Modern Blockchains through the Lens of System Security

Alberto Sonnino

Byzantine Fault Tolerance

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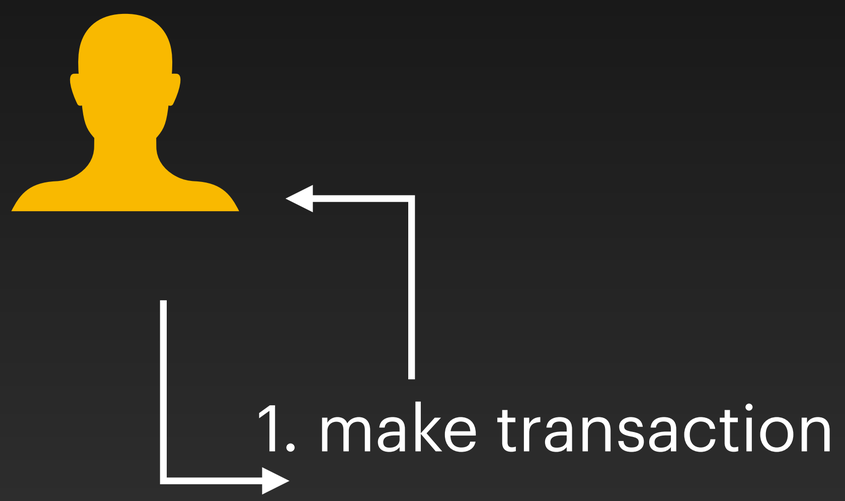
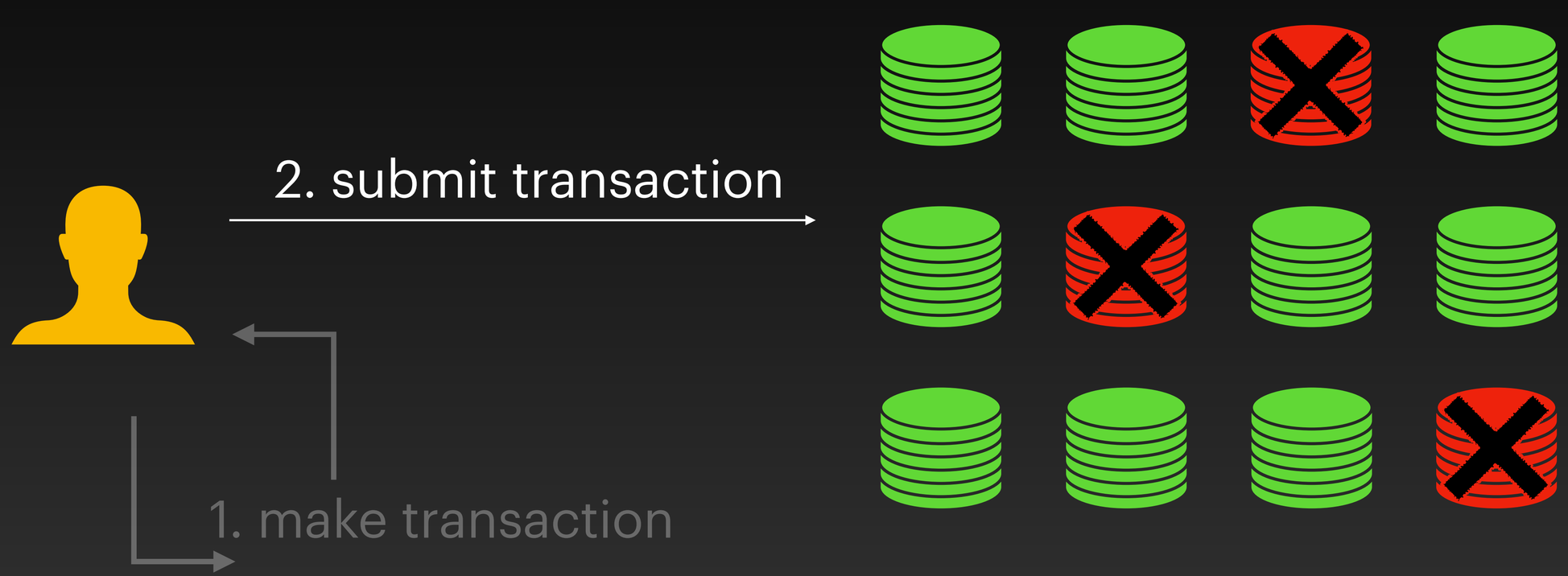
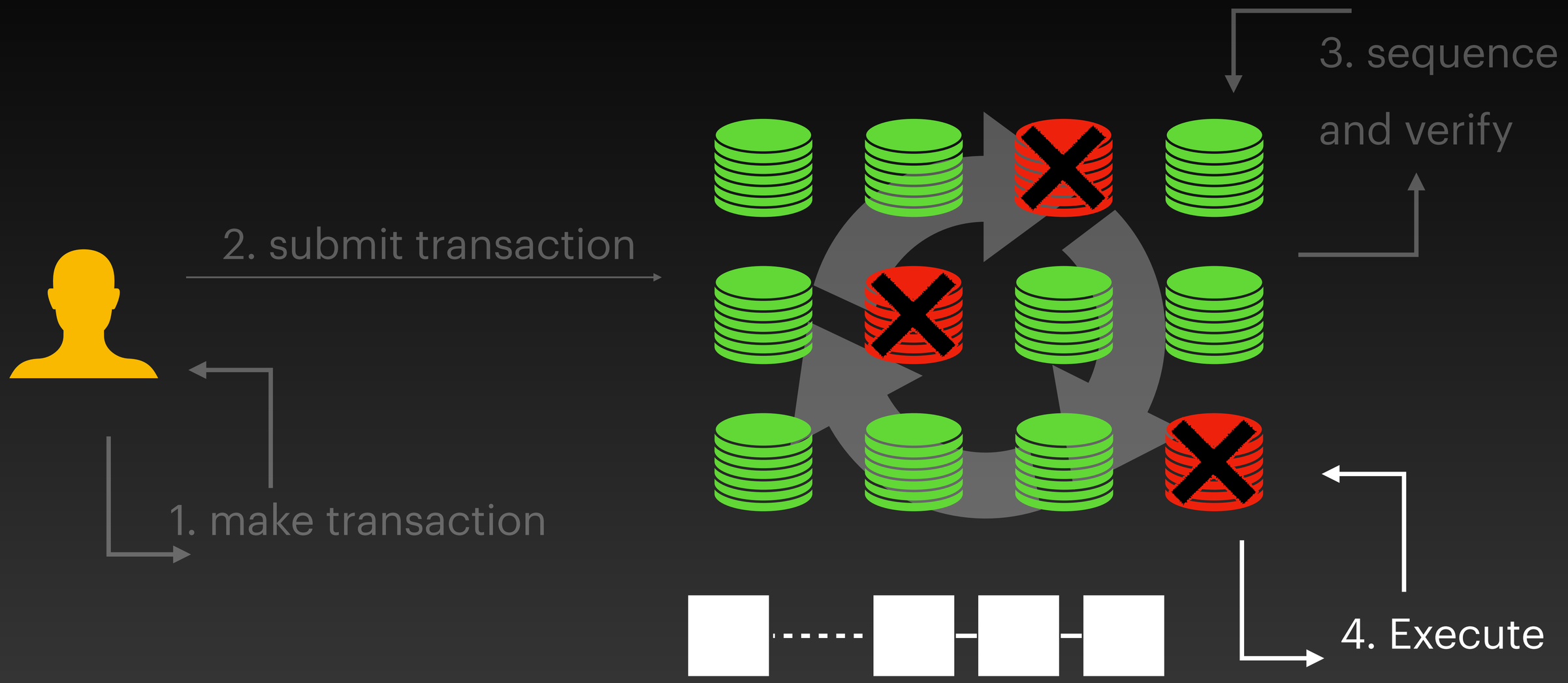

1. make transaction


2. submit transaction
1. make transaction


3. sequence
and verify
2. submit transaction
1. make transaction


3. sequence
and verify
2. submit transaction
1. make transaction
4. Execute
and store

- **Systems Security**
  - Both network and systems security
  - Interaction between networked components
- **Programming Languages**
  - Execute the smart contract & ensure determinism
  - Solidity, Move
- **Cryptography**
  - Validators cannot use secrets to execute smart contracts
  - Anonymous credentials, ZK-proofs
- **DeFi**
  - Funny dynamics different from traditional finance
  - Open to anyone with a computer

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  - **Open to anyone with a computer**

Security Properties

Safety

Undesirable things never happen

Liveness

Desirable things eventually happen

Adversary

#1 The Network: Worst possible schedule

Properties

- **Synchronous**: A message sent will be delivered before a maximum (known) delay.
- **Asynchronous**: A message sent will eventually be delivered at an arbitrary time before a maximum (unknown) delay.
- **Partial Synchronous**: the network is asynchronous but after some time it enters a period of synchrony.

Challenges

- Theoretical models: Need careful implementation to ensure we approximate them, e.g., retransmissions.
- Memory: Naive implementations use infinite buffers. Identify conditions after which retransmissions are not necessary and buffers can be freed.
- Asynchrony means the protocol should maintain properties for any re-ordering of message deliveries.
- Unknown delay means delay should be adaptive to ensure robustness.

Adversary

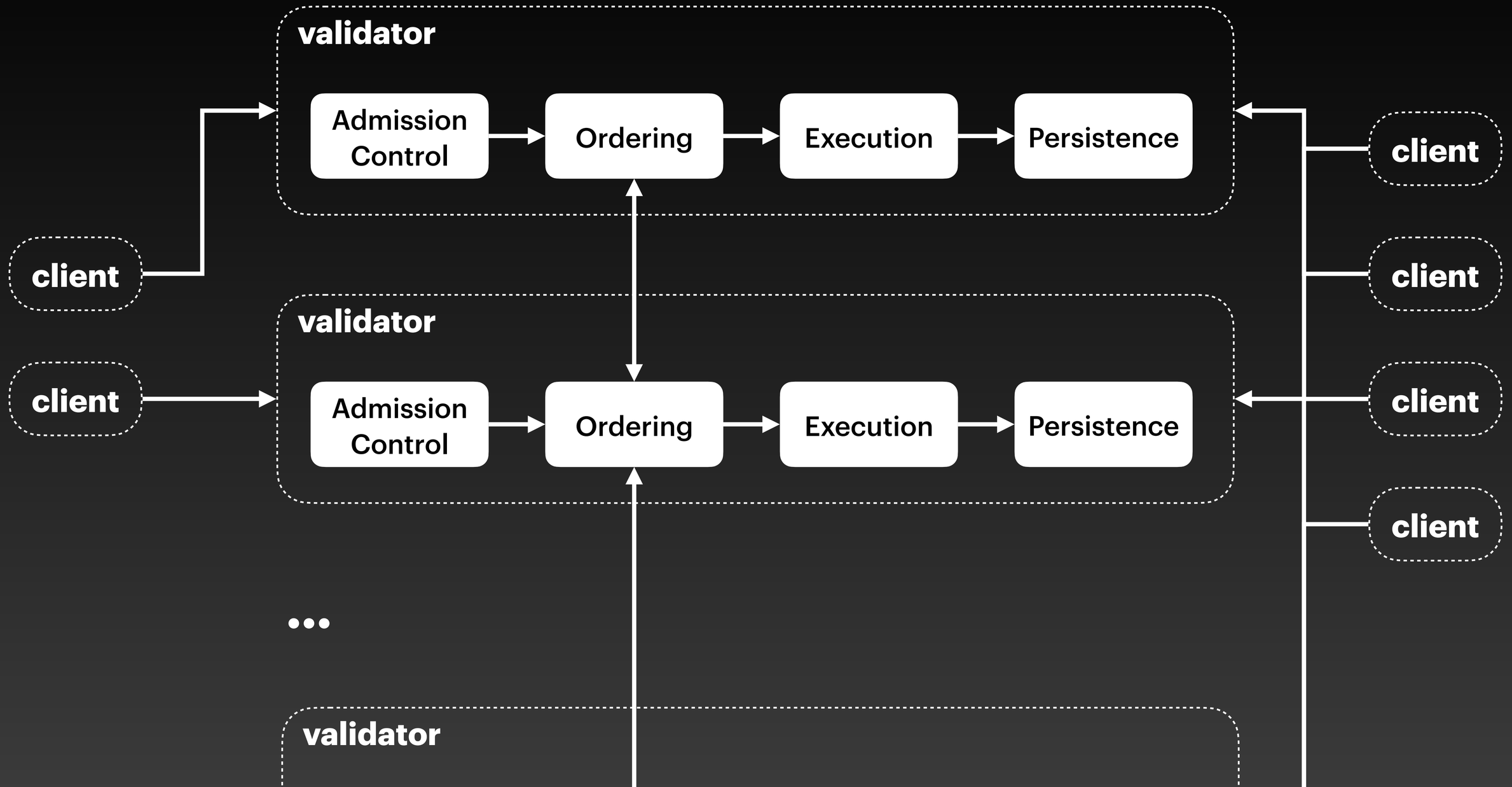
#2 Bad Nodes: Arbitrary behaviour

Properties

- **Correct / honest / good:** Will remain live and follow the protocol as specified by the designers of the system.
- **Byzantine:** will deviate arbitrarily from the protocol. May respond incorrectly or not at all.

Challenges

- **Crash & recover:** still a correct validators with very high latency. Need persistence to ensure this
- **Rational:** honest validators may have some discretion. They may use it to maximise profit


validator
Admission Control
Ordering
Execution
Persistence
client
client
validator
Admission Control
Ordering
Execution
Persistence
client
client
client
client
...
validator

Security

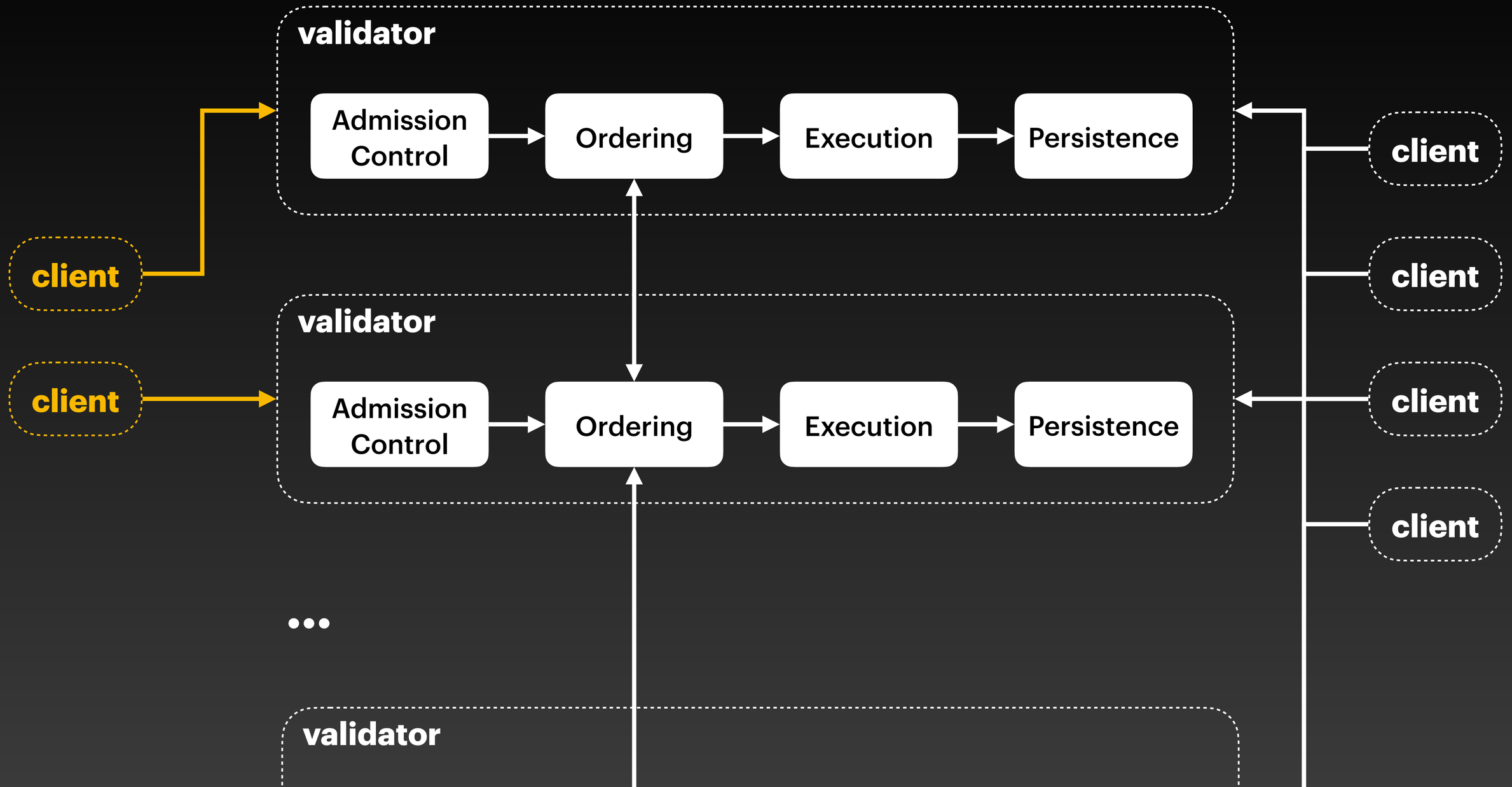
Challenge #1: Validators

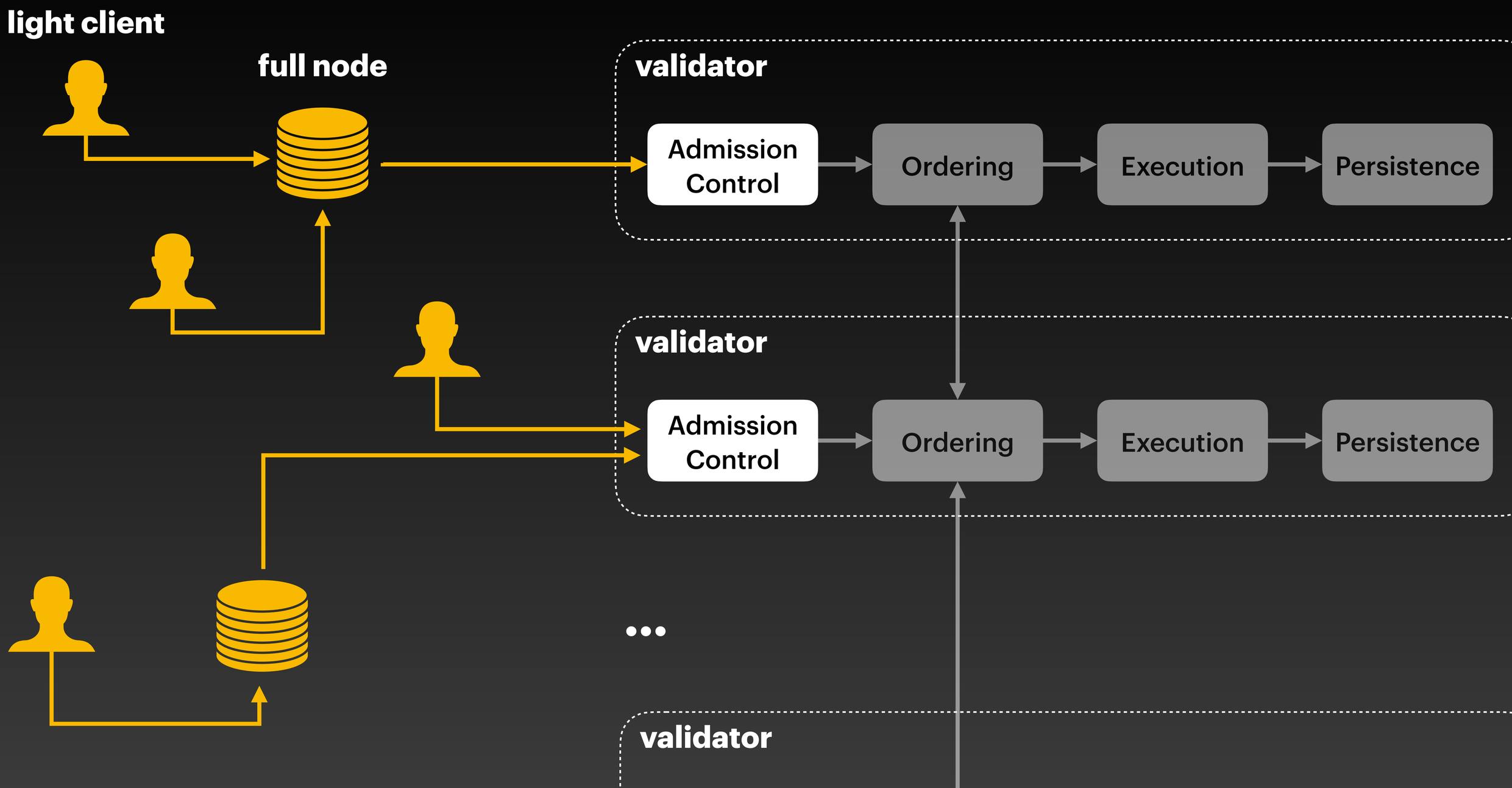
- **Validators are exposed (not in datacenter not on beefy machines)**

Security

Challenge #1: Nodes

- Validators are exposed (not in datacenter no on beefy machines)
- **Highly dynamic set of validators**


validator
Admission Control
Ordering
Execution
Persistence
client
client
validator
Admission Control
Ordering
Execution
Persistence
client
client
client
client
...
validator


light client
full node
validator
Admission Control
Ordering
Execution
Persistence
validator
Admission Control
Ordering
Execution
Persistence
validator

Security

Challenge #2: Clients

- **Different types of target links: clients-validator and validator-validator**

Security

Challenge #2: Clients

- Different types of target links: clients-validator and validator-validator
- **Highly dynamic clients, with different client software**

Security

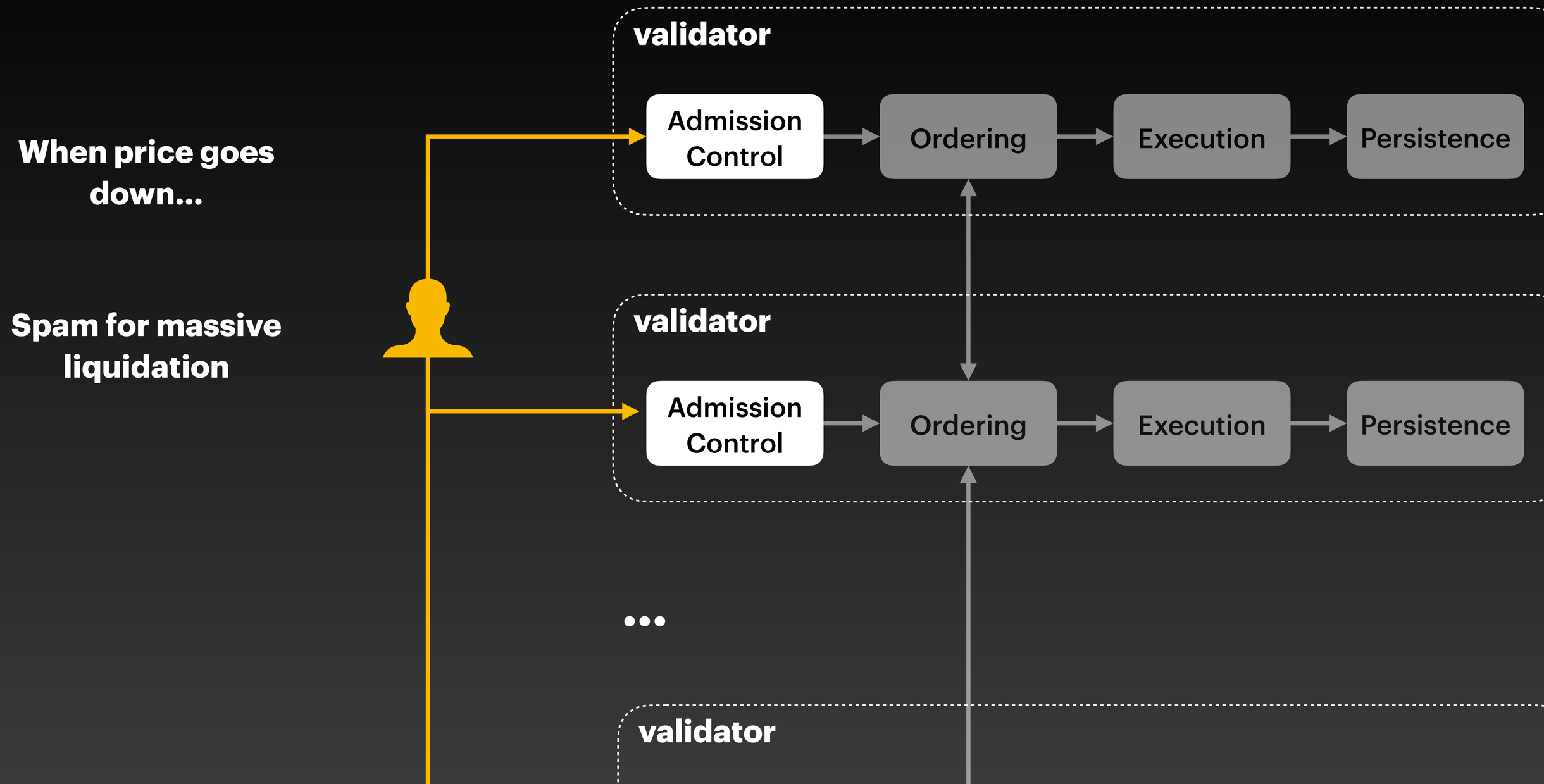
Challenge #2: Clients

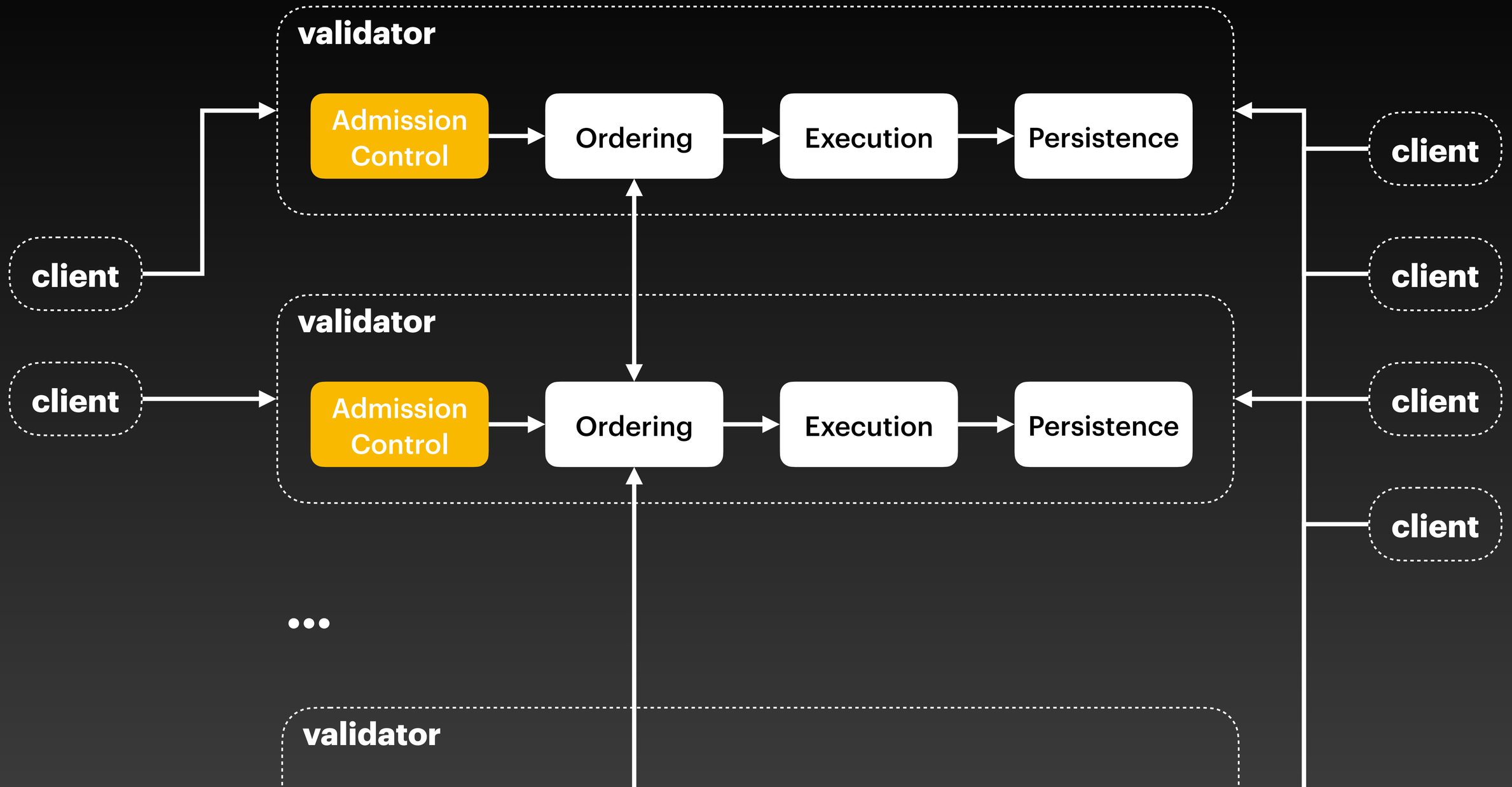
- Different types of target links: clients-validator and validator-validator
- Highly dynamic clients, with different client software
- **Clients have no fixed identity**

Security

Challenge #2: Clients

- Different types of target links: clients-validator and validator-validator
- Highly dynamic clients
- Clients have no fixed identity, with different client software
- **Unclear validator selection algorithm**


When price goes down...
Spam for massive liquidation
validator
Admission Control
Ordering
Execution
Persistence
validator
Admission Control
Ordering
Execution
Persistence
...
validator


validator
Admission Control
Ordering
Execution
Persistence
client
client
validator
Admission Control
Ordering
Execution
Persistence
client
client
client
client
...
validator

Objects:

- Unique ID
- Version number
- Ownership Information
- Type

Transaction's content

Coin::Send

Alice's account

Bob's account, Balance=5

0.001, max=0.005

Example Transaction

T1

Inputs: O1, O2, O3

Output: Mutate O1, Transfer O2, Delete O3, Create O4

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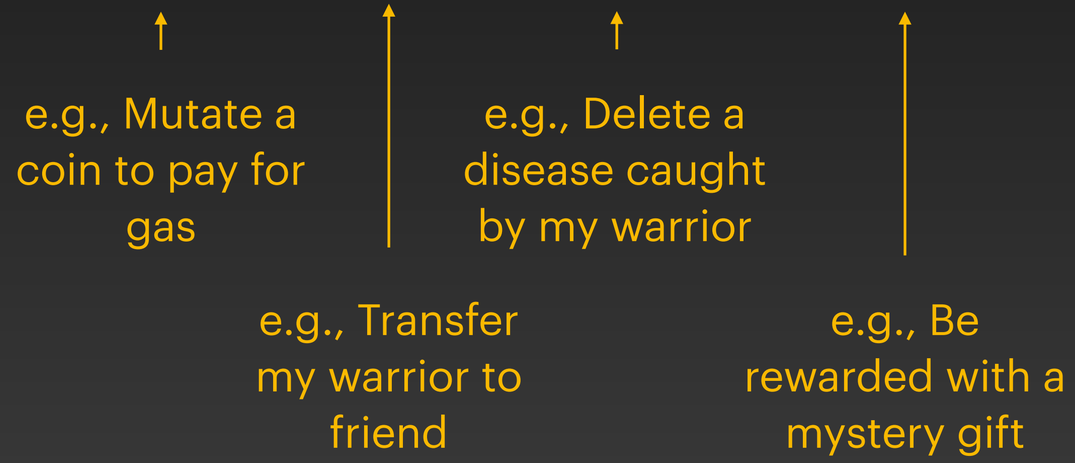
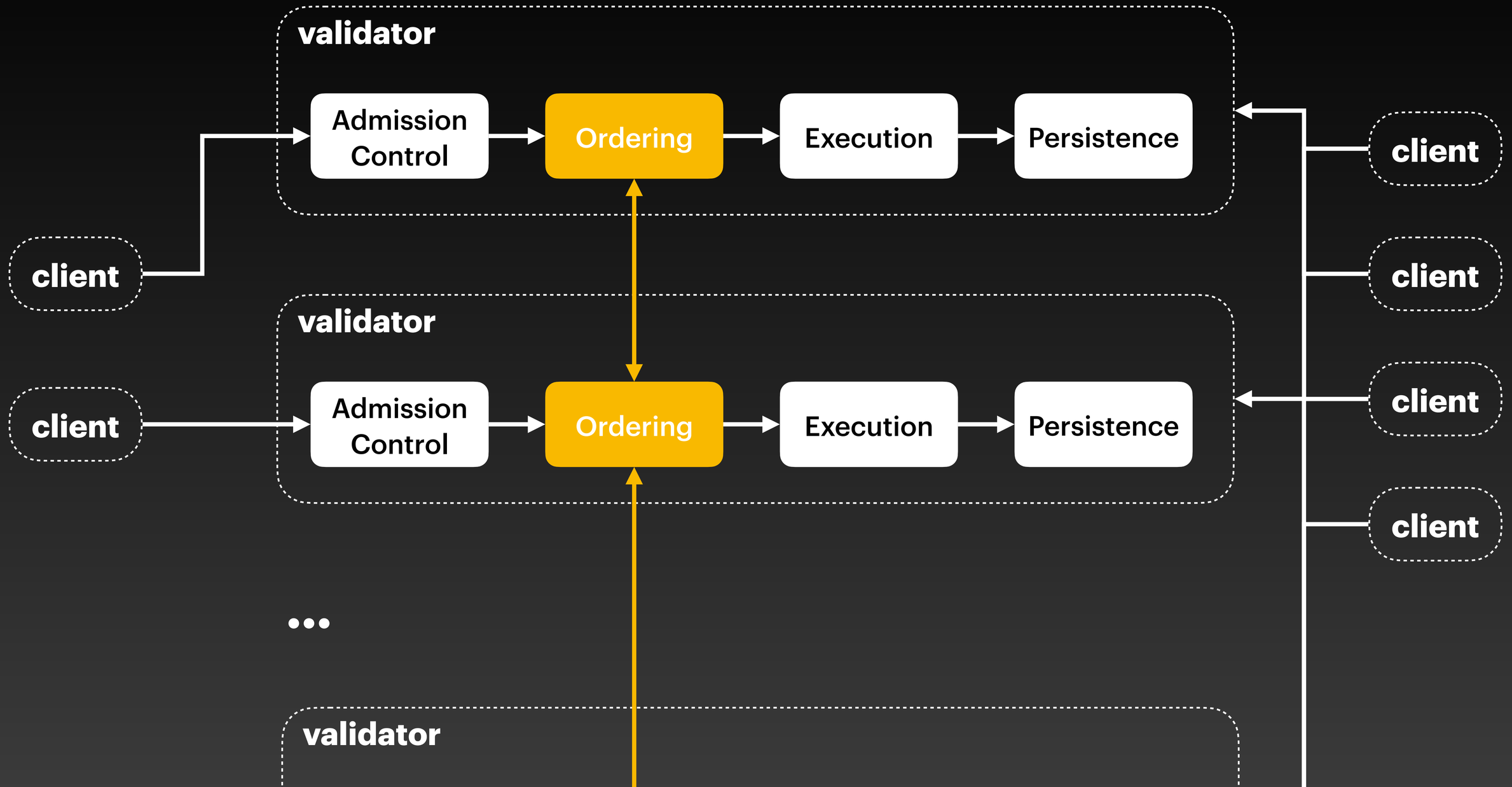
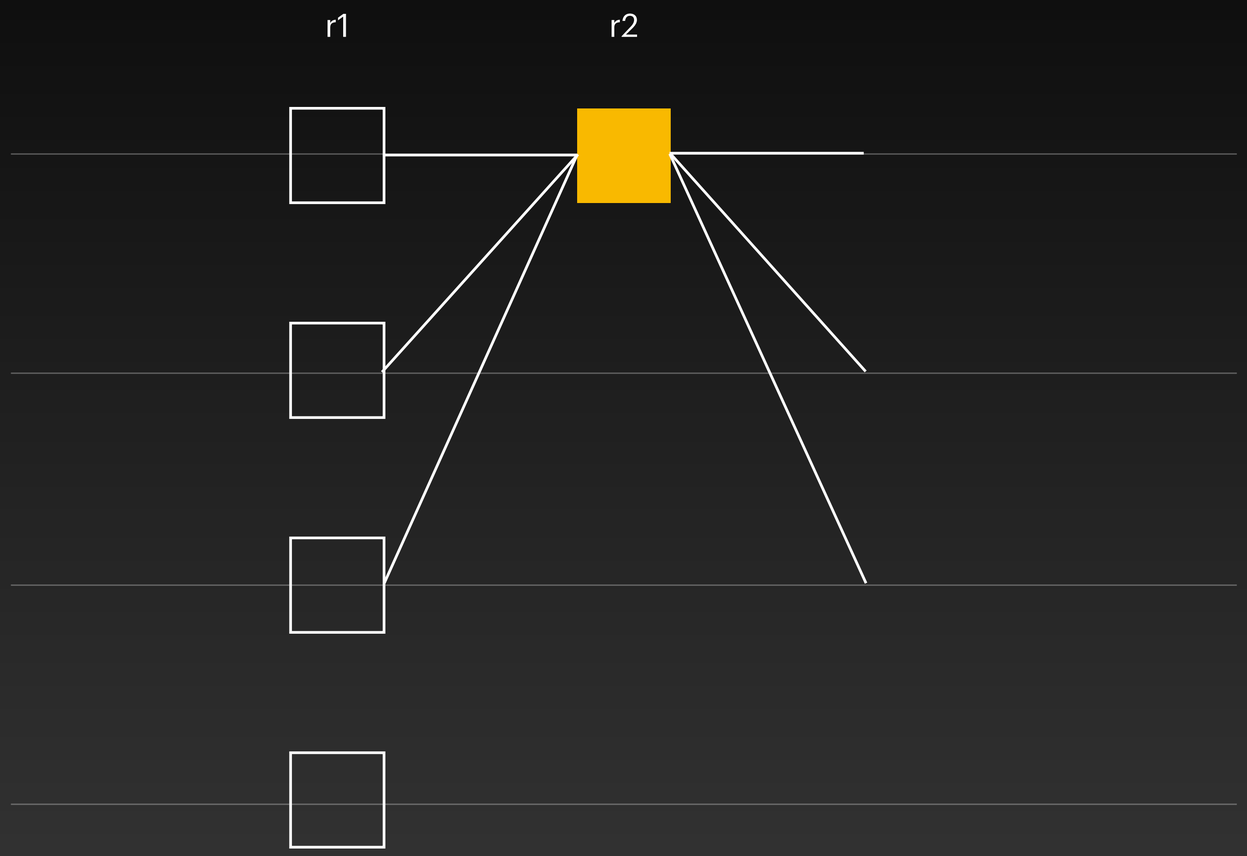


Network Security

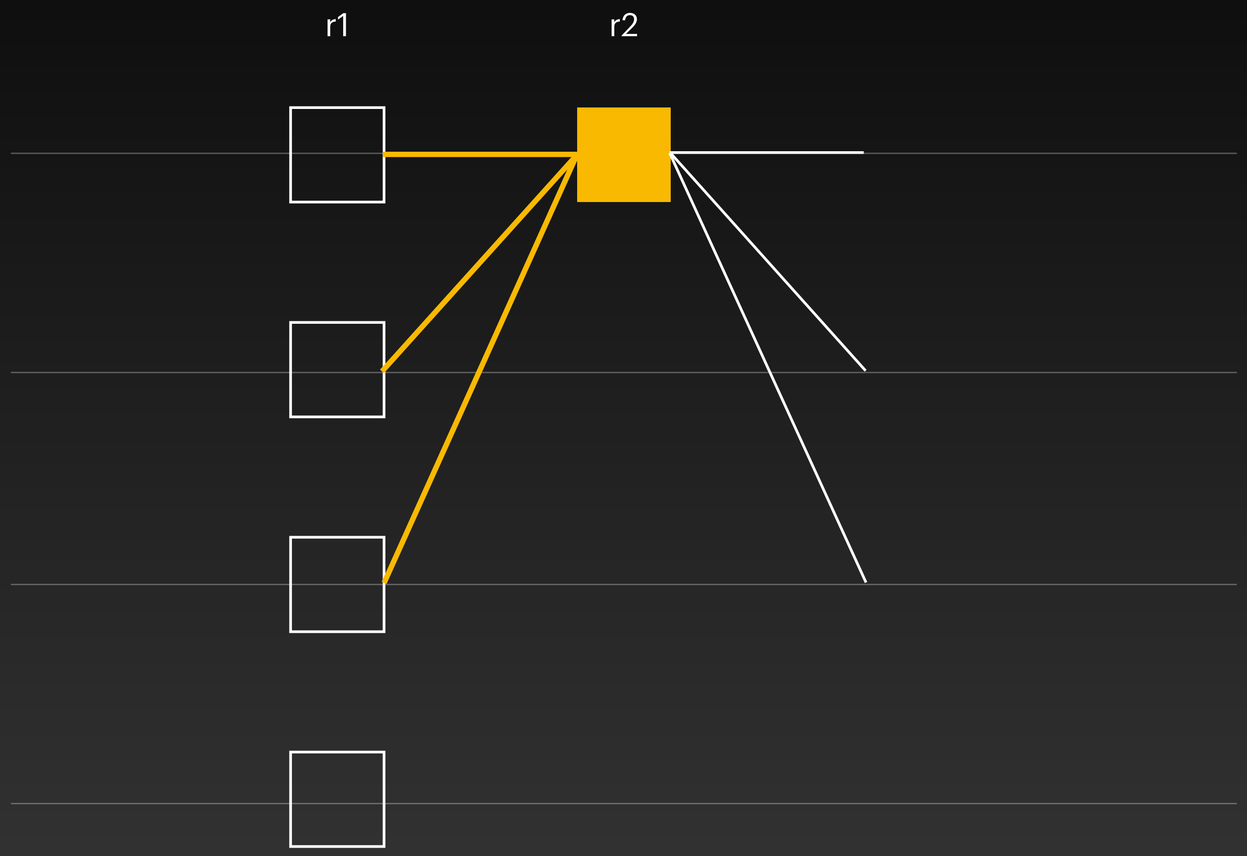
Challenge #3: Admission Control

- **No established way to run pre-checks on input transactions**

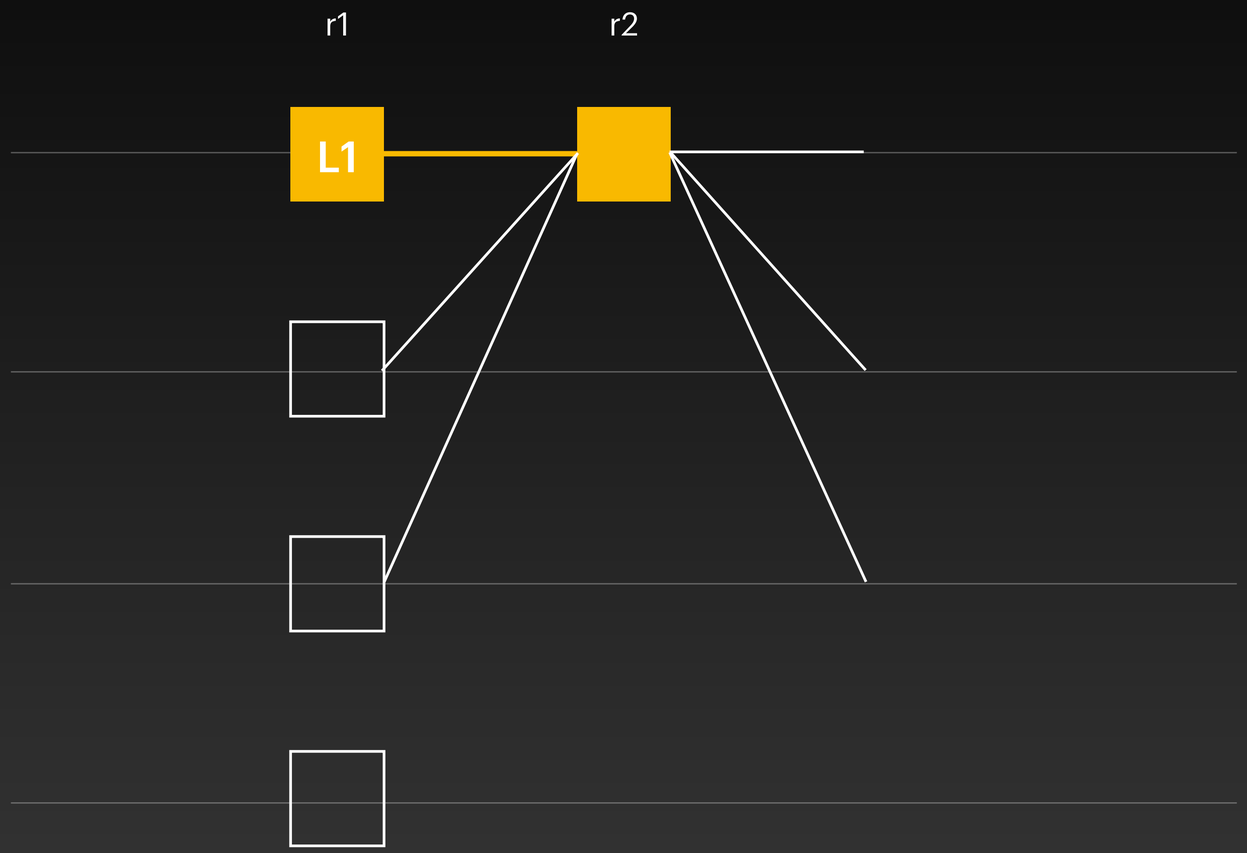

validator
Admission Control
Ordering
Execution
Persistence
client
validator
Admission Control
Ordering
Execution
Persistence
client
validator
client
client
client
client
...



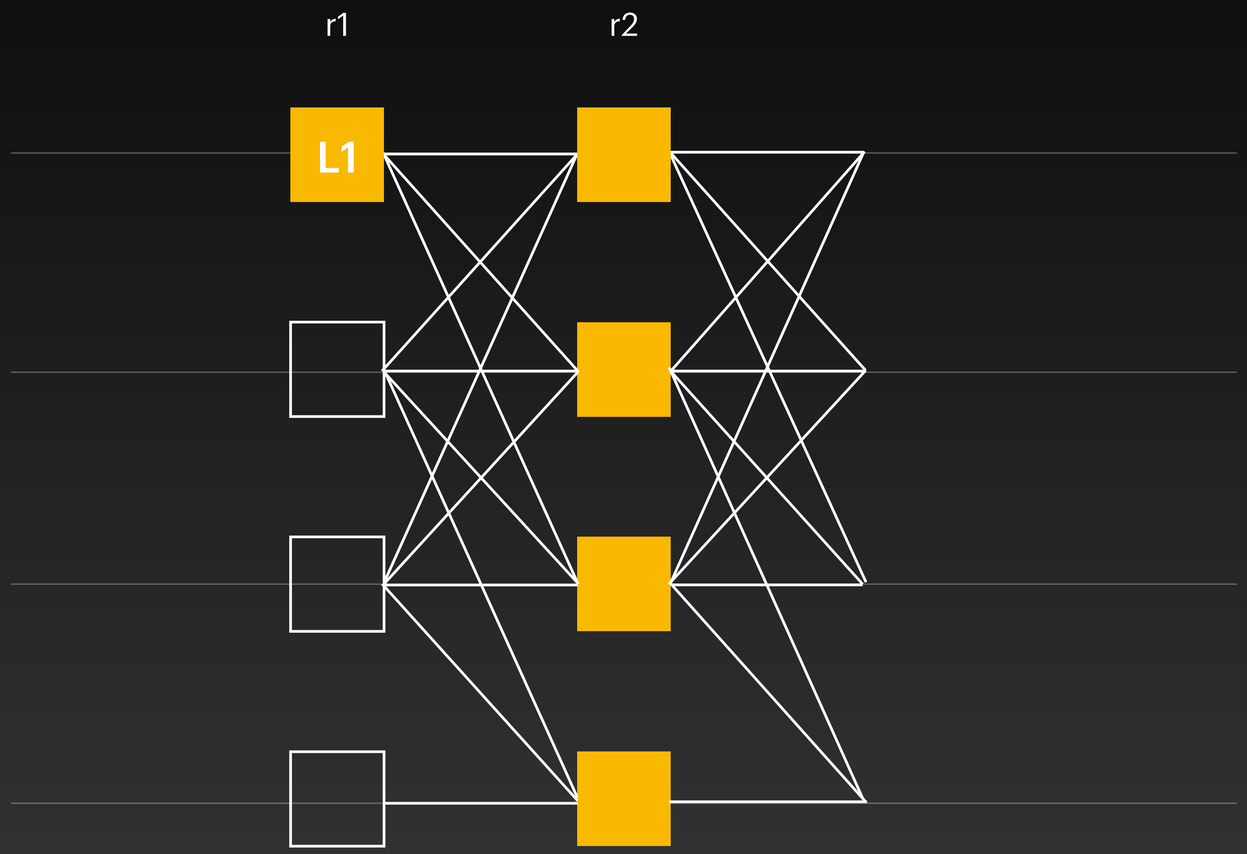
- Round number
- Author
- Payload (transactions)
- Signature



- Link to previous blocks



- Wait for the leader

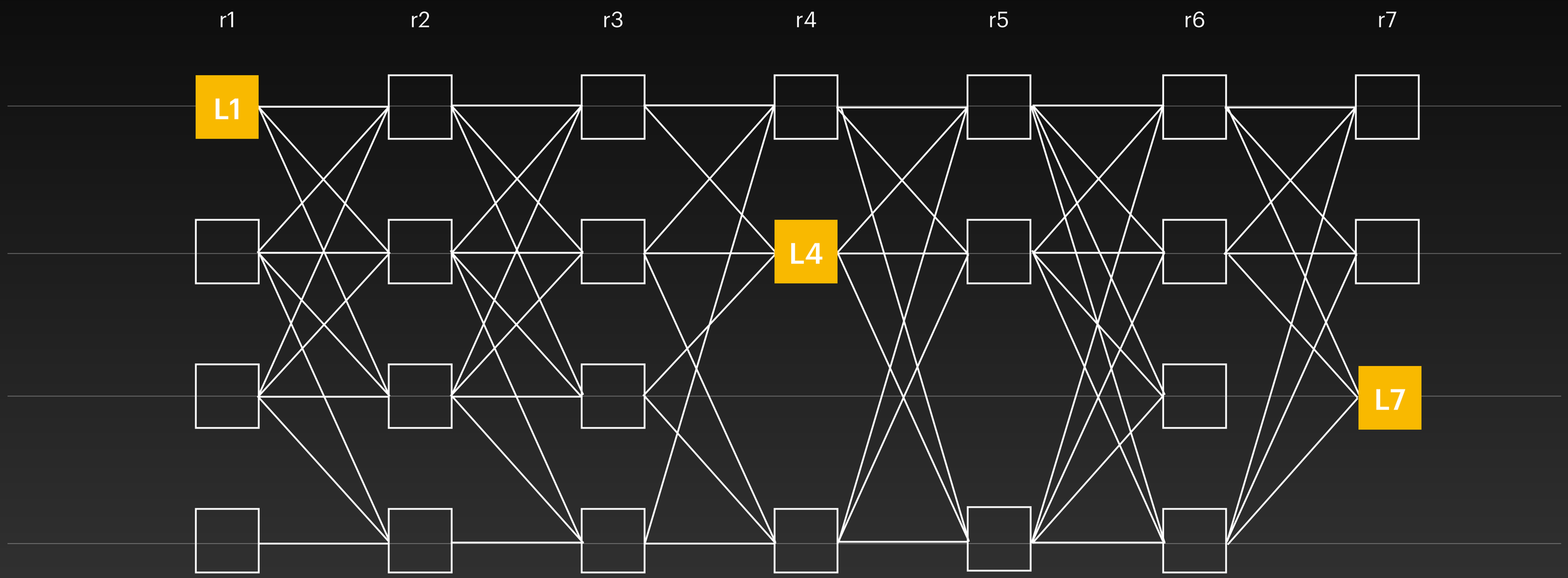


- All validators run in parallel

Network Security

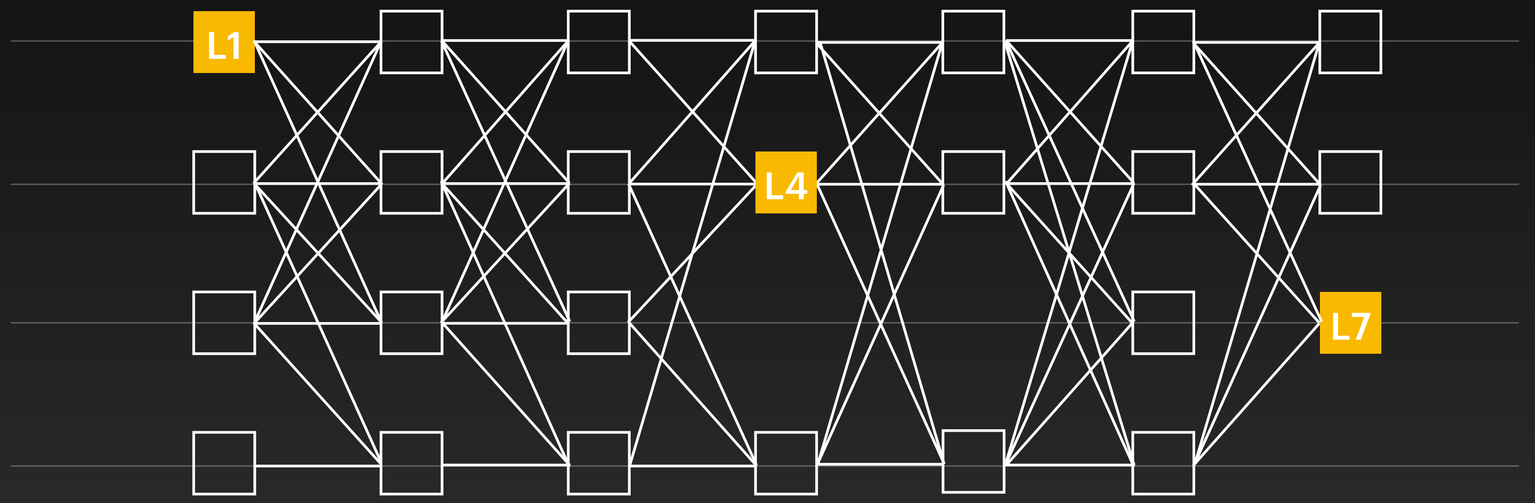
Challenge #4: Ordering

- **How to find the best path to send the block to another node?**


r1
r2
r3
r4
r5
r6
r7
L1
L4
L7

End Goal

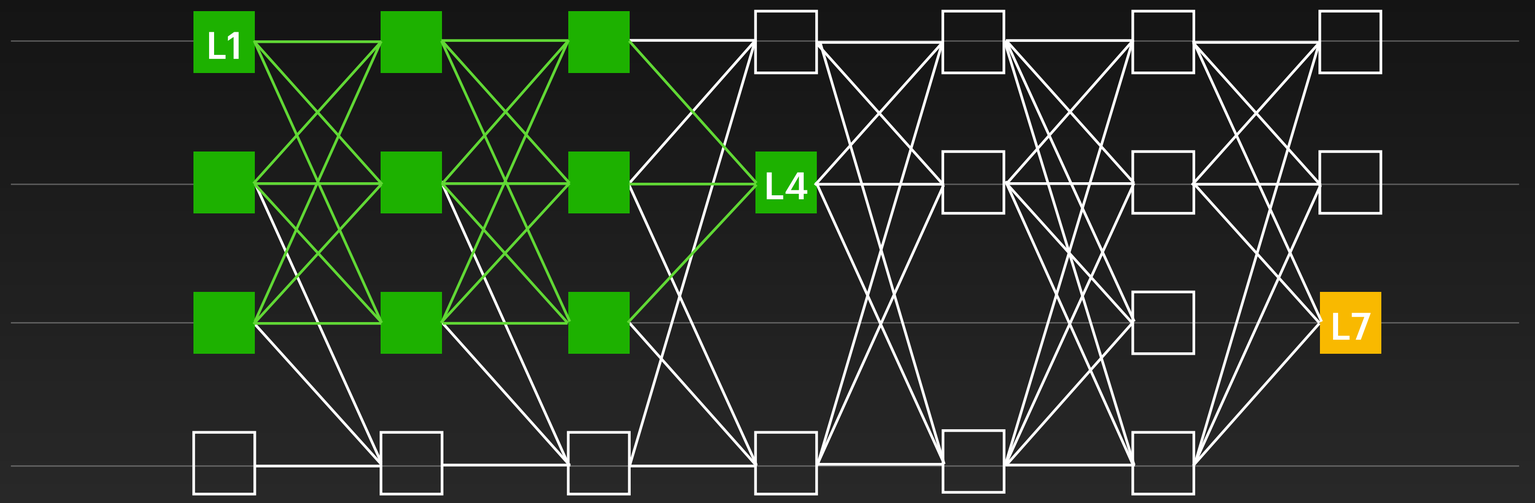
Ordering leaders



- We focus on ordering leaders: L1 L4 L7

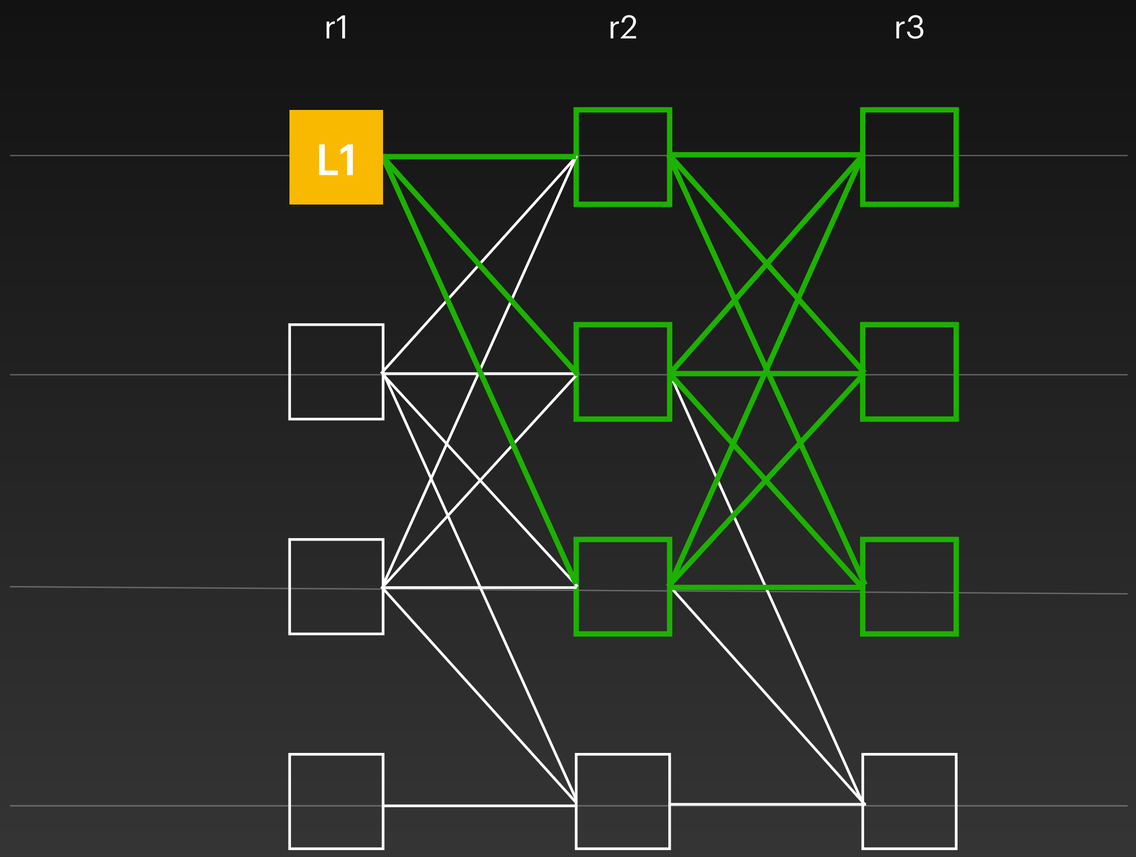
End Goal

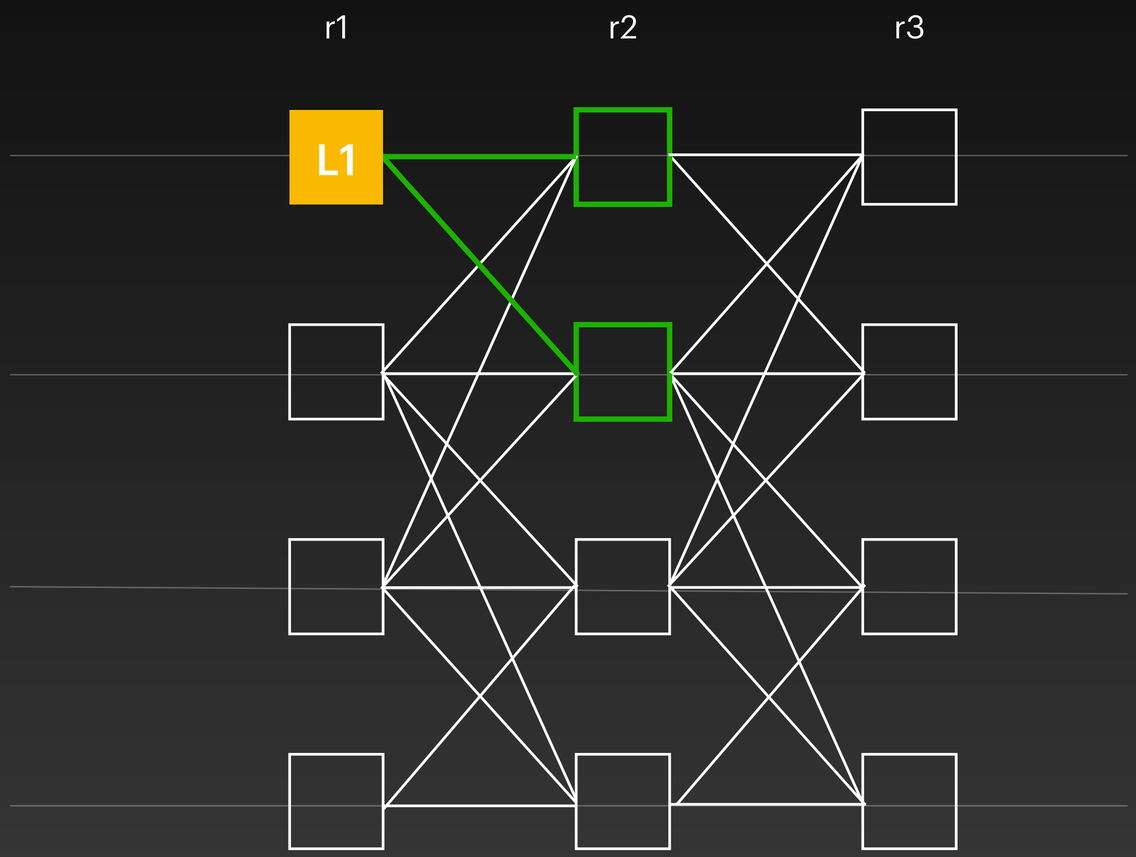
Ordering leaders

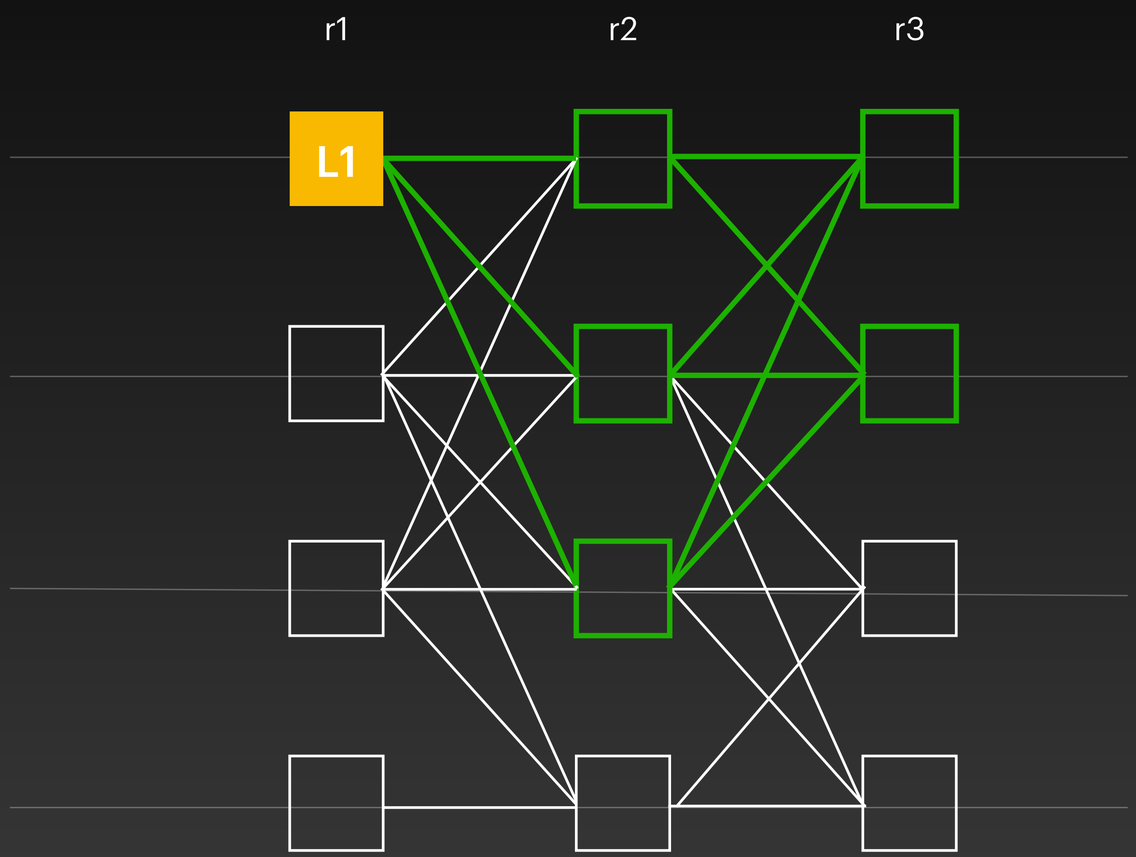


- We focus on ordering leaders: L1 L4 L7
- Linearising the sub-DAG is simple

How is it done?




r1
r2
r3
L1

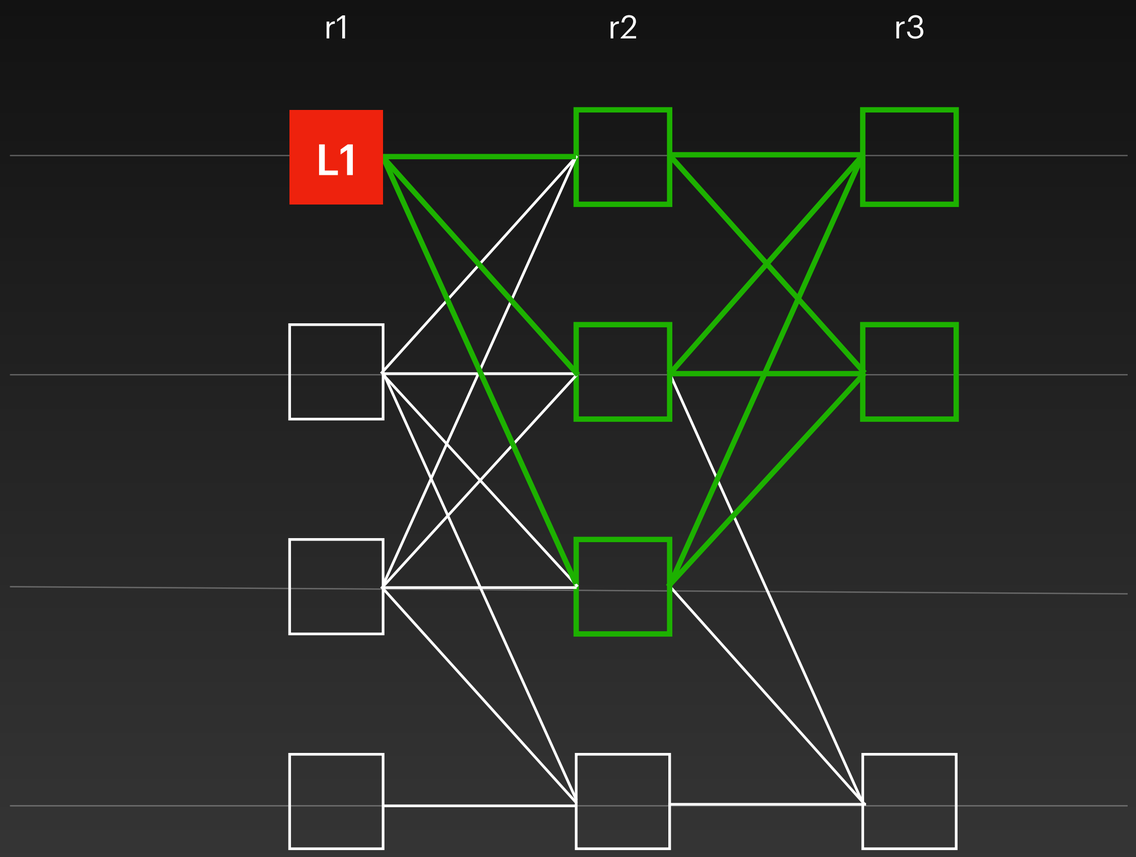

r1
r2
r3
L1

Network Security

Challenge #4: Ordering

- How to find the best path to send the block to another node?
- **DoS against the leader are particularly effective**

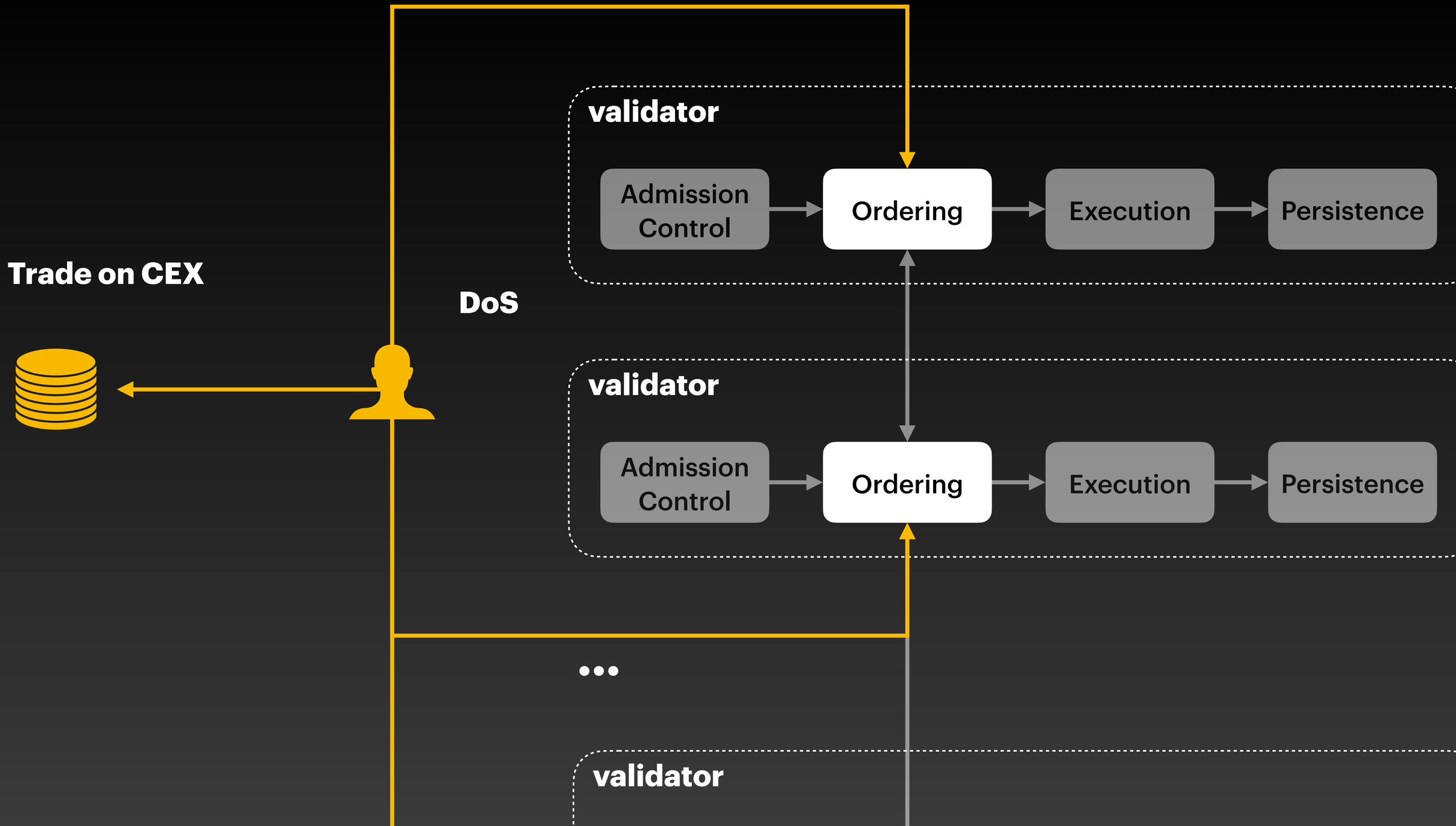
Message not received in order?



- Bad leader?
- Or bad network?

Network Security
Challenge #4: Ordering

- How to find the best path to send the block to another node?
- DoS against the leader are particularly effective
- **Reordering messages causes massive slowdowns**


validator
Admission Control
Ordering
Execution
Persistence
Trade on CEX
DoS
validator
Admission Control
Ordering
Execution
Persistence
...
validator

Network Security
Challenge #4: Ordering

- How to find the best path to send the block to another node?
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- **Nodes don’t know whether they are connected to a malicious node**

Network Security
Challenge #4: Ordering

- How to find the best path to send the block to another node?
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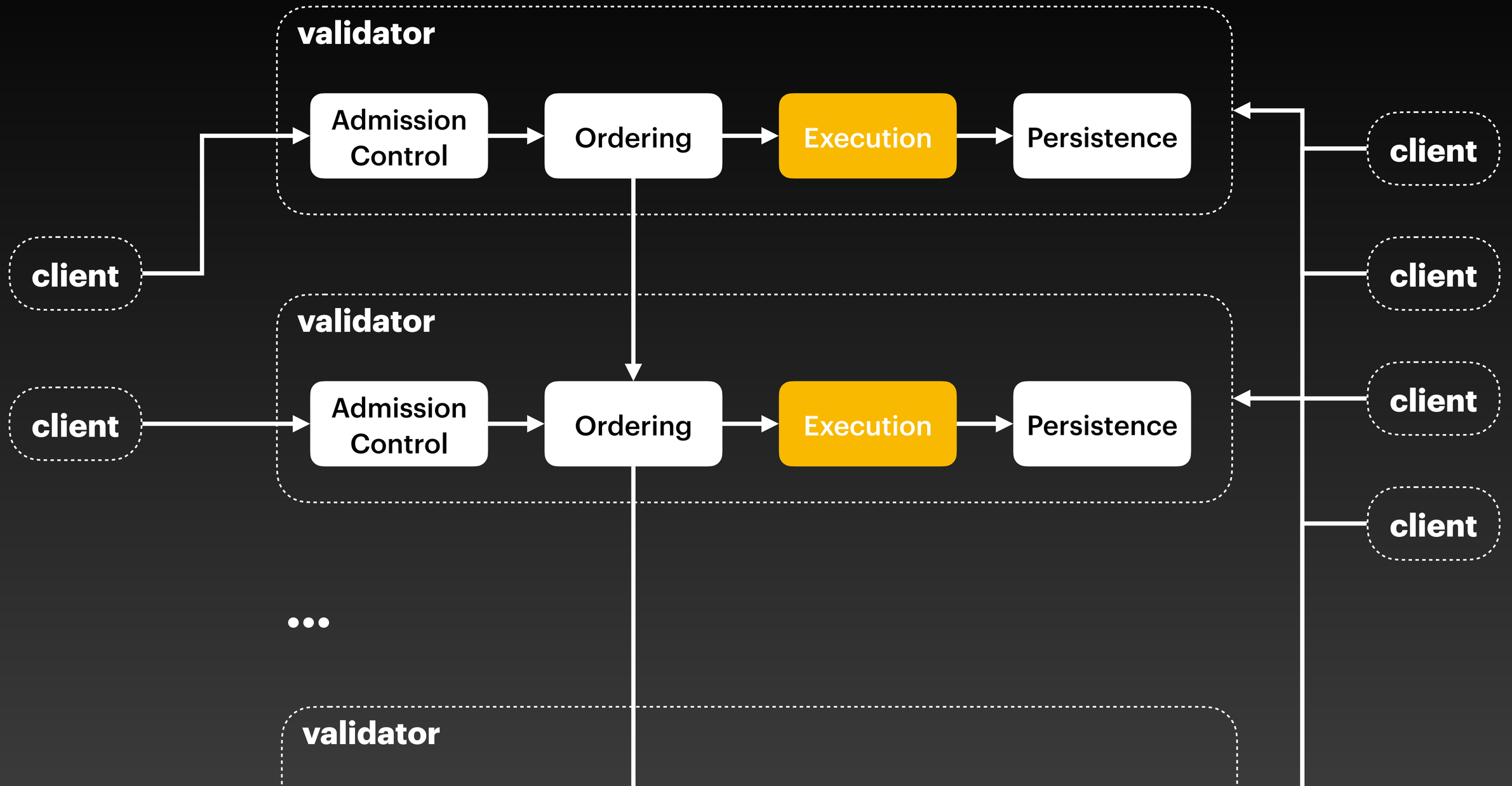
- Reordering messages causes massive slowdowns
- Nodes don’t know whether they are connected to a malicious node
- **Bad nodes have access to insider information (committee addresses)**

Network Security
Challenge #4: Ordering

- How to find the best path to send the block to another node?
- DoS against the leader are particularly effective
- Reordering messages causes massive slowdowns
- Nodes don’t know whether they are connected to a malicious node
- Bad nodes have access to insider information (committee addresses)
- **Not clear from whom to pull the missing block**


validator
Admission Control
Ordering
Execution
Persistence
client
validator
Admission Control
Ordering
Execution
Persistence
client
validator
client
client
client
client
...

Example Transaction

T1

Inputs: O1, O2, O3, O4

Output: Mutate O1, Transfer O2, Delete O3, Create O4

Check transaction, assign locks

O1

Version = 10

Owner = Alice

O2

Version = 27

Owner = Alice

O3

Version = 1001

Owner = Alice

Checks

Input objects exist

Function call details

Signature of Alice

Execute in parallel

O1

Version = 11

Owner = X

O2

Version = 28

Owner = Bob

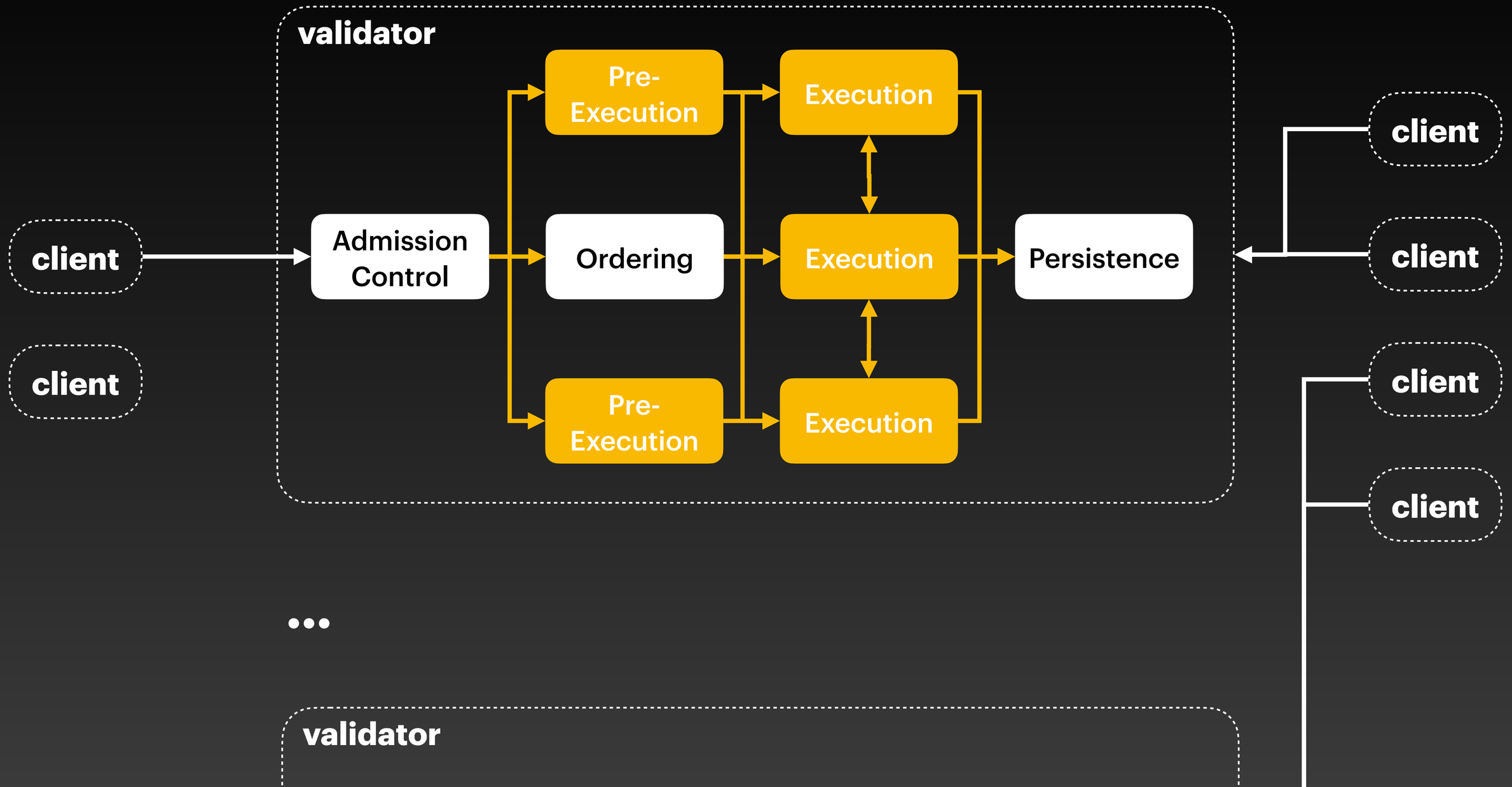
O4

Version = 1

Owner = Alice

Execute T1

- O1 mutated
- O2 transferred
- O3 deleted
- O4 created


validator
Pre-Execution
Execution
client
Admission Control
Ordering
Execution
Persistence
client
client
client
Pre-Execution
Execution
client
client
validator

Example Programmable Transaction Block (PTB)

T2

Inputs: O1, O2, O3

Output: Mutate O1, Transfer O2, Create **O3**

T2

Inputs: O1, **O3**

Output: Mutate O1, Mutate O3

Example Programmable Transaction Block (PTB)

T2

Inputs: O1, O2, O3

Output: Mutate O1, Transfer O2, Create **O3**

T2

Inputs: O1, **O3**

Output: Mutate O1, Mutate O3

Atomic

Either the trade makes profit

Or all transactions are dropped

```
# 0 - Borrow 1,000 USDC from DeepBook (returns: borrowed_coin, FlashLoan receipt)
--move-call $DEEPBOOK::vault::borrow_flashloan_base @$POOL 1000000000

# 1 - Swap USDC→SUI on Cetus
--move-call $CETUS::swap result(0,0) @$CETUS_POOL

# 2 - Swap SUI→USDC on Turbos
--move-call $TURBOS::swap result(1,0) @$TURBOS_POOL

# 3 - Split repayment amount from the USDC you now hold
--move-call 0x2::coin::split result(2,0) 1000000000

# 4 - Repay flash loan with the split coin + hot potato receipt
--move-call $DEEPBOOK::vault::return_flashloan_base @$POOL result(3,0)
result(0,1)

# 5 - Transfer remaining profit to sender
--transfer-objects [result(2,0)] @$SENDER
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```

 # 5 - Transfer remaining profit to sender

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```

This fails if no profit is made...

 # 3 - Split repayment amount from the USDC you now hold

```
--move-call 0x2::coin::split result(2,0) 1000000000
```

No smart contract needed...

Traditional Execution

Gas cost

Each order/cancel is a separate transaction

PTB composability

Updating 20 prices means 20 transactions

Parallelism

All DEX trades go through the same object

Modern Execution

Gas cost

High-frequency trading economically viable

PTB composability

One PTB to update/cancel all

Parallelism

Each pool (USDC/SUI, ..) is a separate object

Security

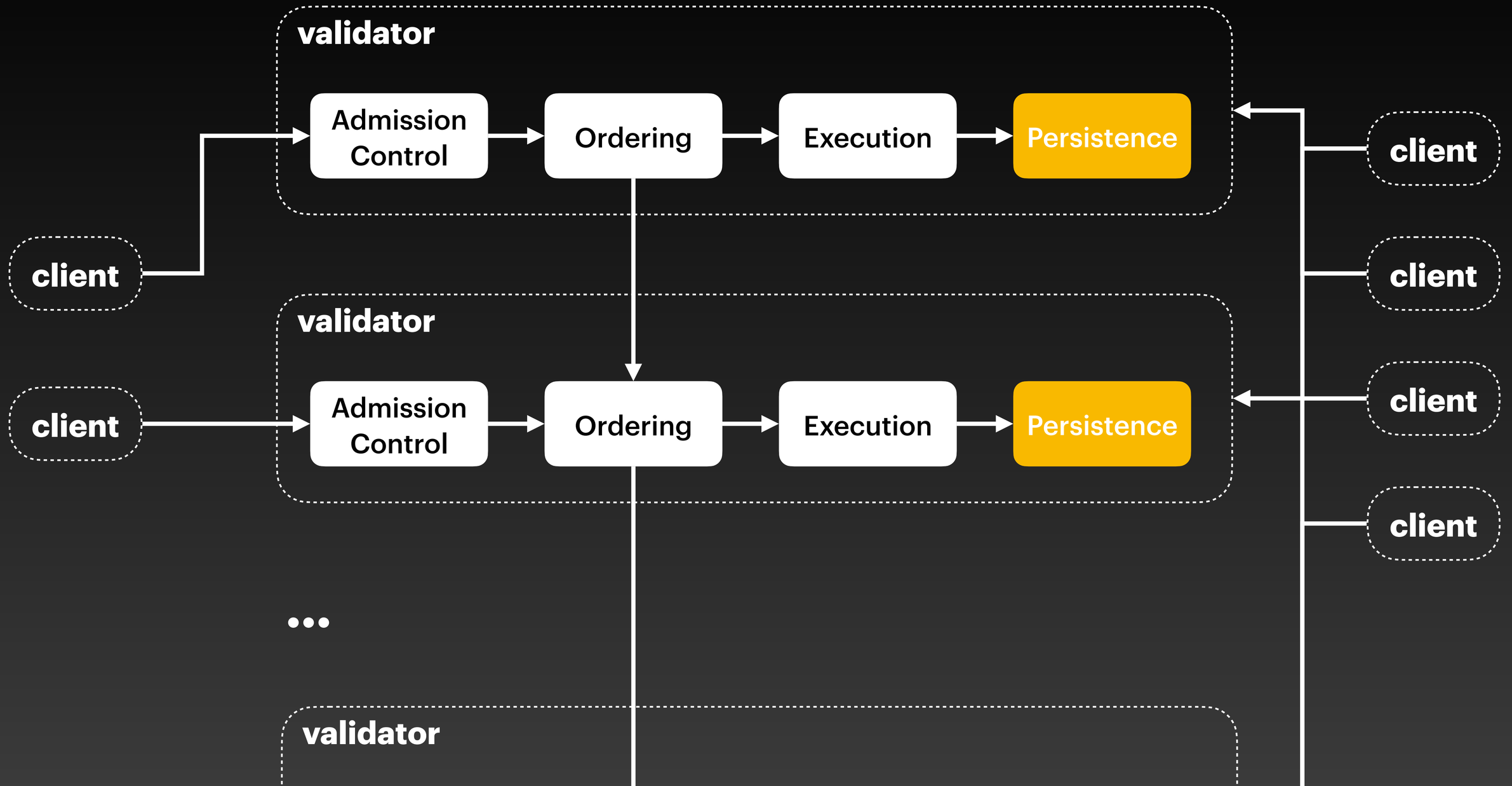
Challenge #5: Execution

- **Intra-datacenter connections but on low power machines**

Security

Challenge #5: Execution

- Intra-datacenter connections but on low power machines
- **Load drastically varies: need elasticity**


validator
Admission Control
Ordering
Execution
Persistence
client
validator
Admission Control
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Execution
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client
validator
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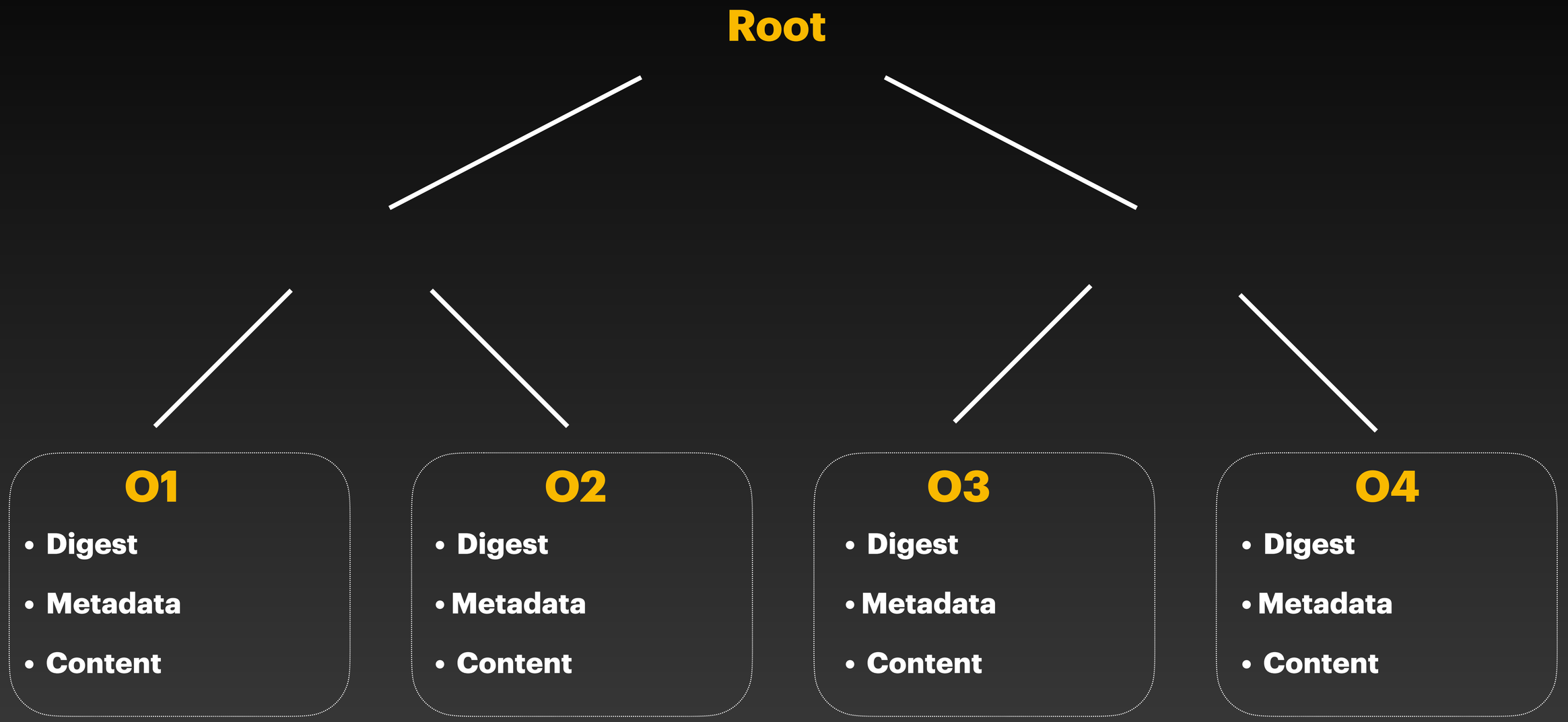
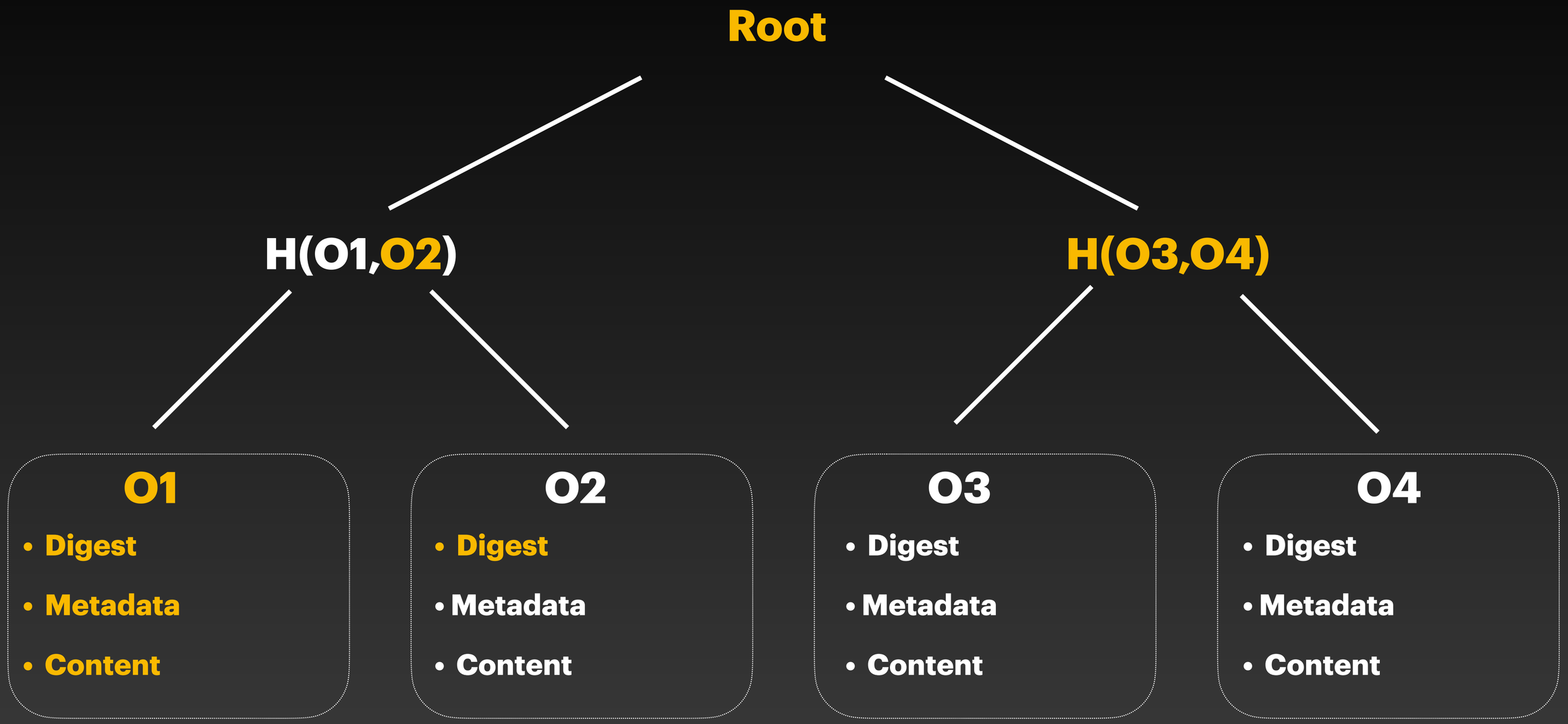
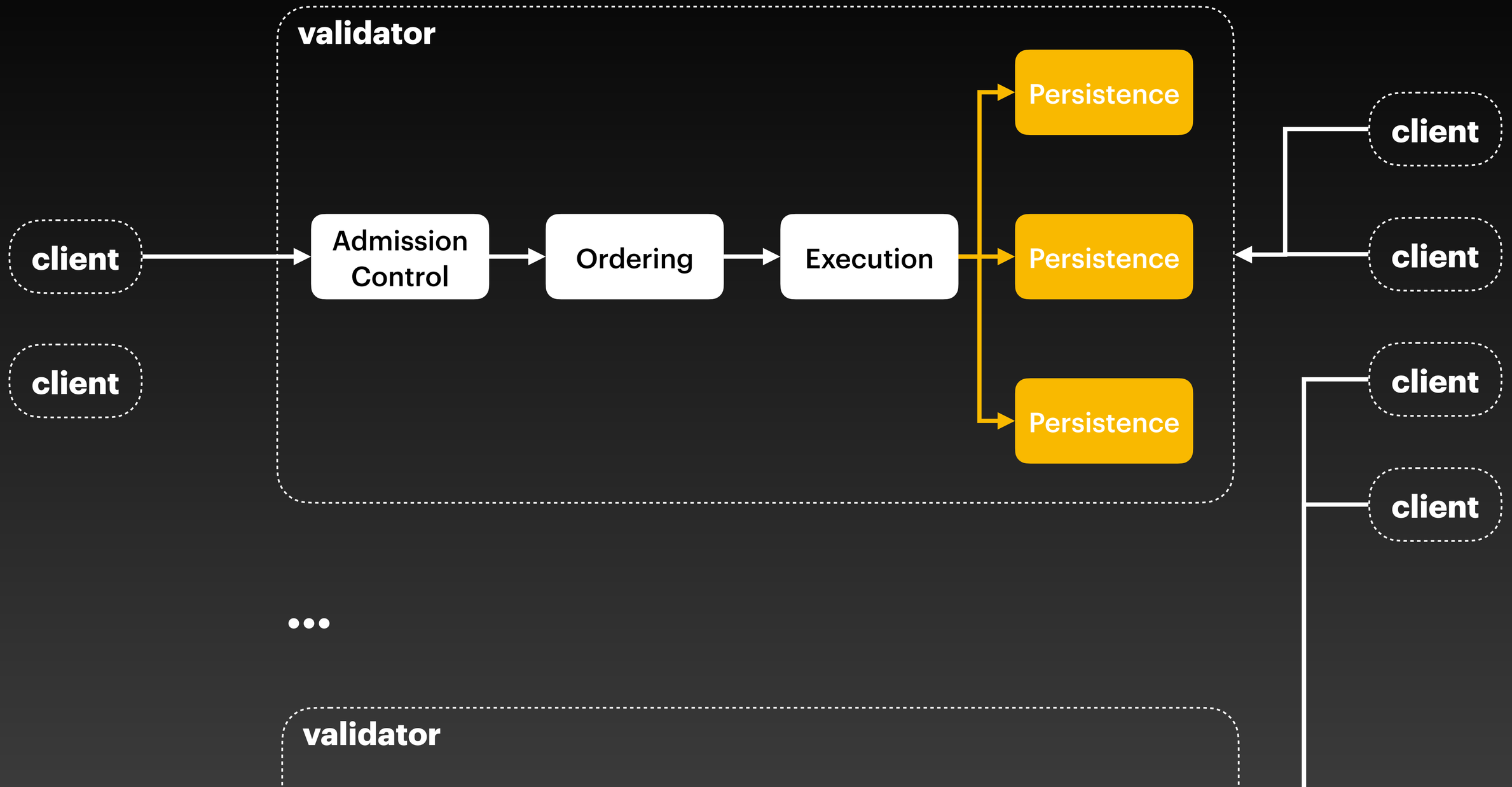
client
client
client
...


Root
01
Digest
Metadata
Content
02
Digest
Metadata
Content
03
Digest
Metadata
Content
04
Digest
Metadata
Content

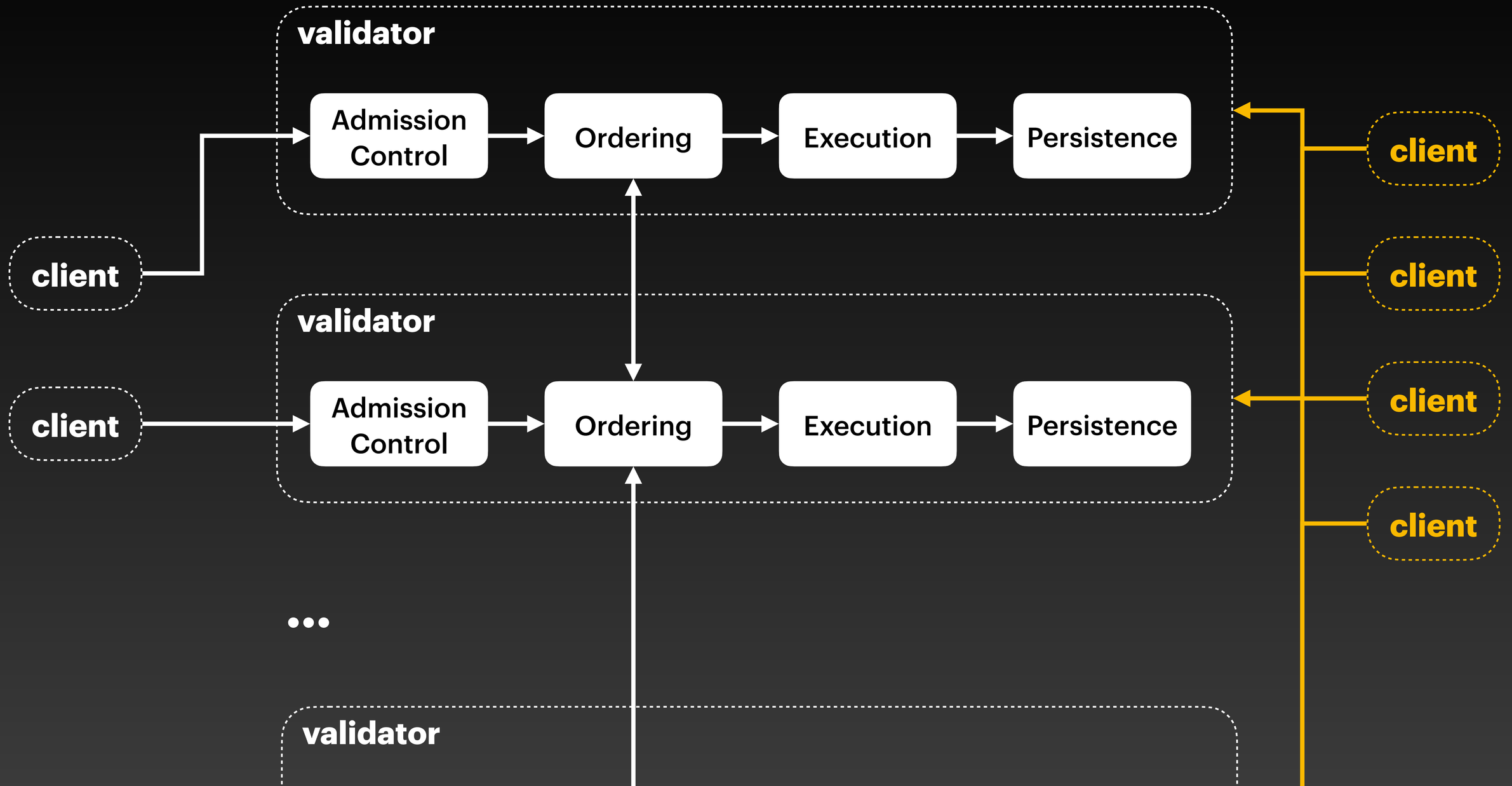

Root
H(O1,O2)
H(O3,O4)
O1
Digest
Metadata
Content
O2
Digest
Metadata
Content
O3
Digest
Metadata
Content
O4
Digest
Metadata
Content

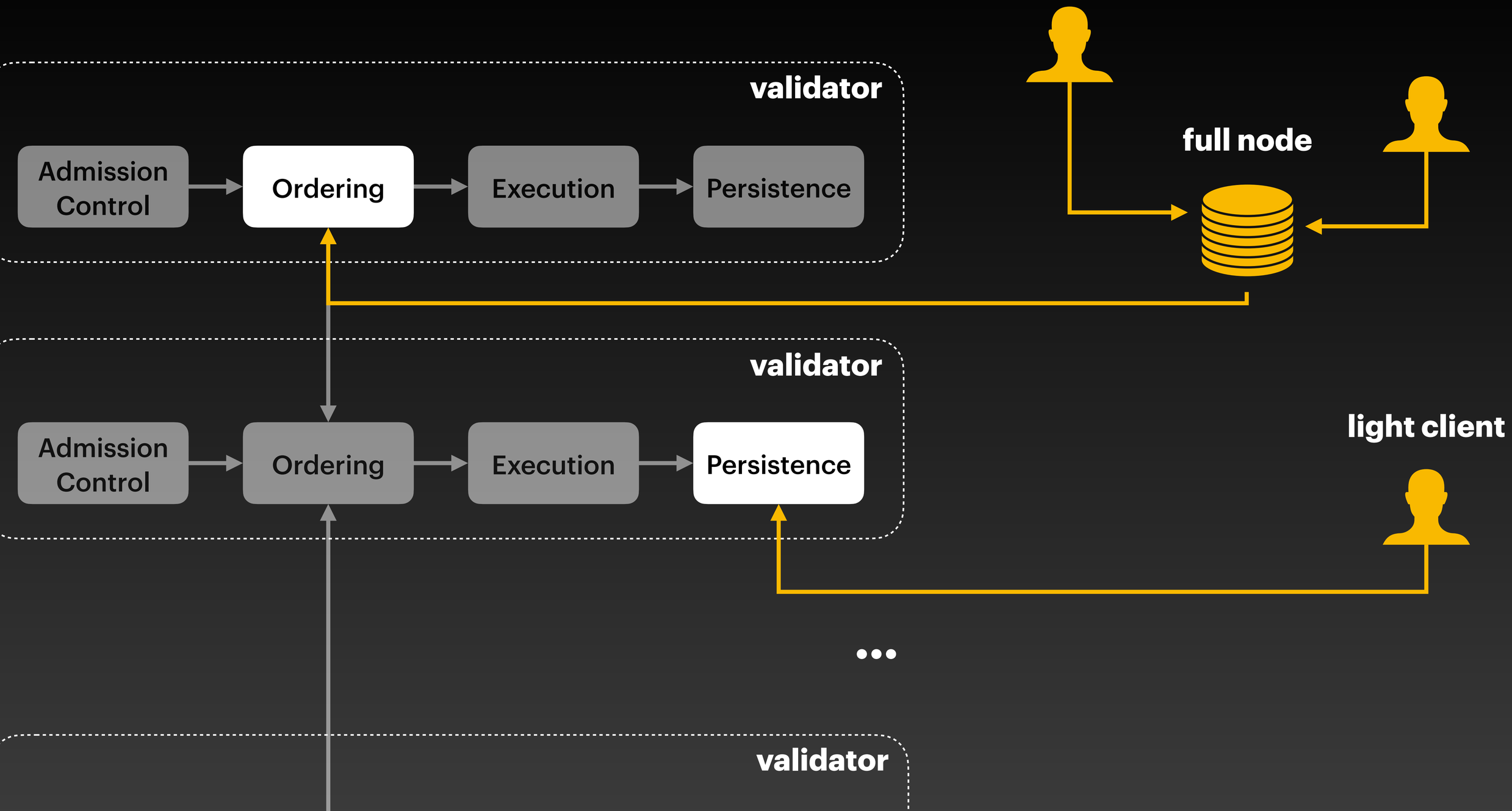

validator
client
client
Admission Control
Ordering
Execution
Persistence
Persistence
Persistence
client
client
client
client
...
validator

Network Security

Challenge #6: Persistence

- **Need low-latency networking to distribute the tree creation**


validator
Admission Control
Ordering
Execution
Persistence
client
validator
Admission Control
Ordering
Execution
Persistence
client
...
validator
client
client
client
client


validator
Admission Control
Ordering
Execution
Persistence
full node
validator
Admission Control
Ordering
Execution
Persistence
light client
validator

Security

Challenge #7: Reads

- **Potentially very large number of readers (>400)**

Security
Challenge #7: Reads

- Potentially very large number of readers (>400)
- **Unpredictable, may read arbitrary data**

Security
Challenge #7: Reads

- Potentially very large number of readers (>400)
- Unpredictable, may read arbitrary data
- **Sometimes require extreme performance**

Security
Challenge #7: Reads

- Potentially very large number of readers (>400)
- Unpredictable, may read arbitrary data
- Sometimes require extreme performance
- **Most reads must be free**

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