Heavy-Hitter Detection Entirely in the Data Plane

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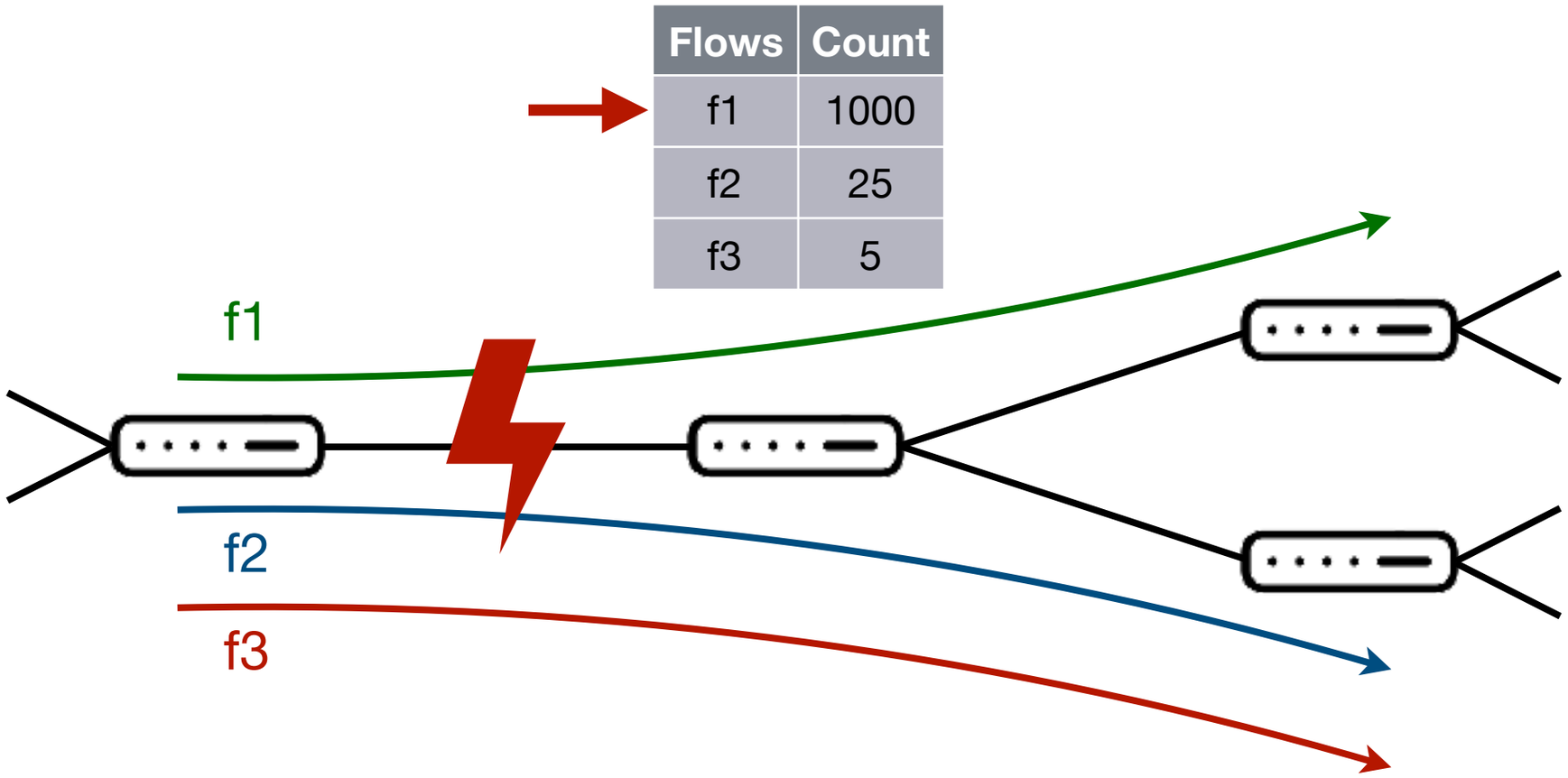
Heavy Hitters



- Trouble shooting (Anomaly detection, DoS detection)
- Traffic engineering (Flow-size aware routing, Dynamic routing)

Heavy Hitters - Definition

- Flows larger than a fraction *t* of the total packets seen on a link

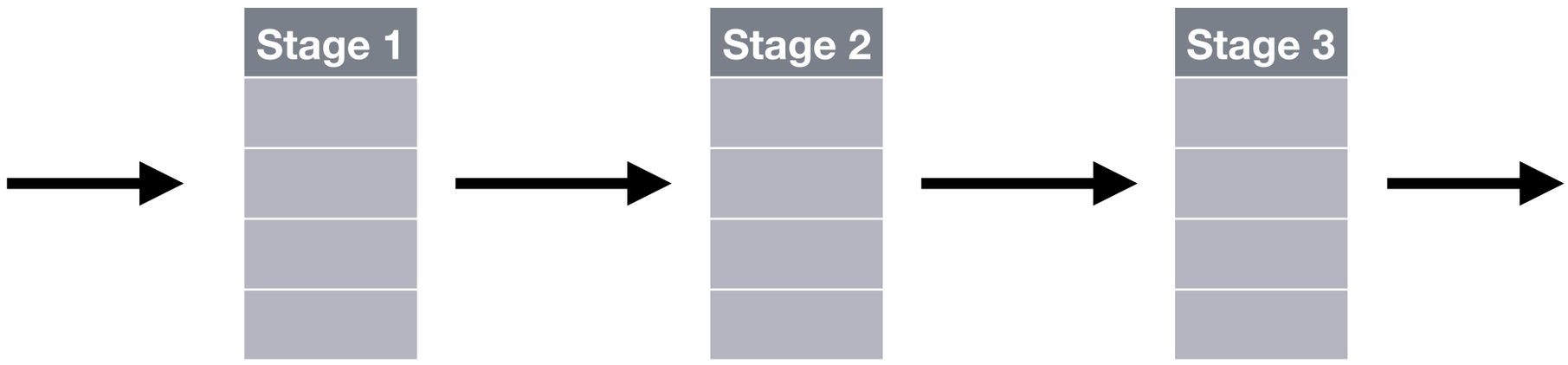
“threshold-*t*” problem

- Top *k* flows by size seen on a link

“top-*k*” problem

Why in the Data Plane?

- Programmable switches with stateful memory
- Basic arithmetic operations on state
- Pipelined operations over multiple states



Challenges

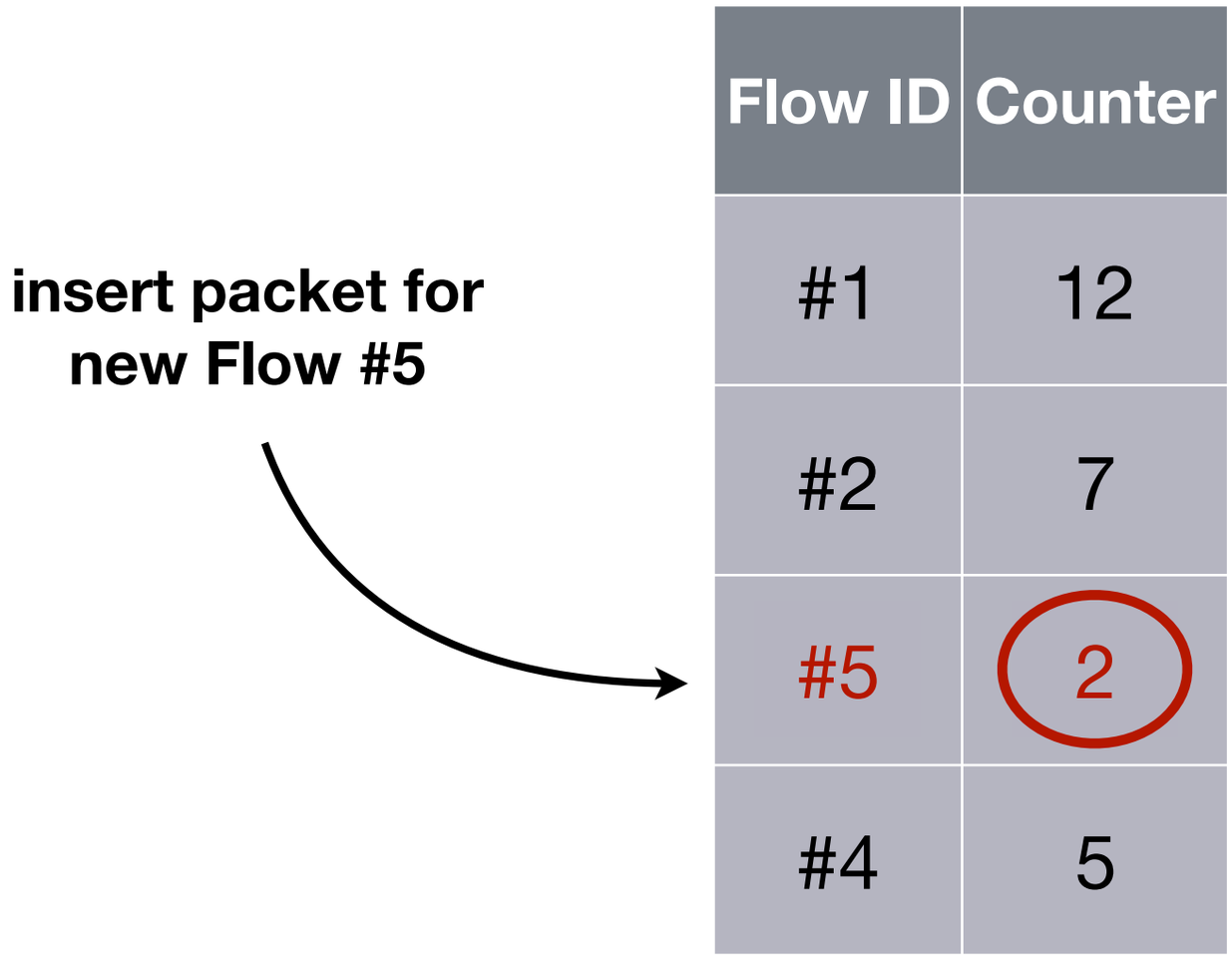
- Processing restricted to data plane
- Limited memory in switching hardware
- Small time budget for processing
- High accuracy of detection
- Line-rate processing

Context

	Sampling-based	Sketching-based	Counting-based
	record a subset of packets by sampling	hash packet & increment counter at hashed location	maintain table of flows and corresponding counts
+	Small memory to track heavy flows	Statistics for all flows in single data structure	Summary structure with heavy flow IDs and counters
−	Underestimates counts for heavy flows	No flow identifier to count association	Occasional updates to multiple counters
	NetFlow NetQRE	SketchVisor	Trumpet PathDump Space-Saving

Space-saving algorithm

- Goal: track the *k* heaviest items using only O(*k*) counters



Space-saving algorithm

- *O(k)* space to store heavy flows
- Provable guarantees on accuracy
- Evict the minimum to insert new flow
- Multiple reads, but exactly one write per packet

Towards HashPipe

- Idea #1: prevent entire table scan by sampling a constant *d* number of values

- Approximate minimum

- Multiple read-modify-write operations in parallel

  Not supported in hardware!

Towards HashPipe

- Idea #2: reduce number of reads to memory by splitting the counter table into *d* disjoint tables
  - Read exactly one slot per table
  - Pipeline memory access
  - Requires multiple passes: find minimum, update counter
  - Possible through recirculation of packet
    needed for every packet? halves bandwidth!

Towards HashPipe

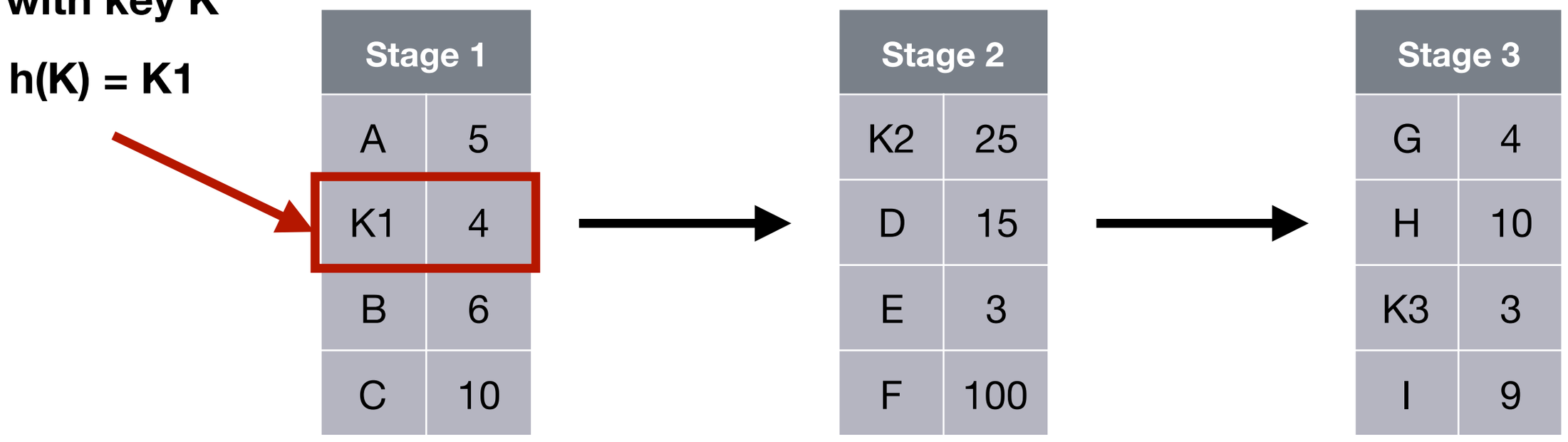
- Idea #3: Feed-forward packet processing and track rolling minimum
  - Track minimum counter value as packet *metadata*
  - Switch hashes into each stage on the *carried key*
  - Always insert in the first stage, evict existing entry into packet metadata

    Duplicate keys!

HashPipe - Example

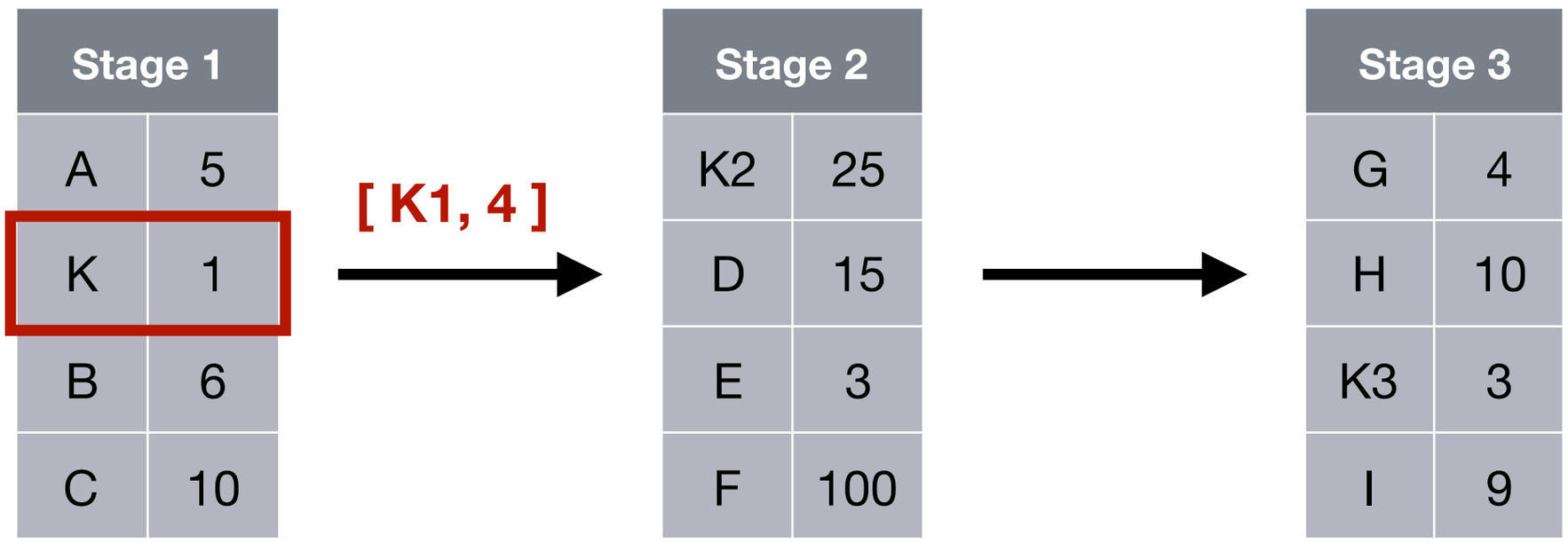
new flow with key K

h(K) = K1



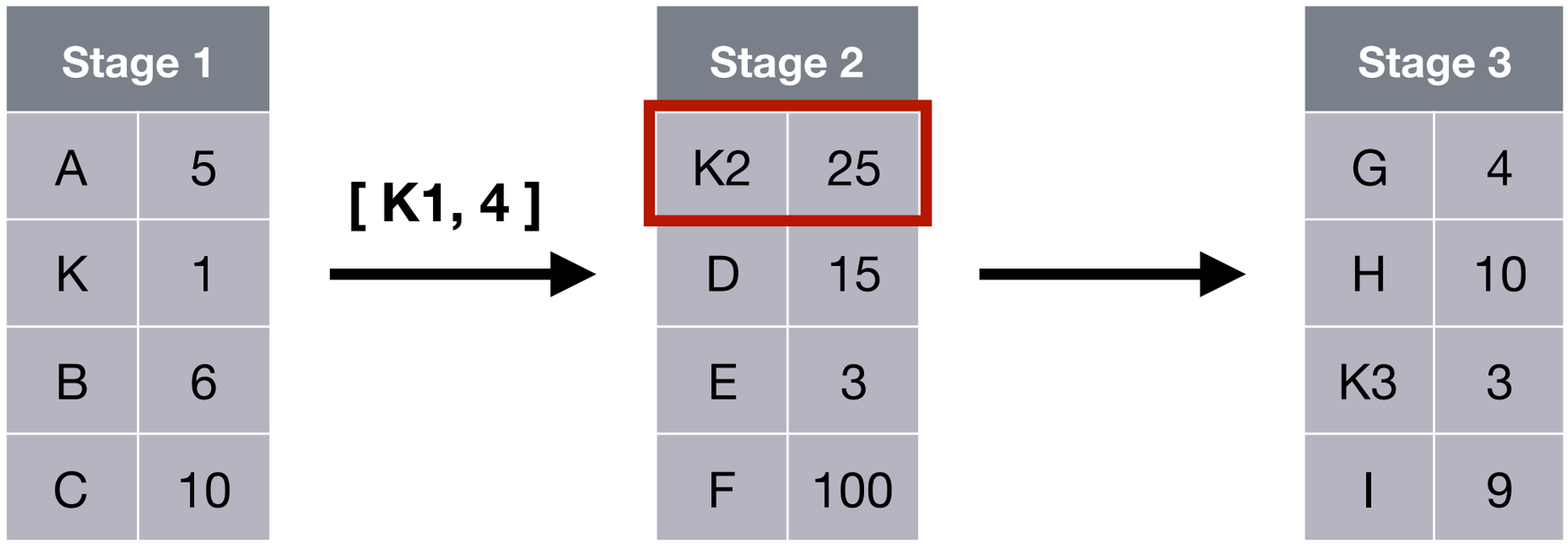
always insert into first stage!

HashPipe - Example



HashPipe - Example

h(K1) = K2
Max(K1, K2) -> K2



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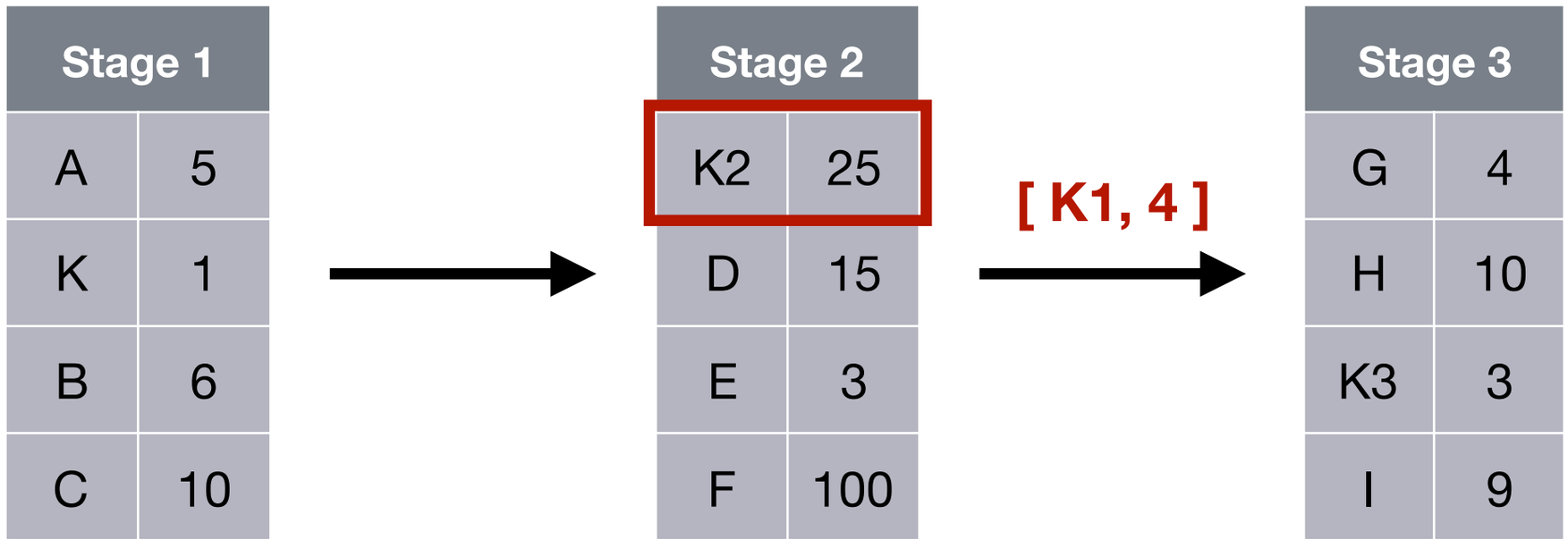

HashPipe - Example

h(K1) = K3
Max(K1, K3) -> K1

Stage 1	
A	5
K	1
B	6
C	10

→

Stage 2	
K2	25
D	15
E	3
F	100

[K1, 4] →

Stage 3	
G	4
H	10
K3	3
I	9

HashPipe - Example

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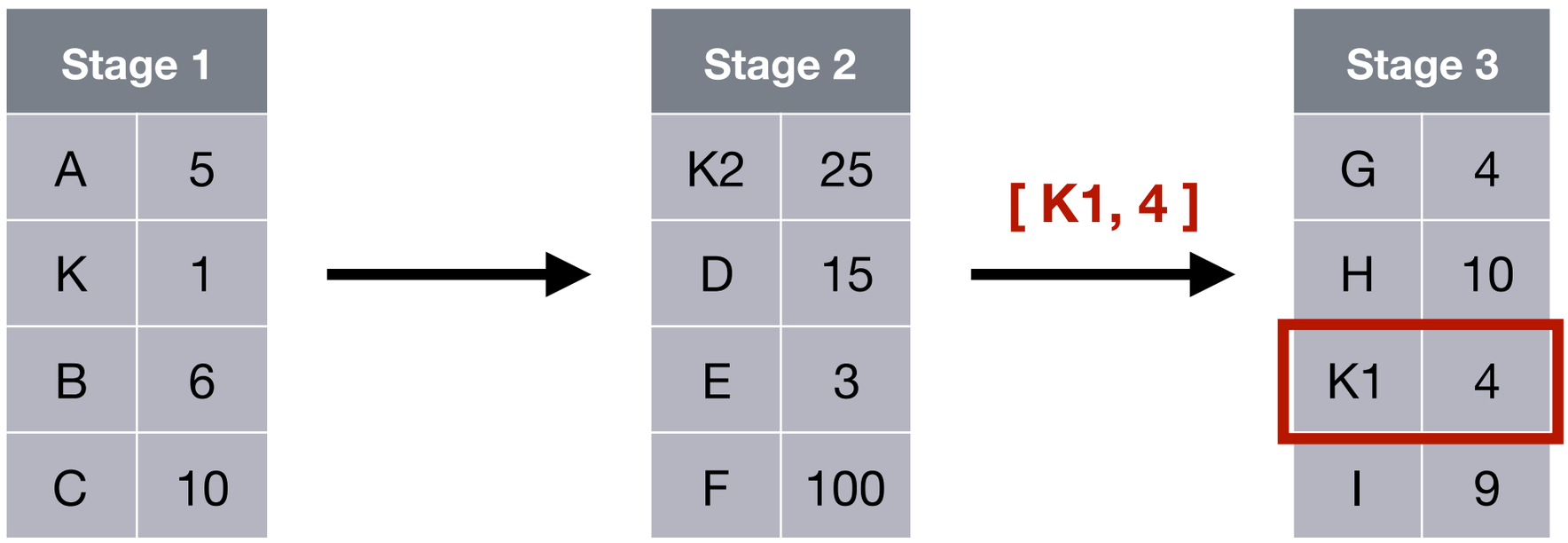
Max(K1, K3) -> K1



Evaluation

- Prototype implementation in P4
- Top-k flows on:
    1. CAIDA traffic traces with 500M packets
    2. Data center trace with 100M packets

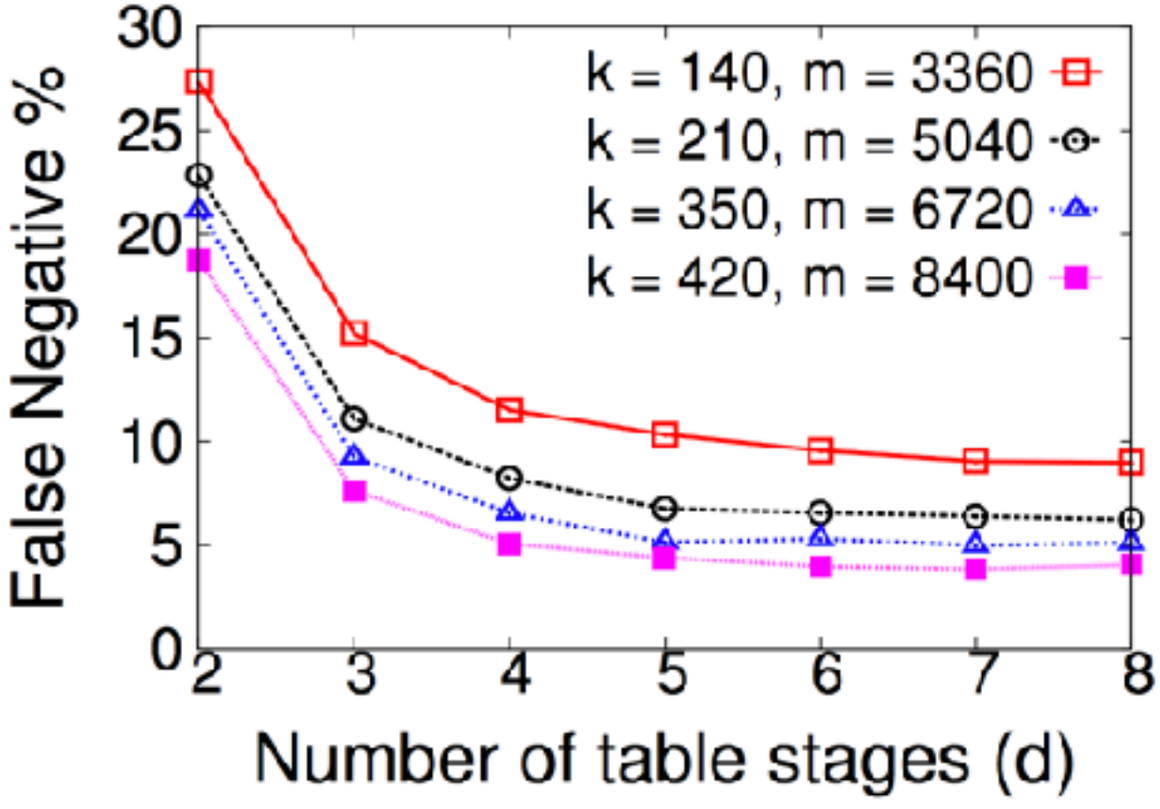
Metrics

- False Positives (FP):
  reporting a non-heavy flow as heavy

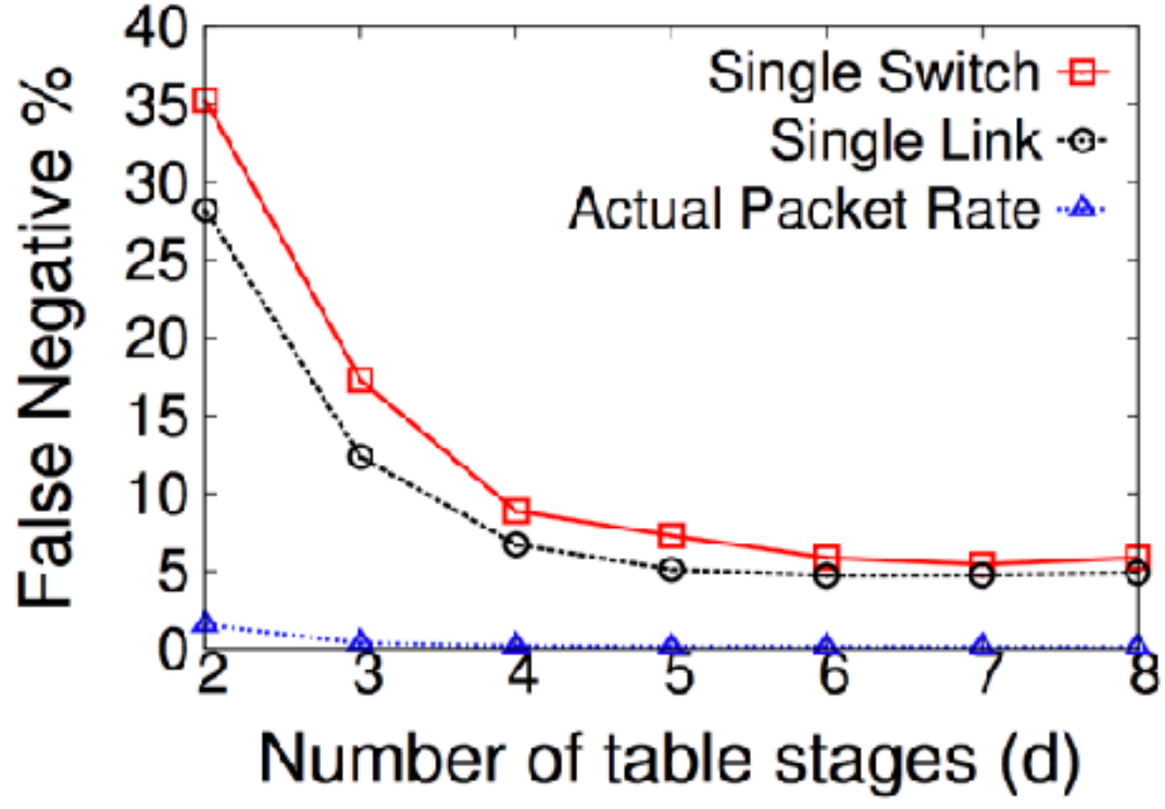
- False Negatives (FN):
  not reporting a heavy flow

- Count Estimation Error (CEE):
  deviation of flow count in data structure vs. actual flow count

How to choose *d*?



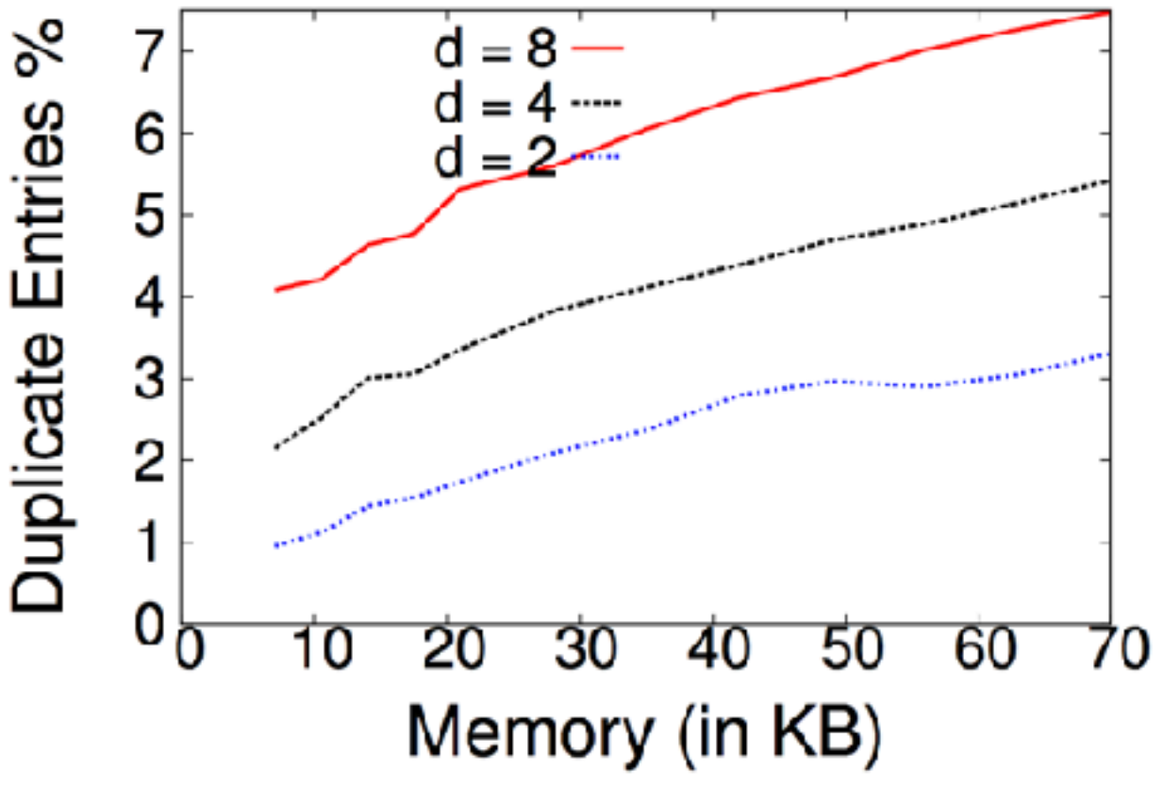
a) Backbone



b) DCN

d=6?

Duplicate Keys



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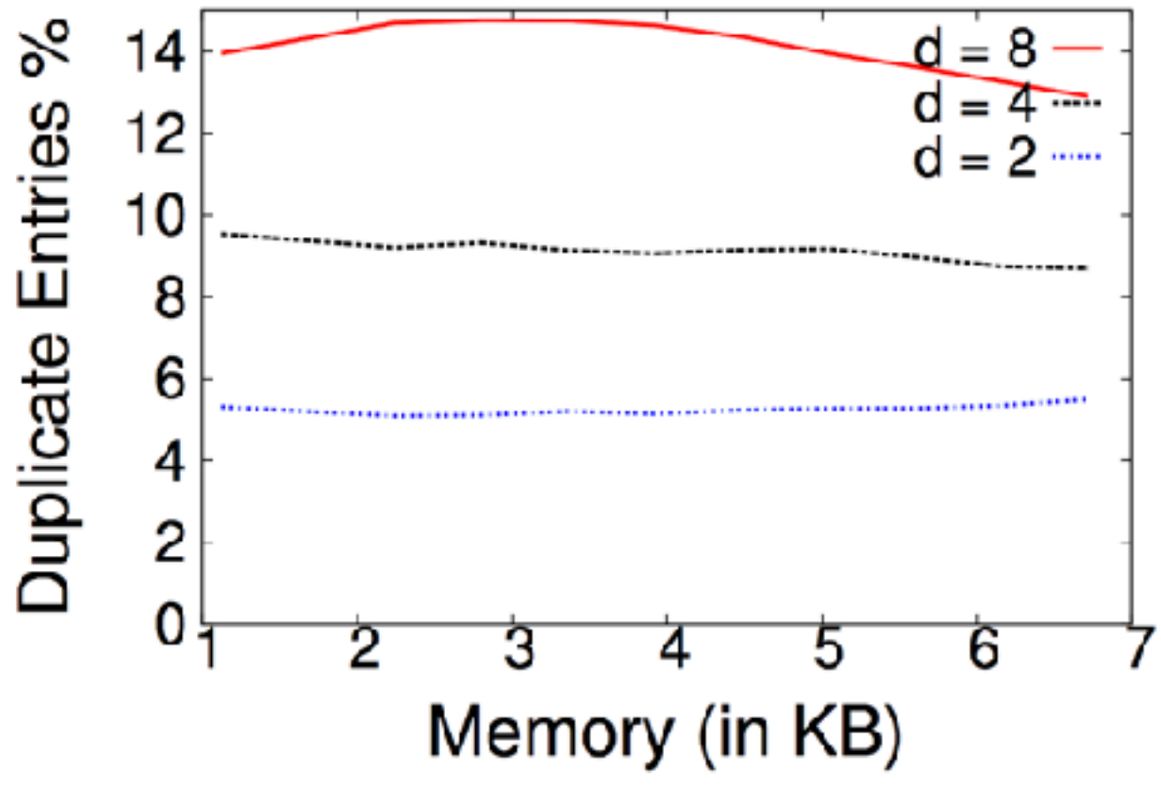


b) DCN

Comments

- Iterative approach to present solution
- Considers underlying hardware architecture for solution
- No modelling / mathematical reasoning about system properties
  (e.g., probability of hash collisions / upper bound on duplicates)
- Solution targets single problem: could it be extended to solve other problems?

Questions / Comments ?

Backup Slides

Space-saving algorithm

Algorithm 1: Space Saving algorithm [28]

```
1  ▷ Table T has m slots, either containing (key_j, val_j)
     at slot j ∈ {1, ..., m}, or empty. Incoming packet
     has key iKey.
2  if ∃ slot j in T with iKey = key_j then
3  |   val_j ← val_j + 1
4  else
5  |   if ∃ empty slot j in T then
6  |   |   (key_j, val_j) ← (iKey, 1)
7  |   else
8  |   |   r ← argmin_{j∈{1,...,m}}(val_j)
9  |   |   (key_r, val_r) ← (iKey, val_r + 1)
10 |   end
11 end
```

if key exists
-> increment counter

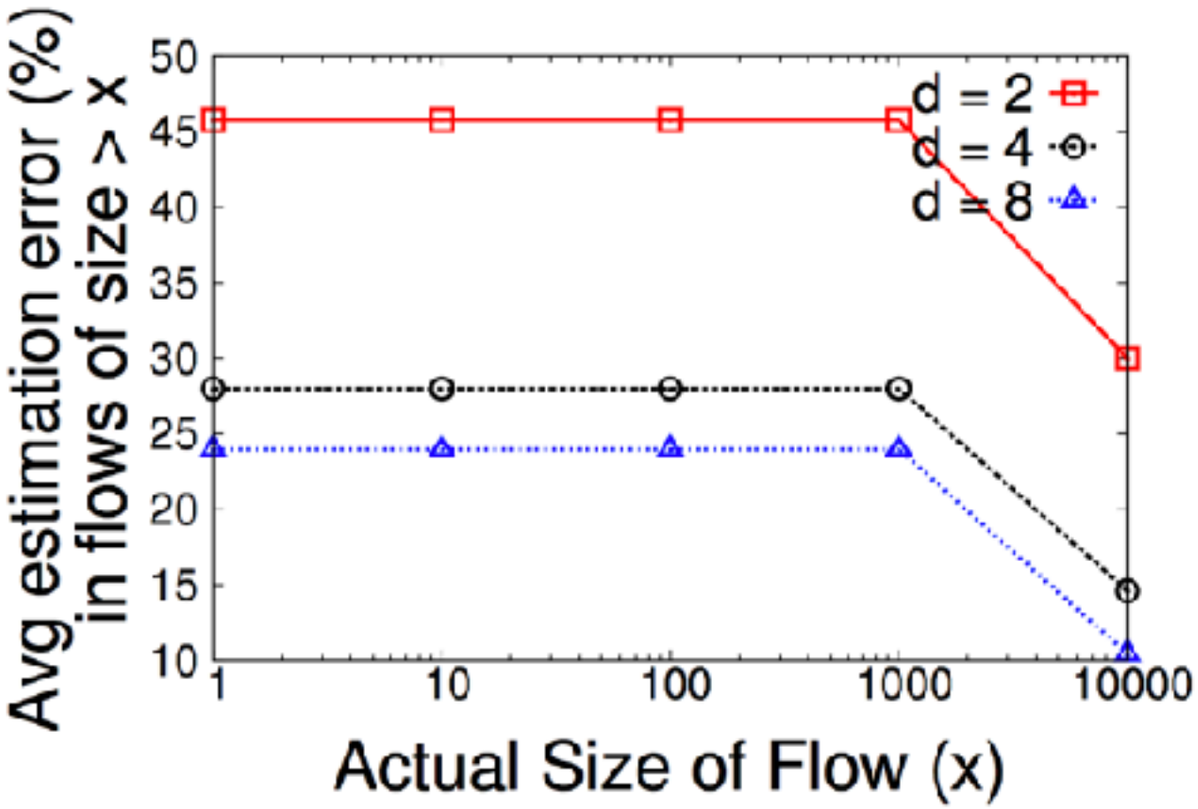
if there exists an empty slot
-> insert key with value 1

find smallest counter
-> increment old value
and store with new key

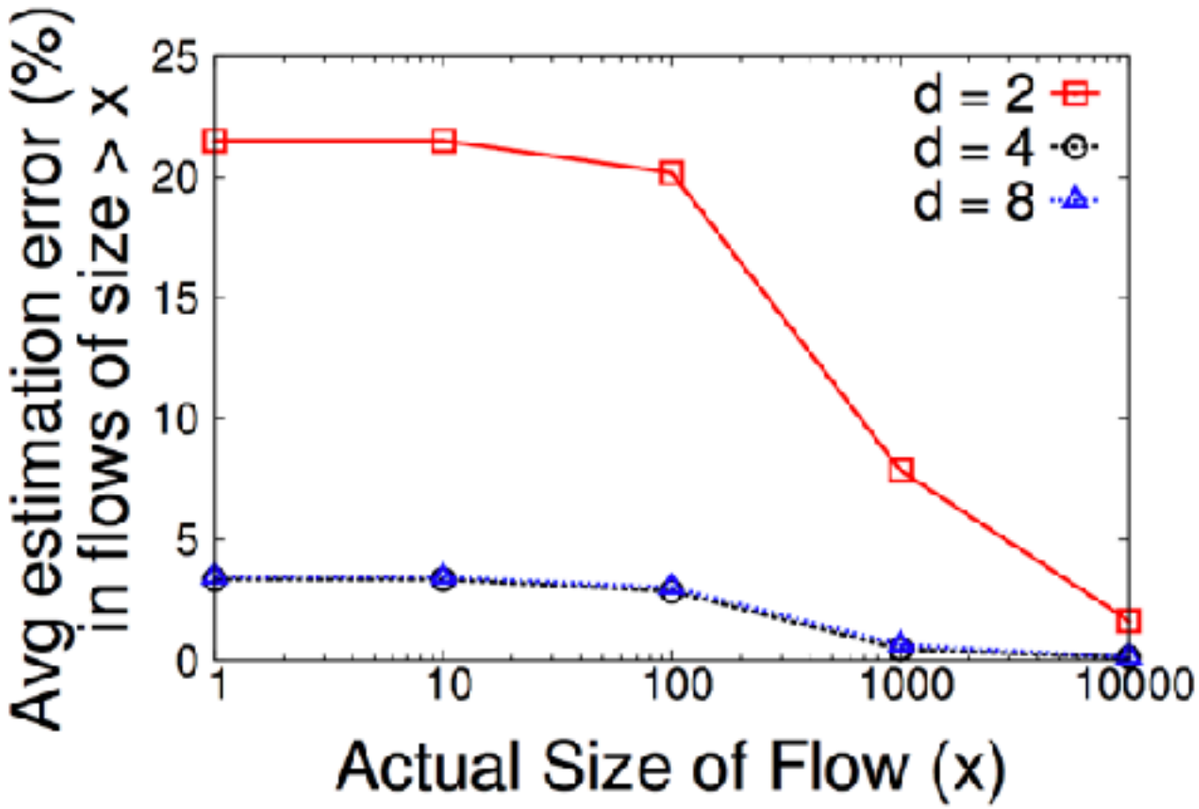
Accuracy Properties

- No flow counter is underestimated
- Minimum value is an upper bound on the overestimation error of any counter
- Any flow with true count higher than the average table count is always present in table

Average Estimation Error

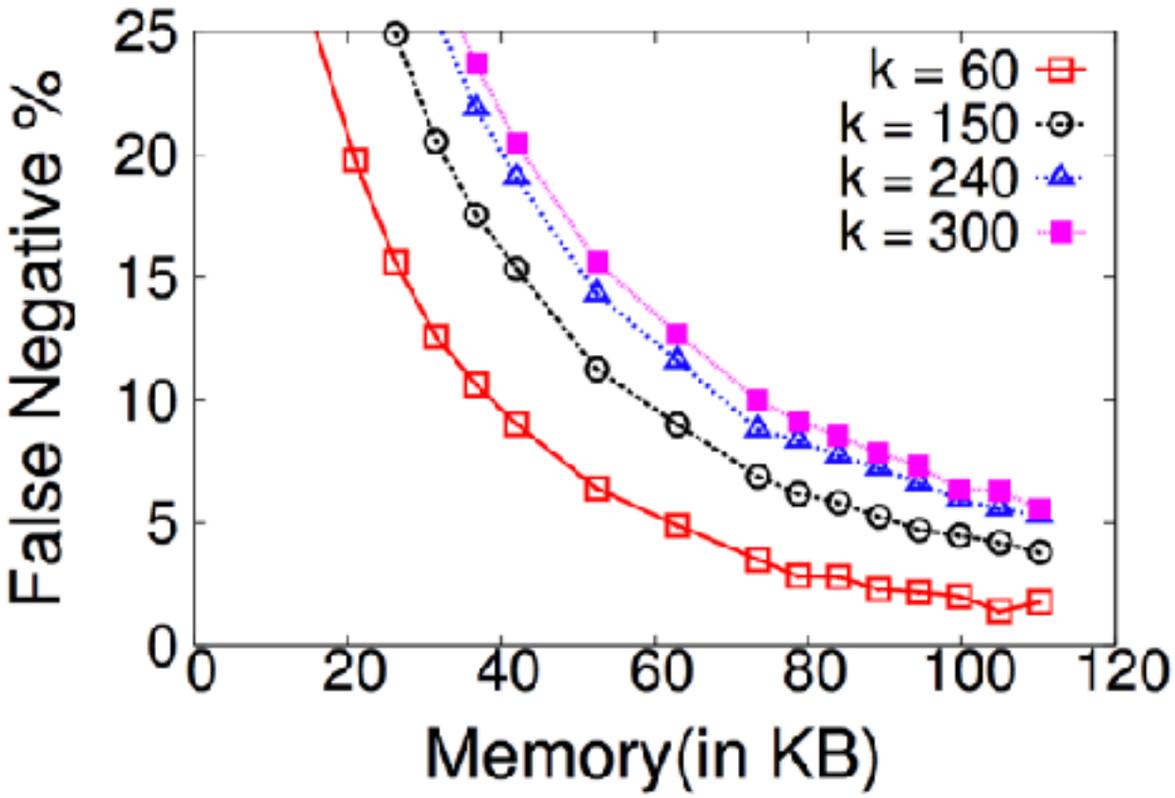


(a) ISP backbone



(b) Data center (link)

FN vs. Memory



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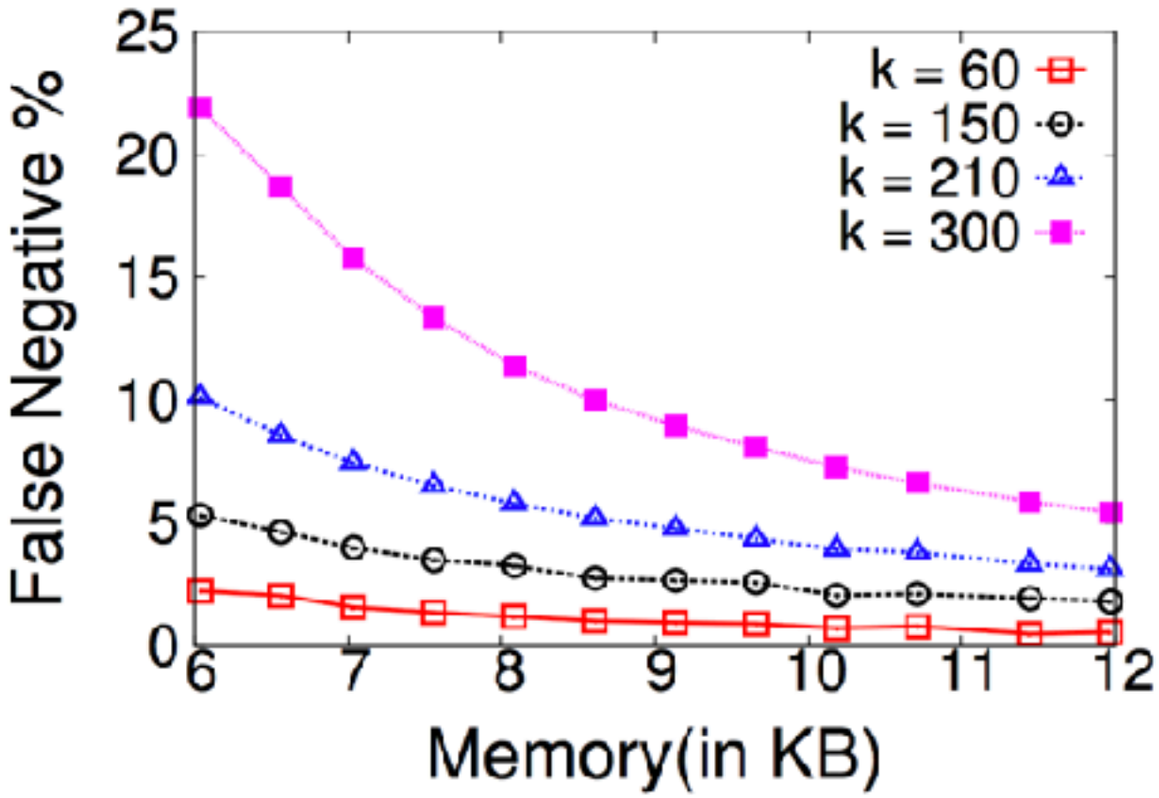
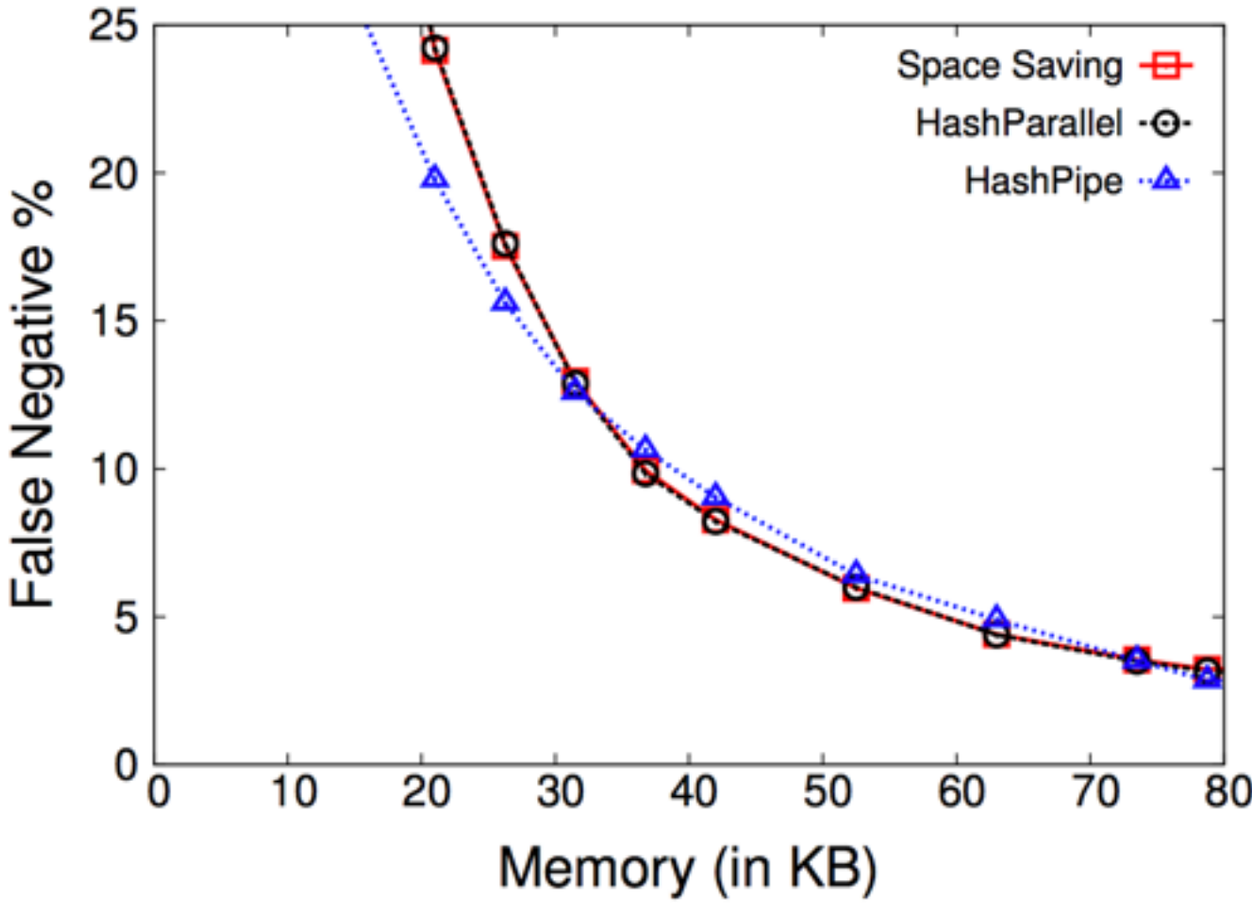
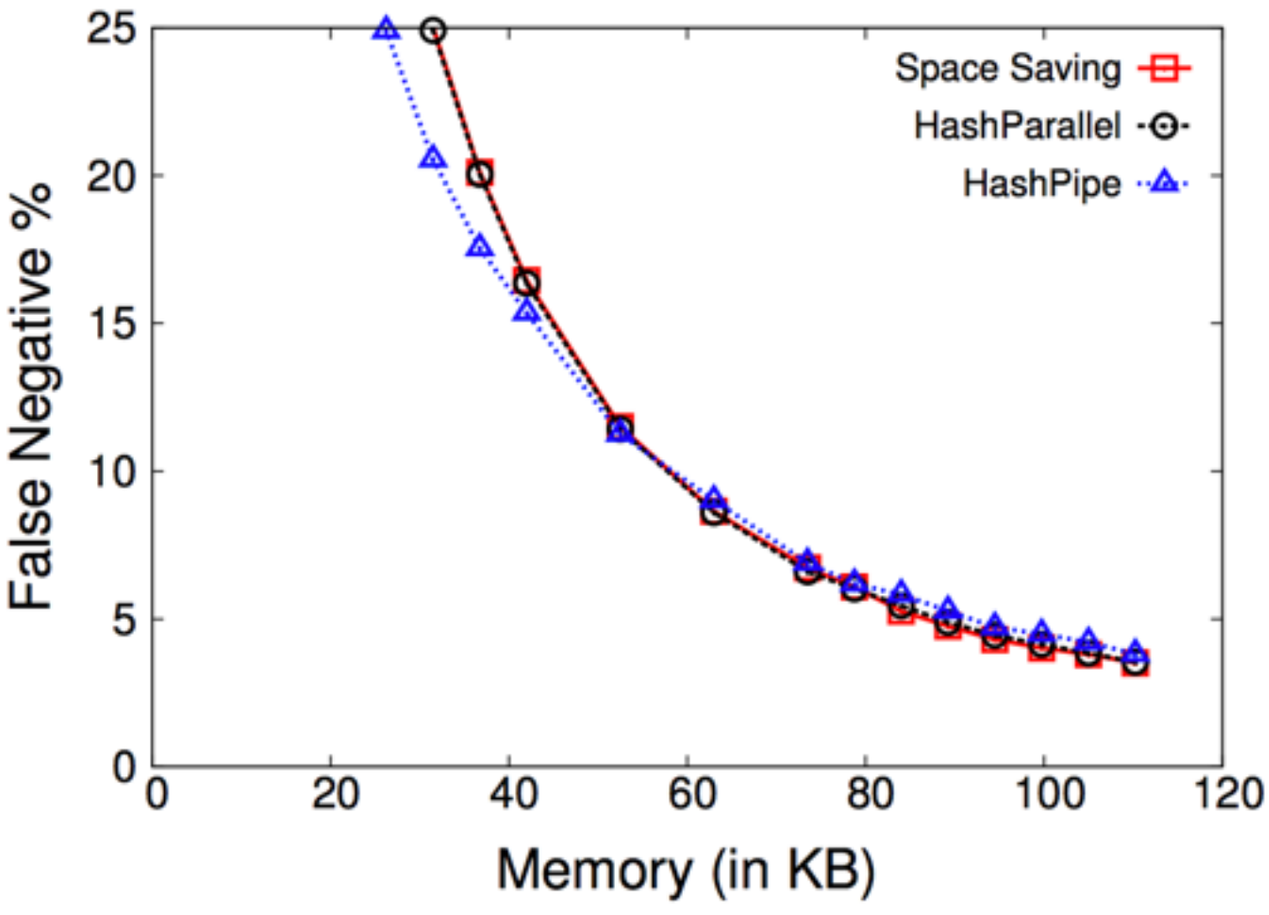


(b) Data center

HashPipe vs. Related Work



k = 60



k = 150