NitroSketch: Robust and General Sketch-based Monitoring in Software Switches

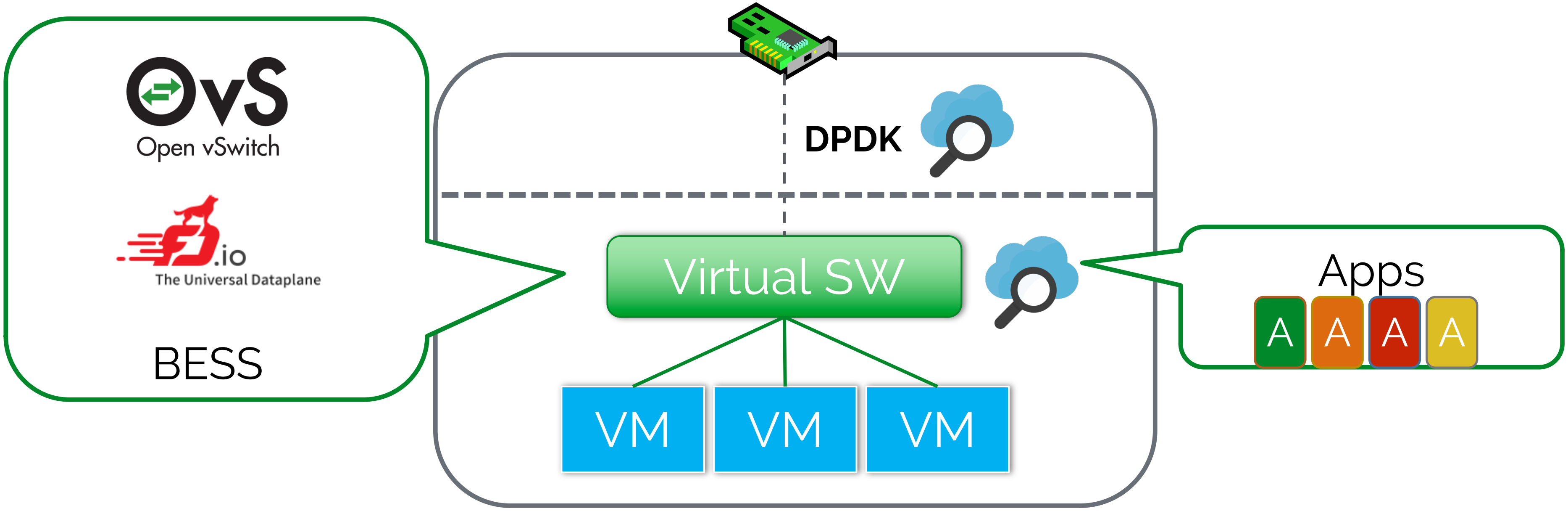
Alan (Zaoxing) Liu

Joint work with Ran Ben-Basat, Gil Einziger, Yaron Kassner, Vladimir Braverman, Roy Friedman, and Vyas Sekar

Carnegie Mellon University
HARVARD School of Engineering and Applied Sciences
Ben-Gurion University of the Negev
TECHNION Israel Institute of Technology
JOHNS HOPKINS UNIVERSITY

Need for network telemetry in software switches

Where: Virtual switches, White-box switches, DPDK, FD.io,...



Need for network telemetry in software switches

Where: Virtual switches, White-box switches, DPDK, FD.io ……

Traffic Engineering

“Flow Size Distribution”

Anomaly Detection

“Entropy”, “Traffic Changes”

Worm Detection

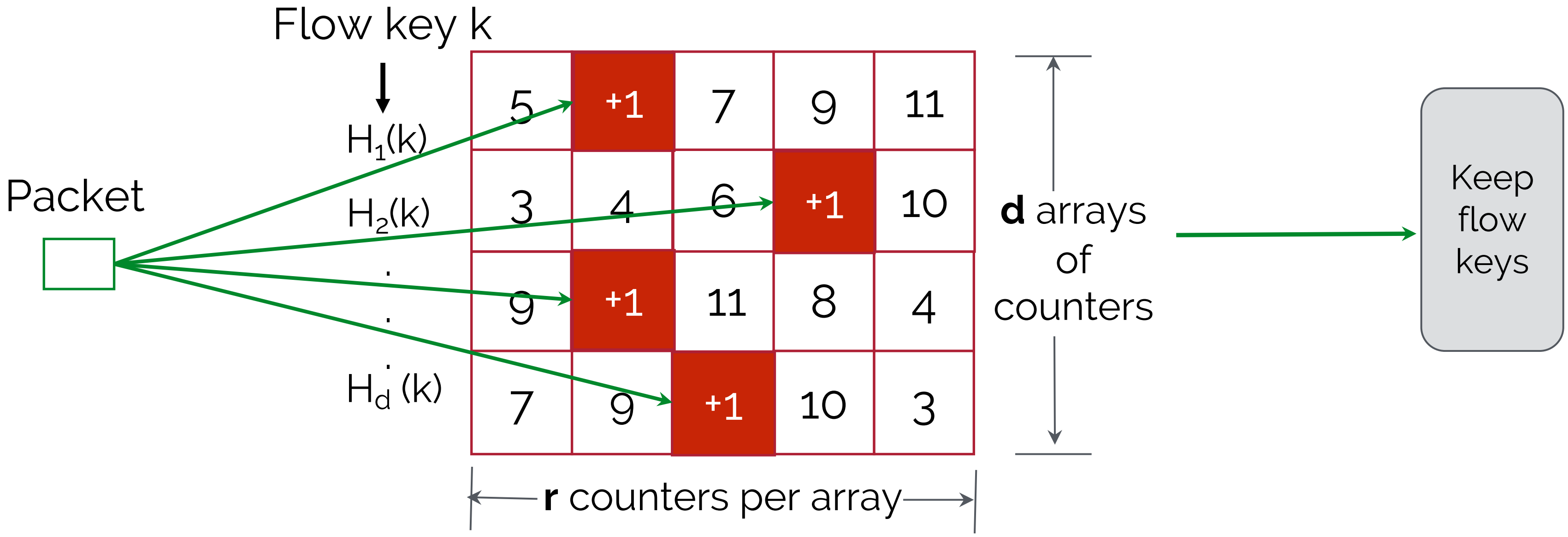
“SuperSpreaders”

Accounting

“Heavy Hitters”

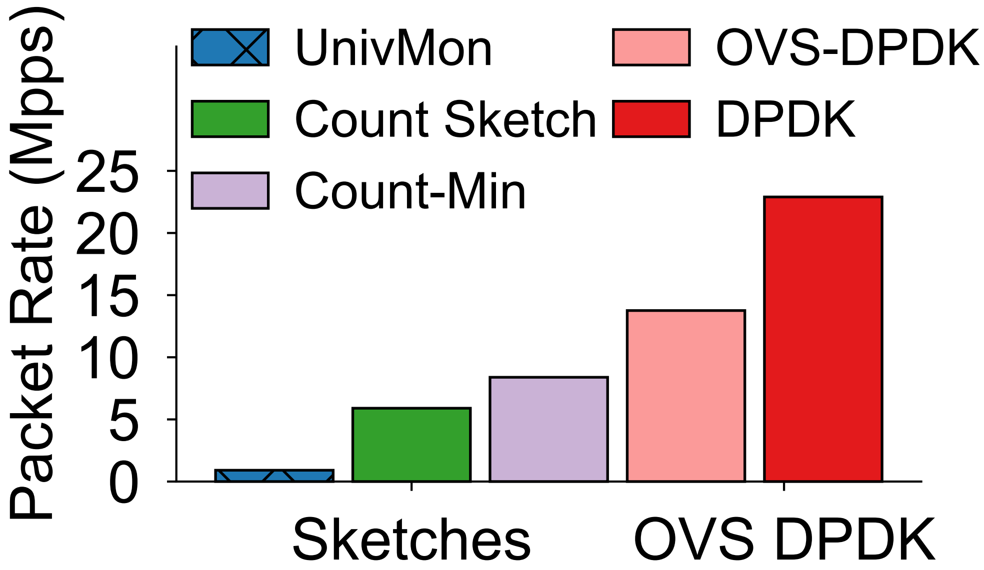
Requirements: Performance, Accuracy

Sketches appear to be a promising alternative



- Require **small** memory with **bounded** error rates.
- Guaranteed fidelity with arbitrary workloads.

Reality: Sketches in software switches not performant!



- Single core 100% CPU.
- Cannot meet high line-rates: < 10Gbps

Existing proposals to speed up sketches?

- SketchVisor [SIGCOMM’17]:

  Performance increase (still < 10 Mpps)

  X Not robust on arbitrary workloads.

- Elastic Sketch [SIGCOMM’18]:

  Performance increase (> 14.8 Mpps)

  X Not robust on arbitrary workloads.

- R-HHH [SIGCOMM’17]:

  Performance increase (up to 14.8 Mpps)

  X Not general towards many tasks.

NitroSketch in a nutshell

A software-switch based sketching framework that simultaneously has:

- ❑ **Performance**: line-rate (40G) with minimal CPU and memory.
- ❑ **Generality**: support a variety of measurement tasks.
- ❑ **Robustness**: accuracy guarantees for any workload.

NitroSketch Approach

- Systematically analyze the performance bottlenecks.
- Learn key insights from strawman solutions (sampling, one-level hash).
- Reformulate sketching for software from first principles
  - Tradeoff slight memory increase, Novel counter sampling rather than packet.

Outline for this talk

- Motivation
- Understanding bottlenecks
- Design Insights
  - Strawman ideas
  - Our proposals
- Evaluation
- Conclusions and future work

Outline for this talk

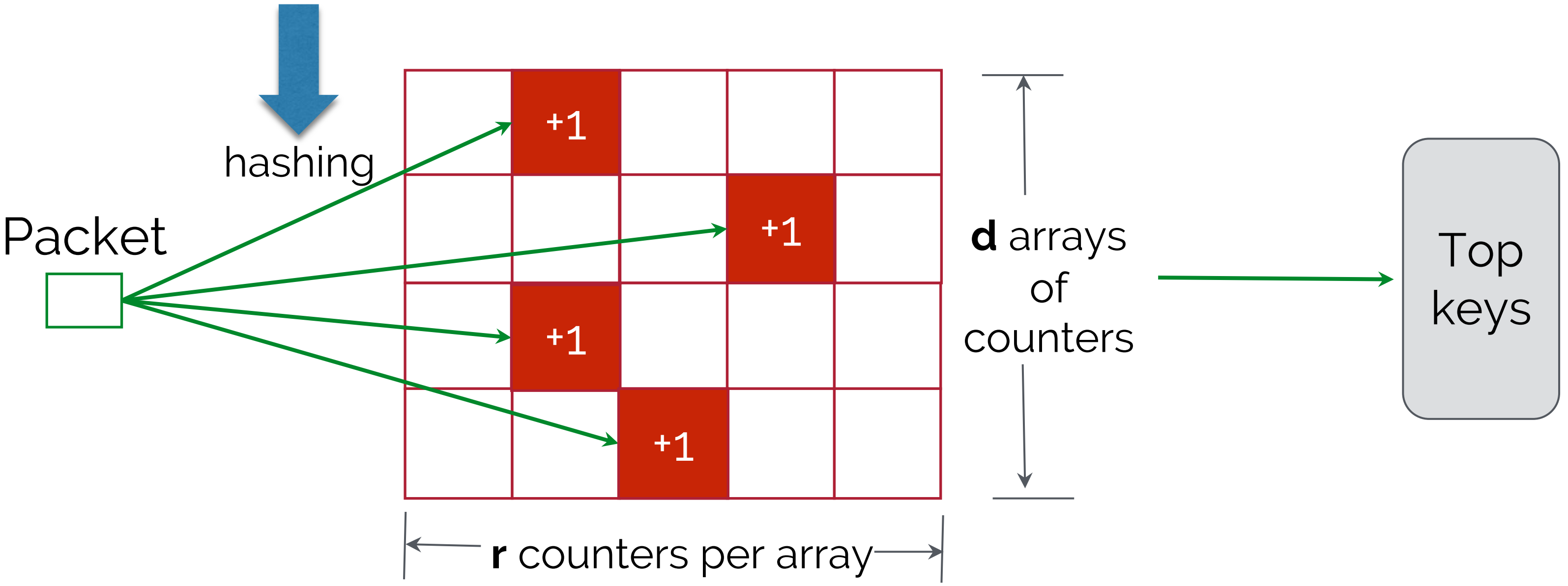
- Motivation
- Understanding bottlenecks
- Design Insights
  - Strawman ideas
  - Our proposals
- Evaluation
- Conclusions and future work

Bottleneck Analysis

- Performance benchmarks using Intel VTune Amplifier.
- Hotspots for UnivMon [SIGCOMM'16].

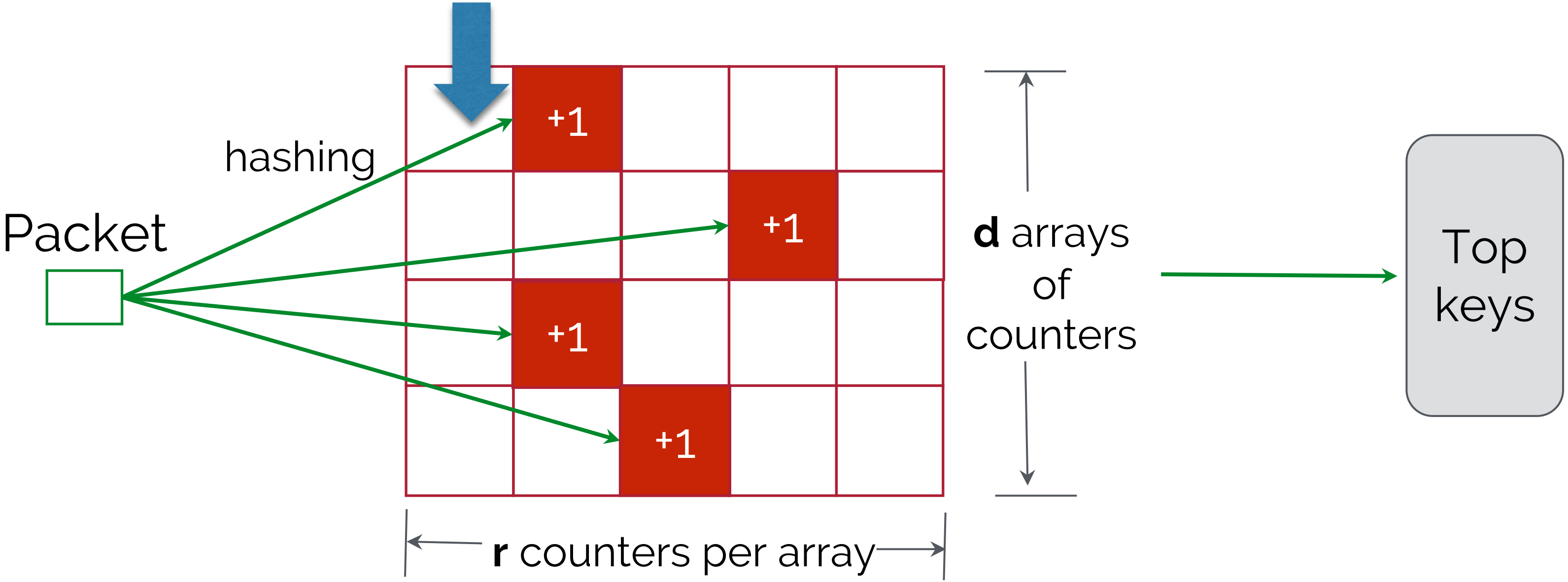
Func/Call Stack	Description	CPU Time
`xxhash32`	hash computations	37.29%
`__memcpy`	memcpy and counter update	15.91%
`heap_find`	heap operation	10.71%

Bottleneck B1: Many hash computations per packet



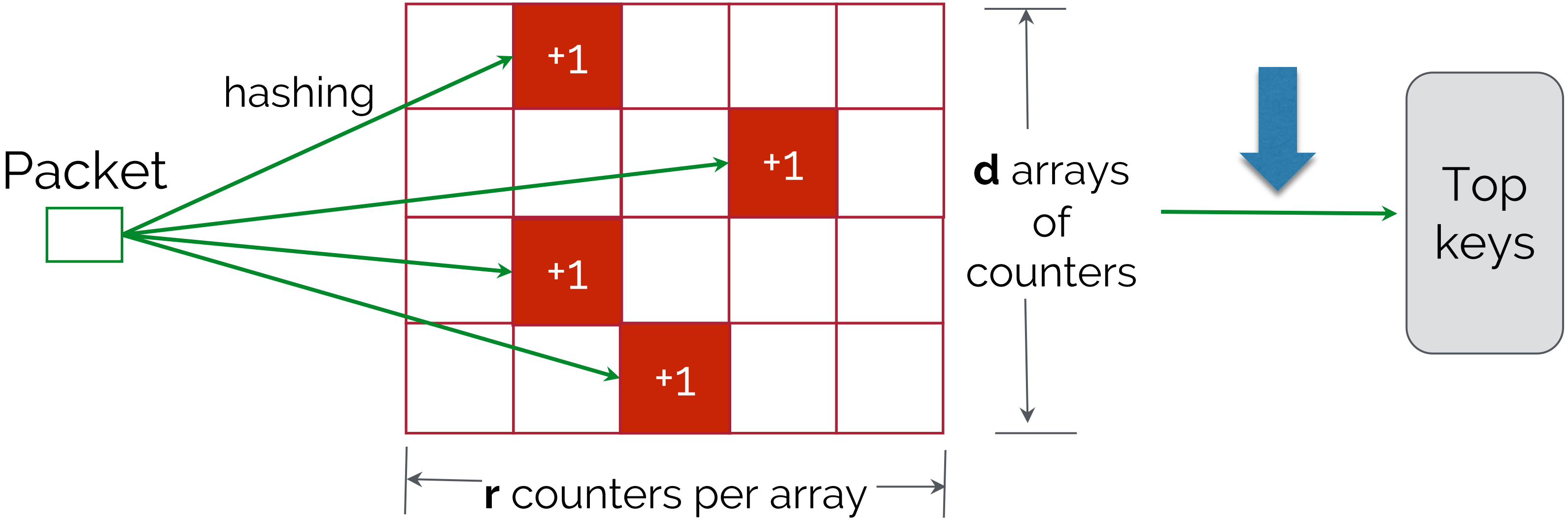
B1: Many (independent) hash computations per packet (~37% CPU)

Bottleneck B2: Many counter updates per packet



B2: Many counter updates (~15% CPU)

Bottleneck B3: Tracking keys is also expensive



B3: Expensive flow key data structure operations (e.g., heap (~10% CPU))

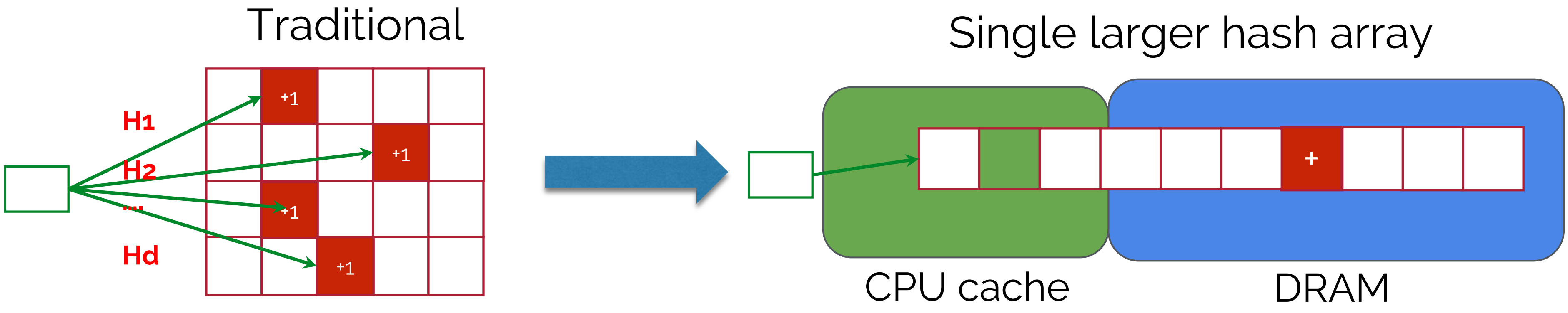
Outline for this talk

- Motivation
- Understanding bottlenecks
- Design Insights
  - Strawman ideas
  - Our proposals
- Evaluation
- Conclusions and future work

Outline for this talk

- Motivation
- Understanding bottlenecks
- Design Insights
  - Strawman ideas
  - Our proposals
- Evaluation
- Conclusions and future work

Strawman 1: Reduce hashes by using single array?

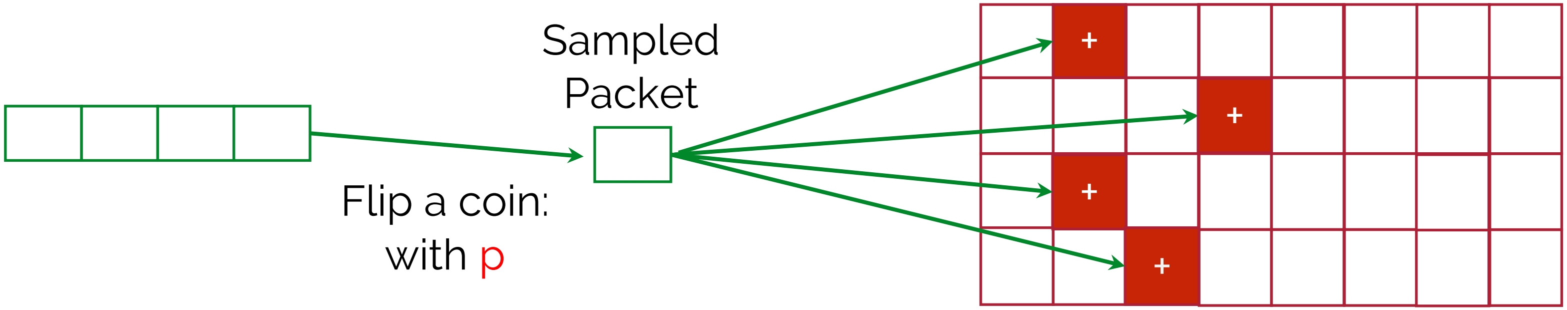


Pros: Simple idea to reduce hash computations.

Cons:

- Memory increase may cause cache misses.
- Even one lightweight hash per packet may be high!

Strawman 2: Reduce updates by packet sampling?



Pros: Simple idea to reduce hash/counter updates.

Cons:
- Memory increase may cause cache misses.
- Even one coin flip per packet may be high!
- Incurs accuracy-convergence tradeoff.

Key lessons from strawman solutions

- Can tradeoff memory for CPU reduction

  But need to ensure cache residency

- Sampling is promising

  But need to manage per-packet ops and convergence

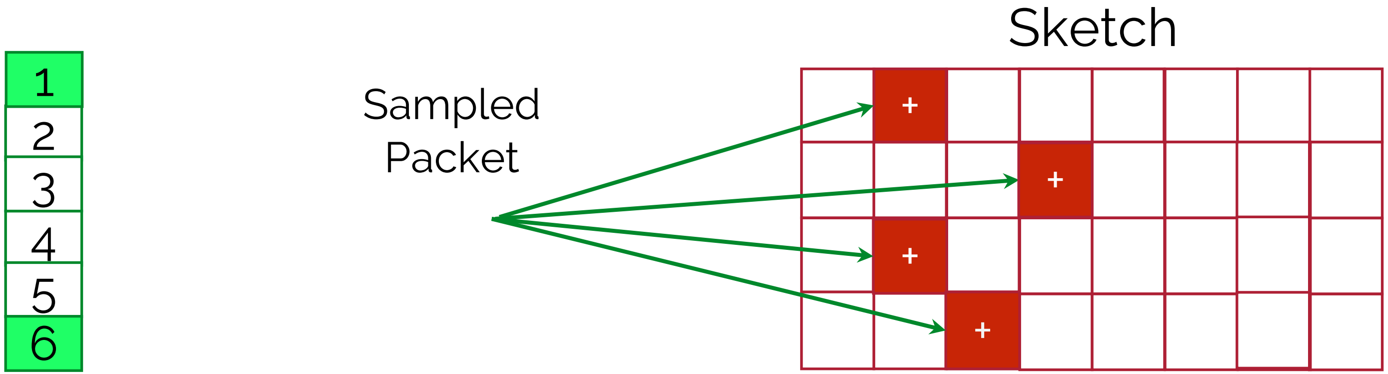
How do we tackle this?

- We trade memory for CPU reduction
  while ensuring cache residency

- Sampling is promising
  But need to manage per-packet ops and convergence

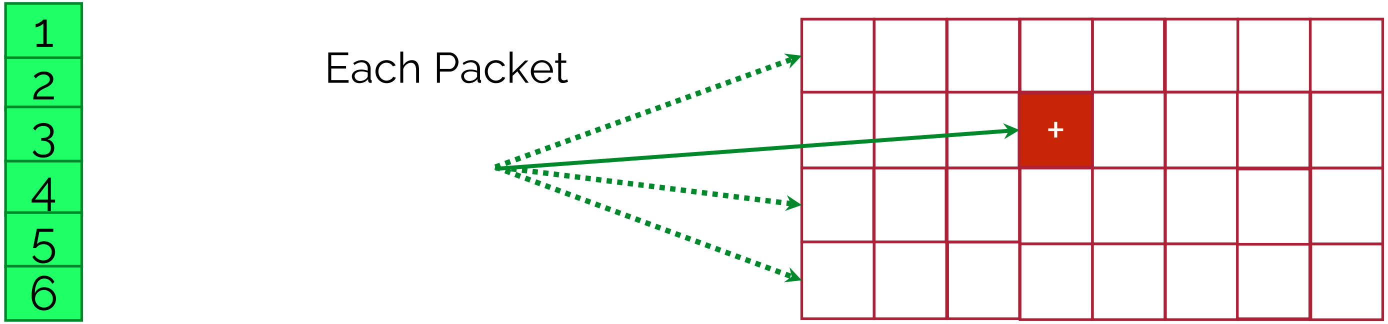
Key Idea: Sample counter updates not packets!

Uniform Packet Sampling



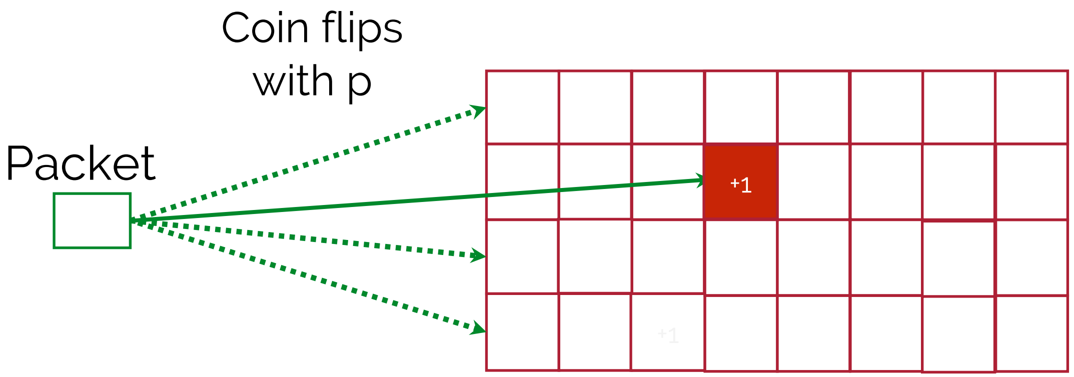
Rethinking the way of doing sampling with sketches

Uniform Counter Sampling



Key Idea: Sample counter updates not packets!

Multiple independent hashes key for memory efficiency

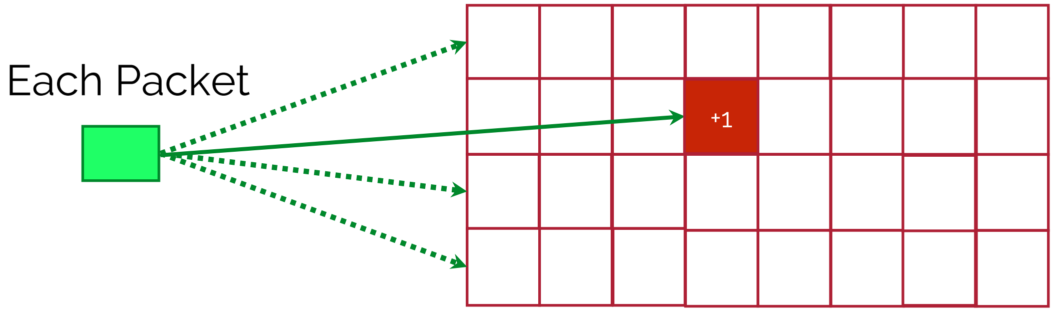


- Per-packet hash/counter updates can be reduced to **less than one**.
- Memory increase by O(1/p): Much better than uniform packet sampling.

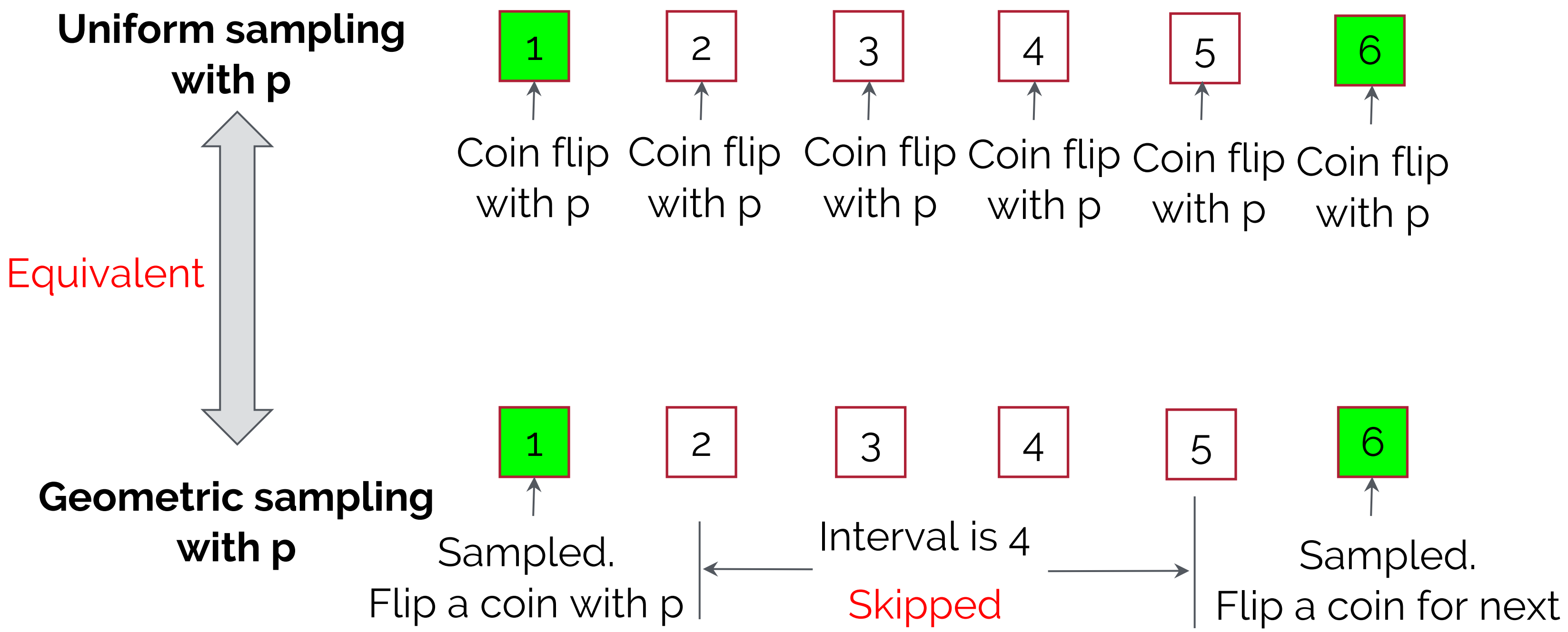
How do we tackle this?

- Can tradeoff memory for CPU reduction
  But need to ensure still cache resident

- Sampling works!
  but need to manage per-packet ops and convergence



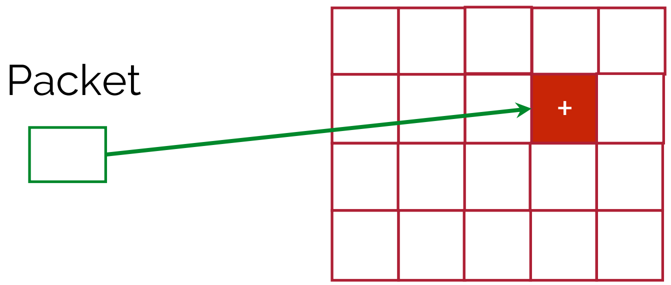
Trick: Geometric sampling to reduce per-packet ops



Trick: Adapt sampling rate to manage convergence

- Sampling-based approach needs to receive enough packets before becoming accurate (need convergence).

- When packet rate isn't high,
  - we can sample more packets ⇒ faster converge



Datarate Adaptive

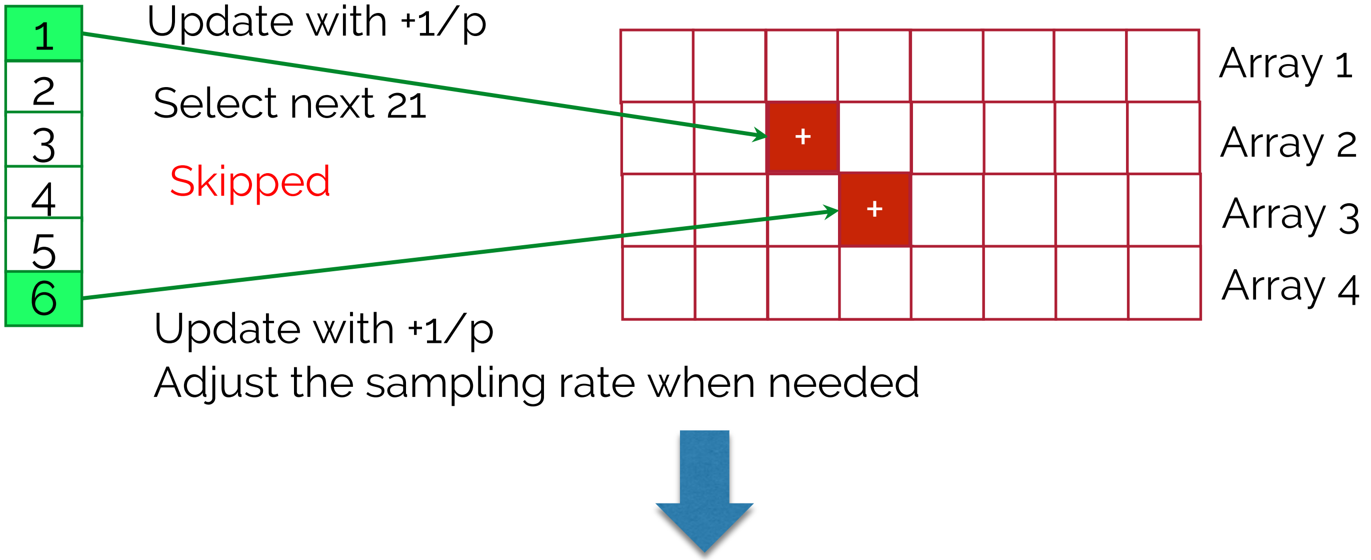
Adaptively adjusting sampling rate:

Packet rate: 1Mpps, sample with 1/1

Packet rate: 8Mpps, sample with 1/8

Packet rate: 64Mpps, sample with 1/64

NitroSketch: Putting it together



Trade small space for speedup on CPU

NitroSketch is theoretically robust!

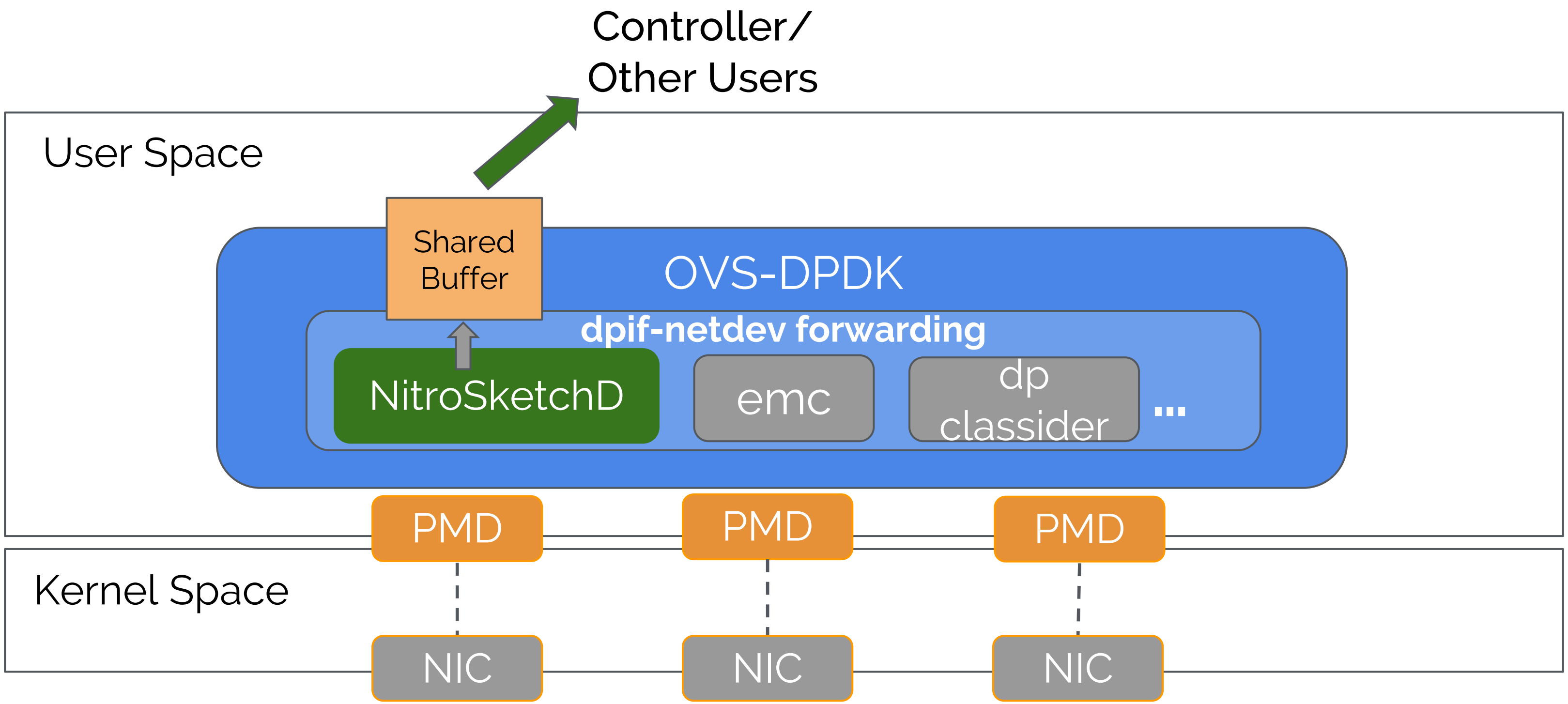
- NitroSketch offers accuracy guarantees for a variety of measurement tasks.

Our theoretical analysis holds after receiving enough packets.

- In practice, we need ~2-4 Mil packets to converge.

Check out our paper for more details!

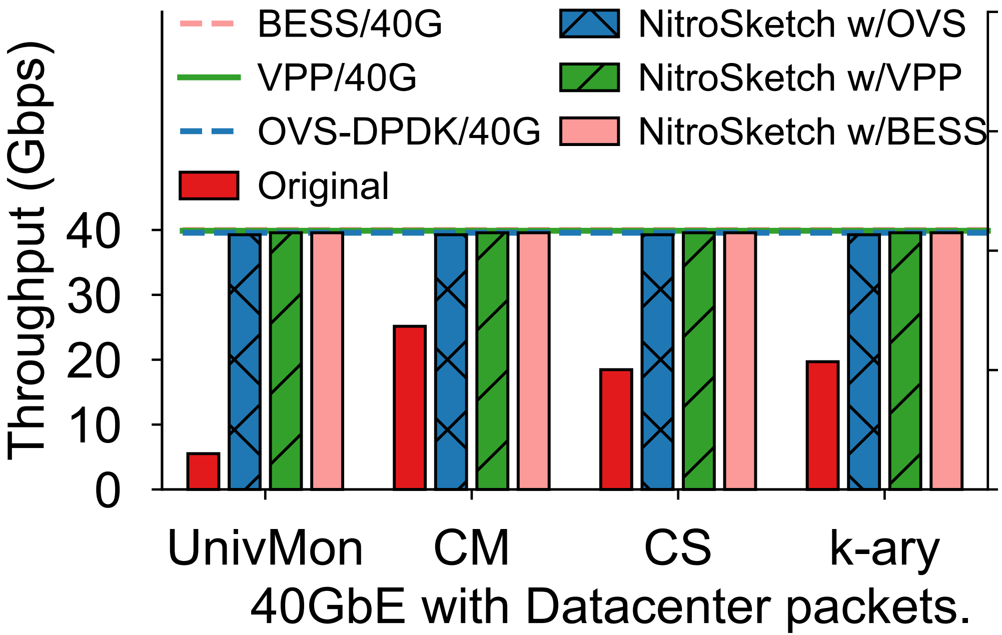
NitroSketch Inline Implementation



- Other versions: FD.io-VPP, BESS

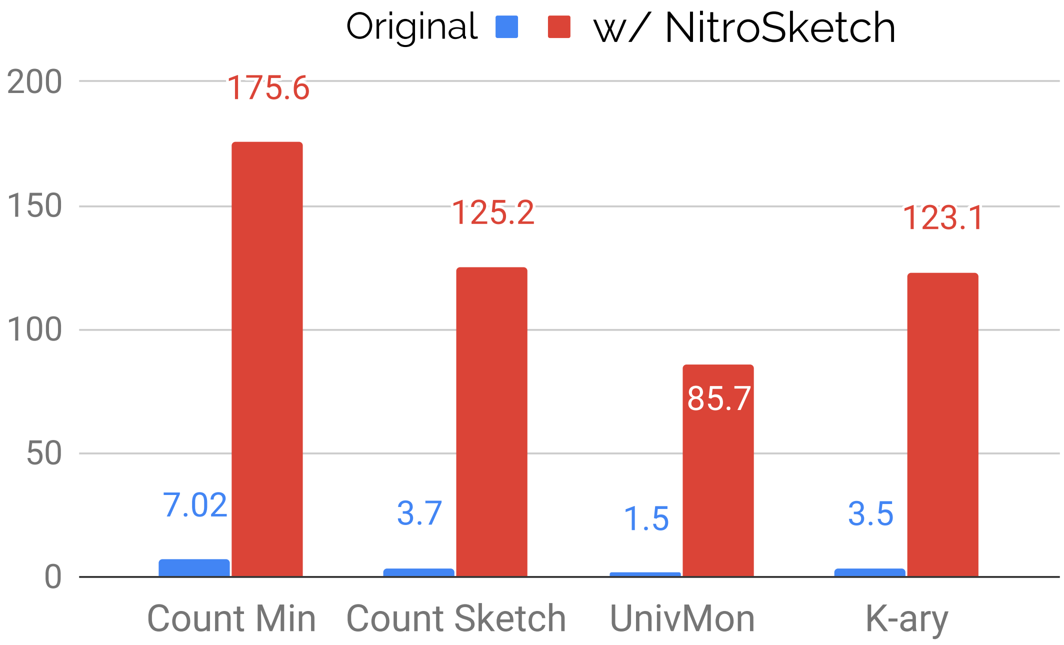
NitroSketch achieves 40G on software switches

- Two threads with OVS-DPDK, VPP and BESS on Intel XL710 NIC.
- NitroSketch uses **no extra cores**.



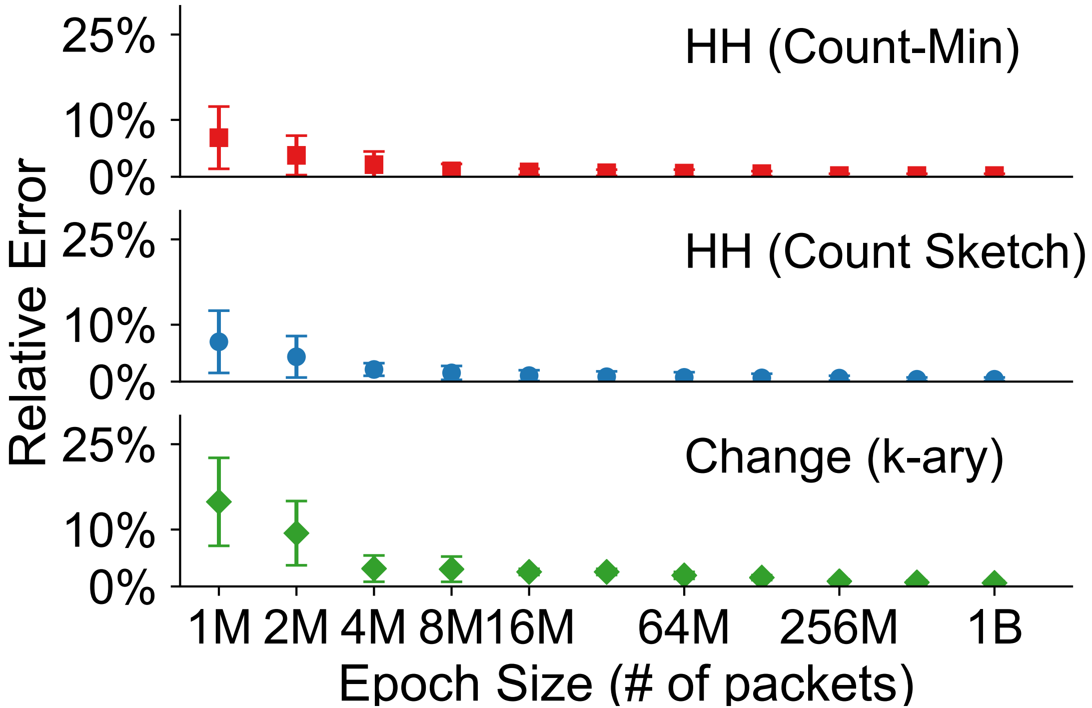
NitroSketch can achieve higher throughput

- In-memory single thread (Intel E5 2620 v4 CPU)
- Algorithms use 5~10 independent hash functions



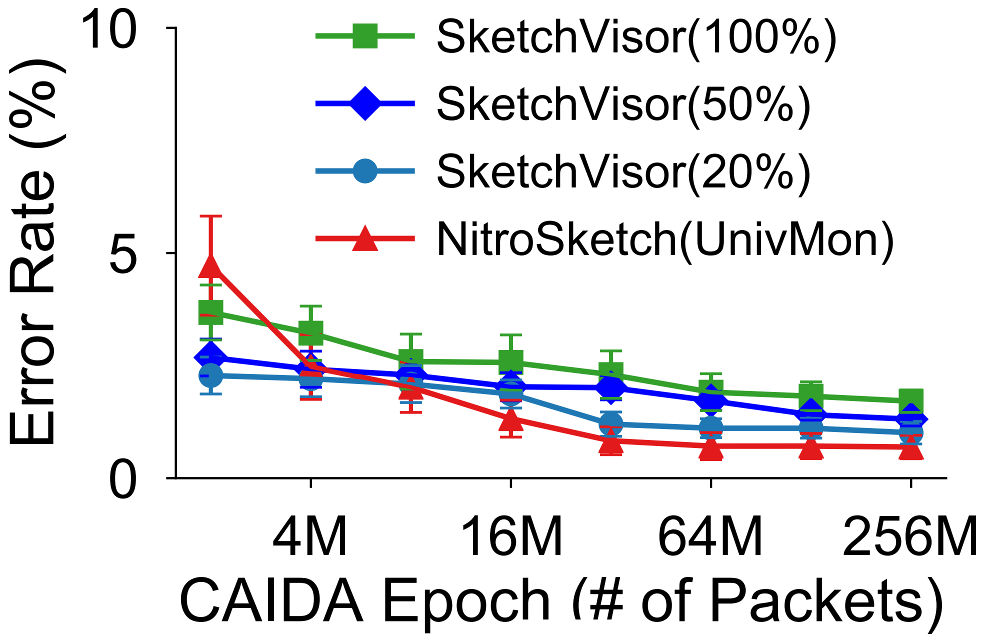
Guaranteed accuracy after convergence

- After received 2~4 Mil packets, Sketches achieve comparable (or better) accuracy as the original sketches.



NitroSketch outforms other solutions

- NitroSketch achieves higher accuracy when converged.



Conclusions

- Sketching is a promising alternative for software switch based telemetry.
- Performance of sketches is far from optimal.
- Existing efforts missing in performance, robustness, or generality.
- NitroSketch key ideas:
  Tradeoff small memory increase, Sample counters not packets,
  Geometric sampling to reduce packet ops, Adaptive sampling
- NitroSketch improves the performance of sketches by 1~2 orders of magnitude while retaining the robustness and generality

https://github.com/zaoxing/NitroSketch