Streaming Analysis:
An Alternate Analysis Paradigm

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Overview

- The Landscape
- A Streaming Workflow Prototype
- Results
- The Fathom Framework
- Discussion & Future Work

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The Landscape

- Right now, we can only find simple and obvious attacks
- In order to stop the smarter attackers, we need to first build a better detection infrastructure, this needs:
  - Situational Awareness: We don't understand what's on our networks or what they do
  - Reconnaissance Detection: We treat each attack as a completely new event
  - Automation and Efficiency: Everything is still done by hand and by heroes
- We are building the next generation detection infrastructure, and by doing so will catch progressively stealthier attacks

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Streaming Analytics

- The next generation demands streaming to relieve the volume of stored data and decrease threat reaction time
- We initially implemented using IBM's InfoSphere Streams
  - More recent work uses our own Fathom framework
- Challenge of streaming
  - Only stateless analytics directly convert
  - Complex analytics require rethinking
  - Understanding the streams improves success
- Benefits of streaming: on-the-fly analyses
  - Near real-time products & actions
  - Selective capture to reduce retained volumes
  - Limited but productive state (context) can be maintained
  - Compile these on-the-fly analyses into long term knowledge

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Stream Computations for Analytic Network Security

- We implement real-time streaming analysis using workflows
- Describe several computations in this presentation
  - Scan detection via Threshold Random Walk
  - Situational awareness via Continuous Statistics
  - A reimplementation of AMP
    - With extensions to capture flow

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Advancing the State-of-the-art

- Scan detection using Threshold Random Walk
  - Faster oracle based approached
  - Efficiently implemented
  - Extendable to continuous operation via oracle and table maintenance
- Situational awareness using Continuous Statistics
  - Finer granularity than previous efforts
  - Detailed network knowledge
  - Working implementation proves this task is less daunting than previously thought

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Benefits of the streaming approach

- Scalable
  - Pipelines: many work steps in a row
  - Divide and conquer: parallel streams
  - Physical distribution: reduced volume at source
- Efficient
  - No bottlenecks
- Replicable
  - Easy to add new analytics

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Analytic Capabilities (InfoSphere streams prototypes)

1. Threshold Random Walk (TRW)
   - Detects network scanners
     - Processes 1 hour of data in less than 1 minute
     - Detects all the scans detected by CERT's `rwscan` and more
     - Graphic display of detections and internal state
2. Continuous Statistics
   - Partial statistics for 260K+ entities in network stream
     - Data into dark /8 at ~1.5Mpkts/minute
     - 1 minute epoch aggregates compared with 60 epoch horizon
     - Alerts for outliers
     - Graphic display of traffic rates and alerts

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Source Data

TRW

- Synthetic data created for IARPA by DHS PREDICT Project
- Traffic on 100.0.0.0/11 network (OSIS)
- Multiple attacks injected into data, including scans
- 1 to 2 hr. scenarios
- ~ 2GB/Hr Data

Continuous Statistics

- Live network traces collected from CAIDA network telescope
- Dark space consisting of a single /8
- 72 hour sample of incoming traffic used to generate statistics
- ~ 6GB/Hr Data

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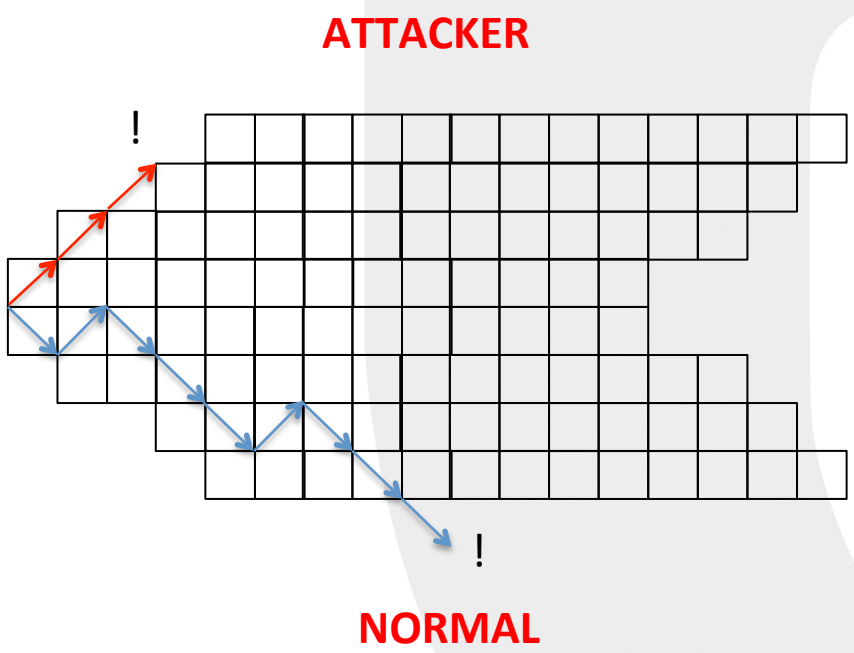
1. Threshold Random Walk



- Connections to nonexistent targets are considered suspicious
- TRW *sequentially* tests suspicious connections and raises an alarm
- TRW only cares about the current state, and the next test

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TRW and oracles

- An *oracle* tracks internal network services
  - Updated dynamically by outgoing traffic
  - Used to evaluate connection attempts
- The *TRW table* tracks hosts connecting to the network
  - Behavior judged by connection success / failure
    - predicted by oracle
  - Host score is a function of success and failure counts
  - When score crosses a threshold, classify the host as a *Scanner* or as *Benign*
- The Oracles and TRW tables are SPL maps
  - This may have scaling problems

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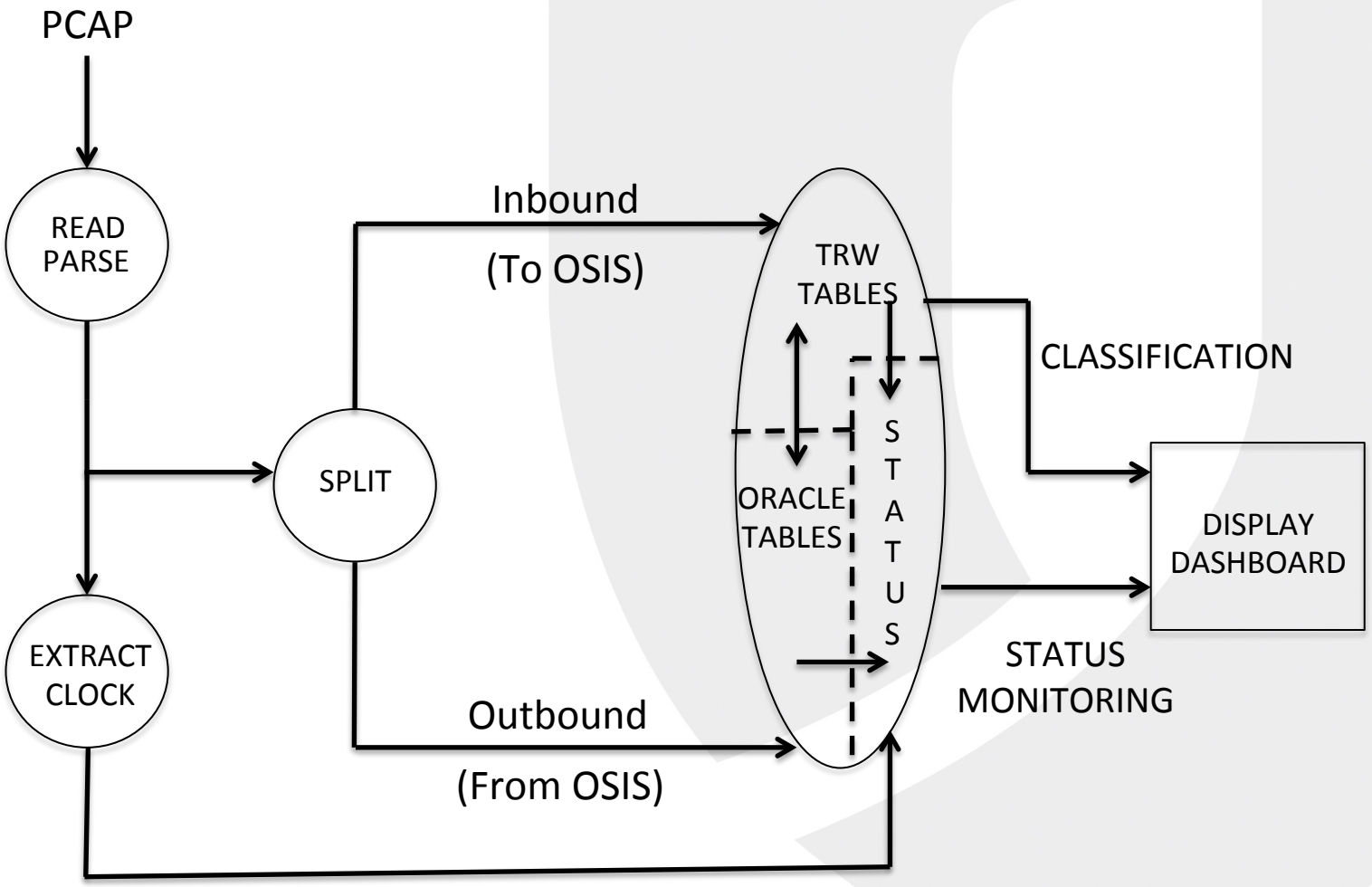
The TRW Workflow



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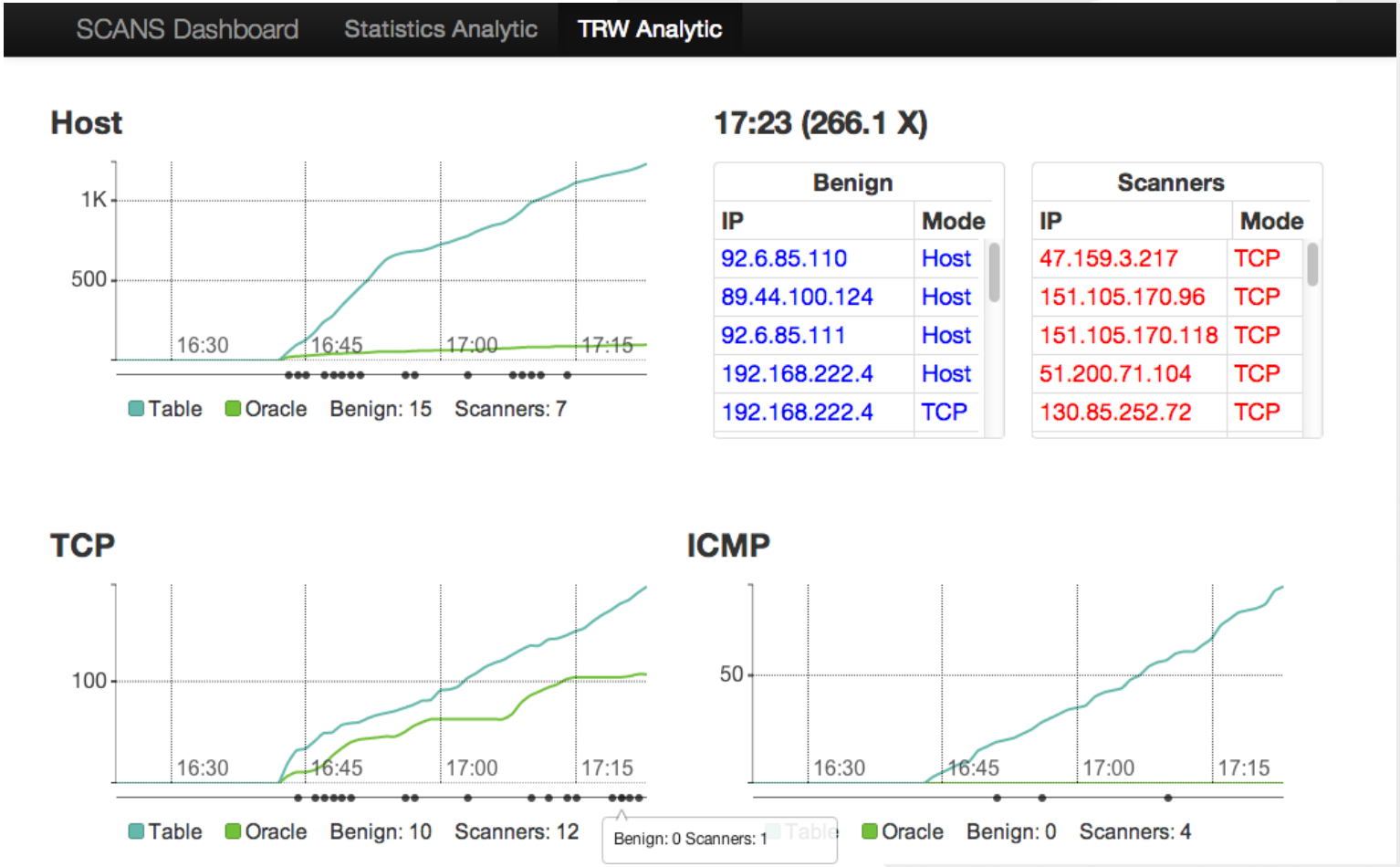
Demo (static screen shot)



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- Implemented a real-time scan detection algorithm using streaming data
  - Multiple oracles effective for TCP / ICMP / UDP
  - Runs at 100x bandwidth capability (slowed for demo)
- Oracle provides dynamically updated information about network composition
  - Provides real-time attack detection and long-term situational awareness
- Integration with existing systems
  - TRW diagnostics can feed firewall or router ACL list to block scanners & inventory benign users
- Long term use requires oracle and table maintenance functionality to be added.

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2. Continuous Statistics

- Implement situational awareness using statistics
  - Current statistics show current network behavior
  - Statistical models predict the network behavior
  - Significant departures from prediction raise alerts
- We calculate partial statistics from streaming data
- Partial statistics can be composed to form long term statistical models
- Our proof of concept implementation is simple but effective.

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Building a Statistical Model

- Break traffic into one-minute *epochs* and accumulate data over each epoch
- Aggregate over various packet attributes
  - Examples: TCP flags, ports, ICMP Type & Code
  - Currently aggregate over ~260k dimensions
- Measure partial statistics (counts, squares) using *tumbling windows*
  - Developed aggregator which generates longer-term (1 hour horizon) statistical models from partial statistics
  - Calculate mean, σ
- Alert on excessive change in current observed values

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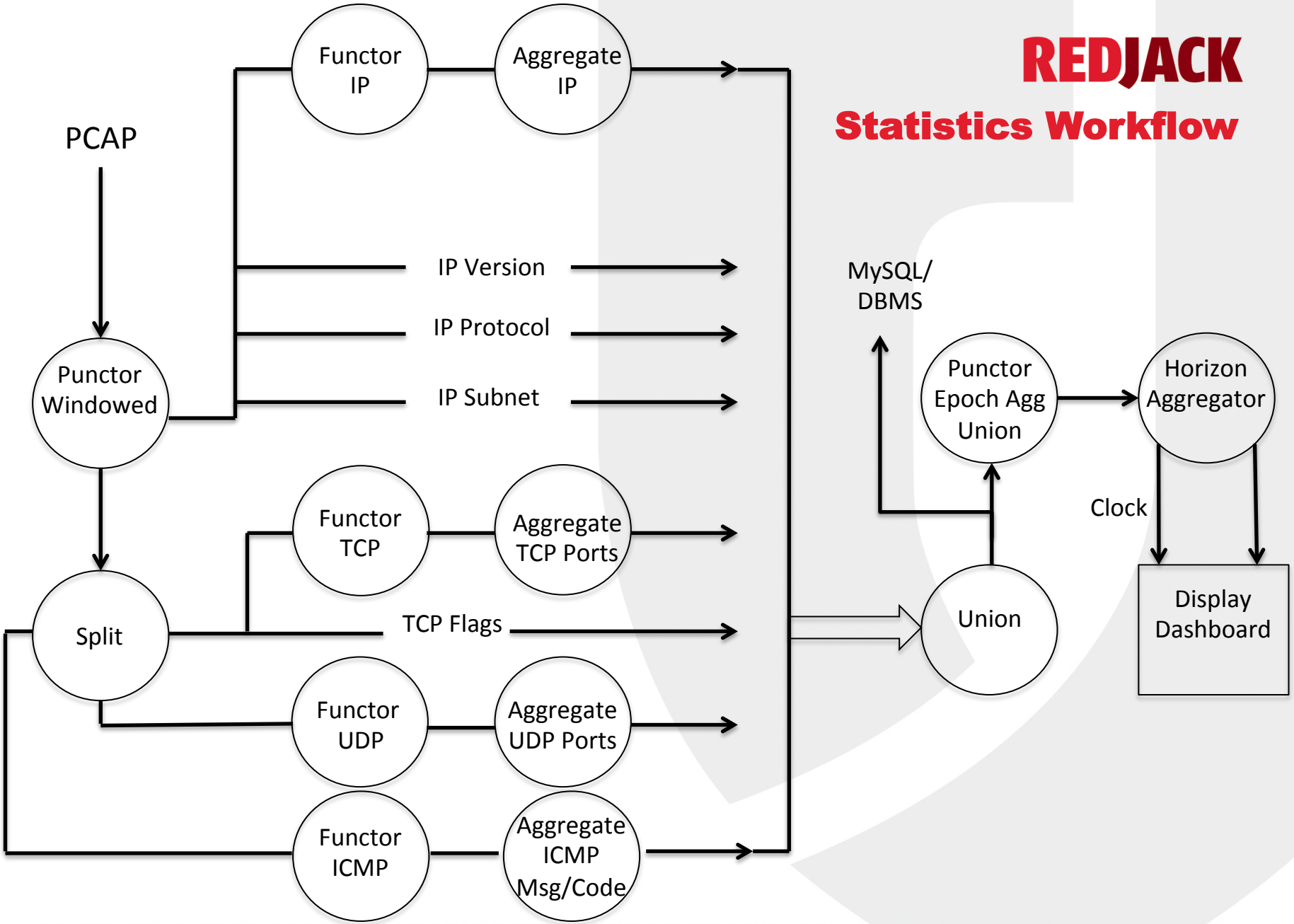
Statistics Workflow



Demo (static screen shot)

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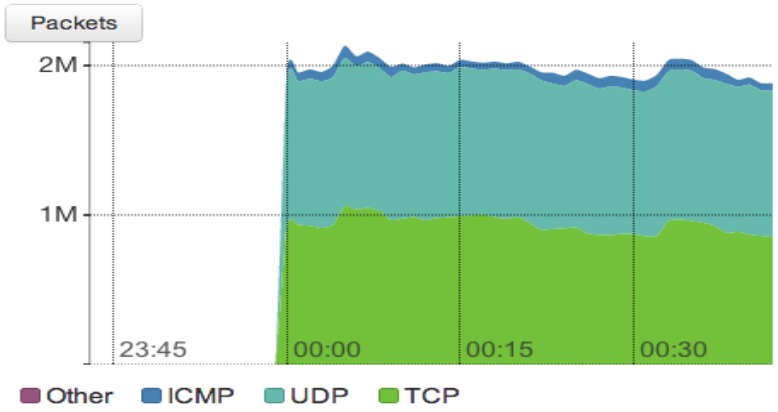
SCANS Dashboard | **Statistics Analytic** | TRW Analytic

Overall Traffic — Bytes/Second



2012-01-01T00:42Z (6.7 X) — 236 Alerts

Immediate: 148 Critical: 7 Serious: 15 Warning: 66

Name	Source	Severity	Time
ICMP 3/3	Volume	Serious	00:42
116.212.0.0/16	Count	Warning	00:42
183.102.0.0/16	Count	Warning	00:42
66.94.0.0/16	Volume	Warning	00:42
78.251.0.0/16	Count	Warning	00:42
200.53.0.0/16	Count	Warning	00:42
90.188.0.0/16	Count	Critical	00:42
91.135.0.0/16	Count	Warning	00:42

☑ TCP Port ☑ TCP Flags ☑ UDP Port ☑ ICMP Type/Code ☐ IP Subnet ☐ IP Protocol

	TCP Port					TCP Flags					UDP Port					ICMP Type/Code				
Rank	Port	Volume	R1	R2	R3	Flags	Volume	R1	R2	R3	Port	Volume	R1	R2	R3	Type/Code	Volume	R1	R2	R3
1	445	667059	1	1	1	S	852218	1	1	1	10320	223549	1	1	1	8/0	44362	1	1	1
2	80	90874	2	2	2	SA	167035	2	2	2	1434	19934	2	2	2	3/3	1961	3	3	3
3	6031	86517	3	3	3	RA	7761	3	3	3	10318	9557	3	3	3	11/0	1204	2	2	2
4	23	38259	4	4	4	R	2778	4	4	4	27005	8159	4	4	4	0/0	197	10	8	10
5	22	32192	5	5	5	A	212	5	5	5	5060	2834	5	5	5	3/4	95	4	4	4
6	3389	22392	6	6	6	SR	33	6	6	6	39455	2100	6	6	6	3/1	64	5	5	5
7	8080	12036	7	7	7	FRA	8	8	7	7	23887	1761	7	7	7	3/2	41	6	6	6
8	5900	8623	8	8	8	FA	4	7	9	8	53	1498	8	10	10	3/0	23	7	7	7
9	6020	8449	9	9	9	F	2	9	8	9	15399	1314	10	—	—	4/0	16	8	9	9
10	6005	6358	—	10	10	FR	1	—	—	—	10021	1311	9	8	9	3/13	9	9	—	8

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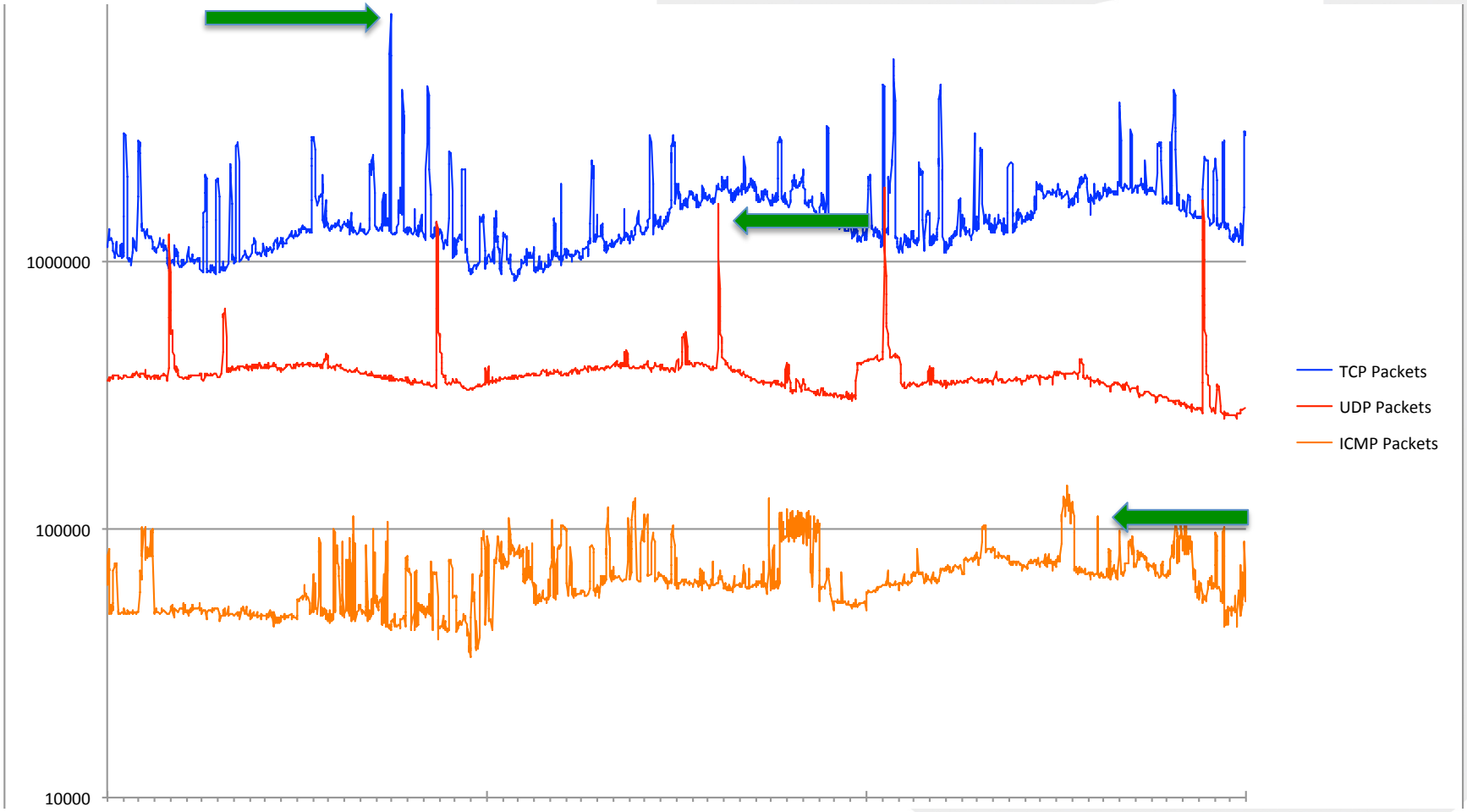
Statistics results (72 hrs Jan 1-3 2012)



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Selected spikes – MySQL results

- TCP at 2012-01-01T17:54:00
  - 8M pkts in peak minute,
  - port 80 SYN from 204.145.0.0/16 anonymized
- UDP at 2012-01-02T14:39:00
  - 1.2M pkts in peak minute
  - port 22 (no comparable TCP activity at this time)
- ICMP at 2012-01-03T14:35:00
  - spike is “port unreachable” (3,3)
    - Back scatter from a SYN flood (spoofed source) ?
  - baseline is mostly “ping”

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Overall Results / Conclusions

- Using streaming data…
  - We can implement automated attack detection / response i.e. scan detection / blocking
  - We can acquire situational awareness by collecting partial statistics and combining them into statistical models
- We can generate both real-time alerts and long-term situational awareness from the same data
- Our implementation is efficient, can run at higher rates.
  - unable to use InfoSphere Streams SPL's distribution as it does not support our multicore, shared memory, architecture.

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Rolling our own

- InfoSphere Streams uses a fairly heavyweight IPC based on Corba Middleware for parallelism.
- This is not bad if the computation to communications ratio is high.
  - Our analytics execute a few instructions per packet
  - Communications costs are much more
  - Packet level parallelism or pipelining is not effective
- We want a platform that can use inexpensive IPC on multicore shared memory processors as well as work effectively in a single thread.
- Thus Fathom …

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The Fathom platform

- Fathom is RedJack's platform for implementing streaming analytics.
- It has both sensing and analytic components.
- Initial driving application is a re-implementation of RedJack's AMP (Analytic MetaData Producer) platform. This implemenation is called *Ampmill*.
- Ampmill produces a variety of aggregated data products
  - TCP stack analysis
  - DNS analysis
  - HTTP banner capture
  - etc.

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Comparison with AMP

- On a single threaded platform, Fathom is about 10% faster than the original AMP implementation.
- It also uses less memory giving additional platform headroom.
- AMP data supplements and extends traditional NetFlow capture.
- We are incorporating flow capture into the AMP code
  - Take advantage of existing packet parsing
  - Resource usage will be substantially less than separate AMP and flow capture programs.

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Flomill

- Flomill is an implementation of a flow capture program used by one of our customers.
  - biflow collection – Ascii output records, heavy on packet statistics, payload & wire lengths, etc.
  - 32 pkt TCP flag history (27 early, 5 late) adjustable
- Work in progress.
  - Current performance for file playback is 0.6s-0.7s for a 512MB pcap file (Predict IARPA 2005 dataset) or about 6 gbs
  - Improvements clearly possible
    - hash tables and memory pool ops sub optimal
    - printf for output slower than binary

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The workflow

- Fathom is based on workflow descriptions. These can be coded as C programs or YAML scripts
- Types: characterize information flowing in system

```
packet: !type
  type: fm_net_packet
```

- Connections: carry a type 1:1, 1:M, M:1, M:M

```
ticked-packets: !connection
  properties:
    type: !ref packet
```

- Computations: operate on data
  - Data may come from connection(s) or “outside” src
  - Data may go to connection(s) or outside sink

The workflow (computations)

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- Computations can be parameterized (workflow or cmd)

```
assign-flows: !computation
  computation: fm_net_assign_flows
  properties:
    in: !ref ticked-packets
    out: !ref flows
    inactive_timeout: 120
    hash_size: 512
    hash_stats: false

aggregate-flows: !computation
  computation: aggregate_flos
  properties:
    in: !ref flows
    out: !ref ascii_flos
    site: "test"
    sensor: "flo30"
    active_timeout: 1800
    wrap: 27
    out_file_name: ""
    out_dir_path: "/tmp/"
    hash_size: 512
    hash_stats: false
    file_stats: false
```

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flexibility

- The whole workflow contains computations for packet capture, parsing, assembly, punctuation, etc.
  - Equivalent computations can be interchanged
    - Read pcap file, device, list of files, compressed files, etc.
    - Produce SiLK uniflows, ipfix biflows, Argus flows, etc.
  - Multiple computations can use same connection
    - ampmill and flowmill on same packet stream.
  - Punctuation allows actions to be keyed to inserted events in data stream.
    - File Rotation
    - Periodic statistics or reports

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More flexibility

- Computation boundaries are useful distribution points
  - In a single thread, pointers are passed (no copy)
    - Doing this in SiLK showed major performance increase
  - In a shared memory multicore box, disruptor queues can be used to improve efficiency, stabilize response
  - ZeroMQ like transport between platforms. Avro to reduce volume, serialize wire traffic
  - Publish / Subscribe mechanisms can be used to reconfigure computations on the fly adding or removing analytics without rebuild or restart of the computational pipeline.

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Future Work

- Assist analysts in a transition to streaming data and away from the “collect, archive, analyze” mode, provisioning ever larger data centers.
- Extend to disparate streams, logs, messages, etc. and use the streaming results to guide or temper archiving.
- Adapt to stream various data types / sources (non-cyber) on Continuous Statistics.
- Deploy streaming analytics near or at high volume sensors to aid it the triage of large data streams, perhaps discarding that which is understood to be benign allowing analysts to concentrate on the needles rather than the haystack.

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Questions?

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Contact Information

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