Bitcoin Network Layer and Information Propagation

Sergi Delgado Segura

sr_gi

WHAT ARE WE GOING TO COVER?

Differences between client/server and peer-to-peer paradigms

How a new node joins the network

- How it learns about the network
- How others learn about it

Actors and their role in the network

The gossip protocol

Data propagation

- Transactions and blocks
- 0-conf and double-spending

Node misbehavior

Network based attacks

Network topology

BEFORE WE START

We will use Bitcoin as an 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 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 where actors are split into **clients** and **servers**

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 or 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

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

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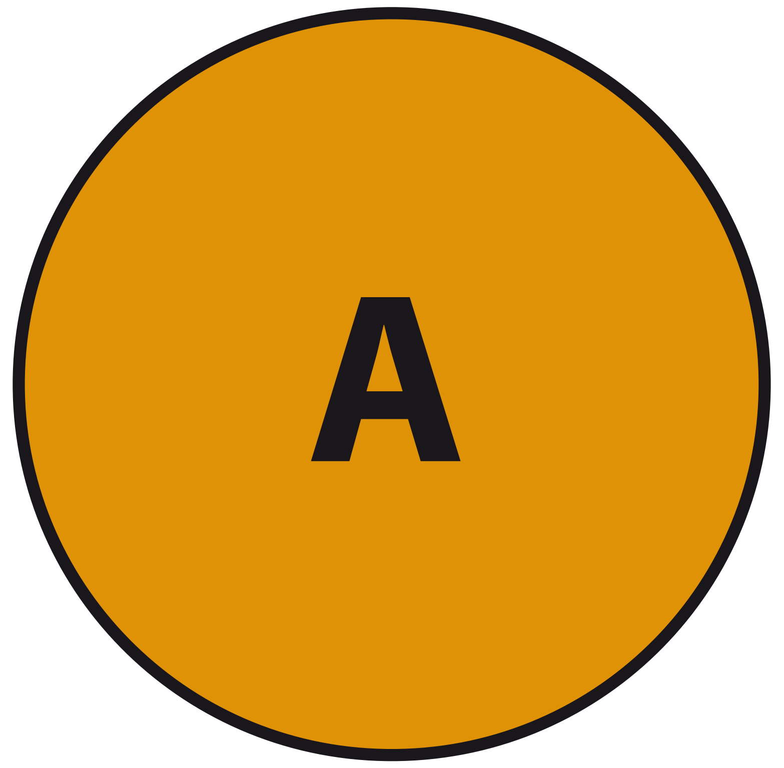
How do peers announce their presence in the network?

PEER DISCOVERY?



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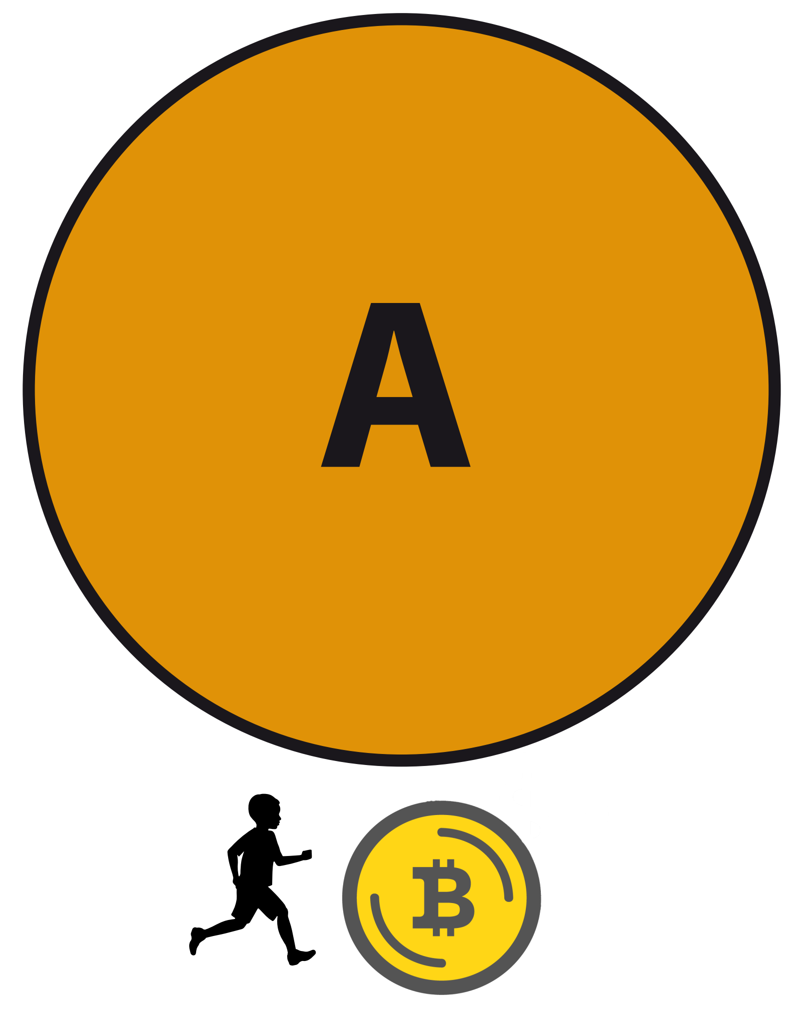

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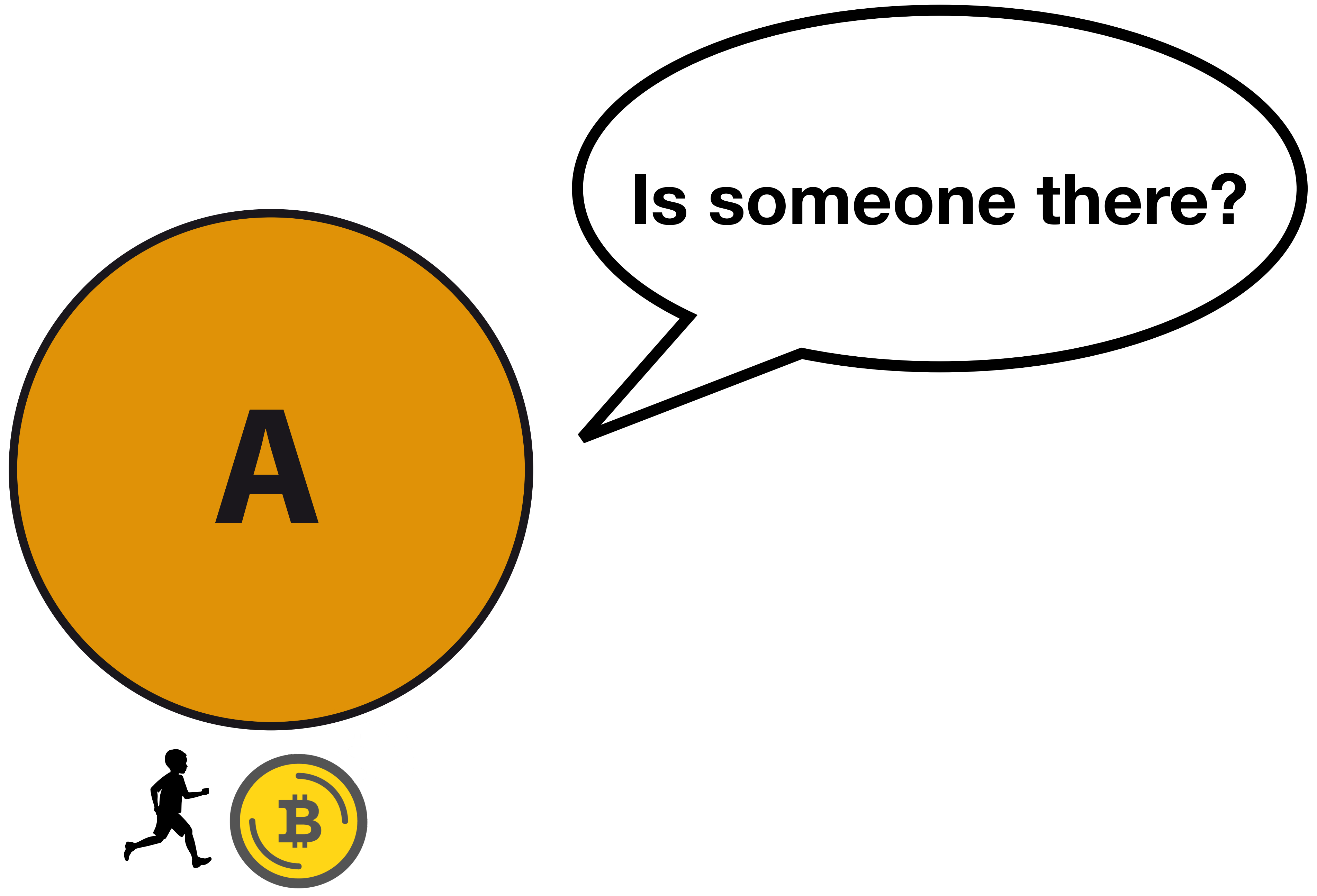

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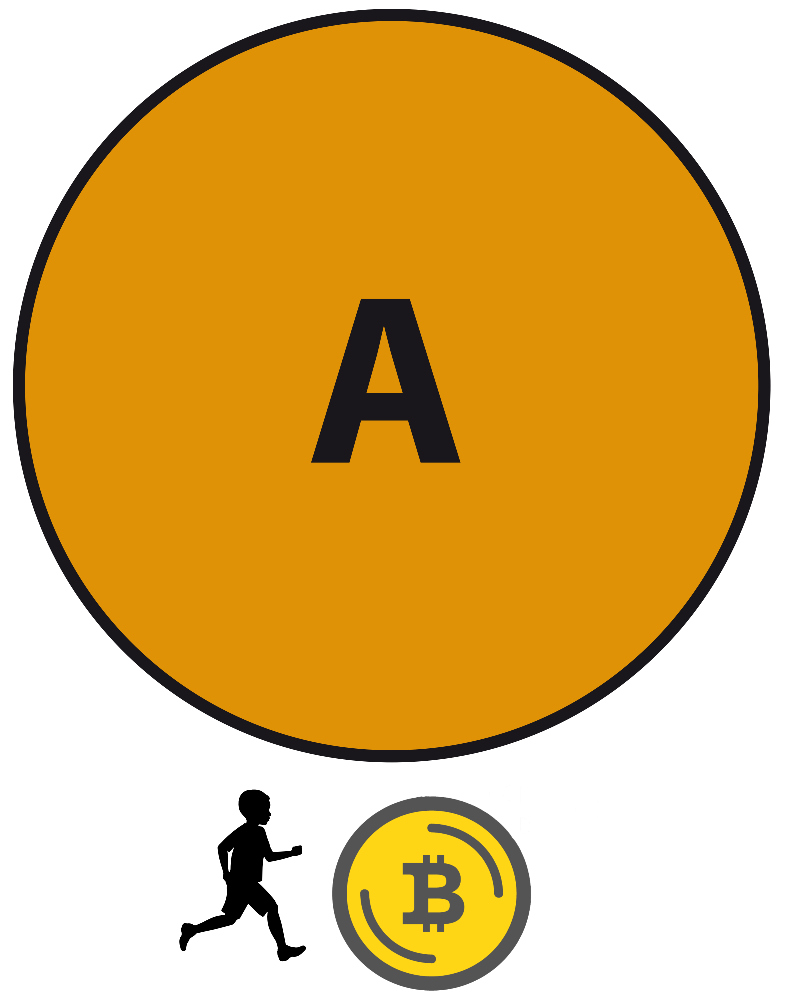

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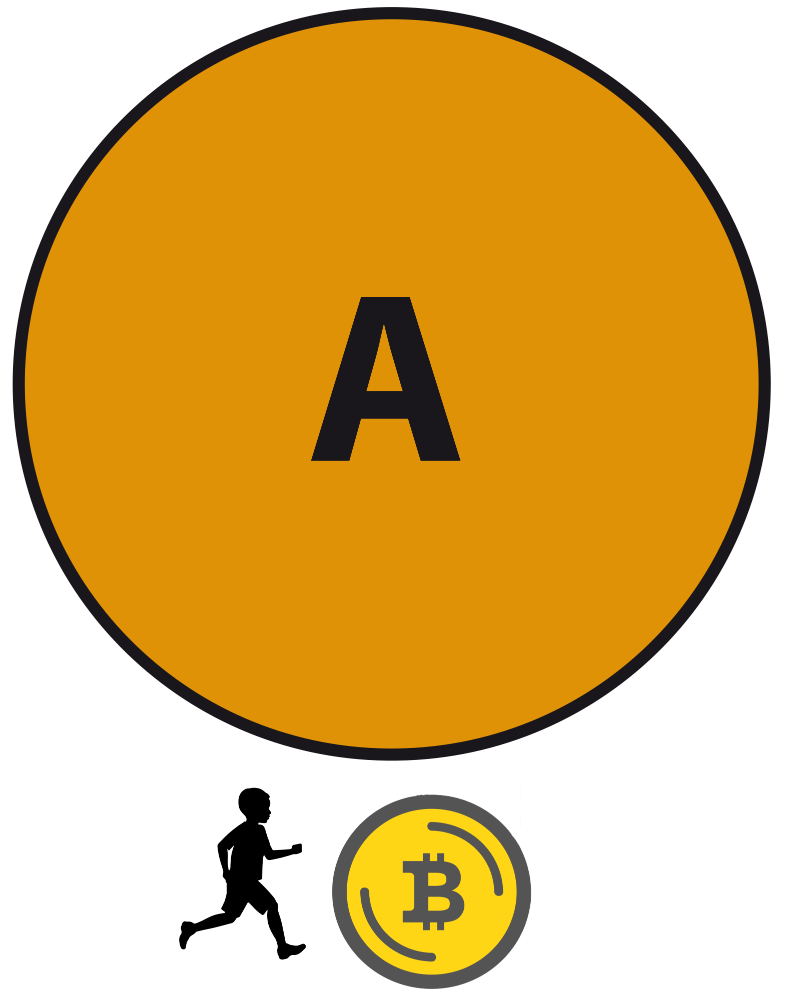

tumbleweed

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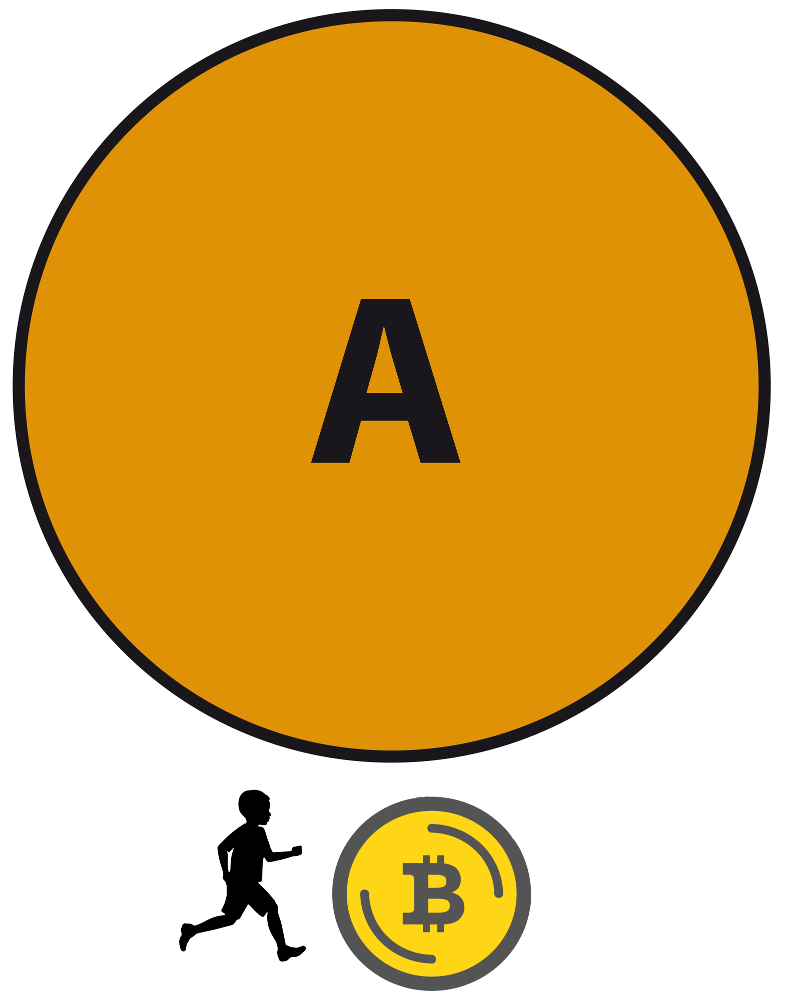

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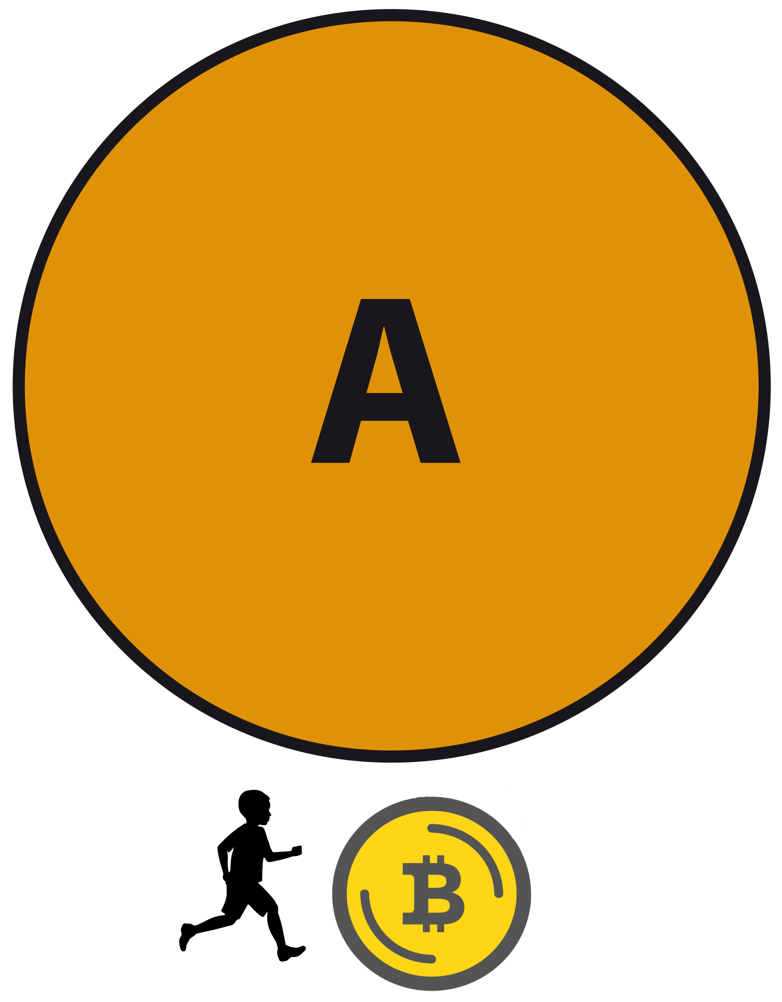

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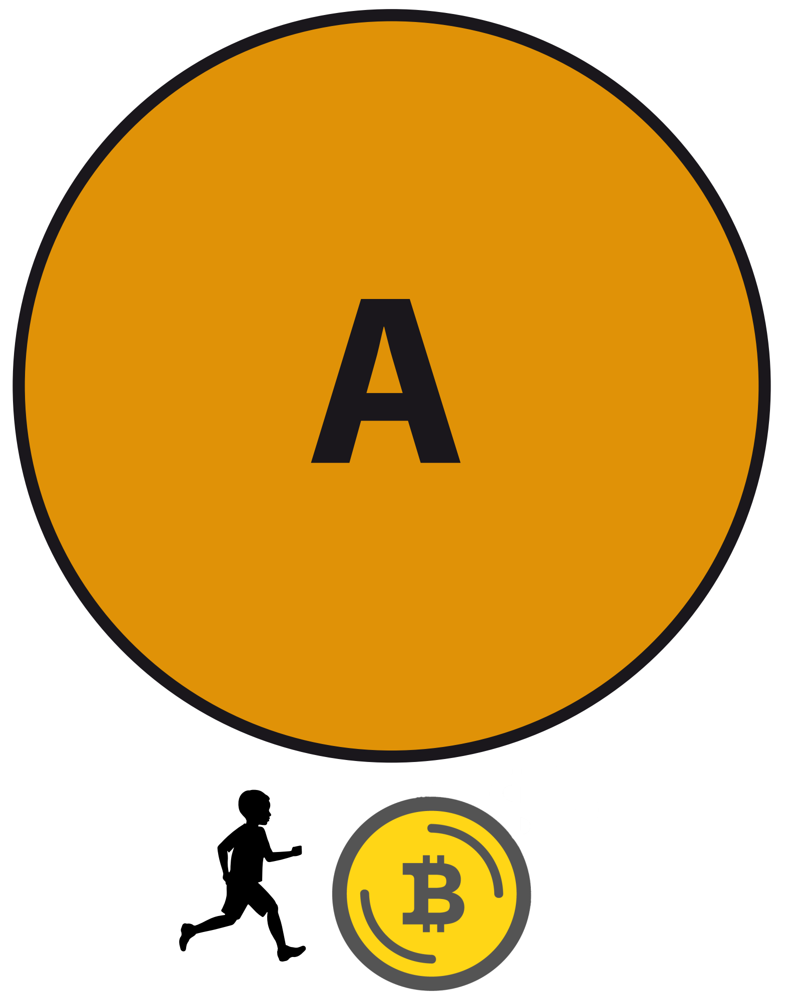

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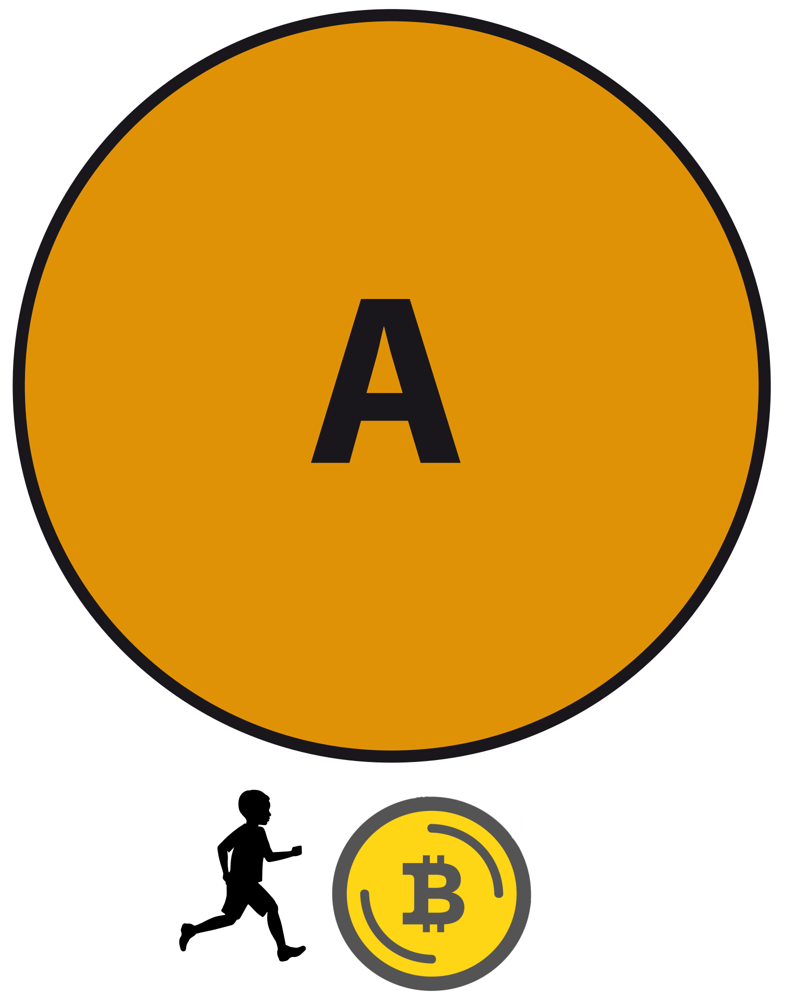

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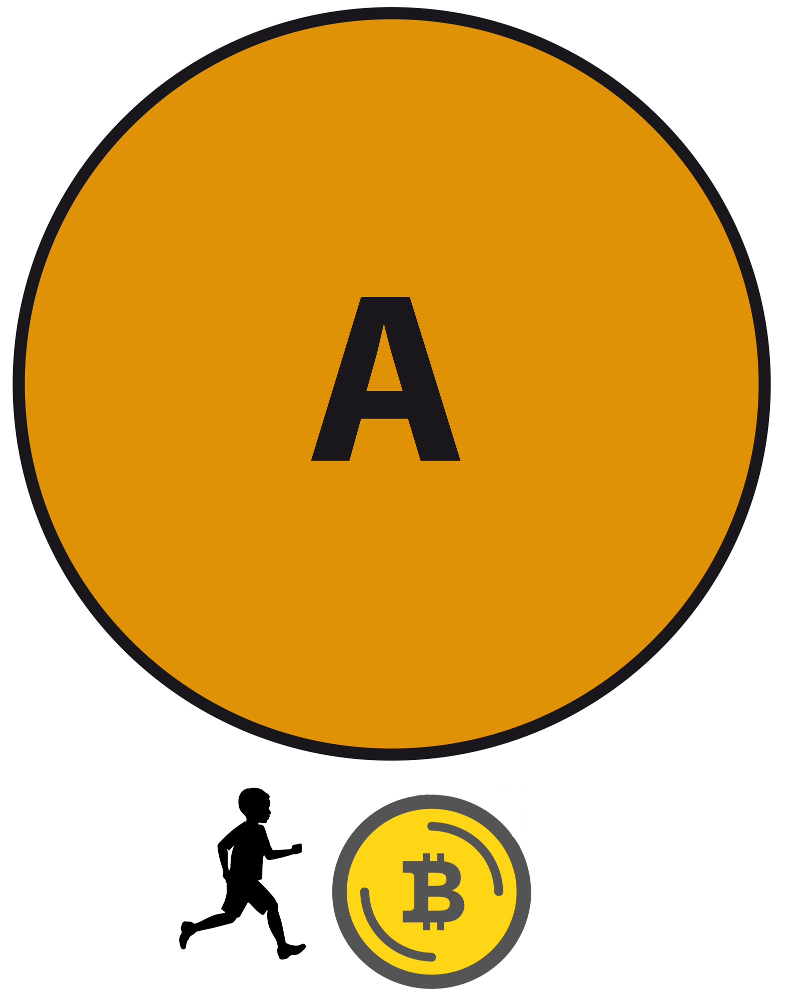

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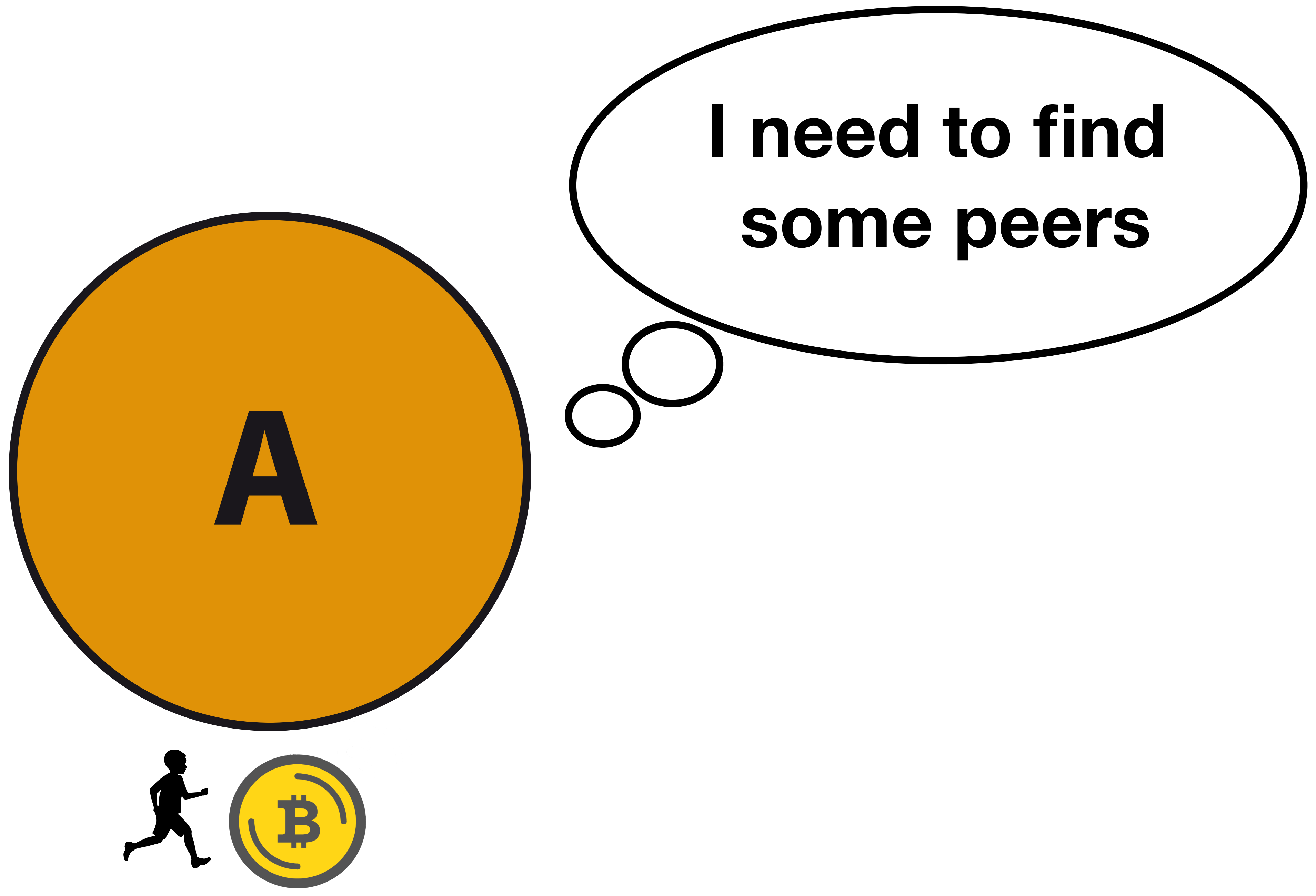

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Hardcoded trusted addresses / IRC bootstrapping / Trusted DNS seeds / etc

P2P FILE SHARING (1/2)

How to identify what other nodes are sharing (who knows what)?

How are files served?

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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 (e.g: DHT, trackers, etc)

Announce paradigm: Files are announced to peers, which will decide whether they would like a copy or not. No lookup protocol is required (e.g: gossip protocols)

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What paradigm do cryptocurrency networks follow?

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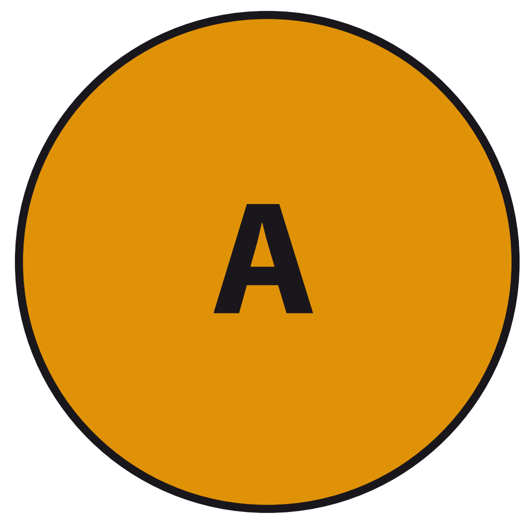
What paradigm do cryptocurrency networks follow? **Announce**

REQUEST PARADIGM (BitTorrent)



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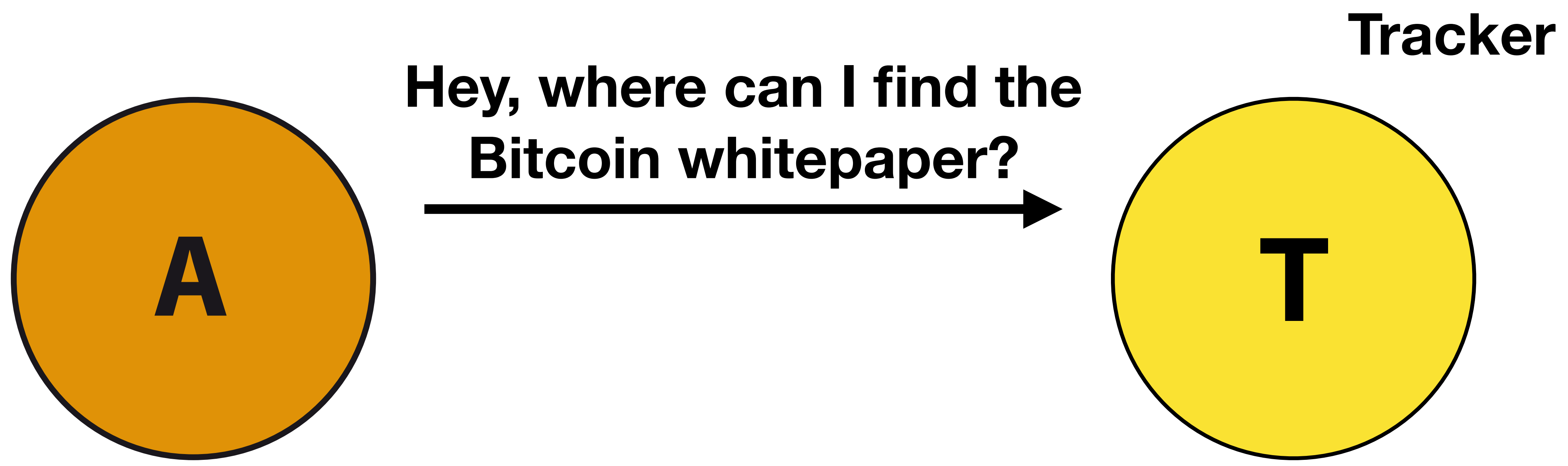

- Get file information from a tracker

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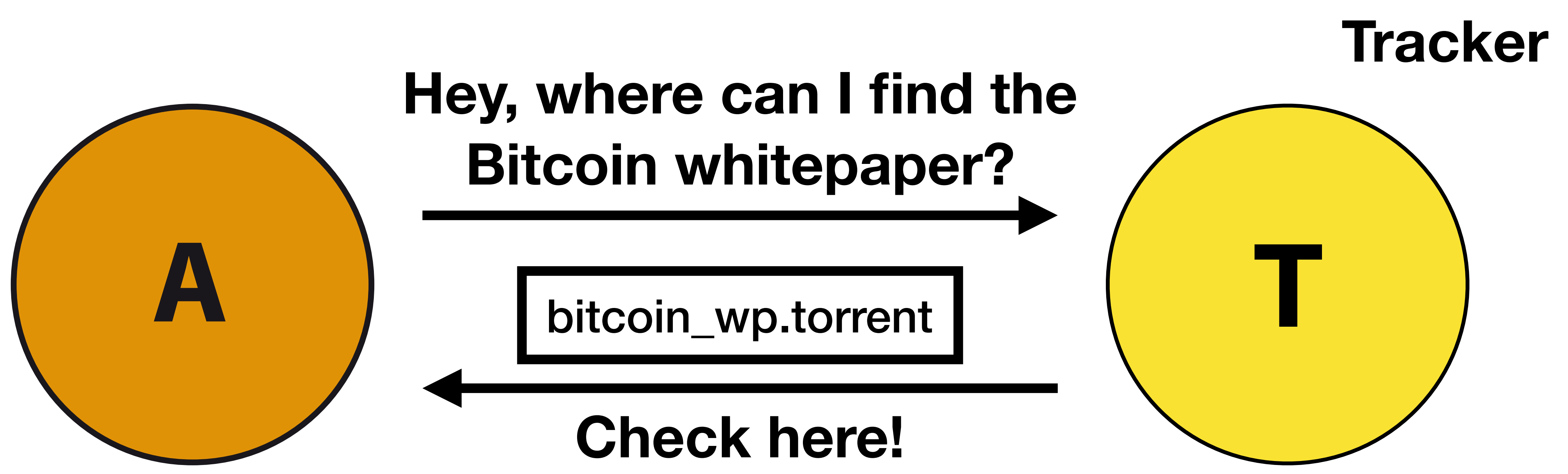

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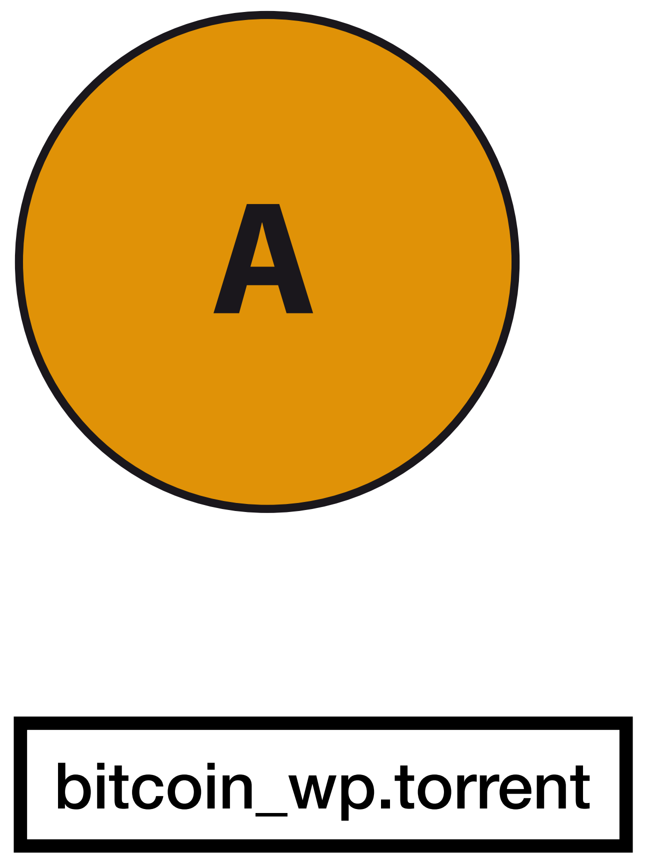

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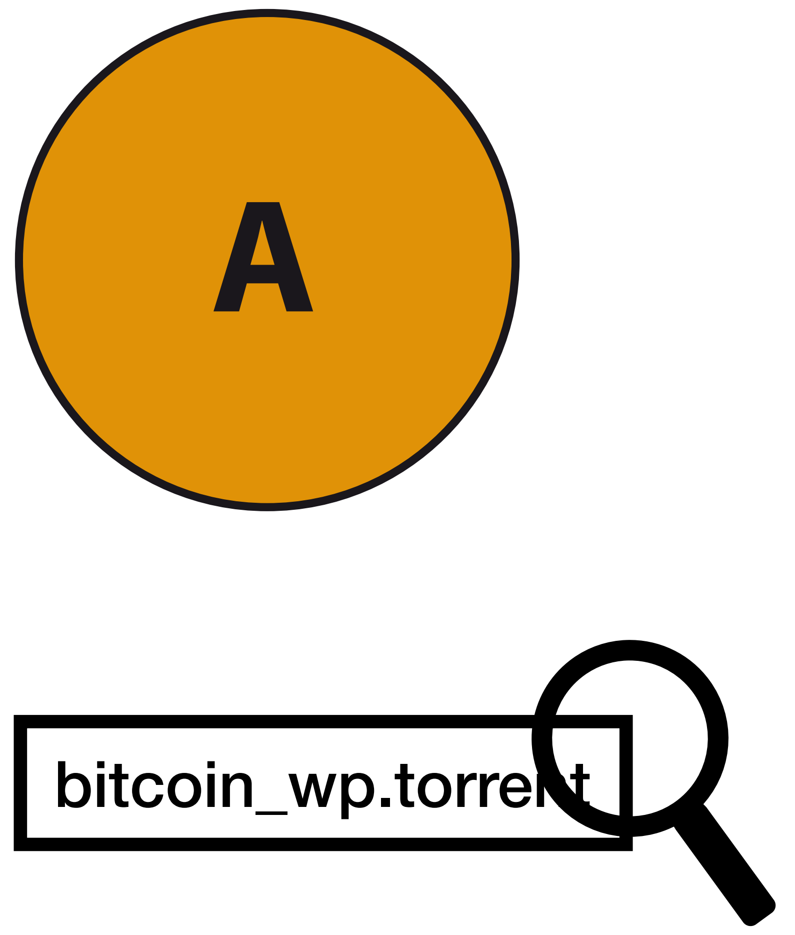

- Get file information from a tracker
- Check the .torrent file

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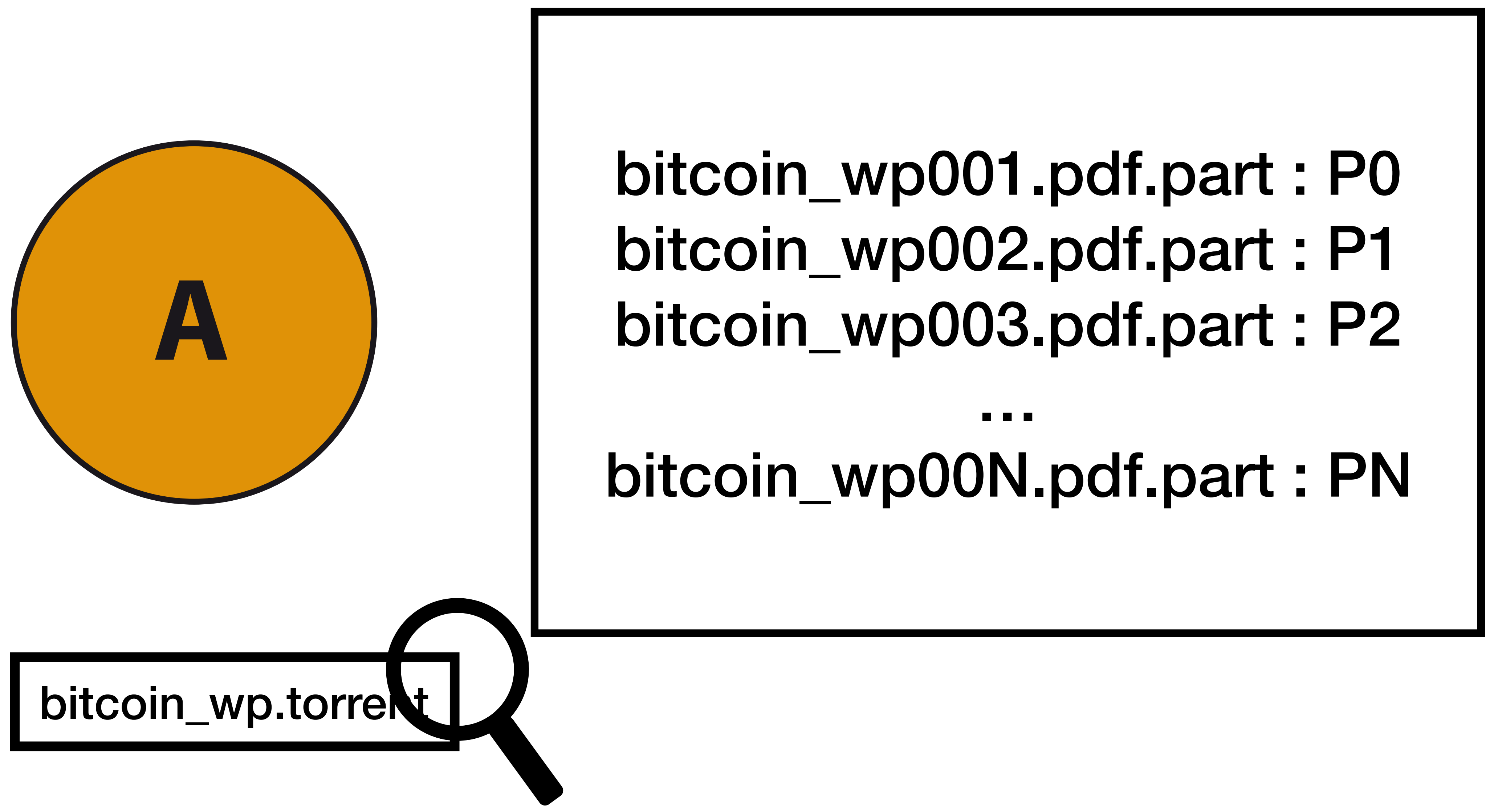

bitcoin_wp001.pdf.part : P0
bitcoin_wp002.pdf.part : P1
bitcoin_wp003.pdf.part : P2
...
bitcoin_wp00N.pdf.part : PN

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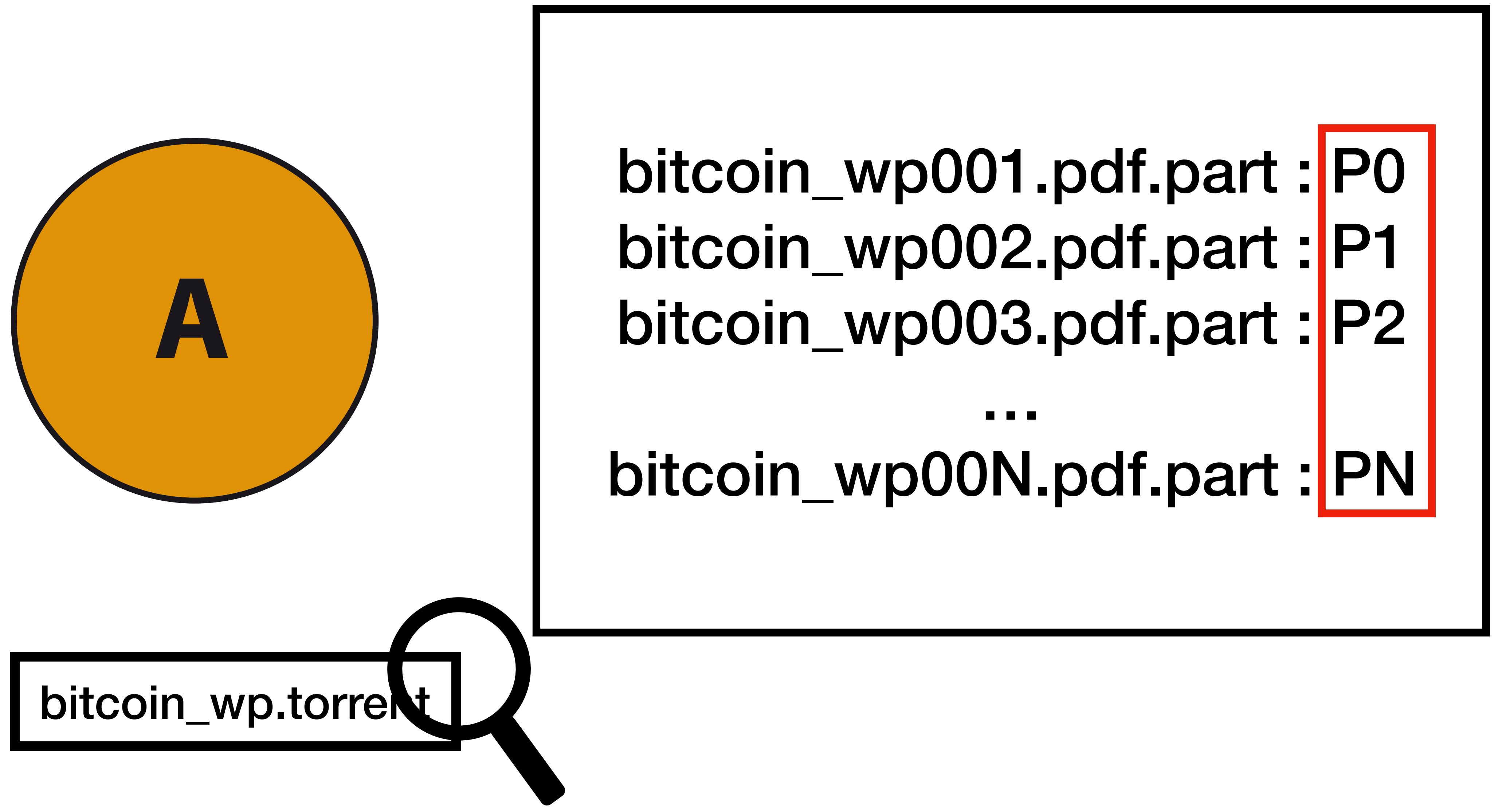
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bitcoin_wp.torrent
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- Get file information from a tracker
- Check the .torrent file
- Connect to peers and retrieve the file parts

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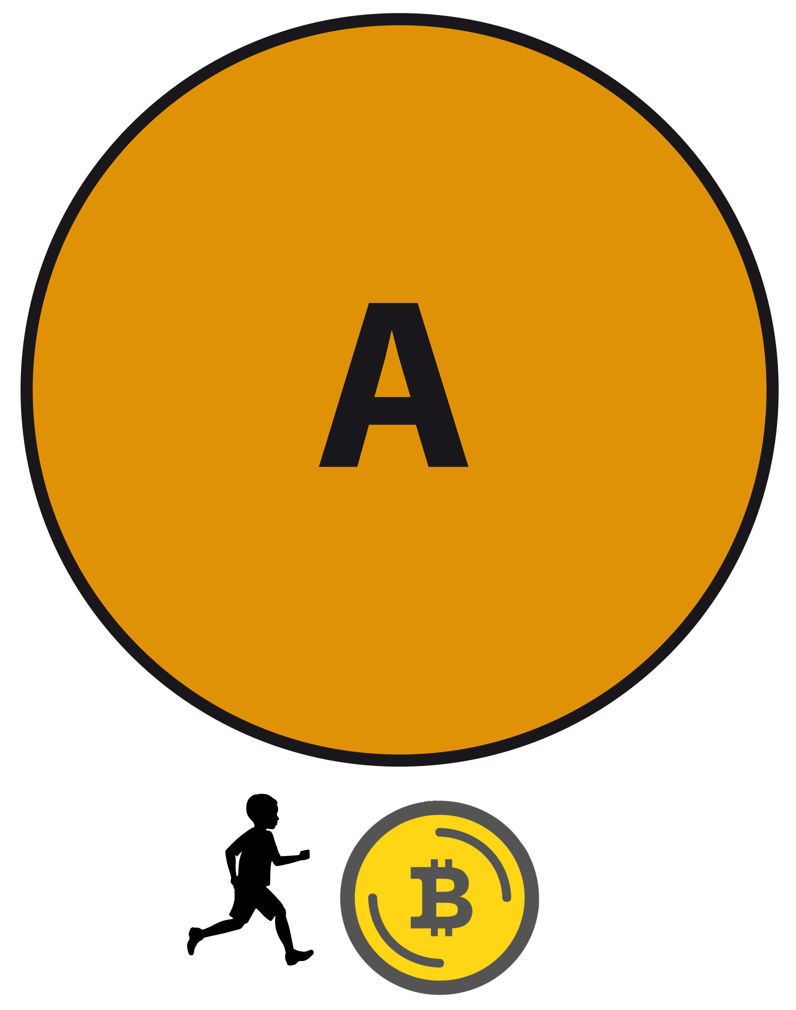
What information should a node know about the system?

A (full) node needs all the information in order to validate new items

Node bootstrapping and peer discovery

BITCOIN PEER DISCOVERY



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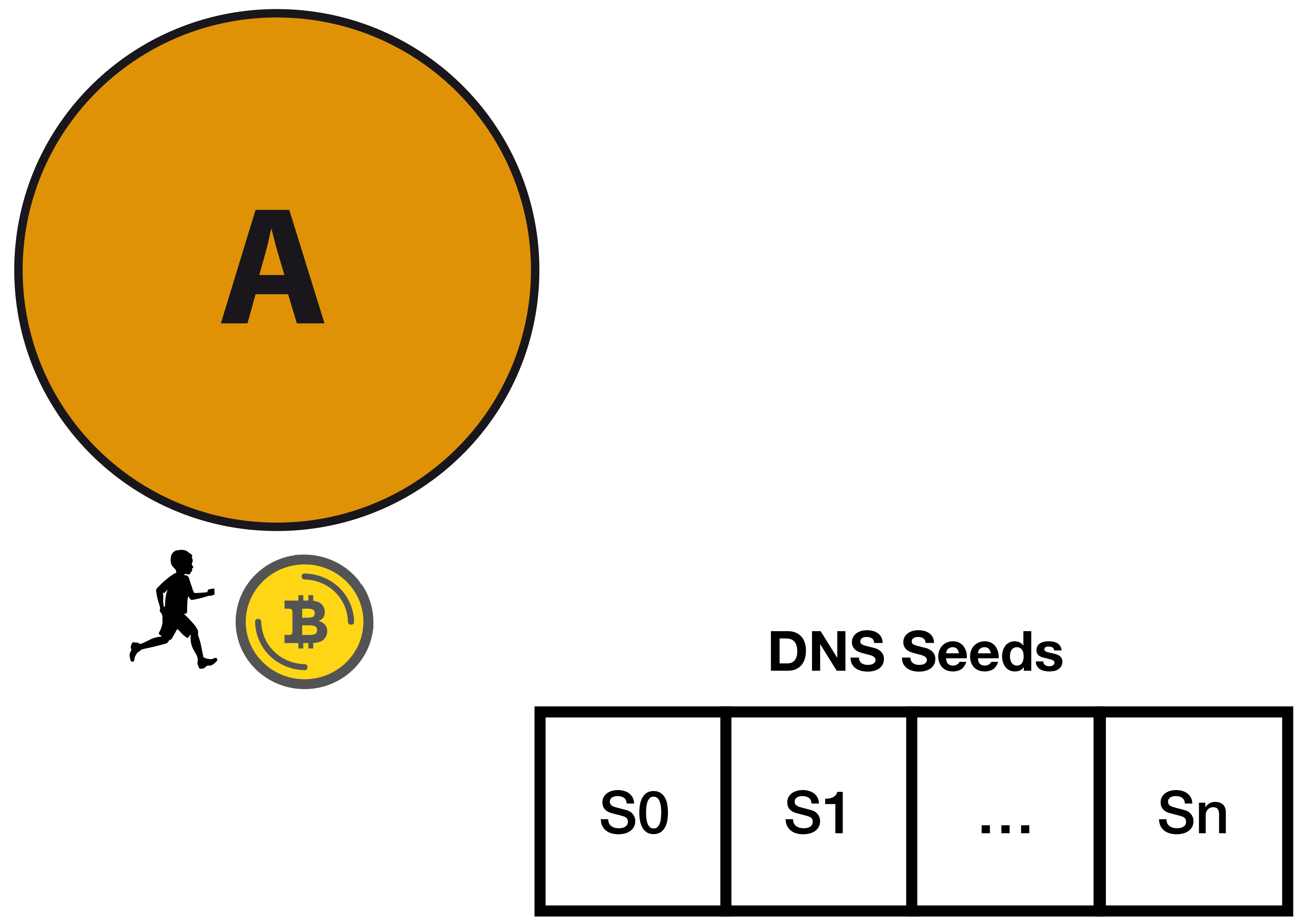

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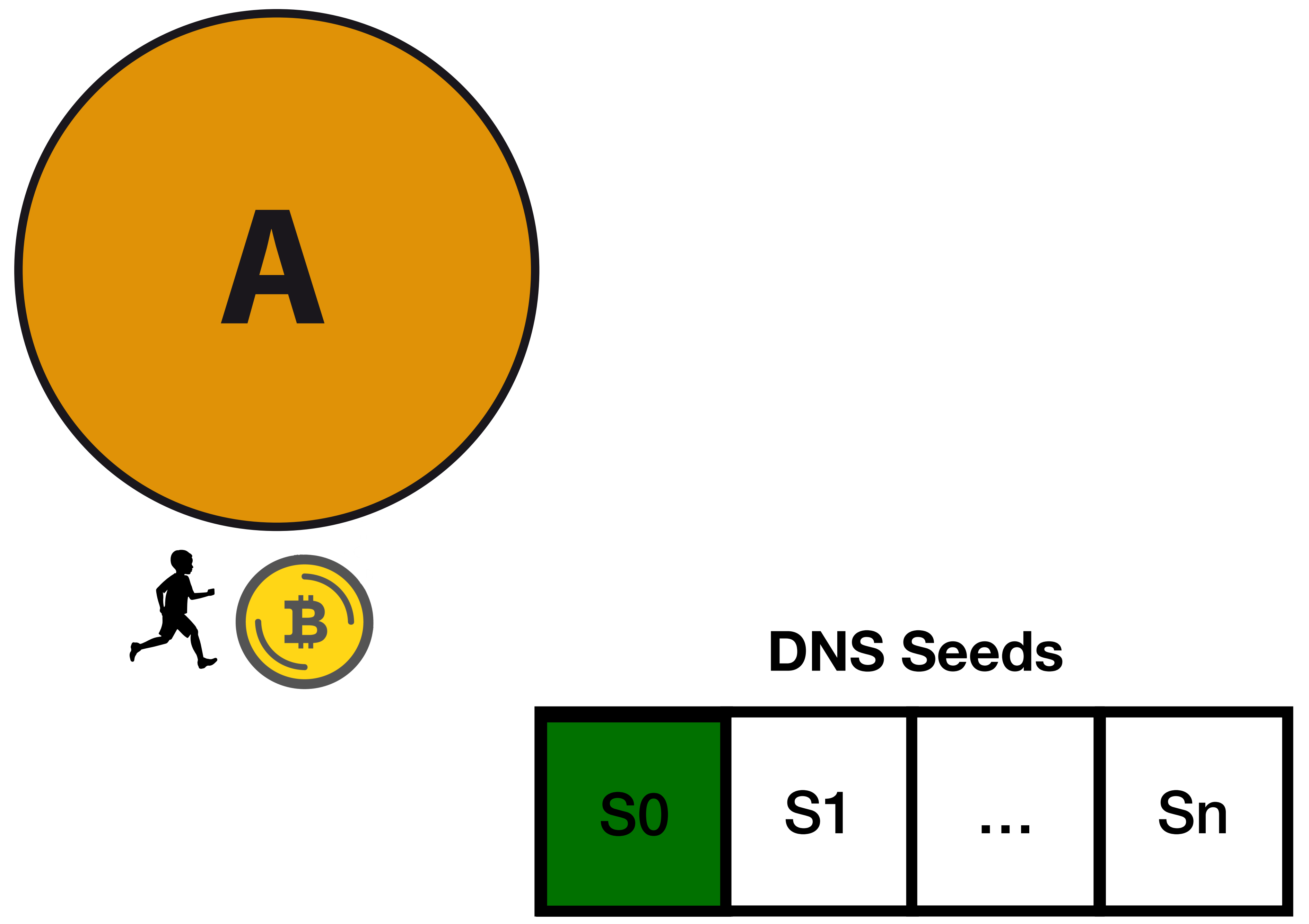

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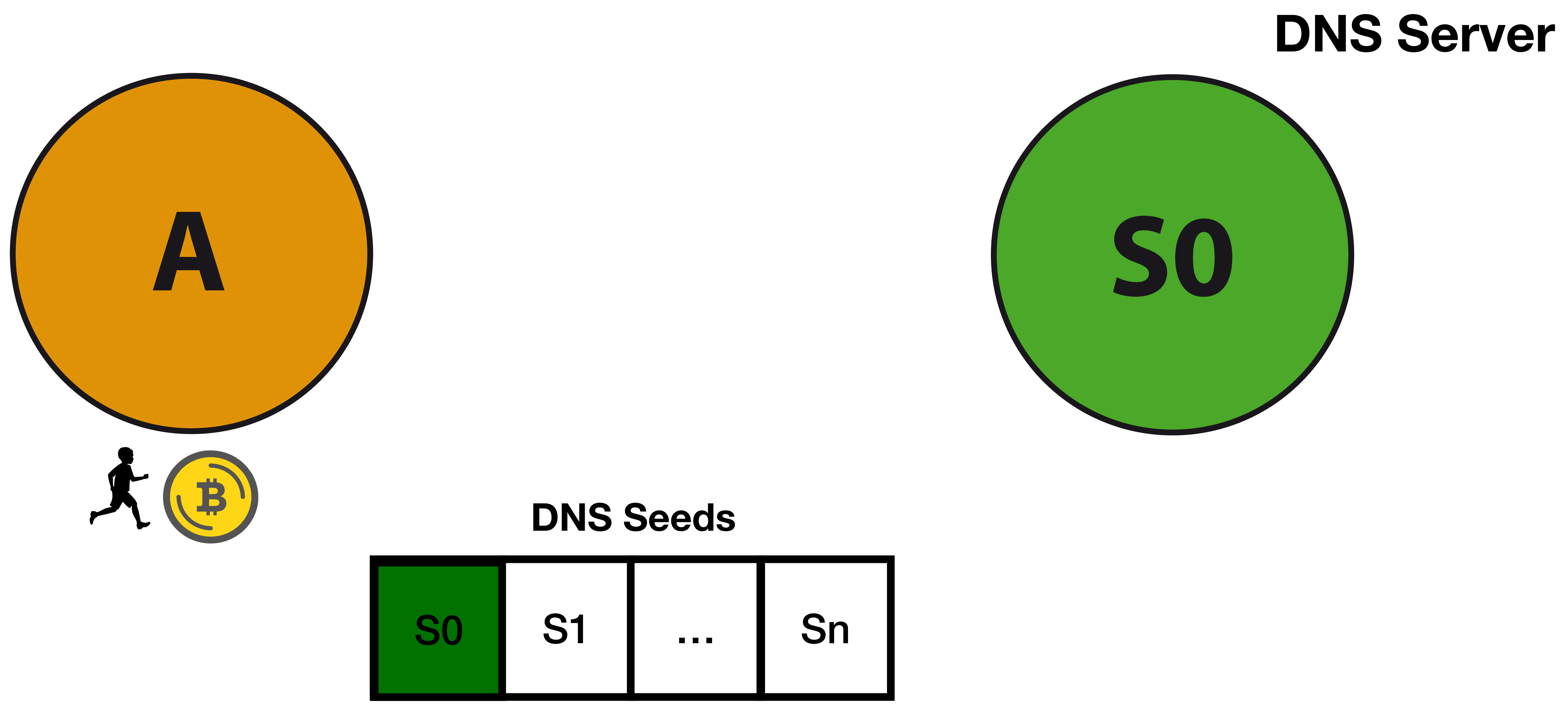

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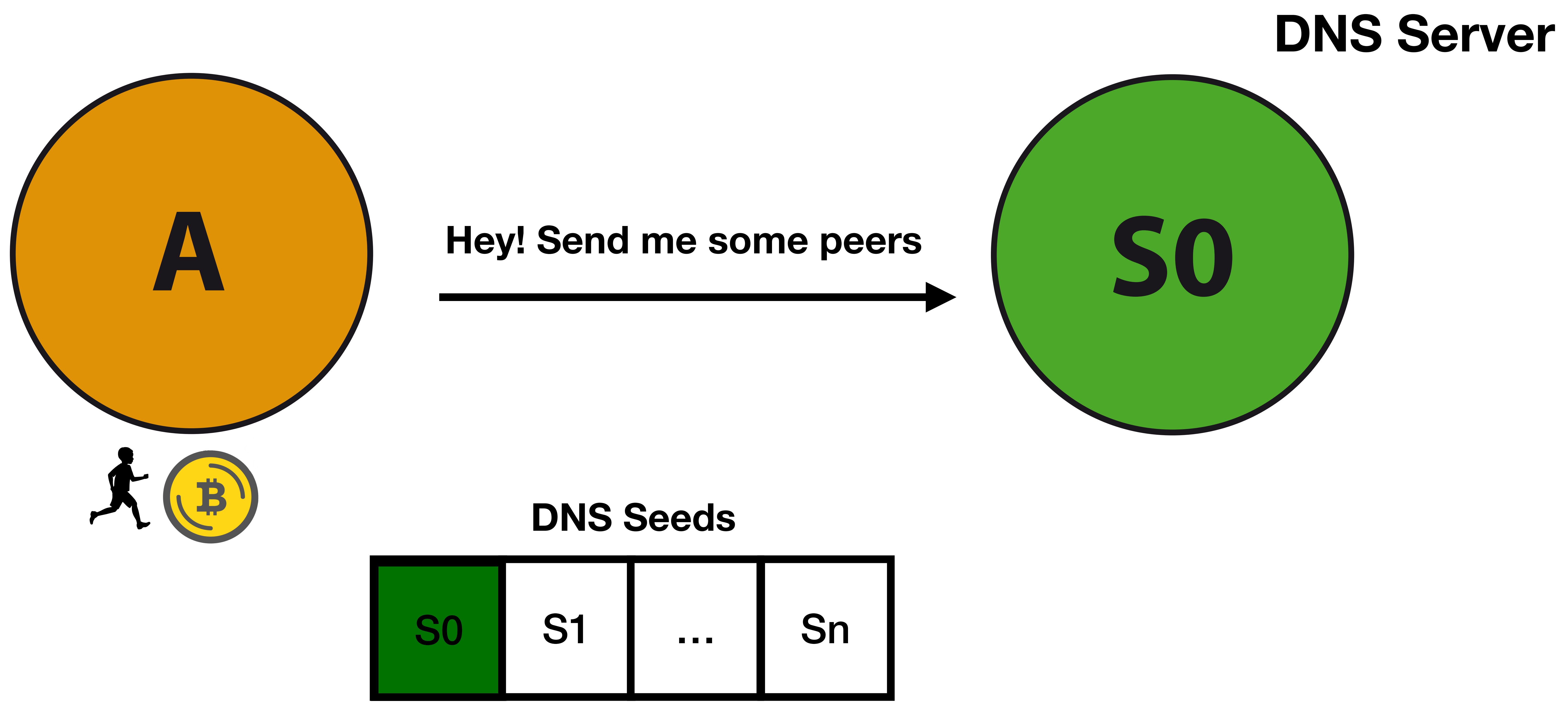

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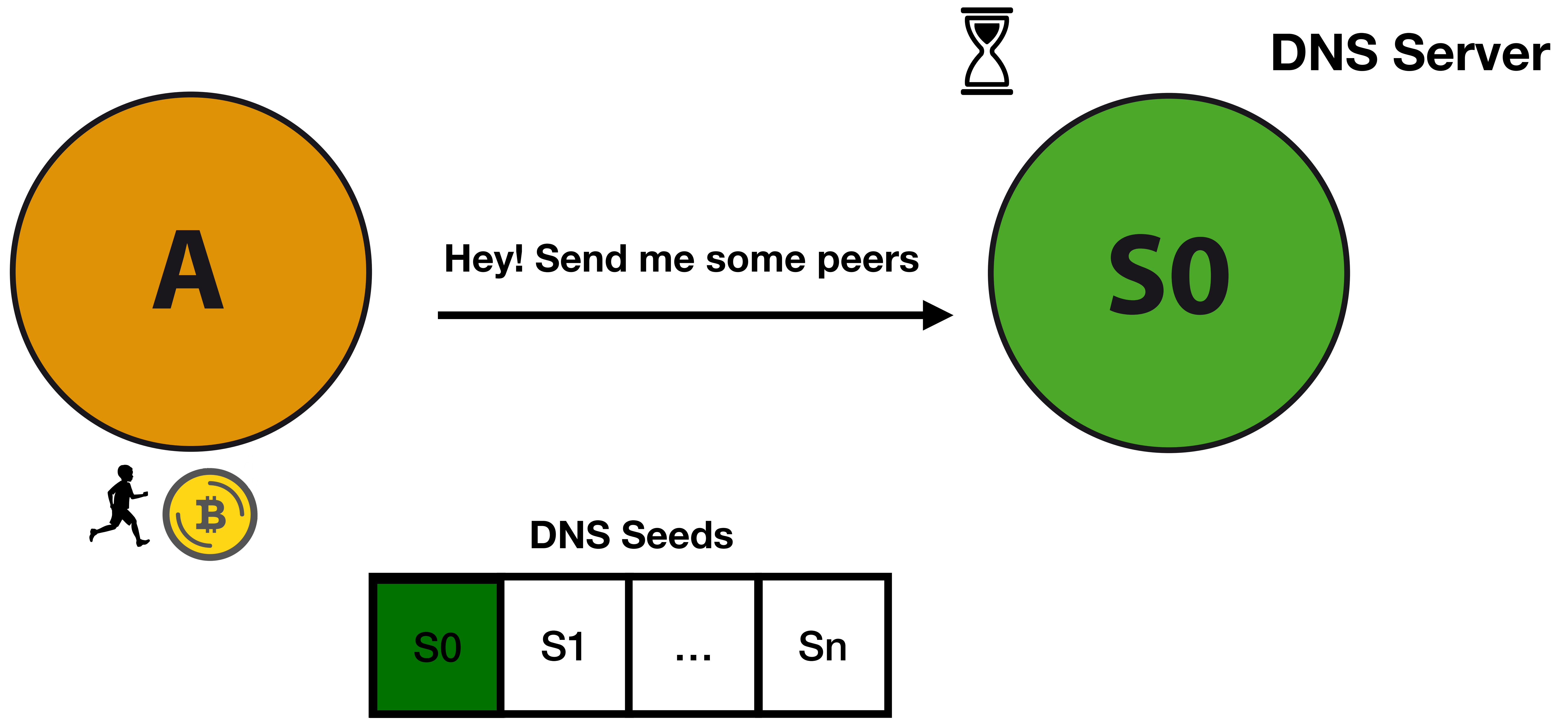

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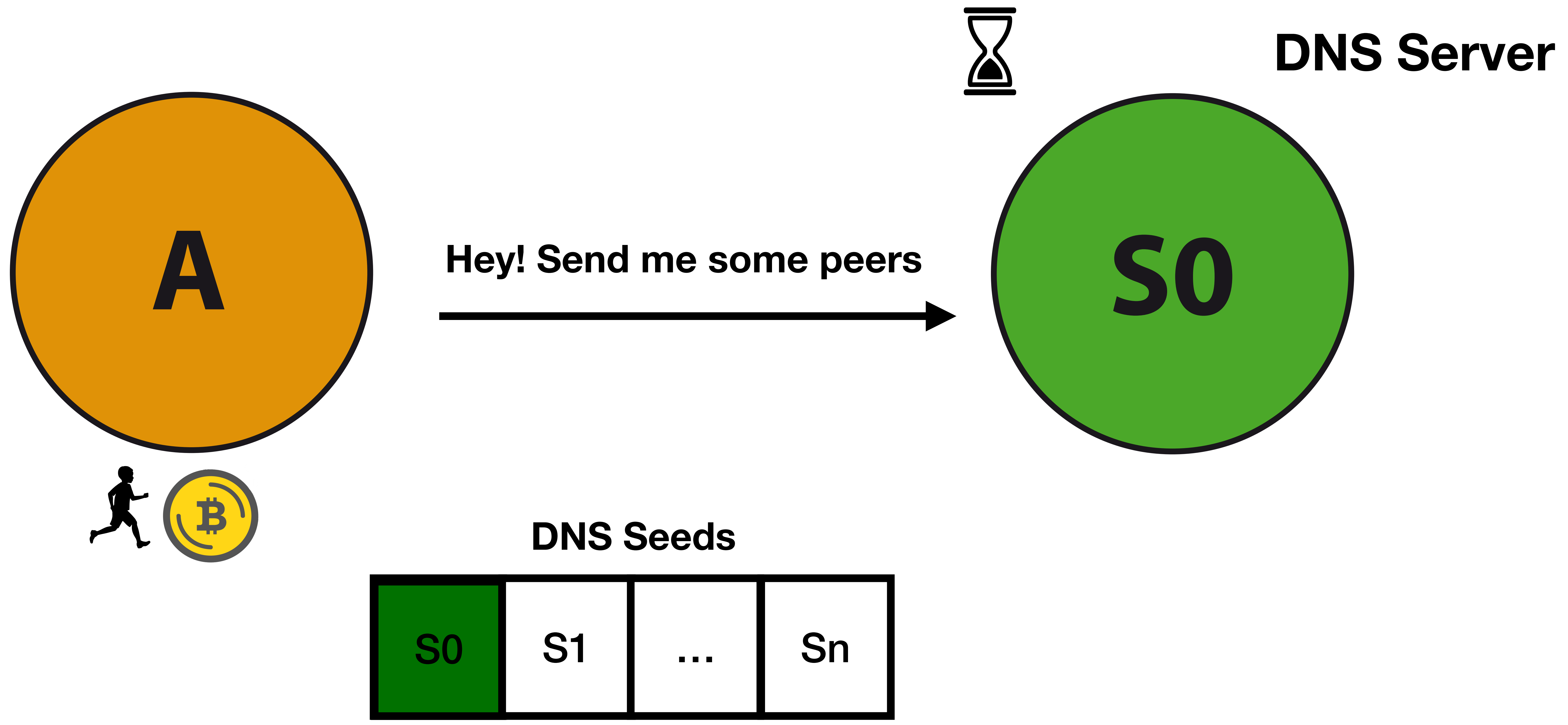

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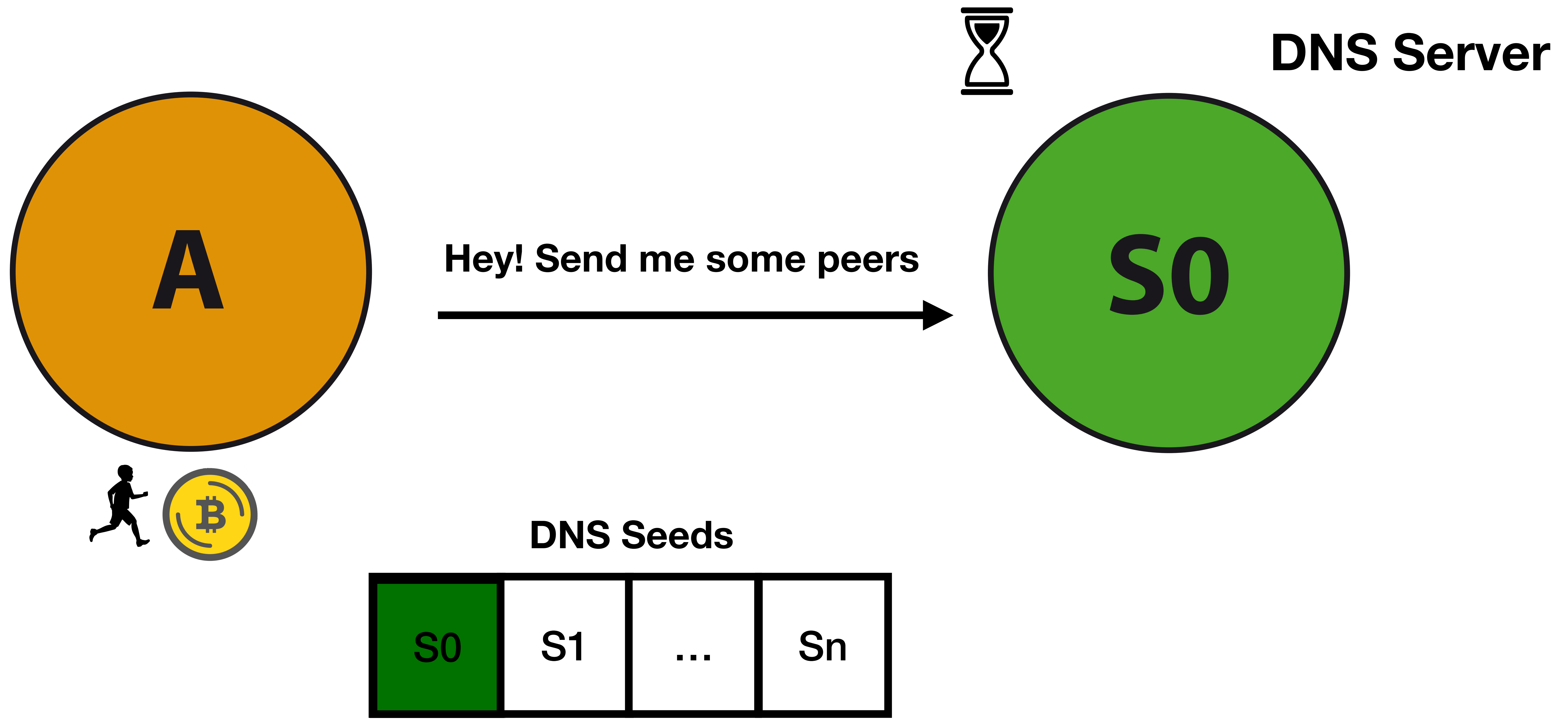

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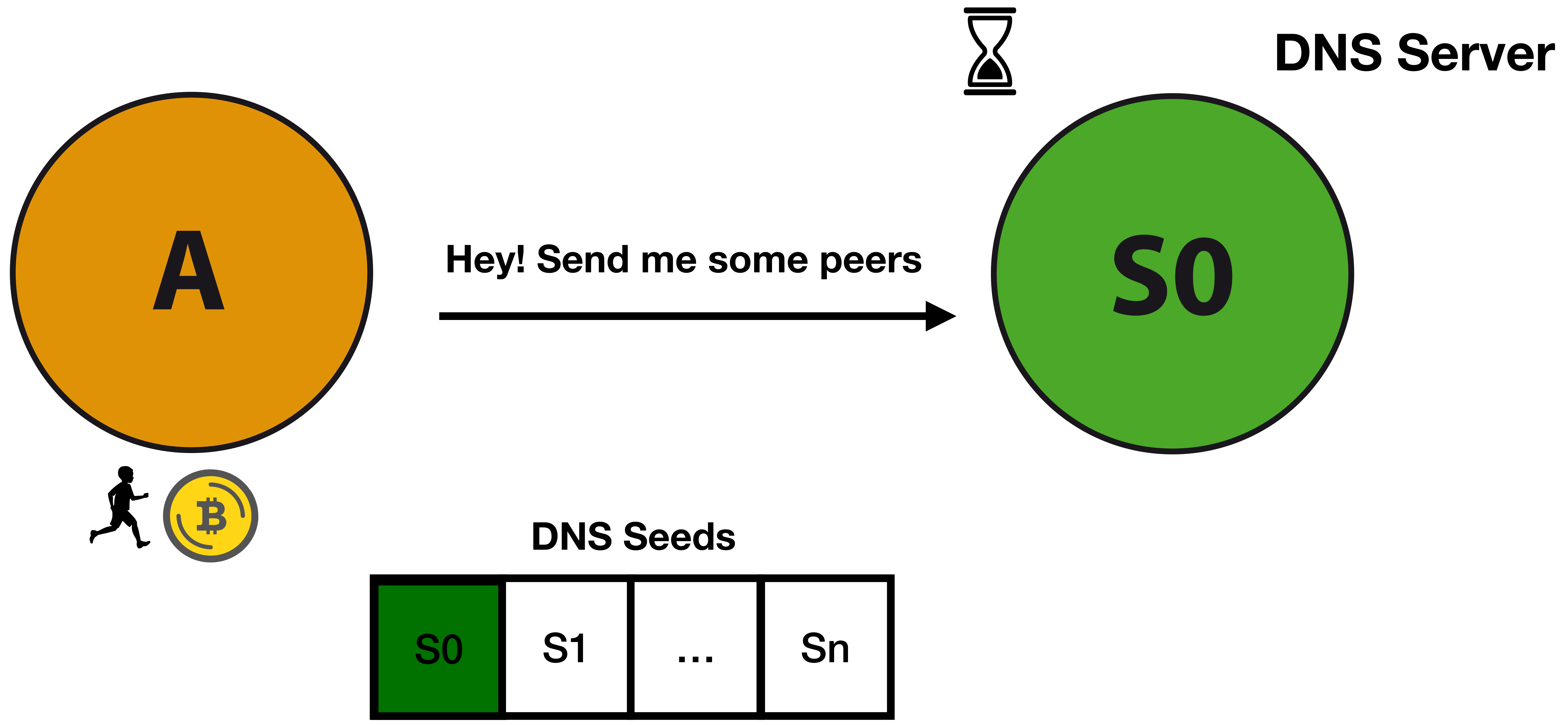

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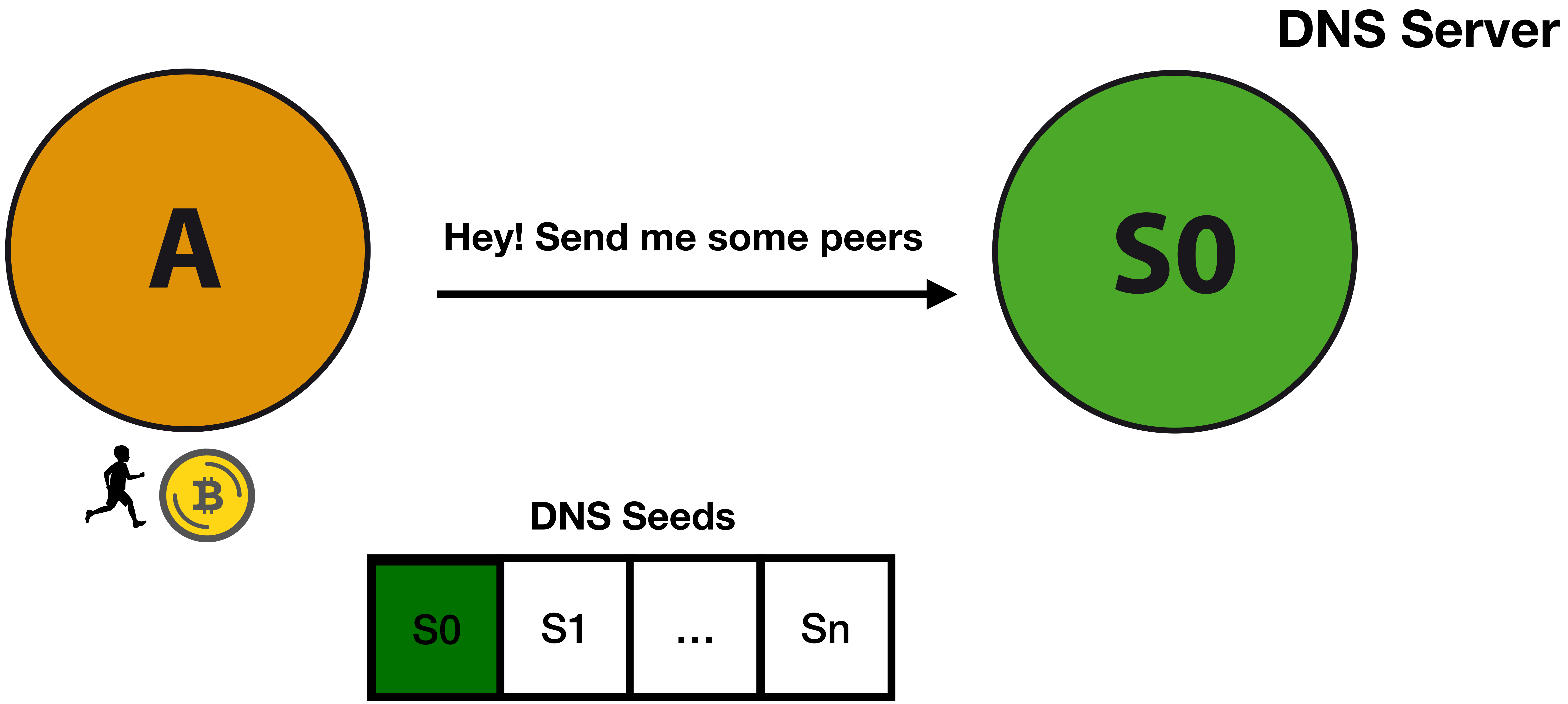

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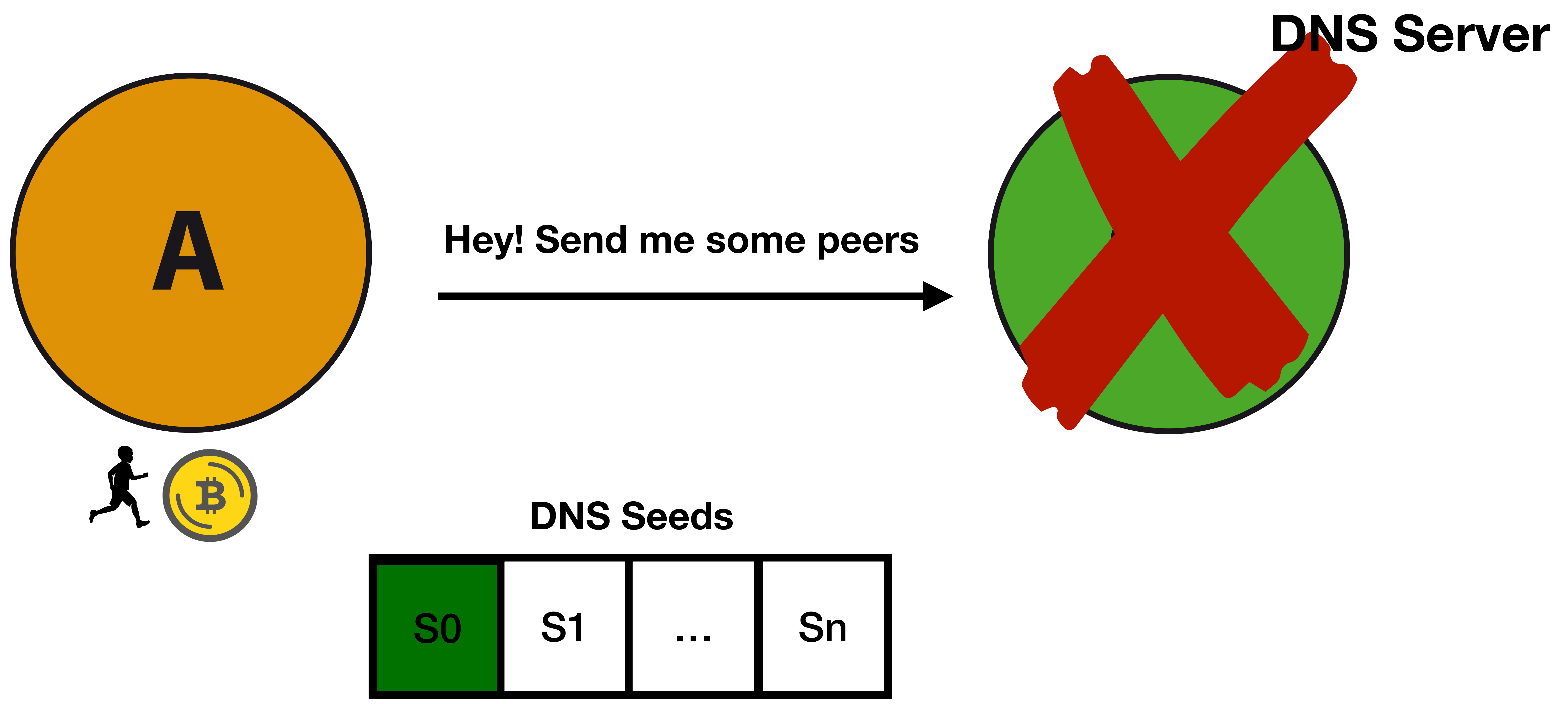

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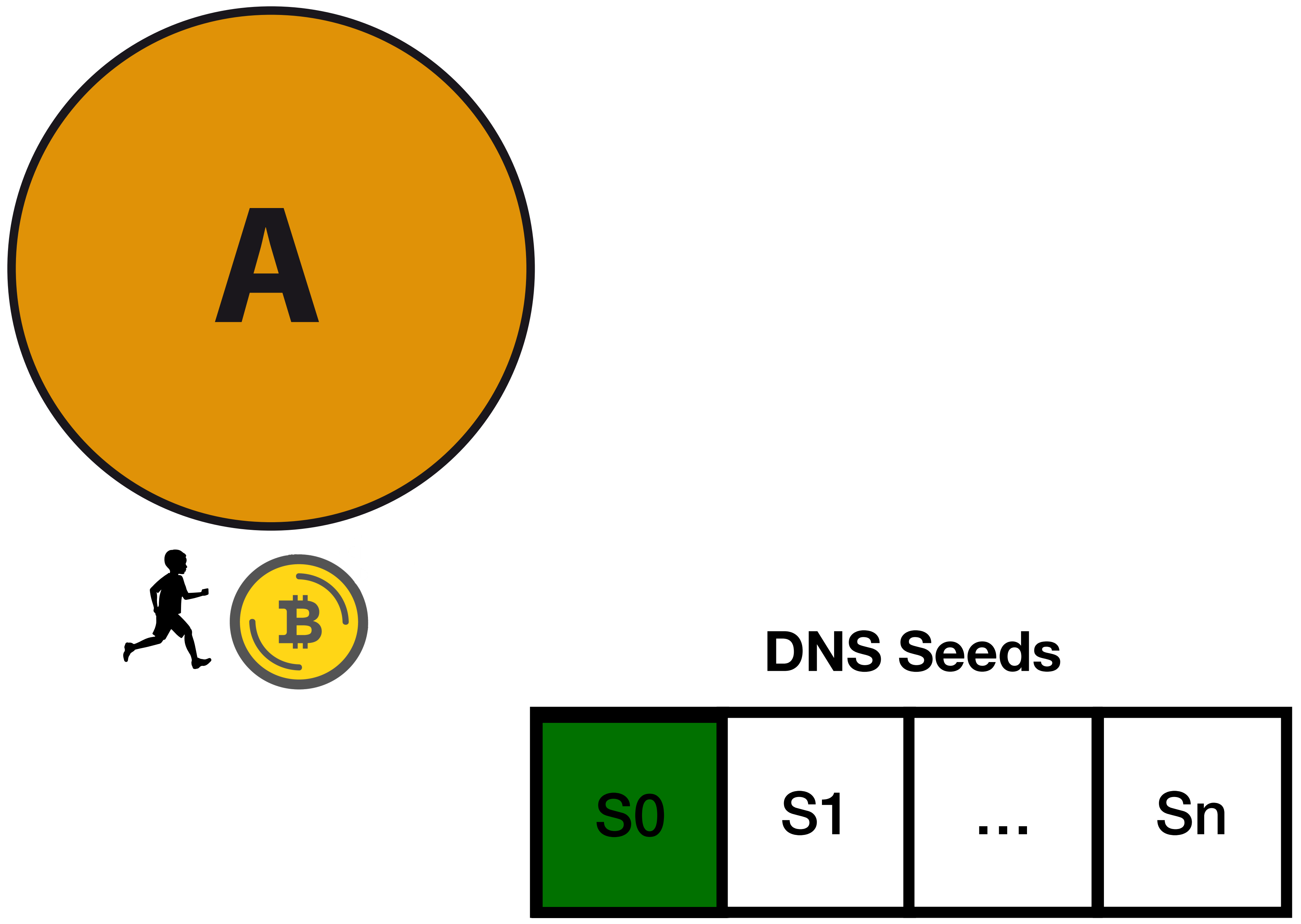

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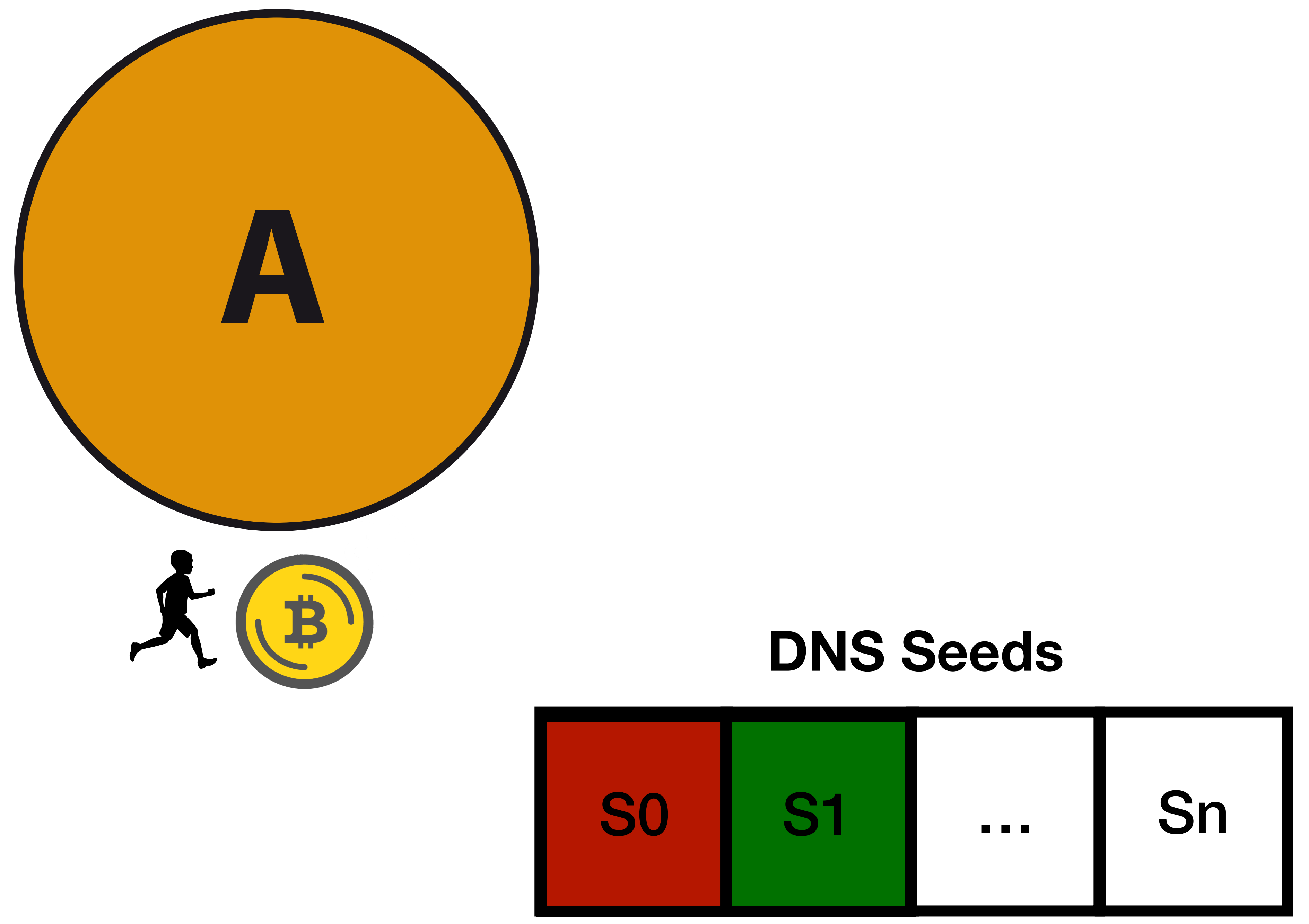

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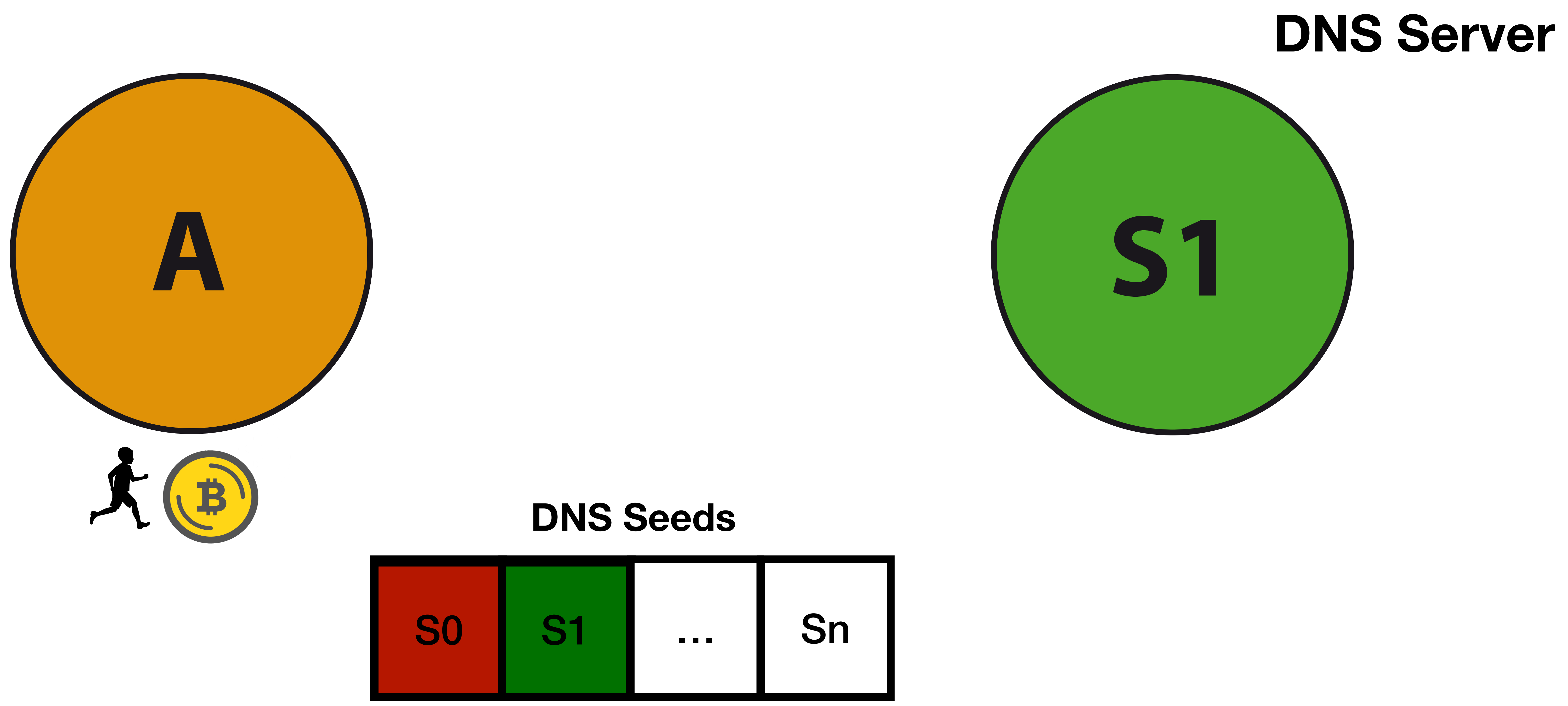

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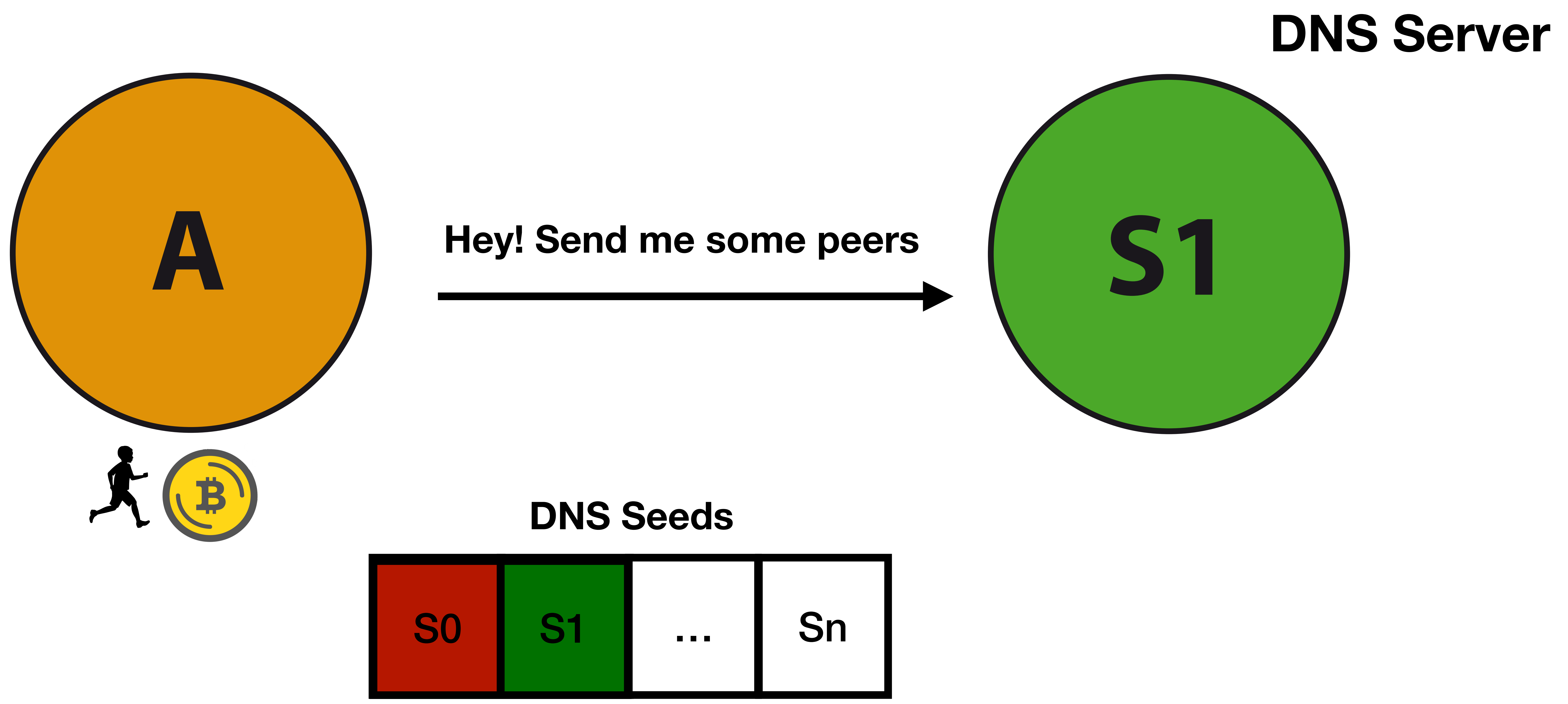

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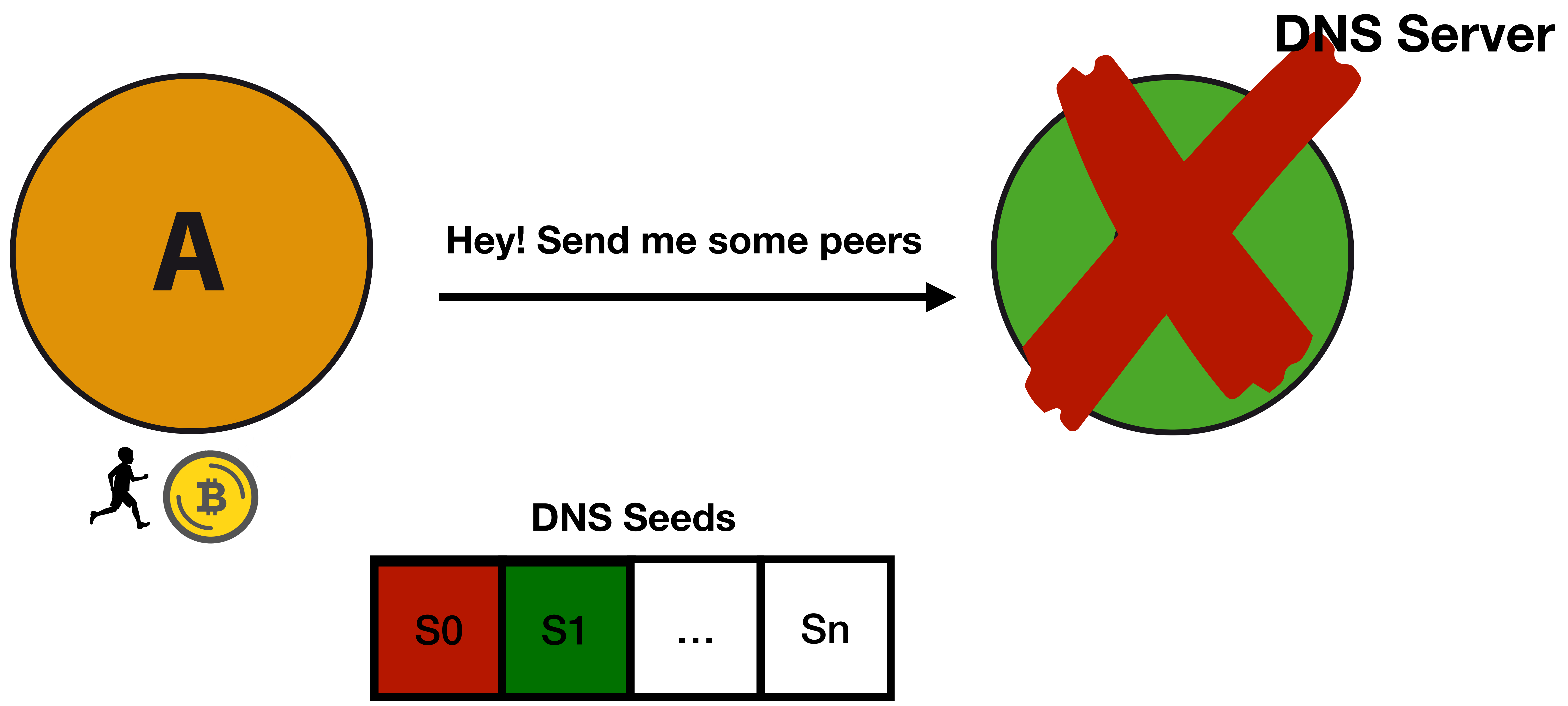

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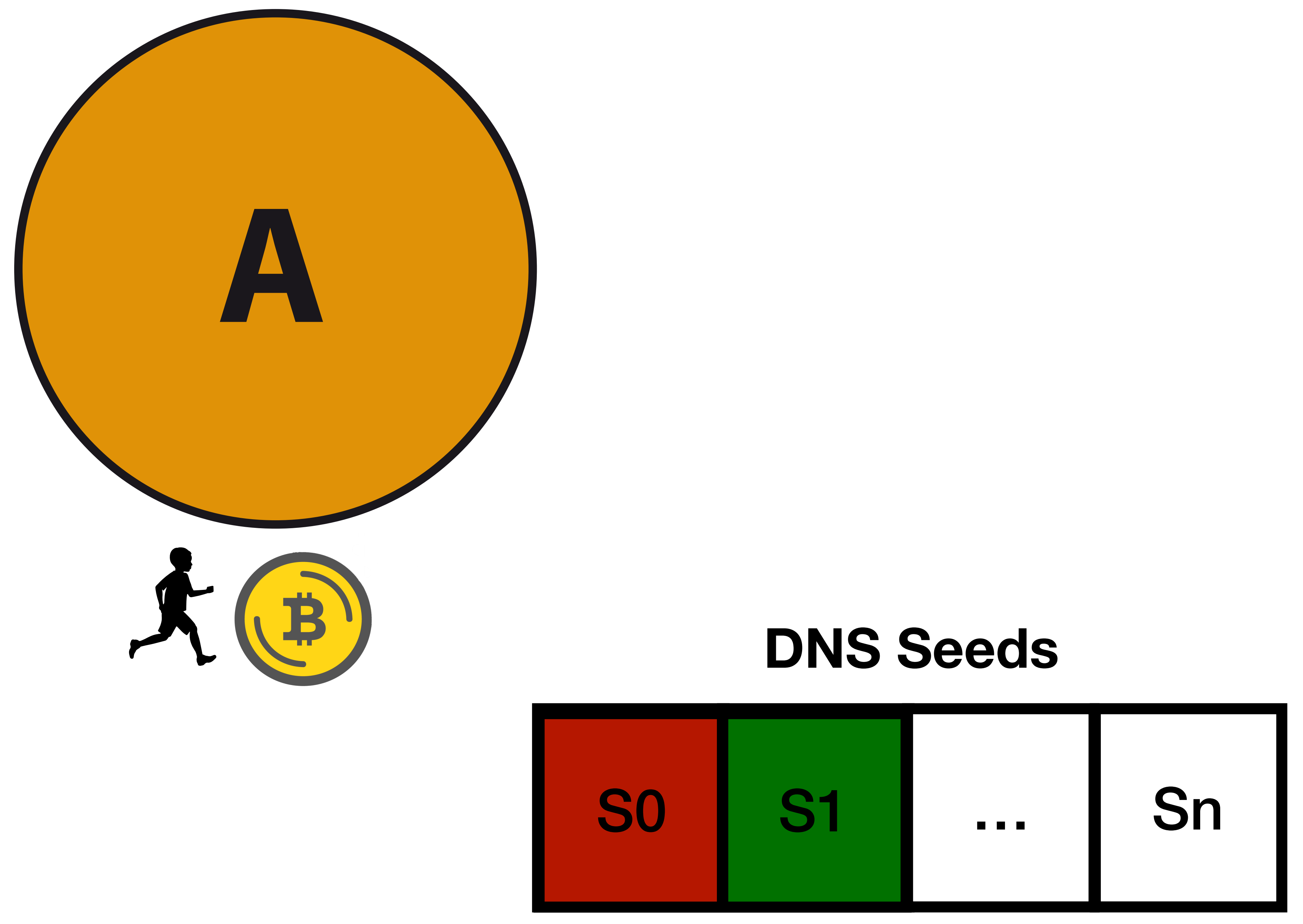

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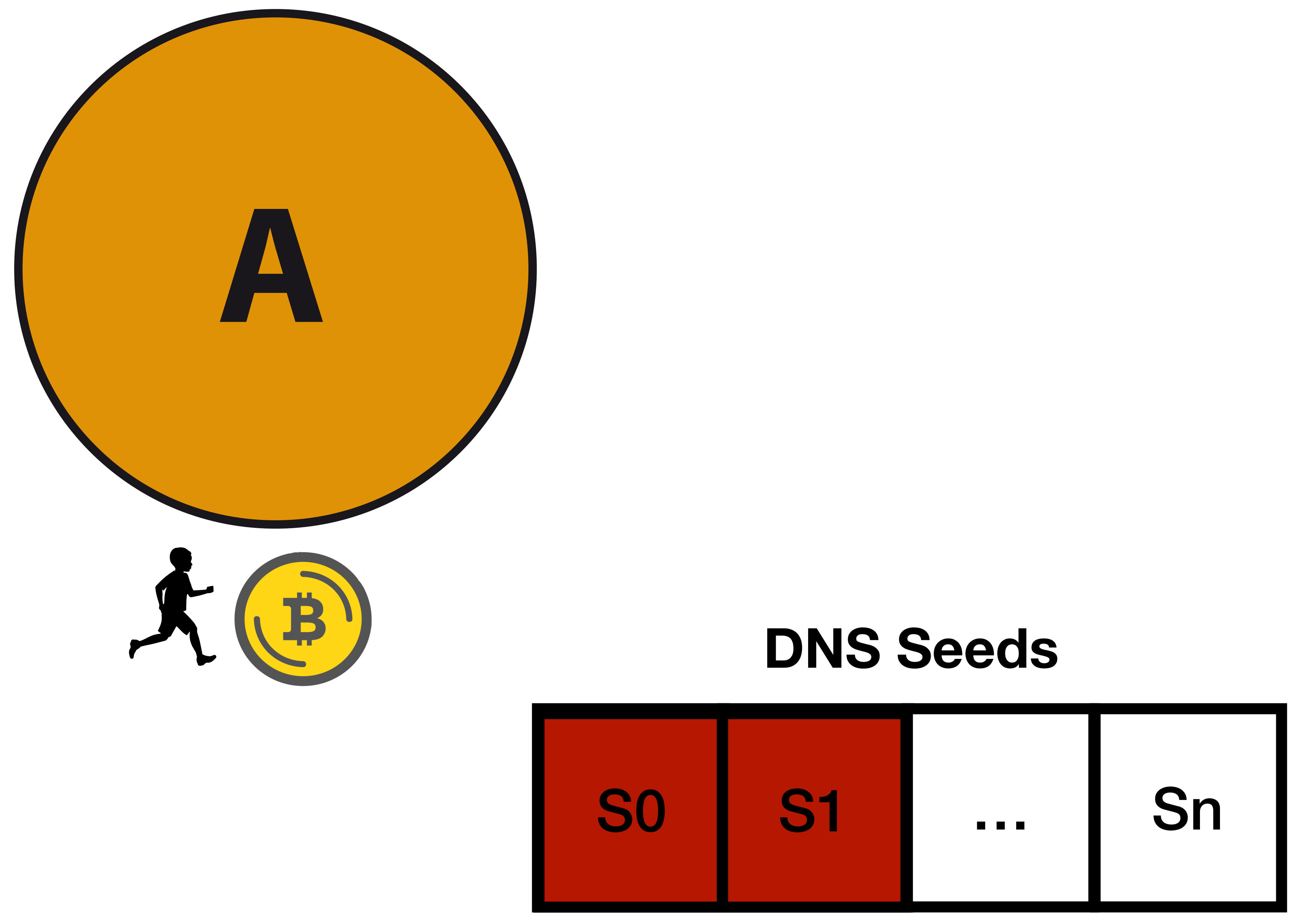

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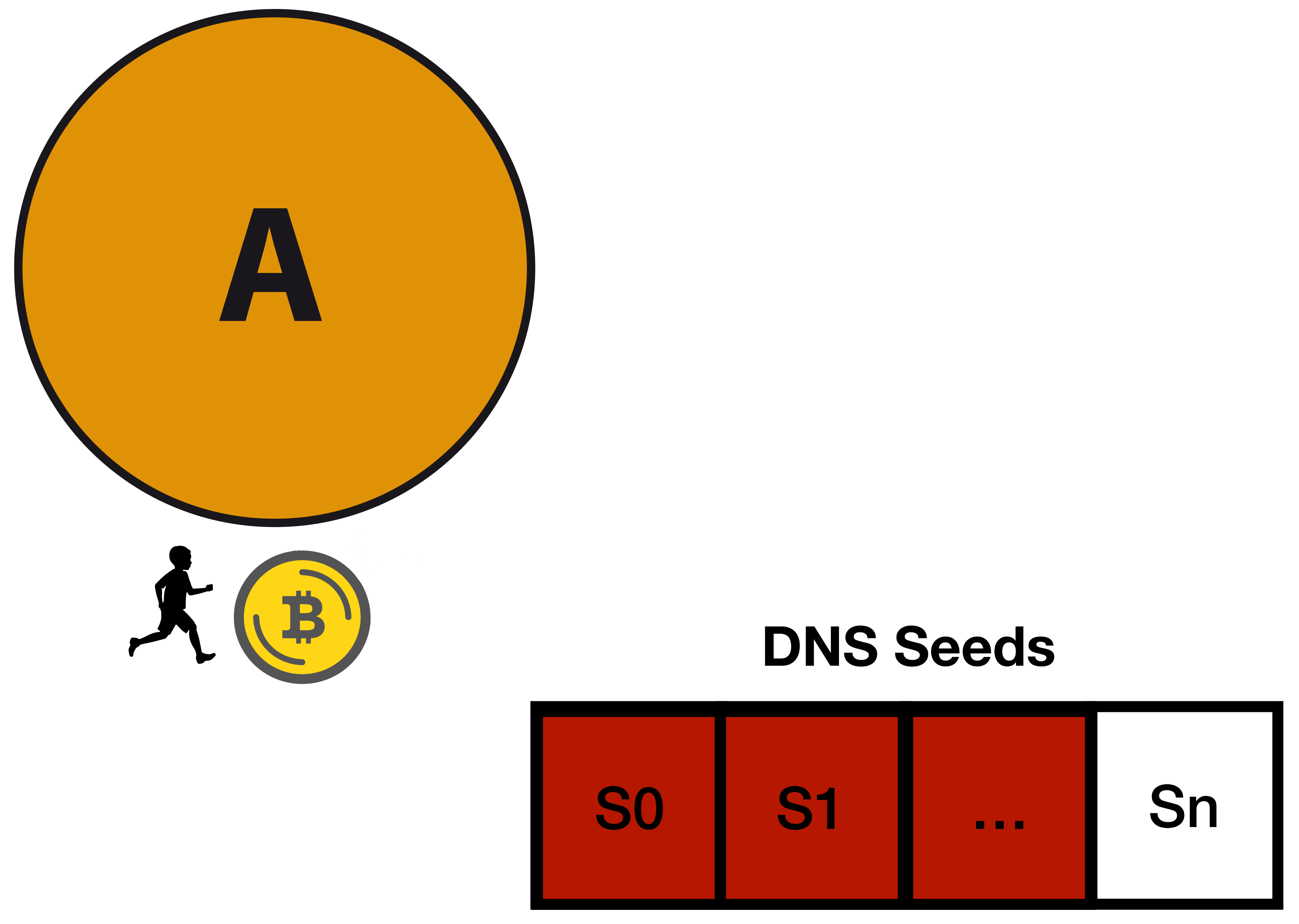

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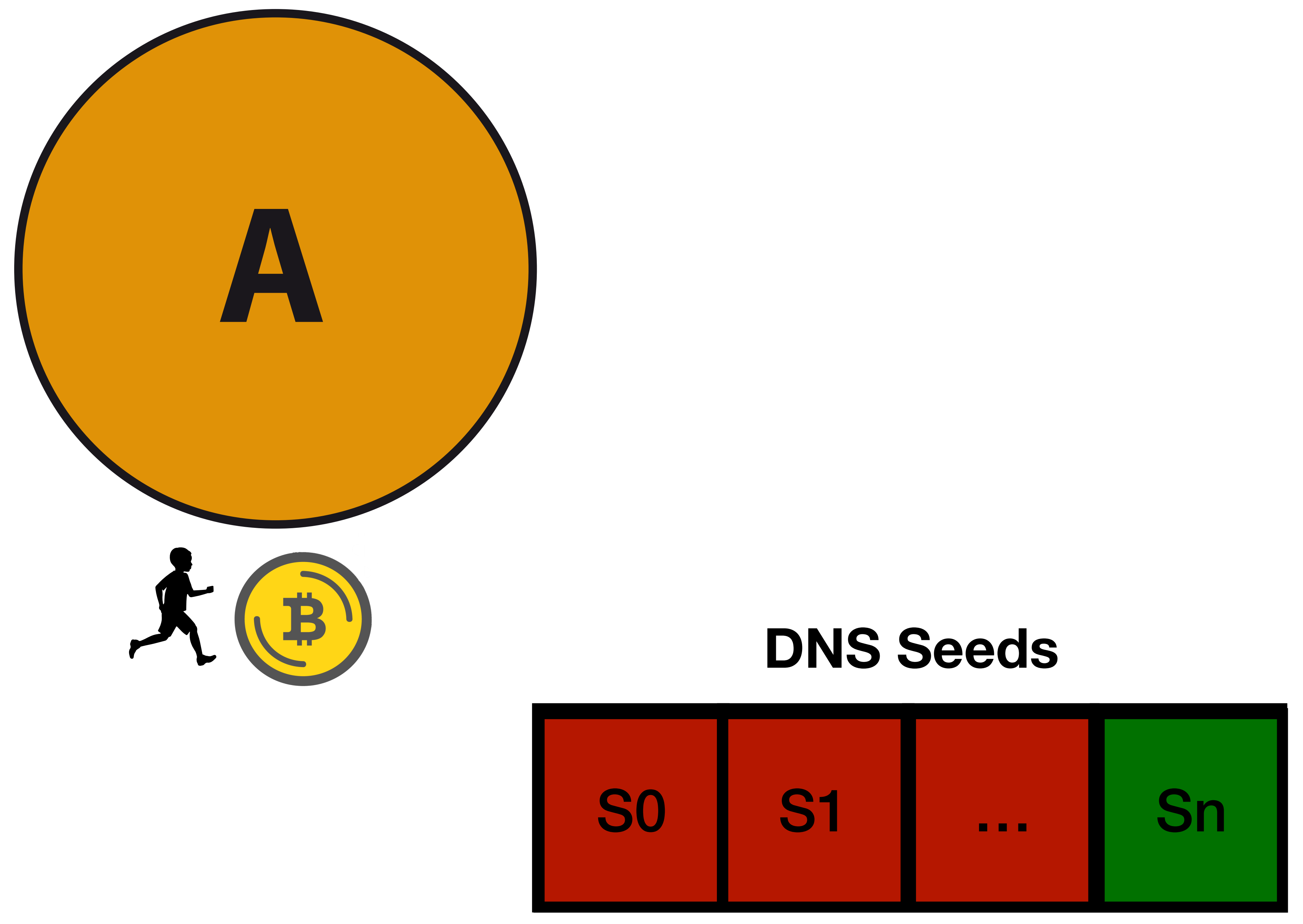

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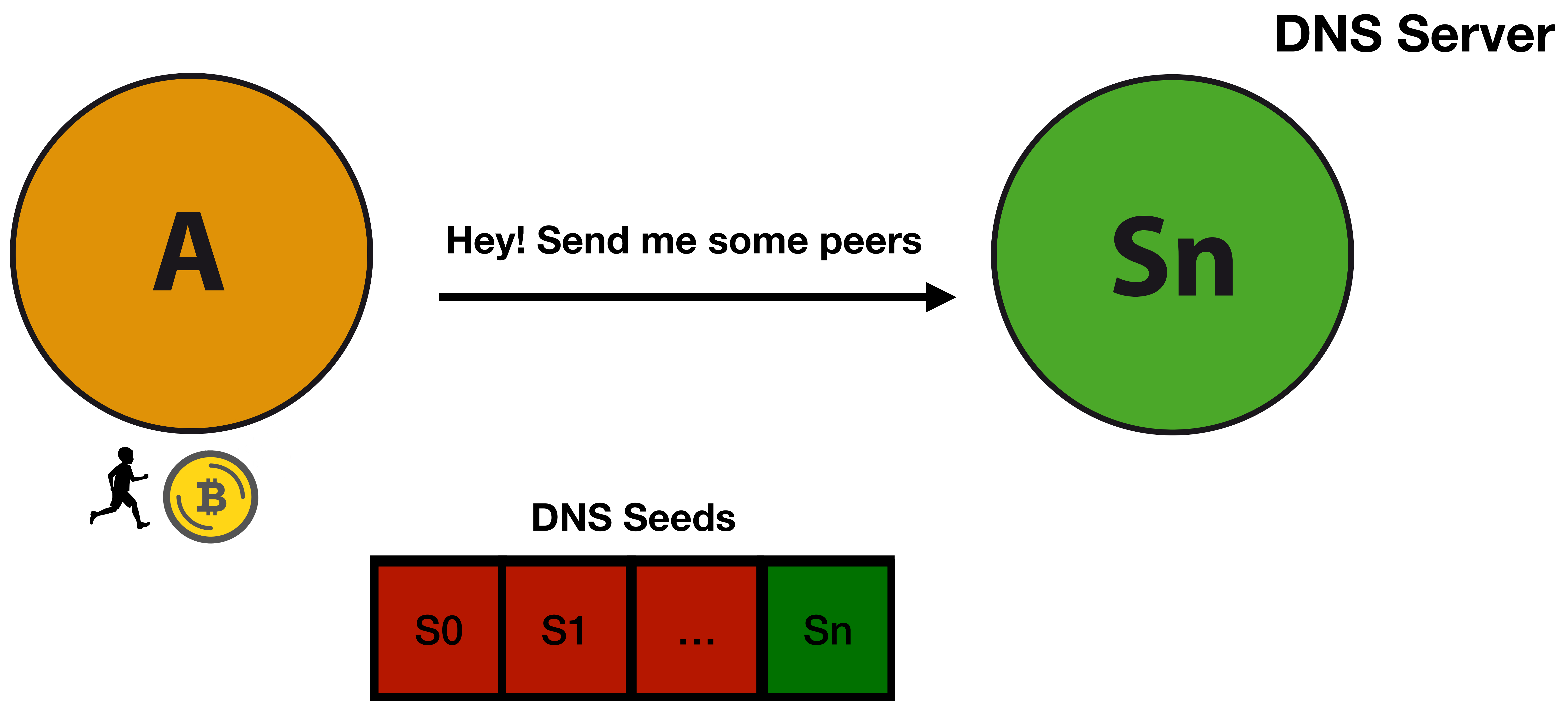

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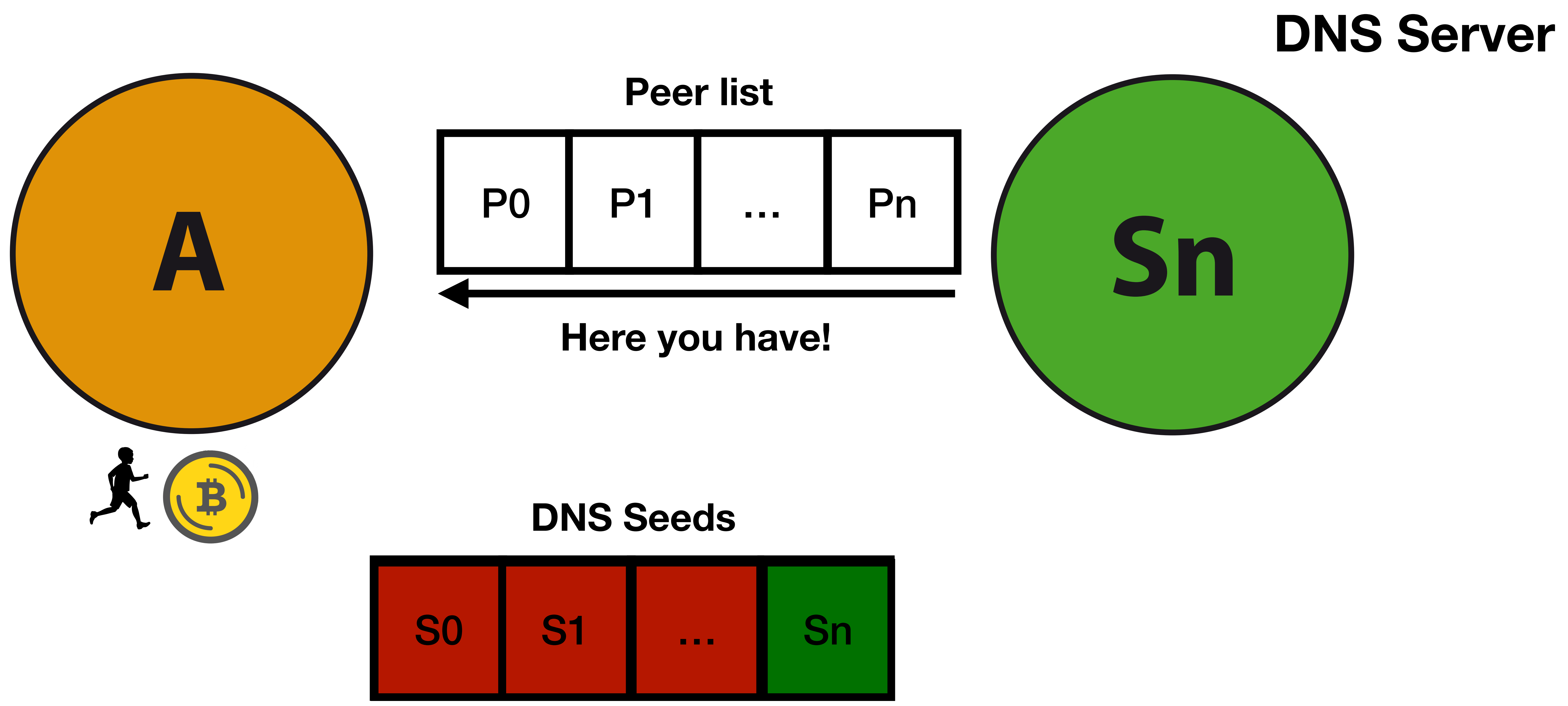
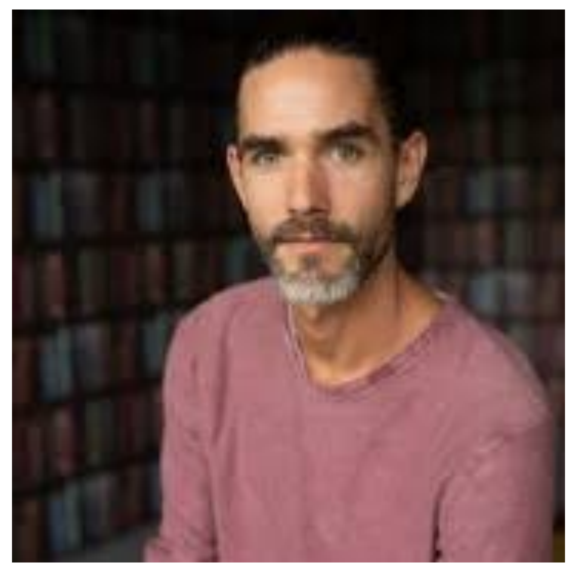


BITCOIN DNS SERVER HOSTS

```
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
```

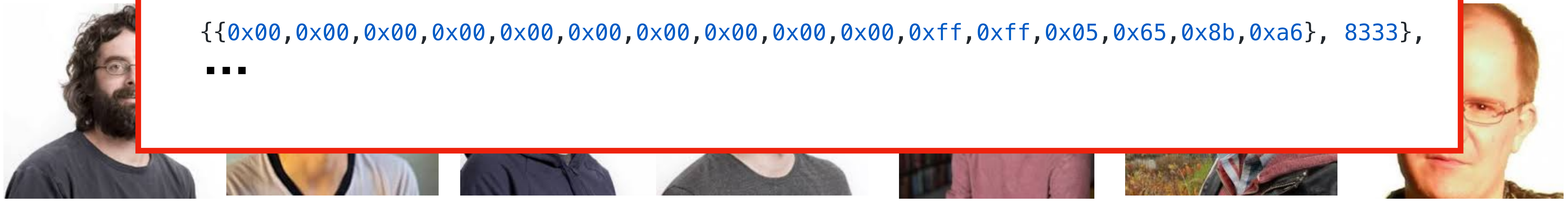


BITCOIN DNS SERVER HOSTS

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
vSeeds.
vSeeds.
vSeeds.
vSeeds.
vSeeds.
vSeeds.
```

```
static SeedSpec6 pnSeed6_main[] = {
    {{0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0xff,0xff,0x02,0x84,0x64,0x2f}, 8333},
    {{0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0xff,0xff,0x05,0x01,0x61,0x04}, 8333},
    {{0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0xff,0xff,0x05,0x27,0xae,0x74}, 8333},
    {{0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0xff,0xff,0x05,0x2d,0x4f,0x0e}, 8333},
    {{0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0xff,0xff,0x05,0x35,0x10,0x85}, 8333},
    {{0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0x00,0xff,0xff,0x05,0x65,0x8b,0xa6}, 8333},
    ...
```



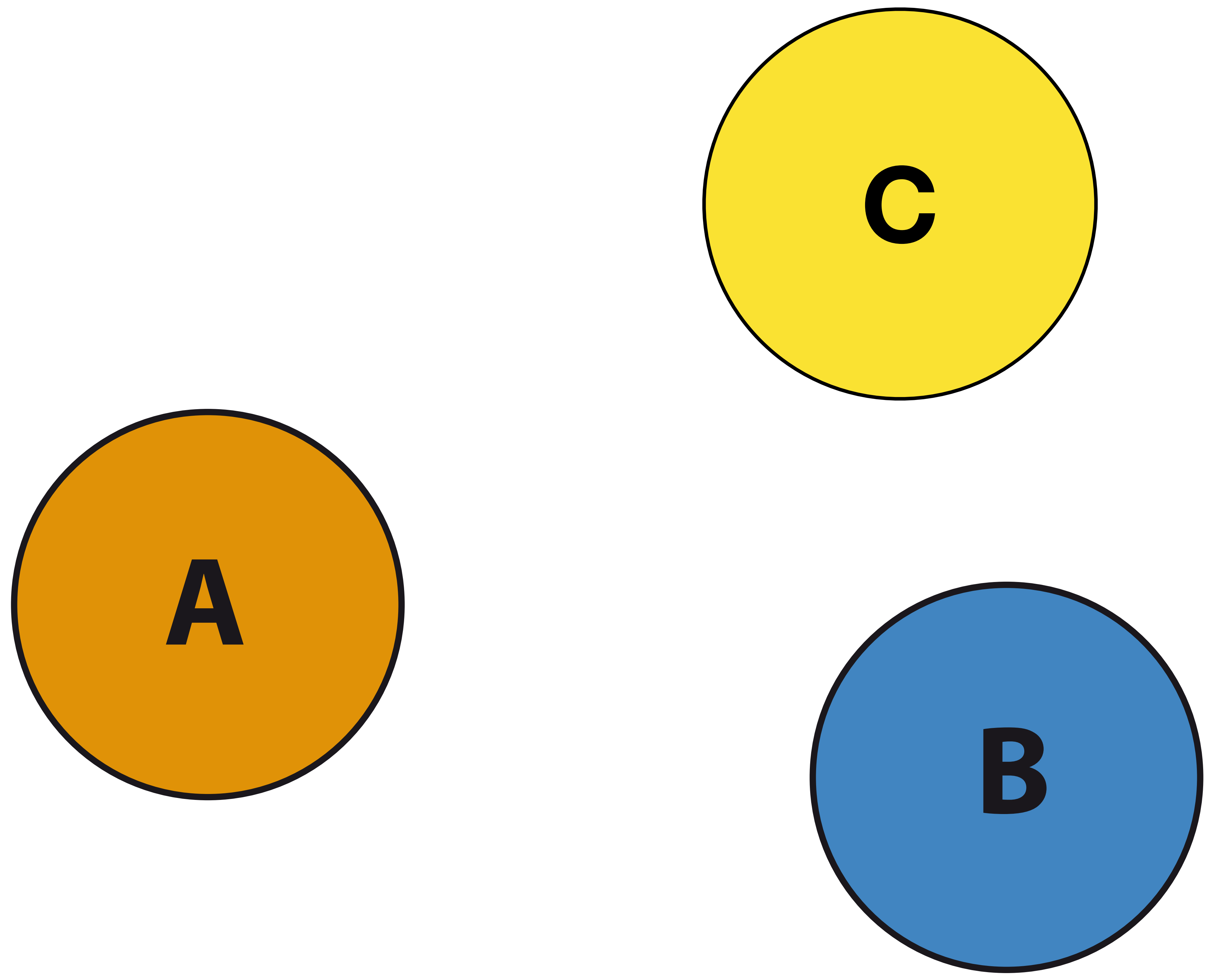
BITCOIN P2P BOOTSTRAPPING (RECAP)

A node bootstraps with no known peers

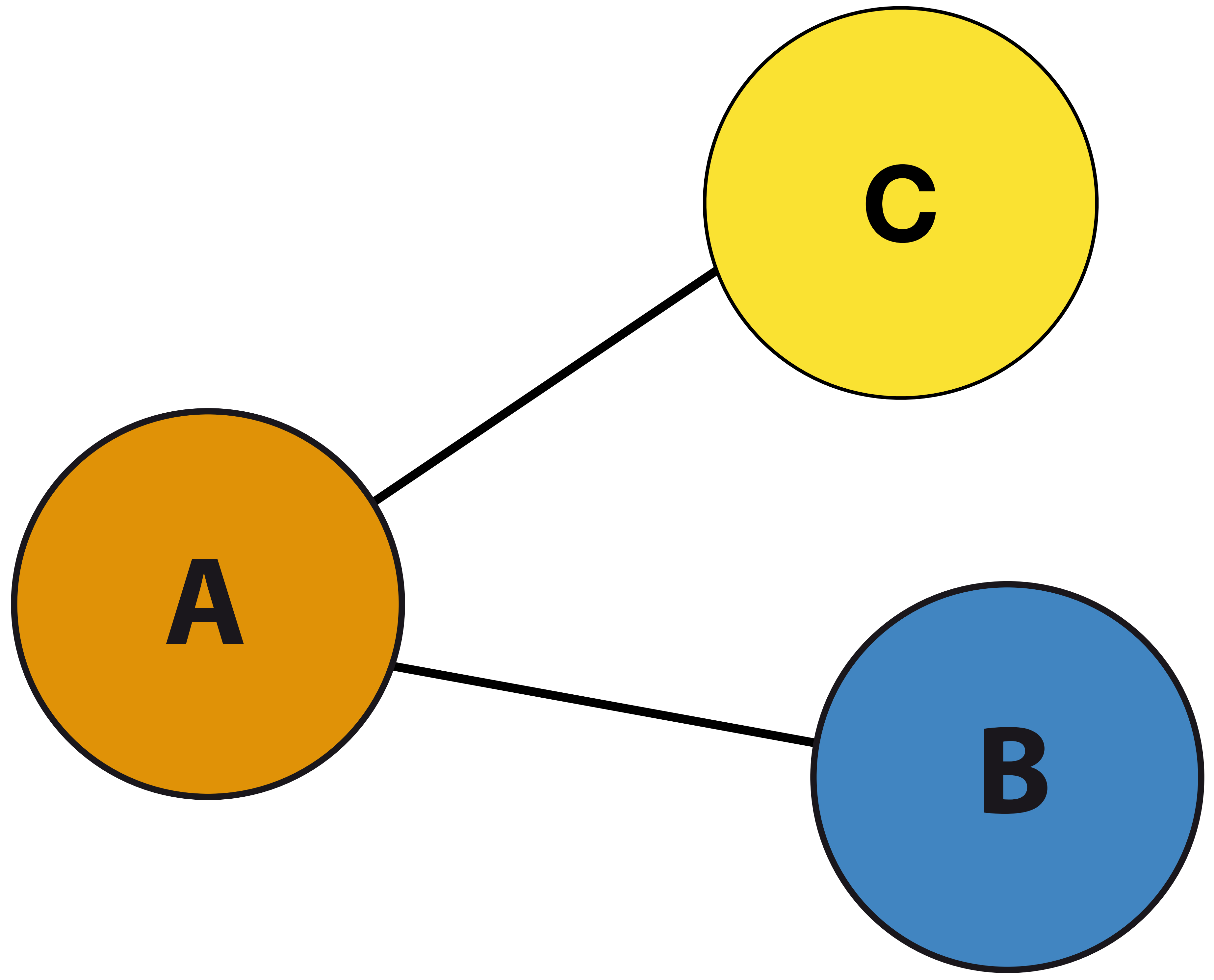
First it tries to query a list of well known DNS seeds

As a **last resource** it uses a hardcoded seed

POPULATING THE PEERS DATABASE



POPULATING THE PEERS DATABASE



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

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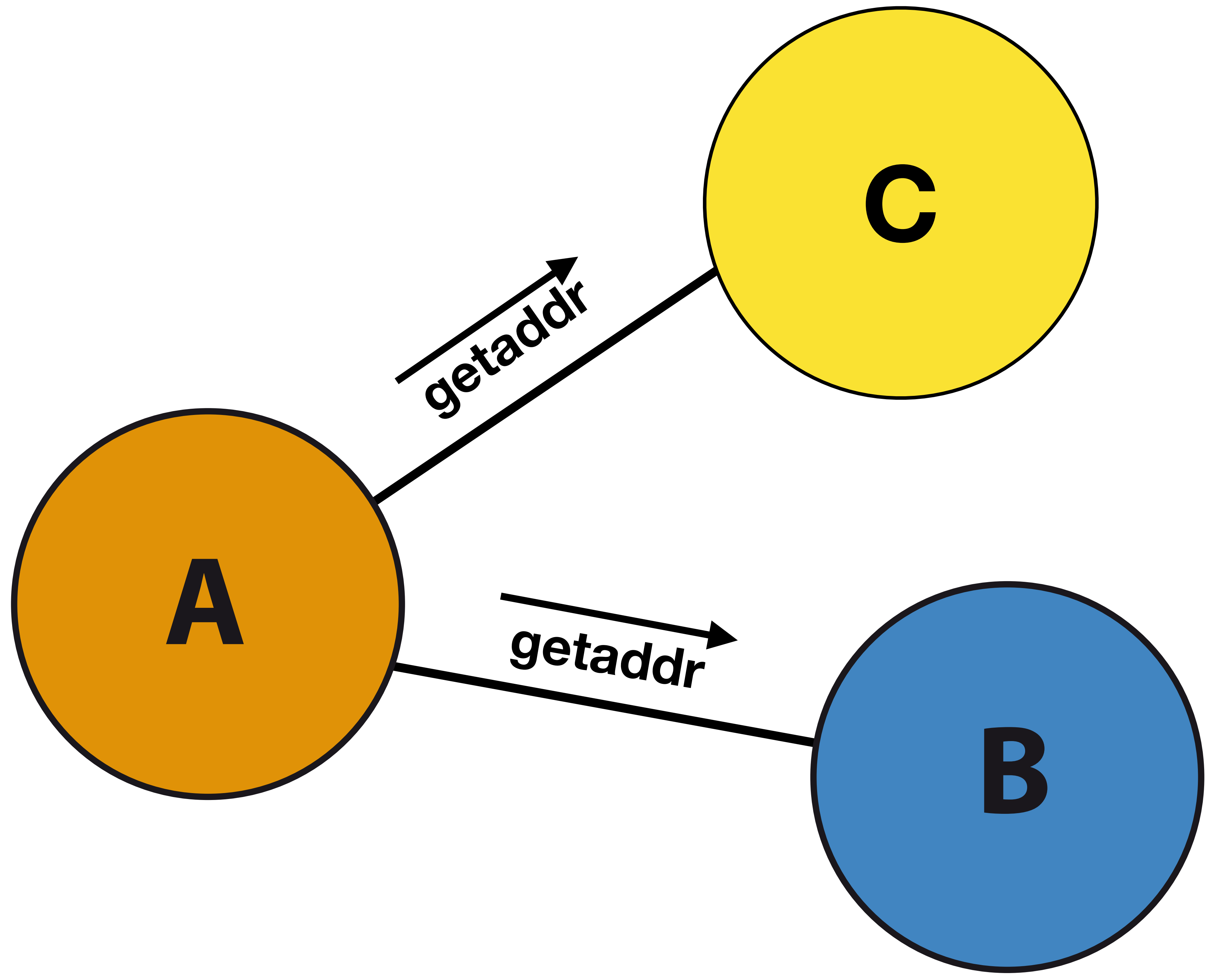

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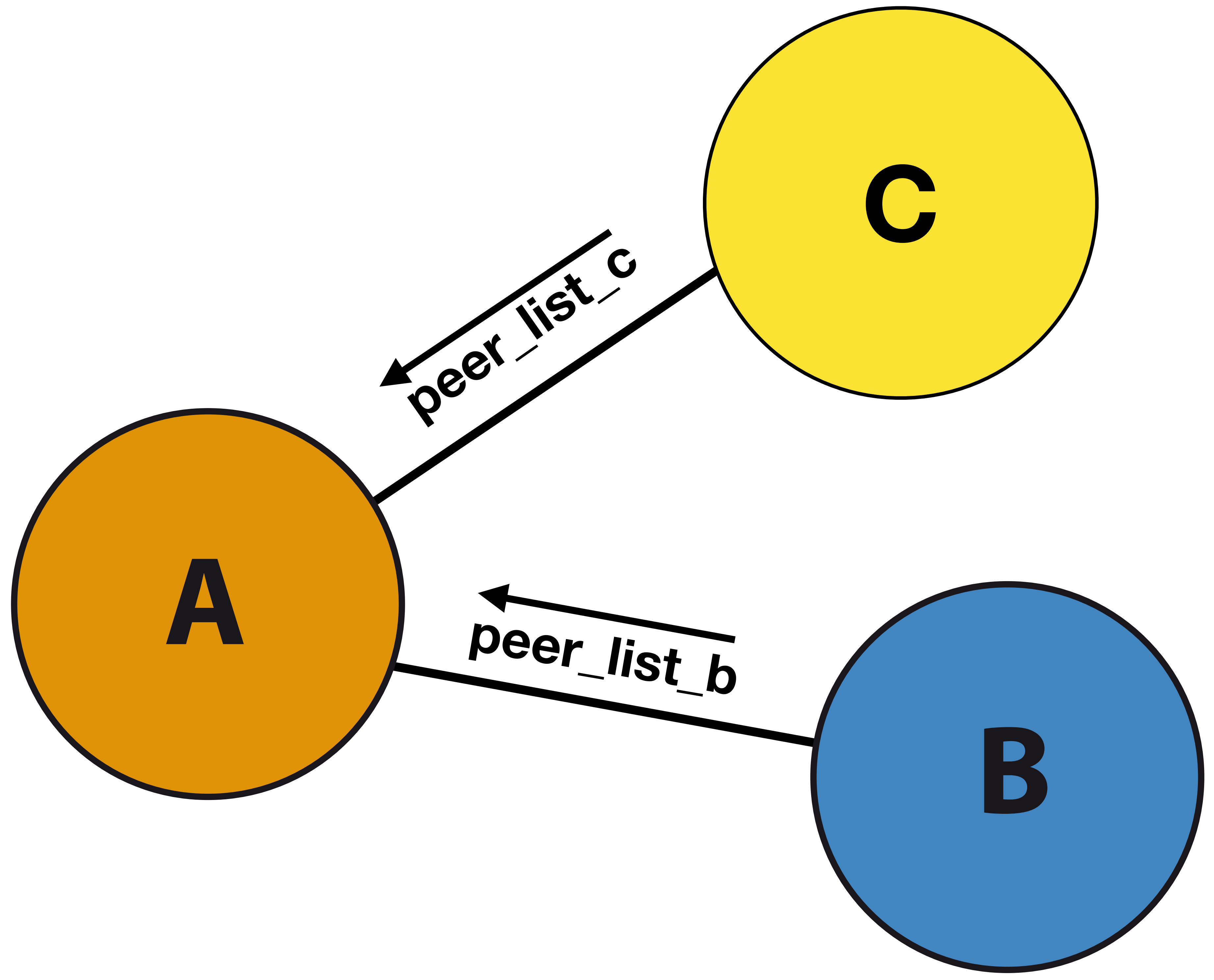
- A requests more peers to his neighbors (**getaddr**)

POPULATING THE PEERS DATABASE



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

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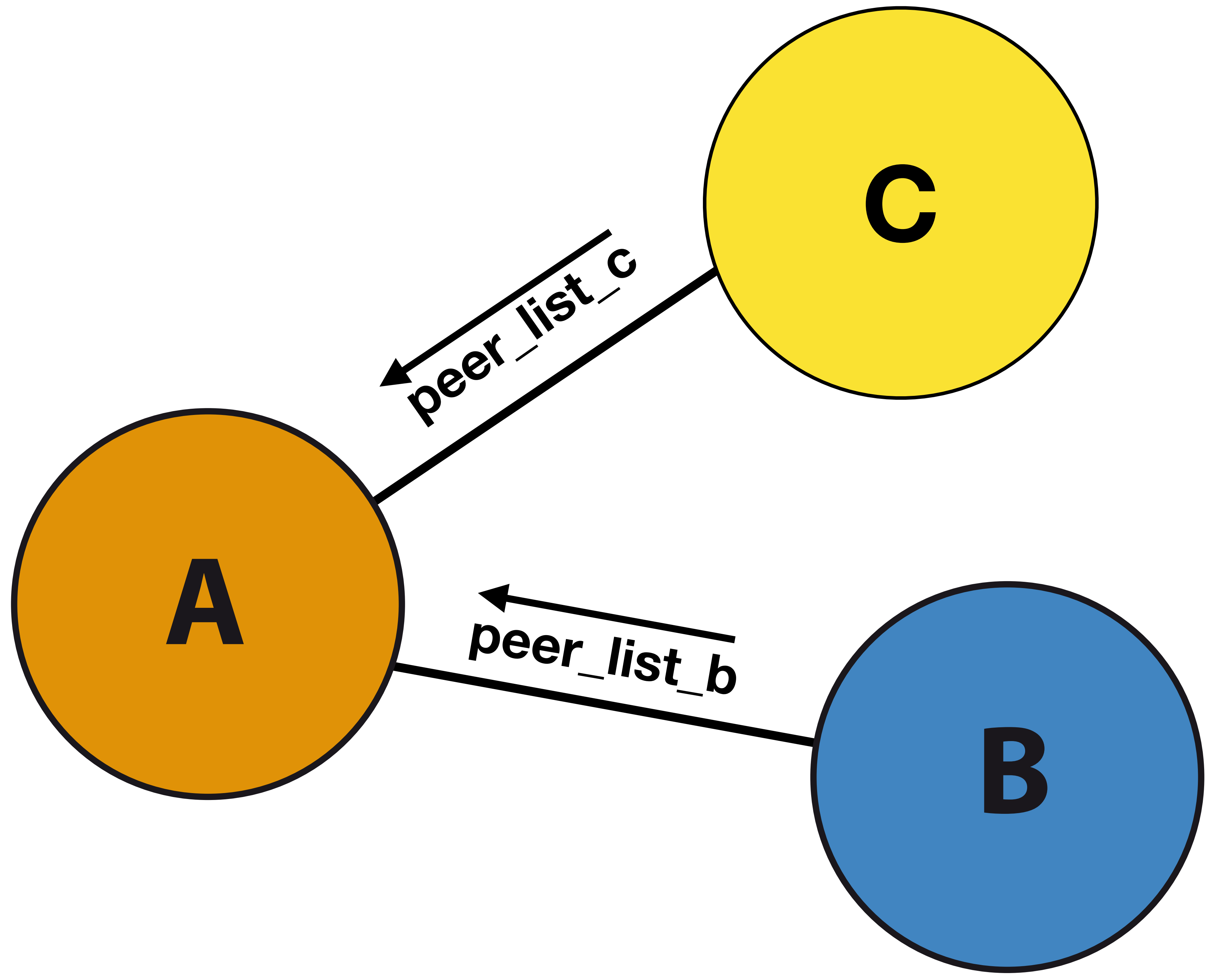

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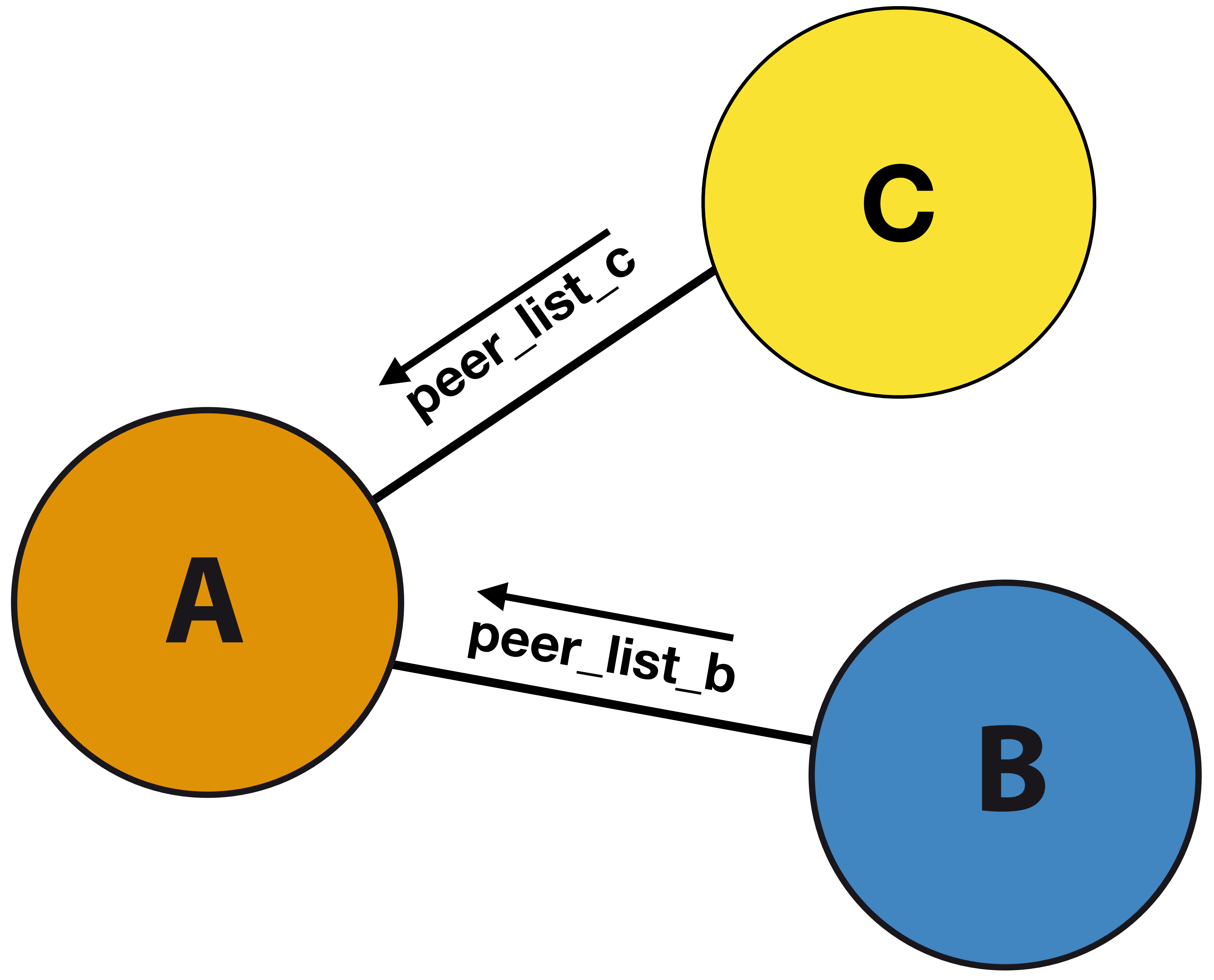

A's addrman = A's addrman U peer_list_c U peer_list_b

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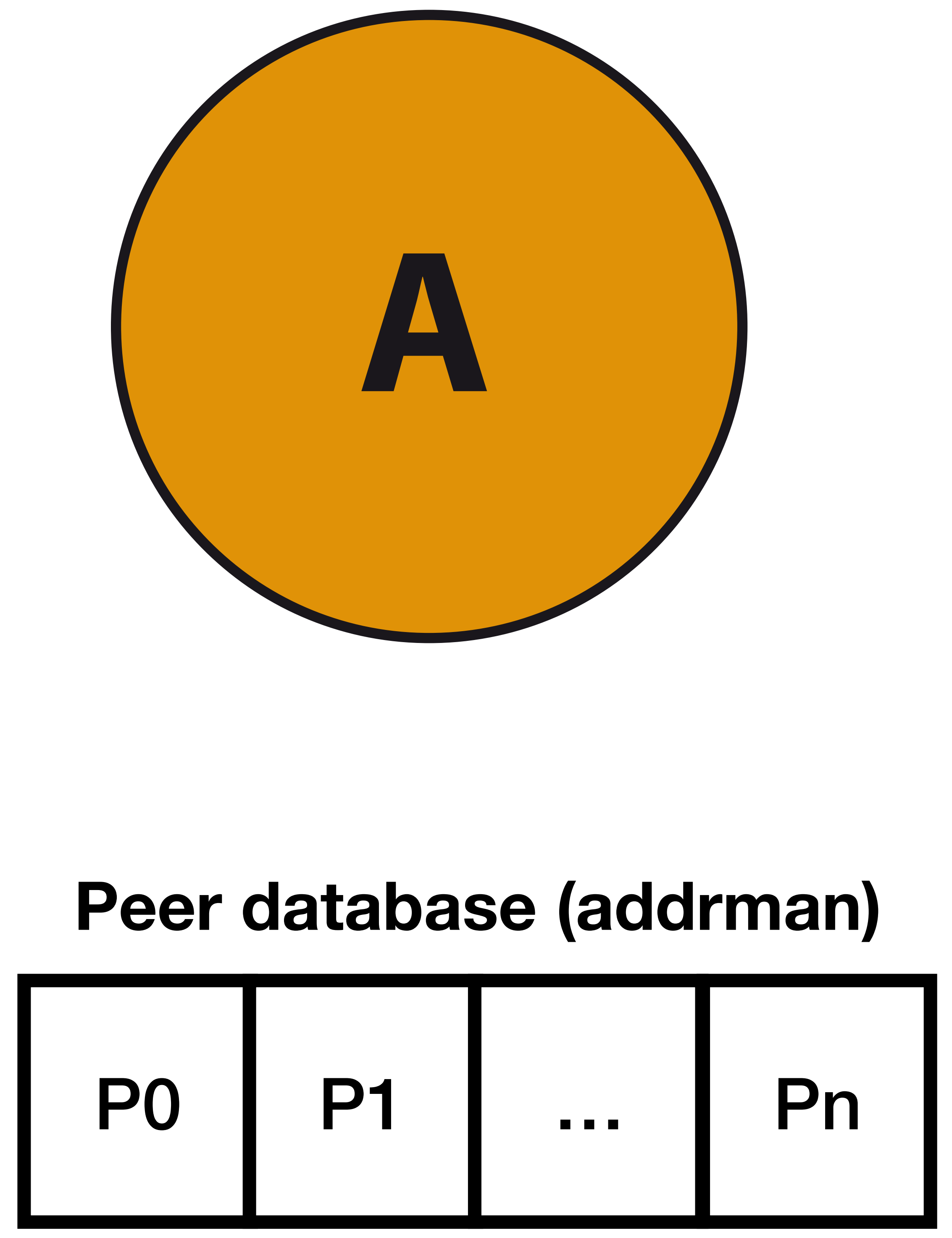
- The database is known as **the addrman**

INCOMING/OUTGOING CONNECTIONS



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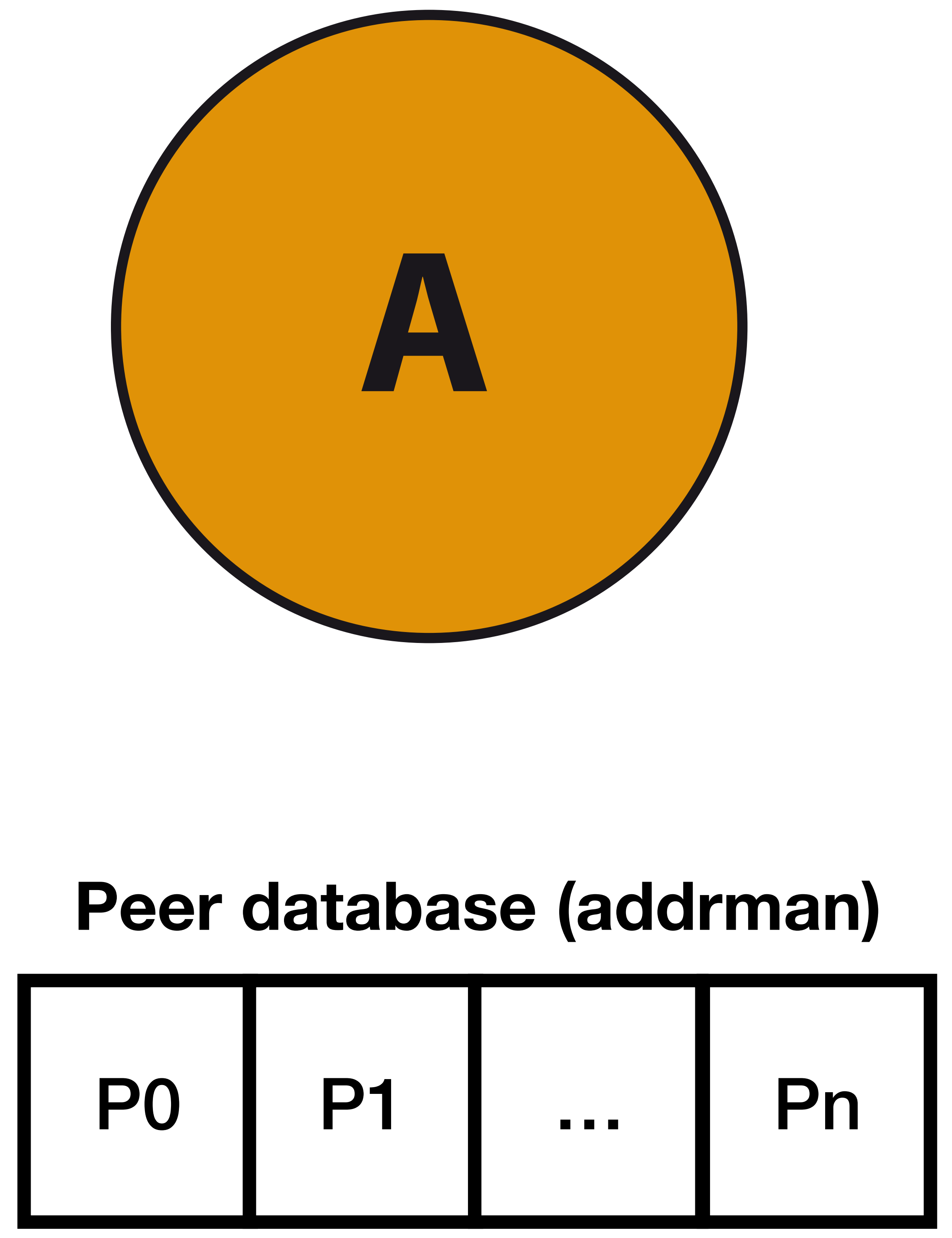

- During bootstrap, a node will start some **outgoing connections** with peers it has learnt about (**8 by default**) and tries to maintain them

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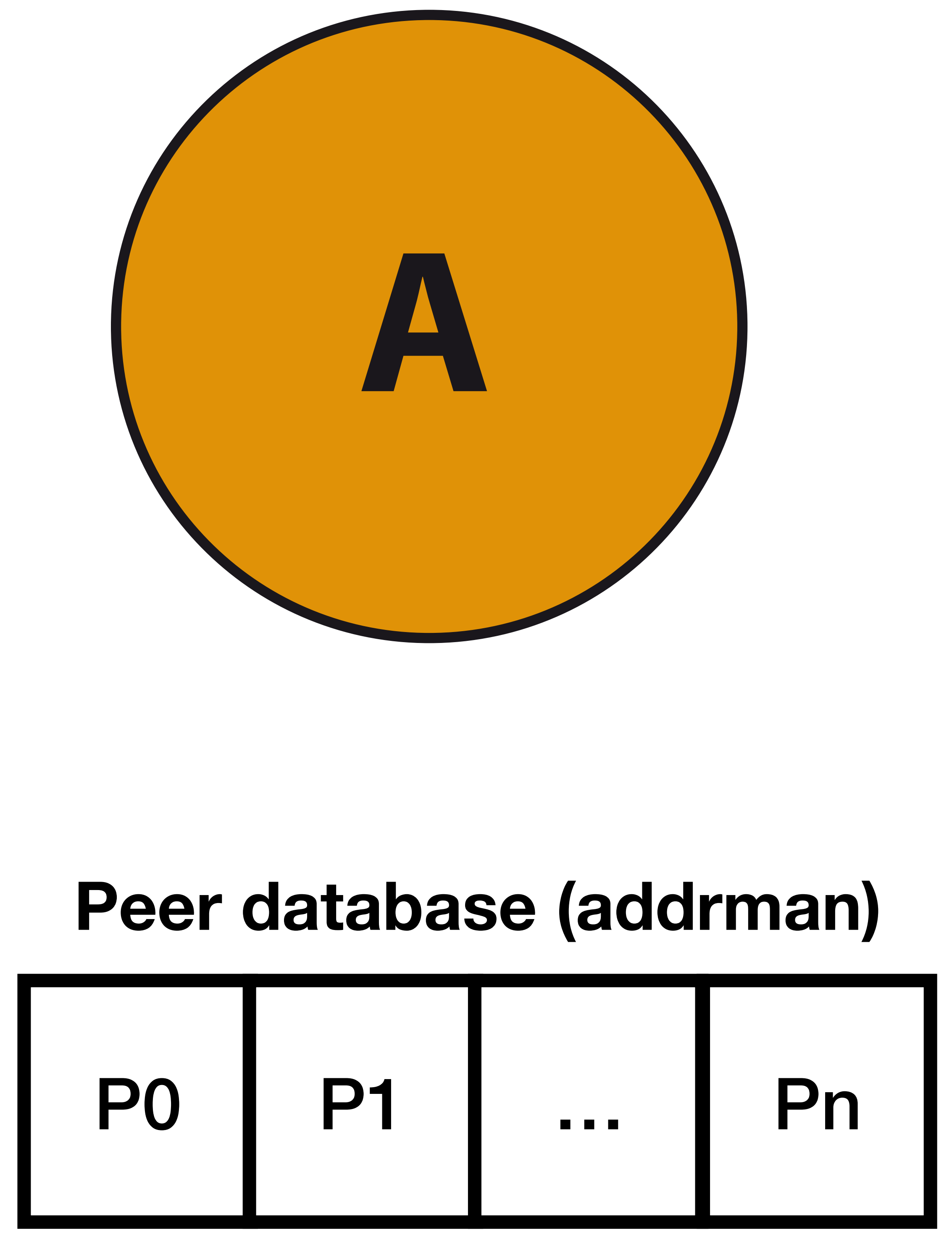

- During bootstrap, a node will start some **outgoing connections** with peers it has learnt about (**8 by default**) and tries to maintain them
- A node will also accept **some incoming** connections (**117 by default**)

ADDRESS PROPAGATION (1/2)

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

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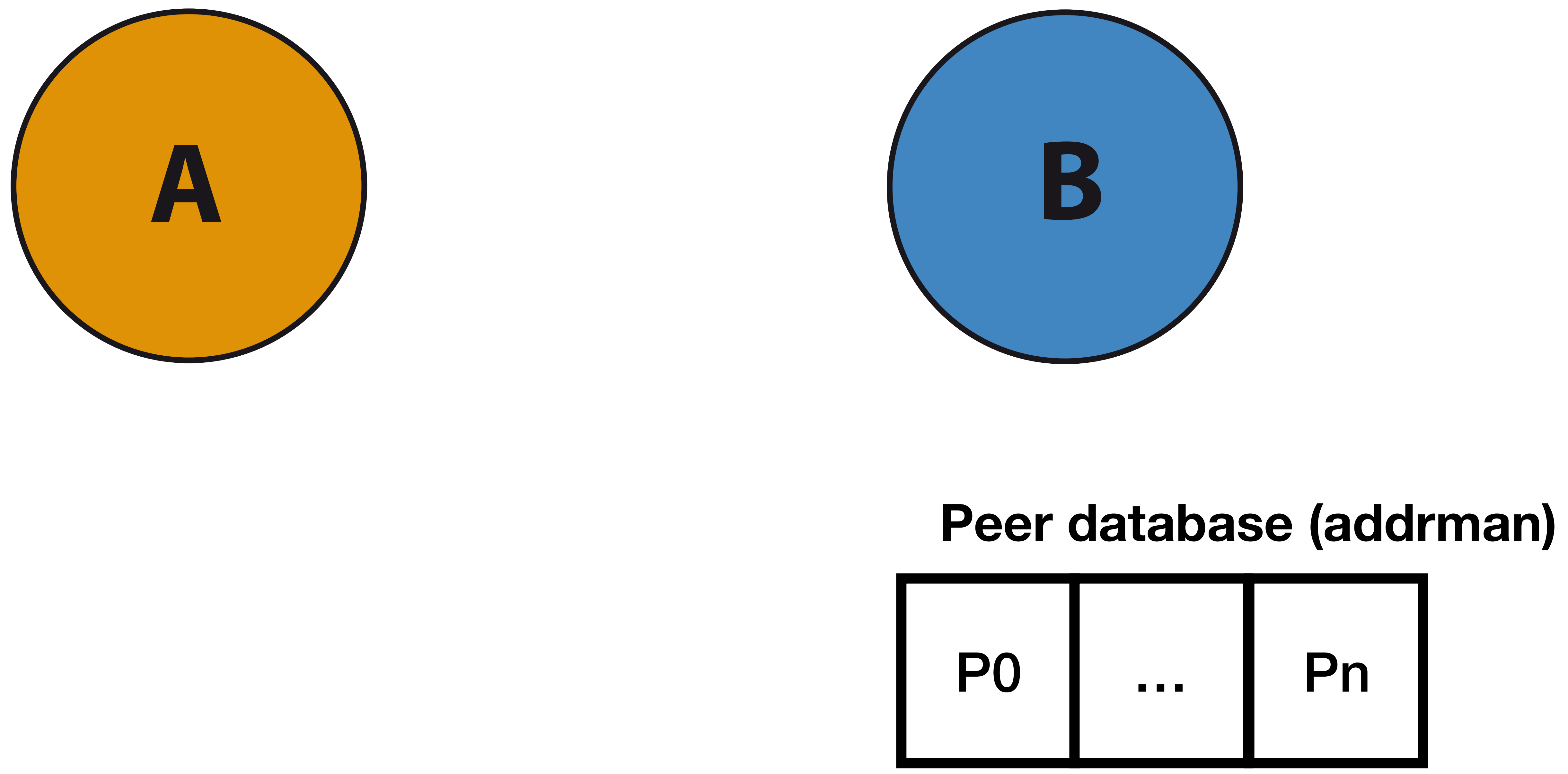

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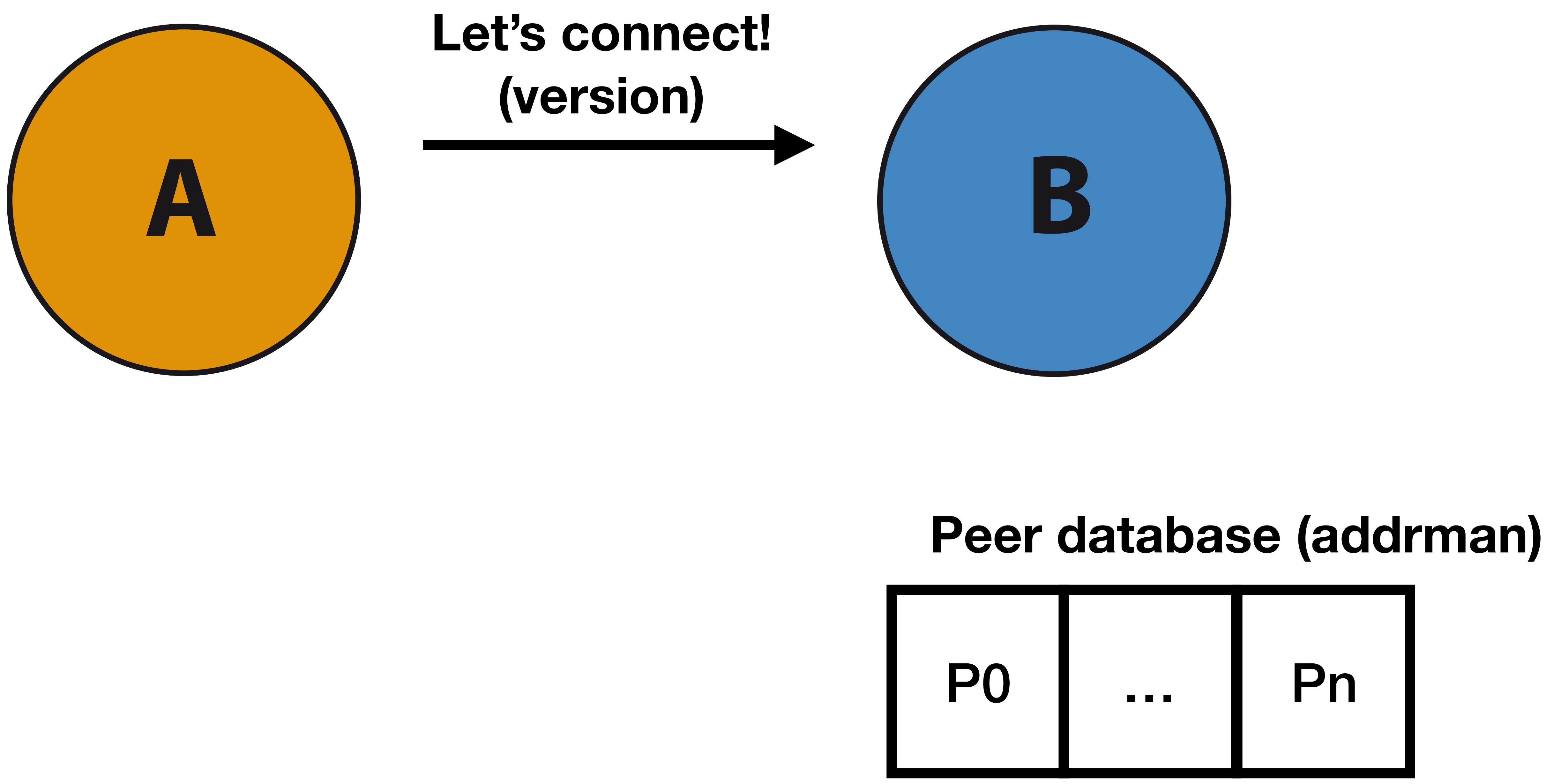

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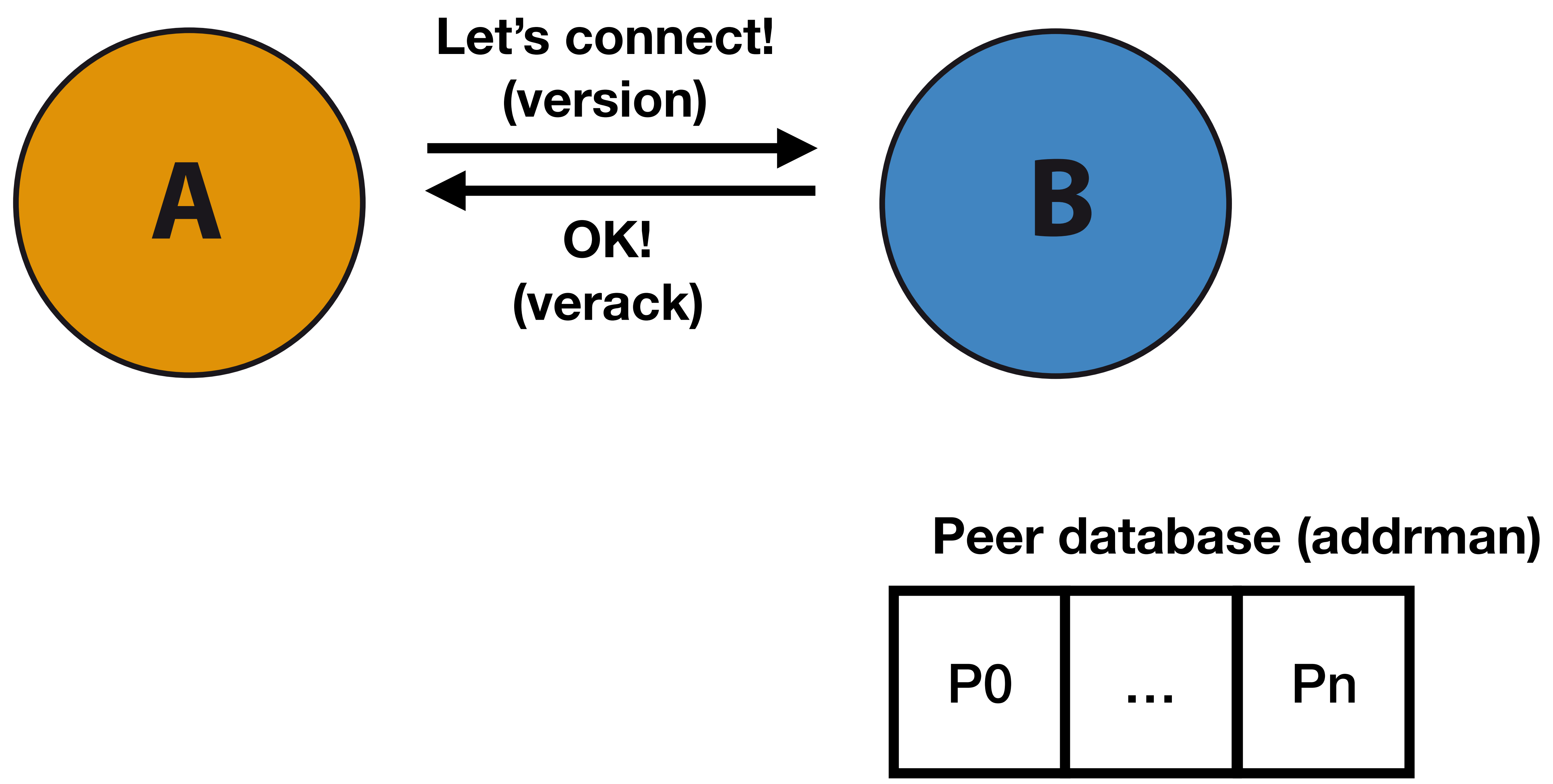

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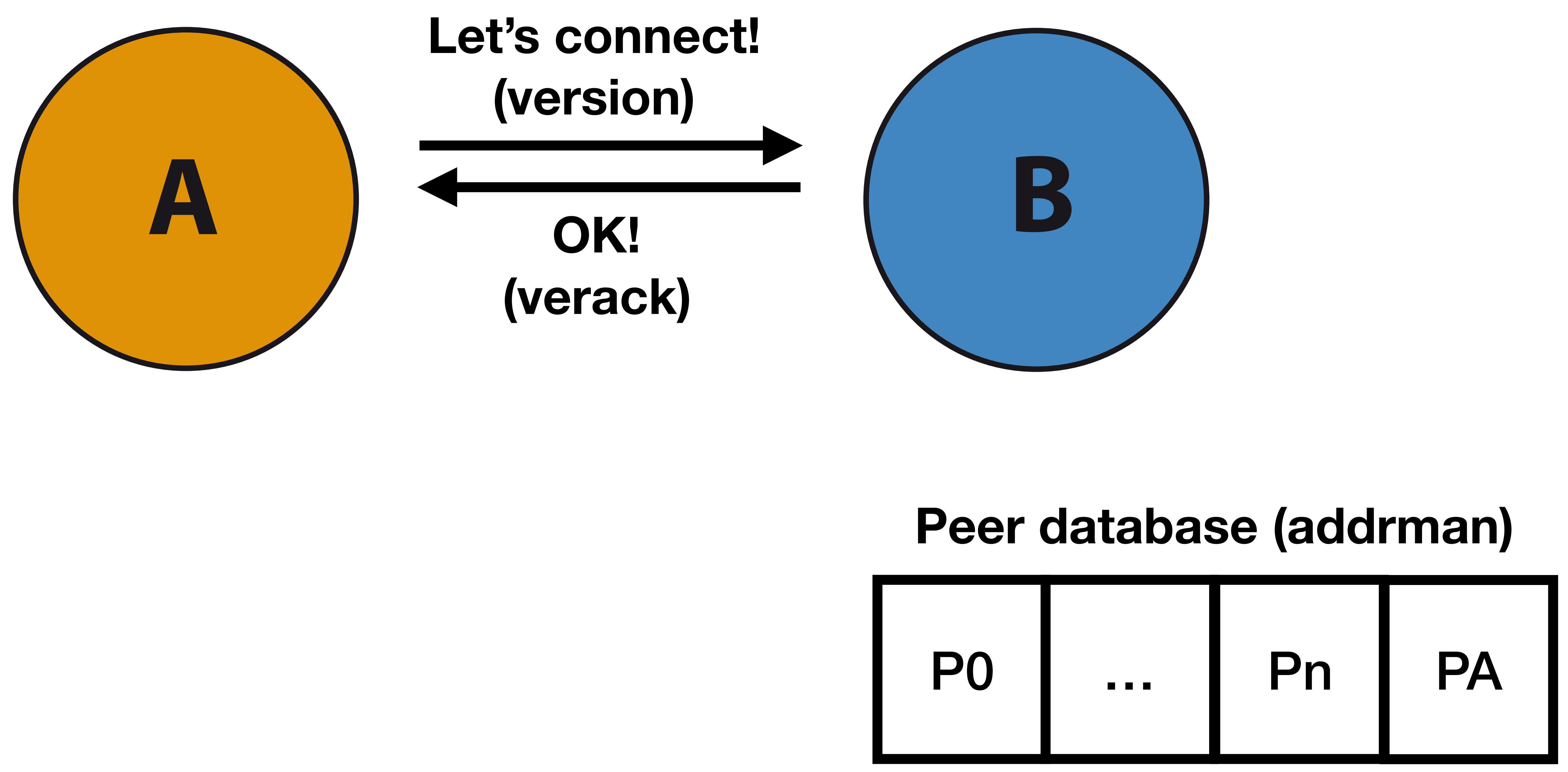

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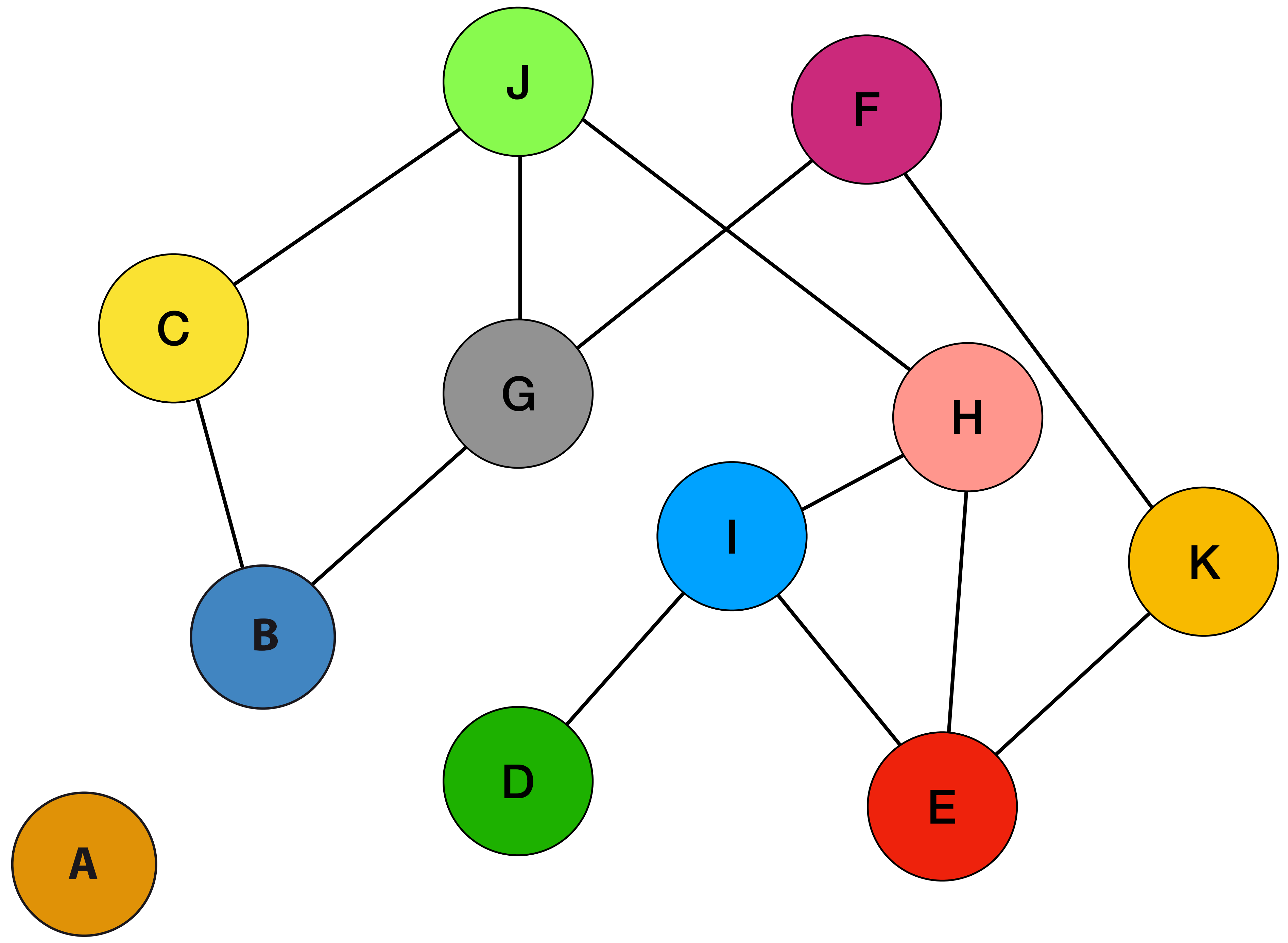

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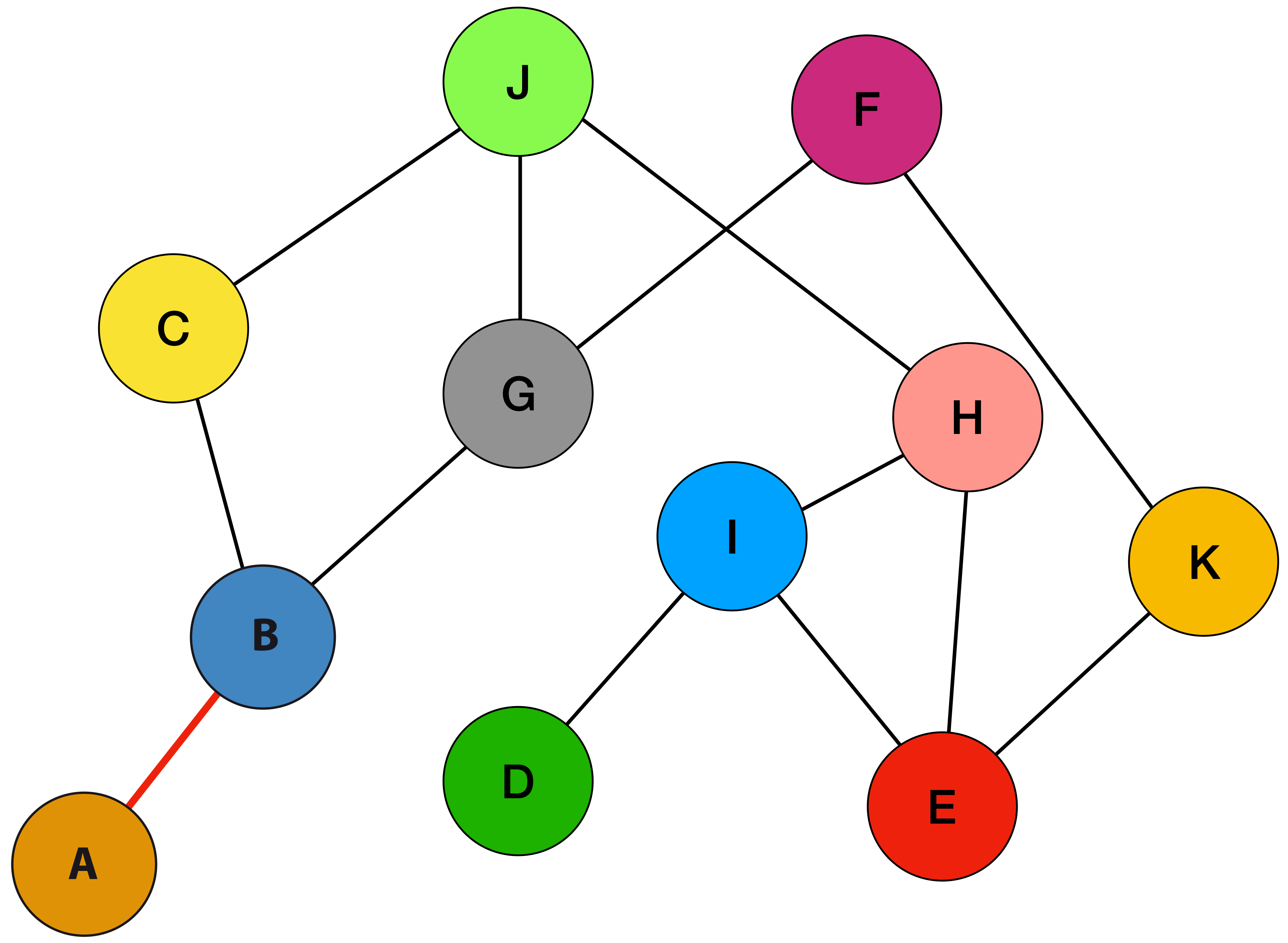

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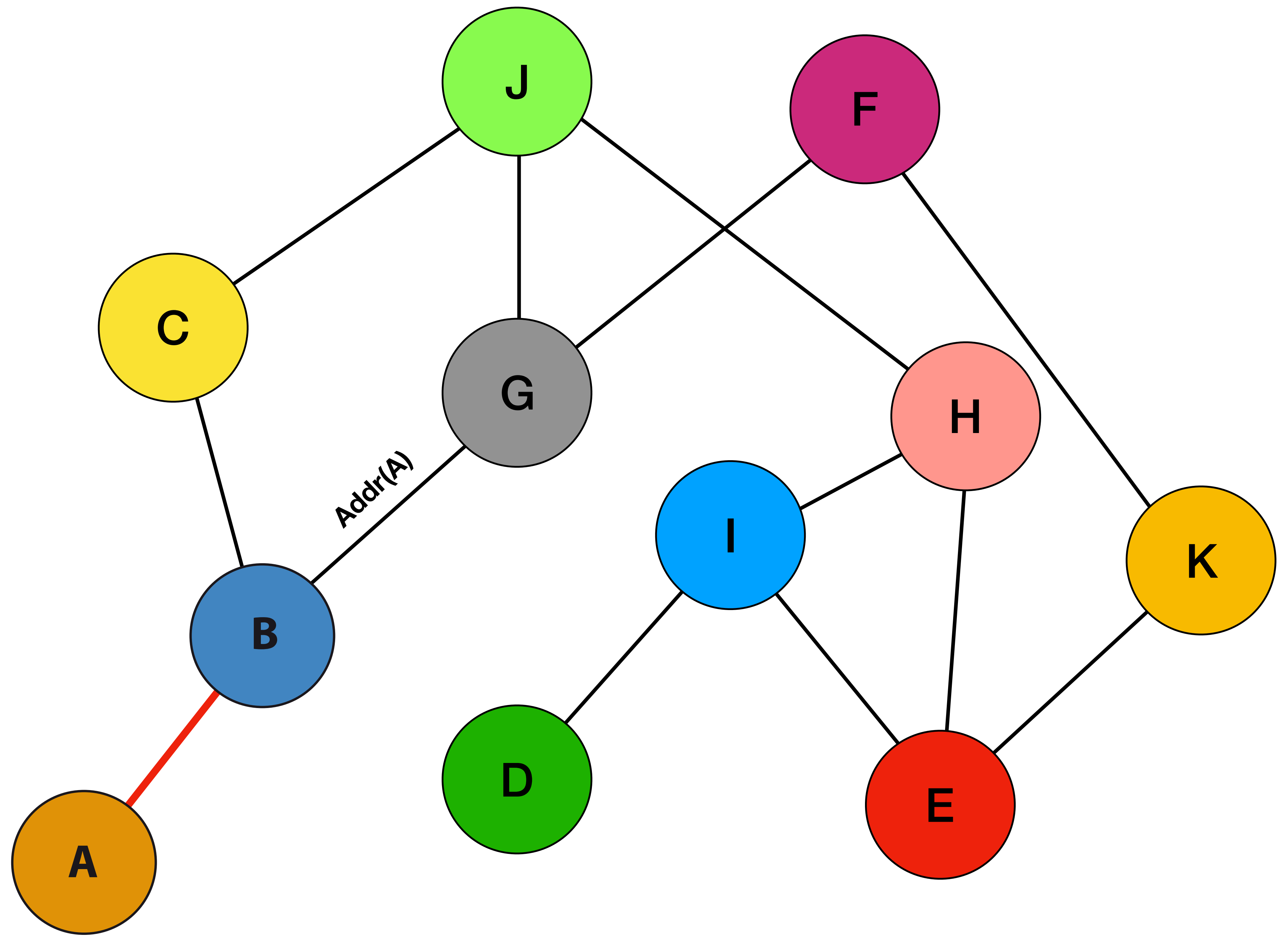

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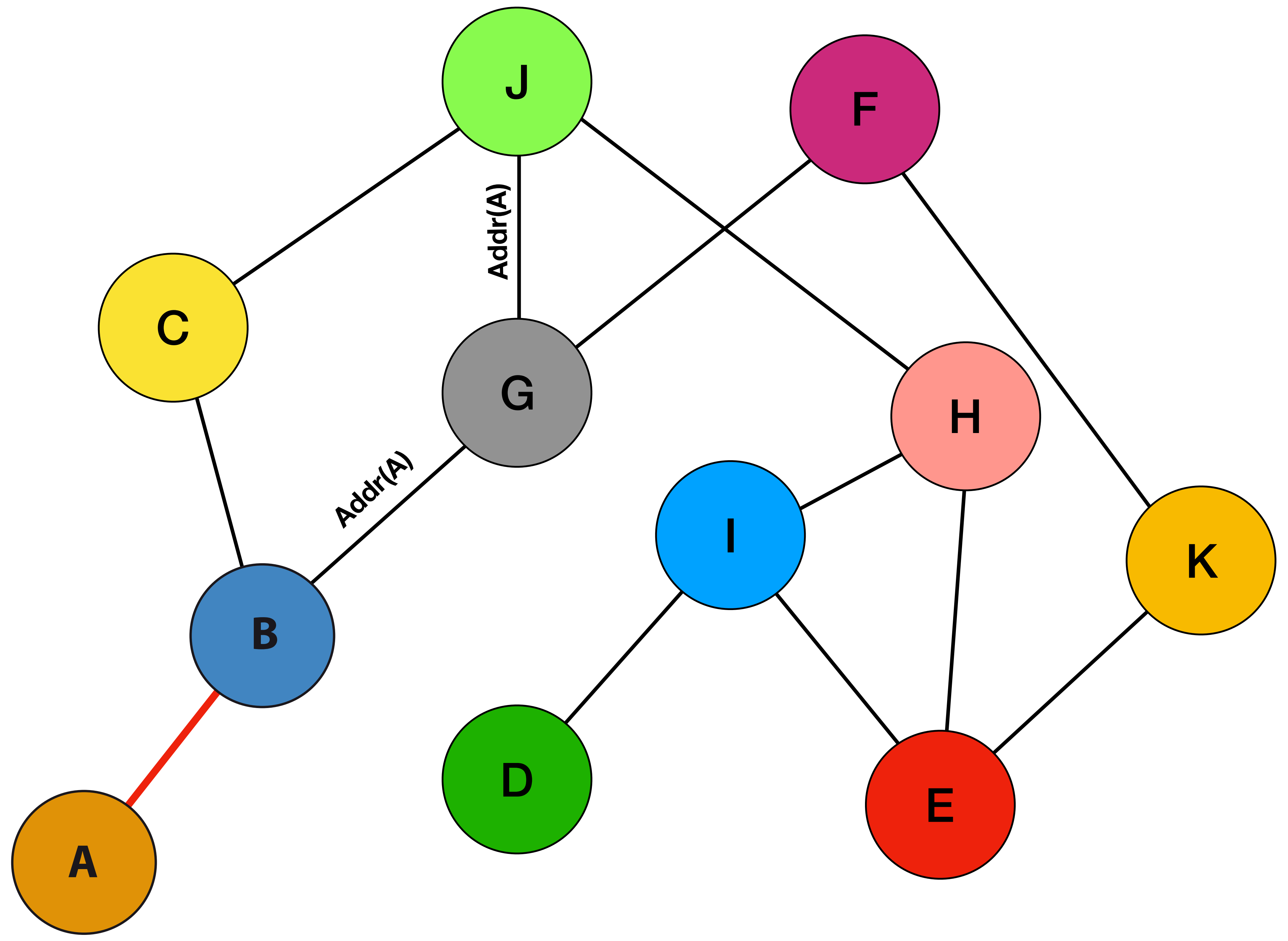

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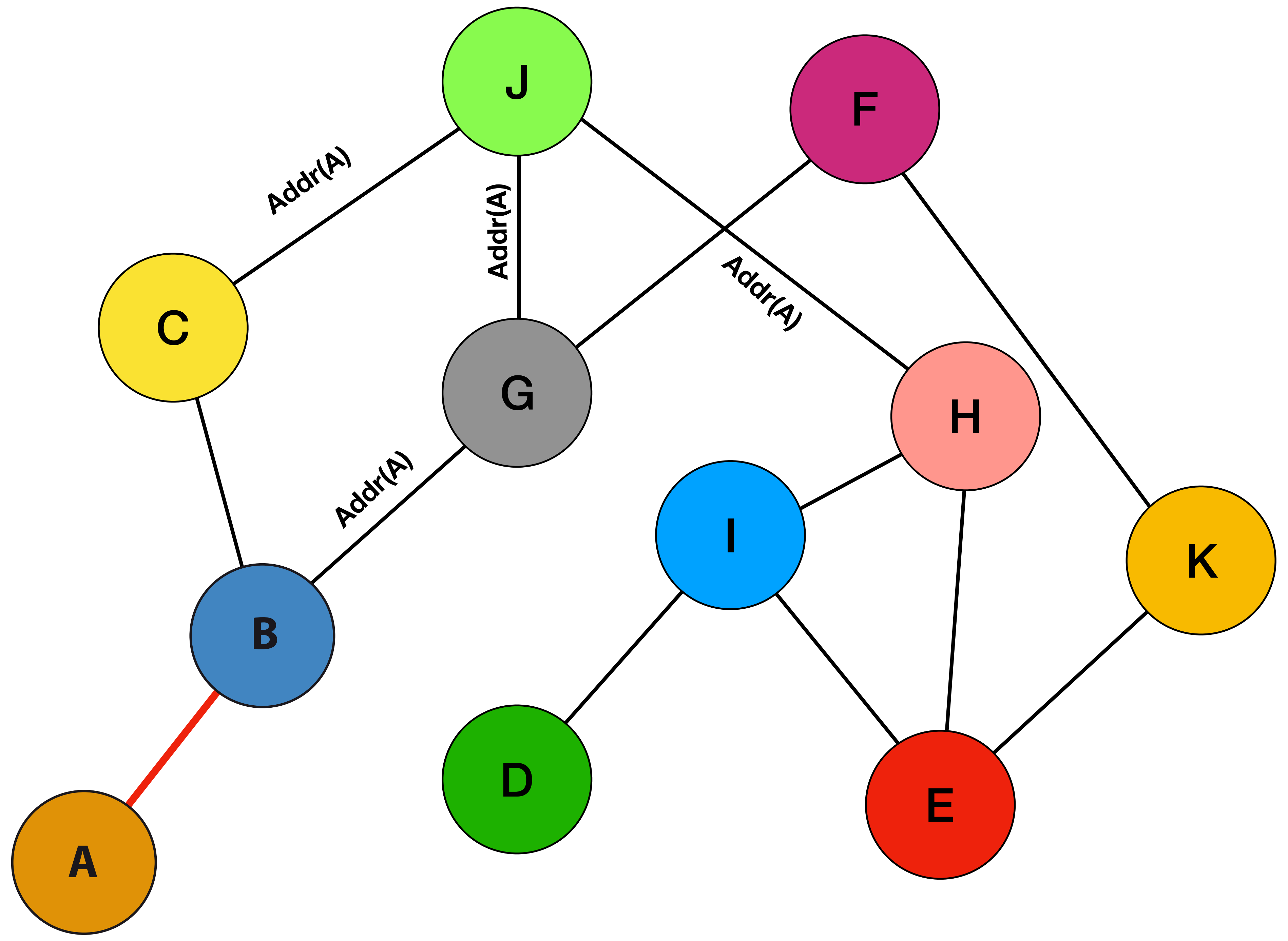

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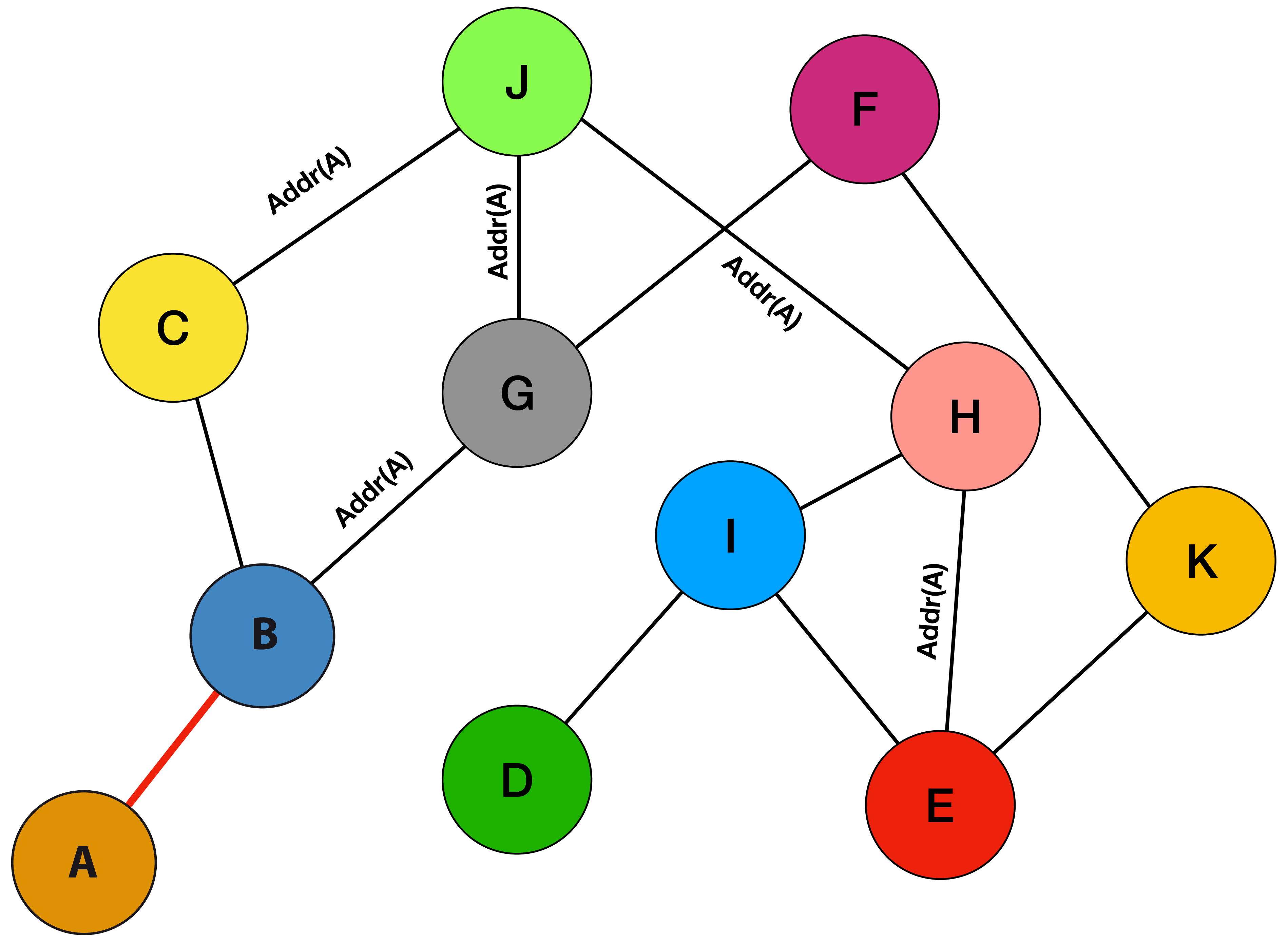

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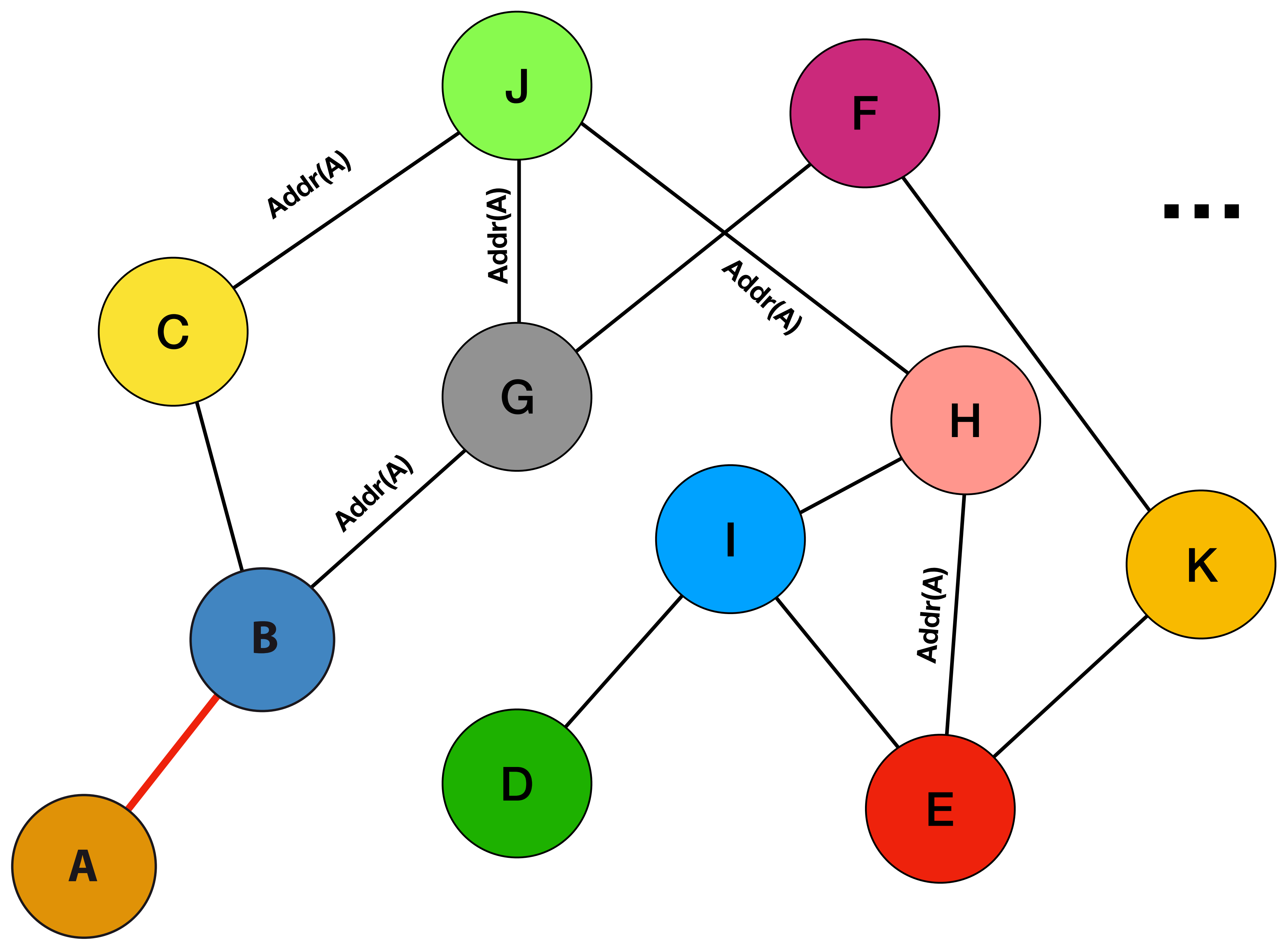

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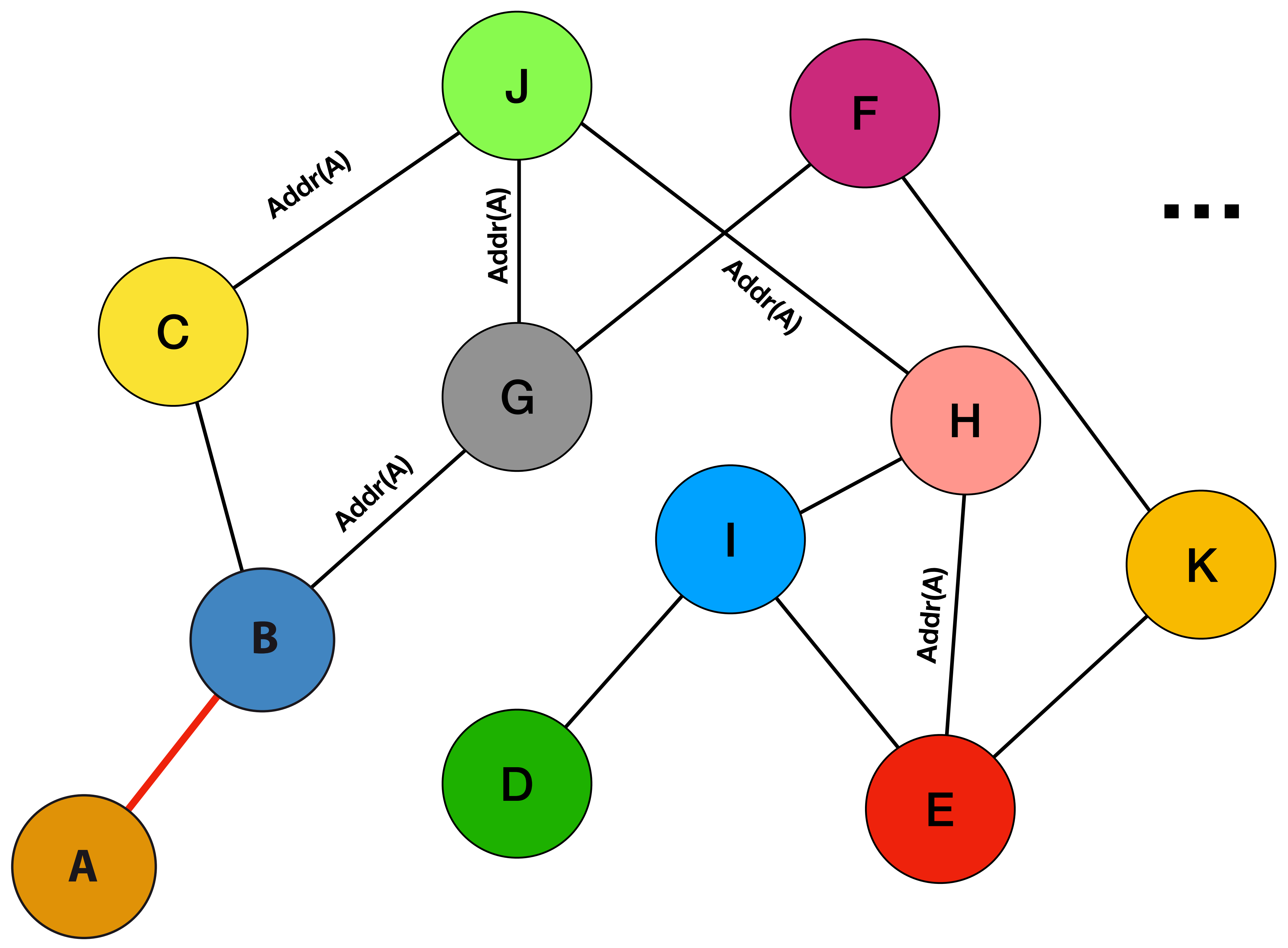

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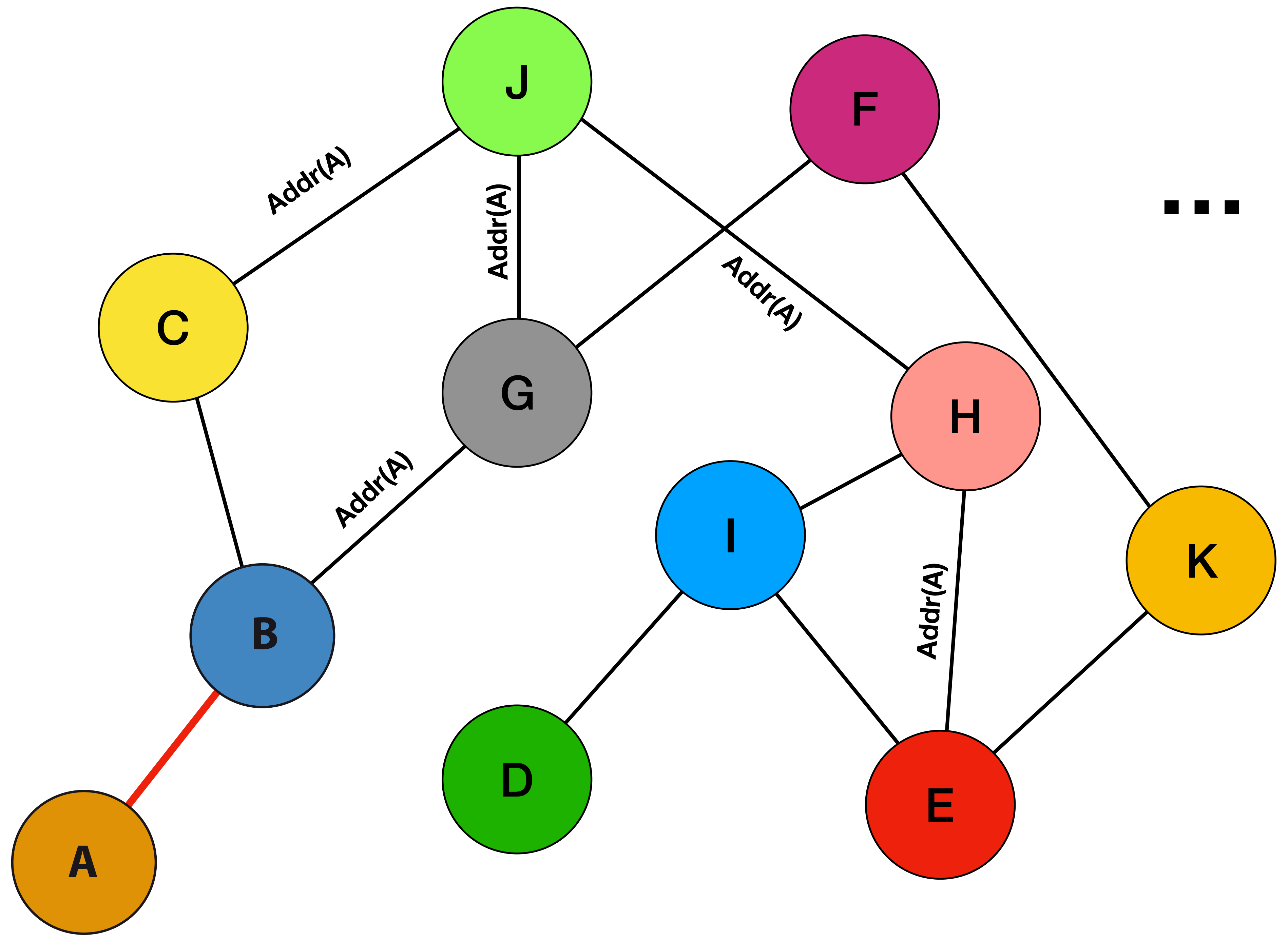

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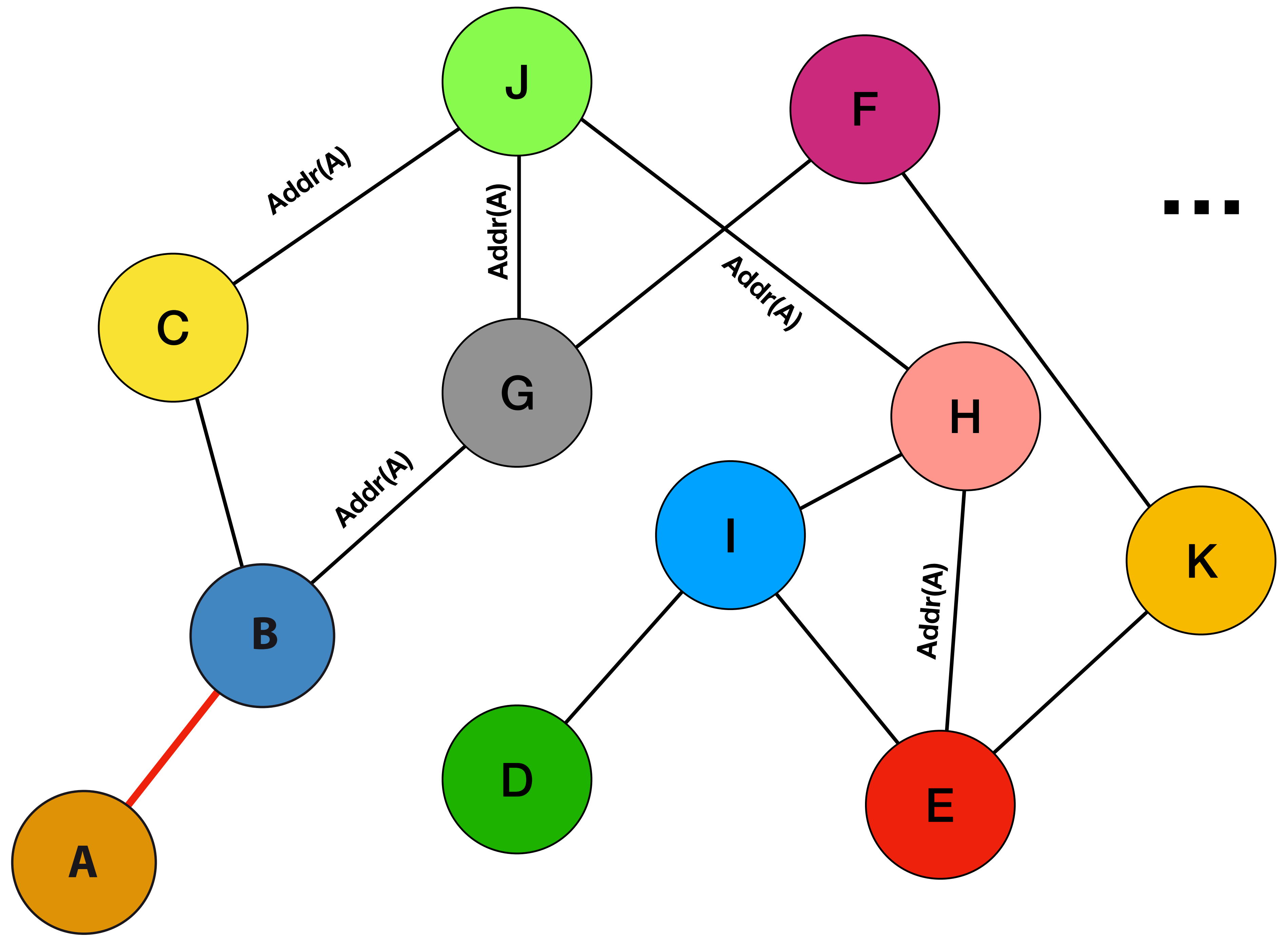

- The address will eventually be spread throughout the network
- Nodes learning about the new peer will add it to their peers database

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

THE ACTORS (WHO?) (1/2)

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

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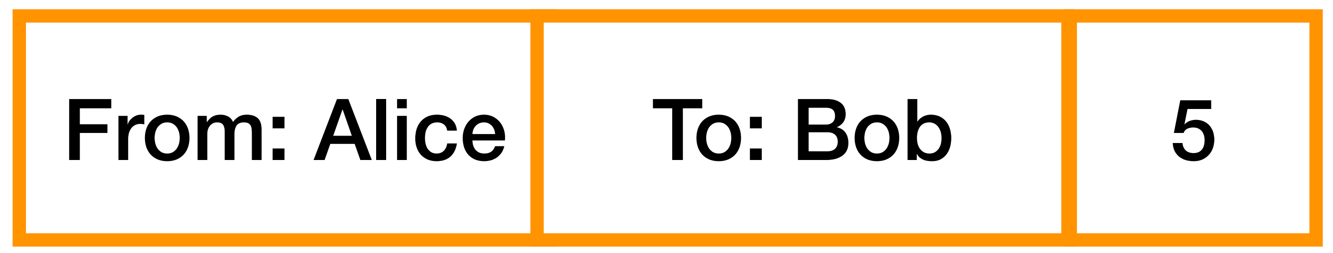
- Can **create transactions** that spend some of their bitcoins



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From: Alice	To: Bob	5

✗ ✓

THE ACTORS (WHO?) (1/2)

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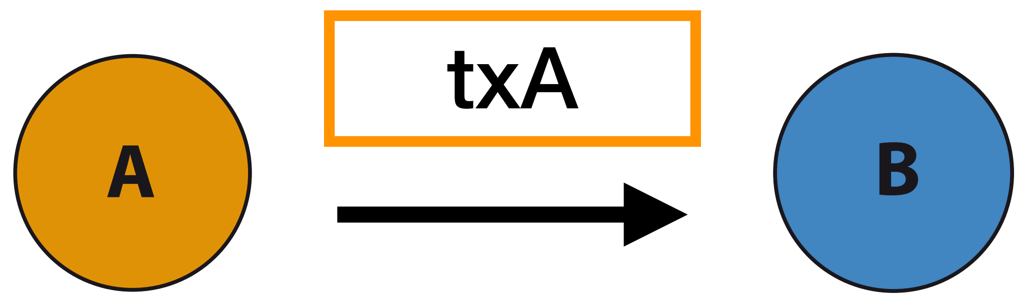
(Normal) **Peers:**

- 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)

From: Alice	To: Bob	5

✗ ✓



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- Can everything a **peer** could do*

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THE ACTORS (WHO?) (2/2)

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

Miners:

- Can everything a **peer** could do*
- Can **generate blocks** through a process known as mining

* 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 their reward (and also the transactions fees)

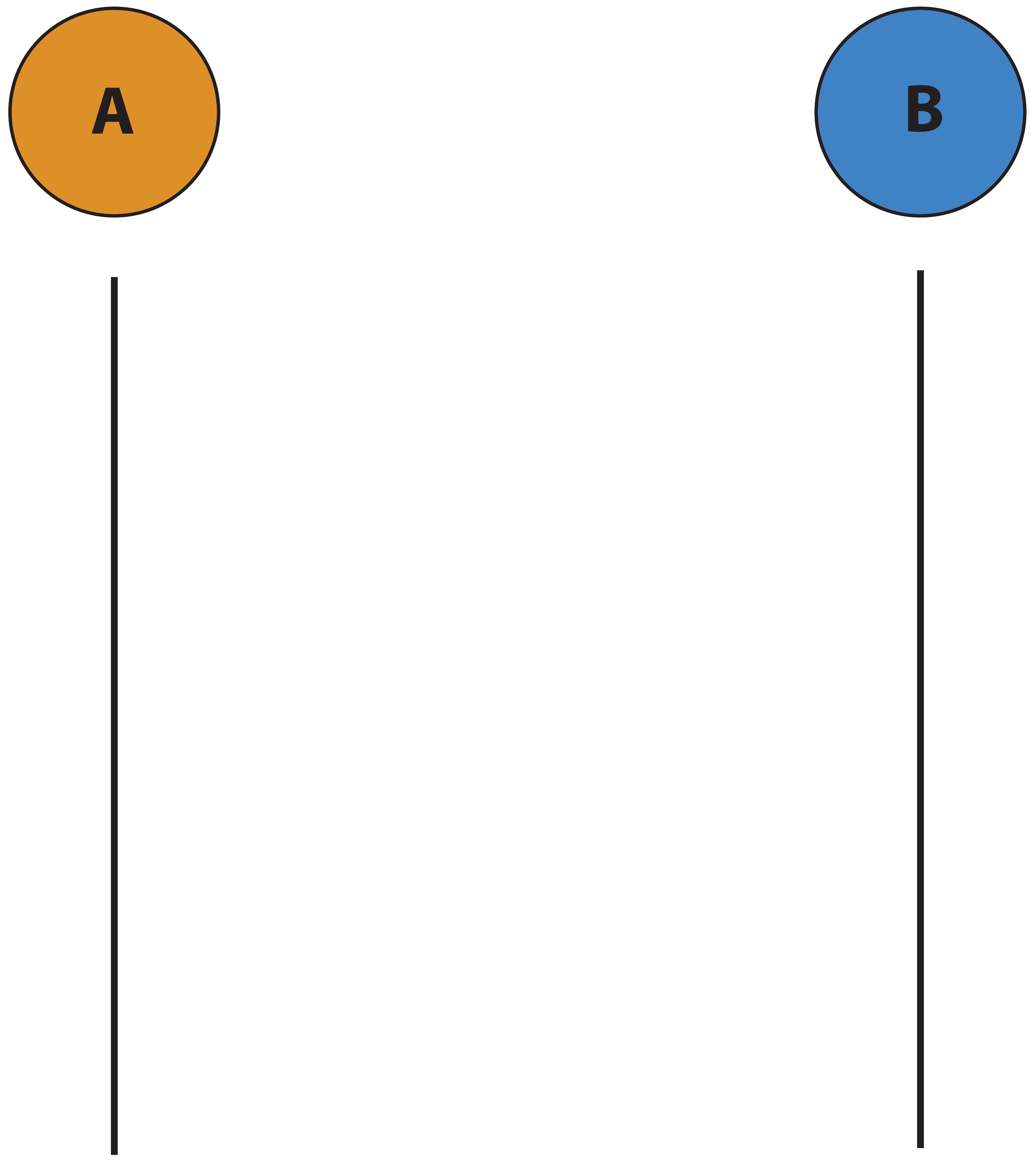
Blocks are relayed to ultimately achieve a consistent view of the blockchain

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?)

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

Announce paradigm



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When a peer receives / generates a new item he announce it to his neighbors (**announce**)

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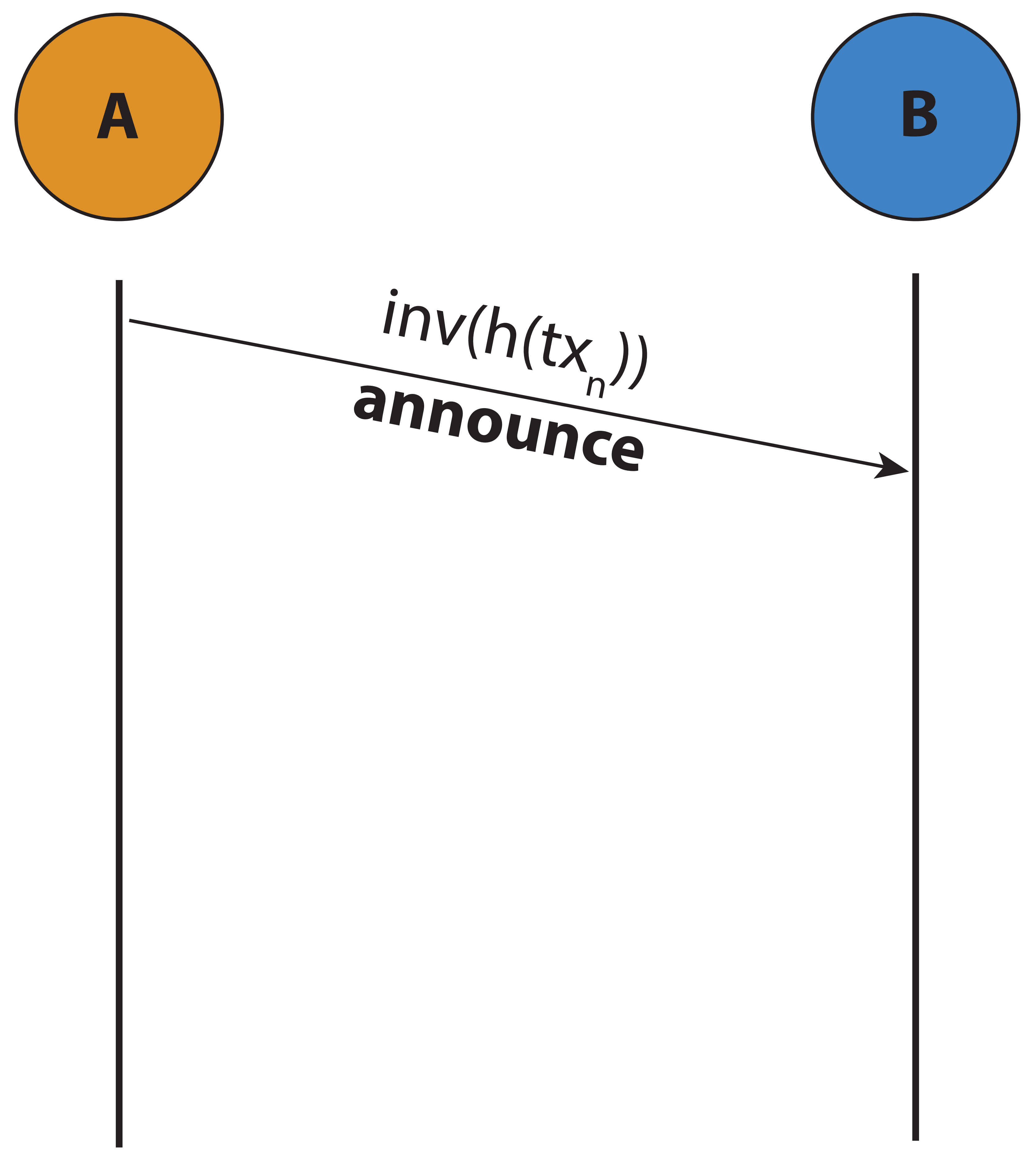

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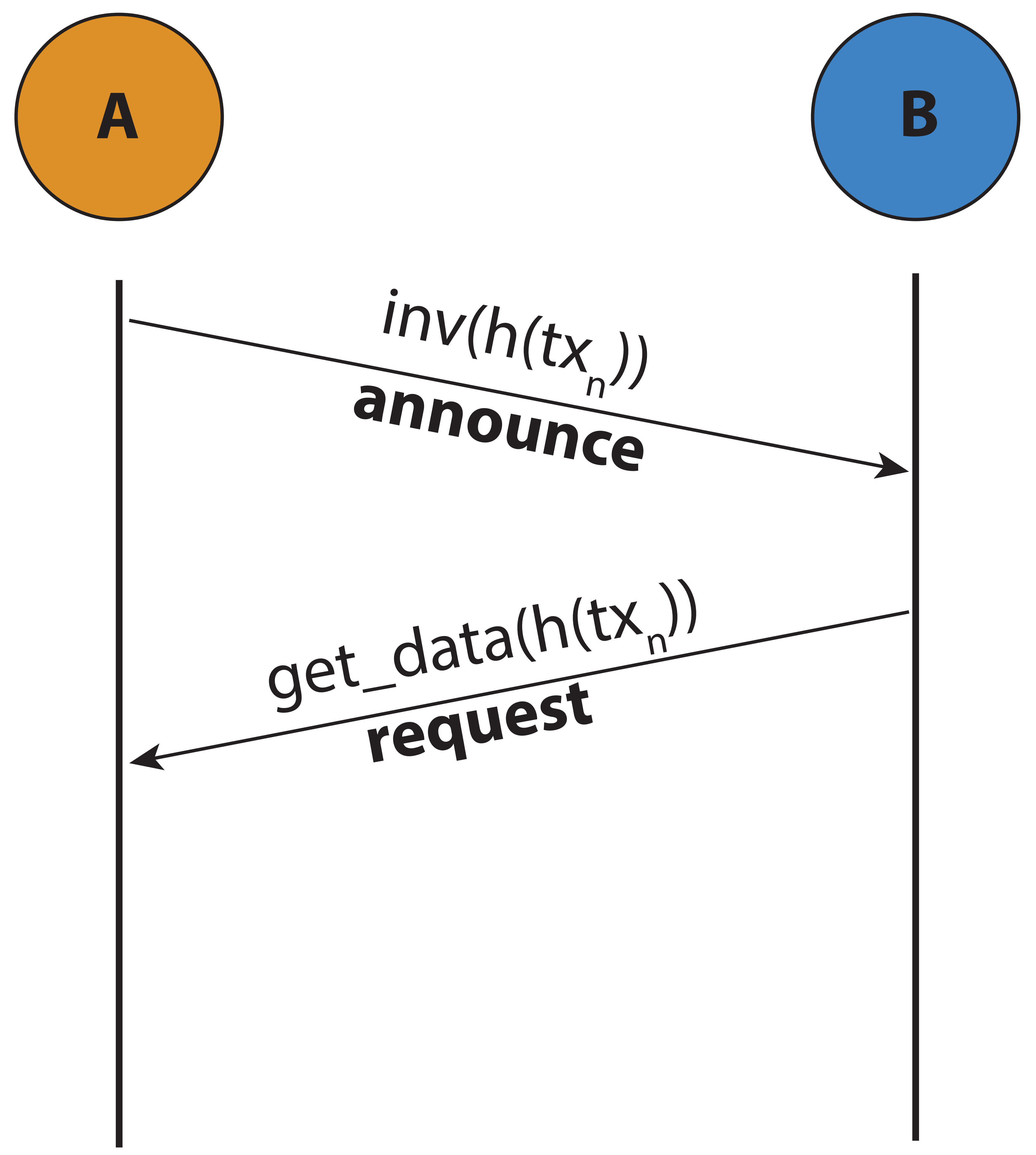

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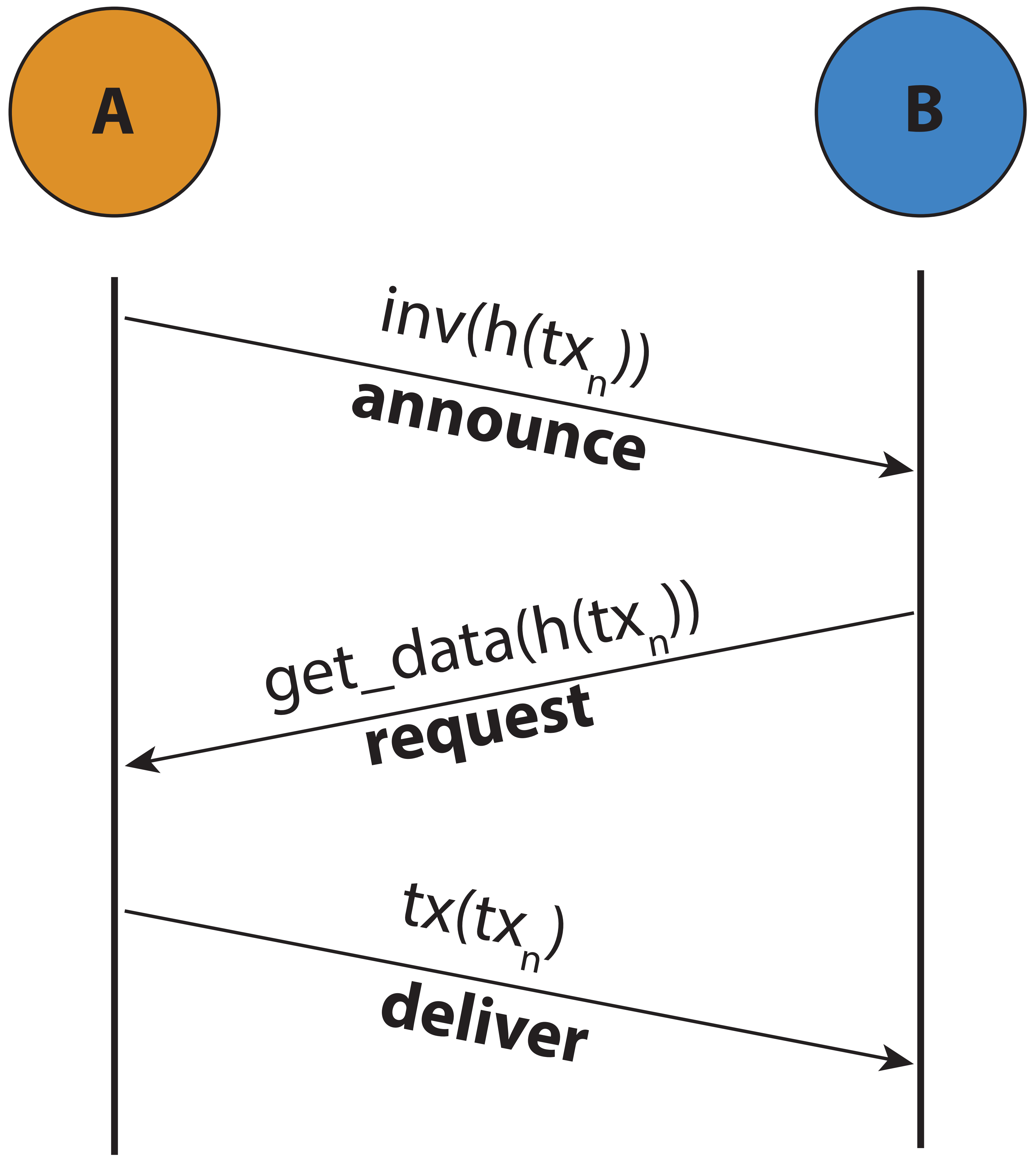
Upon receiving a request of a known item, a node will reply back with it (**deliver**)

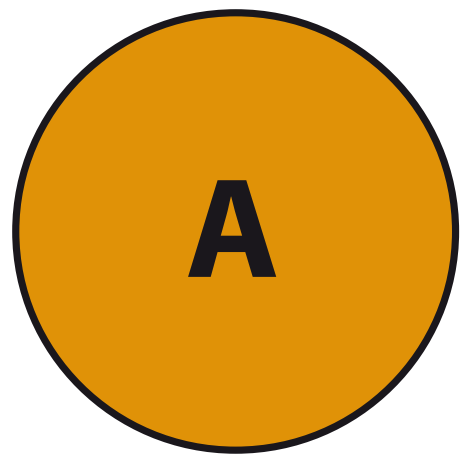
Announce paradigm



BREAK
TIME

Information propagation

INFORMATION PROPAGATION (1/3)



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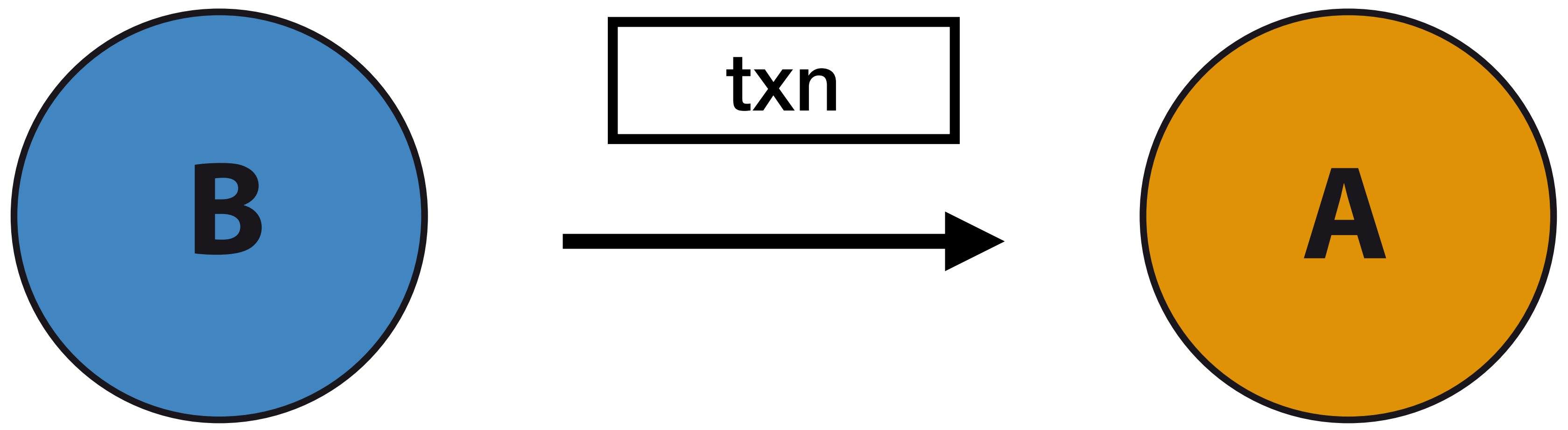

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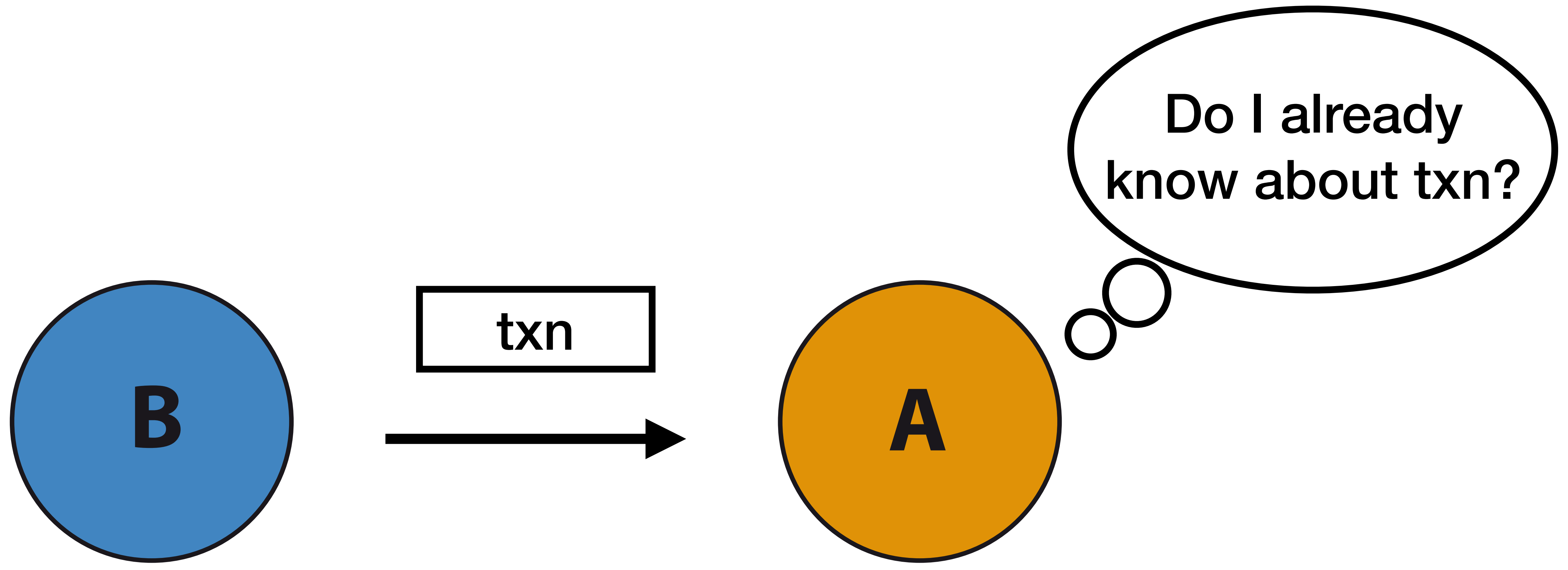

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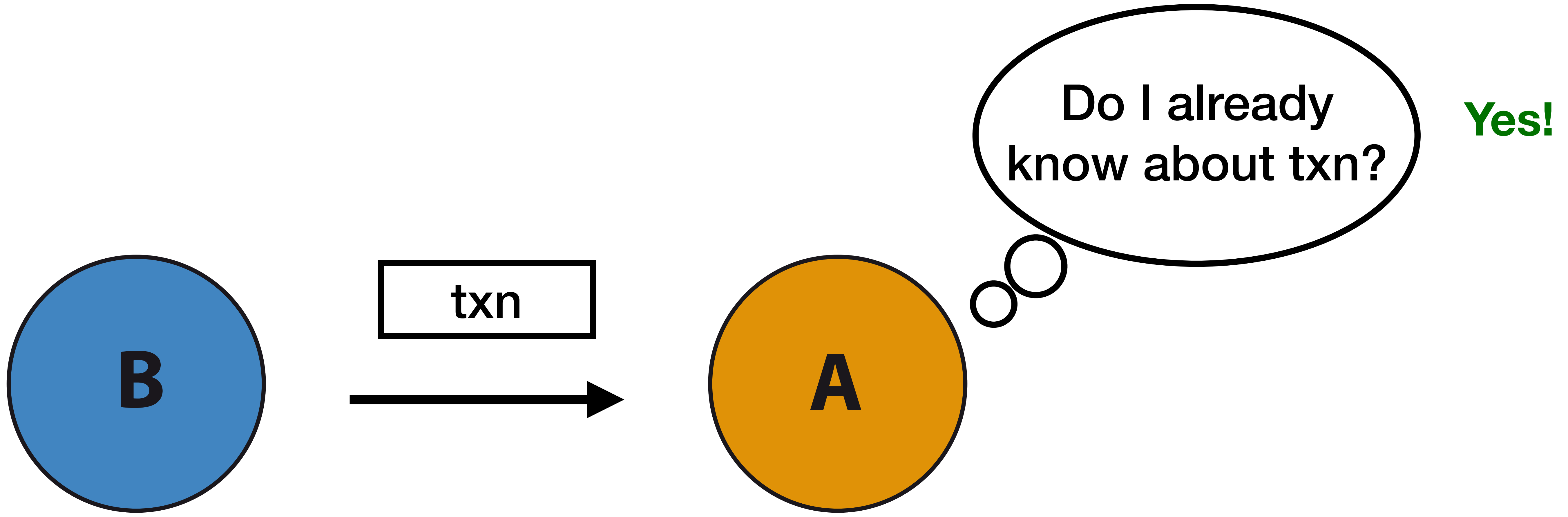

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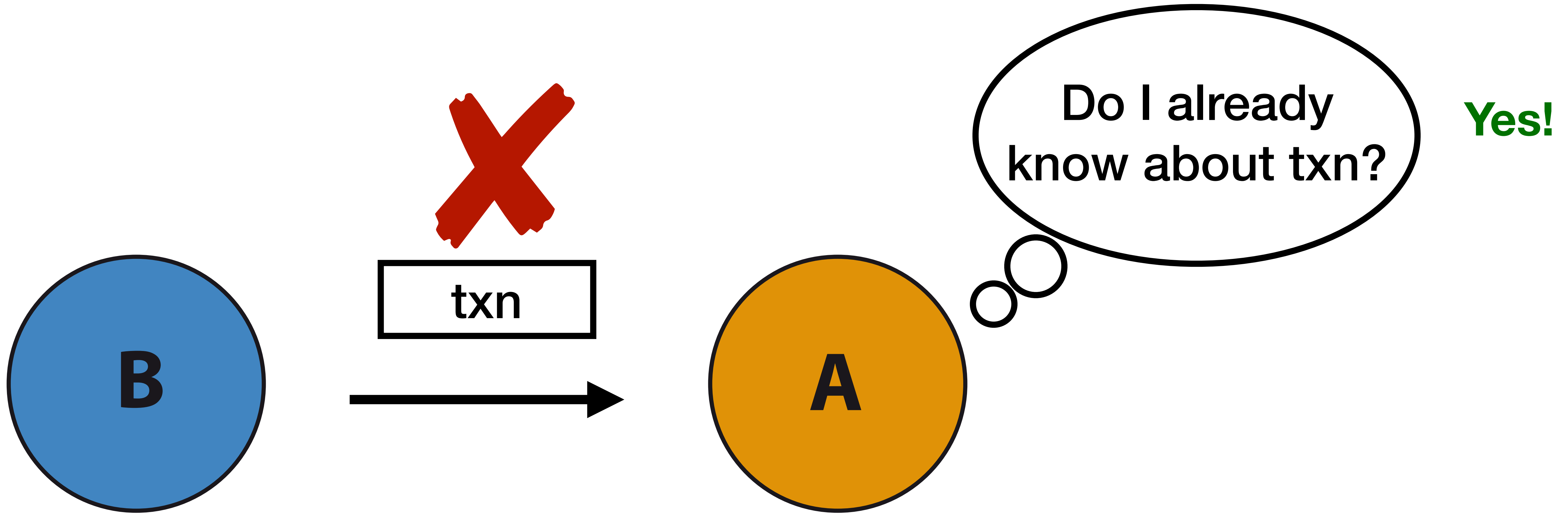

- Known transaction will be rejected

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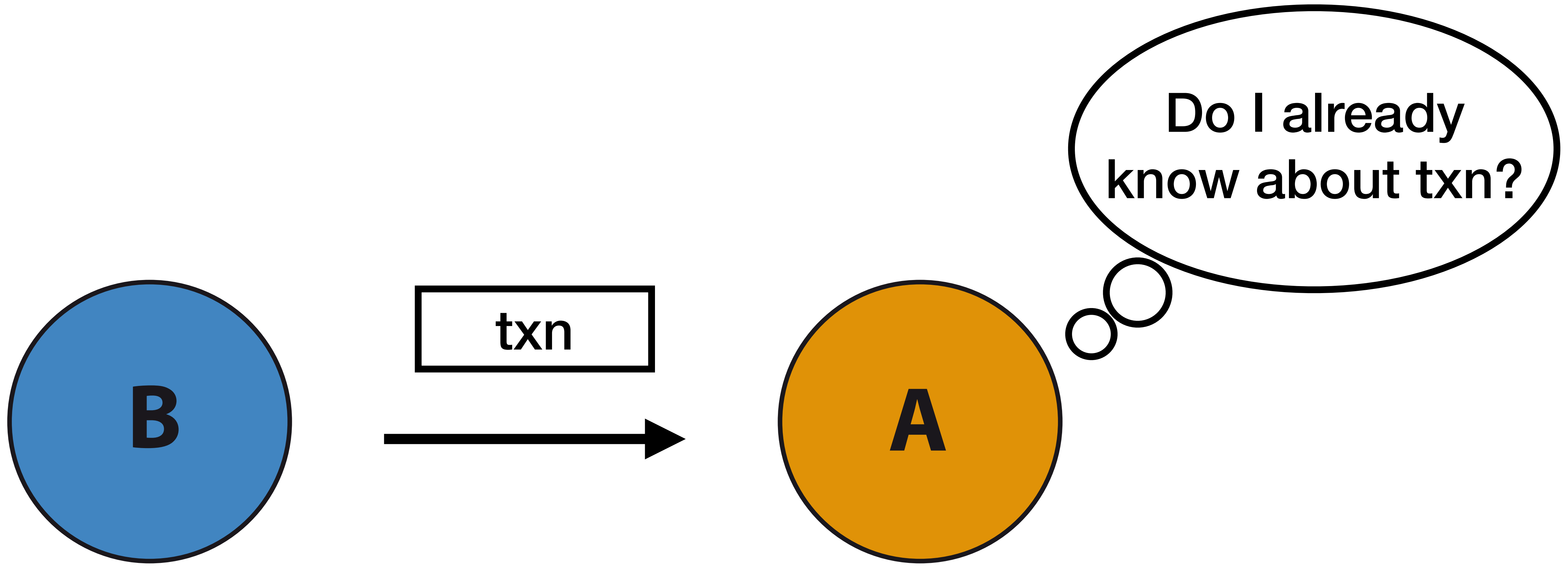

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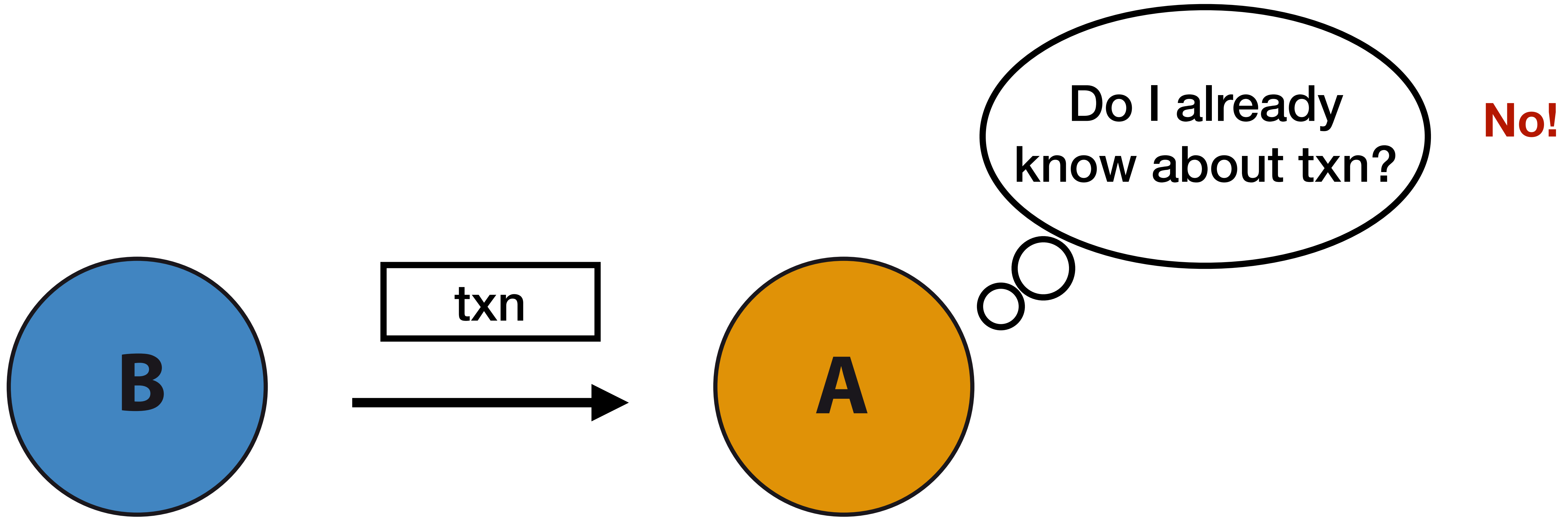

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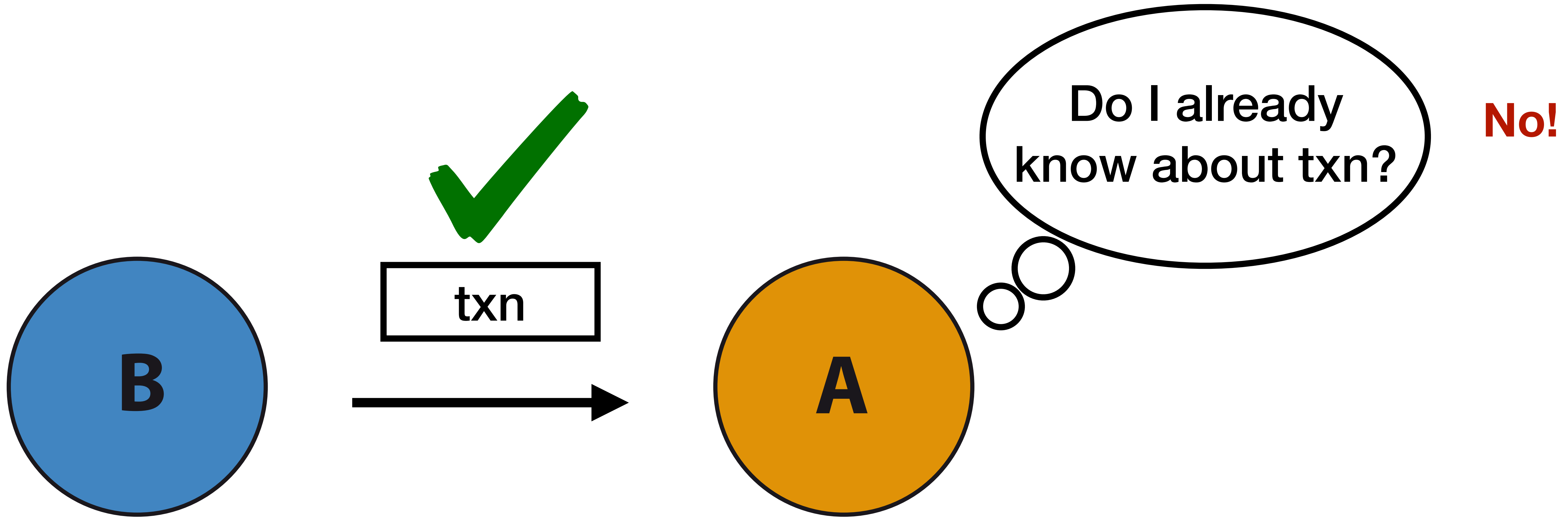

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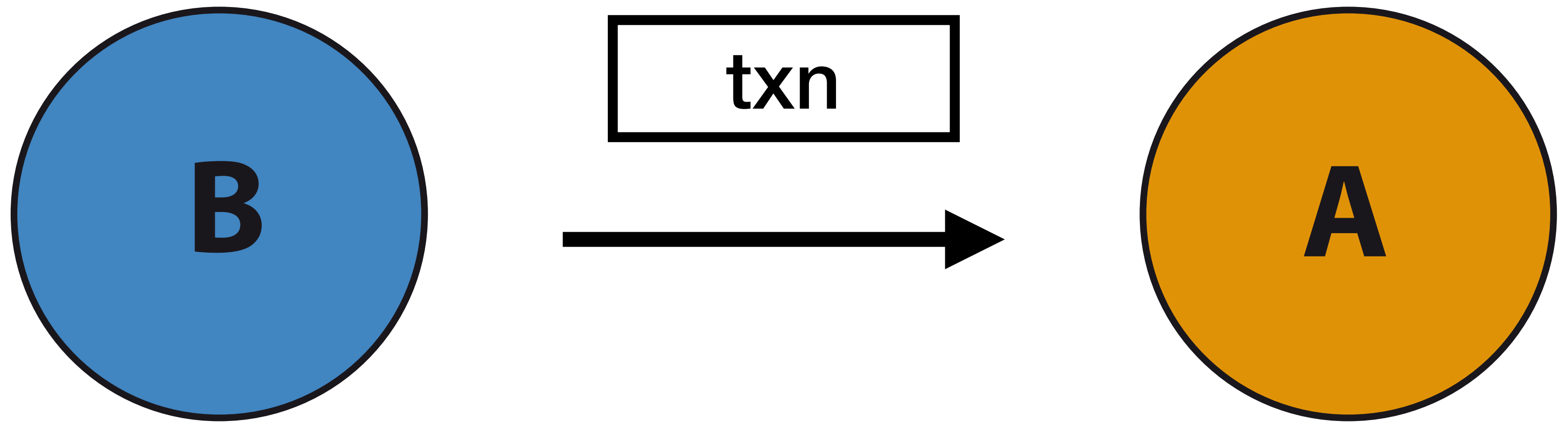

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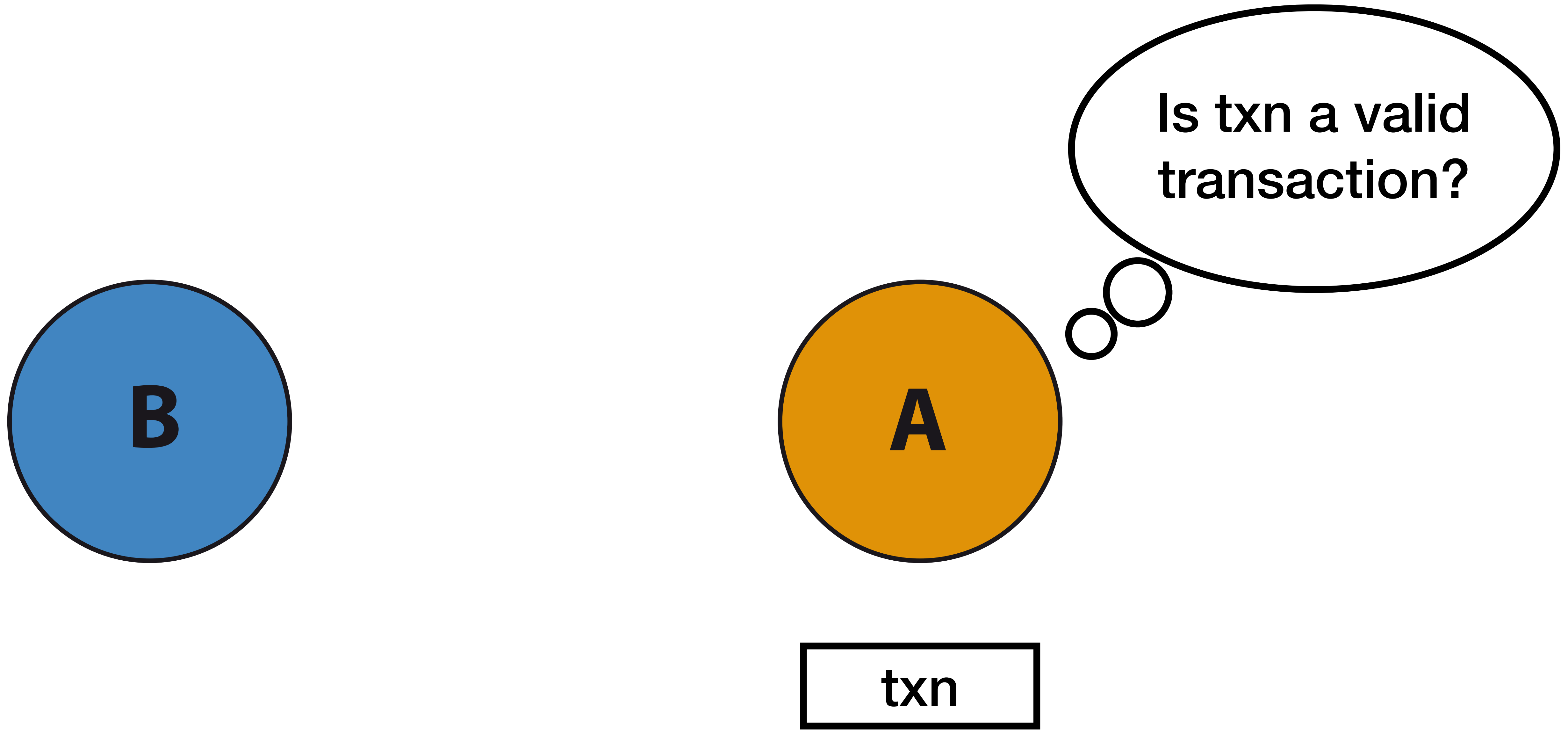

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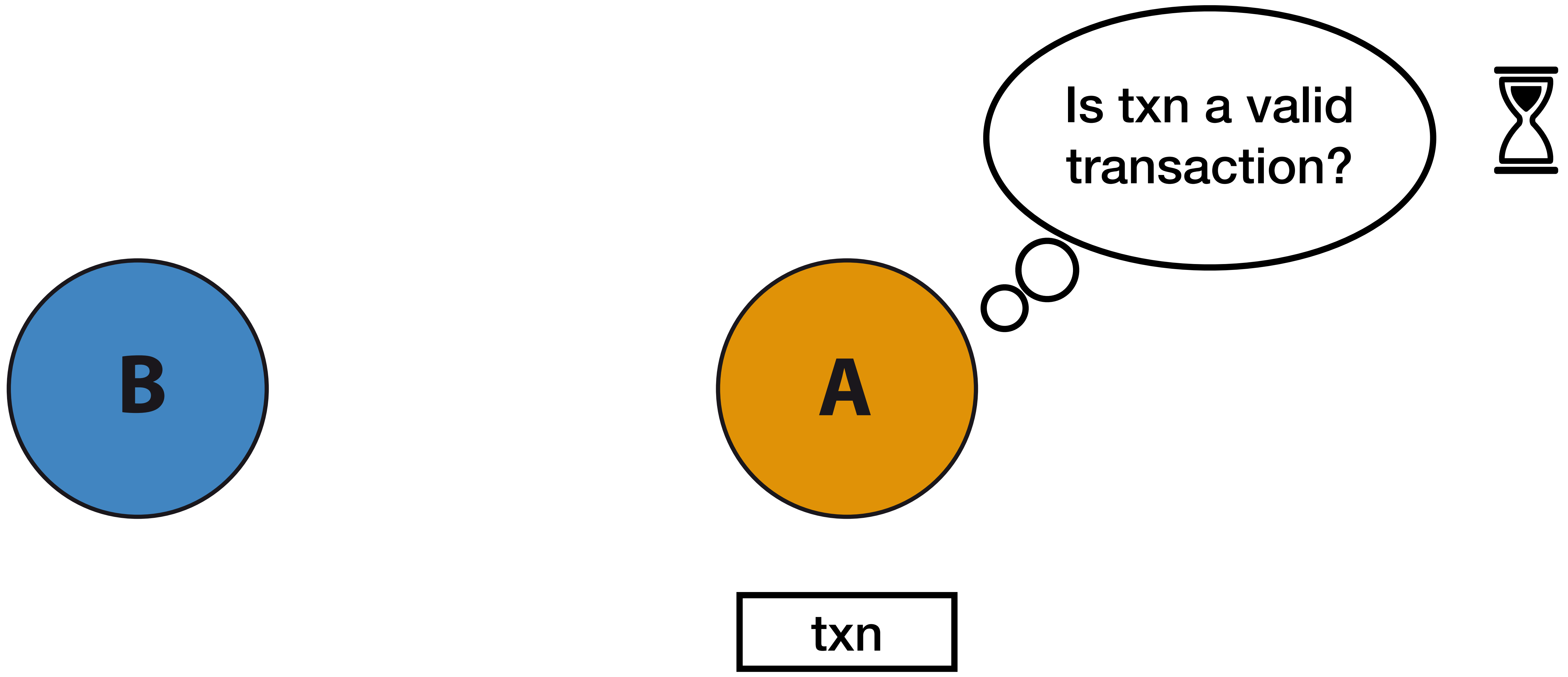

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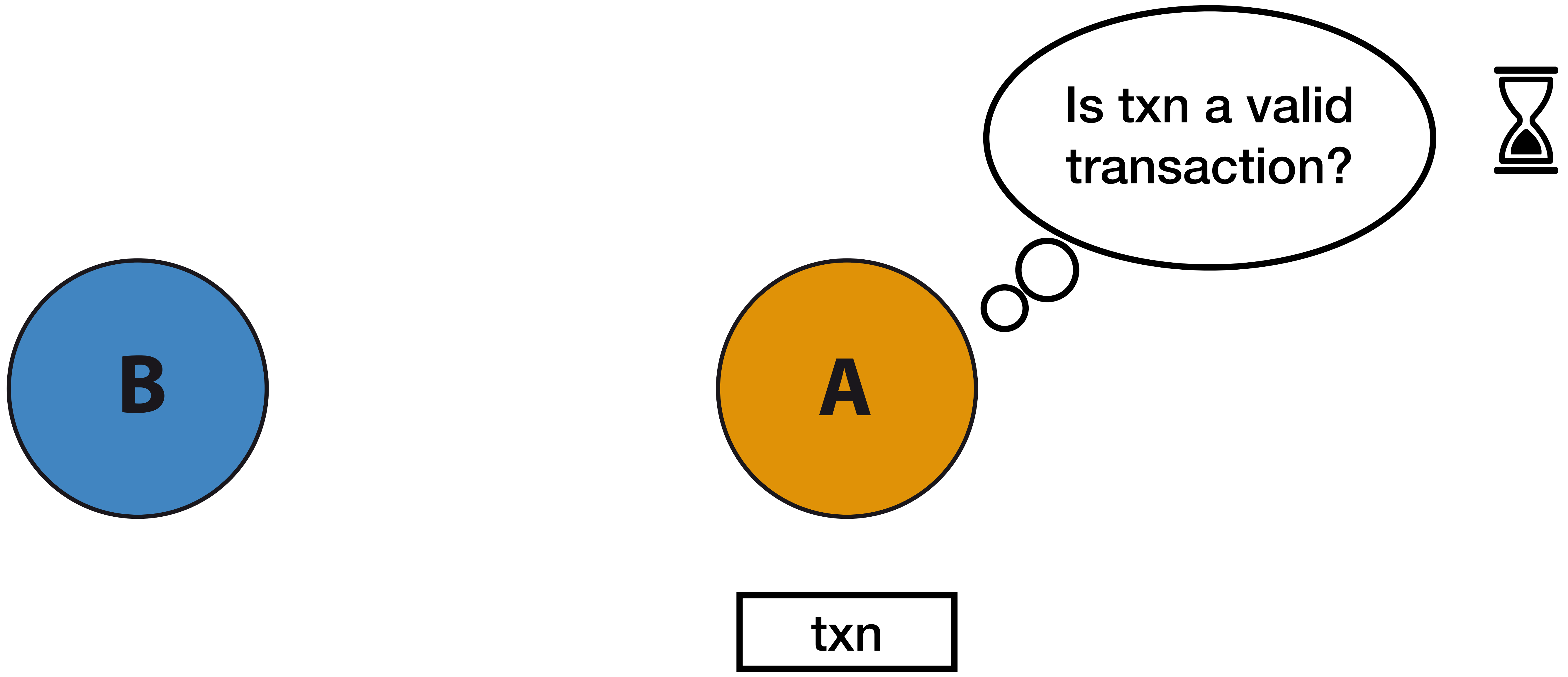

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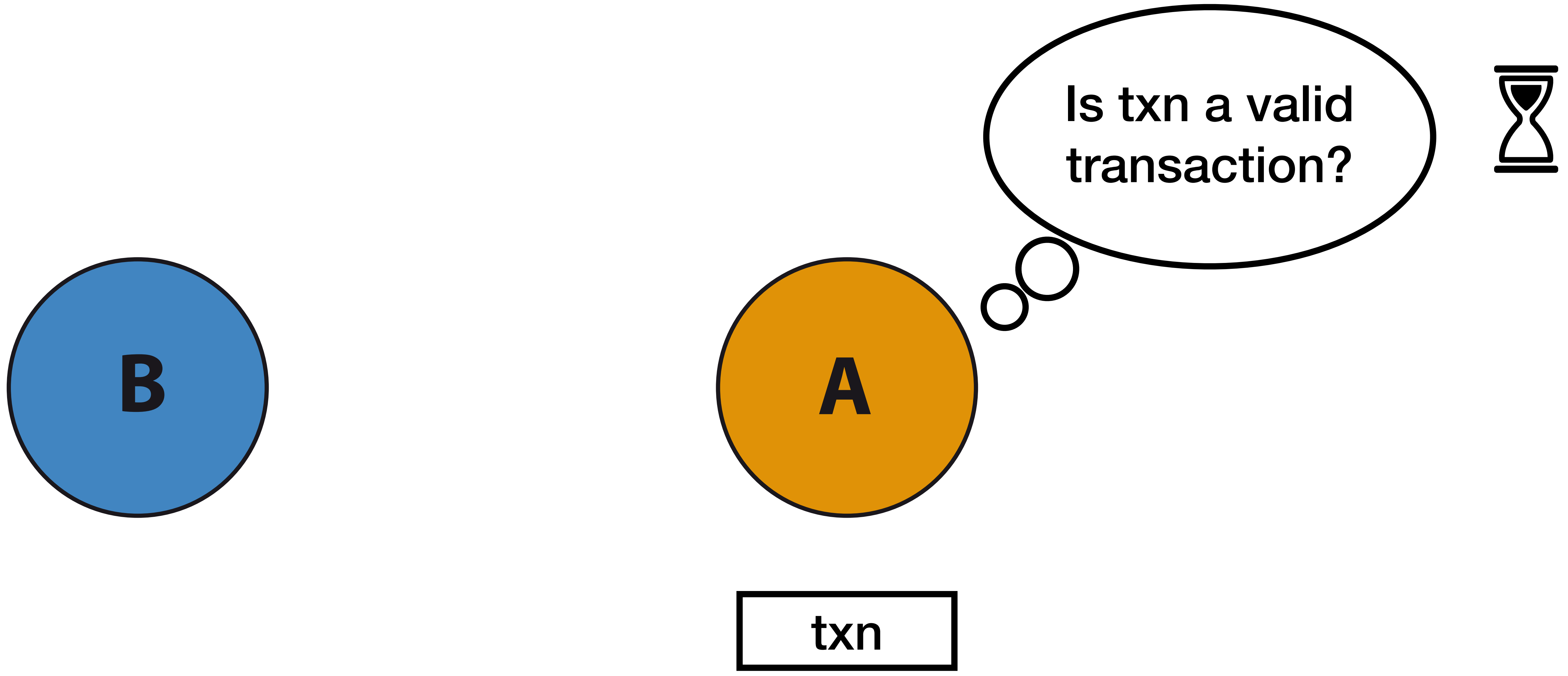

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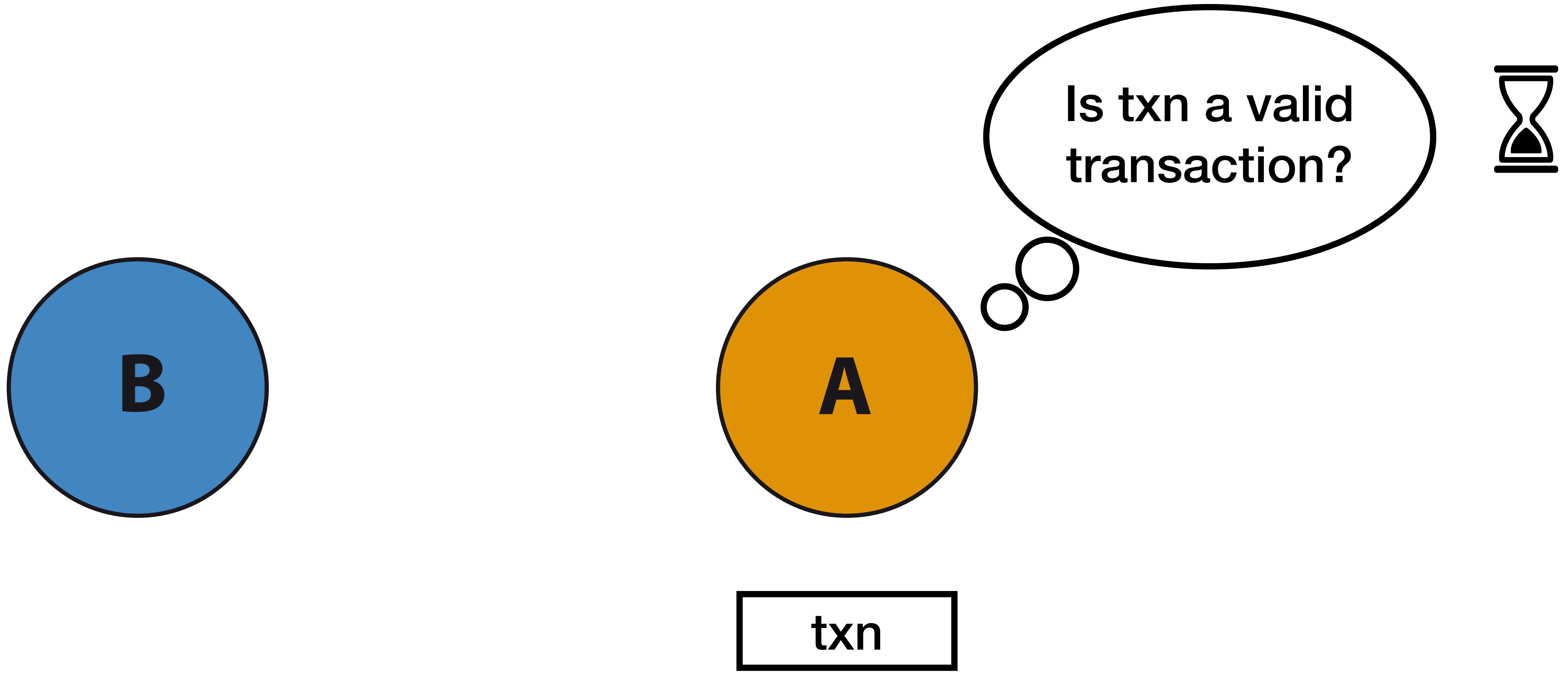

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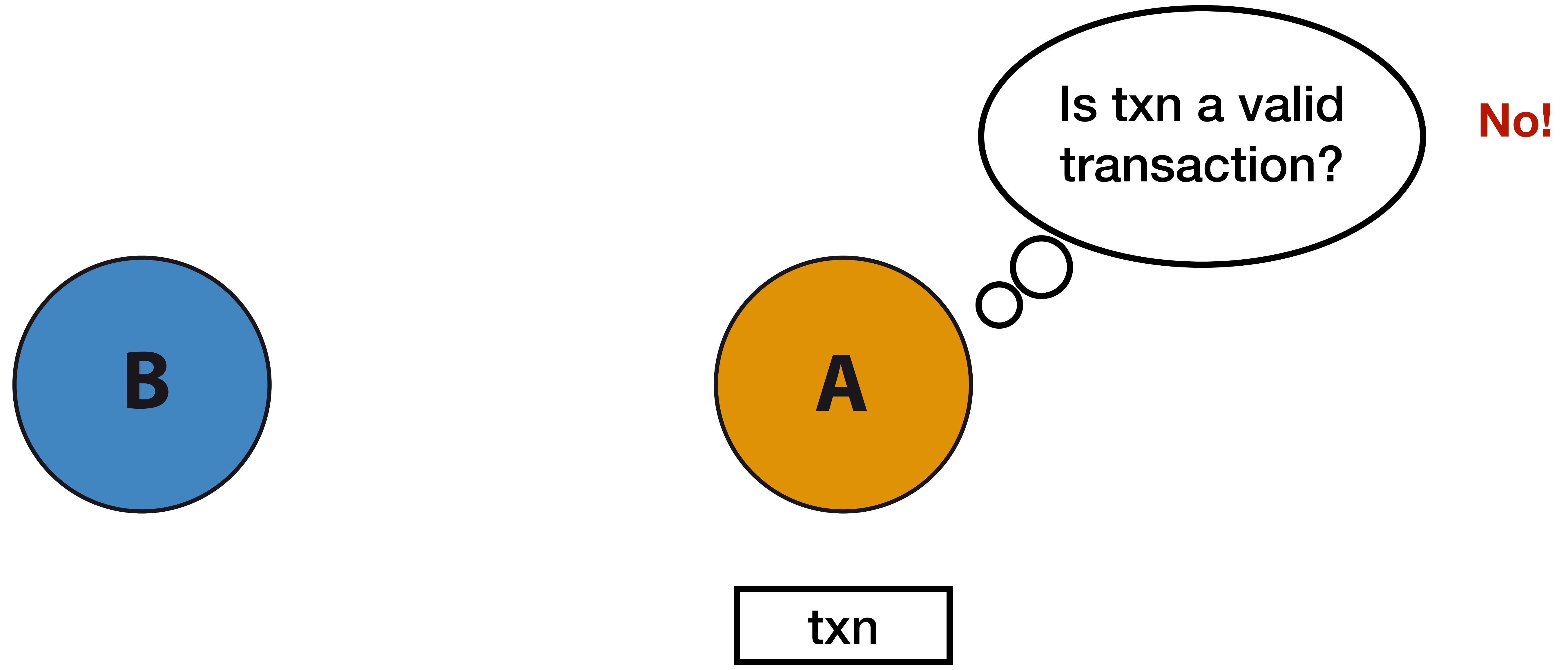

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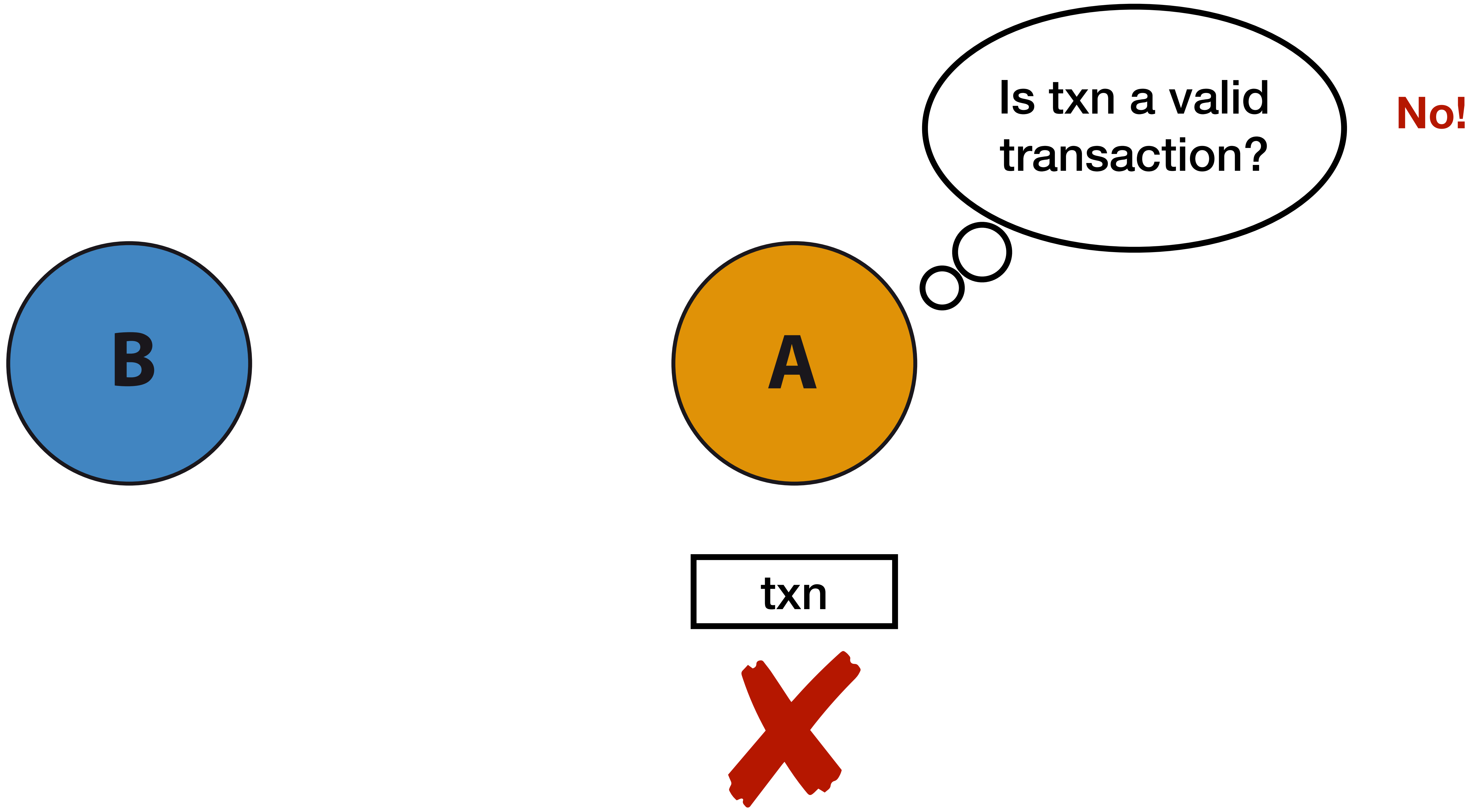

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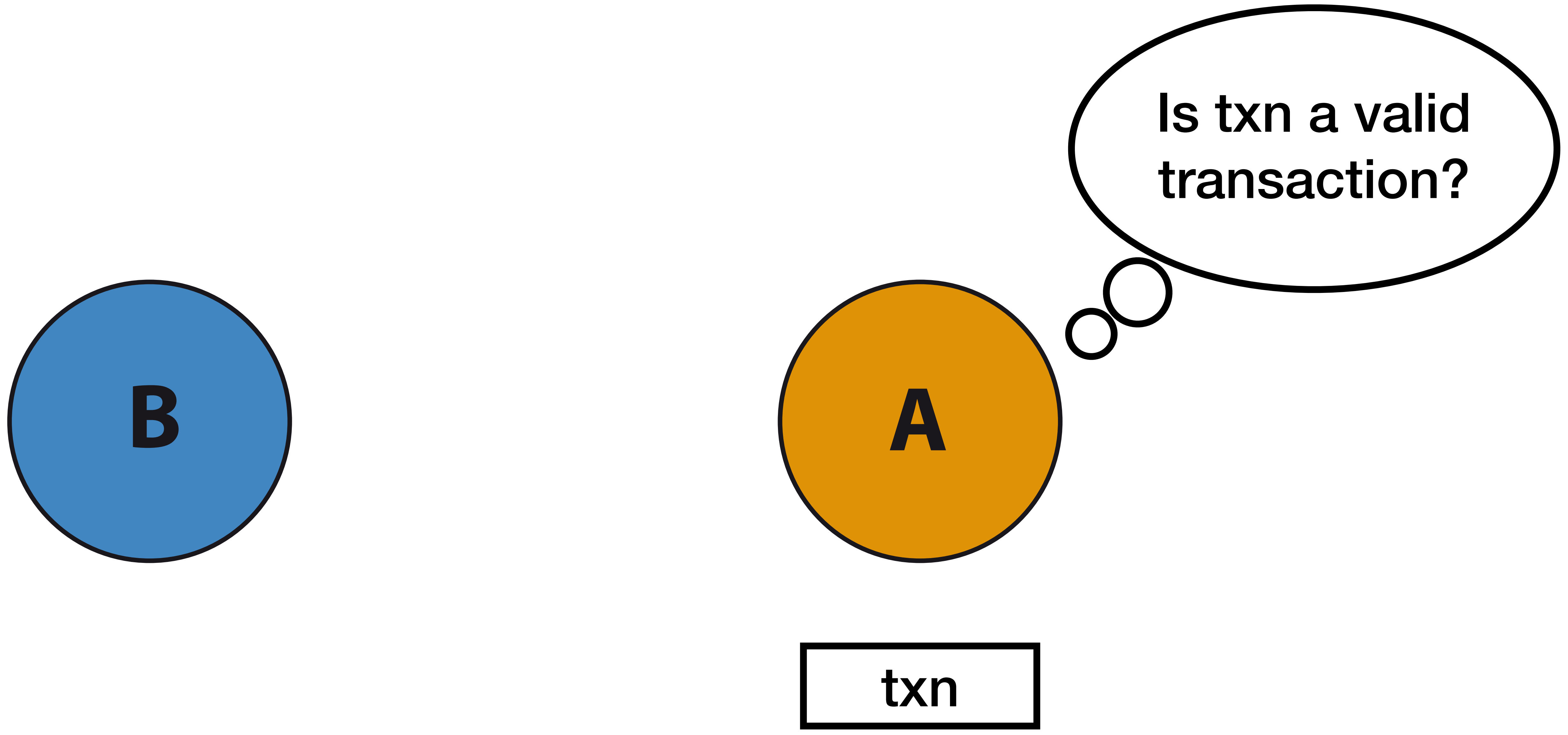

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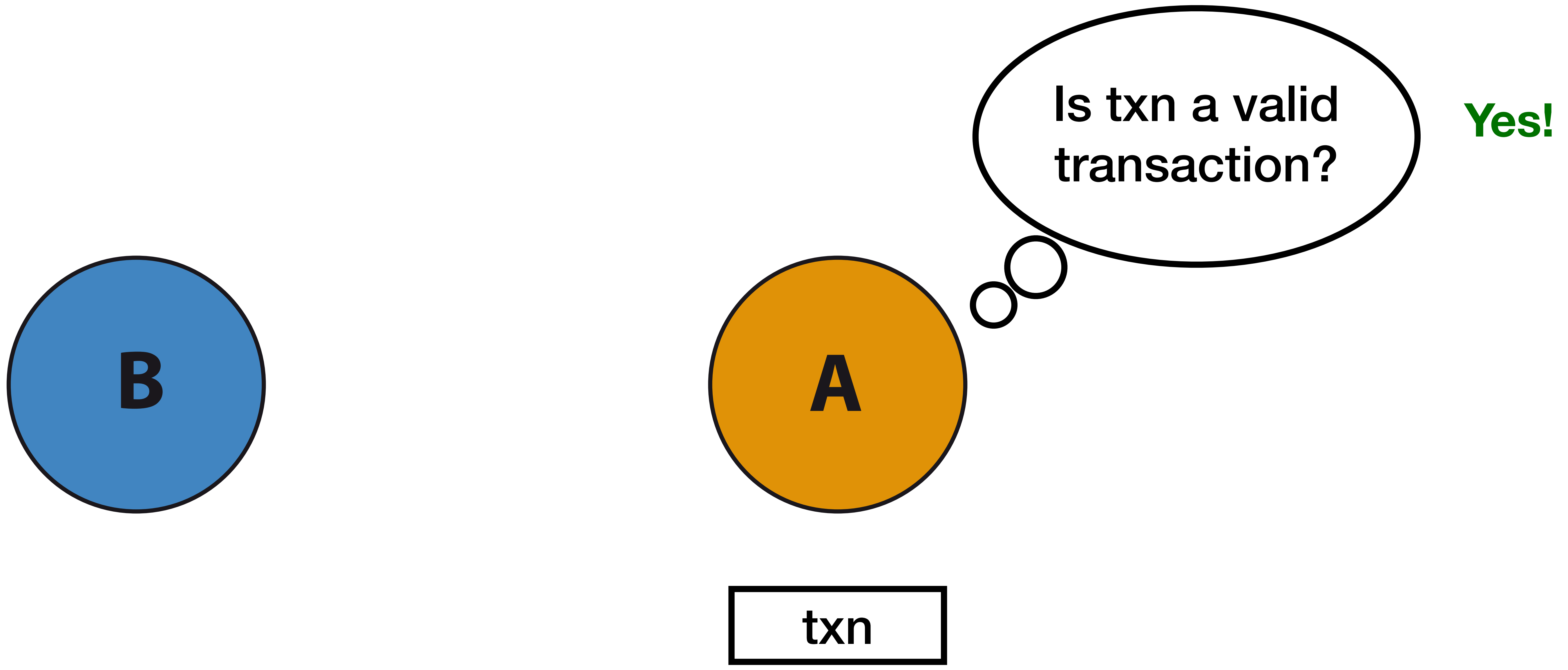

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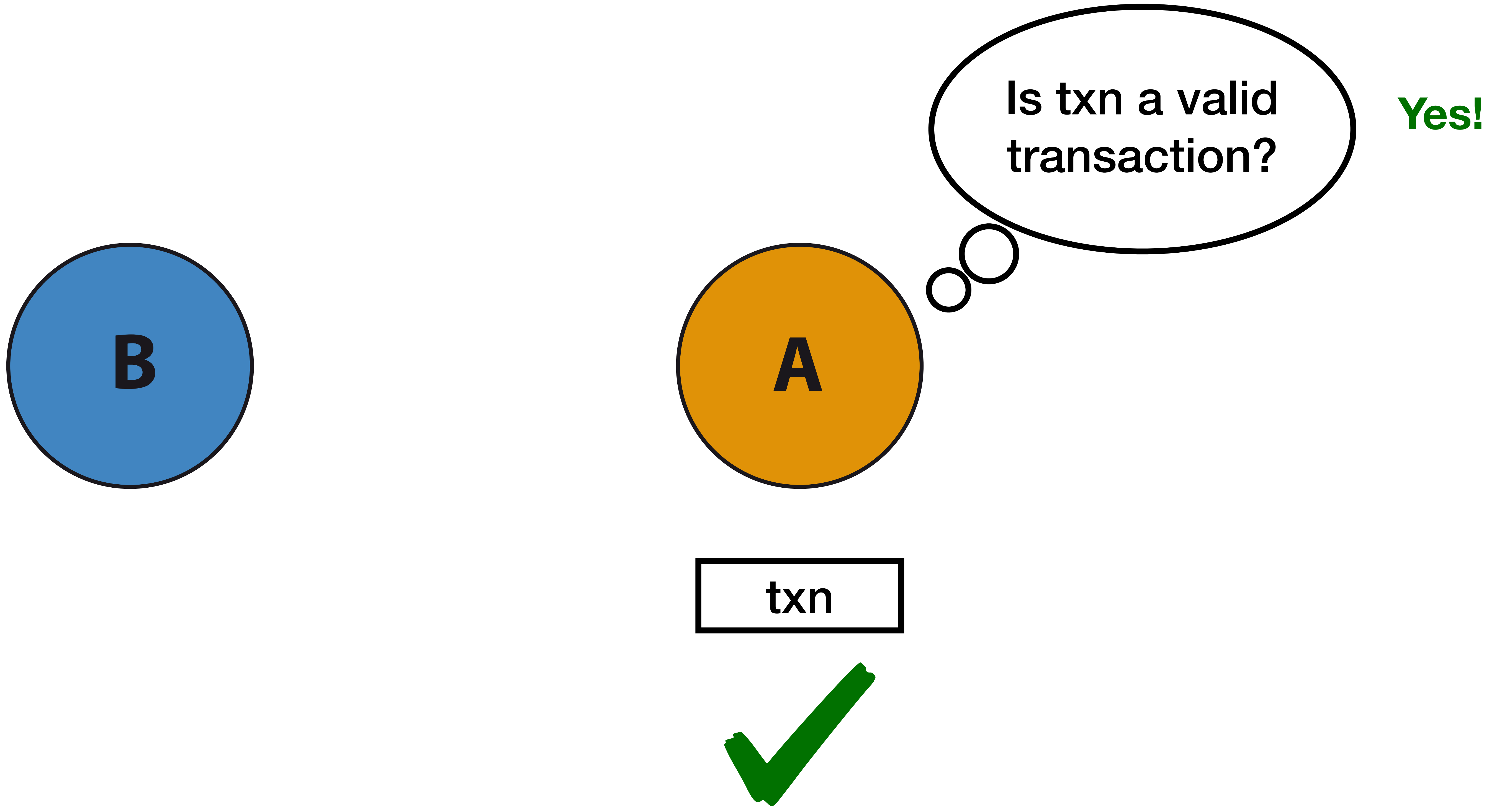

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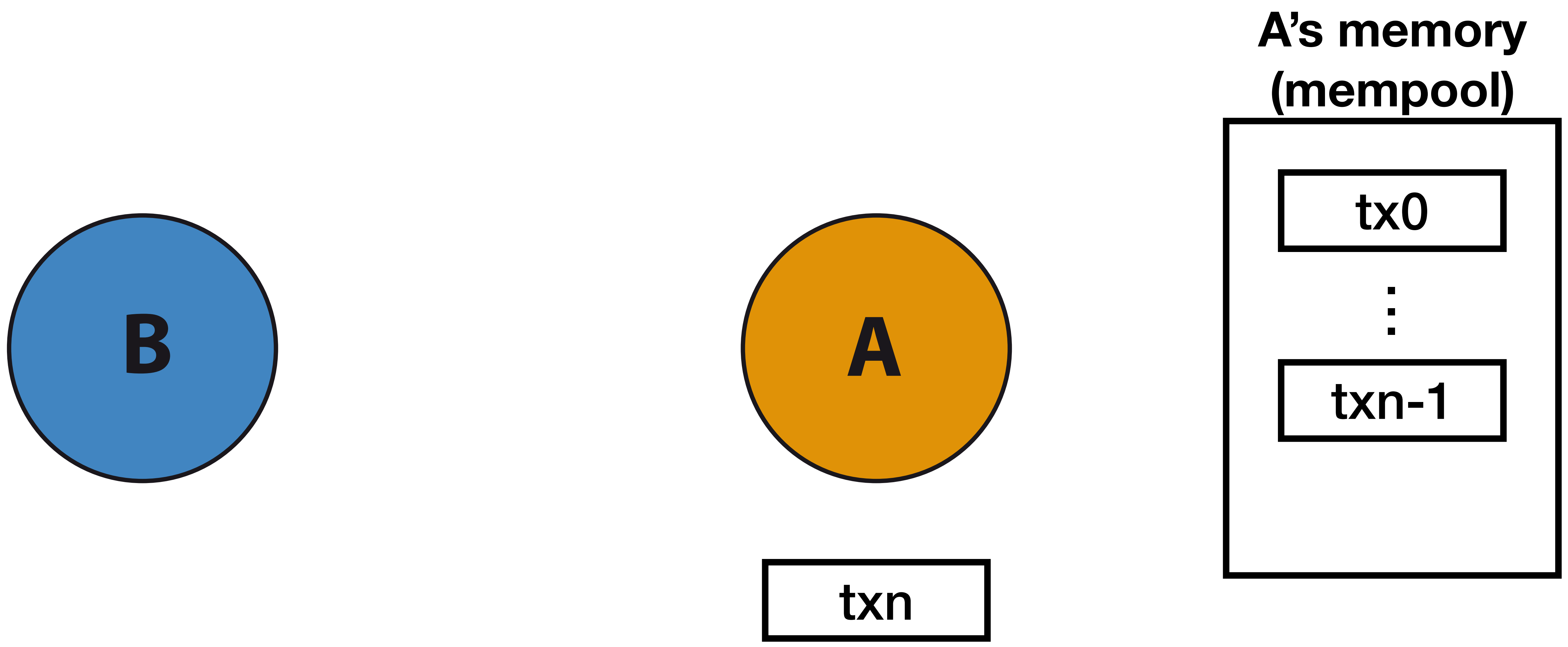

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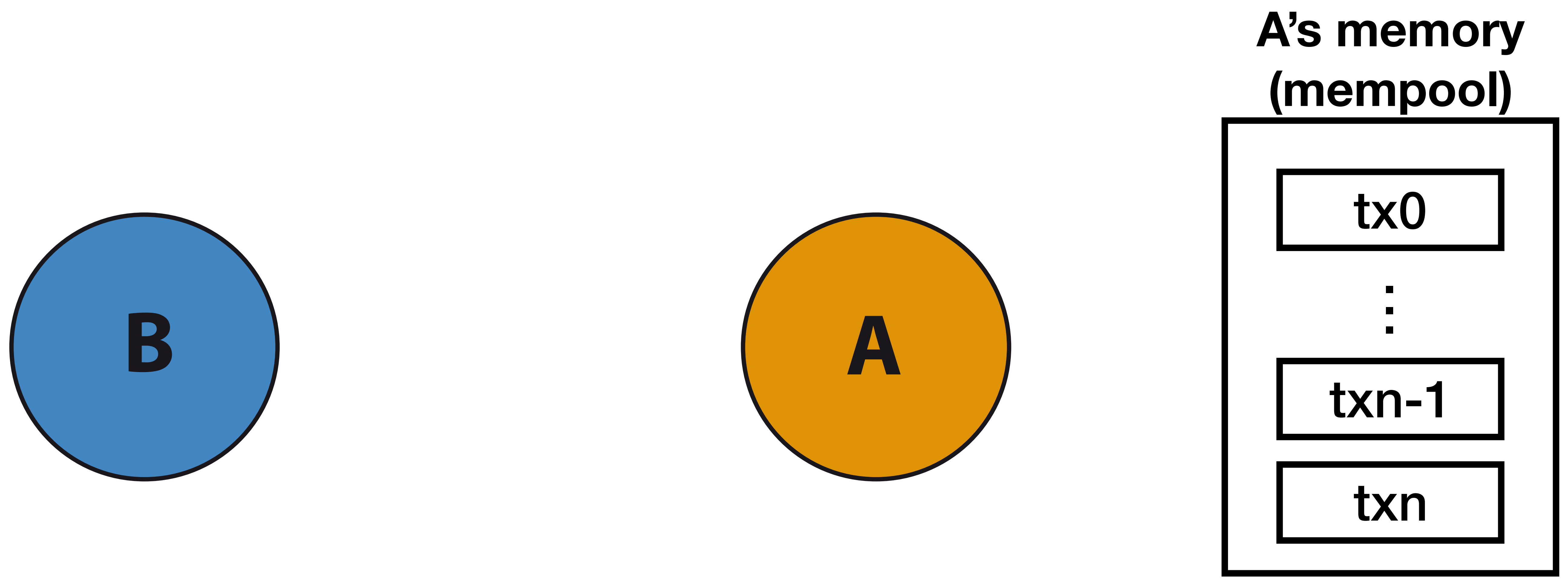

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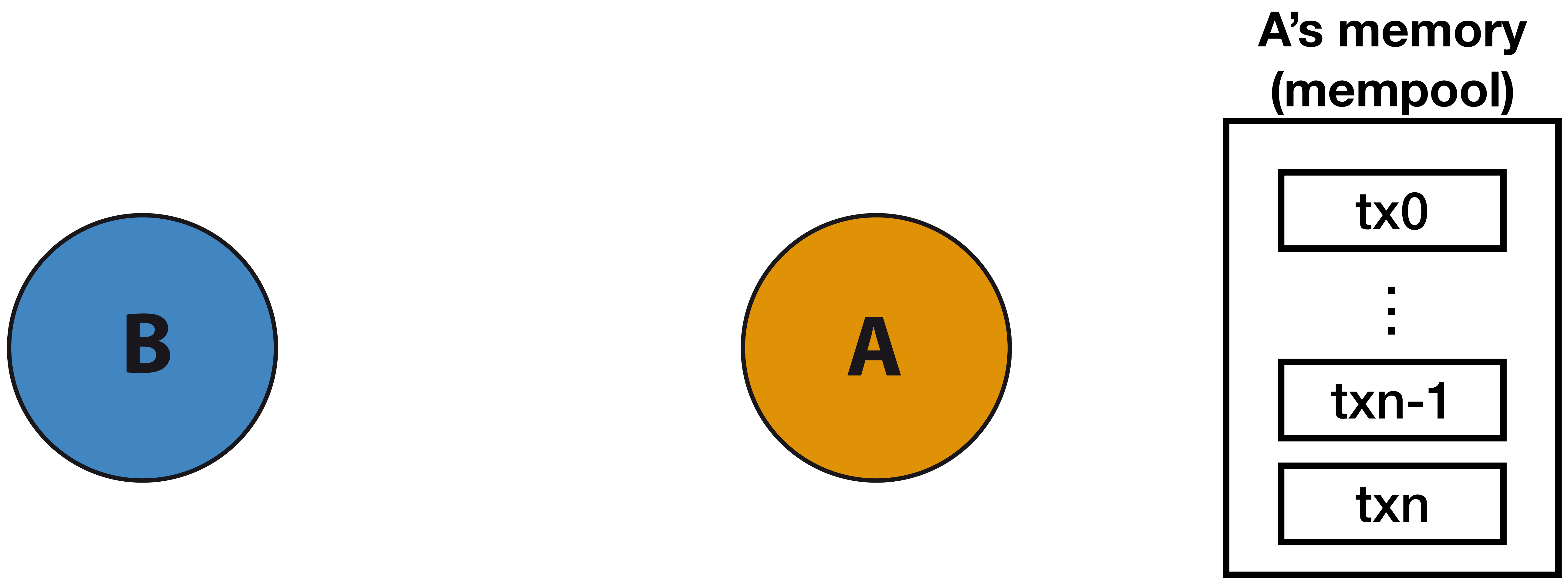

- Known transaction will be rejected
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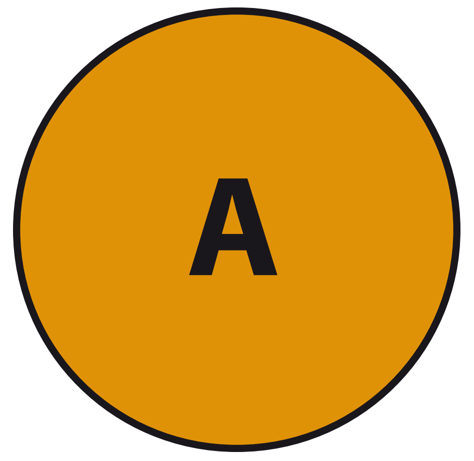
- Valid (new) transactions will be kept in memory (mempool)

INFORMATION PROPAGATION (2/3)



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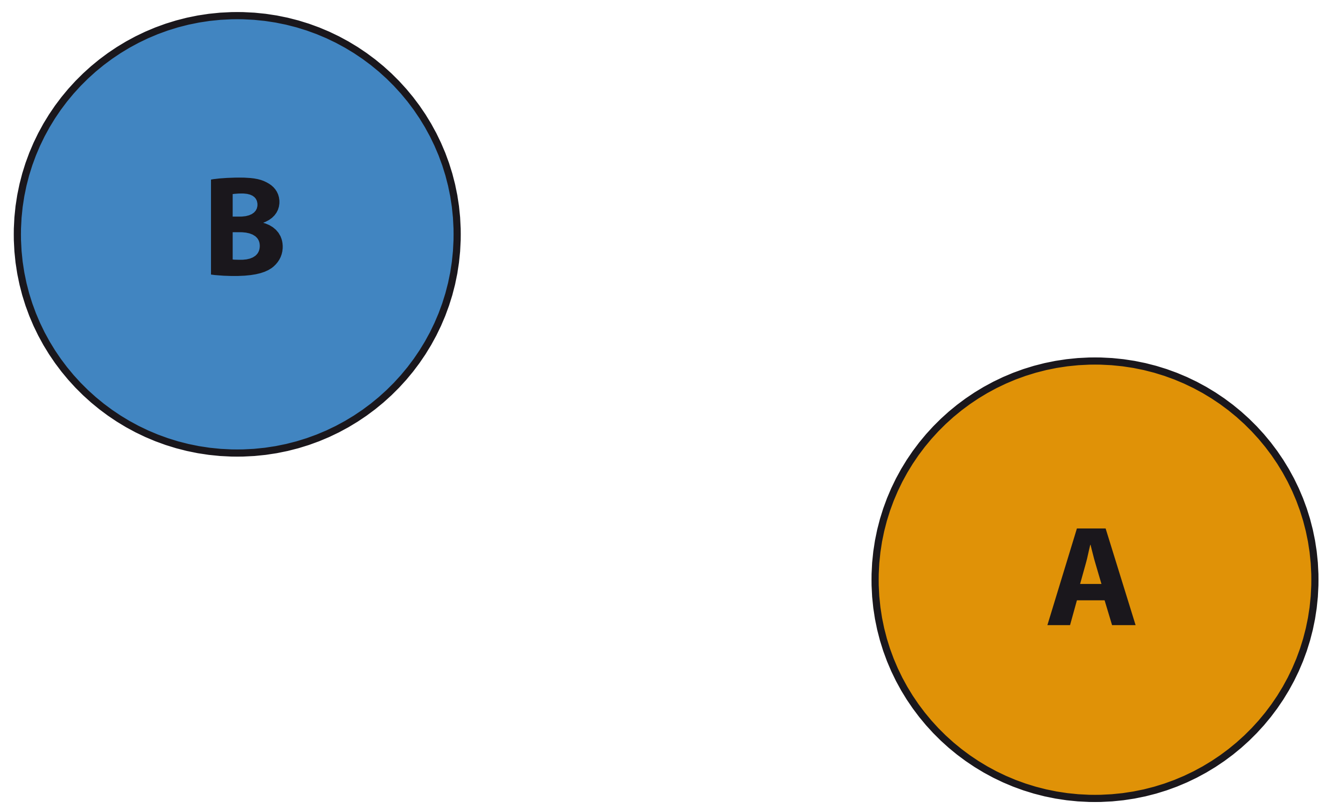

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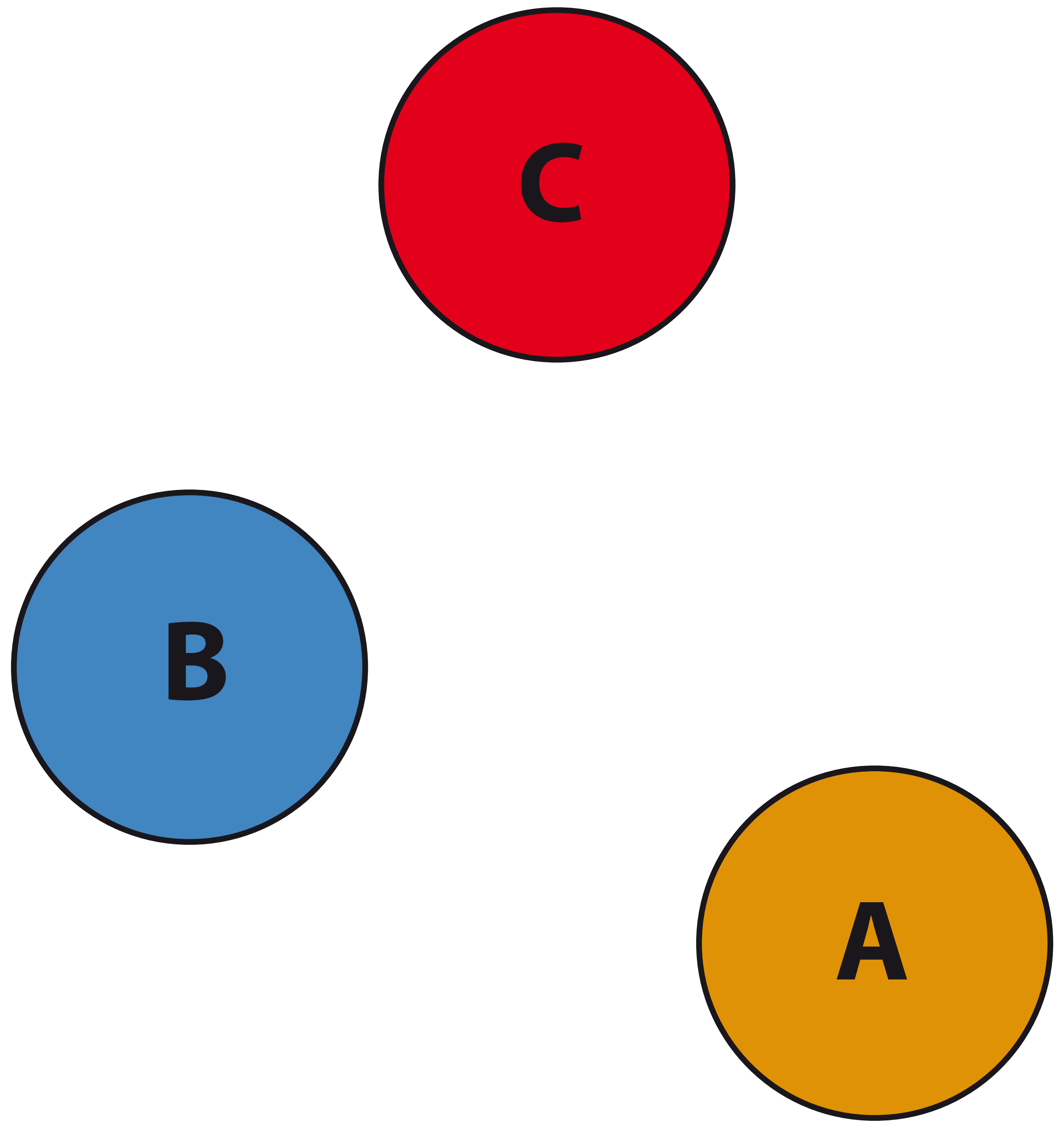

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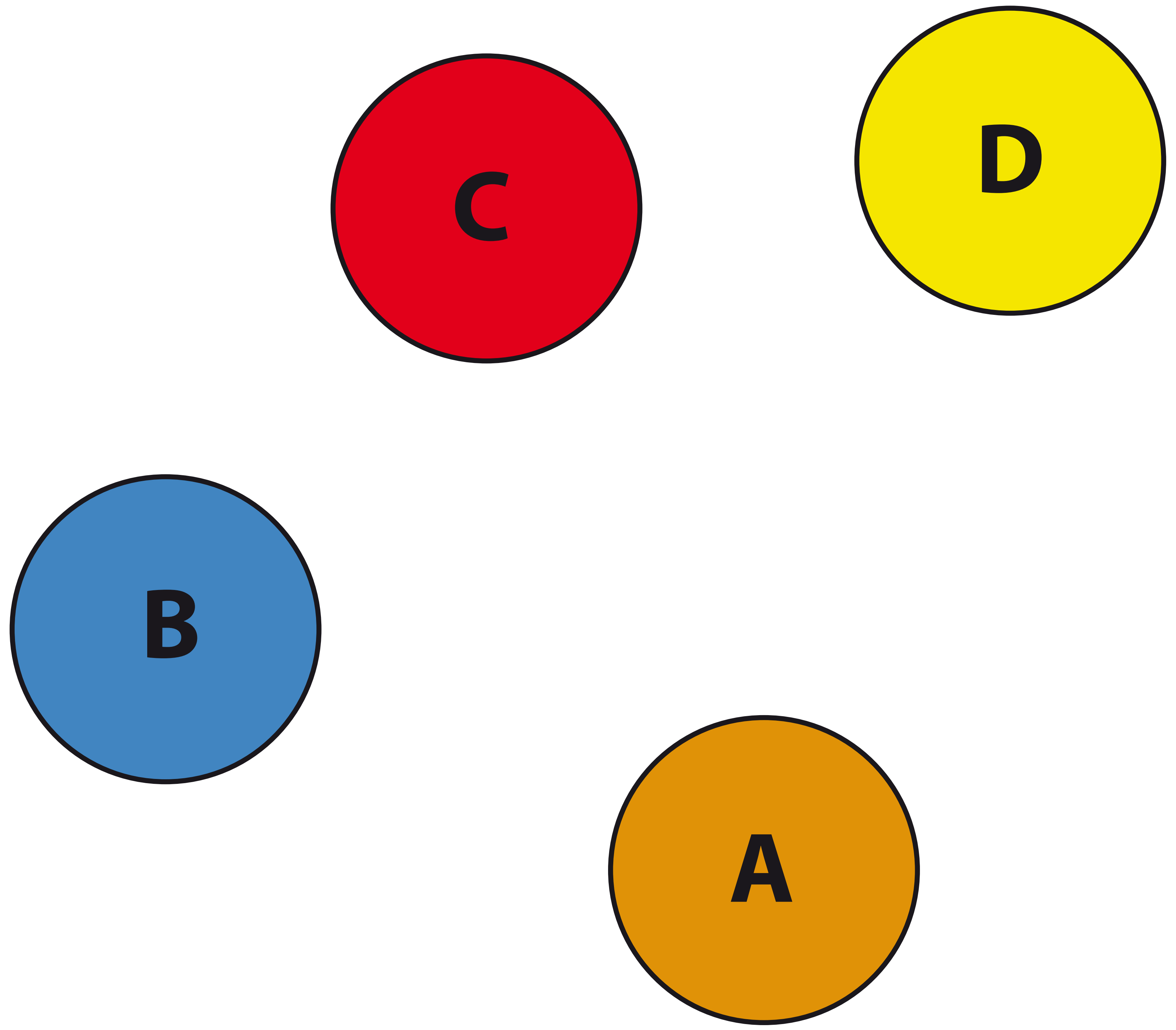

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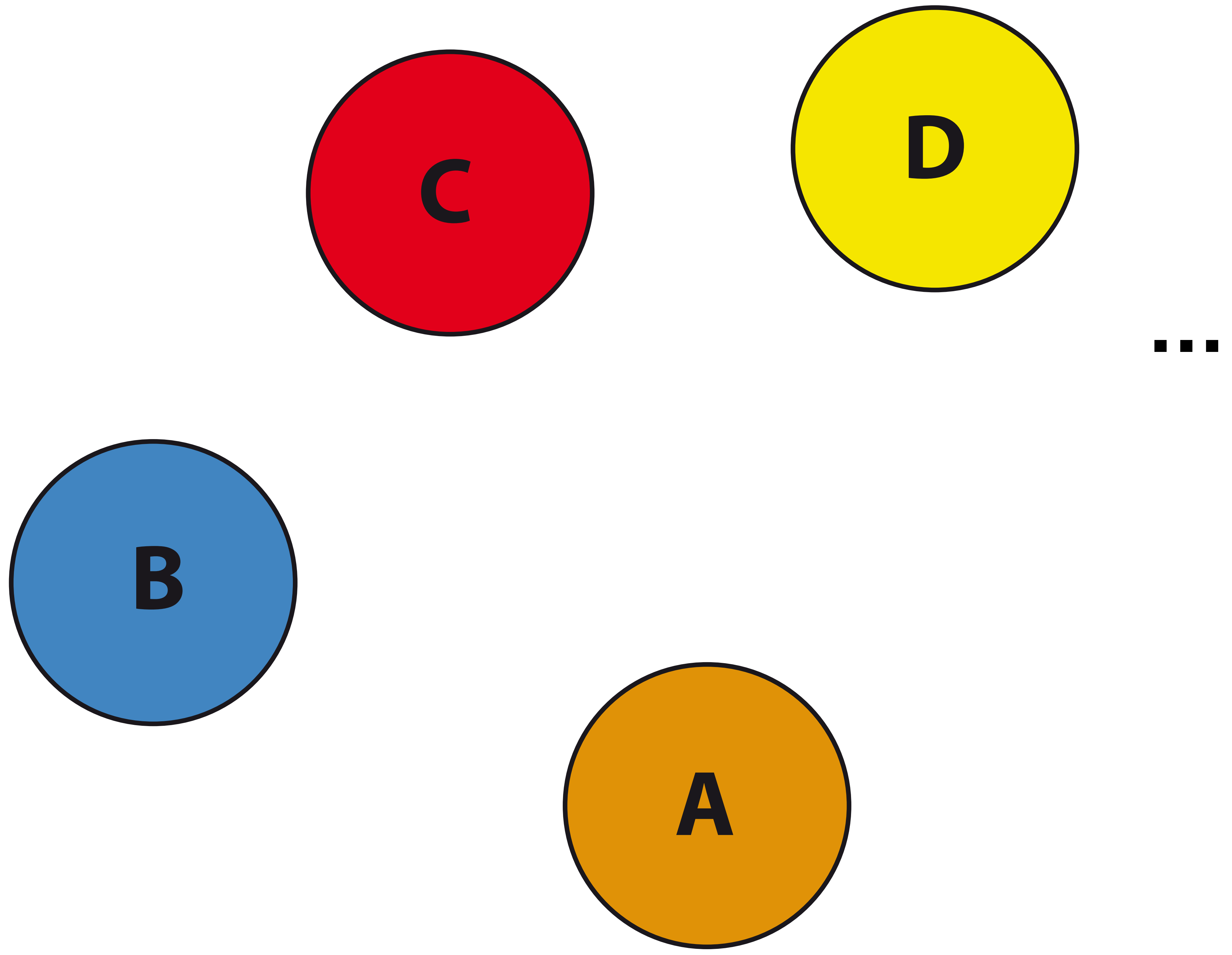

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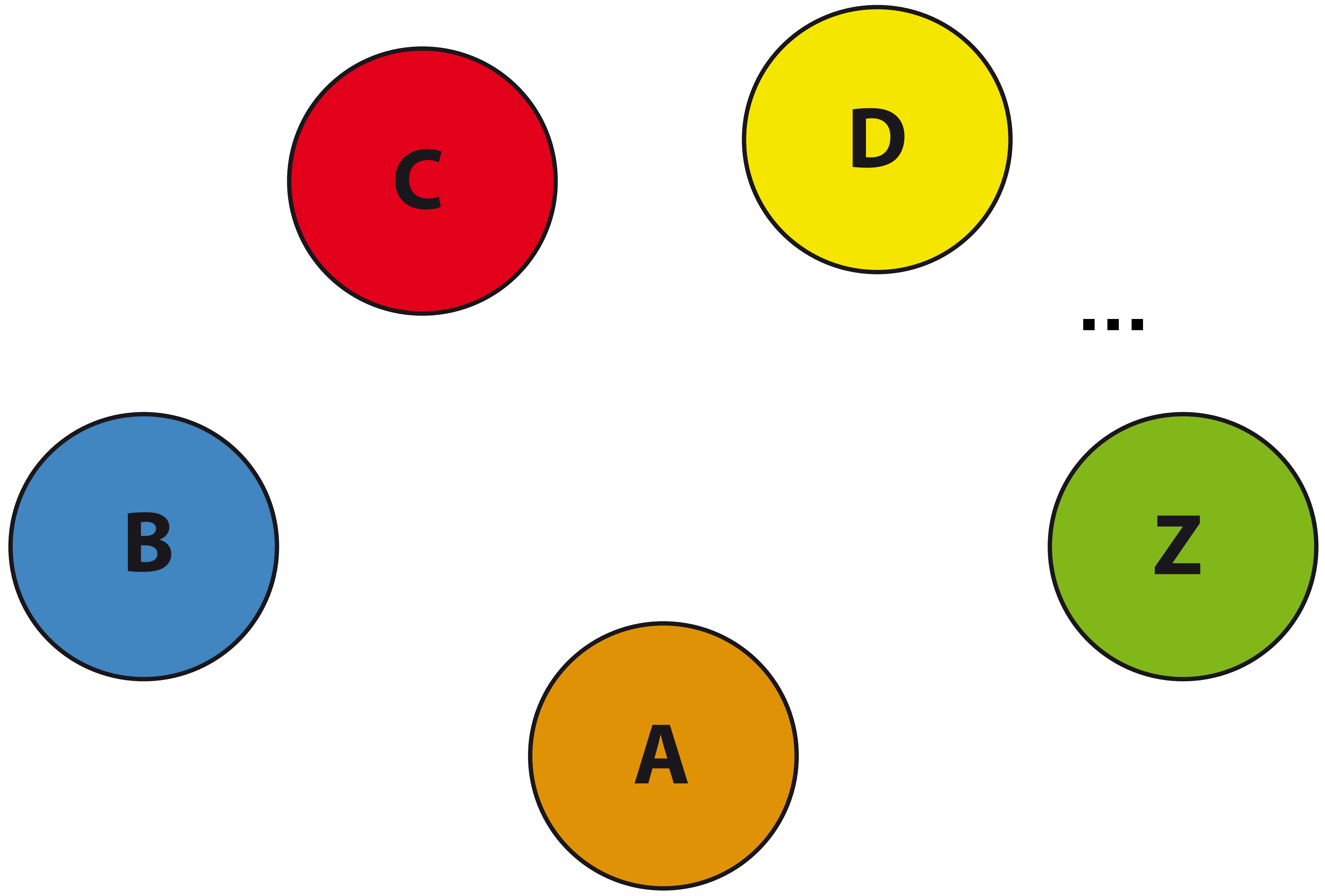

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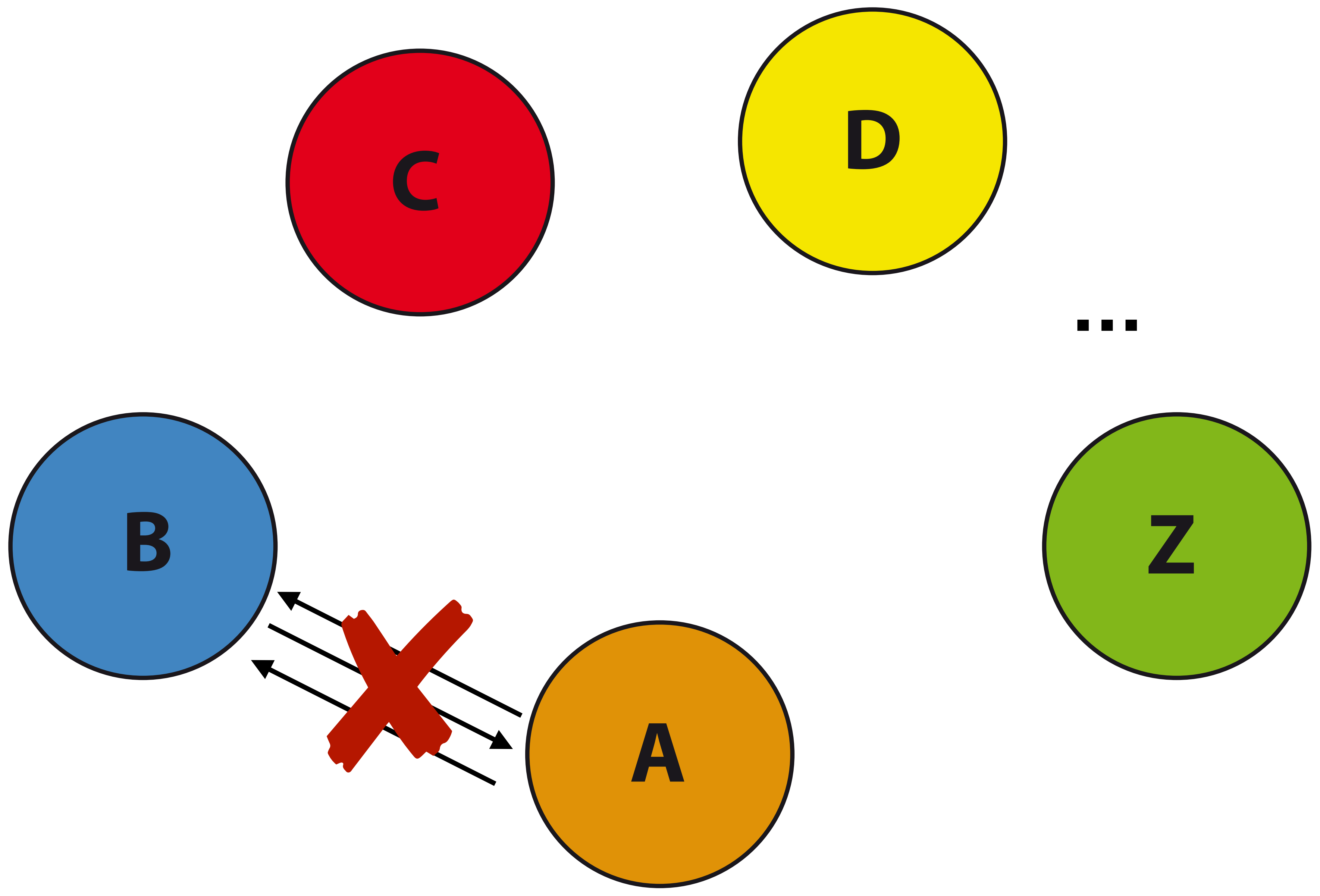

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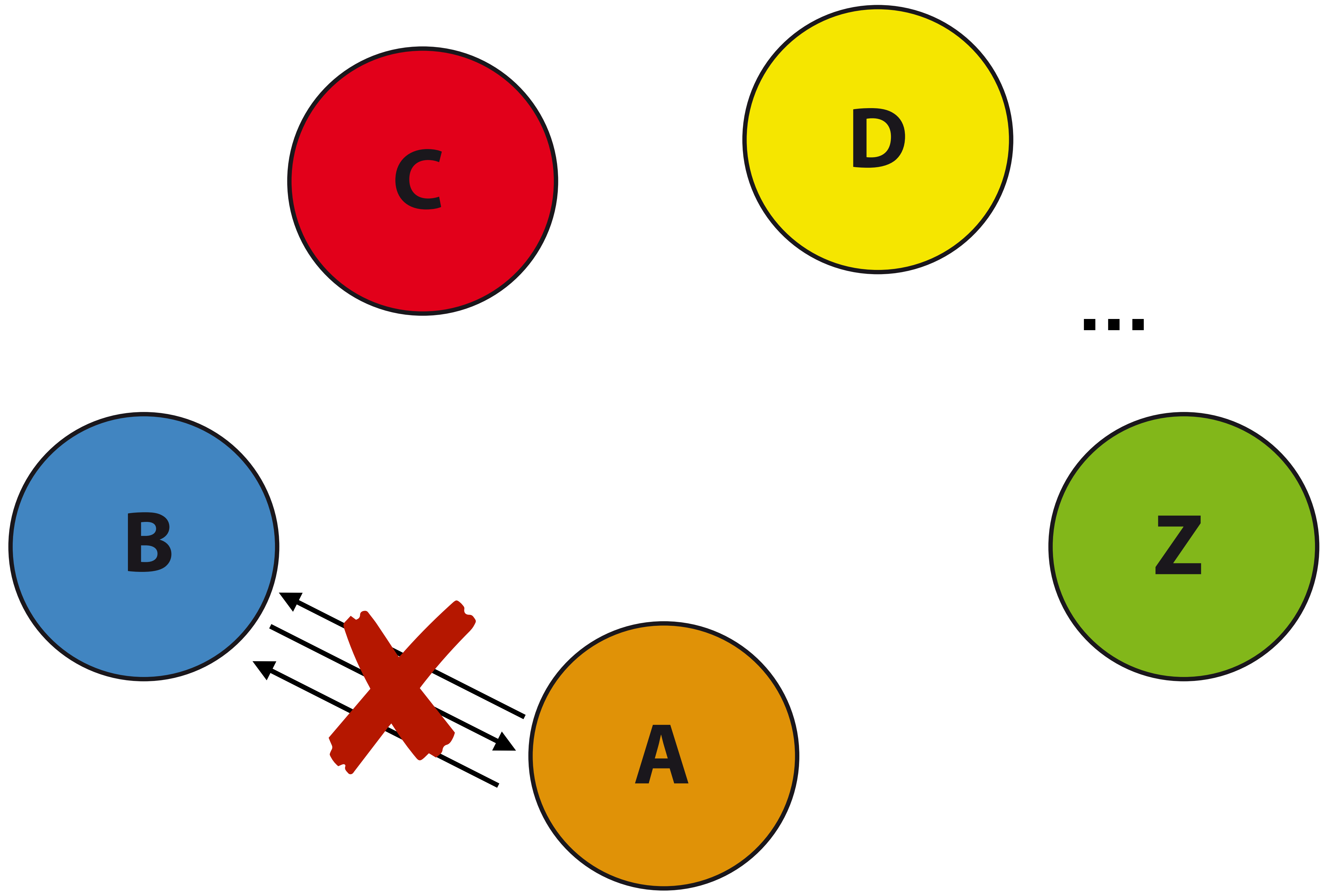

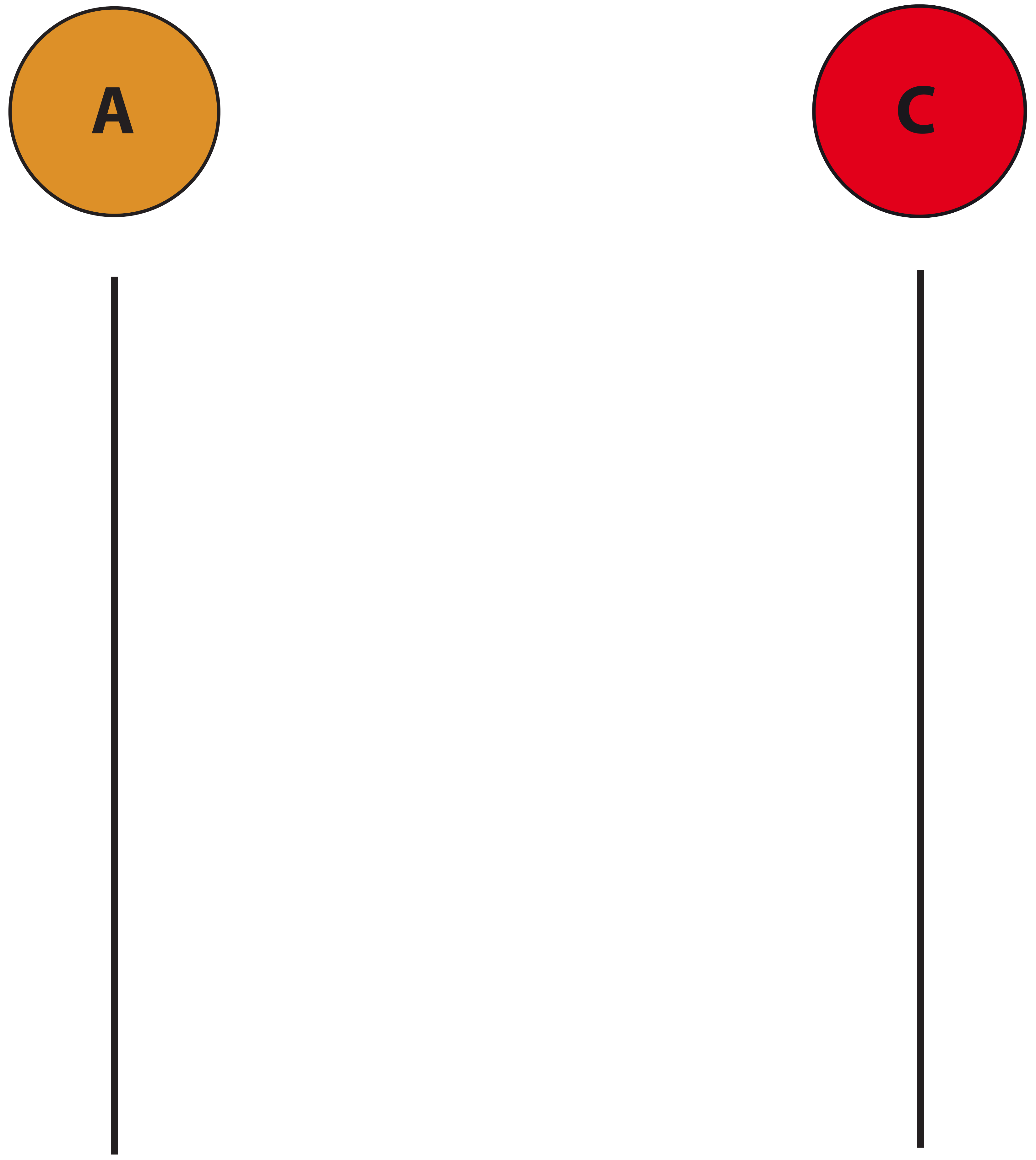

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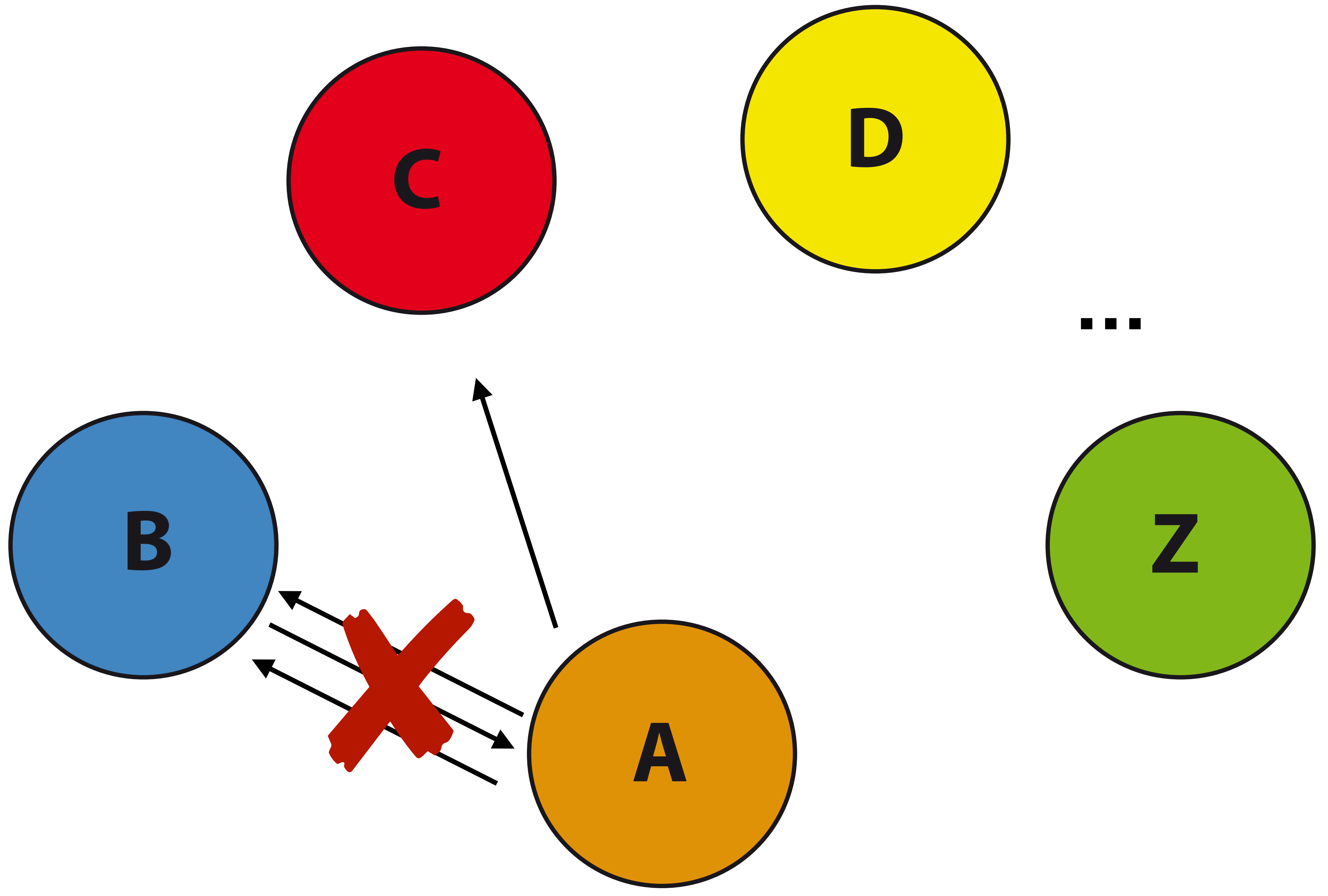

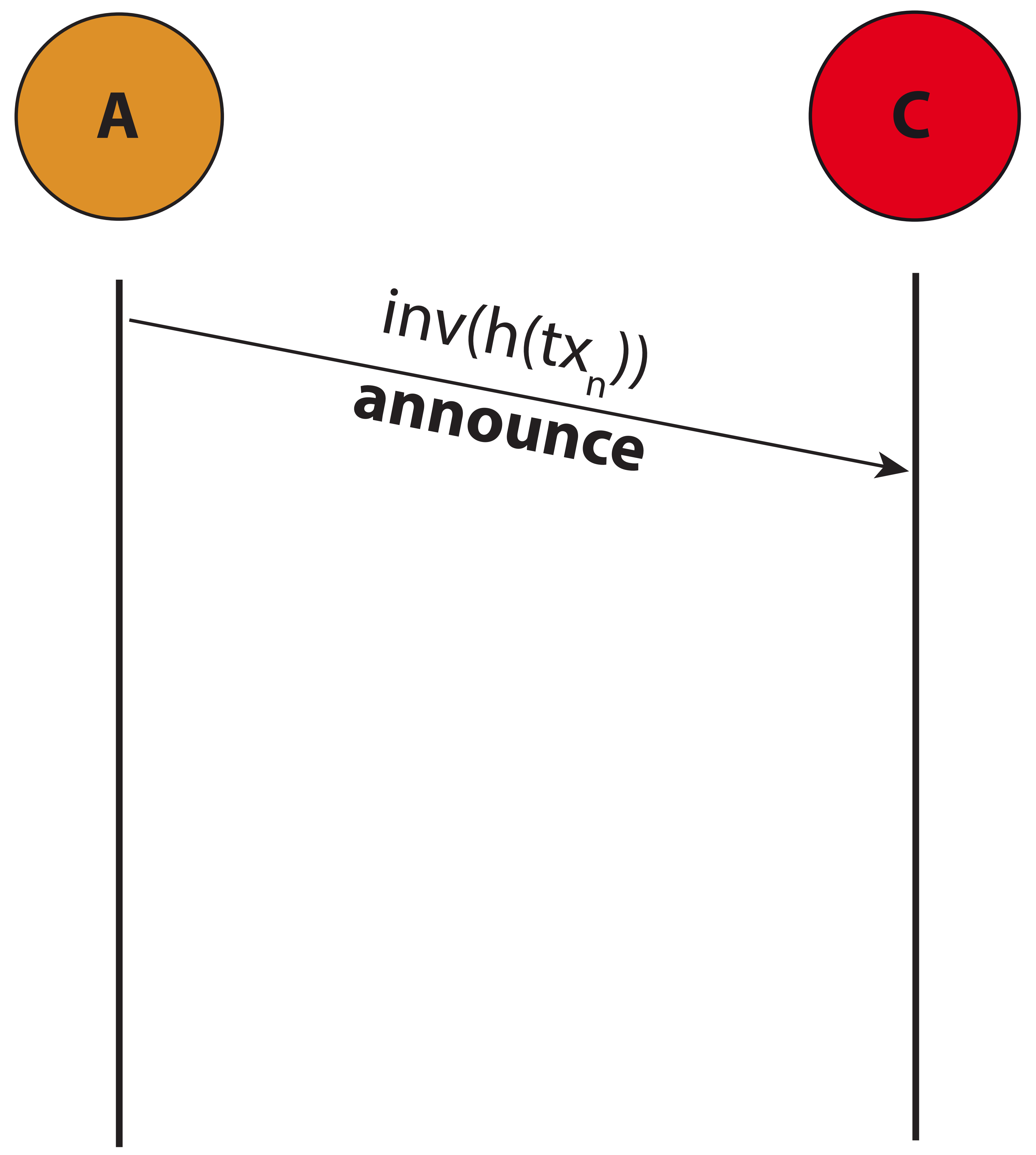

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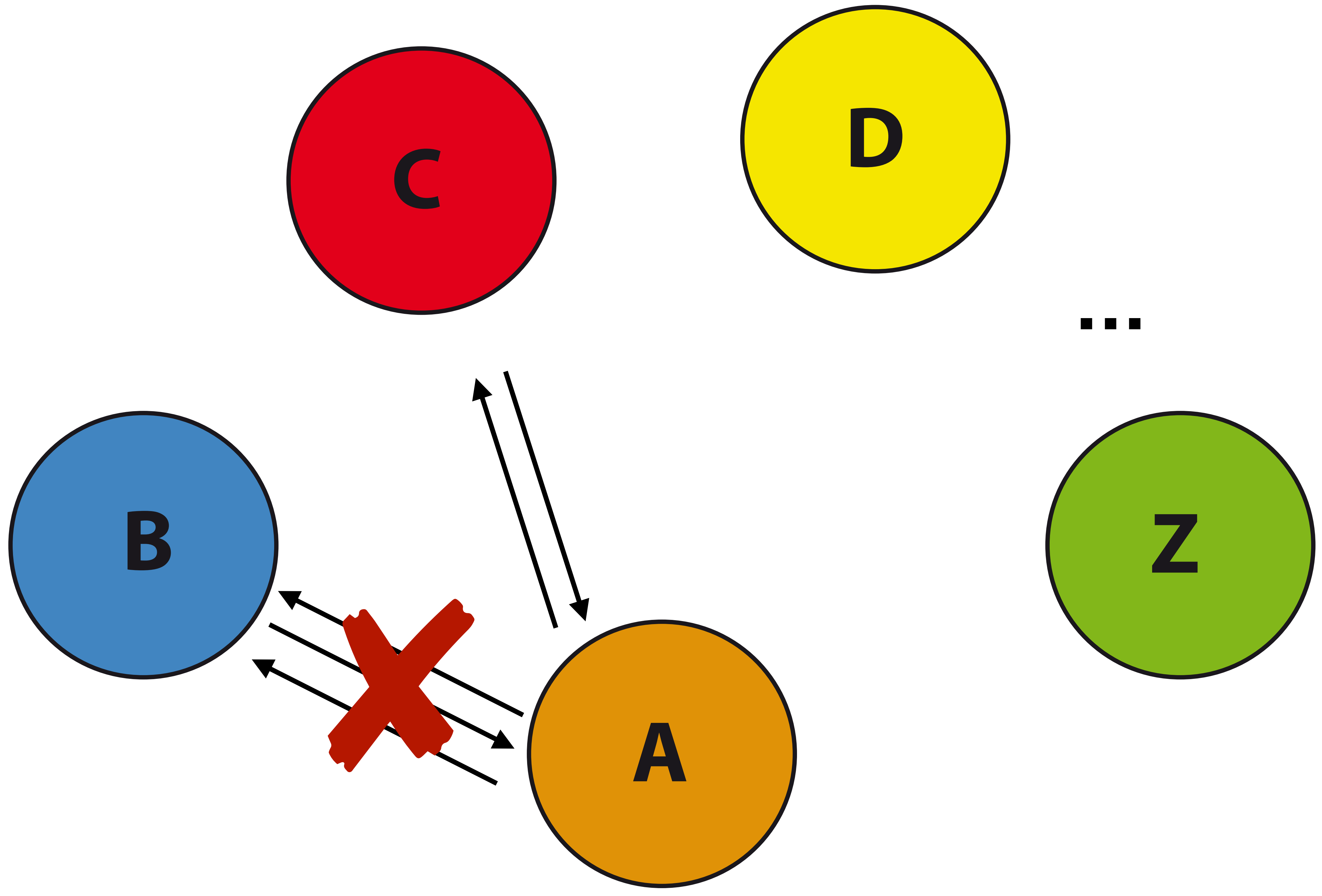

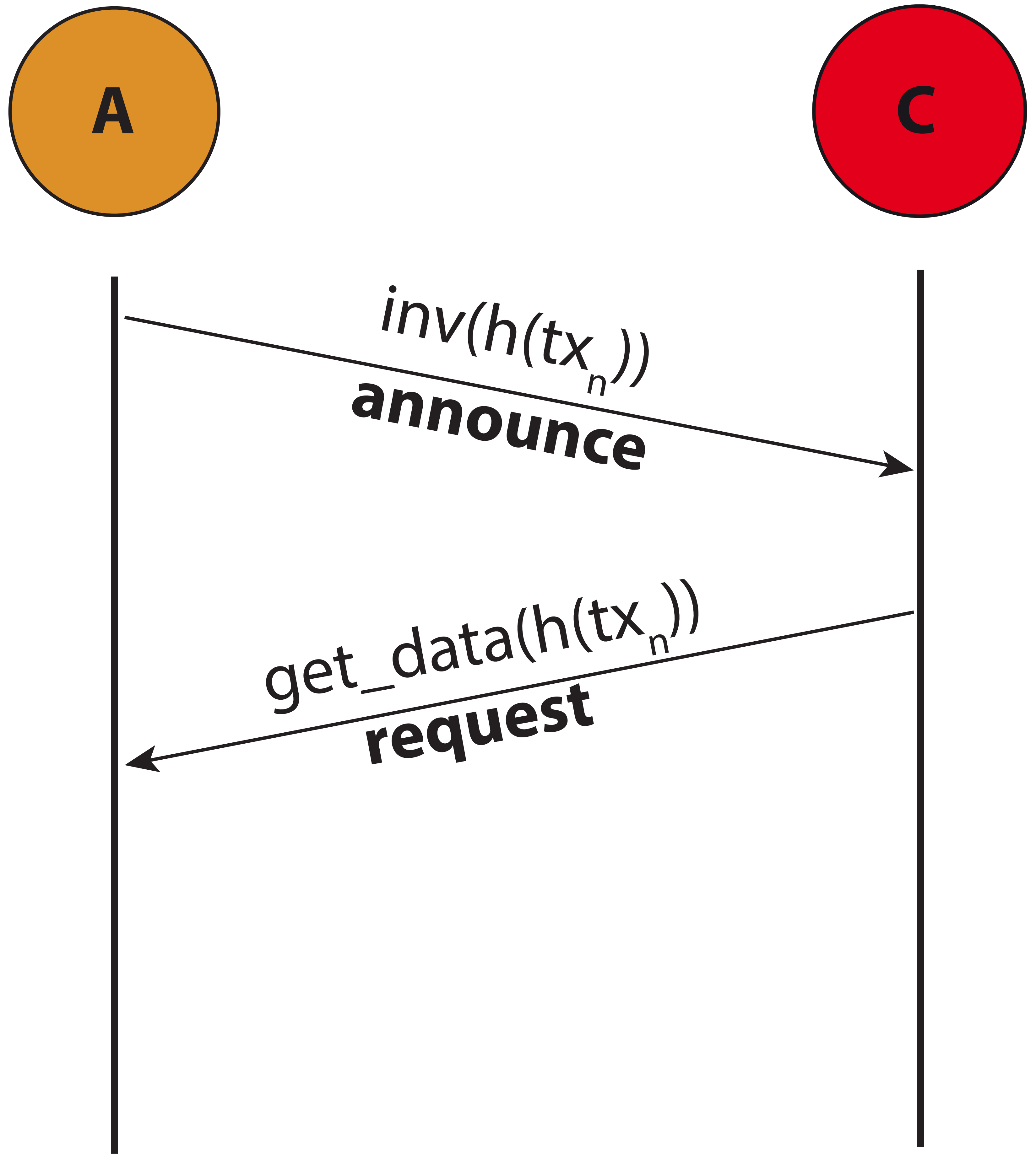

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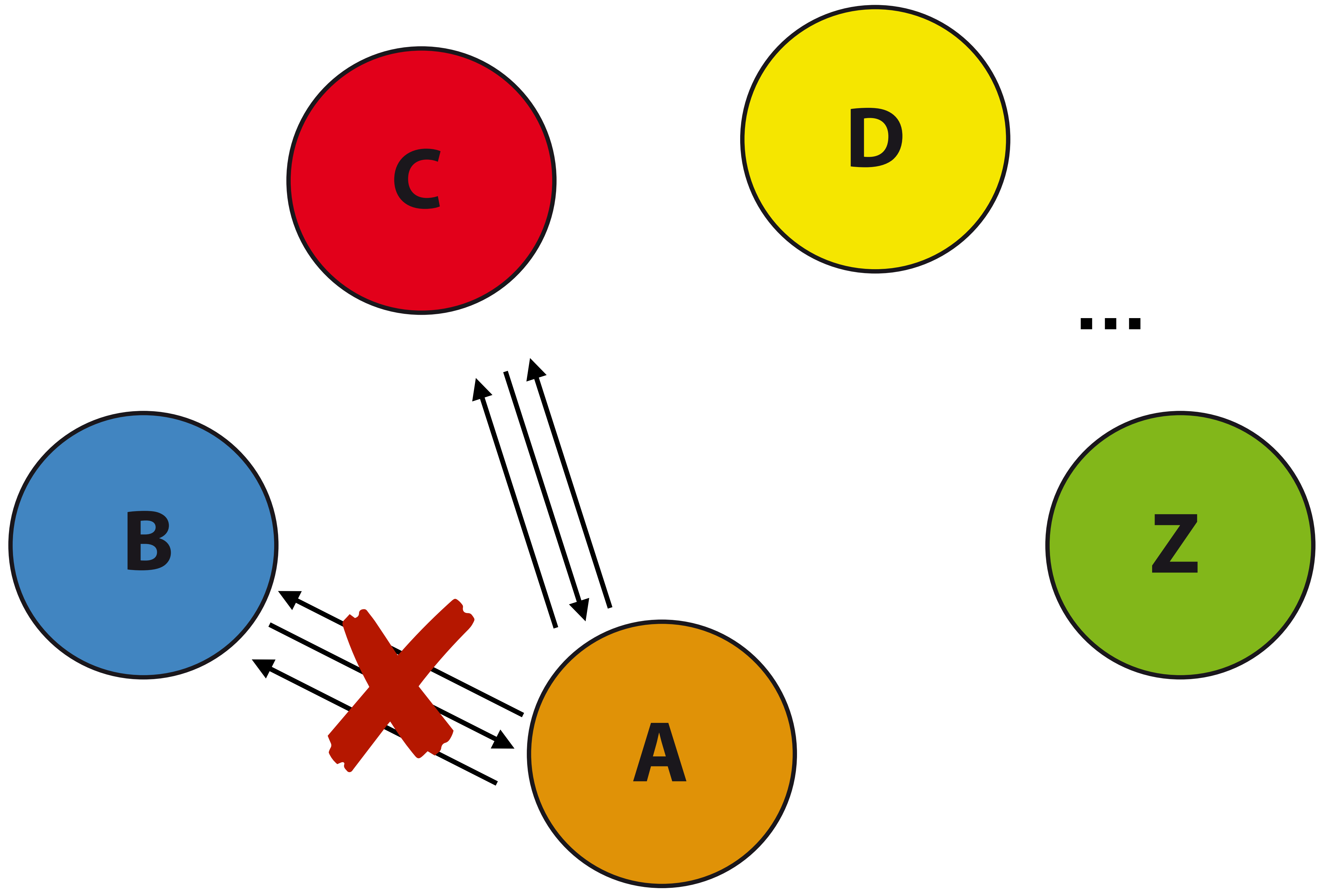

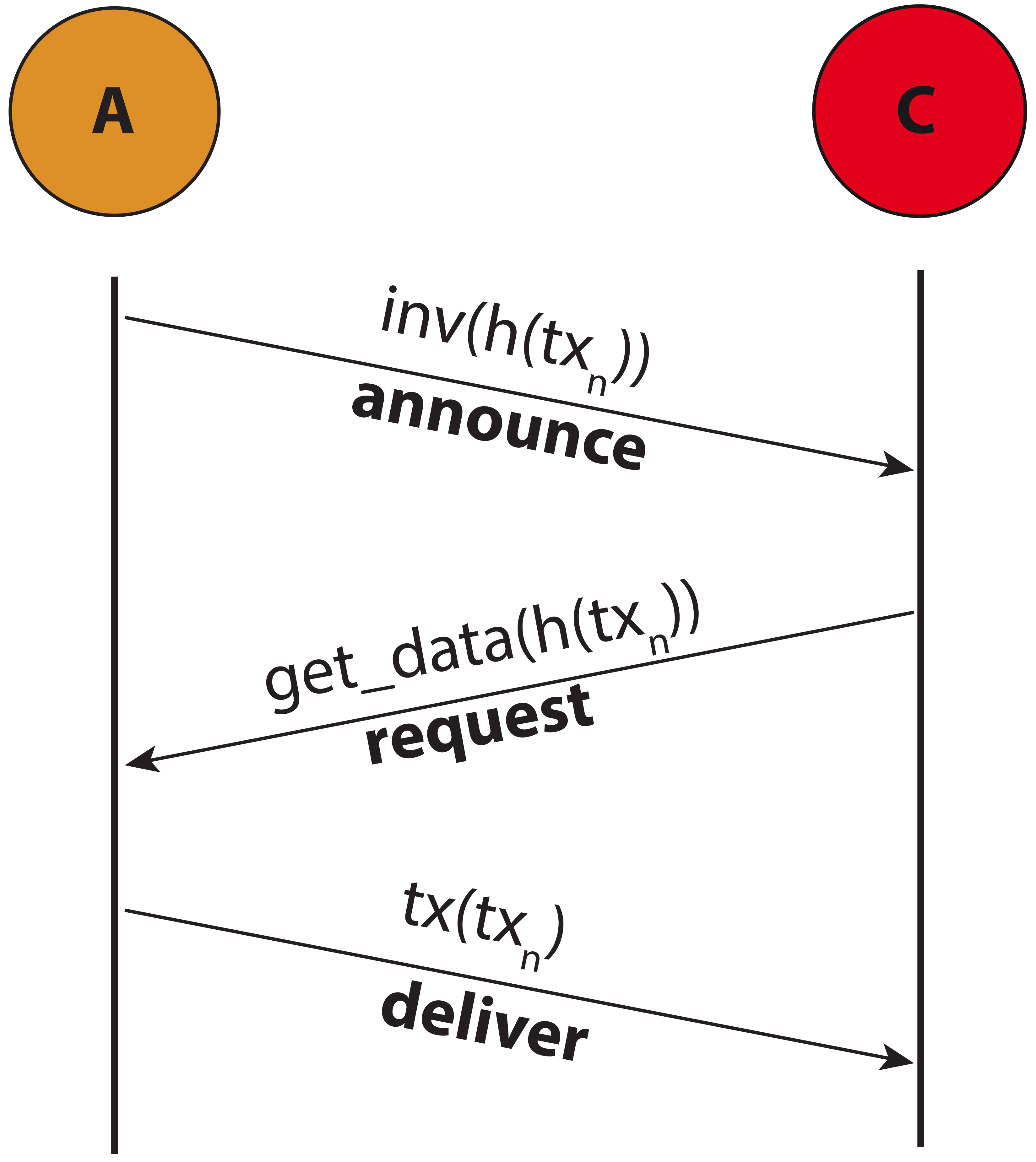

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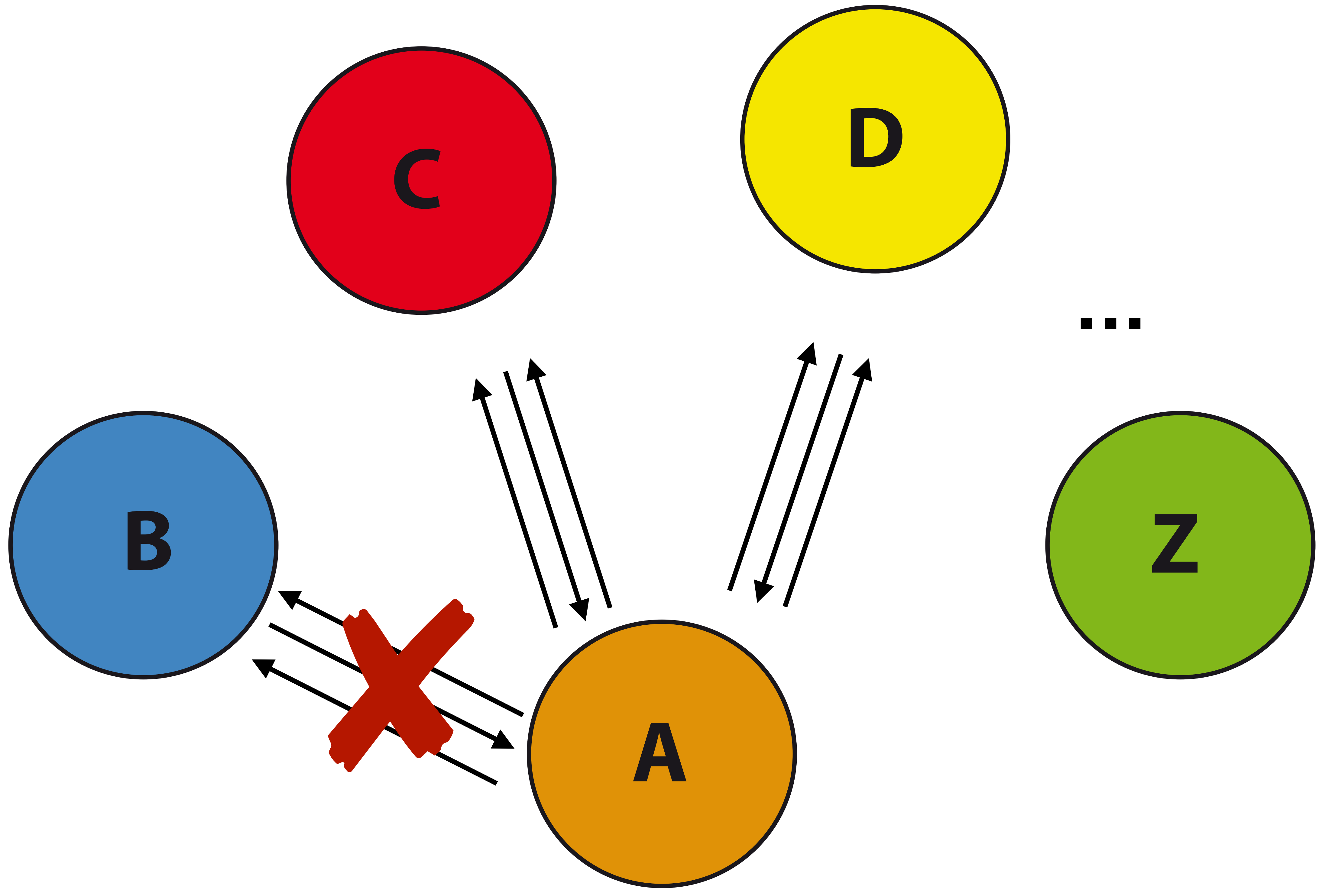

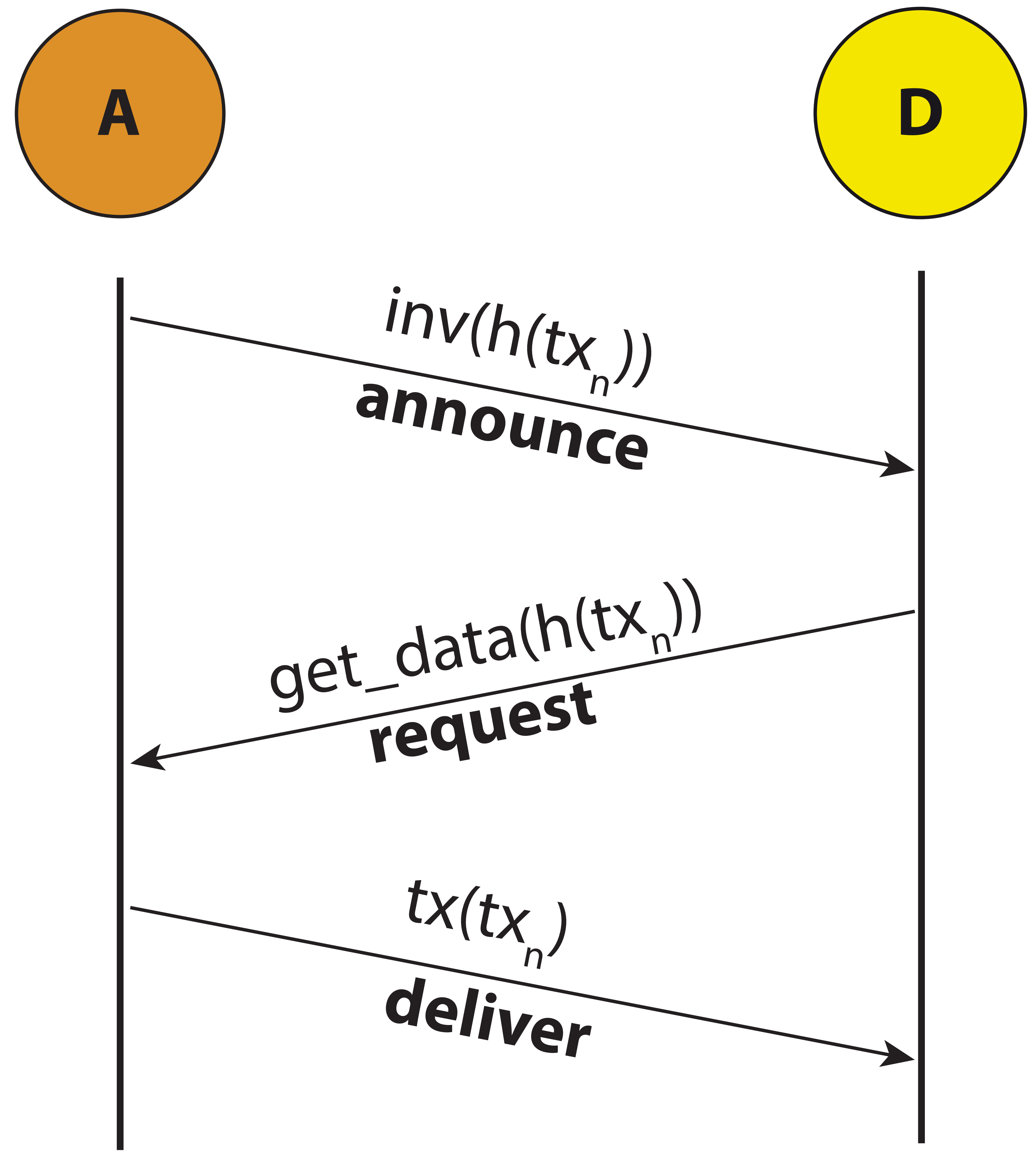

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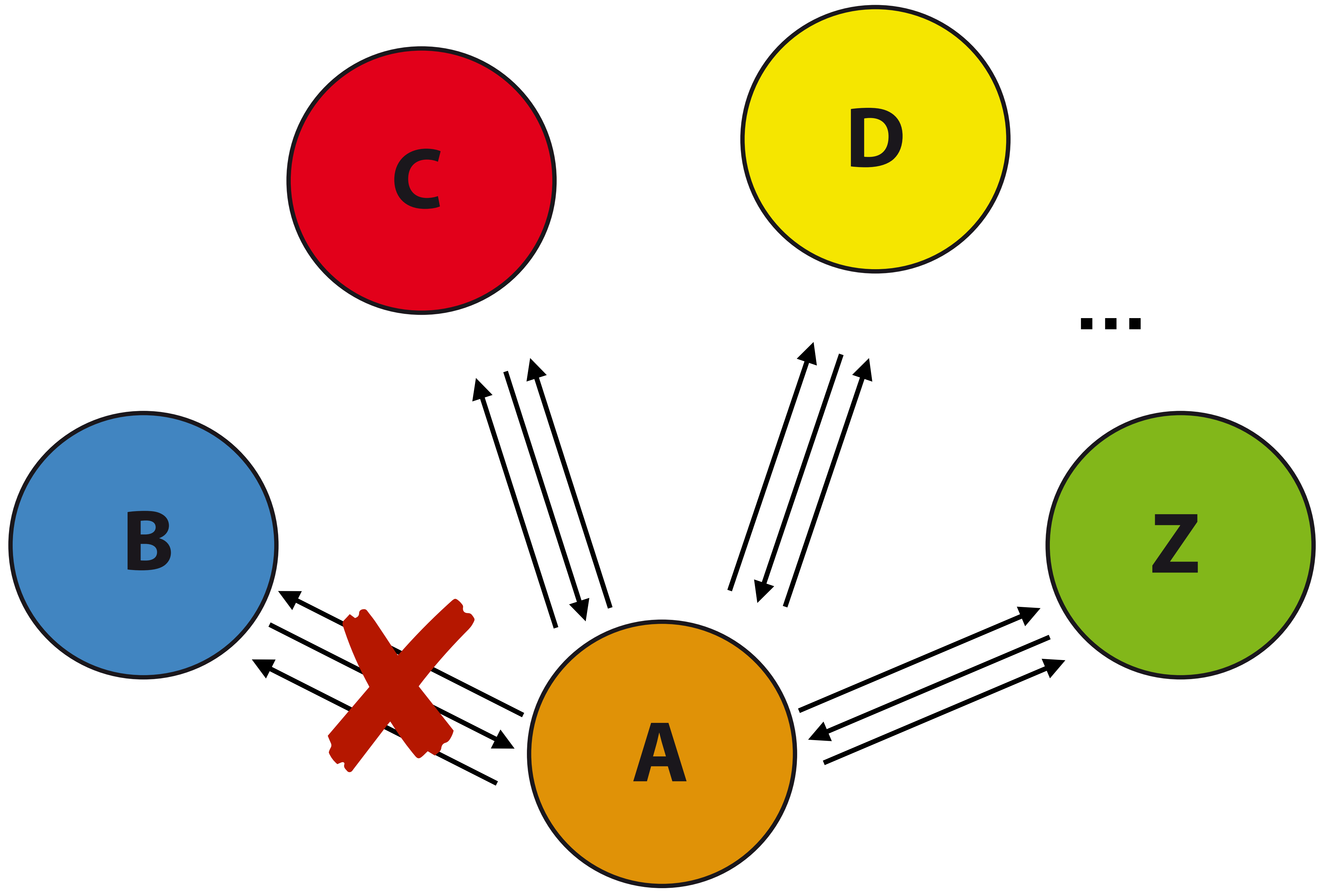
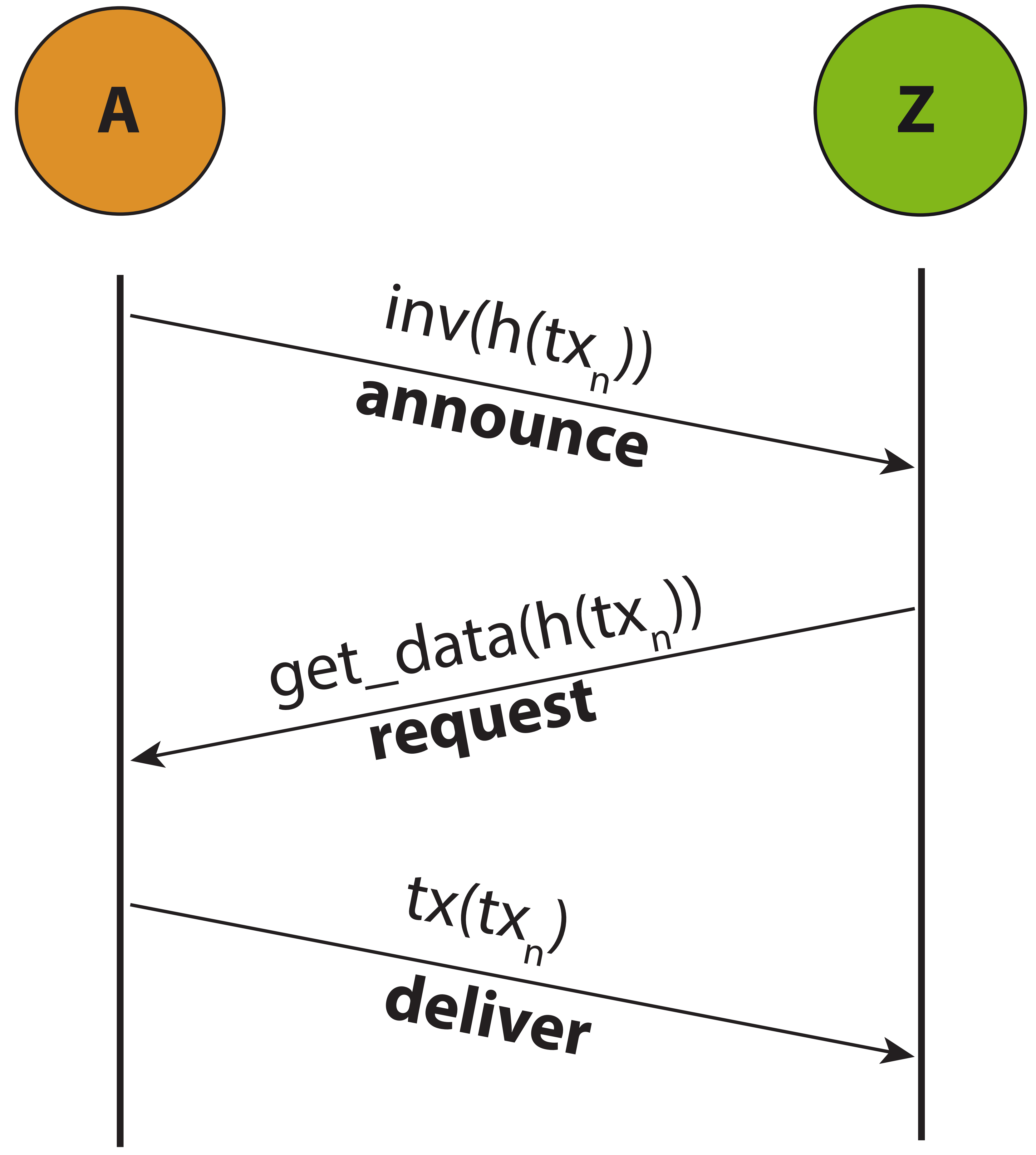
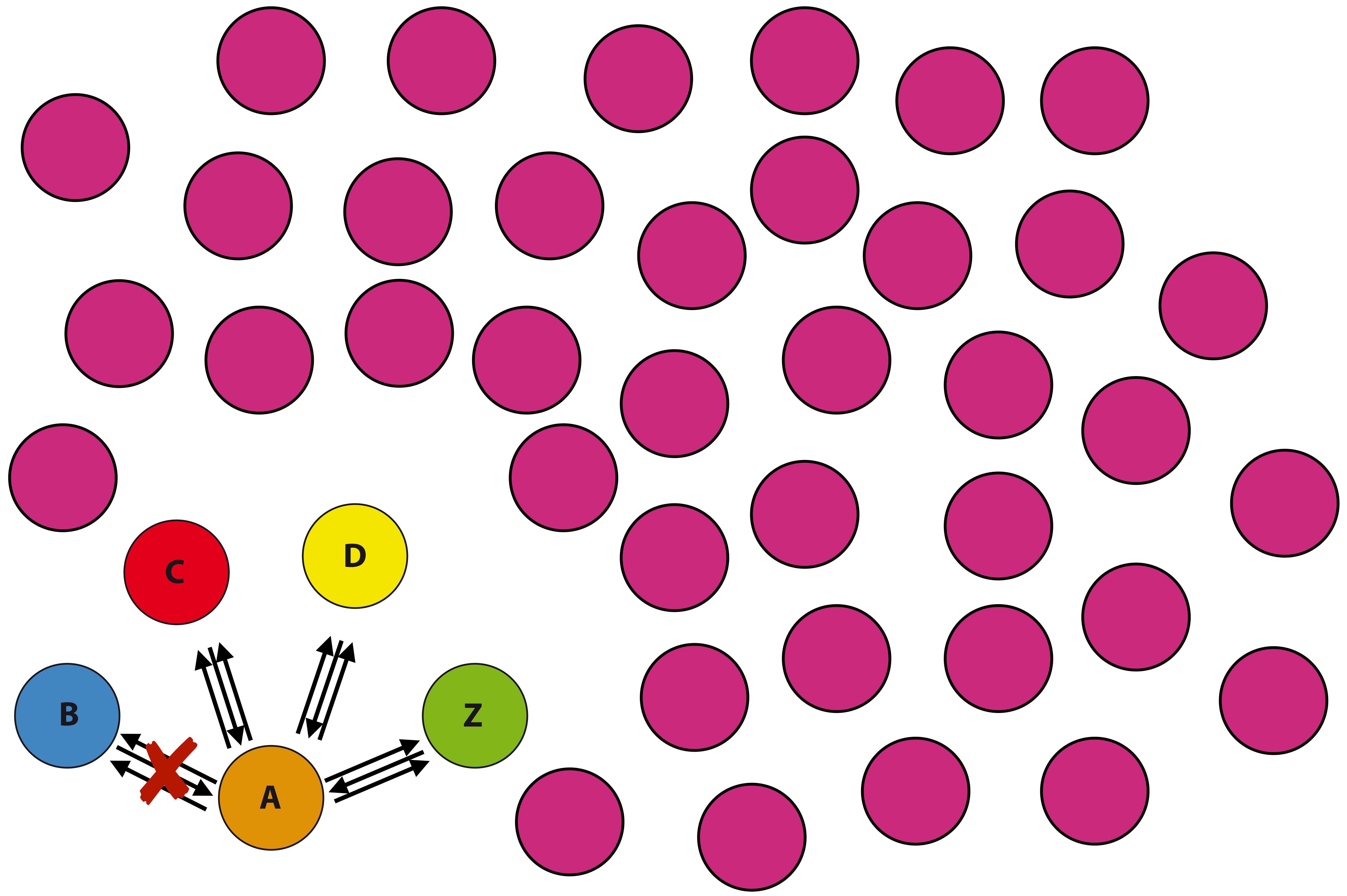




INFORMATION PROPAGATION (3/3)



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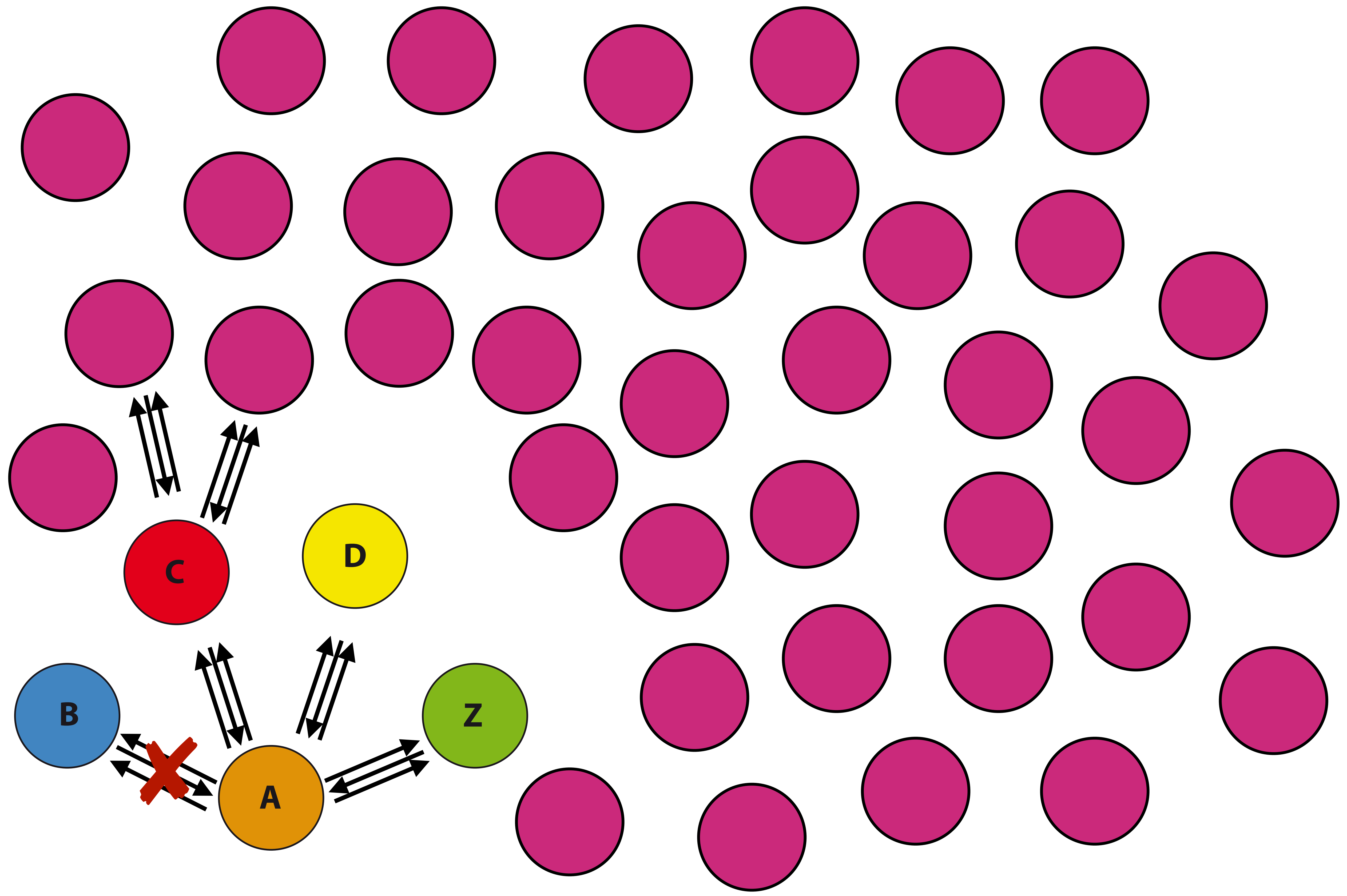

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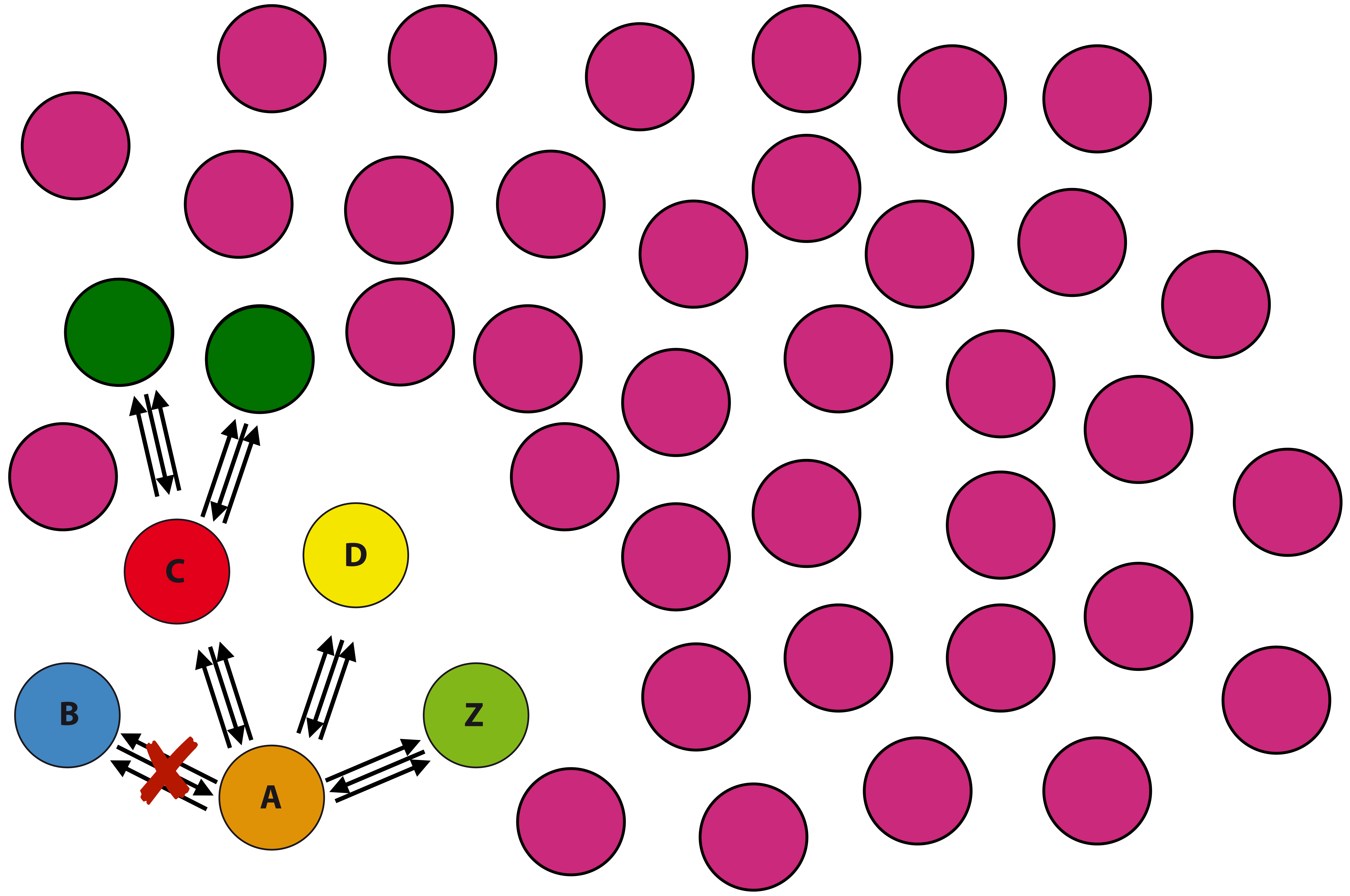

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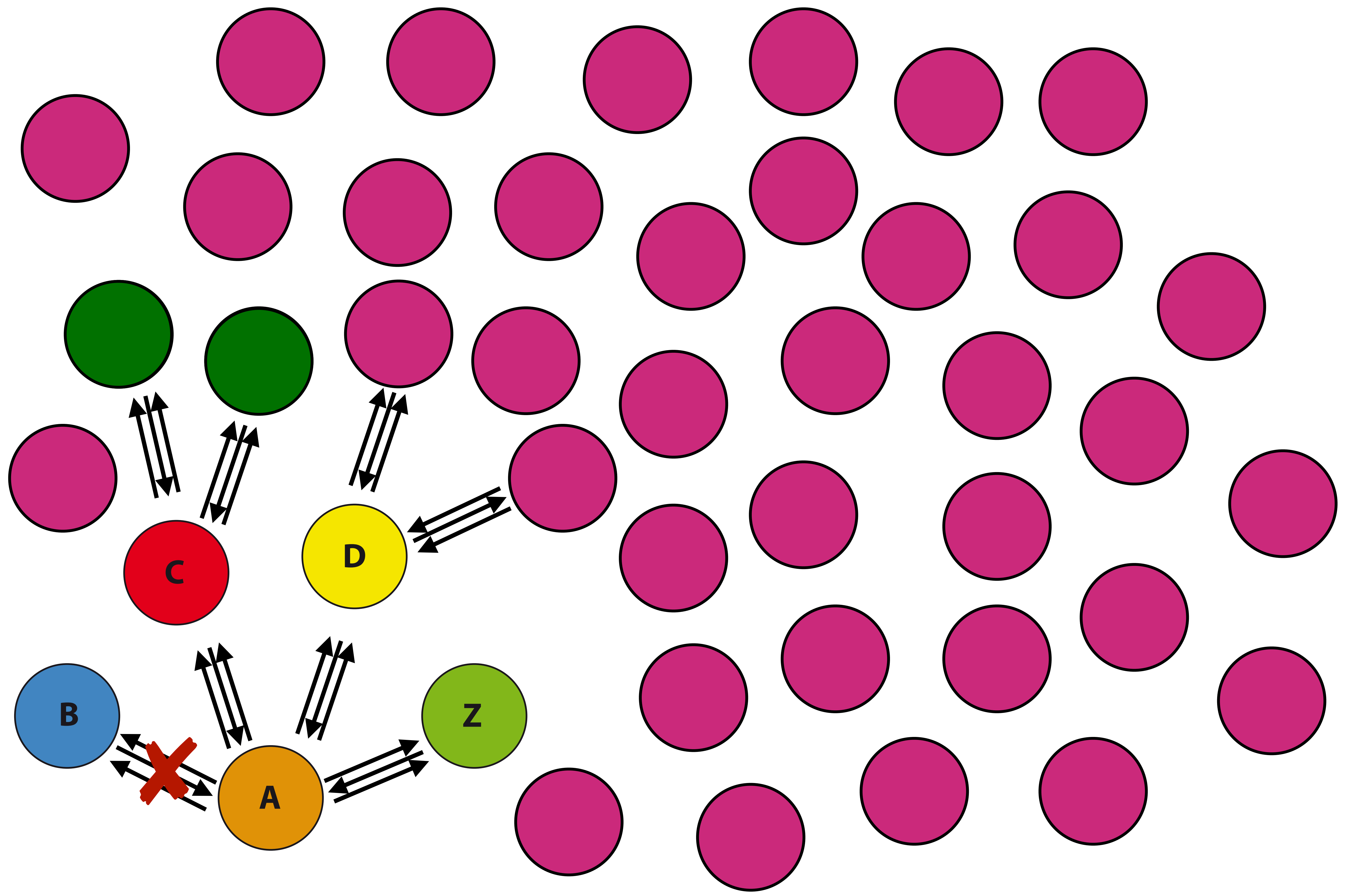

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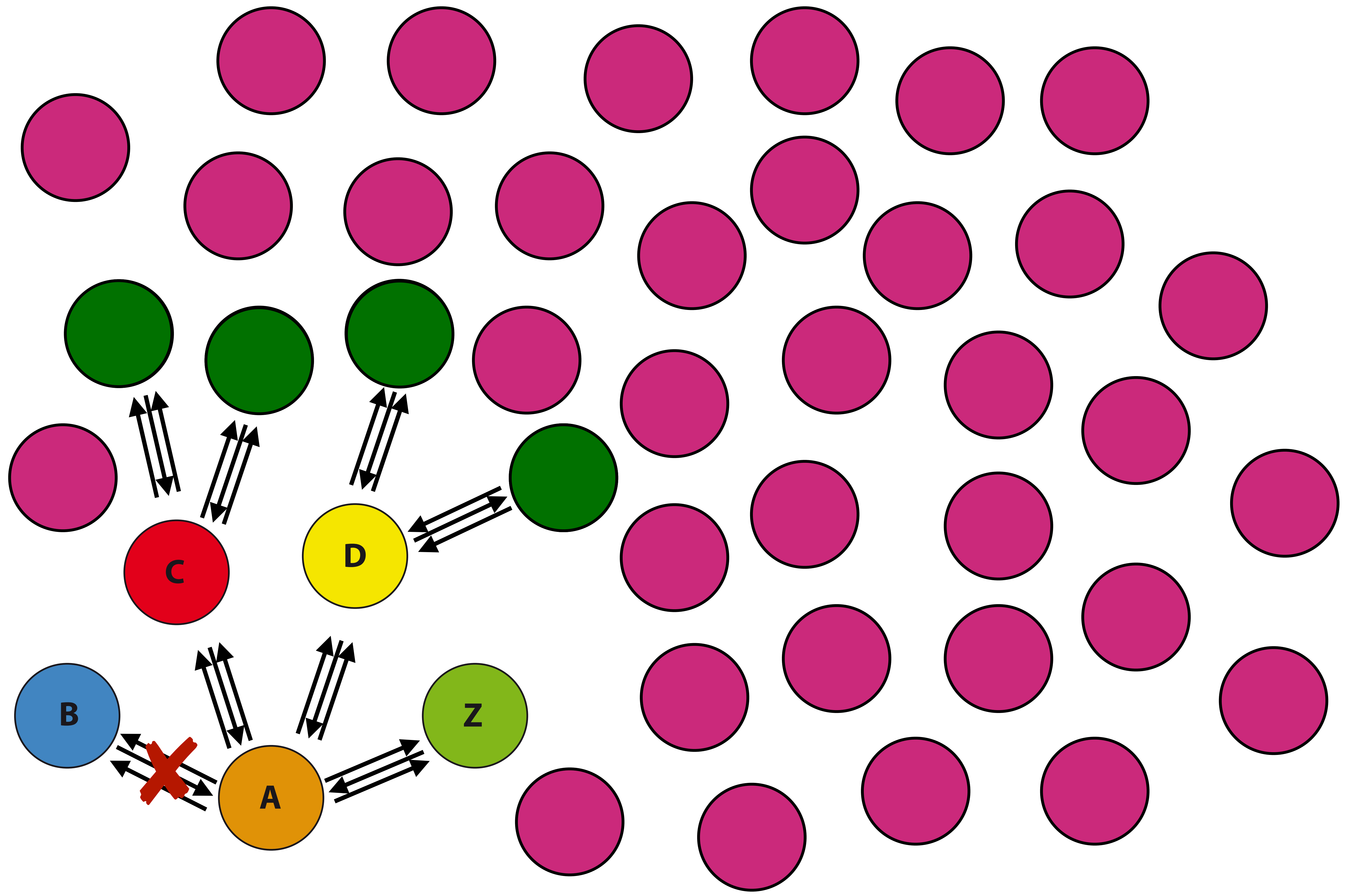

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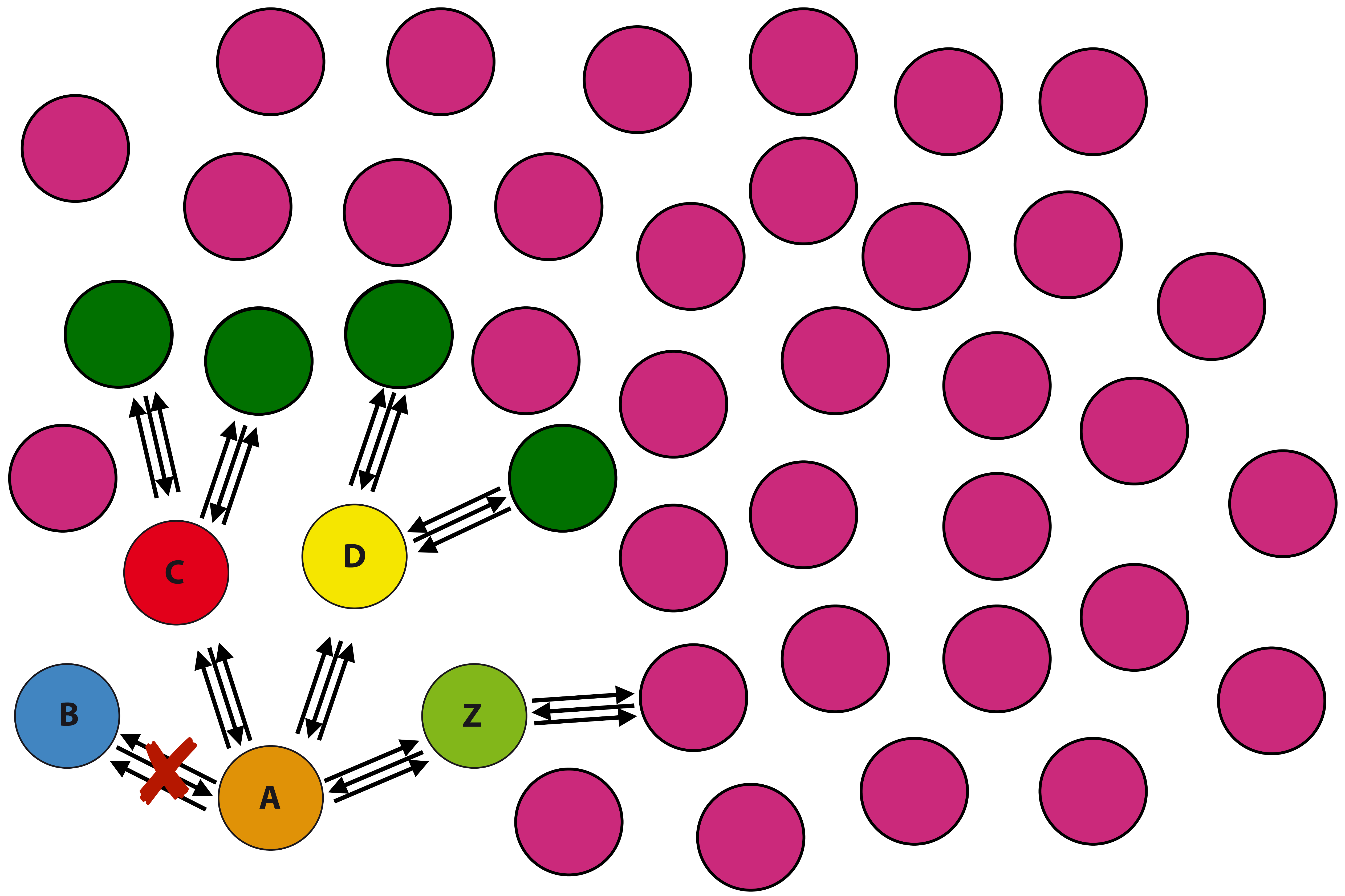

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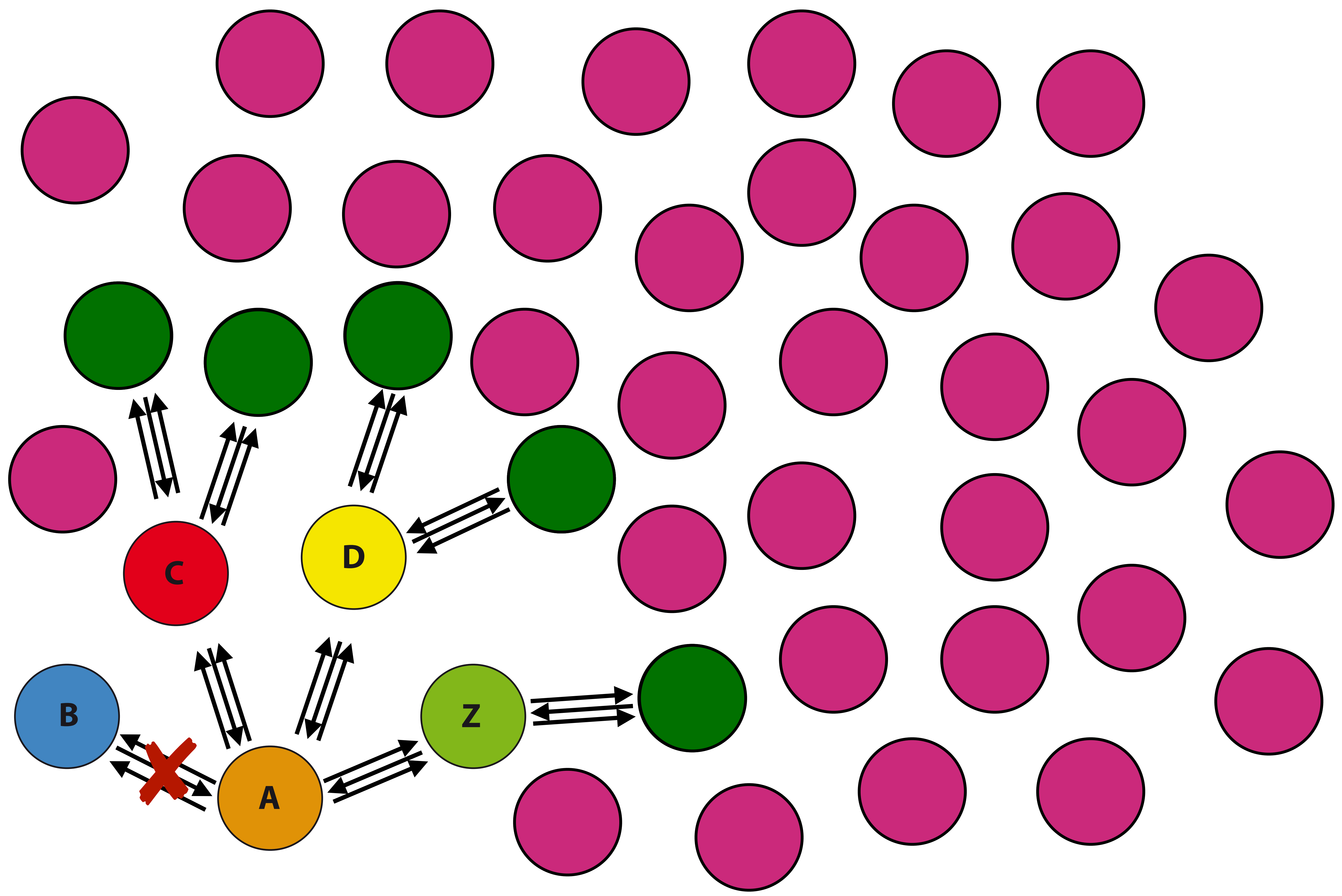

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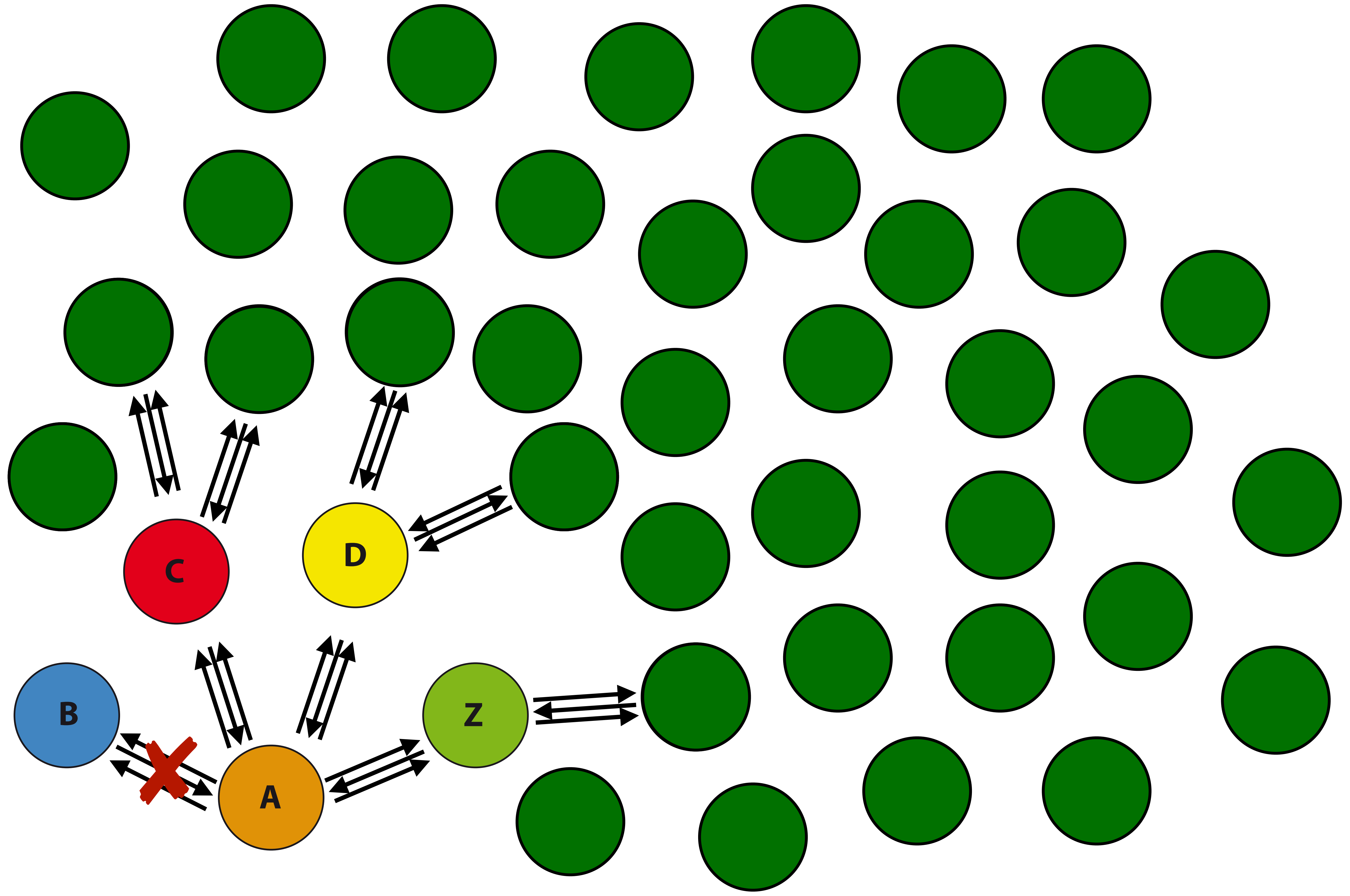

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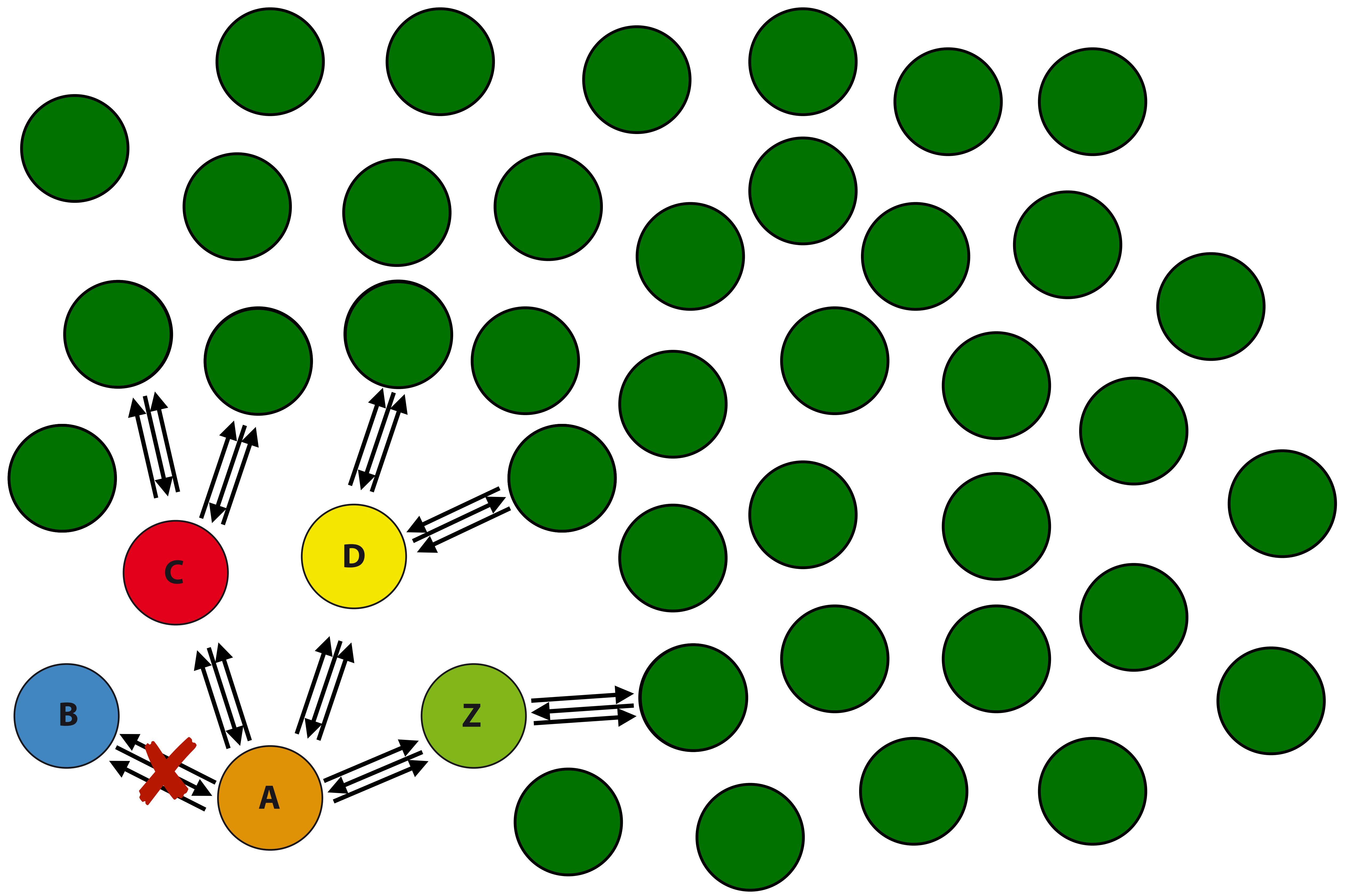

- And so on and so forth until all the nodes are reached

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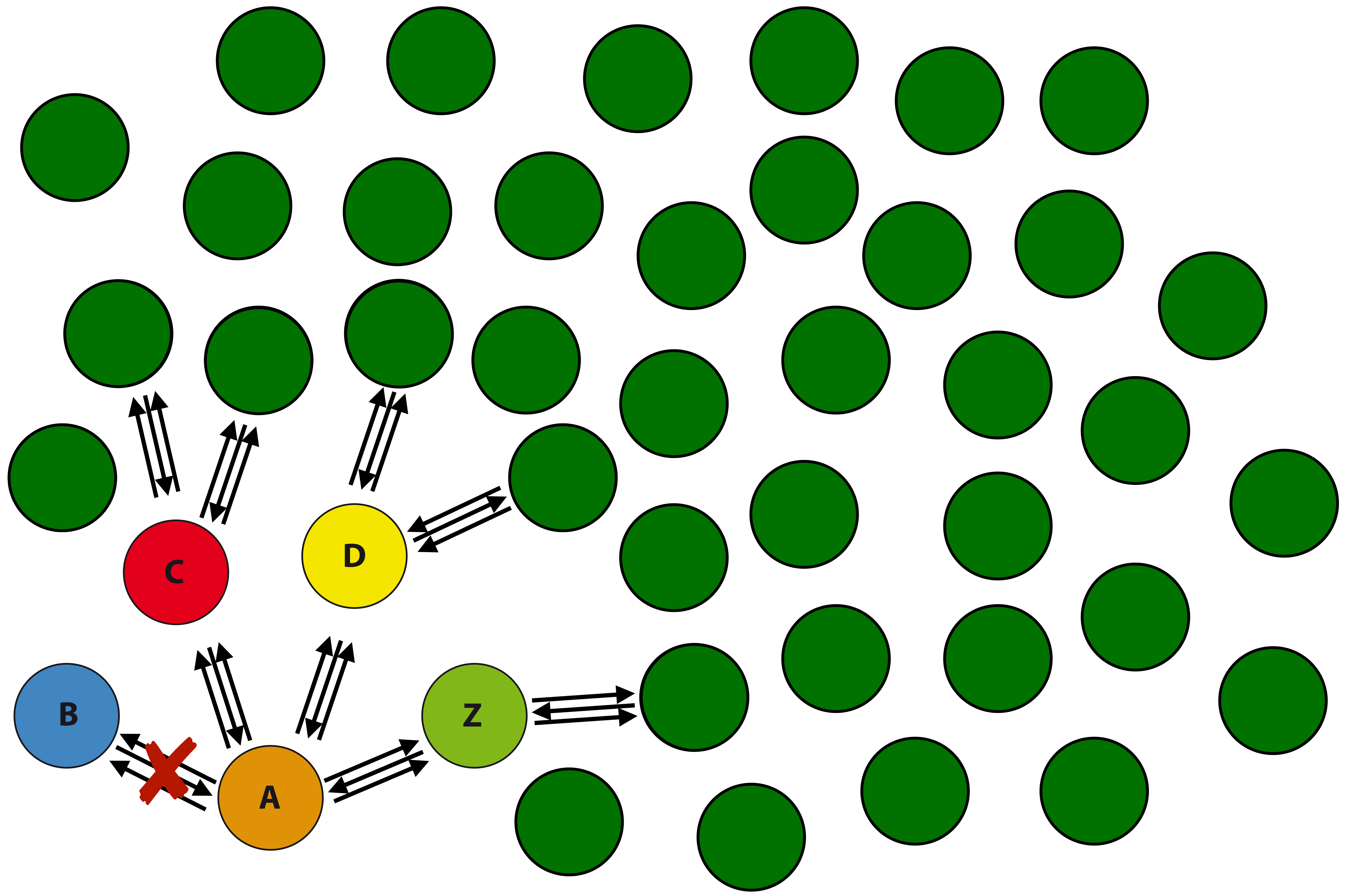

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- Recall that a node will reject a transaction if it has already learnt about it from any of its neighbors

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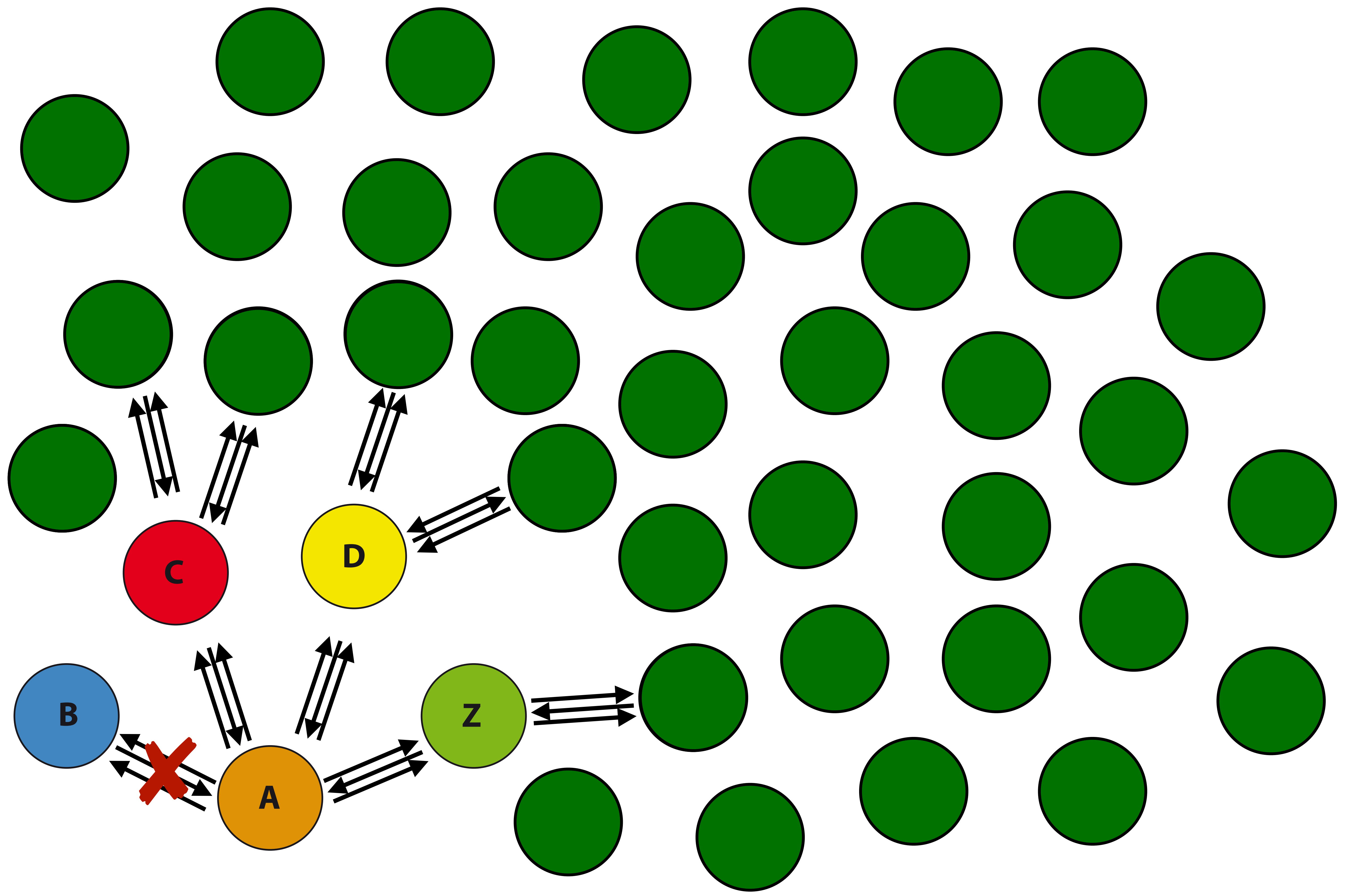

- And so on and so forth until all the nodes are reached
- Recall that a node will reject a transaction if it has already learnt about it from any of its neighbors
- The same procedure applies for blocks

IMPLICATIONS

The bigger the network the more it takes for an item to propagate (**this can be counterintuitive**)

Long propagation times (**for blocks**) imply bigger likelihood of forking the blockchain

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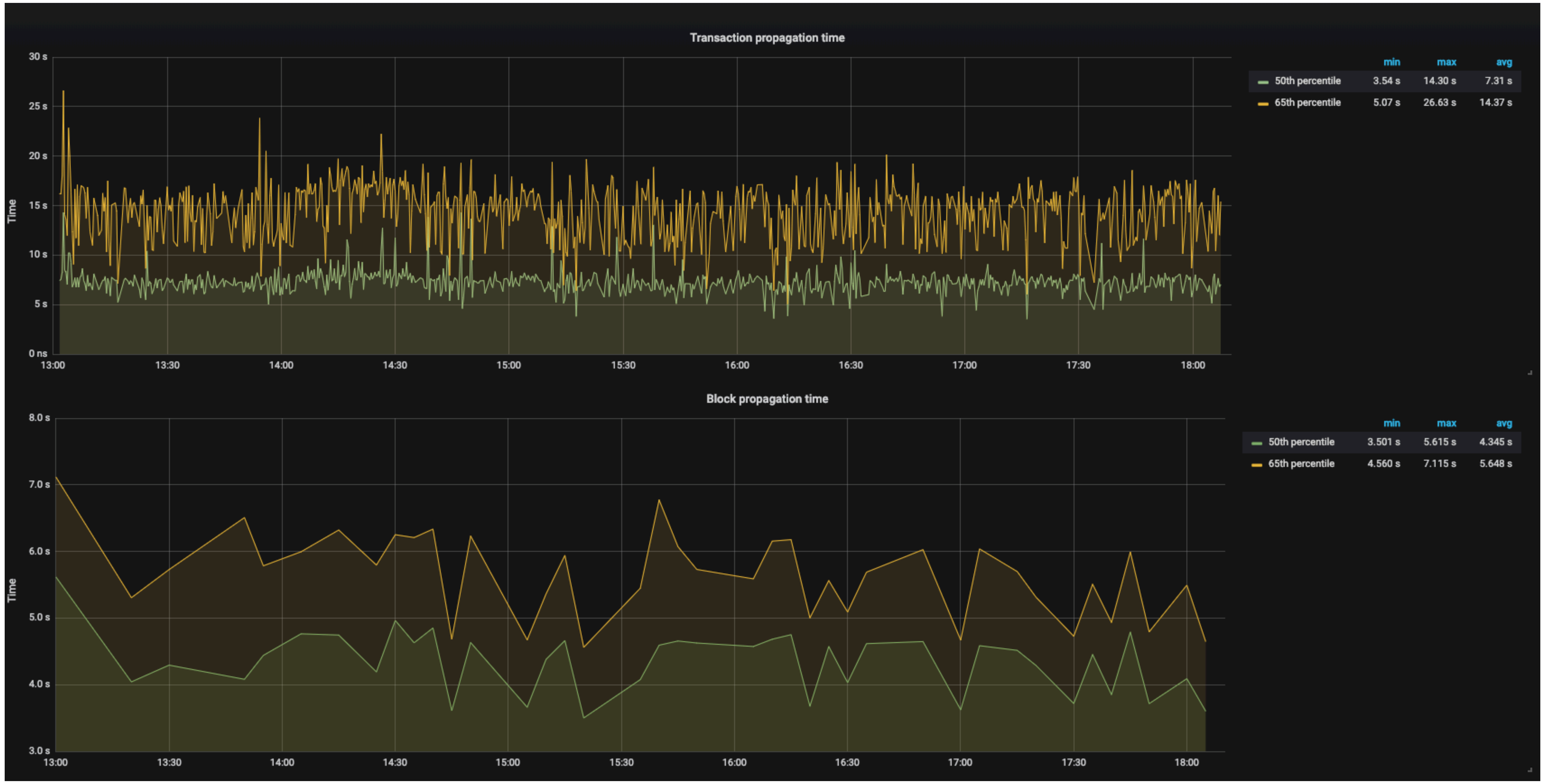
Christian Decker and Roger Wattenhofer
Information propagation in the Bitcoin network
https://ieeexplore.ieee.org/document/6688704

DATA PROPAGATION TIMES (TESTNET)

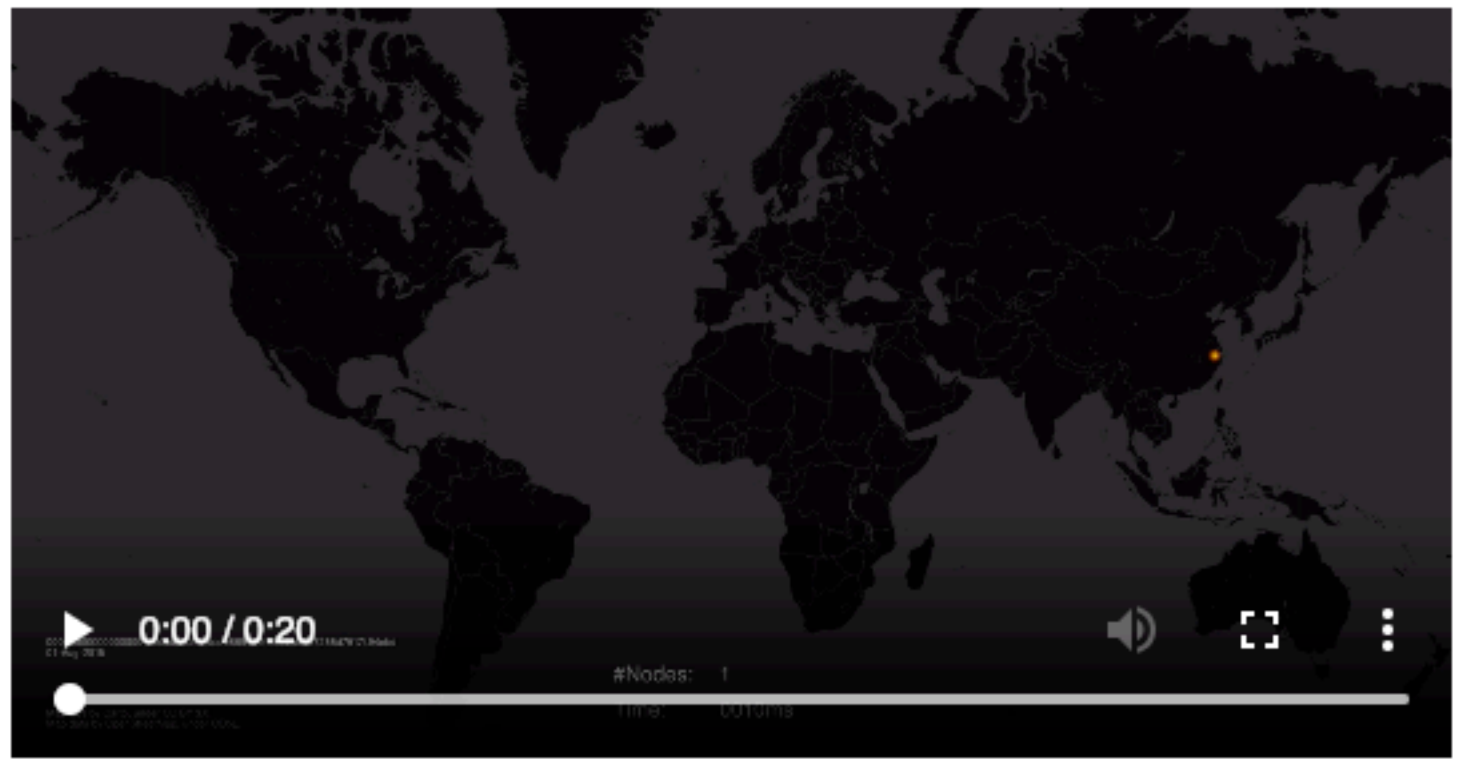


	min	max	avg
🟩 50th percentile	3.54 s	14.30 s	7.31 s
🟨 65th percentile	5.07 s	26.63 s	14.37 s

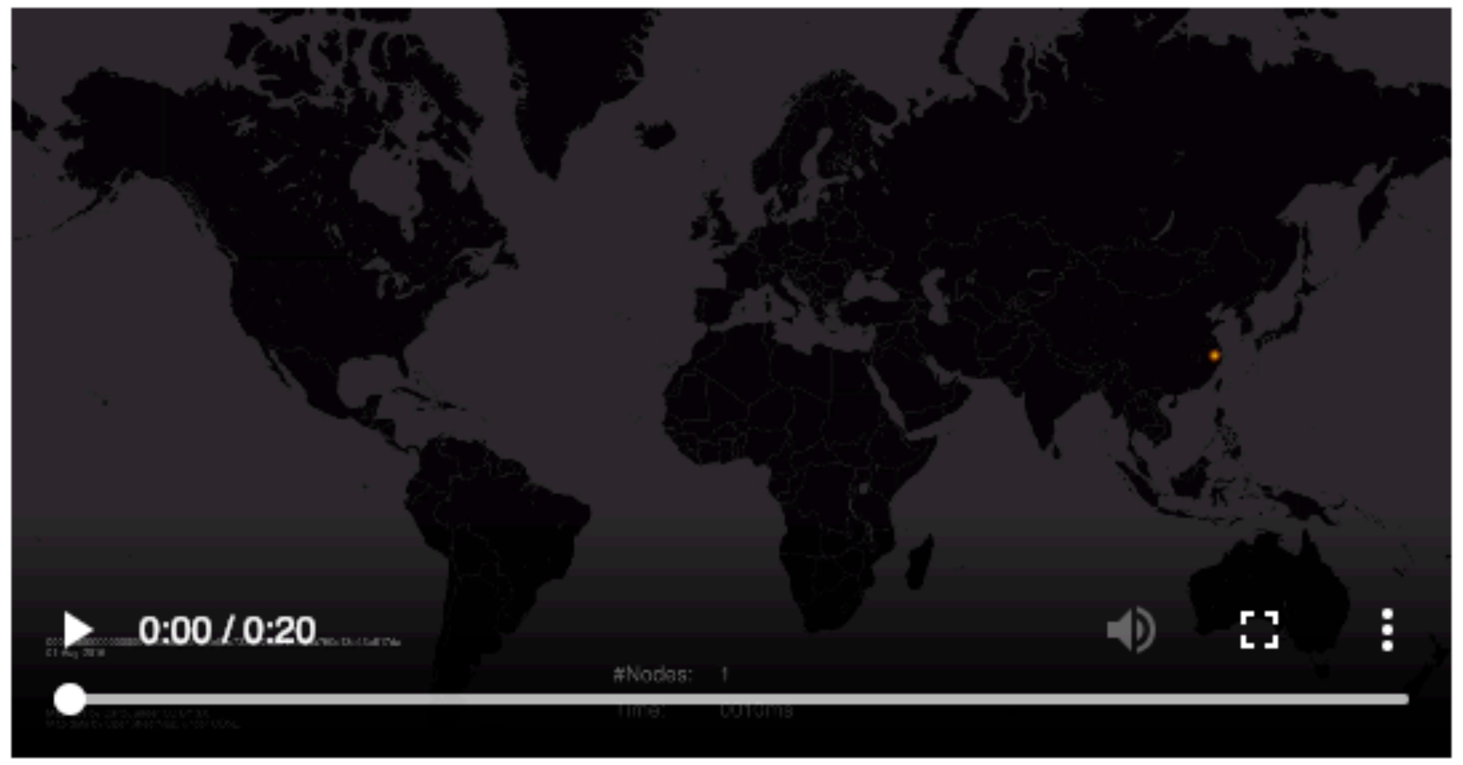
	min	max	avg
🟩 50th percentile	3.501 s	5.615 s	4.345 s
🟨 65th percentile	4.560 s	7.115 s	5.648 s

source: charts.satoshi.uab.cat

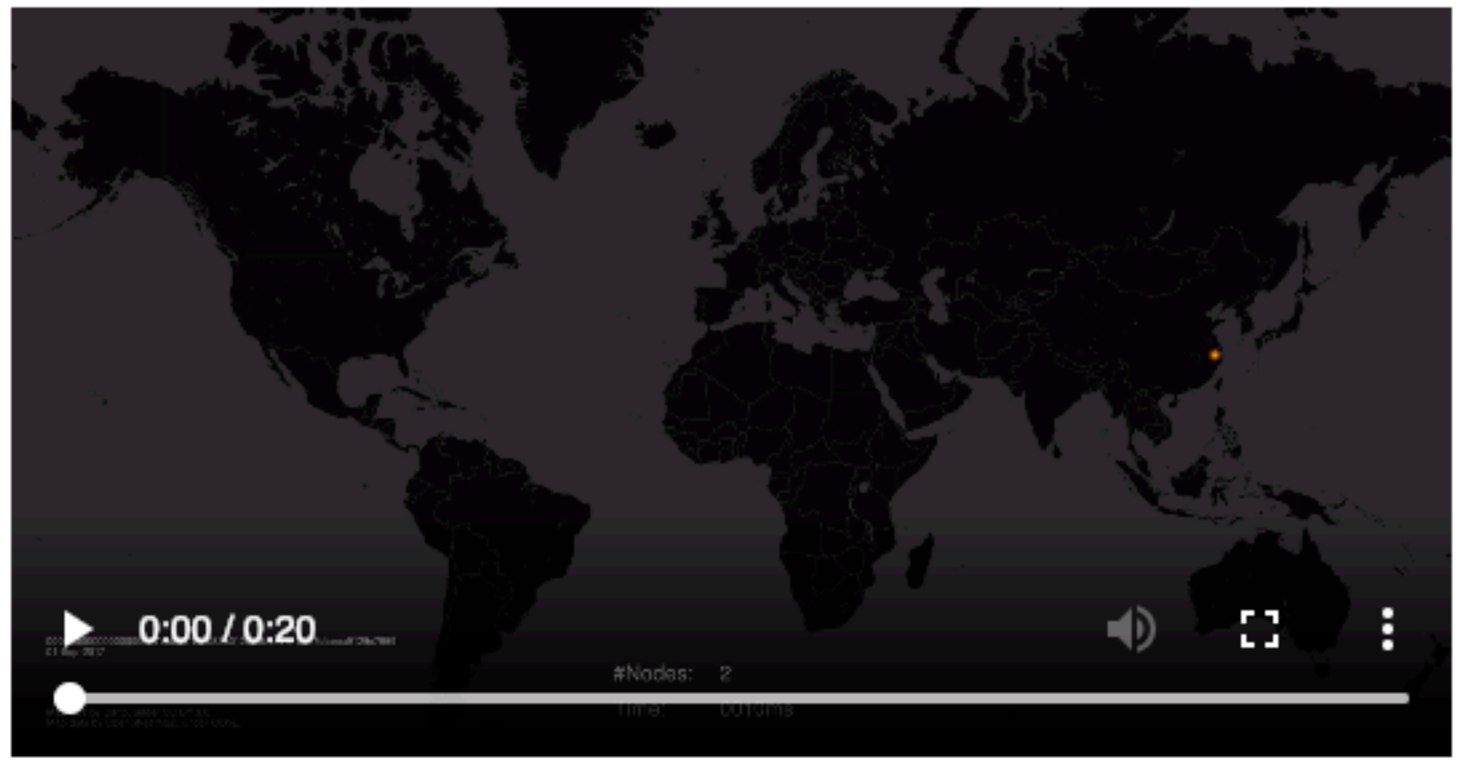
MORE ABOUT PROPAGATION TIMES



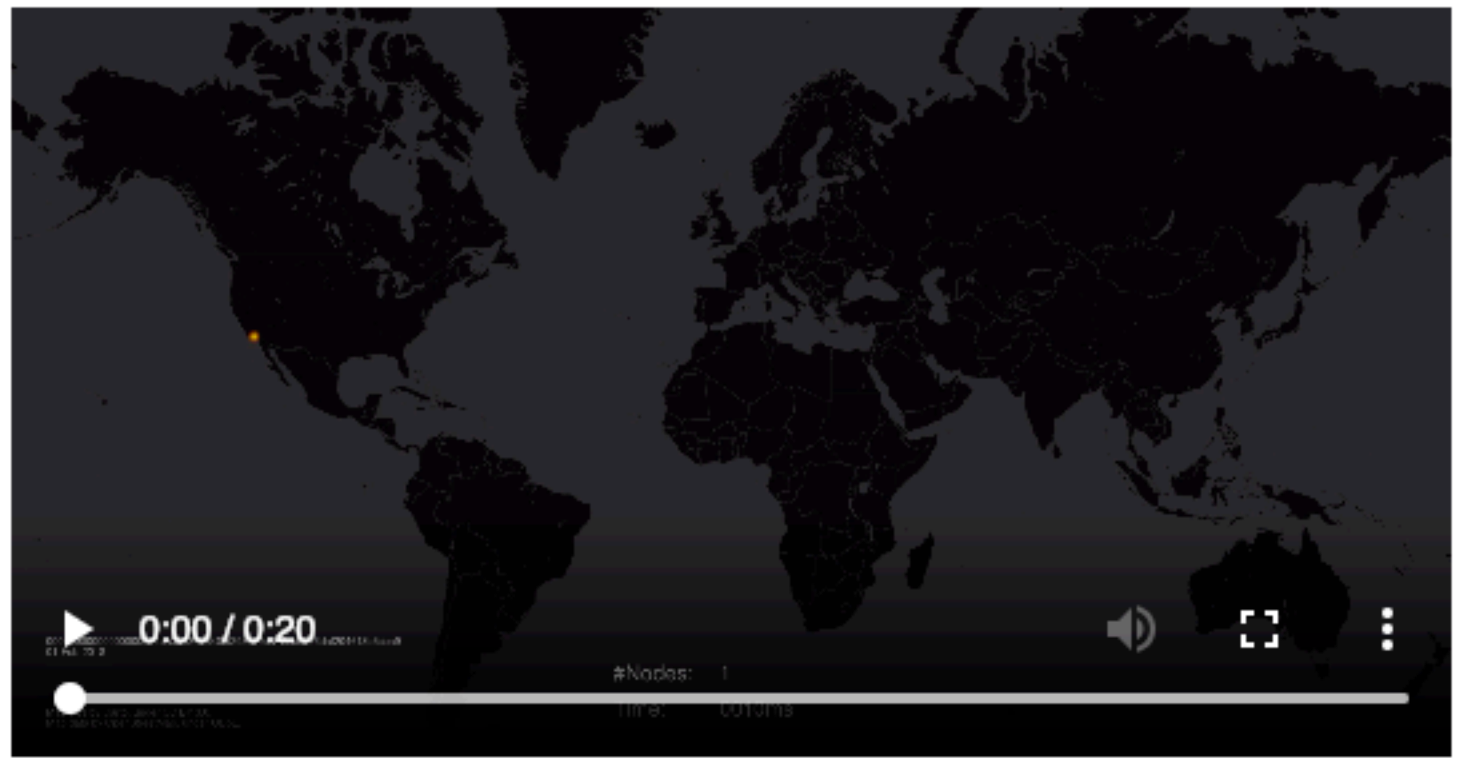
Block propagation | 01.08.2015



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)

How can blocks propagate faster than transactions if the former are bigger than the later?

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- Transactions are accumulated in buffers and forwarded in batches to break the link between first relayer and origin of a transaction

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)

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

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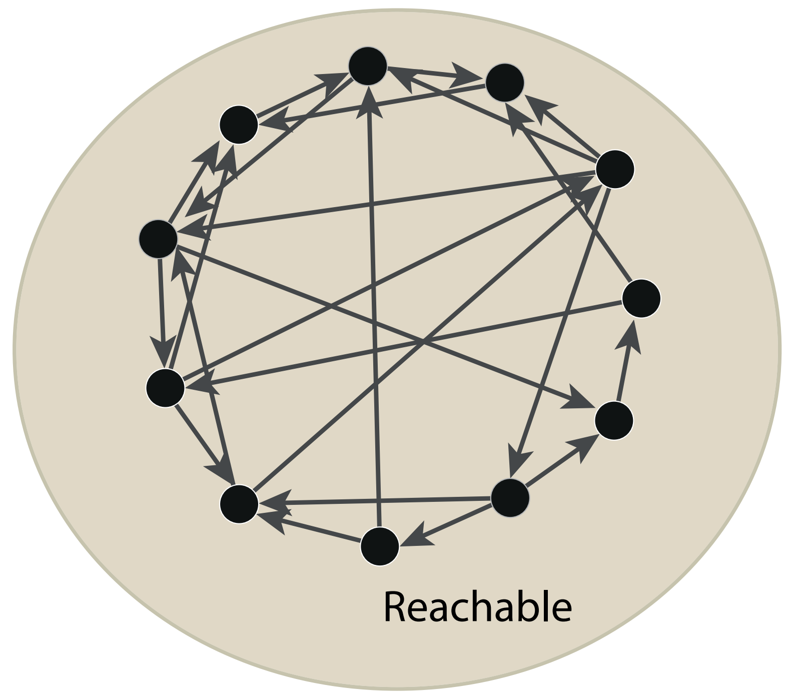
But blocks are way bigger than transactions, how can they be propagated so fast!?

- 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

NETWORK TAXONOMY

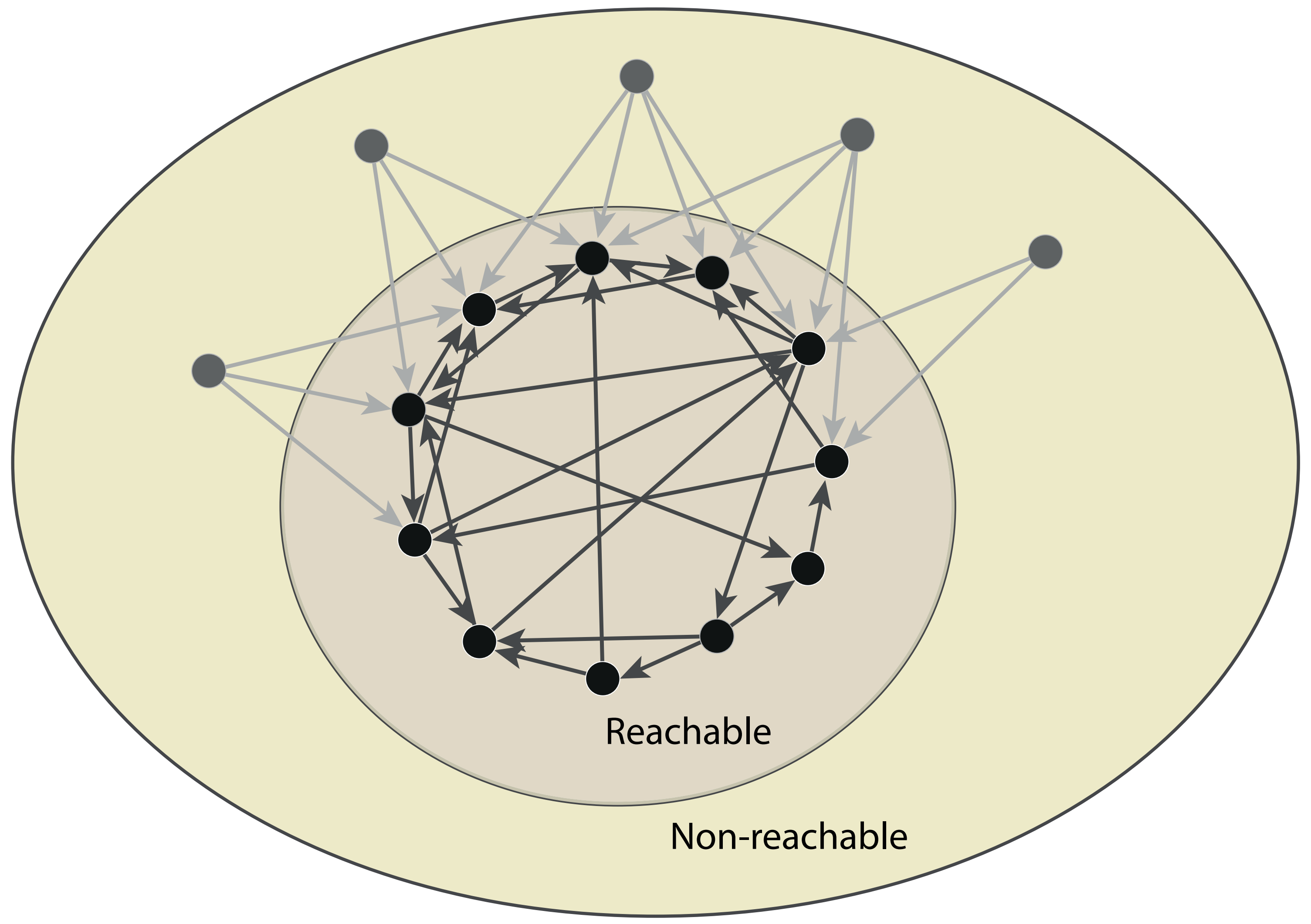
Reachable network: all nodes accept incoming / outgoing connections



NETWORK TAXONOMY

Reachable network: all nodes accept incoming / outgoing connections

Non-reachable: nodes do not accept incoming connections / cannot be reached (NAT/firewalls/…)



NETWORK TAXONOMY

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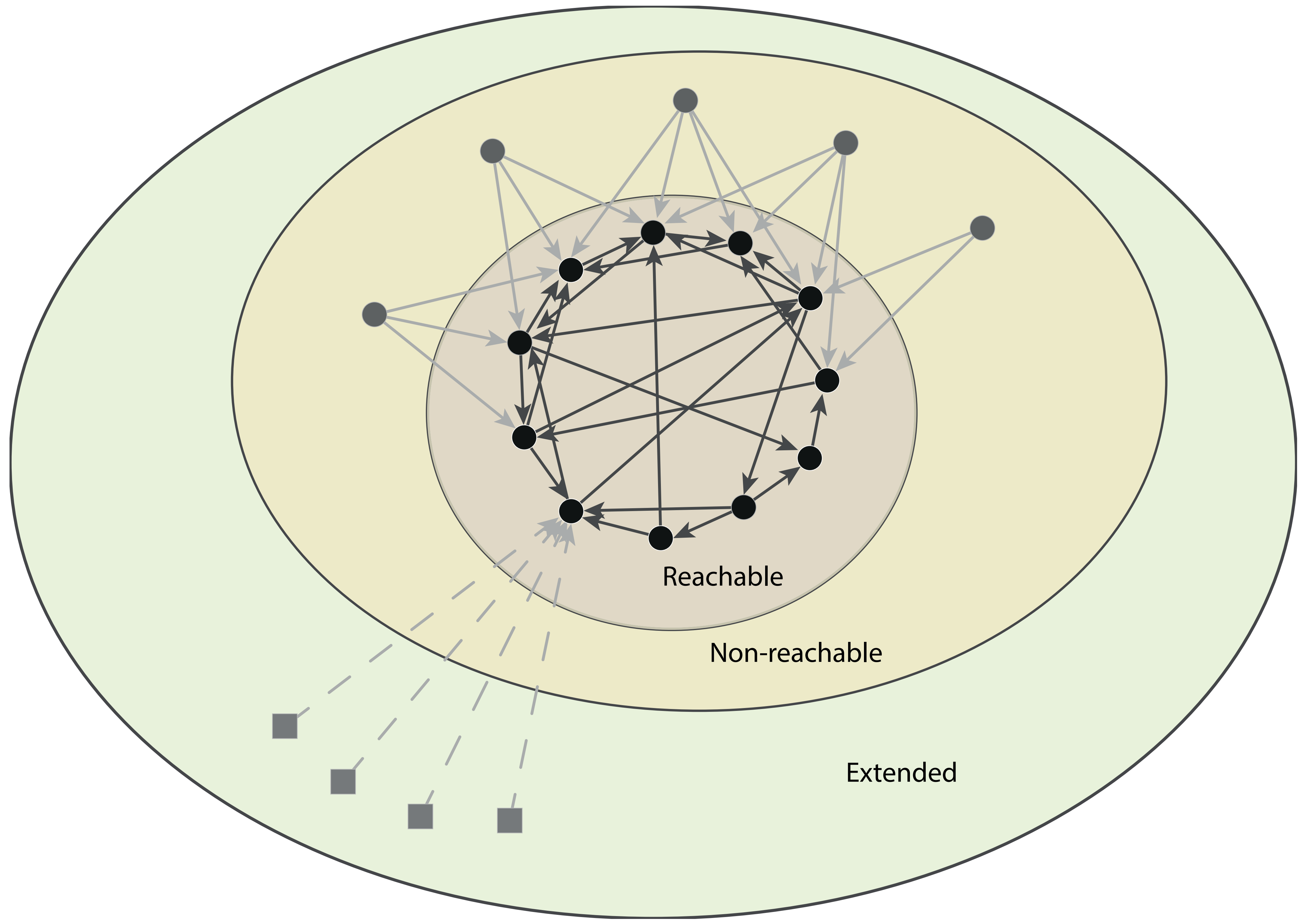
Extended network: nodes use different protocol to communicate (not always P2P)



Nodes misbehavior

Nodes misbehavior

Every node maintains a **banscore** with each of its neighbors

If a node finds that one if its peers is misbehaving, the former will increase the banscore of the later

If the banscore of a neighbor reaches (or surpasses) its maximum (**100 by default)**, the node will ban that neighbor for a certain time (**24h by default**)

The banscore increase depends on how the neighbor is misbehaving

Banscore

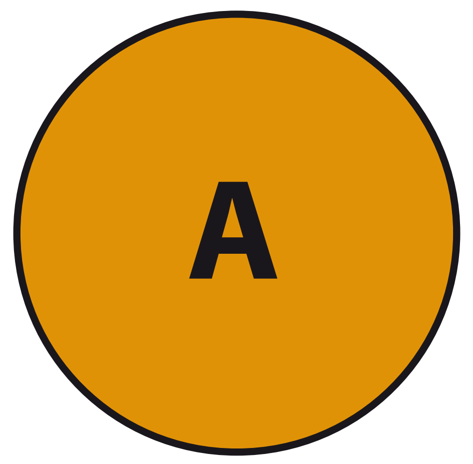
Examples of banscore increase:

- Not sending a version message as the first message in a handshake (**1**)
- Sending more than 1000 addresses in a single address message (**1**)
- Sending more than 50000 ids in a single inventory message (**20**)
- Sending a transaction with a script too big (**100)**

src/net_processing.cpp for more

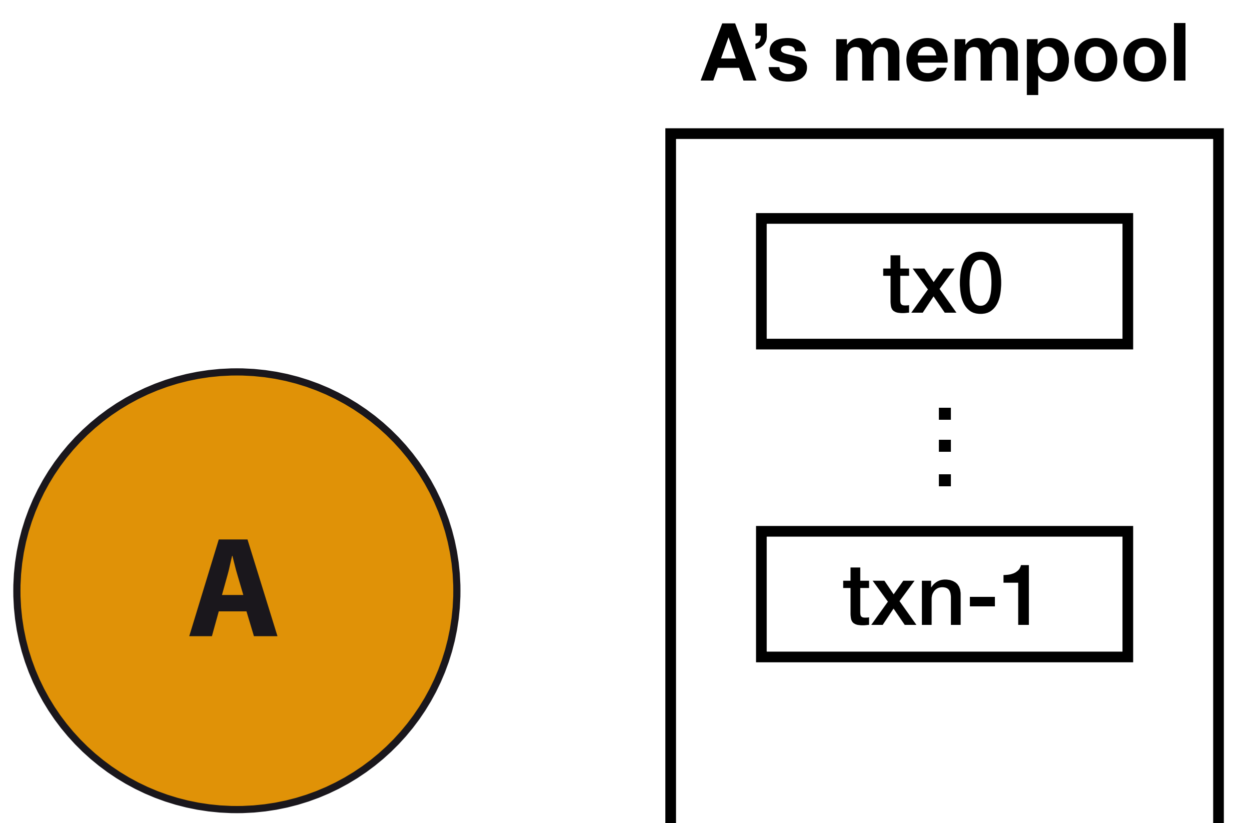
0-conf transactions and double-spending

UNCONFIRMED TRANSACTIONS



- **0-conf** transactions / **unconfirmed** transactions are those that are not part of the blockchain (**they are stored in the mempool**)
- 0-conf transactions are not covered by the double-spending protection offered by the blockchain (they are not part of it)
- Different nodes can have conflicting version of the **“same transaction”**

UNCONFIRMED TRANSACTIONS



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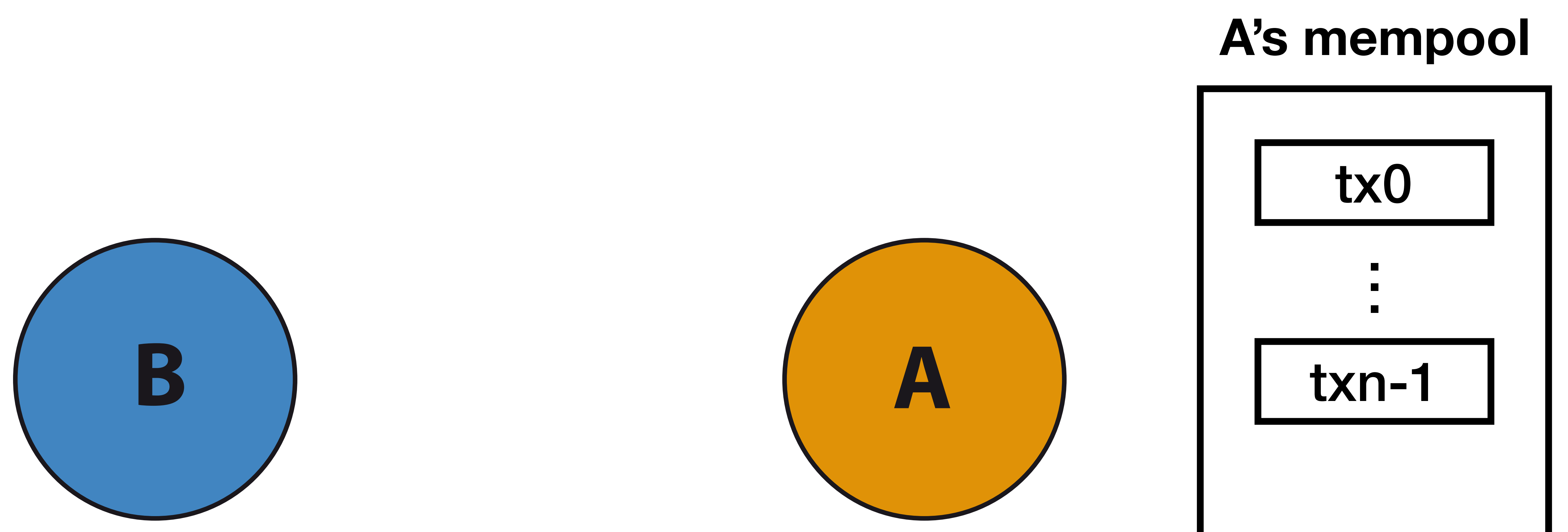

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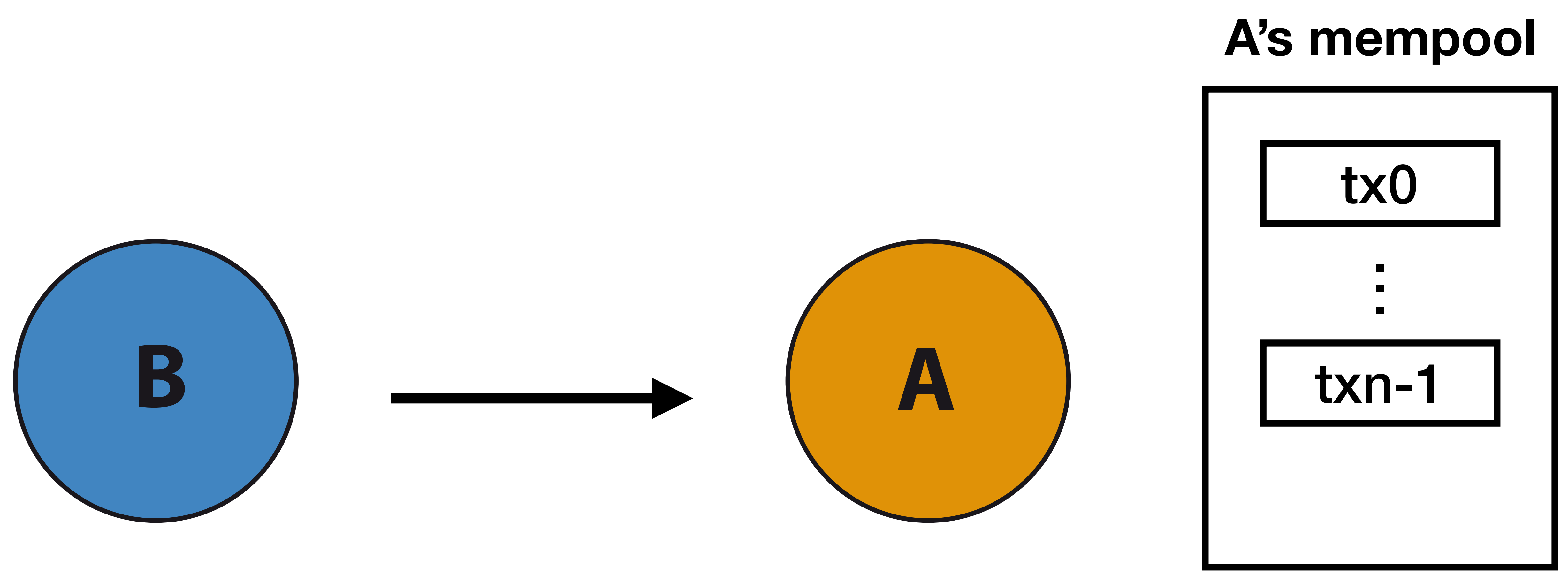

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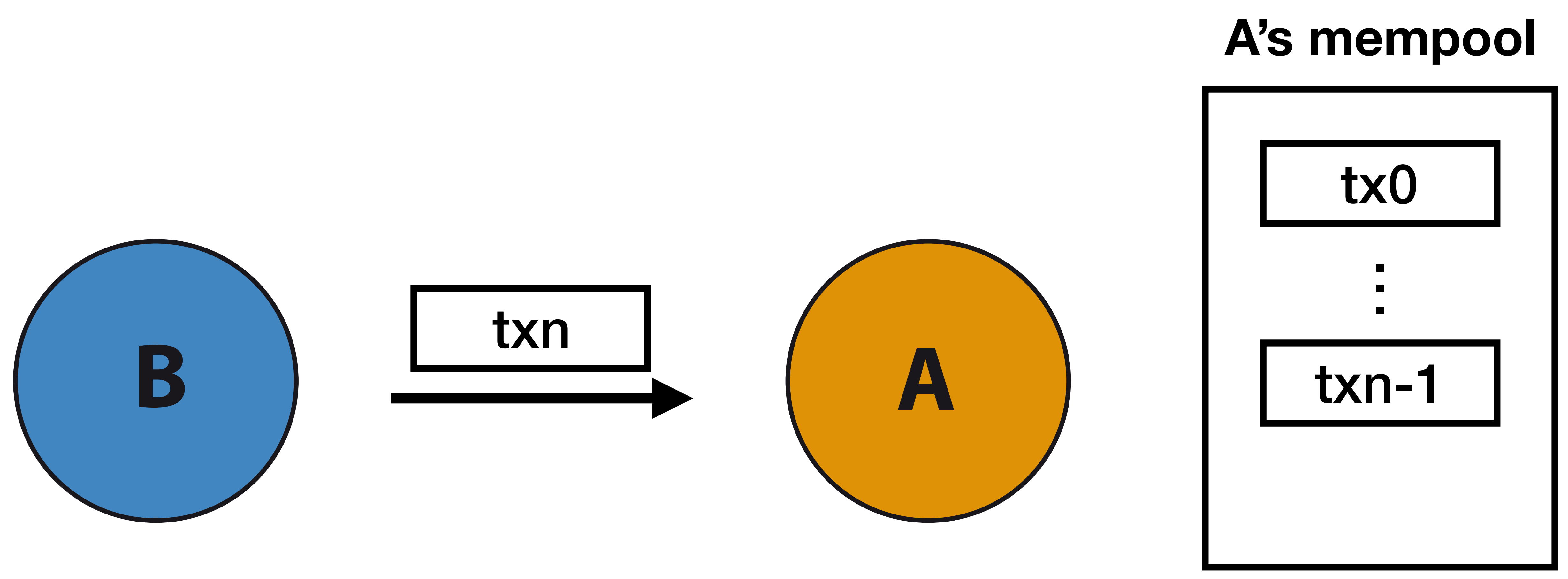

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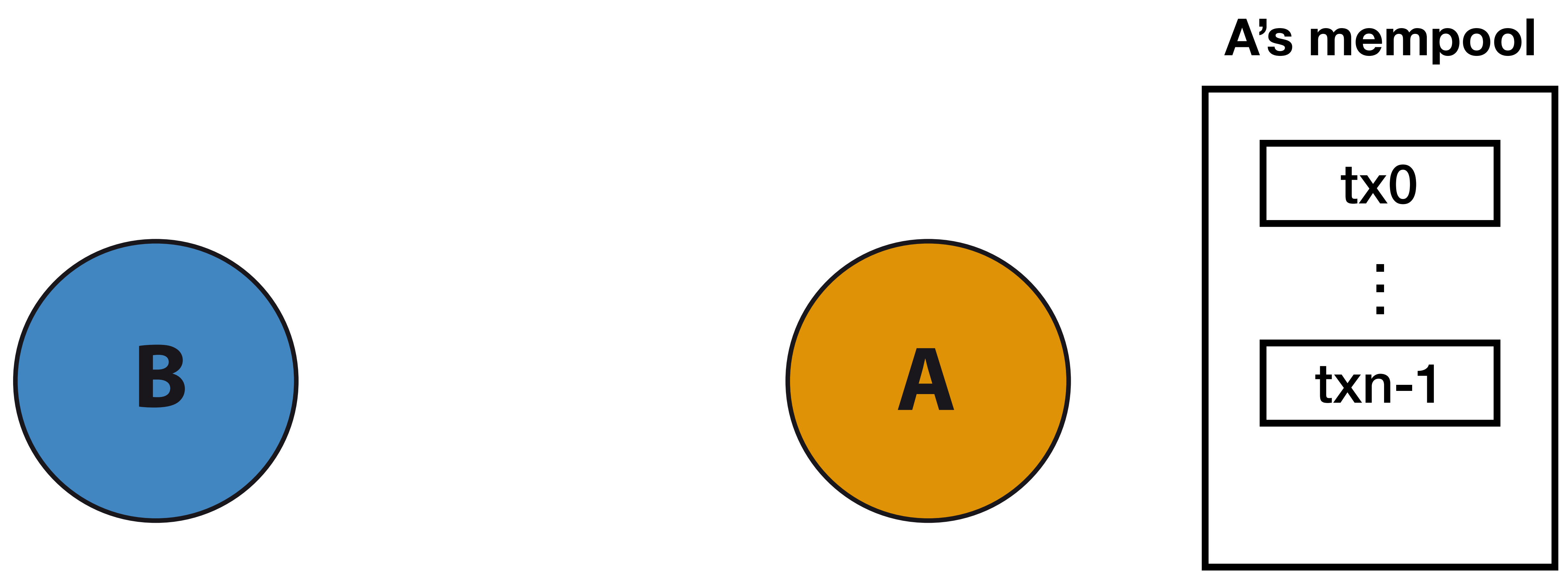

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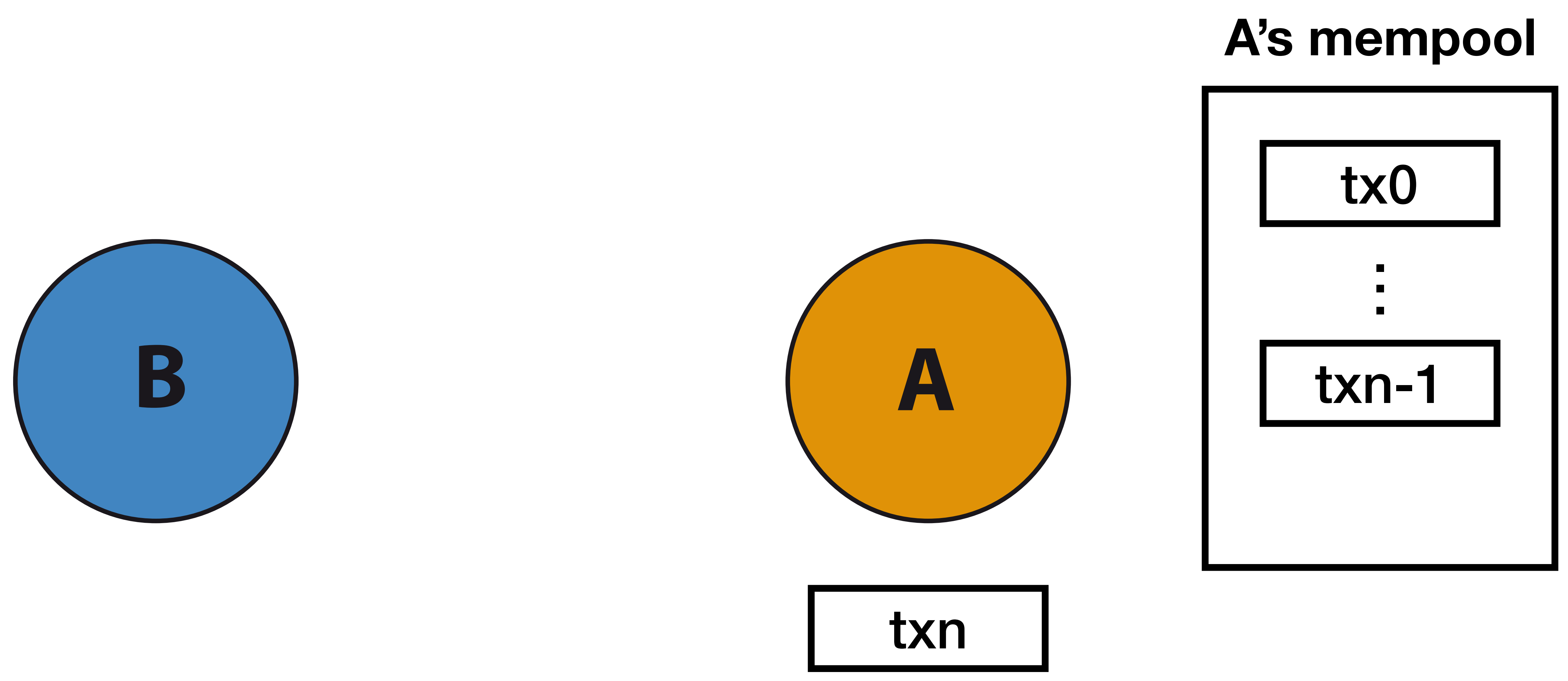

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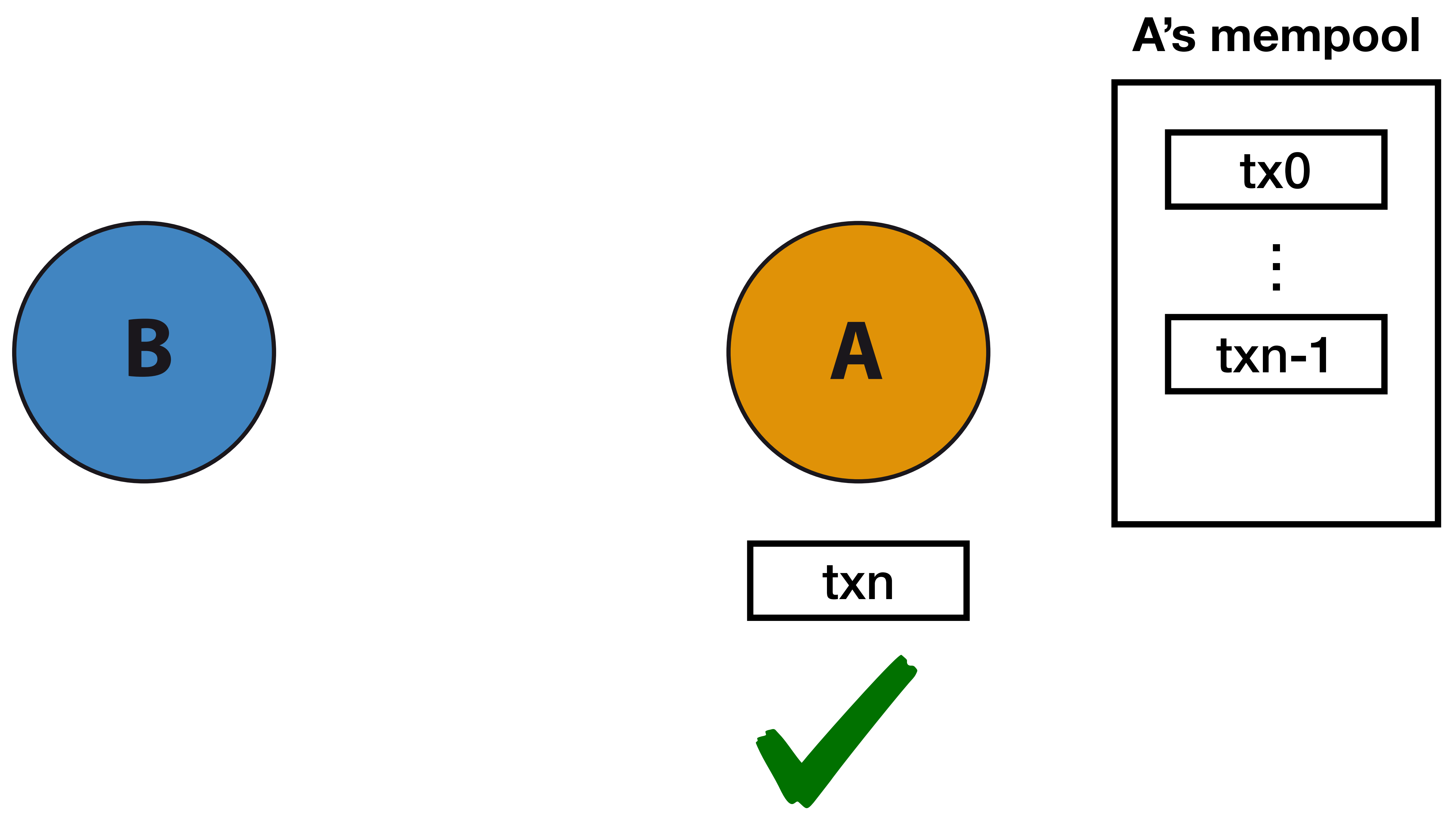

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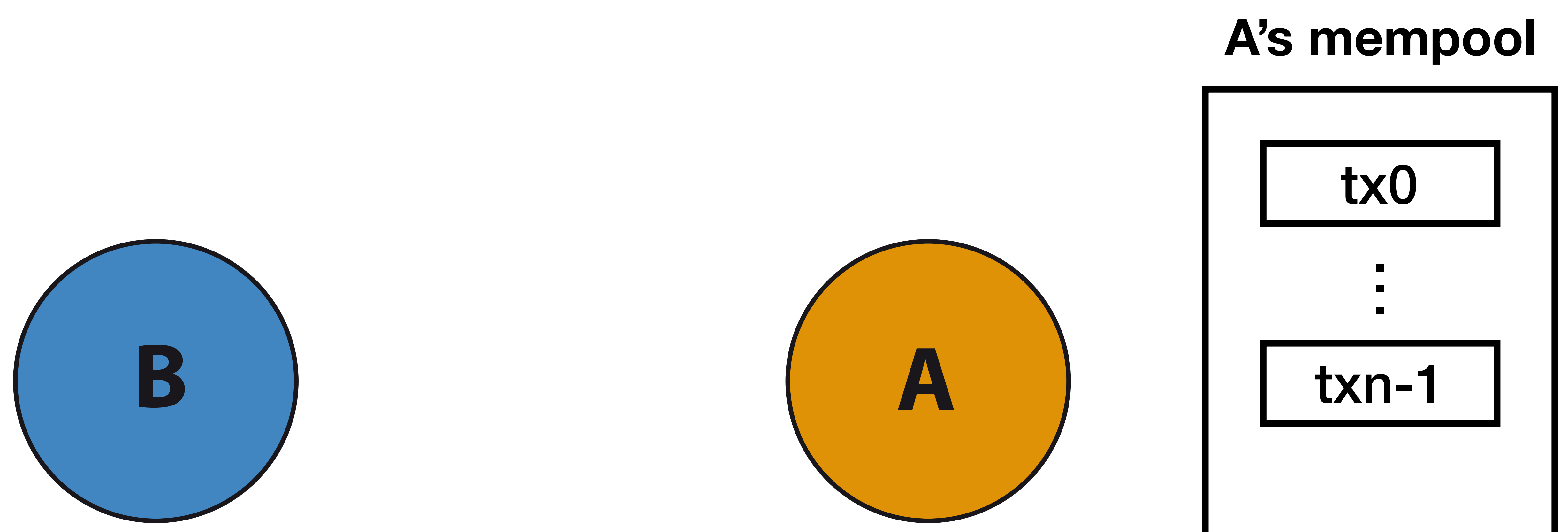

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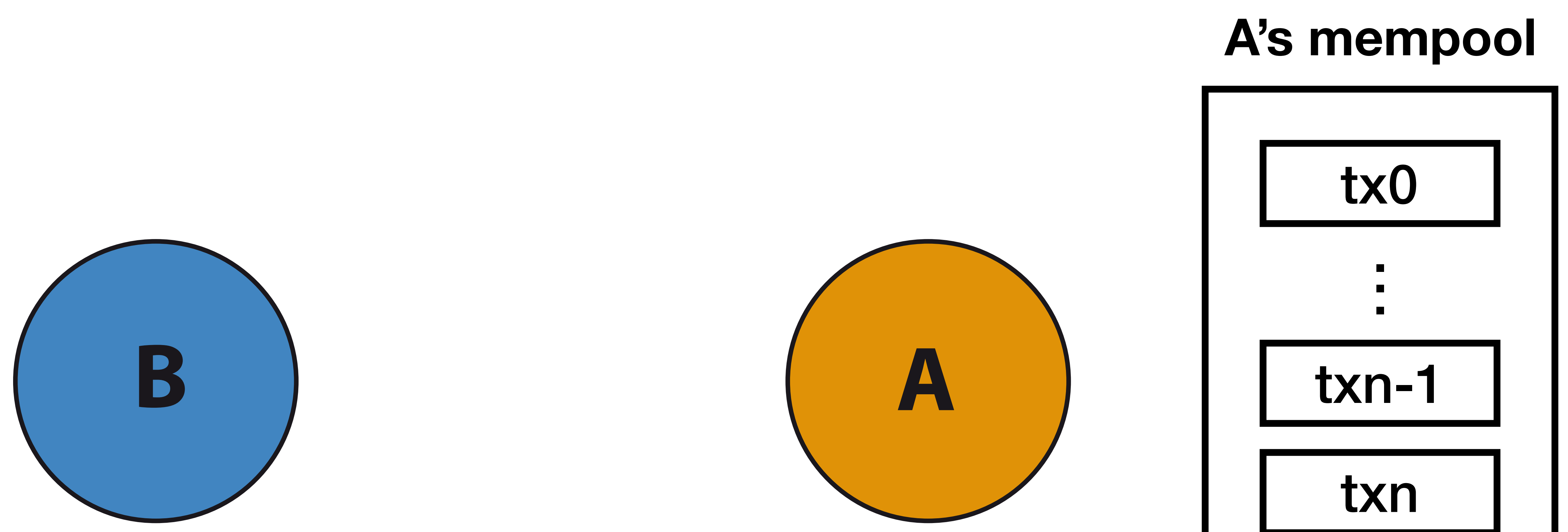

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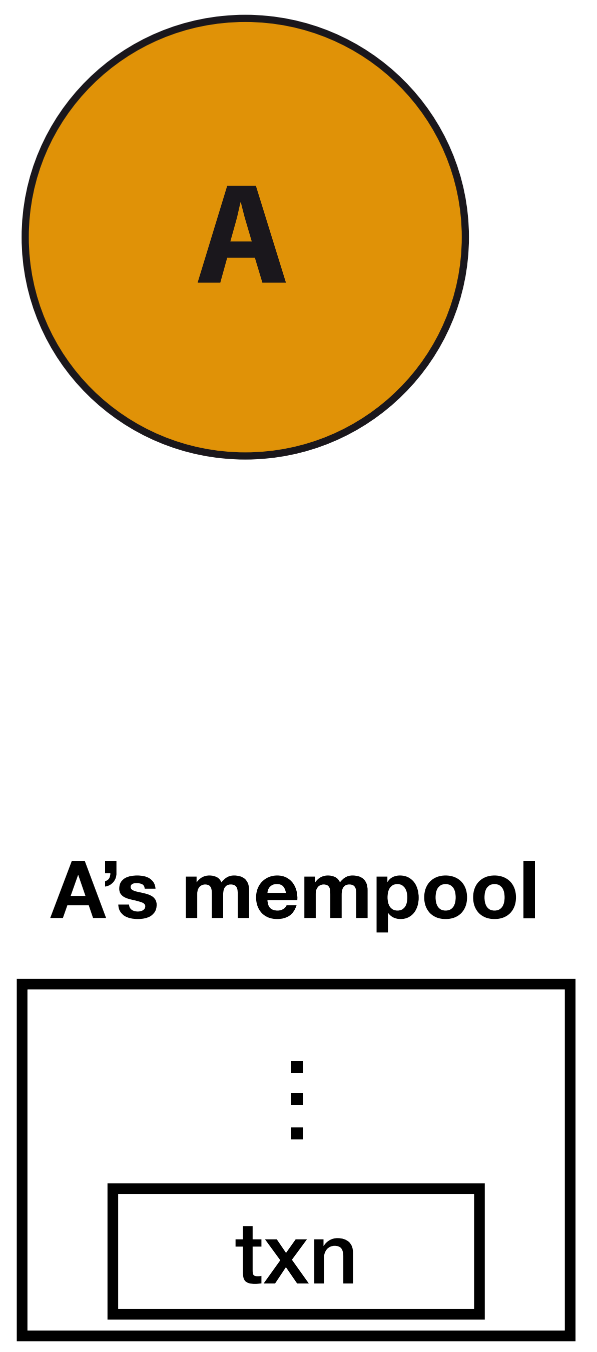

The de facto confirmation time is **6 blocks** (5 on top of the one including a certain transaction)

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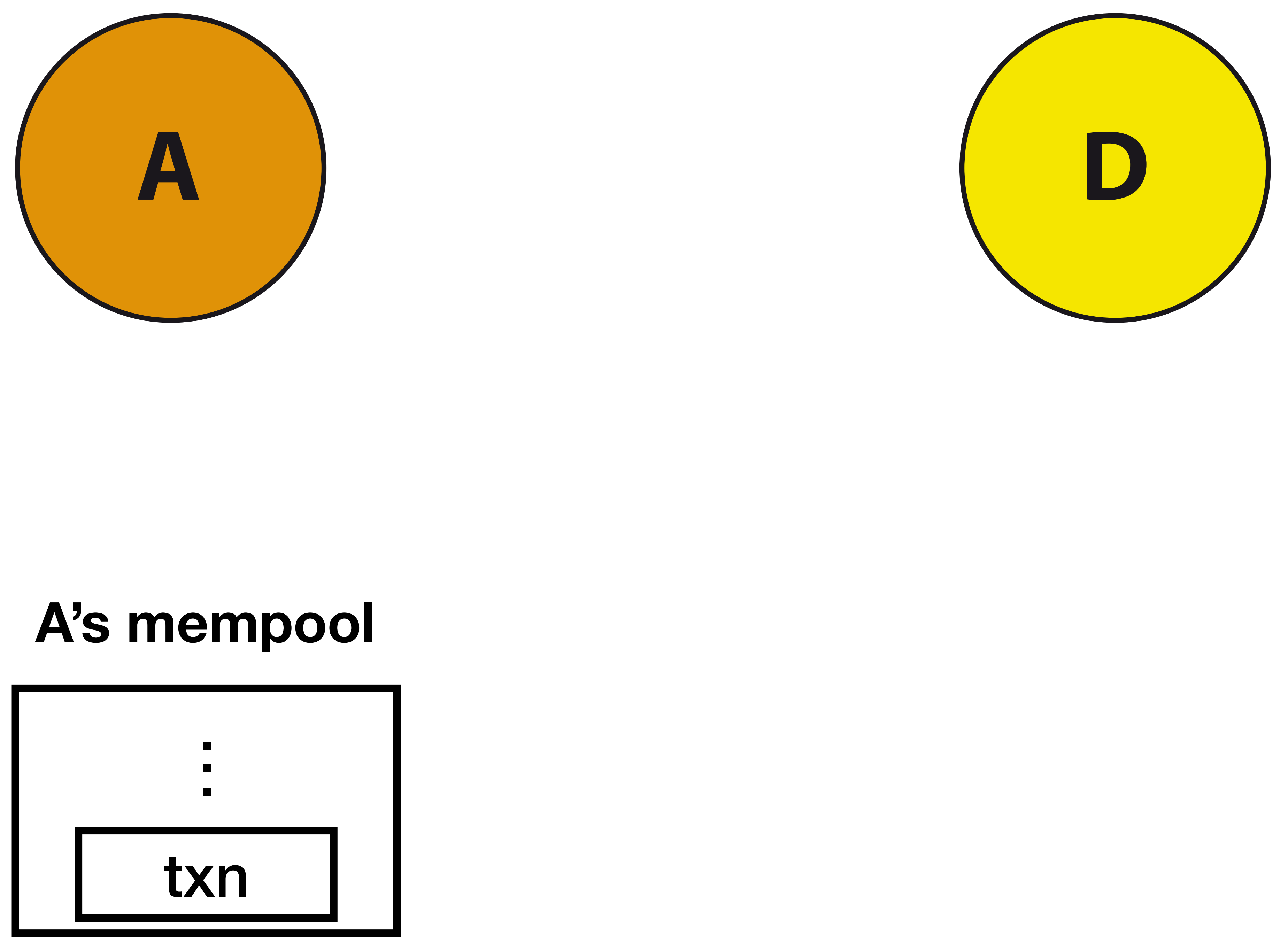

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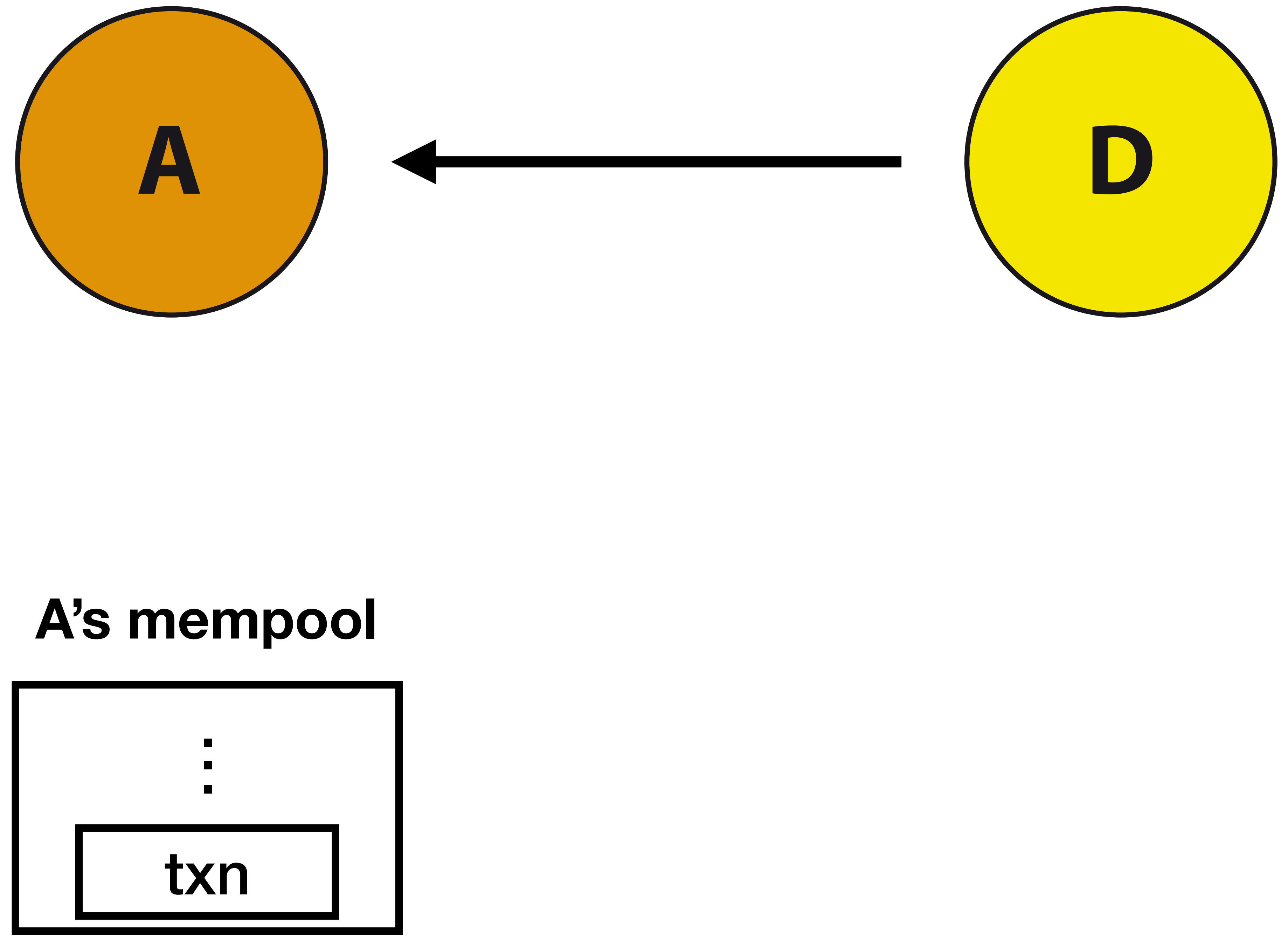

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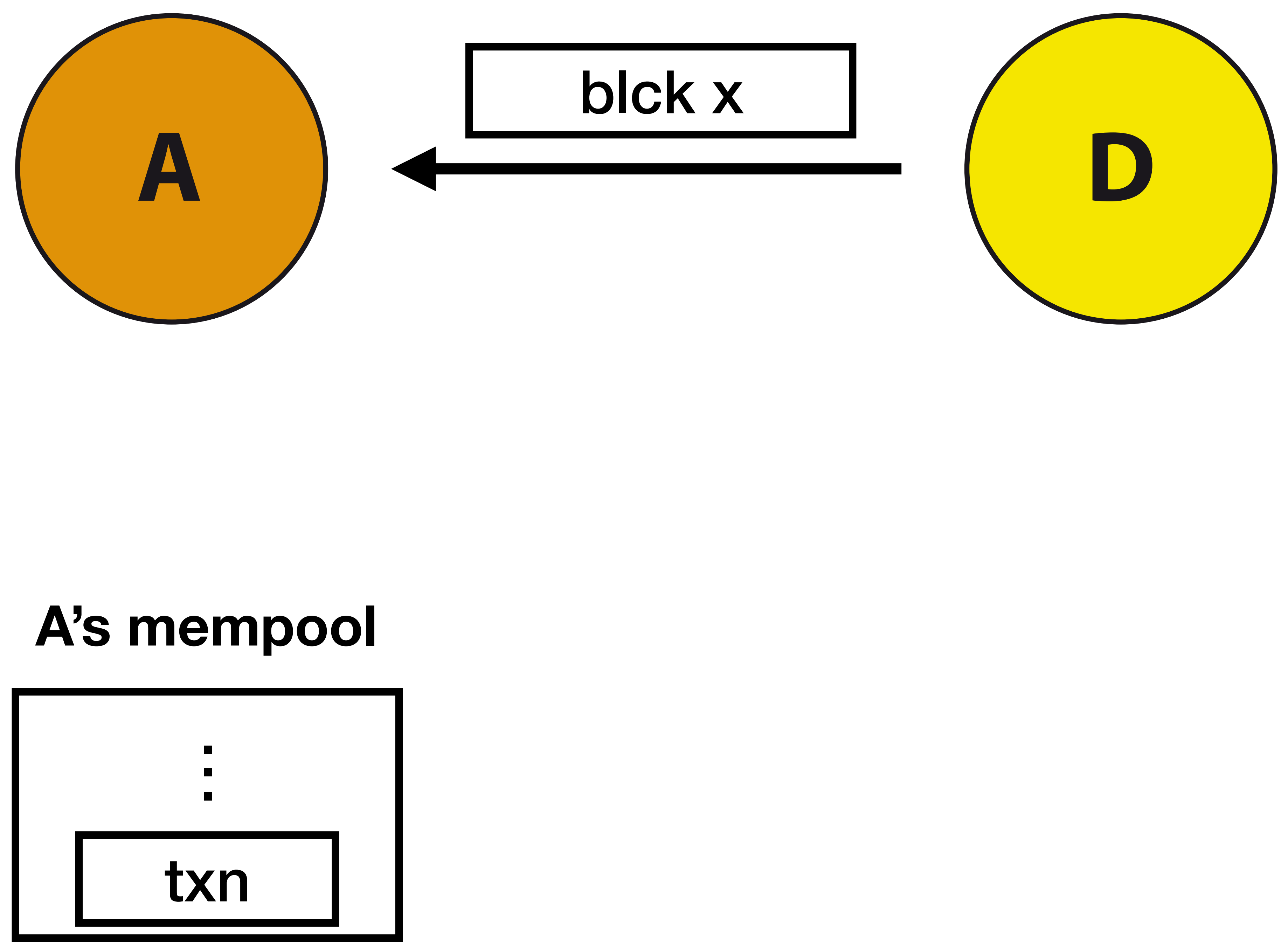

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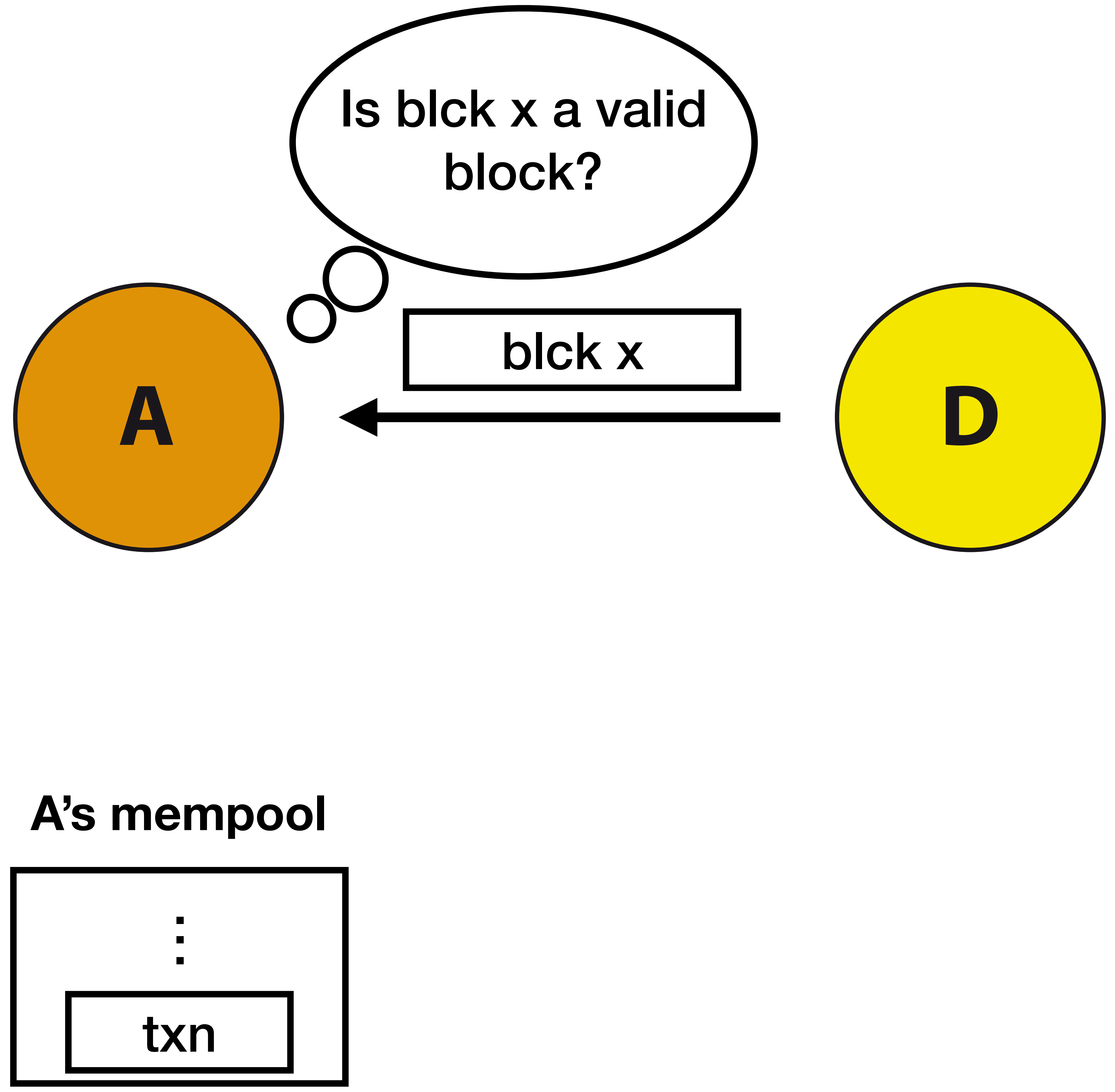

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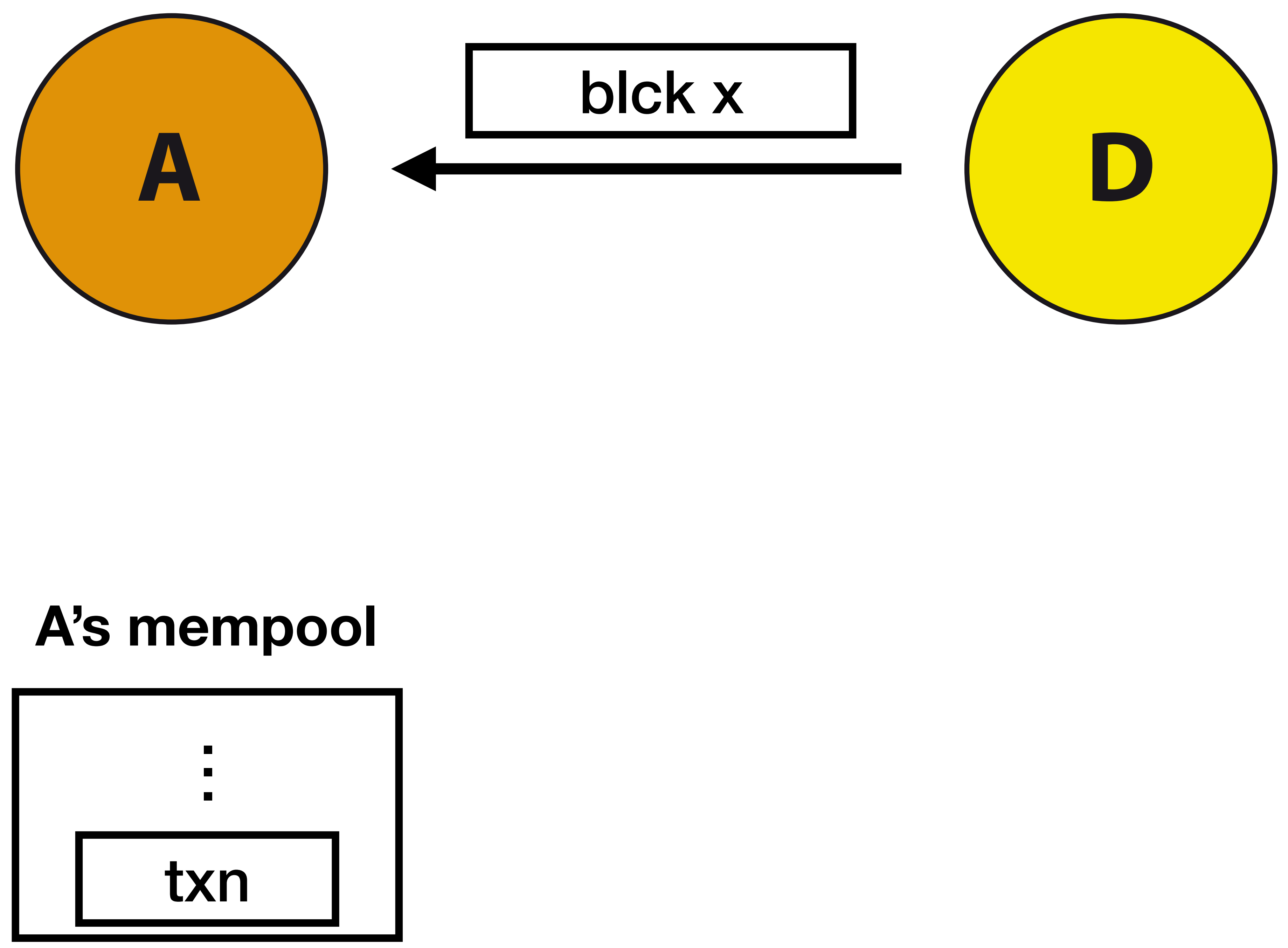

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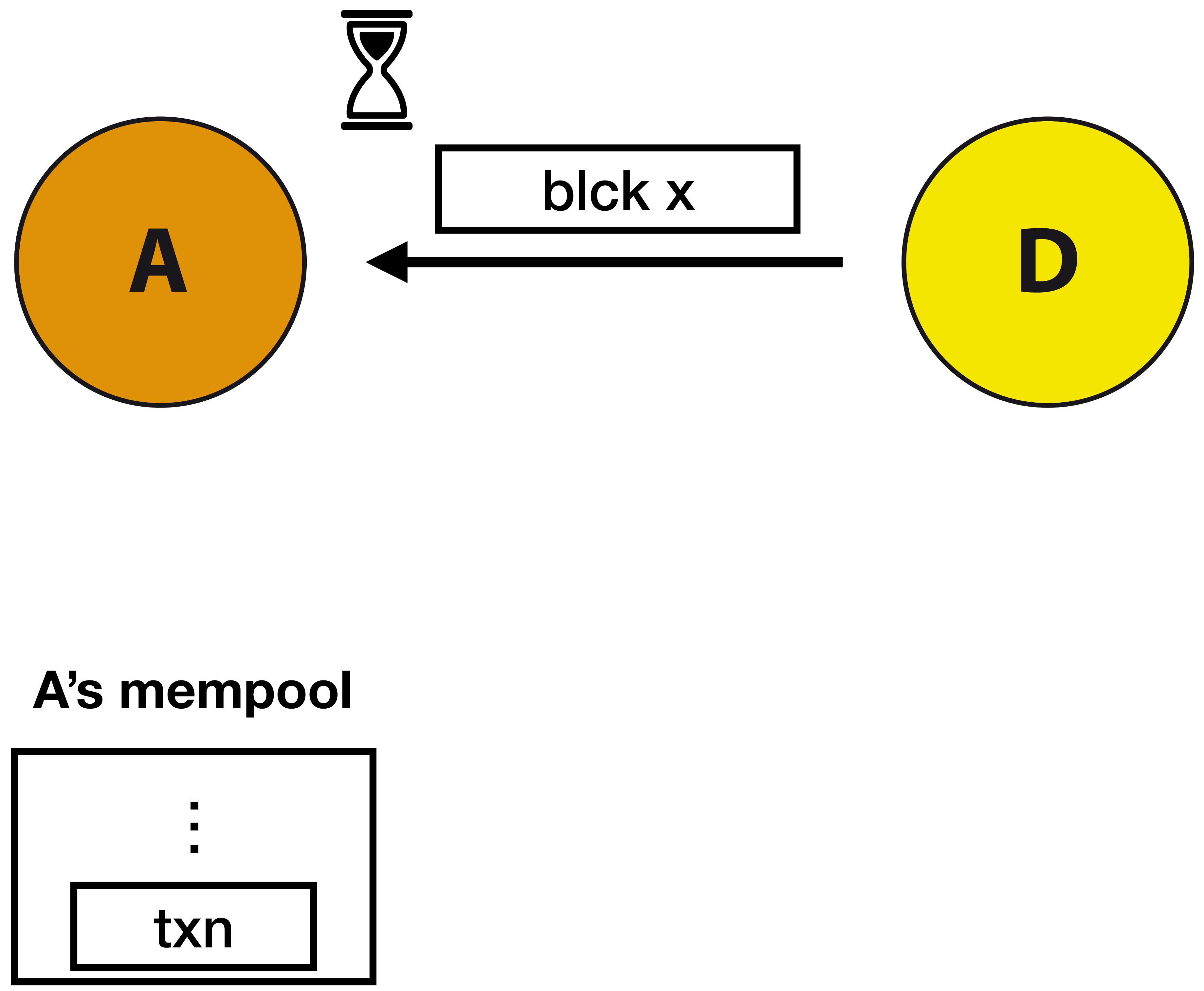

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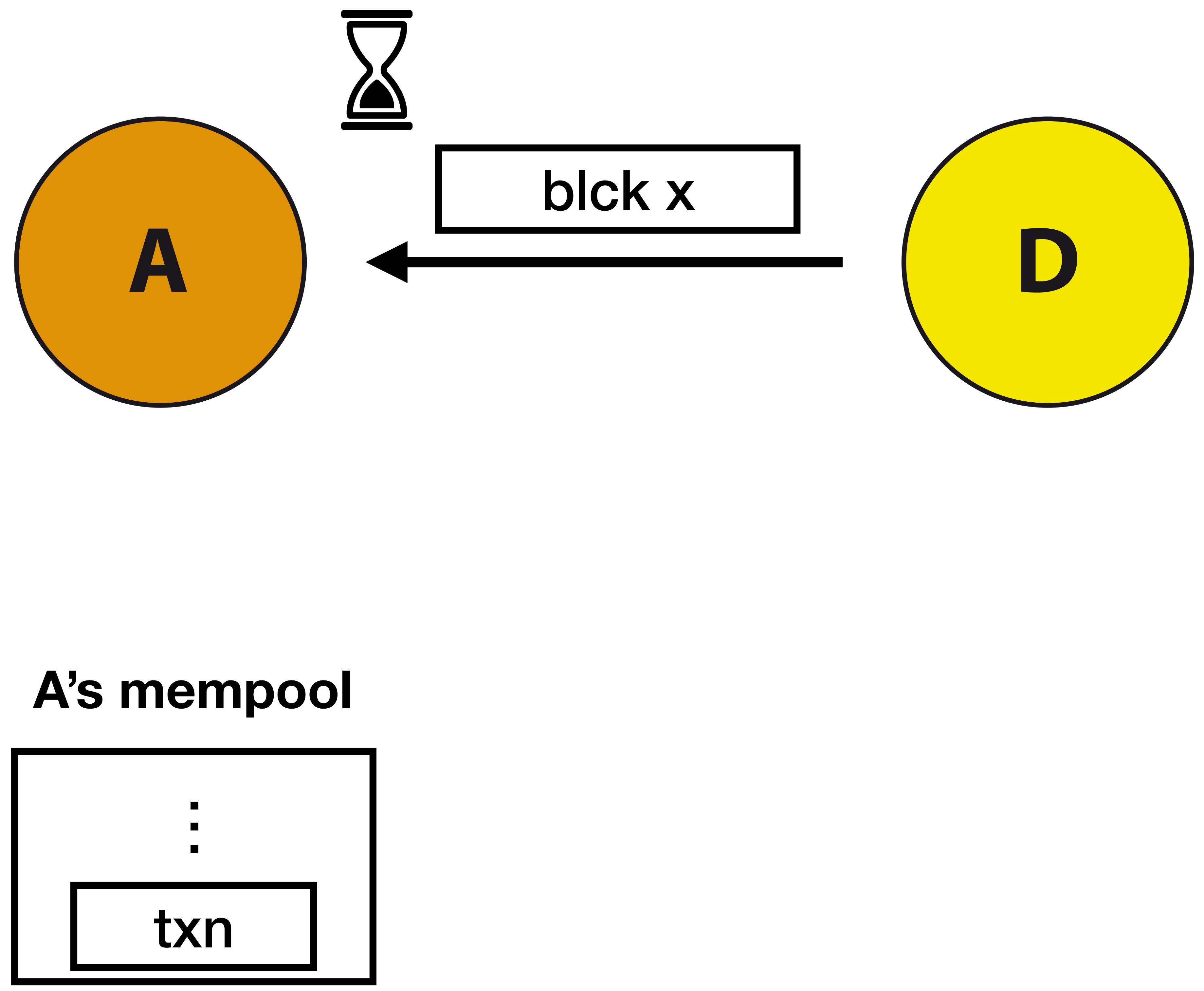

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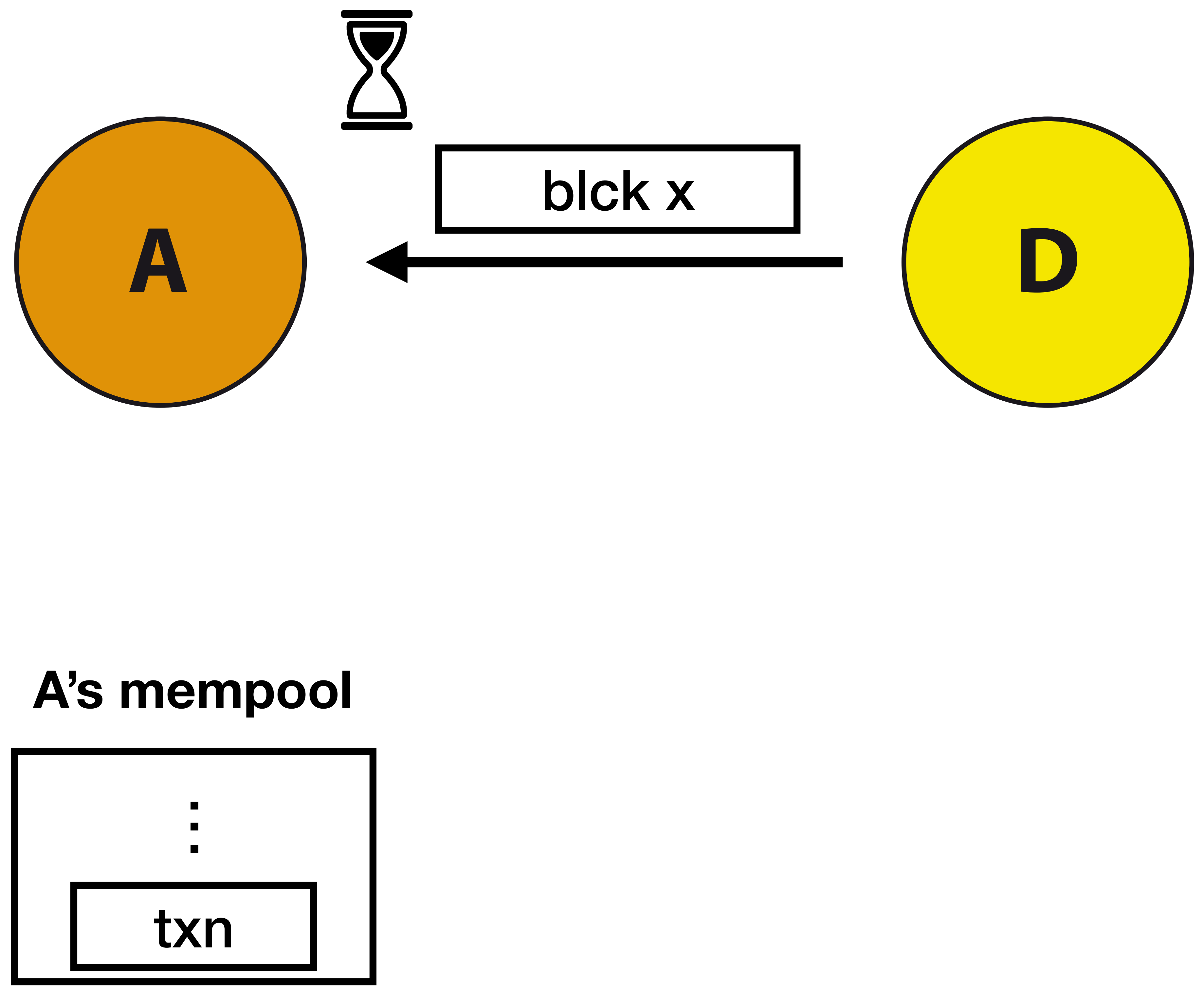

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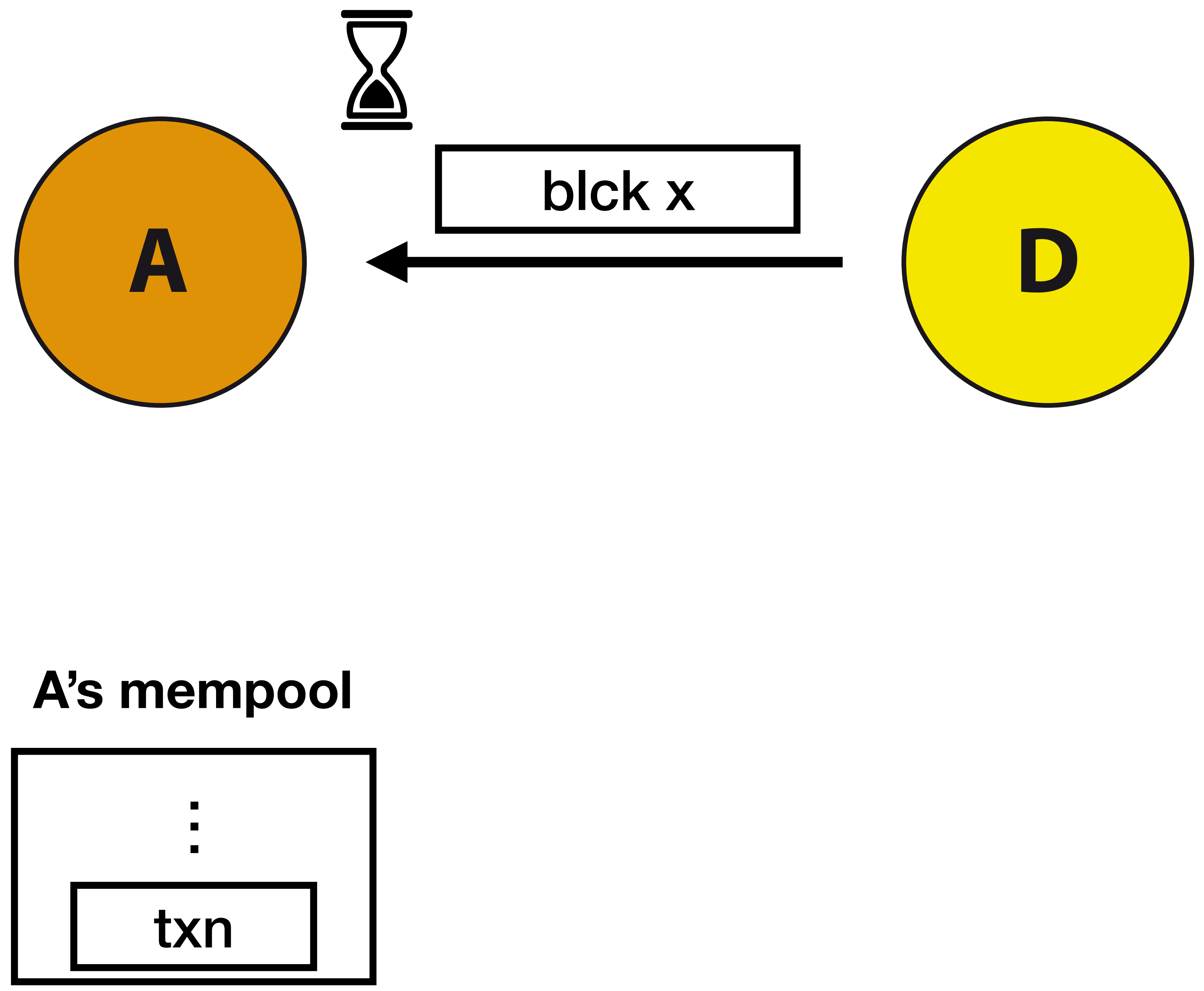

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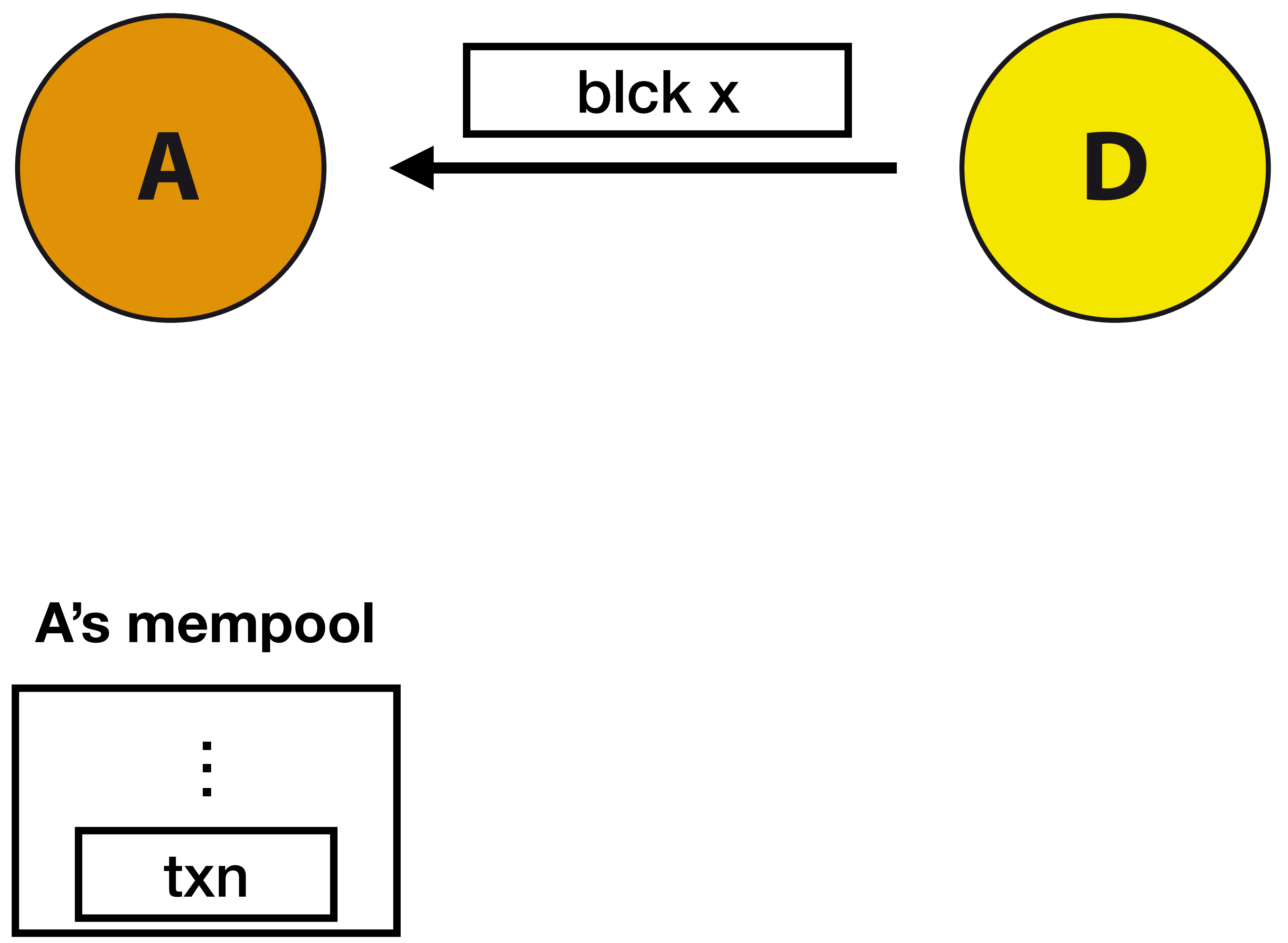

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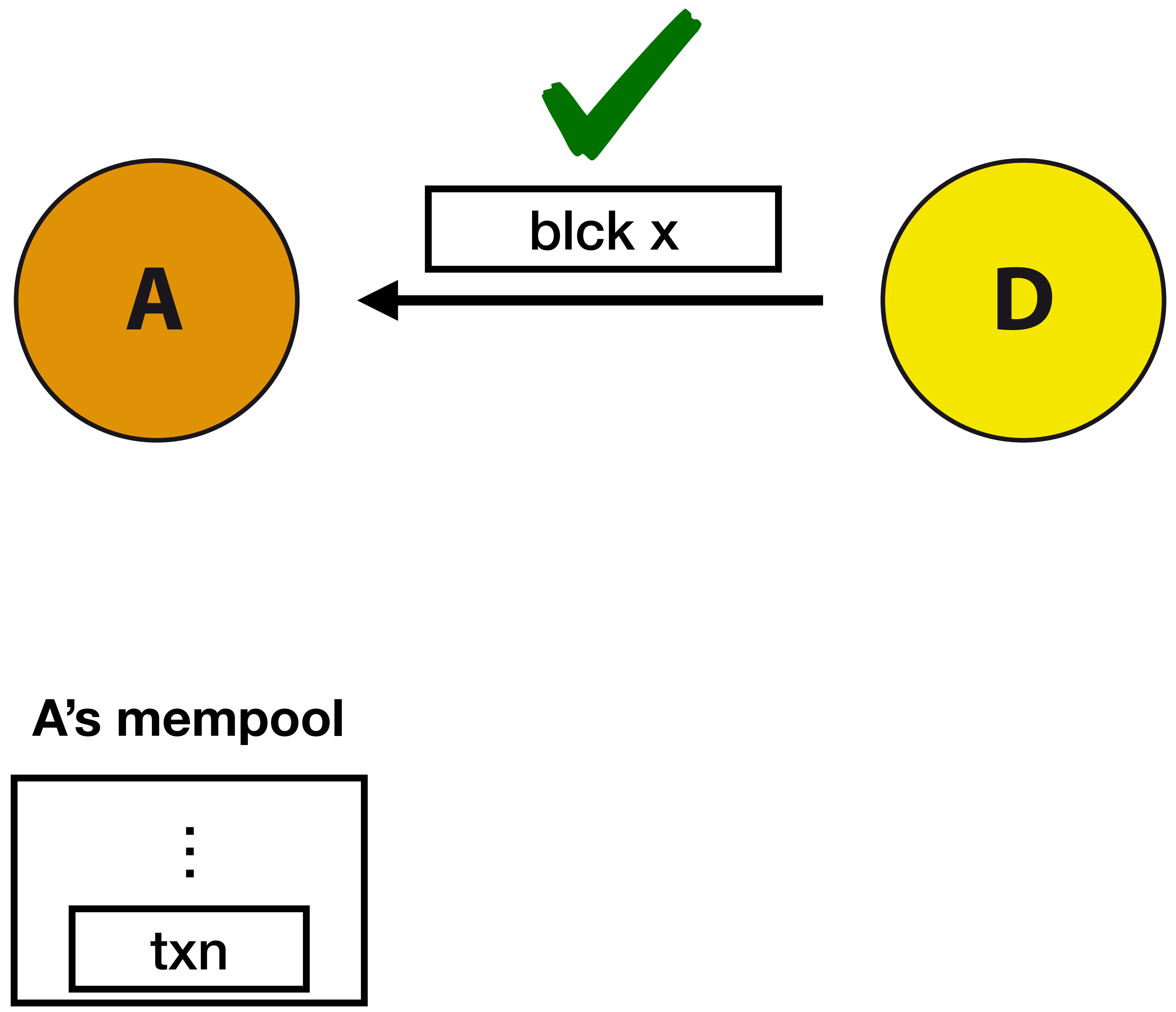

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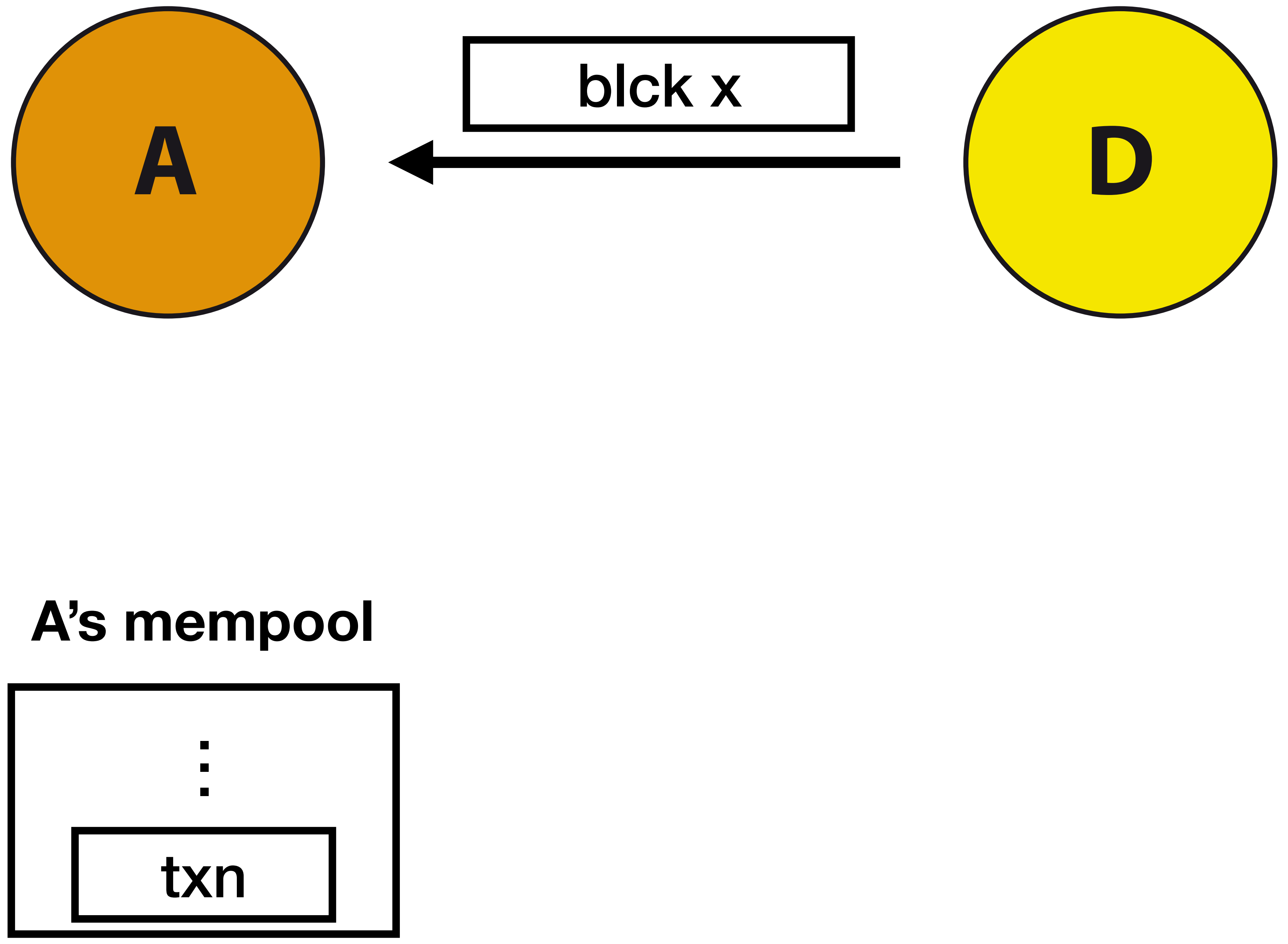

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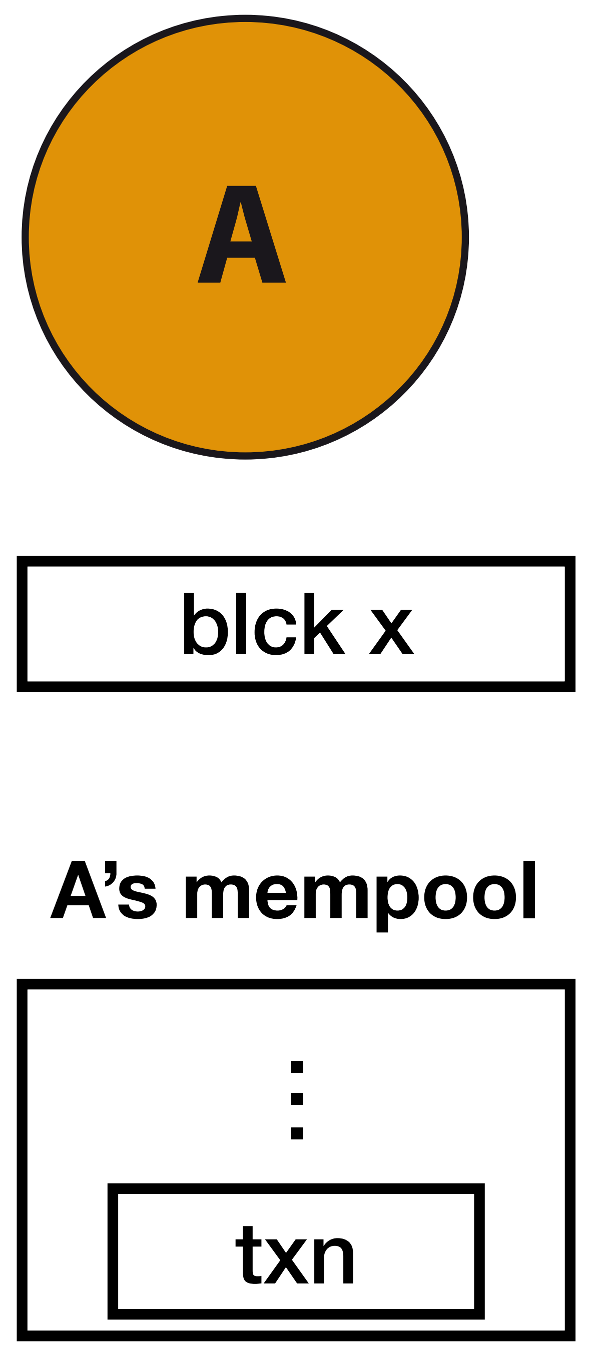

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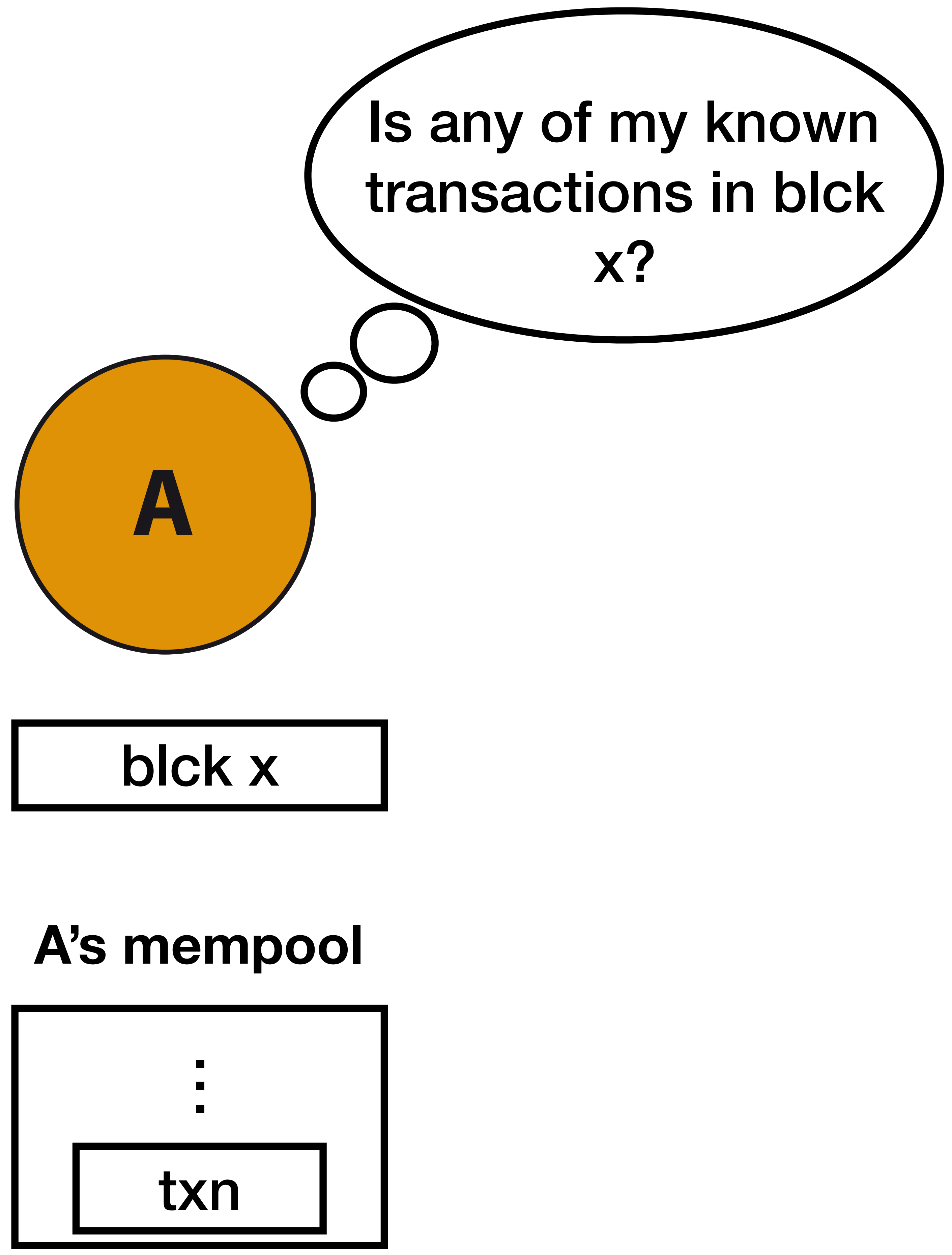

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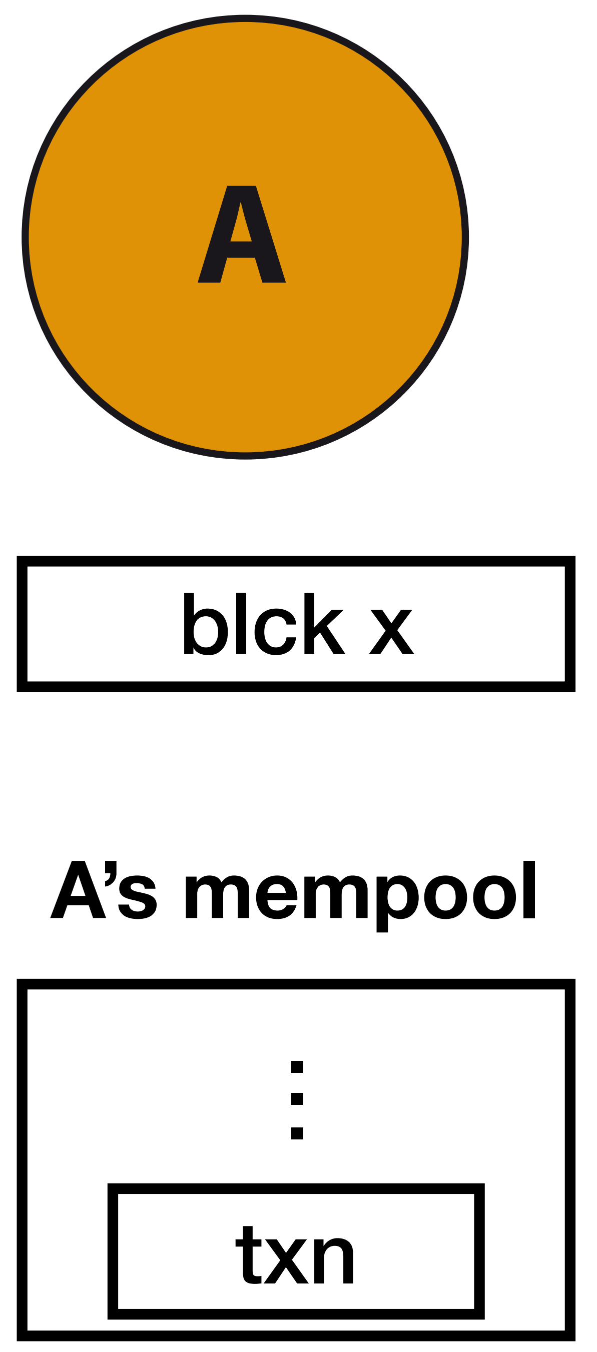

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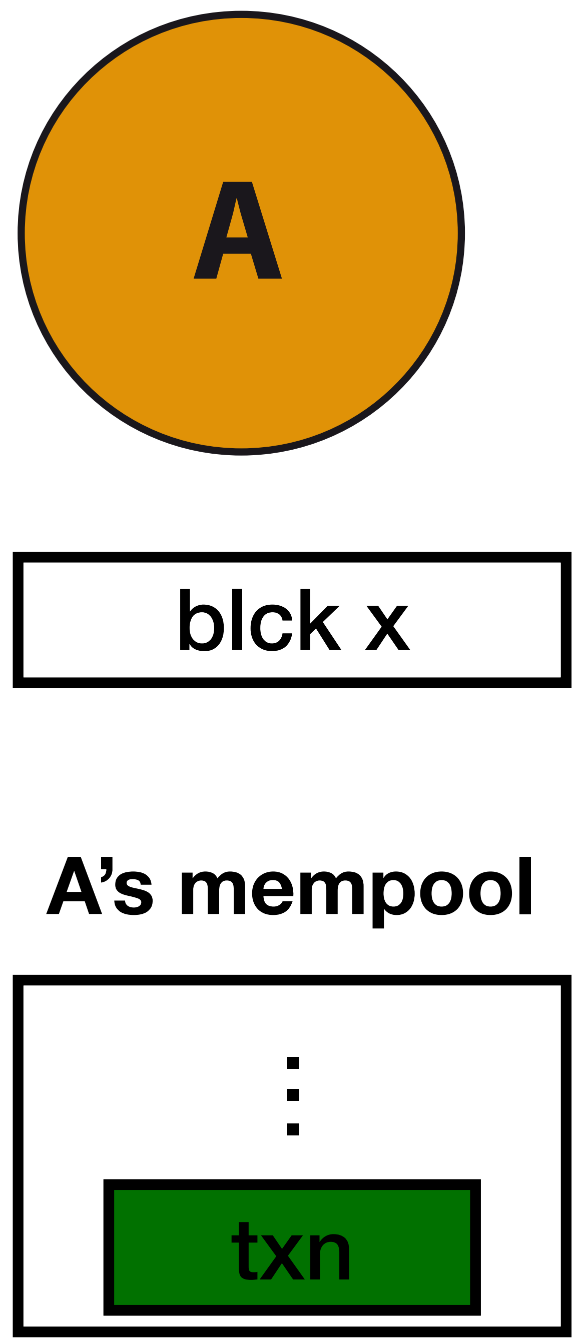

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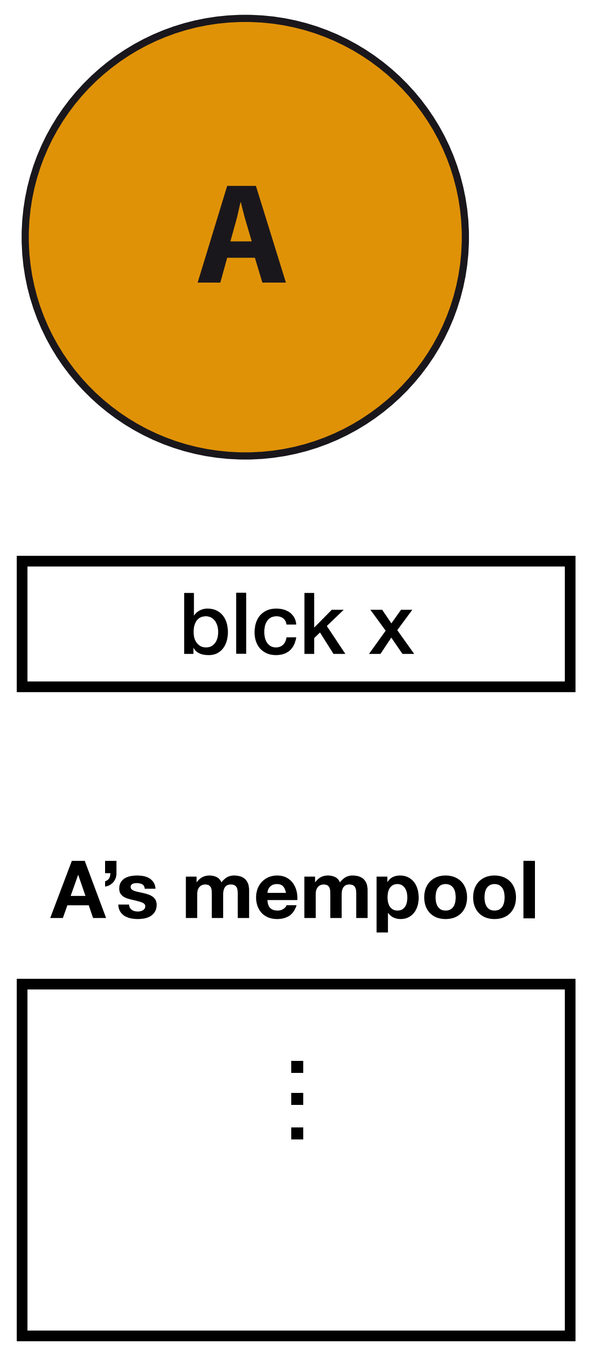

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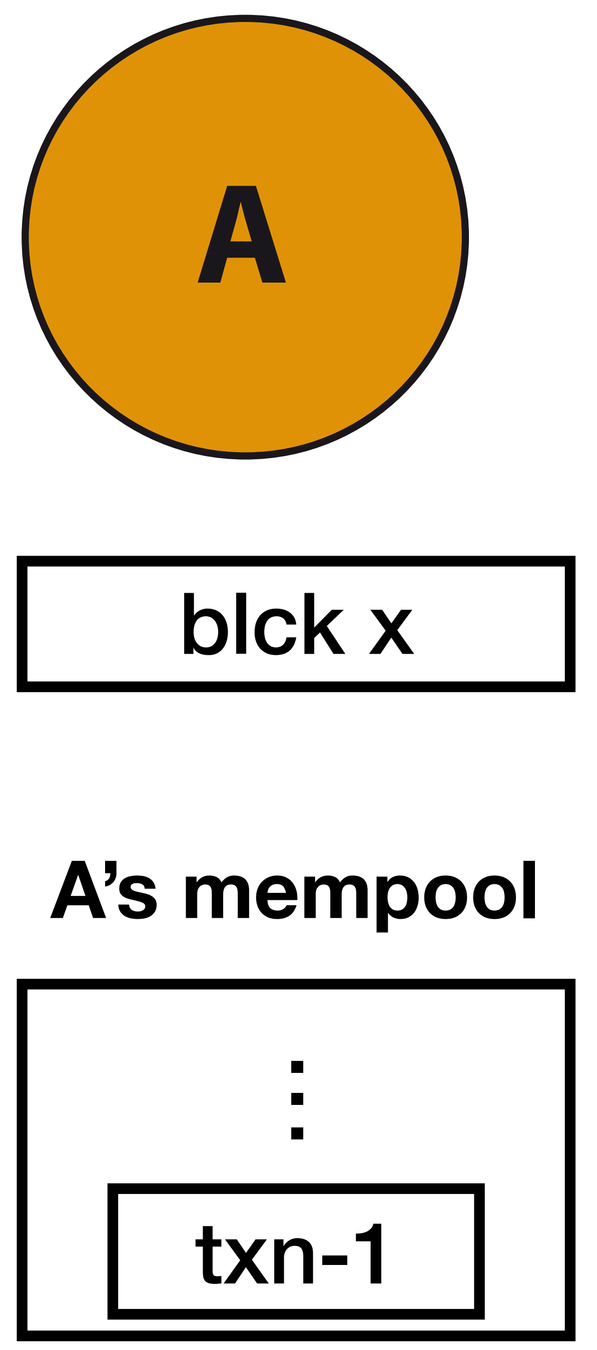

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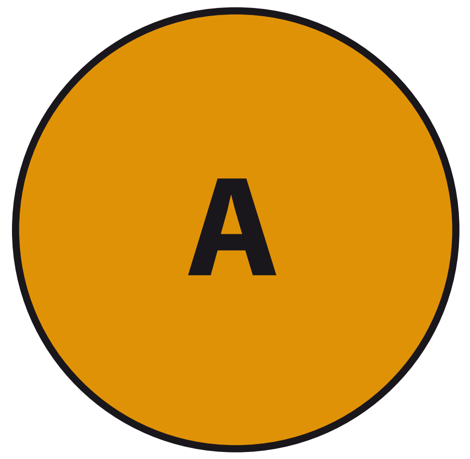
DOUBLE-SPENDING TRANSACTIONS (1/2)



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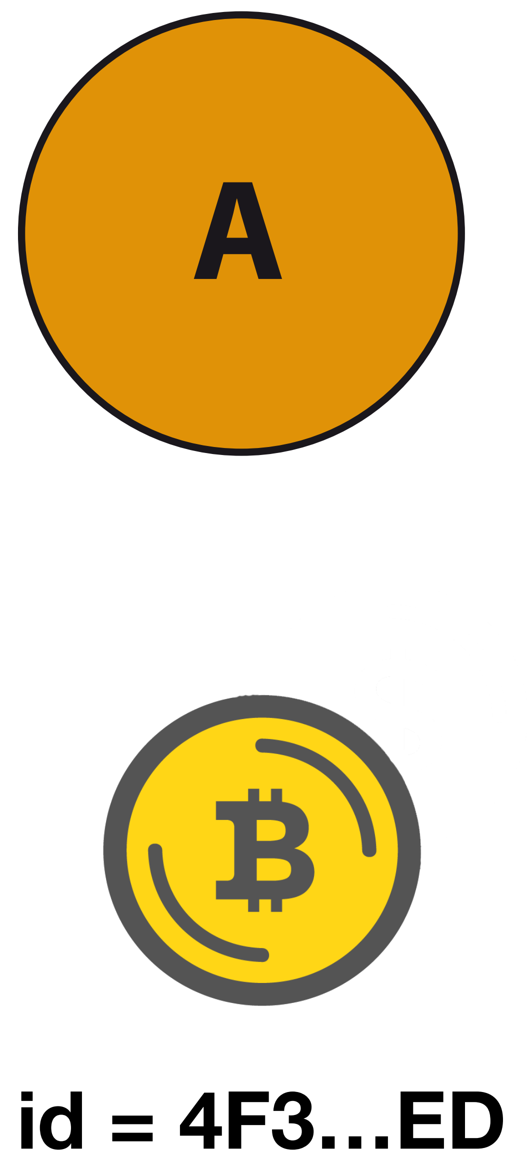

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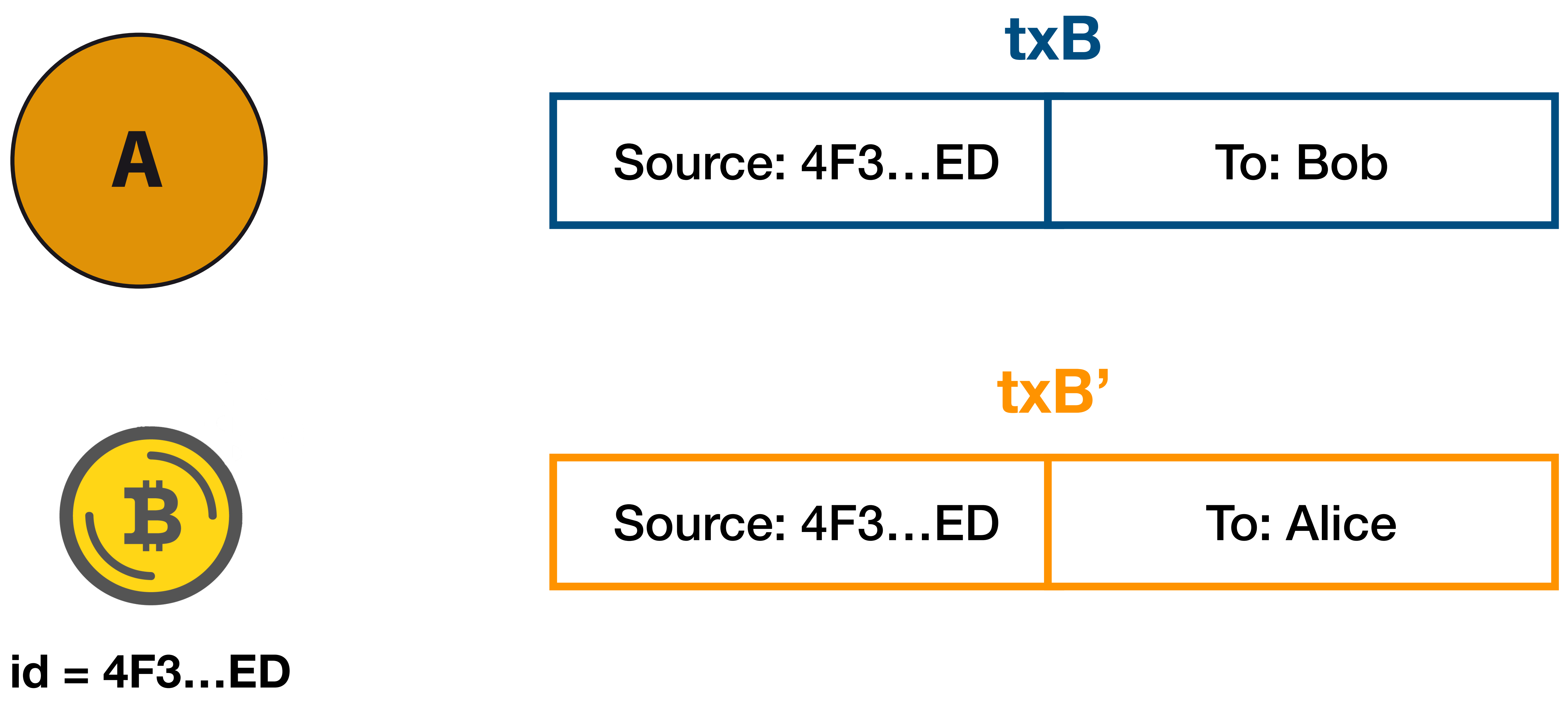

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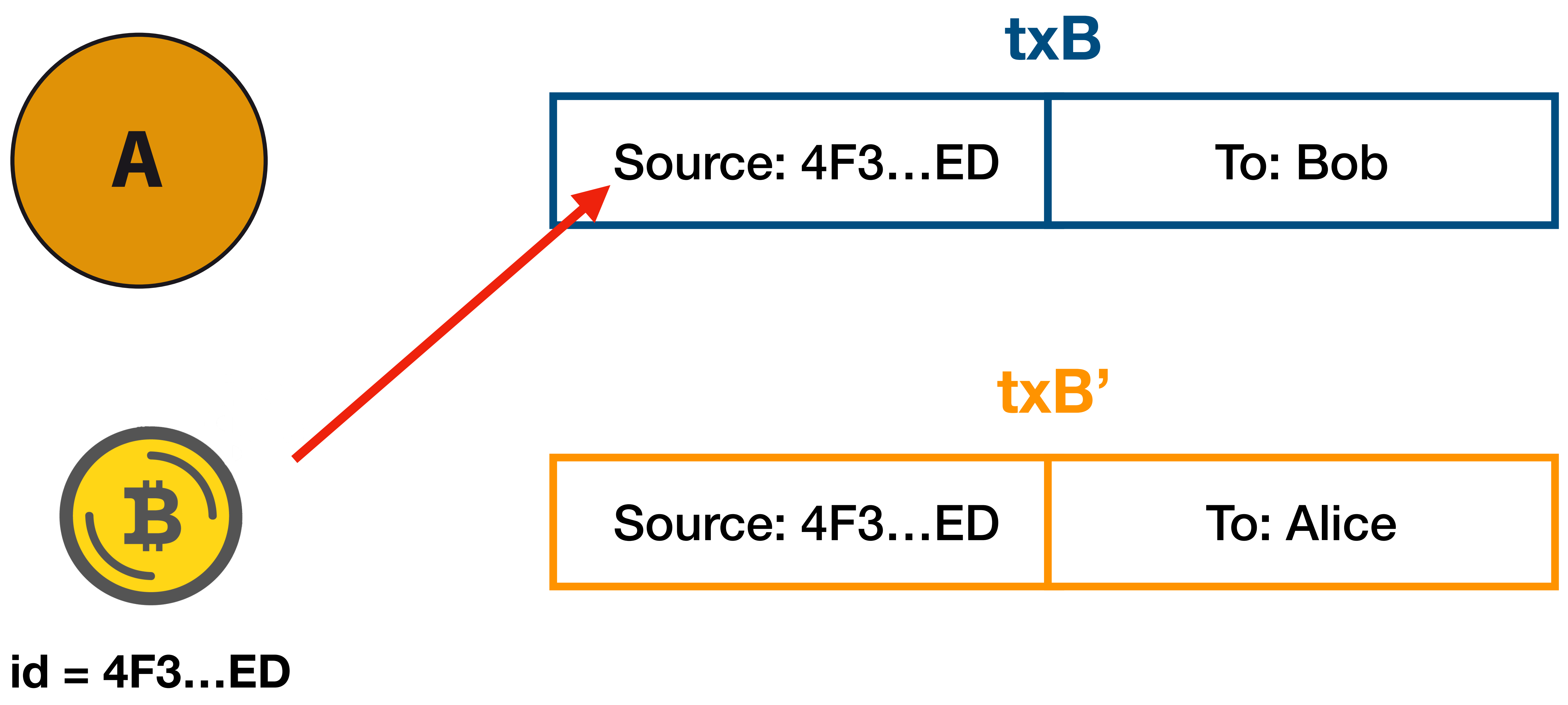

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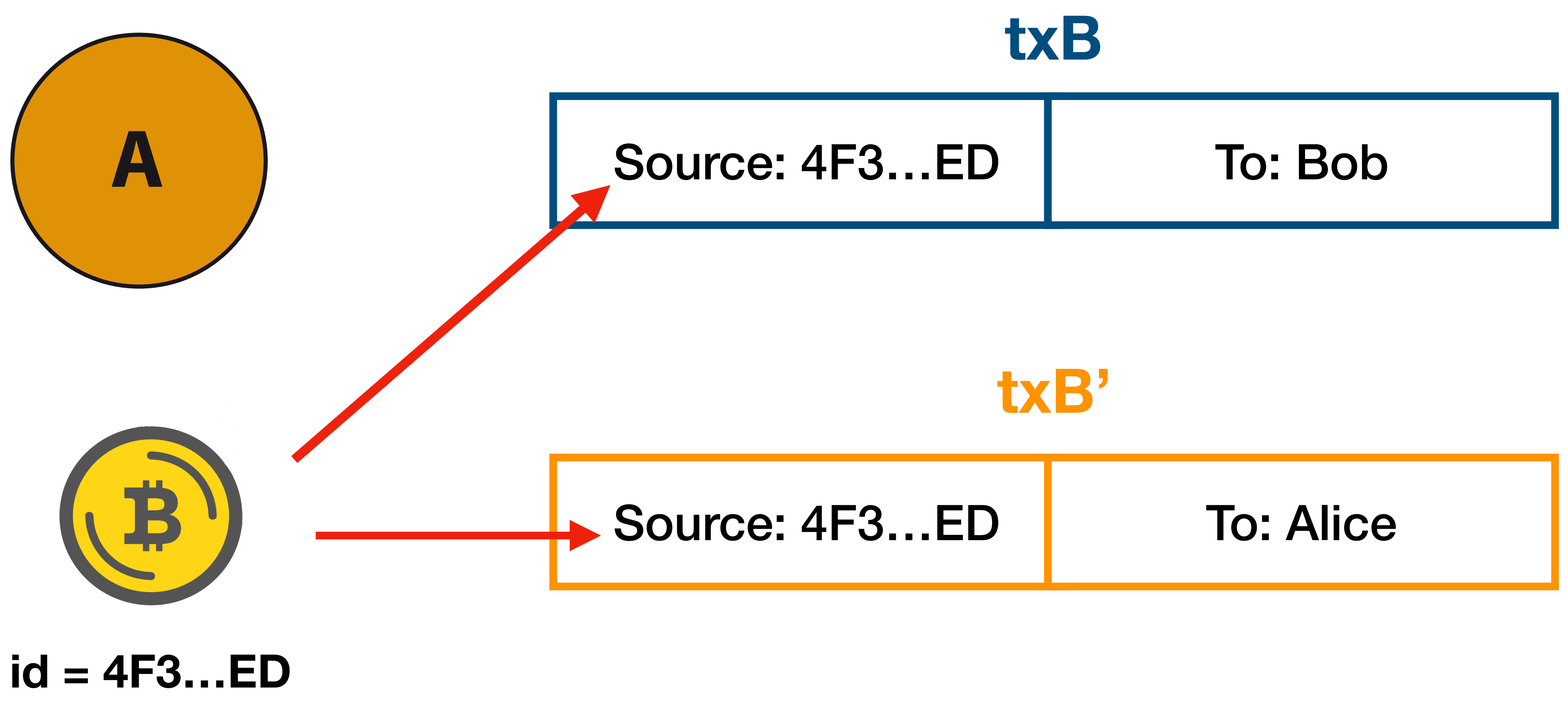

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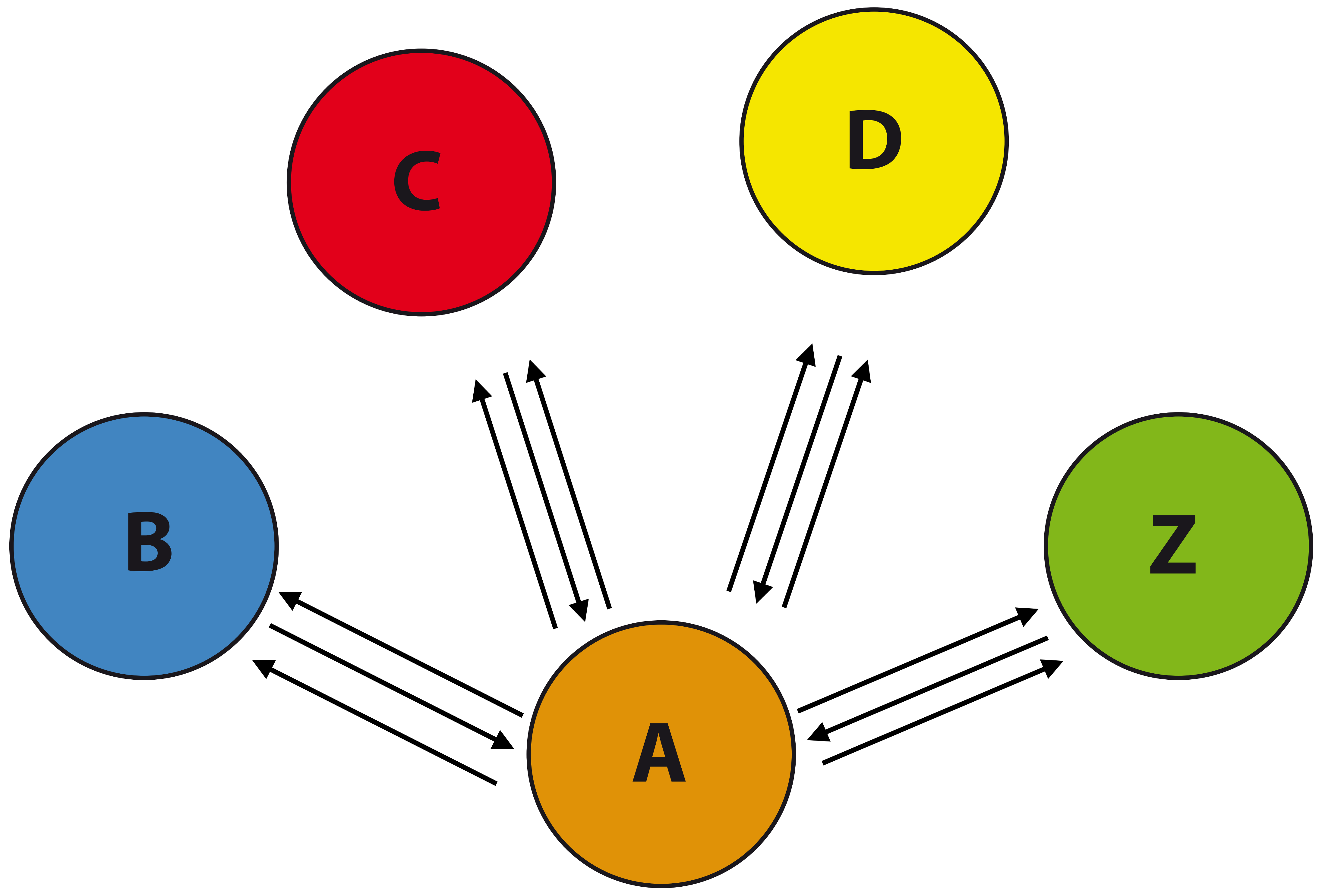

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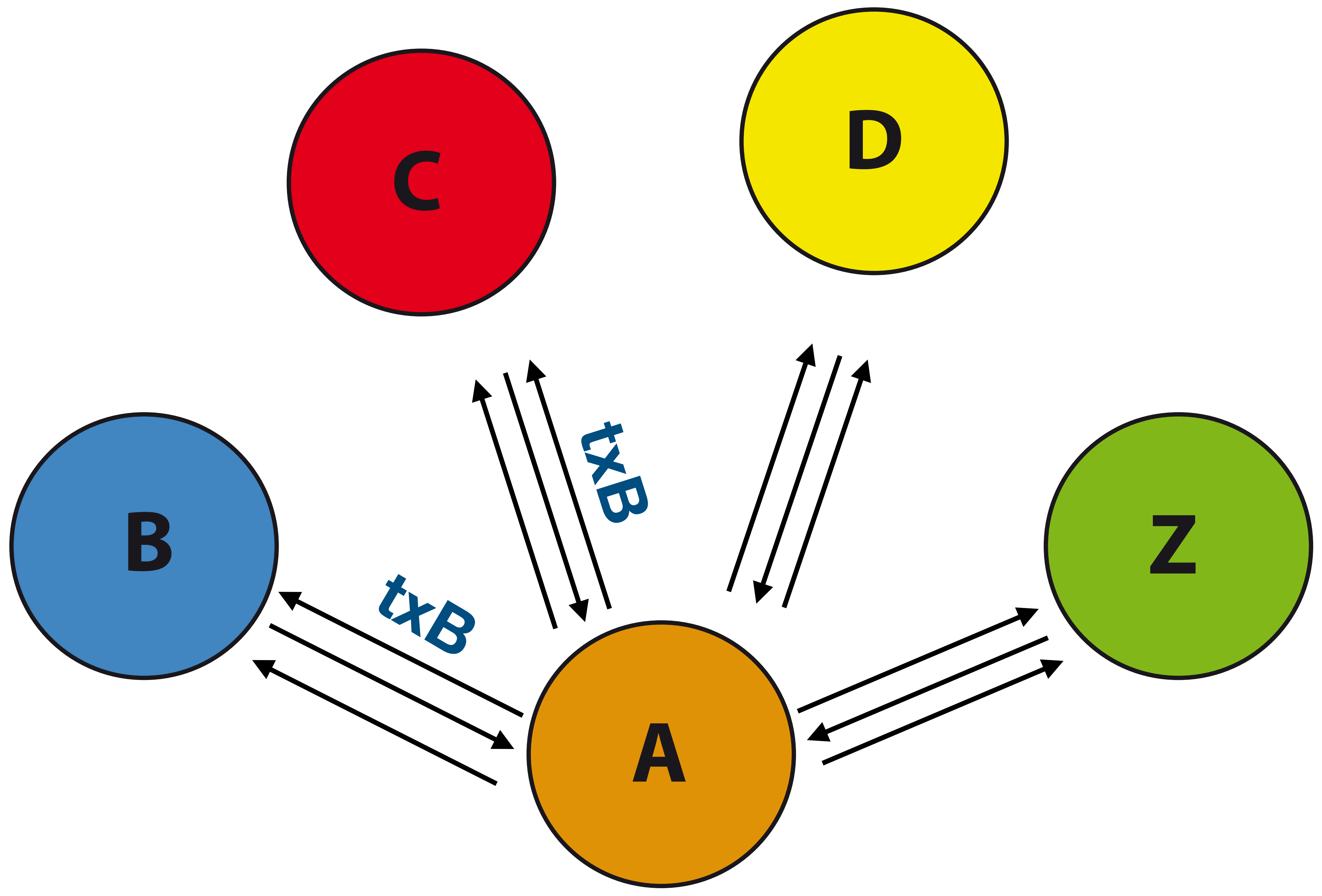

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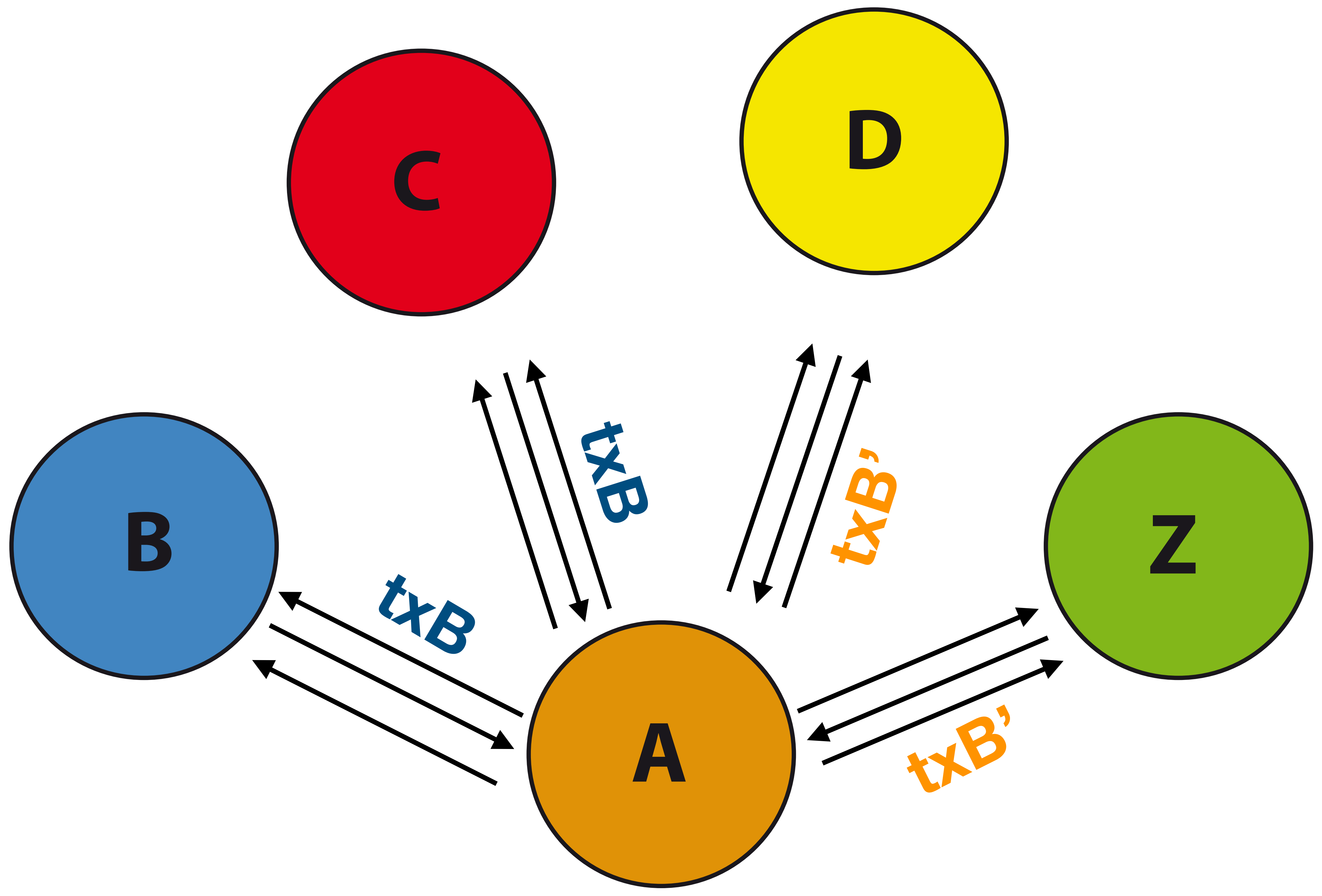

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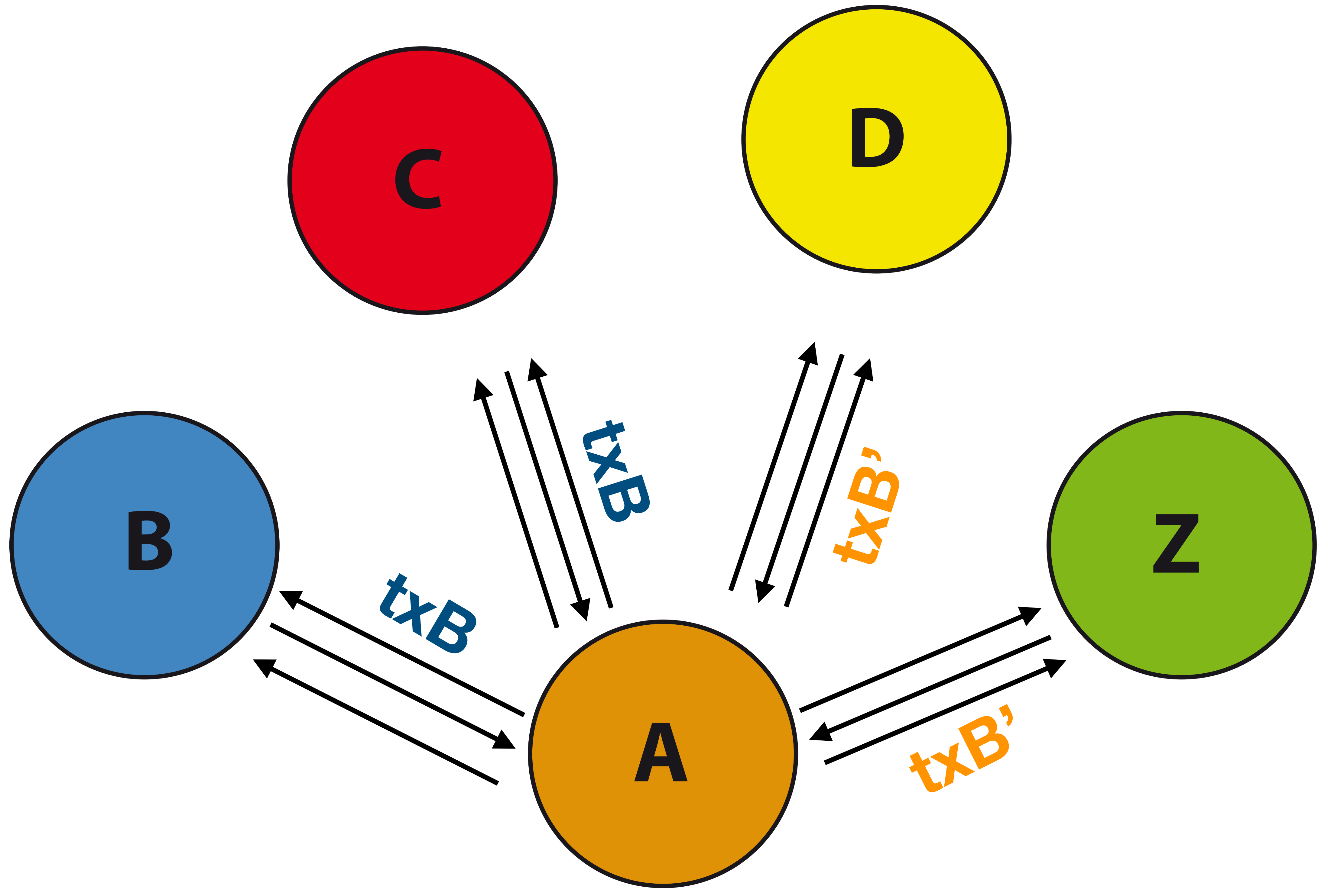

- **0-conf** transactions should not be trusted

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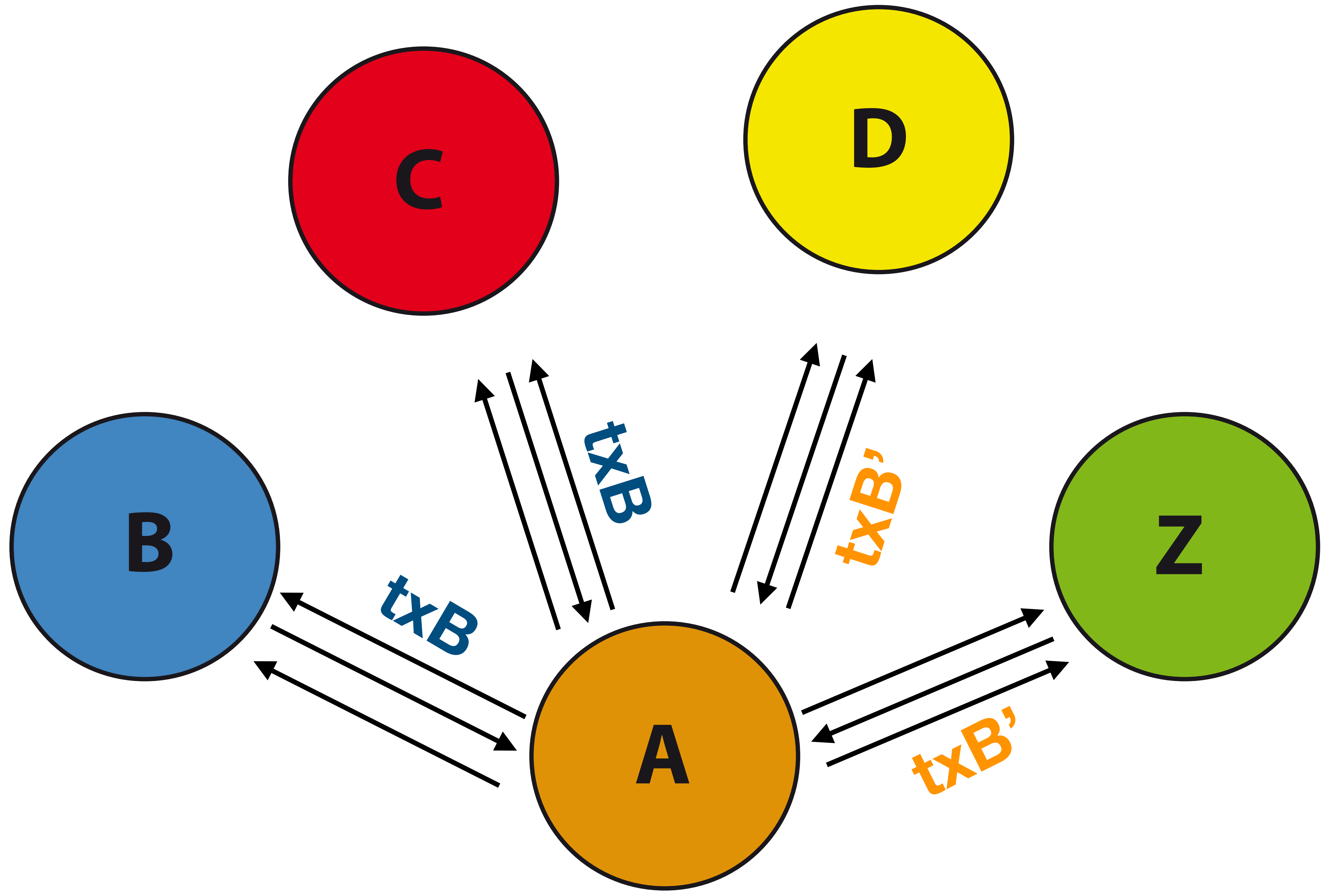
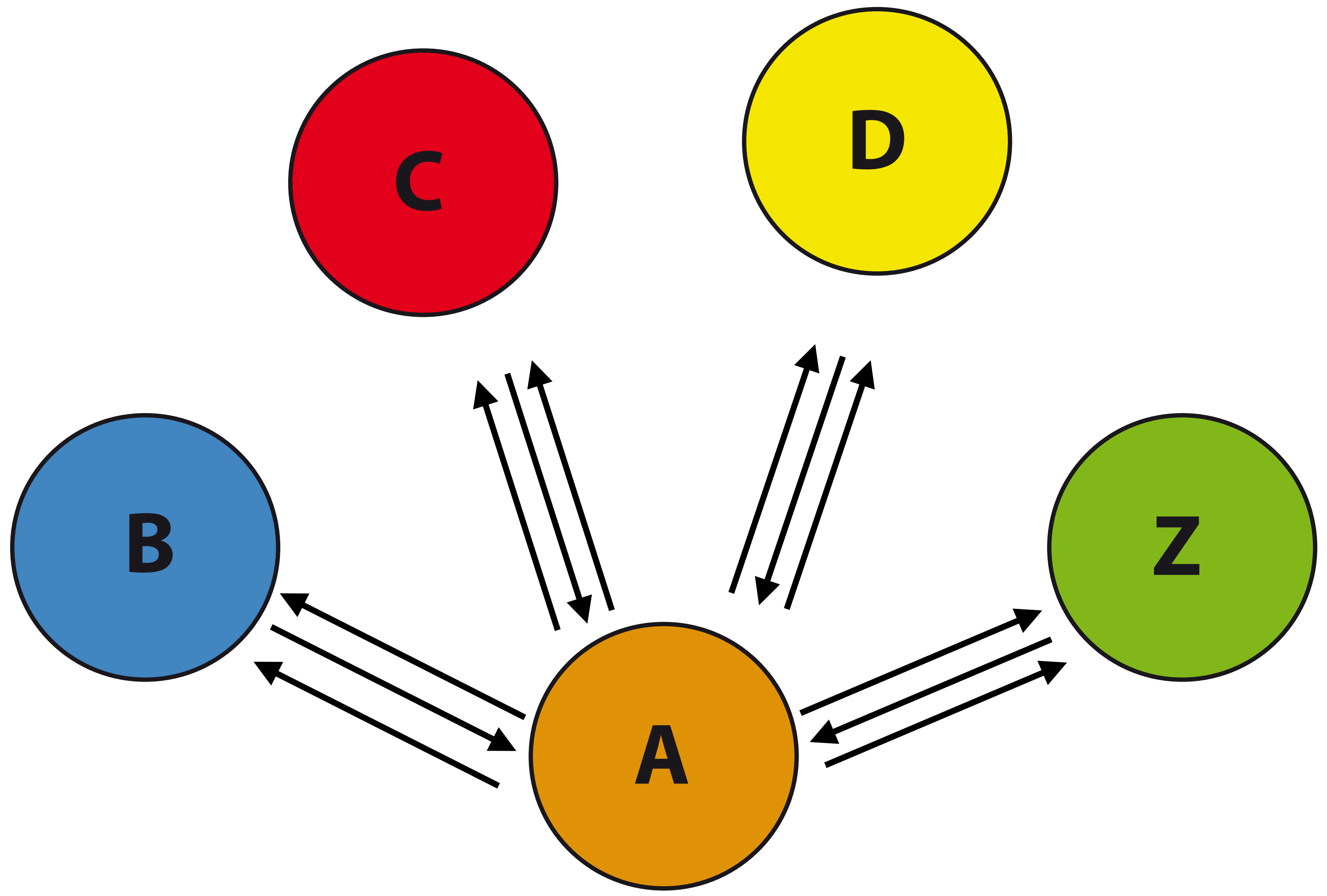


- **0-conf** transactions should not be trusted
- If B accepts txB before it appears in a block he **can be deceived** by A

WHEN THINGS GO SOUTH



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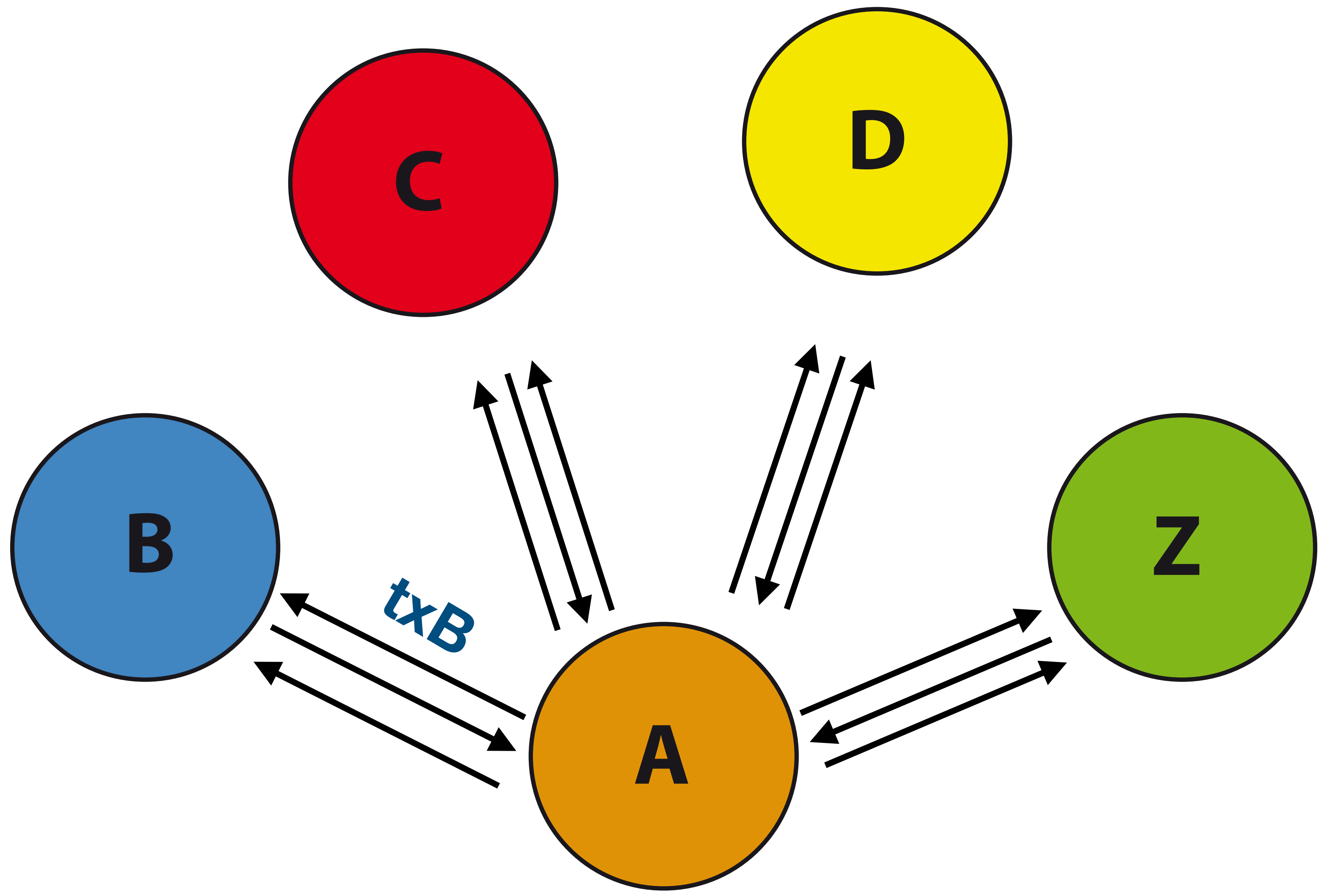

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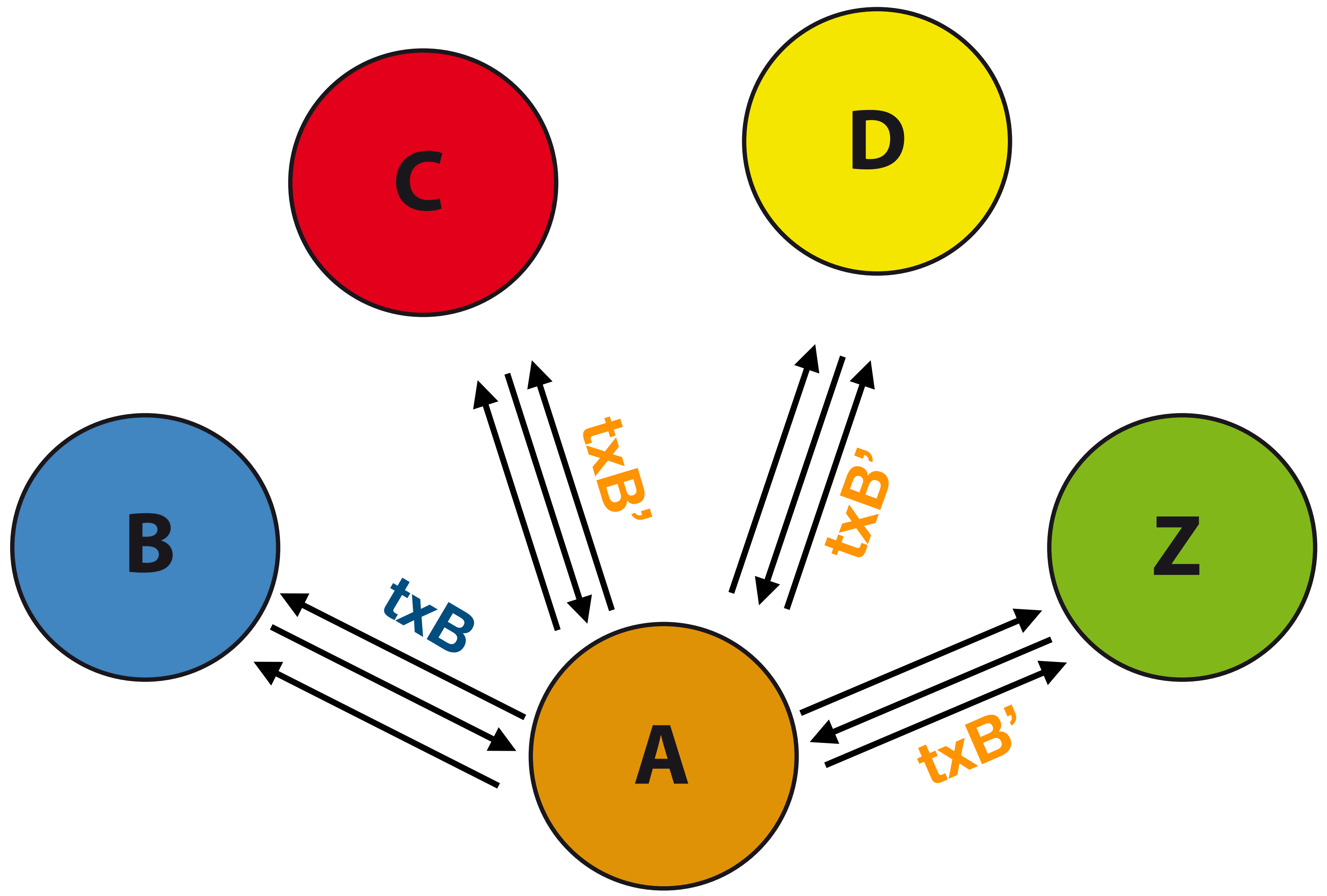

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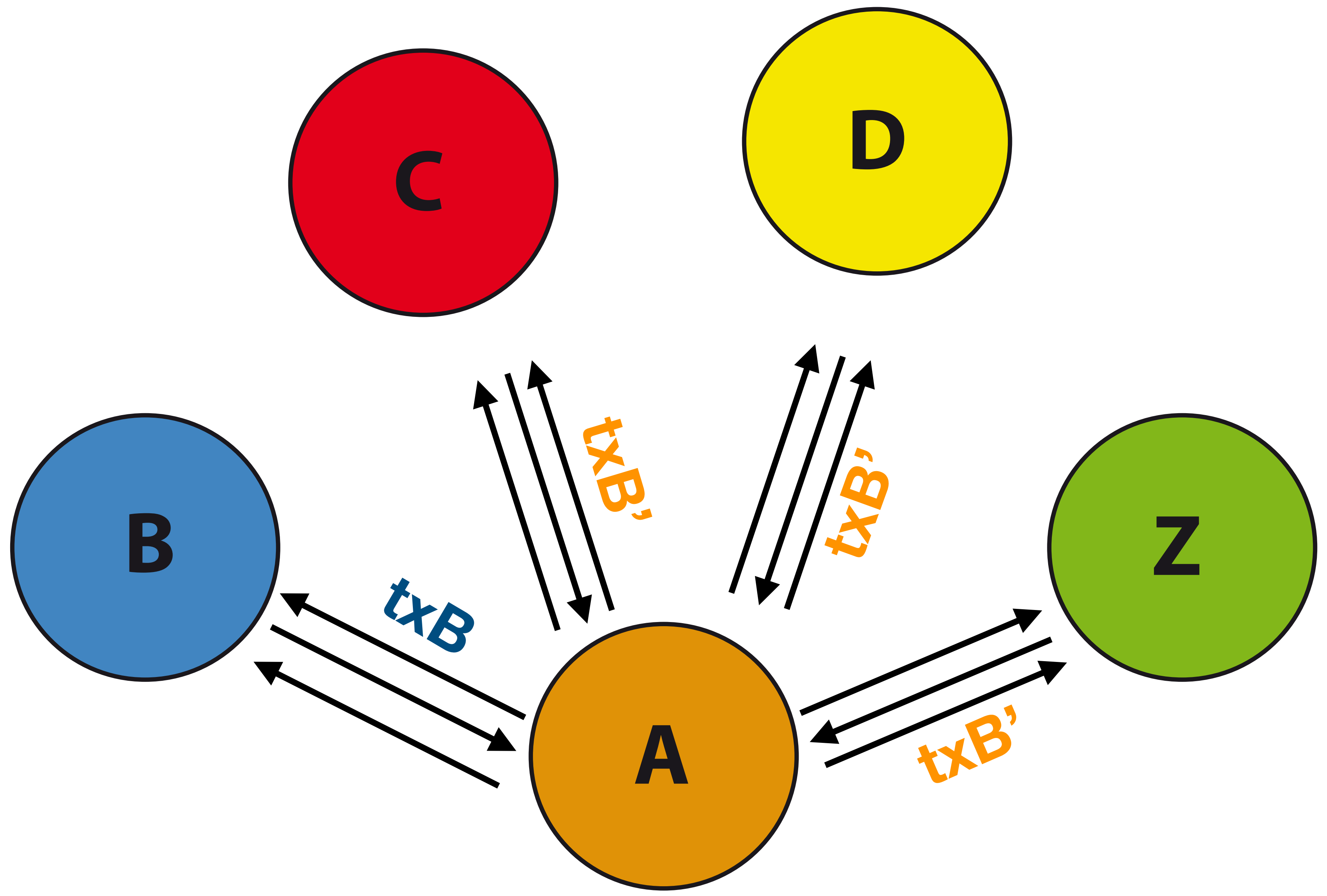

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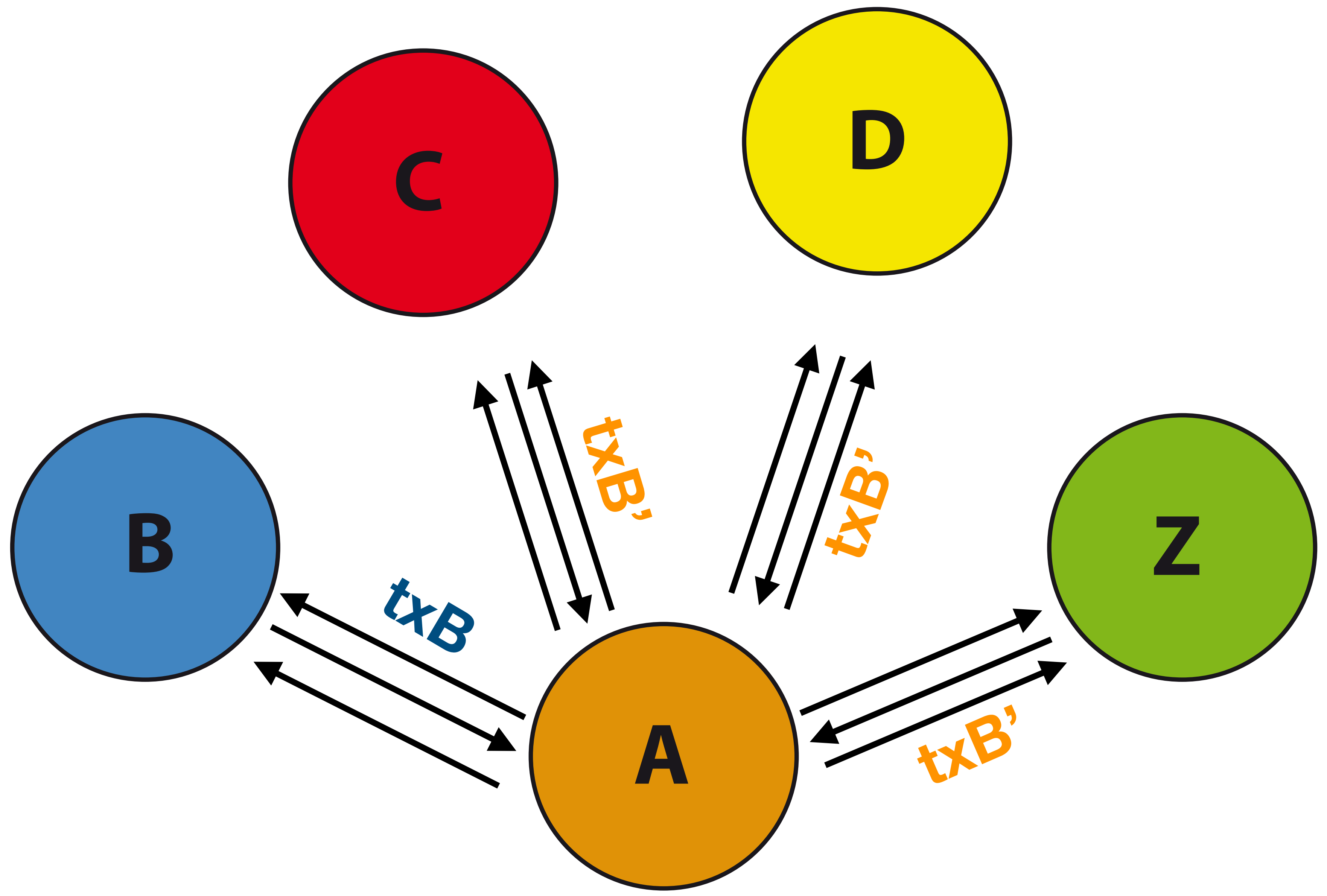

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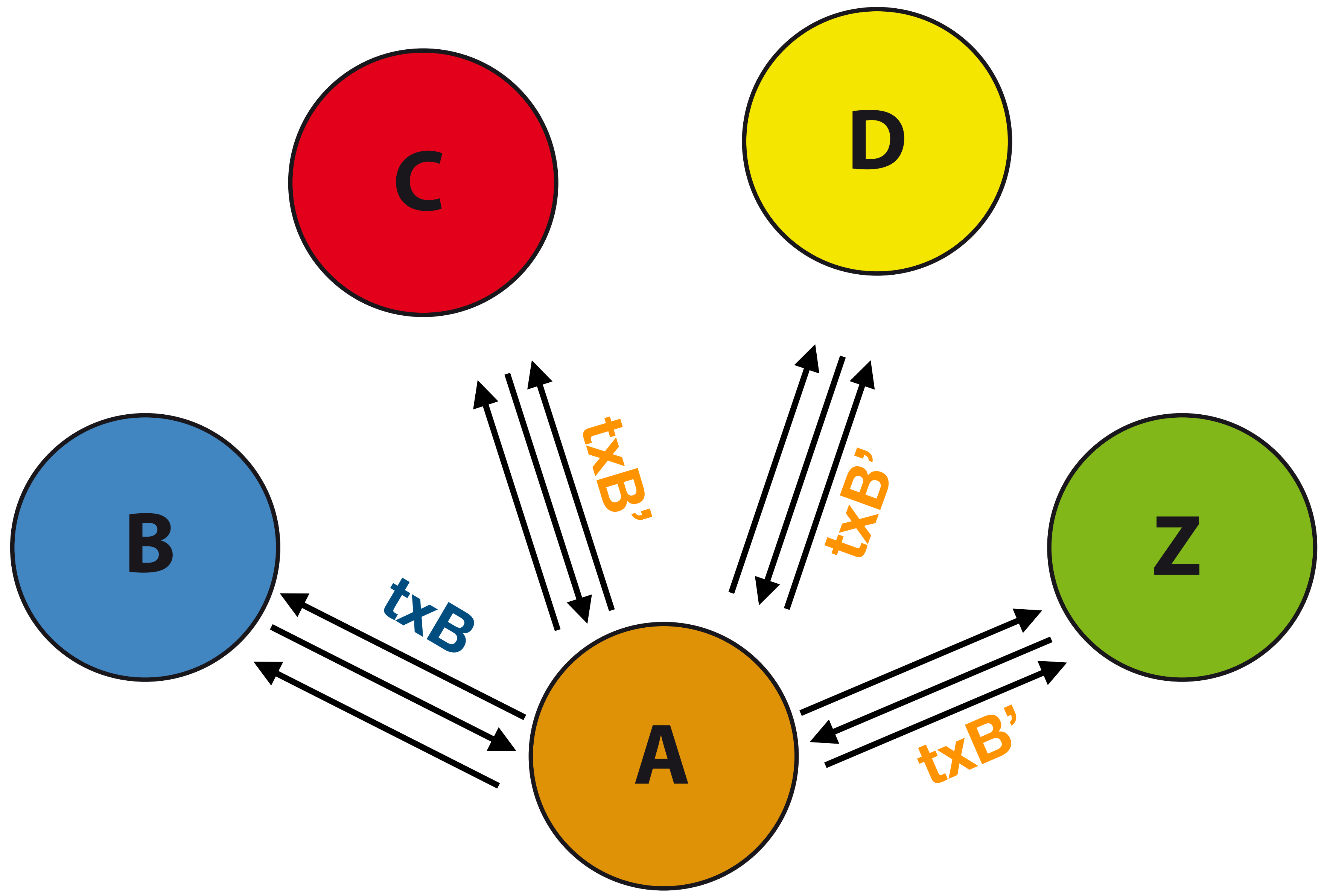

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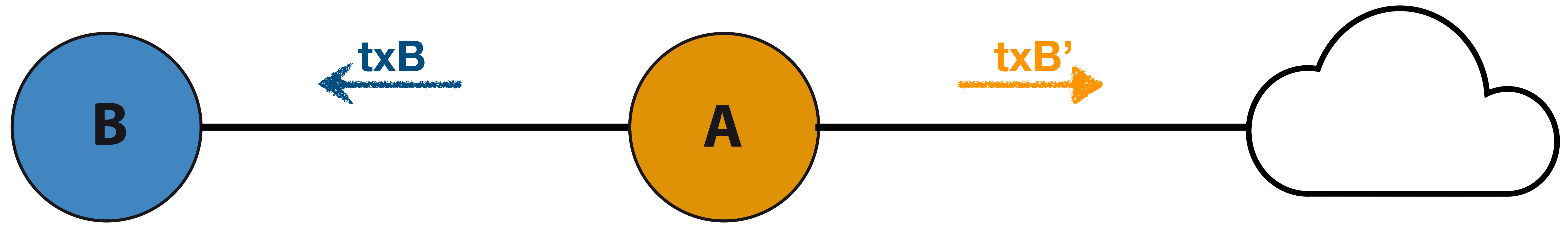
Ethan Heilman, Alison Kendler, Aviv Zohar and Sharon Goldberg
Eclipse Attacks on Bitcoin's Peer-to-Peer Network
https://www.usenix.org/node/190891

ECLIPSE ATTACKS (1/2)



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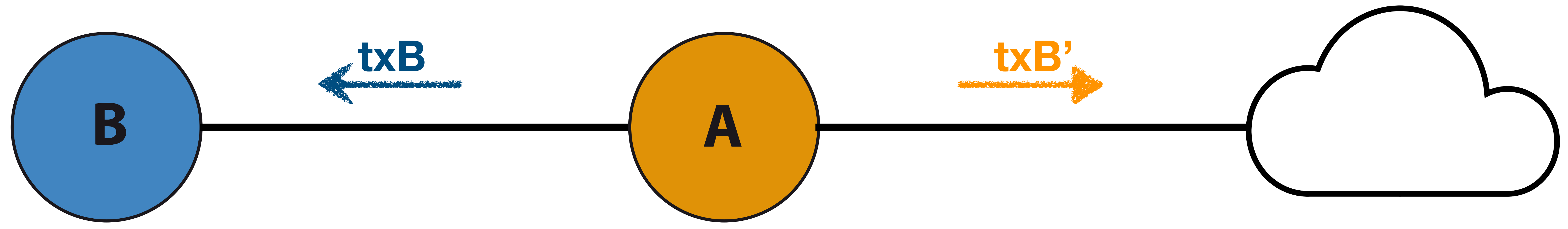

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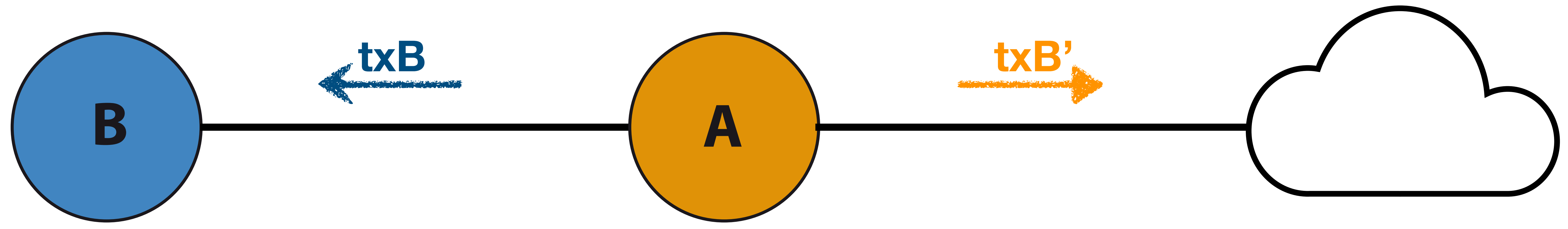

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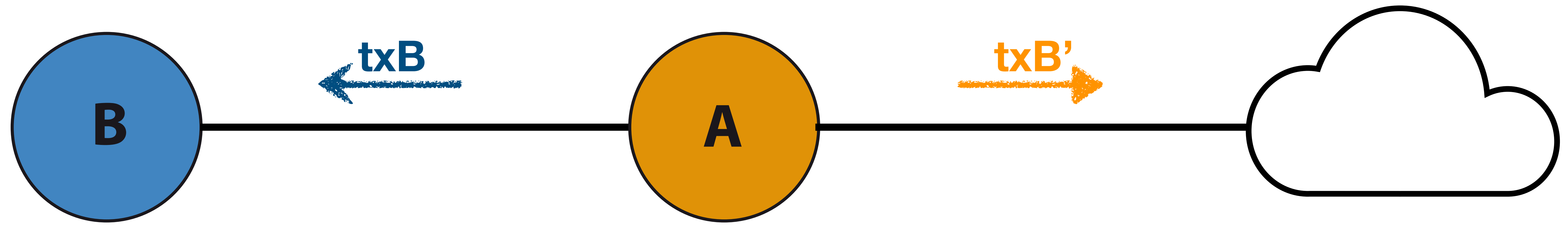
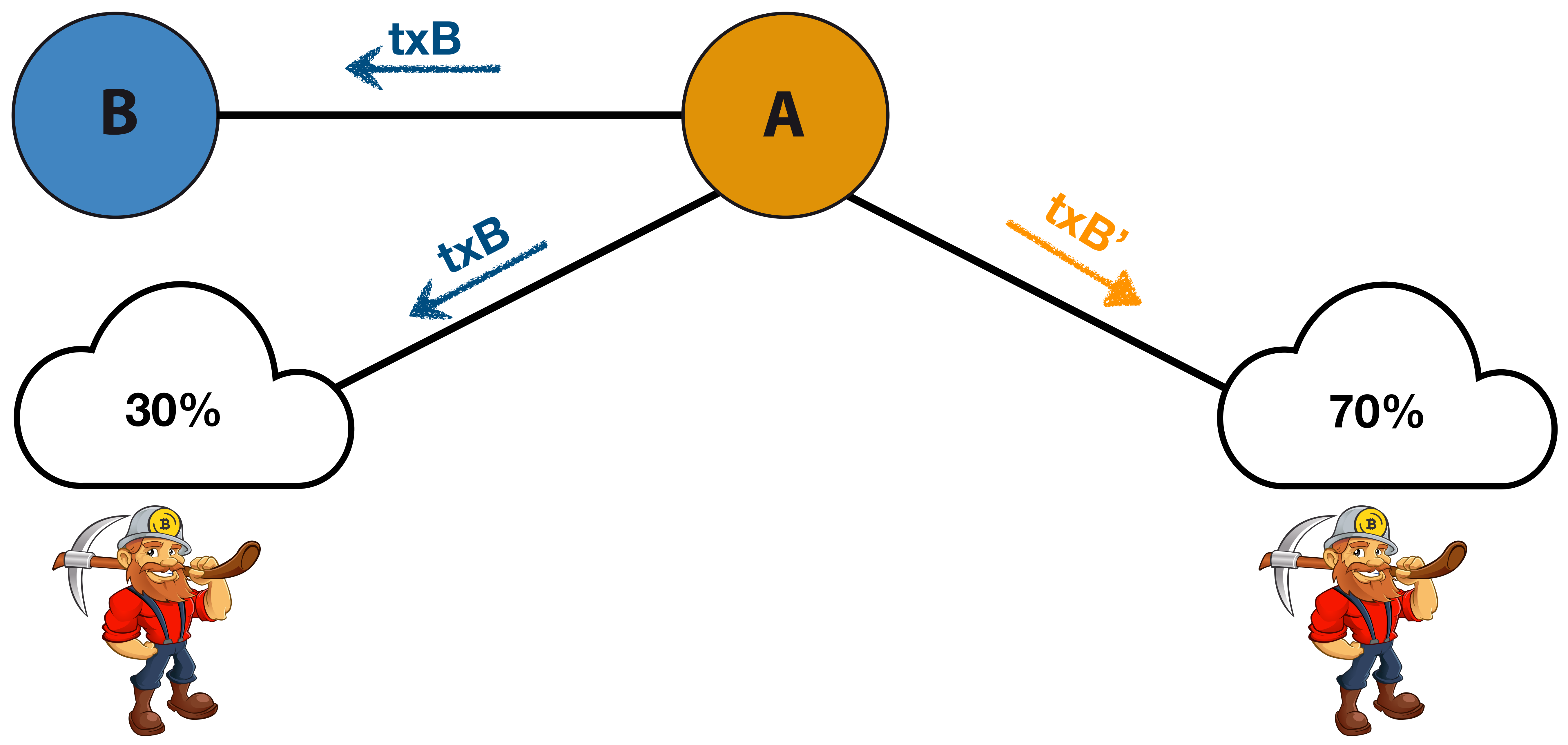


B will be deceived provided:

- B accepts 0-conf transactions
- A has enough hash power to generate blocks in a reasonable time

ECLIPSE ATTACKS (2/2)



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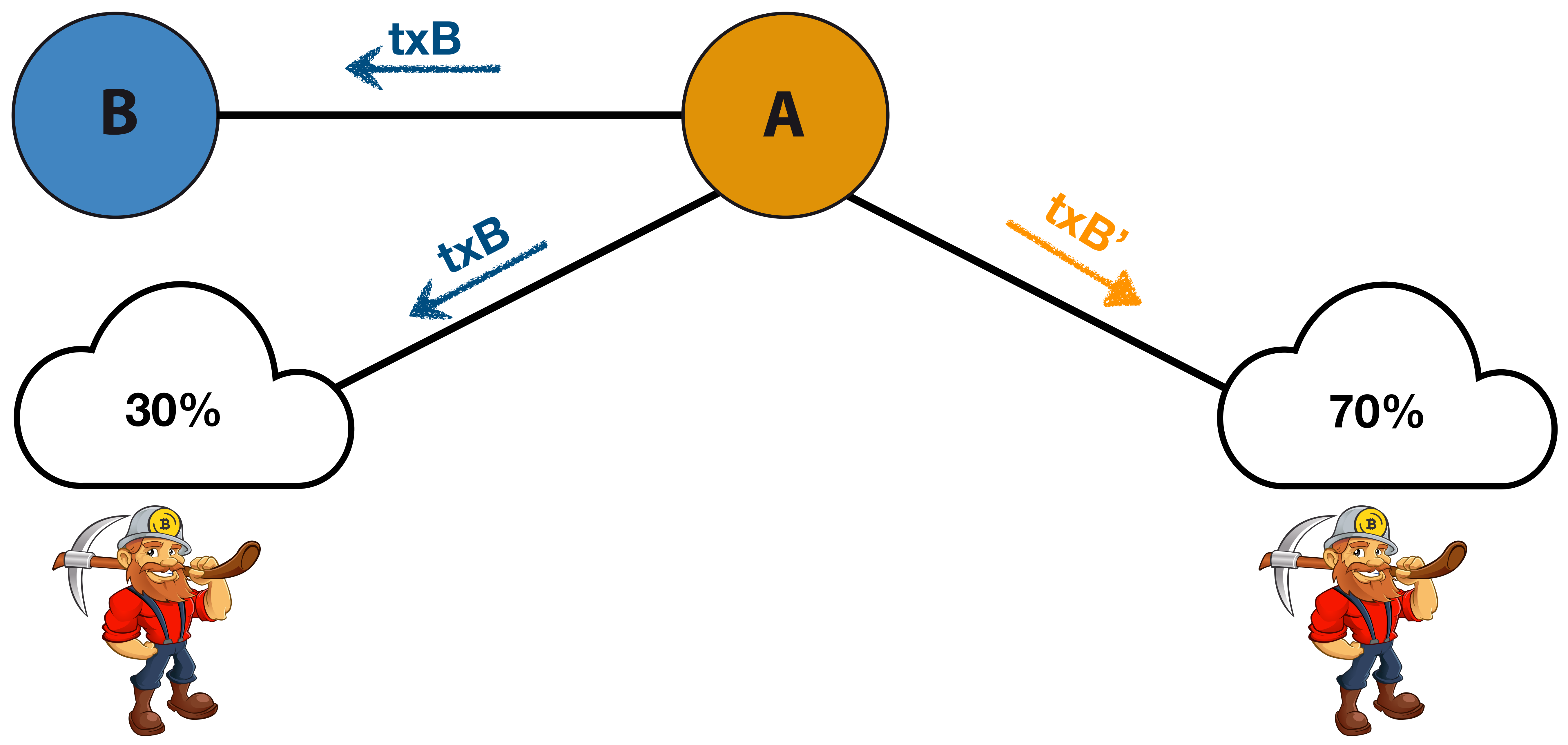

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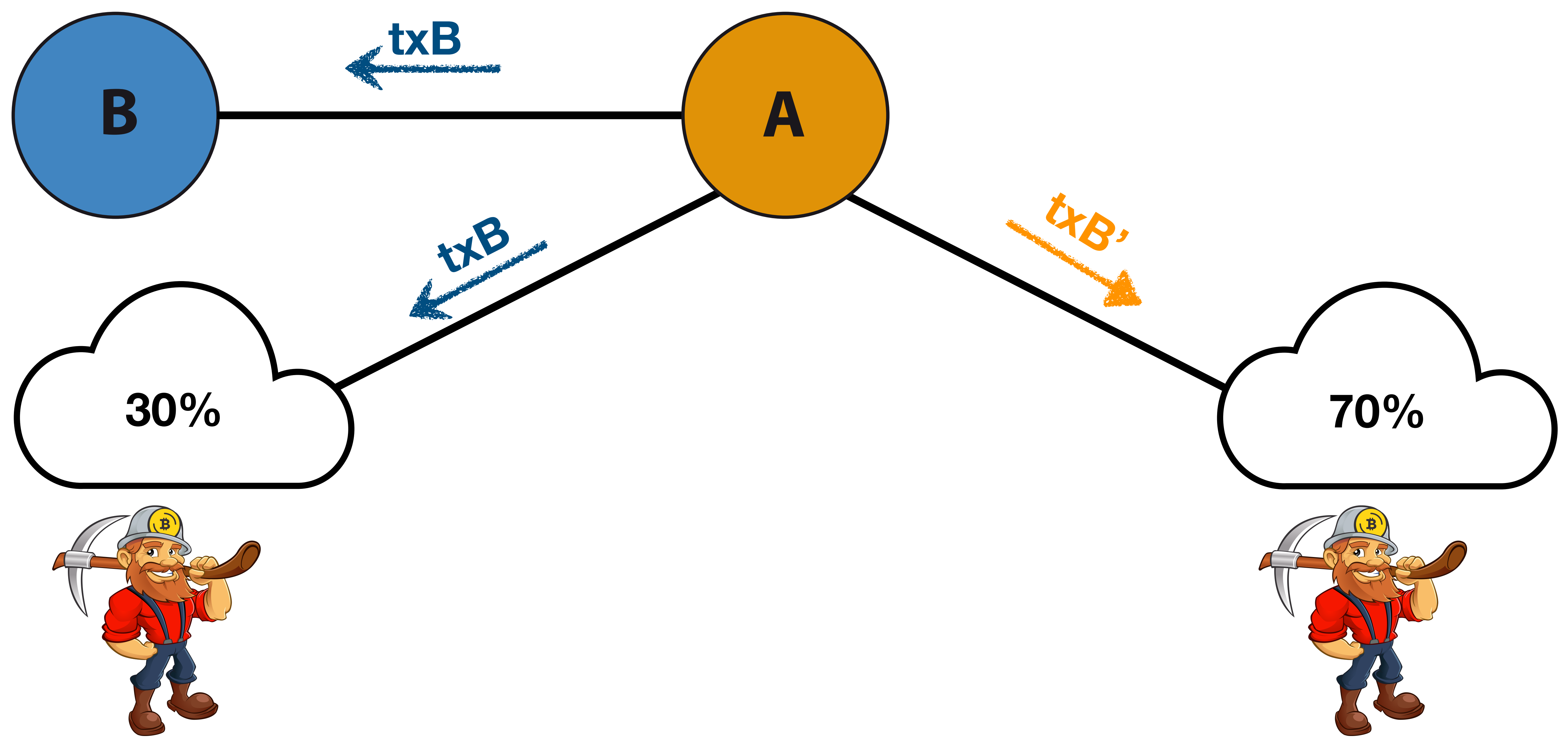

- A does not even need to hold any mining power
- With the right information it can participate the network in the most beneficial way for her

Network topology

UNKNOWN TOPOLOGY BY DESIGN

Peers are chosen pseudorandomly from the peer database of a node in order to become neighbors

Peers can be requested from other peers, but no information about whether the responder is (or has been) a neighbor of any of the provided peers is given

The network topology should mimic a random network

INFERRING THE TOPOLOGY

Does the network really look random?

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How can we known if we don’t know what the topology looks like?

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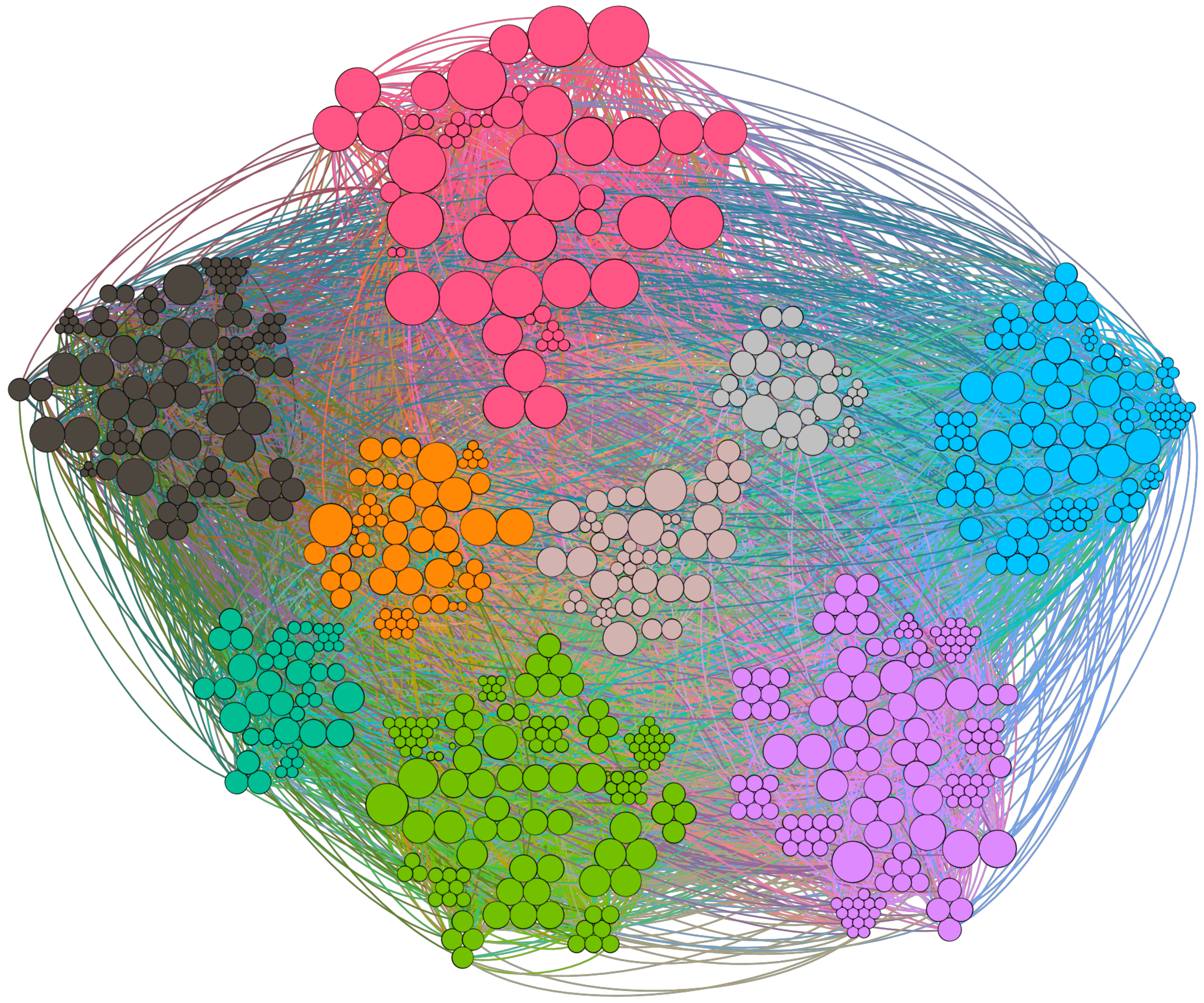
TESTNET TOPOLOGY



- Several communities can be easily identified
- The network looks far from a random graph of similar characteristics
- The topology can be used to identify undesired centralization
- But also to target some potential victims (e.g: Eclipse attacks)

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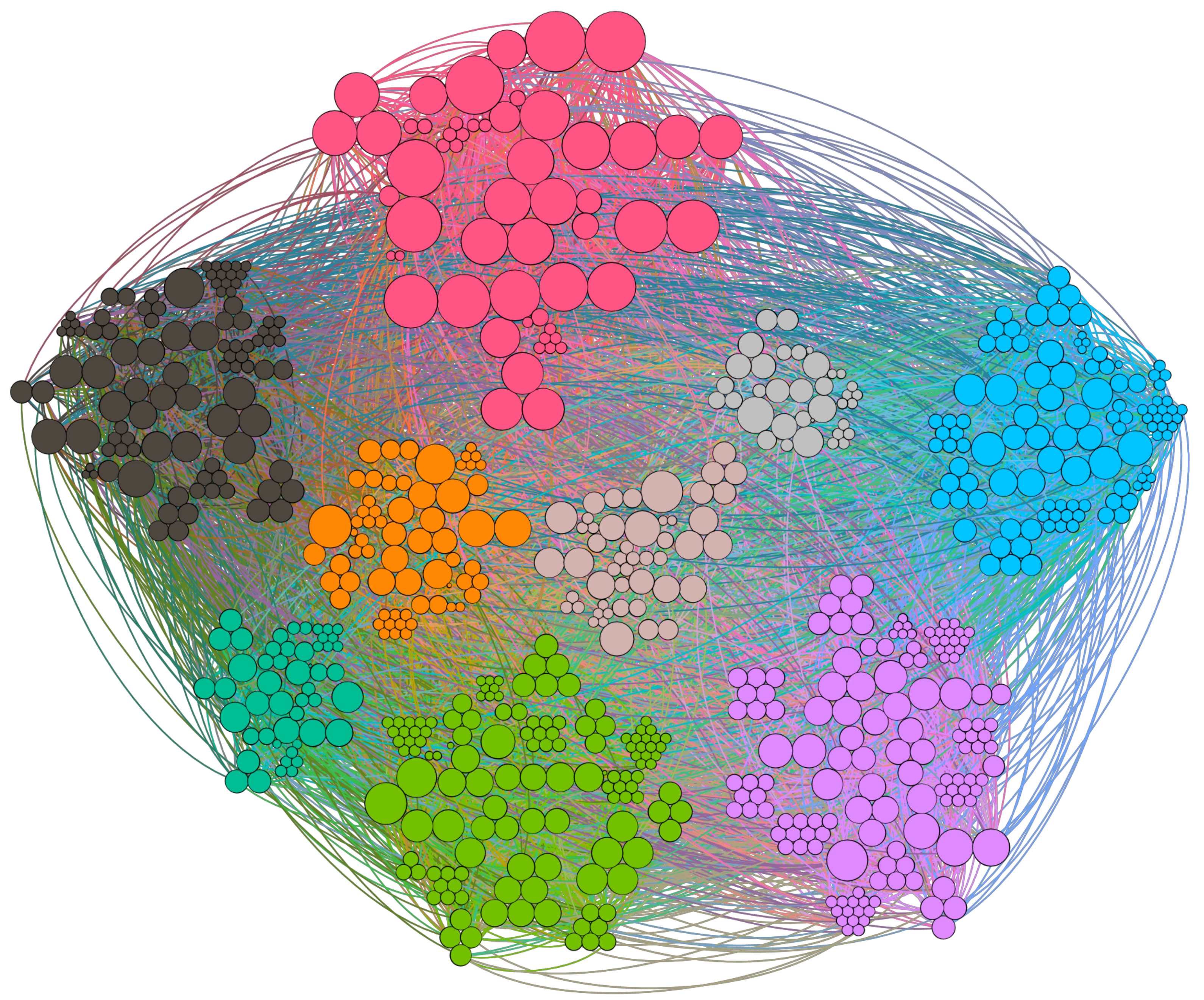

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TxProbe: Discovering Bitcoin's Network Topology Using Orphan Transactions
https://fc19.ifca.ai/preproceedings/58-preproceedings.pdf