Monitoring Containerised Application Environments with eBPF

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About ntop.org

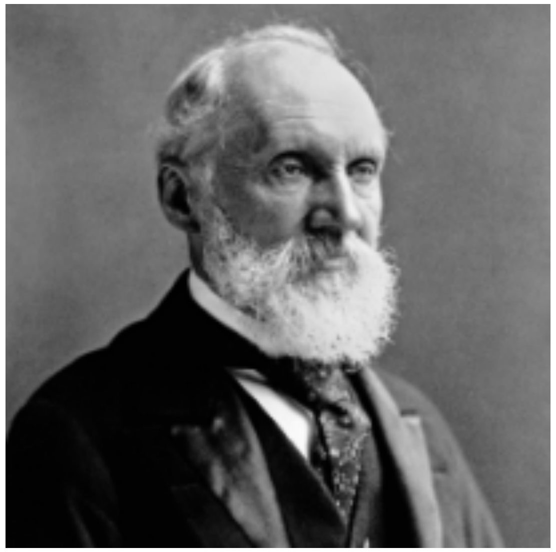
- ntop develops of open source network traffic monitoring applications.
- ntop (circa 1998) is the first app we released and it is a web-based network monitoring application.
- Today our products range include
  - Traffic monitoring tools
  - High-speed packet processing
  - Deep-packet inspection
  - Cybersecurity applications

What is Network Traffic Monitoring?

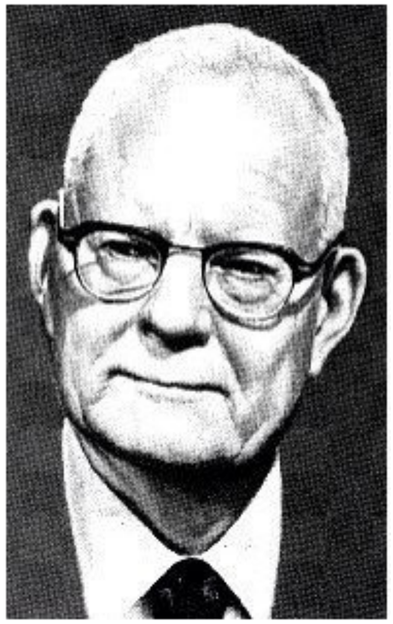
- The key objective behind network traffic monitoring is to *ensure availability and smooth operations on a computer network*. Network monitoring incorporates network sniffing and packet capturing techniques in monitoring a network. Network traffic monitoring generally requires reviewing each incoming and outgoing packet.

https://www.techopedia.com/definition/29977/network-traffic-monitoring

Motivation For Traffic Monitoring



If you can't measure it, you can't improve it
(Lord Kelvin, 1824 – 1907)



Without data you're just another persone with an opinion
(W. Edwards Deming, 1900 – 1993)

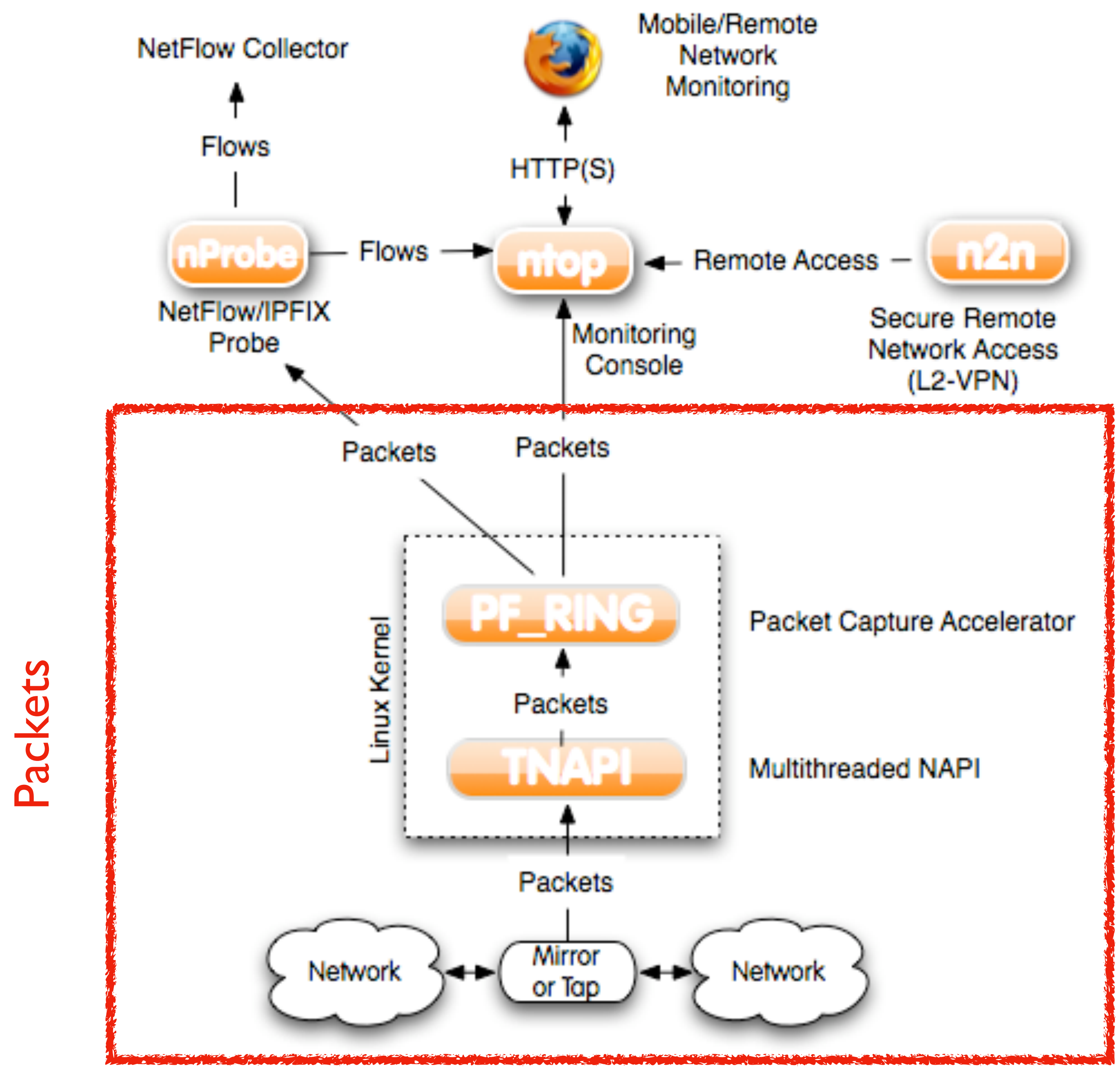
What Happens in Our Network?

- Do we have control over our network?
- It’s not possible to imagine a healthy network without a clear understanding of traffic flowing on our network.
- Knowledge is the first step towards evaluation of potential network security issues.
- Event correlation can provide us timely information about our network health.

(We Used to Say) Packets Never Lie

- Packet analysis provide useful information for understanding:
  - Network traffic issues.
  - Network usage not compliant with network policies (note: firewalls cannot help here).
  - Non-optimal performance.
  - Potential security flaws.
  - Ongoing (latent) attacks.
  - Data breach.
- But… packets are too fine grained so we need to aggregate them into flows (5 tuple IP/port src/dst, protocol).

ntop Ecosystem (2009): Packets Everywhere



ntop Ecosystem (2019): Still Packets [1/2]

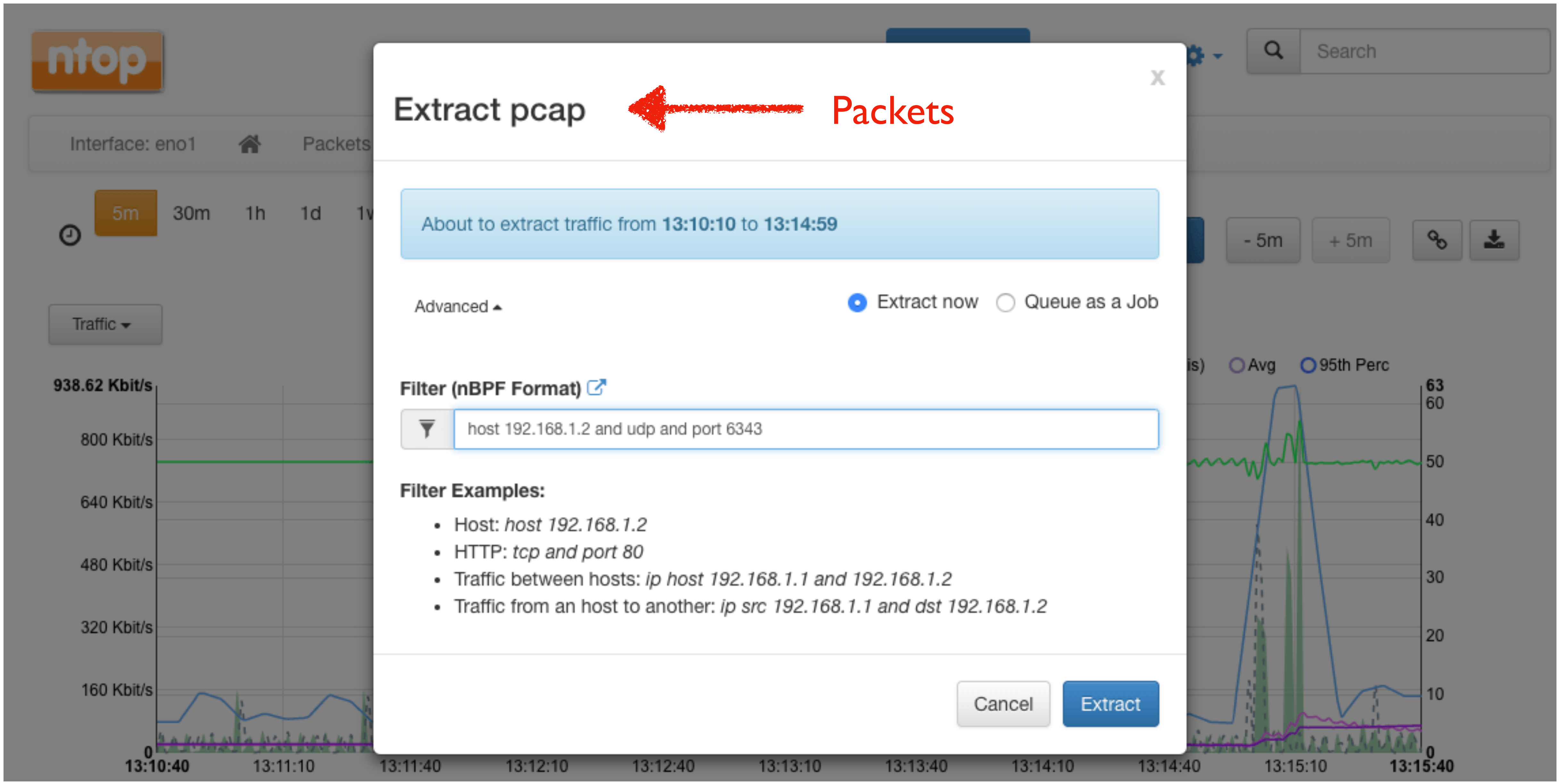
Packets

Top Clients · 10 · IP Version · Explorer

Flows

Host Name	IP Address	Bytes Sent to Servers	Throughput	Actions
192.168.2.130	192.168.2.130	193.51 KB	22.02 kbit/s	
devel	192.168.2.222	10.18 KB	1.16 kbit/s	
192.168.2.136	192.168.2.136	1.26 KB	143.22 bit/s	
192.168.2.126	192.168.2.126	864 Bytes	96 bit/s	
192.168.2.182	192.168.2.182	860 Bytes	95.56 bit/s	
192.168.2.142	192.168.2.142	258 Bytes	28.67 bit/s	
192.168.1.100	192.168.1.100	258 Bytes	28.67 bit/s	
NoIP	0.0.0.0	98 Bytes	10.89 bit/s	

ntop Ecosystem (2019): Still Packets [2/2]

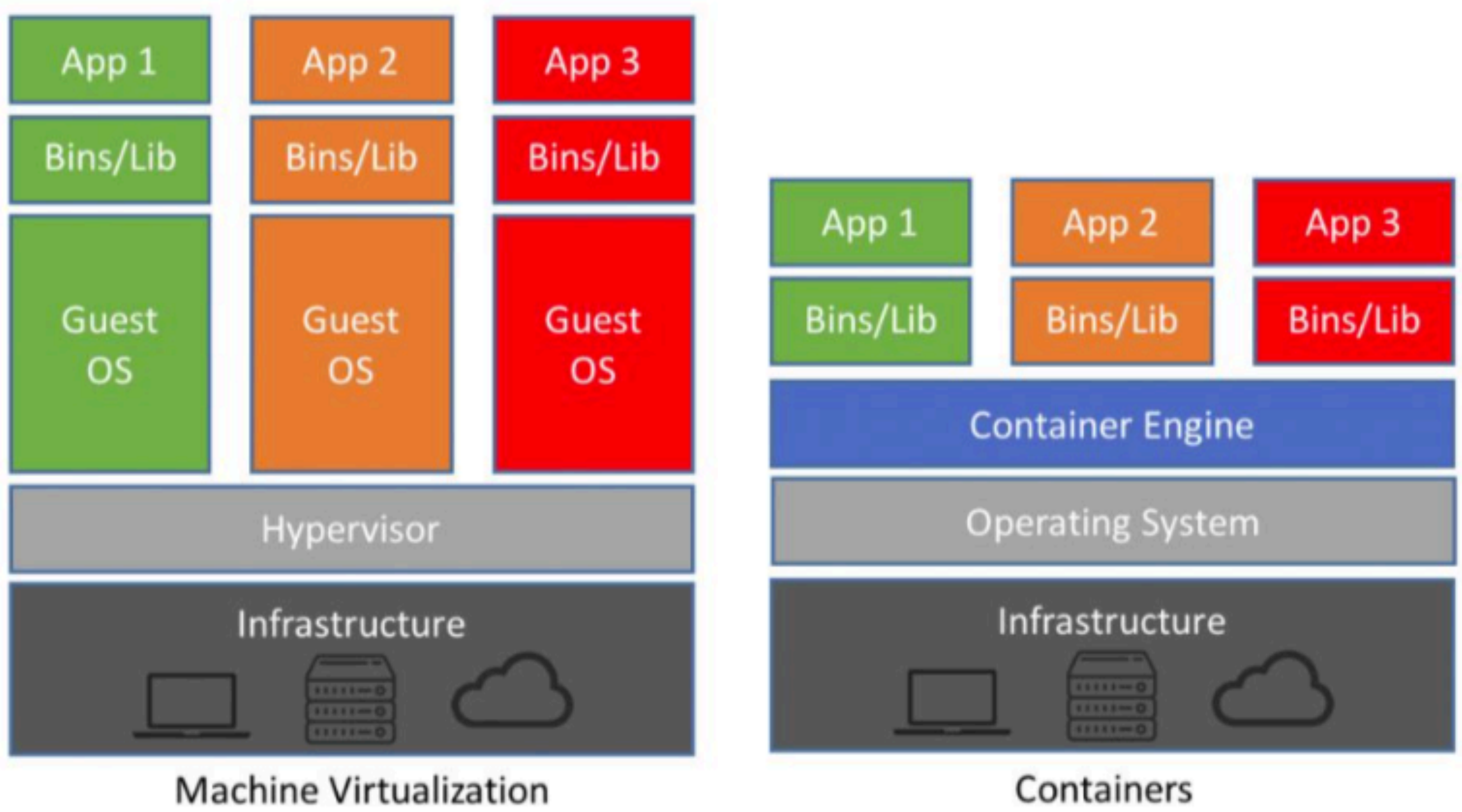


What's Wrong with Packets?

Nothing in general but…

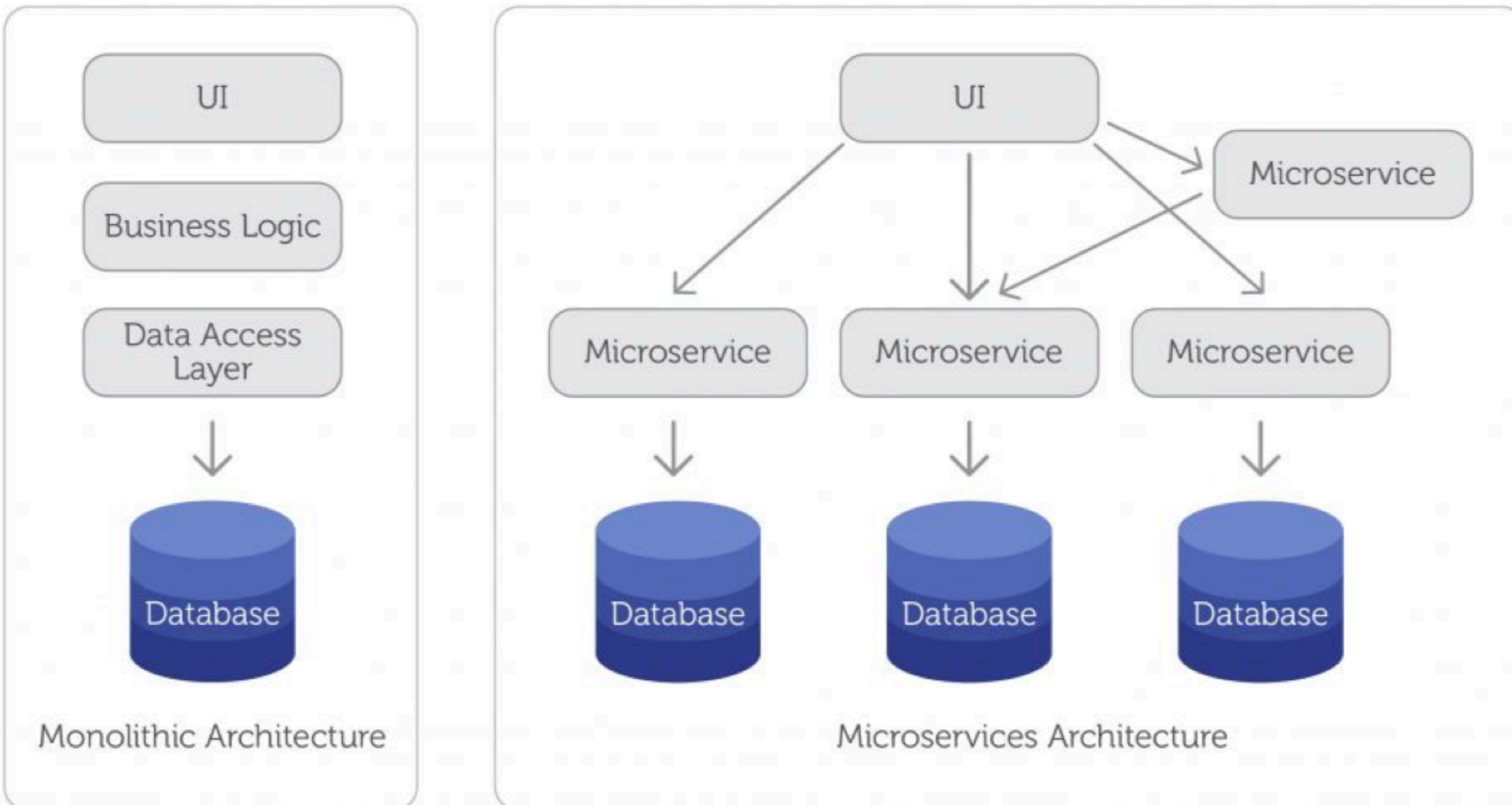
- It is a paradigm good for monitoring network traffic from outside of systems on a passive way.
- Encryption is challenging DPI techniques (BTW ntop maintains an open source DPI toolkit called nDPI).
- Developers need to handle fragmentation, flow reconstruction, packet loss/retransmissions… metrics that would be already available inside a system.

What about Containers?



- Make services portable across host platforms.
- Provide an additional layer of isolation over processes.
- Allow each service to use its own dependencies.

From Monolith to Microservices [1/2]



From Monolith to Microservices [2/2]

- Code of *each microservice* is stored in an *isolated container*, runs its own memory space, and functions independently.
- Scaling of one component is possible.
- Clearly organised architecture. Decoupled units have their specific jobs, can be reconfigured without affecting the entire application.
- Deployments don’t require downtime.
- If a microservice crashes, the rest of the system keeps going.
- Each microservice can be scaled individually according to its needs.
- Services can use different tech stacks (developers are free to code in any language).

What's Wrong with Packets on Containerised Environments?

- Container lifecycle and cardinality changes according to the workload.
- Each container has a virtual ethernet interface so commands such as "tcpdump -i veth40297a6" won't help as devops think in terms of container name, pod and namespace rather than veth.
- Intra-container traffic stays inside the system without hitting the wire, thus monitoring traffic from/to the host won't help.

From Challenges to Solutions

- Enhance network visibility with system introspection.
- Handle virtualisation as first citizen and don't be blind (yes we want to see containers interaction).
- Complete our monitoring journey and…
  - System Events: processes, users, containers.
  - Flows
  - Packets
- …bind system events to network traffic for enabling continuous drill down: system events uncorrelated with network traffic are basically useless.

Network and System Visibility

- Even on a container-centric sites we still need to:
  - Monitor the infrastructure where containers are deployed: SNMP, NetFlow/IPFIX.
  - Enable system introspection also to (legacy) non-containerised systems so the whole infrastructure is monitored seamlessly.
  - Export visibility metrics to existing monitoring tools on a format they can understand. This to enhance the existing monitoring console and avoid custom solutions.

What about NETLINK ? [1/3]

- AF_NETLINK sockets are used for IPC between kernel and userspace processes, heavily used for monitoring and configuration (e.g. iproute2).
- What about using NETLINK_INET_DIAG for monitoring sockets?
- Good idea but events are limited to socket close

```
enum sknetlink_groups {
        SKNLGRP_NONE,
        SKNLGRP_INET_TCP_DESTROY,
        SKNLGRP_INET_UDP_DESTROY,
        SKNLGRP_INET6_TCP_DESTROY,
        SKNLGRP_INET6_UDP_DESTROY,
        __SKNLGRP_MAX,
};
```

From linux/sock_diag.h

What about NETLINK ? [2/3]

```
for(std::map<u_int32_t,u_int32_t>::iterator it=namespaces.begin(); it!=namespaces.end(); ++it) {
  u_int32_t ns  = it->first;
  u_int32_t pid = it->second;

  switch_namespace(ns, pid);
  ...
    if(send_diag_msg(nl_sock, (j == 0) ? AF_INET : AF_INET6, i) < 0) {
      perror("sendmsg: ");
      return EXIT_FAILURE;
    }

    while(do_loop) {
      numbytes = recv(nl_sock, recv_buf, sizeof(recv_buf), 0);
      nlh = (struct nlmsghdr*) recv_buf;

      while(NLMSG_OK(nlh, numbytes)) {
        if(nlh->nlmsg_type == NLMSG_DONE)  {  do_loop = 0; break; }

        diag_msg = (struct inet_diag_msg*) NLMSG_DATA(nlh);
        rtalen = nlh->nlmsg_len - NLMSG_LENGTH(sizeof(*diag_msg));
        parse_diag_msg(&inodes, diag_msg, rtalen, &results, i, ns);

        nlh = NLMSG_NEXT(nlh, numbytes);
      }
    }

  close(netns); /* Close namespace */
}
```

Jump on the container namespace

Read network information

What about NETLINK ? [3/3]

[TCP4][deri/1000][/home/deri/.dropbox-dist/dropbox-lnx.x86_64-70.4.93/dropbox][PID: 15972][192.168.1.23:48050 <-> 34.228.137.164:443][CLOSE-WAIT][Retrans 0][UnackSegments 0][LostPkts 0][RTT 103.67 ms (variance 5.712 ms)]

[TCP4][deri/1000][/home/deri/.dropbox-dist/dropbox-lnx.x86_64-70.4.93/dropbox][PID: 15972][192.168.1.23:47178 <-> 162.125.18.133:443][ESTABLISHED][Retrans 0][UnackSegments 0][LostPkts 0][RTT 103.57 ms (variance 15.179 ms)]

[TCP4][root/0][/home/deri/ntopng/ntopng][PID: 11346][127.0.0.1:39156 <-> 127.0.0.1:6379][ESTABLISHED][Retrans 0][UnackSegments 0][LostPkts 0][RTT 0.031 ms (variance 0.007 ms)]

[TCP4][root/0][/home/deri/ntopng/ntopng][PID: 11346][127.0.0.1:39154 <-> 127.0.0.1:6379][ESTABLISHED][Retrans 0][UnackSegments 0][LostPkts 0][RTT 0.101 ms (variance 0.074 ms)]

[TCP4][deri/1000][/usr/lib/thunderbird/thunderbird][PID: 8177][192.168.1.23:51580 <-> 93.62.150.157:993][ESTABLISHED][Retrans 0][UnackSegments 0][LostPkts 0][RTT 7.675 ms (variance 0.229 ms)]

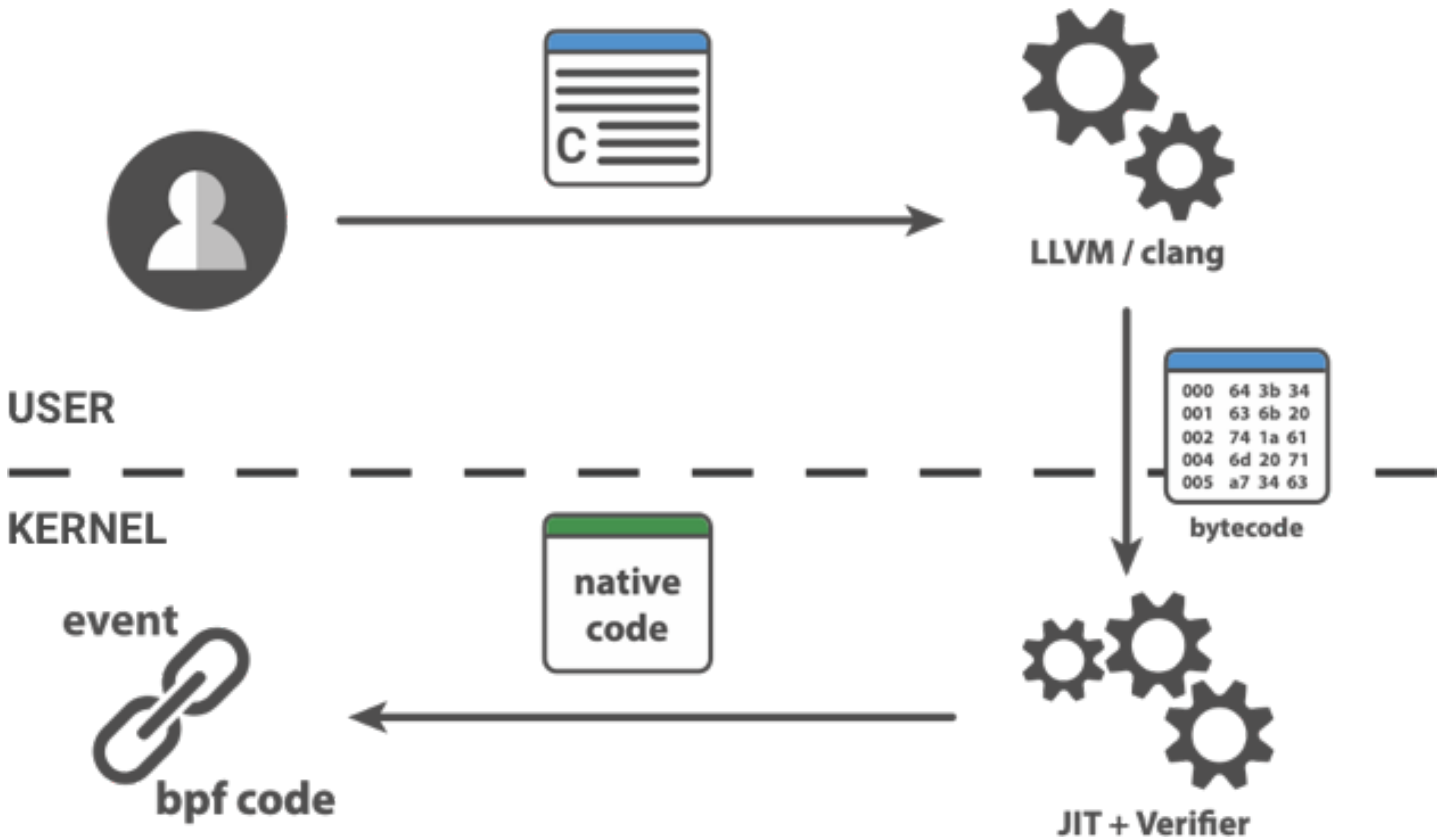
[TCP4][redis/118][/usr/bin/redis-check-rdb][PID: 1960][127.0.0.1:6379 <-> 127.0.0.1:39154][ESTABLISHED][Retrans 0][UnackSegments 0][LostPkts 0][RTT 13.701 ms (variance 20.28 ms)]

[TCP4][deri/1000][/home/deri/.dropbox-dist/dropbox-lnx.x86_64-70.4.93/dropbox][PID: 15972][192.168.1.23:46300 <-> 162.125.18.133:443][ESTABLISHED][Retrans 0][UnackSegments 0][LostPkts 0][RTT 100.092 ms (variance 0.043 ms)]

Welcome to eBPF

- In 1997, it was introduced in Linux kernel as a technology for in-kernel packet filtering. The authors are Steven McCanne and Van Jacobson from Lawrence Berkeley Laboratory.
- eBPF extended the original BPF virtual machine, allowing it to process other kind of events execute various actions other than packet filtering.

How eBPF Works



eBPF and Containers

- Container can be found in proc/cgroup, however retrieving information from there is a too slow operation.
- Because containers are processes, we can navigate through kernel data structures and read information from inside the kernel where the container identifier can be collected.
- Further interaction with the container runtimes (e.g. containerd or dockerd) in use is required to collect detailed information

Why eBPF is Interesting for Monitoring

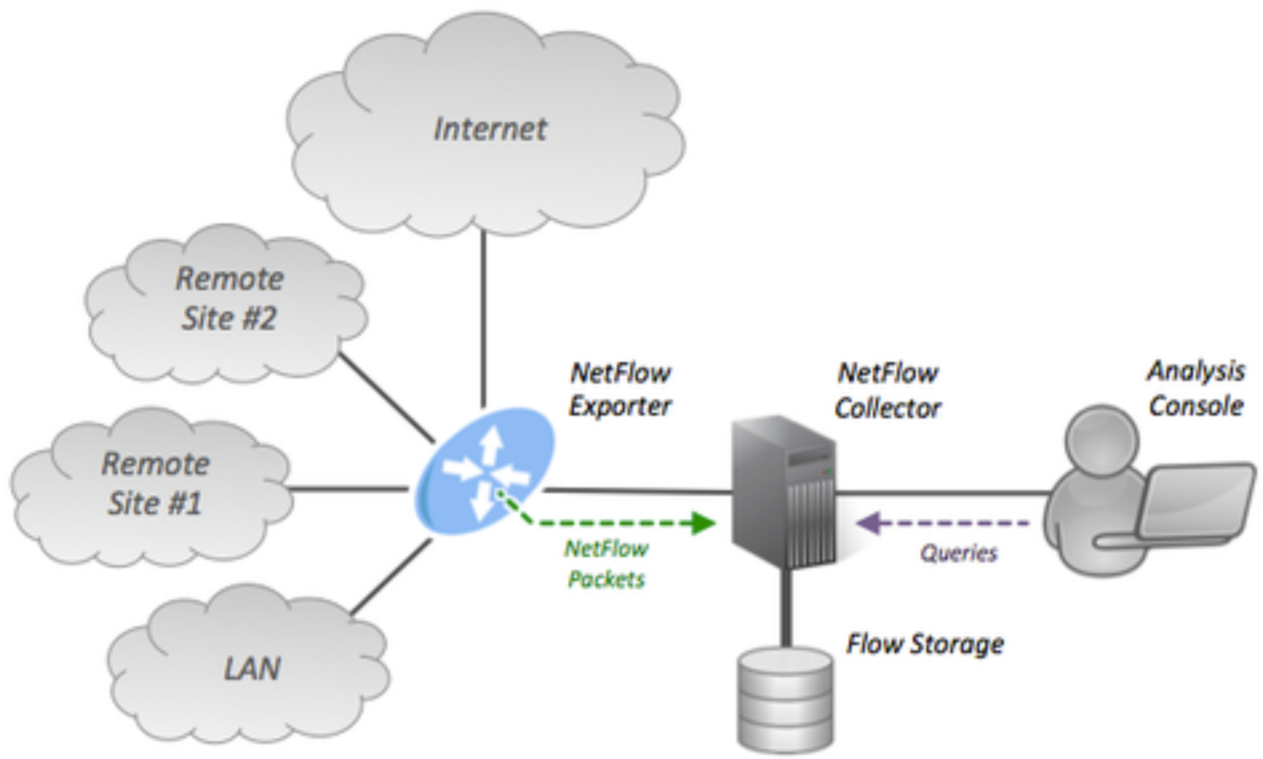
- It gives the ability to avoid sending everything to user-space but perform in kernel computations and send metrics to user-space.
- We can track more than system calls (i.e. be notified when there is a transmission on a TCP connection without analyzing packets).
- It is part of modern Linux systems (i.e. no kernel module needed).

libebpflow: eBPF for System Visibility

- Our aim has been to create an open-source library that offers a simple way to interact with eBPF network events in a transparent way.
- Reliable and trustworthy information on the status of the system when events take place.
- Low overhead event-based monitoring
- Information on users, network statistics, containers and processes
- Go and C/C++ support
- https://github.com/ntop/libebpfflow (GNU LGPL)

nProbe: A Container-aware Probe [1/2]

- nProbe is a home-grown packet-based NetFlow/IPFIX probe and collector that can generate flow information (i.e. 5-tuple key with traffic counters).



nProbe: A Container-aware Probe [2/2]

- The original nProbe has been extended with libebpf and Netlink support for exporting network traffic information and statistics.

	eBPF	Netlink
Availability	Modern Linux (Centos 7, Ubuntu 16.04+)	Any Linux
Admin Rights	Root	Any User
Purpose	Provide information about traffic flows (creation, deletion, and updates such as retransmissions).	Periodic network status (e.g. established connections) and traffic statistics (e.g. interface stats)

Monitoring Features

- Ability to track (TCP and UDP, IPv4/v6):
  - Flow creation/deletion
  - Periodic events (e.g. in case of TCP retransmission)
  - Periodic flow counter export
  - Container/process/user to traffic
- Minimum CPU/memory requirements

```
top - 13:04:42 up 19 days,  3:05,  4 users,  load average: 0.33, 0.23, 0.25
Tasks:   1 total,   0 running,   1 sleeping,   0 stopped,   0 zombie
%Cpu(s):  1.5 us,  0.8 sy,  0.0 ni, 97.6 id,  0.1 wa,  0.0 hi,  0.0 si,  0.0 st
KiB Mem : 16366308 total,   179176 free, 10970808 used,  5216324 buff/cache
KiB Swap: 16716796 total, 14830332 free,  1886464 used.  4970688 avail Mem

  PID USER      PR  NI    VIRT    RES    SHR S  %CPU %MEM     TIME+ COMMAND
 4760 root      20   0  332132 110604  43372 S   0.7  0.7   1:56.50 nprobe_mini
```

Flow Creation / Termination / Status

9/Apr/2019 12:09:54 [EBPF.cpp:178] [eBPF] { "timestamp": "1556532594.175074", "LOCAL_PROCESS": { "PID": 17932, "UID": 135, "GID": 145, "PROCESS_PATH": "\/usr\/bin\/influxd" }, "LOCAL_FATHER_PROCESS": { "PID": 1, "UID": 0, "GID": 0, "PROCESS_PATH": "\/lib\/systemd\/systemd" }, "EVENT_TYPE": "**ACCEPT**", "IP_PROTOCOL_VERSION": 4, "PROTOCOL": 6, "L4_LOCAL_PORT": 51176, "L4_REMOTE_PORT": 8086, "IPV4_LOCAL_ADDR": "127.0.0.1", "IPV4_REMOTE_ADDR": "127.0.0.1", "EXPORTER_IPV4_ADDRESS": “x.x.x.x” }

29/Apr/2019 12:09:54 [EBPF.cpp:178] [eBPF] { "timestamp": "1556532594.187459", "LOCAL_PROCESS": { "PID": 31141, "UID": 135, "GID": 145, "PROCESS_PATH": "\/usr\/bin\/influxd" }, "LOCAL_FATHER_PROCESS": { "PID": 1, "UID": 0, "GID": 0, "PROCESS_PATH": "\/lib\/systemd\/systemd" }, "EVENT_TYPE": "**CLOSE**", "IP_PROTOCOL_VERSION": 4, "PROTOCOL": 6, "L4_LOCAL_PORT": 51176, "L4_REMOTE_PORT": 8086, "IPV4_LOCAL_ADDR": "127.0.0.1", "IPV4_REMOTE_ADDR": "127.0.0.1", "EXPORTER_IPV4_ADDRESS": "x.x.x.x" }

28/Apr/2019 23:48:51 [Netlink.cpp:830] [**Netlink**] [flow] { "timestamp": "1556488131.124793", "PROTOCOL": 6, "IP_PROTOCOL_VERSION": 4, "USER_NAME": "influxdb", "IPV4_LOCAL_ADDR": "127.0.0.1", "IPV4_REMOTE_ADDR": "0.0.0.0", "L4_LOCAL_PORT": 8088, "L4_REMOTE_PORT": 0, "TCP": { "CONN_STATE": "**LISTEN**" }, "LOCAL_PROCESS": { "PROCESS_ID": 31127, "USER_ID": 135, "PROCESS_PATH": "\/usr\/bin\/influxd" }, "EXPORTER_IPV4_ADDRESS": “x.x.x.x" }

sFlow/SNMP-like Interface Stats

28/Apr/2019 23:46:29 [Netlink.cpp:1159] [Netlink] [counters] { "timestamp": "1555983411.568049", "ifName": "veth70b1674b", "ifIndex": 12, "LOCAL_CONTAINER": { "**KUBE**": { "NAME": "dnsmasq", "POD": "kube-dns-6bfbdd666c-2wflq", "NS": "kube-system" } }, "ifInOctets": 17973342, "ifInPackets": 75520, "ifInErrors": 0, "ifInDrops": 0, "ifOutOctets": 17525175, "ifOutPackets": 77059, "EXPORTER_IPV4_ADDRESS": "x.x.x.x" }

28/Apr/2019 23:46:29 [Netlink.cpp:1159] [Netlink] [counters] { "timestamp": "1555983411.568269", "ifName": "veth9999d981", "ifIndex": 14, "LOCAL_CONTAINER": { "**KUBE**": { "NAME": "heapster", "POD": "heapster-v1.5.2-6b5d7b57f9-qx6kz", "NS": "kube-system" } }, "ifInOctets": 49552061, "ifInPackets": 50511, "ifInErrors": 0, "ifInDrops": 0, "ifOutOctets": 55473238, "ifOutPackets": 57081, "EXPORTER_IPV4_ADDRESS": "x.x.x.x" }

28/Apr/2019 23:46:29 [Netlink.cpp:1159] [Netlink] [counters] { "timestamp": "1555983411.568510", "ifName": "vethd0da6da5", "ifIndex": 15, "LOCAL_CONTAINER": { "**KUBE**": { "NAME": "microbot", "POD": "microbot-7cc7d85487-7mmkg", "NS": "default" } }, "ifInOctets": 1538, "ifInPackets": 21, "ifInErrors": 0, "ifInDrops": 0, "ifOutOctets": 349756, "ifOutPackets": 1100, "EXPORTER_IPV4_ADDRESS": "x.x.x.x" }

28/Apr/2019 23:46:29 [Netlink.cpp:1159] [Netlink] [counters] { "timestamp": "1556487989.626129", "ifName": "veth973a1f7", "ifIndex": 23, "LOCAL_CONTAINER": { "**DOCKER**": { "NAME": "ubuntu_test" } }, "ifInOctets": 220771, "ifInPackets": 3066, "ifInErrors": 0, "ifInDrops": 0, "ifOutOctets": 70740354, "ifOutPackets": 78749, "EXPORTER_IPV4_ADDRESS": "x.x.x.x" }

28/Apr/2019 23:46:29 [Netlink.cpp:1159] [Netlink] [counters] { "timestamp": "1556487989.626174", "ifName": "veth40297a6", "ifIndex": 21, "LOCAL_CONTAINER": { "**DOCKER**": { "NAME": "tecmint-web3" } }, "ifInOctets": 32477, "ifInPackets": 328, "ifInErrors": 0, "ifInDrops": 0, "ifOutOctets": 13110951, "ifOutPackets": 40902, "EXPORTER_IPV4_ADDRESS": "x.x.x.x" }

Flow Information: eBPF

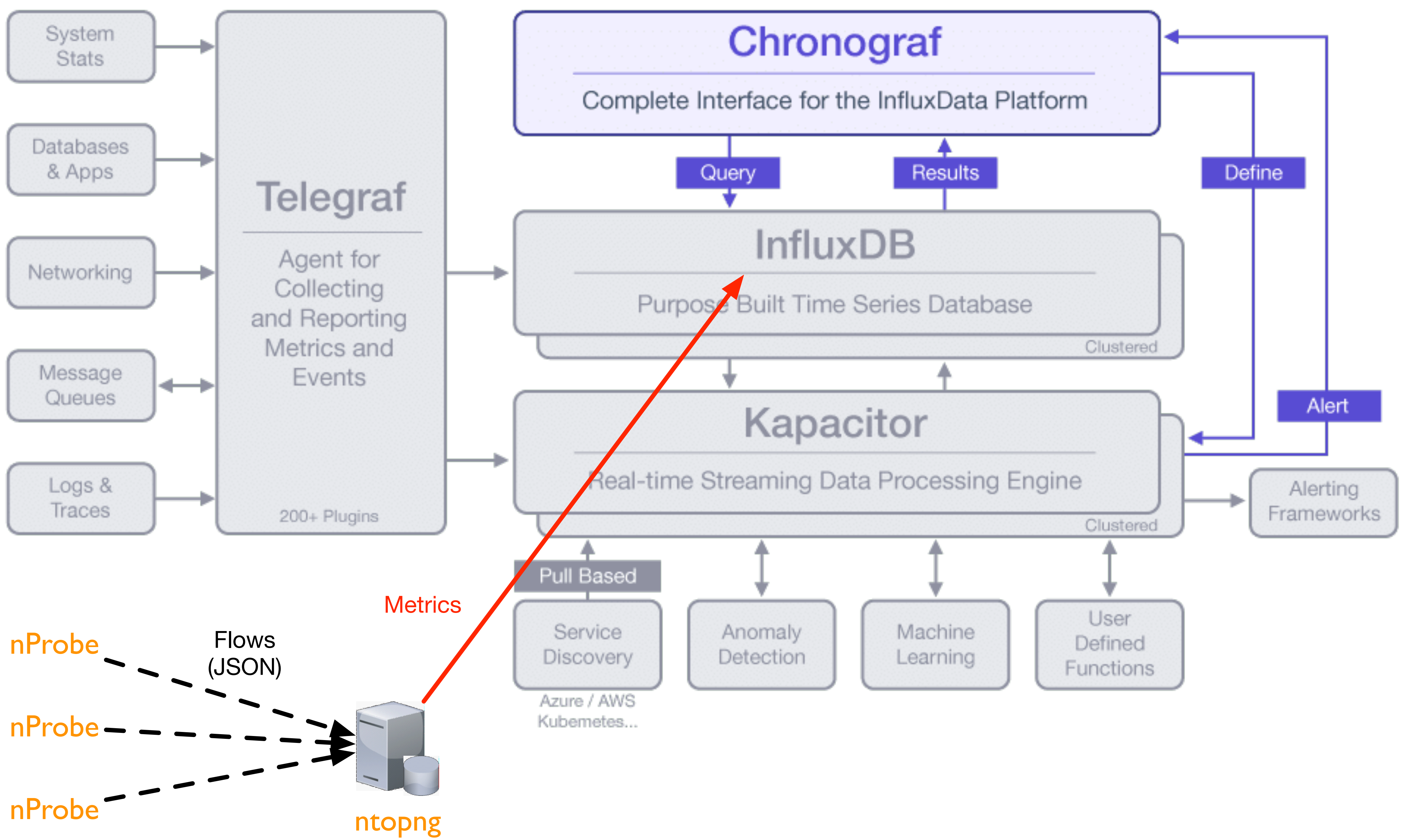

```
{
        "timestamp": "1556532359.110896",
        "LOCAL_PROCESS": {
                "PID": 8950,
                "UID": 100,
                "GID": 65534,
                "PROCESS_PATH": "\/usr\/lib\/apt\/methods\/http"
        },
        "LOCAL_FATHER_PROCESS": {
                "PID": 8947,
                "UID": 0,
                "GID": 0,
                "PROCESS_PATH": "\/usr\/bin\/apt-get"
        },
        "EVENT_TYPE": "SEND",
        "IP_PROTOCOL_VERSION": 4,
        "PROTOCOL": 17,
        "L4_LOCAL_PORT": 57756,
        "L4_REMOTE_PORT": 53,
        "IPV4_LOCAL_ADDR": "192.12.193.11",
        "IPV4_REMOTE_ADDR": "192.12.192.6",
        "LOCAL_CONTAINER": {
                "DOCKER": {
                        "ID": "cf5485c07181",
                        "NAME": "docker_monitor"
                }
        },
        "EXPORTER_IPV4_ADDRESS": "192.12.193.11"
}
```

Flow Information: Netlink

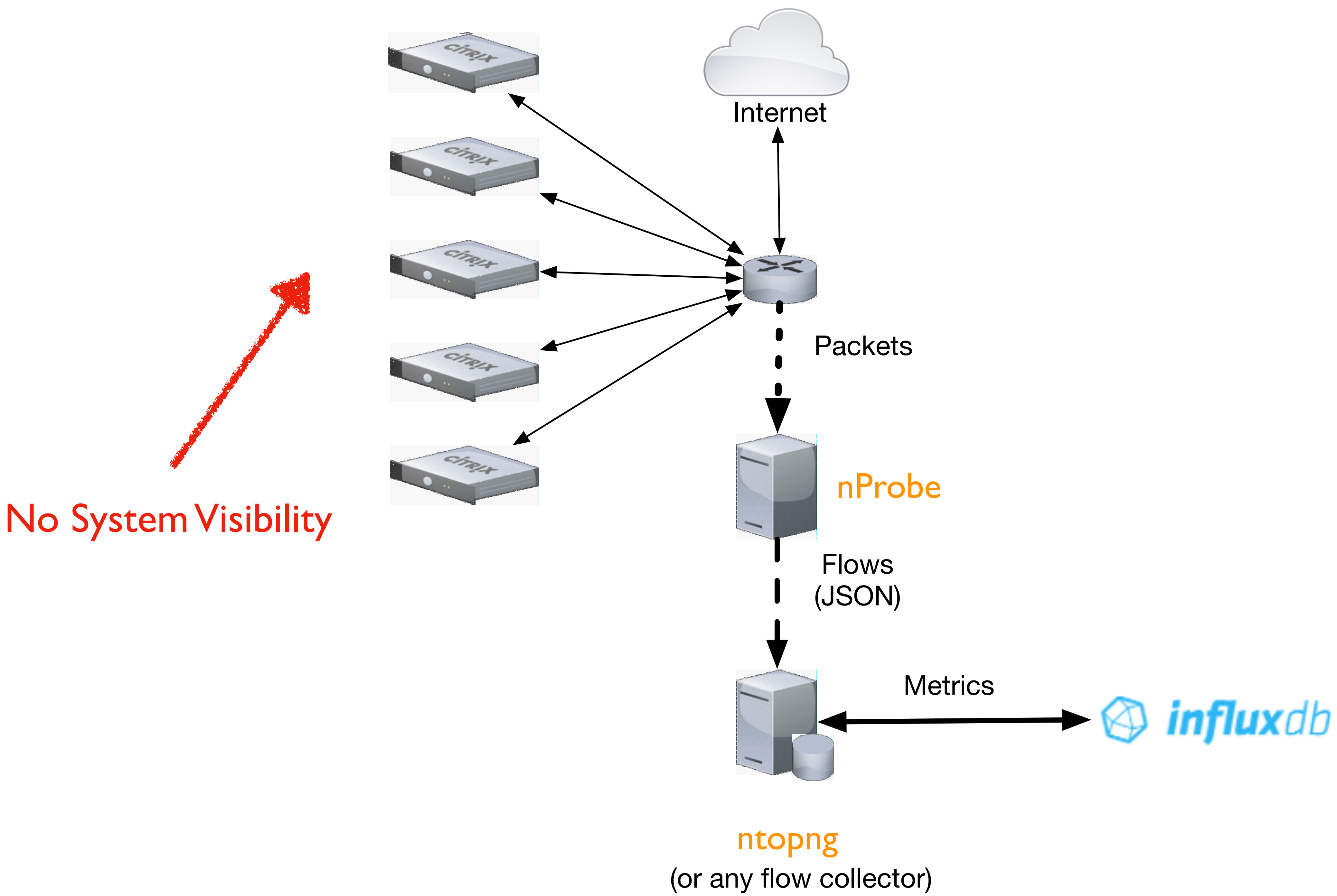

```
{
    "timestamp": "1556532168.971859",
    "PROTOCOL": 6,
    "IP_PROTOCOL_VERSION": 6,
    "USER_NAME": "deri",
    "IPV6_LOCAL_ADDR": "2a00:d40:1:3:x:x:x:x",
    "IPV6_REMOTE_ADDR": "2a00:d40:1:1:x:x:x:x",
    "L4_LOCAL_PORT": 41234,
    "L4_REMOTE_PORT": 22,
    "TCP": {
        "CONN_STATE": "ESTABLISHED",
        "RETRAN_PKTS": 0,
        "UNACK_SEGMENTS": 0,
        "LOST_PKTS": 0,
        "SEGS_IN": 3786,
        "SEGS_OUT": 5426,
        "BYTES_RCVD": 378173,
        "RTT": 4.1440,
        "RTT_VARIANCE": 5.3220,
        "CURRENT_RATE": 55125152.0,
        "DELIVERY_RATE": 6720000.0
    },
    "LOCAL_PROCESS": {
        "PID": 22581,
        "UID": 1000,
        "UID_NAME": "deri",
        "GID": 1000,
        "GID_NAME": "deri",
        "VM_SIZE": 53704,
        "VM_PEAK": 53876,
        "PROCESS_PATH": "\/usr\/bin\/ssh"
    },
    "LOCAL_FATHER_PROCESS": {
        "PID": 8562,
        "UID": 1000,
        "UID_NAME": "deri",
        "GID": 1000,
        "GID_NAME": "deri",
        "VM_SIZE": 21468,
        "VM_PEAK": 21468,
        "PROCESS_PATH": "\/bin\/tcsh"
    },
    "LOCAL_CONTAINER": {
        "DOCKER": {
            "NAME": "docker_monitor"
        }
    },
    "EXPORTER_IPV4_ADDRESS": “192.12.193.11"
}
```


Read from Kernel

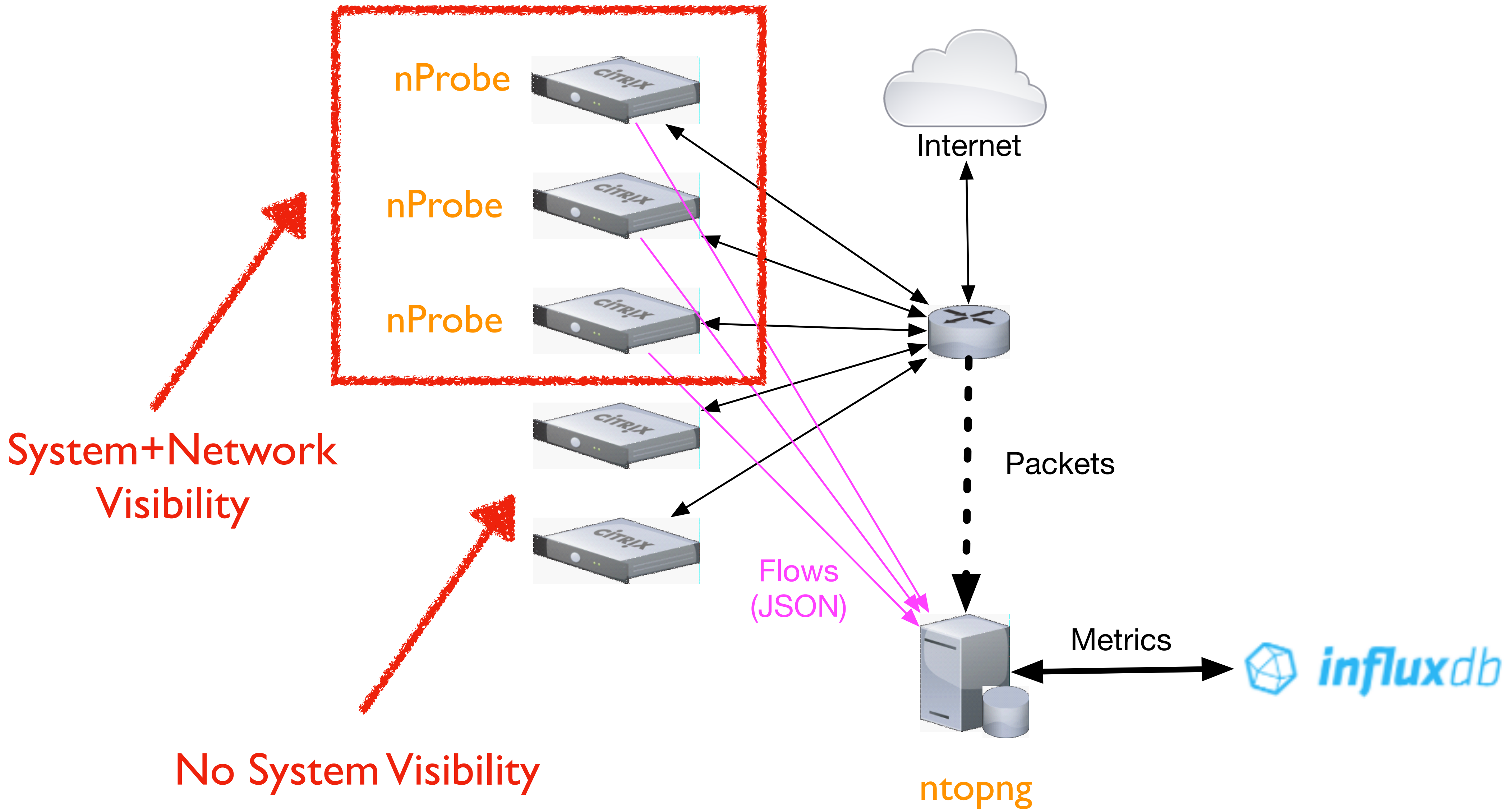
Data Collection Architecture



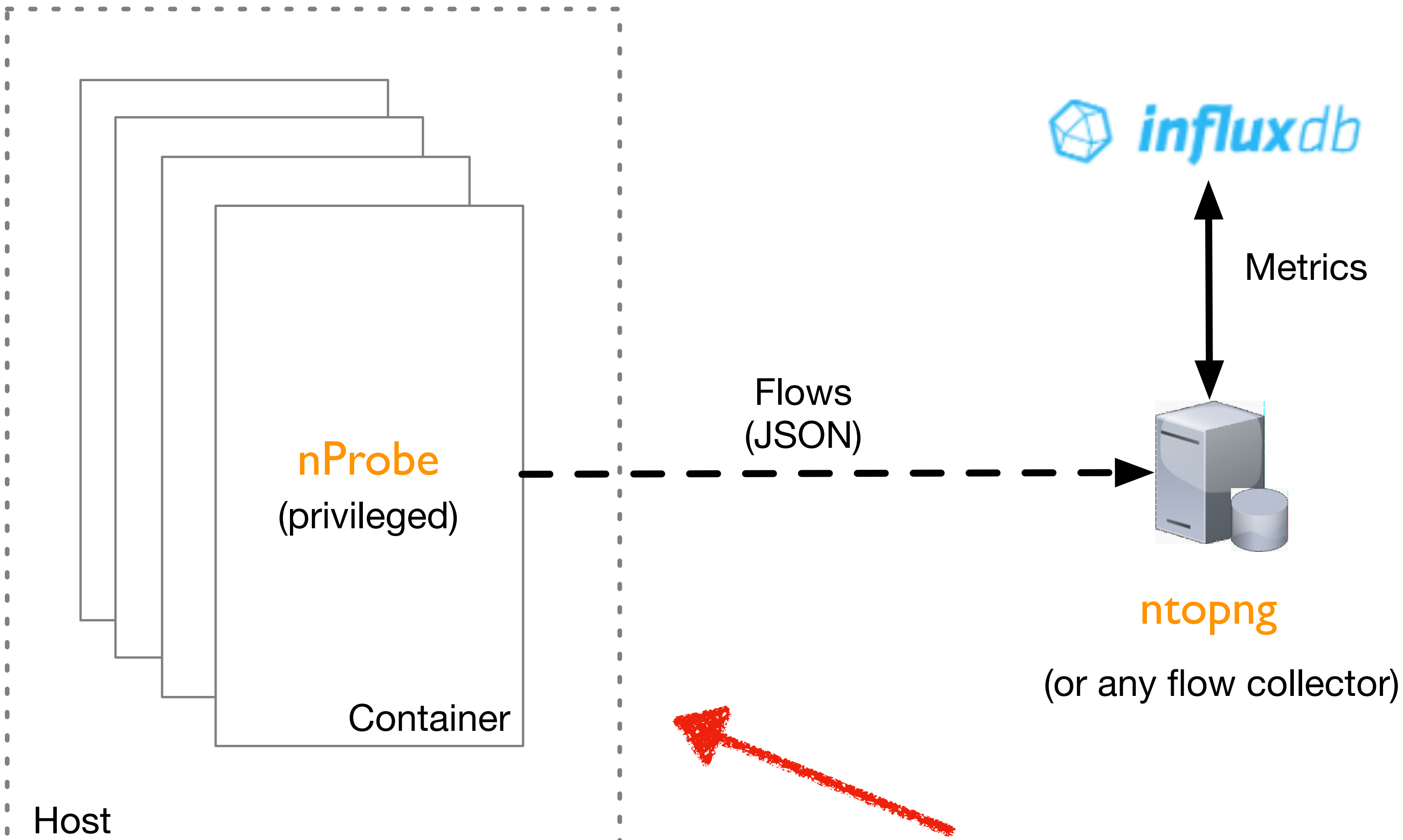
Packet-only Deployment



Packets + Metadata Deployment



Packetless Deployment

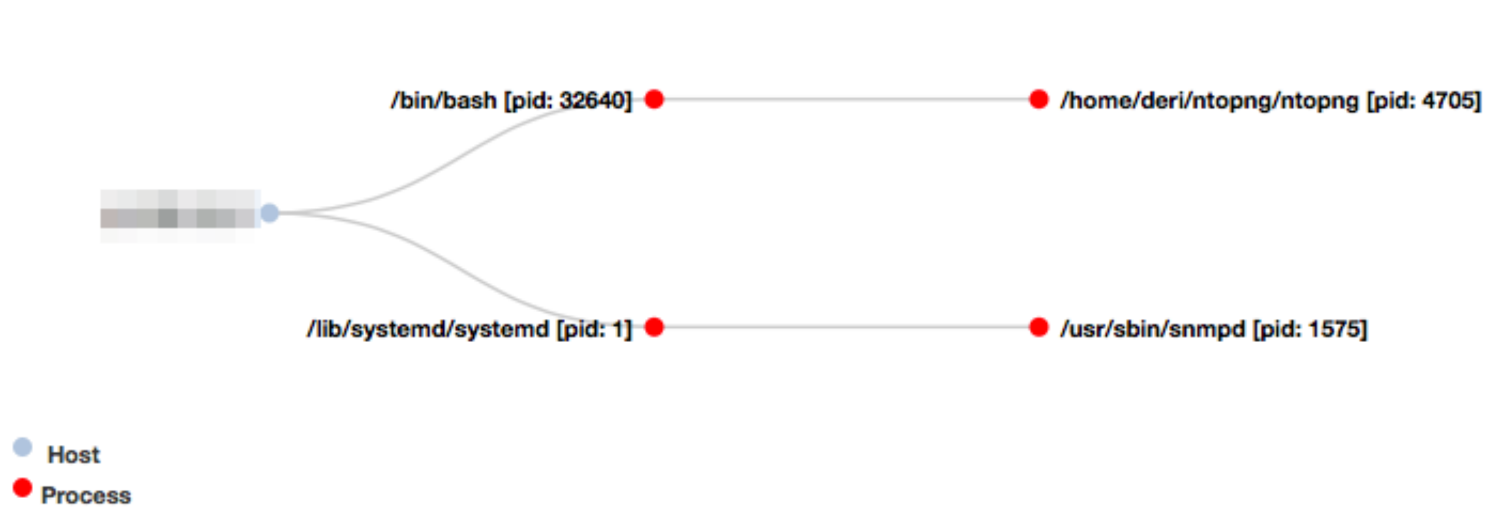


Full Visibility
(need 1 nProbe container per system)

ntopng: Process Hierarchy

Flow: :54748 ⇄ :161 | Overview

Flow Peers [Client / Server]	:54748 ⇄ :161	
Protocol / Application	UDP / SNMP (Network)	
First / Last Seen	29/04/2019 12:48:21 [< 1 sec ago]	29/04/2019 12:48:21 [< 1 sec ago]



Client Process Information	
User Name	nobody
Process PID/Name	/home/deri/ntopng/ntopng [pid: 4705] son of /bin/bash [pid: 32640]
Server Process Information	
User Name	Debian-snmp
Process PID/Name	/usr/sbin/snmpd [pid: 1575] son of /lib/systemd/systemd [pid: 1]

ntopng: Containers/Pod Overview

Containers List

10

	Container	Flows as Client	Flows as Server	Avg RTT as Client	Avg RTT as Server	Avg RTT Variance as Client	Avg RTT Variance as Server
Flows	23f492221784	4		< 0.1 ms		< 0.1 ms	
Flows	3dd3f17ad9ba	1					

Showing 1 to 2 of 2 rows

Pods List

10

Pod	Containers	Flows as Client	Flows as Server	Avg RTT as Client	Avg RTT as Server	Avg RTT Variance as Client	Avg RTT Variance as Server
heapster-v1.5.2-6b5d7b57f9-g2cjz	4	12	2	3.6 ms	6.6 ms	5.0 ms	8.0 ms
kube-dns-6bfbdd666c-jjt75	3	136	110				
kubernetes-dashboard-6fd7f9c494-hpcx7	1	8	3	0.8 ms		0.8 ms	
monitoring-influxdb-grafana-v4-78777c64c8-kmjr4	2	13	2				

ntopng: Container Flows

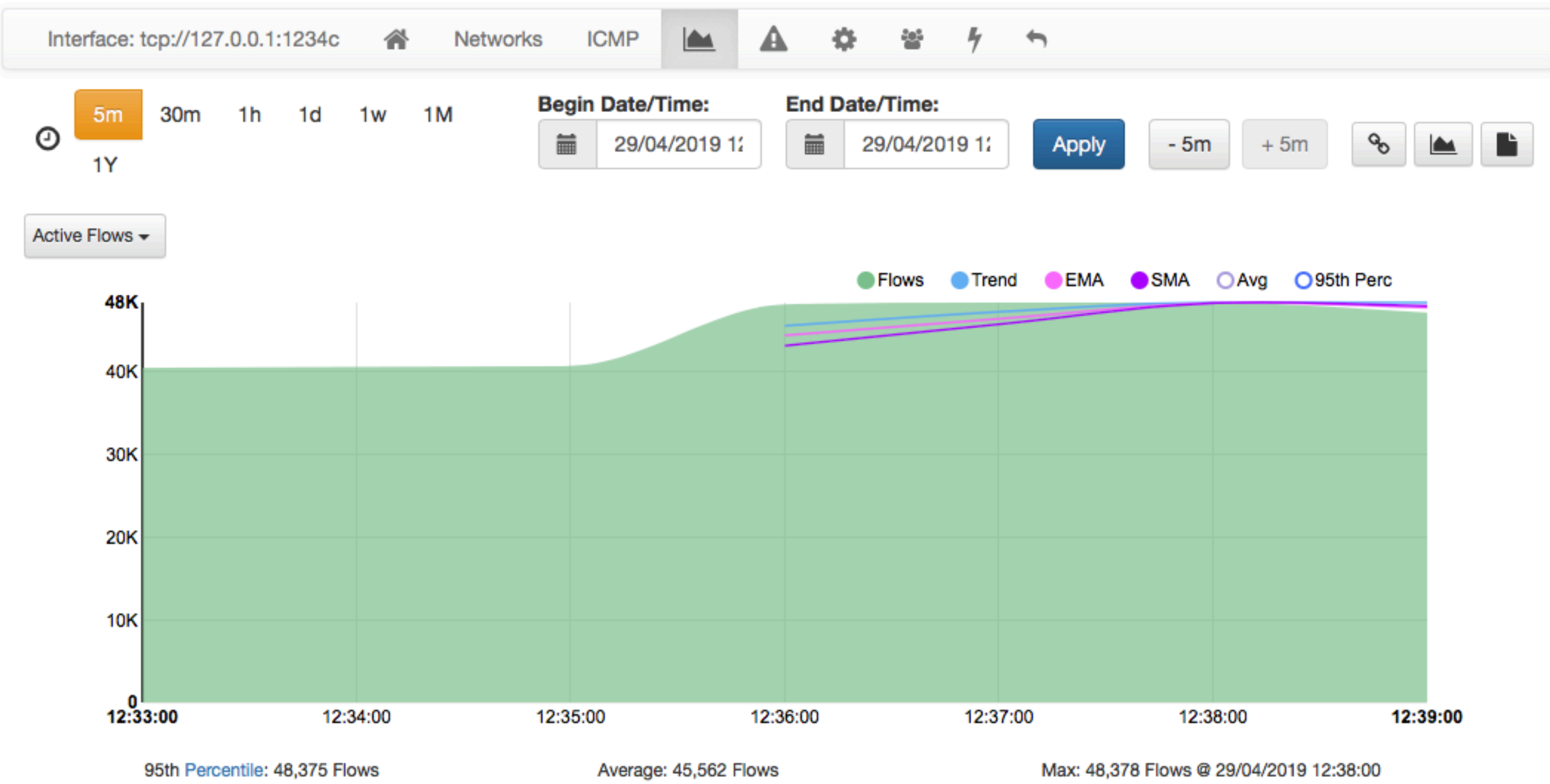
Recently Active Flows [Container ubuntu_test]

10 ▾ Hosts▾ Status▾ Container▾ Applications ▾ Categories ▾ Flow Exporter▾ IP Version▾

	Application	Protocol	Client	Server	Client Container	Server Container	Client RTT	Server RTT	Info
Info	SSH	TCP	localhost :53216 [root >_telnet.netkit]	localhost :ssh	ubuntu_test		0.1 ms		
Info	? Unknown	TCP	NoIP:ssh [root >_sshd]	NoIP	ubuntu_test				
Info	? Unknown	TCP	:: :ssh [root >_sshd]	::	ubuntu_test				

Showing 1 to 3 of 3 rows. Idle flows not listed.

ntopng: Traffic Report



Top Categories

10

Category	Total Bytes	Percentage
Unspecified	5.21 GB	70.2 %
Email	1.92 GB	25.9 %
Database	193.91 MB	2.6 %
Web	85.11 MB	1.1 %
RemoteAccess	14.65 MB	0.2 %

Final Remarks

- It is now possible to complement network visibility with system/container information.
- Devops can deploy a resource-savvy libebpf-based container able to monitor all the containers running on a host with limited resources.
- InfluxDB is used to collect system and network metrics using ntopng as data feed.
- Users can choose ntopng or Chronograf/Grafana to implement powerful monitoring dashboards.