Verifying Reachability for Stateful Networks

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Stateless vs Stateful Networks

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- Packets forwarded based on static rules.
- Rules change slowly in response to:
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  - Changes in policy.

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  - Every time packet is forwarded.

Why consider *stateful* networks?

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Not supported by most existing verification tools.

State impacts invariants

Invariants We Consider

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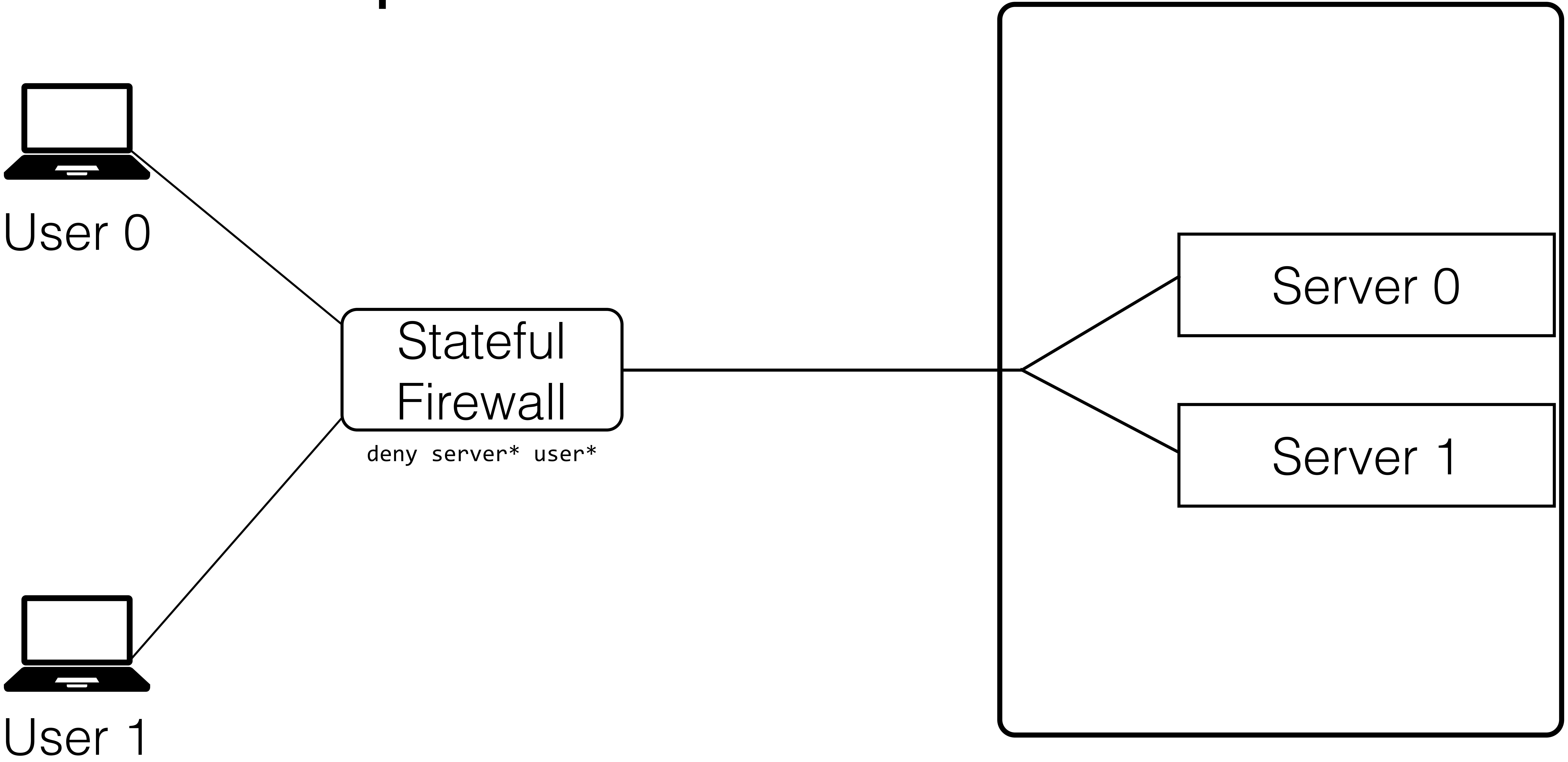
    - Invariants can include temporal aspects.
    - Might need to consider more than just packets.

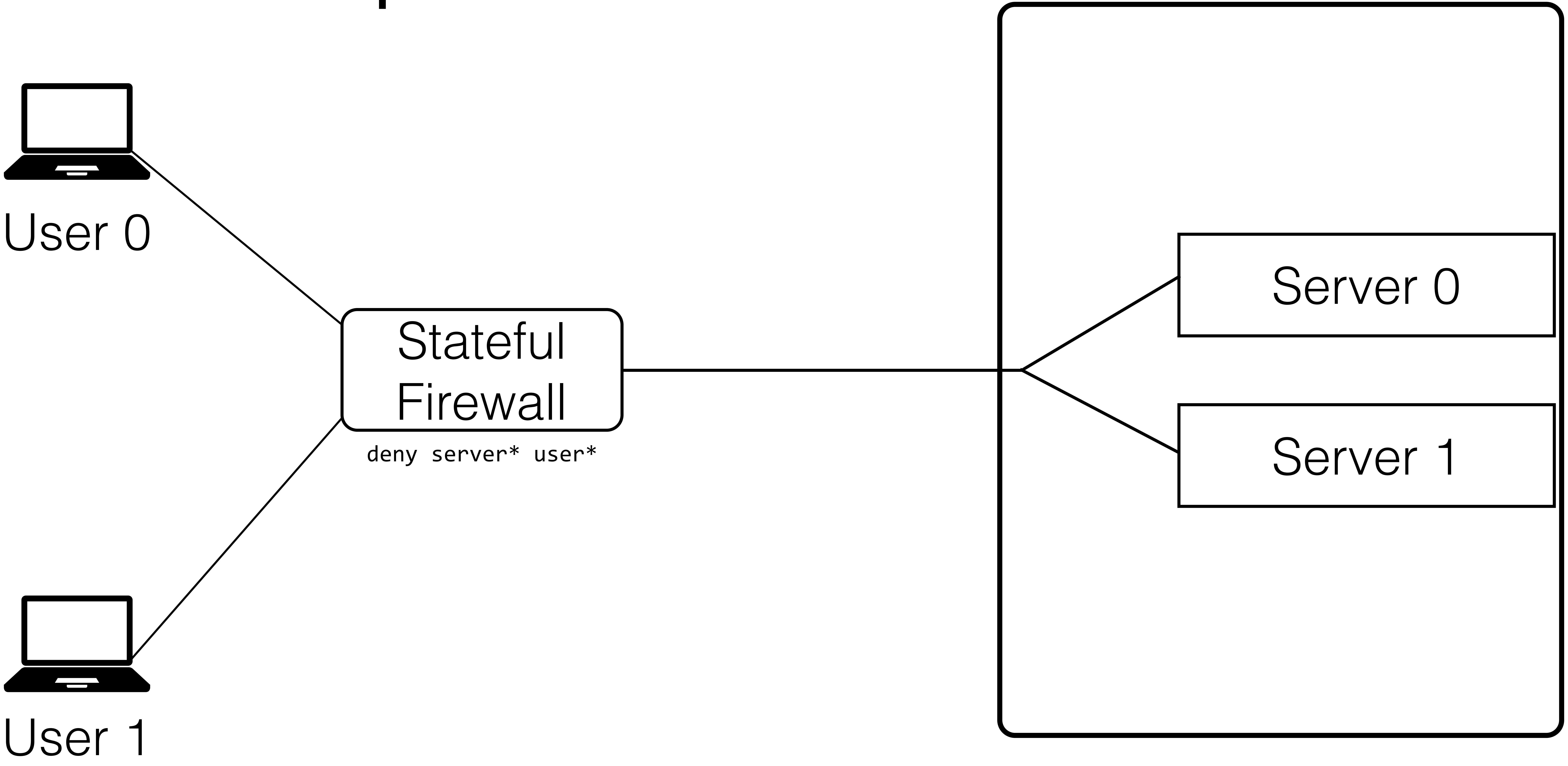
Temporal Invariants



User 1 receives no packets from server 0

Standard Reachability

Temporal Invariants

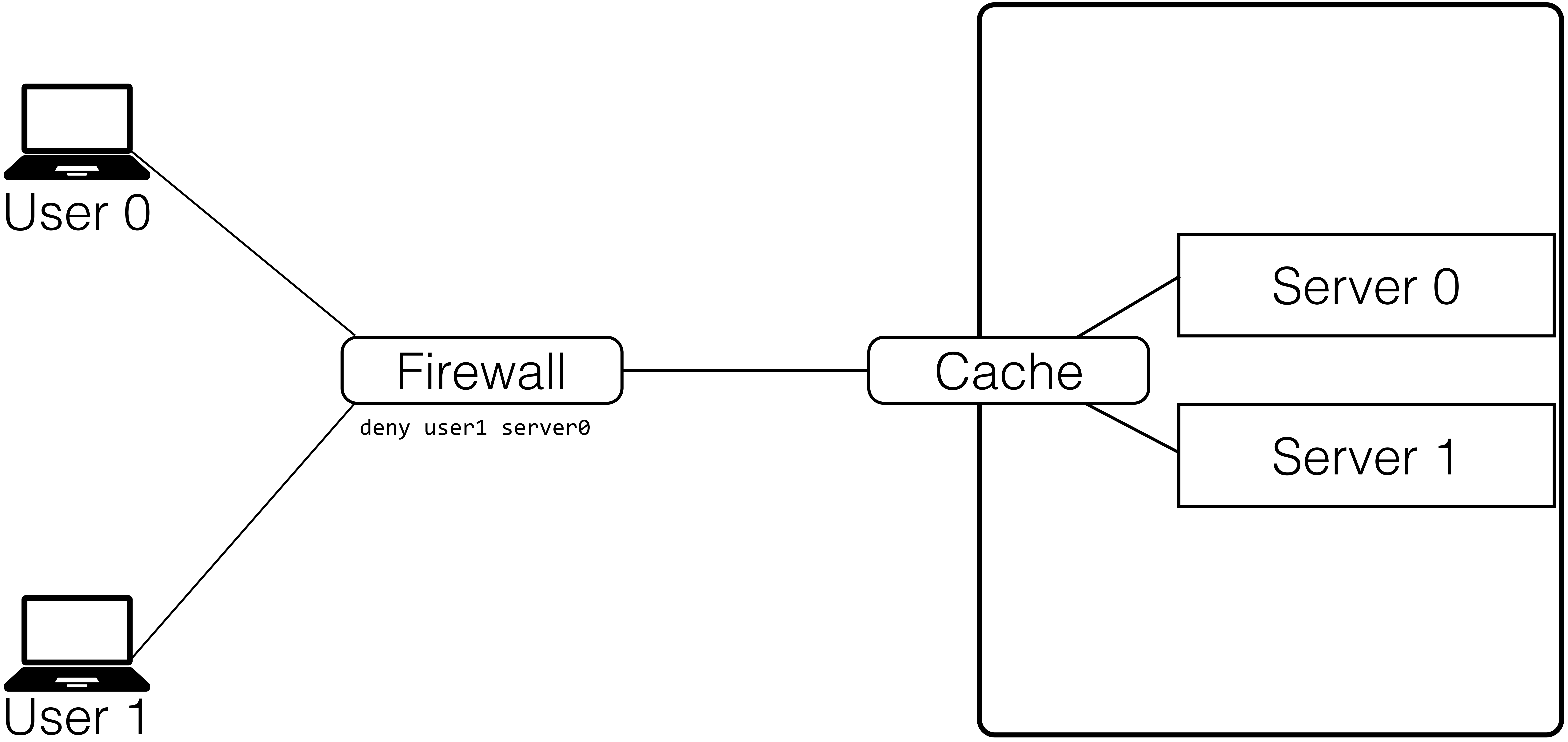


User 1 receives no packets from server 0 without initiating a connection

Standard Reachability

Temporal Property

Consider Data Instead of Packets



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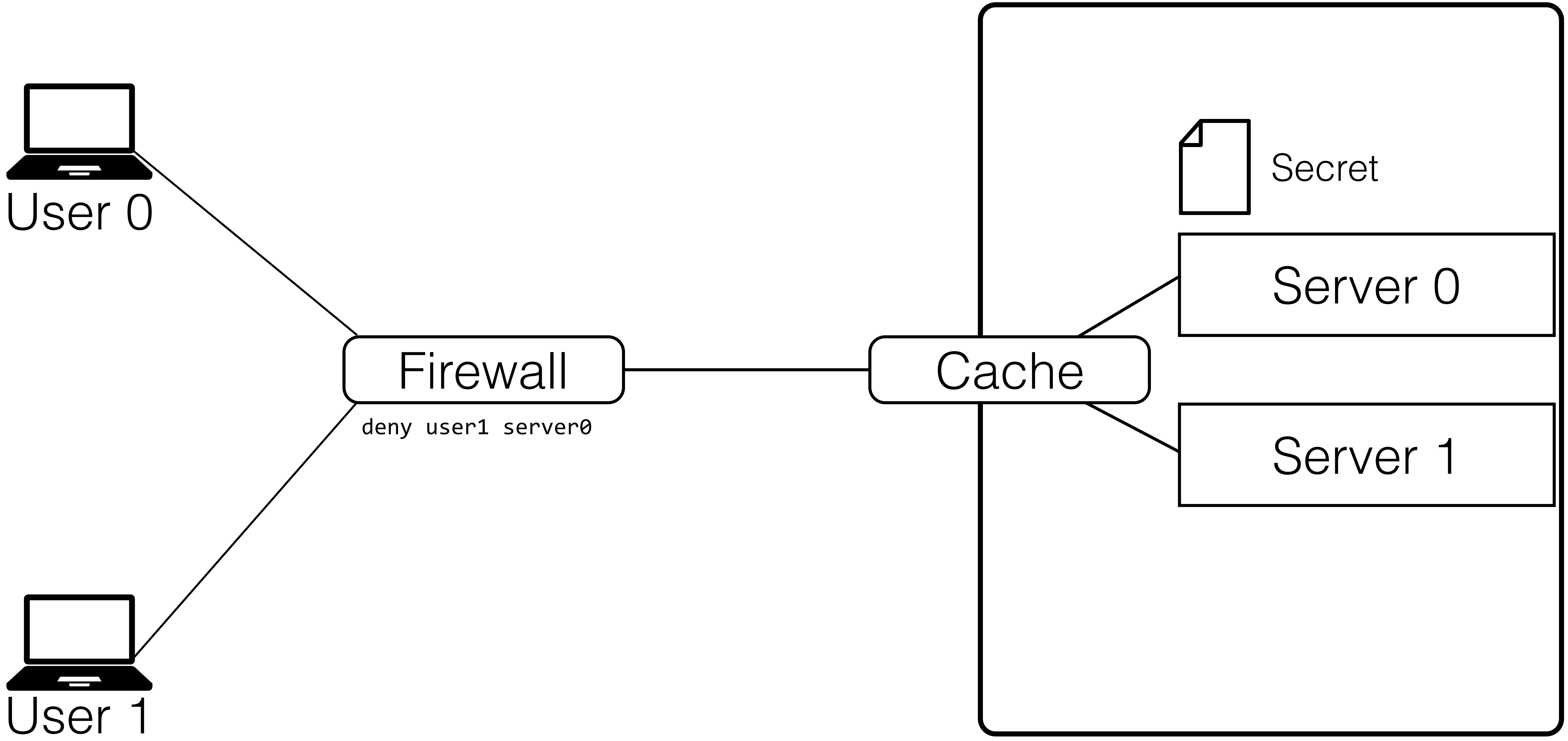

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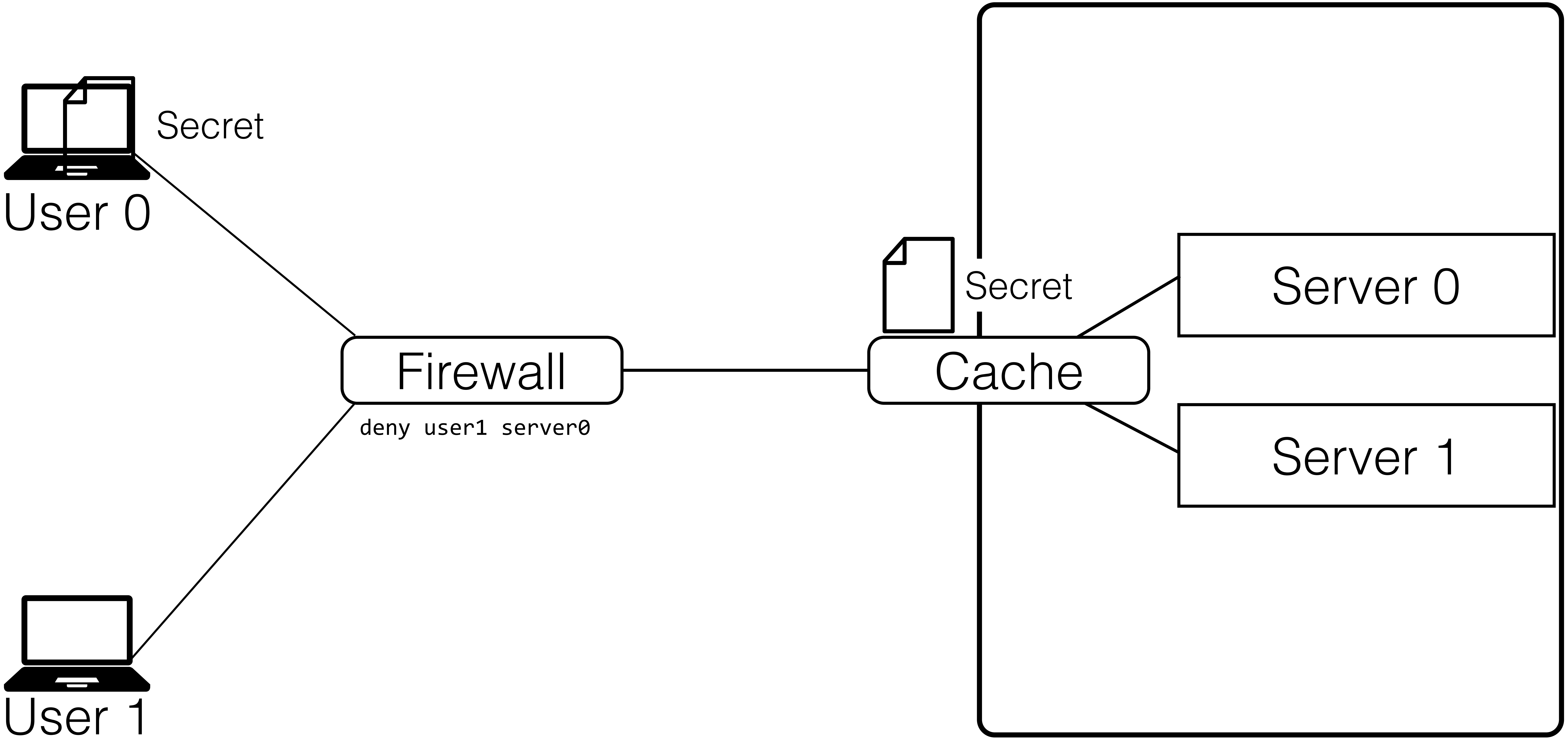

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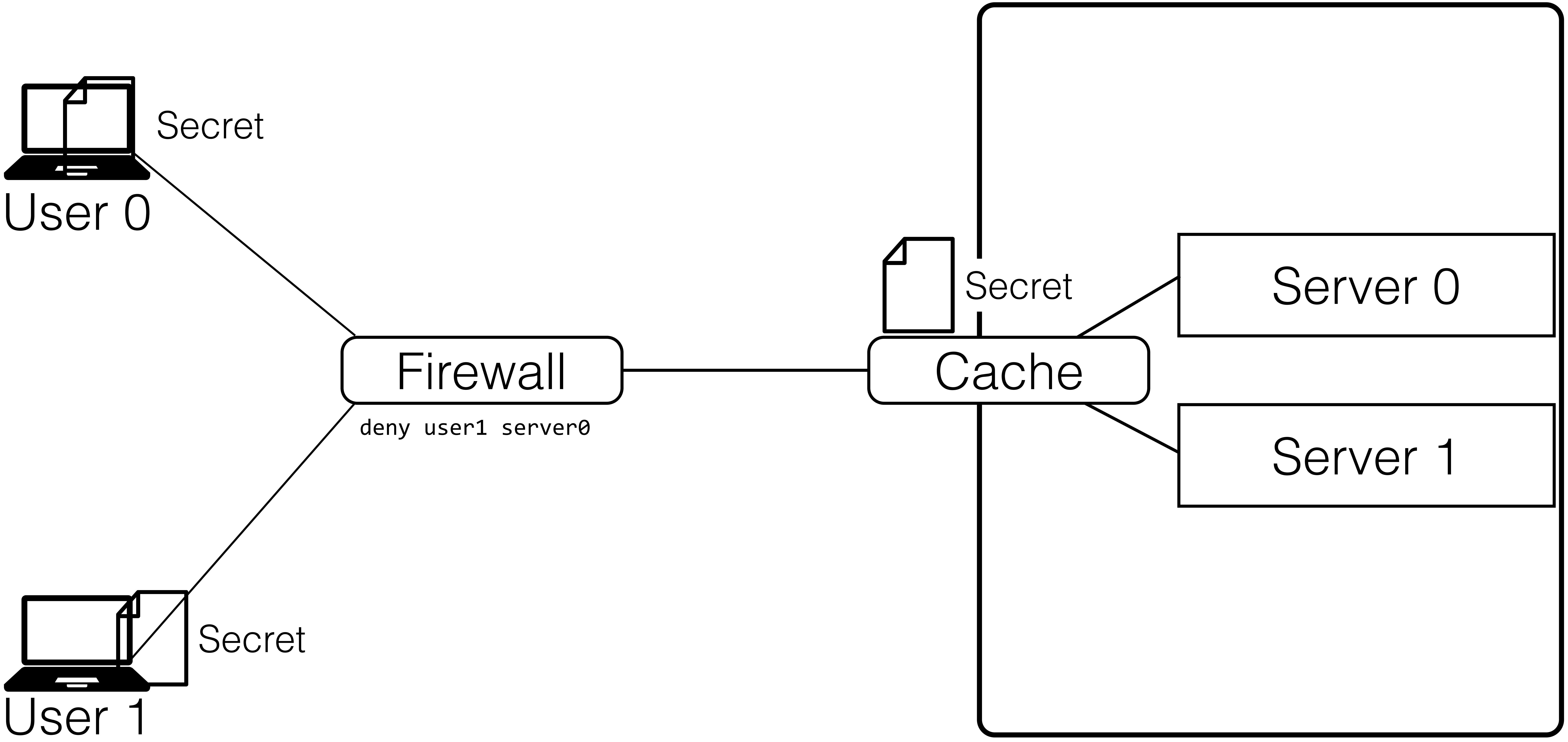

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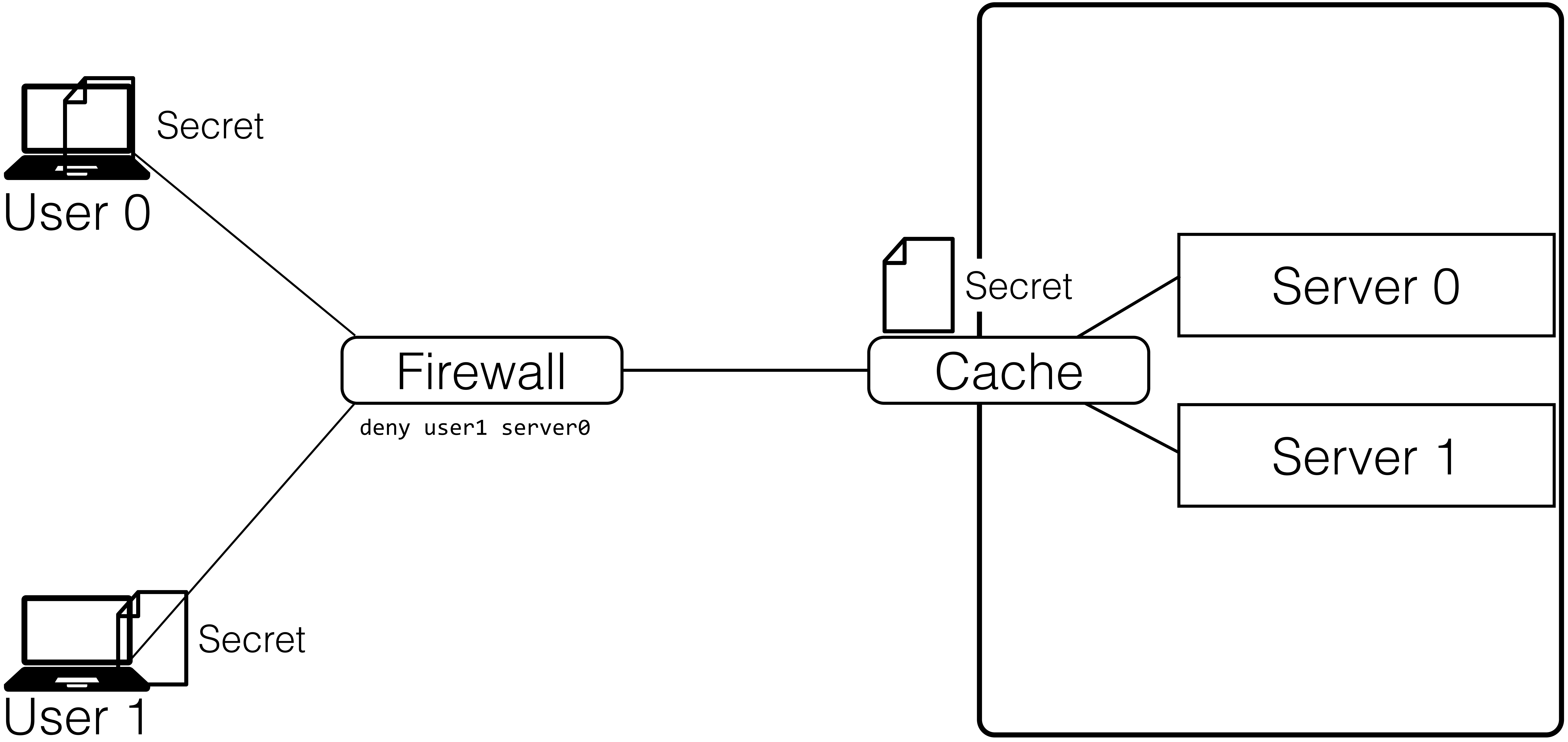

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Roadmap

- ~~Why stateful networks, and how does state affect invariants?~~
- Existing work on network verification.
- VMN: Our system for verifying networks with state.
- Scaling verification.

Network Verification Today

- Switches and Controllers: Static forwarding rules in switches.

    HSA, Veriflow, NetKAT, Vericon, FlowLog, etc.

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- Verification for networks with mutable datapaths

  SymNet: Uses symbolic execution, limited state and behaviors.

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VMN: System for **scalable** verification of **stateful networks.**

VMN Flow

Model each middlebox in the network

↓

Build network forwarding model

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Logical Invariants

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SMT Solver (Z3 from MSR)

↓ Invariant Holds

↓ Example of violation

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  - **Code** written to match bit patterns in packet, etc.
  - **Configuration** is in terms of **higher level abstractions**
    - Example source and destination addresses, payload is infected, etc.
- Verify invariants which are also expressed in these terms.

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- Complexity of matching code prevents verification in even small networks.

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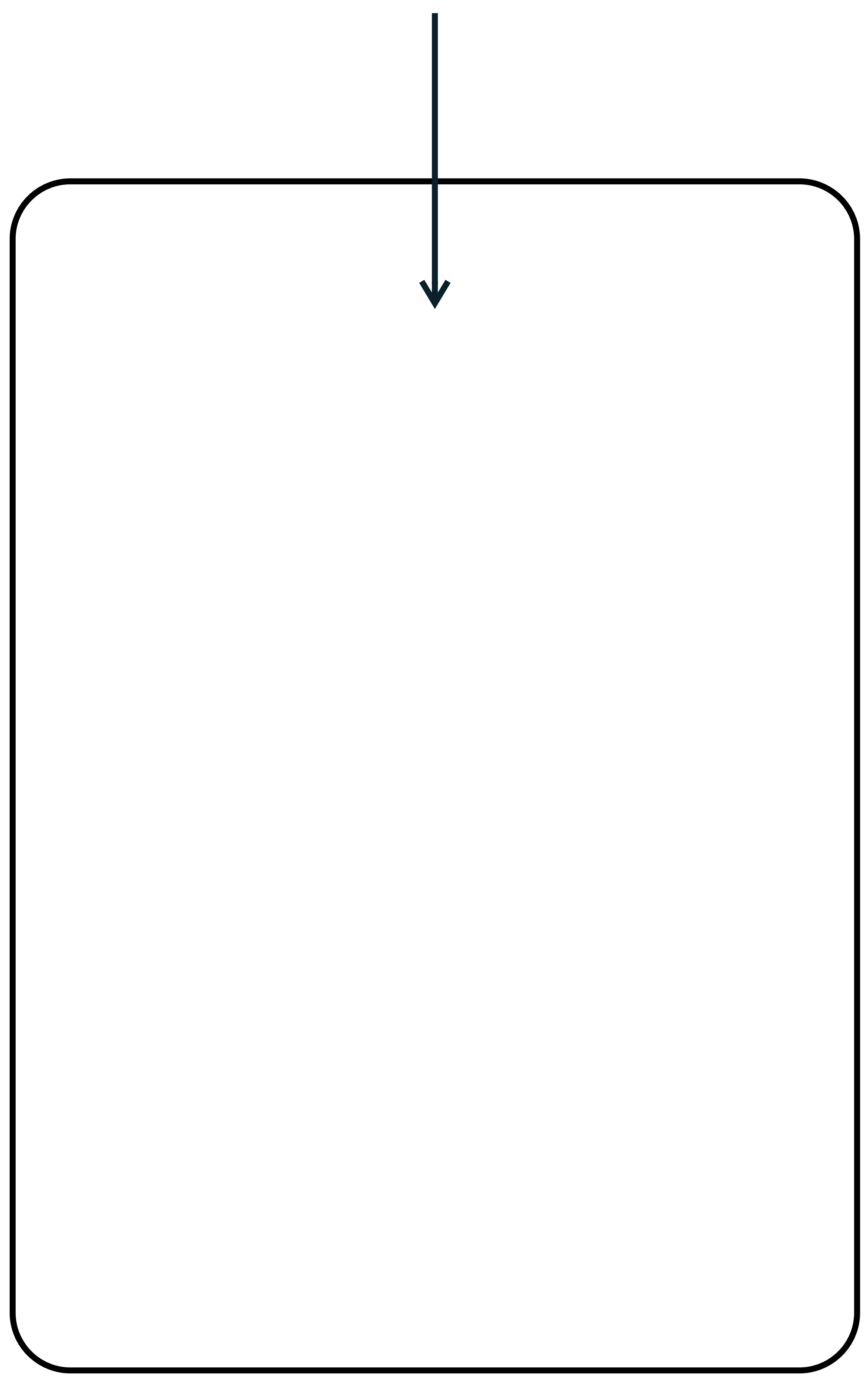

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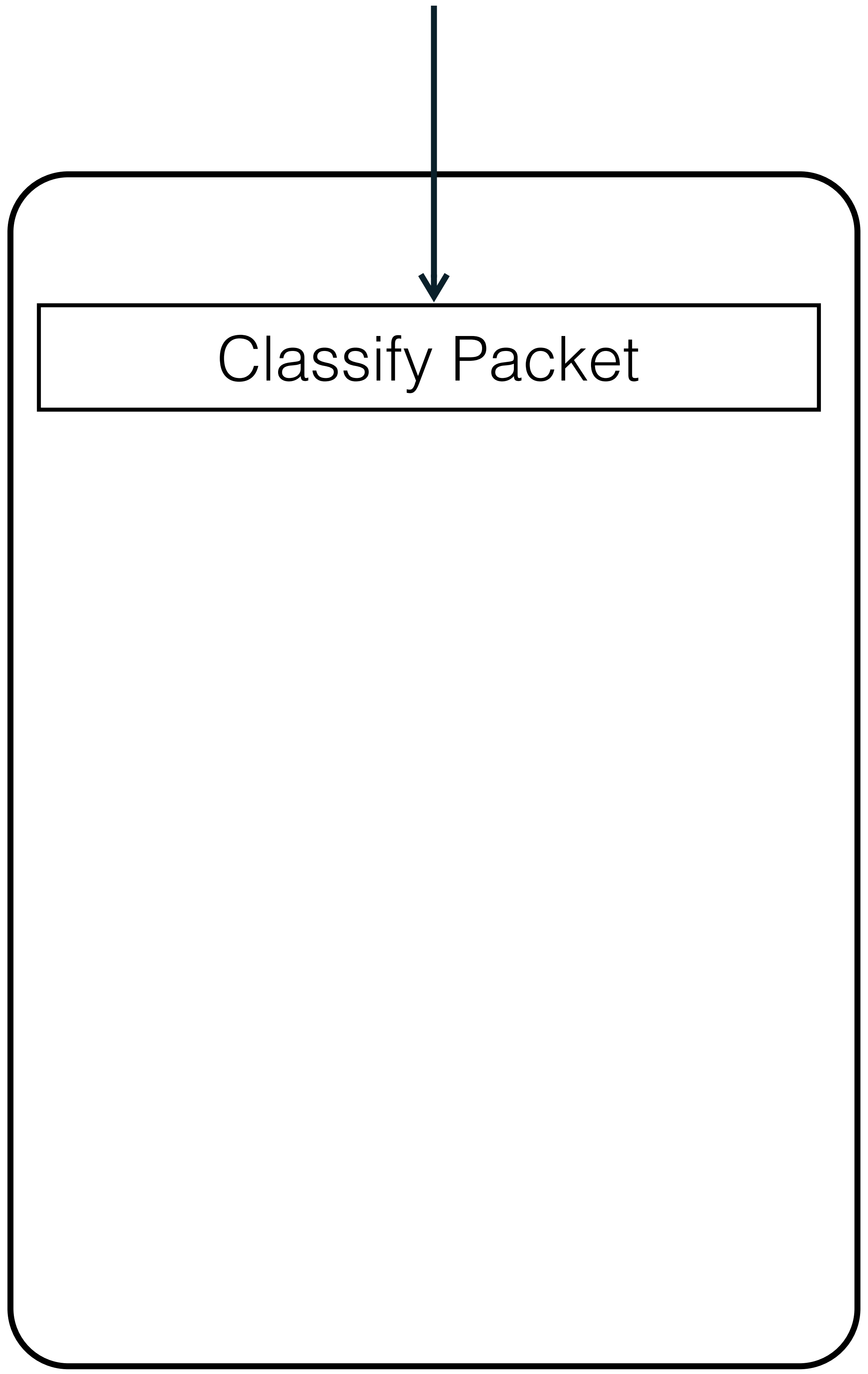

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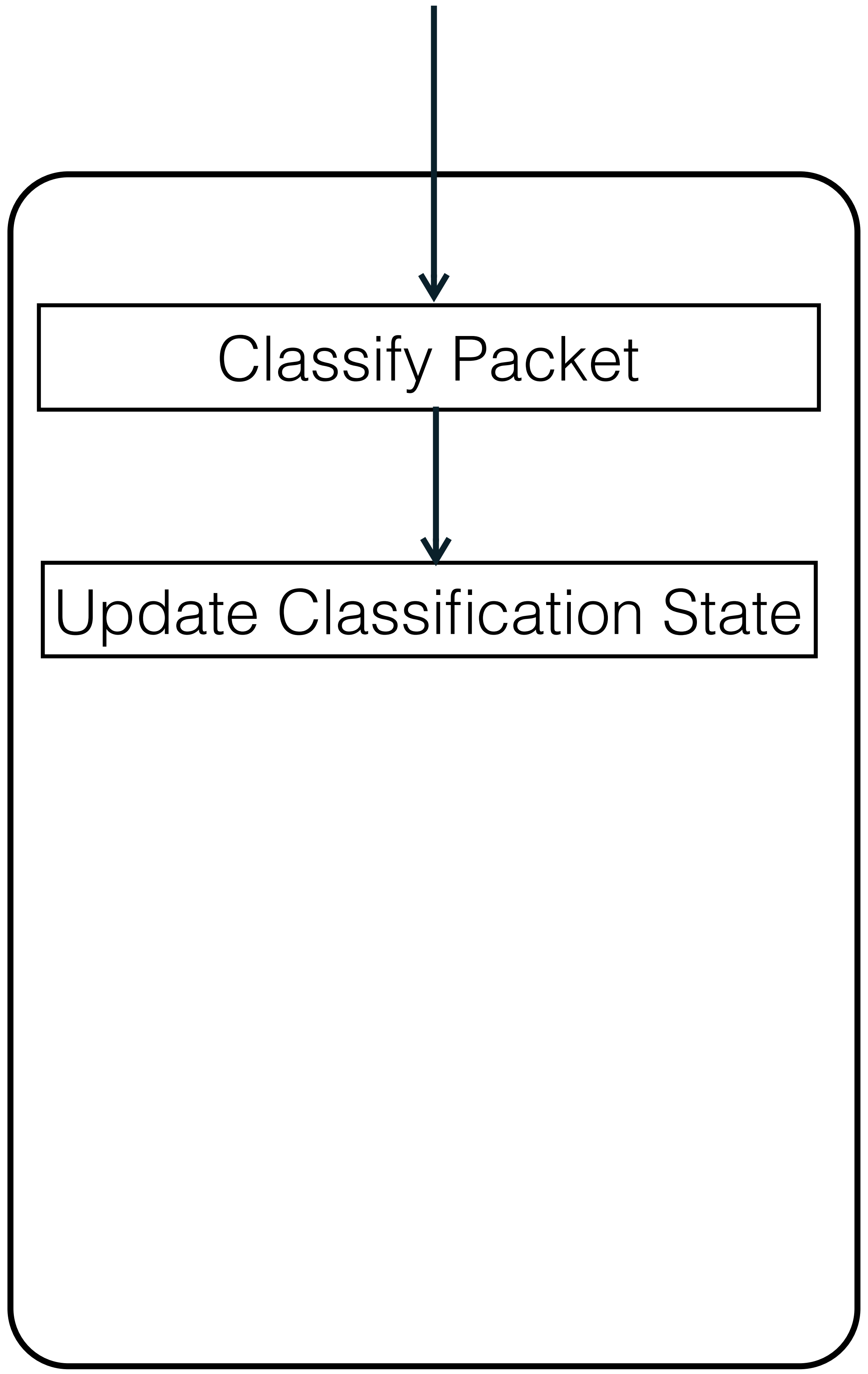

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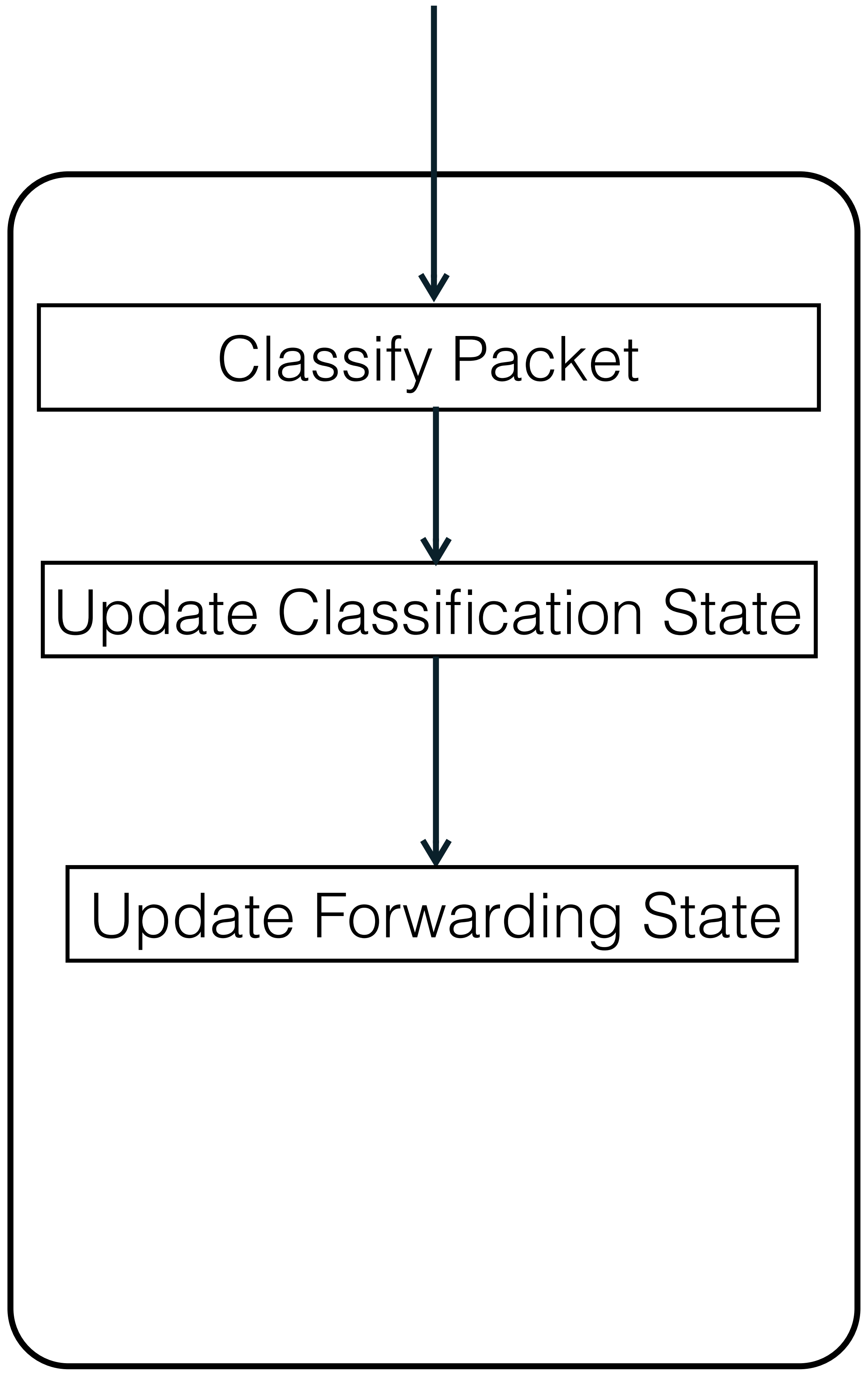

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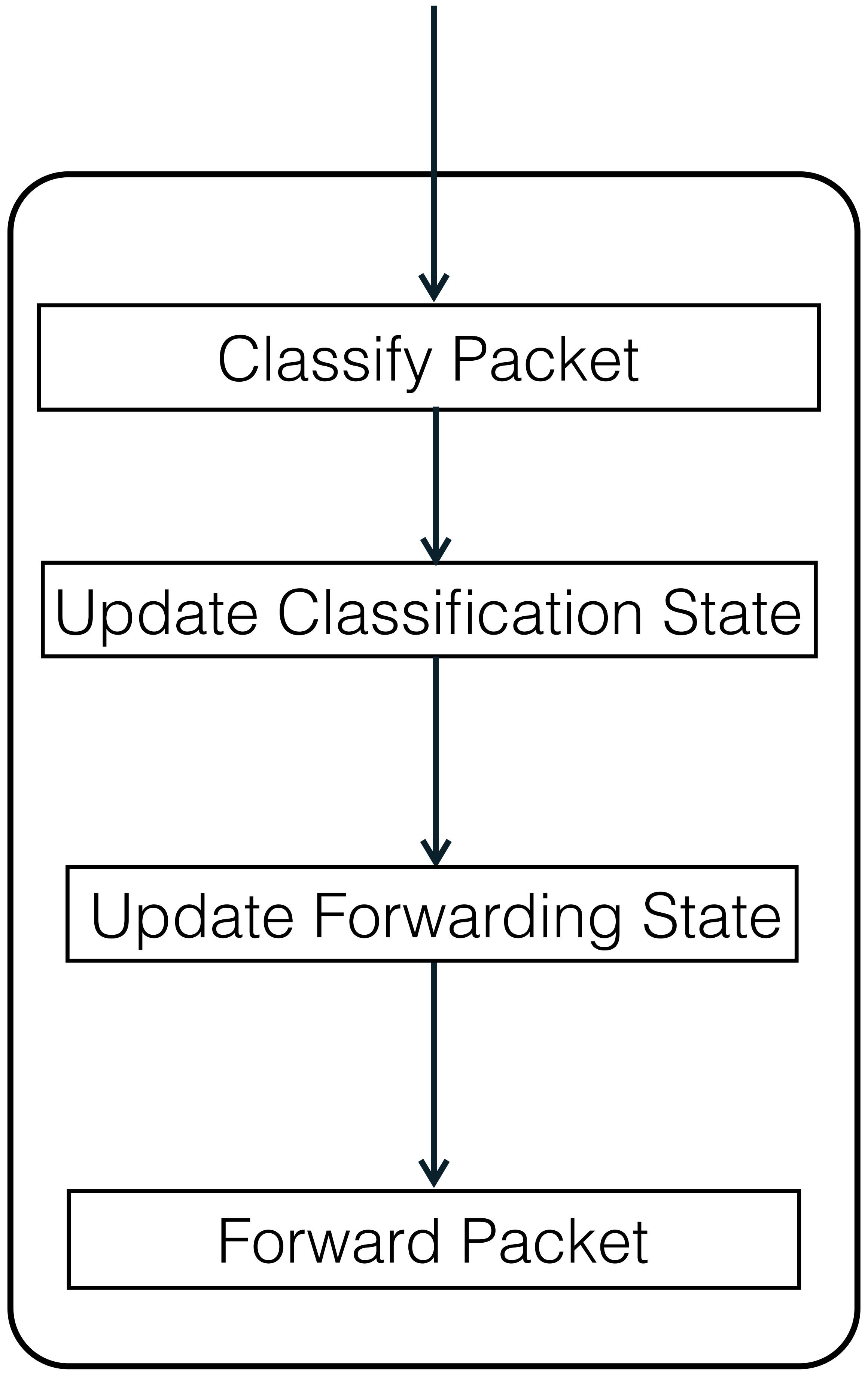

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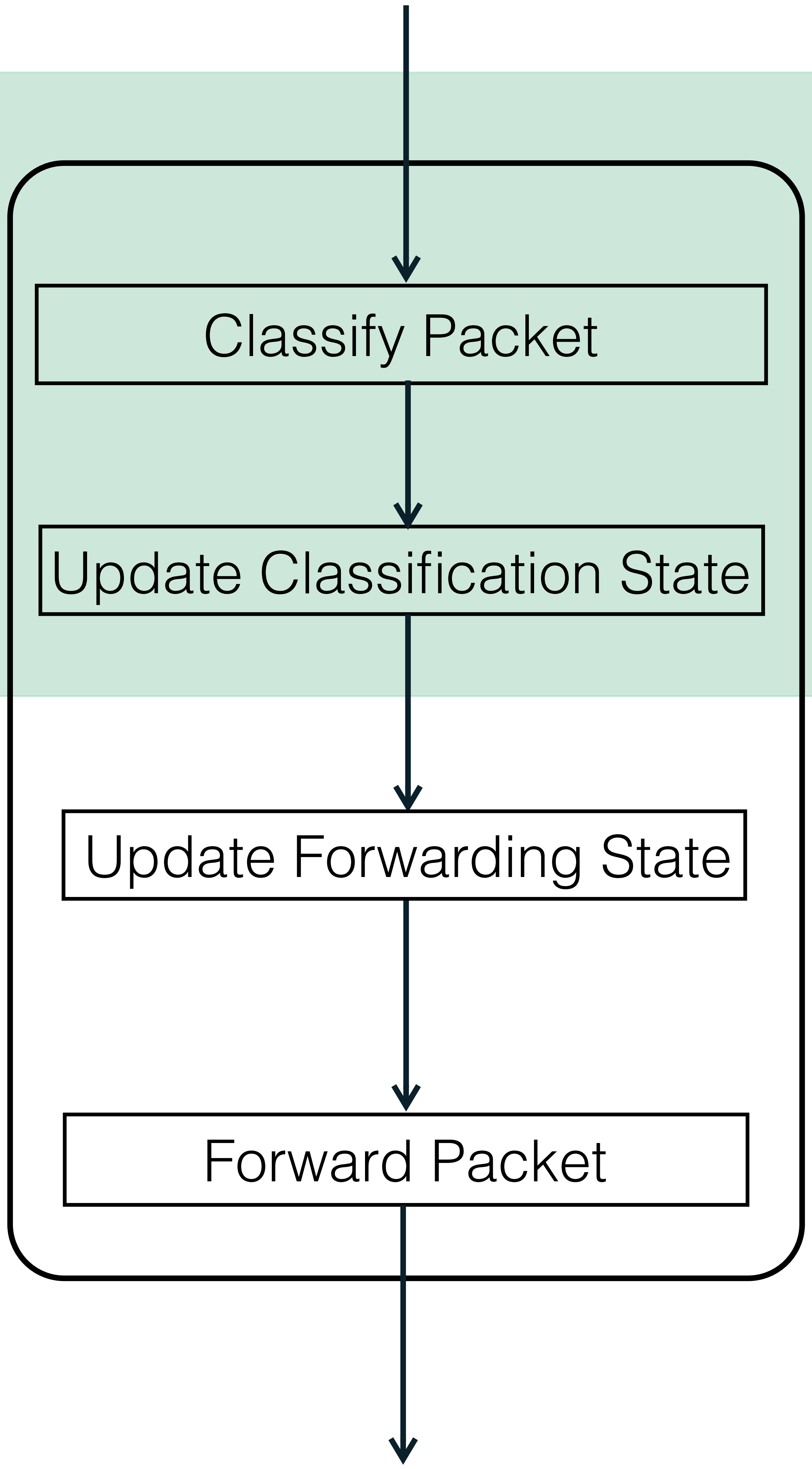

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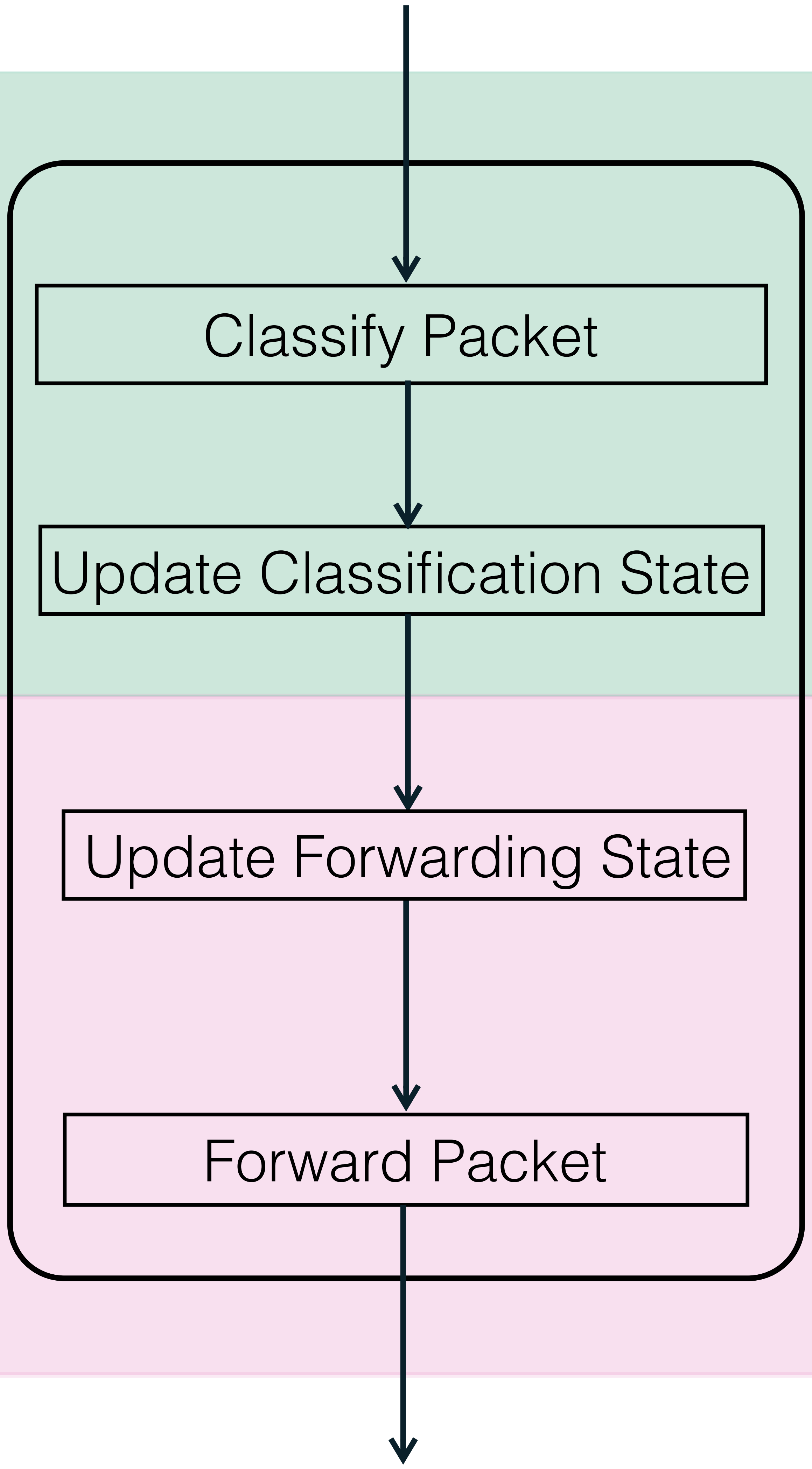

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Forwarding Model: Specify Completely

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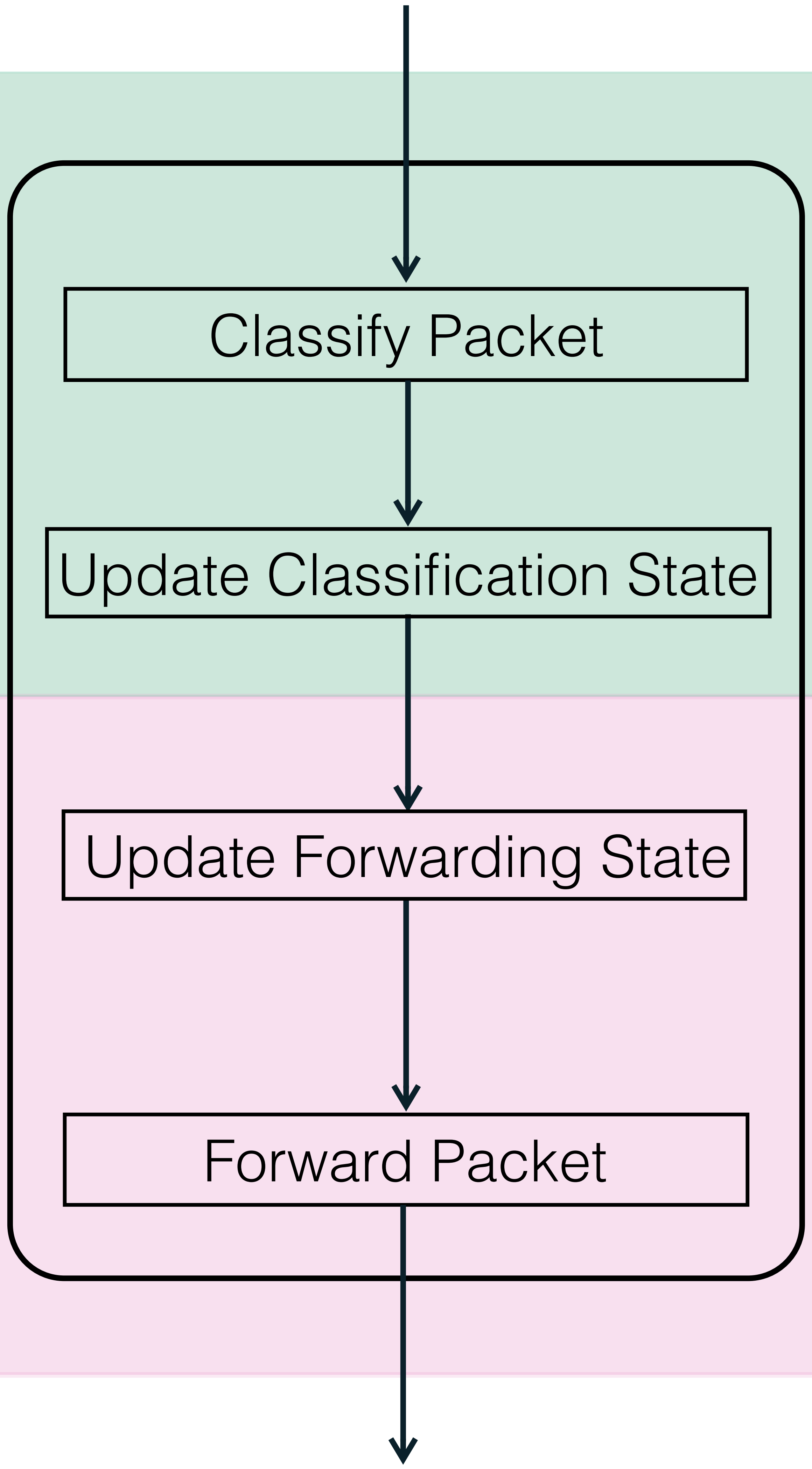

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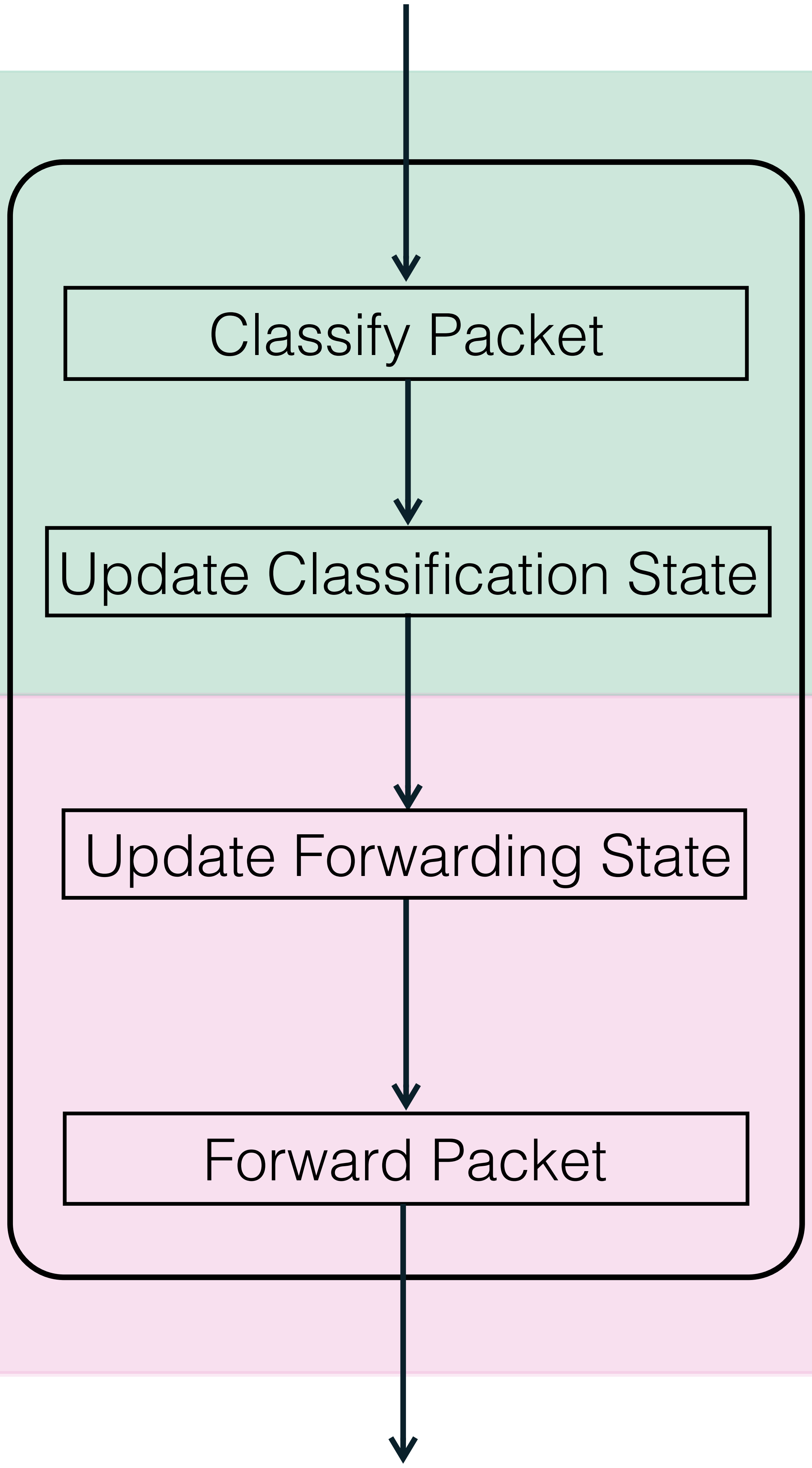

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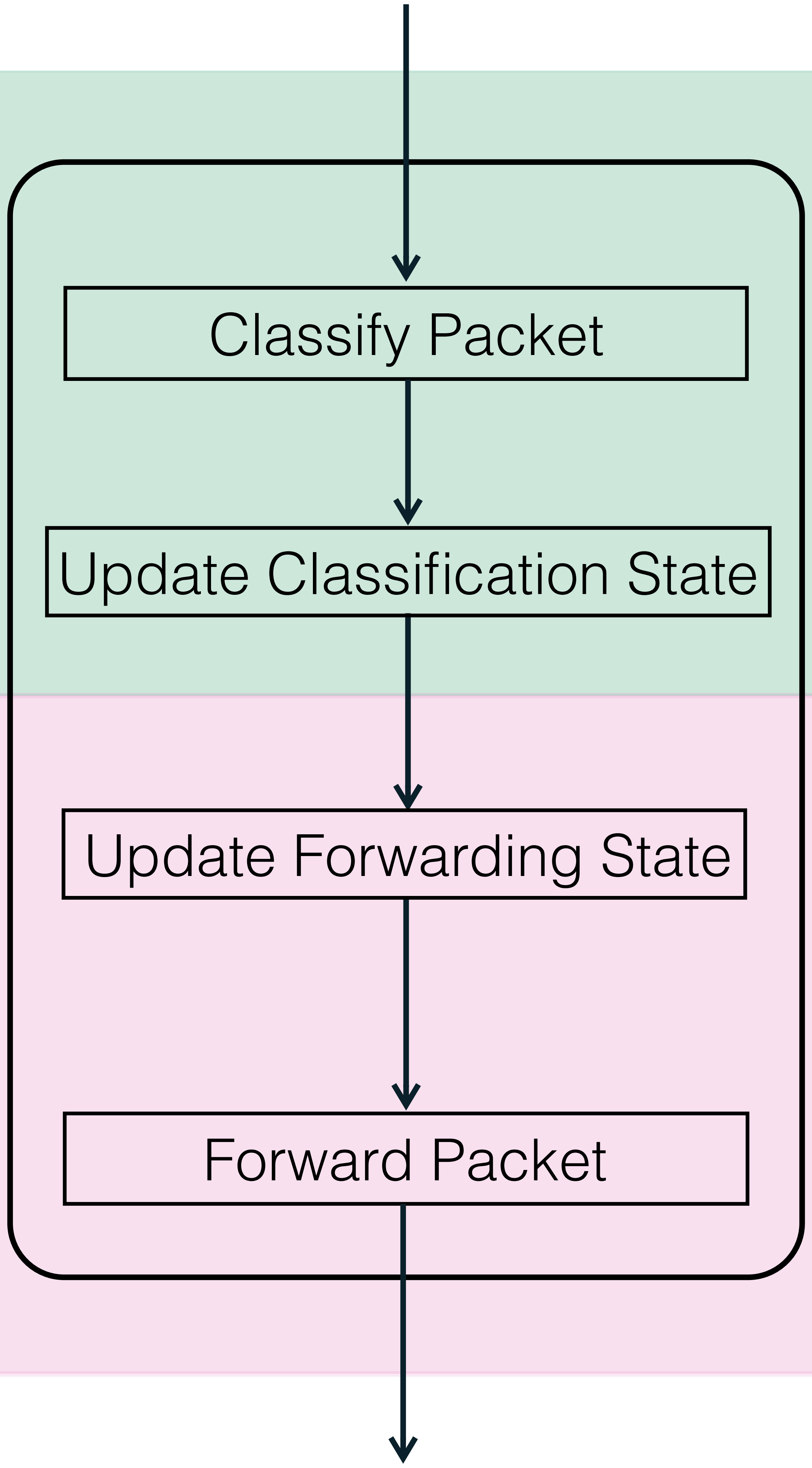

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if (**packet.flow** not in **infected_connections**) {
    forward (packet);
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class Firewall (acls: Set[(Address, Address)])
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  abstract malicious(p: Packet): bool
  val tainted: Set[Address]
  def model (p: Packet) = {
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- ~~Why consider stateful networks?~~
- ~~The current state of stateful network verification?~~
- ~~VMN: Our system for verifying networks with state.~~
- Scaling verification.

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  - In datacenter each machine might be one or more middlebox.
- How do we address this?

Scaling Techniques Thus Far

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- Our techniques work for small instances, what to do about large instances?

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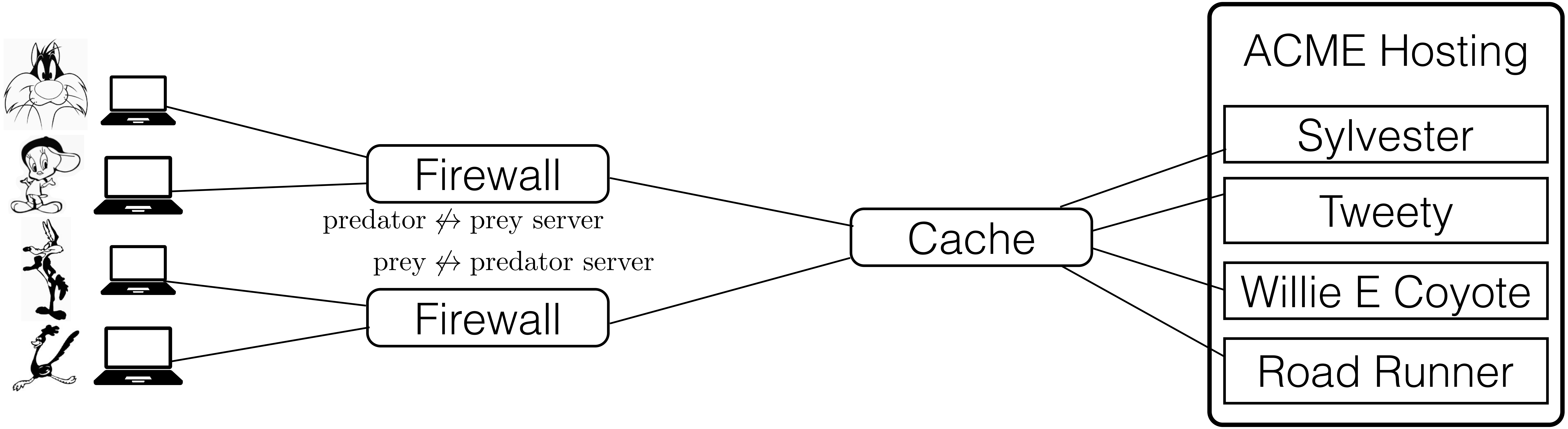
- **Slicing**: Run verification on a subnetwork of size independent of network.
- **Symmetry**: Reduce number of invariants to verify by leveraging symmetry in policy.

Network Slices

- **Slices:** Subnetworks for which a bisimulation with the original network exists.
  - Ensures equivalent step in subnetwork for each step in the original network
- Slices are selected depending on the invariant being checked.

Network Slices



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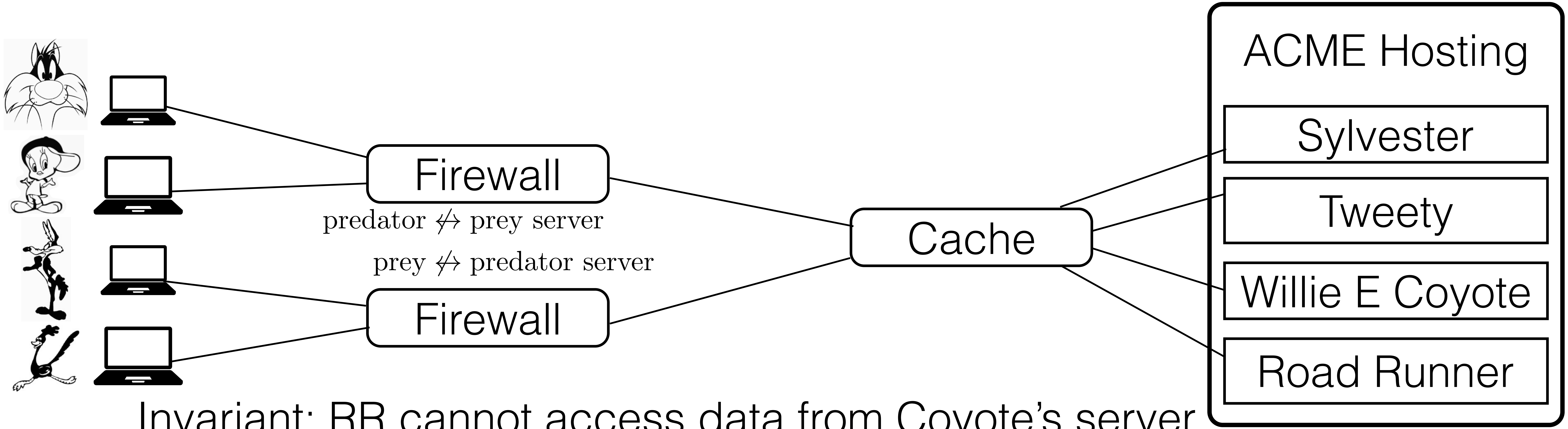

Invariant: RR cannot access data from Coyote's server

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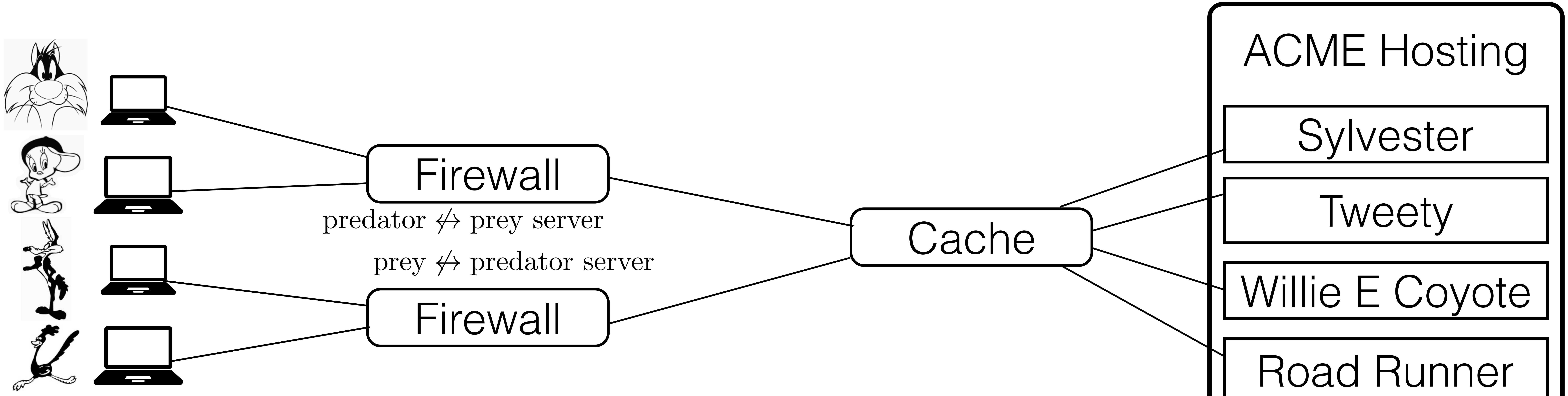

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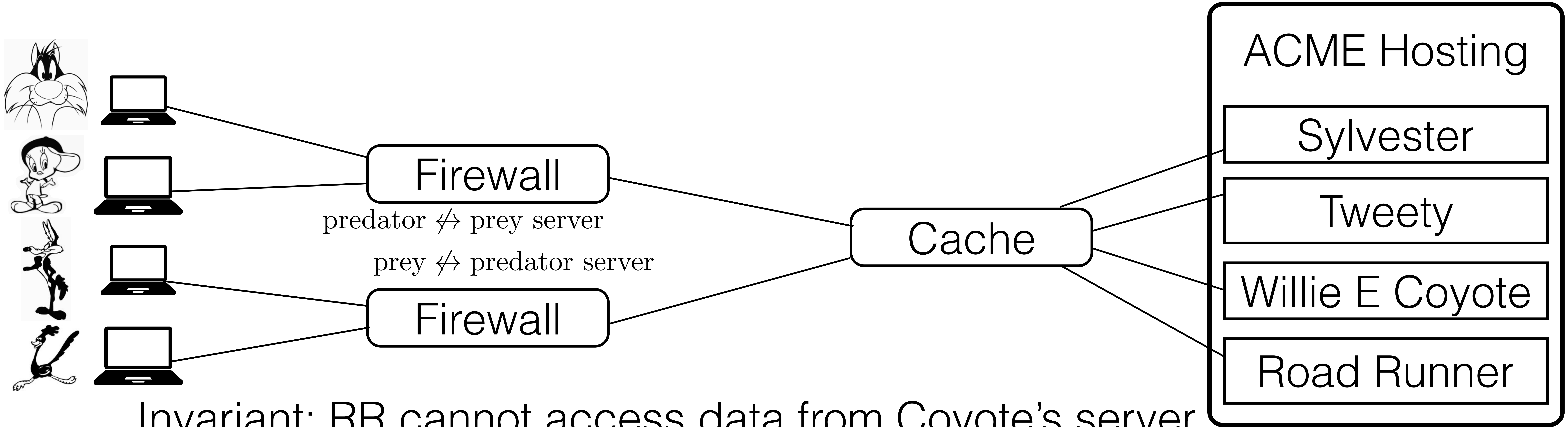

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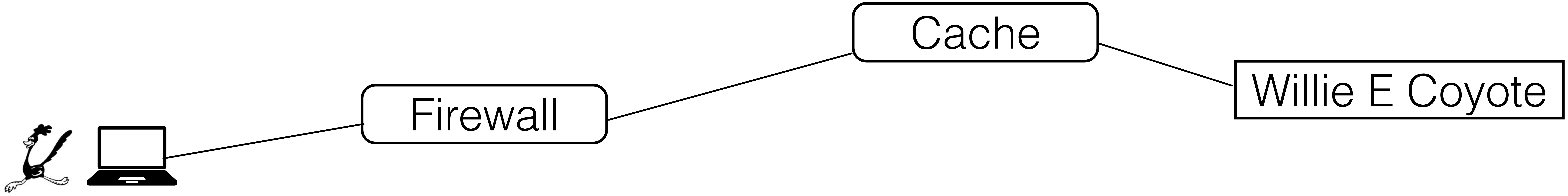

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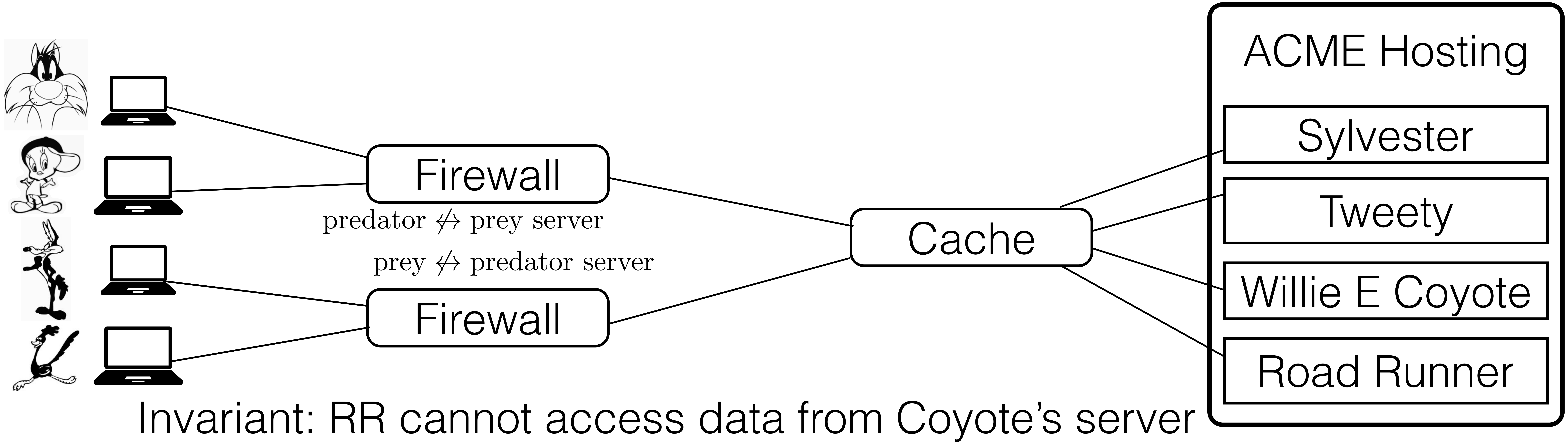

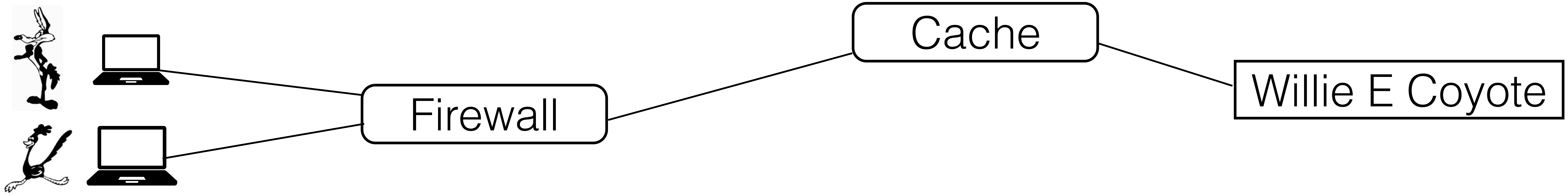

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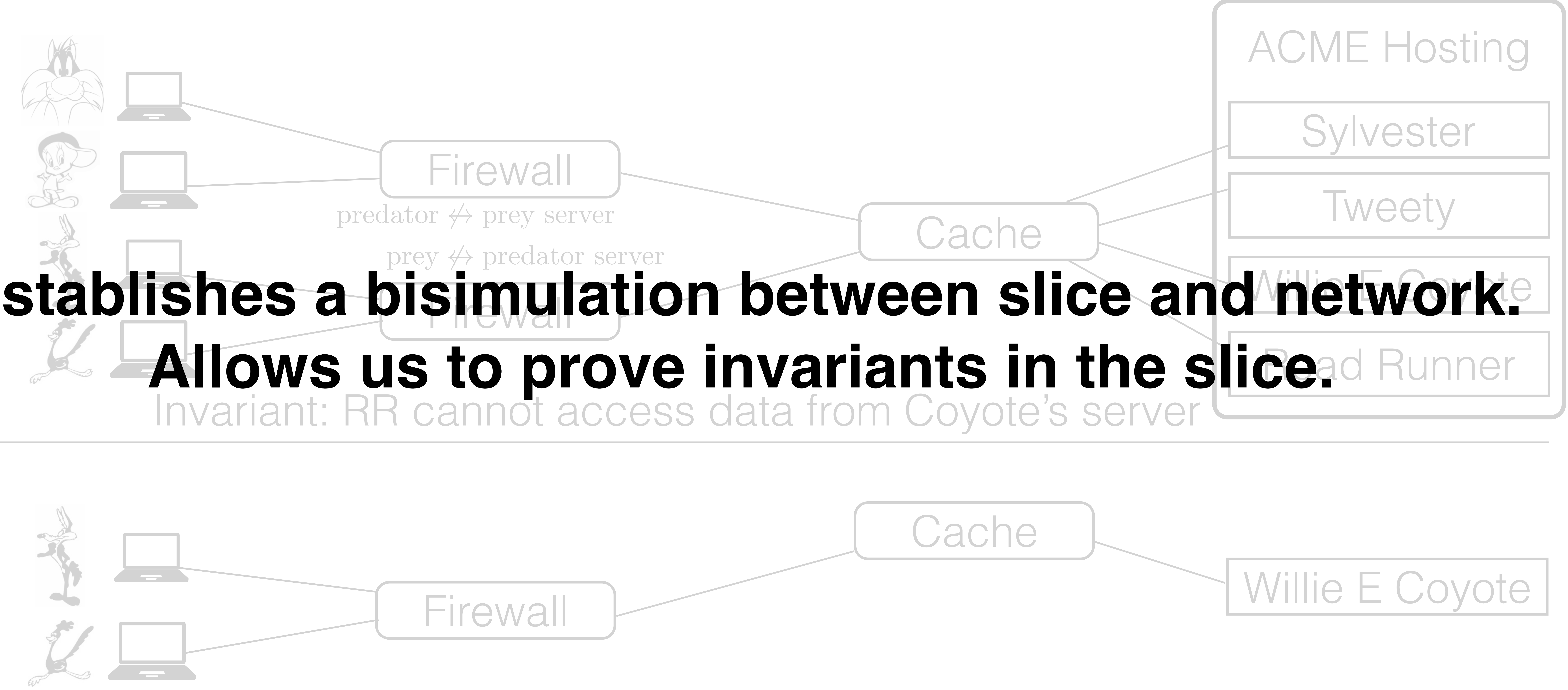

Establishes a bisimulation between slice and network.

Allows us to prove invariants in the slice.

Cannot always find such a slice.

Finding Slices

- **Flow parallel middleboxes** - partition network by flows.
- **Origin agnostic middleboxes** - partition network by policy equivalence class.
- Details in paper.

Evaluation Setup: Datacenter

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- Each tenant has policies for private and public hosts.
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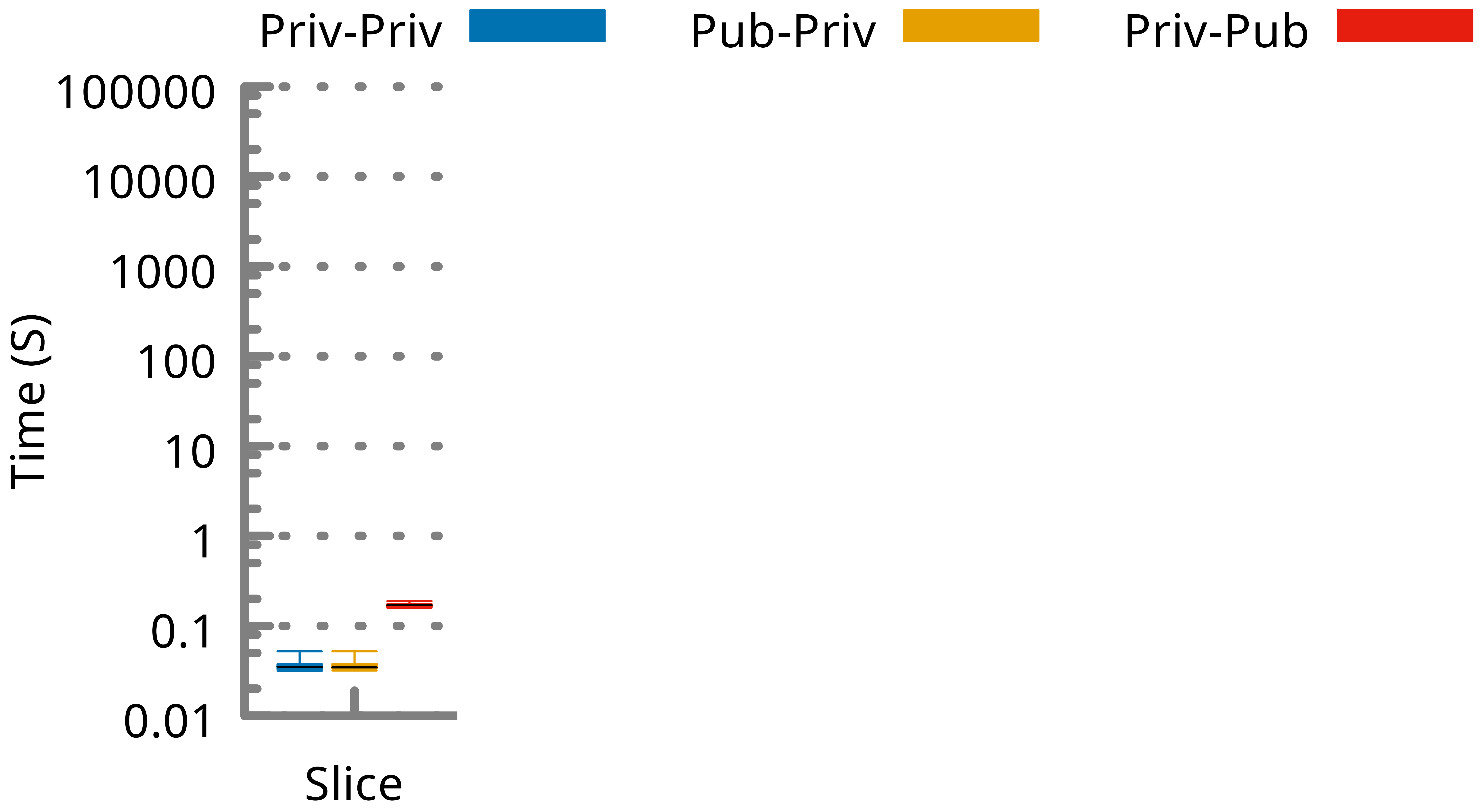
  - Private hosts for one tenant cannot reach another
  - Public host for one tenant cannot reach private hosts for another
  - Public hosts are universally reachable.

Verification Time (Datacenter)



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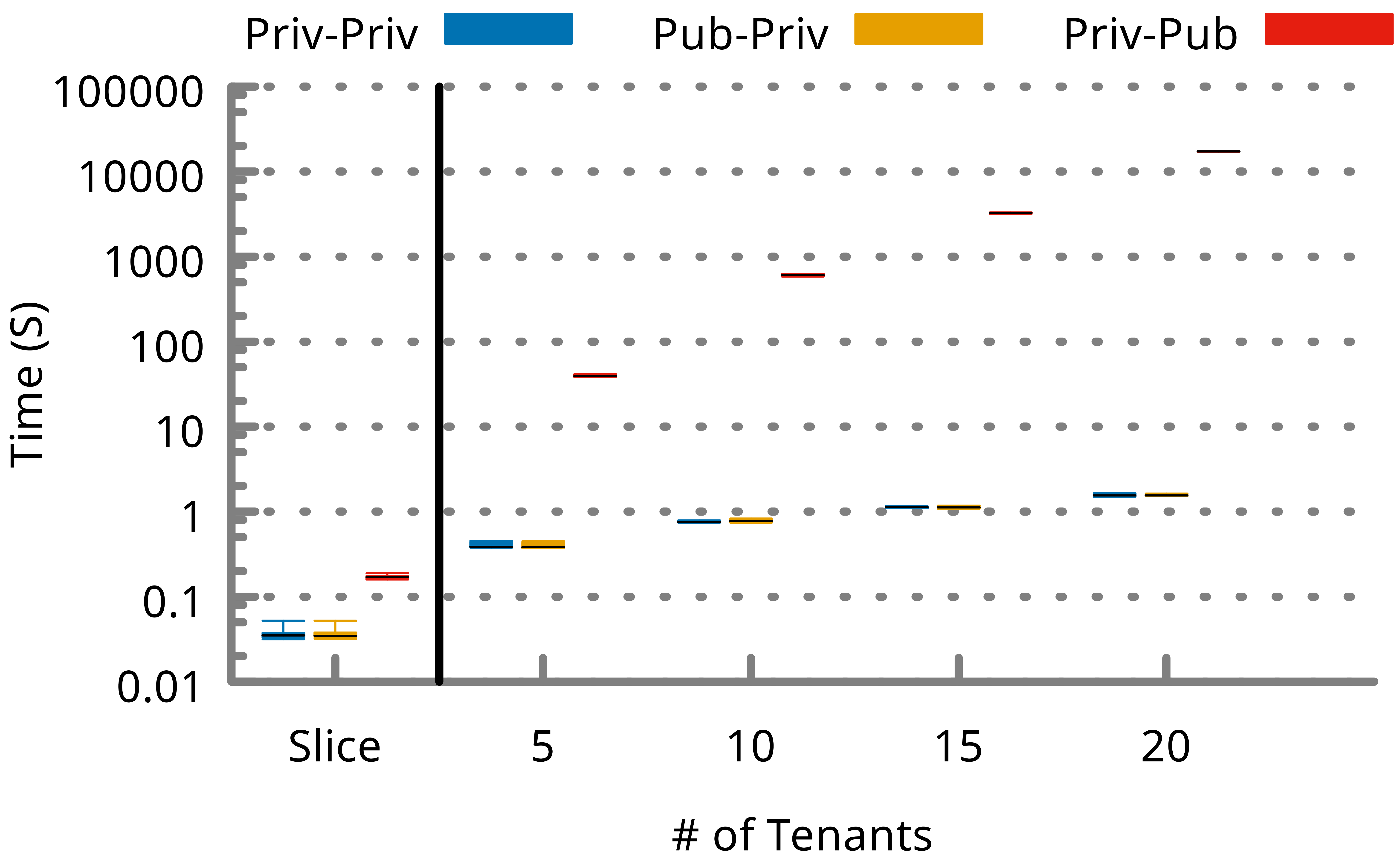

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- Bugs include
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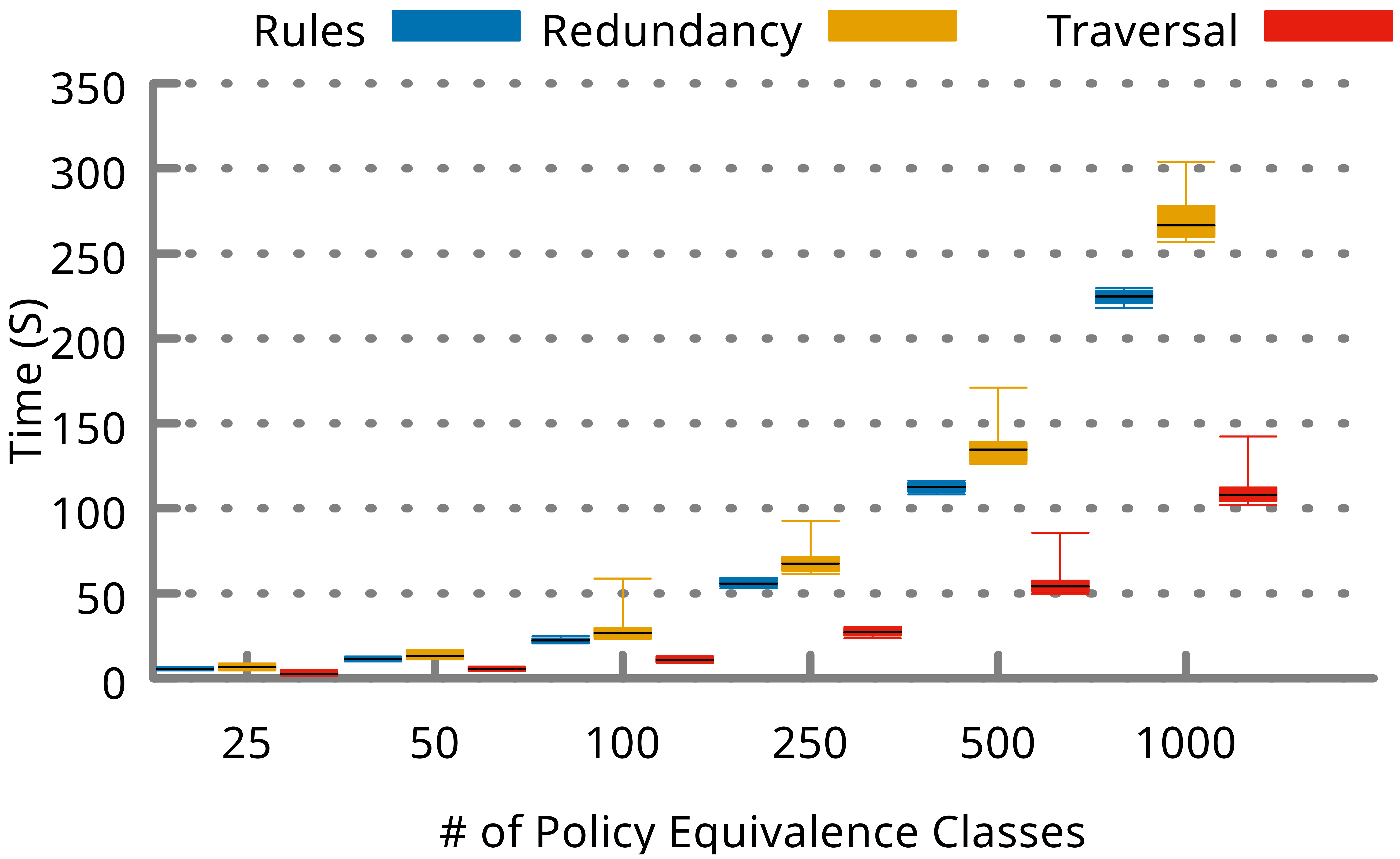
  - Misconfigured redundant firewalls
  - Misconfigured redundant routing
- Measure time to verify as a function of number of symmetric policy groups

Verification Time (With Symmetry)



Conclusion

- Verifying stateful networks is increasingly important.
- The primary challenge is scaling to realistic network.
- Two methods to scale
  - Models where oracles are separated from forwarding behavior.
  - Split the network into smaller verifiable portions is necessary.