PF_RING Tutorial

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Overview

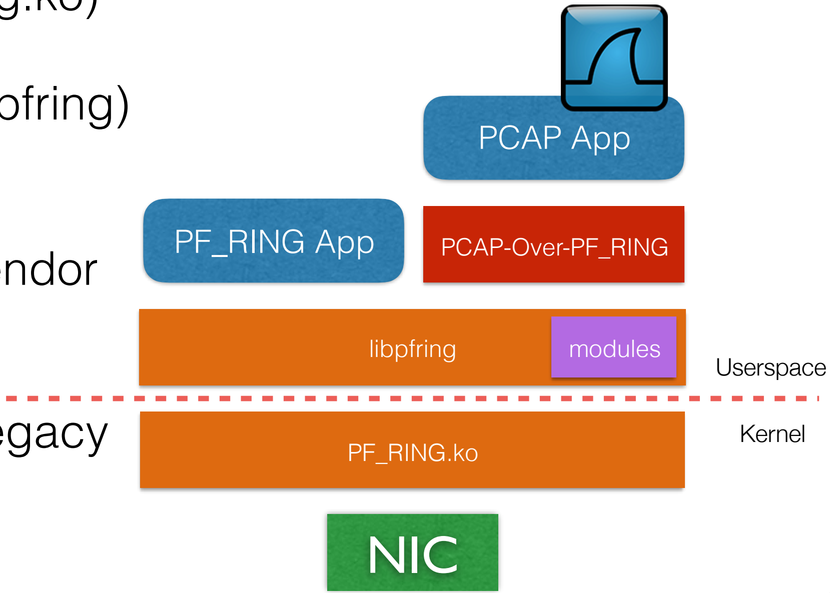
- Introduction
- Installation
- Configuration
- Tuning
- Use cases

PF_RING

- Open source packet processing framework for Linux.
- Originally (2003) designed to accelerate packet capture on commodity hardware, using patched drivers and in-kernel filtering.
- Today it supports almost all Intel adapters with kernel-bypass zero-copy drivers and almost all FPGAs capture adapters.

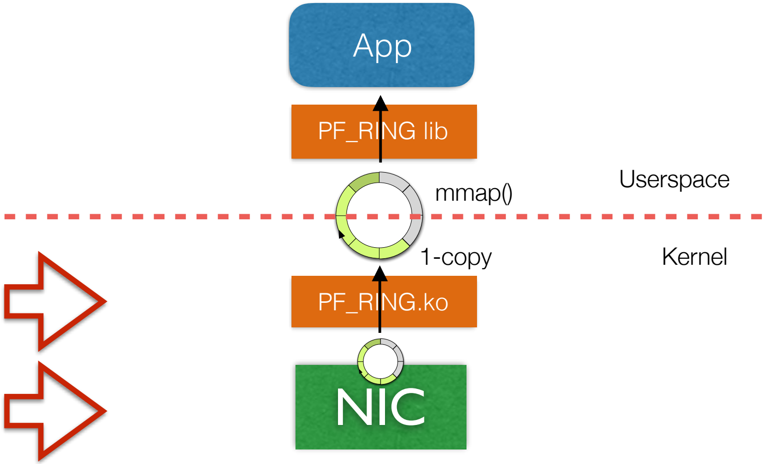
PF_RING's Main Features

- PF_RING consists of:
  - Kernel module (pf_ring.ko)
  - Userspace library (libpfring)
  - Userspace modules implementing multi-vendor support
  - Patched libpcap for legacy applications



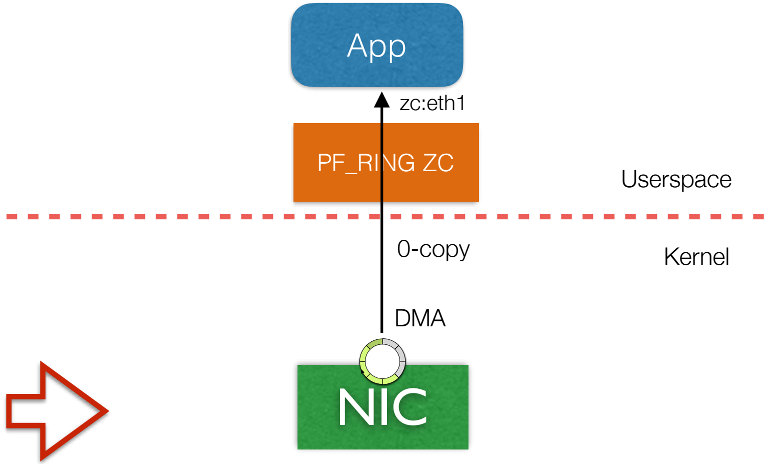
Standard Drivers

- Standard kernel drivers, NAPI polling.
- 1-copy by the NIC into kernel buffers (DMA).
- 1-copy by the PF_RING kernel module into memory-map'ed memory.



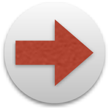
PF_RING ZC Drivers

- Userspace drivers for Intel cards, kernel is bypassed.
- 1-copy by the NIC into userspace memory (DMA).
- Packets are read directly by the application in zero-copy.



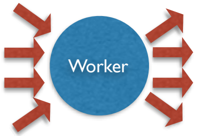
PF_RING ZC API

- PF_RING ZC is not just a zero-copy driver, it provides a flexible API for creating full zero-copy processing patterns using 3 simple building blocks:



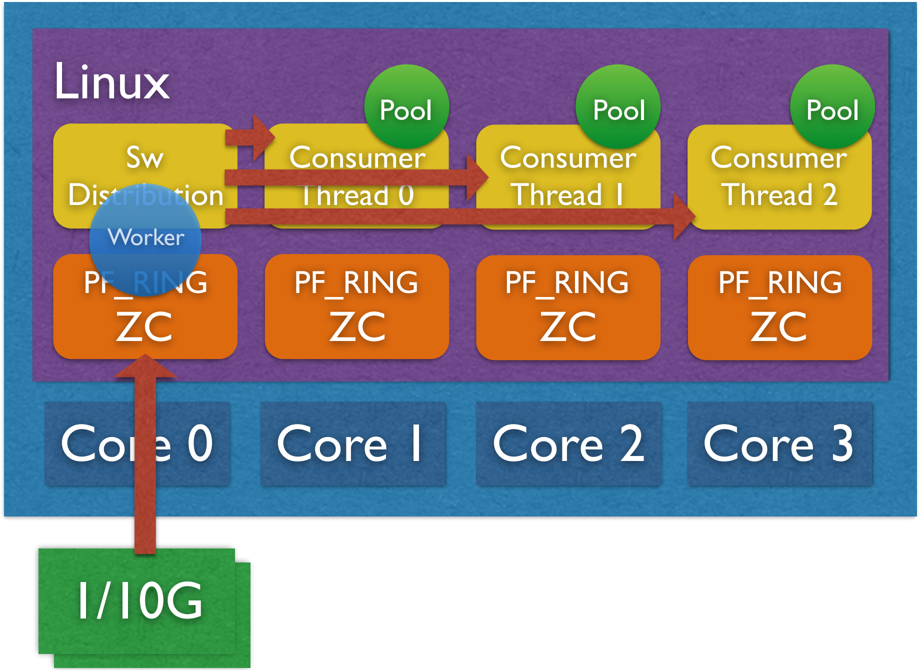
  - Queue
    - Hw Device Queue
    - Sw SPSC Queue

  - Pool: DMA buffers resource.



  - Worker: execution unit able to aggregate traffic from M ingress queues and distribute it to N generic egress queues using custom functions.

PF_RING ZC API - zbalance Example



PF_RING ZC API - zbalance code

- Code for aggregation and load-balancing using ZC:

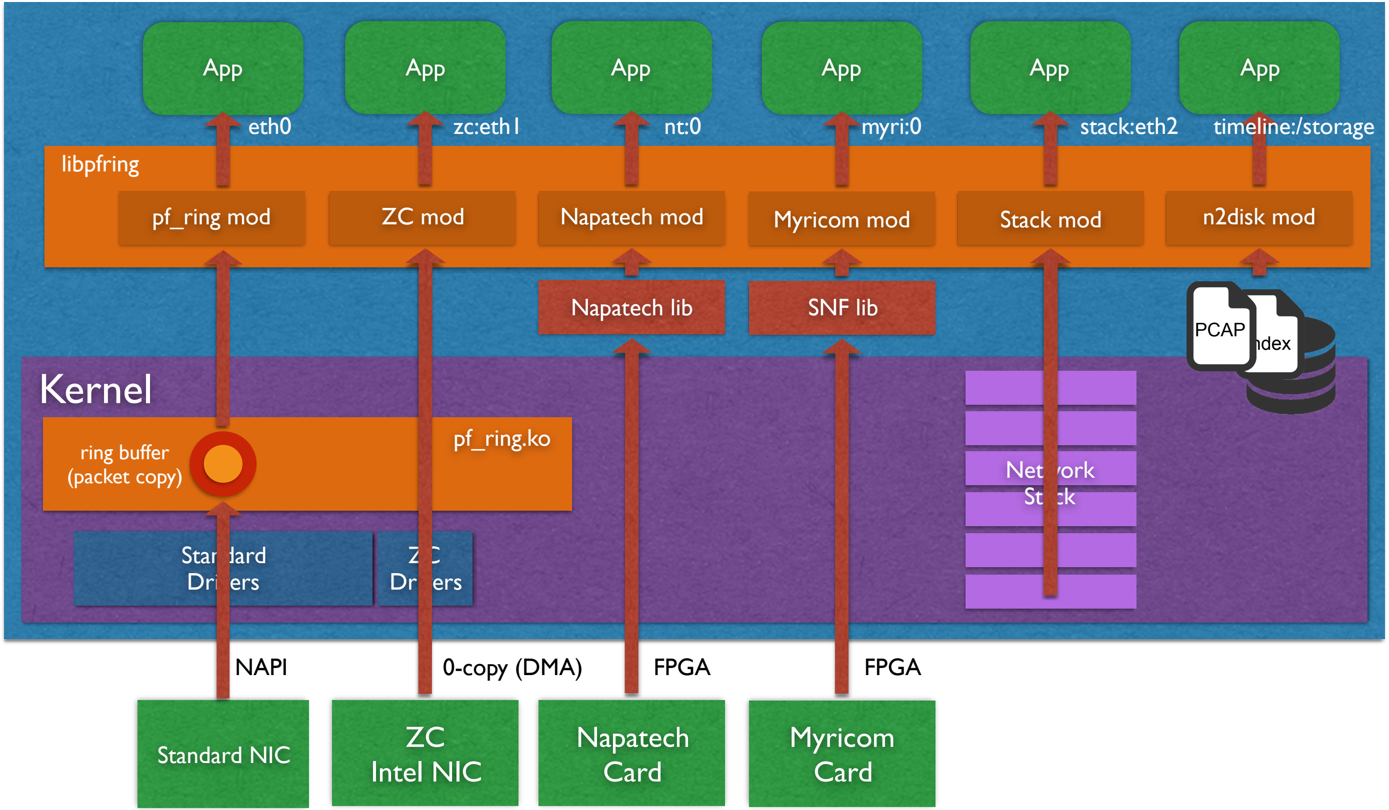
```
zc = pfring_zc_create_cluster(ID, MTU, MAX_BUFFERS, NULL);
for (i = 0; i < num_devices; i++)
 inzq[i] = pfring_zc_open_device(zc, devices[i], rx_only);
for (i = 0; i < num_slaves; i++)
  outzq[i] = pfring_zc_create_queue(zc, QUEUE_LEN);
zw = pfring_zc_run_balancer(inzq, outzq, num_devices,
        num_slaves, NULL, NULL, !wait_for_packet, core_id);
```

FPGAs Support

- Currently PF_RING natively supports the following vendors (1/10/40/100 Gbit)

- PF_RING-based applications transparently select the module by means of the interface name. Example:
    - `pfcount -i eth1` [Vanilla Linux adapter]
    - `pfcount -i zc:eth1` [Intel ZC drivers]
    - `pfcount -i nt:1` [Napatech]
    - `pfcount -i myri:1` [Myricom]
    - `pfcount -i exanic:0` [Exablaze]

Many modules, single API.



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Installation

- Two options for installing PF_RING:
  - Source Code (GitHub)
  - Packages 
    - Stable
    - Dev (aka "nightly builds")

Installation - Source Code

- Download

```
# git clone https://github.com/ntop/PF_RING.git
```

- Installation:

```
# cd PF_RING/kernel
# make && make install
# cd ../userland
# make && make install
```

- ZC drivers installation (optional):

```
# cd PF_RING/drivers/intel/<model>/<model>-<version>-zc/src
# make && make install
```

- Support for FPGAs (Napatech, Myricom, etc) is automatically enabled if drivers are installed.

Installation - Packages

- CentOS/Debian/Ubuntu stable/devel repositories at http://packages.ntop.org
- Installation:

```
# wget http://apt.ntop.org/16.04/all/apt-ntop.deb
# dpkg -i apt-ntop.deb
# apt-get clean all
# apt-get update
# apt-get install pfring
```

- ZC drivers installation (optional):

```
# apt-get install pfring-drivers-zc-dkms
```

- Support for FPGAs (Napatech, Myricom, etc) is already there.

Overview

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Loading PF_RING

- If you compiled from source code:

```
# cd PF_RING/kernel
# insmod ./pf_ring.ko
```

- If you are using packages:

```
# tree /etc/pf_ring/
|-- pf_ring.conf
`-- pf_ring.start
# /etc/init.d/pf_ring start
```

Loading ZC Drivers

- ZC drivers are available for almost all Intel cards based on e1000e, igb, ixgbe, i40e, fm10k

- ZC needs hugepages for memory allocation, the pf_ring init script takes care of reserving them.

- A ZC interface acts as a standard interface (e.g. you can set an IP on ethX) until you open it using the “zc:” prefix (e.g. zc:ethX).

Loading ZC Drivers

- If you compiled from source code:

```
# cd PF_RING/drivers/intel/<model>/<model>-<version>-zc/src
# ./load_driver.sh
```

- In essence the script loads hugepages and dependencies and load the module with:

```
# insmod <model>.ko RSS=1,1 [other options]
```

- You can check that the ZC driver is actually running with:

```
# cat /proc/net/pf_ring/dev/eth1/info | grep ZC
Polling Mode: ZC/NAPI
```

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Loading ZC Drivers

- If you are using packages (ixgbe driver in this example):

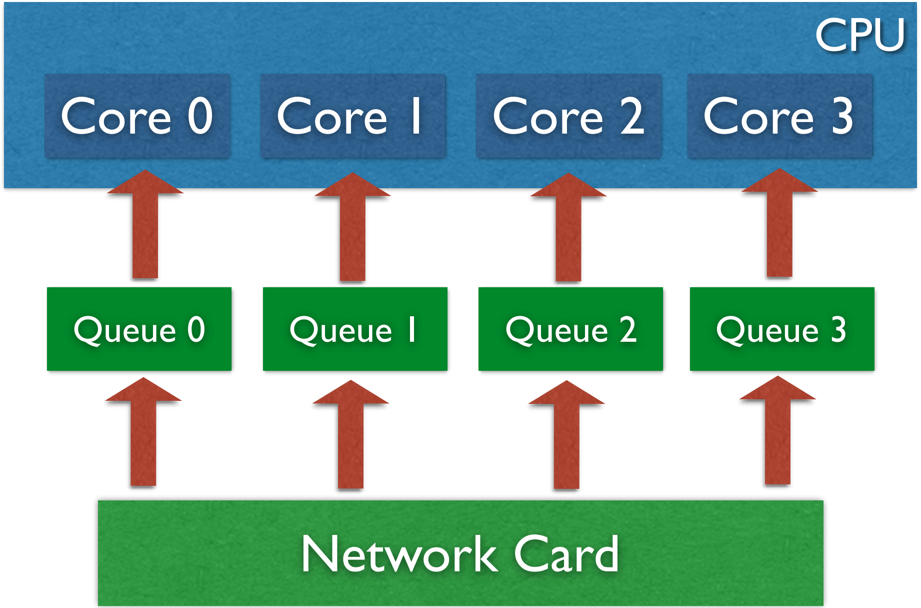
```
# tree /etc/pf_ring/
|-- hugepages.conf
|-- pf_ring.conf
|-- pf_ring.start
`-- zc
    `-- ixgbe
        |-- ixgbe.conf
        `-- ixgbe.start
```

- Where:

```
# cat /etc/pf_ring/hugepages.conf
node=0 hugepagenumber=1024
# cat /etc/pf_ring/zc/ixgbe/ixgbe.conf
RSS=1,1
```

RSS

- RSS distributes the load across the specified number of RX queues based on an hash function which is IP-based (or IP/Port-based in case of TCP)



RSS

- Set the number of RSS queues using the insmod option or ethtool:

```
# ethtool --set-channels eth1 combined 4
# cat /proc/net/pf_ring/dev/eth1/info | grep Queues
TX Queues:     4
RX Queues:     4
```

- In order to open a specific interface queue, you have to specify the queue ID using the "@<ID>" suffix.

```
# tcpdump -i zc:eth1@0
```

Note: when using ZC, “zc:eth1” is the same as “zc:eth1@0”! This happens because ZC is a kernel-bypass technology, there is no abstraction (queues aggregation) provided by the kernel.

Indirection Table

- Destination queue is selected in combination with an indirection table:

```
queue = indirection_table[rss_hash(packet)]
```

- It is possible to configure the indirection table using ethtool by simply applying weights to each RX queue.

Indirection Table

```
# ethtool --set-channels eth1 combined 4
# ethtool -x eth1
RX flow hash indirection table for eth1 with 4 RX ring(s):
    0:      0     1     2     3     0     1     2     3
    8:      0     1     2     3     0     1     2     3
   16:      0     1     2     3     0     1     2     3
   24:      0     1     2     3     0     1     2     3
   32:      0     1     2     3     0     1     2     3
   40:      0     1     2     3     0     1     2     3
   48:      0     1     2     3     0     1     2     3
   56:      0     1     2     3     0     1     2     3
   64:      0     1     2     3     0     1     2     3
   72:      0     1     2     3     0     1     2     3
   80:      0     1     2     3     0     1     2     3
   88:      0     1     2     3     0     1     2     3
   96:      0     1     2     3     0     1     2     3
  104:      0     1     2     3     0     1     2     3
  112:      0     1     2     3     0     1     2     3
  120:      0     1     2     3     0     1     2     3
```

destination queue ID

hash

Indirection Table

```
# ethtool -X eth1 weight 1 0 0 0
# ethtool -x  eth1
RX flow hash indirection table for eth1 with 4 RX ring(s):
    0:      0     0     0     0     0     0     0     0
    8:      0     0     0     0     0     0     0     0
   16:      0     0     0     0     0     0     0     0
   24:      0     0     0     0     0     0     0     0
   32:      0     0     0     0     0     0     0     0
   40:      0     0     0     0     0     0     0     0
   48:      0     0     0     0     0     0     0     0
   56:      0     0     0     0     0     0     0     0
   64:      0     0     0     0     0     0     0     0
   72:      0     0     0     0     0     0     0     0
   80:      0     0     0     0     0     0     0     0
   88:      0     0     0     0     0     0     0     0
   96:      0     0     0     0     0     0     0     0
  104:      0     0     0     0     0     0     0     0
  112:      0     0     0     0     0     0     0     0
  120:      0     0     0     0     0     0     0     0
```

destination queue ID

hash

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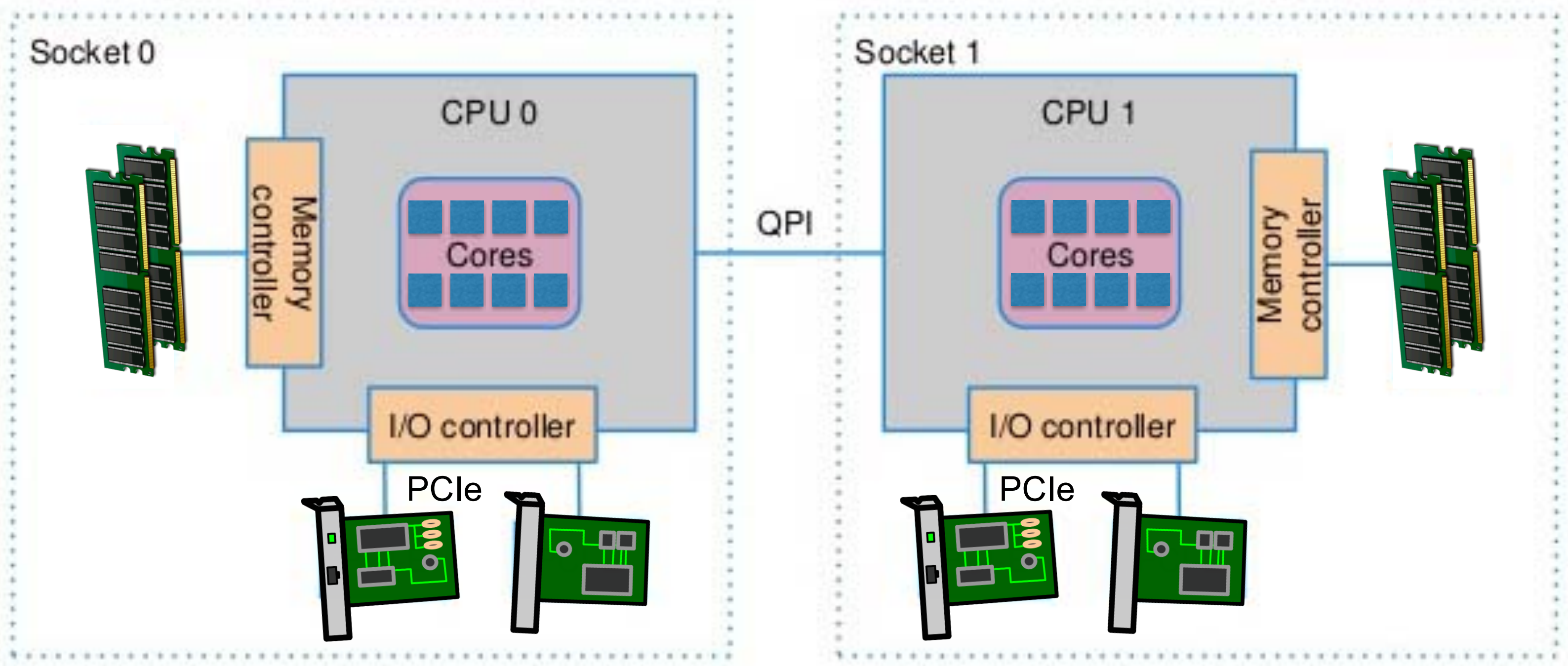
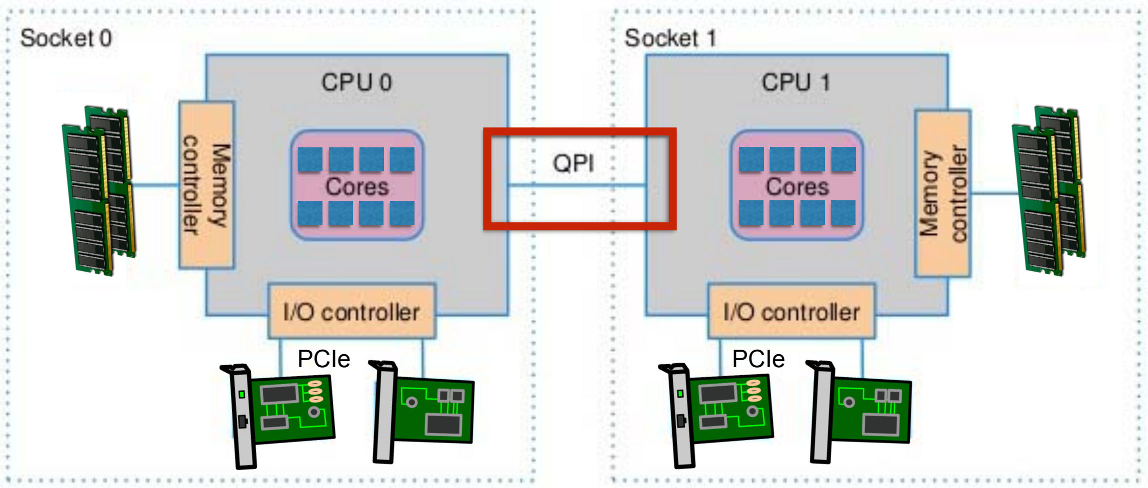
Xeon Architecture



QPI

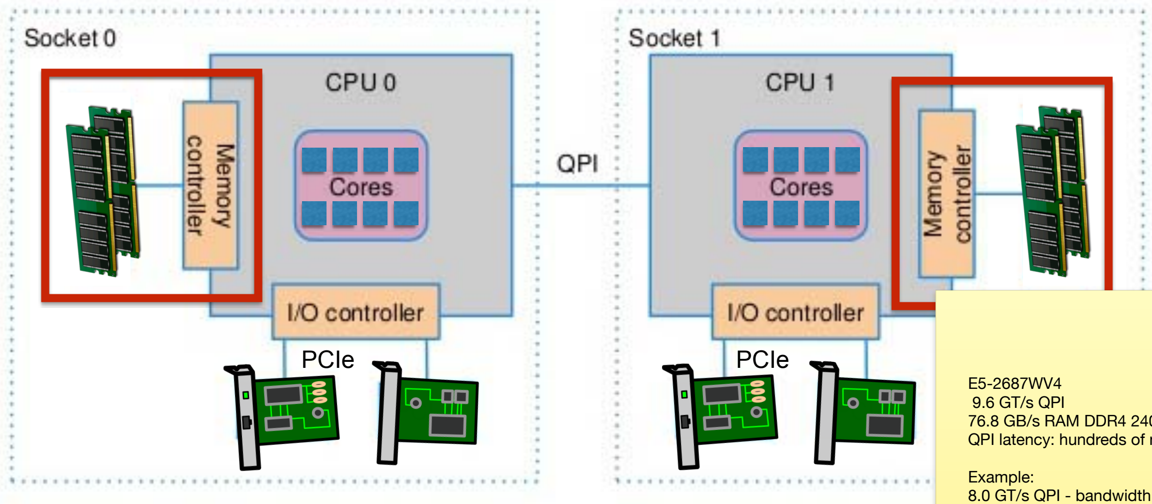
- QPI (Quick Path Interconnect) is the bus that interconnects the nodes of a NUMA system.

- QPI is used for moving data between nodes when accessing remote memory or PCIe devices. It also carries cache coherency traffic.



Memory

- Each CPU has its local memory directly attached.
- Accessing remote memory is slow as data flows through the QPI, which has lower bandwidth and adds latency.

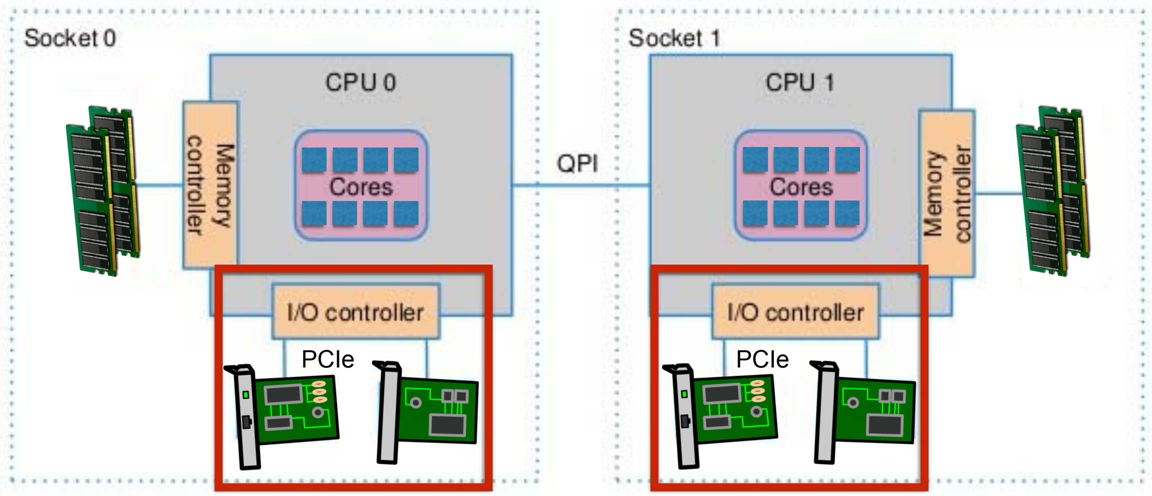


E5-2687WV4
9.6 GT/s QPI
76.8 GB/s RAM DDR4 2400
QPI latency: hundreds of nanosec

Example:
8.0 GT/s QPI - bandwidth 32 GiB/s ~32 GB/s

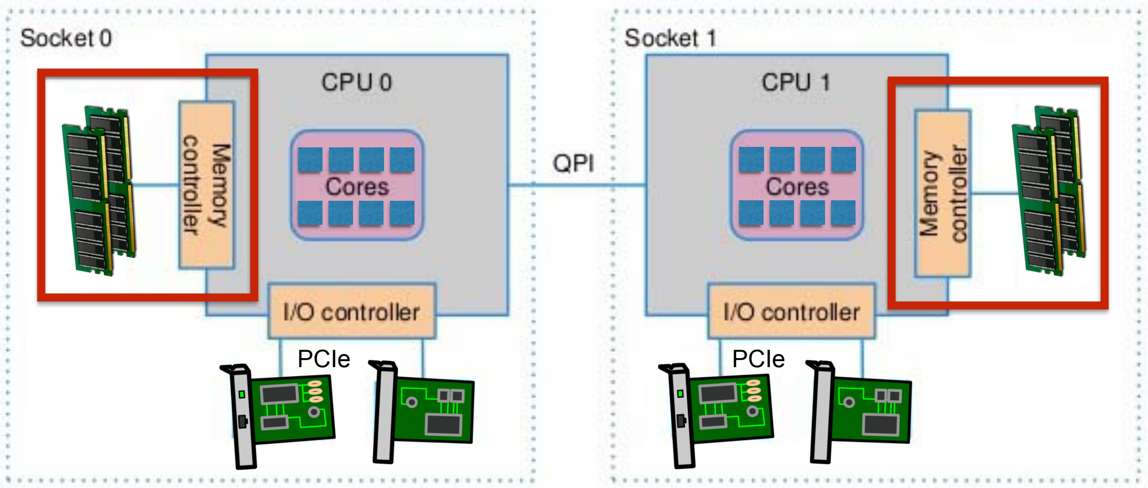
PCIe

- Each node has its dedicated PCIe lanes.
- Plug the Network Card (and the RAID Controller) to the right slot reading the motherboard manual.



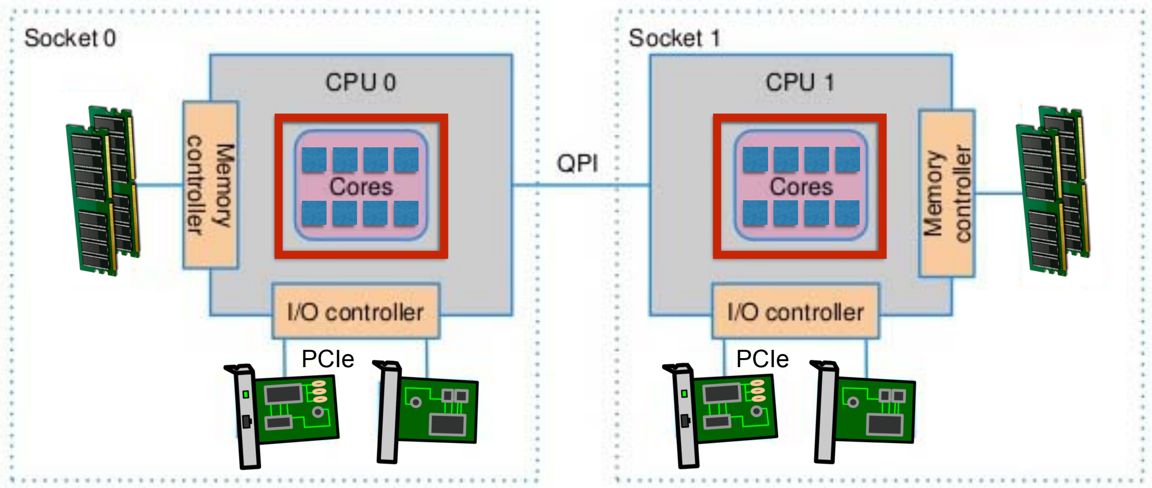
Memory Channels

- Multi-channel memory increases data transfer rate between memory and memory controller. You can use `n2membenchmark` as benchmark tool.
- Check how many channels your CPU supports and use at least as many memory modules as the number of channels (check `dmidecode`).



CPU Cores

- CPU pinning of a process/thread to a core is important to isolate processing and improve performance.
- In most cases dedicating a physical core (pay attention to hyper-threading) to each thread is the best choice for optimal performance.



Core Affinity

- All our applications natively support CPU pinning, e.g.:

```
# nprobe -h | grep affinity
[--cpu-affinity|-4] <CPU/Core Id> | Binds
this process to the specified CPU/Core
```

- When not supported, you can use external tools:

```
# taskset -c 1 tcpdump -i eth1
```

NUMA Affinity

- You can check your NUMA-related hw configuration with:
  - `lstopo`
  - `numactl --hardware`
- Configuring CPU pinning, usually the application allocates memory to the correct NUMA node, if this is not the case you can use external tools:

```
# numactl --membind=0 --cpunodebind=0 tcpdump -i zc:eth1
```

- You can check your QPI bandwidth with:

```
# numactl --membind=0 --cpunodebind=1 n2membenchmark
```

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PF_RING ZC Driver NUMA Affinity

- PF_RING ZC drivers allocate data structures (RX/TX ring) in memory, setting NUMA affinity is important. You can do that at insmod:

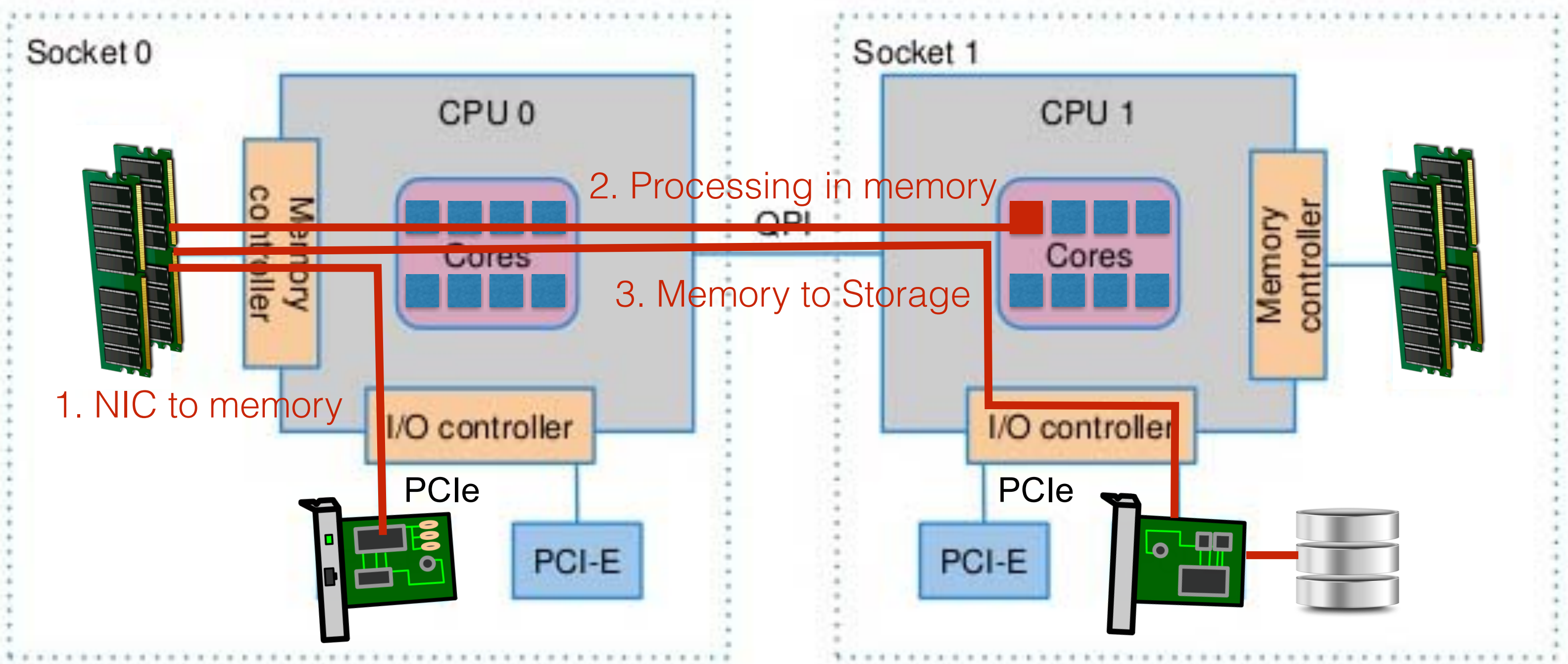
```
# insmod <model>.ko RSS=1,1,1,1 numa_cpu_affinity=0,0,8,8
```

- Or if you are using packages:

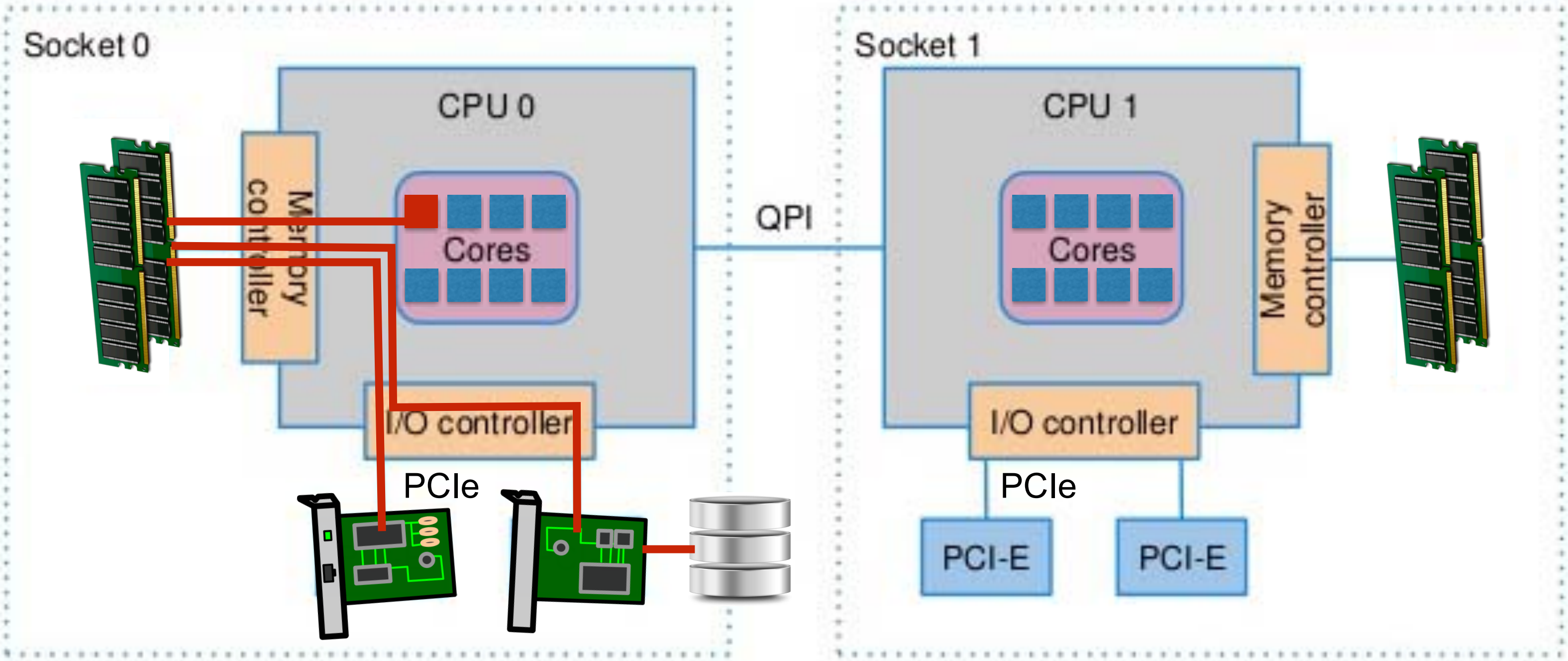
```
# cat /etc/pf_ring/zc/ixgbe/ixgbe.conf

RSS=1,1,1,1 numa_cpu_affinity=0,0,8,8
```

Traffic Recording - Wrong Configuration



Traffic Recording - Correct Configuration



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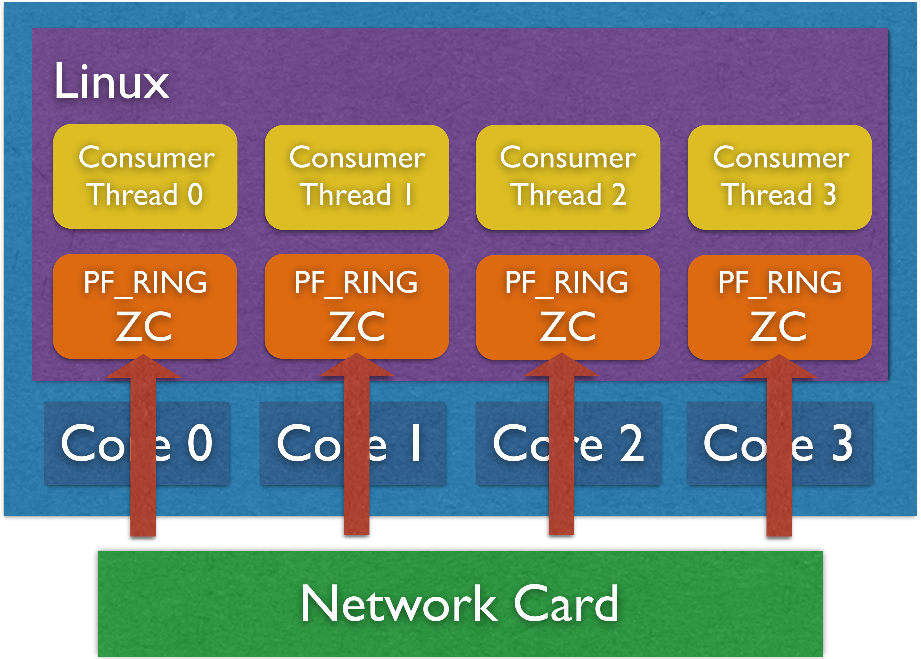
RSS Load Balancing



RSS: When it can be used

- Flow-based traffic analysis (multi-threaded or multi-process) and all the applications where Divide and Conquer strategy is applicable.

- Examples:
    - nProbe (Netflow probe)
    - nProbe Cento
    - Suricata
    - Bro

RSS: nPobe Example

- nProbe instances example with 4 RSS queues:

```
# nprobe -i zc:eth1@0 --cpu-affinity 0 [other options]
# nprobe -i zc:eth1@1 --cpu-affinity 1 [other options]
# nprobe -i zc:eth1@2 --cpu-affinity 2 [other options]
# nprobe -i zc:eth1@3 --cpu-affinity 3 [other options]
```

RSS: Bro Example

- Bro node.cfg example with 8 RSS queues:

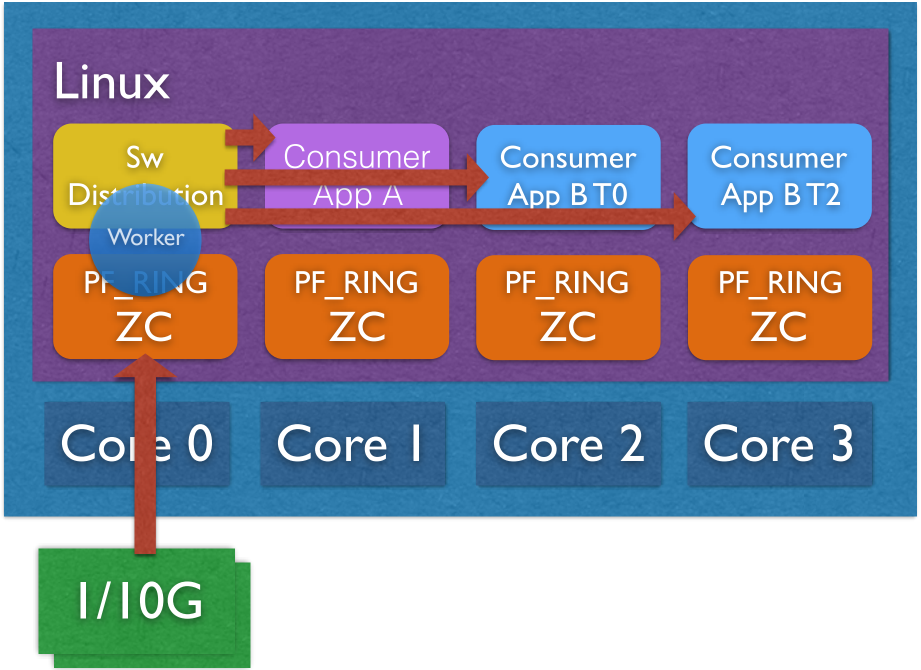
```
# [worker-1]
type=worker
host=10.0.0.1
interface=zc:eth1
lb_method=pf_ring
lb_procs=8
pin_cpus=0,1,2,3,4,5,6,7
```

This is expanded into zc:eth1@0 .. zc:eth1@7

RSS: When it can NOT be used

- Applications where packets order has to be preserved (also across flows), especially if there is no hw timestamping.
- For example in n2disk (traffic recording) we have to keep the original order for packets dumped on disk.

ZC Load Balancing (zbalance_ipc)



ZC Load Balancing: When it is useful

- When RSS is not available or not flexible enough (with ZC you can build your distribution function/hash)
- When you need to send the same traffic to multiple applications (fan-out) while using zero-copy
- When you need to aggregate from multiple ports and then distribute

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ZC Load Balancing - example

- zbalance_ipc is an example of multi-process load balancing application:

```
# zbalance_ipc -i zc:eth1,zc:eth2 -c 99 -n 1,2 -m 1 -g 0
```

Ingress Interfaces (-i zc:eth1,zc:eth2) · ZC ID (-c 99) · Egress Queues (-n 1,2) · Hash Type (-m 1) · CPU Core (-g 0)

- Consumer applications example:

```
# taskset -c 1 tcpdump -i zc:99@0

# nprobe -i zc:99@1 --cpu-affinity 2 [other options]
# nprobe -i zc:99@2 --cpu-affinity 3 [other options]
```

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ZC Load Balancing and Bro

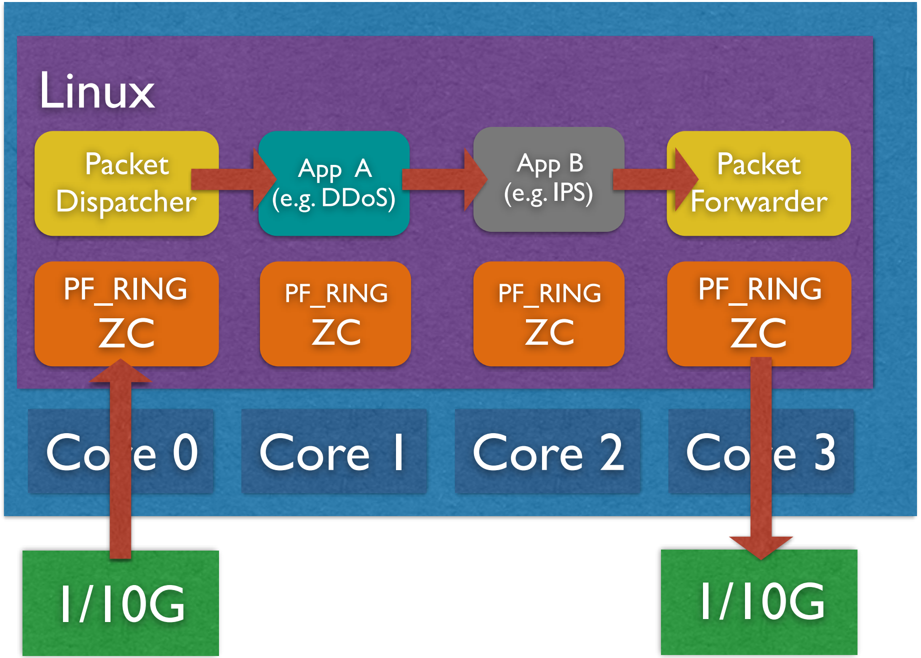
- Bro node.cfg example with 8 ZC queues:

```
# [worker-1]
type=worker
host=10.0.0.1
interface=zc:99
lb_method=pf_ring
lb_procs=8
pin_cpus=0,1,2,3,4,5,6,7
```

This is expanded into zc:99@0 .. zc:99@7

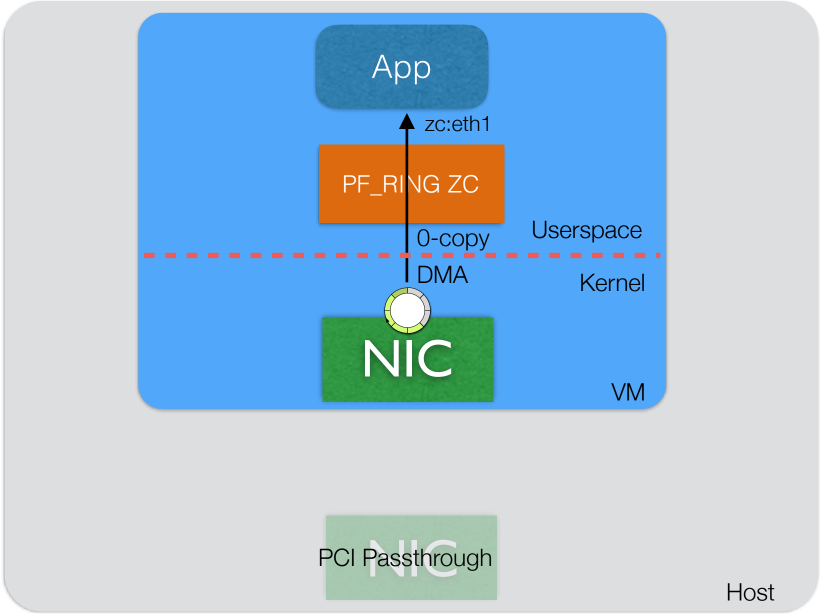
Other processing patterns

- Using the ZC API you can create any multithreaded or multi-process processing pattern. Pipeline example:



ZC & Virtualisation: PCI Passthrough

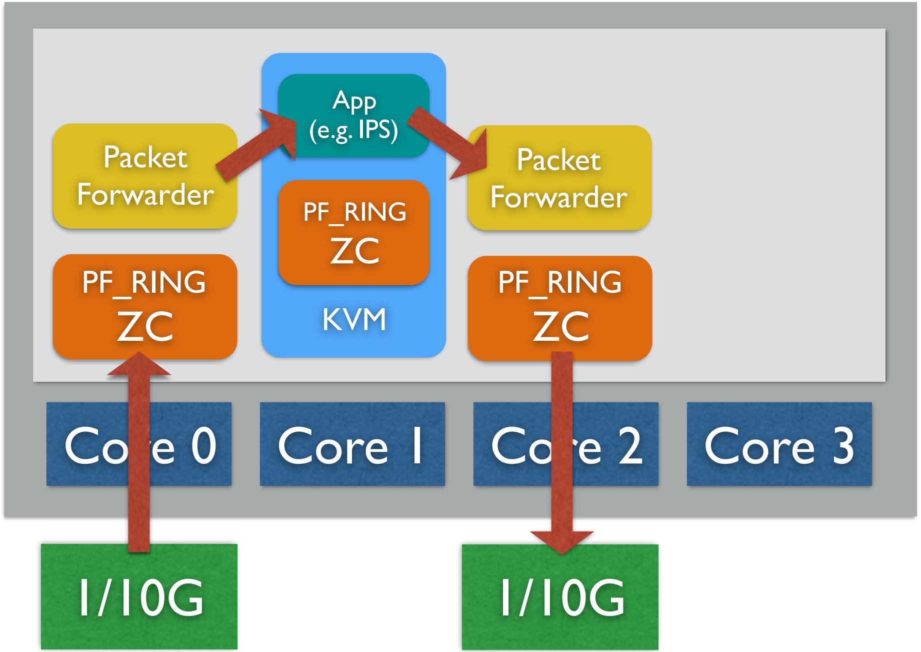
- Any hypervisor is supported: KVM, VMWare (Direct I/O), Xen, etc.



ZC & Virtualisation: Host to VM (KVM)

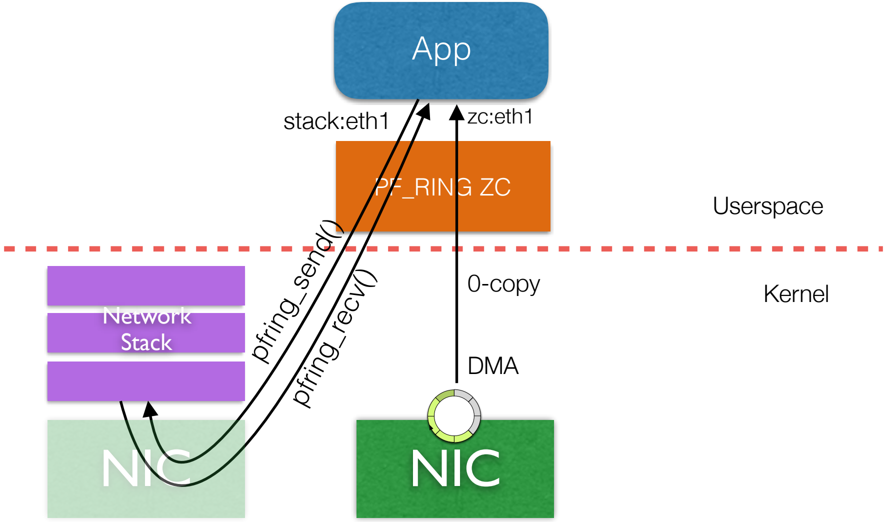
```
(Host) $ zpipeline_ipc -i zc:eth2,0 -o zc:eth3,1 -n 2 -c
99 -r 0 -t 2 -Q /tmp/qmp0

(VM)   $ zbounce_ipc -c 99 -i 0 -o 1 -u
```



Stack Injection

- ZC is a Kernel-Bypass technology: what if we want to forward some traffic to the Linux Stack?



Thank you!