Lecture #15:
Rollups

COMS 4995-001:
The Science of Blockchains

URL: https://timroughgarden.org/s25/

Tim Roughgarden

Bottlenecks to Scaling

Answer: load on validators.

- consensus responsibilities:
  - assembling a block (can be hard to do well, more later)
  - communication/bandwidth
  - computation (e.g., signature verification)

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- storage responsibilities:
  - storing sequence of all processed txs

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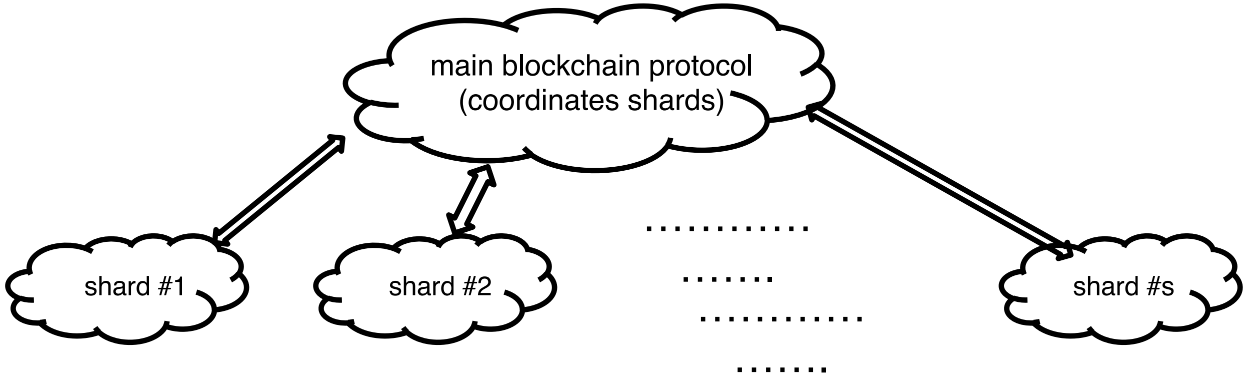
Category #4: "sharding"/horizontal scaling.



Goals for Lecture #15

1. Introduction to “rollups.”
   - an approach to sharding blockchain state and execution
   - piggyback on an “L1” for data availability, liveness, etc.
   - central to the Ethereum ecosystem

2. EIP-4844.
   - modern solution to DA required by rollups: “blob” storage

3. Optimistic rollups. (e.g., Arbitrum, Base, Optimism)
   - rollup state commitments verified via “bisection game”
   - security derived from economic penalties (confiscated collateral)

Introduction to Rollups

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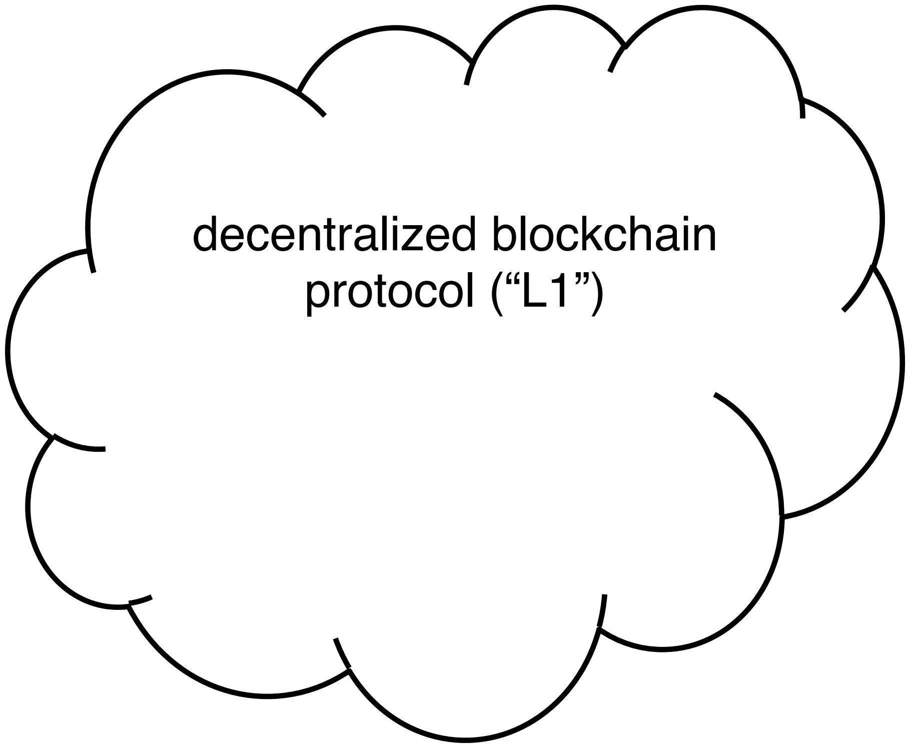
L1 ⇔ Rollup Architecture



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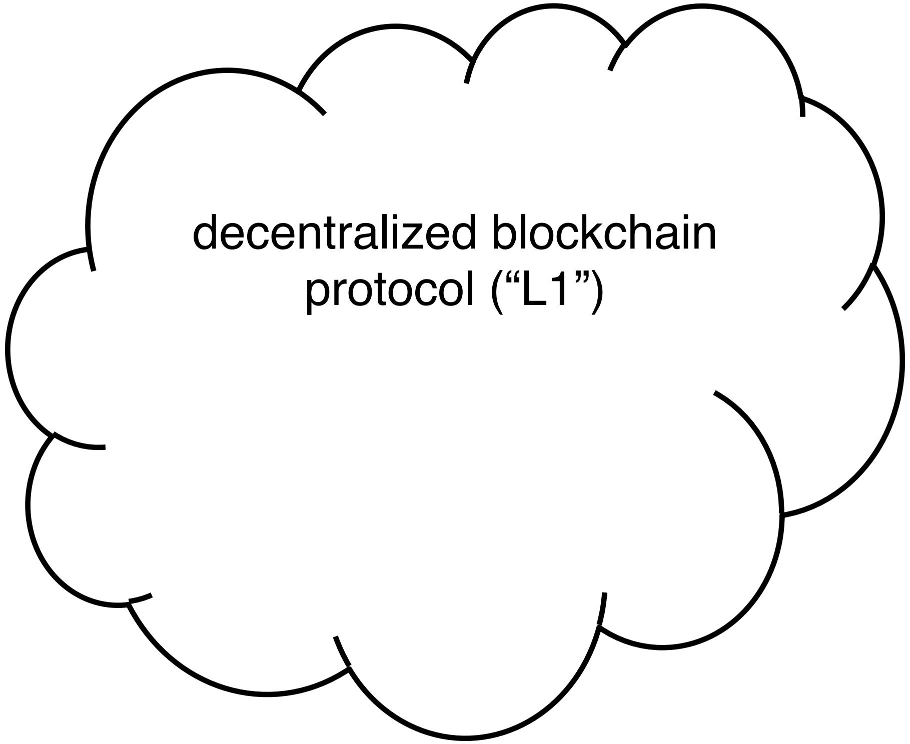

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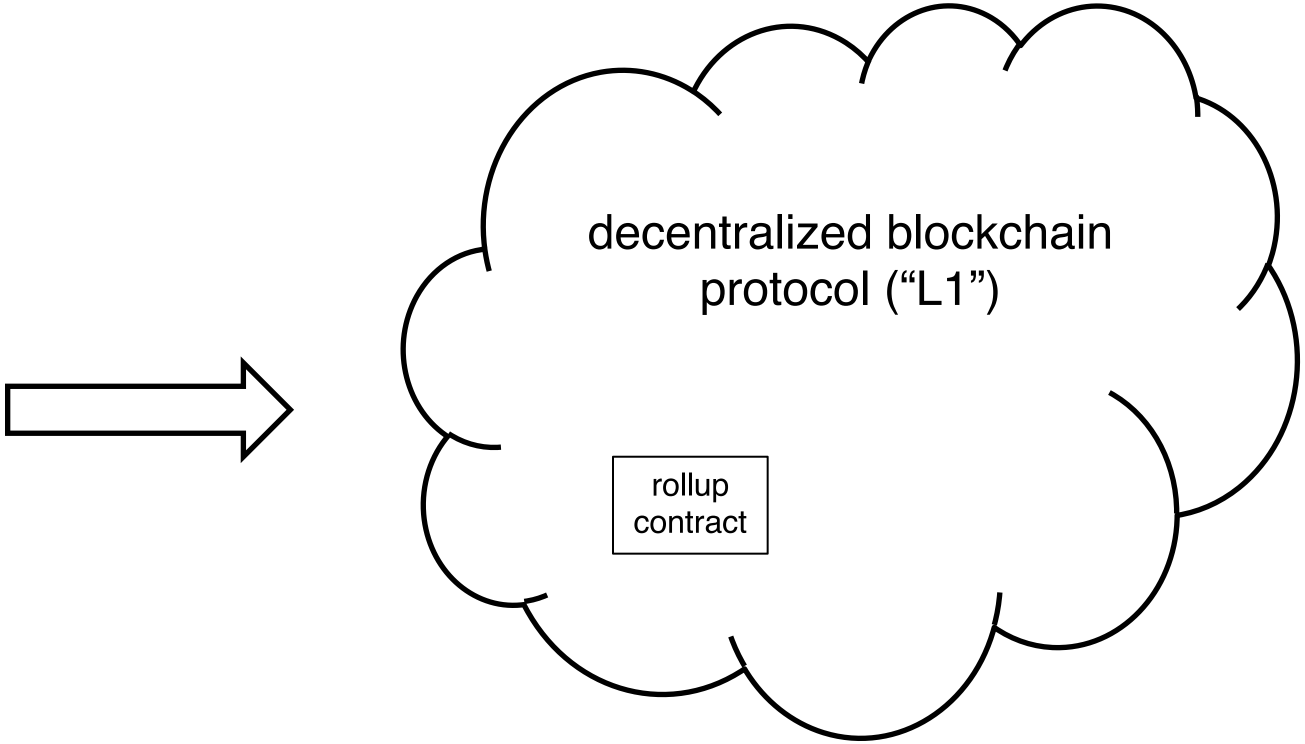

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    - note: anyone can run a rollup full node (i.e., maintain full rollup state)

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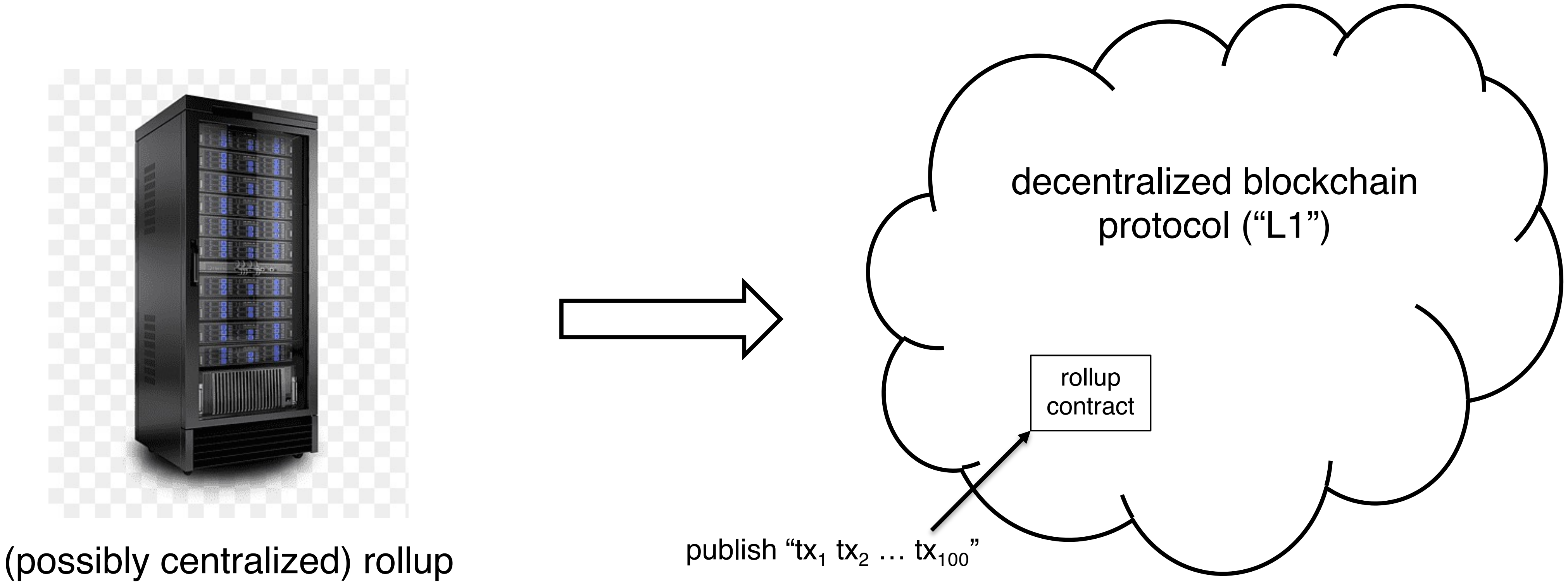

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- periodically publishes commitment to rollup state (e.g. state root) to L1
    - note: any full node can check correctness of commitment

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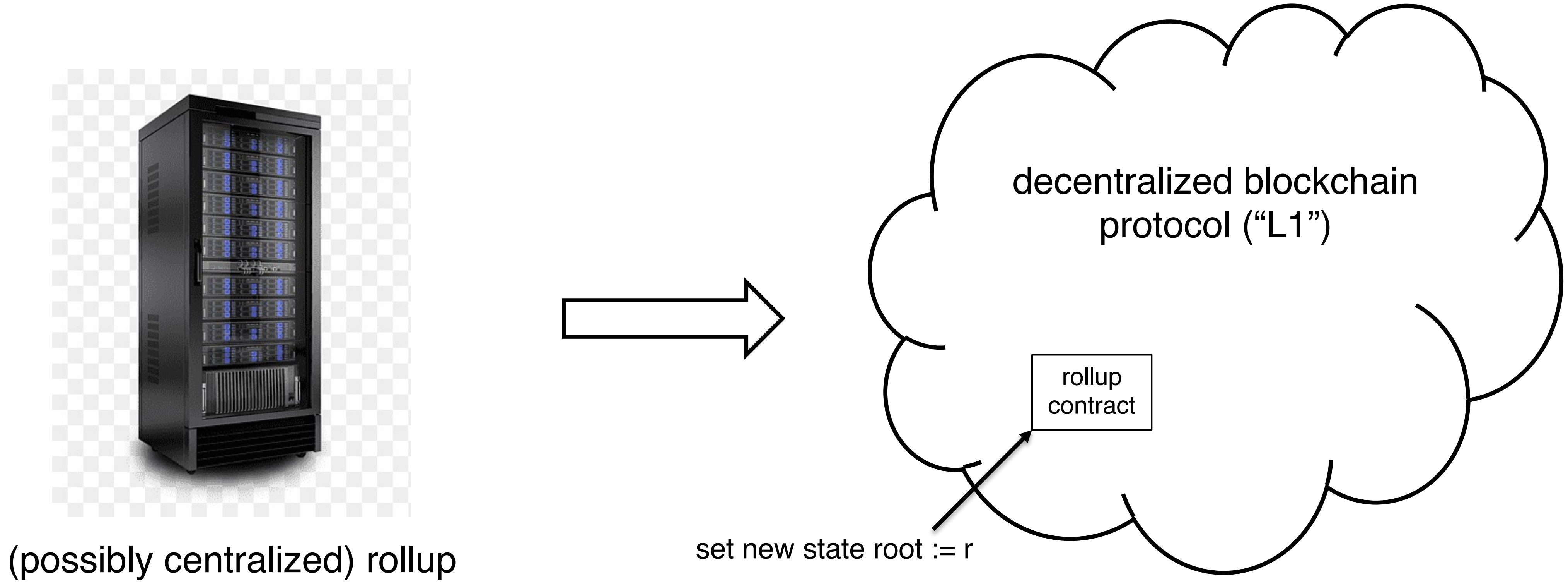

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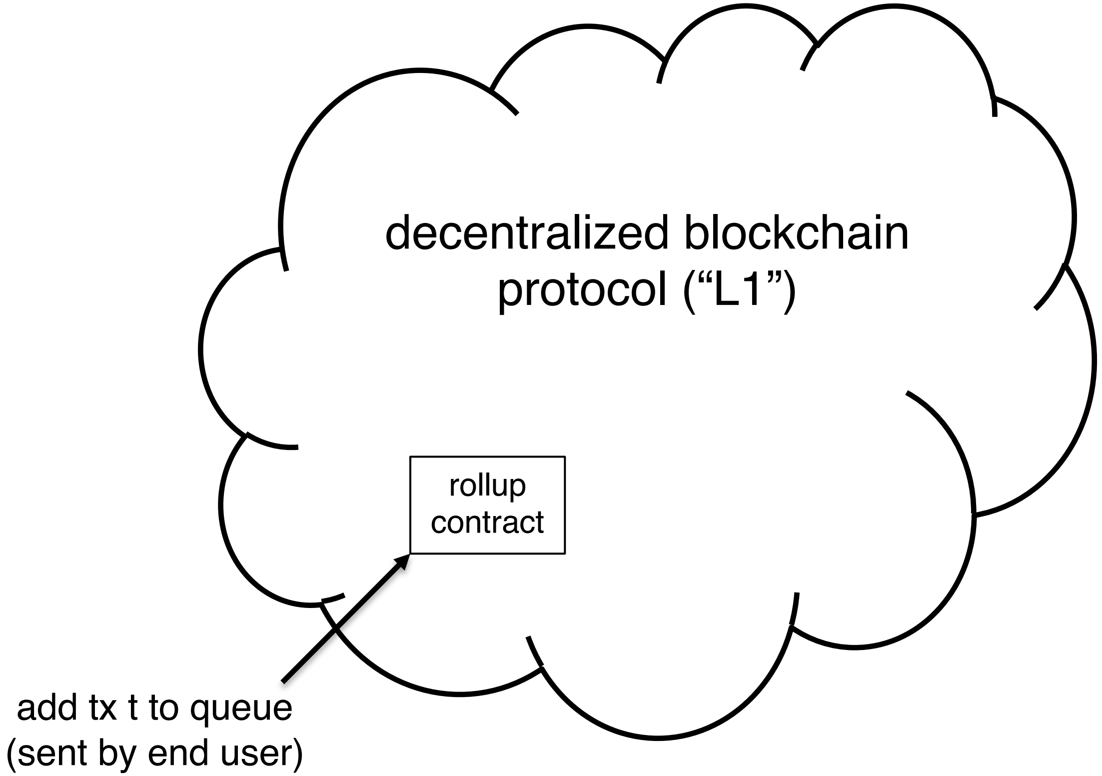
Protection against rollup safety failure: any full node can detect an incorrect state commitment and raise an alarm.

Two Requirements for “Classic” Rollups

1. Escape hatch/forced tx inclusion via the L1.
   - any user can send a rollup tx direct to the rollup’s L1 contract to force its inclusion in the next batch of rollup txs

Forcing the Inclusion of a Rollup Tx

(possibly centralized) rollup



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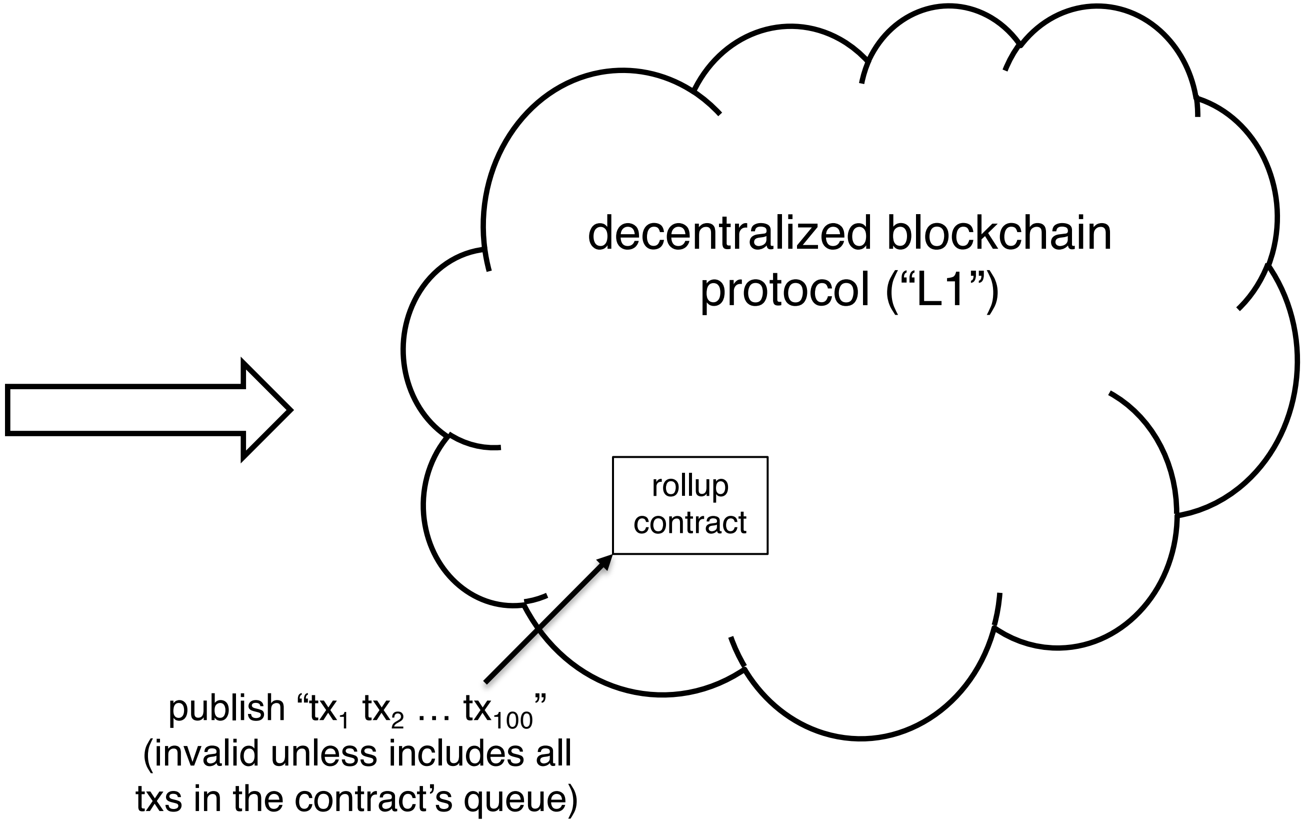

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Question: how can L1 verify correctness without tx re-execution?

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   - SNARKs known since mid-1990s, becoming practical in mid-2020s

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- common case requires little work (optimistic) vs. lots of work (validity)
- rollup txs might get reversed (optimistic) vs. final (validity)

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Upshot: rollup txs became much cheaper (by 10-100x).

– blobs priced separately from regular txs

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Dispute resolution: L1 contract determines correct commitment.

- idea: re-execute minimal amount to determine winner

Dispute Resolution

Canonical scenario: initial state commitment σ_0, assumed correct.

- ordered batch L = $t_1, t_2, \ldots, t_k$ of txs
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- if $\mu_{N/2} \neq \mu'_{N/2}$ ➔ recurse on first half of computation trace
- repeat until locate position i of computation s.t. $\mu_i = \mu'_i$ and $\mu_{i+1} \neq \mu'_{i+1}$

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- L1 contract directly verifies if transition $\mu_i \rightarrow \mu_{i+1}$ correctly computed
  - ≈ simulating one step of the EVM (inside a smart contract)
  - if not, contract rejects σ_1 as invalid, confiscates sequencer's stake
  - if so, contract confiscates challenger's stake

Properties of Optimistic Rollups

Resolving σ'_1 $vs.$ σ_1: view processing of txs in as a sequence of EVM states

- sequencer posts commitment r to its computation $\mu_1, \mu_2, \dots, \mu_N$
- defender posts commitment r' to its computation $\mu'_1, \mu'_2, \dots, \mu'_N$

Bisection game: sequencer, defender reveal midpoints of computations

- repeatedly recurse on first or second half of computation trace until locate position i of computation s.t. $\mu_i = \mu'_i$ and $\mu_{i+1} \neq \mu'_{i+1}$
- L1 contract directly verifies if transition $\mu_i \rightarrow \mu_{i+1}$ correctly computed

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Good news: incorrect state commitment ➔ big economic penalty.

Bad news: requires time (days) for dispute resolution to play out.