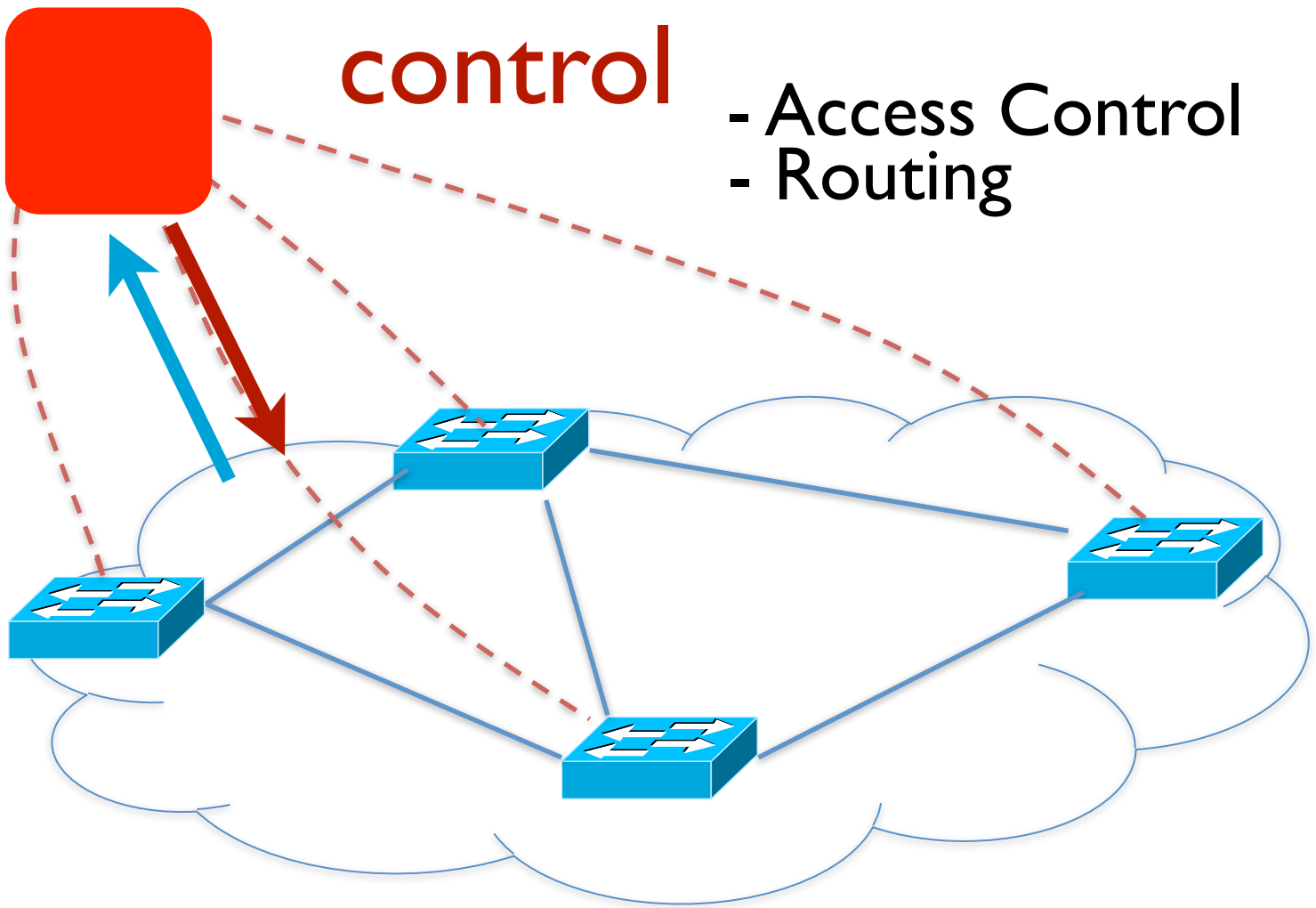
Software-Defined Traffic Measurement with OpenSketch

Ye Tao. 2013.5.8

Reference: Lavanya Jose, nsdi slides

Management is Control + Measurement



Questions we want to ask

1. Who's sending a lot to 10.0.2.0/16? (Heavy Hitters)
2. How are flow sizes distributed?
3. Is someone doing a port scan?
4. Is someone being DDoS-ed?
5. Who's getting traffic from blacklisted IPs?
6. How many people downloaded files from 10.0.2.1?

Switches are great at counting per flow bytes and packets

- NetFlow and sFlow sample packets
- NetFlow maintains per flow byte and packet counts
- Can find count of a particular flow, prefix or counts of heavy flows

Problem: NetFlow counts can't answer my questions

Is someone doing a port scan?

NetFlow samples packets from heavy flows. Missed packets from small "port scanners".

- Increase sampling rate --> inefficient

Streaming algorithms

+ Process efficiently at line rate

+ Accurate answers

- But each answers a specific question

What measurement architecture can answer all my questions?

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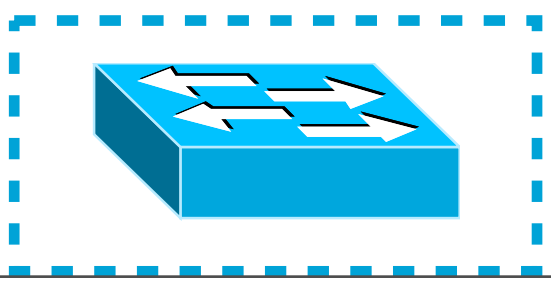

SDN Model: Find Building Blocks

1. Who's sending a lot to 10.0.2.0/16? (Heavy Hitters)
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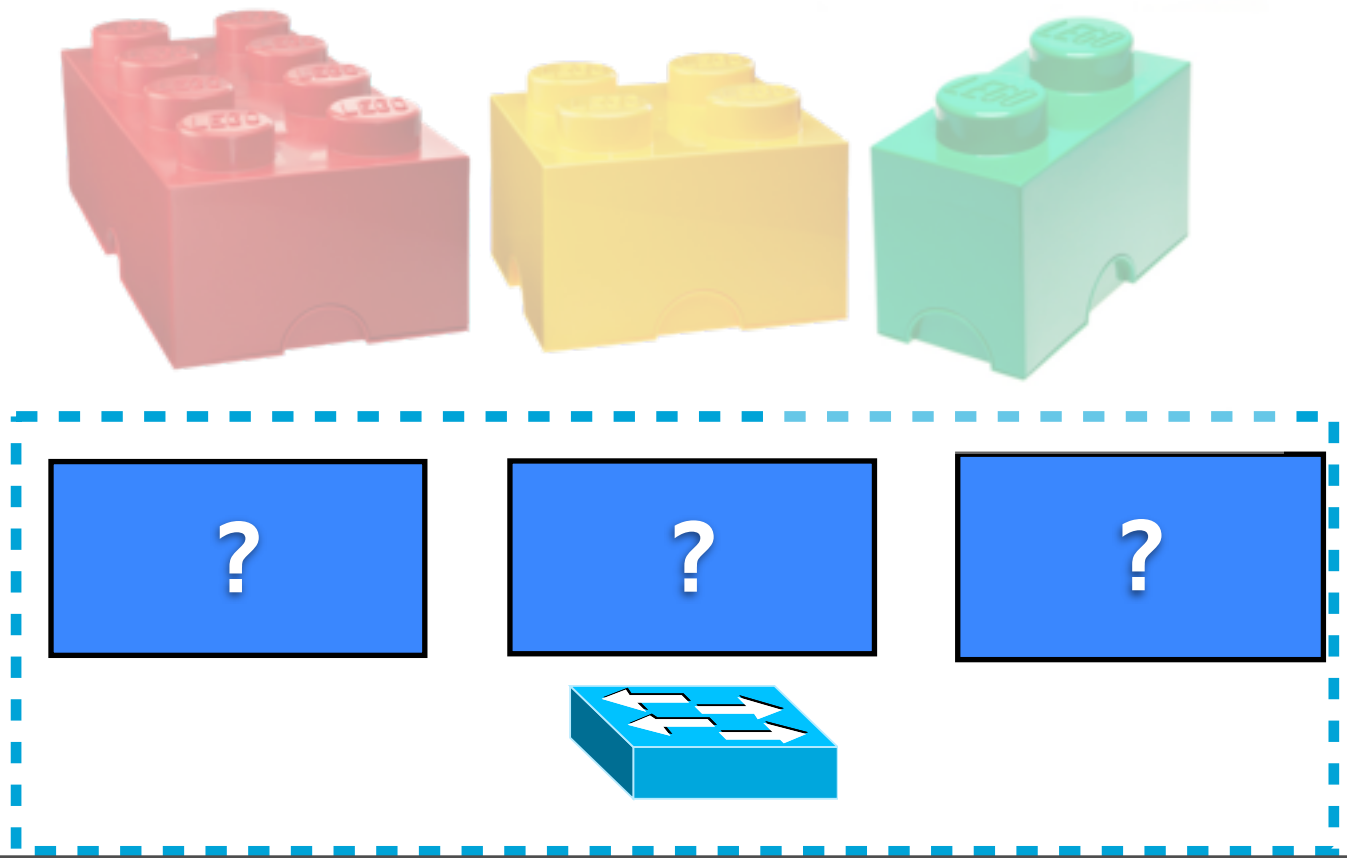
3. Is someone doing a port scan? ...



Sketches as building blocks

- Sketch
  - Data structure
  - Support approx. computing some function of data
  - Much smaller than actual data
  - Streaming, small per-item processing cost
  - Provable space-accuracy tradeoffs

Sketches as building blocks

e.g., Count Min sketch
to store counts of frequent source IP addresses

Packet

h1
h2
h3

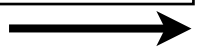
3	2	1	23	0	4
22	4	9	3	2	1
2	3	0	4	22	5

(Cormode 2005)

Sketches as building blocks

e.g., Count Min sketch
to store counts of frequent source IP addresses

Source IP address : 23.43.12.1



h1
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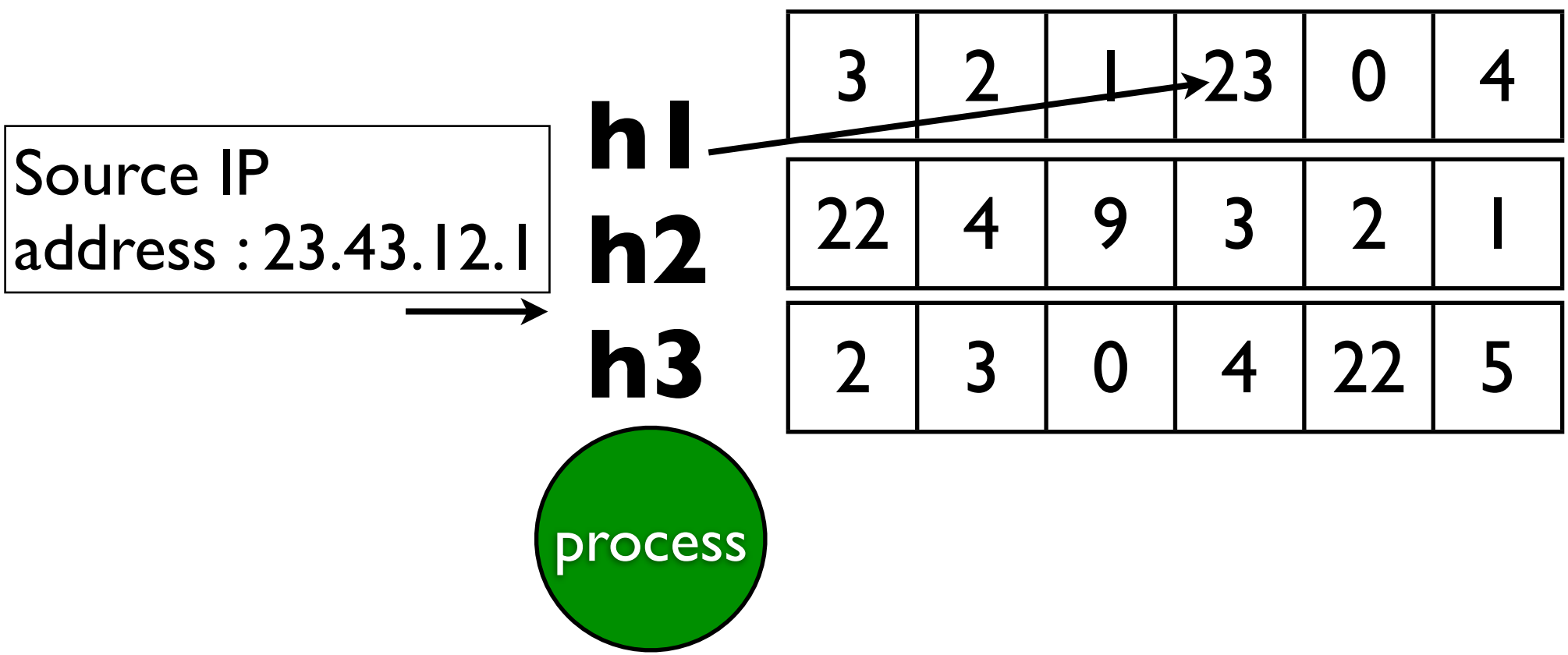

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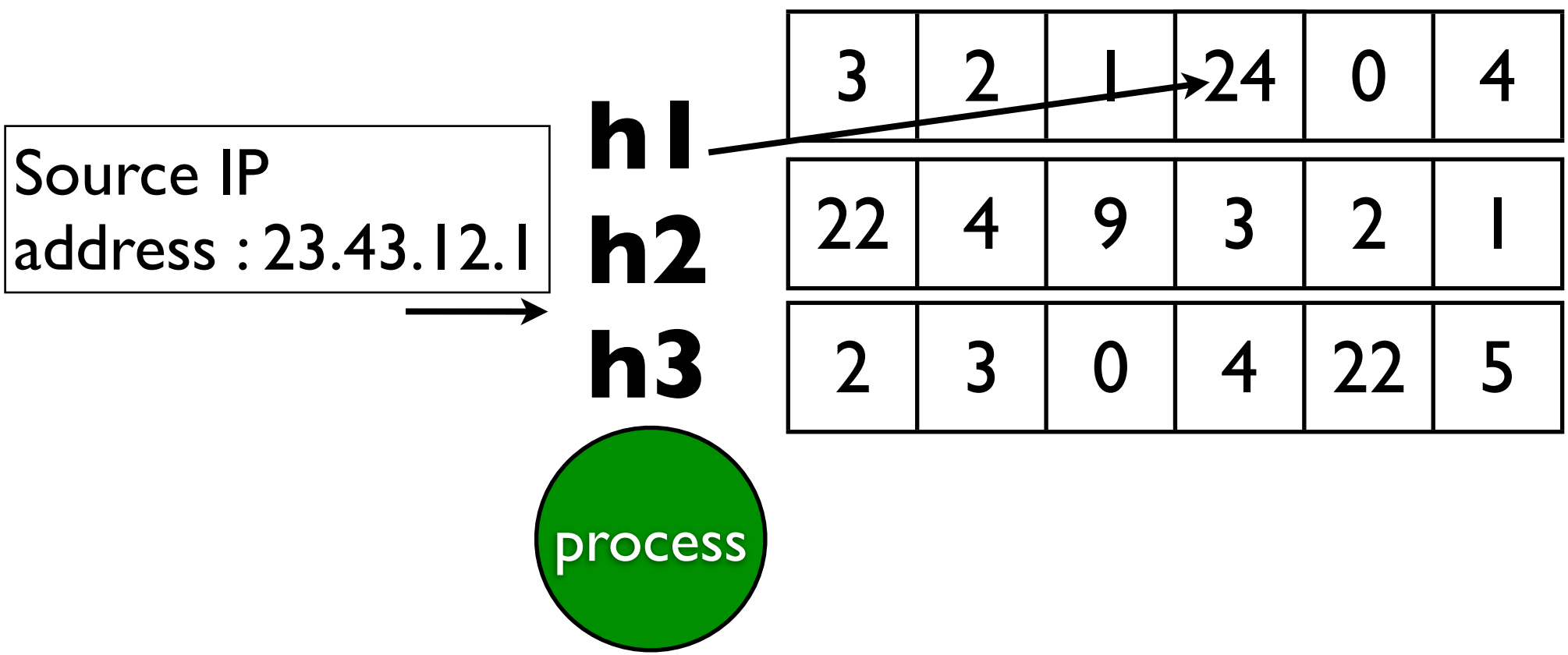

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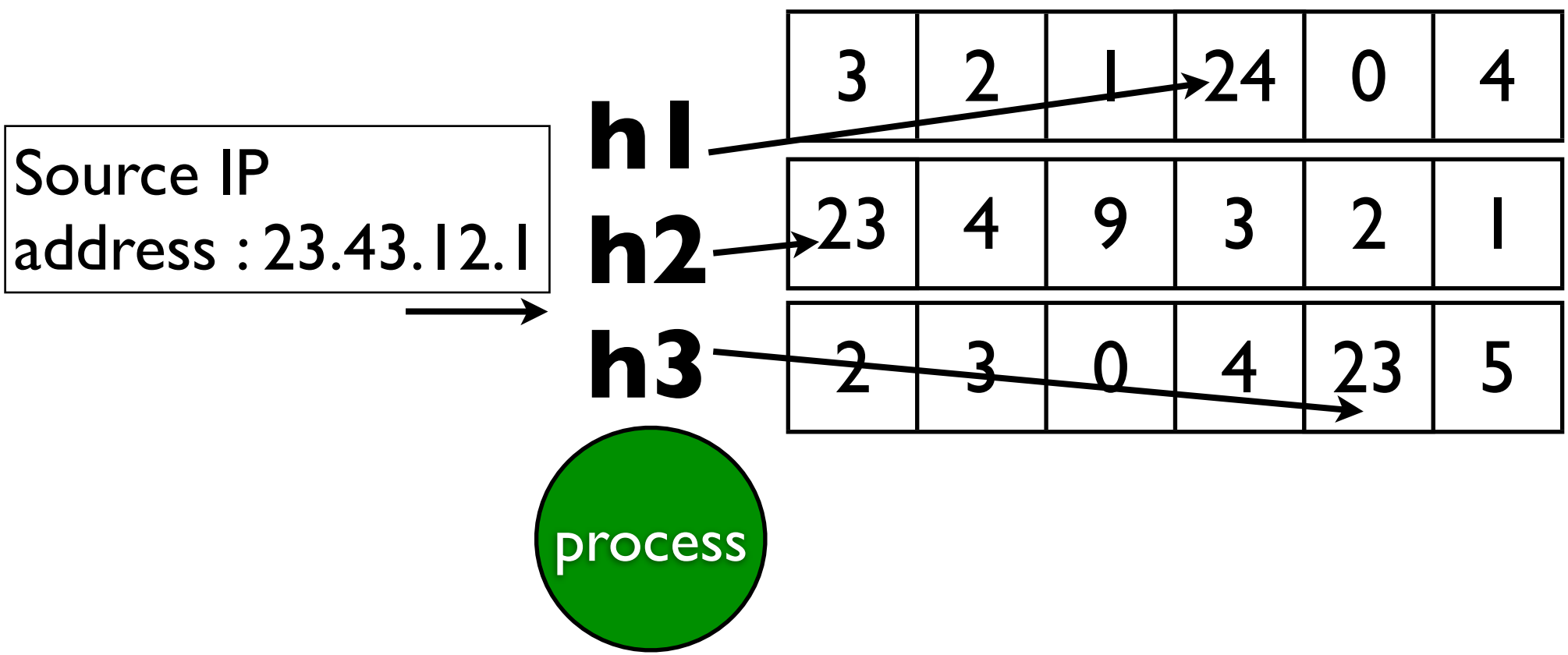

(Cormode 2005)

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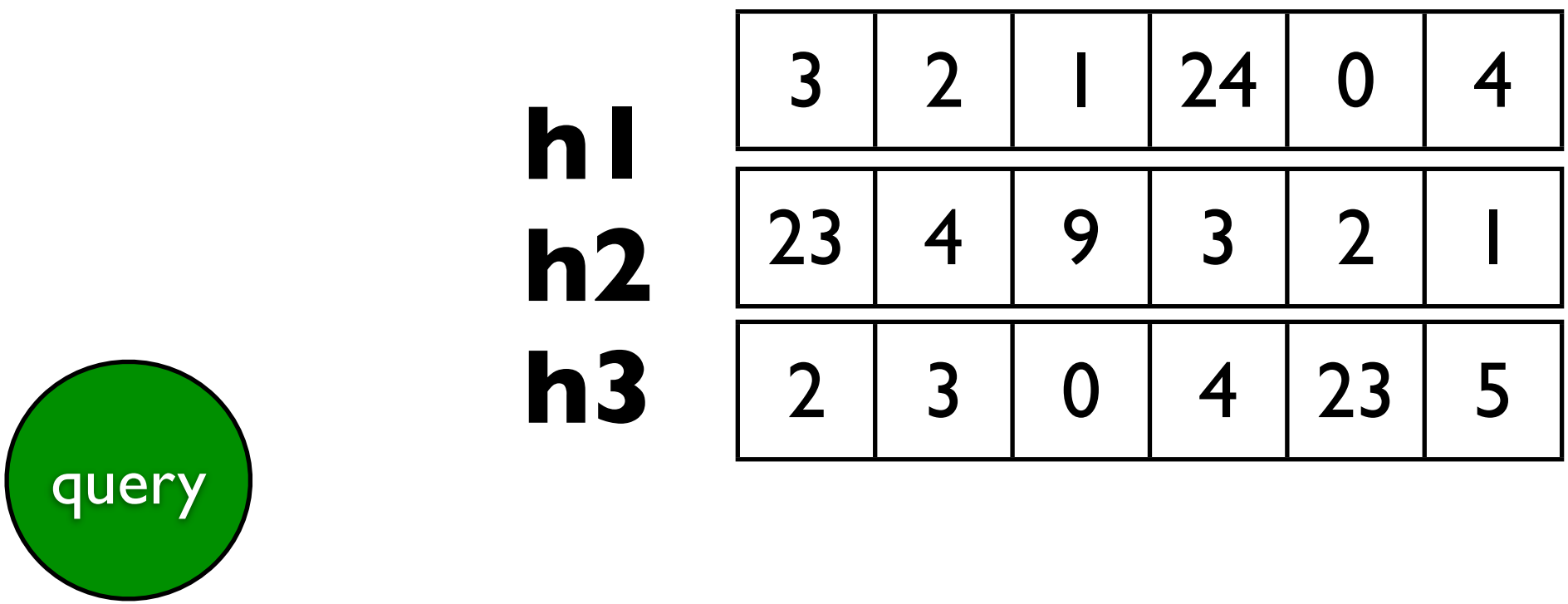


(Cormode 2005)

Sketches as building blocks

e.g., Count Min sketch
to store counts of frequent source IP addresses

packets from 23.43.12.1?

query

h1	3	2	1	24	0	4
h2	23	4	9	3	2	1
h3	2	3	0	4	23	5

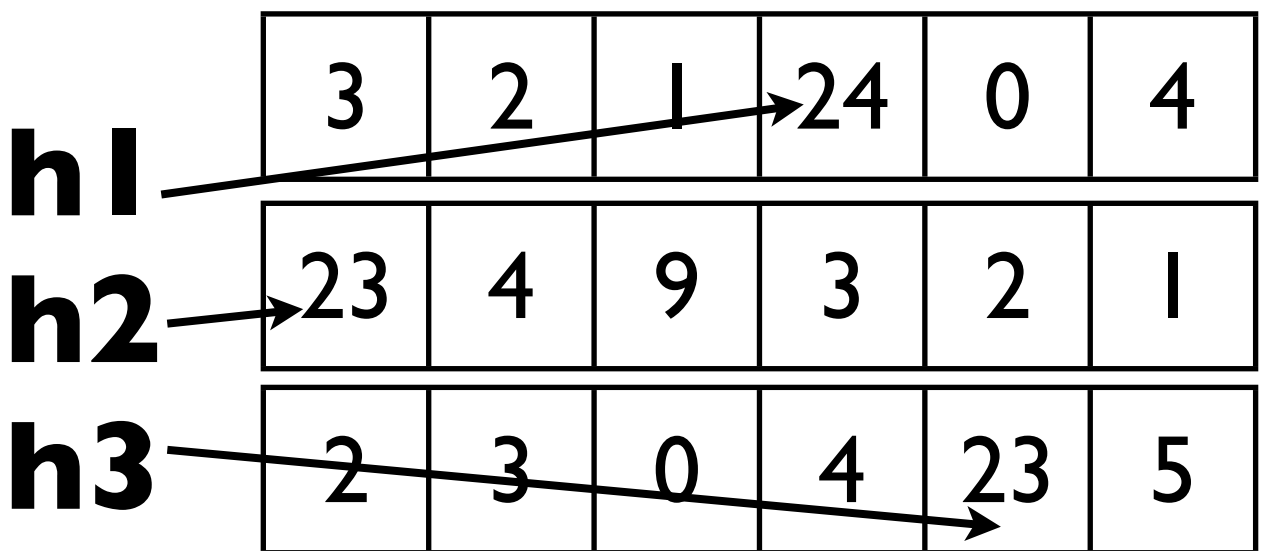
(Cormode 2005)

Sketches as building blocks

e.g., Count Min sketch
to store counts of frequent source IP addresses

packets from 23.43.12.1?

query



estimate

24 23 23

pick min.

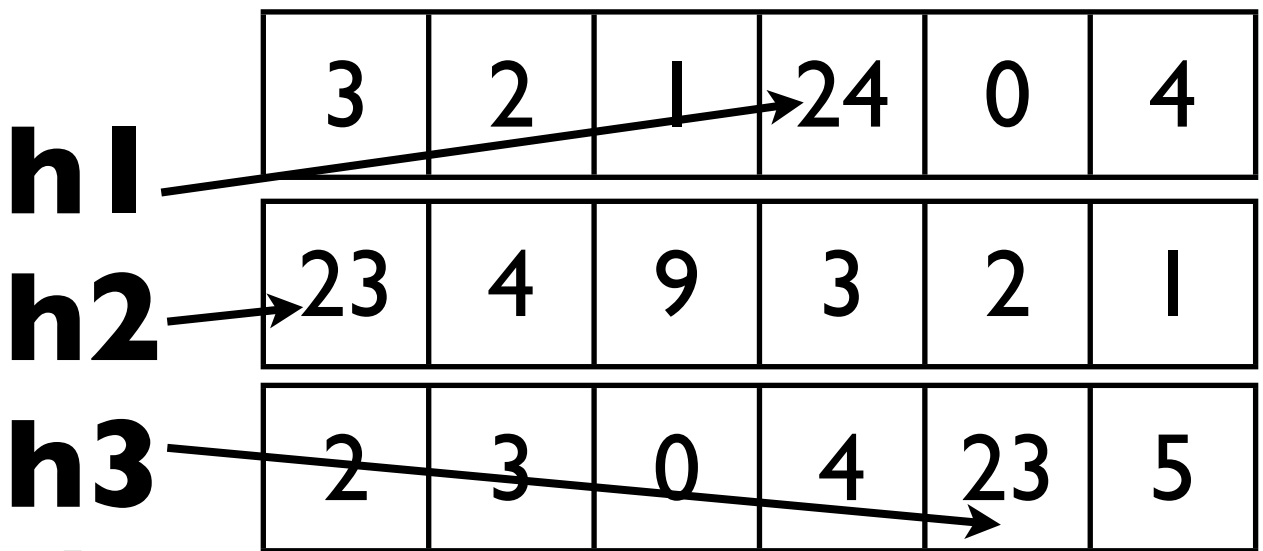
(Cormode 2005)

Sketches as building blocks

e.g., Count Min sketch
to store counts of frequent source IP addresses

packets from 23.43.12.1?

query



estimate

23

pick min.

(Cormode 2005)

Sketches as building blocks

e.g., Count Min sketch
to store counts of frequent source IP addresses

$$\text{within } \epsilon \text{ total packets with high probability}$$

$$\epsilon = \frac{e}{\text{no. of counters}}$$

$$\Pr\{\text{error} > \epsilon \text{ total packets}\} < e^{-\text{ no. of hash functions}}$$

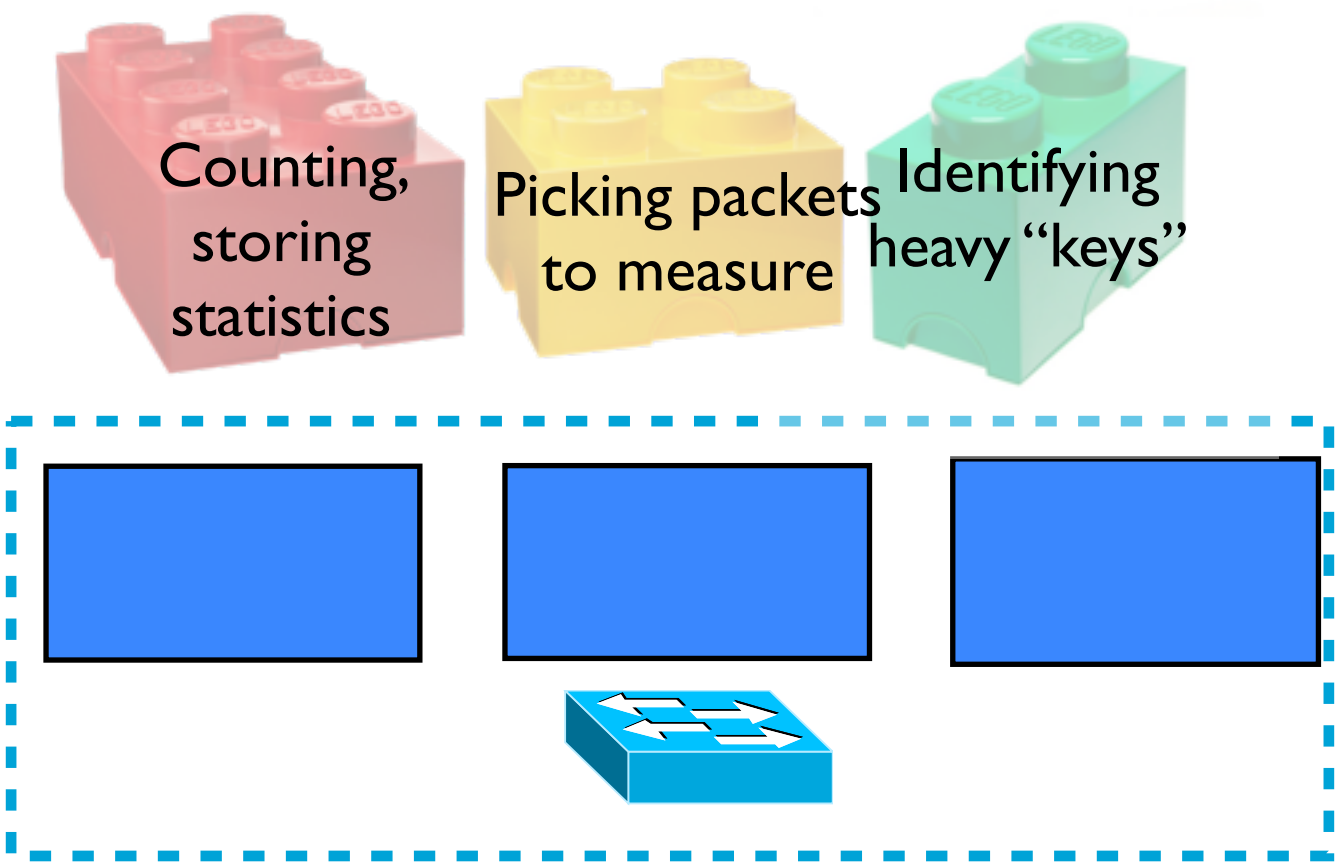
+ Provable space-accuracy tradeoffs

23

estimate
pick min.

(Cormode 2005)

Sketches as building blocks



(Reversible Sketch: Schweller 2004)

. . . answer many questions

1. Who's sending a lot to 10.0.2.0/16? (Heavy Hitters)
2. How are flow sizes distributed?
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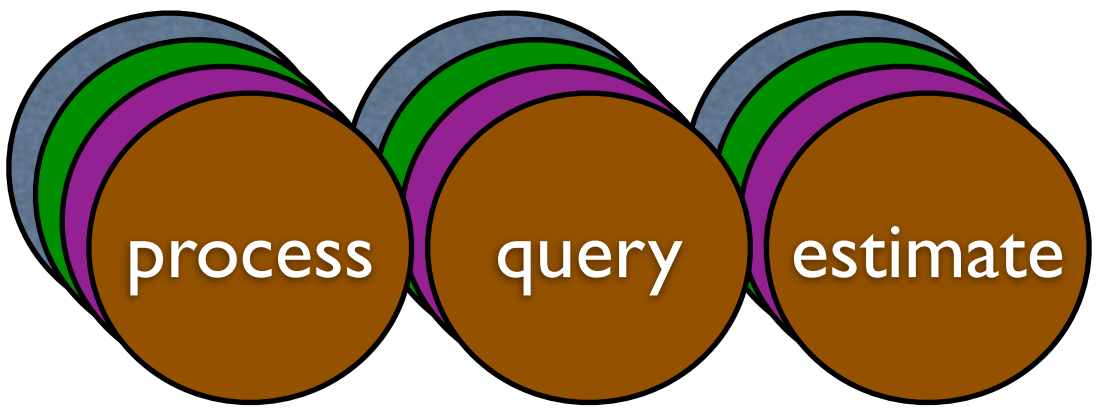
4. Is someone being DDoS-ed?
5. Who's getting traffic from blacklisted IPs?
6. How many people downloaded files from 10.0.2.1?

(Reversible Sketch: Schweller 2004)

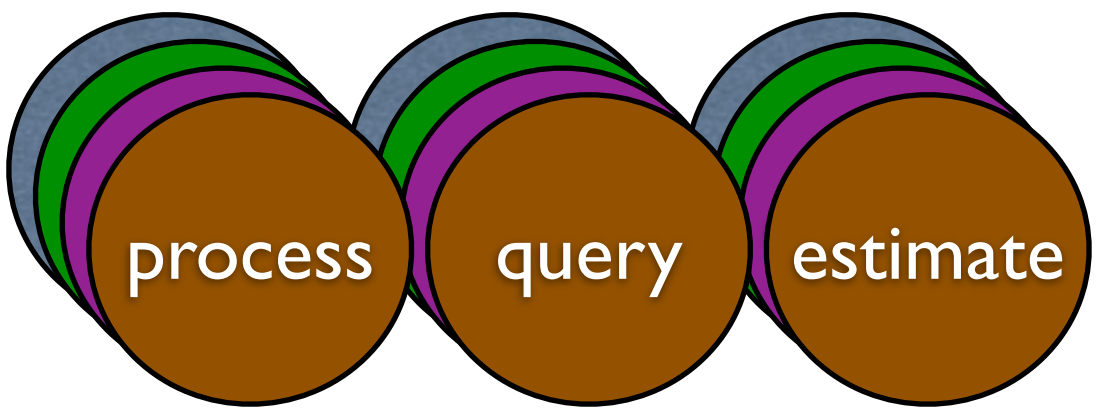
But each sketch estimates only one function

- frequency count
- cardinality
- set membership
- heavy "keys"



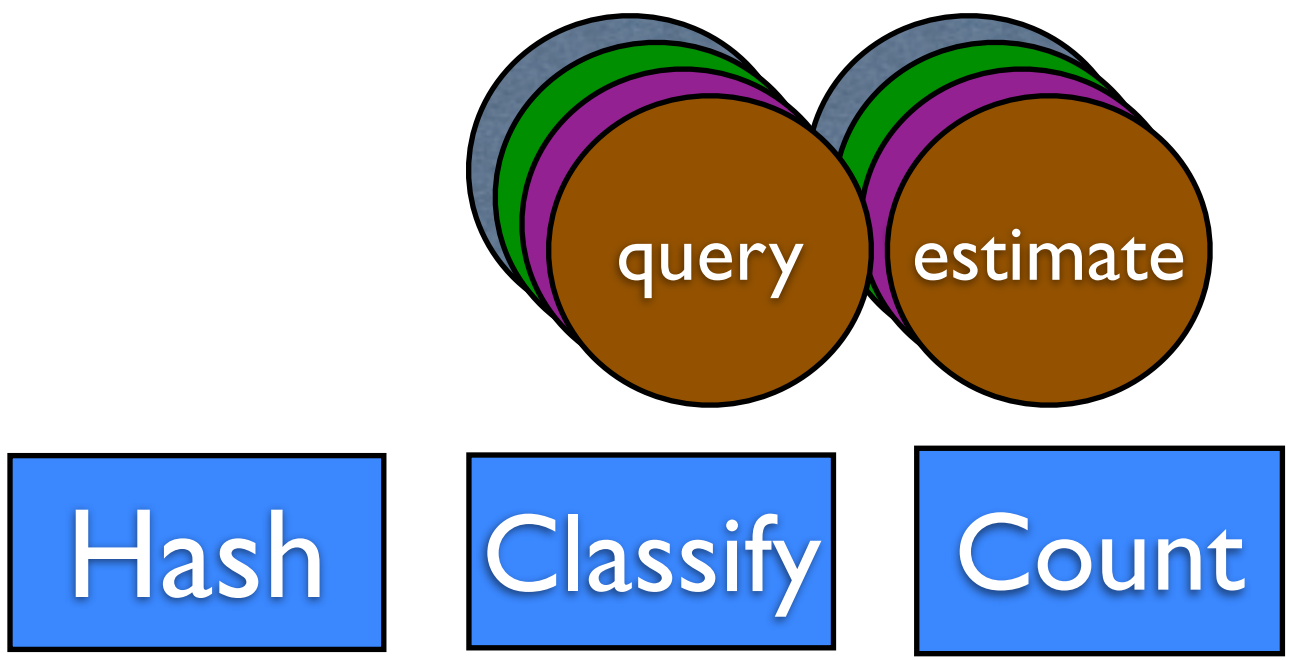
3_stage pipeline

- frequency count
- cardinality
- set membership
- heavy “keys”

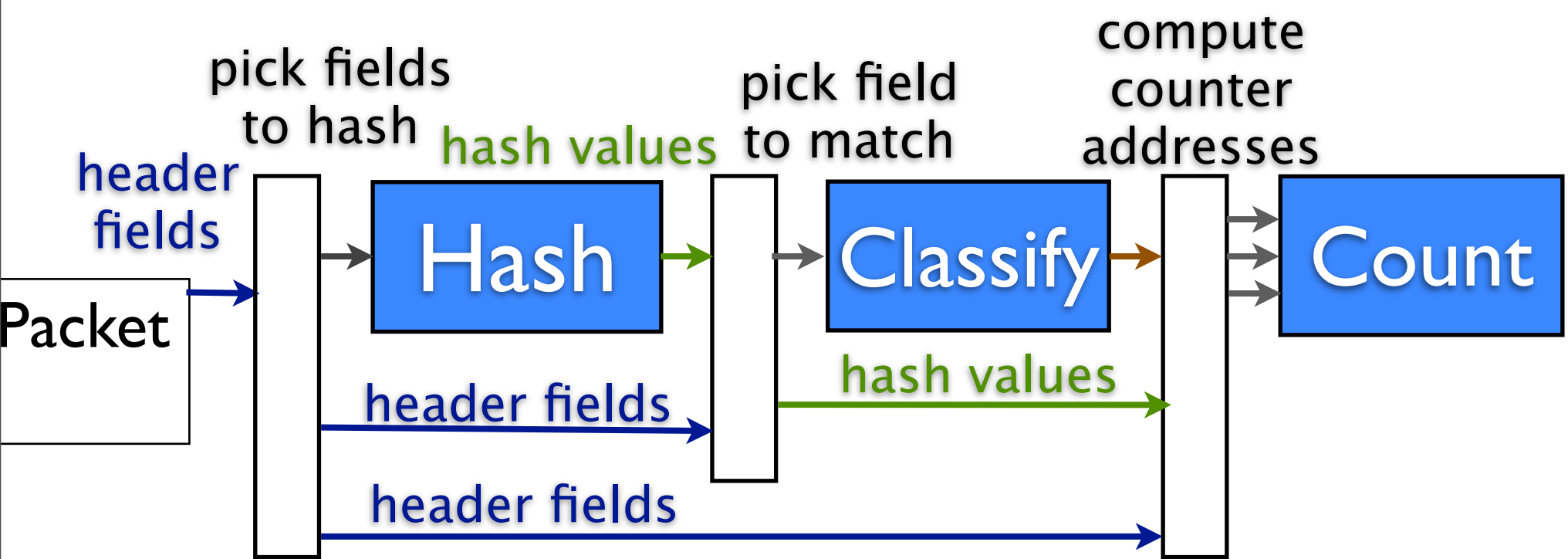


3-stage pipeline

- frequency count
- cardinality
- set membership
- heavy "keys"

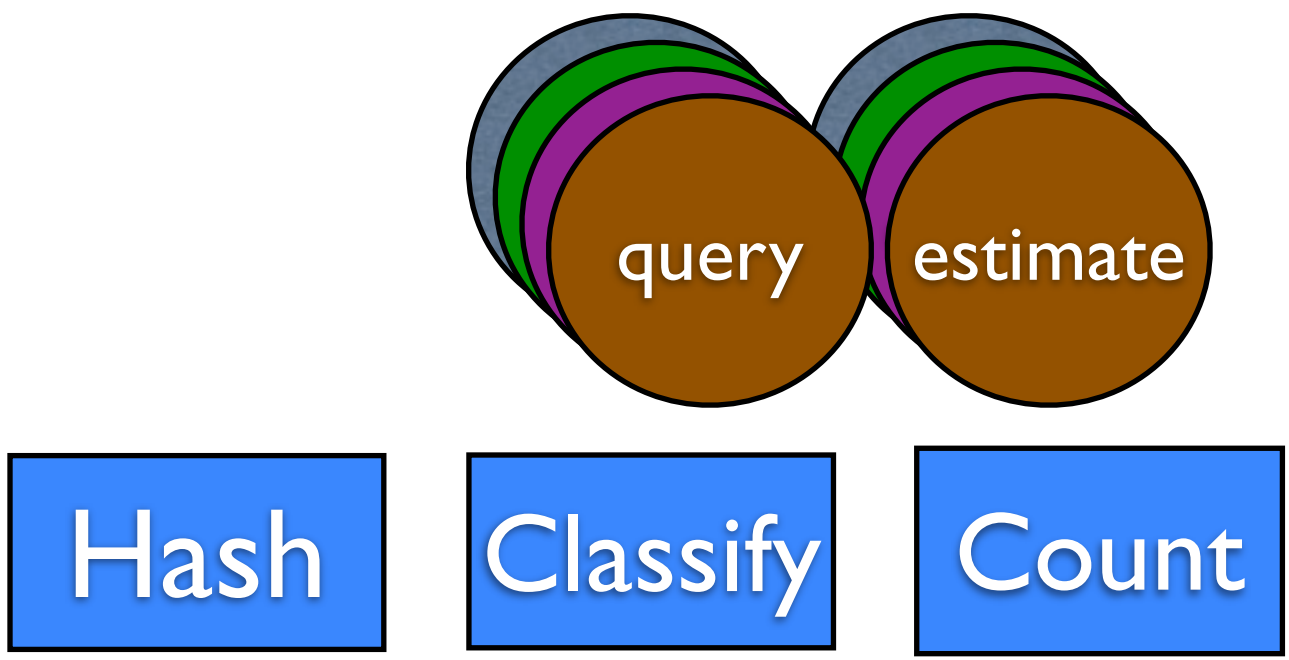


3_stage pipeline



3-stage pipeline

- frequency count
- cardinality
- set membership
- heavy "keys"



3-stage pipeline

Hash | Classify | Count

3-stage pipeline

1. Who's sending a lot to 10.0.2.0/16? (Heavy Hitters)
2. How are flow sizes distributed?
3. Is someone doing a port scan?

OpenSketch Measurement Framework

Controller

1. Who's sending a lot to 10.0.2.0/16? (Heavy Hitters)
2. How are flow sizes distributed?
3. Is ..

Data Plane

Hash | Classify | Count

OpenSketch Measurement Framework

Controller

1. Who's sending a lot to 10.0.2.0/16? (Heavy Hitters)
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3. Is ..

Measurement Library

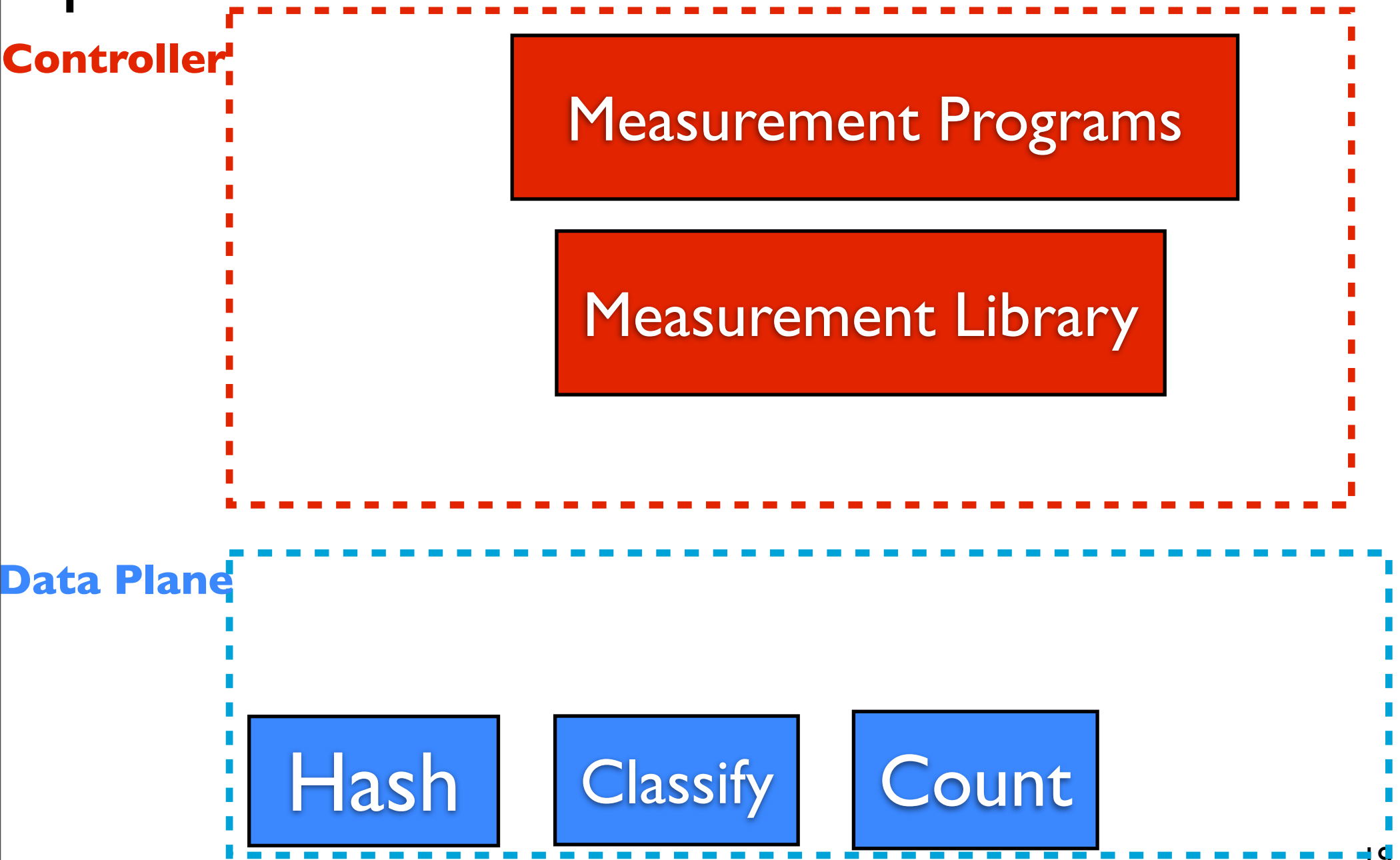
Data Plane

Hash

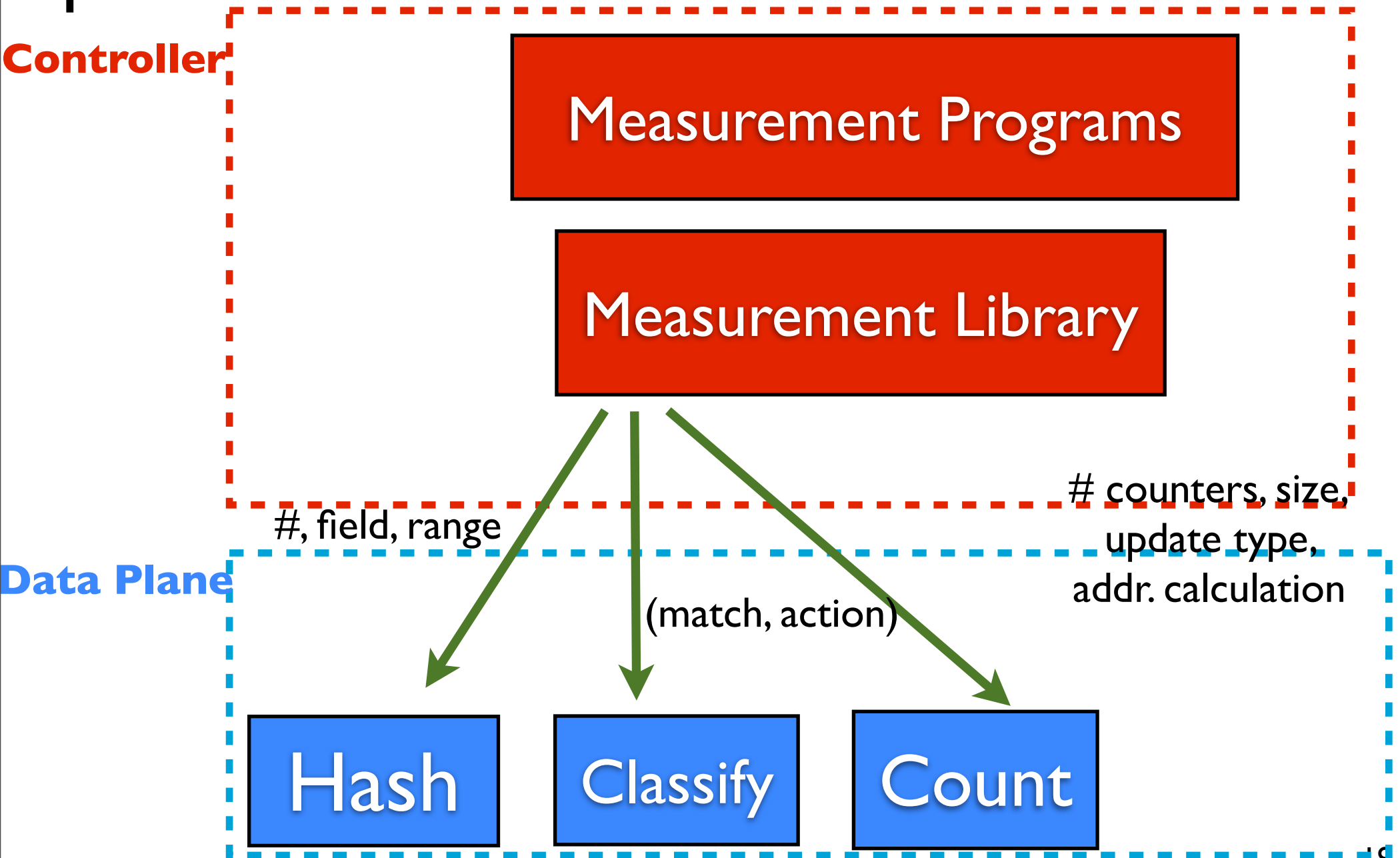
Classify

Count

OpenSketch Measurement Framework



OpenSketch Measurement Framework



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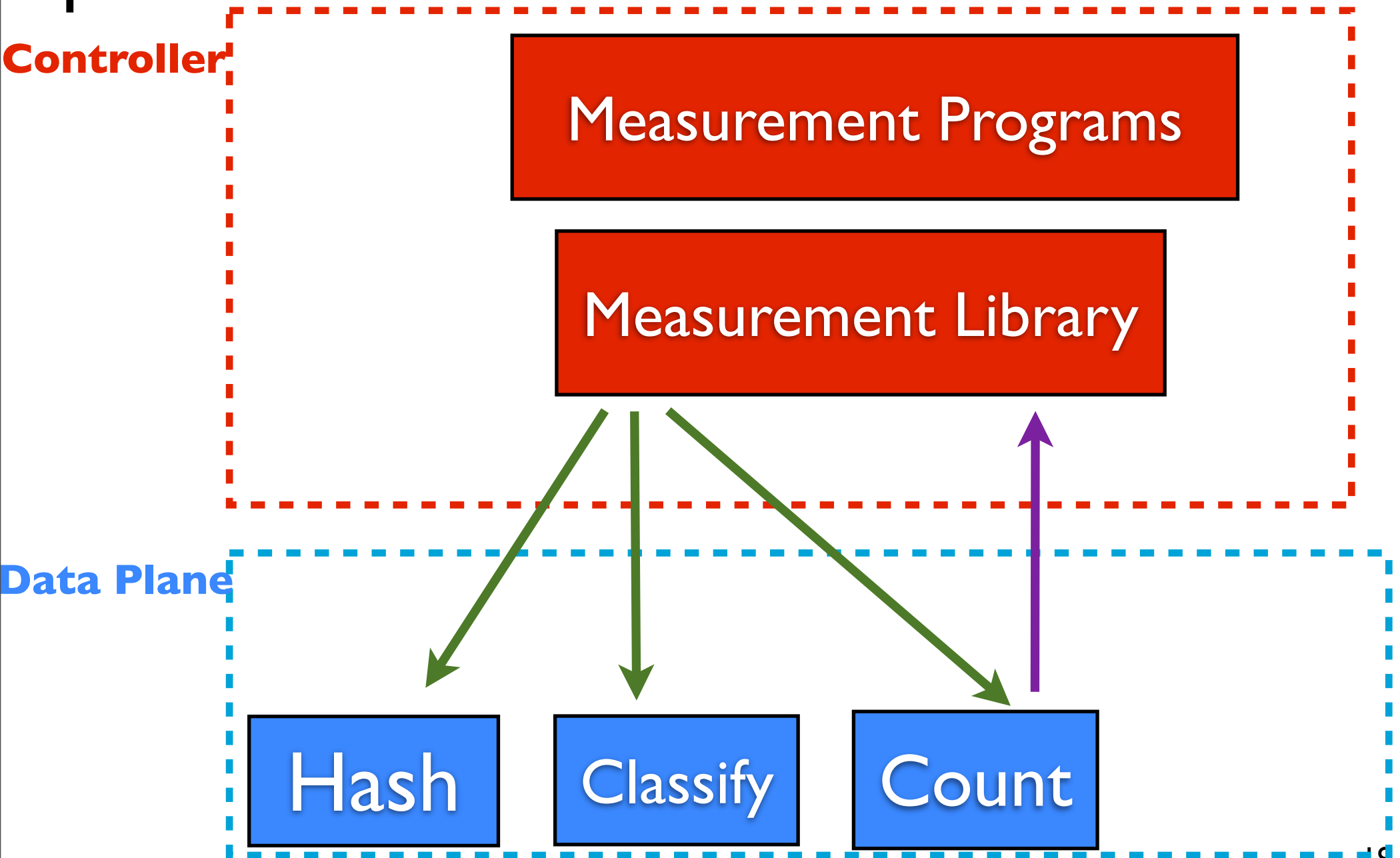


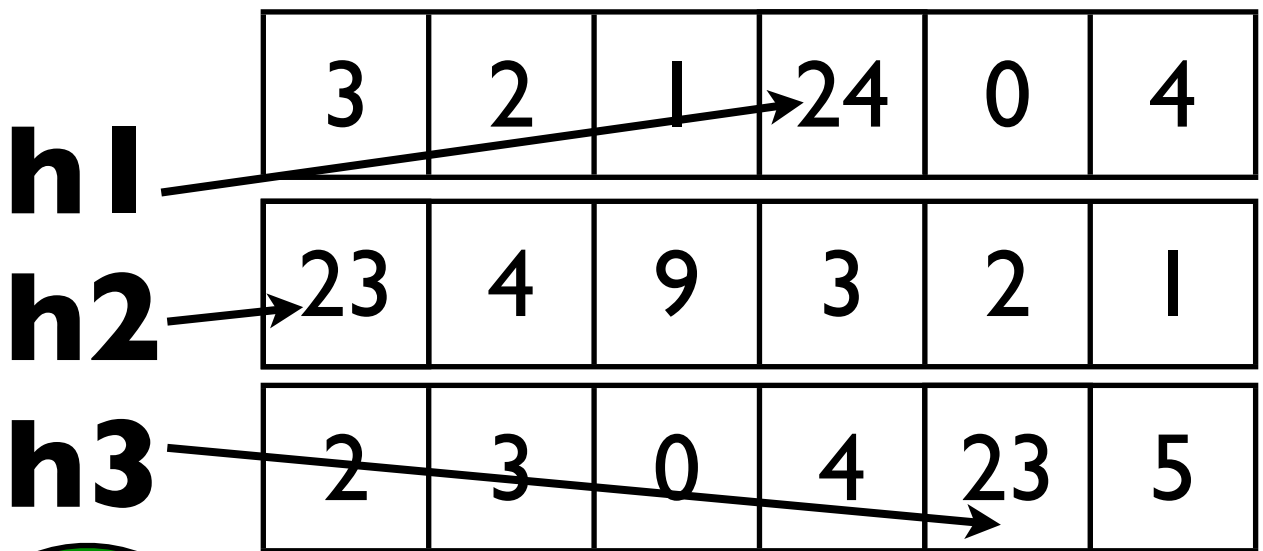
Details

- Implementing sketches with the Pipeline
- Configuring the Pipeline
- Evaluation and NetFPGA prototype

Count Min Sketch with the Pipeline

to store counts of frequent source IP addresses

Source IP address : 23.43.12.1



process

Hash

Count

Bitmap Sketch with the Pipeline

to store number of different destination port numbers

Packet

h

0	0	1	0	0	1	0	0	1	0

process

Hash

Count

Bitmap Sketch with the Pipeline

to store number of different destination port numbers

Destination port number : 5596

h

0	0	1	0	0	1	0	0	1	0

process

Hash

Count

Bitmap Sketch with the Pipeline

to store number of different destination port numbers

Destination port number : 5596

h

1	0	1	0	0	1	0	0	1	0

process

Hash

Count

Bitmap Sketch with the Pipeline

to store number of different destination port numbers

different destination port numbers?

query

1	0	1	0	0	1	0	0	1	0

(Whang 1990)

Bitmap Sketch with the Pipeline

to store number of different destination port numbers

different destination port numbers?

query

estimate

1	0	1	0	0	1	0	0	1	0

6/10

estimate
N = -10 ln(6/10)= 5

Six counters out of ten are 0.

(Whang 1990)

Other Sketches

- K-ary Sketch for heavy changes
- Bloom Filter Sketch to check set membership
- PCSA sketch to count distinct values

(Schweller 2004; Goel 2010; Flajolet 1985)

Efficient implementation of 3_stage pipeline

hash
in parallel

TCAM rules

cheap fast memory
MBs of SRAM

Similar functions, diverse configurations

Hash	Classify	Count
?? hash functions	?? TCAM entries for classify rules	?? MBs of SRAM for tables of counters

Similar functions, diverse configurations

4-8 simple hash functions per question

- Count Min: 3
- Bloom Filters: 7-8
- Fixed size reversible sketch: 5
- Can share hash functions

Similar functions, diverse configurations

30-40 TCAM entries per question maximum

- Match a prefix/ value: 1 rule

- Match a set of values: Bloom Filters

Similar functions, diverse configurations

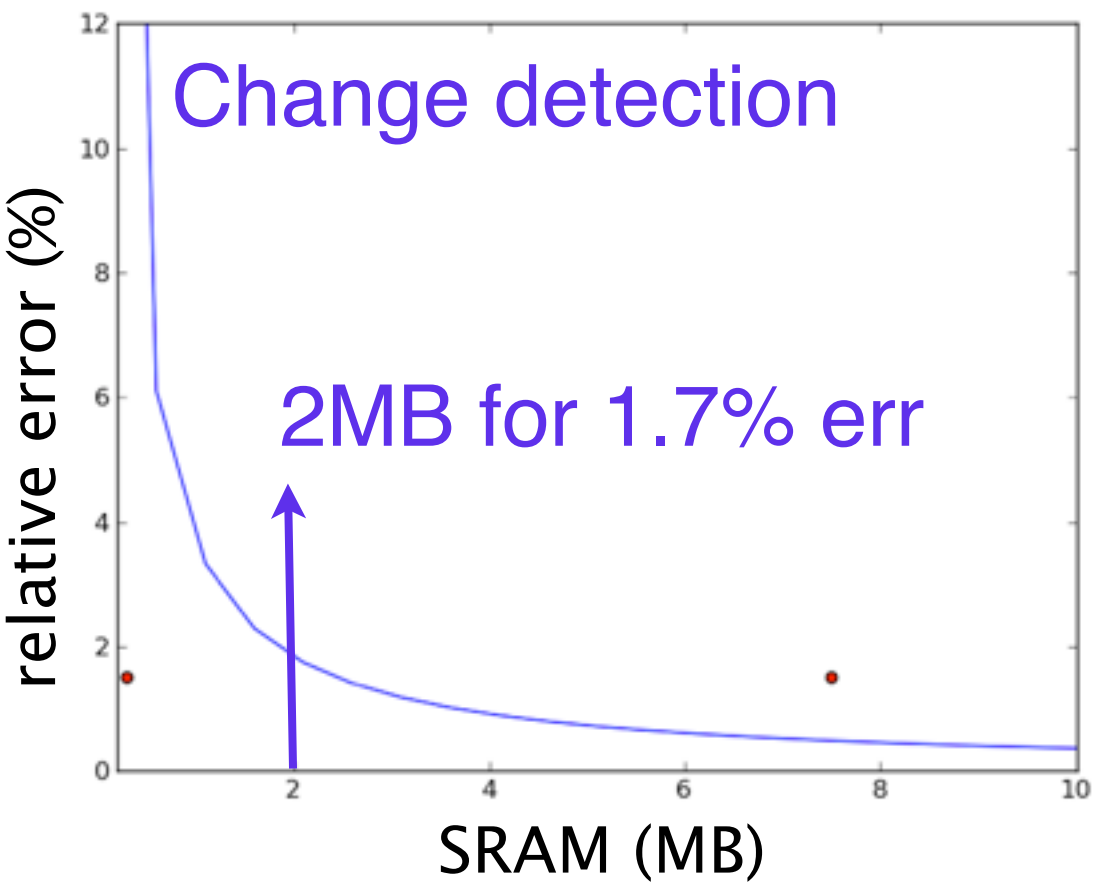
up to 8MB SRAM

From simulation and worst case bounds for different tasks

Similar functions, diverse configurations

Count

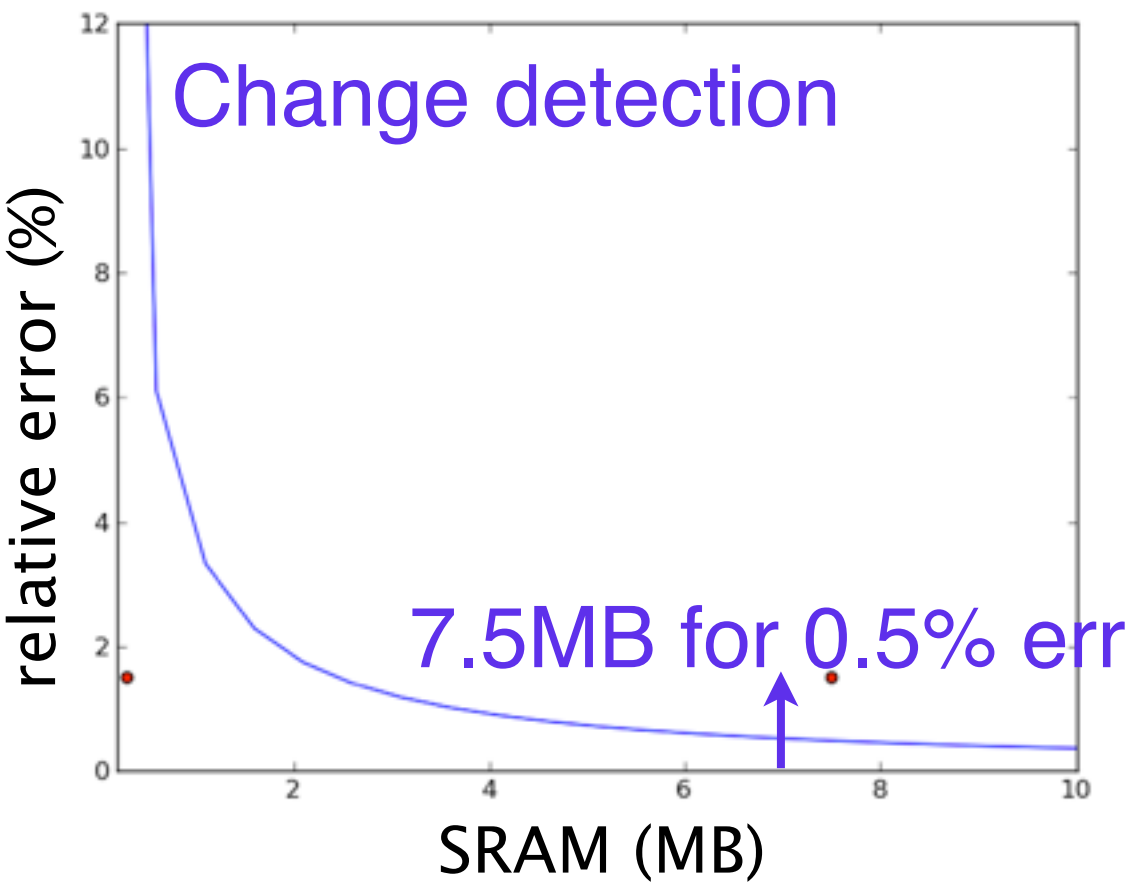
up to 8MB SRAM



Similar functions, diverse configurations

Count

up to 8MB SRAM



Measurement tasks

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5. Who's getting traffic from blacklisted IPs?
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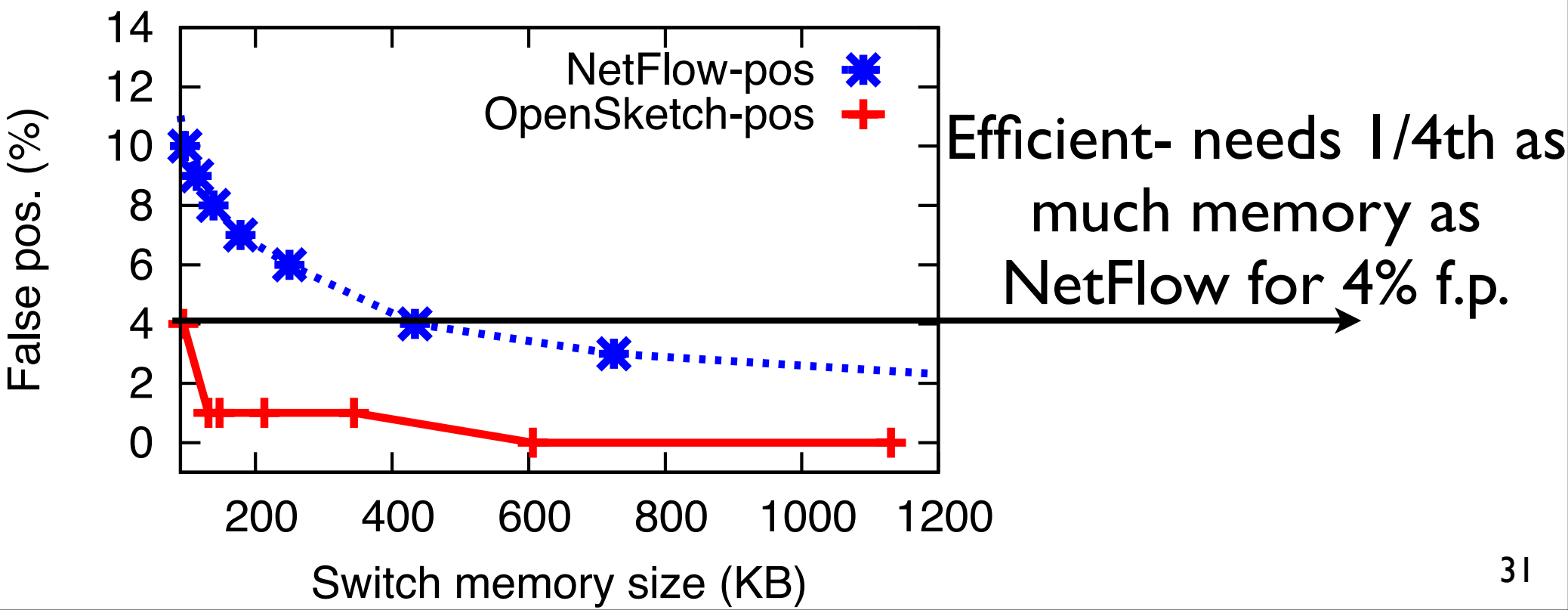
(Heavy Hitters: Cormode 2005; Flow Size Distribution: Kumar 2004;
Change detection: Schweller 2004; DDoS detection: Venkataraman 2005)

More efficient than NetFlow

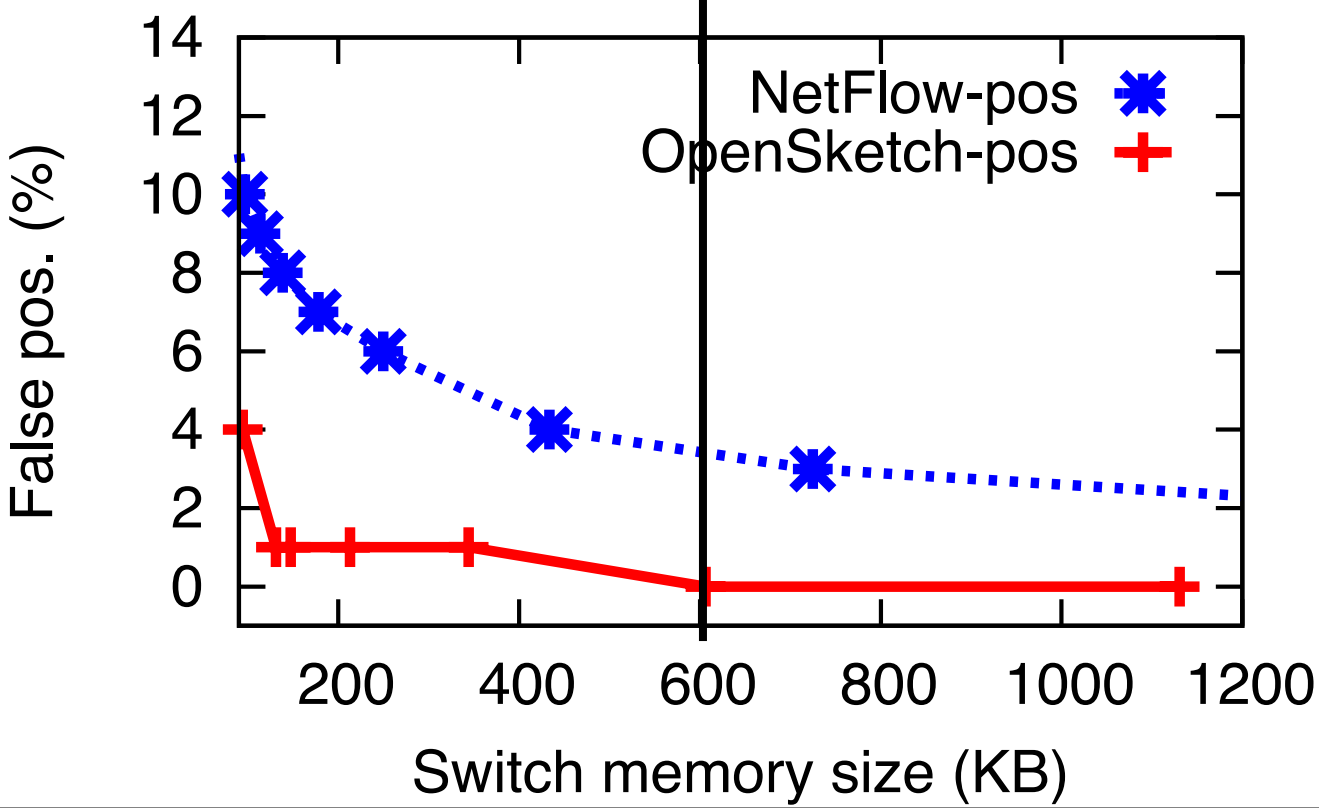
(Heavy Hitters)



More efficient than NetFlow

(Heavy Hitters)

Accurate- with 600KB, OpenSketch has less than 0.05% f.p. NetFlow has around 3%



OpenSketch NetFPGA Prototype

- 3-stage meas. pipeline parallel to forwarding
- Full throughput 1Gbps @ 4 ports
- Measurement pipeline takes fewer cycles than forwarding

Conclusion

- Current switches good for flow statistics
- But they don't answer basic measurement questions
- Like identify heavy hitters, detect DDoS attacks, port scans, traffic from blacklisted IP address etc.

Takeaway

- Hash, classify and count pipeline in the Data Plane
- And sketch based building blocks in the Control Plane
- Make measurement in switches efficient and easy