Carousel --- Scalable and (nearly) complete collection of Information

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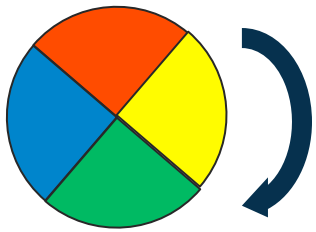
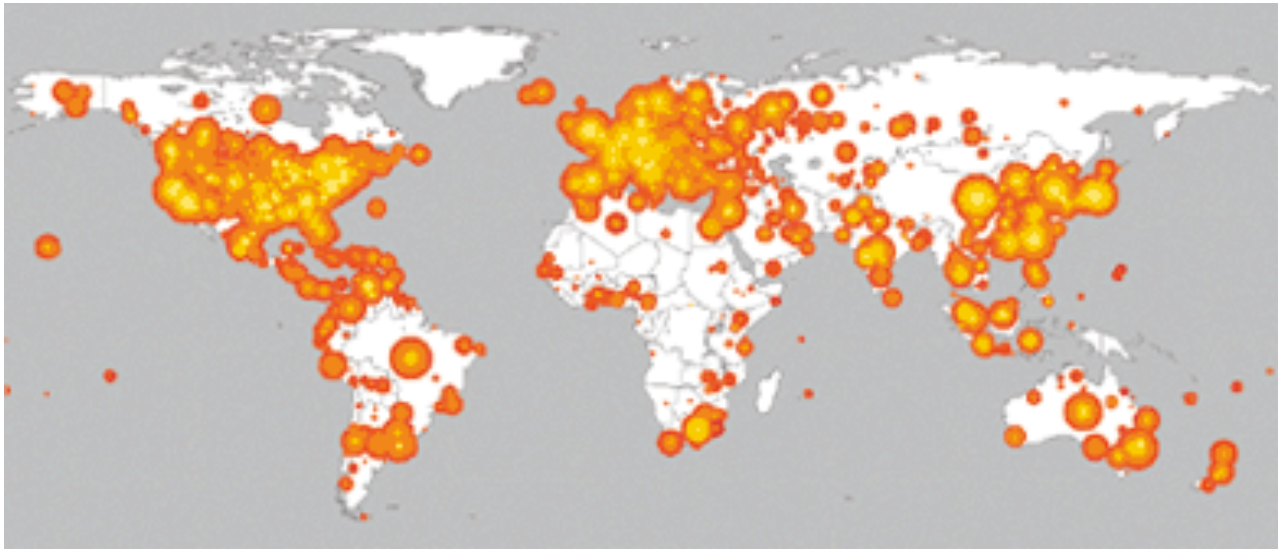


Data deluge in Networks

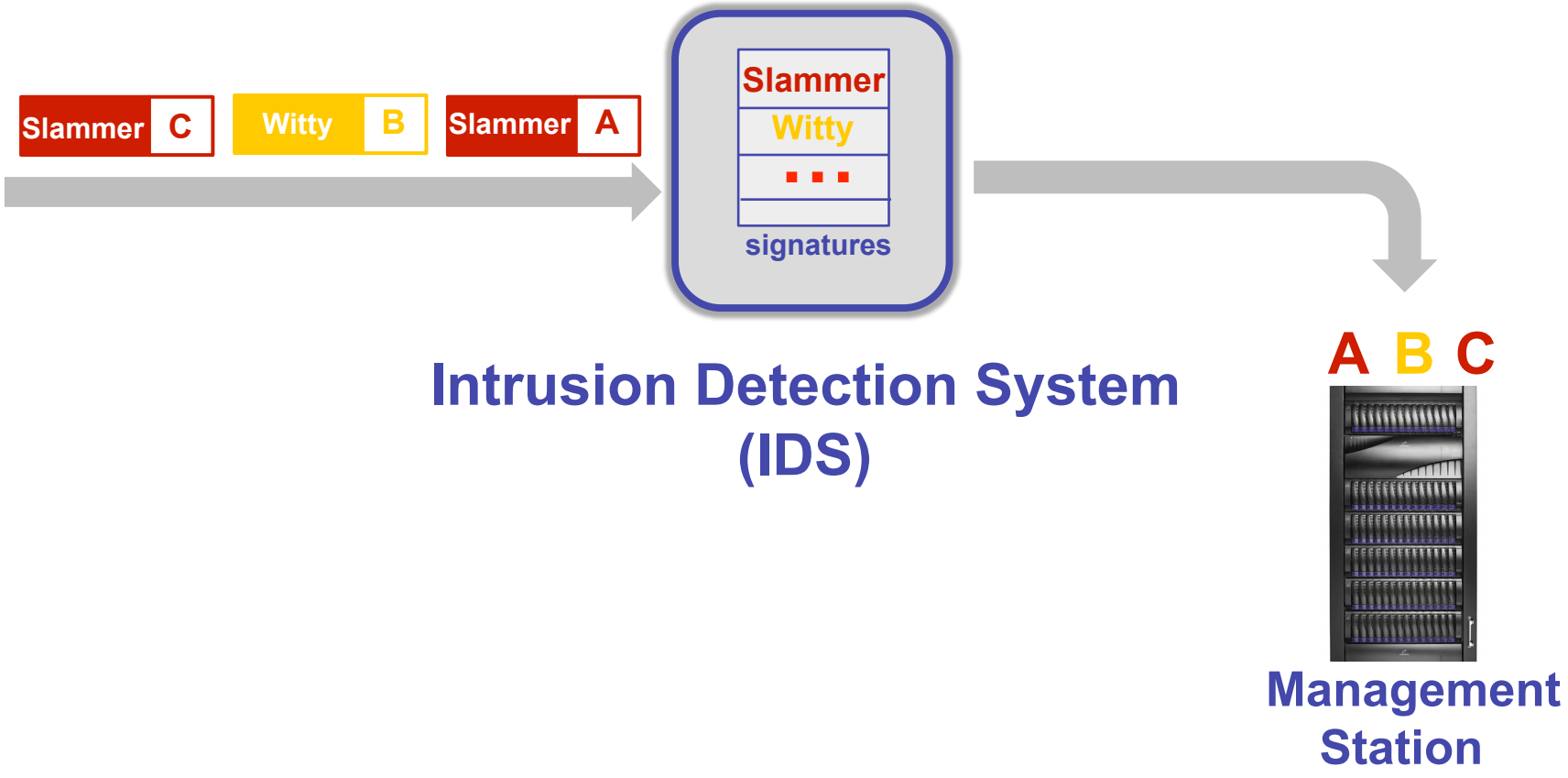
- Millions of potentially *interesting* events
- How to get a coherent view despite bandwidth and memory limits?
- Standard solutions: sampling and summarizing

What if you want complete collection?

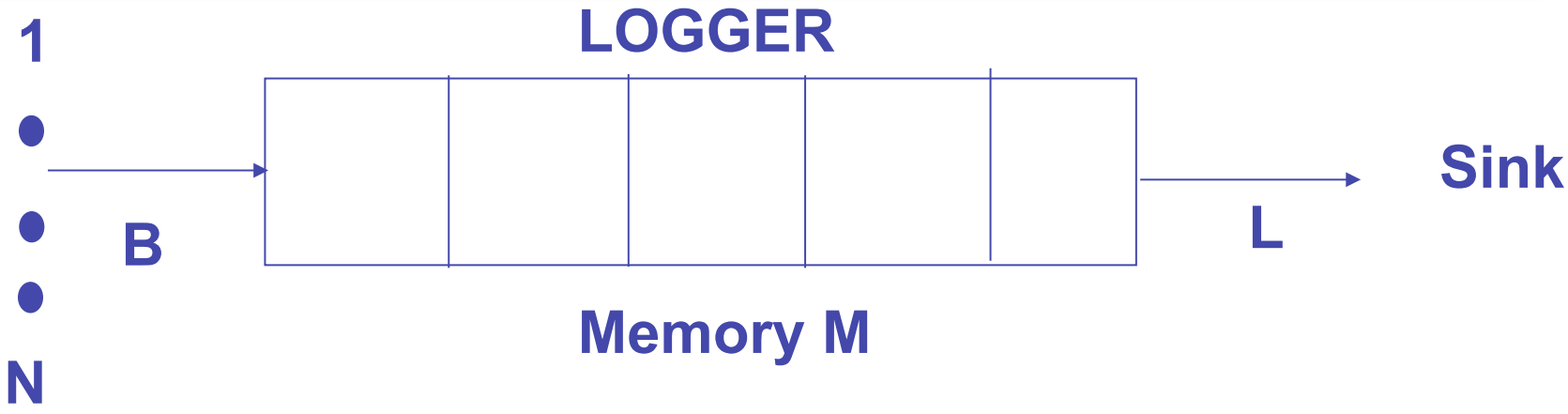


- Need to collect infected stations for remediation
- Other examples of complete collection:
  - List all IPv6 stations
  - List all MAC addresses in a LAN

Example: worm outbreak



Abstract model



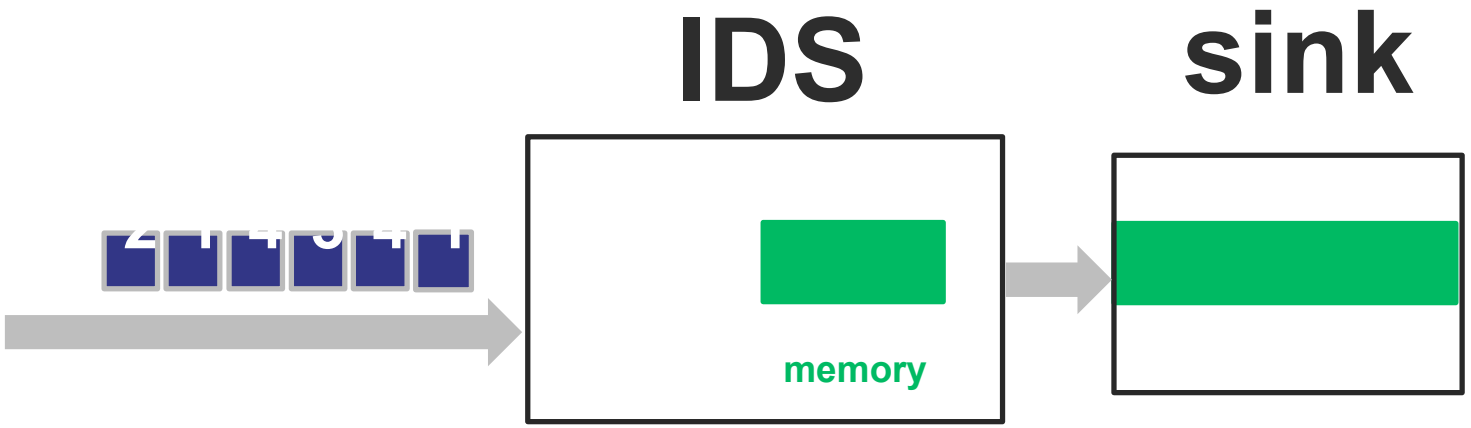
- **Challenges:**
  - *Small* logging bandwidth: L < < arrival rate B
    e.g., L = 1 Mbps; B = 10 Gbps
  - *Small* memory: M < < number of sources N
    - e.g., M = 10,000; N=1 Million
- **Opportunity:**
  - *Persistent sources*: sources will keep arriving at the logger

Our results

- **Carousel**: new scheme, with minimal memory can log *almost all* sources in close to *optimal time (N/L)*

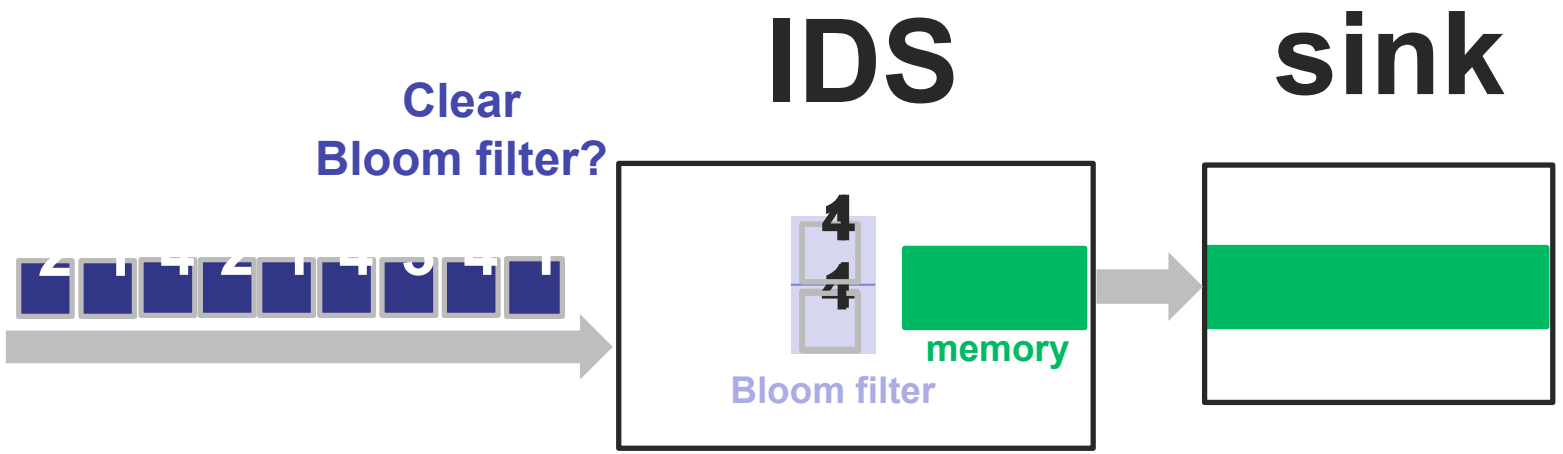
- Standard approach is *much worse*
  - **ln(N)** times worse in an optimistic random model
  - Adding a Bloom filter does not help
  - Infinitely worse in a deterministic adversarial model

Why the logging problem is hard



- Sources 2 and 3 are never collected if pattern repeats
- 1 is logged many times
- In worst case, N – M (many!) sources can be missed

Why the problem is still hard with a Bloom filter



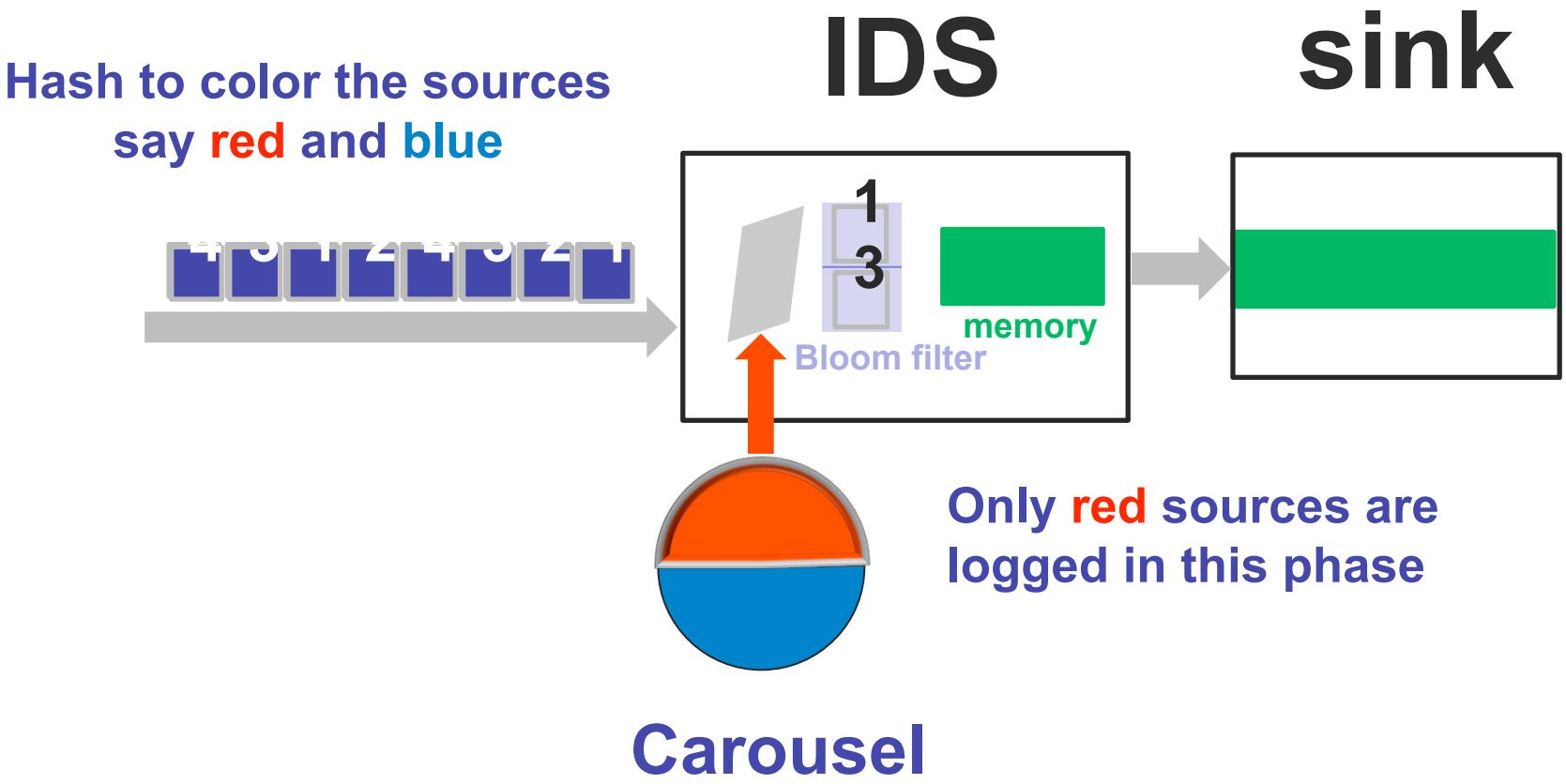
- Similar performance to a standard logger
  - Again, sources 2 and 3 are never collected because of timing

Bloom filter is necessarily small (M) compared to sources (N)

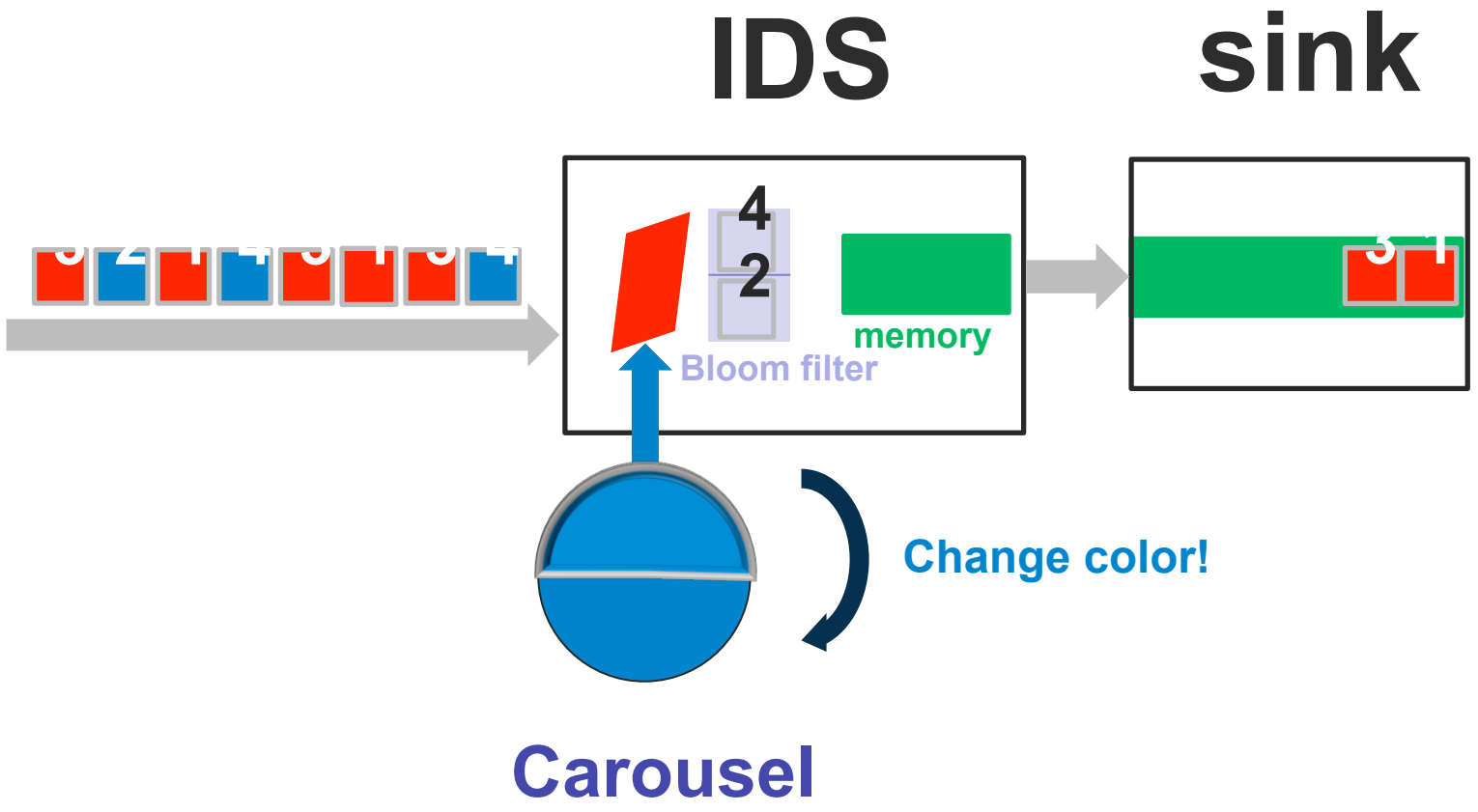
Congestion Control for Logging?

- When input traffic exceeds capacity, standard solution is admission control: but it requires source cooperation
- What can a poor resource do to protect itself unilaterally without cooperation from senders?
- Our approach: Randomized Admission Control.
  - Break sources into random groups and “admit” one group at a time for logging

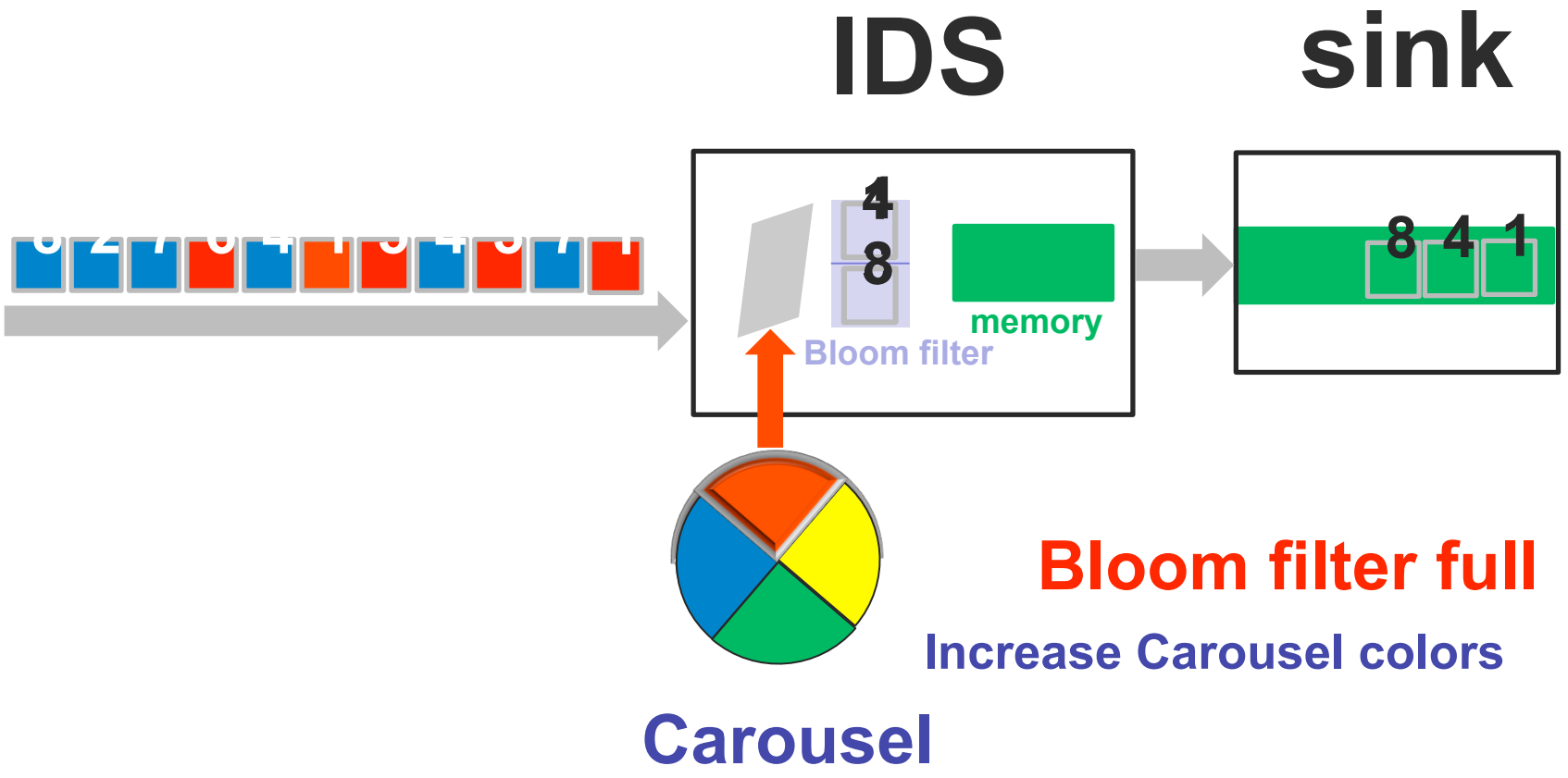
Our solution: Carousel



Rotating the Carousel



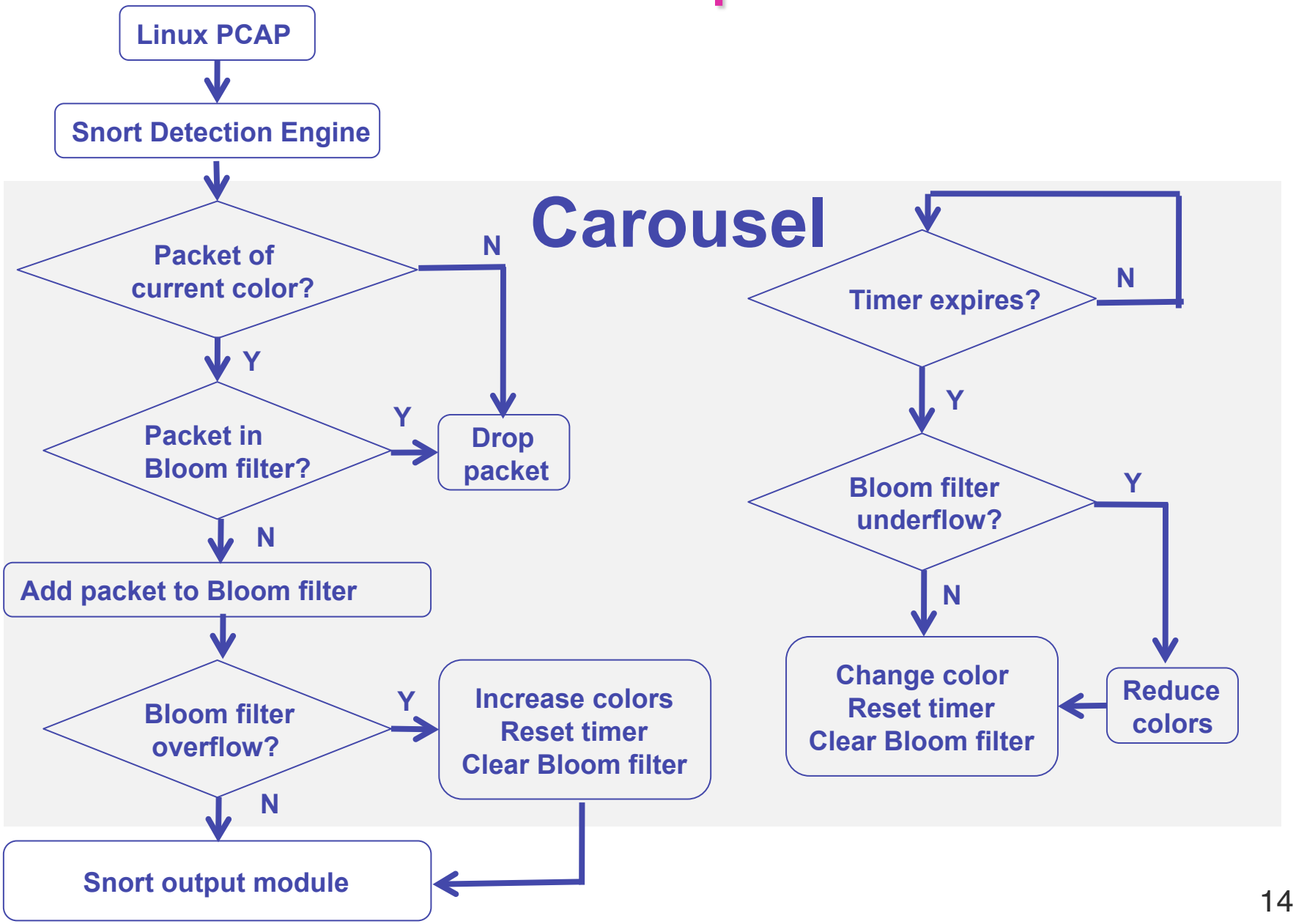
How many colors in Carousel?



Summary of Carousel algorithm

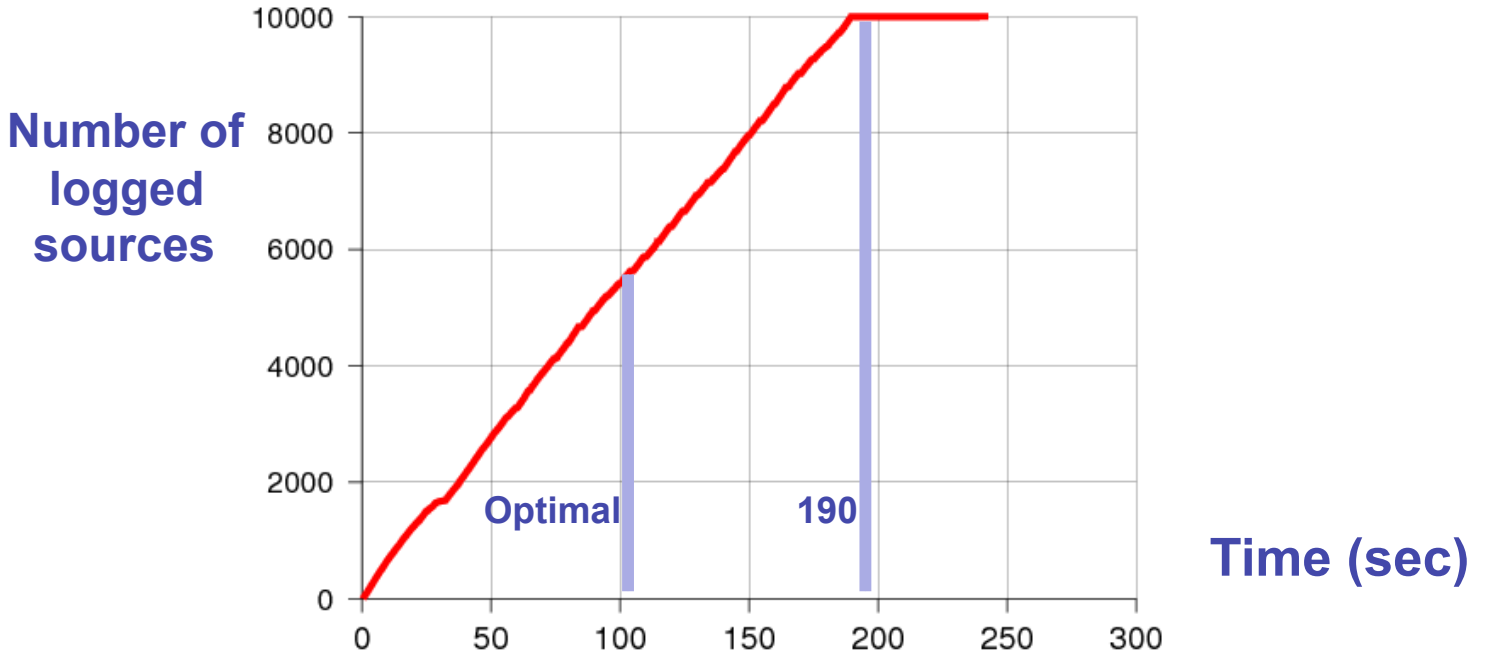
- Partition
  - $H_k(X)$: lower k bits of H(S), a hash function of a source S
  - Divide the population into partitions with same hash value
- Iterate
  - T = M / L (available memory divided by logging bandwidth)
  - Each phase last T seconds, corresponds a distinct hash value
  - Bloom filter weeds out duplicates within a phase
- Monitor (to find right partition size)
  - Increase **k** if Bloom filter is too full
  - Decrease **k** if Bloom filter is too empty

Snort implementation

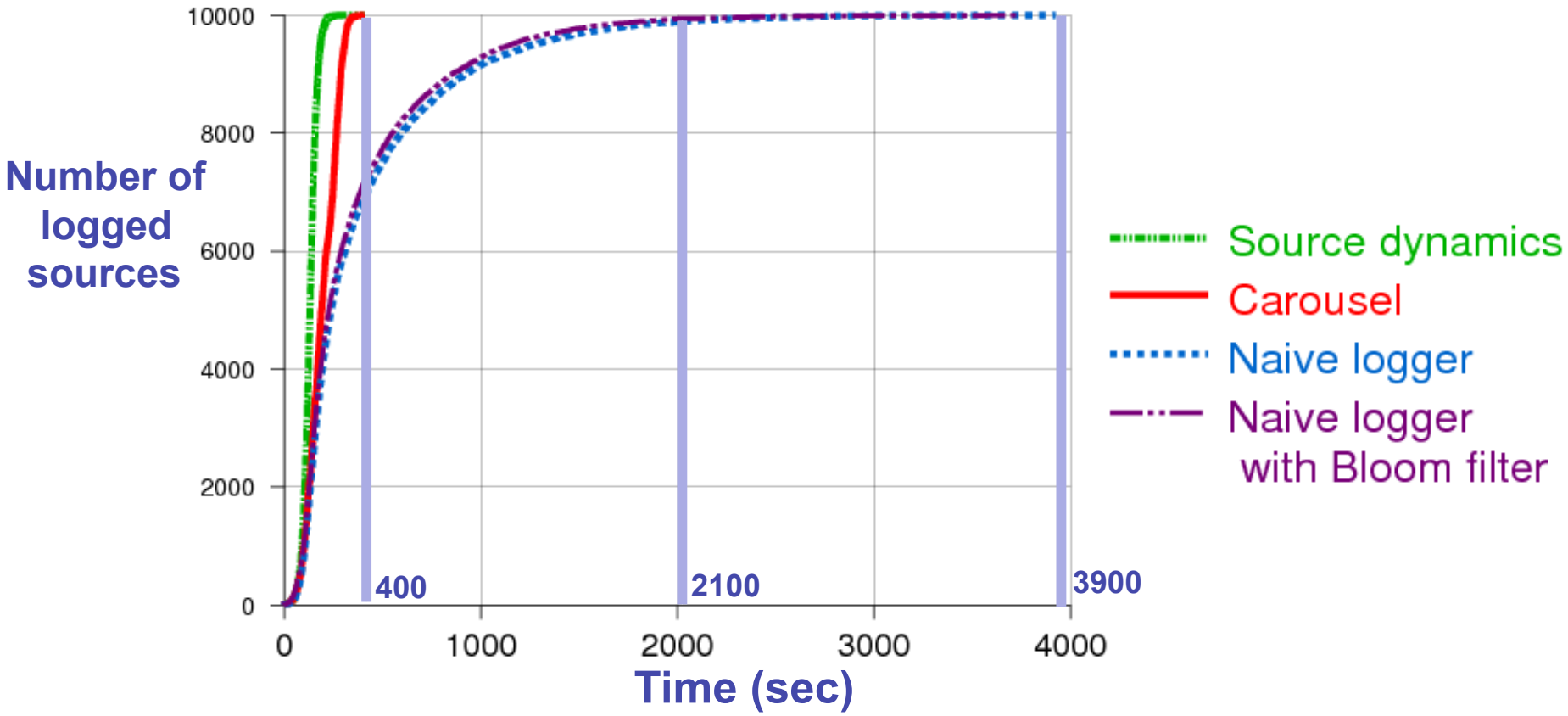


Theoretical results

- Carousel is “competitive” in that it can collect almost all sources within a factor of 2 from optimal time
  - N = sources, L = logging speed, optimal time = N/L
  - Collection time ≈ 2 N/L,
- Example: N = 10,000 M = 500, L = 100

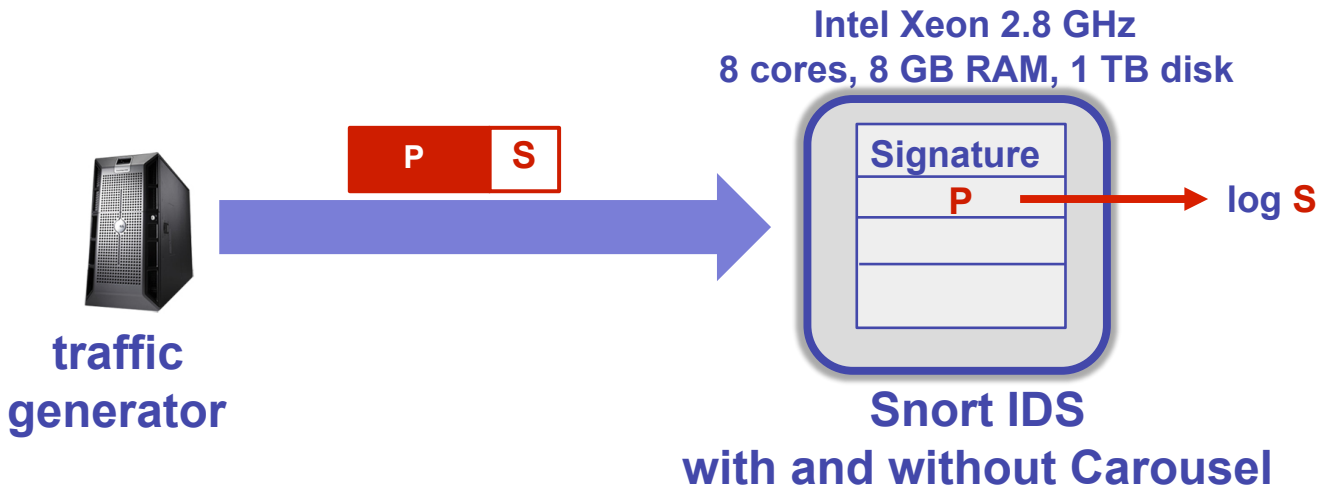


Simulated worm outbreaks



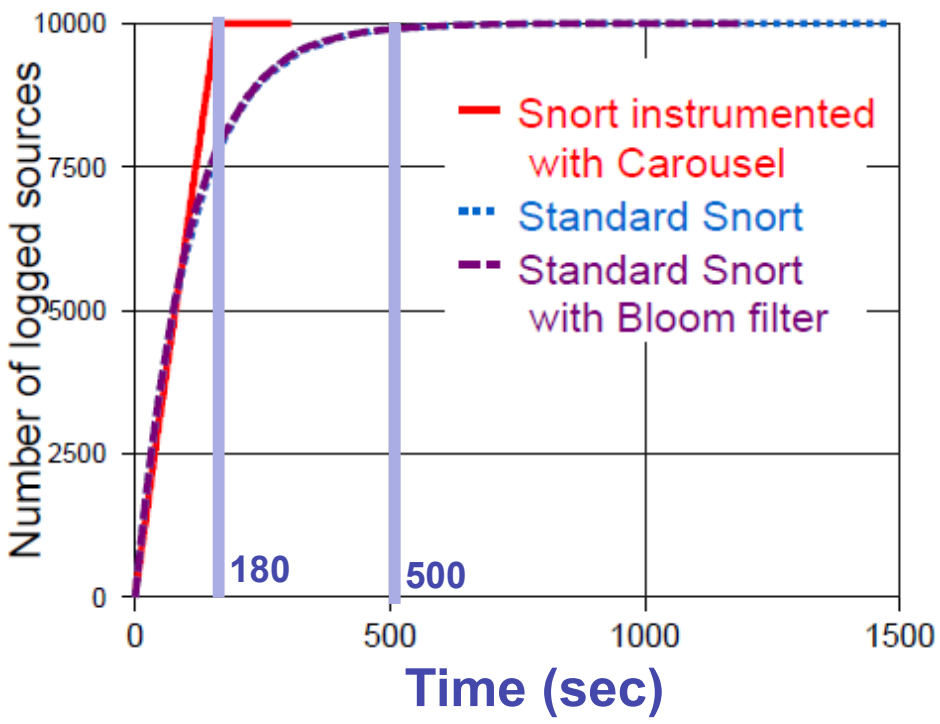
Carousel is nearly ten times faster than naïve collector

Snort Experimental Setup

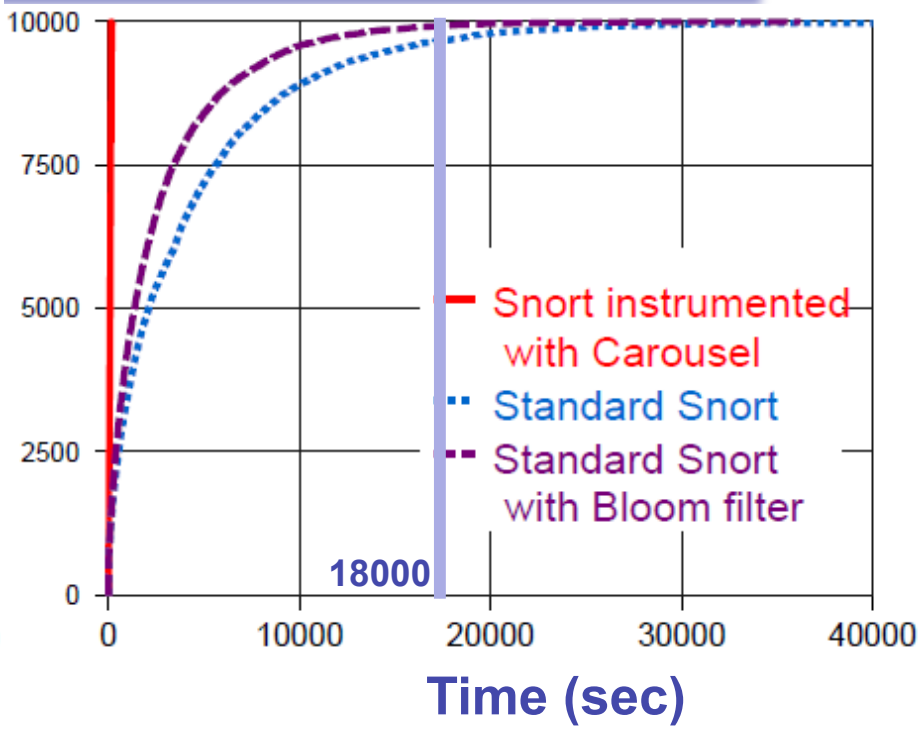


- Scaled down from real traffic: 10,000 sources, buffer of 500, input rate =100 Mbps, logging rate = 1 Mbps
- Two cases: source S picked randomly on each packet or periodically (1,2,3 . . 10,000, 1, 2, 3, . .)

Snort results



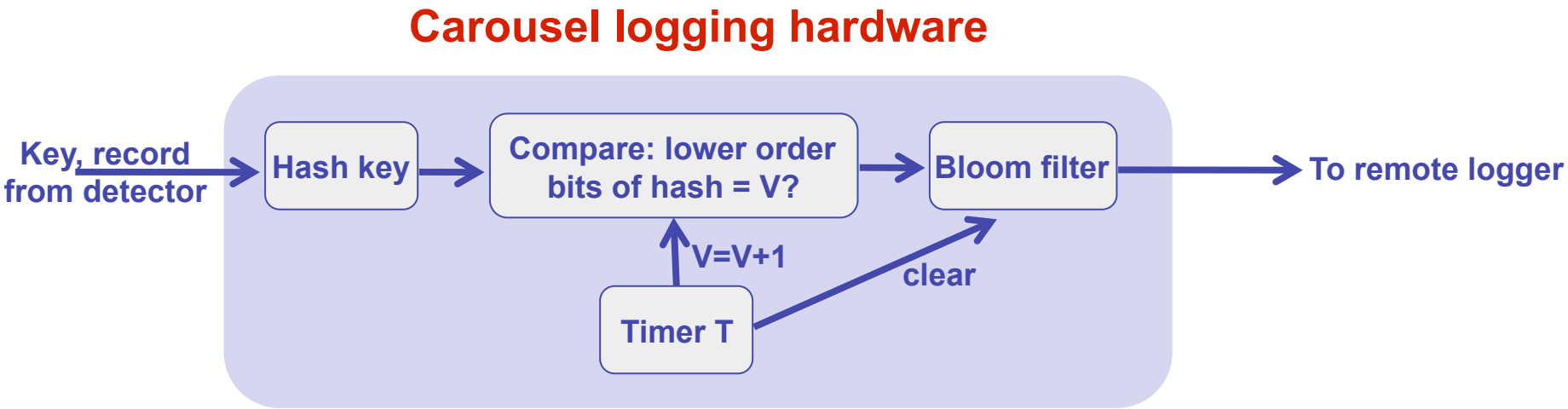
(a) Random traffic pattern



(b) Periodic traffic pattern

3 times faster with random and 100 times faster with periodic

Carousel design in hardware



- Using 1 Mbit of memory, less than 5% of an ASIC
- Can be easily added to hardware IDS/IPS chipsets

Related work

- High speed implementations of IPS devices
  - Fast reassembly, normalization and regular expression
  - No prior work on scalable logging

- Alto file system: dynamic and random partitioning
  - Fits big files into small memory to rebuild file index after crash
  - Memory is only scarce resource
  - Carousel handles *both* limited memory *and* logging speed
  - Carousel has a rigorous competitive analysis

Limitations of Carousel

- Carousel is probabilistic: sources can be missed with low probability ➔ mitigate by changing hash function on each Carousel cycle.
- Carousel relies on a "persistent source assumption"
  - Does not guarantee logging of "one-time" events
- Carousel does not prevent duplicates at the sink but has fast collection time even in an adversarial model.

Conclusions

- Carousel is a scalable logger that
  - Collects nearly all *persistent* sources in nearly optimal time
  - Is easy to implement in hardware and software
  - Is a form of *randomized admission control*

- Applicable to a wide range of monitoring tasks with:
  - High line speed, low memory, and small logging speed
  - And where sources are persistent