Blockchain Primitives

SPEAKER
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[CRYPTO STARTUP SCHOOL]

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What Is a Blockchain?

LAYER 3	**User Interface** (e.g., web3)
LAYER 2	**Applications** (Solidity, Move, Motoko)
LAYER 1.5	**Compute Layer** (blockchain computer)
LAYER 1	**Consensus Layer**

LAYER 1: Consensus Layer (Informal)

A **public data structure** (ledger) that provides:

Persistence: once added, data can never be removed*

Consensus: all honest participants have the same data**

Liveness: honest participants can add new transactions

Open(?): anyone can be a participant (no authentication)

LAYER 1	Consensus Layer

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This Not a New Problem …

State machine replication:
studied since the 1980s

Google, Amazon, Bank of America, all have lots of servers:

- need to ensure state is consistent across all servers
- Known # of servers, and all are authorized.

open consensus

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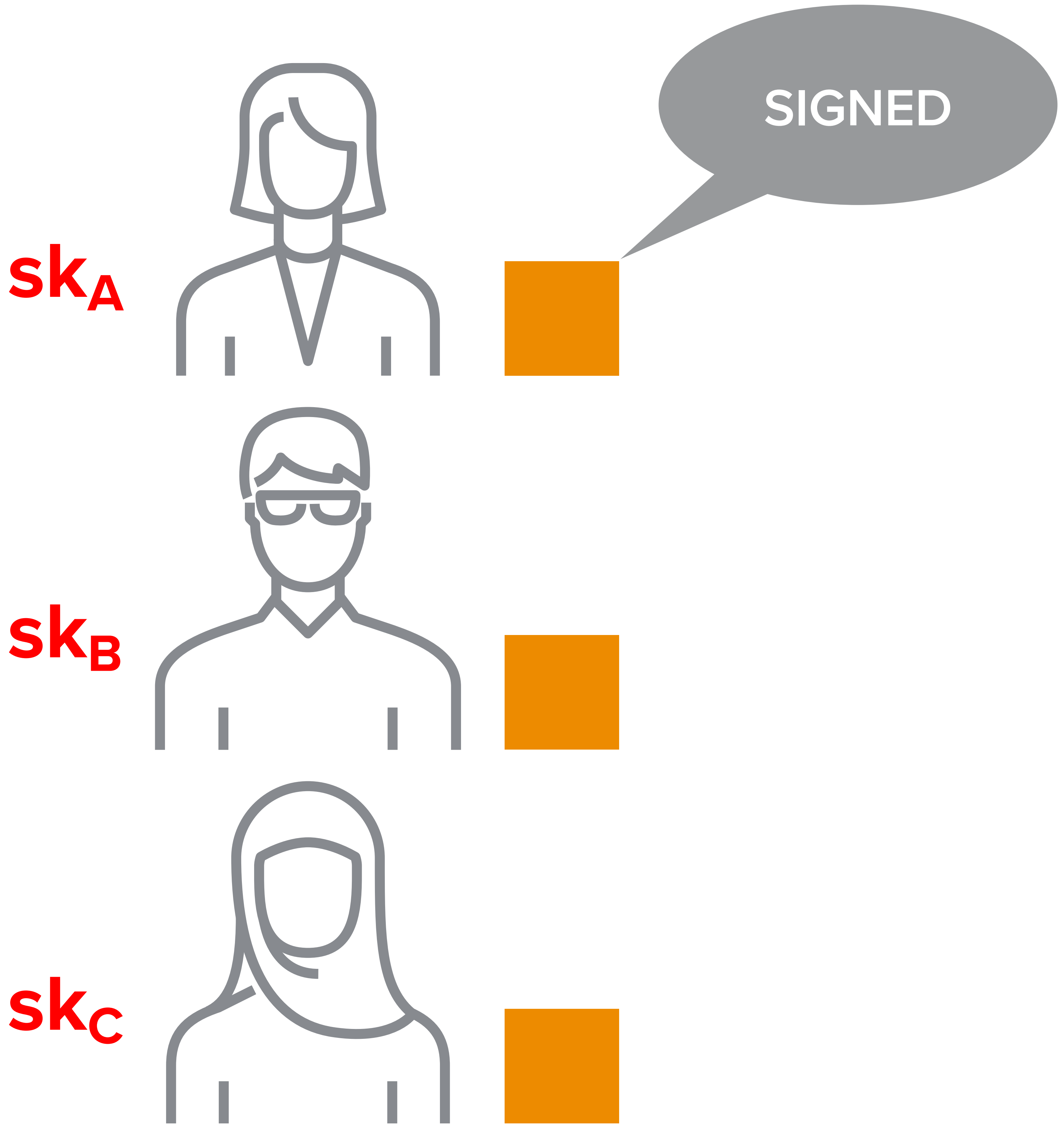
ng proof-of-work

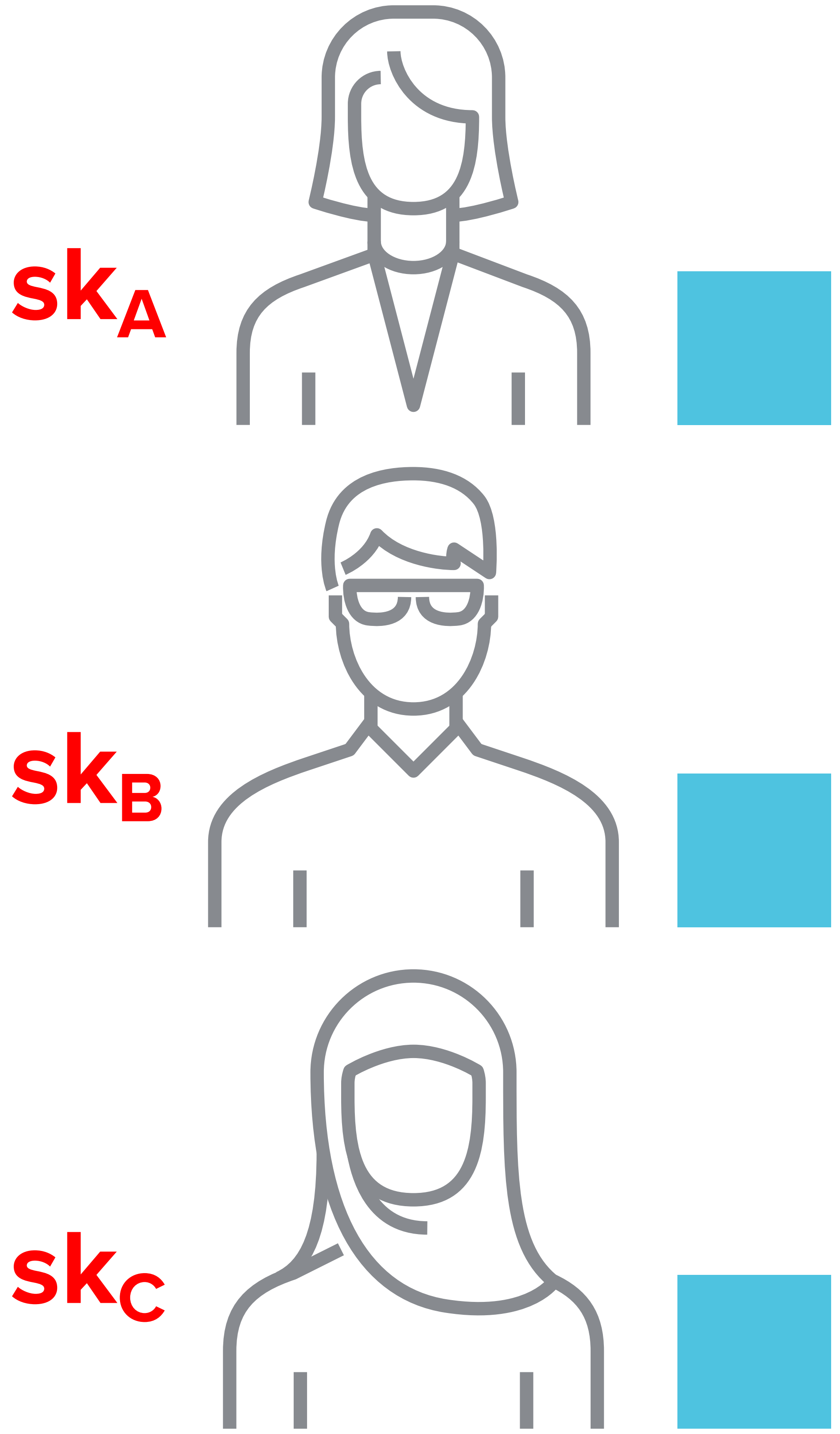
How Are Blocks Added to Chain?

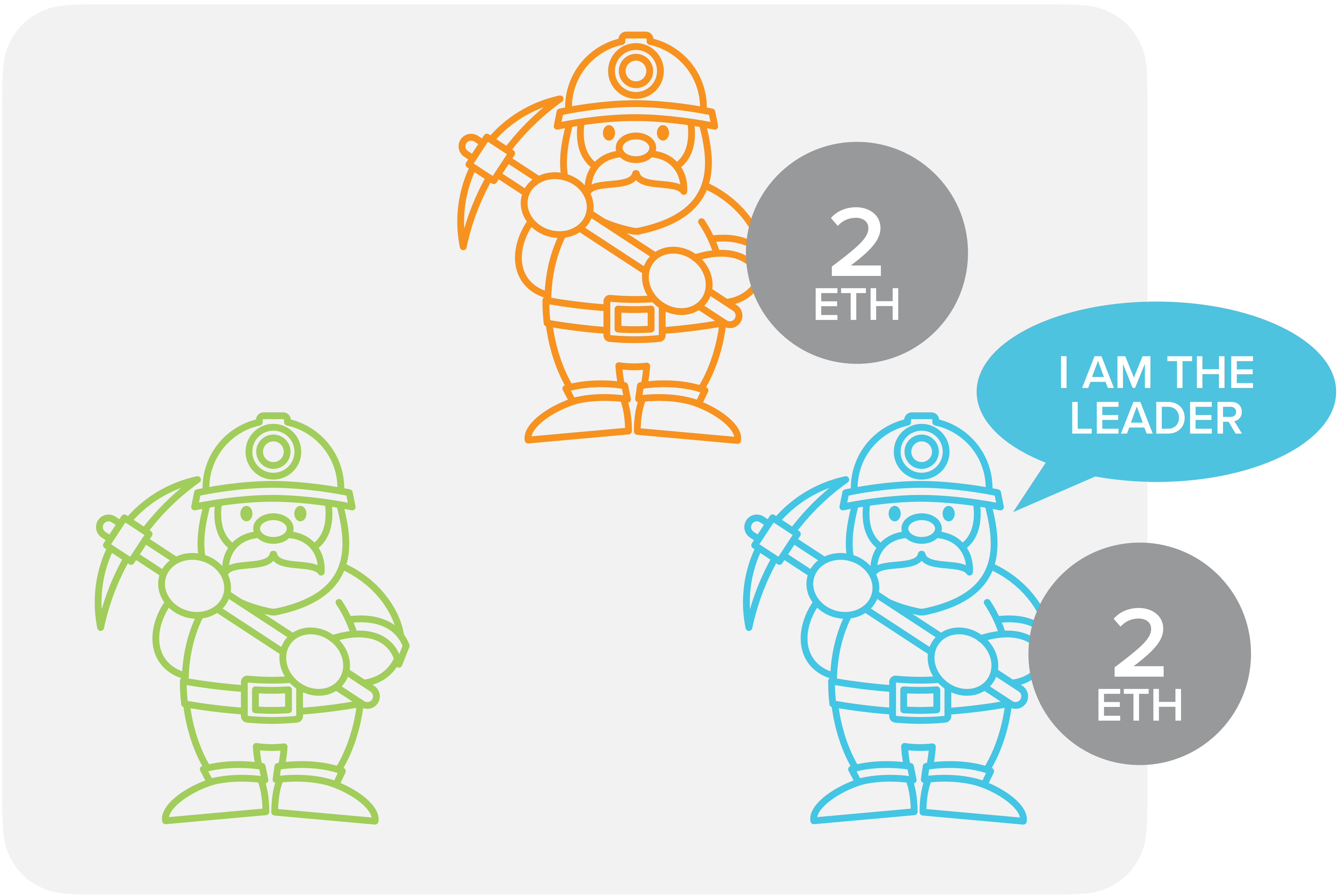
BLOCKCHAIN



How Are Blocks Added to Chain?

BLOCKCHAIN





Open Consensus: How?

PROOF-OF-WORK

First party to solve puzzle creates next block

- sybil resistant selection of a random party

Problems:

- slow, wastes energy

bitcoin

ethereum

PROOF-OF-STAKE

Fast block creation

No energy waste

But more complex

ethereum

Tendermint

DFINITY

celo

Algorand™

PROOF-OF-SPACE

chia

Filecoin

MANY MORE IDEAS

SOLANA

LAYER 1.5: the Blockchain Computer

APP logic is encoded in a program that runs on blockchain

- Rules are enforced by a public program (public source code)
  - ➔ **transparency:** no single trusted 3rd party
- The APP program is executed by parties who create new blocks
  - ➔ **public verifiability:** anyone can verify state transitions

LAYER 1.5	**Compute Layer** (blockchain computer)
LAYER 1	**Consensus Layer**

Running Programs on a Blockchain (APPs)

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Execution Environment

BITCOIN SCRIPT

A LIMITED COMPUTING ENVIRONMENT

- Limited instruction set (no loops)
- Sufficient for some tasks:
  - atomic swaps,
  - payment channels, …

ETHEREUM

GENERAL PROGRAMMING ENVIRONMENT (SOLIDITY, WEB3)

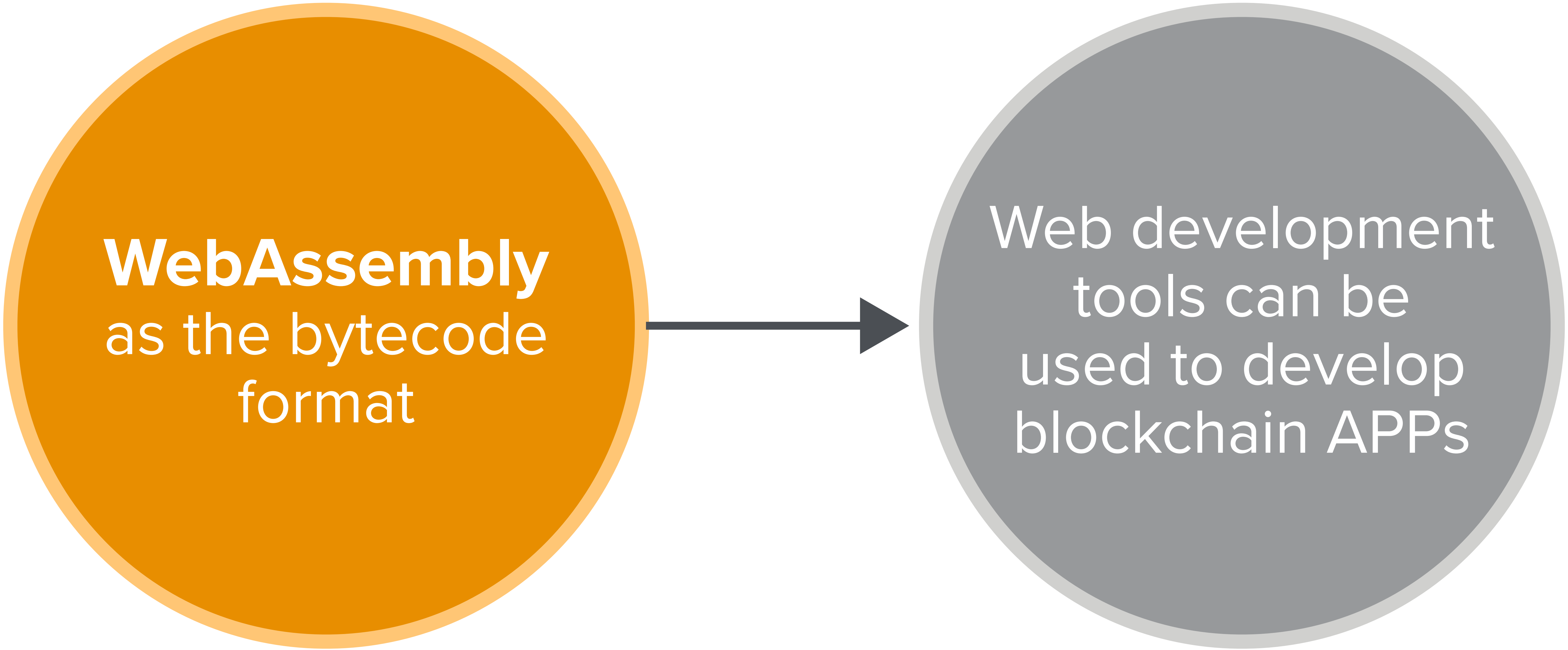
- EVM is a general purpose computing environment
- APP code updates internal state in response to transactions
- Calling APP costs fees (gas)
  - prevents DoS on miners
  - **storing on-chain state costs fees**

General Execution Environments

Recent projects

DFINITY

NEAR



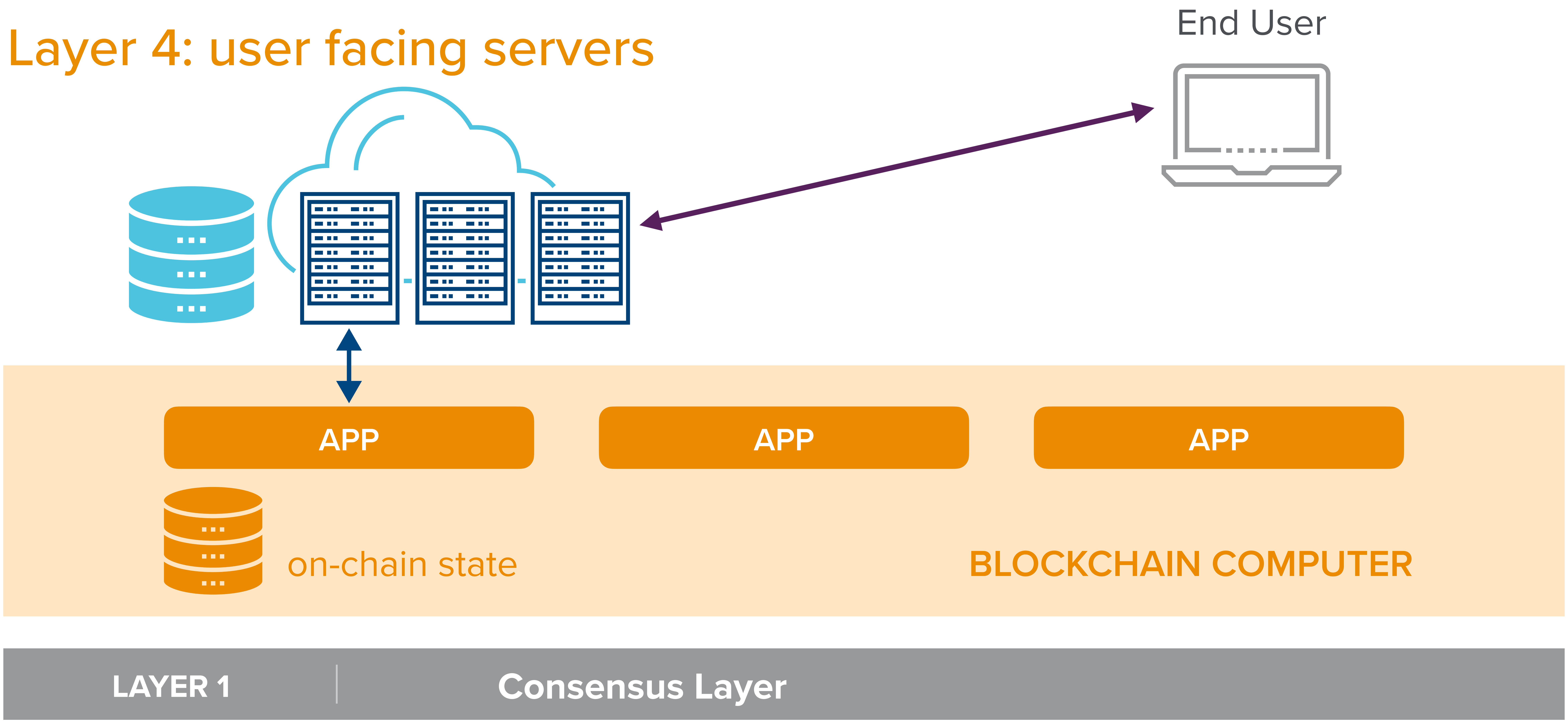
Decentralized Applications (APPs)

Run on blockchain computer

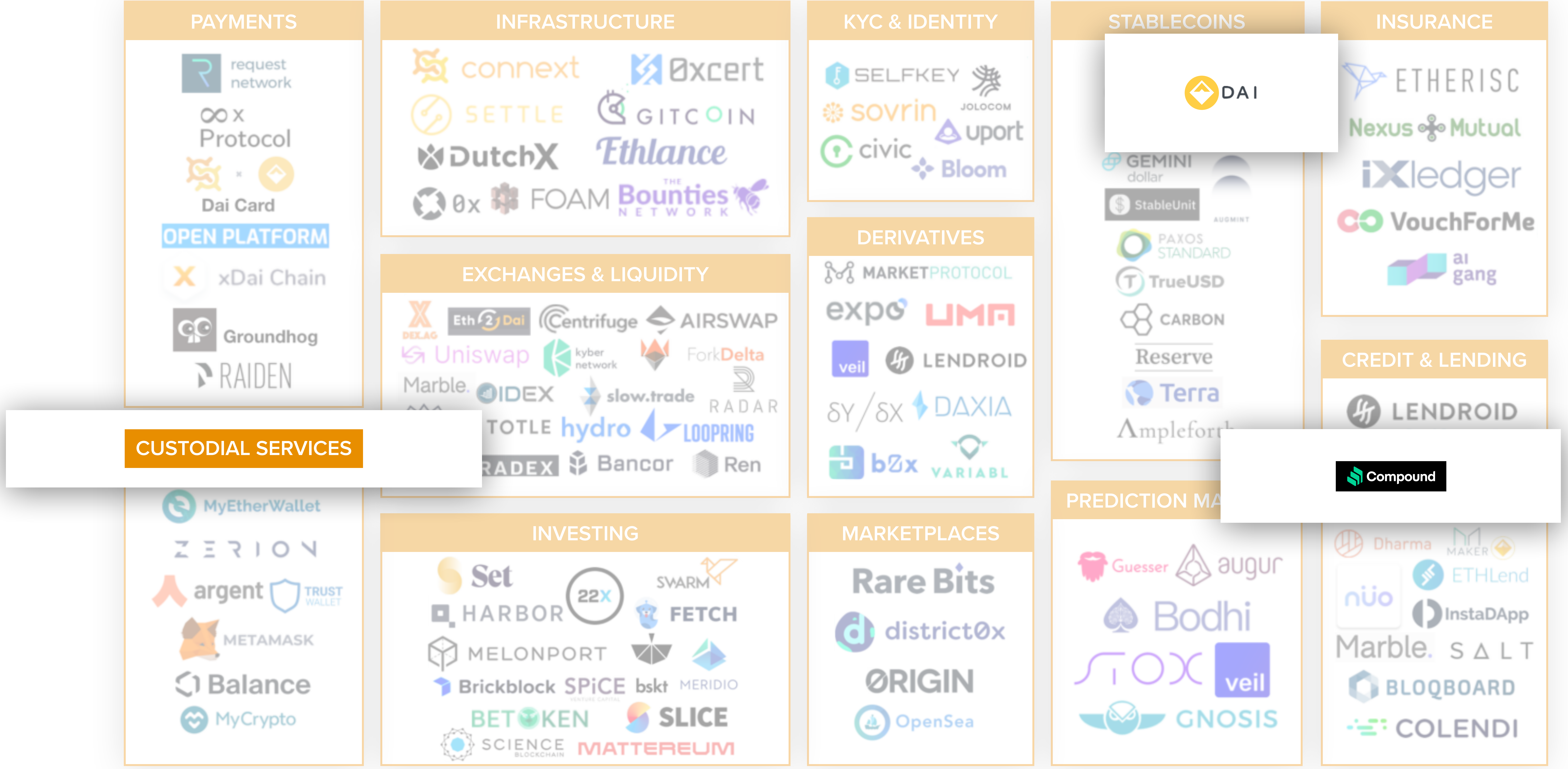
LAYER 2	**Applications** (Solidity, Move, Motoko)
LAYER 1.5	**Compute Layer** (blockchain computer)
LAYER 1	**Consensus Layer**

Common APP Architecture

Layer 4: user facing servers



Ethereum's DeFi



Source: https://www.theblockcrypto.com/genesis/15376/mapping-out-ethereums-defi

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Detailed APPs in Coming Lectures...

Cryptographic Primitives

Blockchain Crypto Primitives

Blockchains are a consumer of advanced cryptographic primitives

Digital signatures + aggregation

Merkle commitments

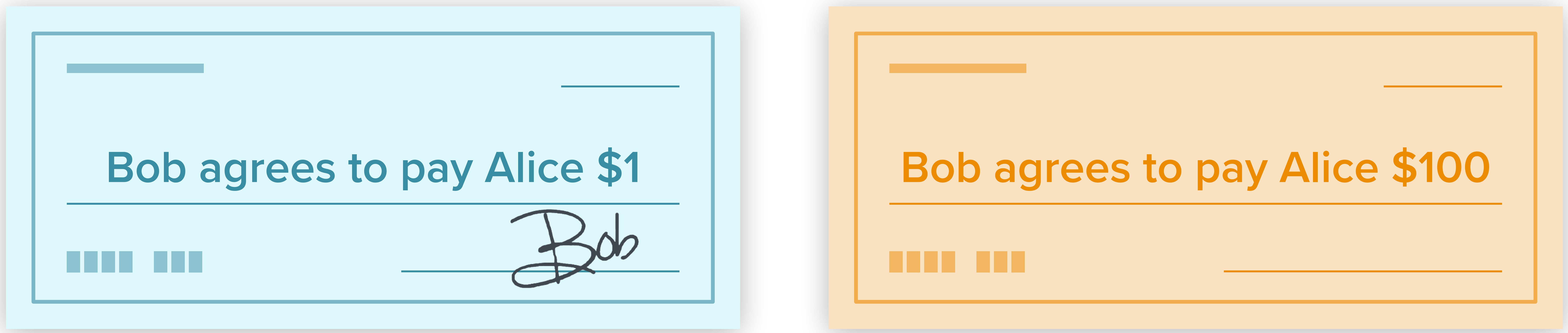
Succinct Zero-Knowledge proof systems

Important Primitives

Digital Signatures

Physical Signatures

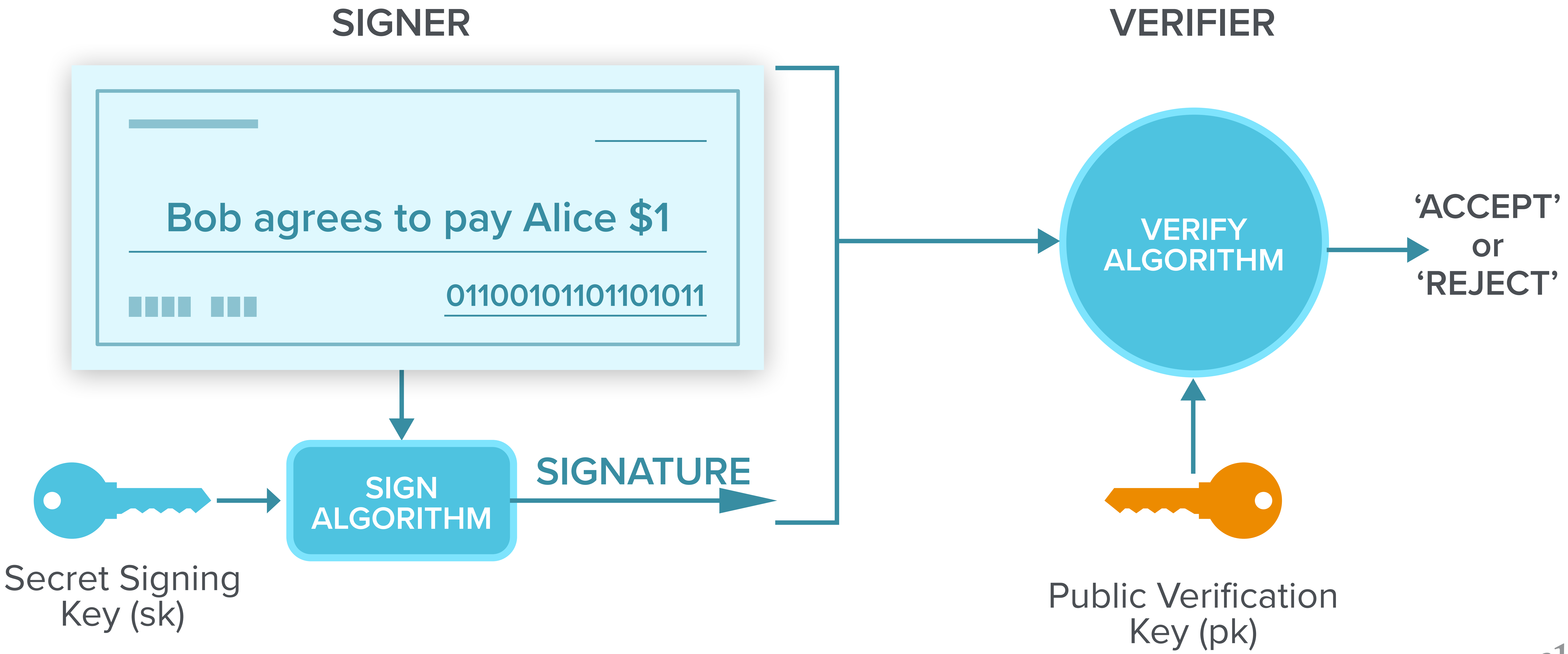
Goal: bind transaction to author



Problem in the digital world…anyone can copy Bob's signature from one doc to another

Digital Signatures

Solution: make signature depend on document



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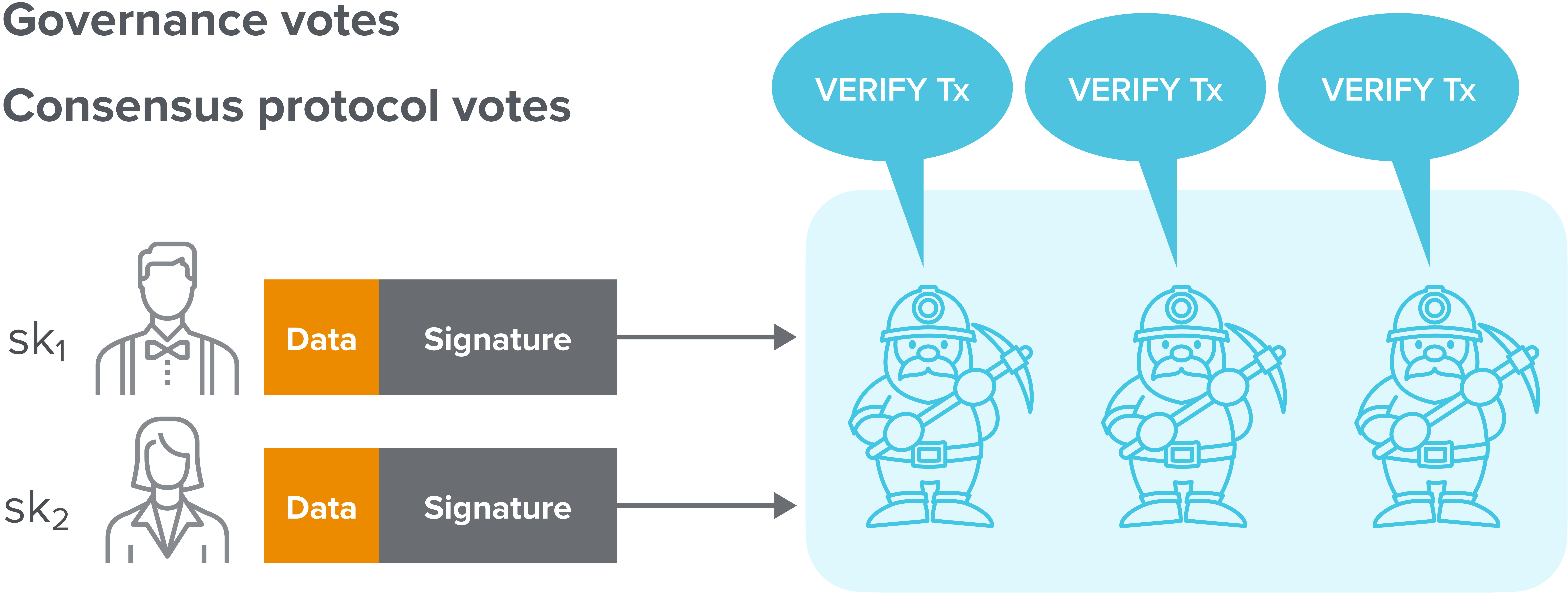
Signatures on the Blockchain: Used Everywhere

- **Ensure Tx authorization**
- **Governance votes**
- **Consensus protocol votes**



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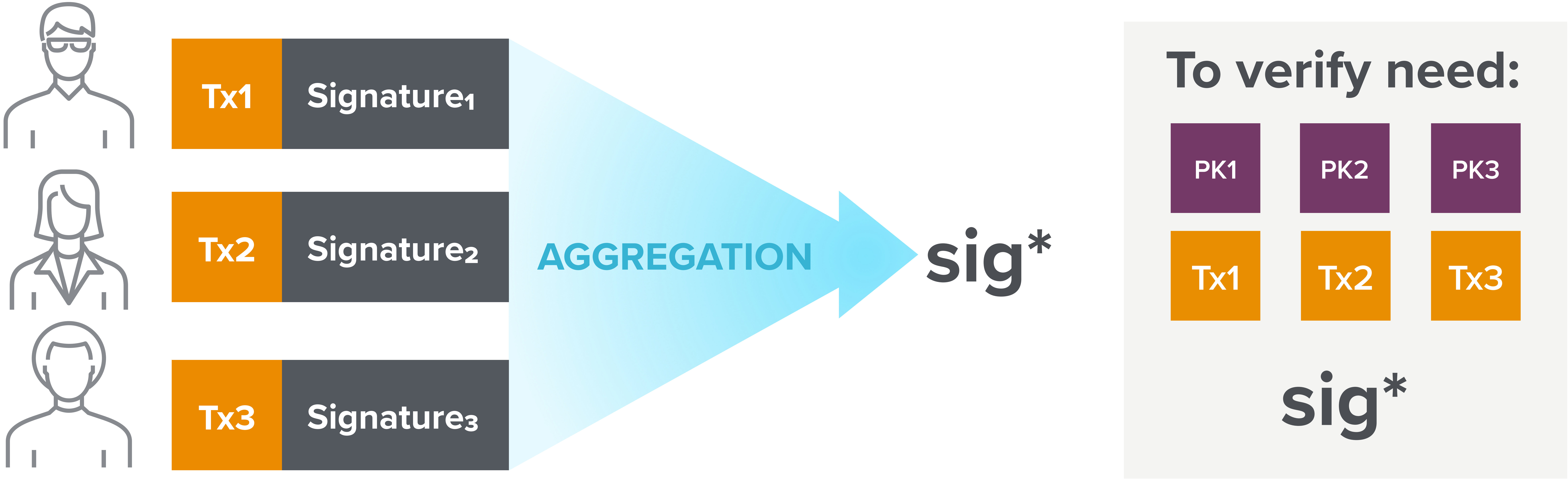
BLS Signature Aggregation

Anyone can compress n signatures into a single signature



No need to store list of signatures on the blockchain

Aggregation on the Blockchain

Merkle Commitments

Commitments

Cryptographic commitment: emulates an envelope

Many applications: e.g., an APP for a **sealed bid auction**

- Every participant **commits** to its bid,
- Once all bids are in, everyone opens their commitment

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Crypto Commitments

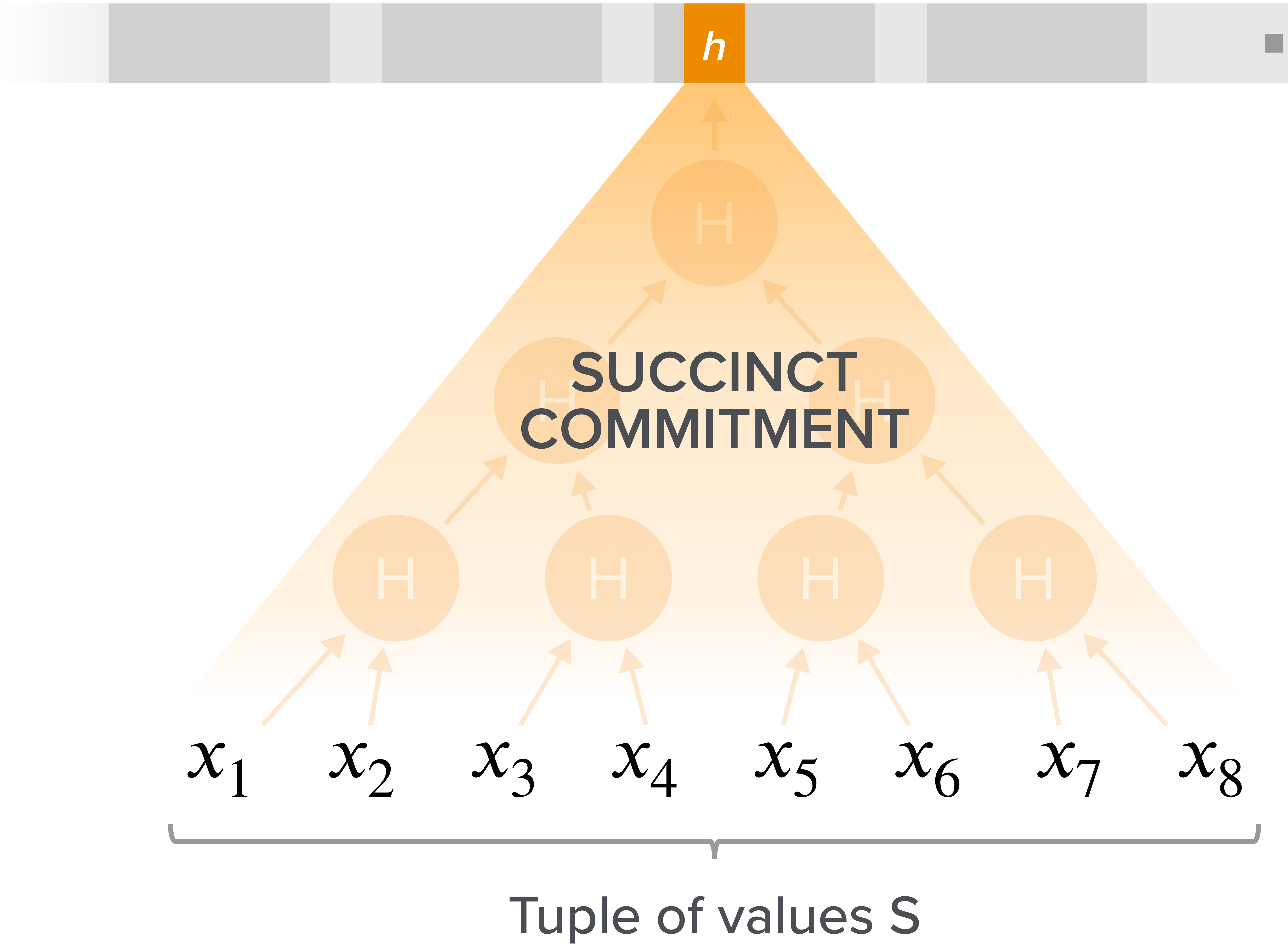
Syntax: a commitment scheme is two algorithms

- Commit (data) $\Longrightarrow$ (com, open)
- Verify (data, com, open) $\Longrightarrow$ ‘accept’ or ‘reject’

Security properties (informal):

- **Binding**: Bob cannot produce two valid openings
- **Hiding**: com reveals nothing about committed data

Committing to a Tuple of Values: Merkle Trees



GOAL:

- Commit to tuple S
- Later, provide a **short** proof that x_4 is the 4th element in S

Proof length = $O(\log |S|)$

Many Applications: **1)** Short Proof of Payment

Bob: has all block hashes

Alice: wants to prove she paid Bob 2ETH

- Alice sends a short Merkle proof to Bob
- 1000 Tx in block → short proof

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2) Keeping State off the Chain

Database of account balances

Alice	10	pk_A
Bob	5	pk_B
Carol	12	pk_C
⋮		⋮
Zoe	8	pk_Z

off-chain servers
store balances,
on-chain:
only **short** commitment

Alice can prove her balance (10) to anyone with a **short** proof

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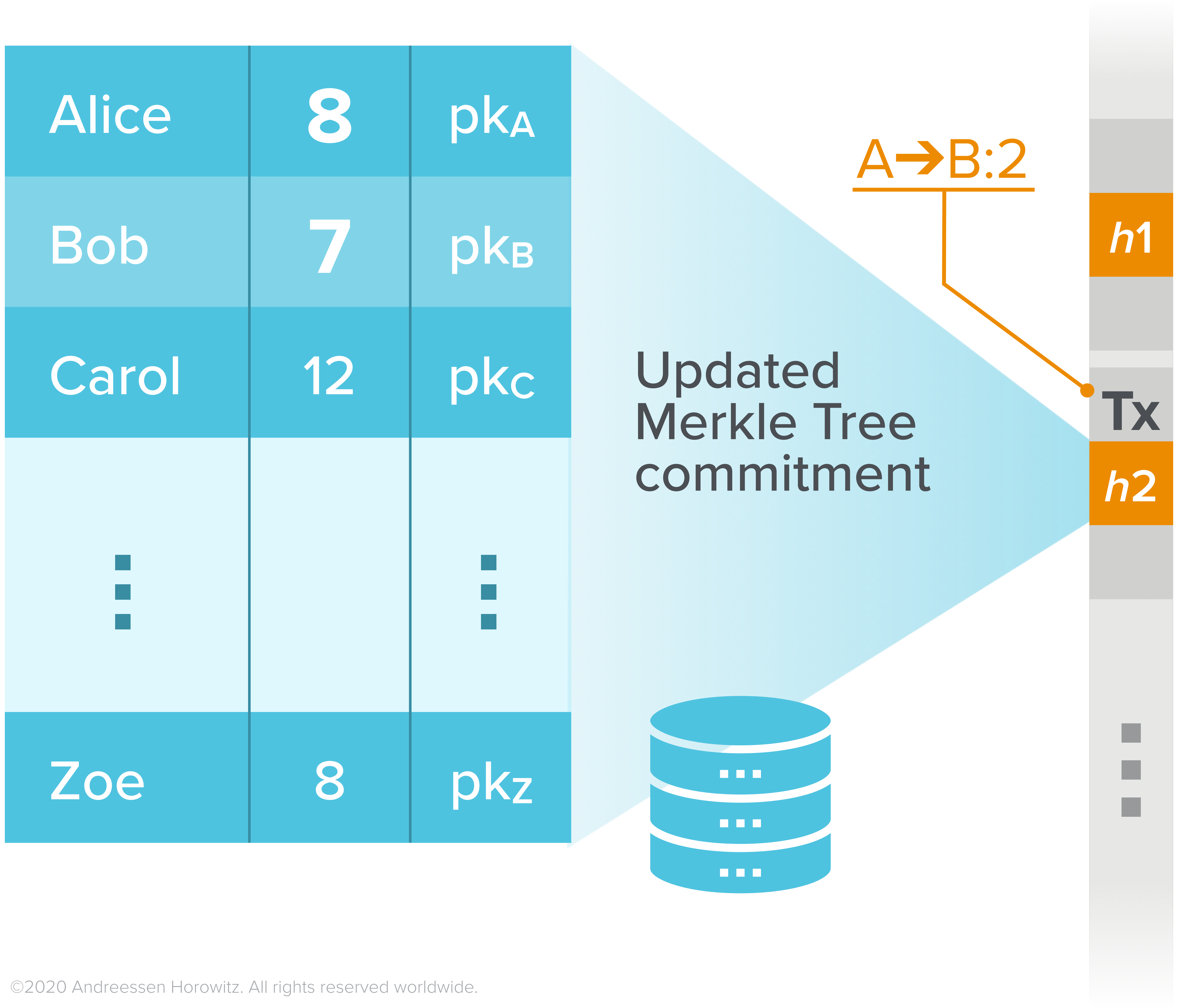
2) Keeping State off the Chain

Database of account balances



off-chain servers
store balances,
on-chain:
only **short** commitment

Alice can prove her balance (10) to anyone with a **short** proof

Tx can update committed state. Chain validates Tx.

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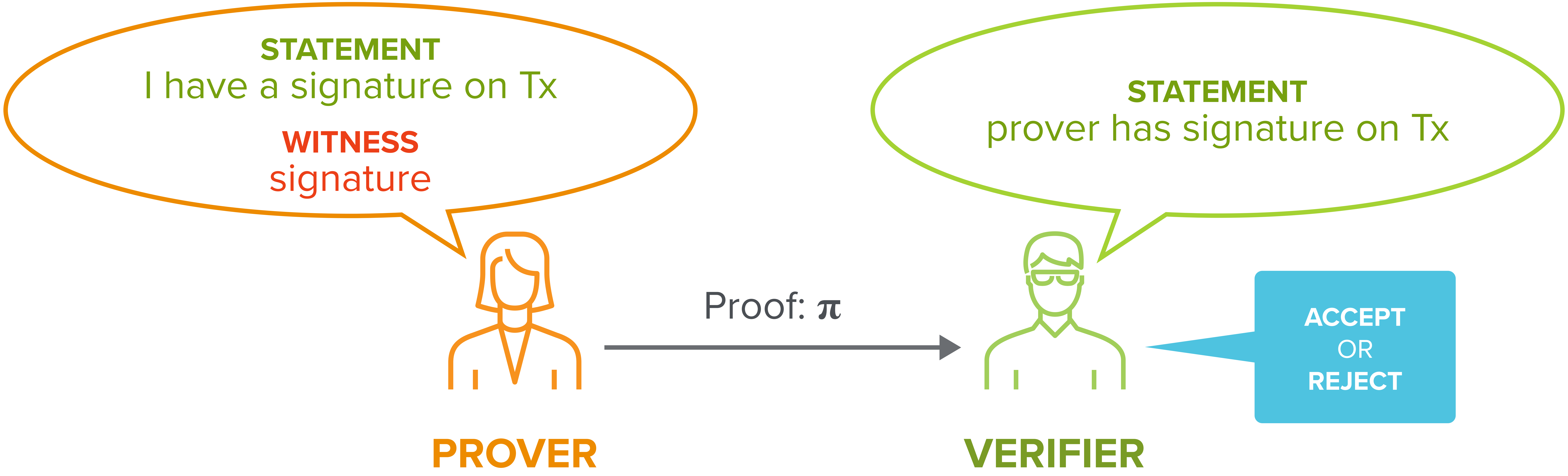
Zero Knowledge Proof Systems

What Is a Proof System? (Informal)

GOAL: prover wants to convince a **verifier** that a **statement** is true



What is a statement: **program**(**statement**, **witness**) → ‘0’ or ‘1’

Properties of a Proof System

Complete: if statement is true, prover can convince verifier

Succinct proof: proof is short (logarithmic in statement size)

Fast verification: verification is fast (logarithmic in statement size)

Efficient proof generation: generating the proof takes linear time

SNARK

SECURITY:

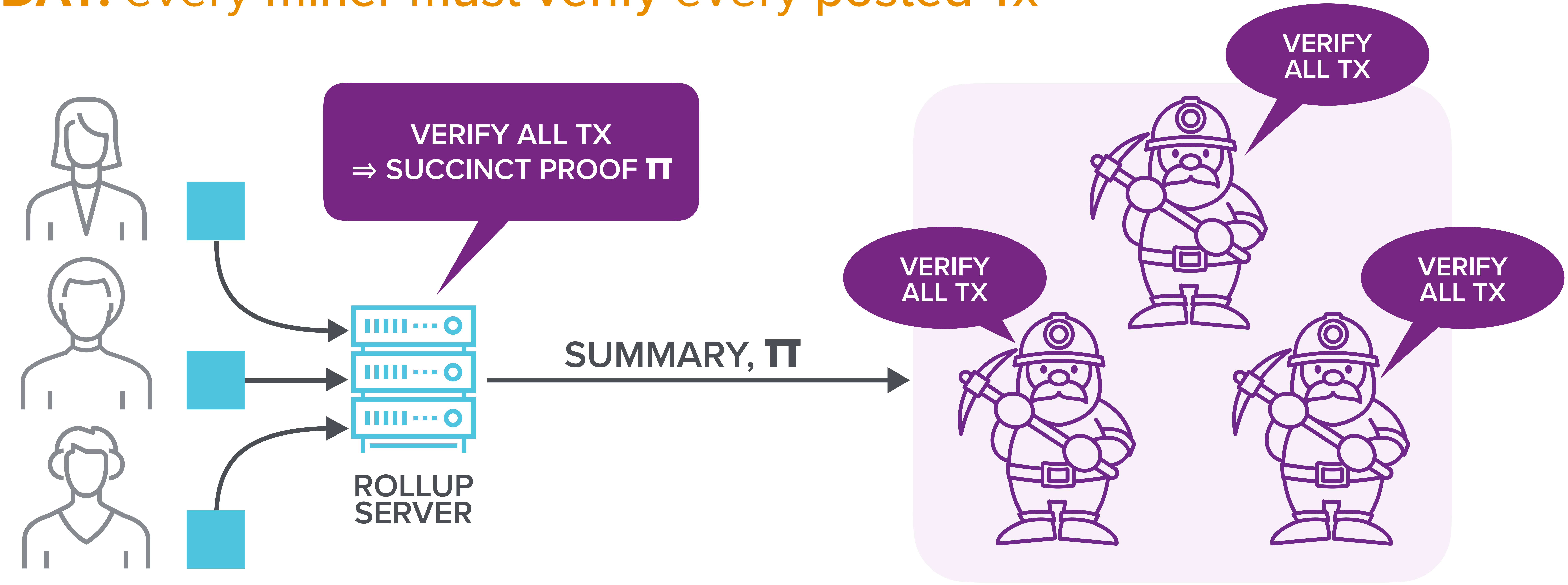
Sound: prover cannot convince verifier of a false statement

Zero knowledge (optional): verifier learns nothing about the witness

zkSNARK

Application 1: Scalability (Rollup) … no ZK

TODAY: every miner must verify every posted Tx



Application 2: Private Data on a Public Blockchain

TODAY: Data on blockchain is public ➔
Businesses cannot use for private B2B applications

PUBLIC VERIFIABILITY

Tx1 | Tx2 | Tx3 | ■ ■ ■

A different approach: only post **hiding commitments** to blockchain

com(APP code), com($state_0$)	com(Tx_1), com($state_1$) ZKP_1	com(Tx_2), com($state_2$) ZKP_2

ZKP: ZK proof that $\underbrace{[state_i,\ Tx_i \rightarrow State_{i+1}]}_{\text{state transition}}$ is consistent with APP code

Final Thoughts

When To Use a Blockchain?

BLOCKCHAIN ≠ DATABASE

Always ask: why not use a centralized system?

- **Blockchain positives:**
  - used when there is no single party trusted by everyone
- **Negatives:** slower and more complex than a centralized system

Trends

The End

Excited To See Your Blockchain Apps!!