Distributed Network Monitoring and Debugging with SwitchPointer



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Network monitoring and debugging is complex

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Marple [SIGCOMM'17], PathDump [OSDI'16], FlowRadar [NSDI'16],
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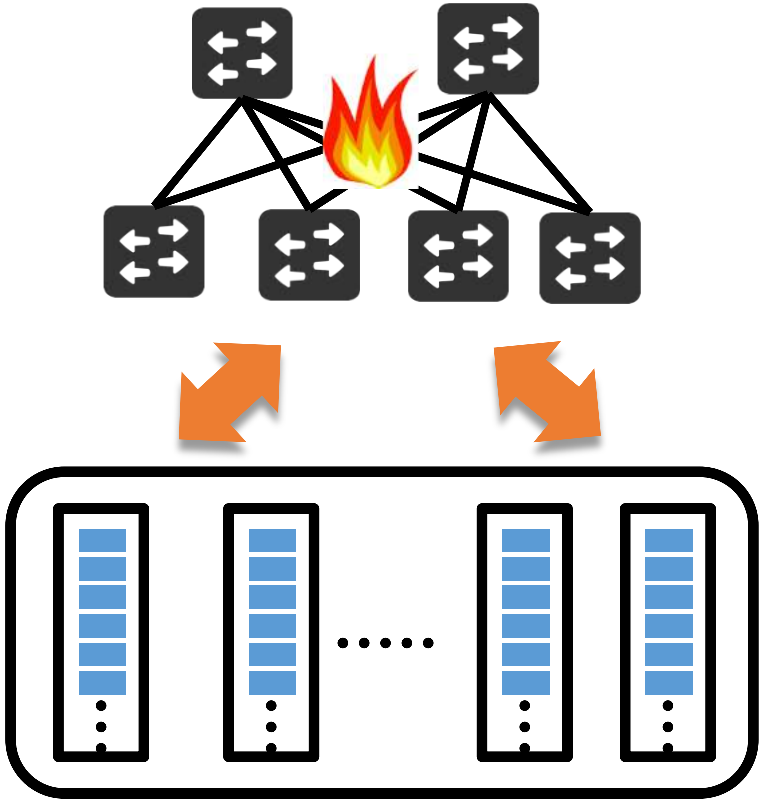
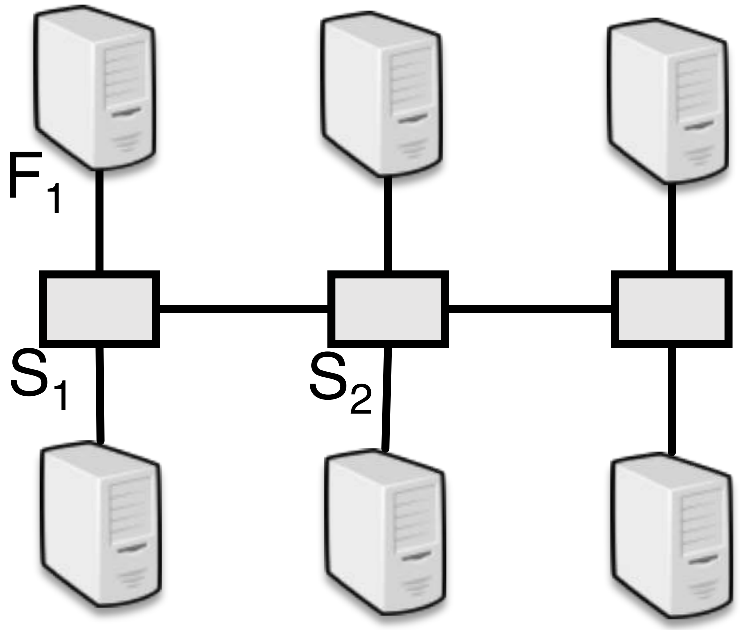
- Increasingly larger scale
  - Over 100k endpoints
  - 10/40/100 GE
  - Aggregate traffic > 100 Tbps



An example: Too many red lights



F_1: Low priority

F_2, F_3: High priority

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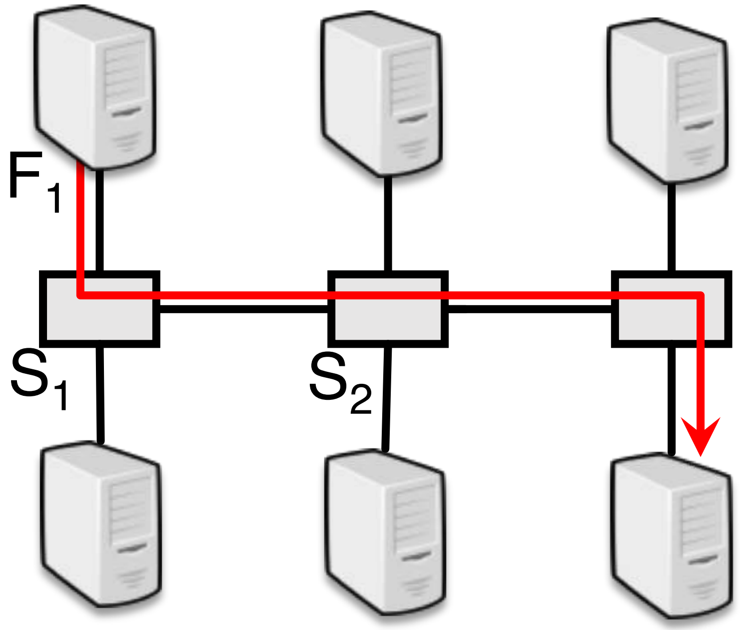

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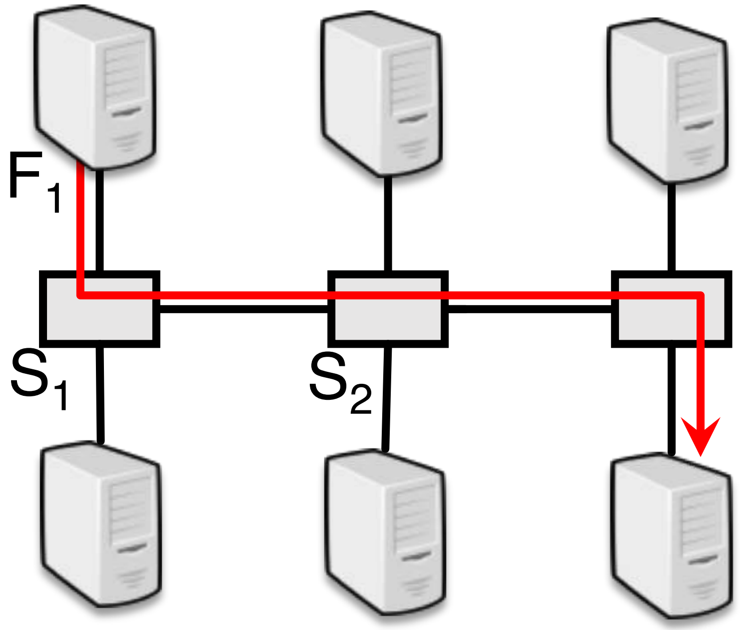

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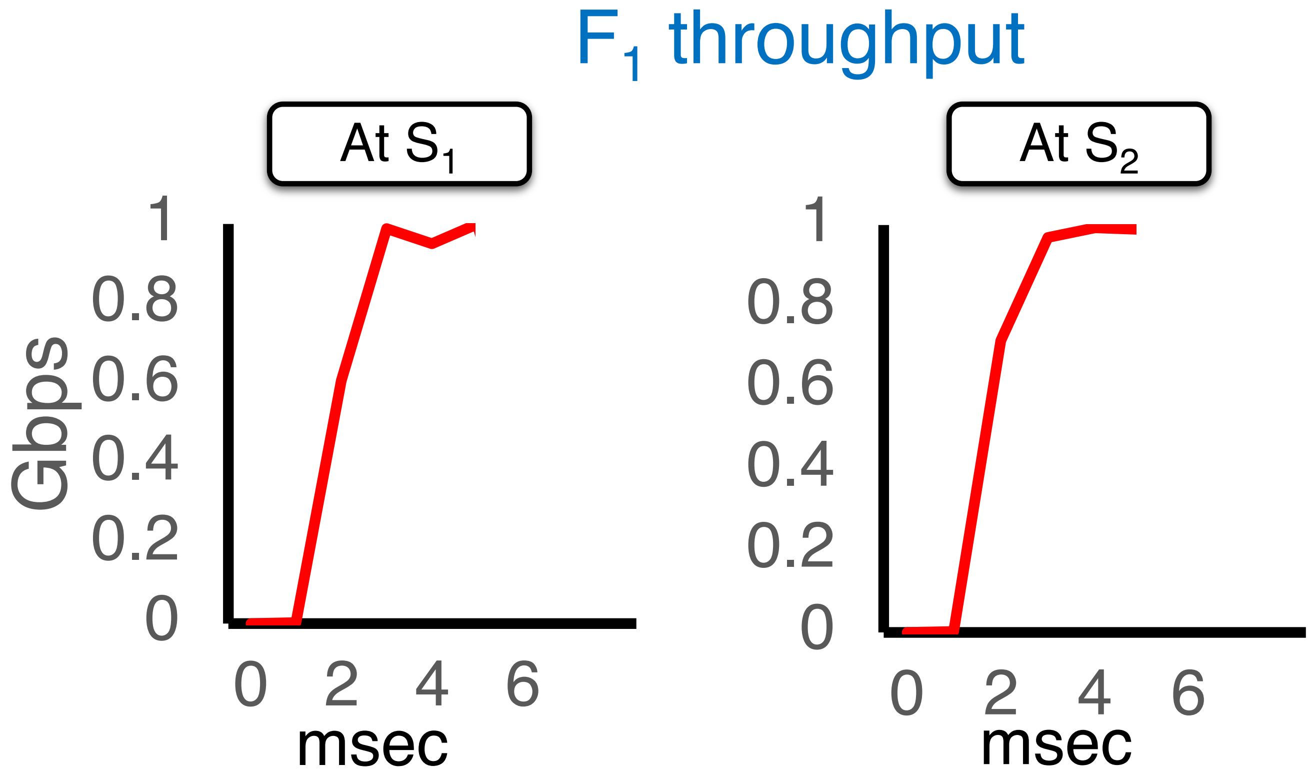

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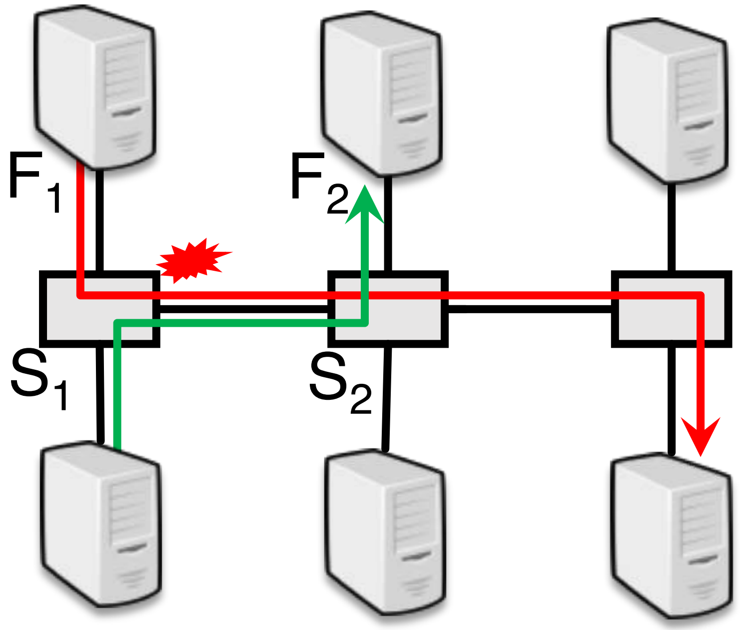

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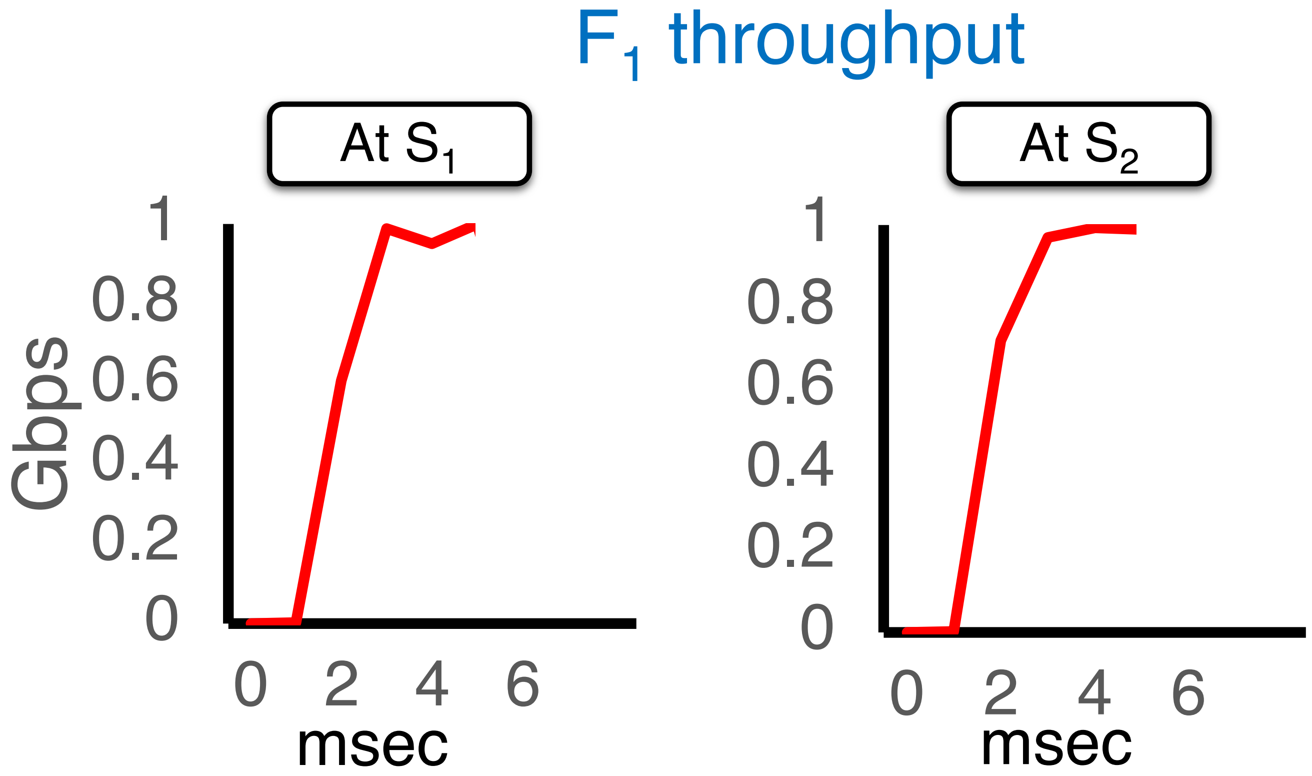

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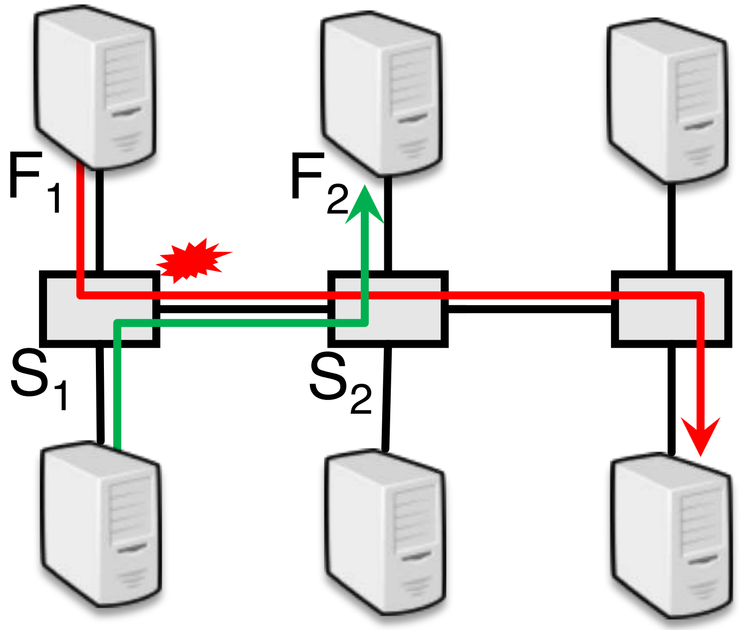

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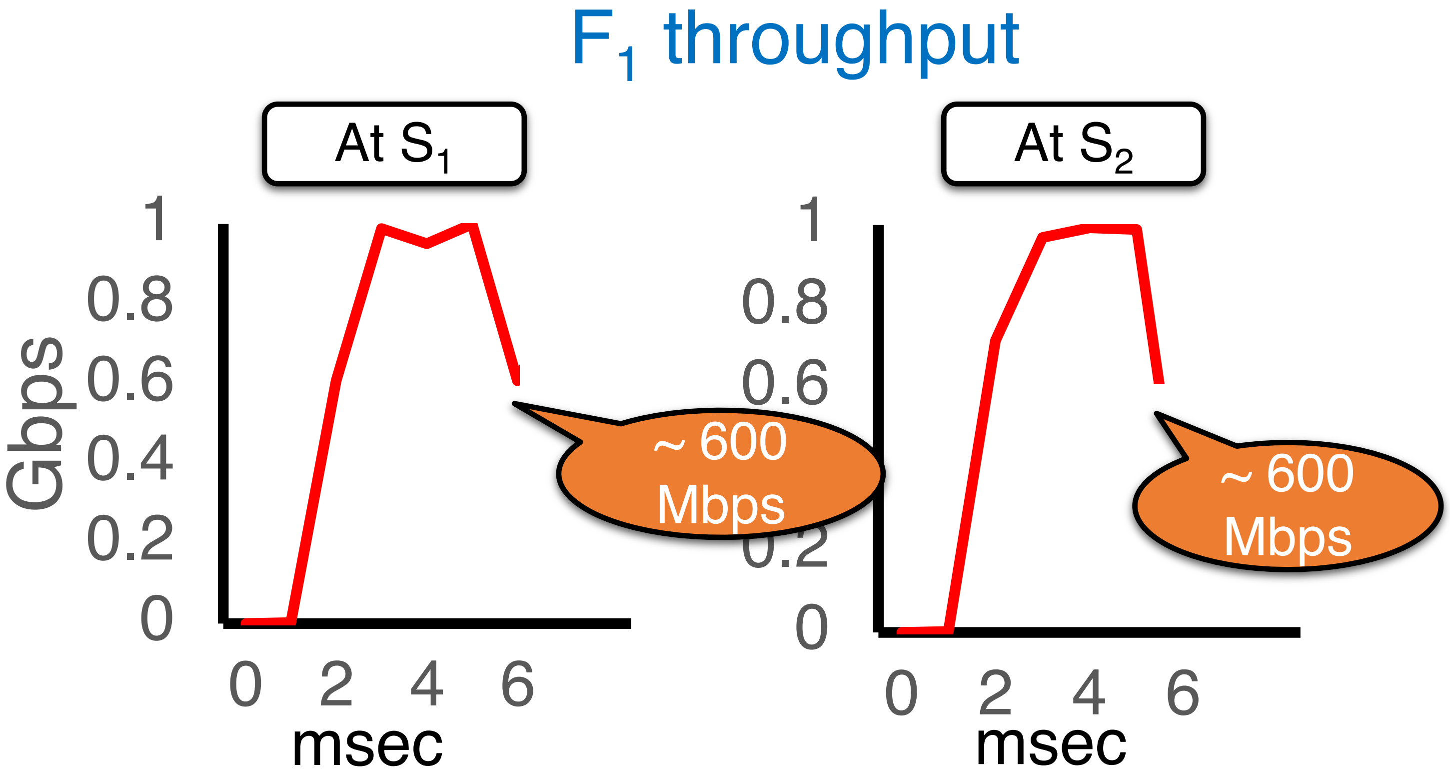

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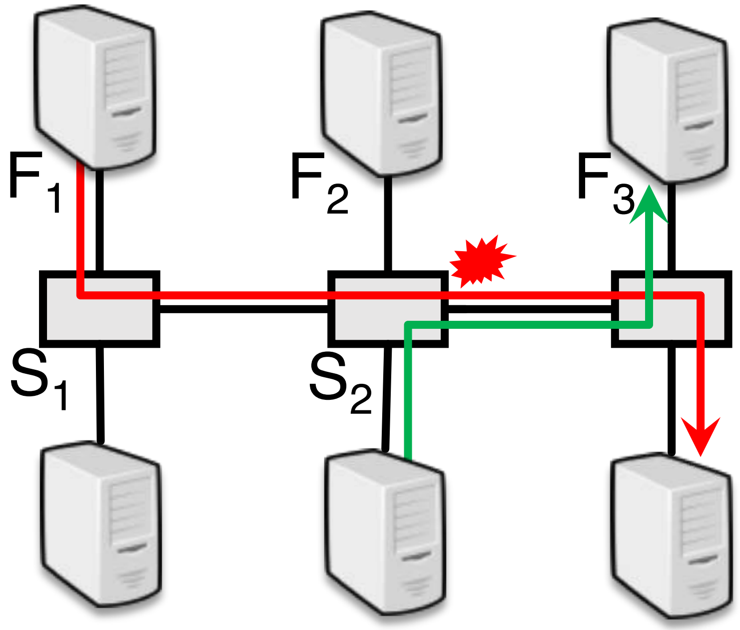

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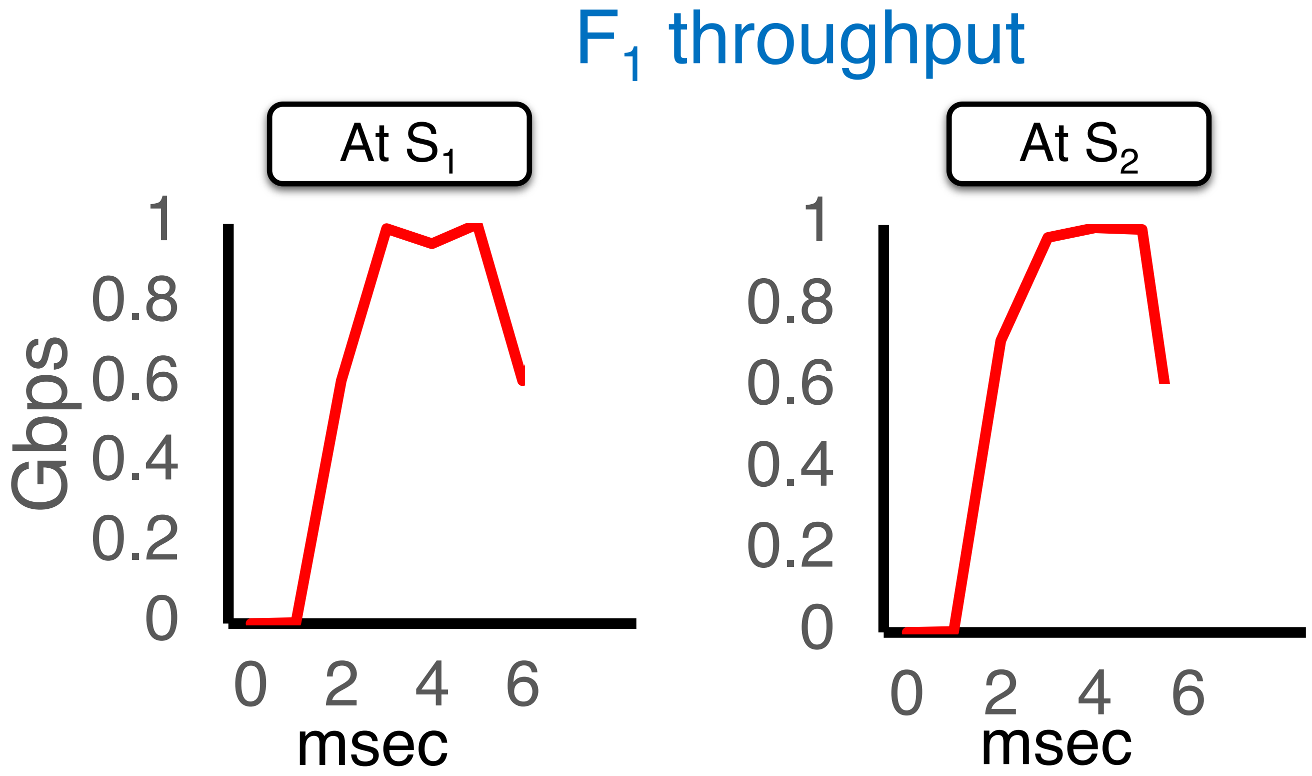

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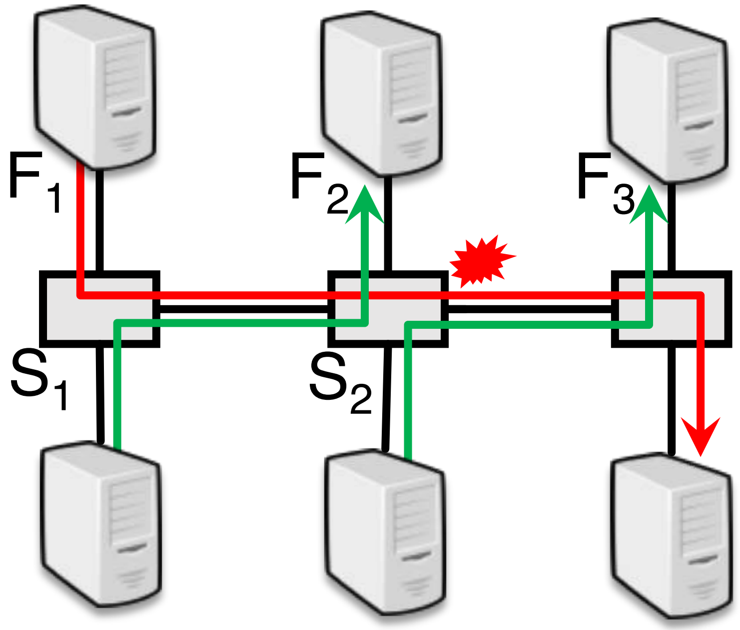

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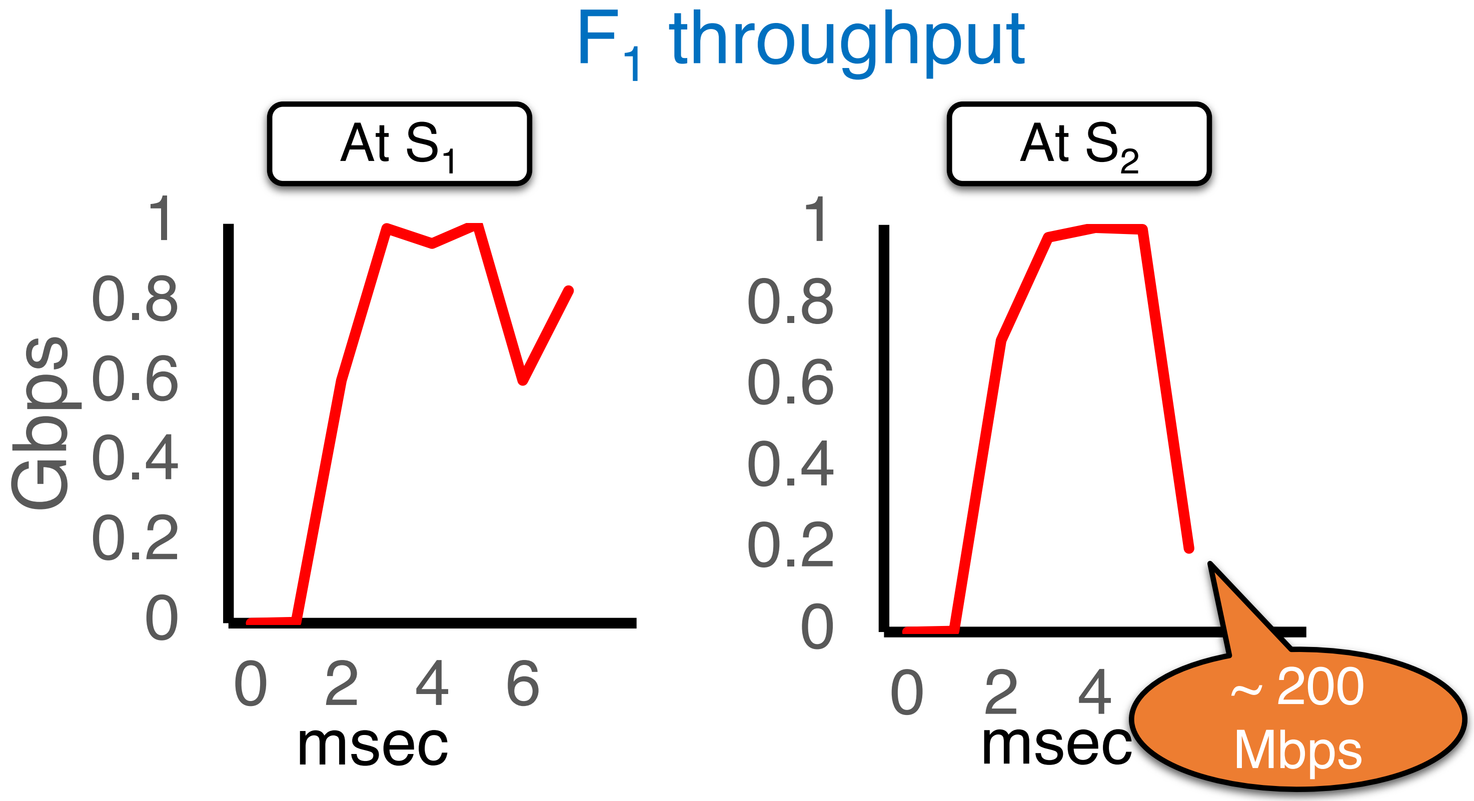

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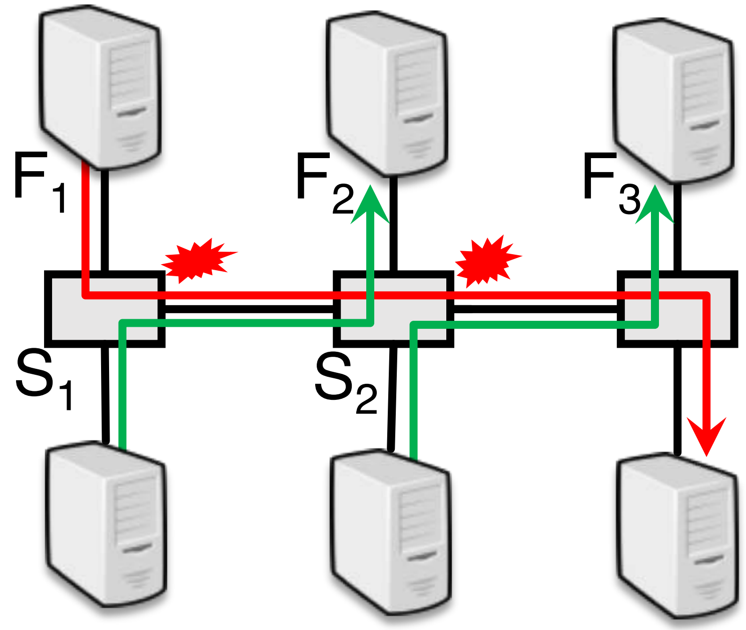

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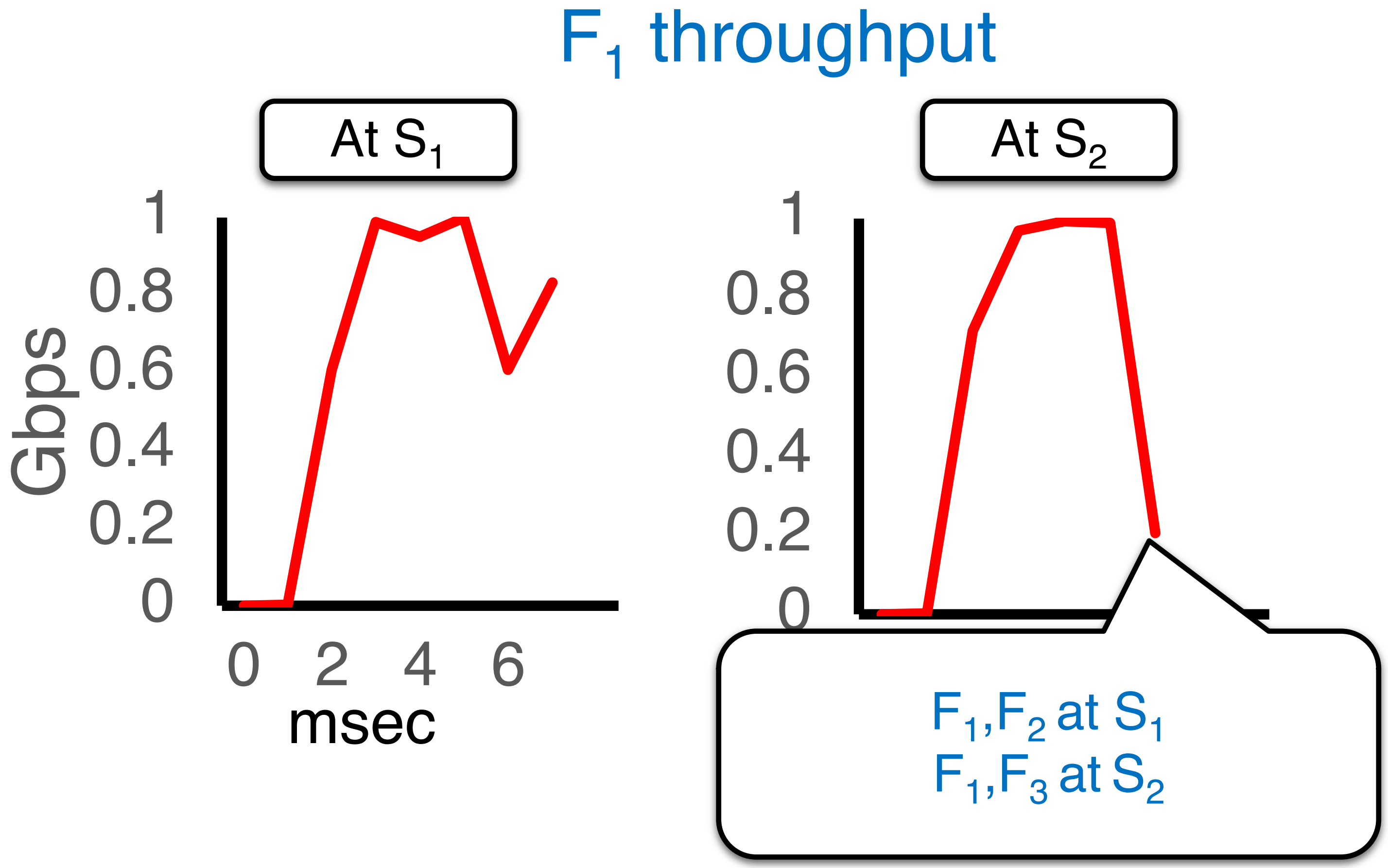

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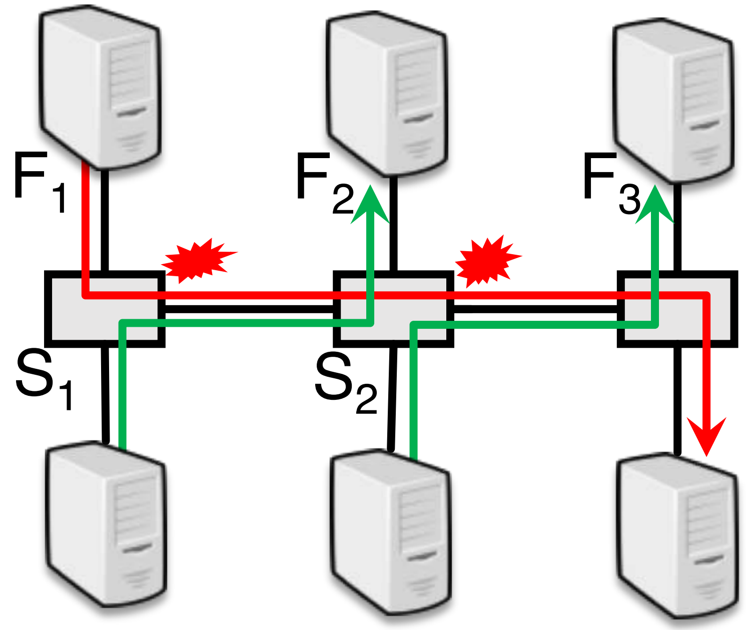

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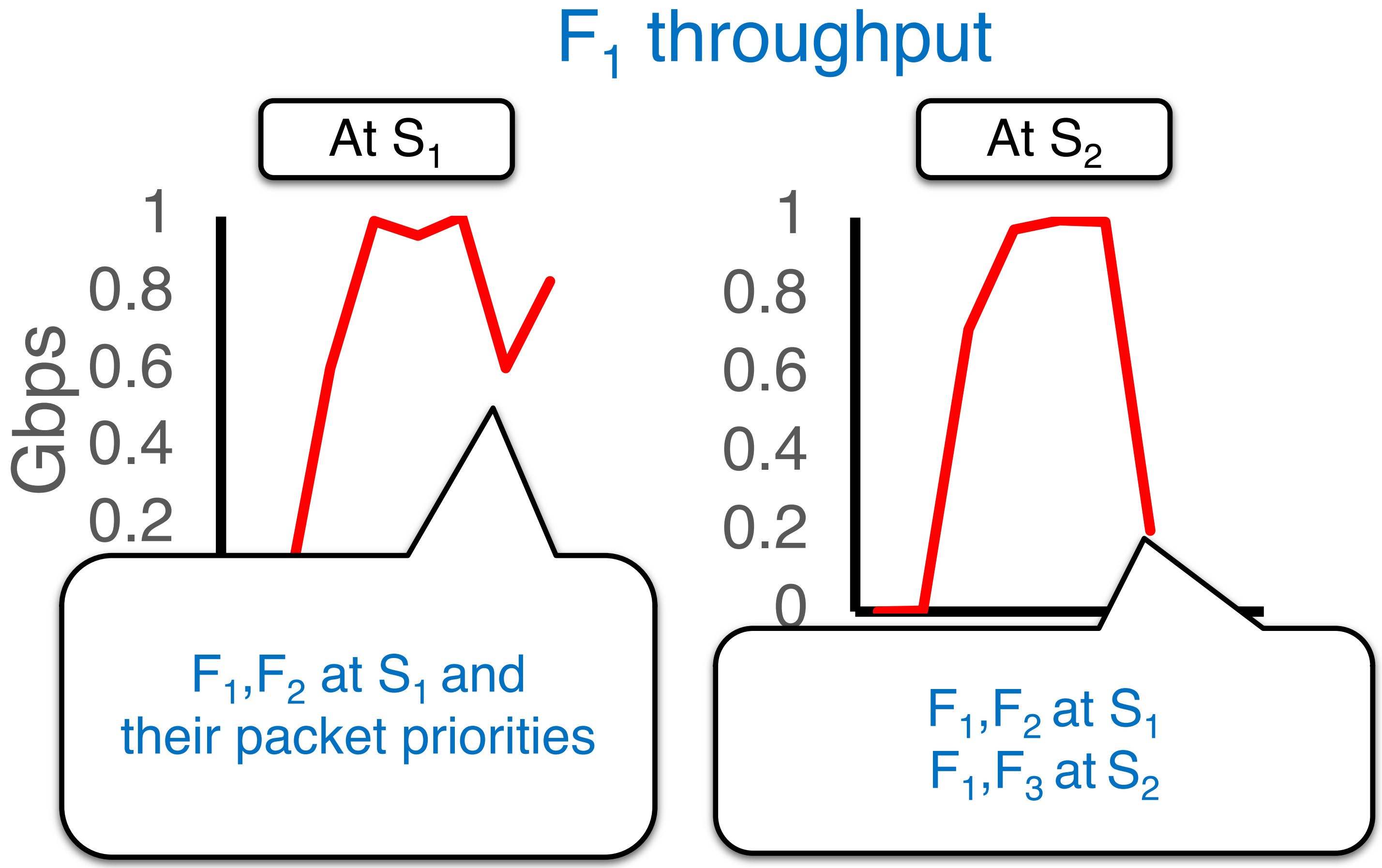
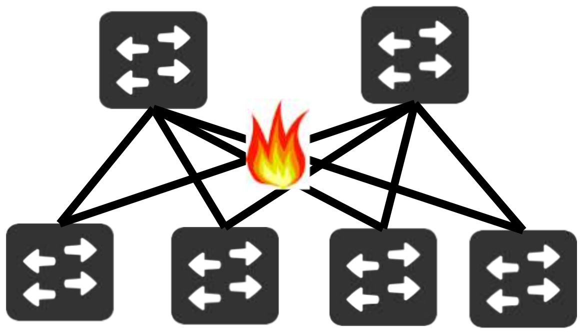


Existing Approaches

In-network techniques



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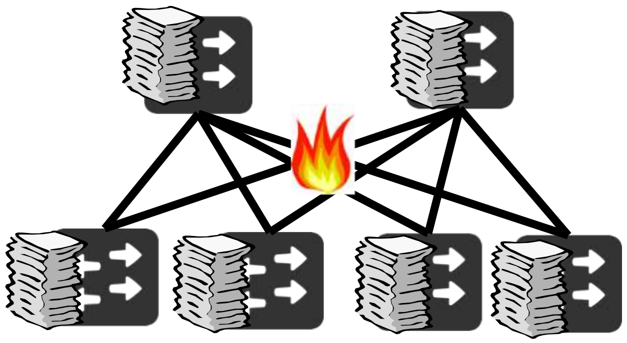

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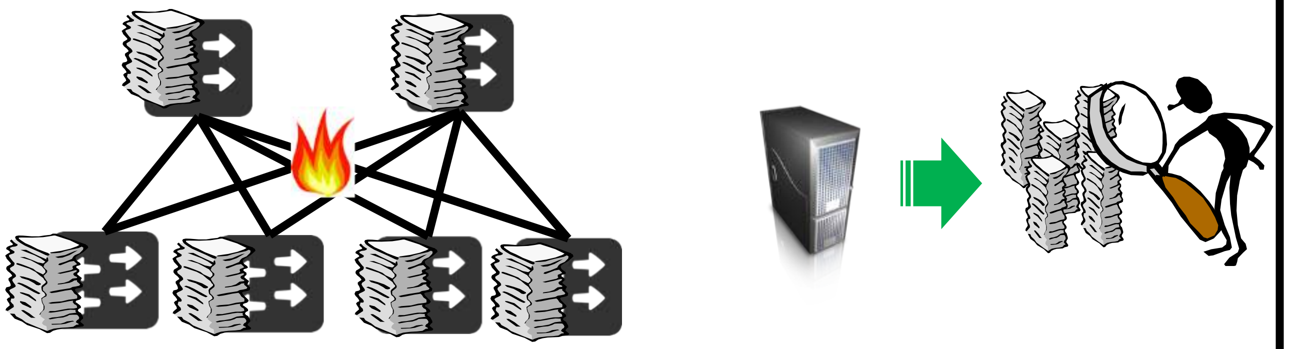

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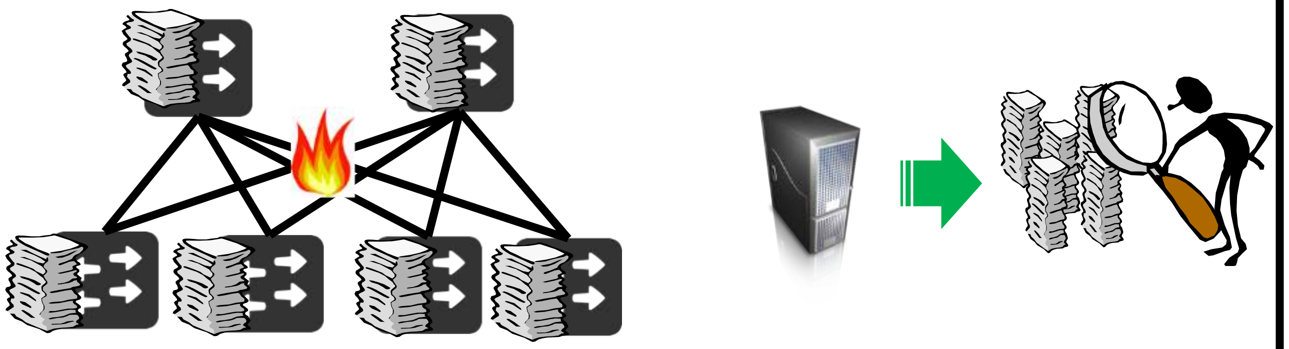

High in-network visibility

Requires more data plane resources

E.g.: Marple, EverFlow, FlowRadar

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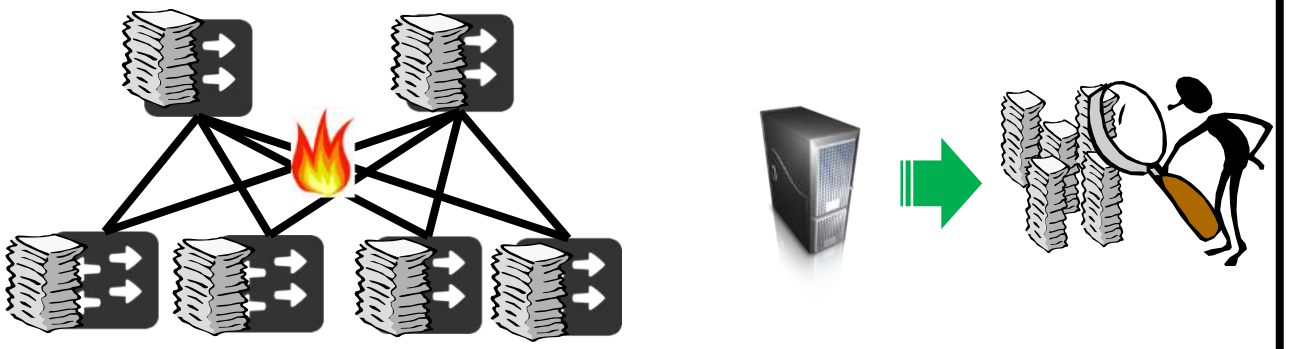

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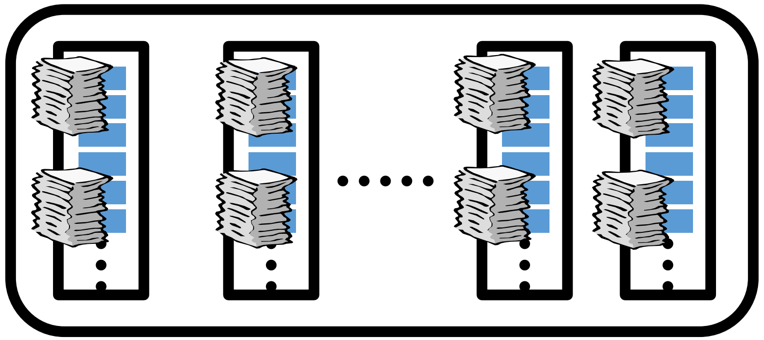
End-host based techniques



More resources & programmability

Lose network visibility

E.g.: PathDump, Trumpet

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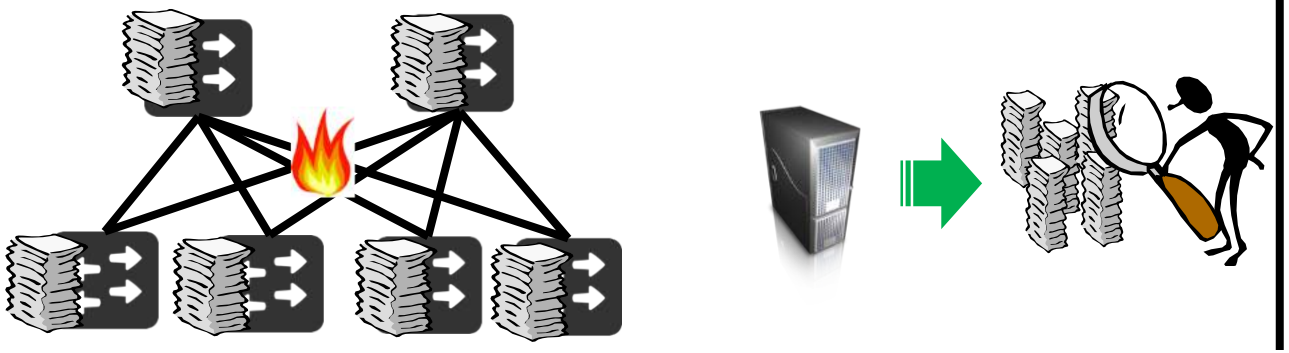

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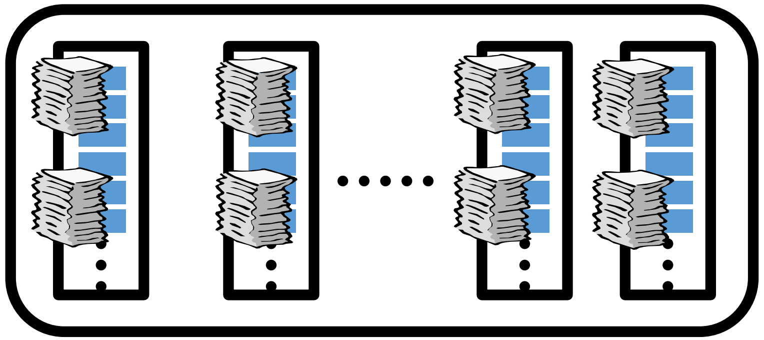

SwitchPointer

High in-network visibility + More resources & programmability

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SwitchPointer

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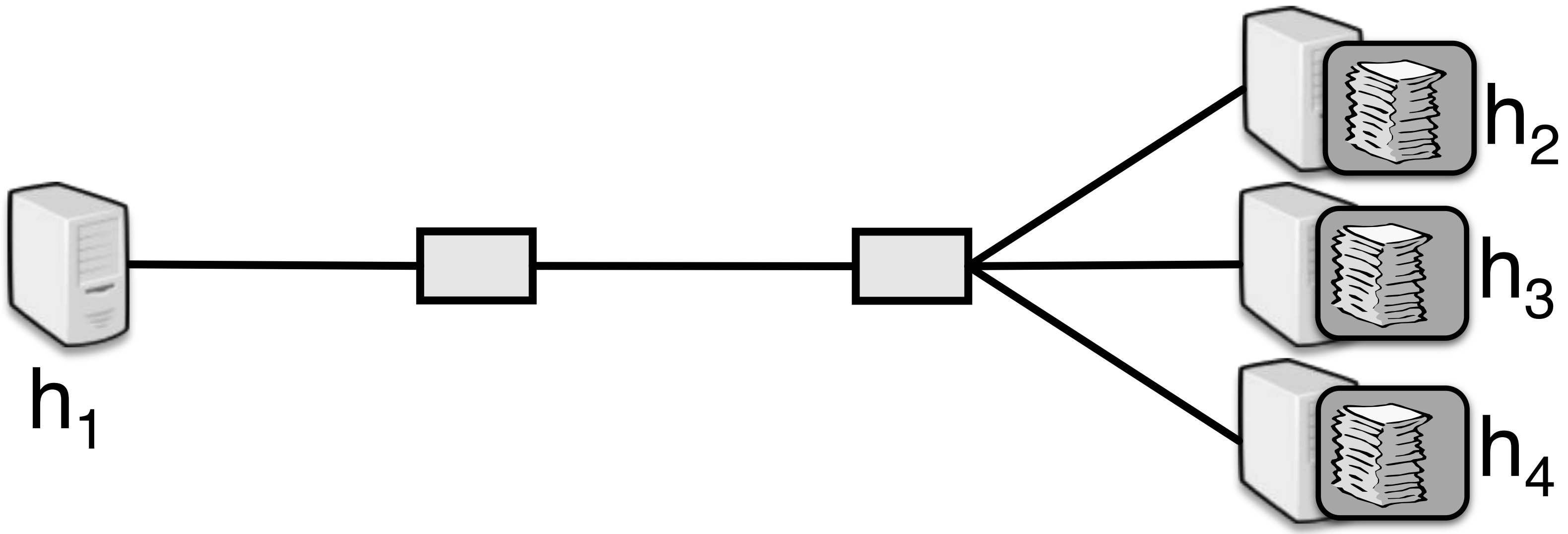
Insight: End-hosts collect and monitor telemetry data



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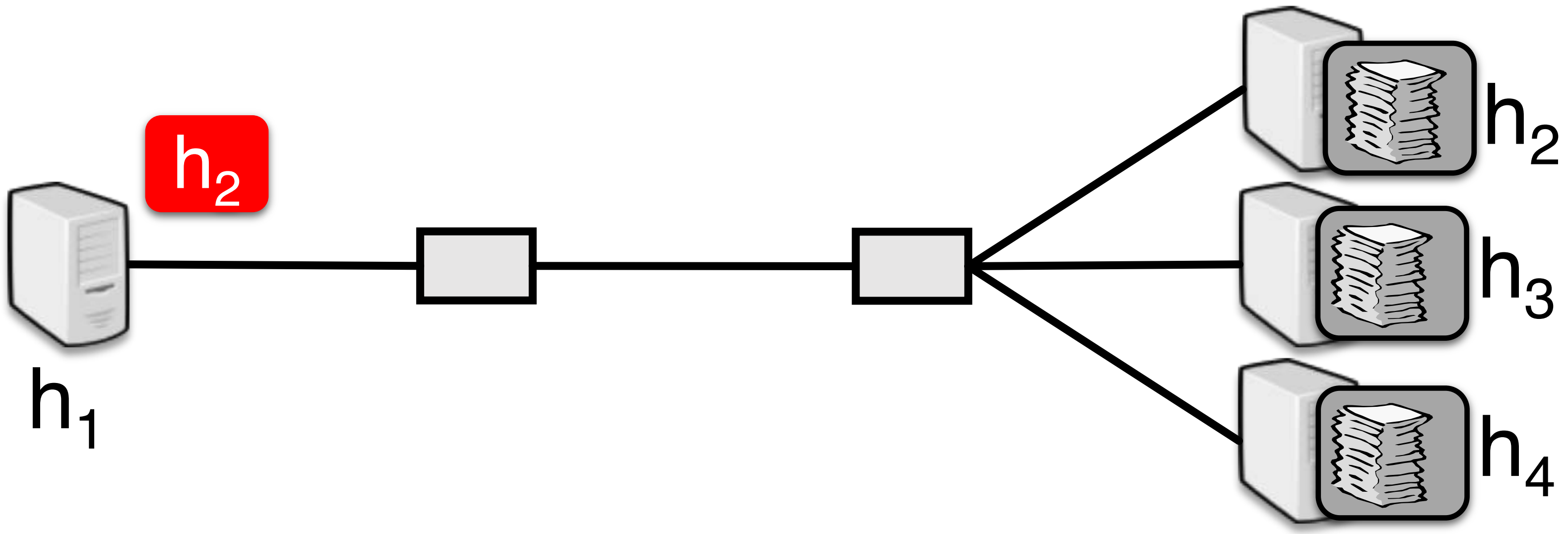
Insight: End-hosts collect and monitor telemetry data

New insight: Switch stores the telemetry data



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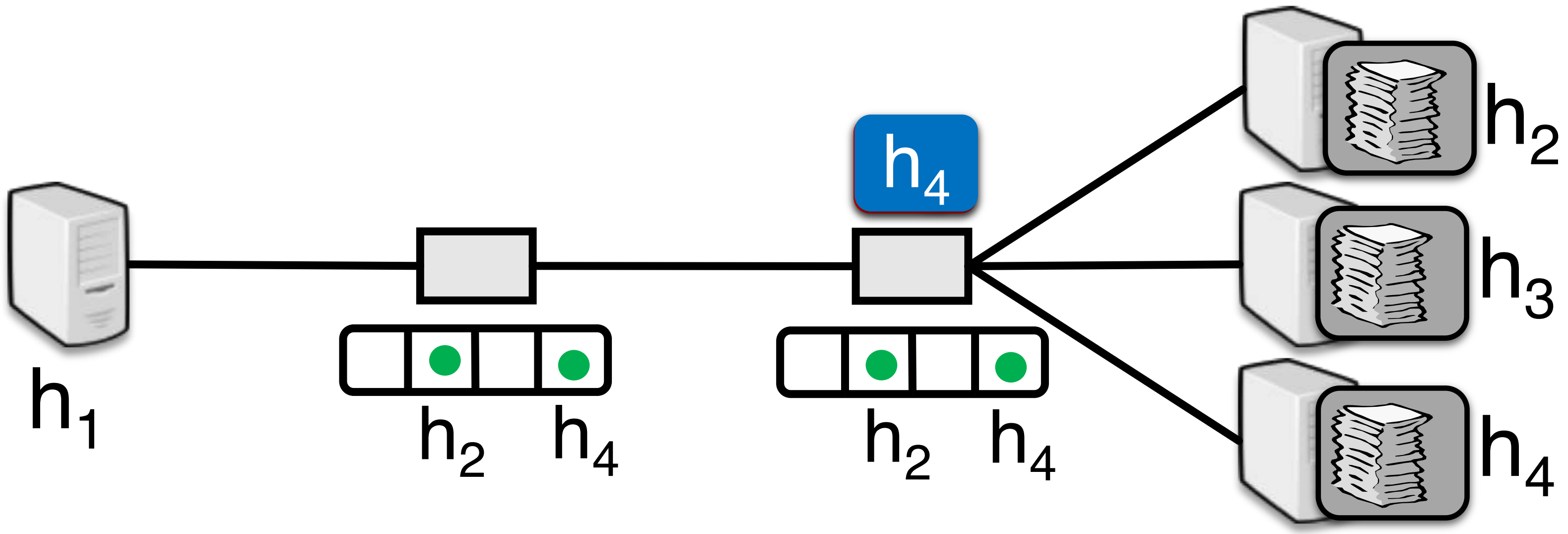

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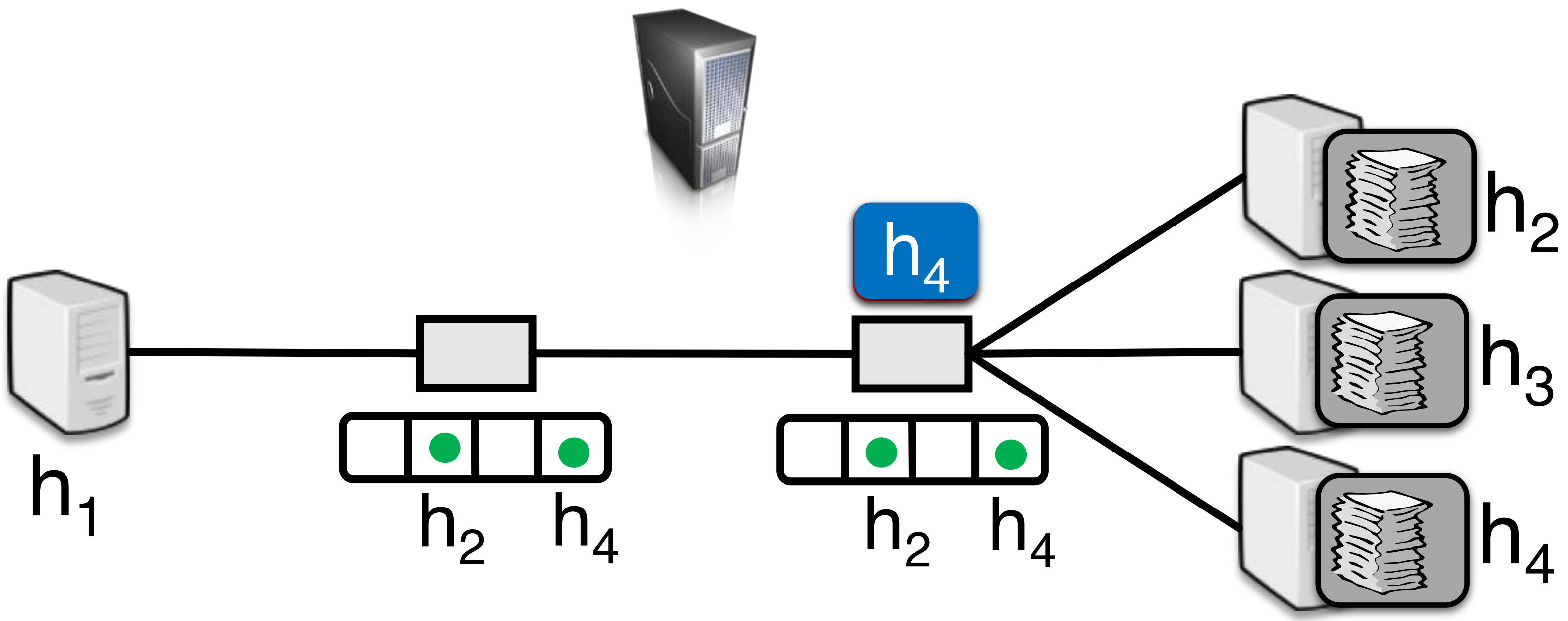

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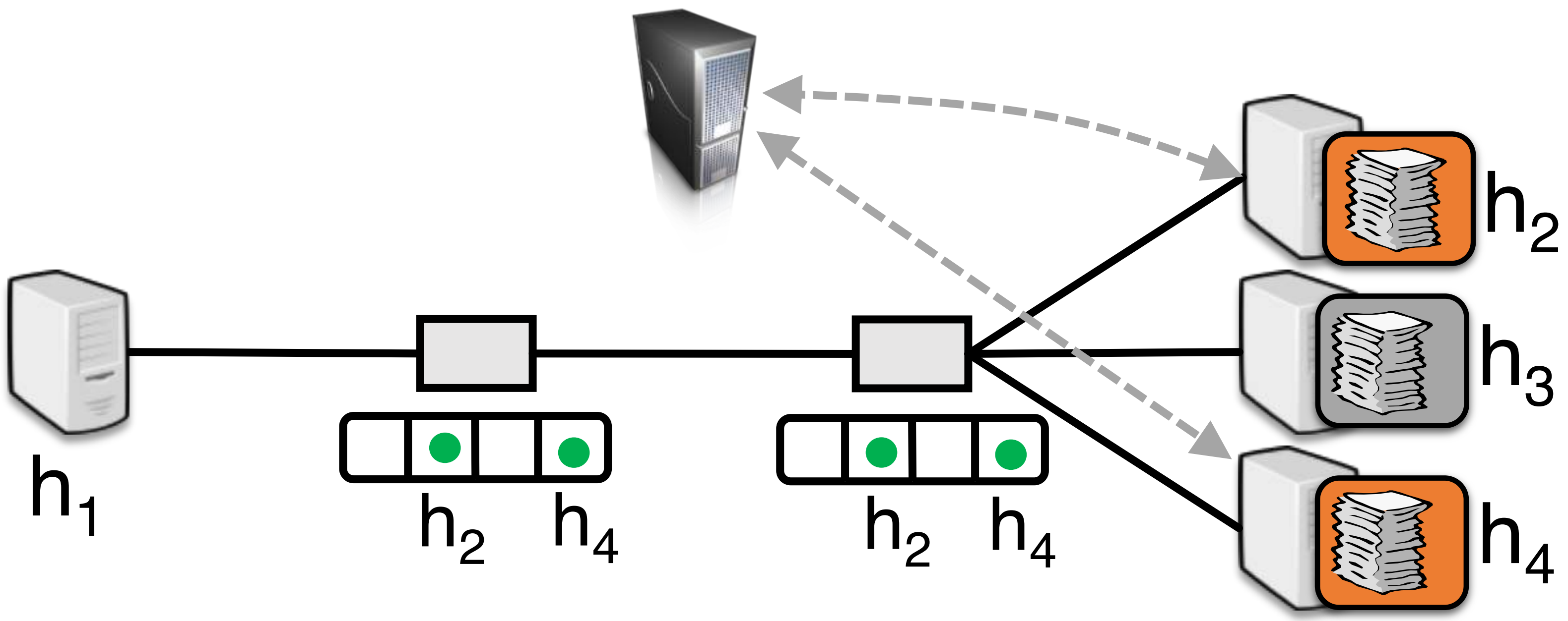
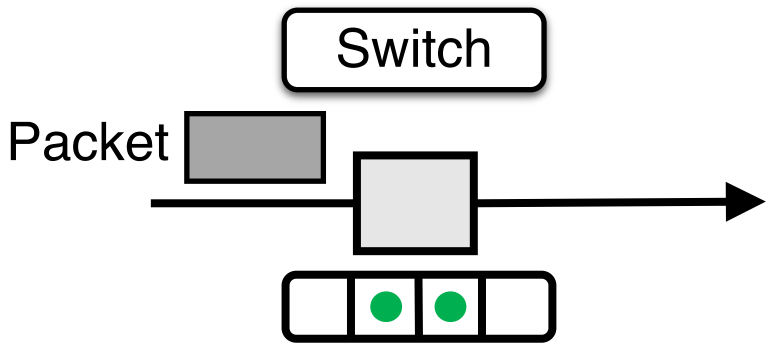


SwitchPointer in a nutshell



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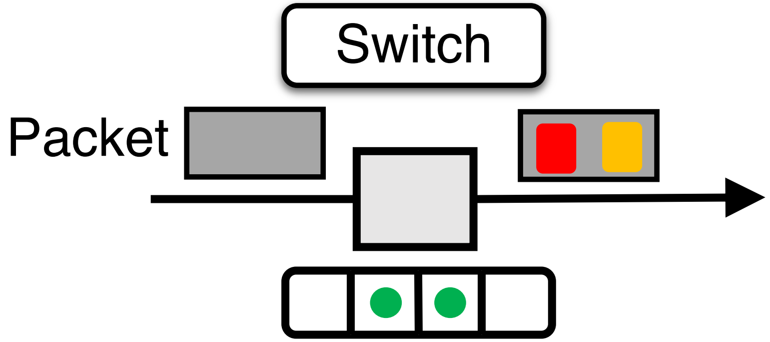

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- Maintains per-epoch pointer to all end-hosts
- Embeds linkID(■) and epochID (■)

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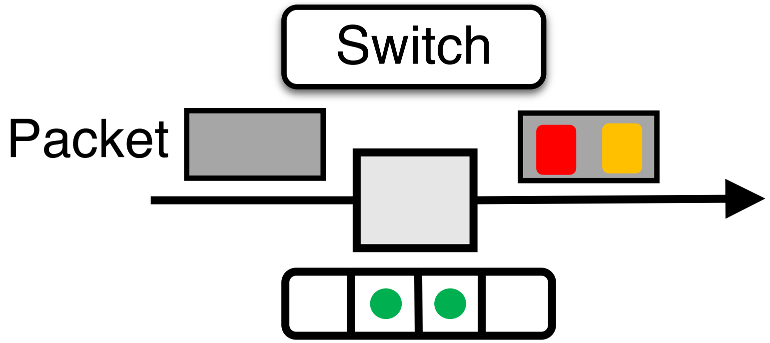

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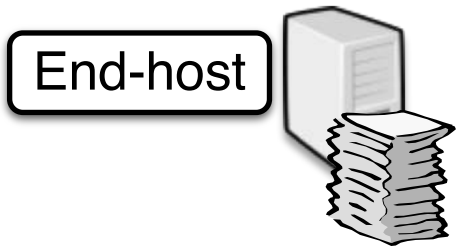

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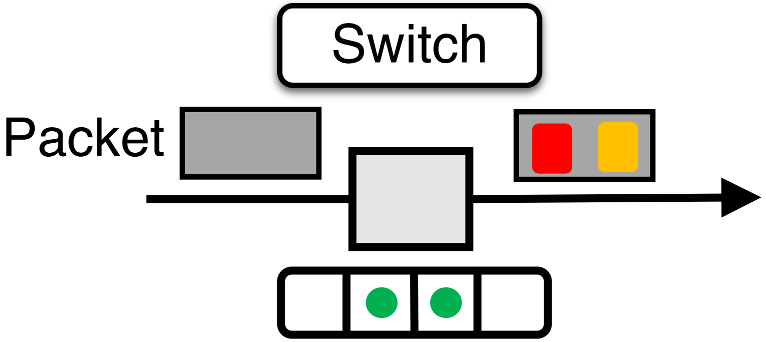

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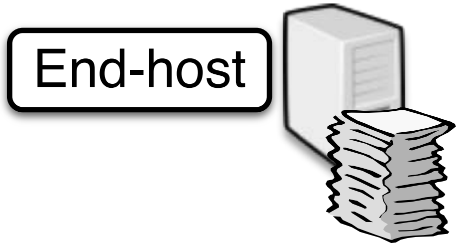

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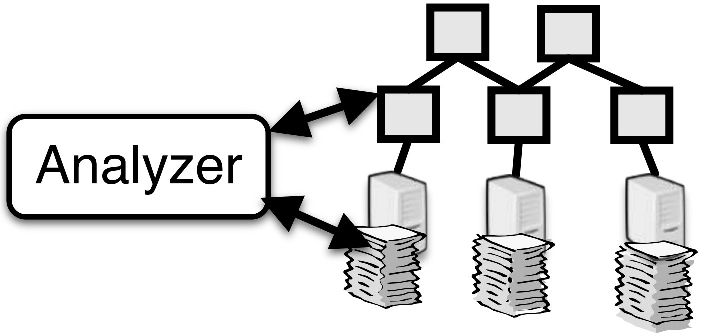
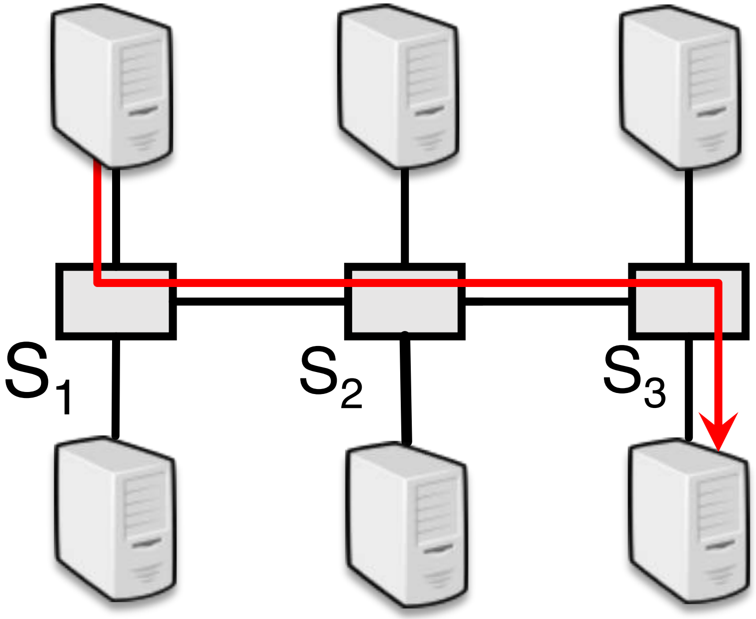


- Uses pointers at switches
- Locates the data necessary for debugging

Let’s revisit “Too many red lights” problem



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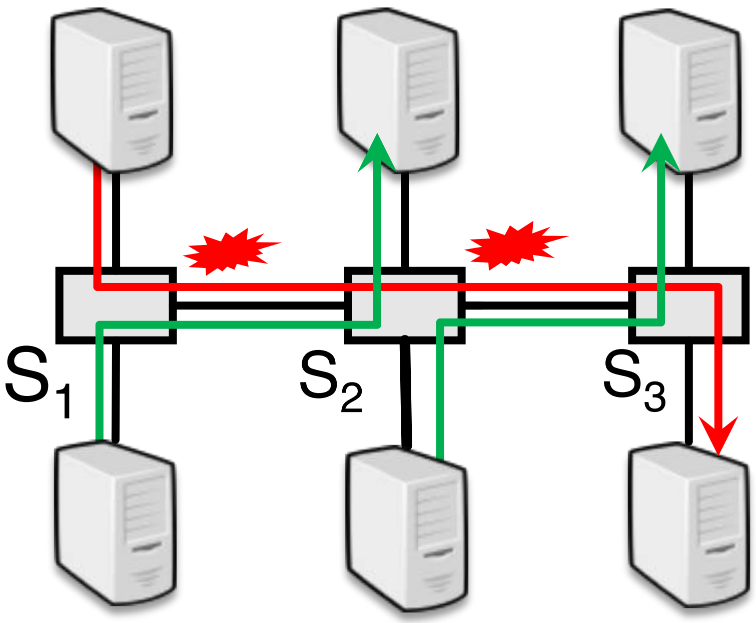

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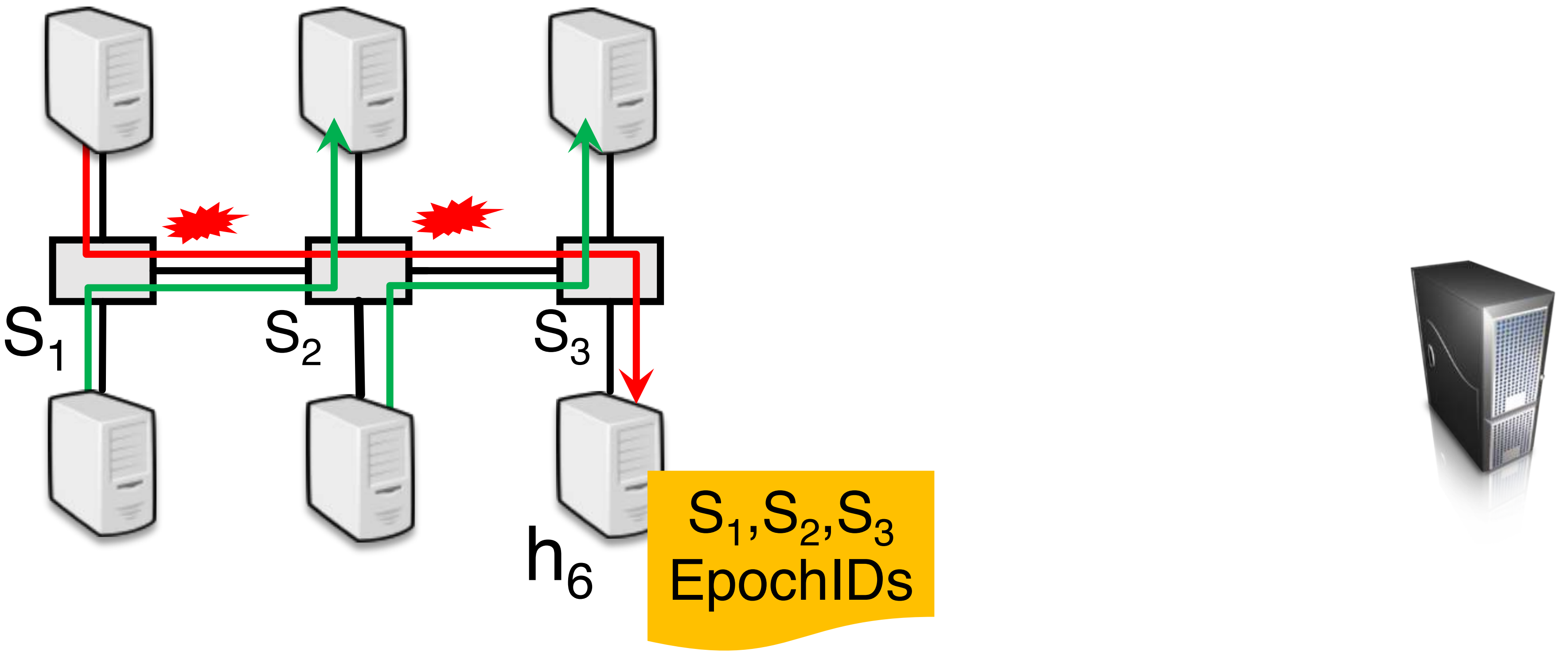

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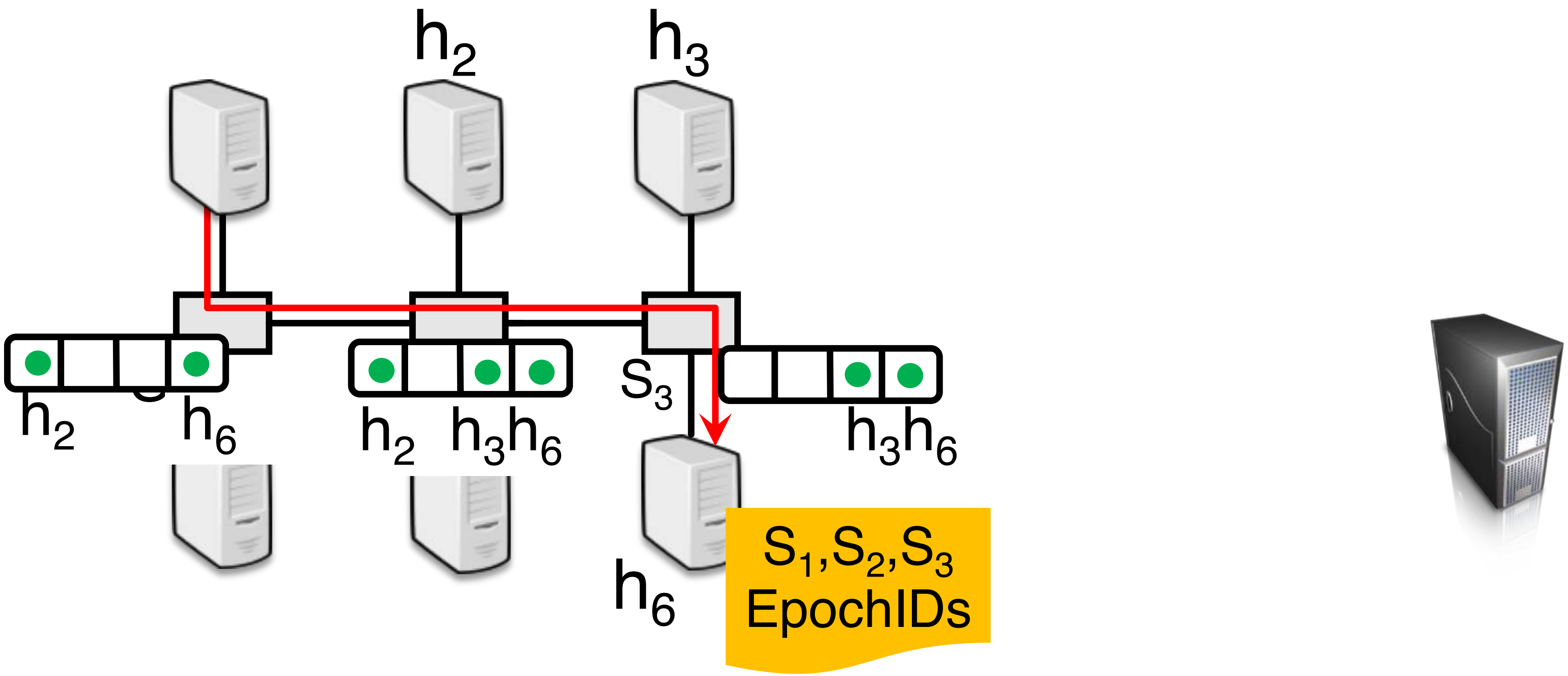

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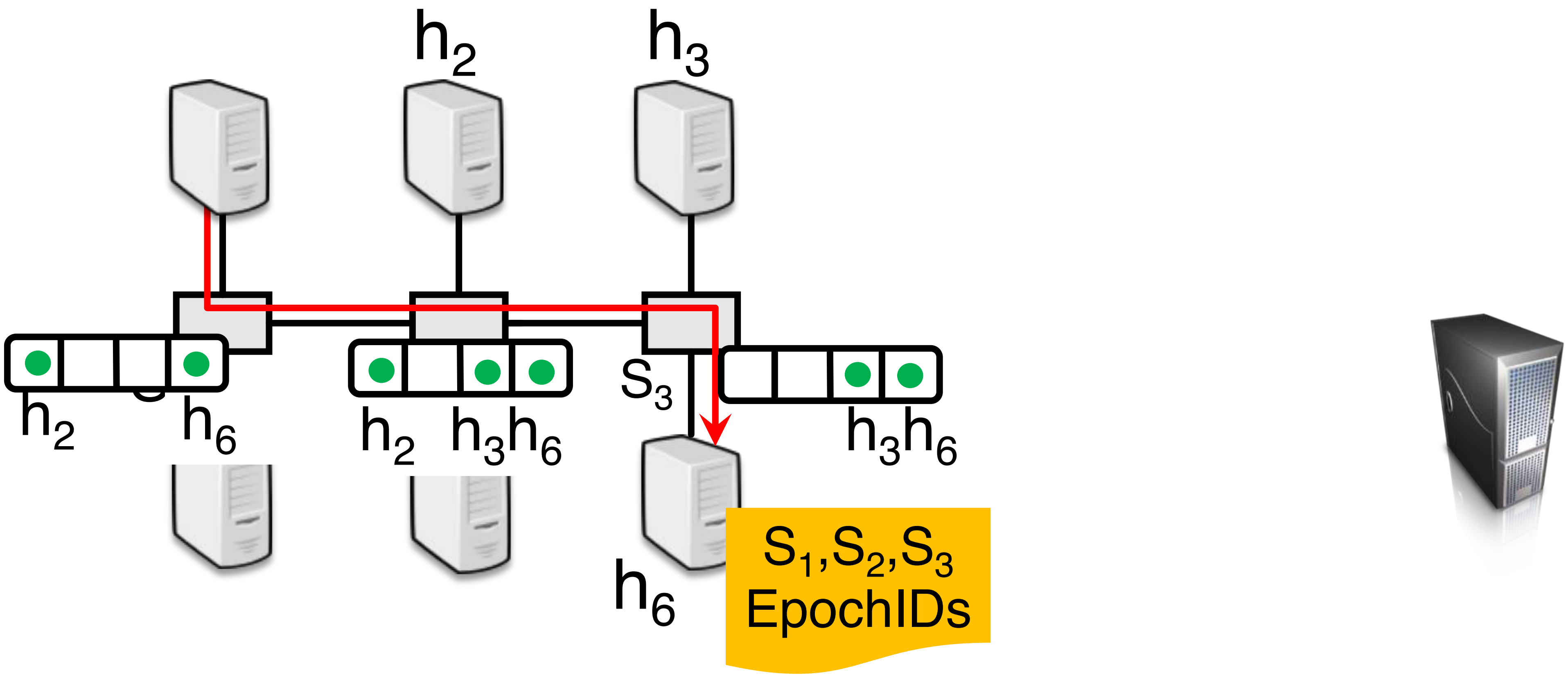

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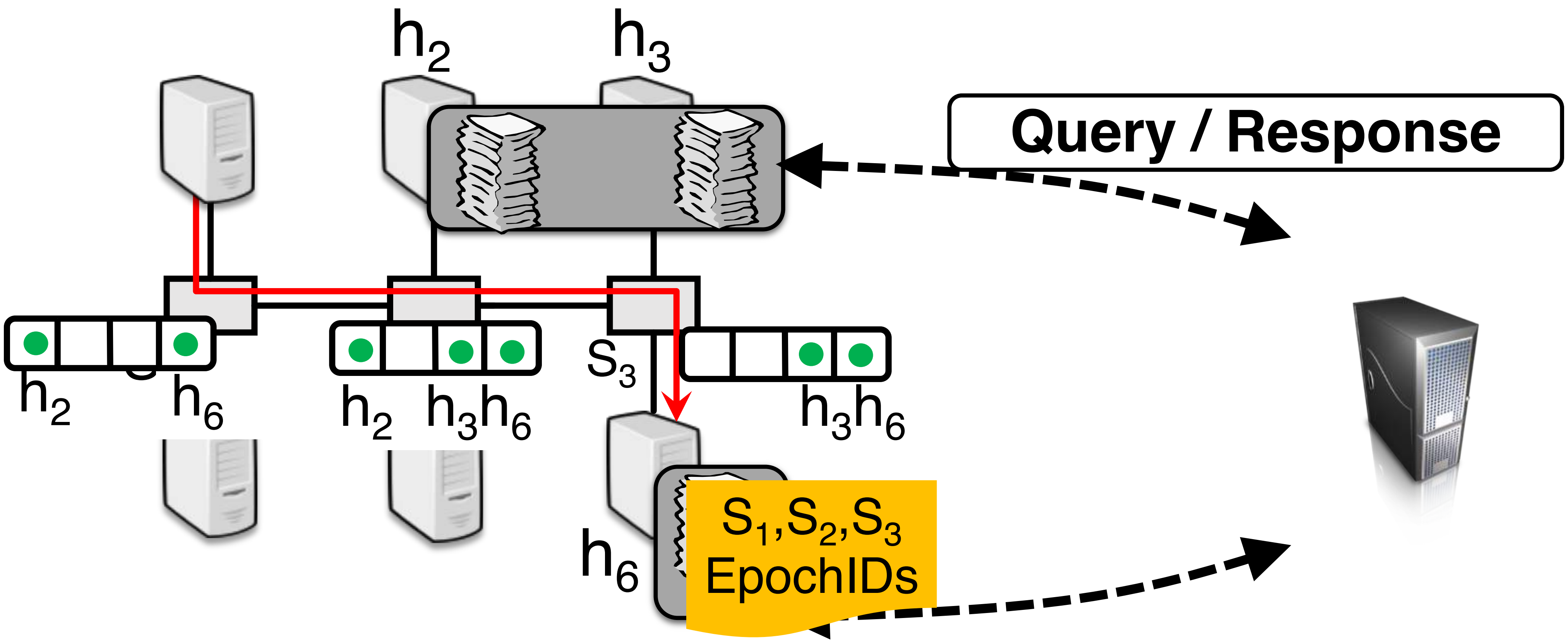

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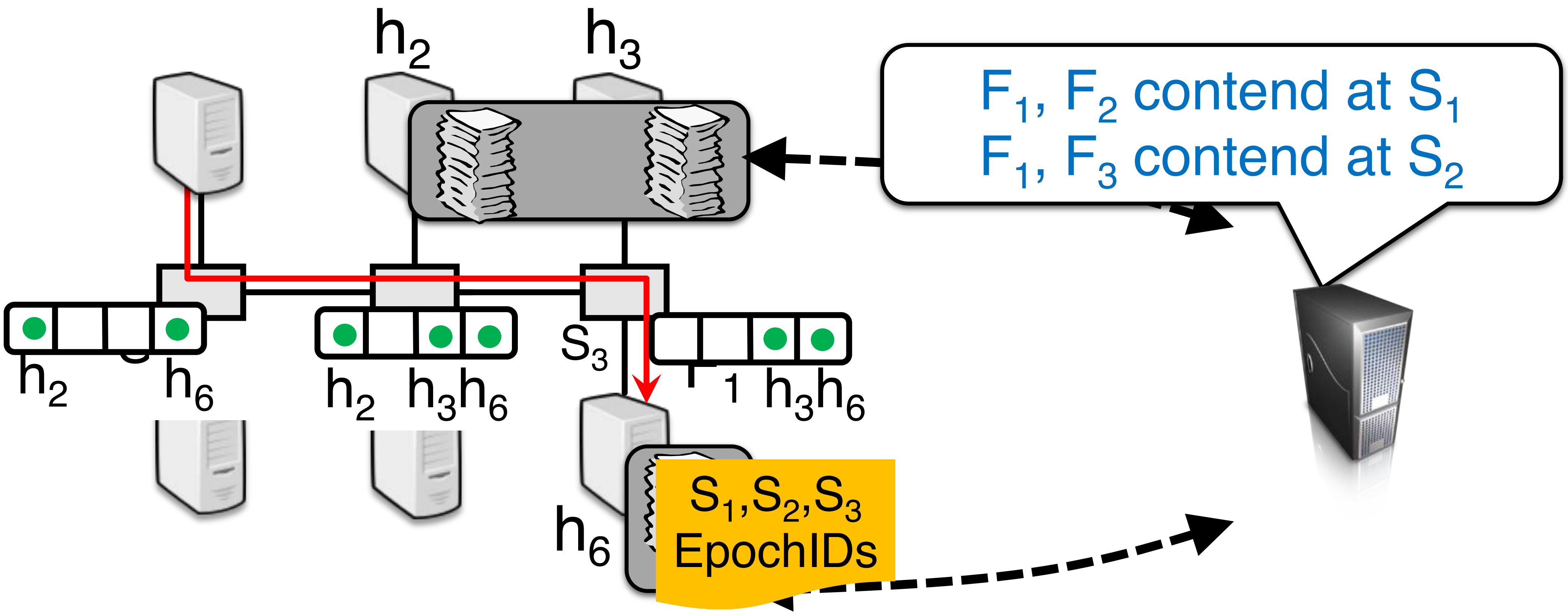

SwitchPointer: Four technical challenges

- How to decide the right epoch size?
- How to efficiently maintain pointers?
- How to efficiently embed telemetry data?
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SwitchPointer design

Data structure for pointers

Tradeoff between memory and bandwidth, and system efficiency

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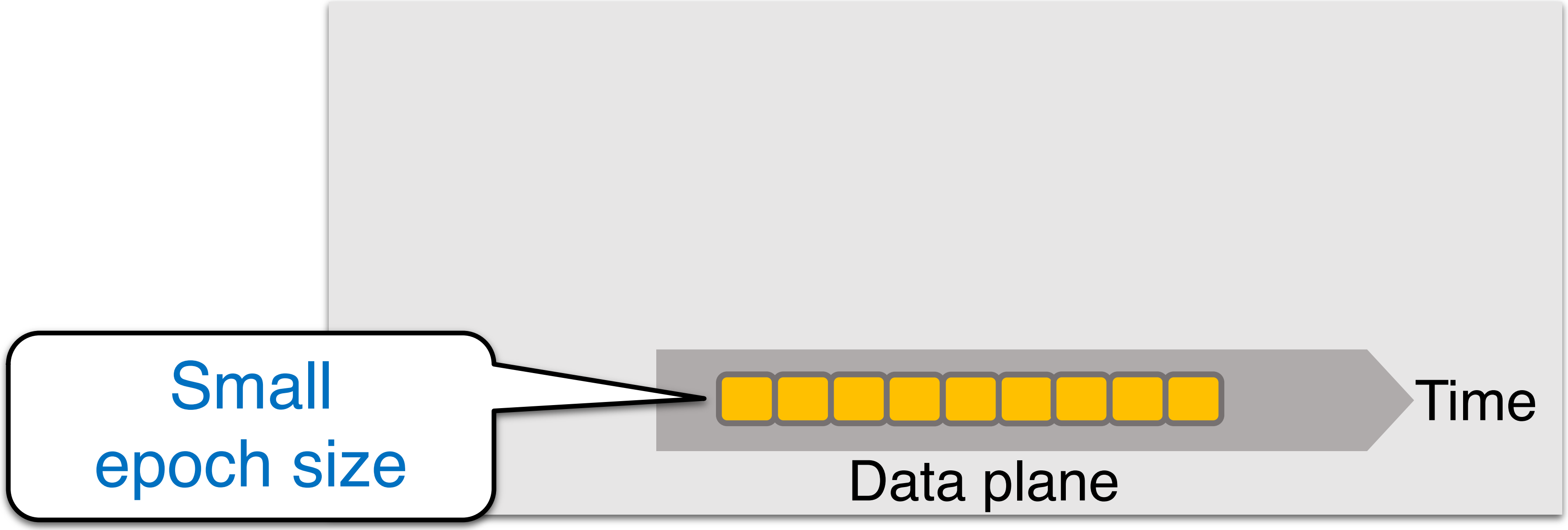

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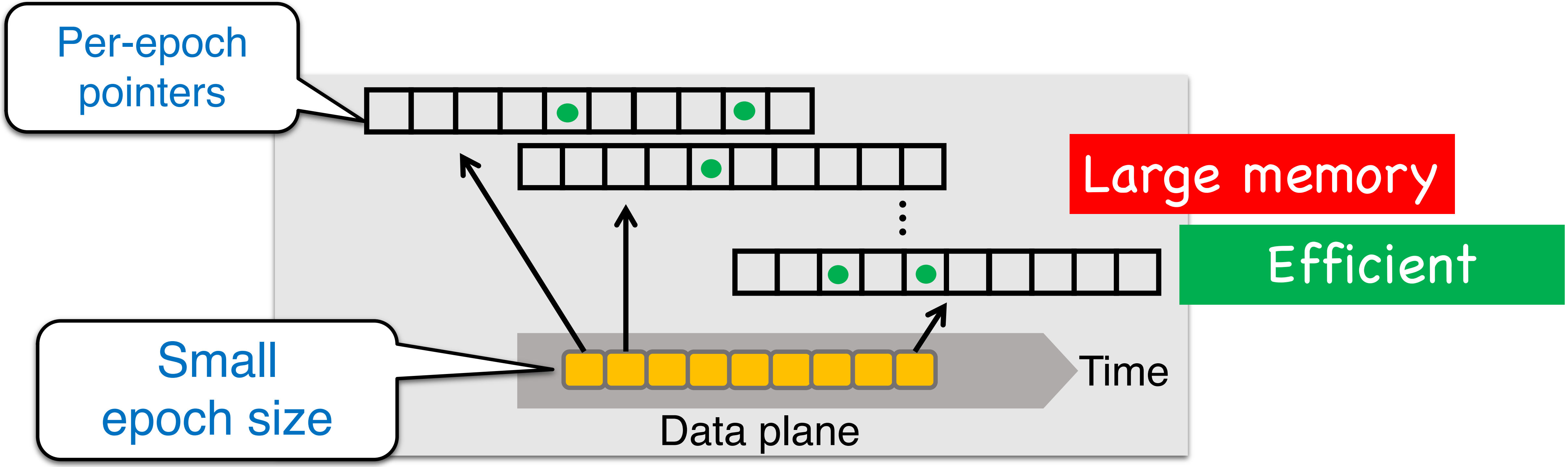

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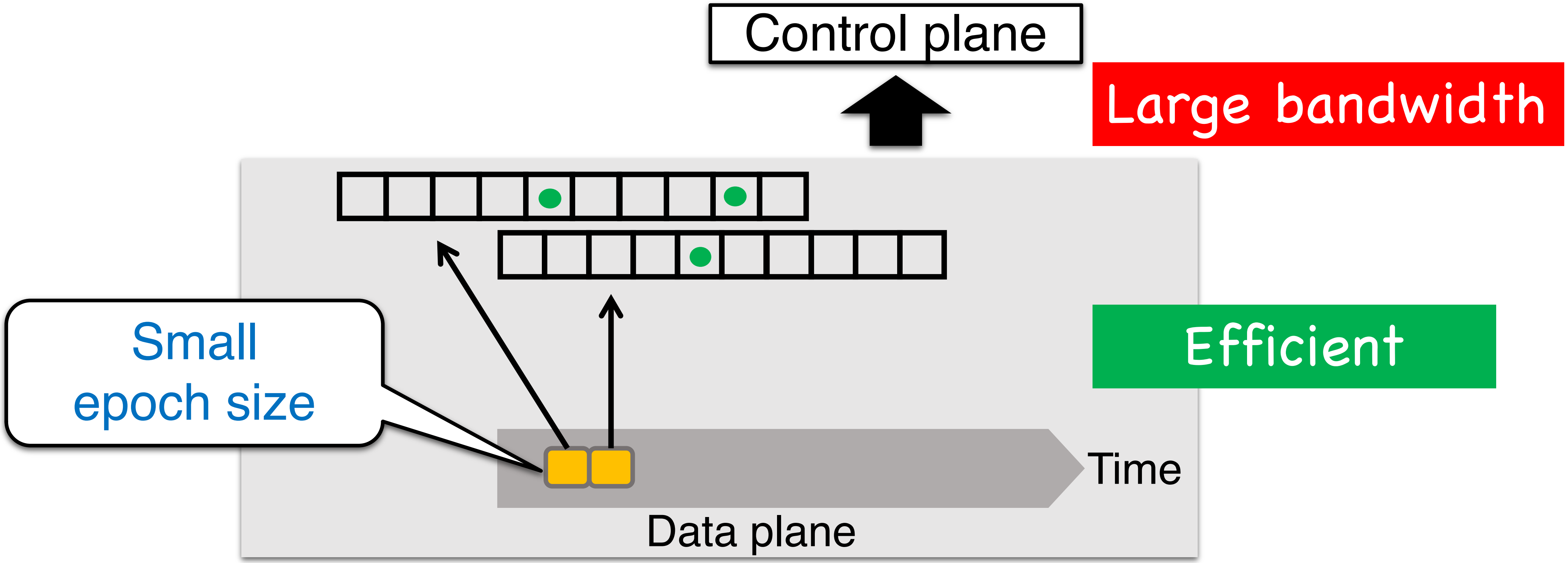

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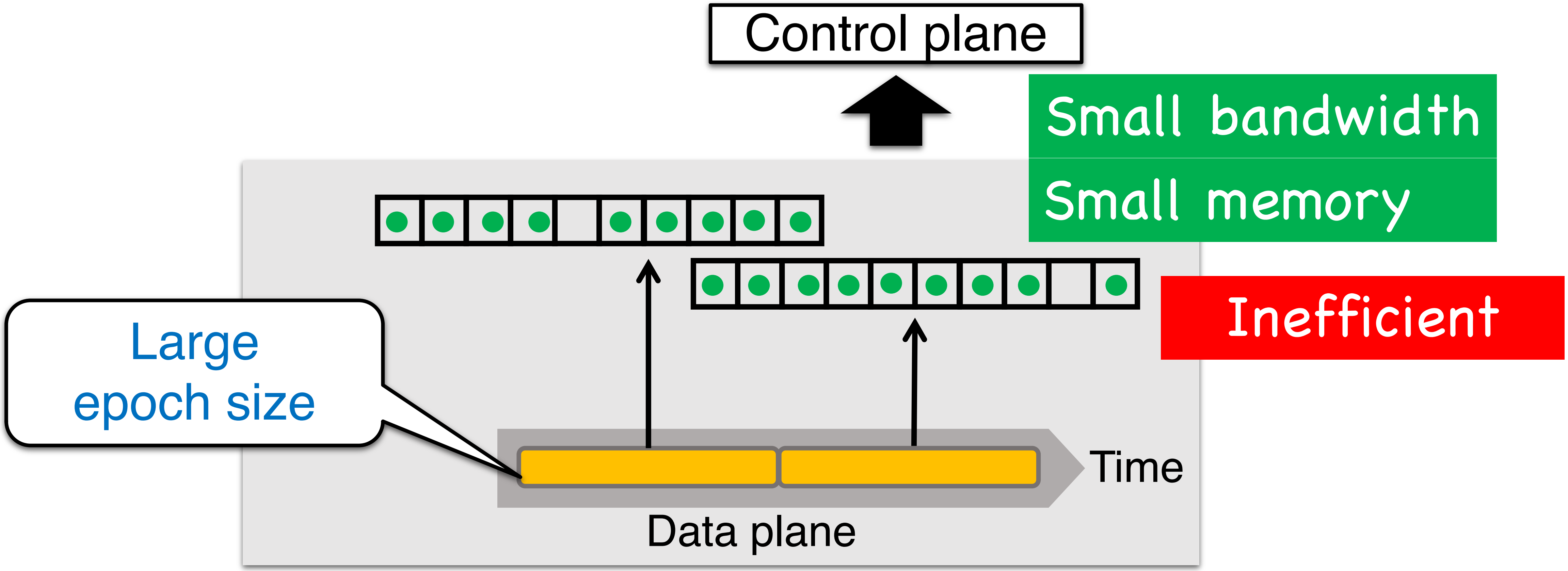

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Our solution: Hierarchical data structure for pointers

Each subsequent level has epochs with exponentially larger time scales

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Epoch size = α

Level 1

SwitchPointer design

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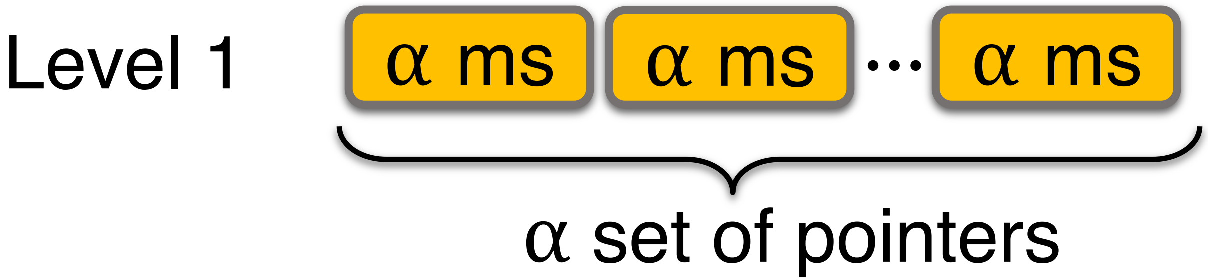

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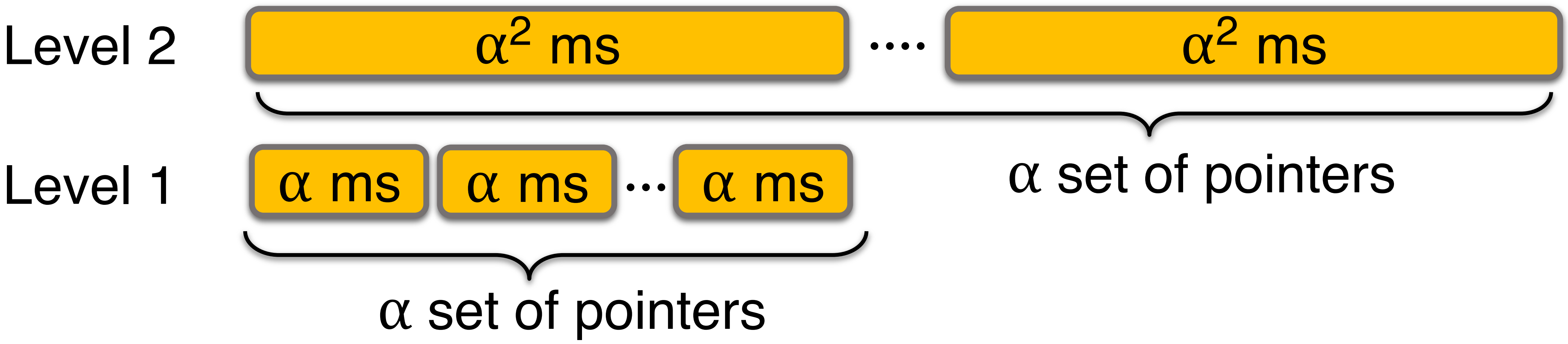

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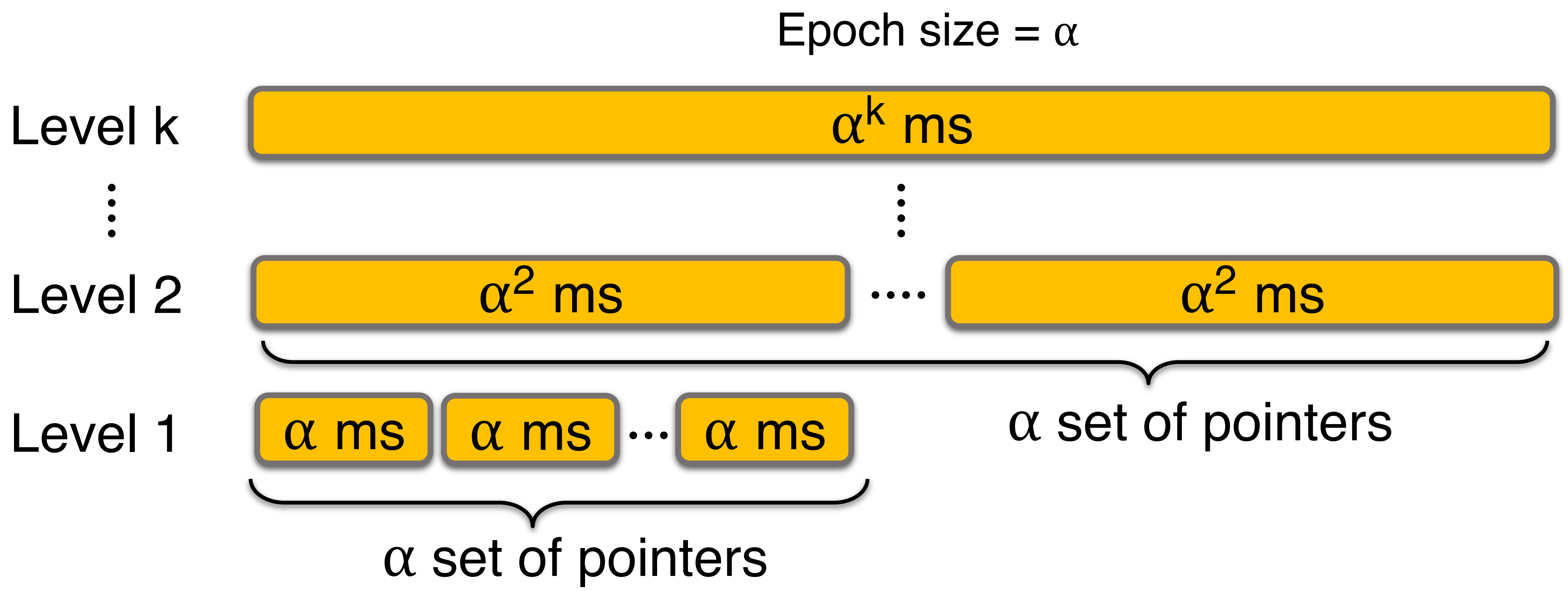

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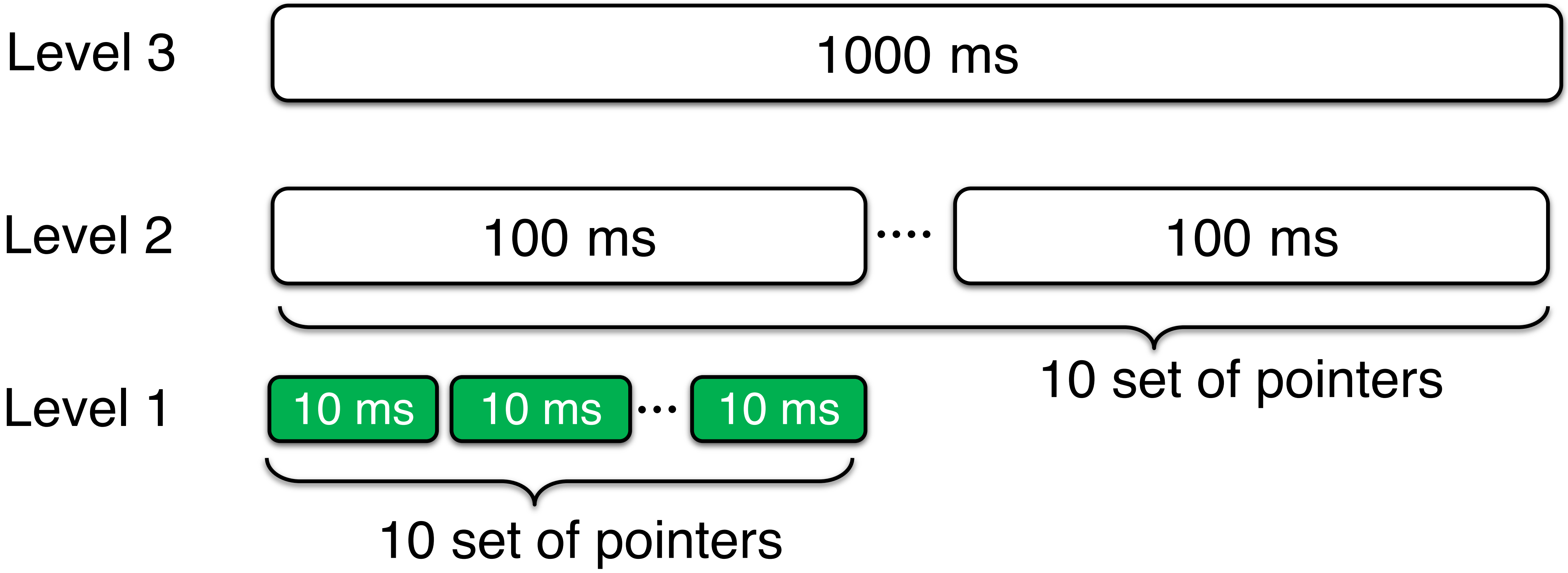

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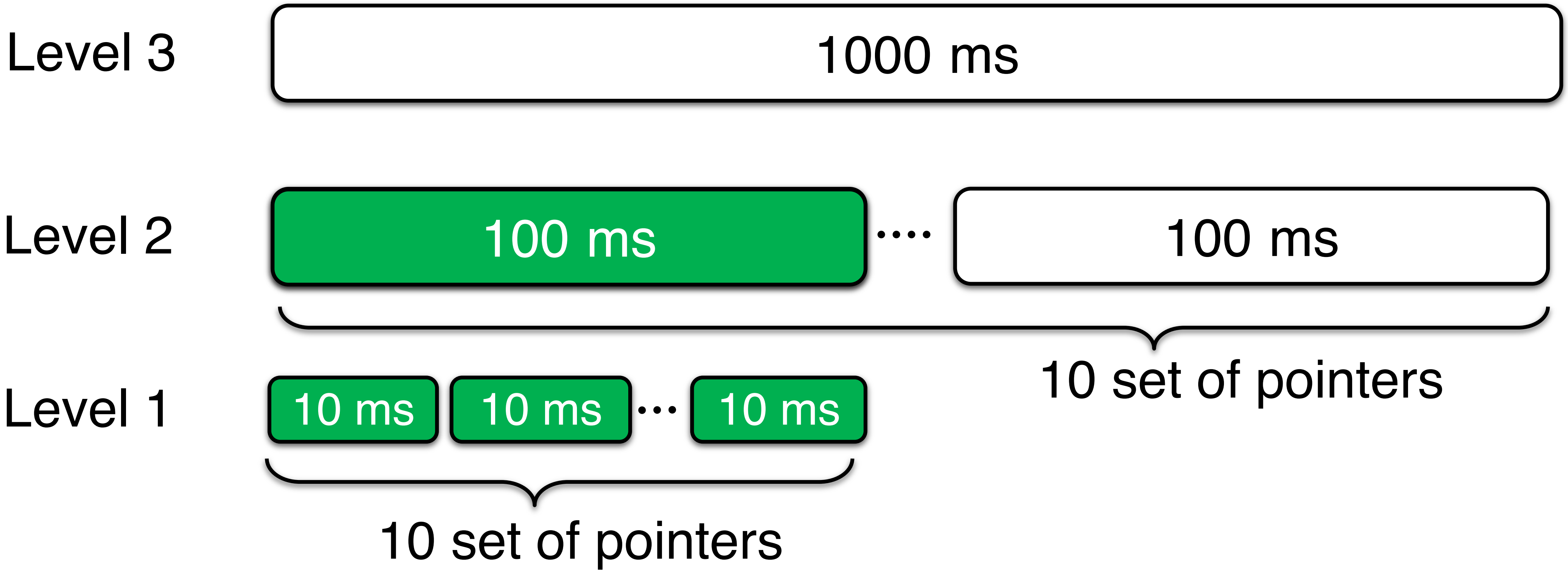

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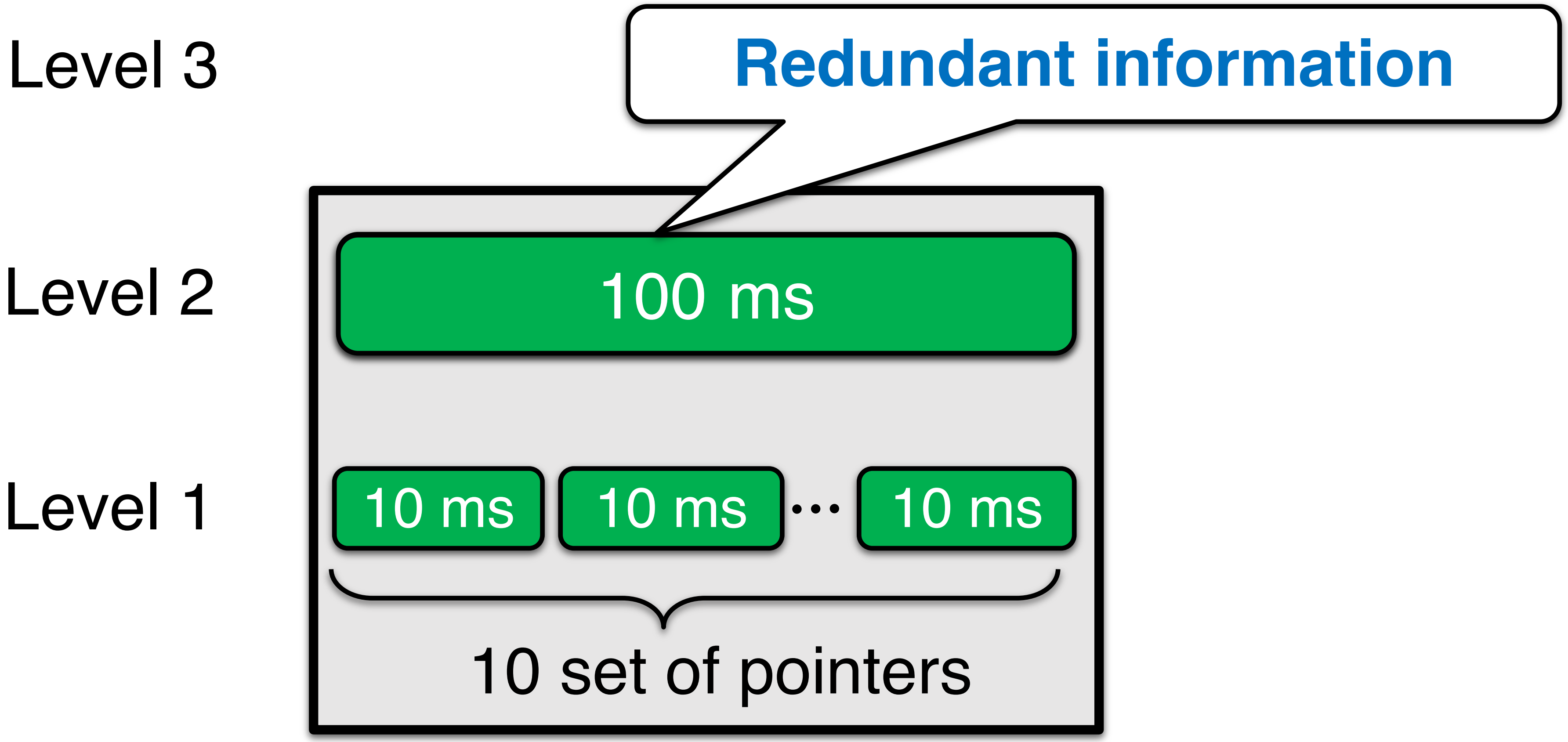

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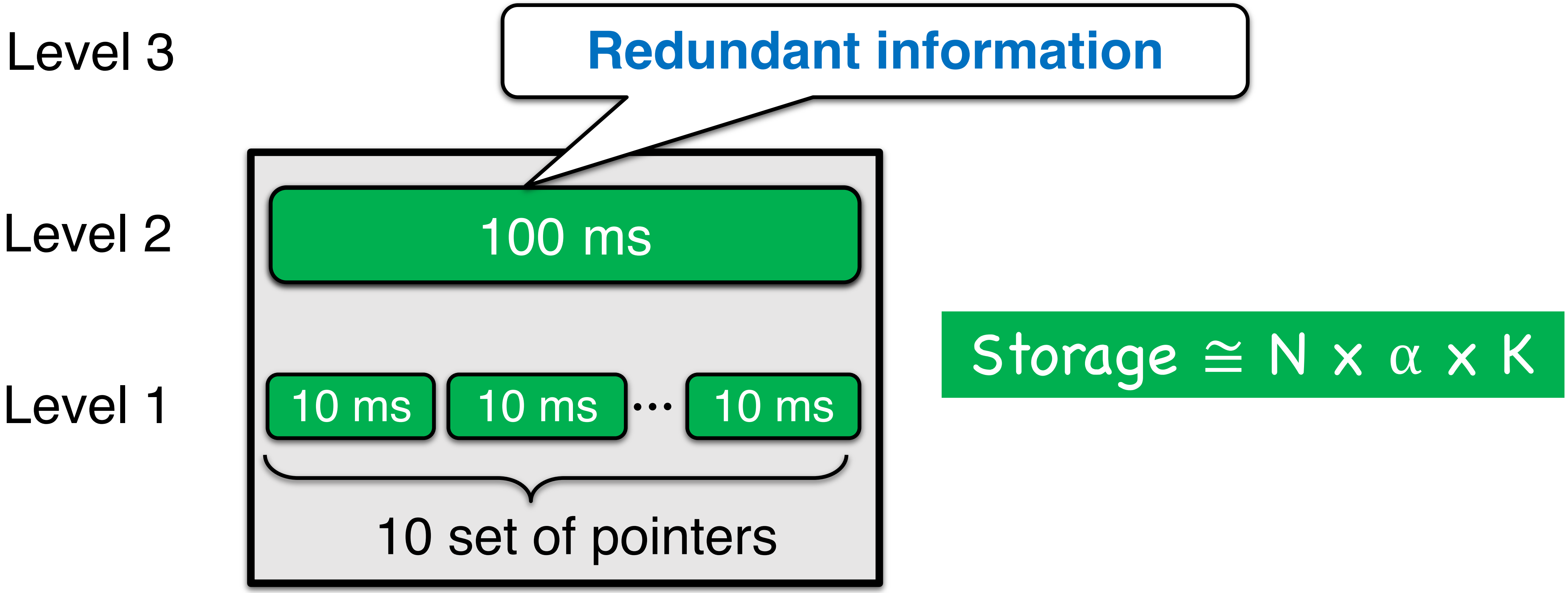

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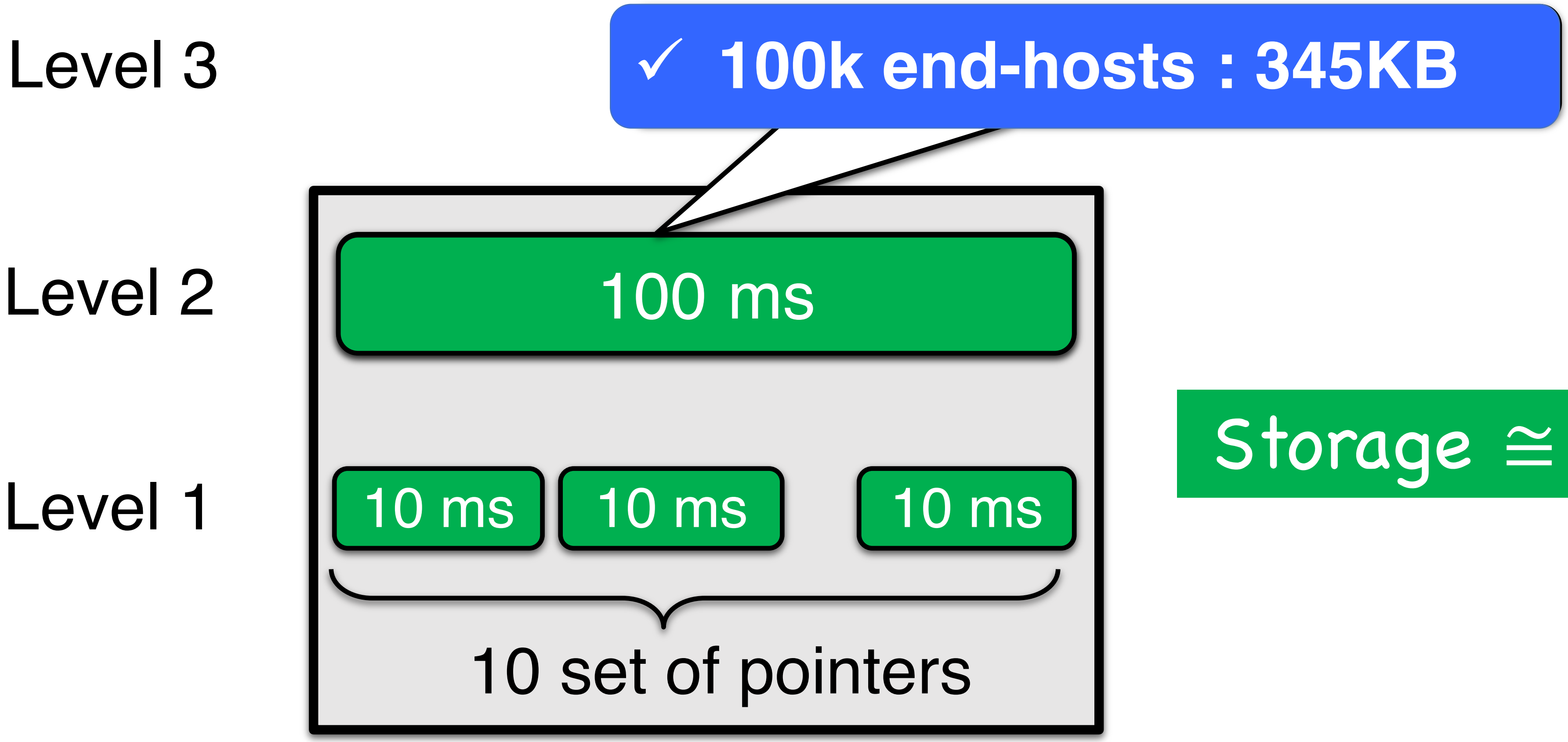

Storage ≅ N x α x K

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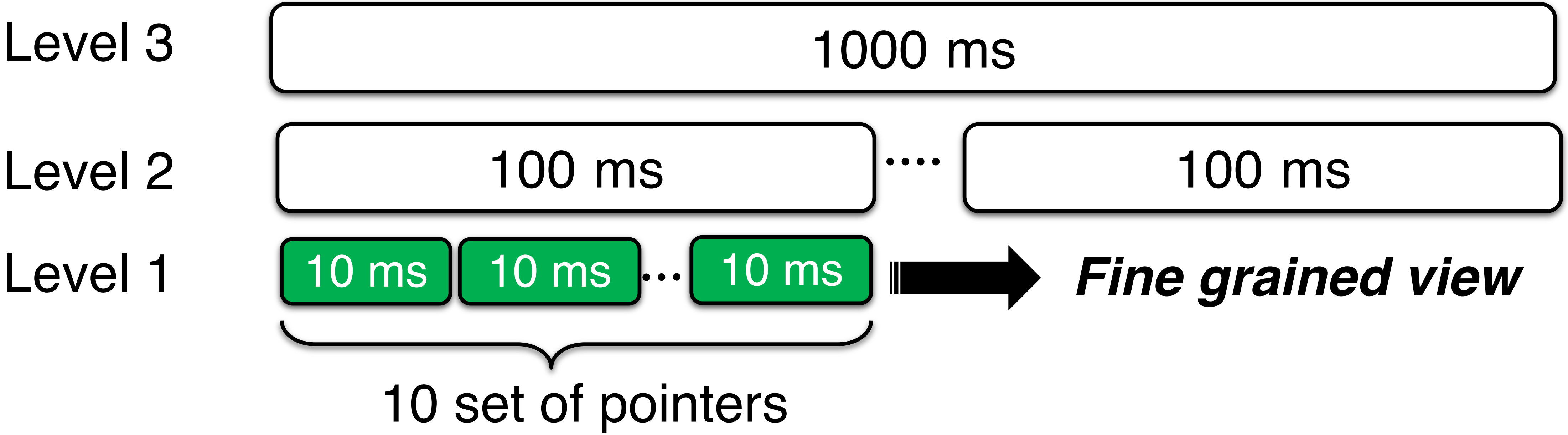

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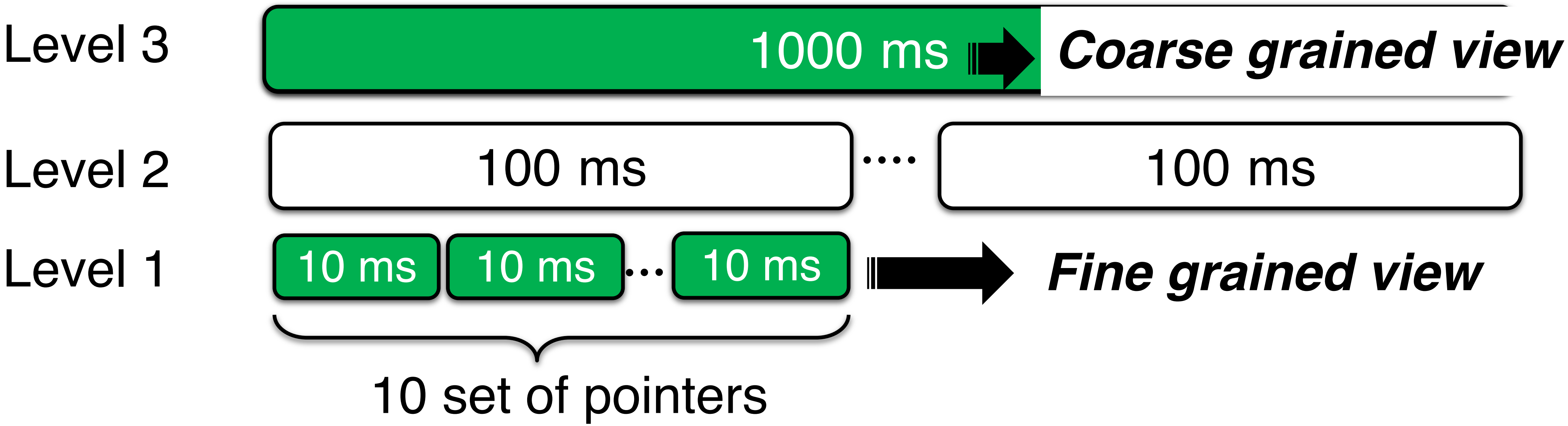

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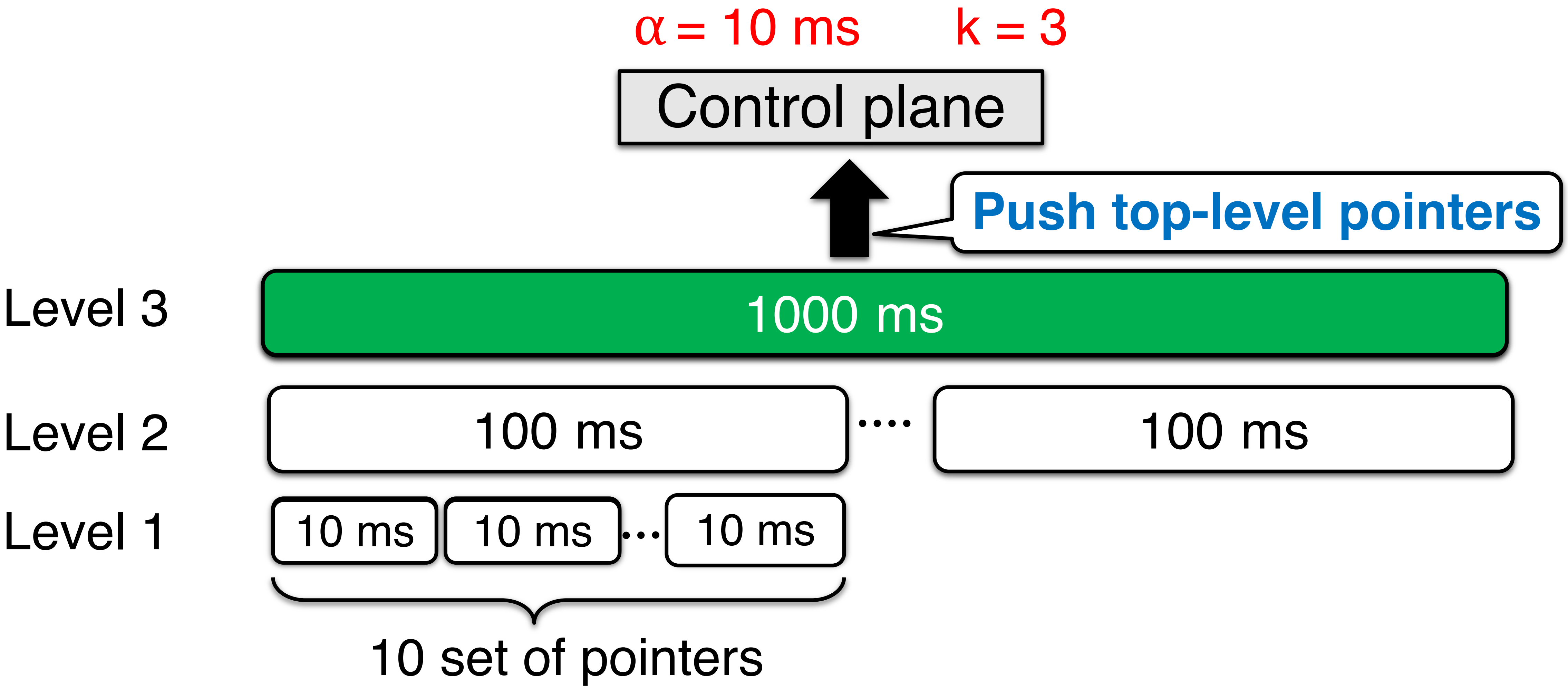

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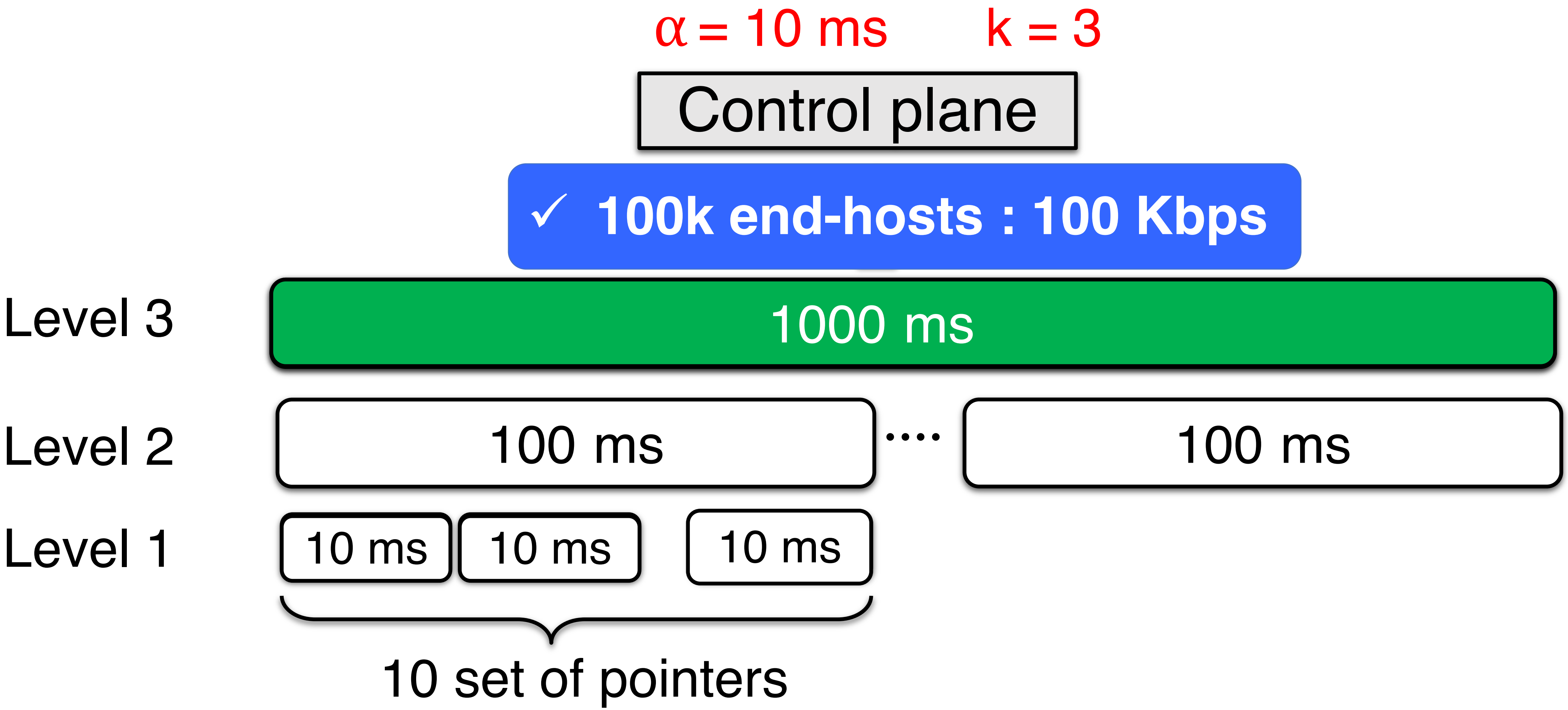

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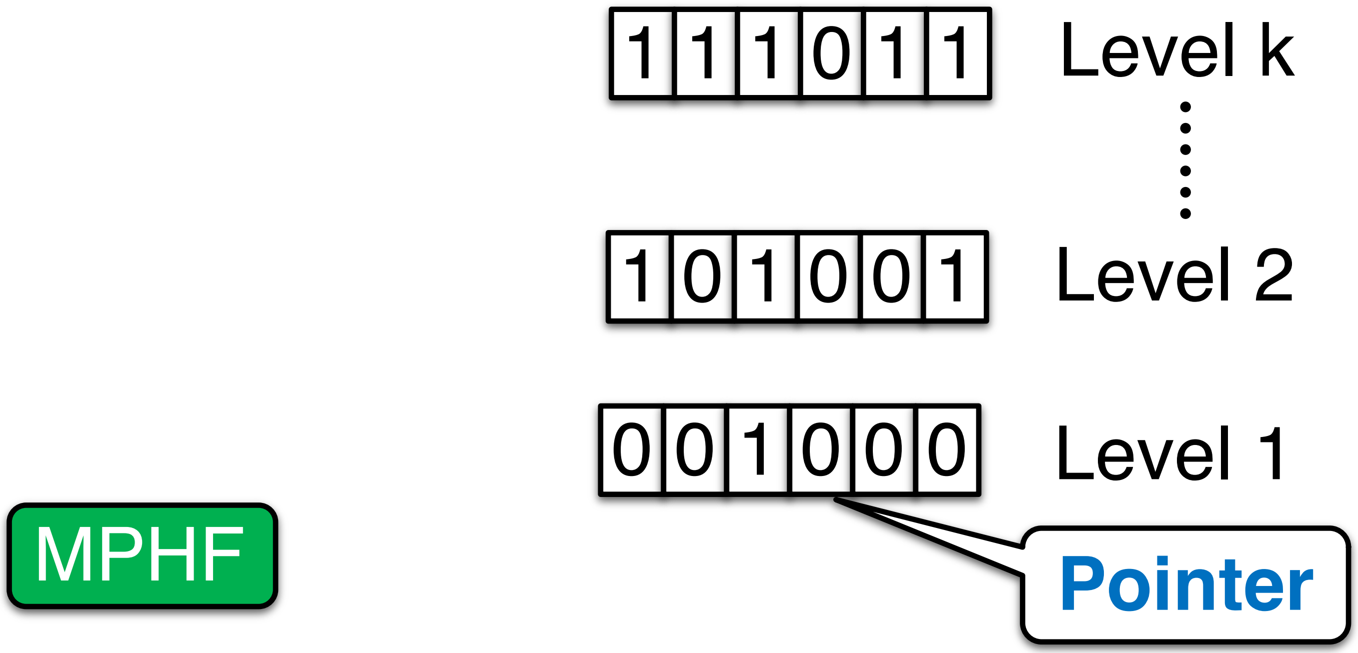
Minimal Perfect Hash Functions

- Maps distinct keys (dest IPs) to a set of integers
- No hash collisions
- 2.1 bits of storage per end-host
- Construction time is large

SwitchPointer design

Maintaining pointers in the hierarchical data structure

Minimal perfect hash function (MPHF)



SwitchPointer design

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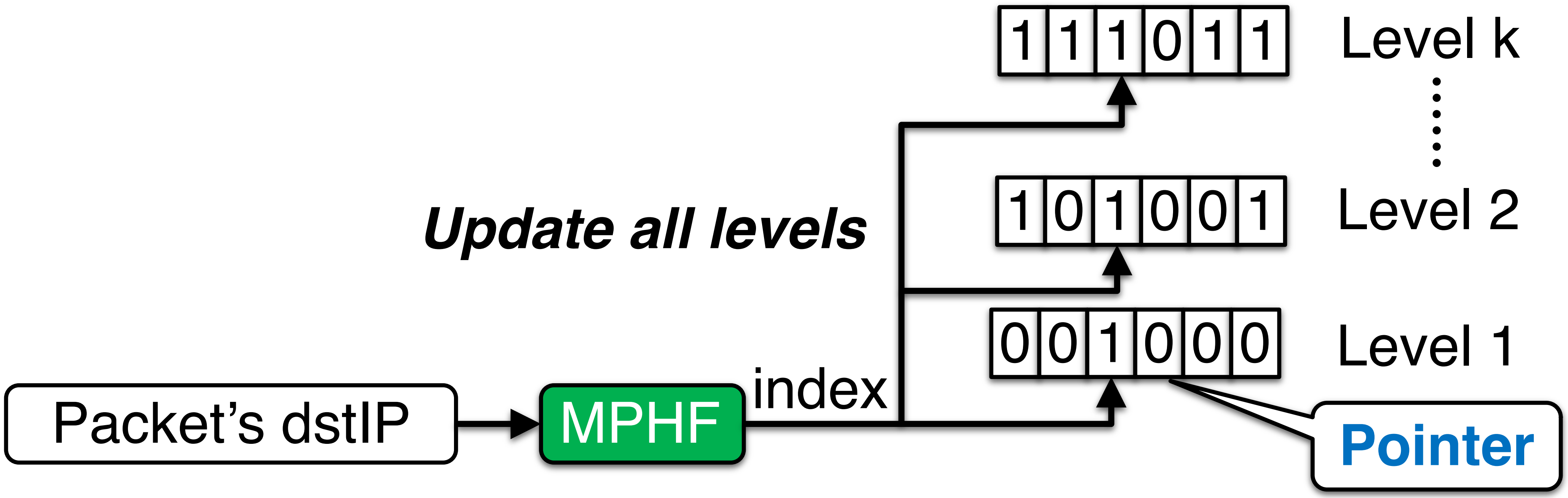

- **Single operation** to find the index to set in all levels

SwitchPointer design

Maintaining updated pointers in the hierarchical data structure

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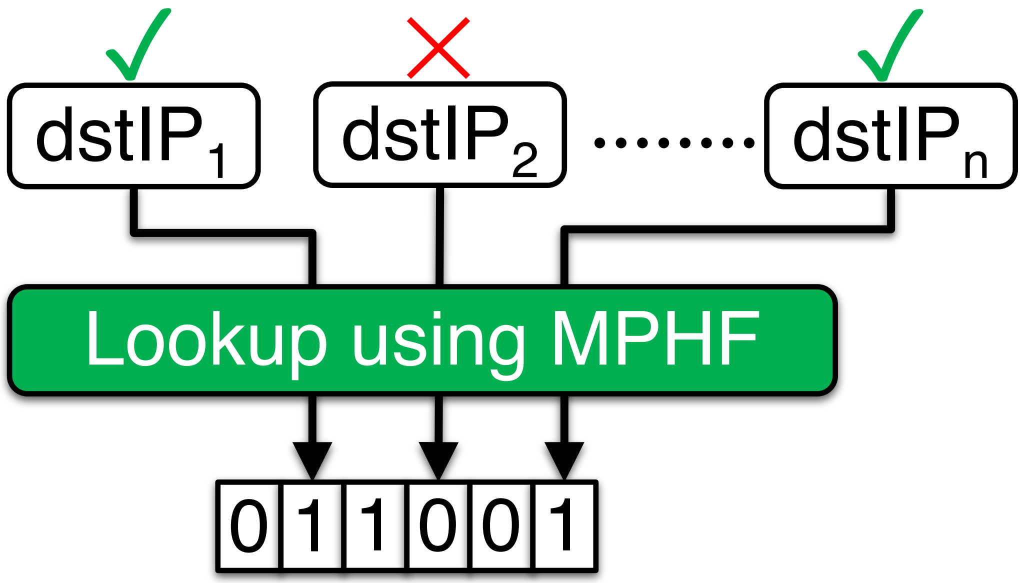

Checks dstIP's corresponding bit in the bit array

SwitchPointer: Four technical challenges

- How to decide the right epoch size?
- How to efficiently maintain pointers?
- How to efficiently embed telemetry data?
- How to handle asynchronous clocks?

SwitchPointer design

Switch embeds telemetry data (e.g., linkID, epochID)

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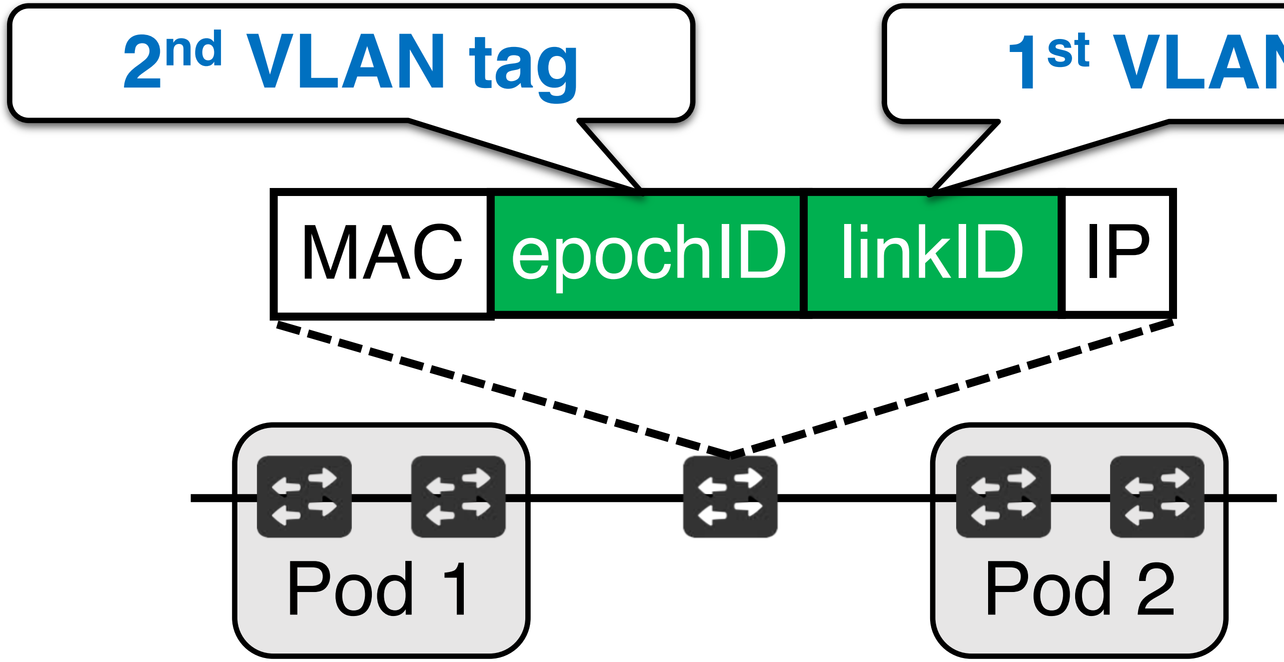

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More details in our paper

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INT simplifies embedding and decoding telemetry data

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Set bound on clock difference between any pair of devices

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SwitchPointer - Coverage

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In-network techniques

- TCP in-cast diagnosis
- Heavy hitter
- ECMP load imbalance diagnosis
- Silent random packet drops
- Traffic matrix
- DDoS

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- TCP out of order packet delivery
- TCP non-monotonic
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- SYN flood attacks
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Spatially and temporally correlated problems
E.g.: Too many red lights, Traffic cascades

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Spatially and temporally correlated problems

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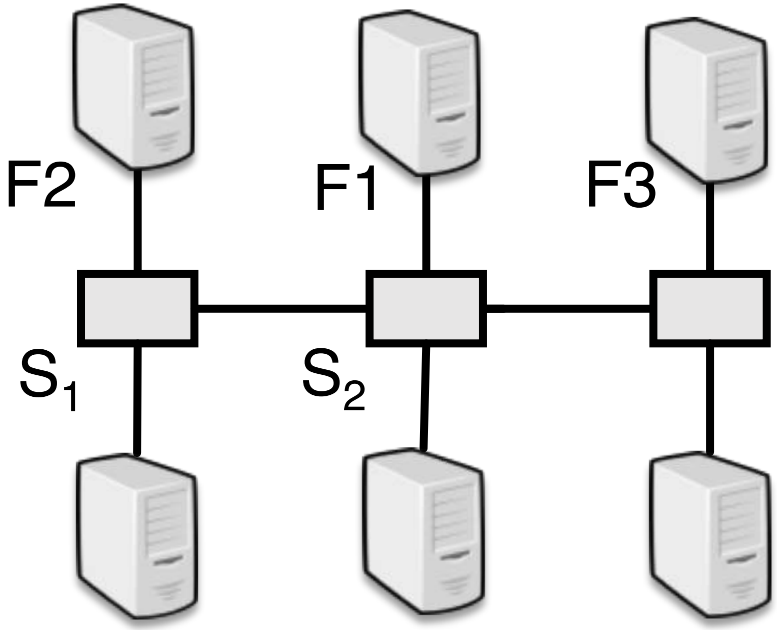
https://github.com/PathDump/Applications

Problems SwitchPointer cannot debug

- Instantaneous queue sizes
- Overlay loop detection
- Incorrect packet modification
- Packet properties at a switch

https://github.com/PathDump/Applications

A more complex example: Traffic cascades



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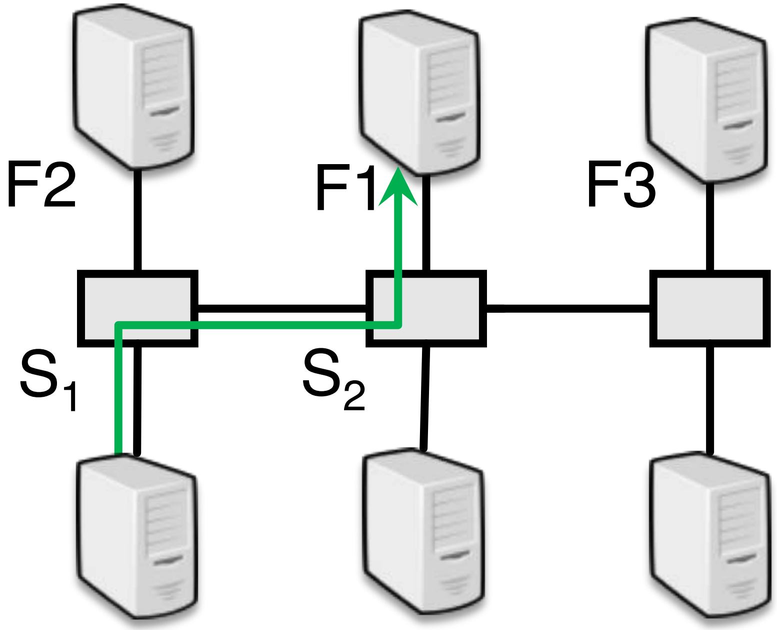

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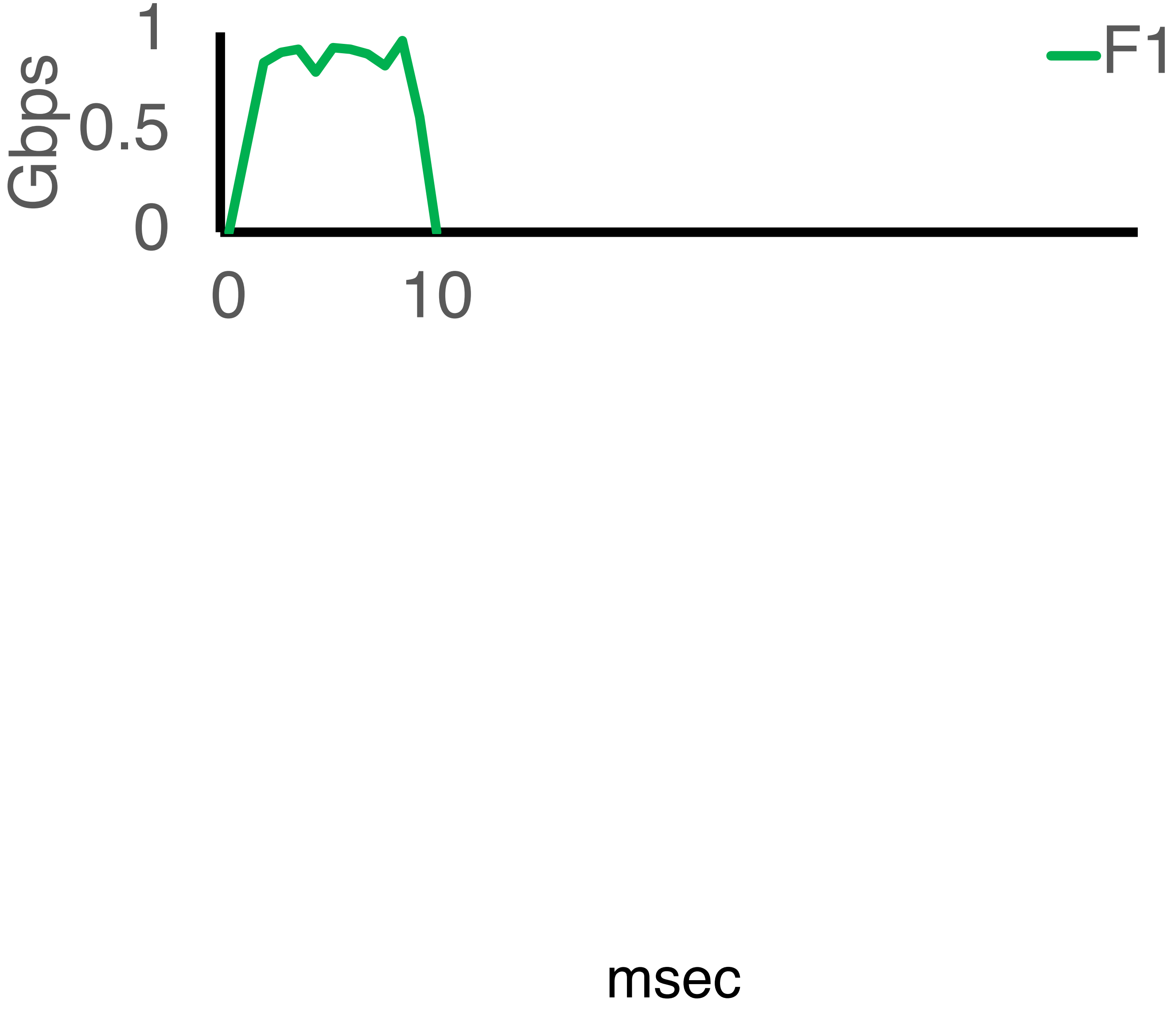

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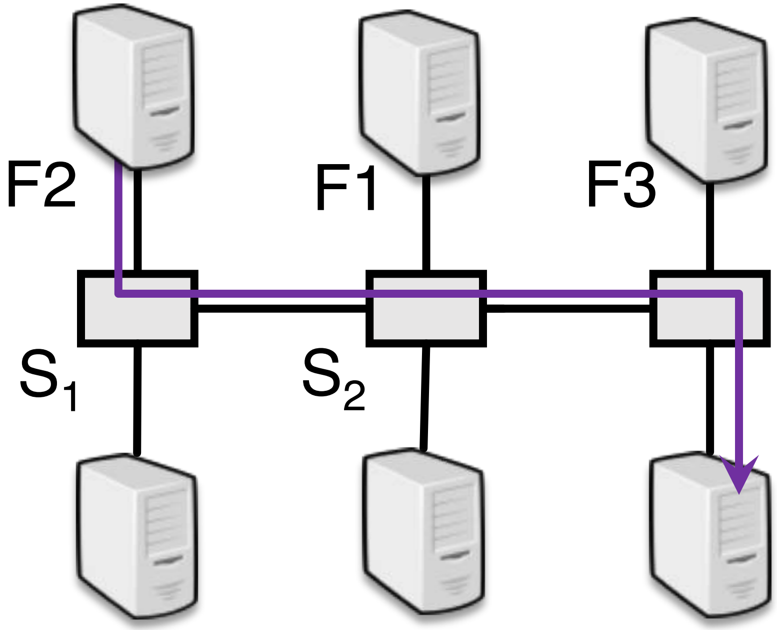

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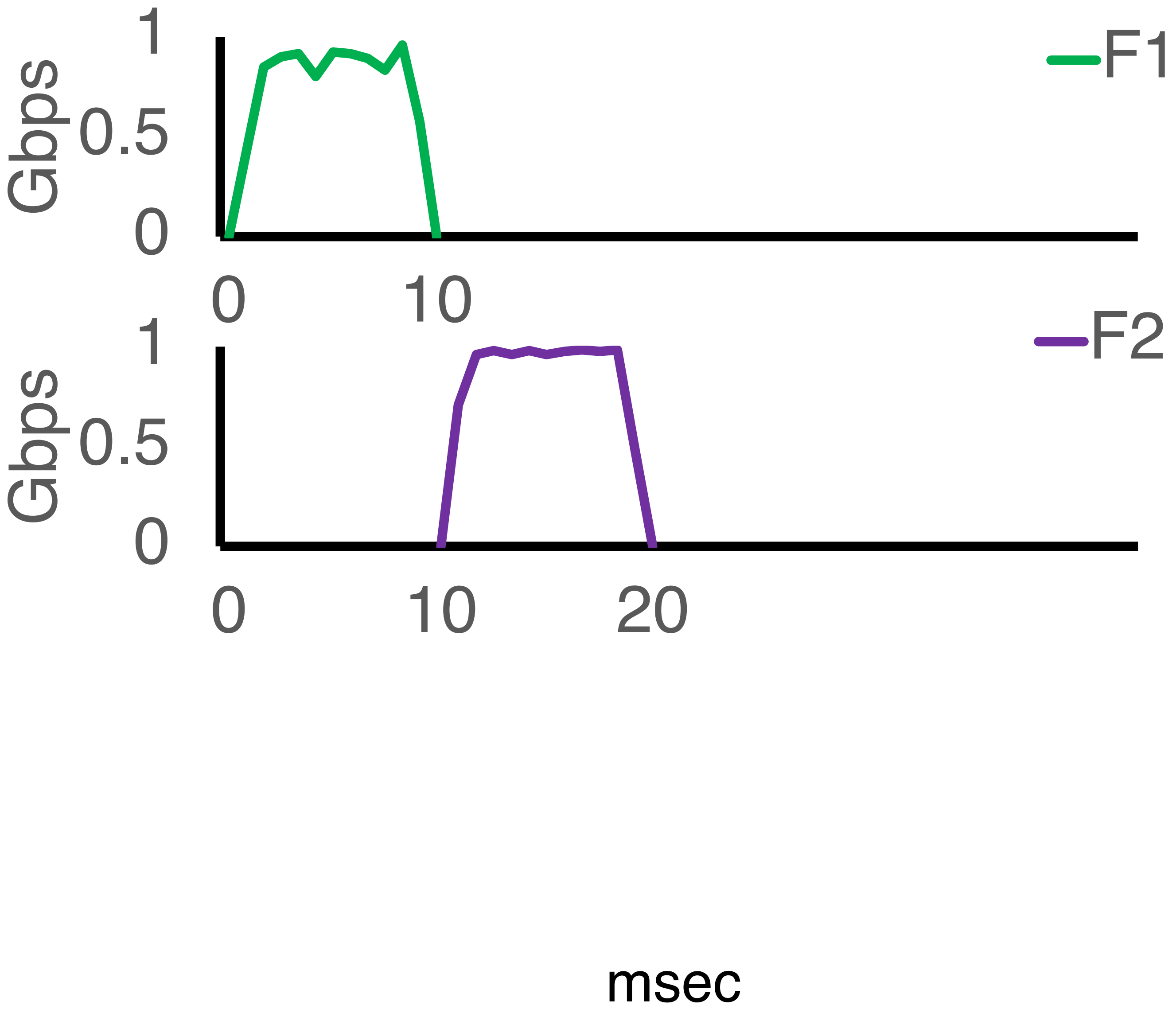

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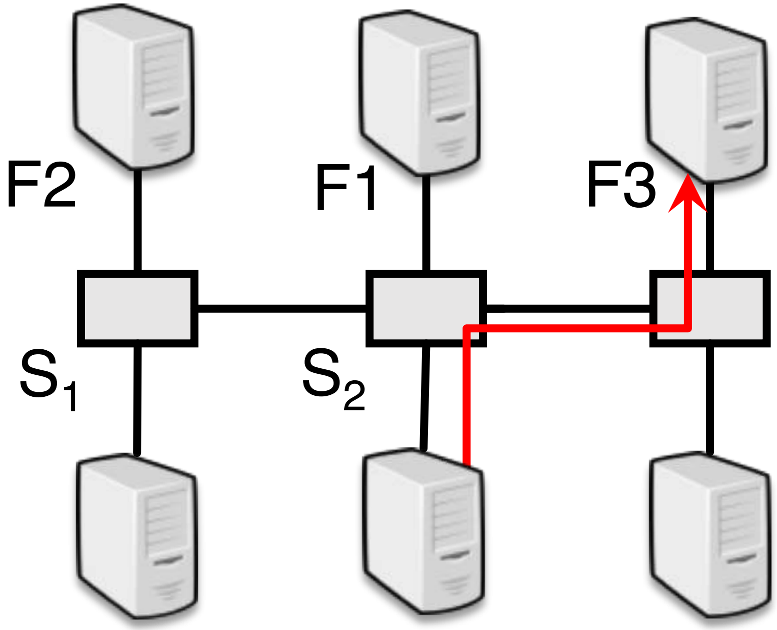

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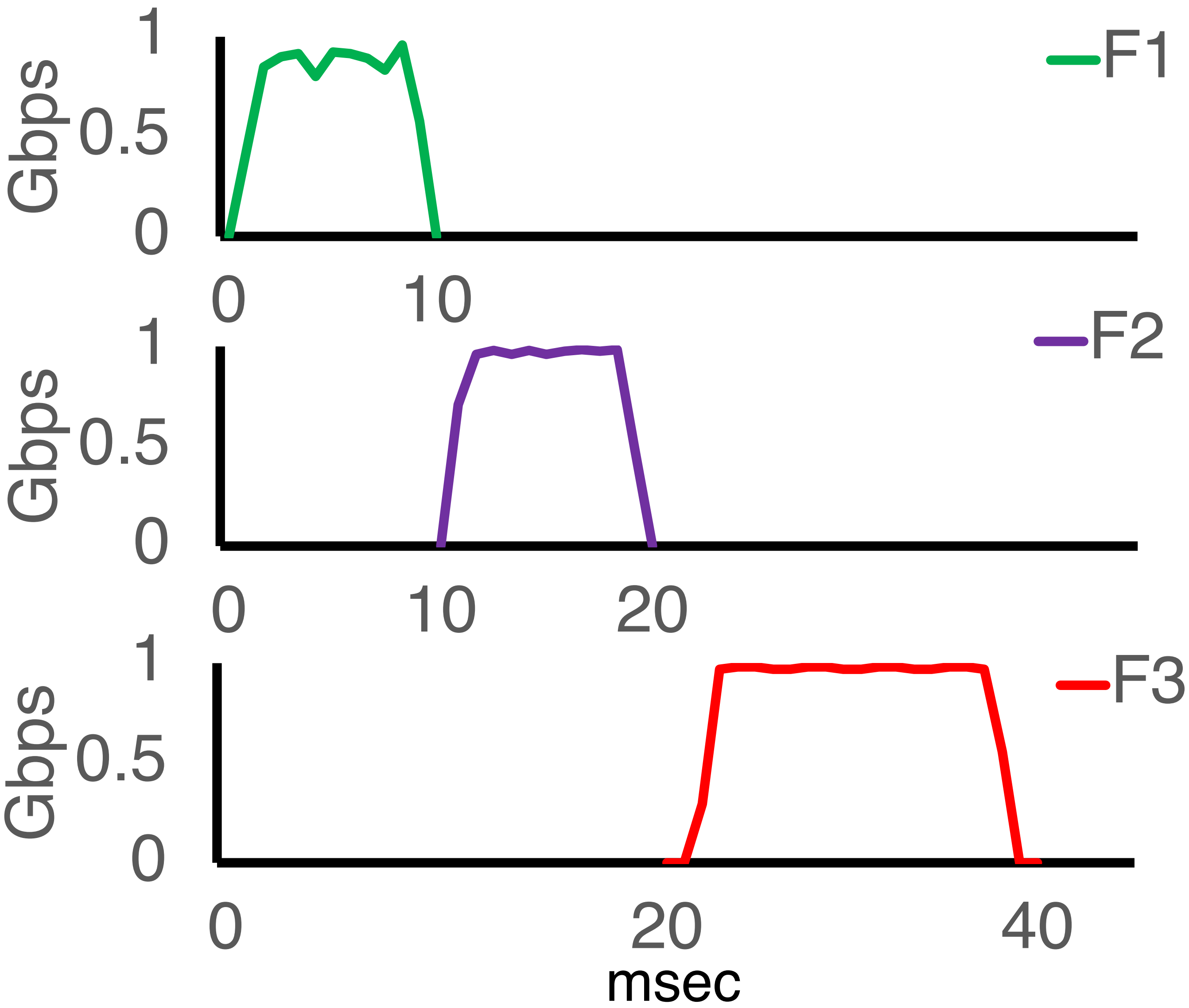

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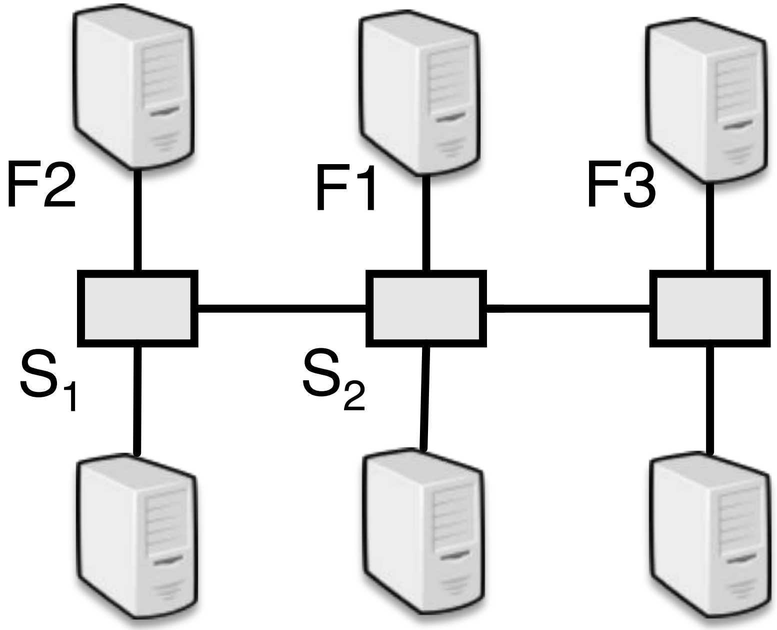

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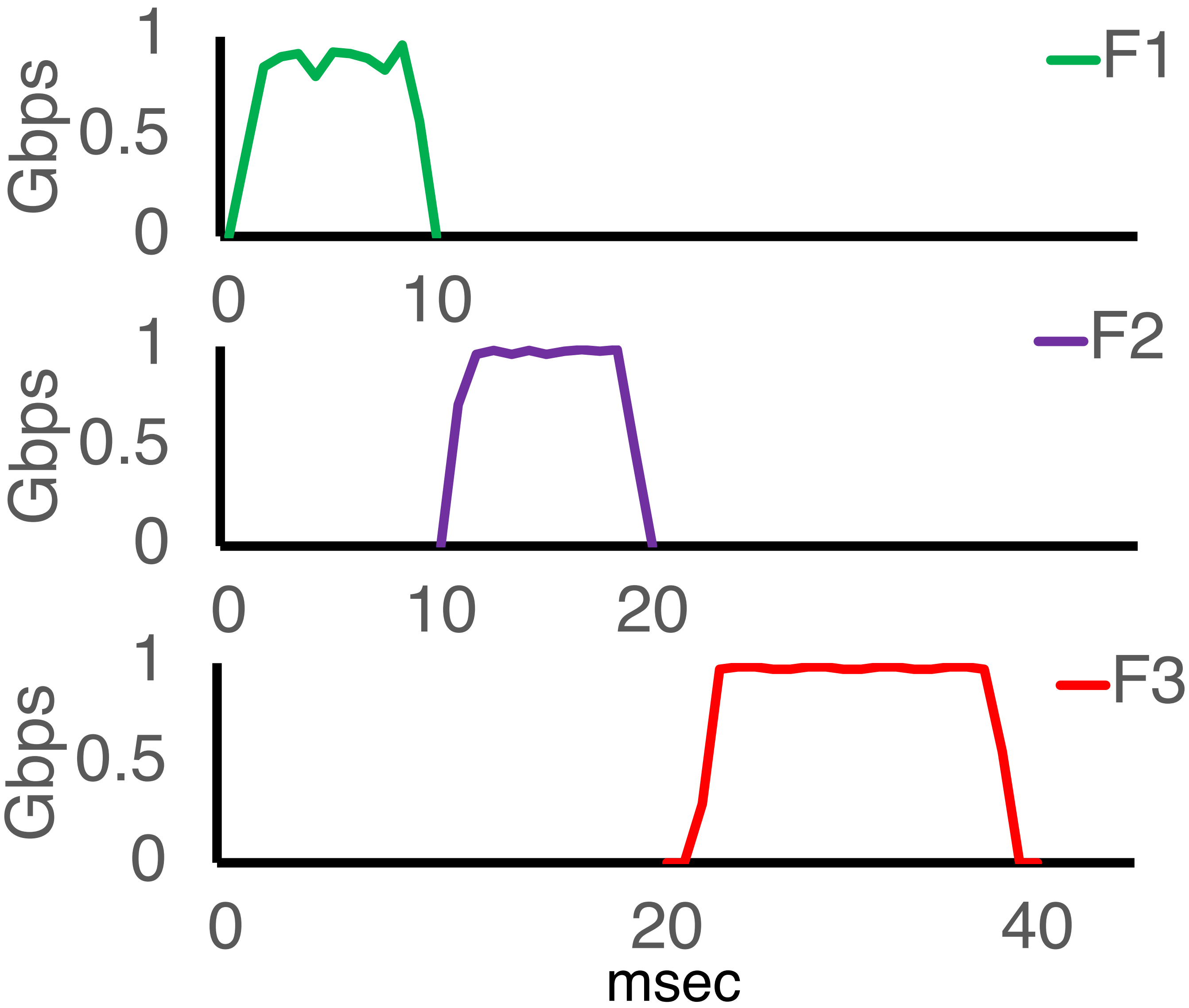

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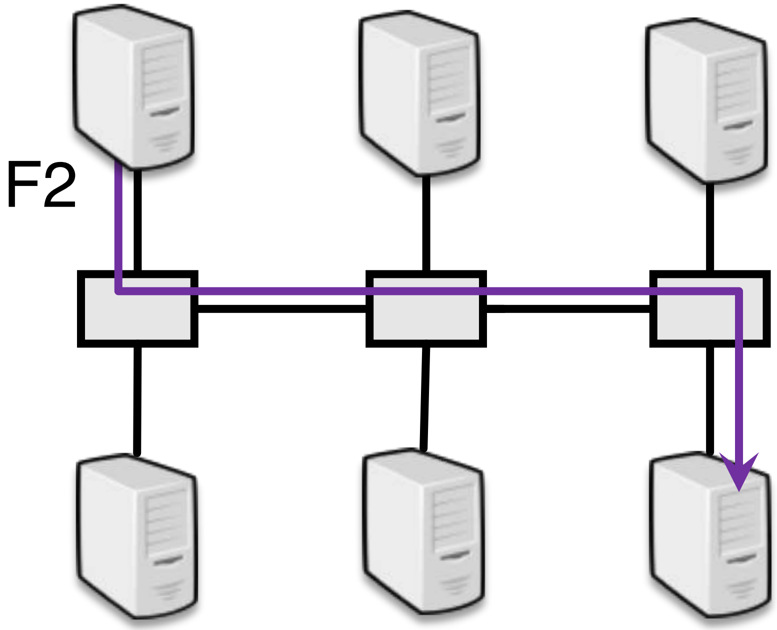

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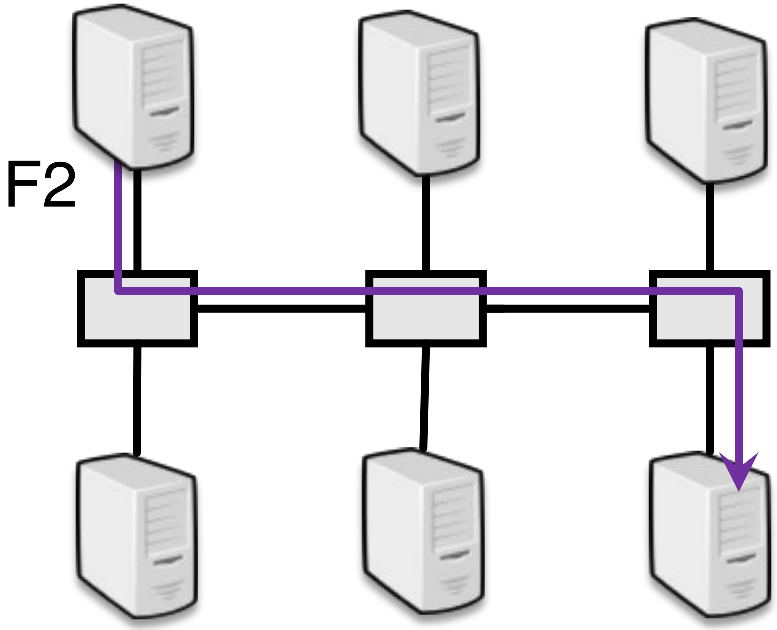

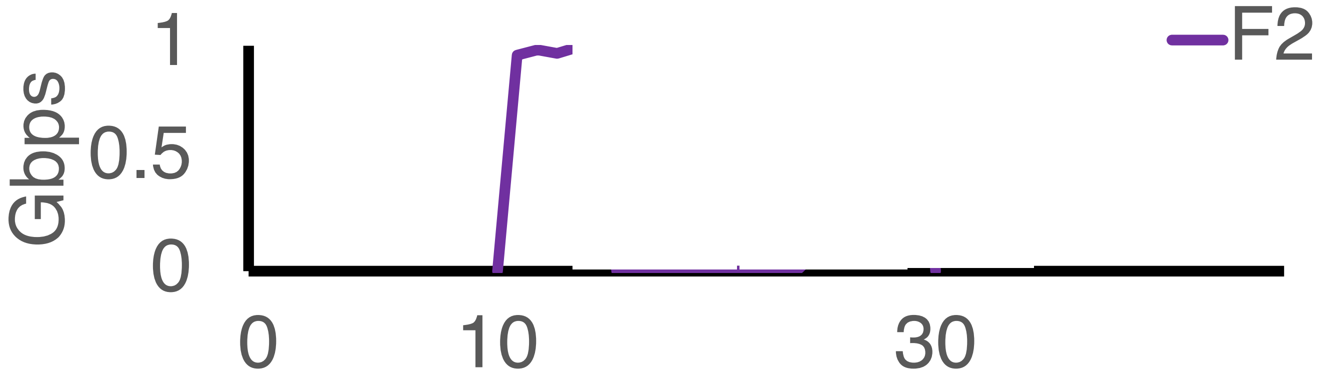

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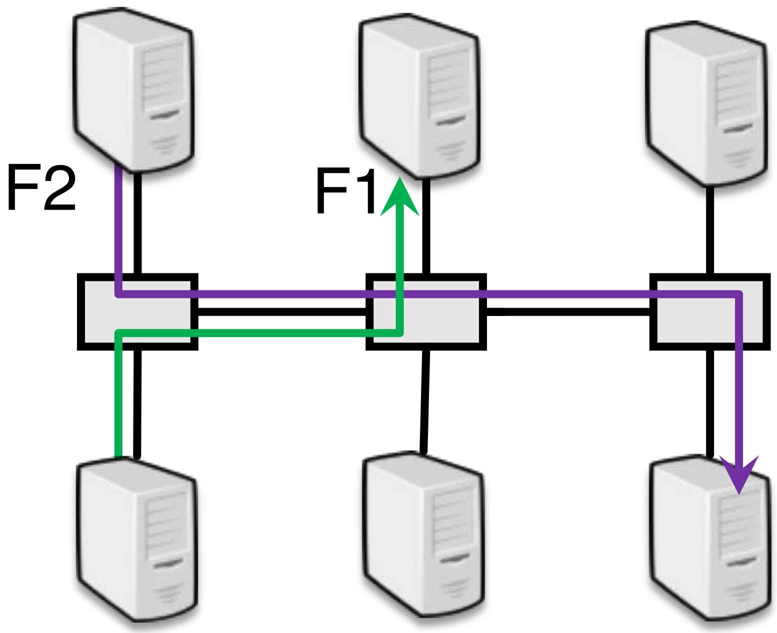

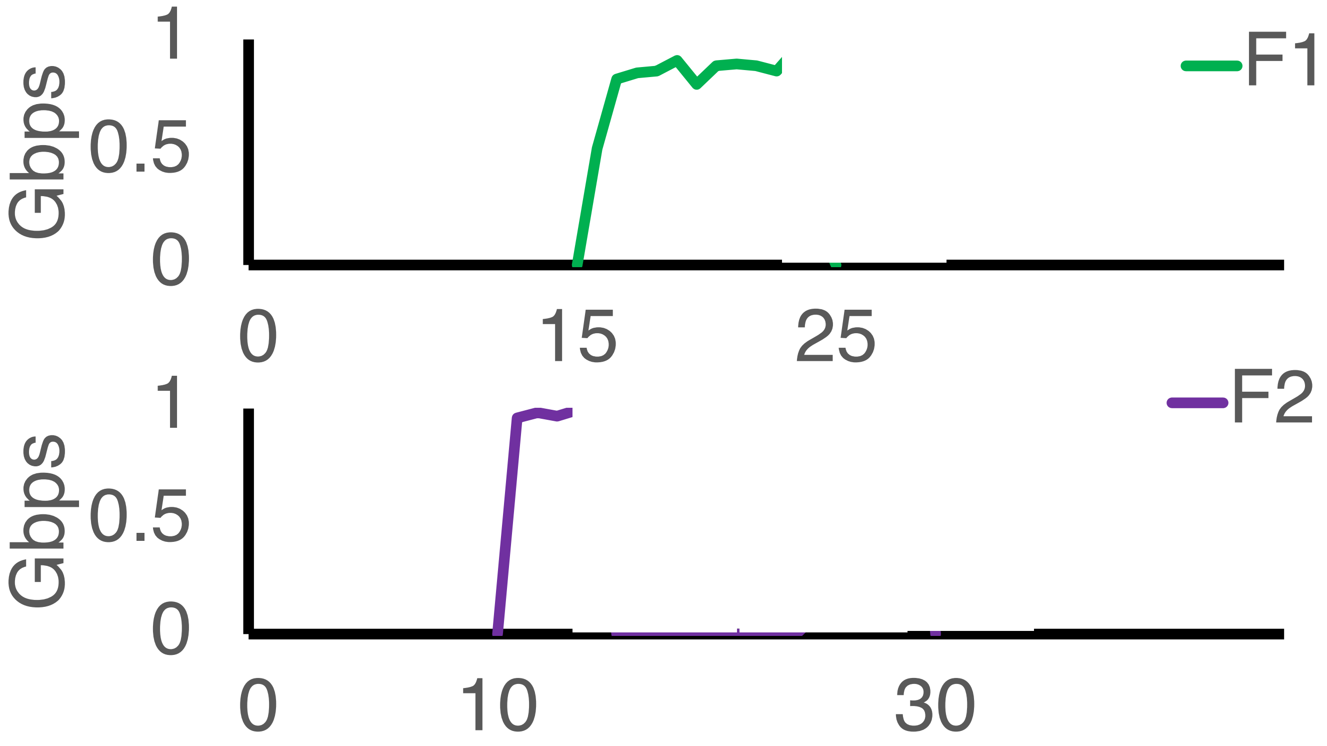

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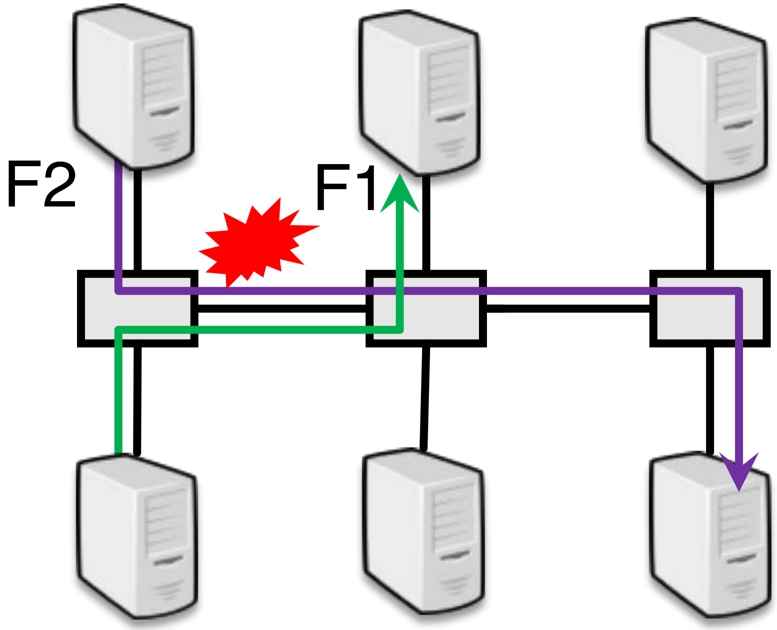

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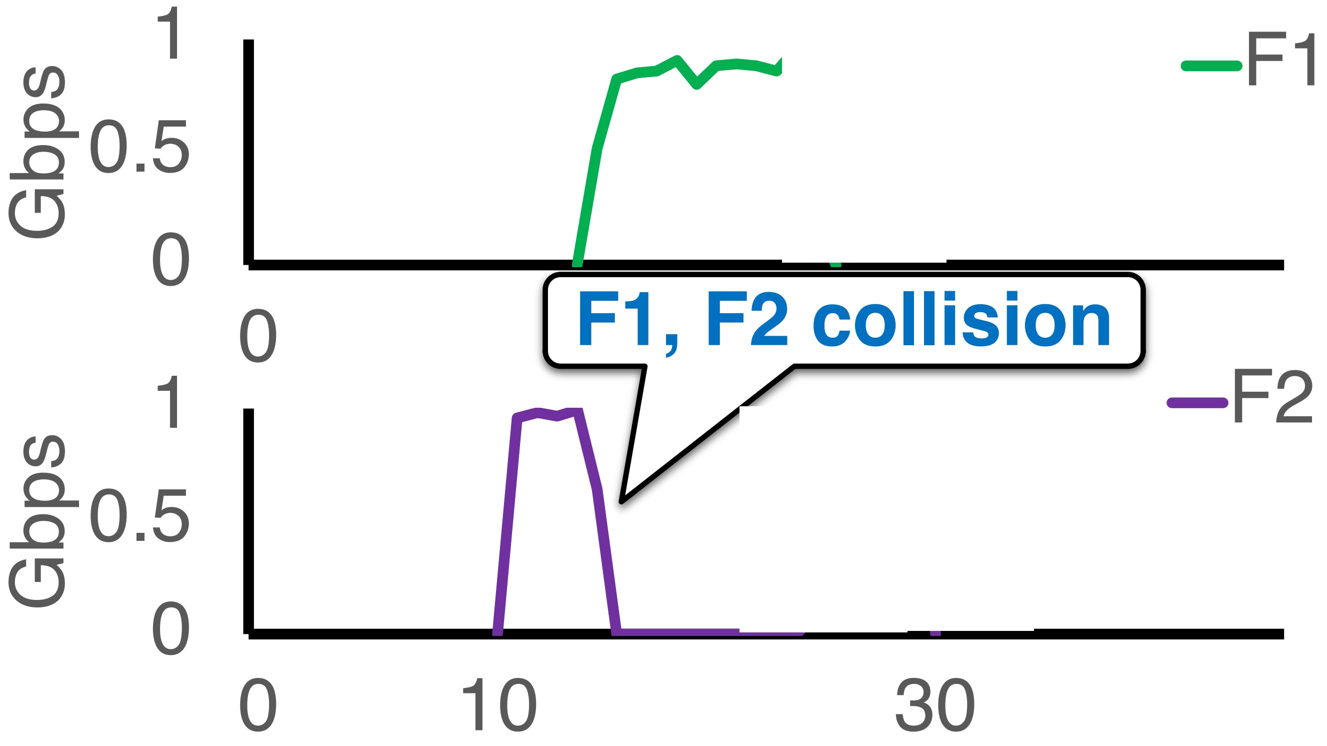

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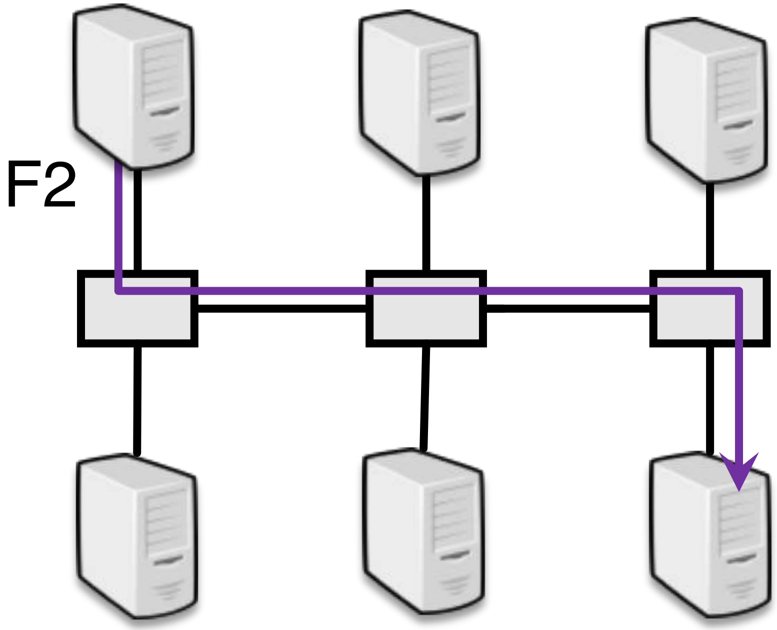

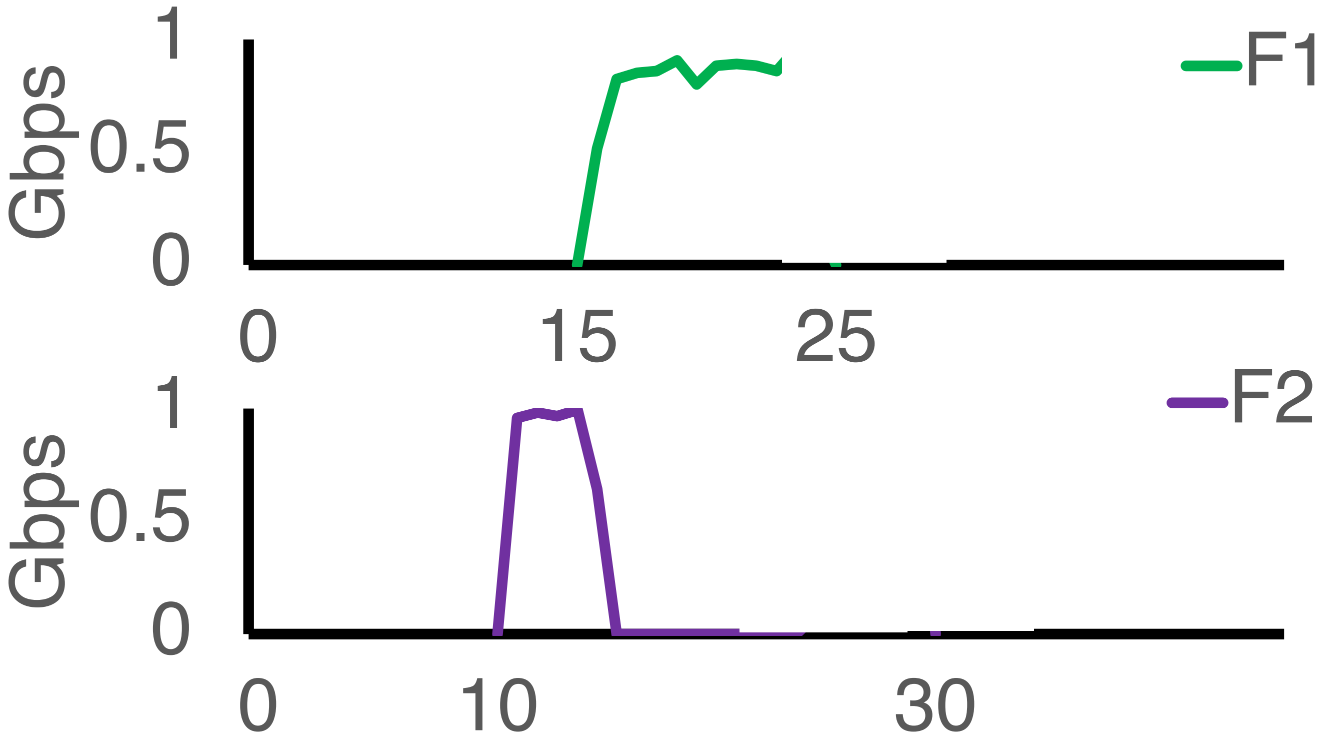

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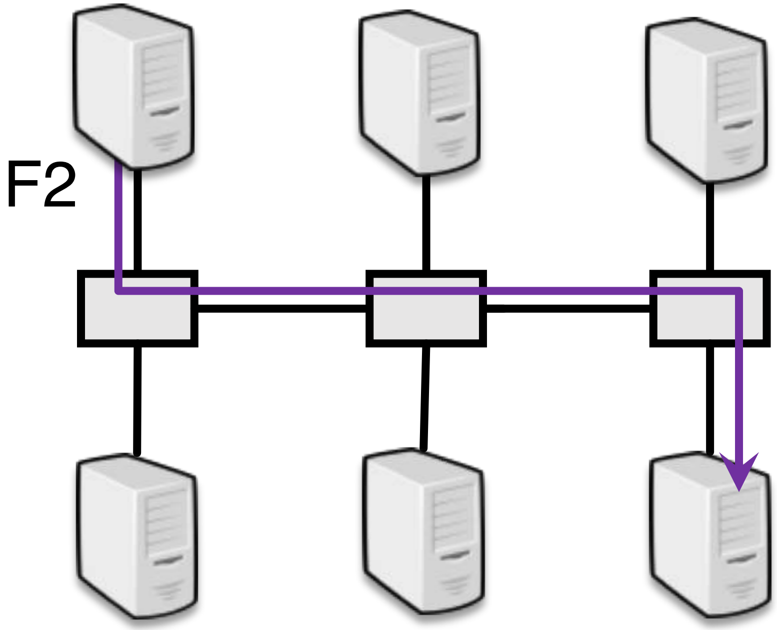

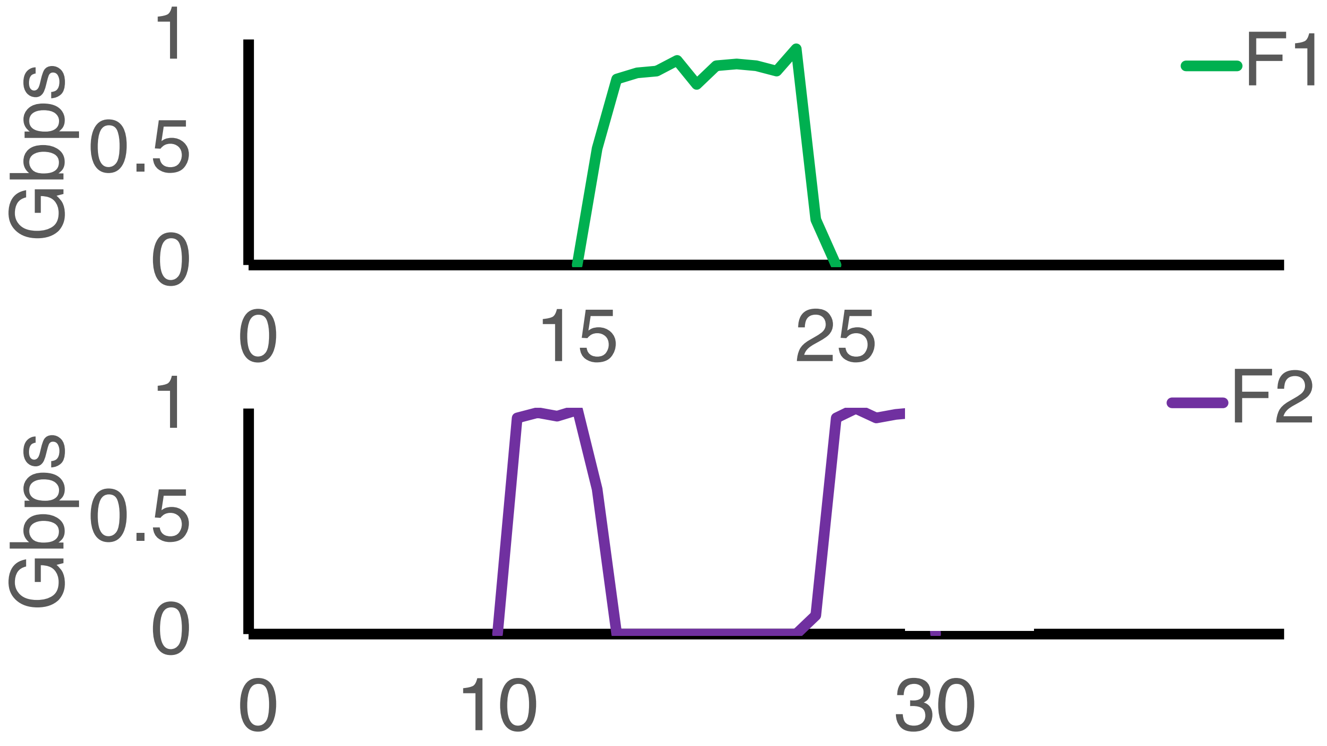

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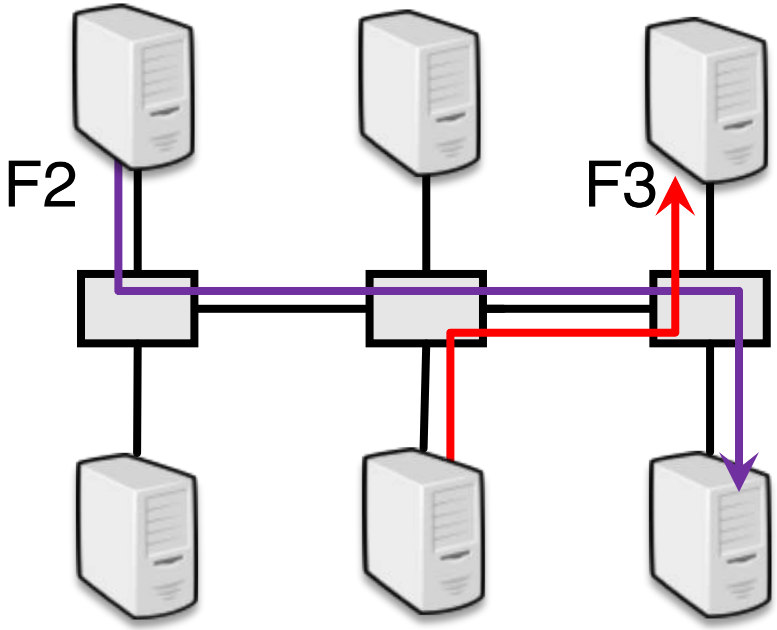

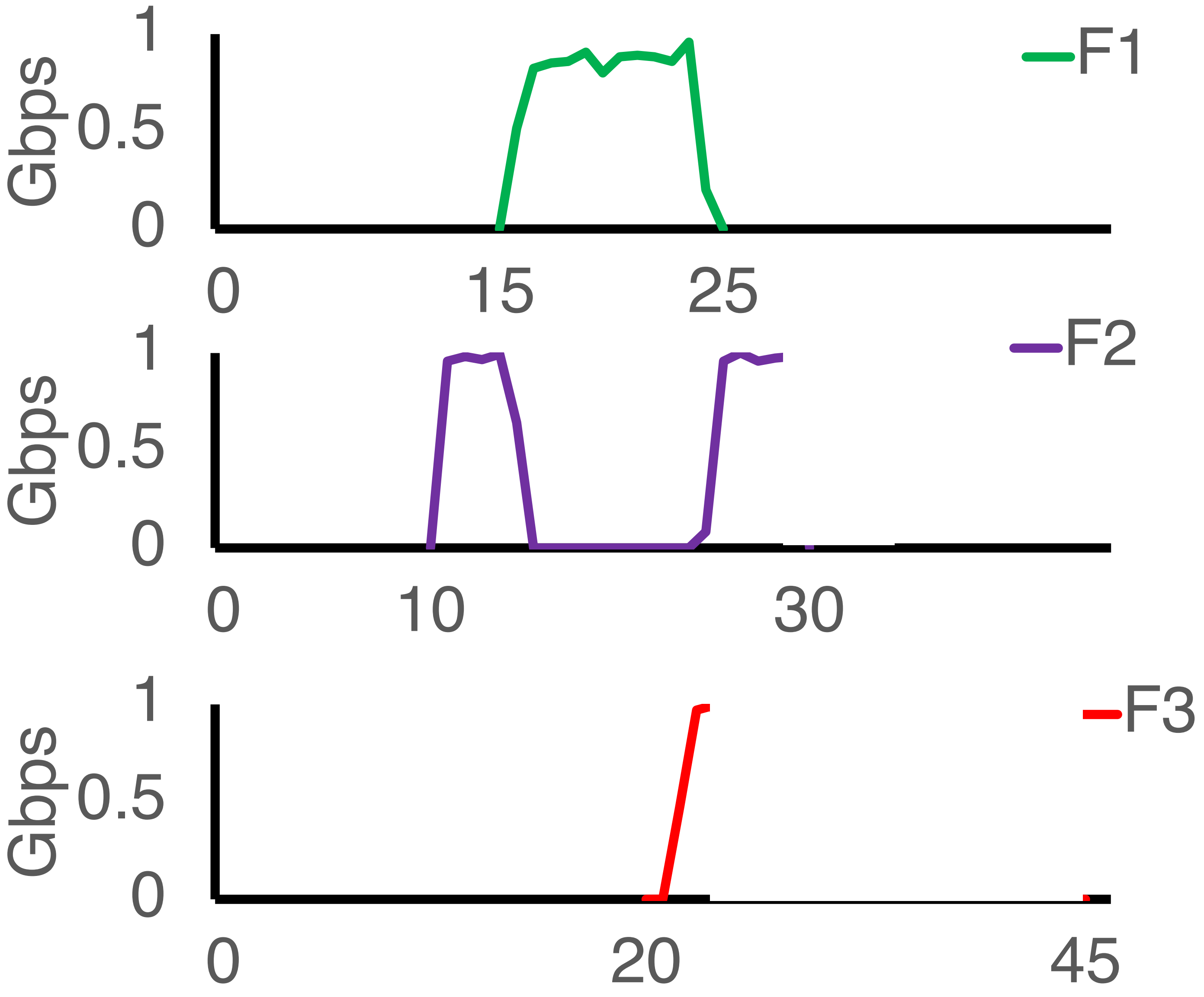

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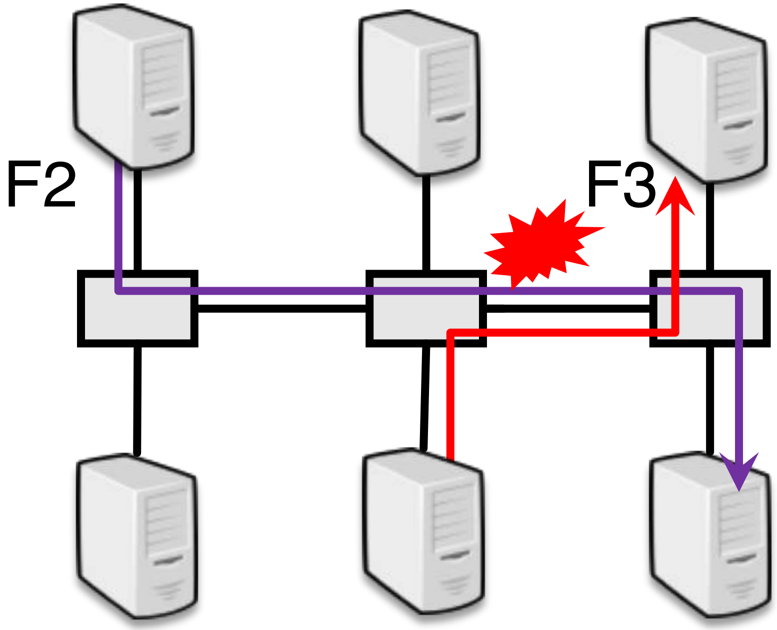

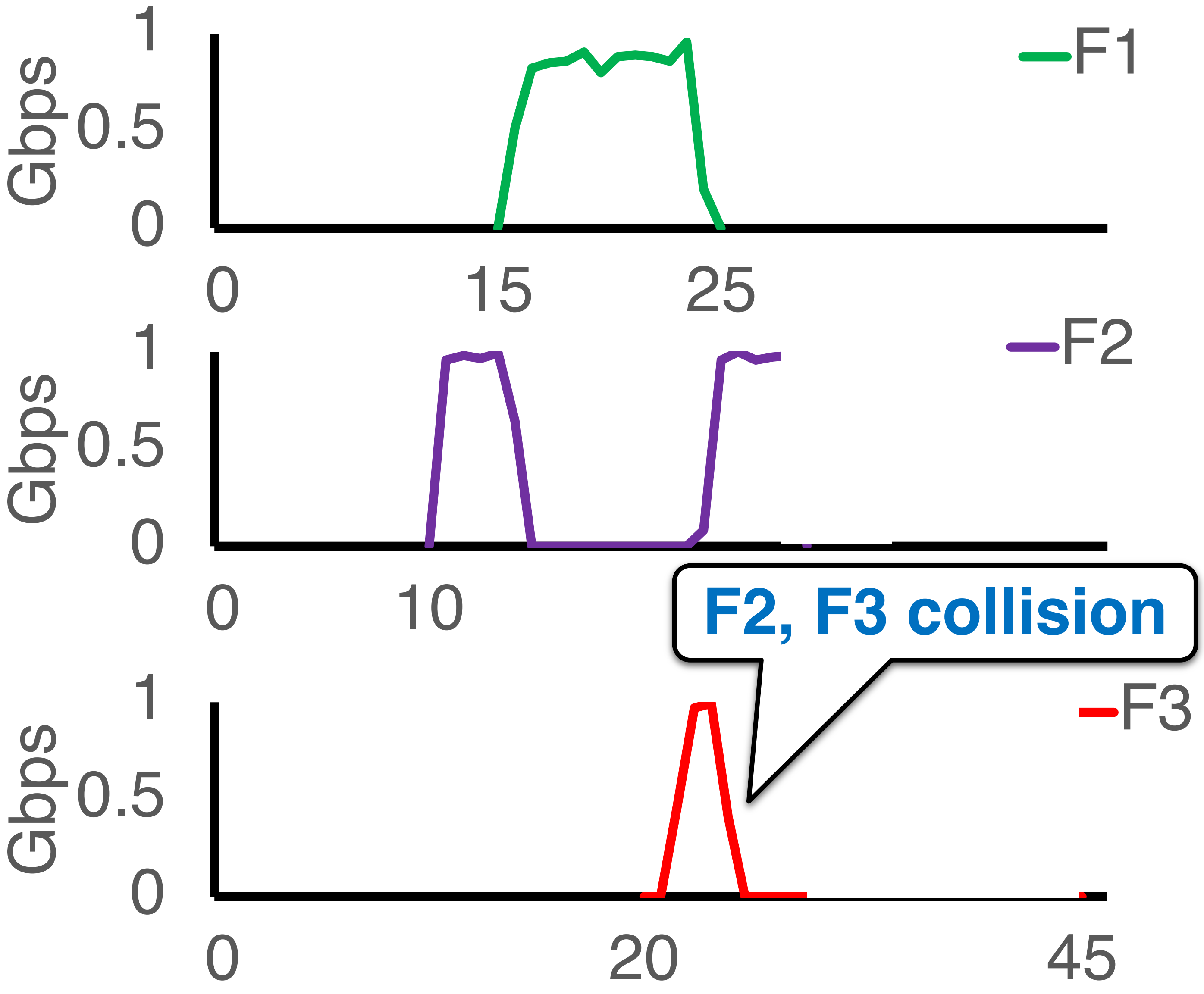

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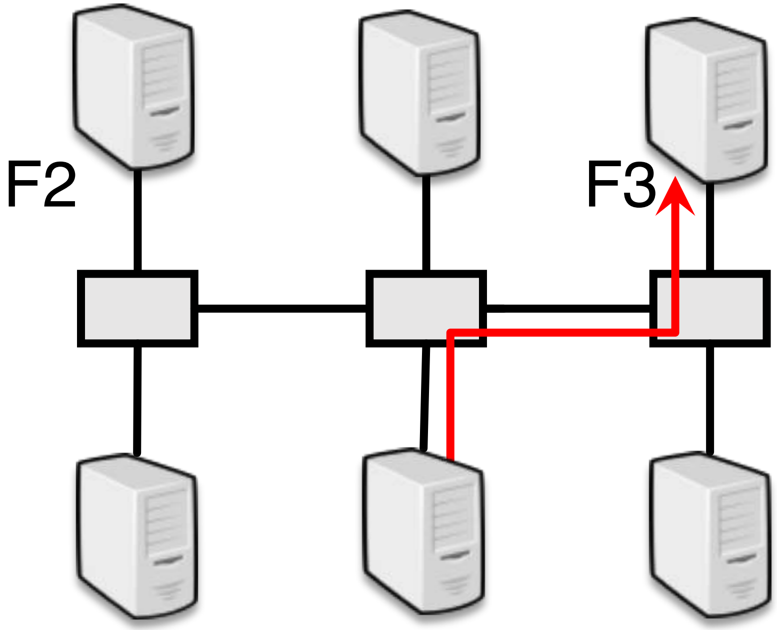

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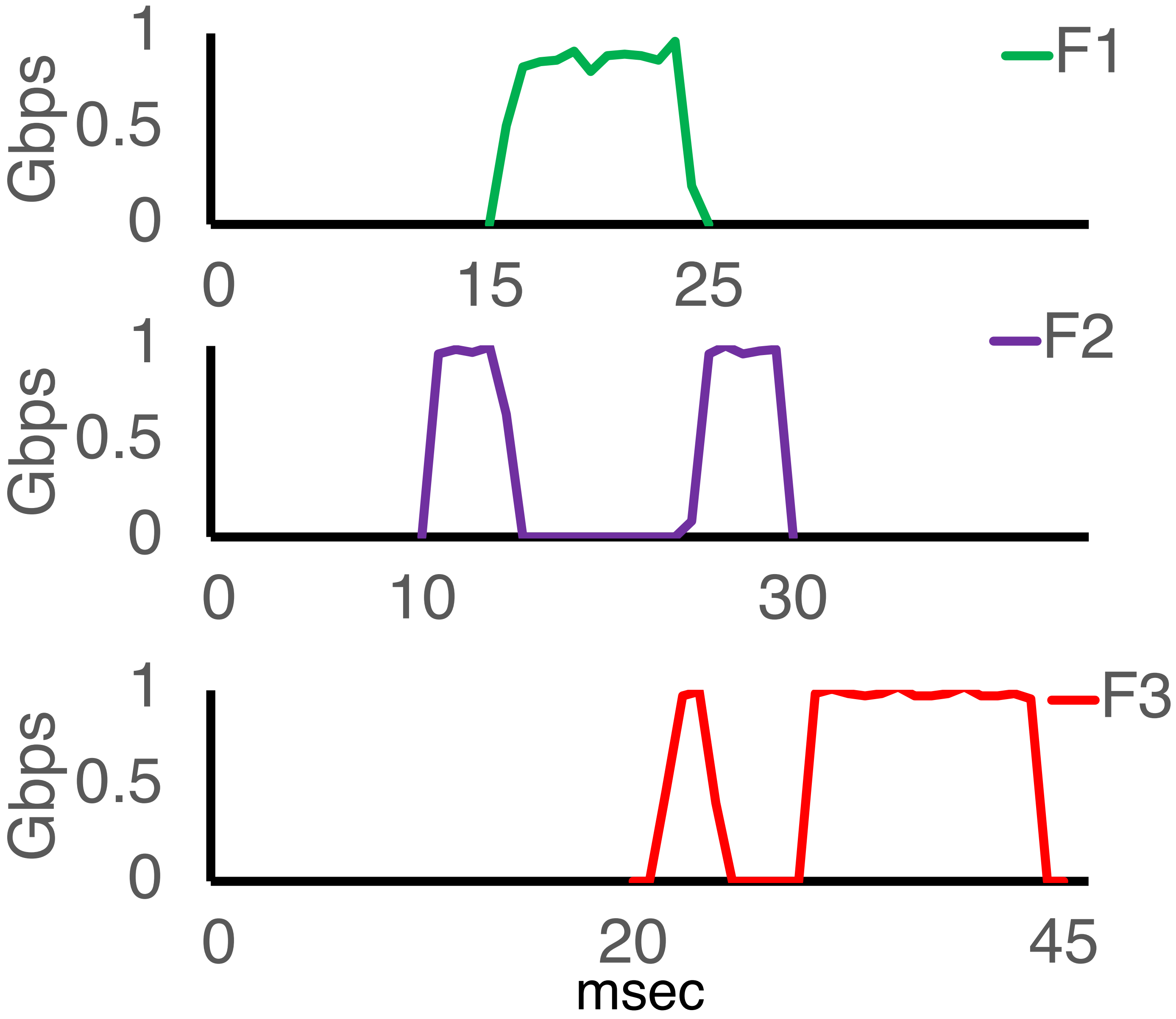

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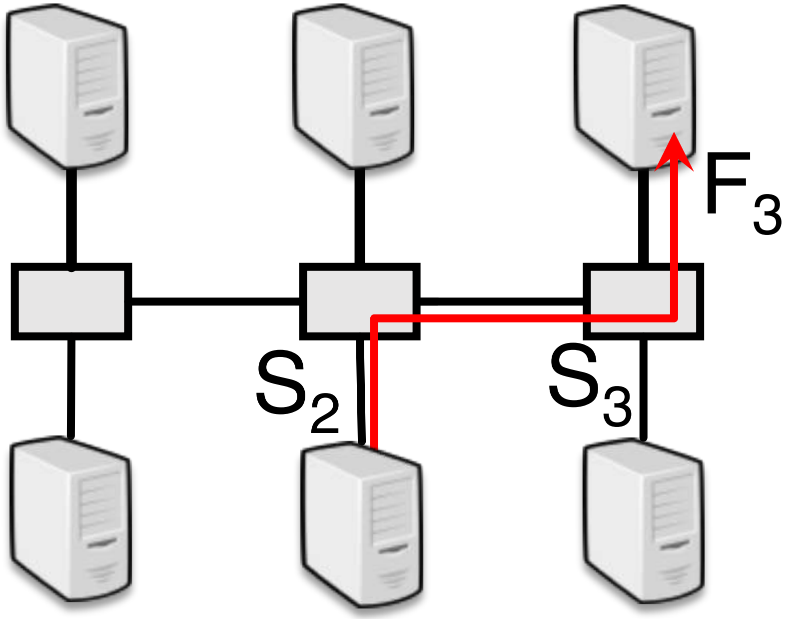

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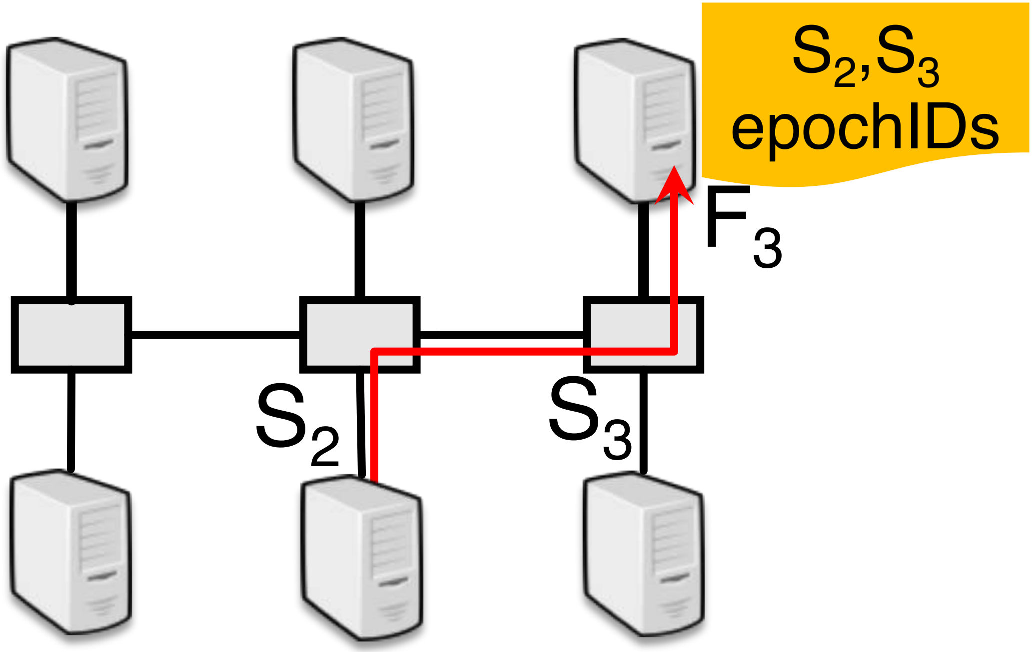

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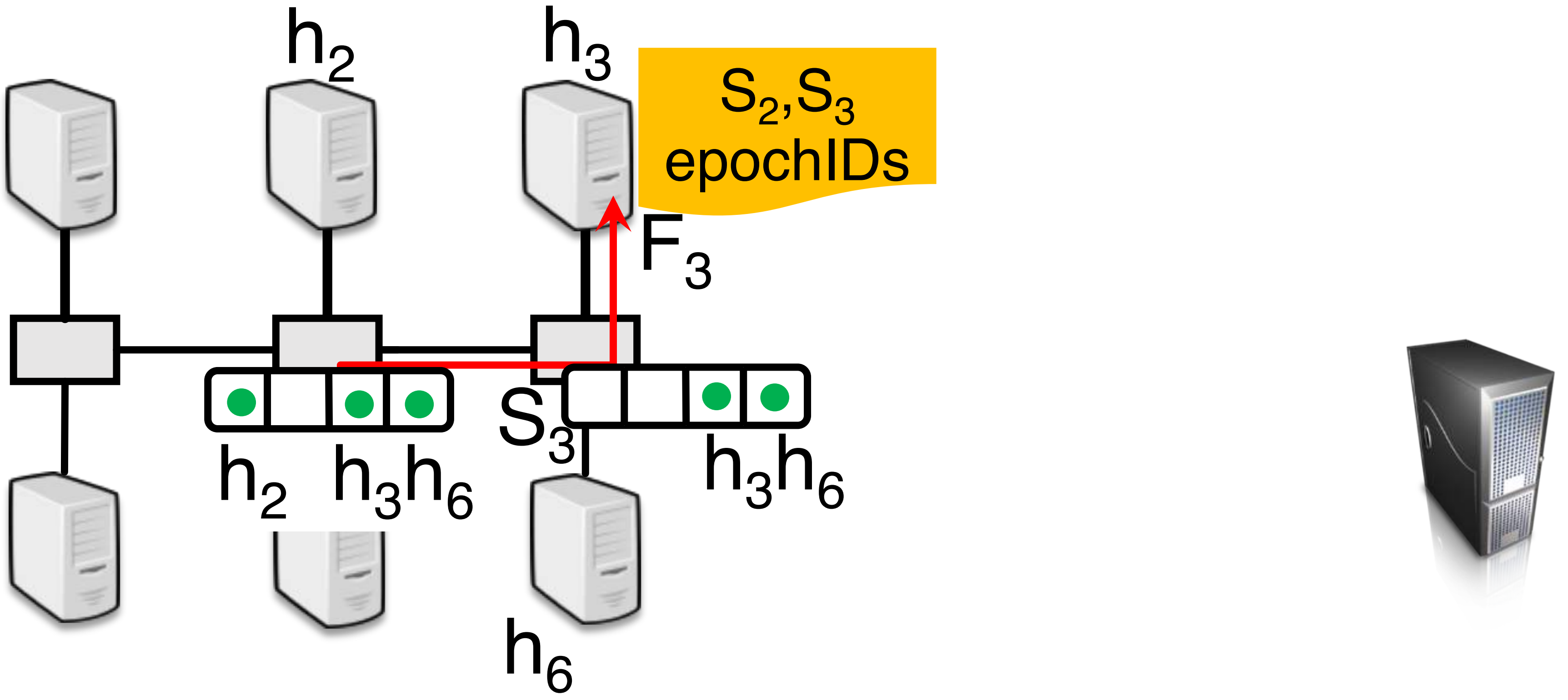

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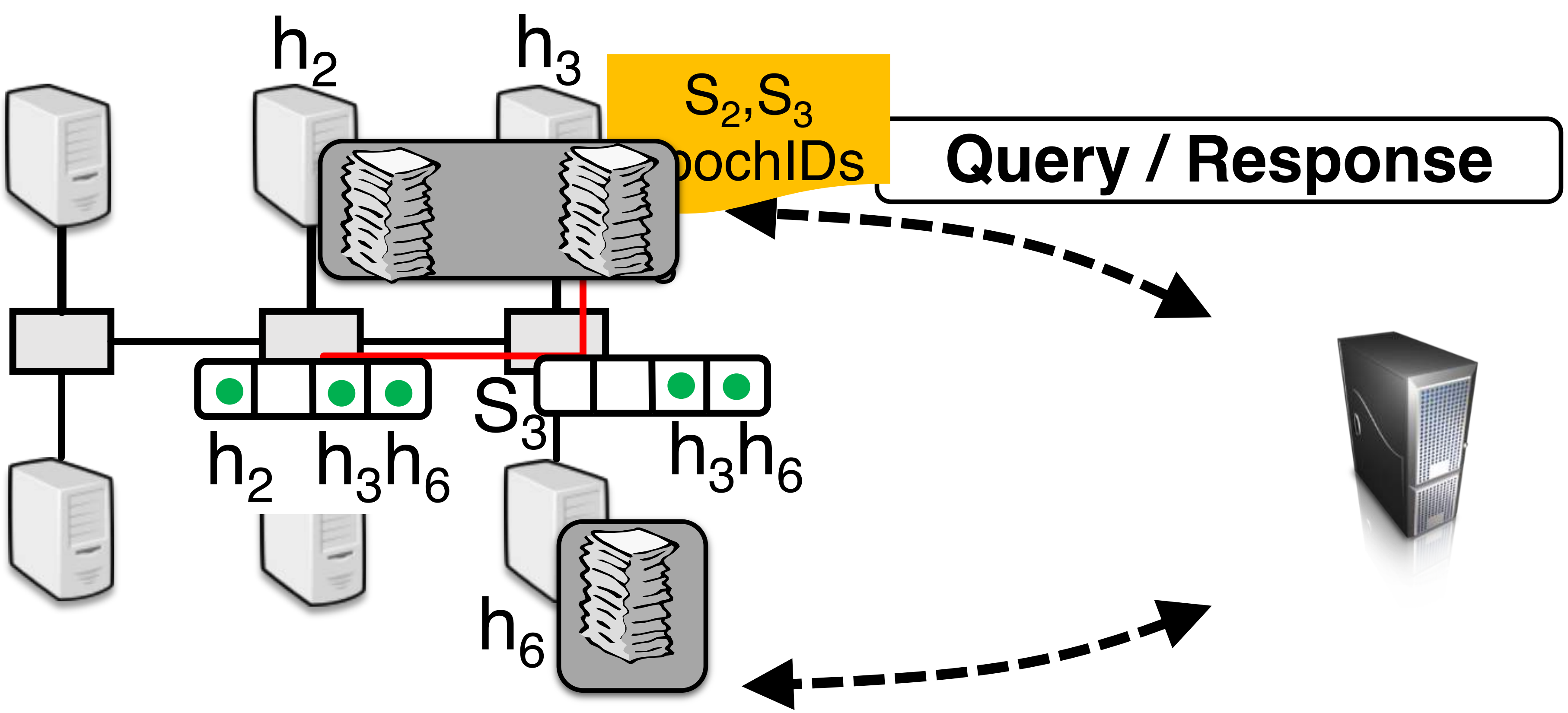

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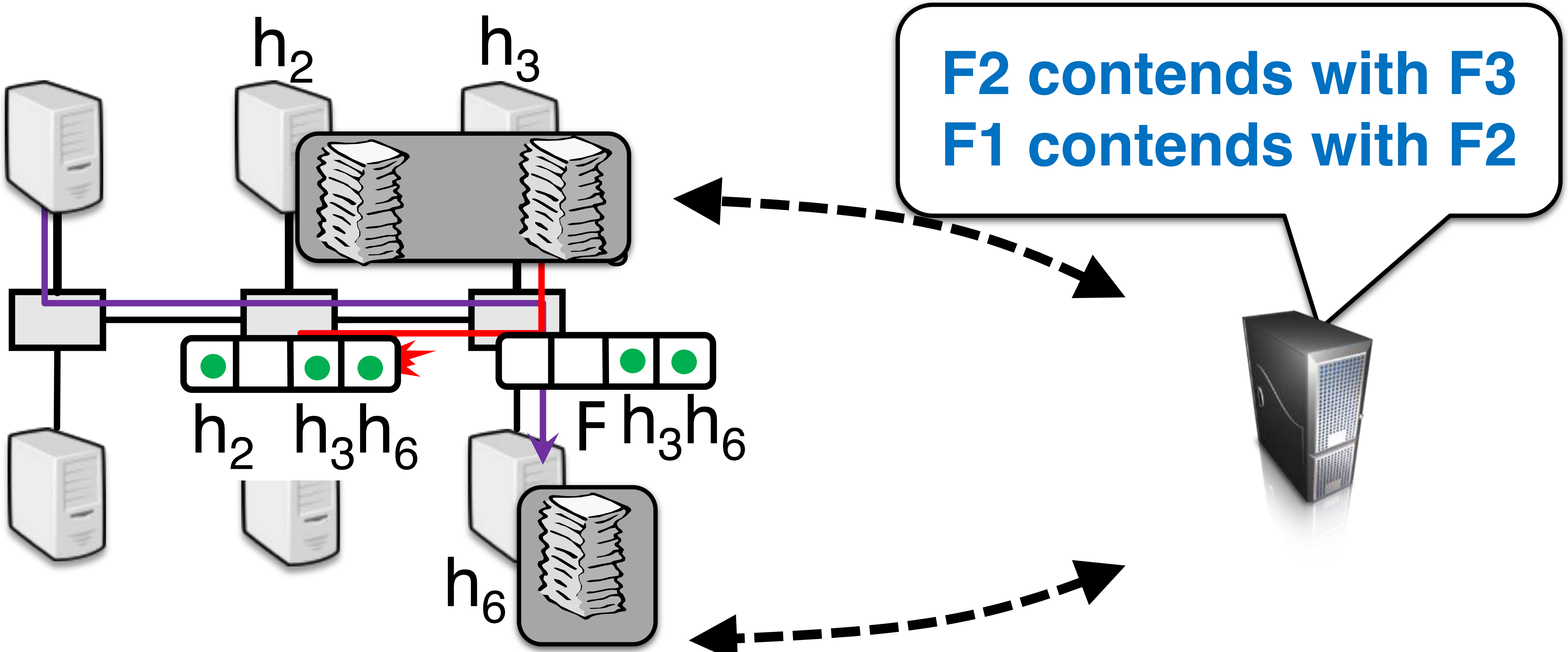

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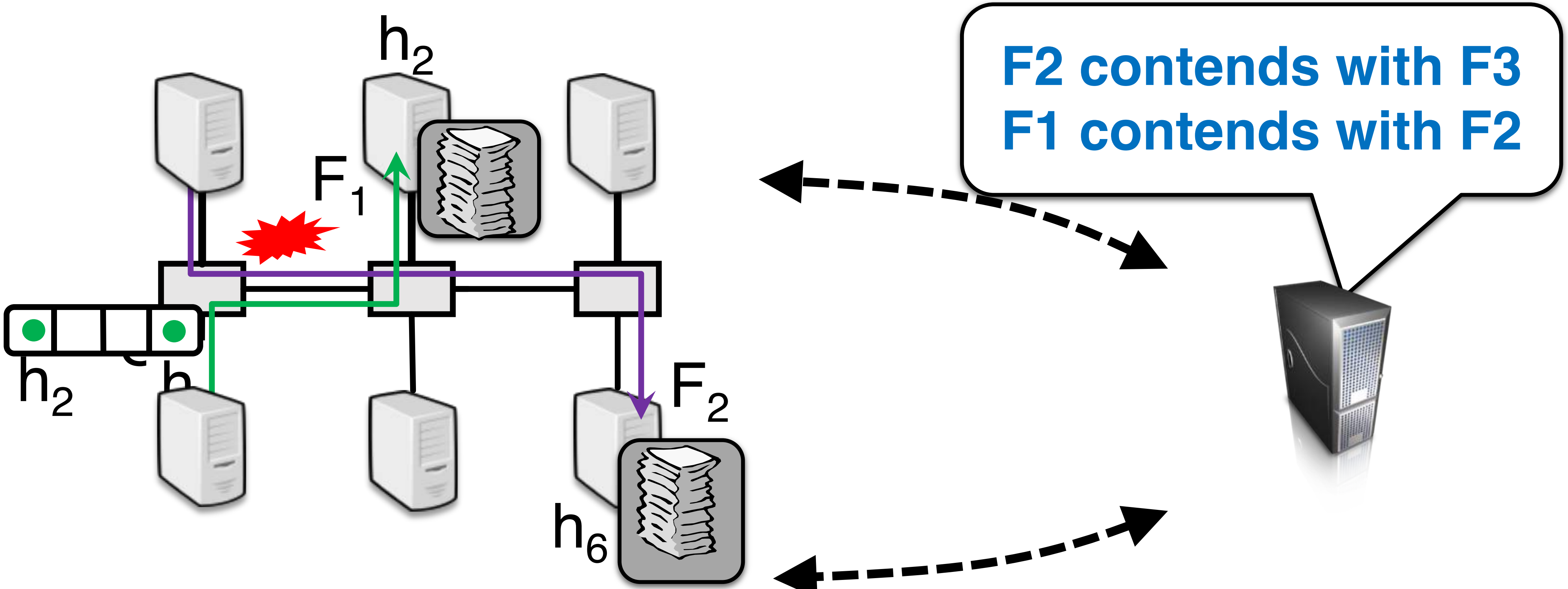

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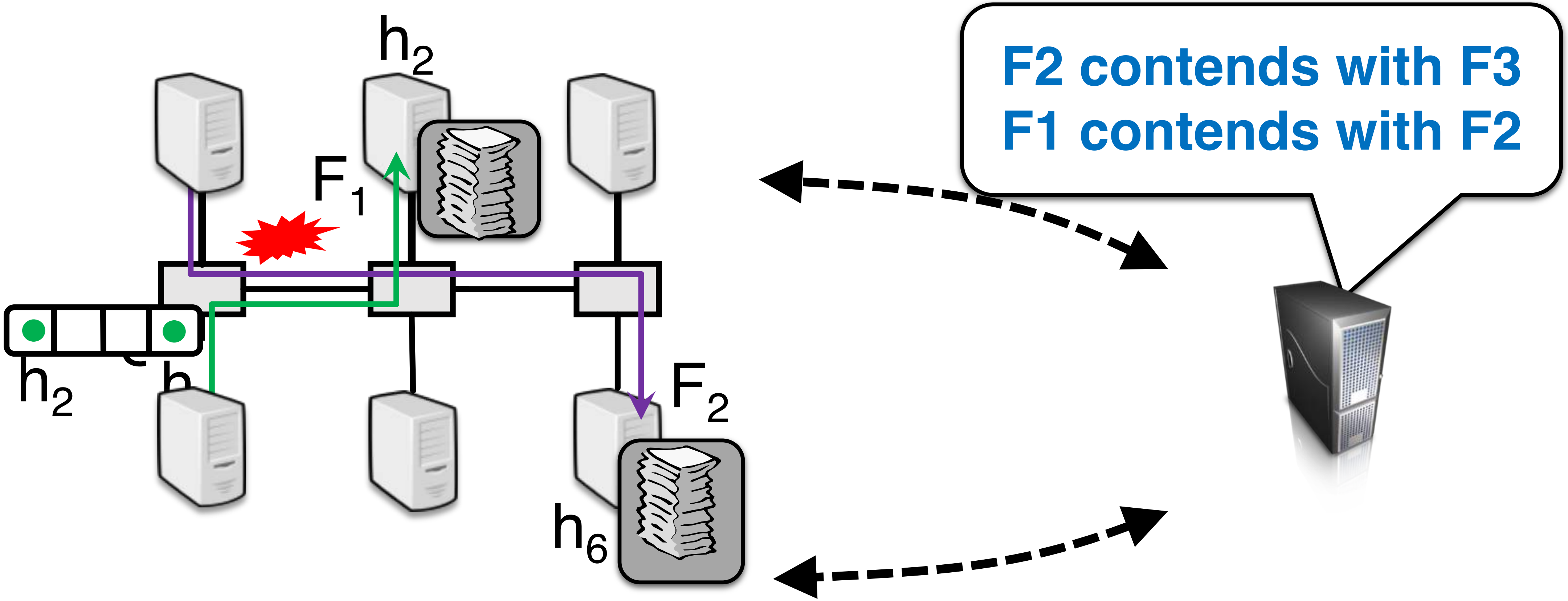

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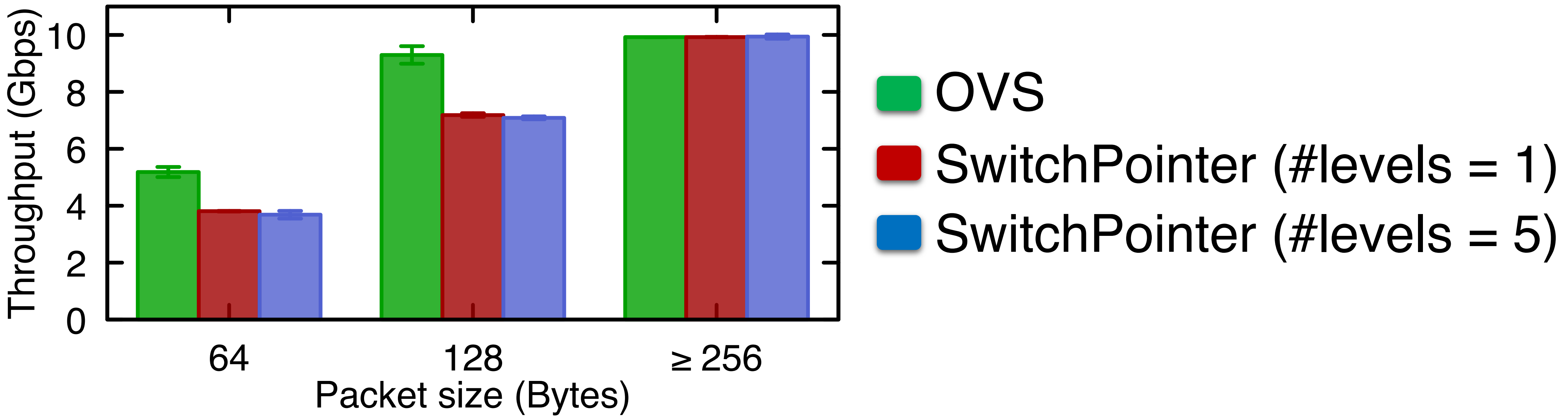
SwitchPointer overhead (software implementation)

- Prototype
  - ✓ Implemented on top of OVS-DPDK version
  - ✓ Build minimal perfect hash function using CMPH library



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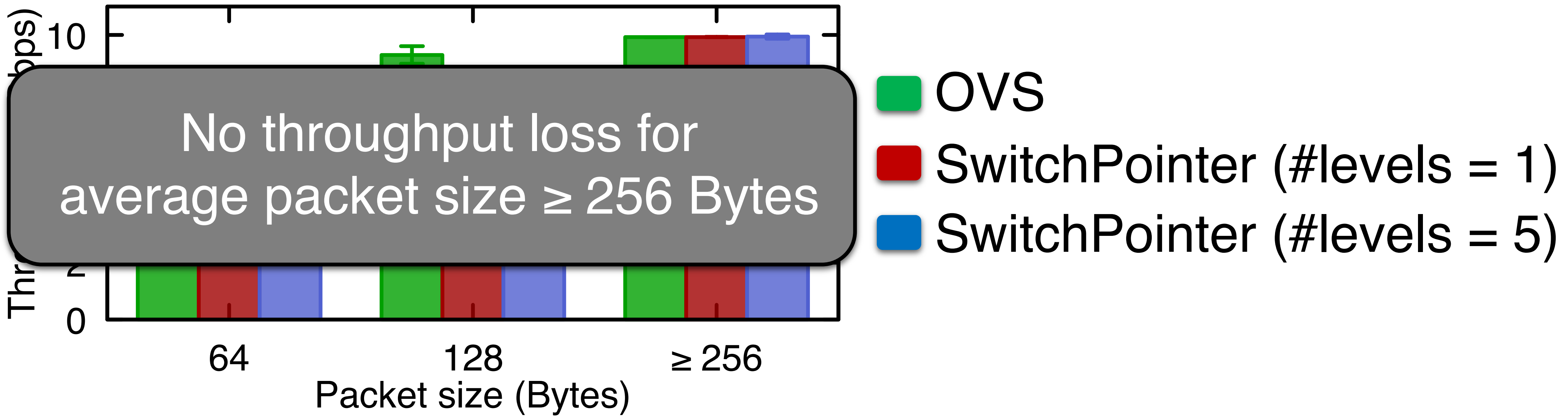

No throughput loss for average packet size ≥ 256 Bytes

Conclusion

- Achieves benefits of both end-host and in-network approaches
- Switch acts as a “directory service”
- Uses end-host resources to collect and monitor telemetry data
- Debugs a large class problems
- Ongoing work: Hardware implementation using P4 and NetFPGA