SONATA: Scalable Streaming Analytics for Network Telemetry

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Conventional Network Telemetry

Collection

Analysis

Compute

Store

Queries

NetFlow, pcap, sFlow, SNMP, etc.
Conventional Network Telemetry

Collection is not driven by Analysis
Problems with Status Quo

• *Expressibility*
  – Configure collection & analysis stages separately
  – Static (and often coarse) data collection
  – Brittle analysis setup---specific to collection tools
Problems with Status Quo

• **Expressibility**
  – Configure collection & analysis stages separately
  – Static (and often coarse) data collection
  – Brittle analysis setup---specific to collection tools

• **Scalability**
  As Traffic Volume or # Monitoring Queries increases
  • Hard to answer queries in real-time

Hard to express & scale queries for network telemetry tasks!
SONATA: Query-Driven Telemetry

• **Idea 1: Uniform Programming Abstraction**
  Express queries as dataflow operations over pkt. tuples

• **Idea 2: Query Partitioning**
  Execute subset of dataflow operations in data plane

• **Idea 3: Iterative Refinement**
  Iteratively zoom-in on traffic of interests

Makes it easier to **express** and **scale** network telemetry tasks!
Idea 1: Uniform Prog. Abstraction

• Extensible Packet-tuple Abstraction
  Queries operate over all packet tuples, at every location in the network

• Expressive Dataflow Operators
  – Most telemetry applications require
    • collecting aggregate statistics over subset of traffic
    • joining results of one analysis with the other
  – Easy to express them as declarative queries composed of dataflow operators
Example Queries

Detecting Traffic Anomalies

Detect hosts for which # of unique source IPs sending DNS response messages exceeds threshold (Th)

```
pvictimIPs = pktStream(W)
  .filter(p => p.srcPort == 53)
  .map(p => (p.dstIP, p.srcIP))
  .distinct()
  .map((dstIP, srcIP) => (dstIP, 1))
  .reduceByKey(sum)
  .filter((dstIP, count) => count > Th)
  .map((dstIP, count) => dstIP)
```

Express queries without worrying about where and how they get executed
Example Queries

Confirming Reflection Attacks

Detect hosts with traffic anomalies that are of type RRSIG

\[
\text{victimIPs}(t) = \text{pktStream}(W)
\]
\[
\quad \text{.filter}(p \Rightarrow p.\text{srcPort} == 53)
\]
\[
\quad \text{.join}(p\text{VictimIPs}(t), \text{key}='\text{dstIP}')
\]
\[
\quad \text{.filter}(p \Rightarrow p.\text{dns.rr.type} == \text{RRSIG})
\]
\[
\quad \text{.map}(p \Rightarrow (p.\text{dstIP}, 1))
\]
\[
\quad \text{.reduceByKey}(\text{sum})
\]
\[
\quad \text{.filter}((\text{dstIP}, \text{count}) \Rightarrow \text{count} > T2)
\]
\[
\quad \text{.map}((\text{dstIP}, \text{count}) \Rightarrow \text{dstIP})
\]

Join different packet tuple streams
Changing Status Quo

• **Expressibility**
  – Express dataflow queries over packet tuples
  – Not tied to low-level (3rd party/platform-specific) APIs
  – Trivial to add new queries and change collection tools

Easier to express network telemetry tasks!
Query Execution
Use Scalable Stream Processors

Process all (or subset of) captured packet tuples using state-of-the-art **Stream Processor**

Expressible but **not** Scalable!
Scalable Query Execution

- **Query Partitioning**
  - Execute subset of dataflow operators in data plane
  - Reduce packet tuples at the cost of additional state in the data plane

- **Iterative Refinement**
  - Iteratively zoom-in on traffic of interests
  - Reduce state at the cost of additional detection delay
Idea 2: Query Partitioning

• **Observation**
  Data Plane can process packets at line rate

• **How it works?** Dataflow operations in data plane,
  – filter, sample operations for OF-based data plane
  – map, reduce, filter, join, sample operations for PISA-based data plane

• **Trade-off**
  Trades packet processing cost with additional state in the data plane
PISA Targets for Query Partitioning

- **Programmable parsing**
  Allow new query-specific header fields for parsing

- **State in packets & registers**
  Support simple stateful computations

- **Customizable hash functions**
  Support hash functions over flexible set of fields

- **Flexible match/action table pipelines**
  Support match/action tables with prog. actions
Compiling Dataflow Operators

• **Map, Filter & Sample**
  Apply sequence of match-action tables

• **Distinct & Reduce**
  – Compute index, & read value from hash tables
  – Apply function (e.g., bit_or for distinct) & then update the hash table
  – Use sketches, e.g. reduce(sum) → CM Sketches

• **Limitations**
  Complex transformations, e.g. log, regex, etc.
Query Partitioning in Action

Runtime Partitions Input Queries
Idea 3: Iterative Refinement

• *Observation*
  Small fraction of traffic satisfies monitoring queries

• *How it works*
  – Augment operators’ query to observe at coarser level
  – Iteratively (over successive window intervals) zoom-in to filter out uninteresting traffic

• *Trade-offs*
  – Reduces packet processing & data plane state cost
  – Introduces additional detection delay cost
Iterative Refinement in Action

Collection is now driven by Analysis!
Scalable Query Execution

• **Query Partitioning**
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• **Iterative Refinement**
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How to select the best query plan?
Query Planning

- **Traffic Anomaly Query**

- **Partitioning Plans**
  - Plan 1: Data Plane only
  - Plan 2: Stream Processor only

- **Refinement Plans**
  - Refinement key: dstIP
  - Refinement levels: {/8, /32}

```java
pktStream(W)
  .filter(p => p.srcPort == 53)
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  .distinct()
  .map(((dstIP, srcIP)=>(dstIP,1))
  .reduceByKey(sum)
  .filter(((dstIP,count)=>count>Th)
  .map(((dstIP, count) => dstIP)
```
Query Planning

• **Traffic Anomaly Query**

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  – Refinement levels: \{/8, /32\}
Query Planning

Src $\rightarrow$ dIP/8,1 $\rightarrow$ dIP/32,2 $\rightarrow$ Tgt

Selects plan with smallest weighted cost
SONATA
Query-Driven Network Telemetry

• **Application Interface**
  Express queries w/o worrying about **where** and **how**
  they will be executed

• **Runtime System**
  Iteratively refines and partitions each input query

• **Data Plane & Streaming Drivers**
  Compile input queries to target-specific configurations/
  queries
Implementation

Collection is now driven by Analysis!
Evaluation

• **Workload**
  Large-IXP network: 2 hours long IPFIX trace, 3 Tbps peak traffic, packet sampling rate = 1/10K

• **Queries**
  DDoS-UDP, SSpreader, PortScan

• **Comparisons**
  Part-OF, Part-PISA, Fixed-Refinement
Benefits of Query Partitioning

Number of pkt tuples processed by Stream Processor

Executing stateful operations in data plane reduces workload on Stream Proc.
Benefits of Iterative refinement

State (KB) required by data plane targets

Iterative refinement reduces state required by the data plane targets
Benefits of Query Planning

- $B_{\text{max}}$: Max. state data plane can support
- $N_{\text{max}}$: Max. pkt. tuples stream processor can process
- Each color represents a unique query plan

SONATA makes best use of available resources
Changing Status Quo

• **Expressibility**
  – Express Dataflow queries over packet tuples
  – Not worry about how and where the query is executed
  – Adding new queries and collection tools is trivial

• **Scalability**
  – Answers hundreds of queries in real-time for traffic volume as high as few Tb/s

Expressible & Scalable!

- tuples processed by the stream processor
- state in the data plane
Summary

• SONATA makes it easier to **express** and **scale** network telemetry tasks using
  – Uniform Programming Abstraction
  – Query Partitioning
  – Iterative Refinement

• Running Code
  – Run test queries or express new ones

[sonata.cs.princeton.edu](https://sonata.cs.princeton.edu)