SysFlow: Scalable System Telemetry for Improved Security Analytics

—

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Network Monitoring

– **Packet analysis** is not feasible at scale

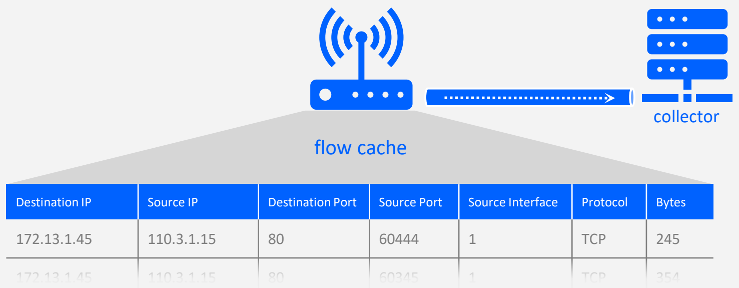
- suitable for in-depth analysis of specific conversations

– **Flow analysis** is a great idea :-)

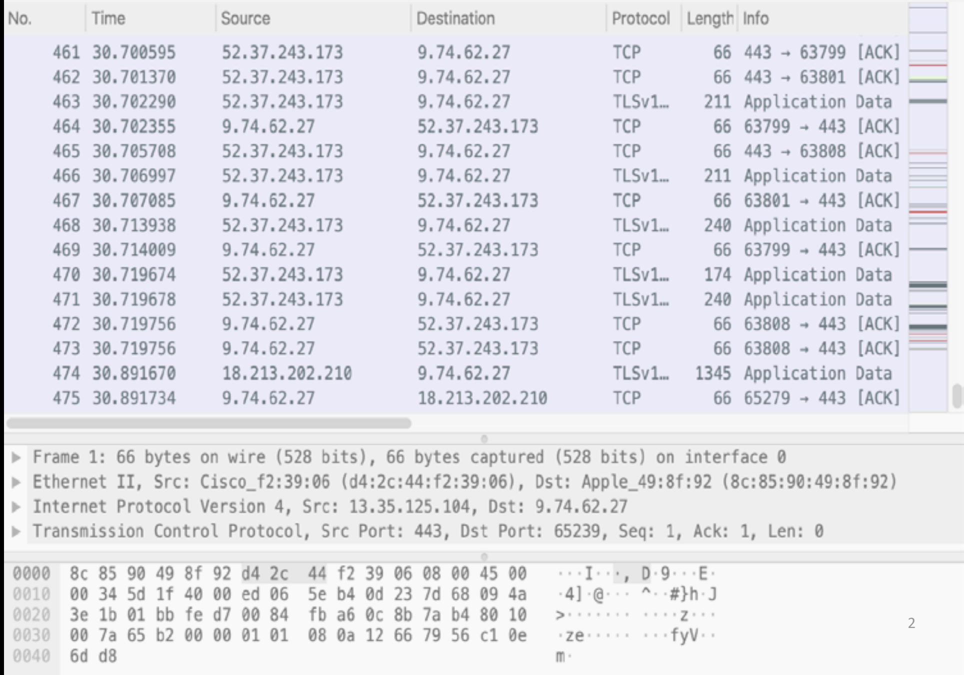
- collect metadata from network traffic and group sequence of packets sharing the same properties
- applications include bandwidth monitoring, network threat detection, and performance analysis

– NetFlow

- Cisco's proprietary network protocol used for flow analysis
- collects and aggregates information about network traffic flowing through a device with an enabled NetFlow feature
- variations: IPFIX, sFlow, NetStream



Destination IP	Source IP	Destination Port	Source Port	Source Interface	Protocol	Bytes
172.13.1.45	110.3.1.15	80	60444	1	TCP	245
172.13.1.45	110.3.1.15	80	60345	1	TCP	354

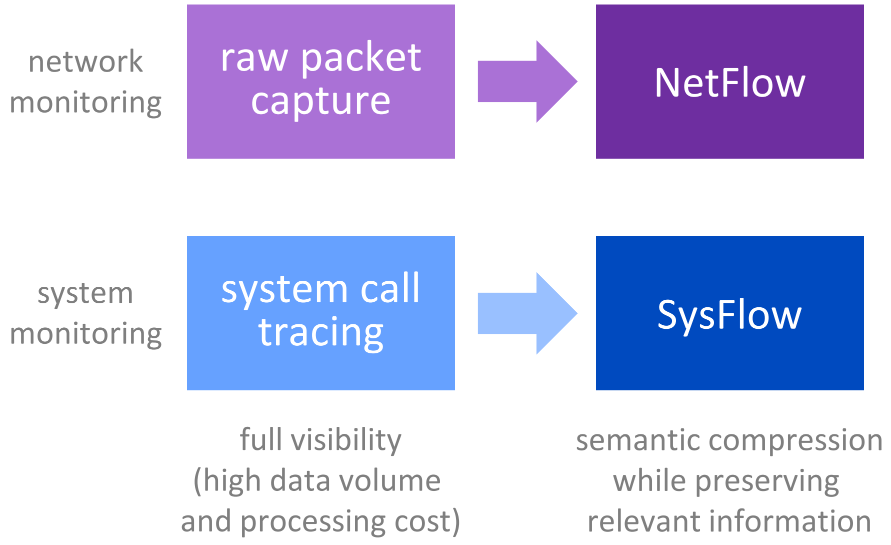


```
No.  Time       Source          Destination     Protocol Length Info
461  30.700595  52.37.243.173   9.74.62.27      TCP        66   443 → 63799 [ACK]
462  30.701370  52.37.243.173   9.74.62.27      TCP        66   443 → 63801 [ACK]
463  30.702290  52.37.243.173   9.74.62.27      TLSv1…    211   Application Data
464  30.702355  9.74.62.27      52.37.243.173   TCP        66   63799 → 443 [ACK]
465  30.705708  52.37.243.173   9.74.62.27      TCP        66   443 → 63808 [ACK]
466  30.706997  52.37.243.173   9.74.62.27      TLSv1…    211   Application Data
467  30.707085  9.74.62.27      52.37.243.173   TCP        66   63801 → 443 [ACK]
468  30.713938  52.37.243.173   9.74.62.27      TLSv1…    240   Application Data
469  30.714009  9.74.62.27      52.37.243.173   TCP        66   63799 → 443 [ACK]
470  30.719674  52.37.243.173   9.74.62.27      TLSv1…    174   Application Data
471  30.719678  52.37.243.173   9.74.62.27      TLSv1…    240   Application Data
472  30.719756  9.74.62.27      52.37.243.173   TCP        66   63808 → 443 [ACK]
473  30.719756  9.74.62.27      52.37.243.173   TCP        66   63808 → 443 [ACK]
474  30.891670  18.213.202.210  9.74.62.27      TLSv1…   1345   Application Data
475  30.891734  9.74.62.27      18.213.202.210  TCP        66   65279 → 443 [ACK]

▶ Frame 1: 66 bytes on wire (528 bits), 66 bytes captured (528 bits) on interface 0
▶ Ethernet II, Src: Cisco_f2:39:06 (d4:2c:44:f2:39:06), Dst: Apple_49:8f:92 (8c:85:90:49:8f:92)
▶ Internet Protocol Version 4, Src: 13.35.125.104, Dst: 9.74.62.27
▶ Transmission Control Protocol, Src Port: 443, Dst Port: 65239, Seq: 1, Ack: 1, Len: 0

0000  8c 85 90 49 8f 92 d4 2c  44 f2 39 06 08 00 45 00   ···I···, D·9···E·
0010  00 34 5d 1f 40 00 ed 06  5e b4 0d 23 7d 68 09 4a   ·4]·@··· ^··#}h·J
0020  3e 1b 01 bb fe d7 00 84  fb a6 0c 8b 7a b4 80 10   >······· ····z···
0030  00 7a 65 b2 00 00 01 01  08 0a 12 66 79 56 c1 0e   ·ze····· ···fyV··
0040  6d d8                                              m·
```

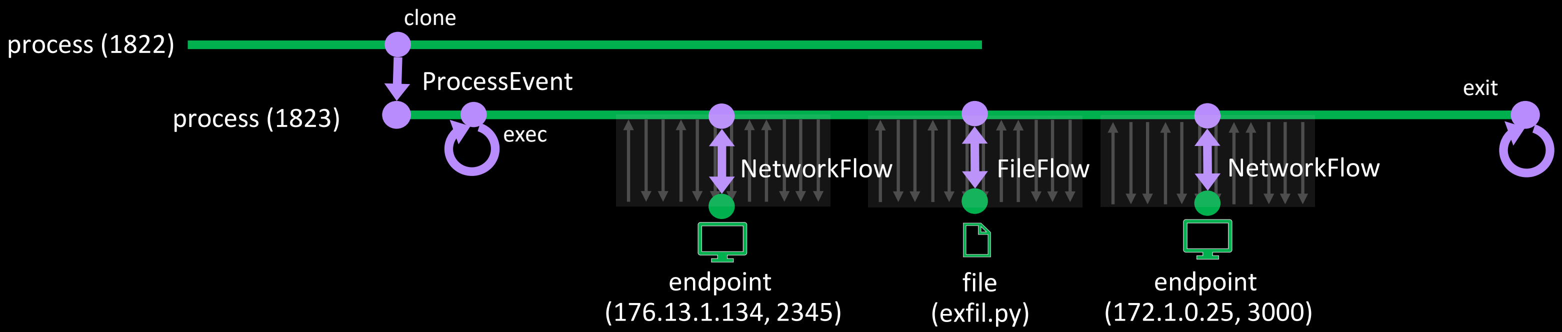
NetFlow only captures <u>half</u> of the telemetry picture.

SysFlow

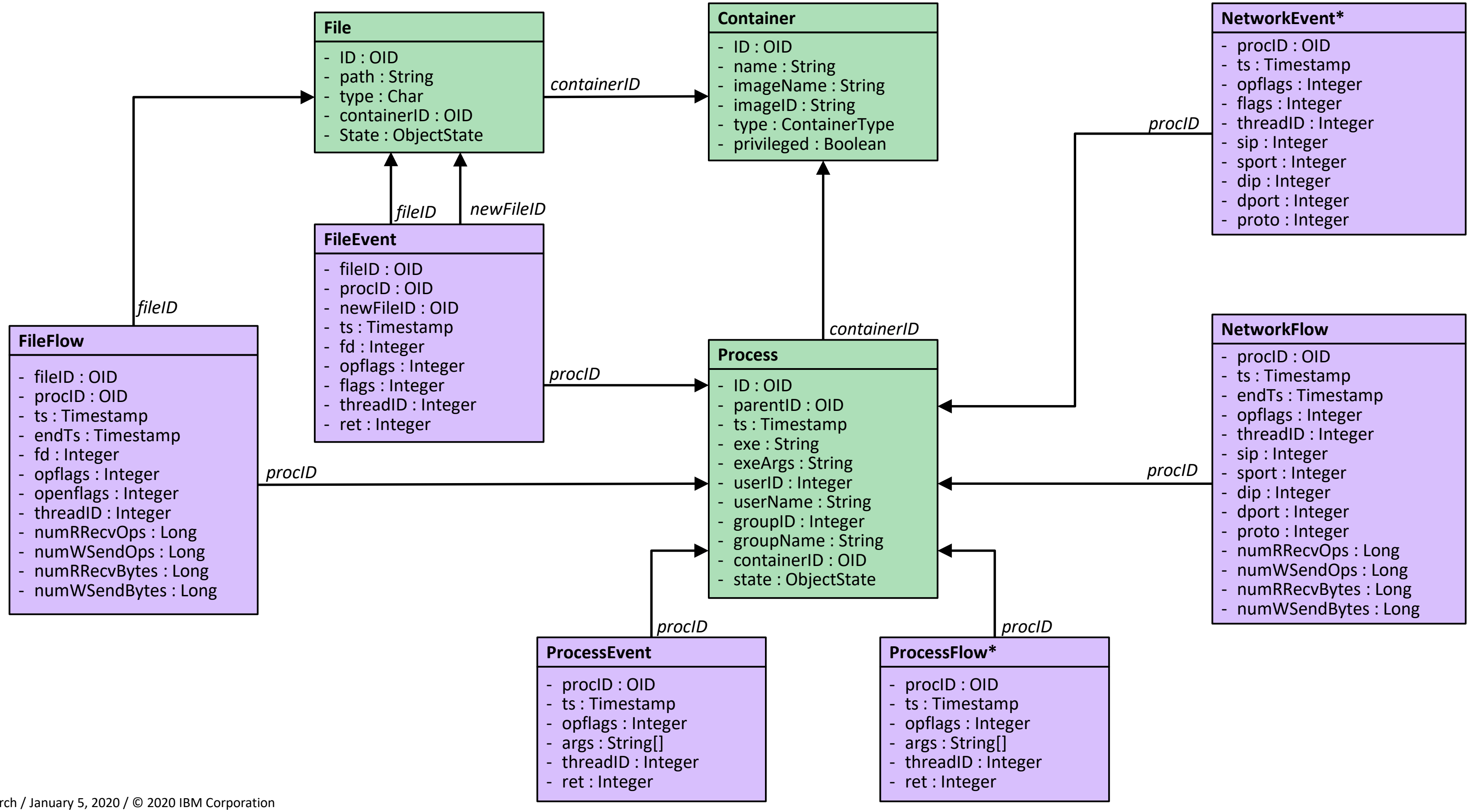
- "NetFlow" for system events
- Captures **process** control flows, **file** interactions, and **network** communications
- Container-aware, flow-centric semantics for system analytics


network monitoring
raw packet capture
NetFlow
system monitoring
system call tracing
SysFlow
full visibility (high data volume and processing cost)
semantic compression while preserving relevant information

“Semantically compressed system events for scalable security, compliance, and performance analytics.”



Object-Relational View



Operations

Process Events			
CLONE (process/thread)	EXEC (new process)	EXIT (process/thread)	SETUID (change uid)

File Events			
MKDIR	RMDIR	LINK	UNLINK
SYMLINK	RENAME		

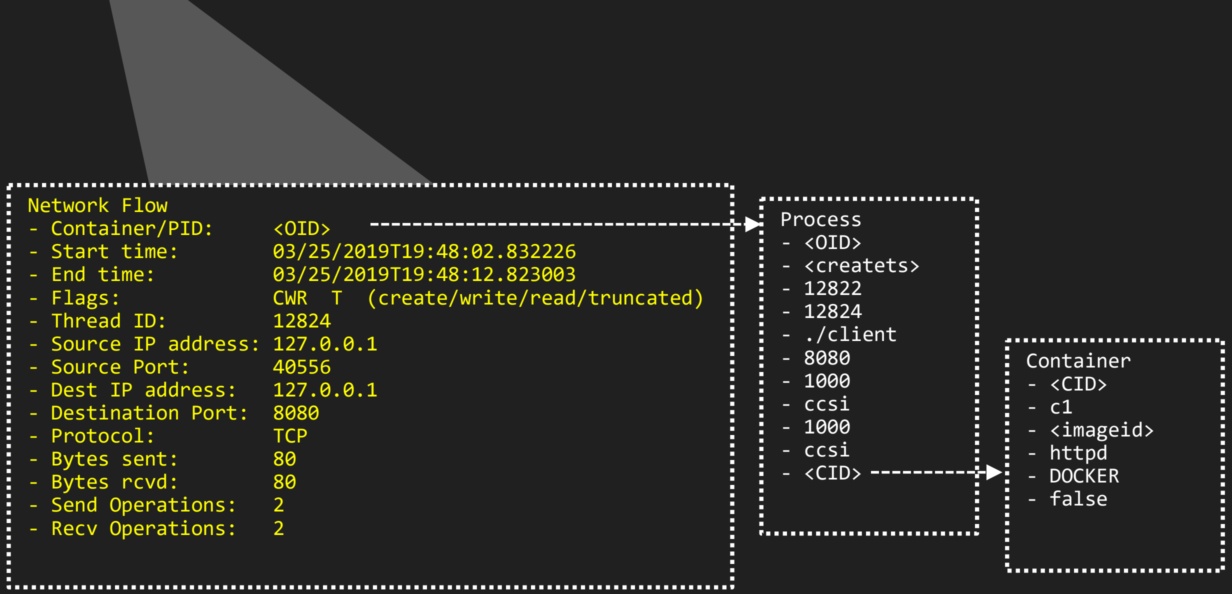
File Flows			
OPEN	SETNS (enter container)	READ	WRITE
CLOSE	MMAP	CHOWN/CHMOD	MOUNT/UMOUNT

Network Flows			
ACCEPT	CONNECT	SEND	RECEIVE
SHUTDOWN	CLOSE		

Implemented in current release
Planned for next release

Pretty-printed SysFlow trace (selected attributes):

```
|Process   |PID  |TID  |Op Flags |Start Time                |End Time                  |Ret |Resource                        |NBRead  |NBWrite |Cont |
|./server  |13823|13823|EXEC     |03/25/2019T19:48:00.704111|                          |   0|                                |        |        |  c1 |
|./server  |13823|13823|O     C  |03/25/2019T19:48:00.704232|03/25/2019T19:48:00.704242|    |/etc/ld.so.cache                |       0|       0|  c1 |
|./server  |13823|13823|O   R C  |03/25/2019T19:48:00.704263|03/25/2019T19:48:00.704310|    |/lib64/libc.so.6                |     832|       0|  c1 |
|./client  |13824|13824|EXEC     |03/25/2019T19:48:02.831502|                          |   0|                                |        |        |  c1 |
|./client  |13824|13824|O     C  |03/25/2019T19:48:02.831617|03/25/2019T19:48:02.831626|    |/etc/ld.so.cache                |       0|       0|  c1 |
|./client  |13824|13824|O   R C  |03/25/2019T19:48:02.831647|03/25/2019T19:48:02.831692|    |/lib64/libc.so.6                |     832|       0|  c1 |
|./client  |13824|13824|  CWR  T |03/25/2019T19:48:02.832226|03/25/2019T19:48:12.823003|    |127.0.0.1:40556-127.0.0.1:8080 |      80|      80|  c1 |
|./client  |13824|13824|EXIT     |03/25/2019T19:48:12.823003|                          |   2|                                |        |        |  c1 |
|./server  |13823|13823| A WR  T |03/25/2019T19:48:02.832197|03/25/2019T19:48:13.422795|    |127.0.0.1:40556-127.0.0.1:8080 |      80|      80|  c1 |
|./server  |13823|13823|EXIT     |03/25/2019T19:48:13.422795|                          |   2|                                |        |        |     |
```

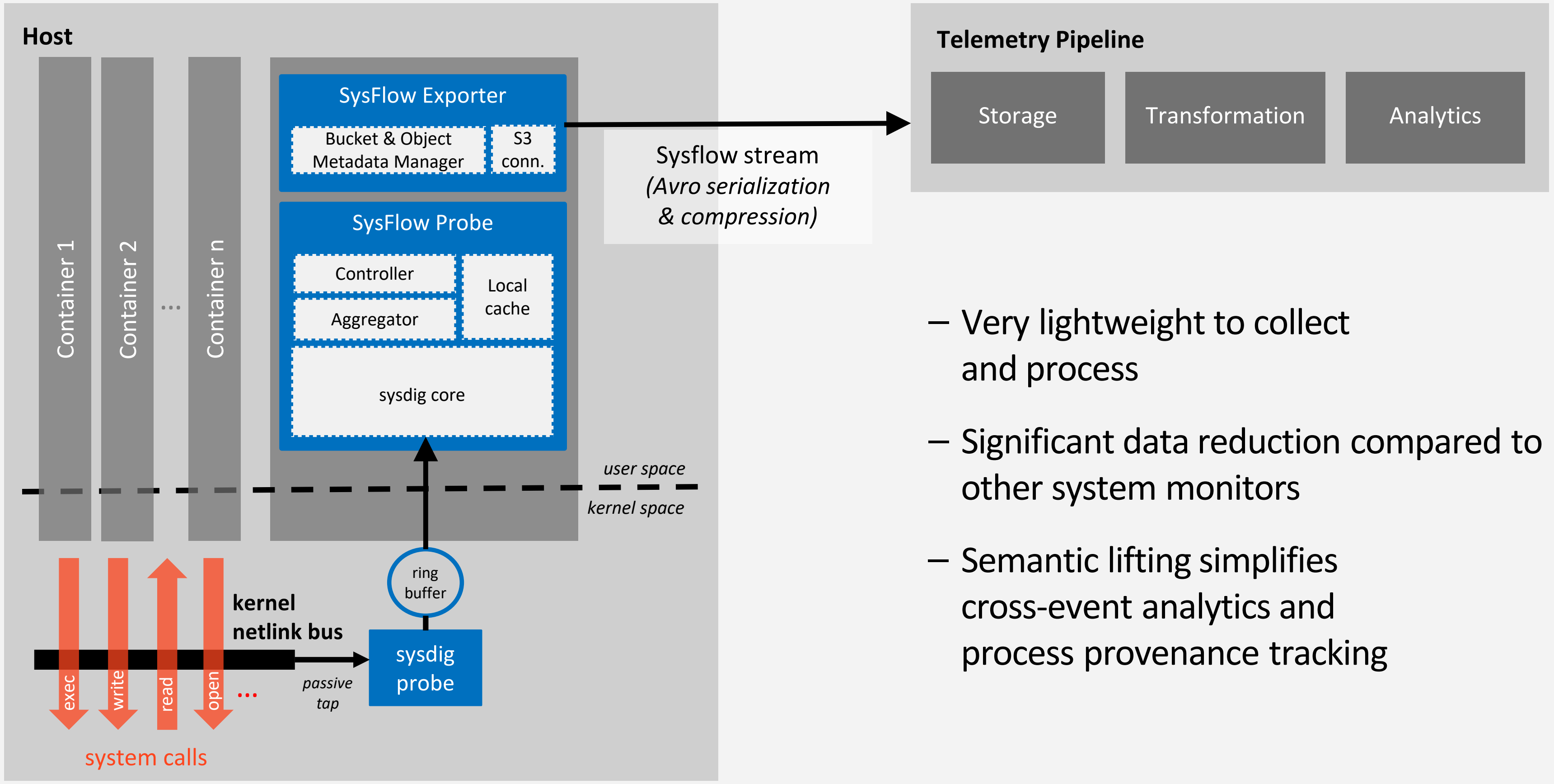


```
Network Flow
- Container/PID:      <OID>
- Start time:         03/25/2019T19:48:02.832226
- End time:           03/25/2019T19:48:12.823003
- Flags:              CWR  T  (create/write/read/truncated)
- Thread ID:          12824
- Source IP address:  127.0.0.1
- Source Port:        40556
- Dest IP address:    127.0.0.1
- Destination Port:   8080
- Protocol:           TCP
- Bytes sent:         80
- Bytes rcvd:         80
- Send Operations:    2
- Recv Operations:    2
```

```
Process
- <OID>
- <createts>
- 12822
- 12824
- ./client
- 8080
- 1000
- ccsi
- 1000
- ccsi
- <CID>
```

```
Container
- <CID>
- c1
- <imageid>
- httpd
- DOCKER
- false
```

Architectural Overview



- Very lightweight to collect and process
- Significant data reduction compared to other system monitors
- Semantic lifting simplifies cross-event analytics and process provenance tracking

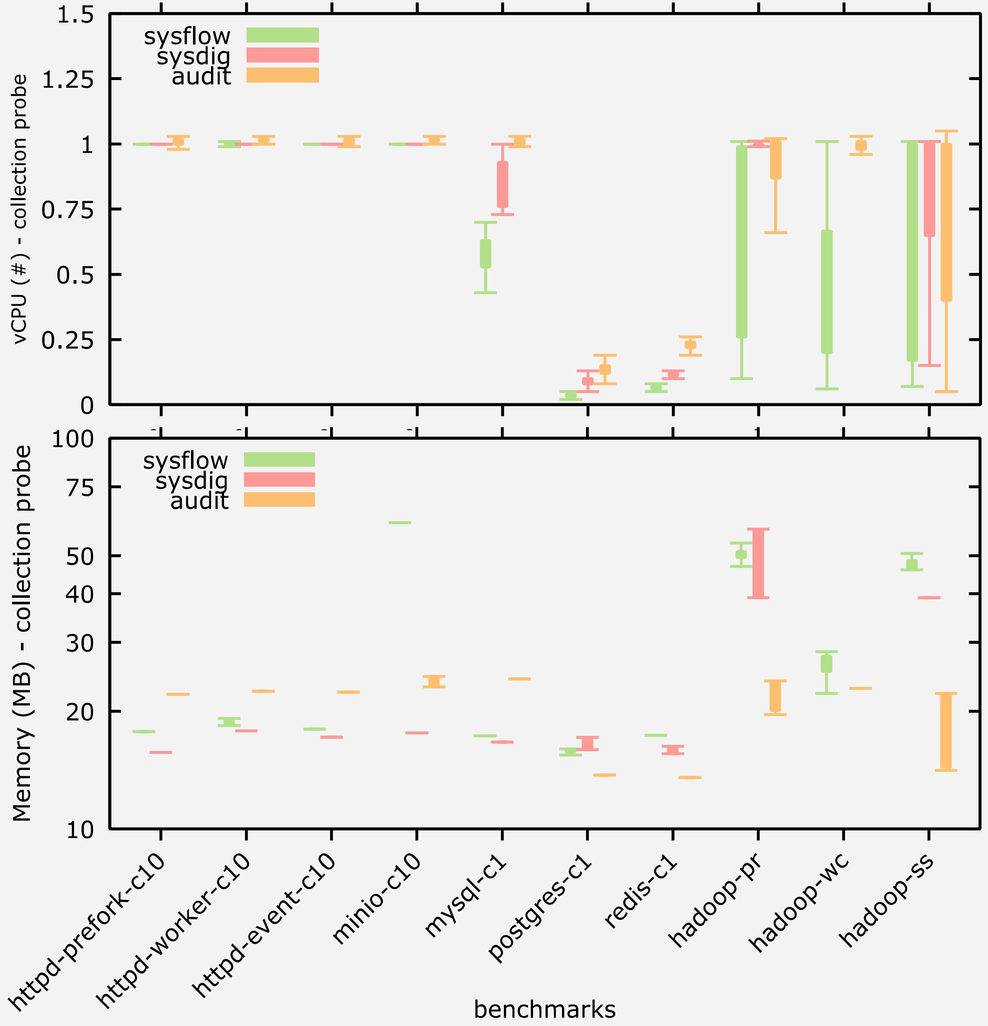
SysFlow Project

- Open source
  github.com/sysflow-telemetry
- Growing set of APIs
  Python, C/C++, Go, …
- Non disruptive and easily deployable
  helm and docker deployments

Collection Probe Performance

Benchmarks

HTTPD	Apache Benchmark (HTTP)
Minio	Wasabi S3 BM
Mysql	TPC-H HDB
Postgres	TPC-H HDB
Redis	TPC-H HDB
Hadoop	HiBench



Compression Factors

Trace sizes (# records) for different benchmarks

Benchmark	SysFlow		Sysdig		Audit	
	# records	Size	# records	Size	# records	Size
httpd_prefork	8.19E+05	11	7.45E+06	62	1.94E+05	78
httpd_worker	6.29E+05	7.9	6.40E+06	58	1.93E+05	80
httpd_event	6.42E+05	7.8	5.90E+06	53	1.85E+05	75
minio	7.52E+05	19.5	2.62E+07	552	2.19E+06	966
mysql	1.89E+02	0.09	1.56E+08	2592	7.86E+05	327
postgres	7.08E+03	0.22	9.31E+06	169.2	4.29E+06	2000
redis	9.10E+03	0.15	1.52E+07	68	8.31E+06	4100
hadoop	6.27E+05	16.4	1.09E+07	234	2.47E+06	1700

NetworkFlow (SysFlow)

- Operates at the transport layer
  - monitors system calls (e.g., accept, recv, send)
  - no concept of packet; no remote scan detection*
- Process-centric
  - links network activity to process thread

```
Network Flow
- Container/PID:     <OID>
- Start time:        03/25/2019T19:48:02.832226
- End time:          03/25/2019T19:48:12.823003
- Syscall Flags:     CWR  T
(create/write/read/truncated)
- Thread ID:         12824
- Source IP address: 127.0.0.1
- Source Port:       40556
- Dest IP address:   127.0.0.1
- Destination Port:  8080
- Protocol:          TCP
- Bytes sent:        80
- Bytes rcvd:        80
- Send Operations:   2
- Recv Operations:   2
```

NetFlow

- Operates at the network layer
  - can monitor passive network traffic (to host ports not listening)
- Network-centric
  - no process/workload correlation
  - centralized collection points

```
NetFlow
- Start time:         03/25/2019T19:48:02.832226
- End time:           03/25/2019T19:48:12.823003
- TCP Flags           SA  F
- Source IP address:  127.0.0.1
- Source Port:        40556
- Dest IP address:    127.0.0.1
- Destination Port:   8080
- Protocol:           TCP
- Bytes sent:         80
- Bytes rcvd:         80
- Packets sent:       2
- Packets rcvd:       2
```

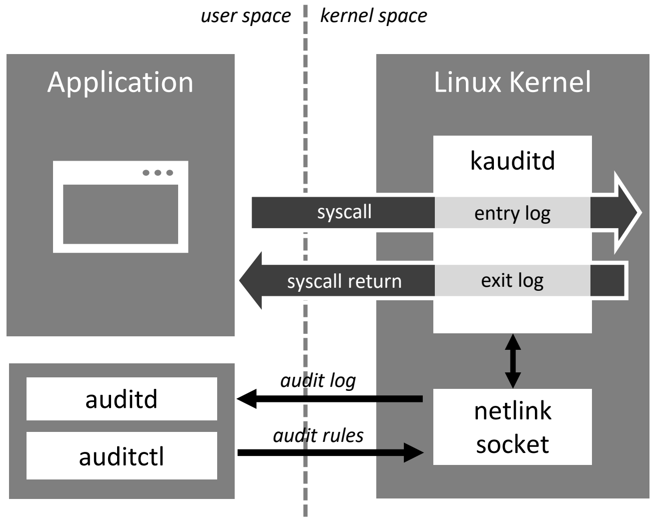
How about Linux Audit?

– Uses pre-configured rules to track system events
  - can be coupled with LSMs for **runtime monitoring**

– Lacks container-awareness
  - containers are user space constructs; kernel cannot track container provenance and actions
  - *nsID* proposal discarded; *container ID* RFE

– Does not support binary output formats

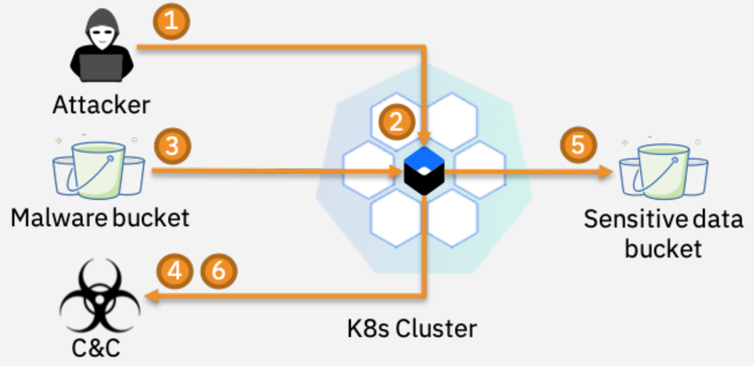
– Can suffer from log spills due to backlog queue limits
  - kernel backlog queue can be increased, but takes up kernel memory; difficult to monitor large process trees



Demo

Simplified attack kill chain

1. Perform reconnaissance on the cluster's public services and look for vulnerabilities
2. Exploit identified vulnerabilities to drop and run malicious code in one of the containers
3. The malicious payload downloads malware, installs and bootstraps it
4. The malware connects to the C&C and get instructions
5. The malware connects to a data store and retrieves sensitive data
6. The data is exfiltrated through the C&C



Thank you

github.com/sysflow-telemetry

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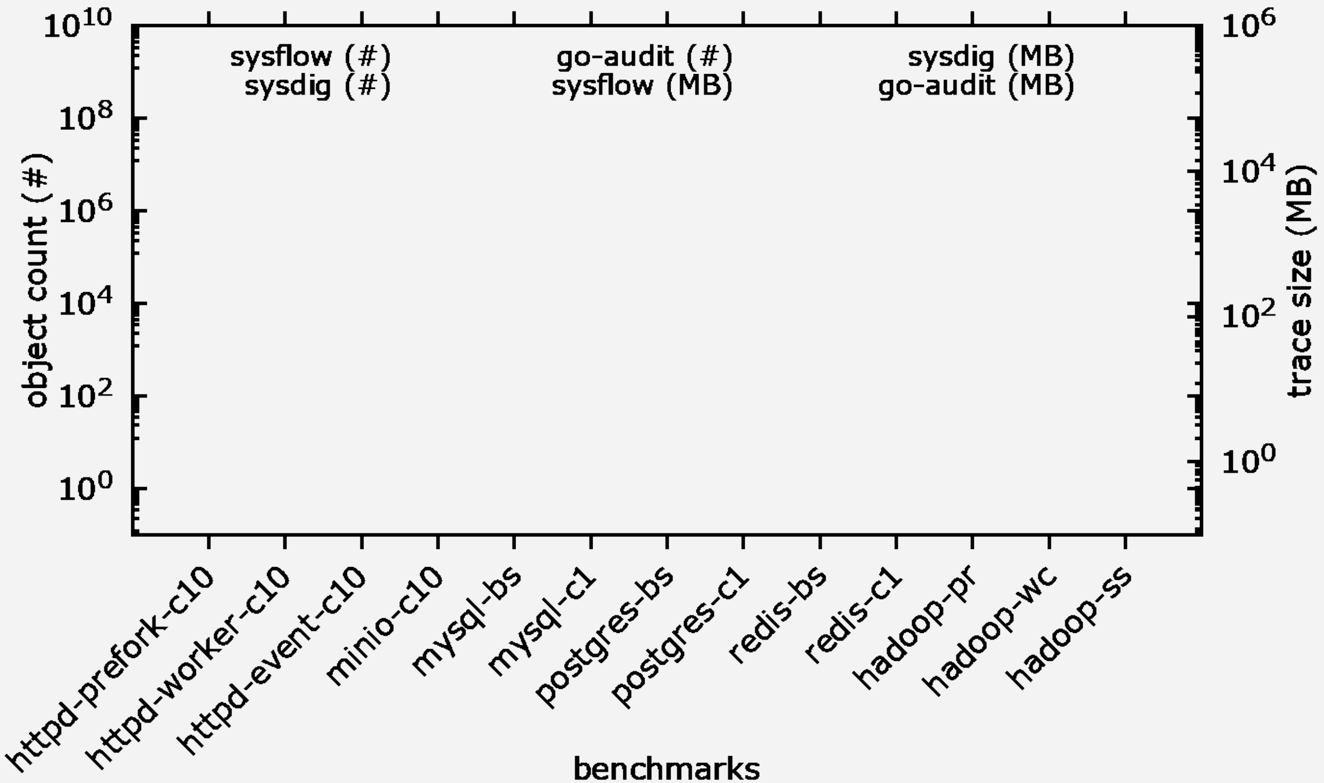
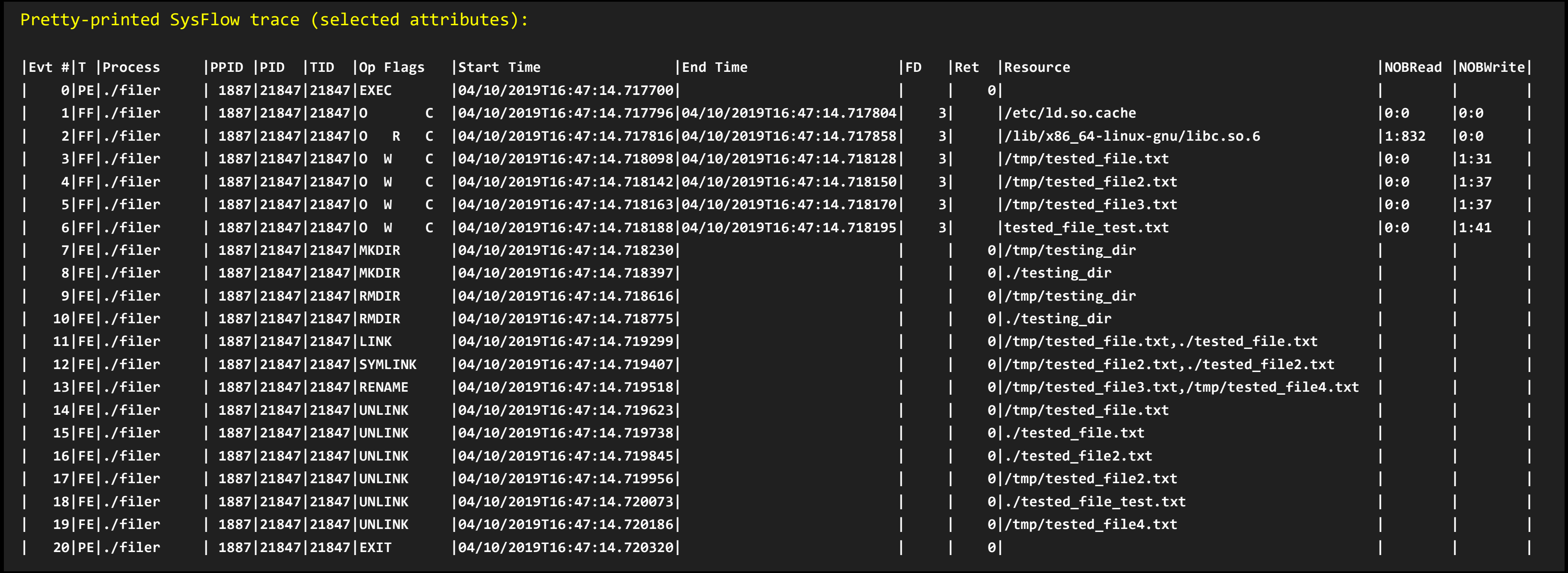
sysflow-telemetry.slack.com
sysflow@us.ibm.com

SysFlow is an open source research project and not an IBM proprietary product. We hope to establish an open-source community around the project.

Compression Factors





```
Pretty-printed SysFlow trace (selected attributes):

|Evt #|T |Process     |PPID |PID  |TID  |Op Flags    |Start Time                |End Time                  |FD   |Ret  |Resource                                     |NOBRead |NOBWrite|
|    0|PE|./filer     | 1887|21847|21847|EXEC        |04/10/2019T16:47:14.717700|                          |     |    0|                                             |        |        |
|    1|FF|./filer     | 1887|21847|21847|O       C   |04/10/2019T16:47:14.717796|04/10/2019T16:47:14.717804|    3|     |/etc/ld.so.cache                             |0:0     |0:0     |
|    2|FF|./filer     | 1887|21847|21847|O   R   C   |04/10/2019T16:47:14.717816|04/10/2019T16:47:14.717858|    3|     |/lib/x86_64-linux-gnu/libc.so.6              |1:832   |0:0     |
|    3|FF|./filer     | 1887|21847|21847|O  W    C   |04/10/2019T16:47:14.718098|04/10/2019T16:47:14.718128|    3|     |/tmp/tested_file.txt                         |0:0     |1:31    |
|    4|FF|./filer     | 1887|21847|21847|O  W    C   |04/10/2019T16:47:14.718142|04/10/2019T16:47:14.718150|    3|     |/tmp/tested_file2.txt                        |0:0     |1:37    |
|    5|FF|./filer     | 1887|21847|21847|O  W    C   |04/10/2019T16:47:14.718163|04/10/2019T16:47:14.718170|    3|     |/tmp/tested_file3.txt                        |0:0     |1:37    |
|    6|FF|./filer     | 1887|21847|21847|O  W    C   |04/10/2019T16:47:14.718188|04/10/2019T16:47:14.718195|    3|     |tested_file_test.txt                         |0:0     |1:41    |
|    7|FE|./filer     | 1887|21847|21847|MKDIR       |04/10/2019T16:47:14.718230|                          |     |    0|/tmp/testing_dir                             |        |        |
|    8|FE|./filer     | 1887|21847|21847|MKDIR       |04/10/2019T16:47:14.718397|                          |     |    0|./testing_dir                                |        |        |
|    9|FE|./filer     | 1887|21847|21847|RMDIR       |04/10/2019T16:47:14.718616|                          |     |    0|/tmp/testing_dir                             |        |        |
|   10|FE|./filer     | 1887|21847|21847|RMDIR       |04/10/2019T16:47:14.718775|                          |     |    0|./testing_dir                                |        |        |
|   11|FE|./filer     | 1887|21847|21847|LINK        |04/10/2019T16:47:14.719299|                          |     |    0|/tmp/tested_file.txt,./tested_file.txt       |        |        |
|   12|FE|./filer     | 1887|21847|21847|SYMLINK     |04/10/2019T16:47:14.719407|                          |     |    0|/tmp/tested_file2.txt,./tested_file2.txt     |        |        |
|   13|FE|./filer     | 1887|21847|21847|RENAME      |04/10/2019T16:47:14.719518|                          |     |    0|/tmp/tested_file3.txt,/tmp/tested_file4.txt  |        |        |
|   14|FE|./filer     | 1887|21847|21847|UNLINK      |04/10/2019T16:47:14.719623|                          |     |    0|/tmp/tested_file.txt                         |        |        |
|   15|FE|./filer     | 1887|21847|21847|UNLINK      |04/10/2019T16:47:14.719738|                          |     |    0|./tested_file.txt                            |        |        |
|   16|FE|./filer     | 1887|21847|21847|UNLINK      |04/10/2019T16:47:14.719845|                          |     |    0|./tested_file2.txt                           |        |        |
|   17|FE|./filer     | 1887|21847|21847|UNLINK      |04/10/2019T16:47:14.719956|                          |     |    0|/tmp/tested_file2.txt                        |        |        |
|   18|FE|./filer     | 1887|21847|21847|UNLINK      |04/10/2019T16:47:14.720073|                          |     |    0|./tested_file_test.txt                       |        |        |
|   19|FE|./filer     | 1887|21847|21847|UNLINK      |04/10/2019T16:47:14.720186|                          |     |    0|/tmp/tested_file4.txt                        |        |        |
|   20|PE|./filer     | 1887|21847|21847|EXIT        |04/10/2019T16:47:14.720320|                          |     |    0|                                             |        |        |
```