Deep Packet Inspection Using GPUs

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Background

- Main uses for network traffic analysis
  - Operations & management
  - Capacity planning
  - Performance troubleshooting

- Levels of network traffic analysis
  - Device counter level (snmp data)
  - Traffic flow level (flow data)
  - **Packet level** (The focus of this work)
    - Network securities
    - Application performance analysis
    - Traffic characterization studies

Background (cont.)

Characteristics of packet-based network traffic analysis applications

- Time constraints on packet processing

- Computing and I/O throughput-intensive

- High levels of data parallelism
  - Packet parallelism. Each packet can be processed independently
  - Flow parallelism. Each flow can be processed independently

- Extremely poor temporal locality for data
  - Typically, data processed once in sequence; rarely reused

The Challenges

Packet-based traffic analysis tools face performance & scalability challenges within high-performance networks.

- High-performance networks:
  - 40GE/100GE link technologies
  - Servers are 10GE-connected by default
  - 400GE backbone links & 100GE host connections loom on the horizon

- Millions of packets generated & transmitted per sec

Packet-based Traffic Analysis Tool Platform (I)

- Requirements on computing platform for high performance network traffic analysis applications
  - High compute power
  - Ample memory & IO bandwidth
  - Capability of handling data parallelism inherent with network data
  - Easy programmability

Packet-based Traffic Analysis Tool Platform (II)

- Three types of computing platforms:
  - NPU/ASIC, CPU, GPU

Features	NPU/ASIC	CPU	GPU
High compute power	Varies	✗	✓
High memory bandwidth	Varies	✗	✓
Easy programmability	✗	✓	✓
Data-parallel execution model	✗	✓	✓

Architecture Comparison

Features	cores	Bandwidth	DP	SP	Power	Price
NVidia K80	4992	480 GB/s	2.91 TF	8.73 TF	300W	$4,349
Intel E7-8890	18	102 GB/s	0.72 TF	1.44 TF	165W	$7,174

NVidia K80 vs. Intel E7-8890

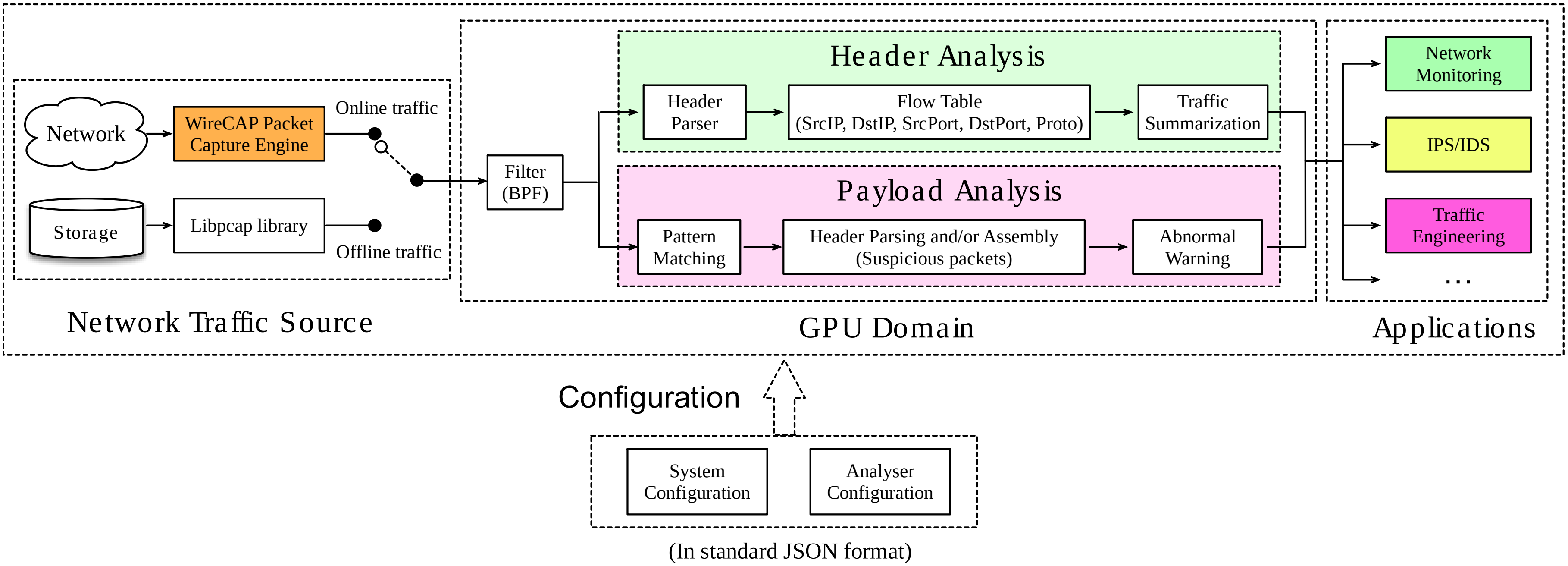
Our Solution

Network Traffic Analysis using GPUs

Highlights of our work:

- Demonstrated GPUs can significantly accelerate network traffic analysis
- Designed/Implemented a generic I/O architecture to capture and move network traffics from wire into GPU domain
- Implemented a GPU-accelerated library for network traffic analysis

GPU-based Network Traffic Analysis Framework



Running modes

- Online analysis
  - Traffic capture
- Offline analysis

GPU-based analysis

- Header analysis
- Payload analysis

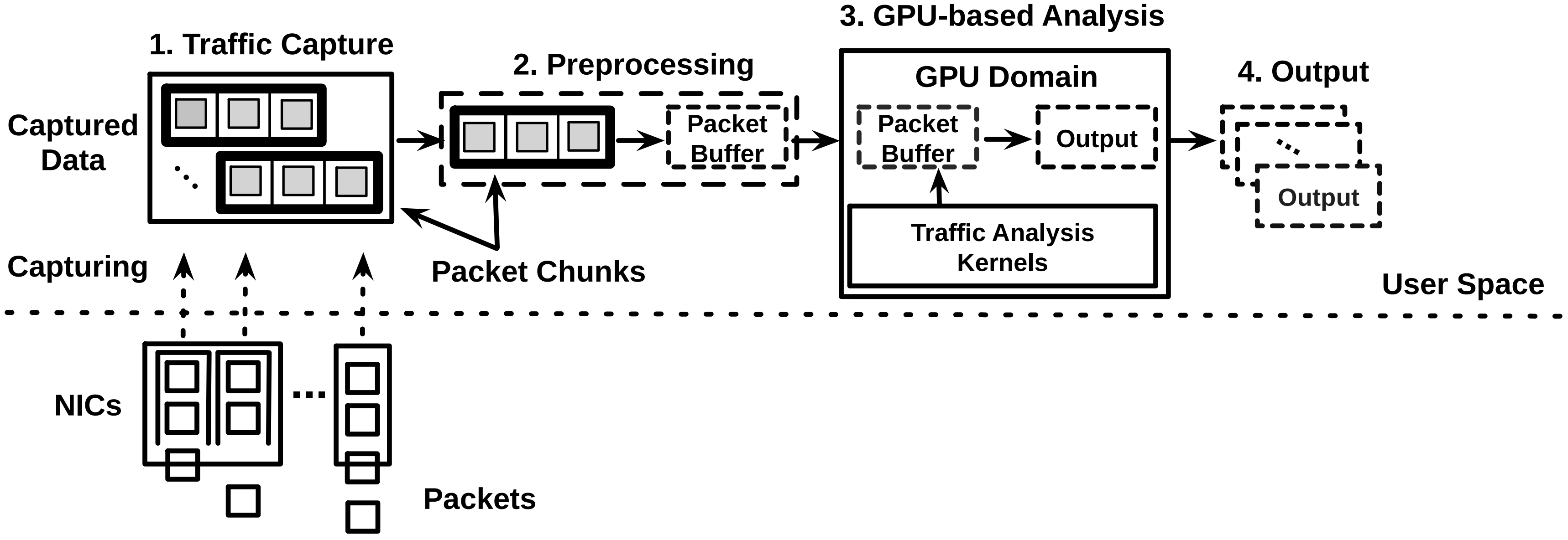
Applications

- Network Monitoring
- IPS/IDS
- Traffic Engineering
- And more

System Architecture – Online Analysis

Four types of logical Entities:

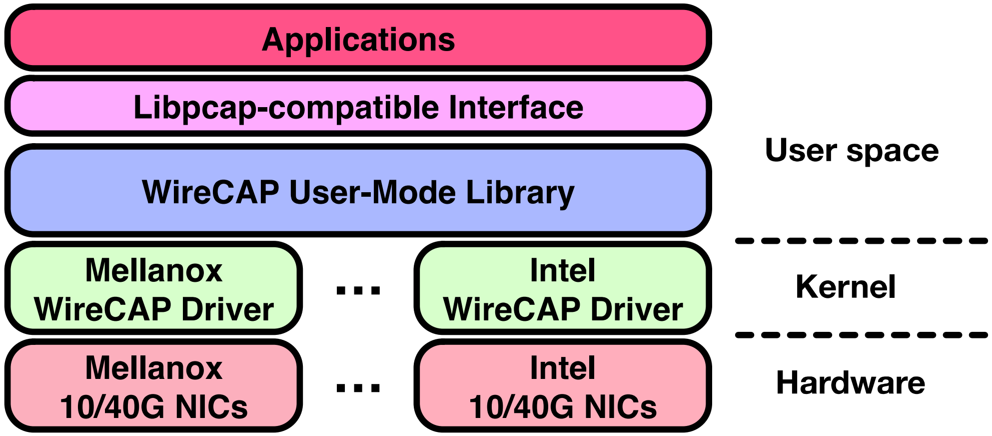
- Traffic Capture
- Preprocessing
- GPU-based Analysis
- Output (in JSON format)



Fermilab

WireCAP Packet Capture Engine

- An advanced packet capture engine for commodity network interface cards (NICs) in high-speed networks
  - Lossless zero-copy packet capture and delivery
  - Zero-copy packet forwarding
  - A Libpcap-compatible interface for low-level network access
- WireCAP project website
  - http://wirecap.fnal.gov (Note: source code is available)



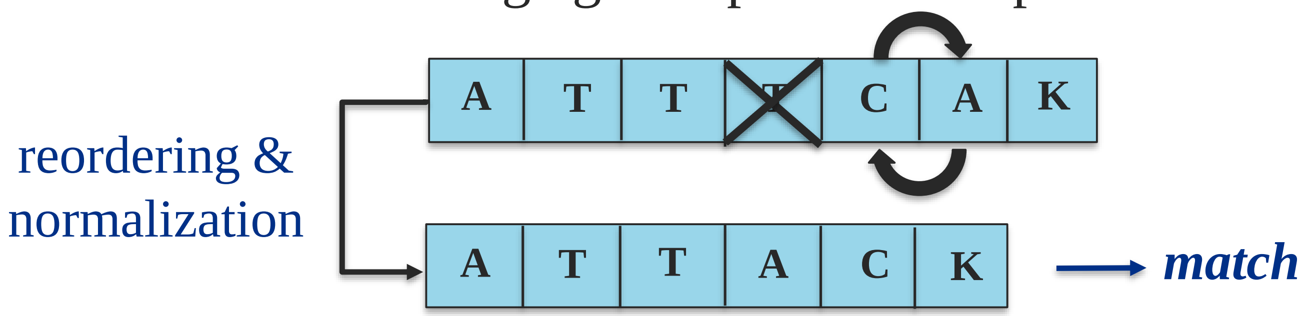
GPU-based Network Traffic Analysis

- A GPU-accelerated library for network traffic analysis
  - Dozens of CUDA kernels
  - Can be combined in a variety of ways to perform intended analysis operations
- Two types of GPU-based network traffic analysis
  - Header analysis (see our GTC'13 talk)
    - http://on-demand.gputechconf.com/gtc/2013/presentations/S3146-Network-Traffic-Monitoring-Analysis-GPUs.pdf
  - Packet payload analysis
    - Deep packet analysis (TCP streams)

Challenges in Stream Reassembly (I) --- Parallelism

Why stream reassembly?

- Payload of packet affiliated to the same TCP stream need to be assembled before matching against pre-defined patterns

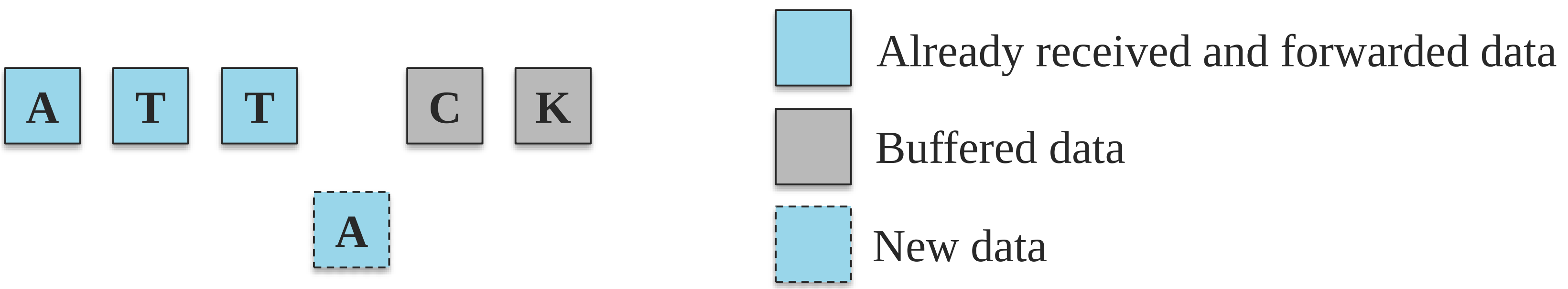


However…

- Stream reassembly via parallel hash-table requires an atomic lock with each hash key (TCP 4-tuple)
- Limited data parallelism when less simultaneous TCP connections are present

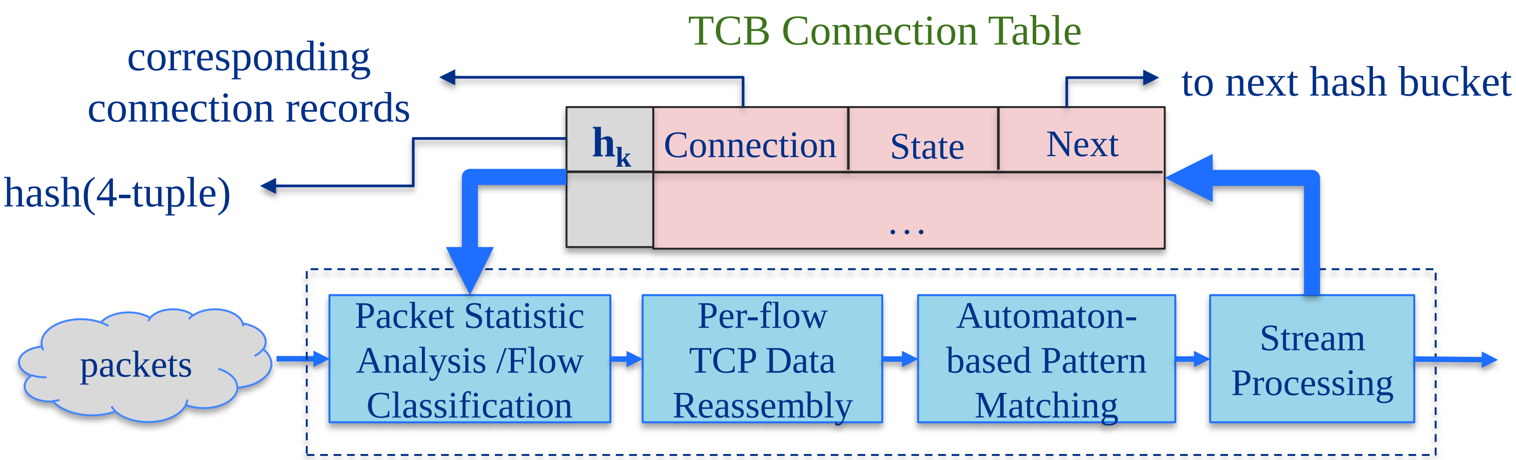
Challenges in Stream Reassembly (II) --- Denial of Service Attack

- To address the problem of out-of-order packets, one widely adopted approach is *packet buffering* and *stream reassembl*y, i.e., buffer all packets following a missing one, until they become in-sequence again.



- This approach is intuitive but vulnerable to denial-of-service (DoS) attacks, whereby attackers exhaust the packet buffer capacity by sending long segments of out-of-order packets.

GPU-based Deep Packets Analysis Pipeline



Hybrid Pattern Matching Pipeline

- Intra-batch TCP packets reordering & assembly
- Inter-batch split detection

Pattern matching wo/ buffering or dropping out-of-order packets

Key Mechanisms (I)

Observation 1

- According to previous internet traffic analysis report, only 2%-5% packets are affected by re-ordering
- When processing packets in batch (~1e6 packets), 0.1%-0.5% TCP streams spread across batches

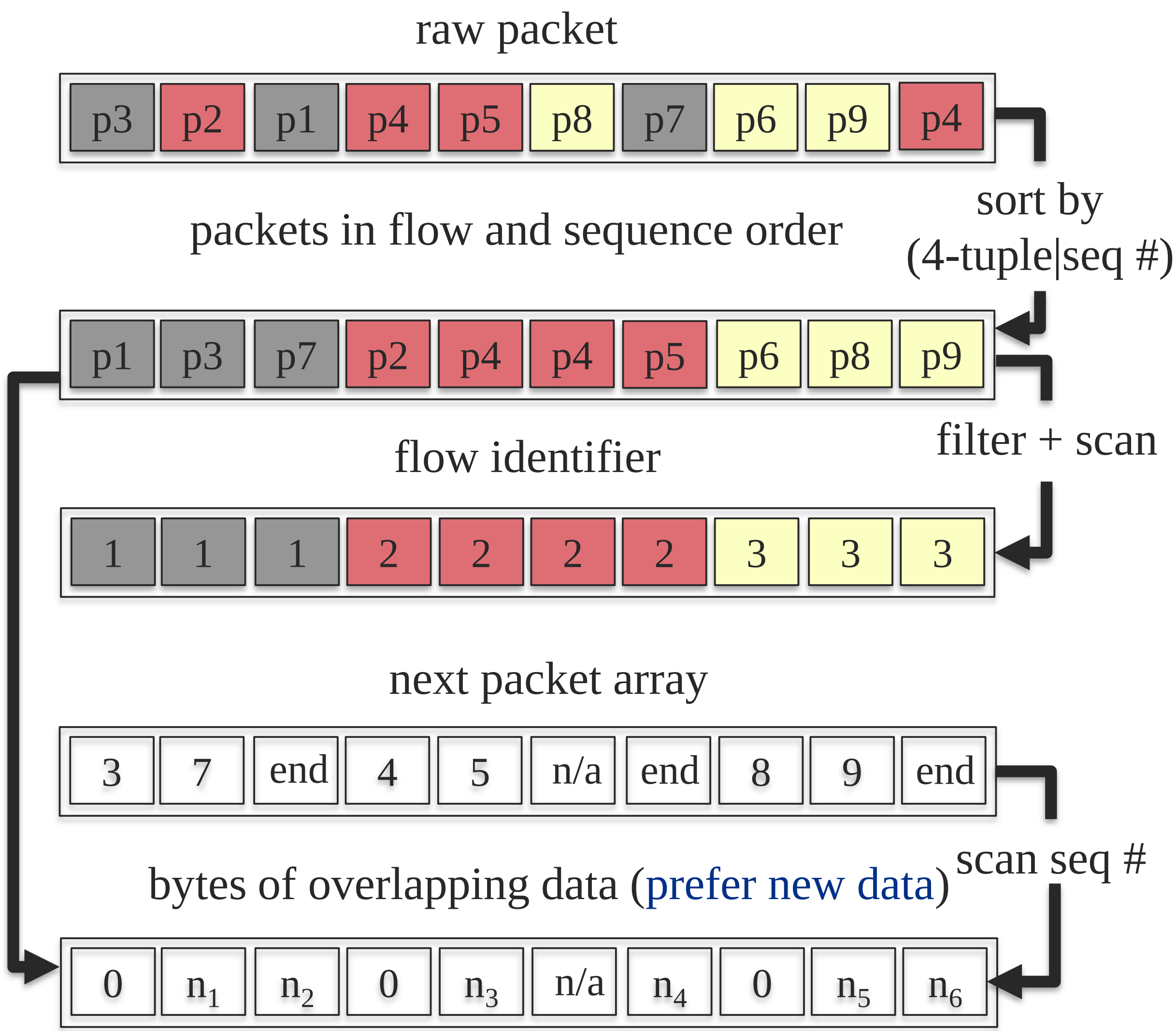
Mechanism 1 --- intra-batch stream reassembly

+ Load packets from network to GPUs in batch
+ In-batch packet reordering and reassembly via parallel sorting

GPU-based TCP Stream Reassembly

Packet Reordering

Stream Normalization



Fermilab

Key Mechanisms (II)

Observation 2

- If a string S is matched across a list of packets $P_1P_2\ldots P_N$, the suffix of P_1 must match a prefix of S, the prefix of P_N must match a suffix of S, and $P_2\ldots P_{N-1}$ must match the prefixes of a suffix-S.

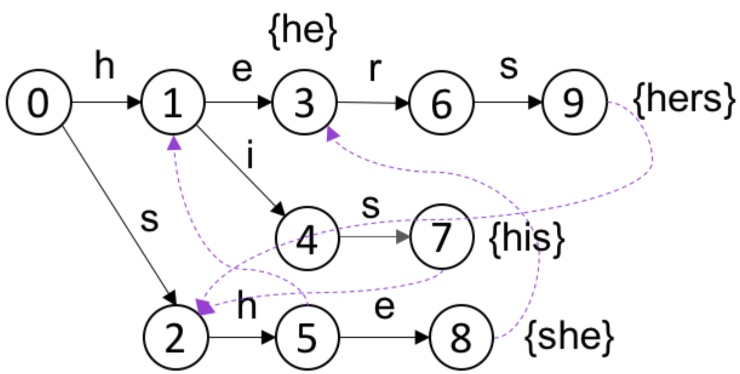
Mechanism 2 --- inter-batch split detection

+ Combine the Aho-Corasick (AC) and suffix-AC automatons to detect signatures spread over different batches

GPU-based Pattern Matching for Out-of-order Packets

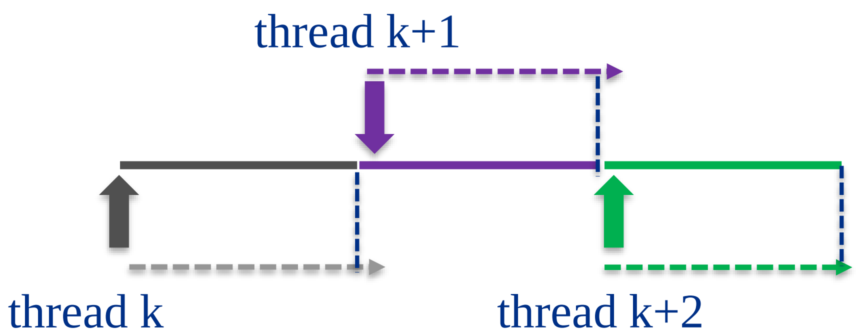
Intra-batch: AC automaton

State transition automaton



Keywords: X = {he, his, she, hers}

Parallel execution mode

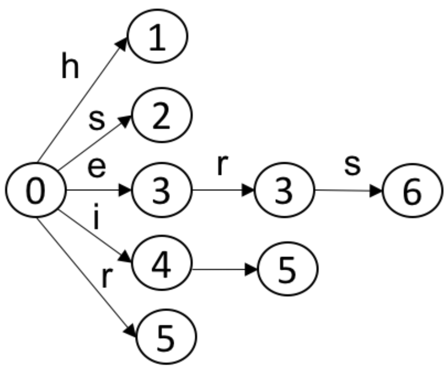


- One thread per packet
- Each thread scans extra N bytes towards its consecutive packet

GPU-based Pattern Matching for Out-of-order Packets

Inter-batch: AC automaton & Suffix-AC automaton

Suffix Pattern Tree (PST)

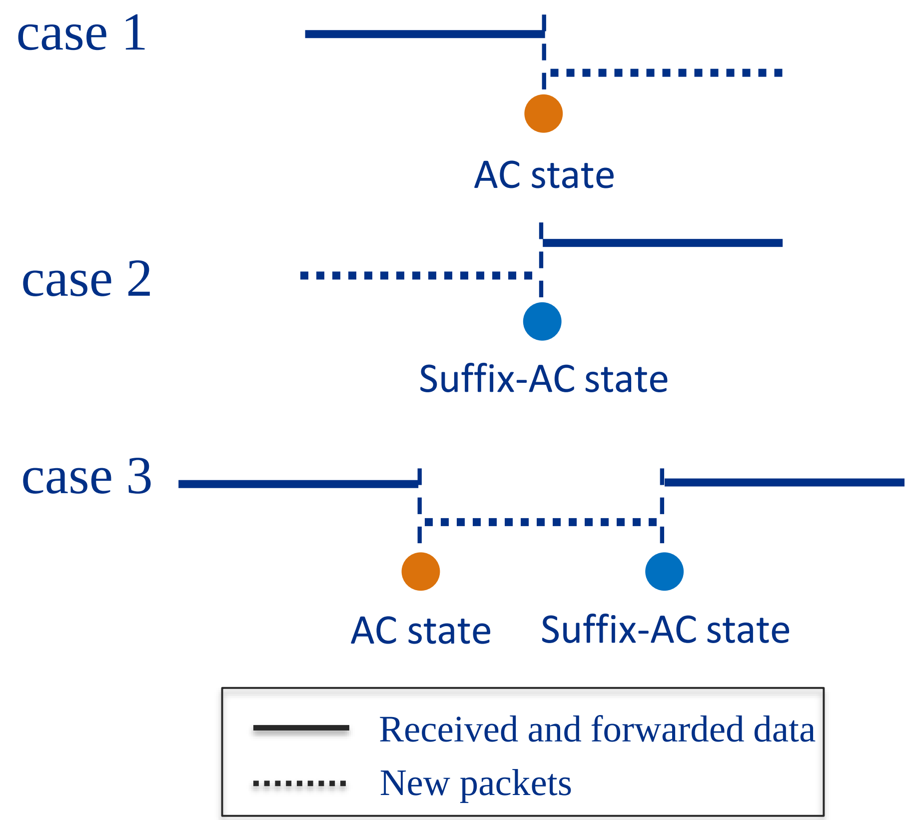


Suffix set of *X*: {e,is,s,he,ers,rs}

```
struct {
    nextState[256];
    preState;
    preChar;
}PST;
```

suffix string = *path*(state)

Out-of-order Packets



Performance Evaluation

Traffic Statistics

- Traffic source: real traffics mirrored from the Fermilab gateway
- Traffic pattern (average per batch)

# of packets	1 million
# of data packets	776,207
mean packet length	1415-byte
# of connections	15,500

Base Systems:

- Intel Xeon CPU E5-2650 @ 2.30 GHz, NVIDIA K40

Throughput (wo/ memory transfer)

- TCP reassembly: **72.96** Mpps (✕192 speedup comparing to libnids on CPU)
- TCP state management: 286.85 Mpps
- Pattern matching (AC & Suffix-AC): 5.83 Mpps

Comparison to Existing Tools

- Comparison to Snort[1], Split-Detect[2], and GASPP[3]

	Snort	Split-Detect	GASPP	Ours
Computing platform	CPU	CPU	GPU	GPU
Methods	Stream Reassembly	Split detection	Intra-batch stream reassembly	In-batch stream reassembly + inter-batch split detection
Detection over OOO packets	✓	✓	limited	✓
Resistance to fragmentation flood	**N**	**Y**	**N**	**Y**
Throughput	Low	Low	High	High

[1] Roesch, Martin. "Snort: Lightweight intrusion detection for networks." *Lisa*. Vol. 99. No. 1. 1999.
[2] Varghese, George, J. Andrew Fingerhut, and Flavio Bonomi. "Detecting evasion attacks at high speeds without reassembly." *ACM SIGCOMM Computer Communication Review*. Vol. 36. No. 4. ACM, 2006.
[3] Vasiliadis, Giorgos, et al. "Design and Implementation of a Stateful Network Packet Processing Framework for GPUs." *IEEE/ACM Transactions on Networking* (2016).

Functionality Evaluation in the Presence of Adversaries

- Robust stream reassembly in facing of out-of-order packets
- Immune to SYN flood and ‘cold start’ in doing normalization
- Exempt from attacks on available buffer memory with timeout and connection evasion mechanisms

Future Works

- Extended the GPU-based deep packet analysis framework to work with regular expressions

- Complement the header info w/ with the payload detection results for a thorough inspection/analysis

- Optimize and evolve the GPU-based network traffic analysis framework for 40GE/100GE networks

Questions?

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