transaction
- The propagation of blocks is not delayed, in order to reach full network coverage as soon as possible

Propagation delays (2/2)

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- But blocks are way bigger than transactions, how can they be propagated so fast!?

Propagation delays (2/2)

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- Fast relay networks on top of Bitcoin exists (Falcon, FIBRE, etc) to enhance the propagation time of blocks

Propagation delays (2/2)

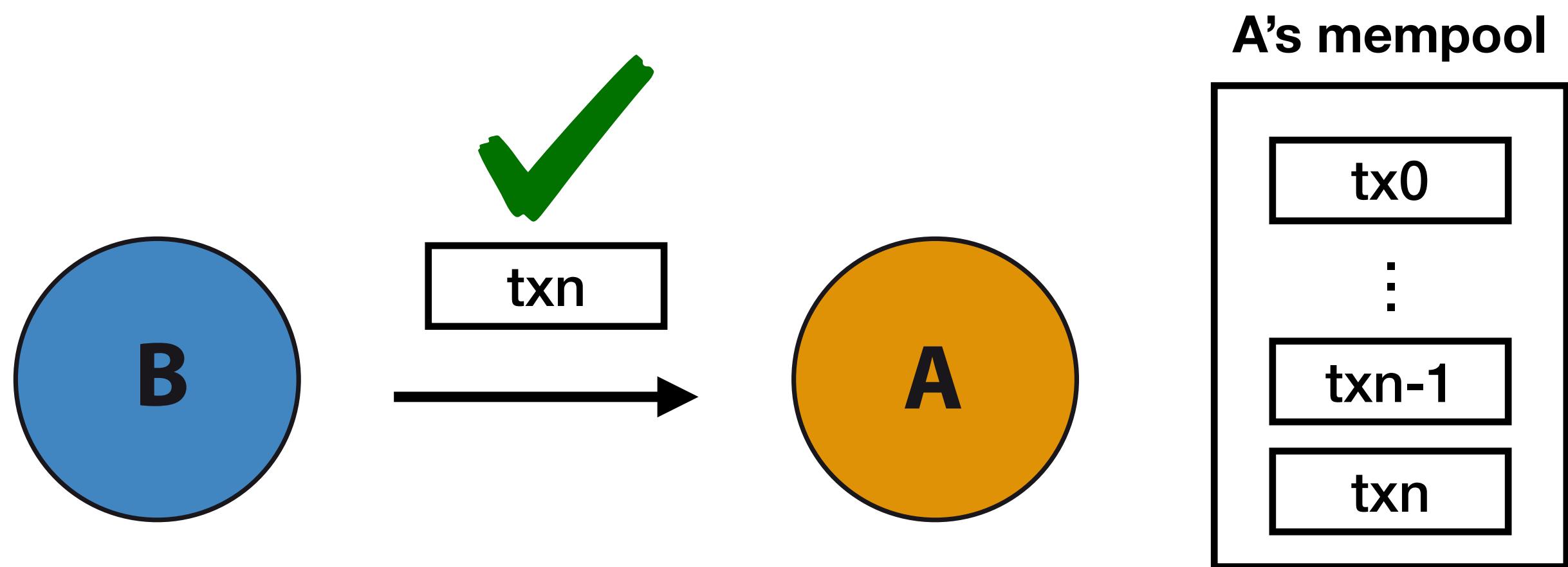
- **But blocks are way bigger than transactions, how can they be propagated so fast!?**
- Fast relay networks on top of Bitcoin exists (Falcon, FIBRE, etc) to enhance the propagation time of blocks
- Miners use such networks to ensure minimal propagation times as well as ensure being mining on top of the most recent block

0-conf transactions and double-spending

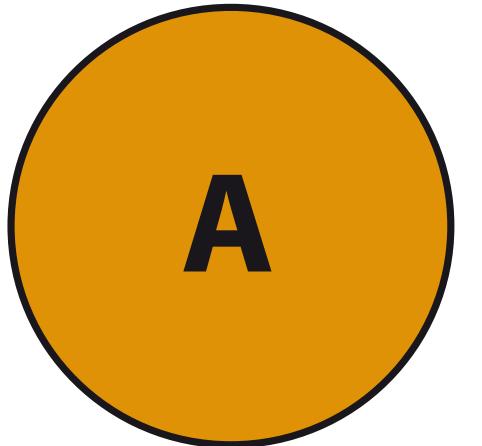
0-confirmation transactions (1/2)

- **0-conf** transactions / **unconfirmed** transactions are those that are not part of the blockchain
- They can be valid transactions that are waiting to be included
- But they can also be invalid (e.g: **double-spending transactions, etc**)
- Different nodes can have conflicting version of the “**same transaction**”

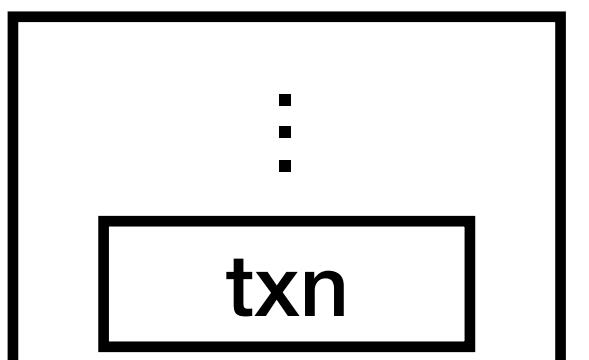
0-confirmation transactions (2/2)



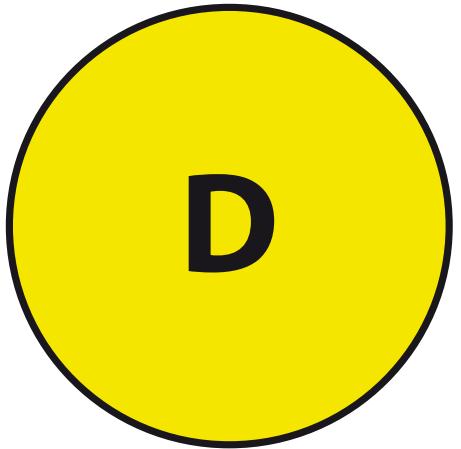
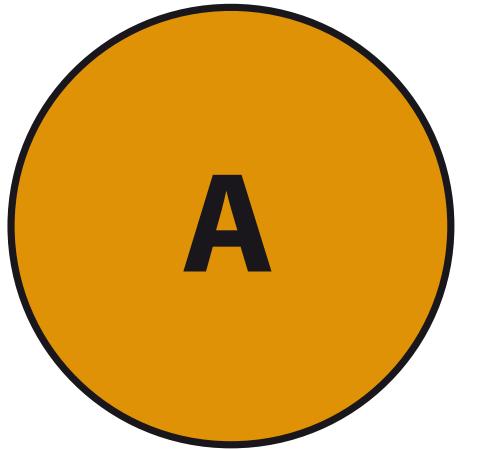
Confirmed transactions



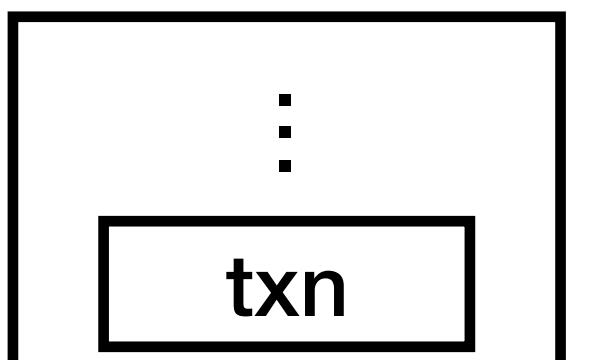
A's mempool



Confirmed transactions



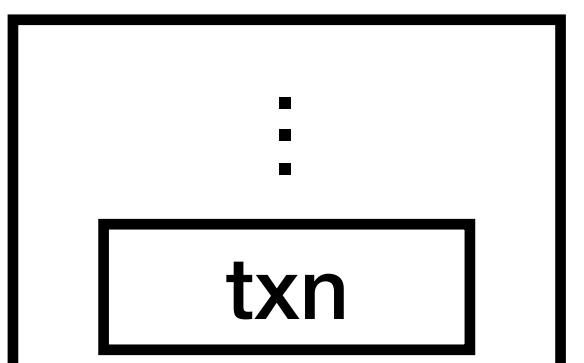
A's mempool



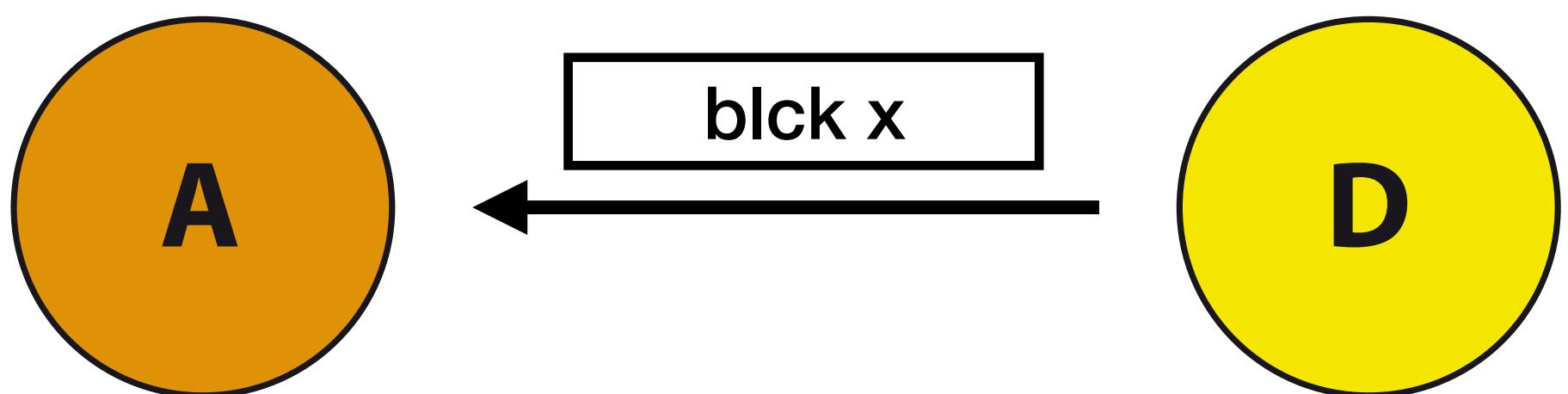
Confirmed transactions



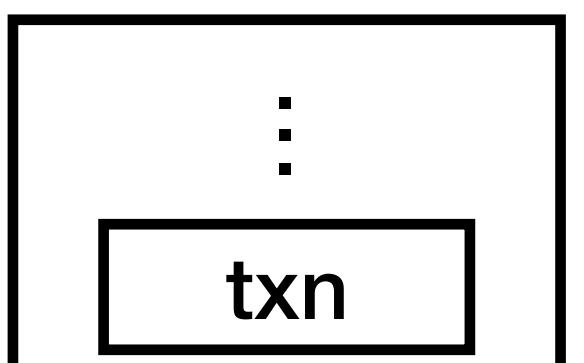
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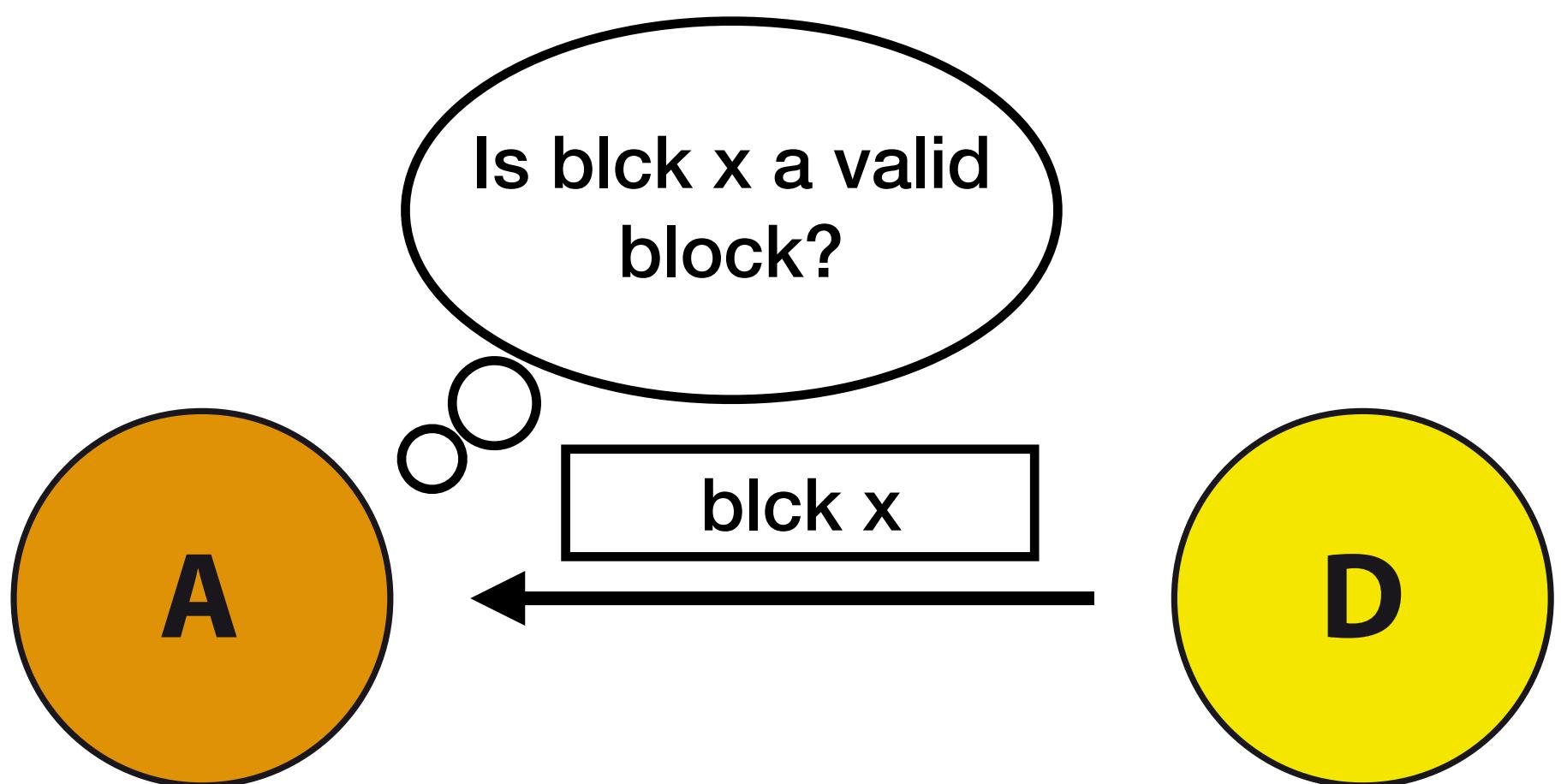
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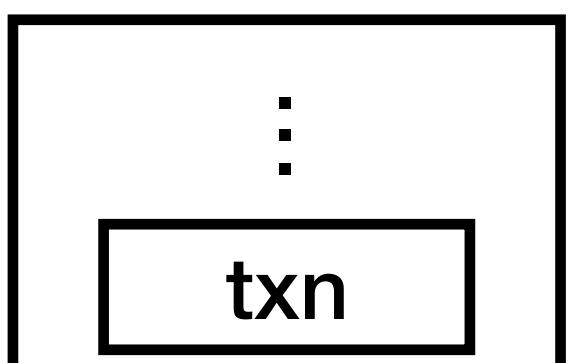
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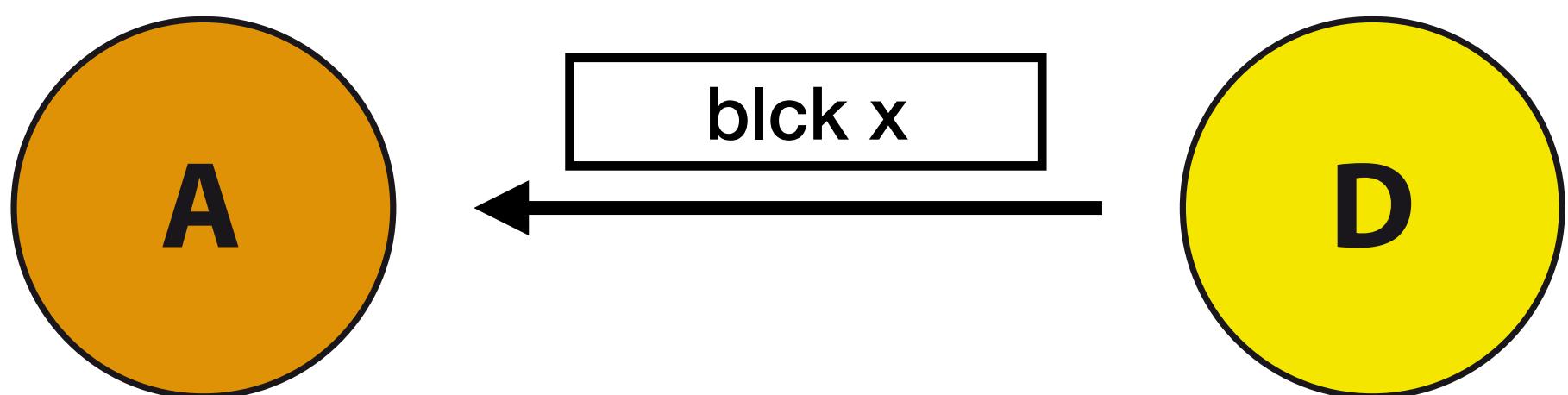
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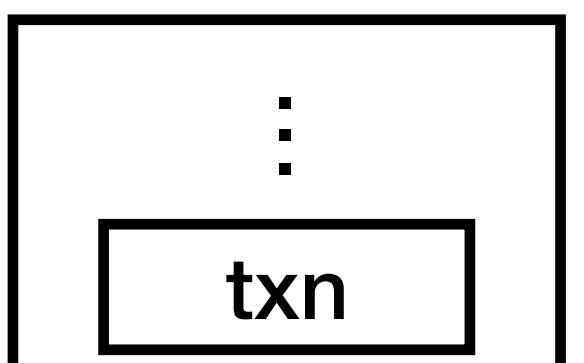
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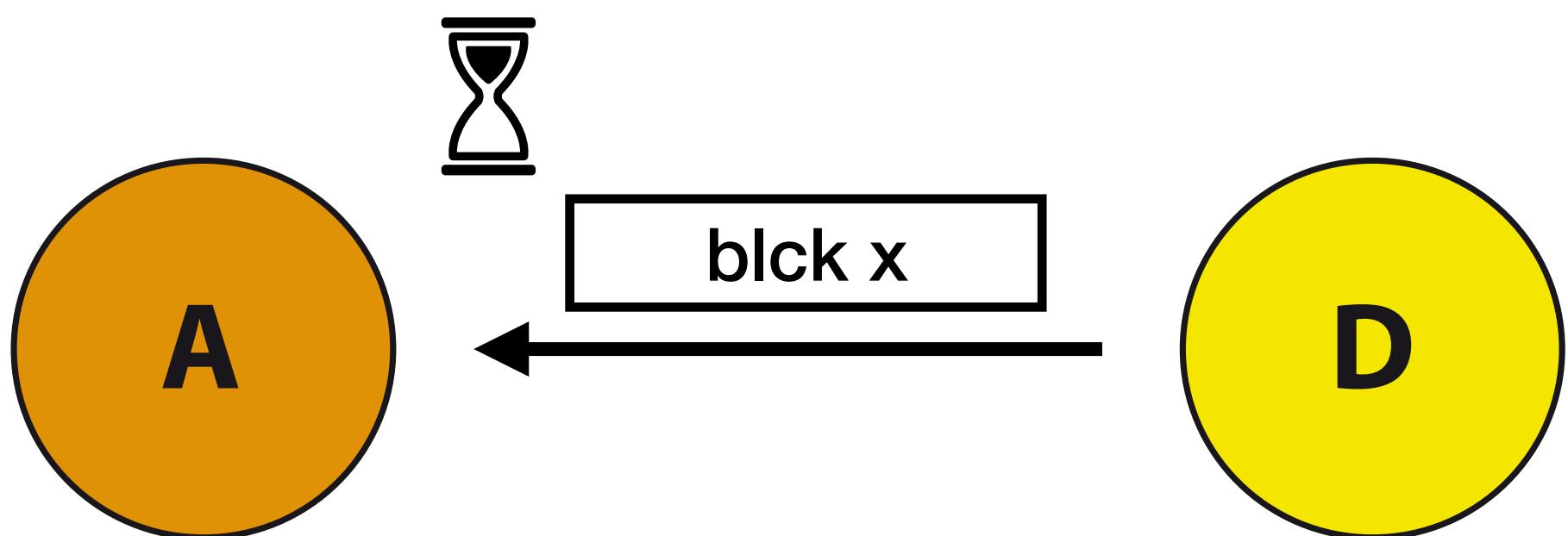
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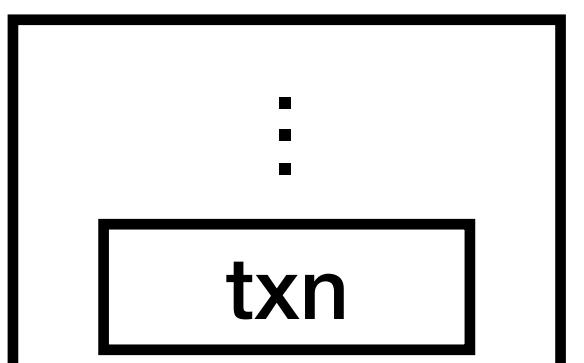
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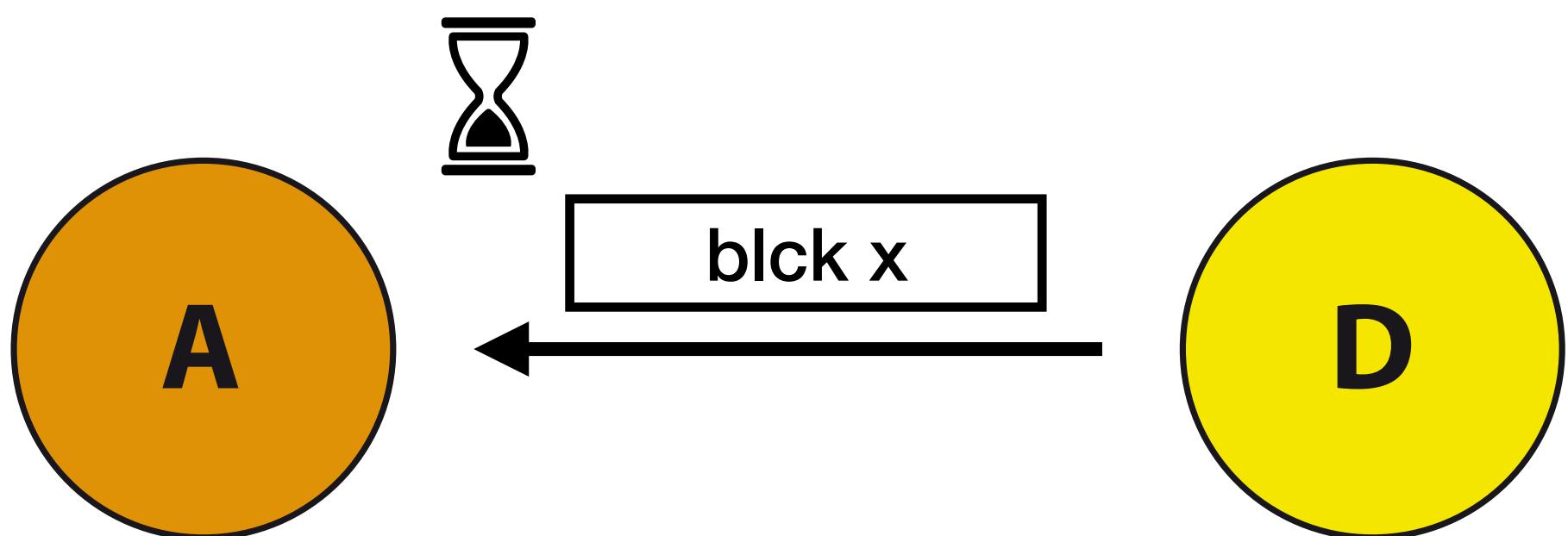
Confirmed transactions



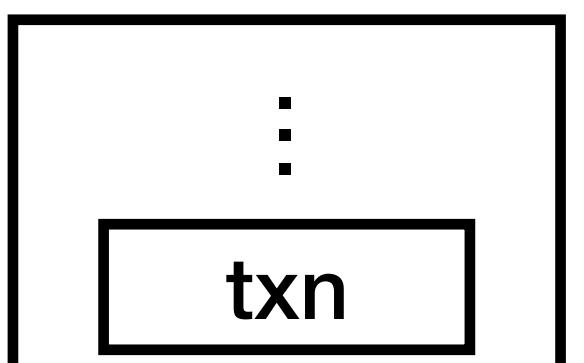
A's mempool



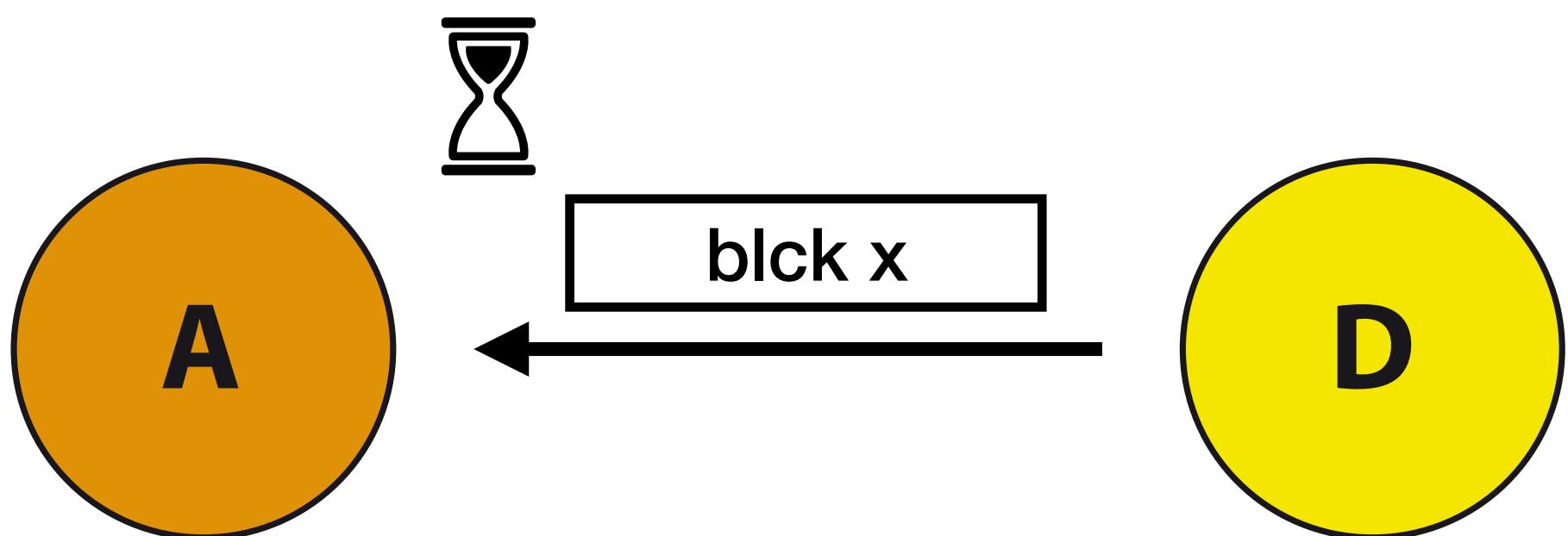
Confirmed transactions



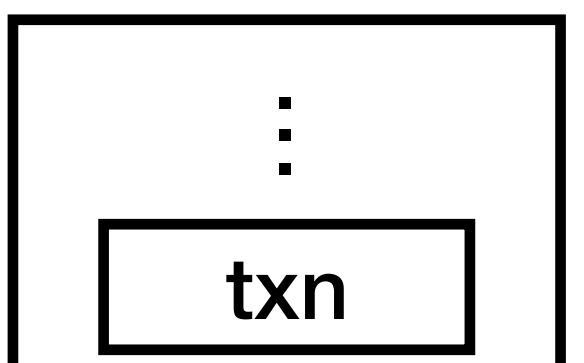
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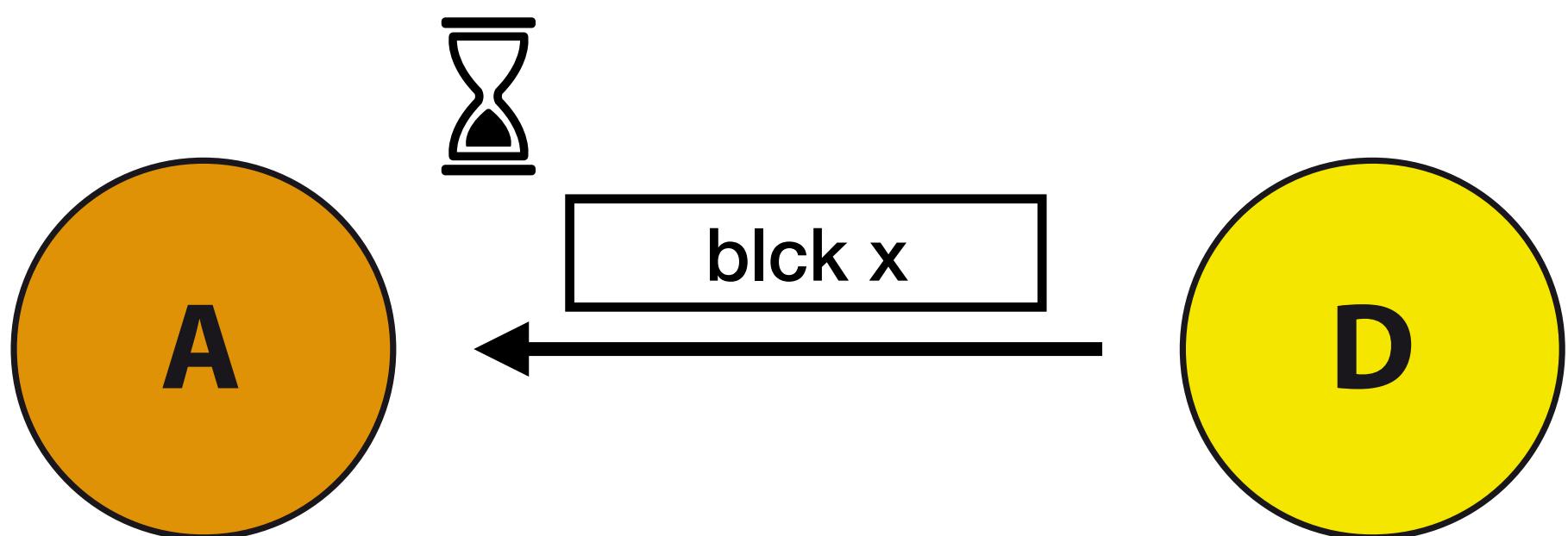
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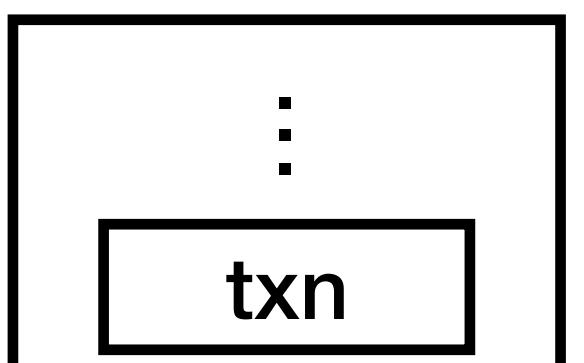
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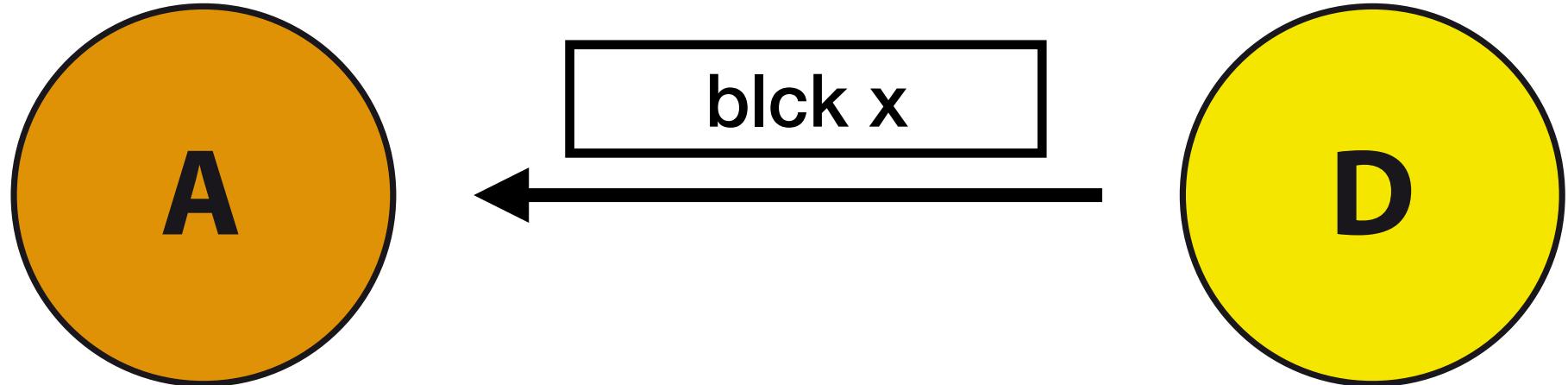
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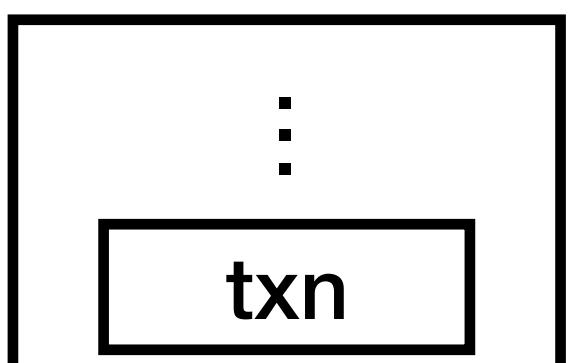
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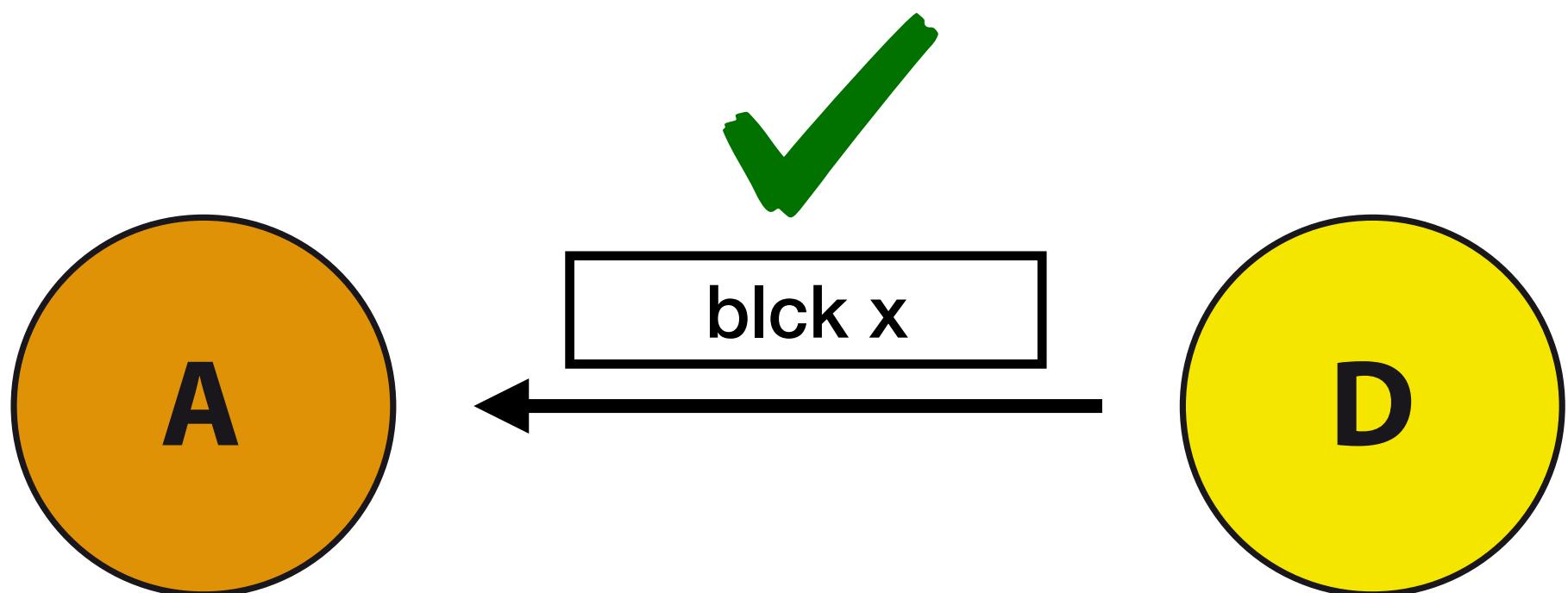
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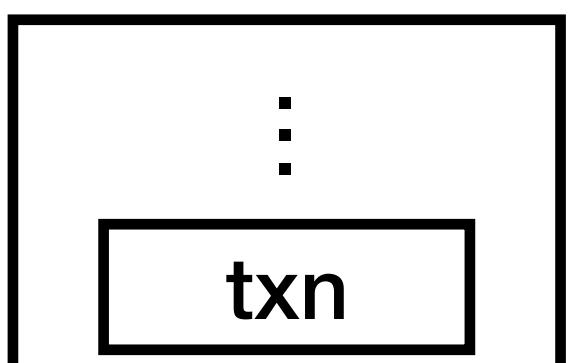
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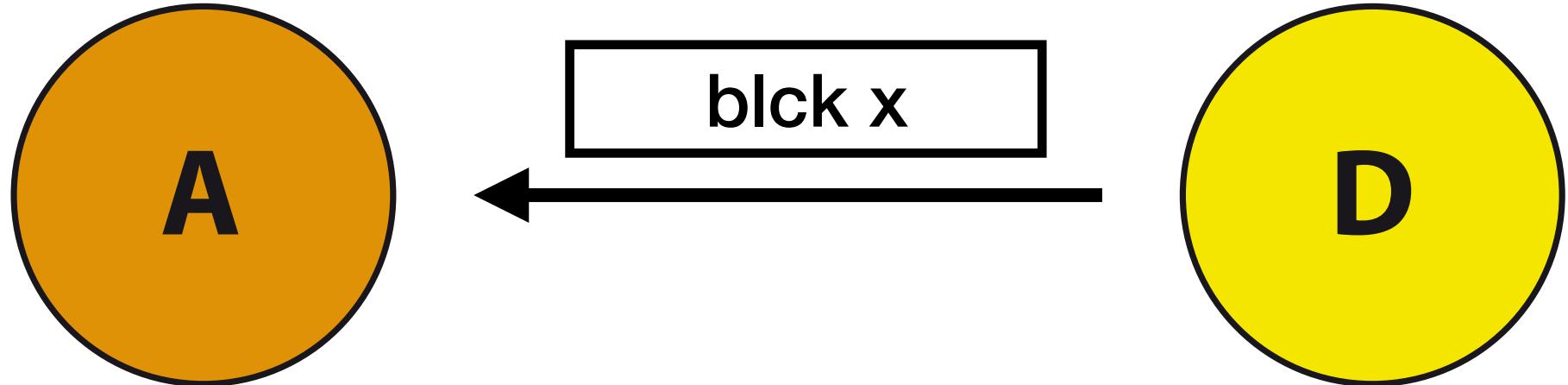
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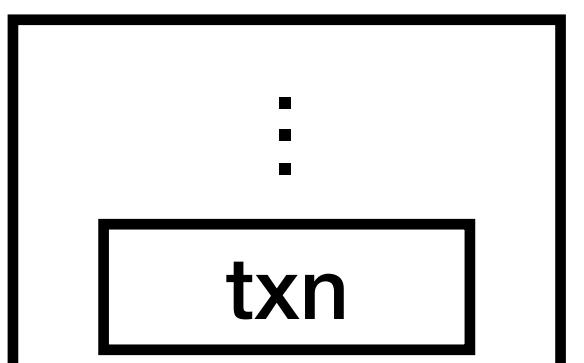
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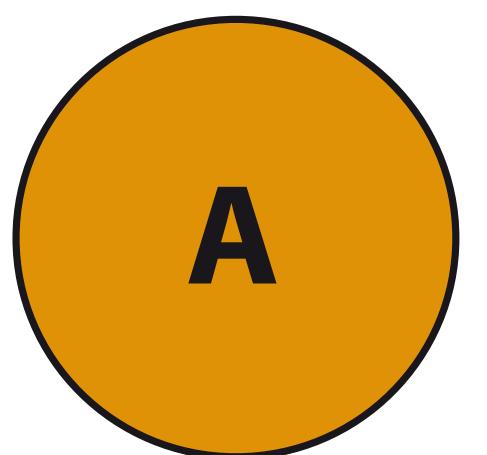
Confirmed transactions



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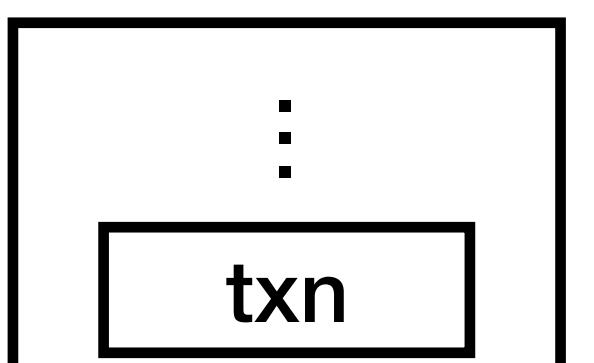


Confirmed transactions

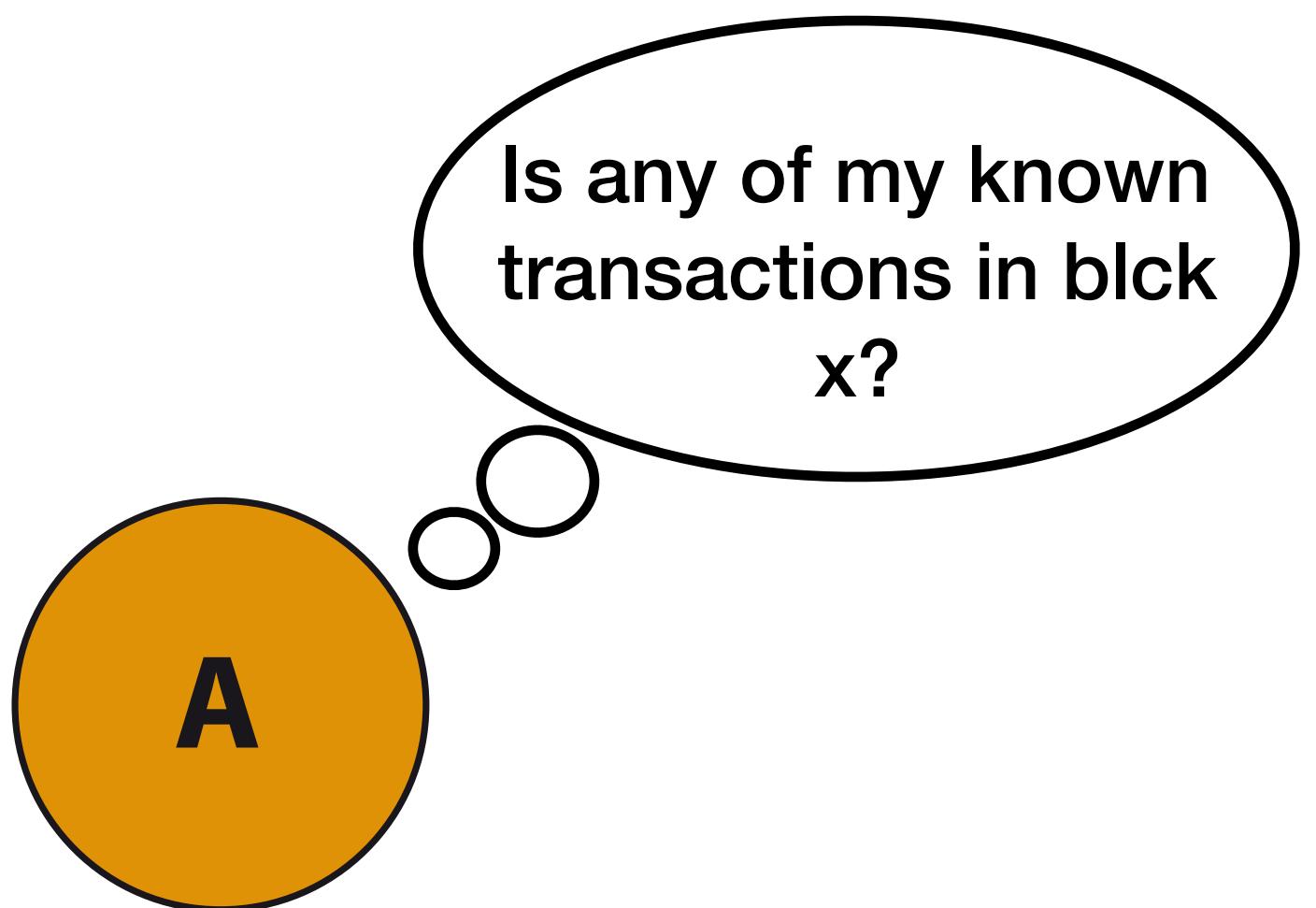


blk x

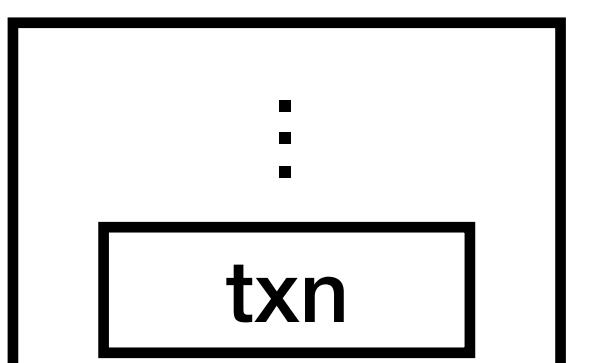
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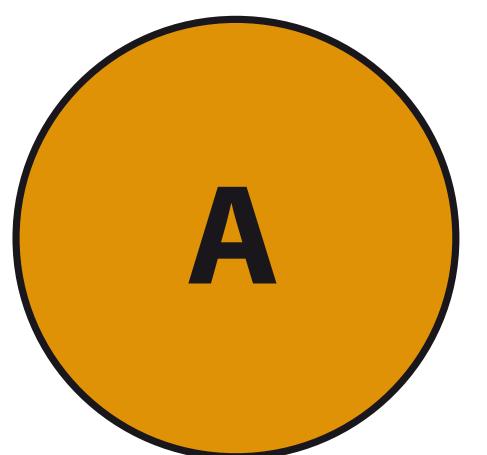
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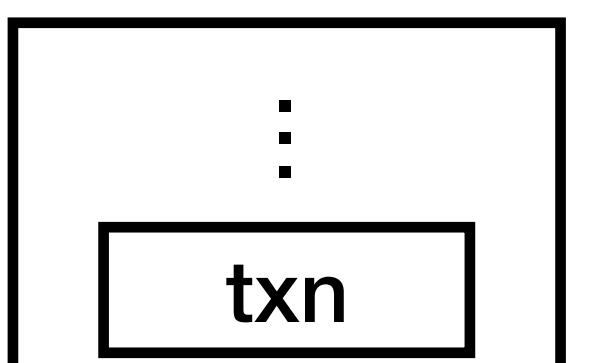


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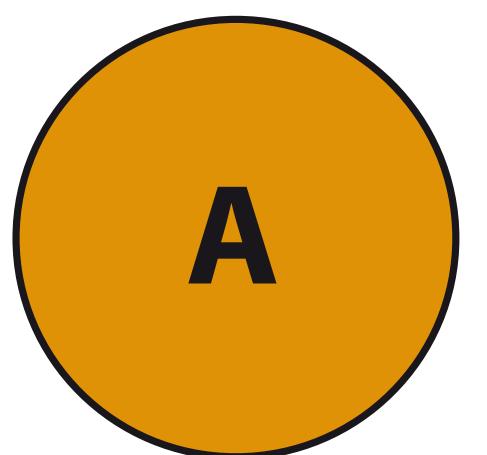


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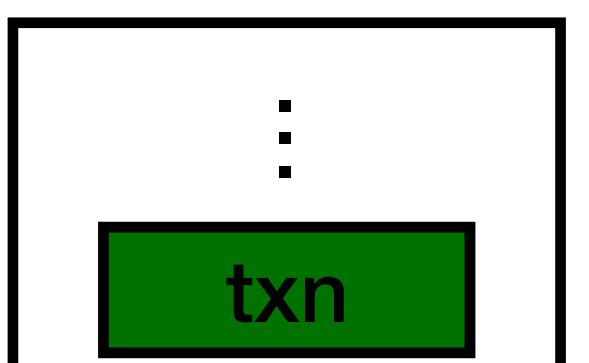


Confirmed transactions

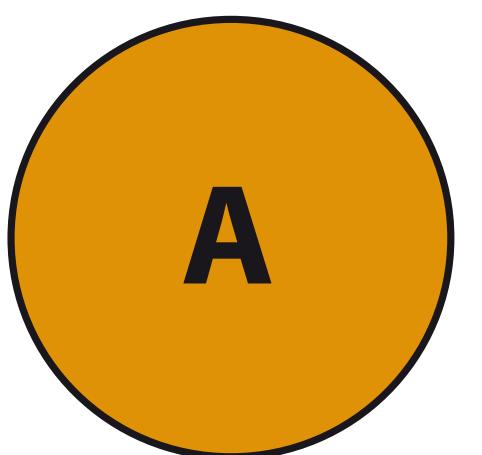


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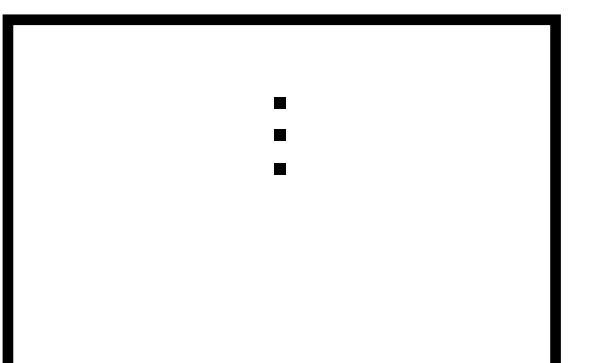


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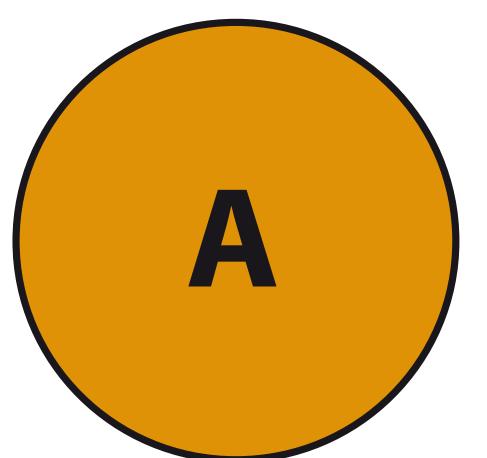


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A's mempool



Confirmed transactions

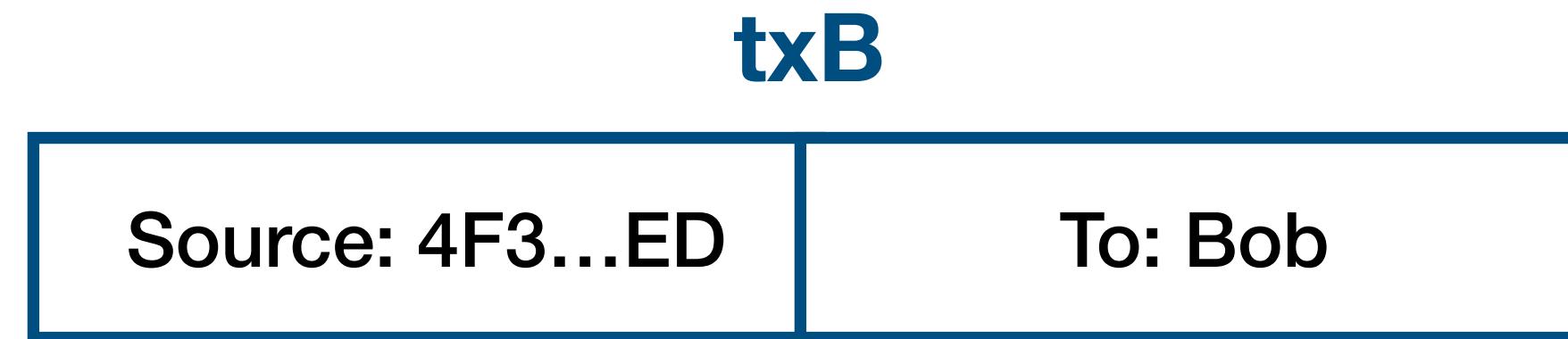


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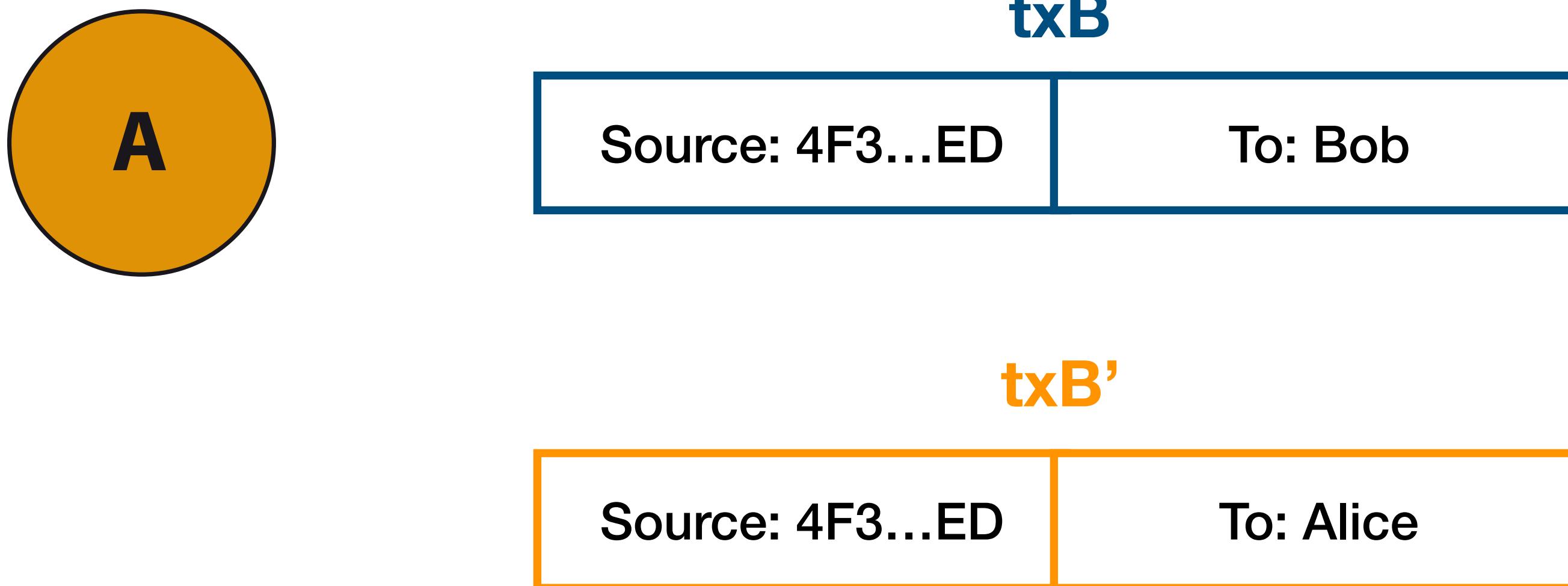
A's mempool

A white rectangular box with a black border. Inside, there is a vertical ellipsis (three dots) centered vertically. At the bottom of the box is another white rectangular box with a black border, containing the text 'txn-1'.

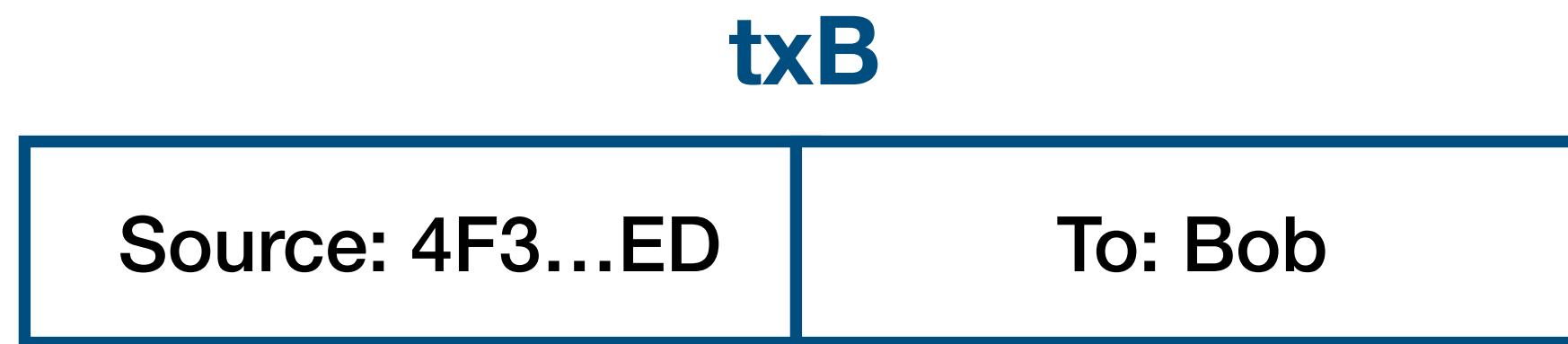
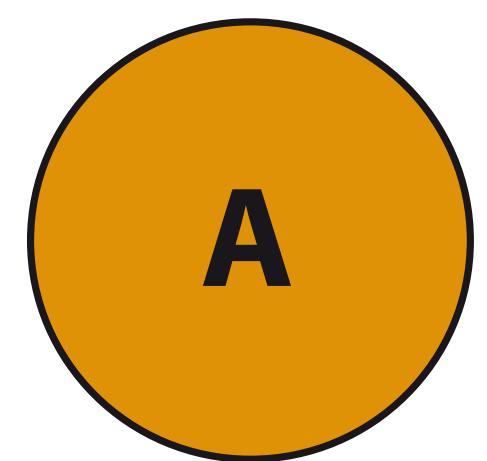
Double-spending transactions (1/2)



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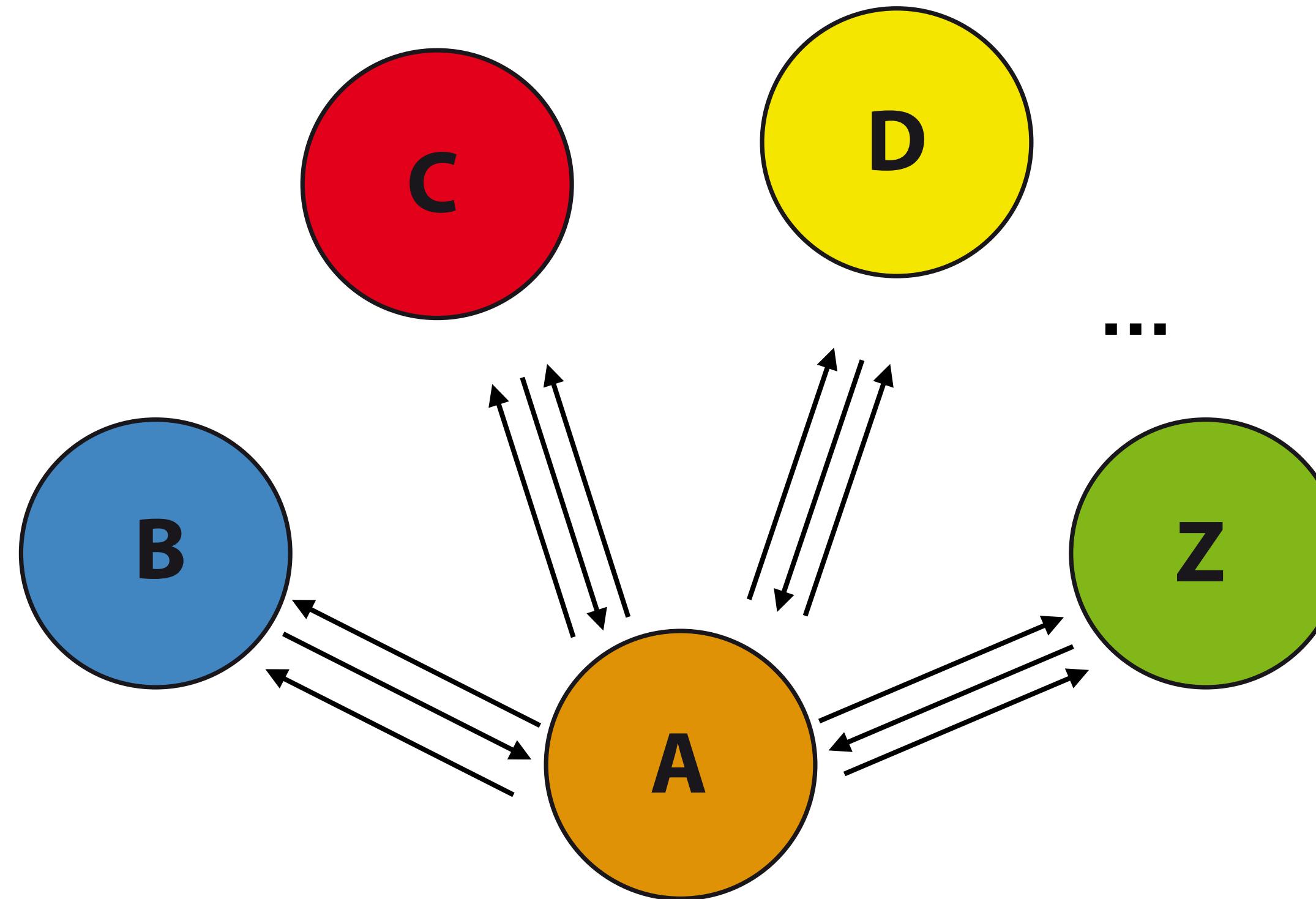
Double-spending transactions (1/2)



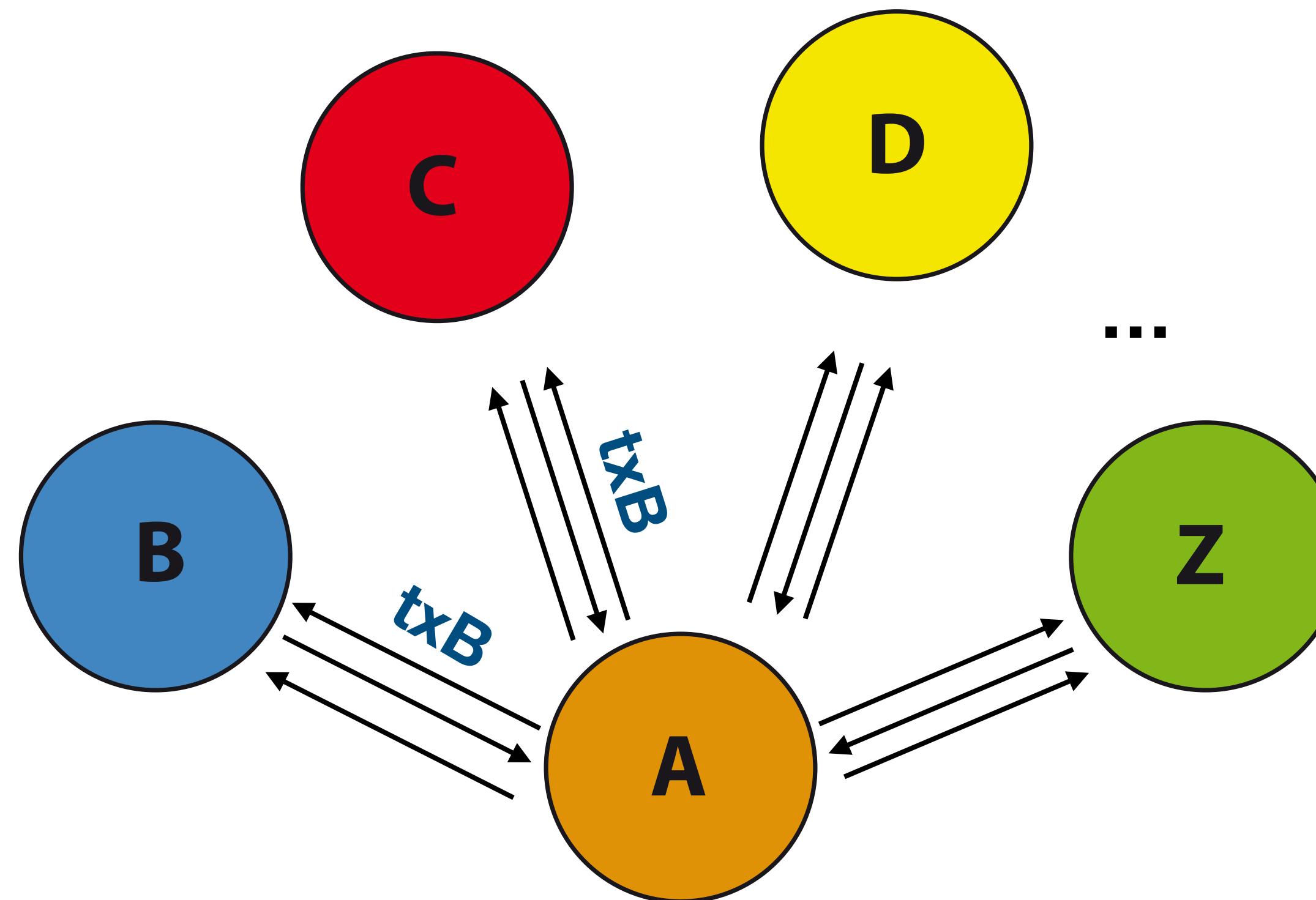
id = 4F3...ED



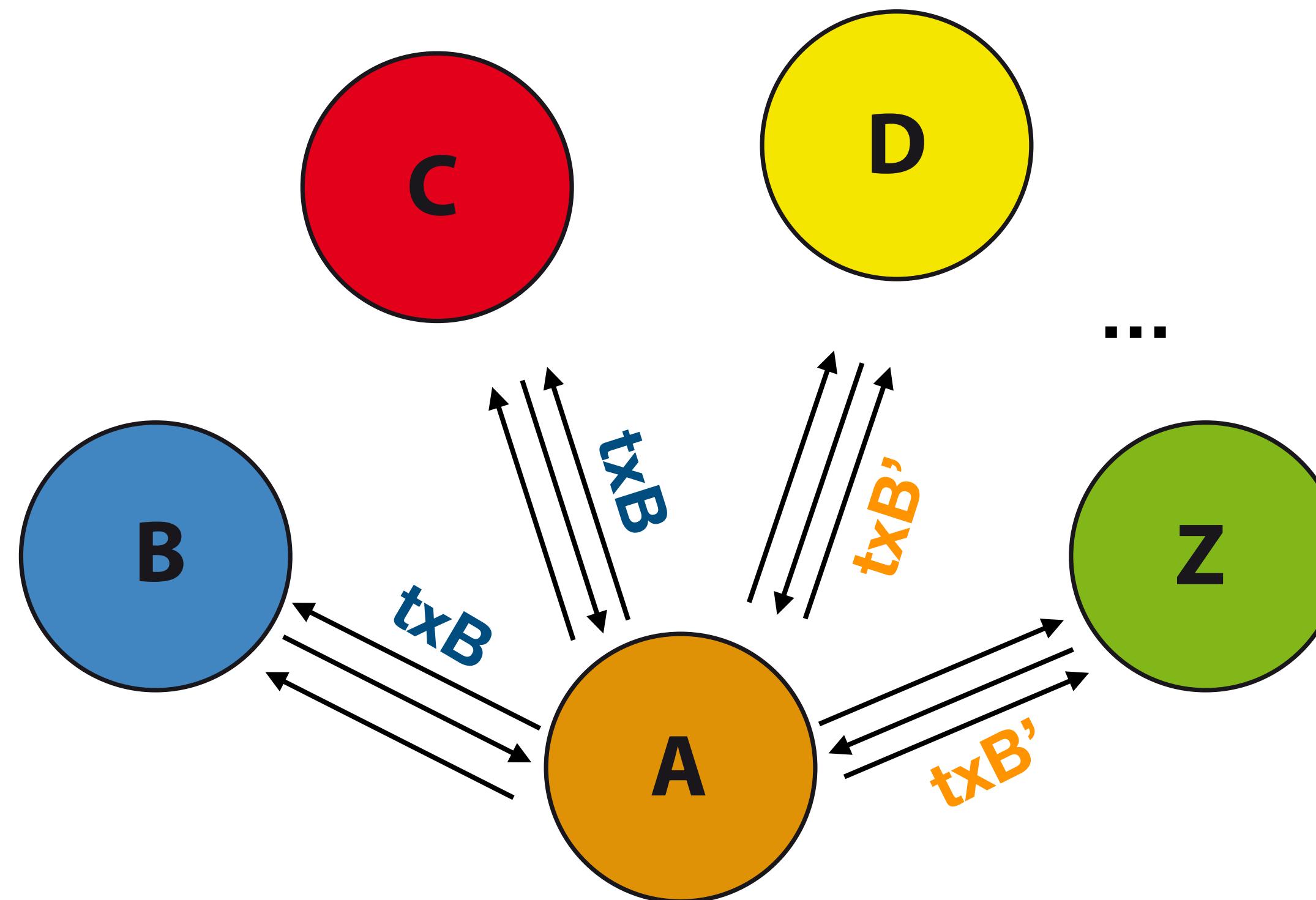
Double-spending transactions (2/2)



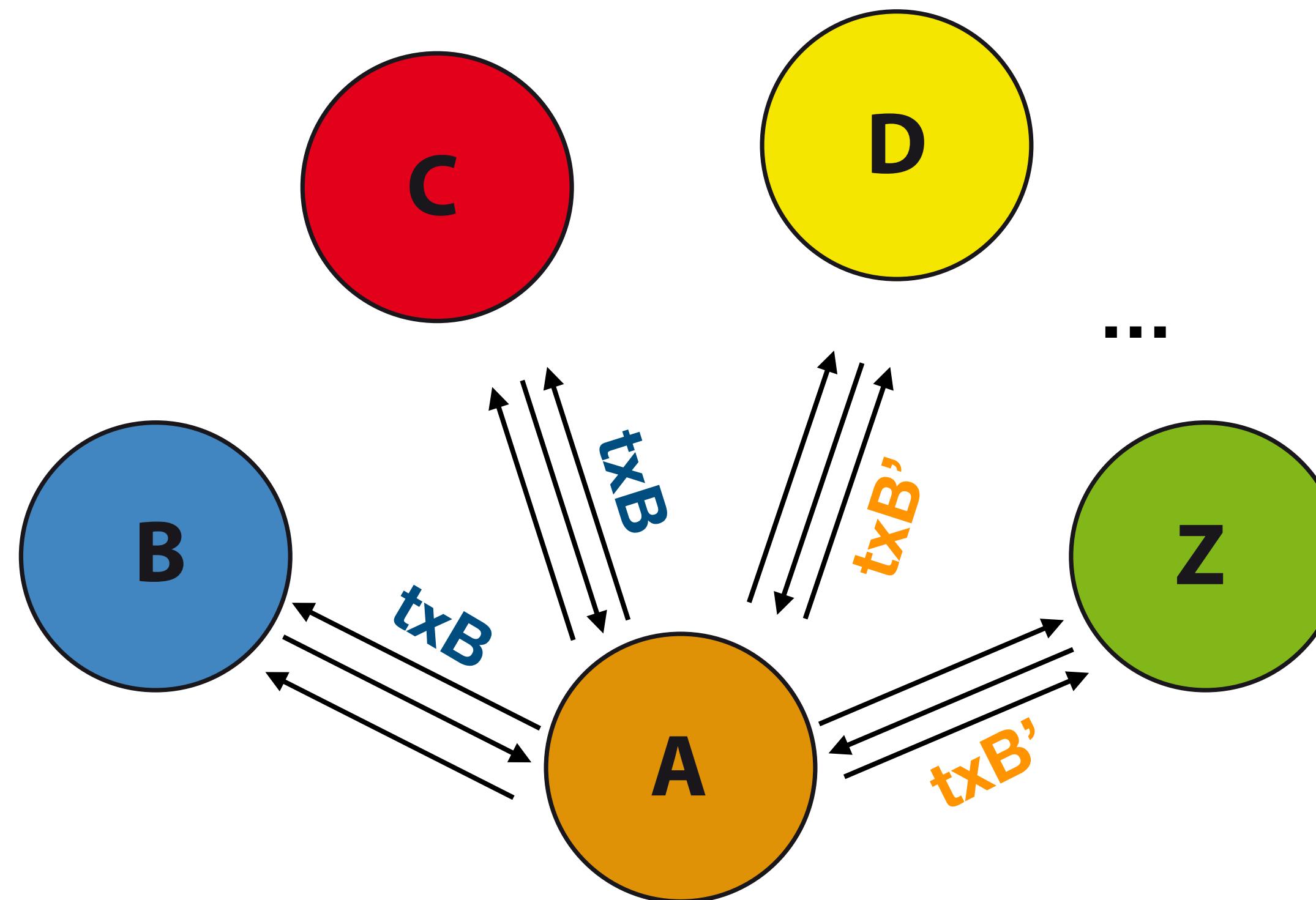
Double-spending transactions (2/2)



Double-spending transactions (2/2)

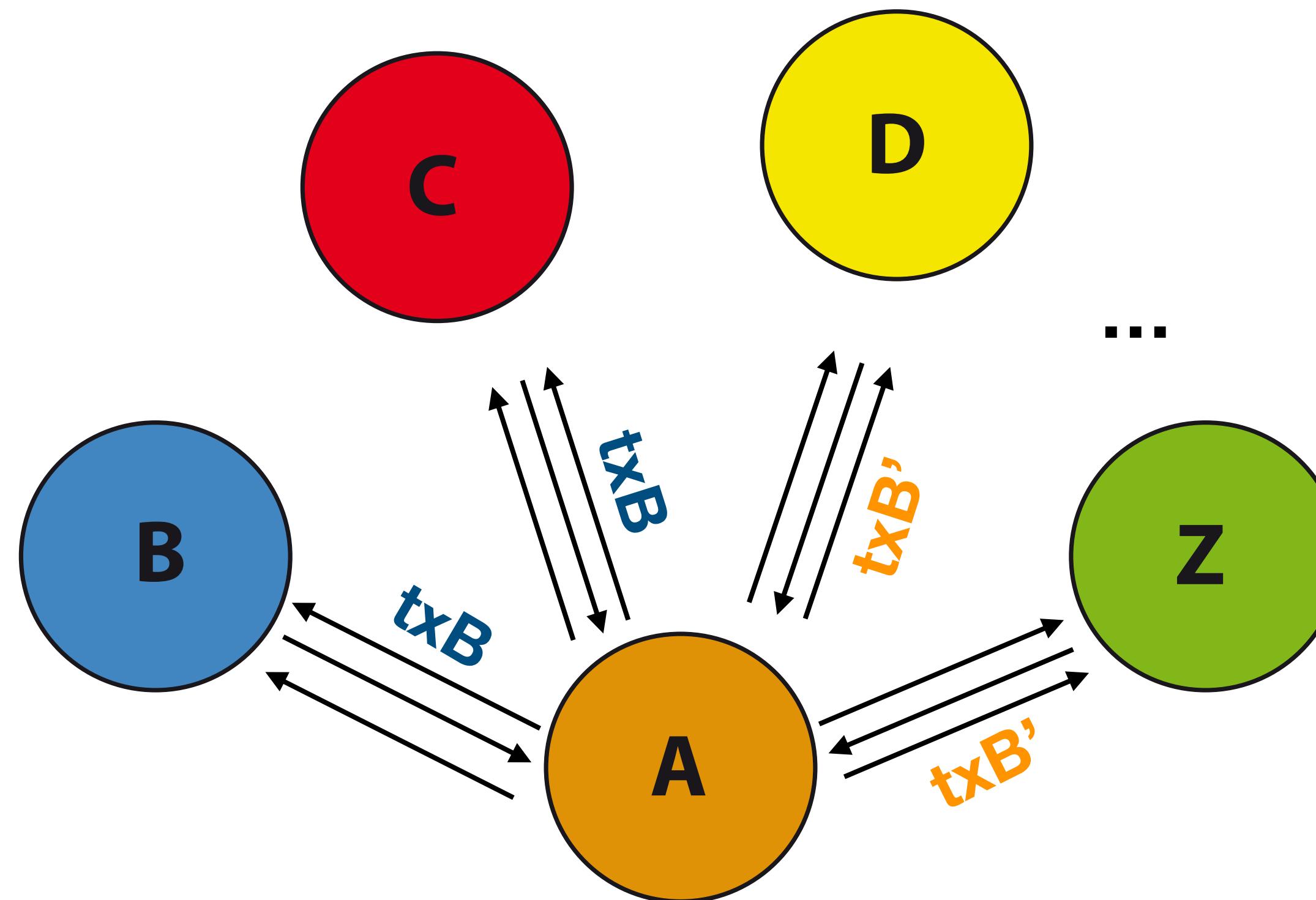


Double-spending transactions (2/2)



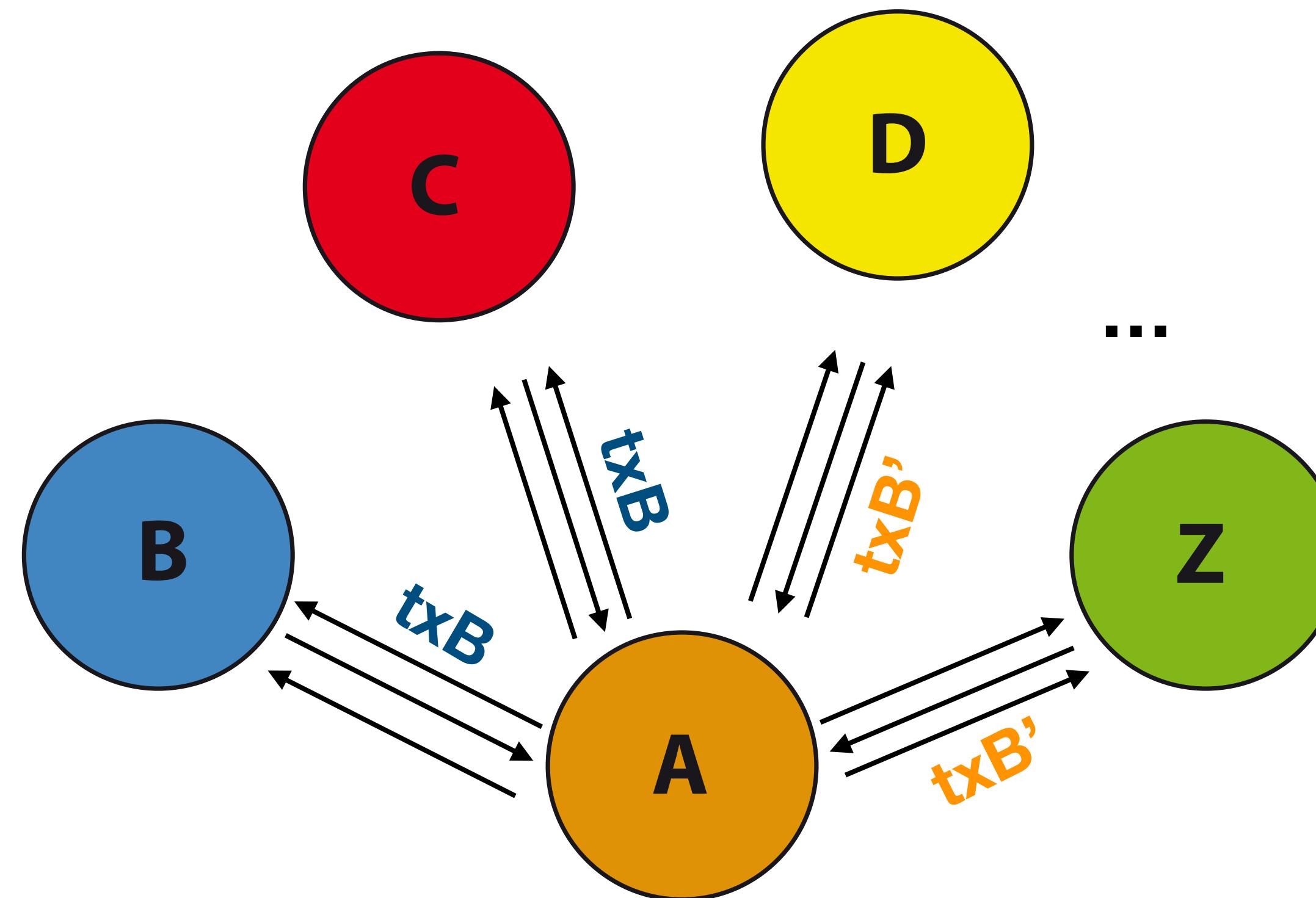
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Double-spending transactions (2/2)



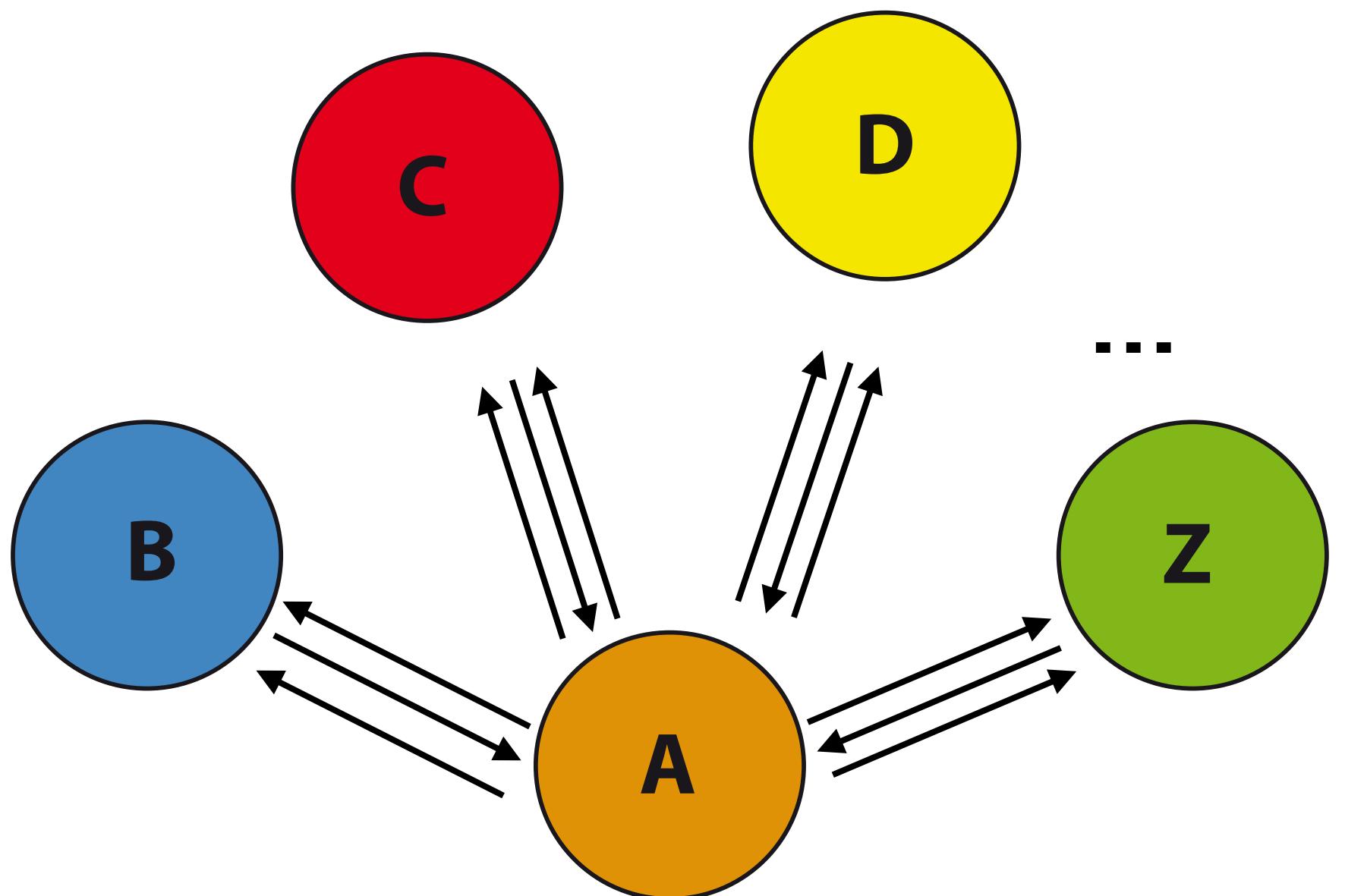
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Double-spending transactions (2/2)

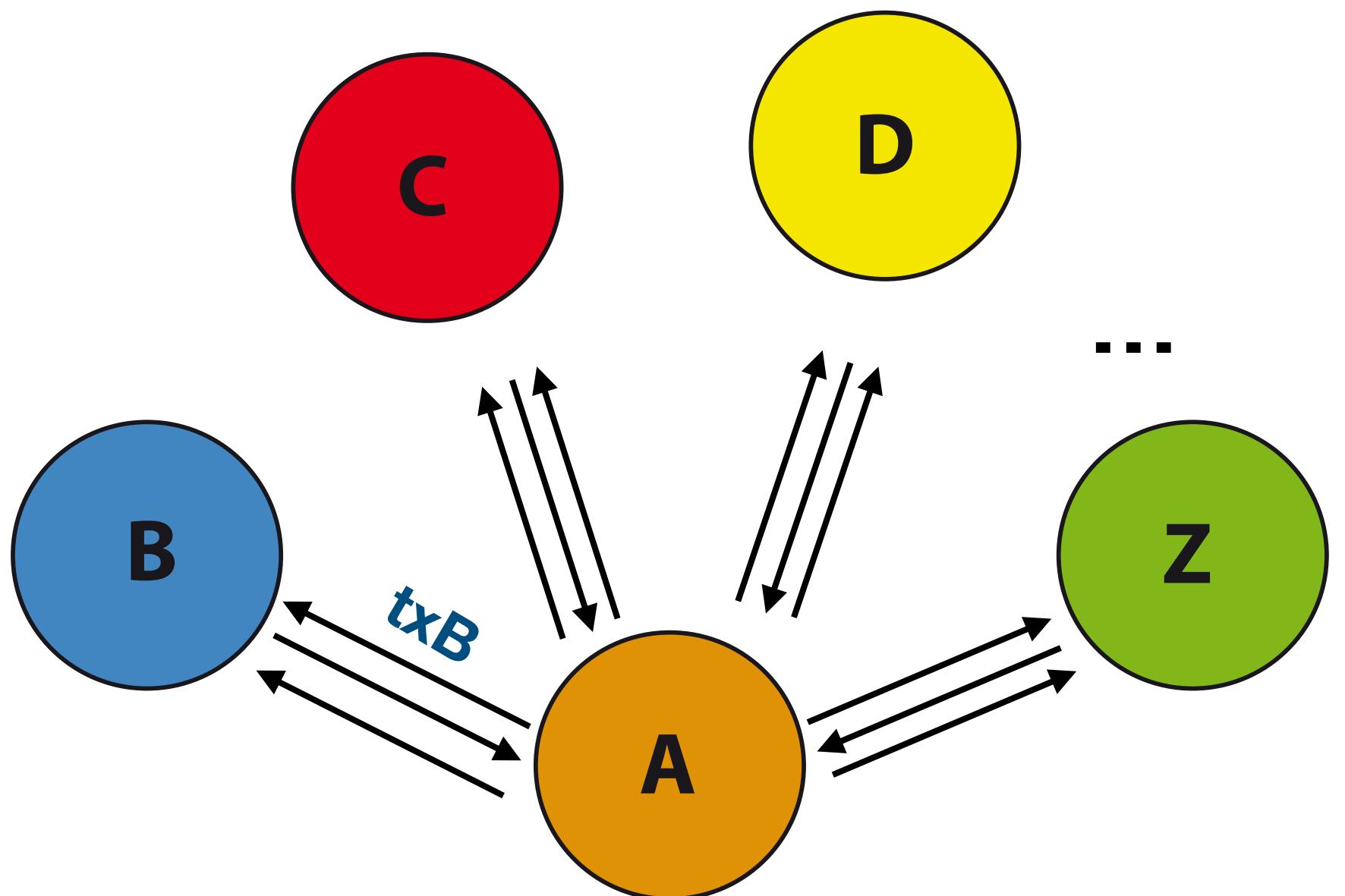


- 0-conf transactions should not be trusted
- If B accepts txB before it appears in a block he **can be deceived** by A
- The de facto confirmation time is **6 blocks** (5 on top of the one including a certain transaction)

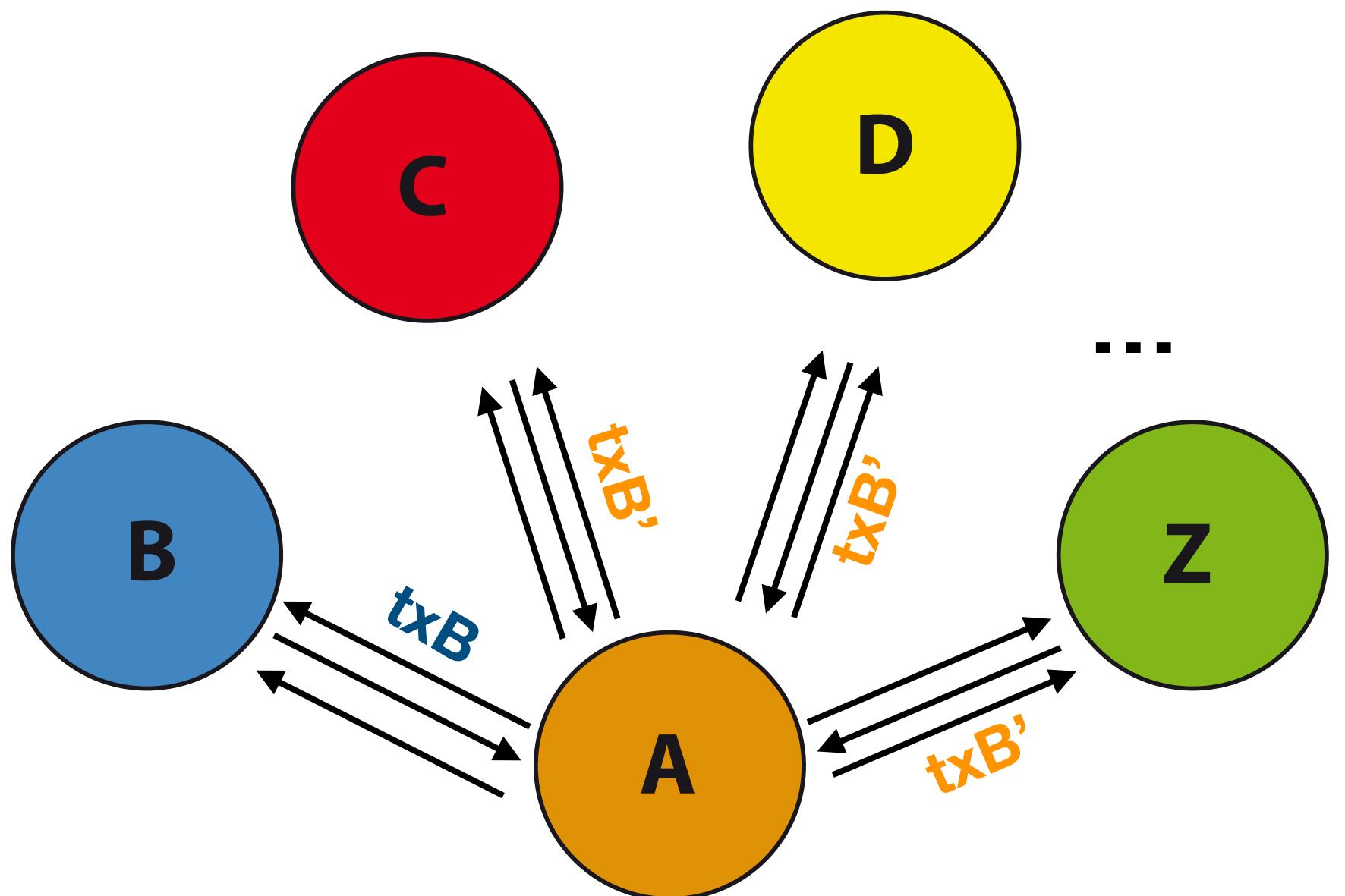
When things go south



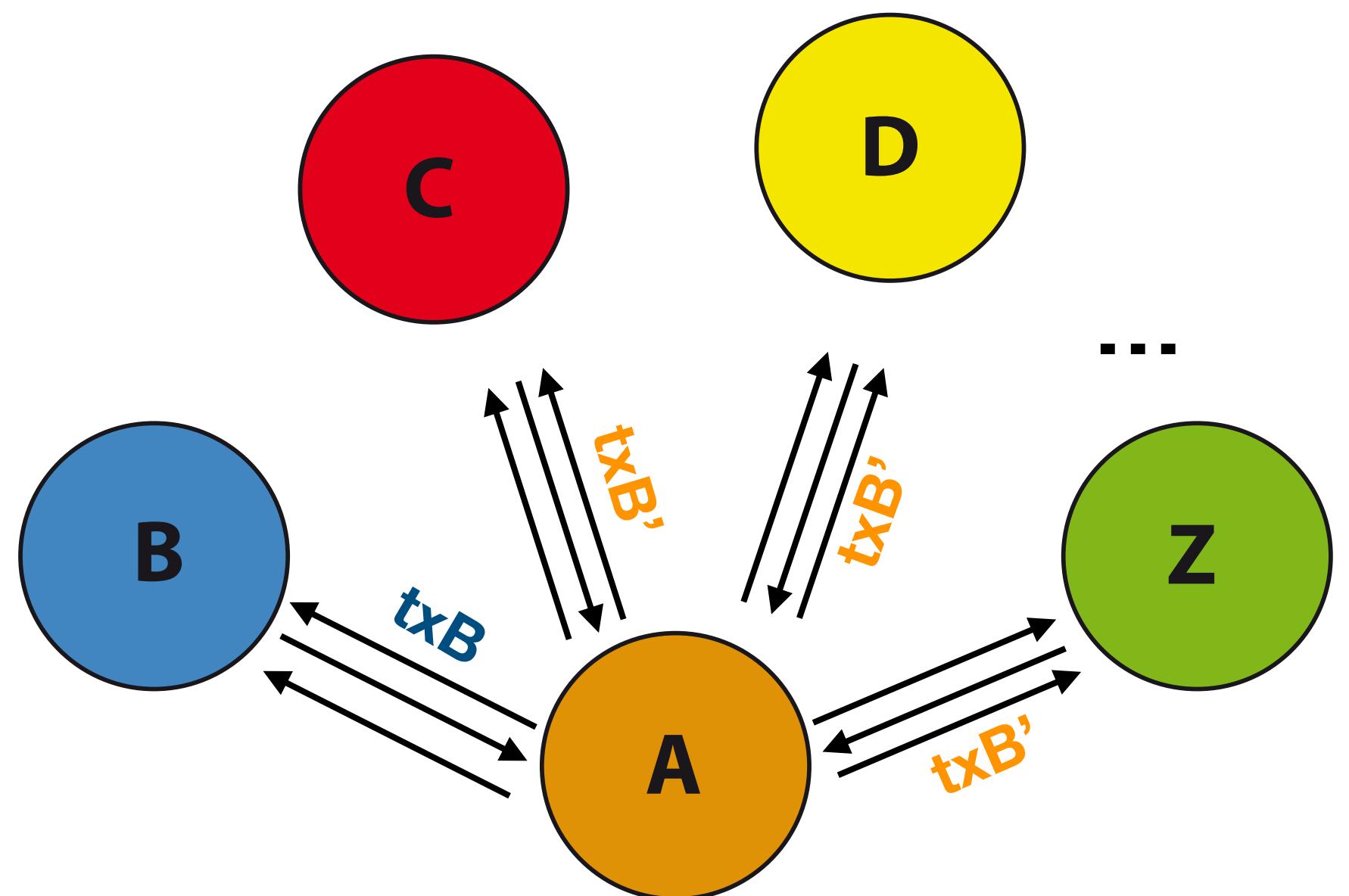
When things go south



When things go south

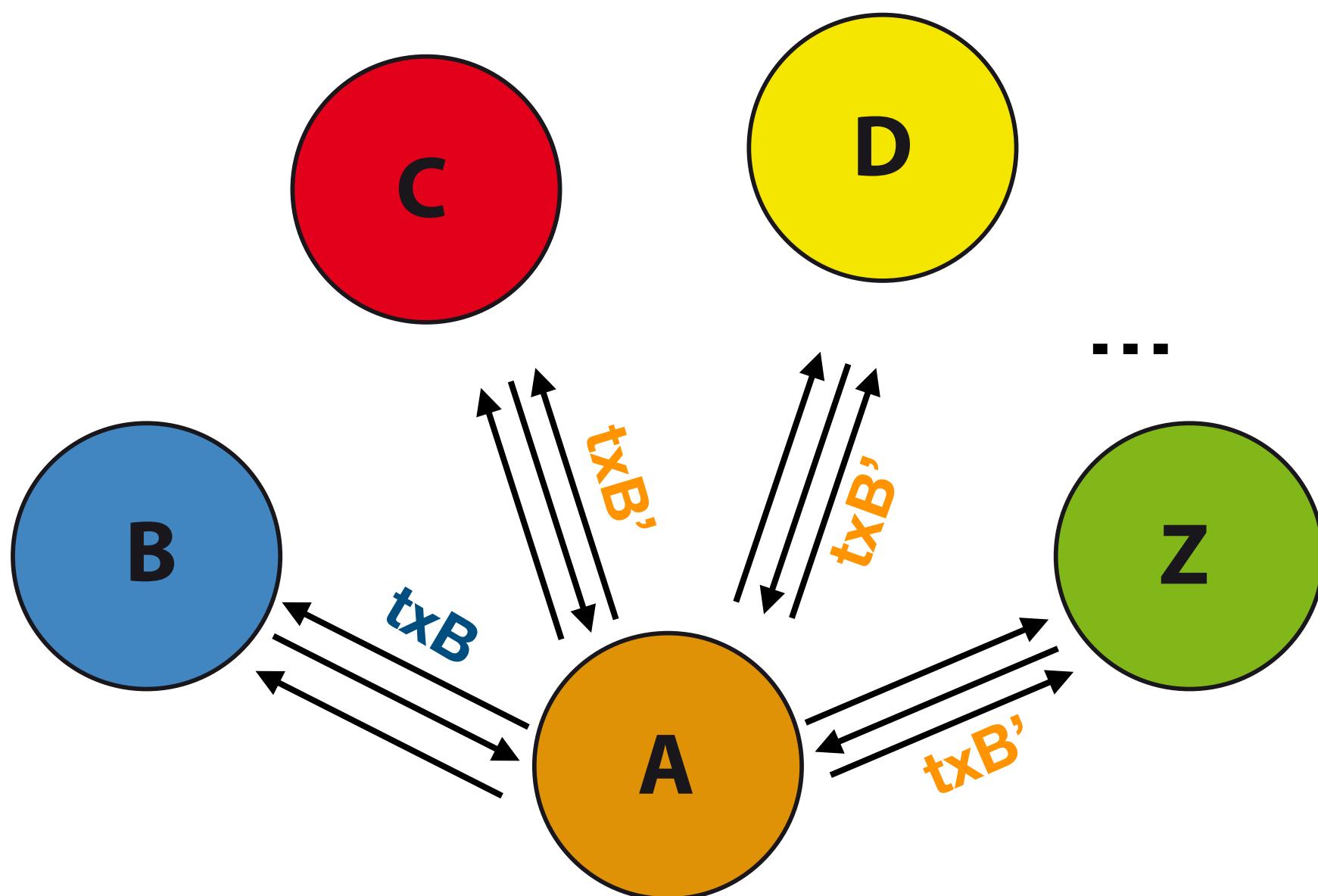


When things go south



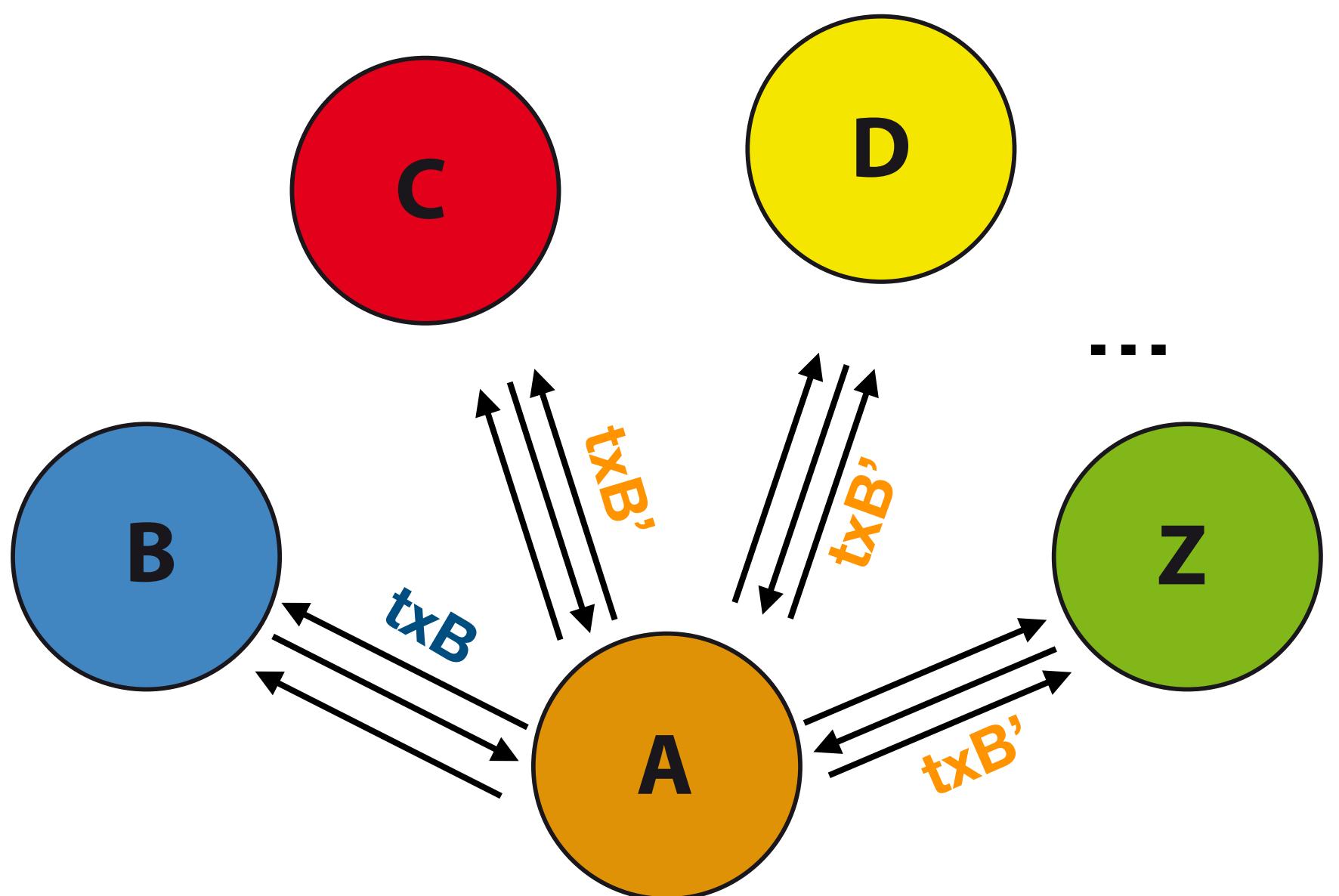
- If A controls the **network view** of B,
A can control what B know about the
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When things go south



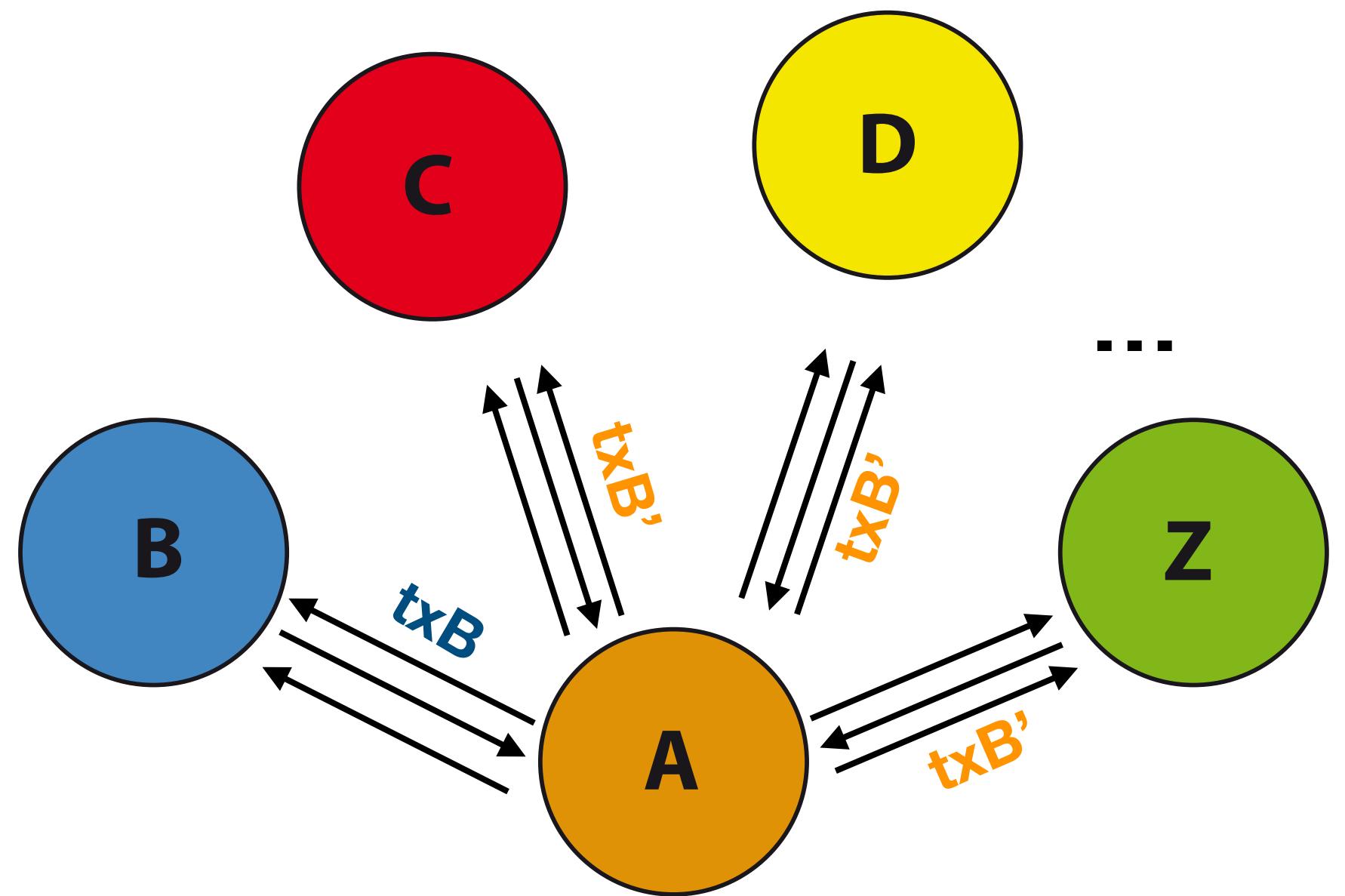
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When things go south



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- A will be able to **easily fool** B

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Network topology

Title



Title

- Random topology and so on



Title

- Random topology and so on



Matthias Grundmann, Till Neudecker, and Hannes Hartenstein

Exploiting Transaction Accumulation and Double Spends for Topology Inference in Bitcoin

<https://fc18.ifca.ai/bitcoin/papers/bitcoin18-final10.pdf>

Title



Title



Sergi Delgado-Segura, Surya Baksni, Cristina Pérez-Sojà, James Litton, Andrew Pachulski, Andrew Miller, Bobby Bhattacharjee



TxProbe: Discovering Bitcoin's Network Topology Using Orphan Transactions
<https://fc19.ifca.ai/preproceedings/58-preproceedings.pdf>

Title

- A little bit about net topology and TxProbe picture



Sergi Delgado-Segura, Surya Baksni, Cristina Pérez-Sojà, James Litton, Andrew Pachulski, Andrew Miller, Bobby Bhattacharjee



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Network topology

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