Lecture #14:
Scaling Blockchain Protocols

COMS 4995-001:
The Science of Blockchains

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

Tim Roughgarden

Goals for Lecture #14

1. Bottlenecks to scaling.
   - consensus, execution, storage
2. Four approaches to scaling.
   - constrain validator set; better protocols and client implementations; outsourcing validator responsibilities; sharding/horizontal scaling
3. 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

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Question: what’s stopping us?

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- storage responsibilities:
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  - explicitly or implicitly e.g. through large staking requirement
- require high-performance validators
  - e.g., requirements on number of cores, RAM, bandwidth, etc.
  - ideological split between Bitcoin/Ethereum and newer blockchains

Approaches to Scaling (con’d)

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  - parallel execution of non-conflicting transactions

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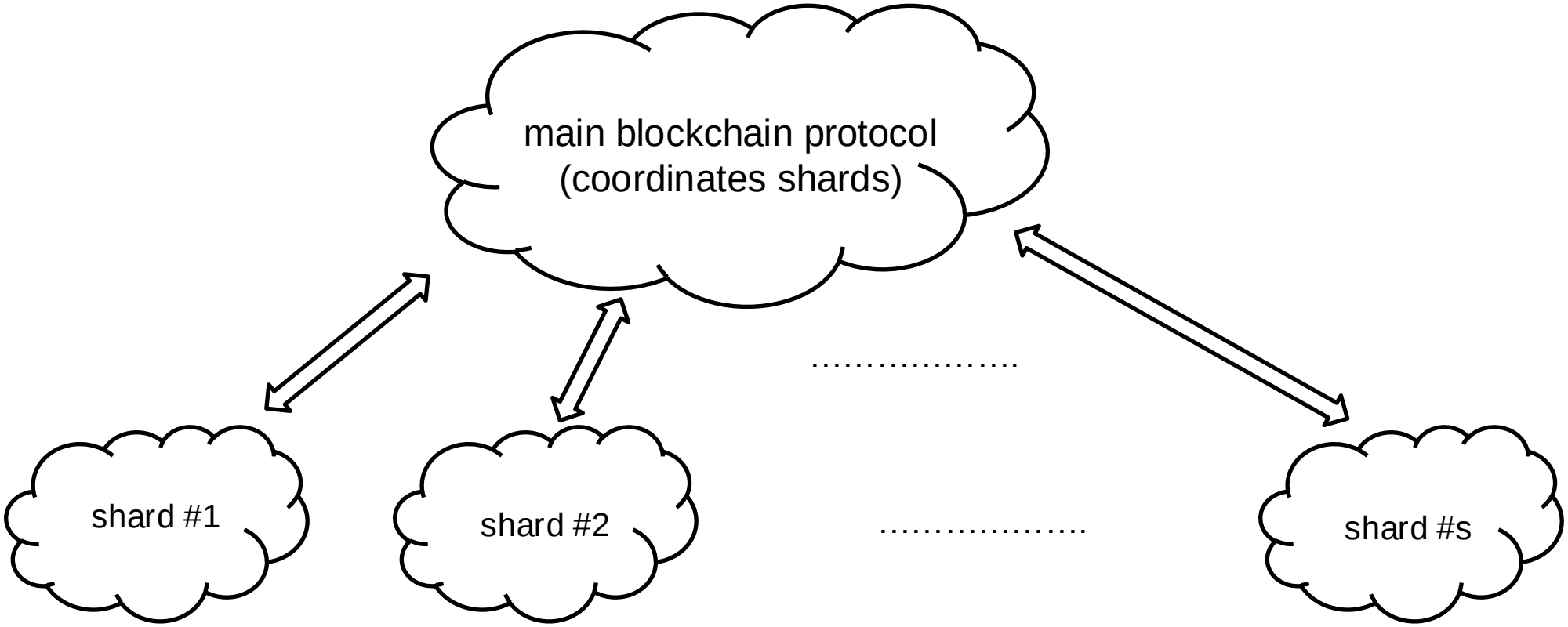
  - possible future: to outsource execution duties
- possible future: execution + maintenance of blockchain state
  - validators still expected to verify correctness of execution
  - cf., stateless clients (see last lecture)

Approaches to Scaling (con’d)

Category #4: “sharding”/horizontal scaling.

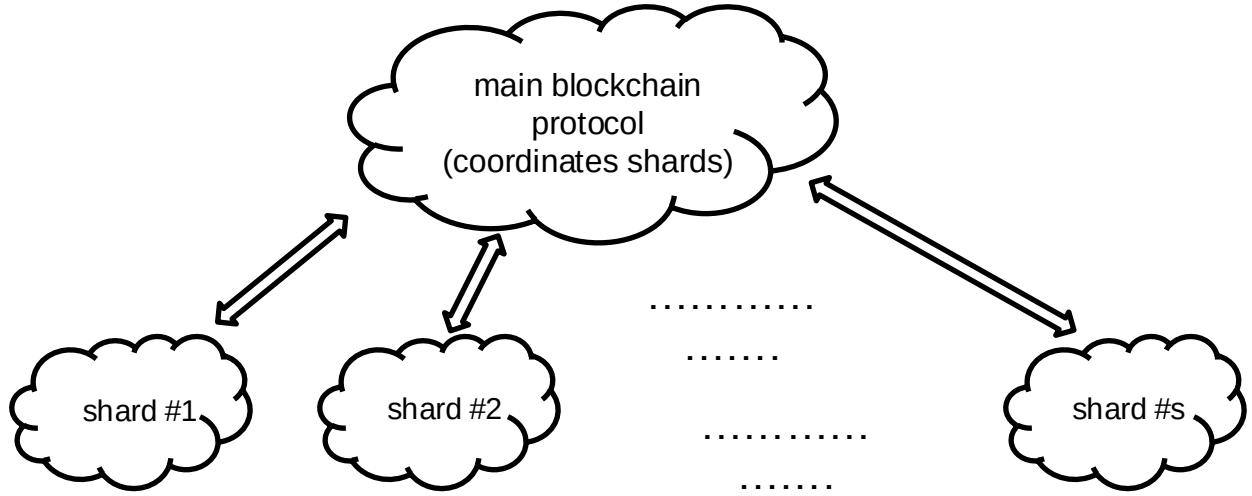
- unlike replication, want more validators ➔ more processing power



Approaches to Scaling (con’d)

Category #4: “sharding”/horizontal scaling.

- sharding storage: conceptually straightforward



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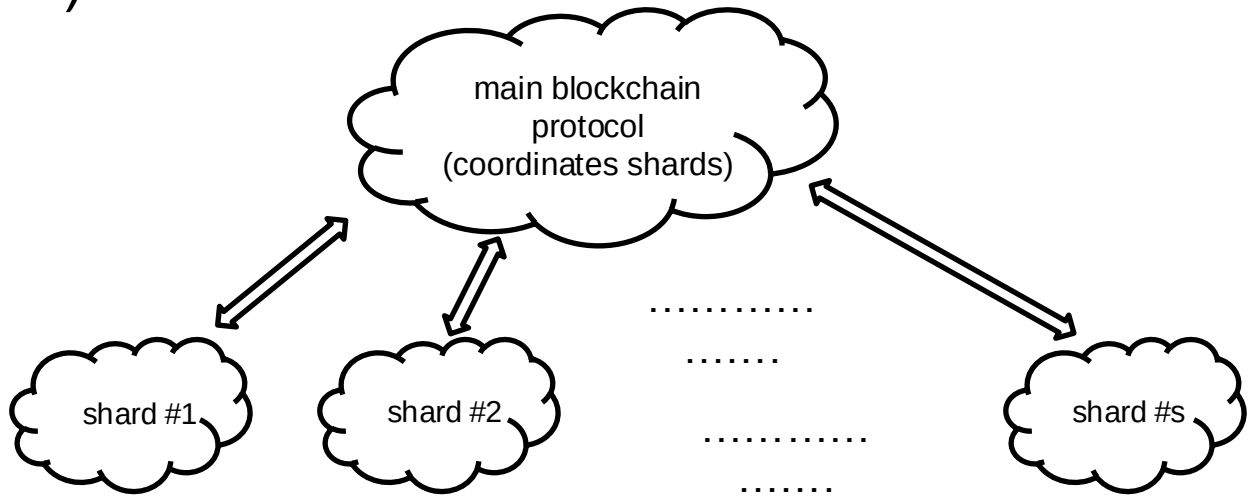

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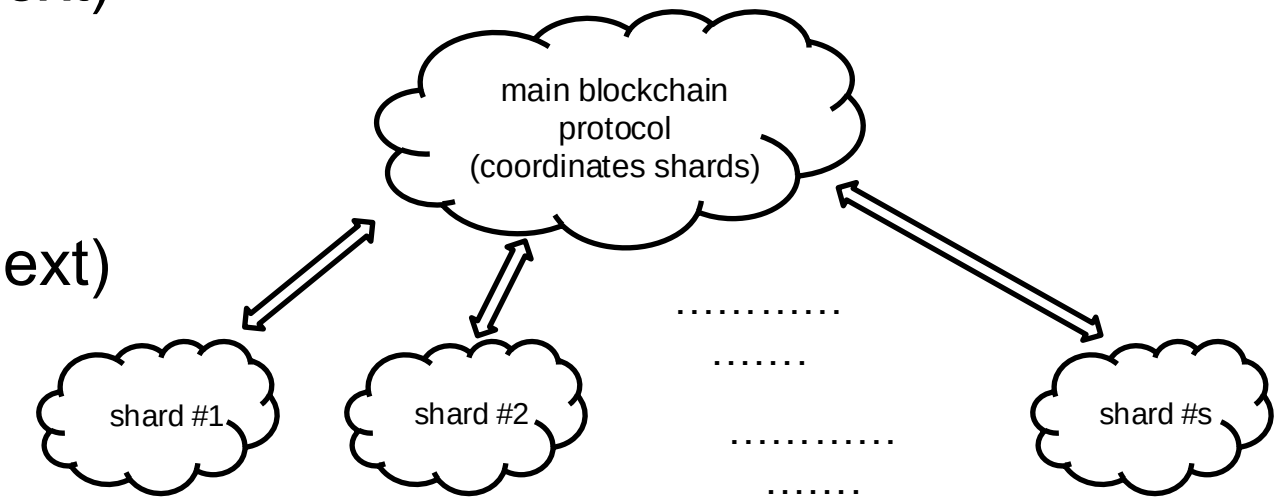

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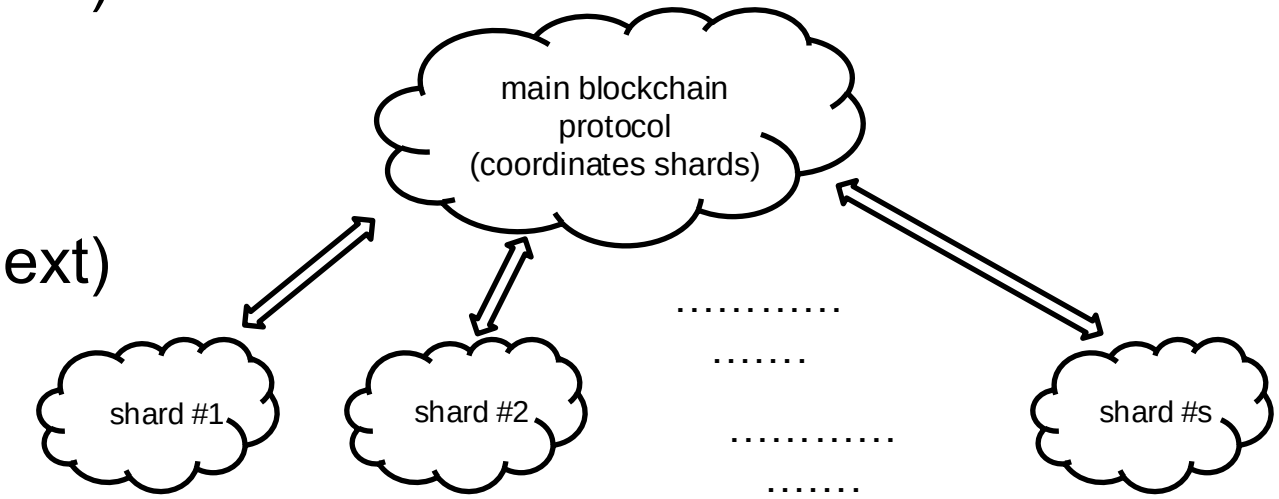
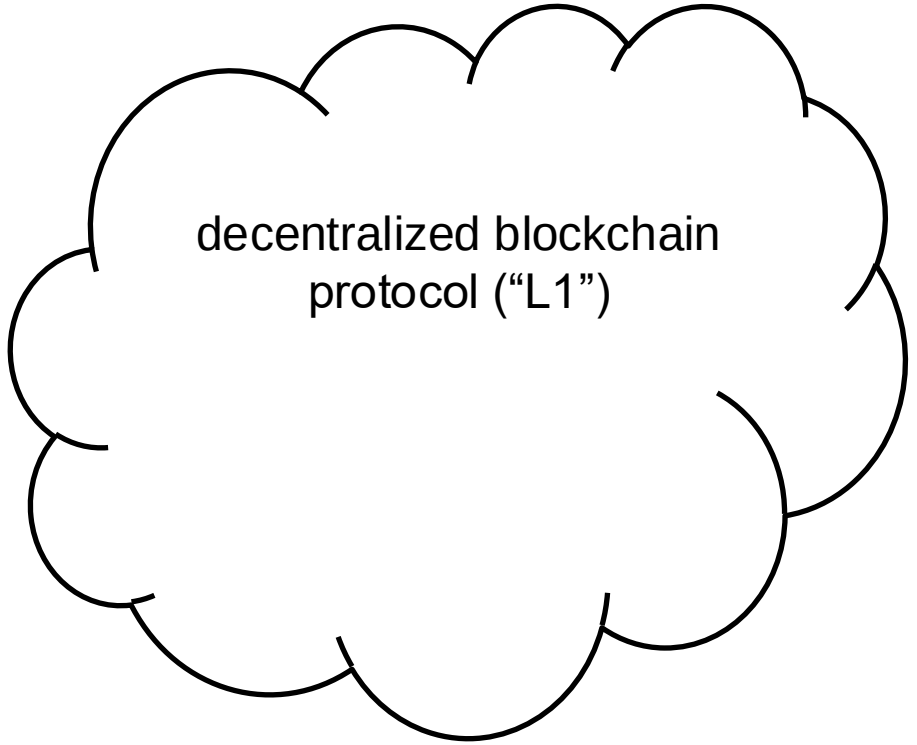
  - with shared state across shards: largely unsolved



Introduction to Rollups

Assume: a decentralized “layer-one” blockchain (“L1”) with strong consistency and liveness guarantees. (e.g., Ethereum)

L1 ⇔ Rollup Architecture



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“Classic” rollup: a blockchain/virtual machine with its own state

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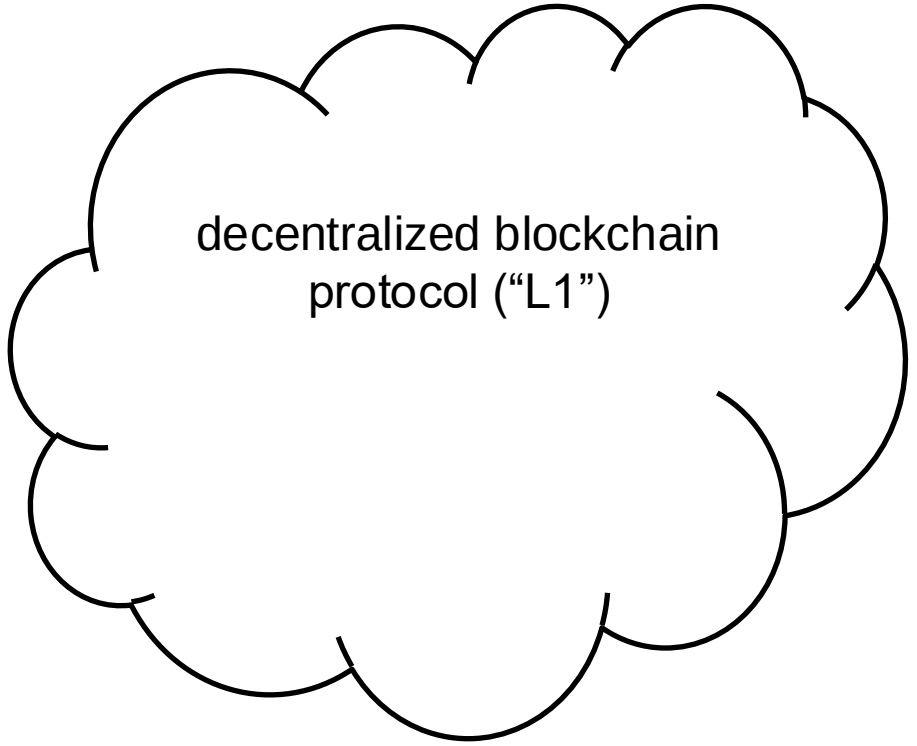
(possibly centralized) rollup



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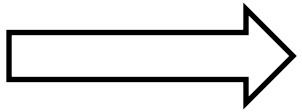

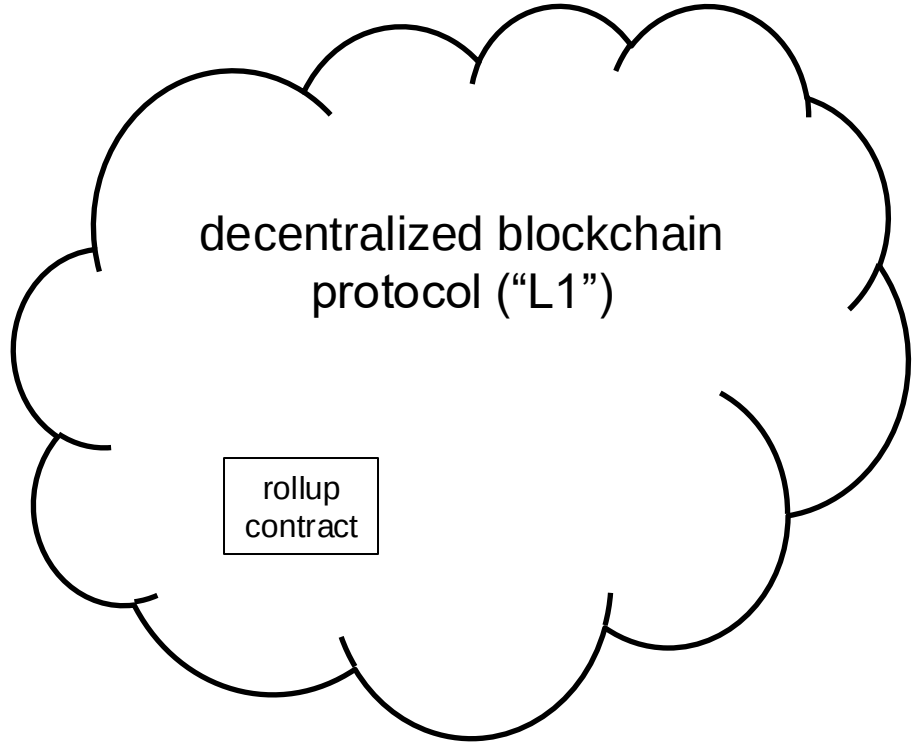

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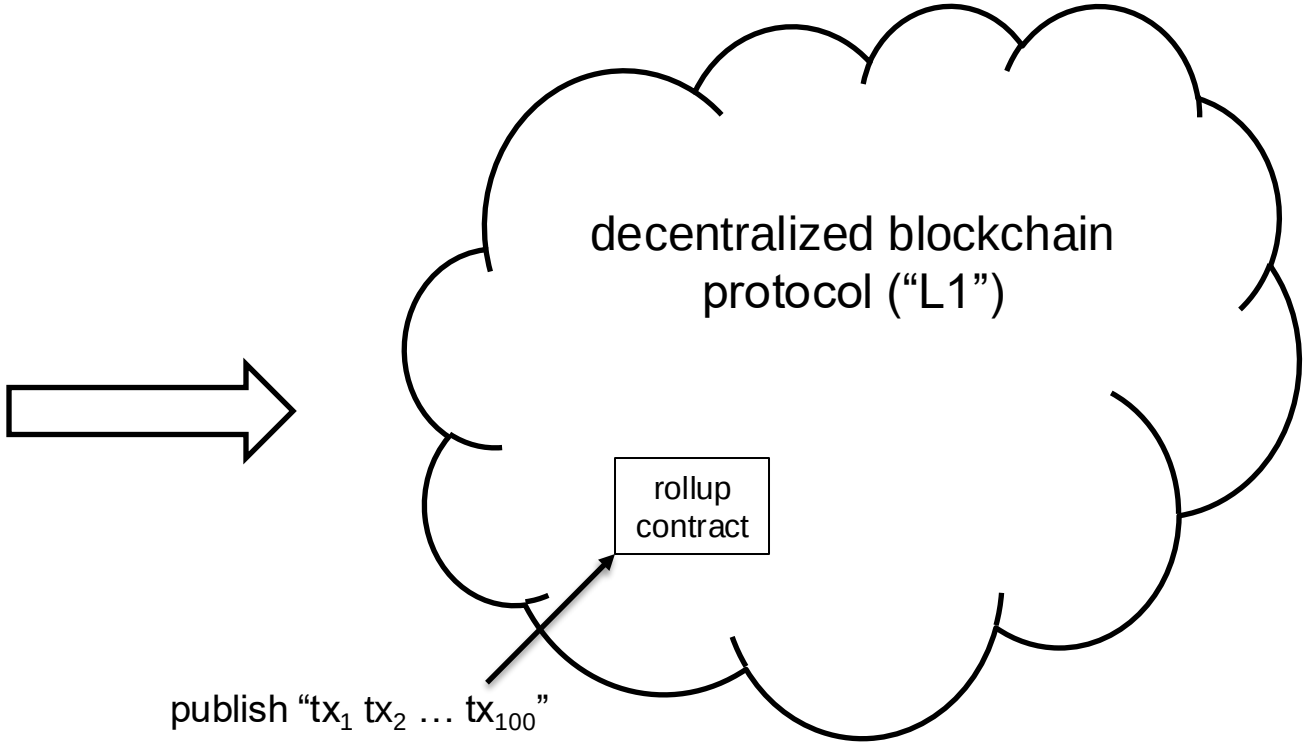

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  - note: any full node can check correctness of commitment

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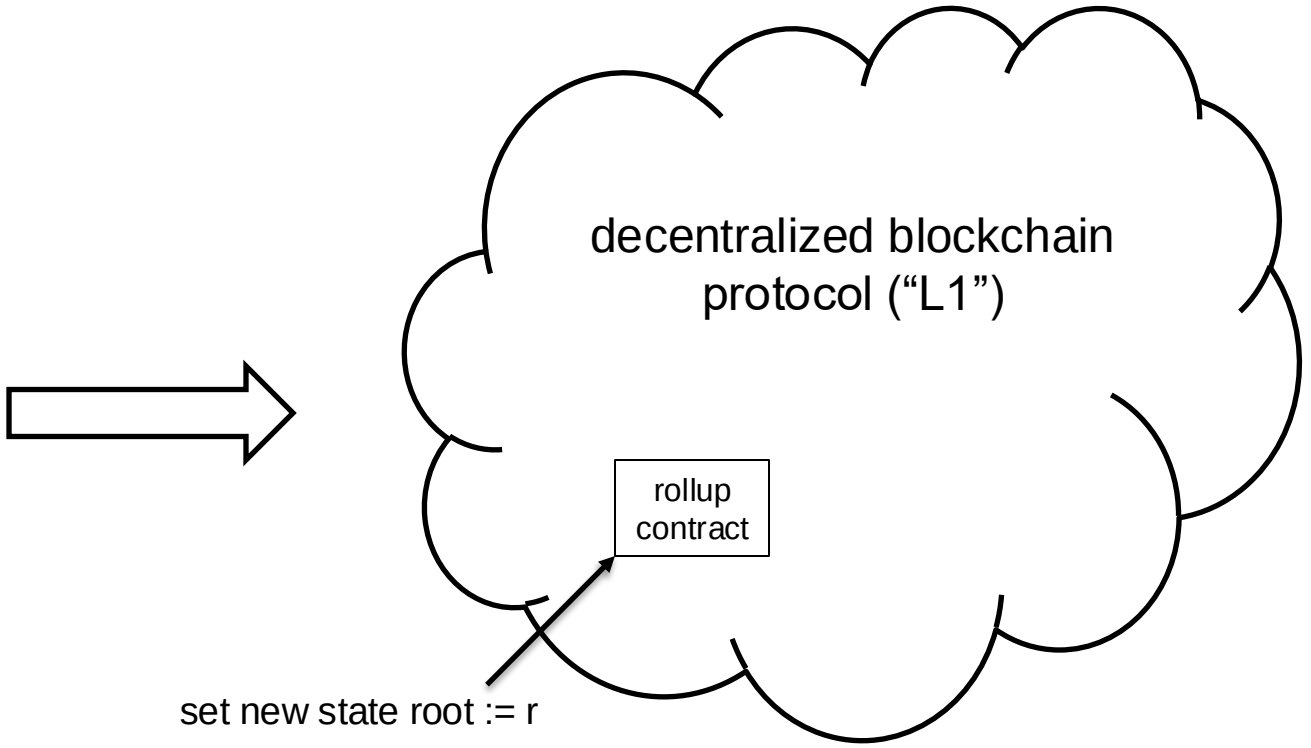

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Protection against rollup safety failure: any full node can detect an incorrect state root and raise an alarm.

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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

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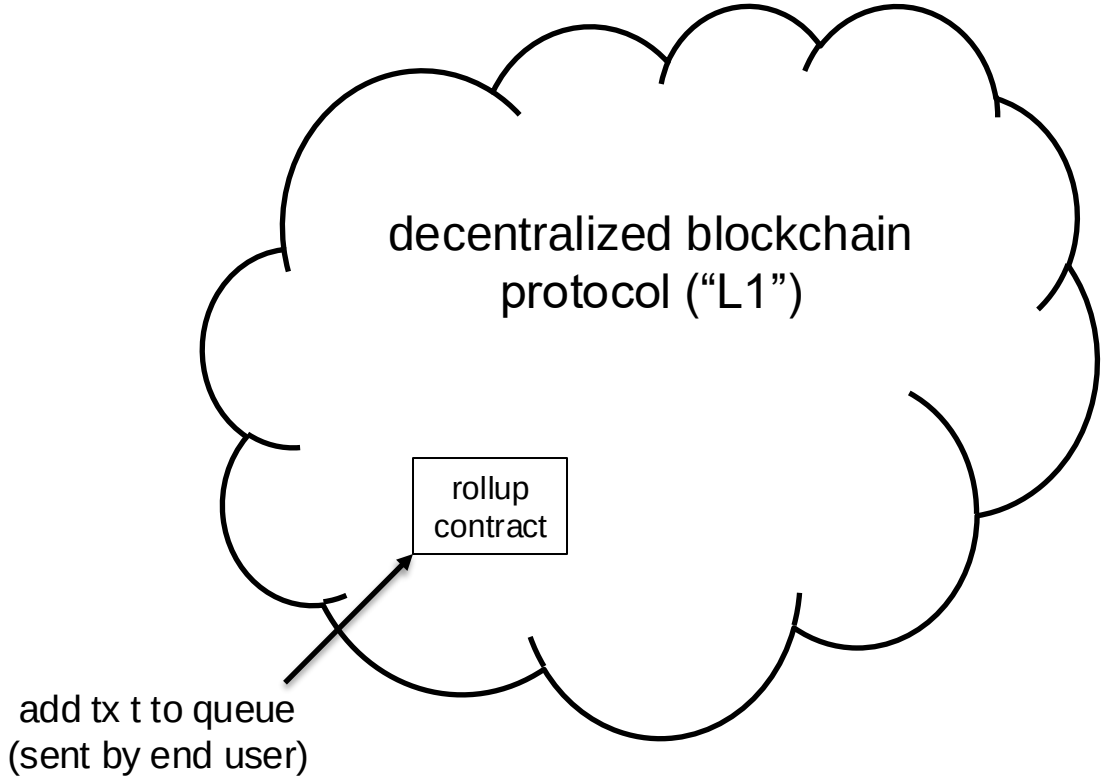

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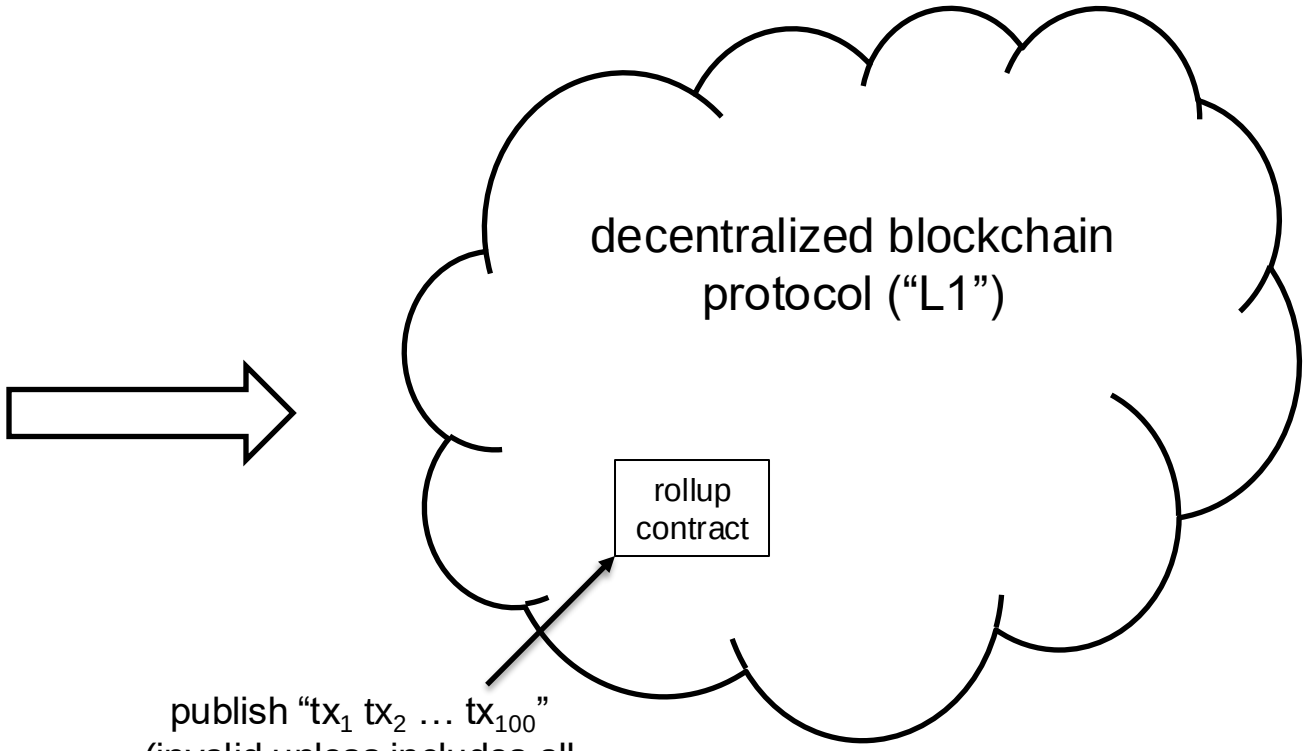

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     - defeats purpose of rollup (to offload execution from L1 validators)

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   - “zk”/validity approach: L1 verifies a “SNARK” which proves the correctness of the state commitment