Intelligent NIC Queue Management in the Dragonet Network Stack

Kornilios Kourtis

kou@zurich.ibm.com

Currently at: IBM Research, Zurich.
This work done while at: Systems Group, ETH Zurich.

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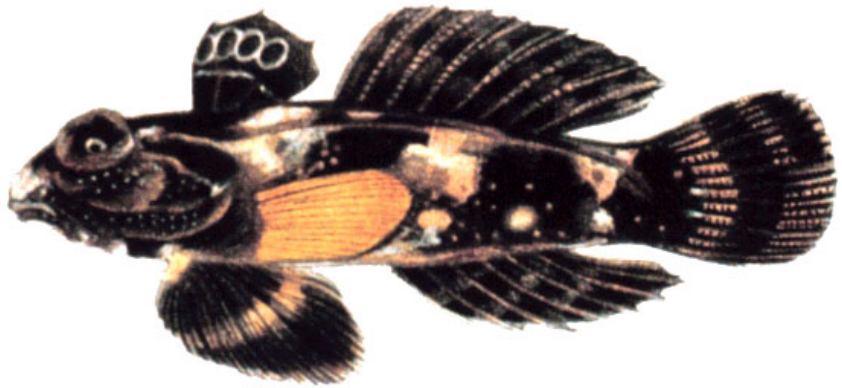
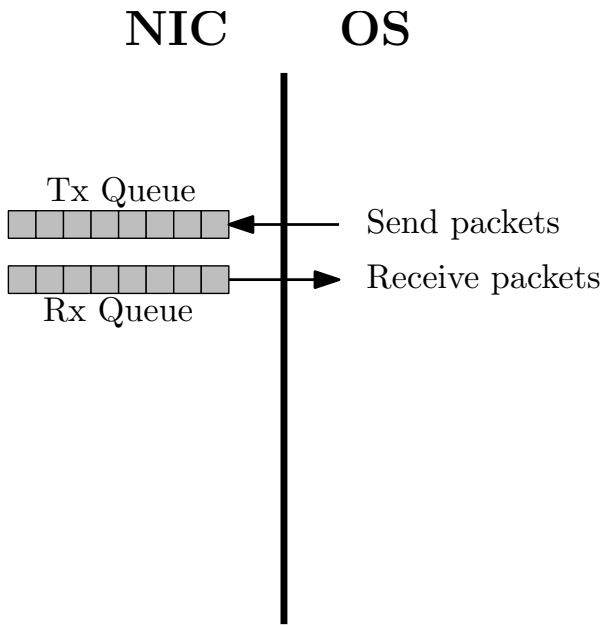
Dragonet



- Cores are not getting faster, the network is
- Network Interface Cards (NICs) offer rich functionality
  (cf. other specialized h/w such as GPUs, FPGAs, etc.)

- Dragonet is a host network stack that aims at a principled approach for utilizing and managing NIC hardware

NIC hardware



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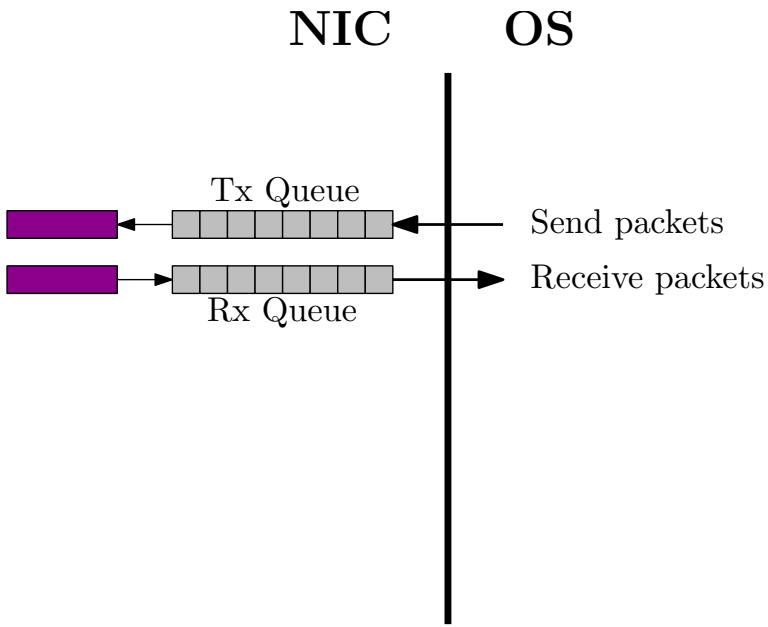
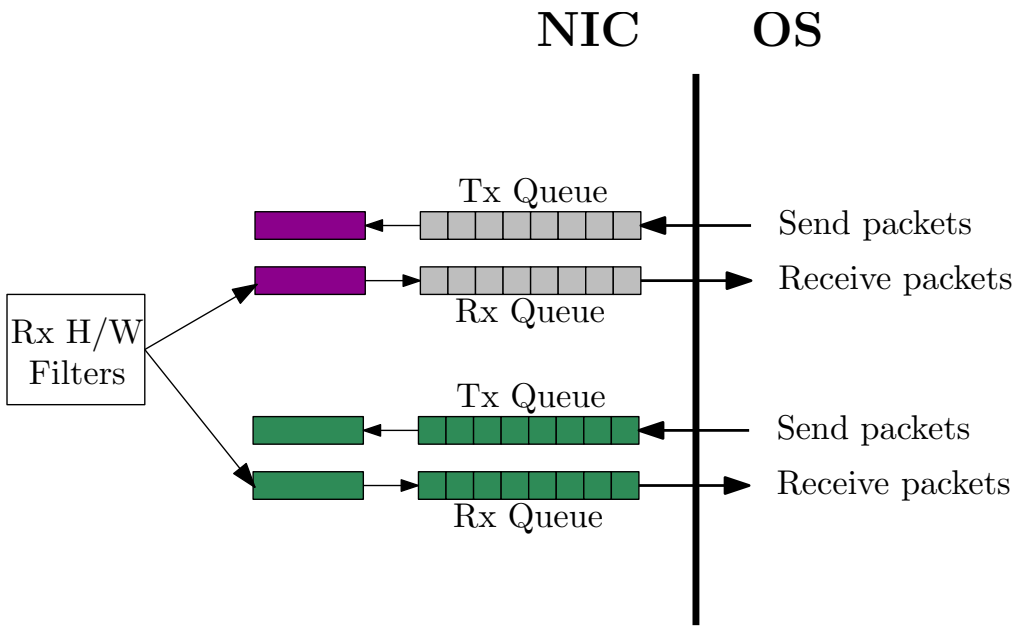


Offload functions:
e.g.: send and receive checksum offload, segmentation offload, full protocol (TCP offload engines, IPSec)

NIC hardware



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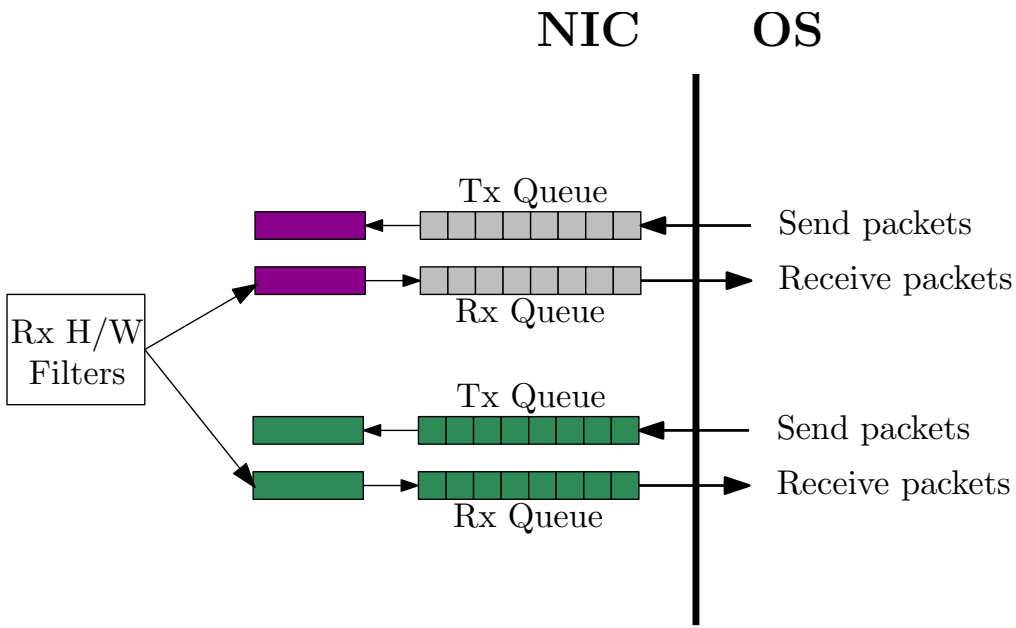
Multiple queues:
network stack can use multiple cores, virtualization, OS dataplanes, QoS.
NIC hardware filters for steering packets into queues

NIC hardware



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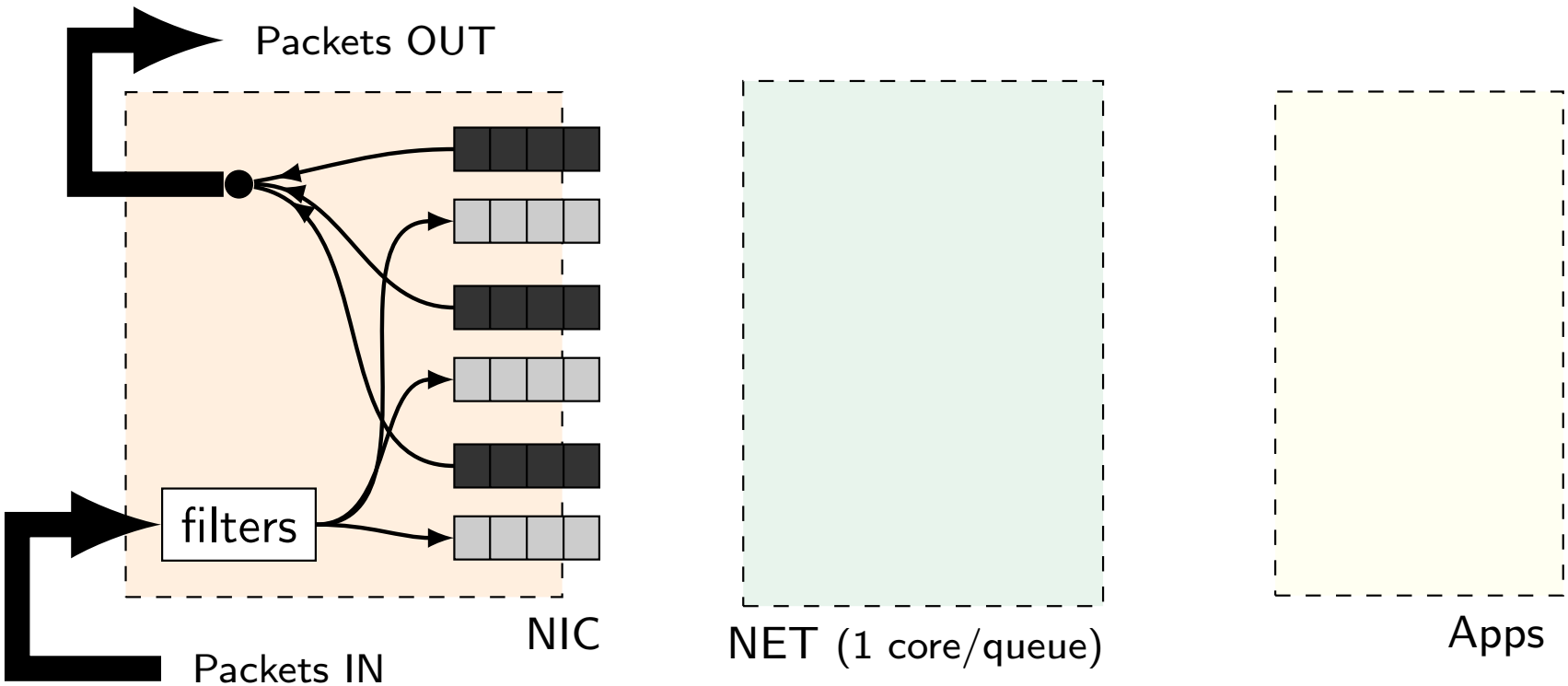
this talk: **dealing with multiple queues**

NIC queues and network stacks



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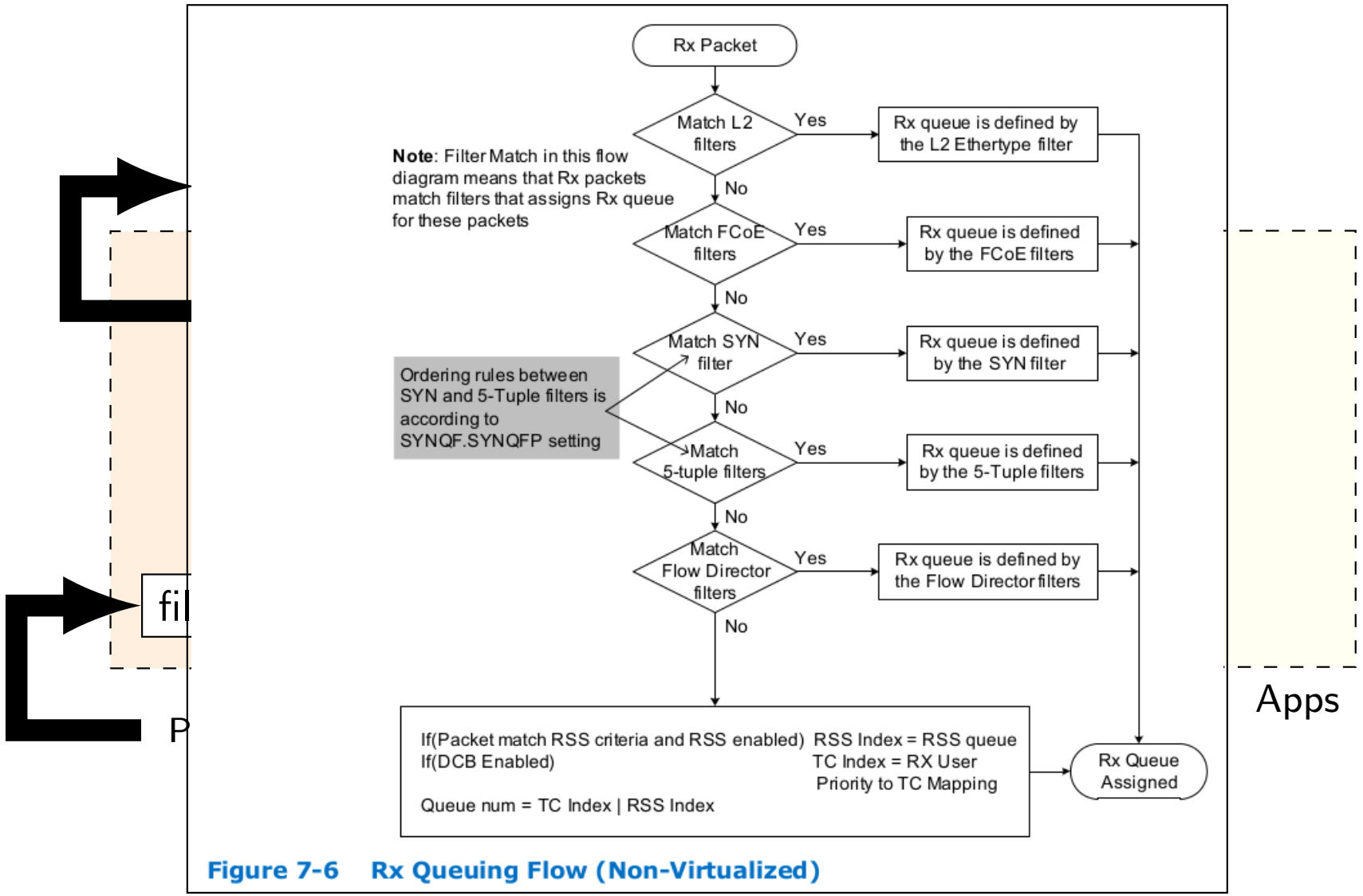
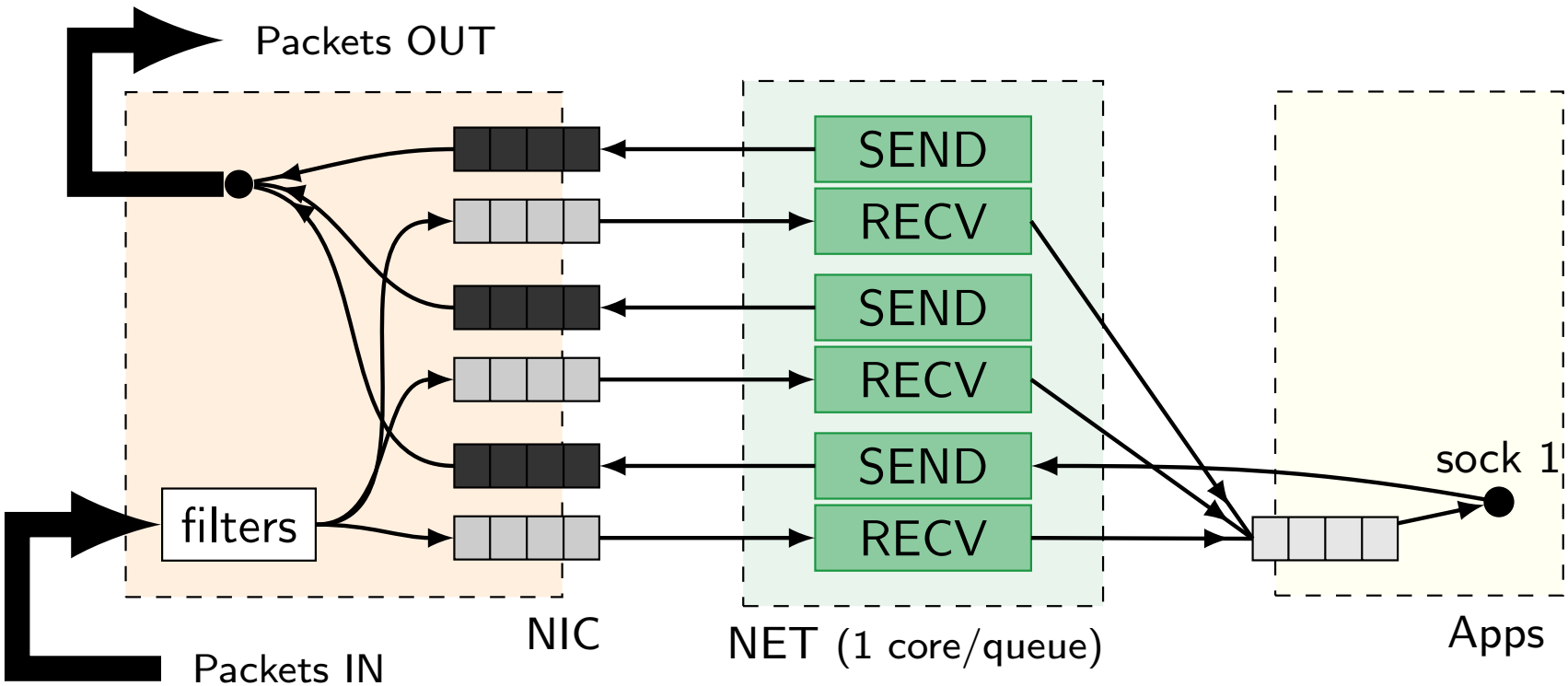


Figure 7-6 Rx Queuing Flow (Non-Virtualized)

NIC queues and network stacks



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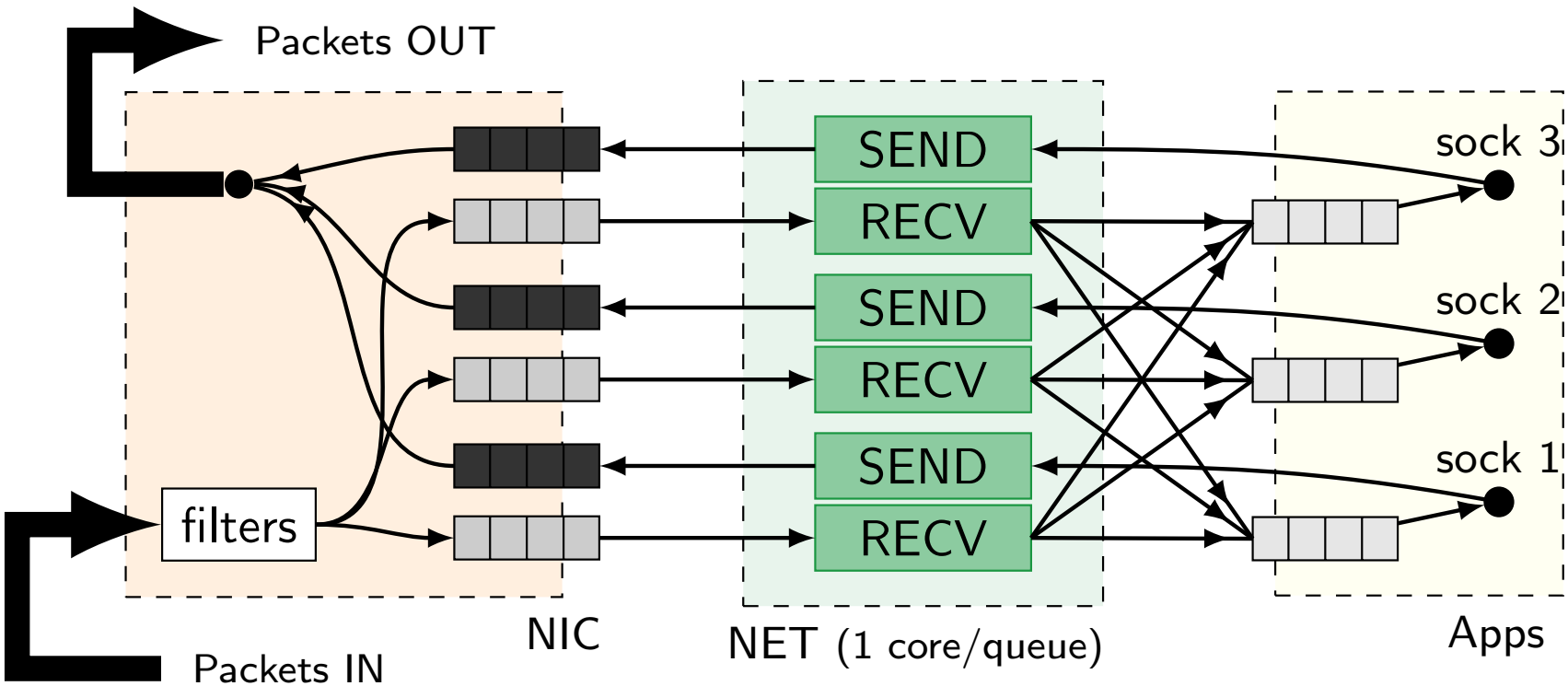

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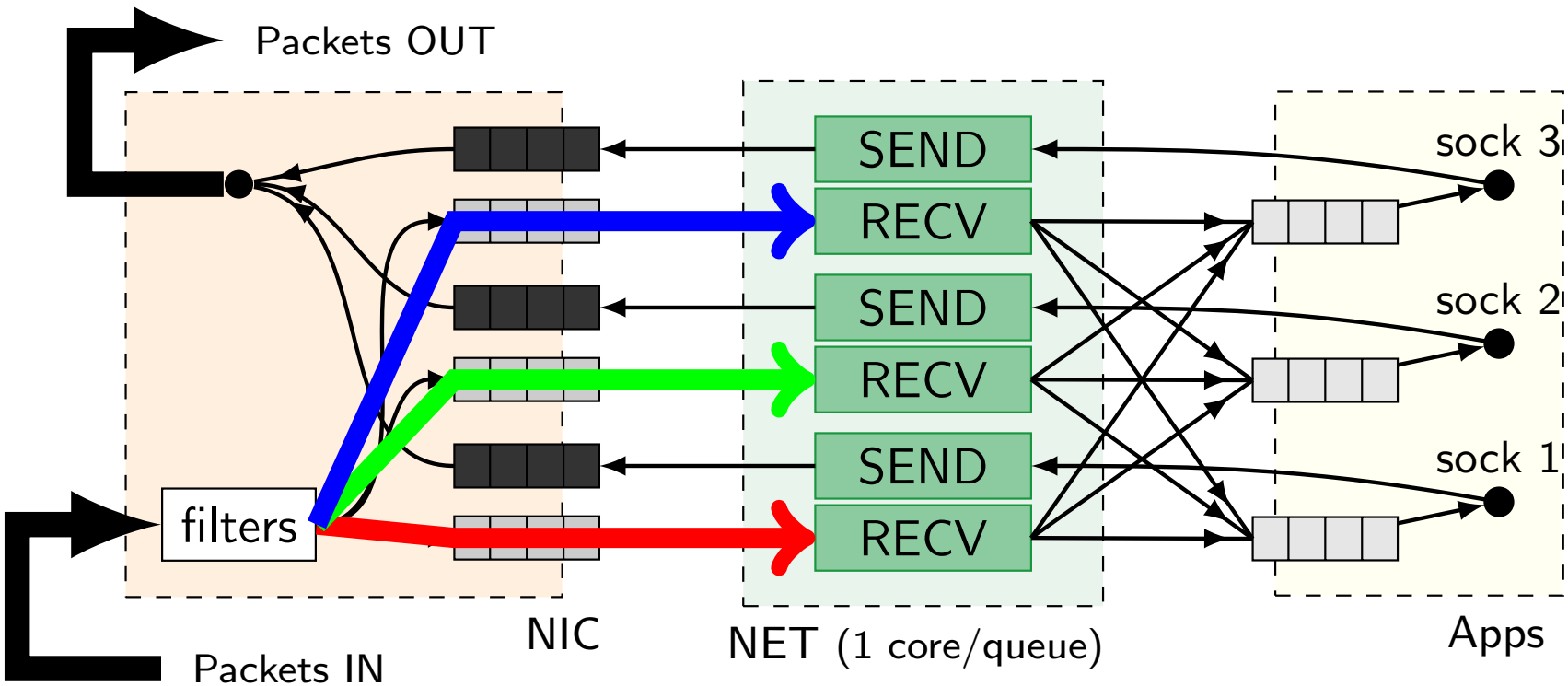
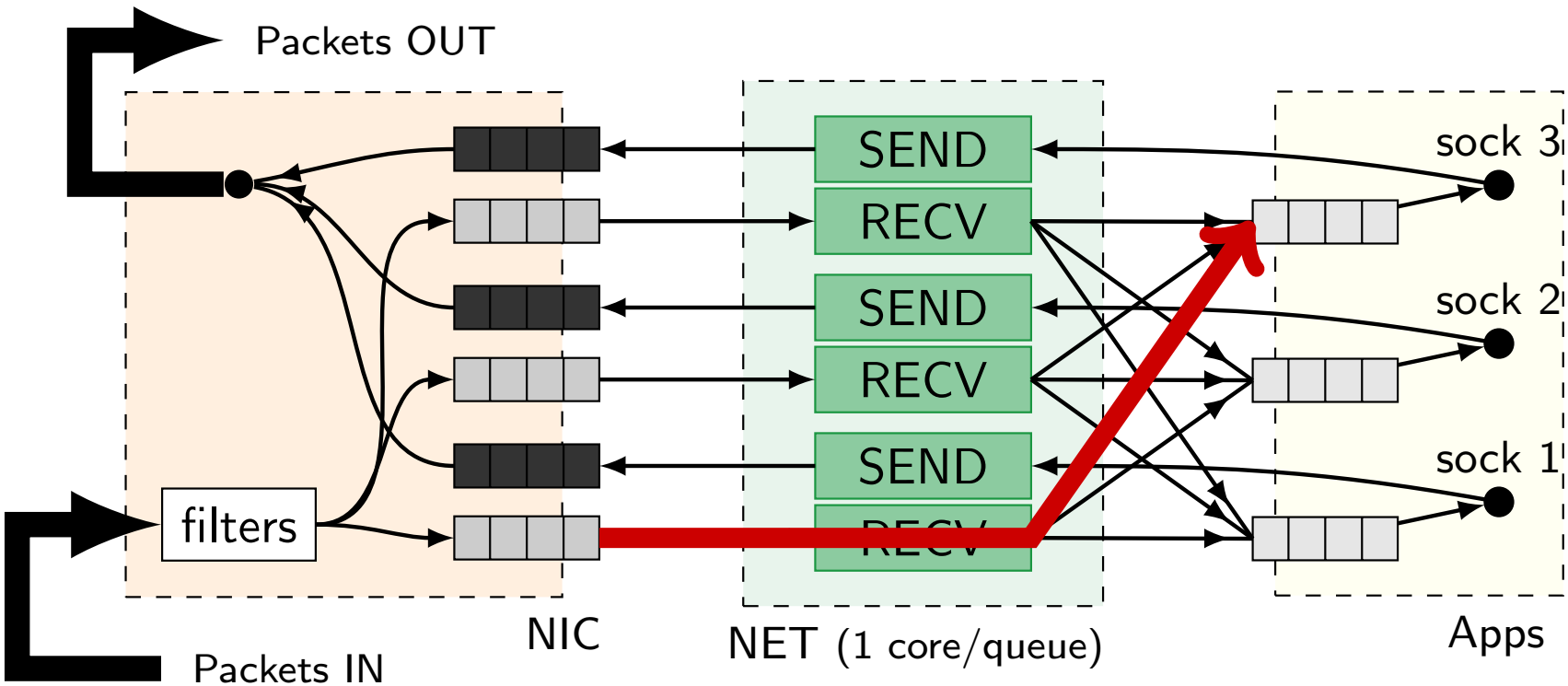


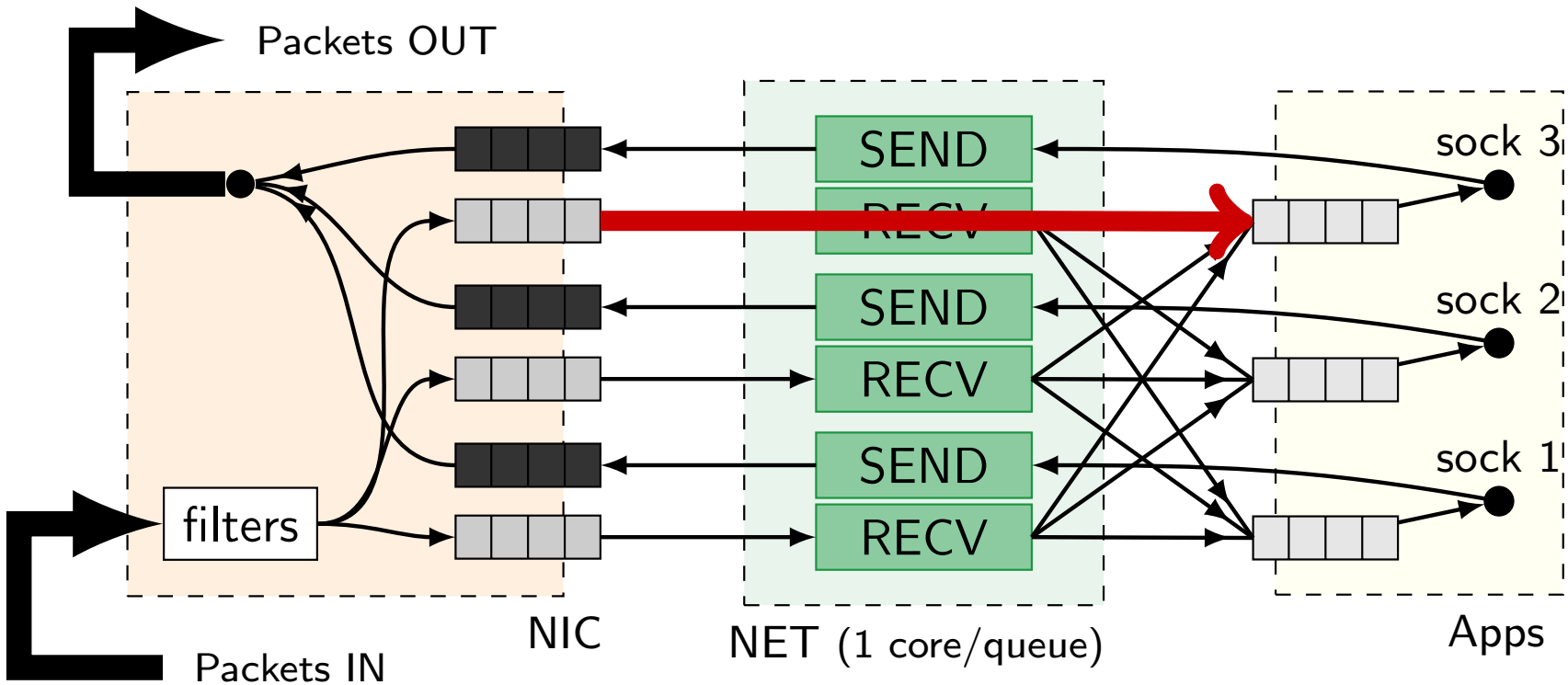
- 1st approach: **policy in the NIC**
- Receive Side Scaling (RSS)

NIC queues and network stacks



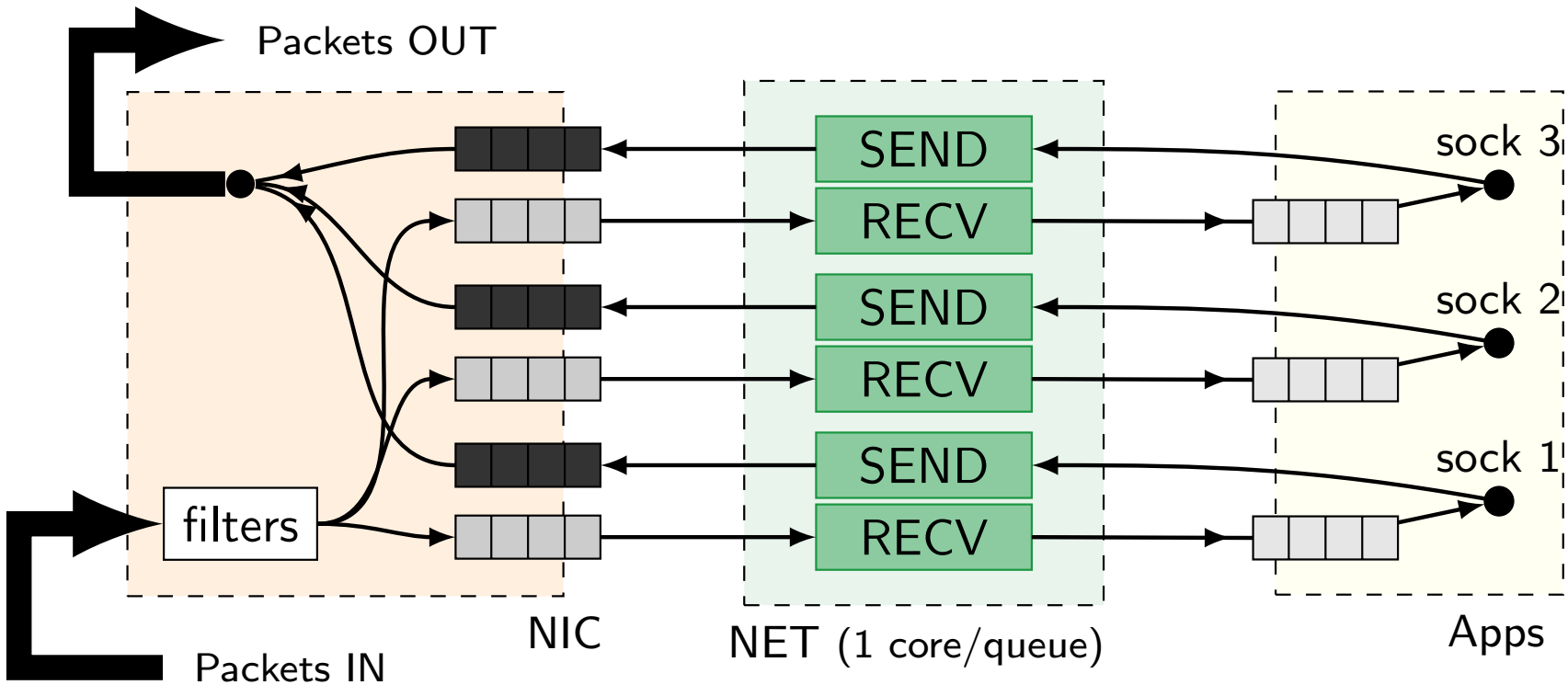
- 1st approach: **policy in the NIC**
- Receive Side Scaling (RSS)
  → poor locality

NIC queues and network stacks



NIC should steer packet in the core the application resides
(aRFS in Linux, ATR in i82599 driver, Affinity-Accept [Eurosys12])

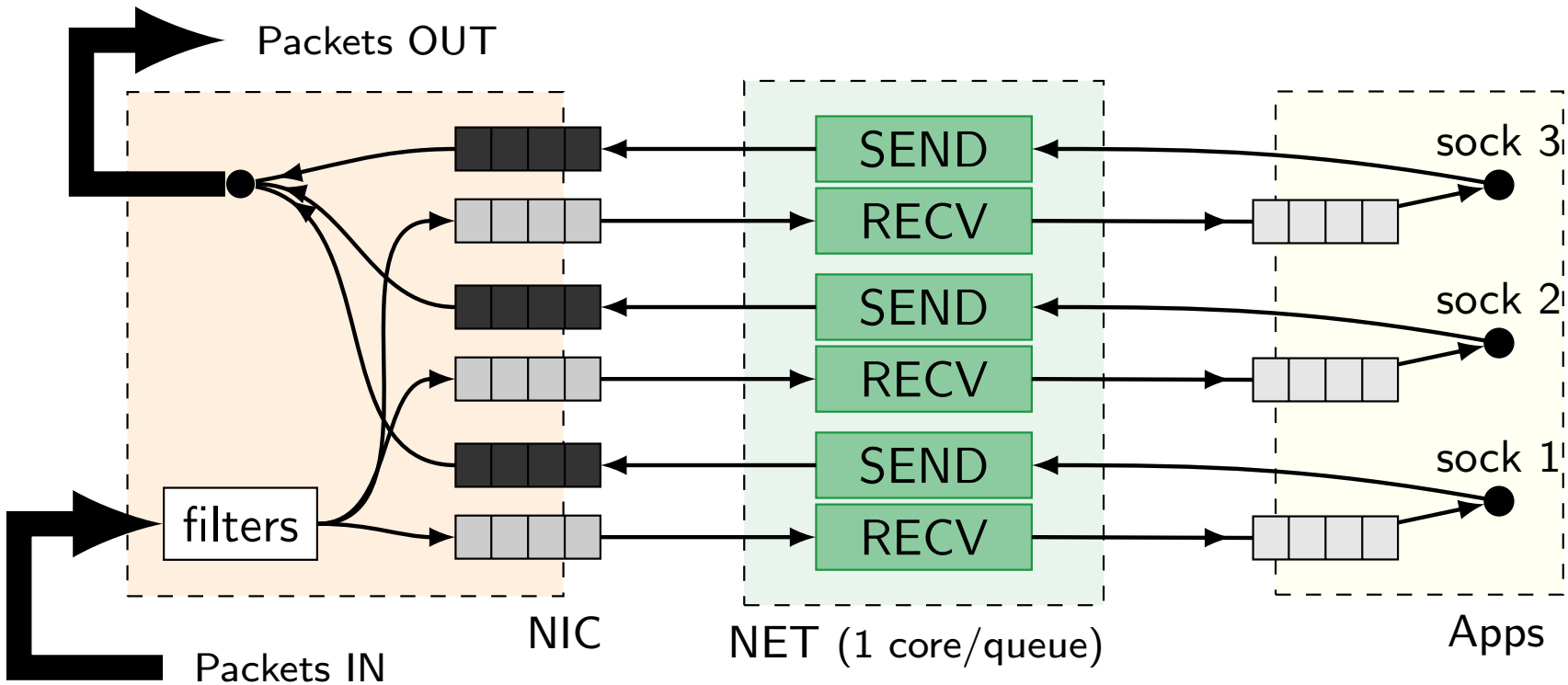
NIC queues and network stacks



Data-plane OSes: Arrakis [OSDI14a], IX [OSDI14b]:

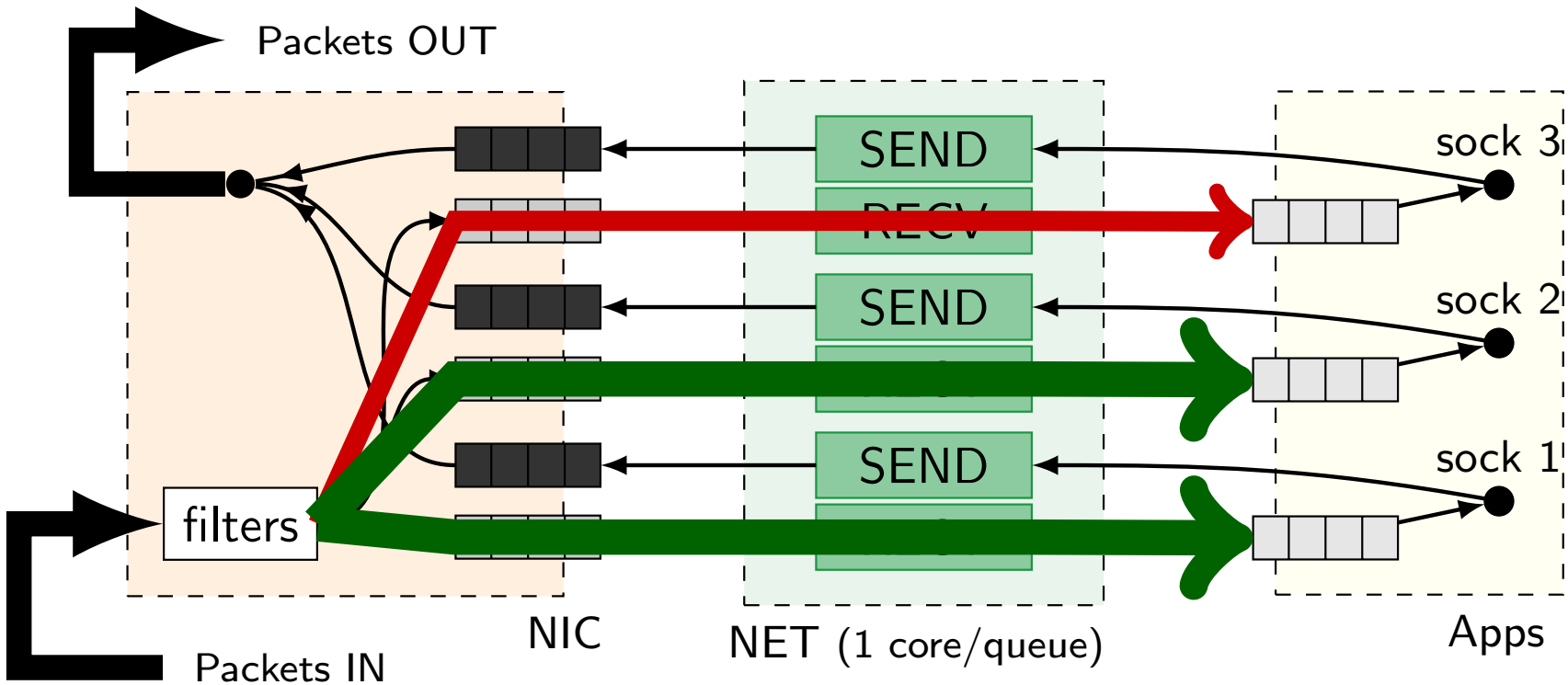
- remove OS from the data path, demultiplexing on NIC

NIC queues and network stacks



- how do you configure the NIC?
- what happens if you run out of filters? or queues?

NIC queues and network stacks



- how do you configure the NIC?
- what happens if you run out of filters? or queues?
- what if you want a different policy (e.g., QoS)?

Dragonet offers an alternative:

- NIC queue policy in the OS (not in the NIC or the driver)
- NIC model that strives to fully capture the NIC capabilities
- NIC-agnostic policies expressed as cost functions

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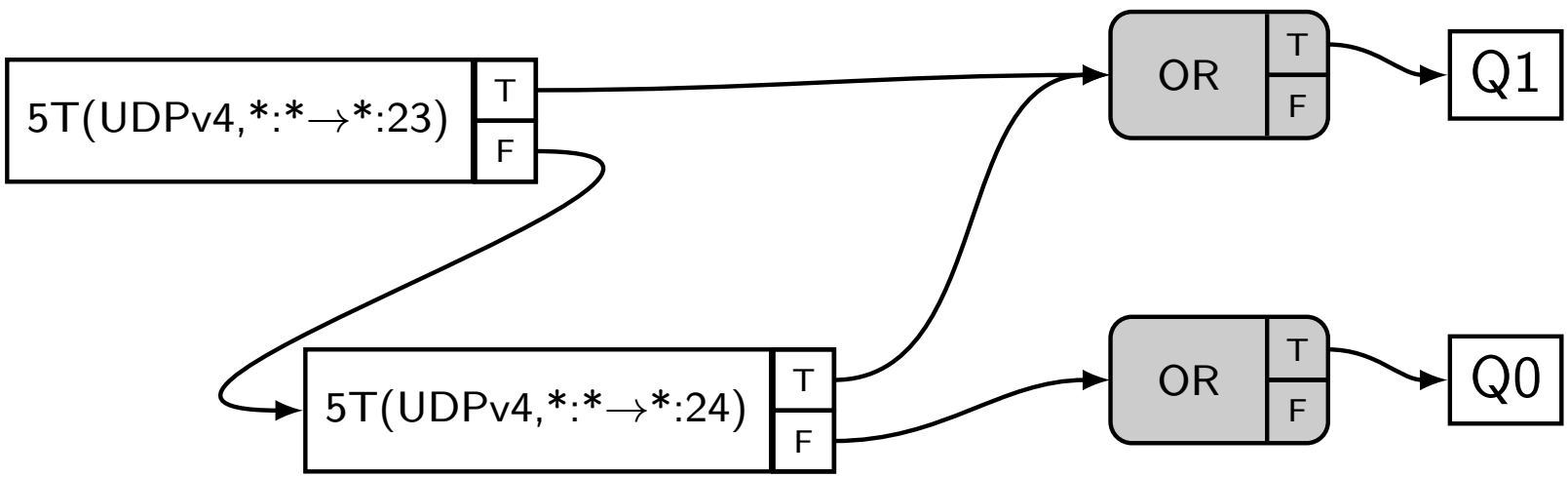
Talk outline

- Dragonet models the NIC as a dataflow graph (called the Physical Resource Graph: **PRG**)
- Using the model to manage queues in Dragonet
- Evaluation

NIC model

F-nodes:

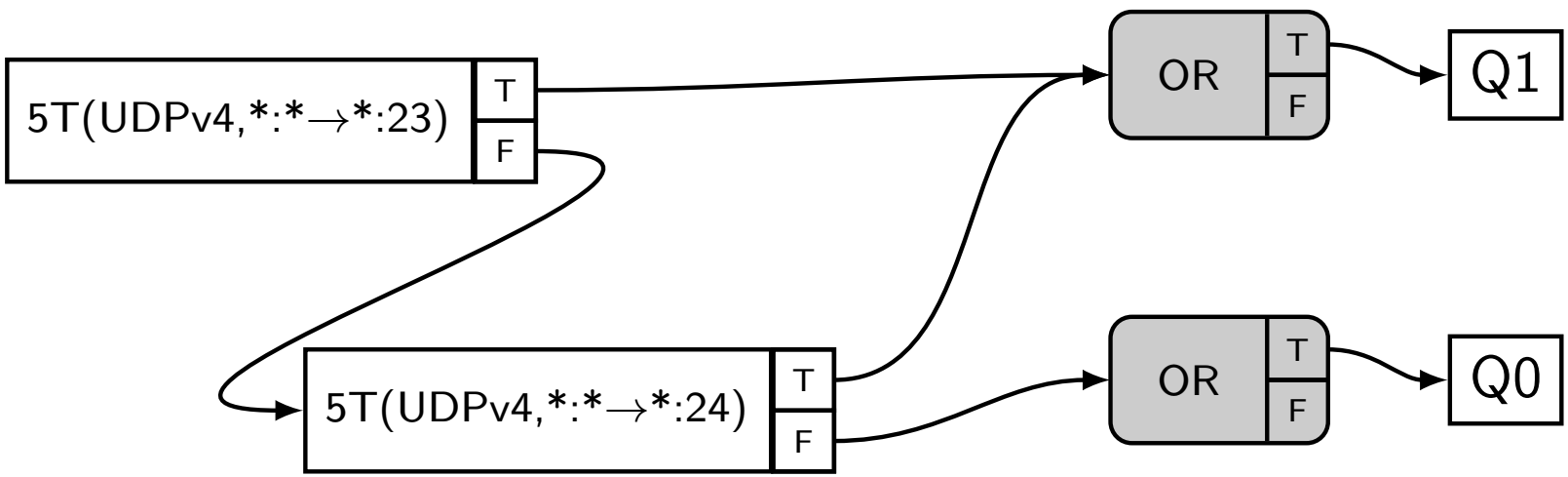
- single input
- ports, each with (possibly) multiple outputs
  - when computation is done, one port is activated
  - subsequently, nodes connected to that port are activated



NIC model

O-nodes:

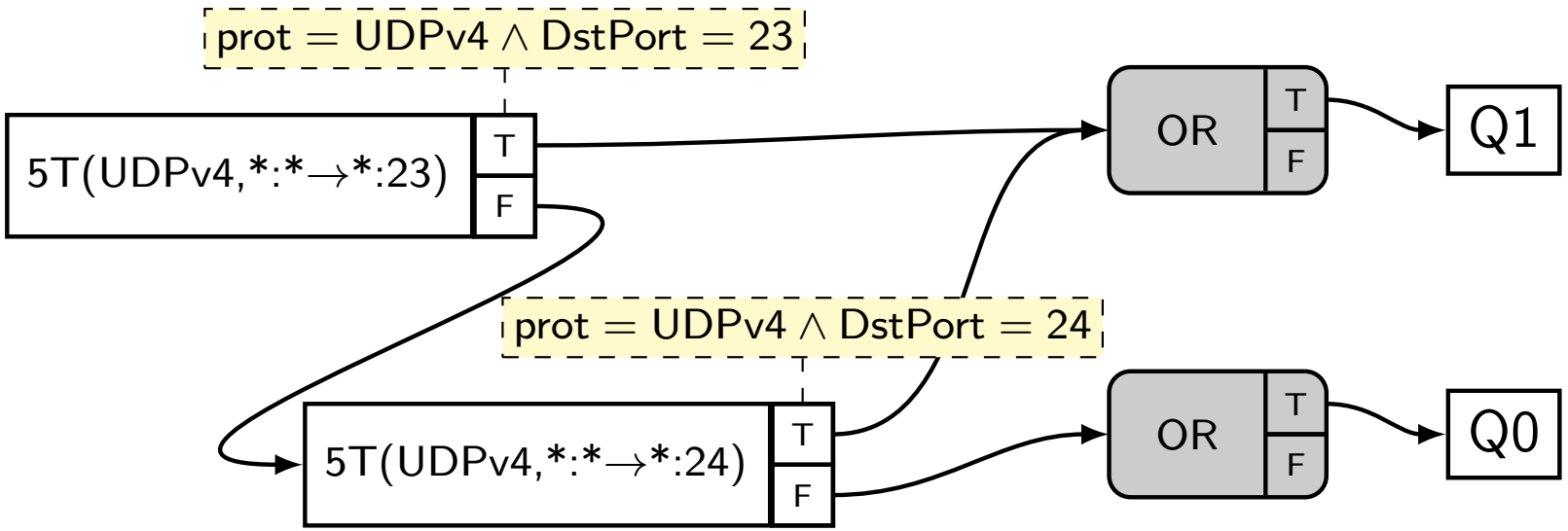
- multiple inputs: $\{T, F\} \times$ operands
- can be short-circuited



NIC model

Predicates:

- boolean expressions about the packet
  (atoms of the form: $k = v$)
- each F-node port has a predicate



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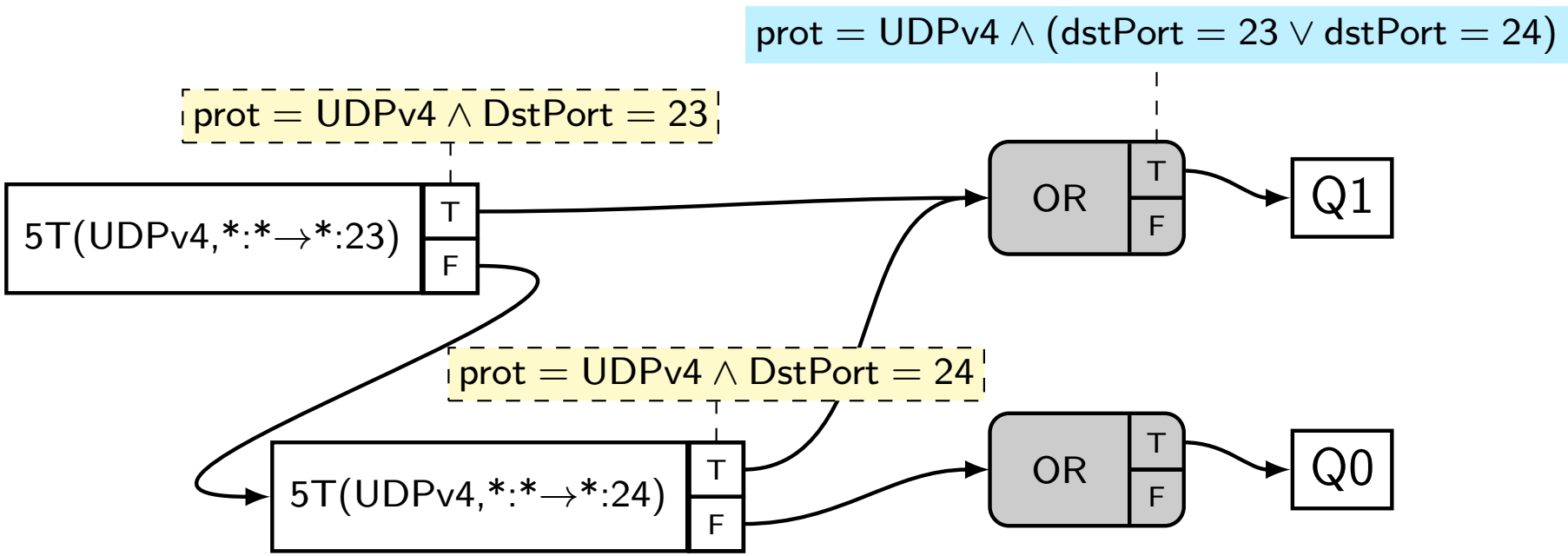


Modeling NIC Configuration

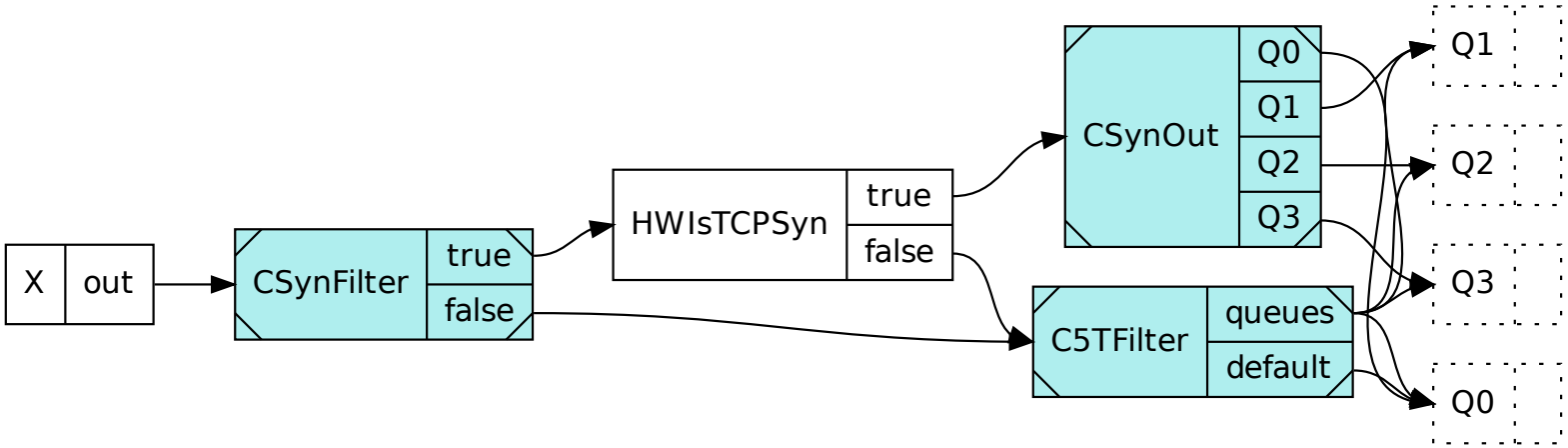
- modern NICs offer rich configuration options
- drastically modify behaviour of NIC

Configuration nodes (C-Nodes)

- apply configuration value:
  - remove C-node and its edges
  - add a subgraph based on configuration value

PRG configuration example

(i82599: SYN filter + 5-tuple filters)



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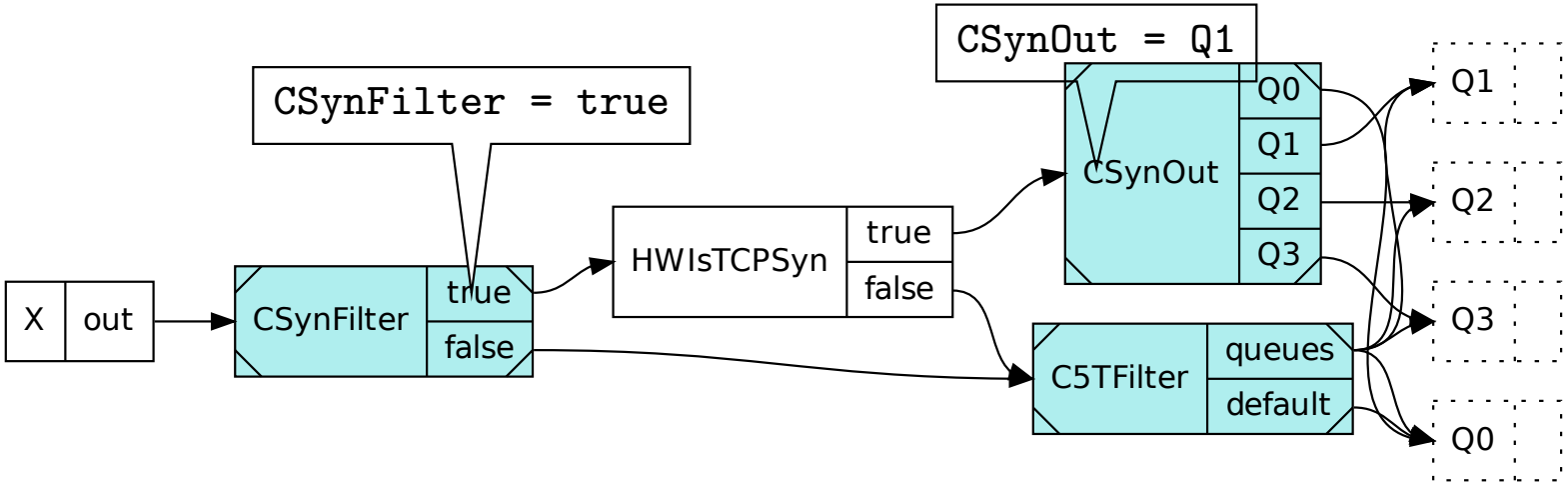

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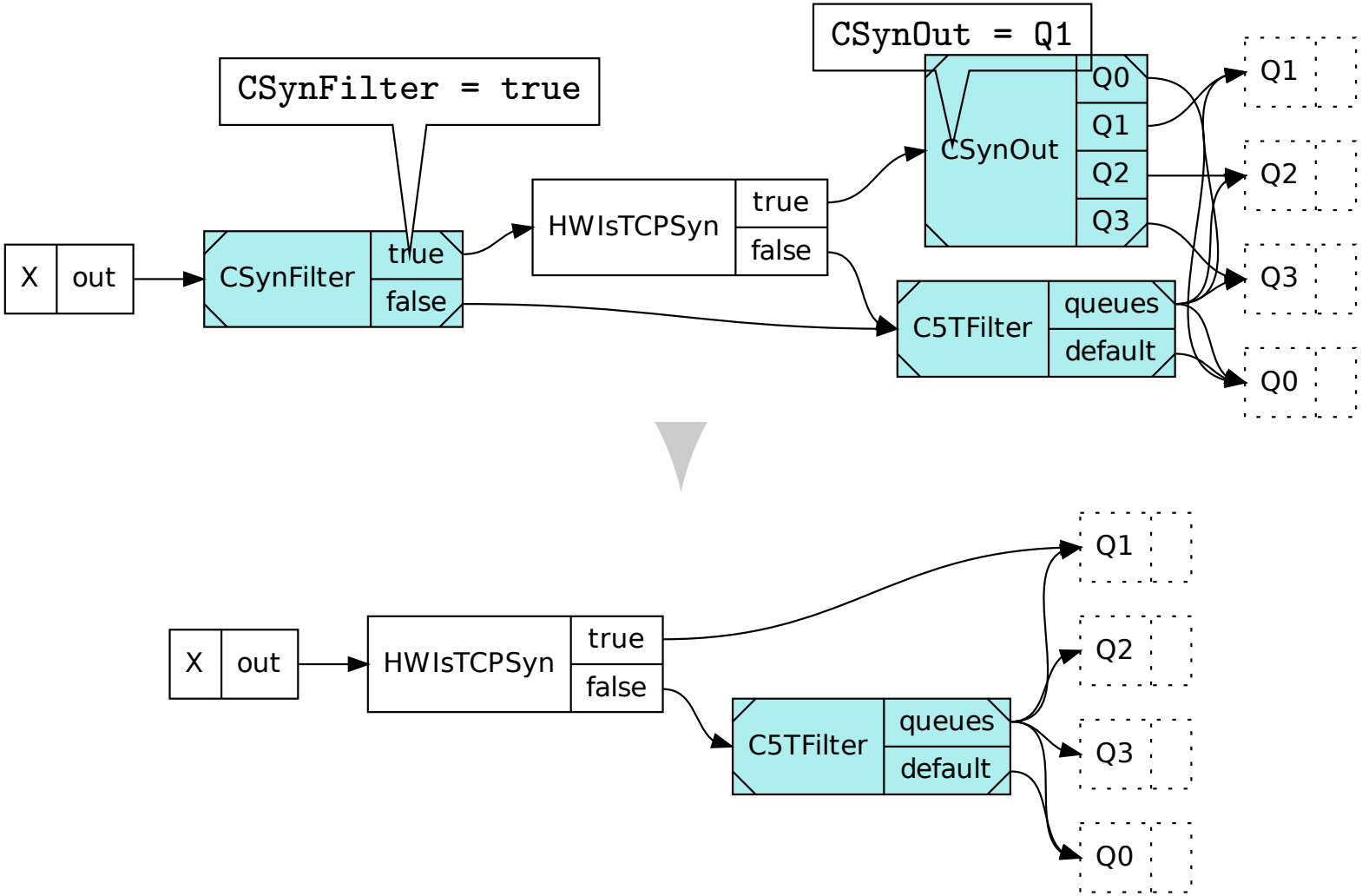
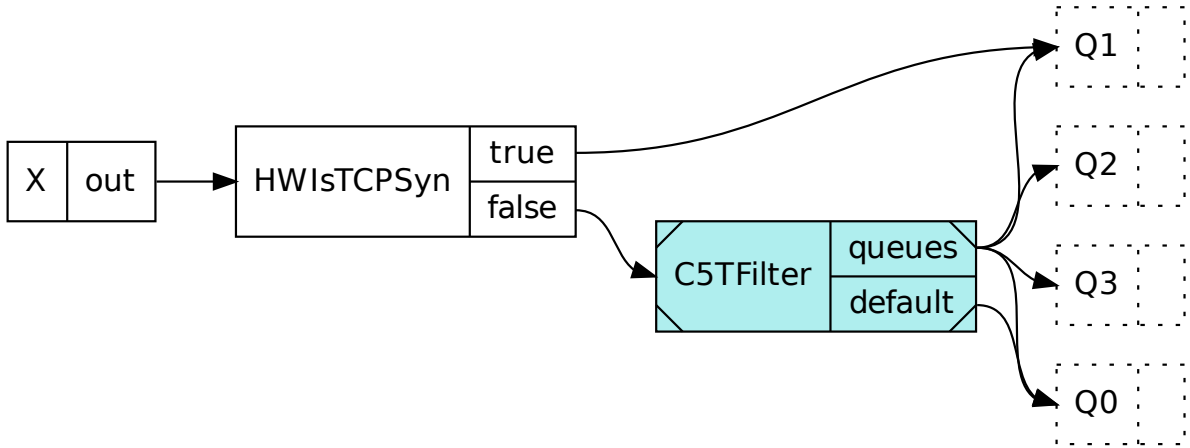


PRG configuration example (cont'd)

(i82599: SYN filter + 5-tuple filters)



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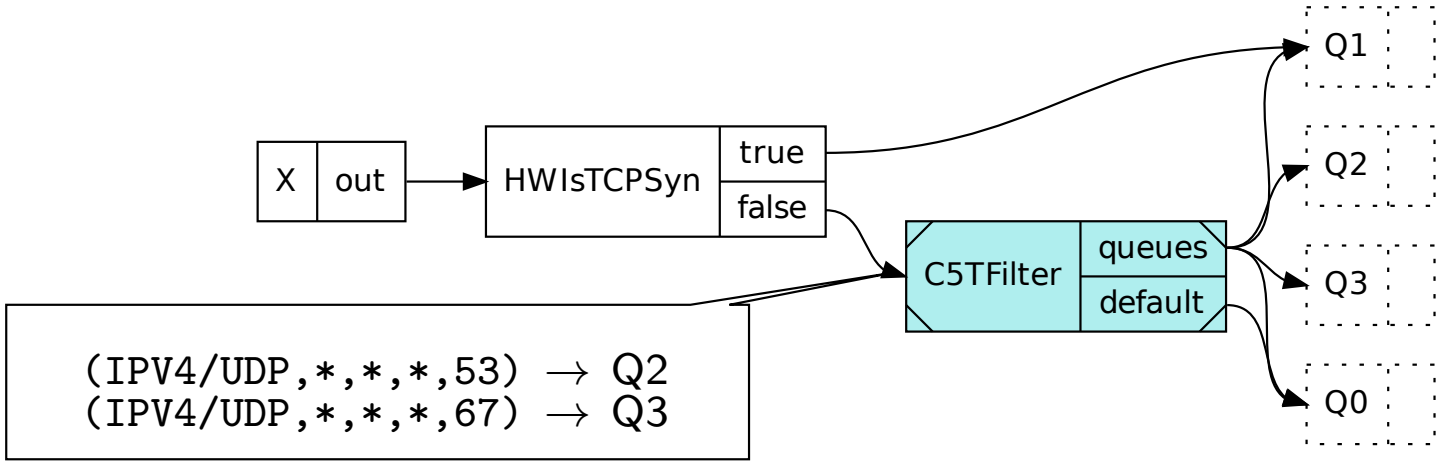

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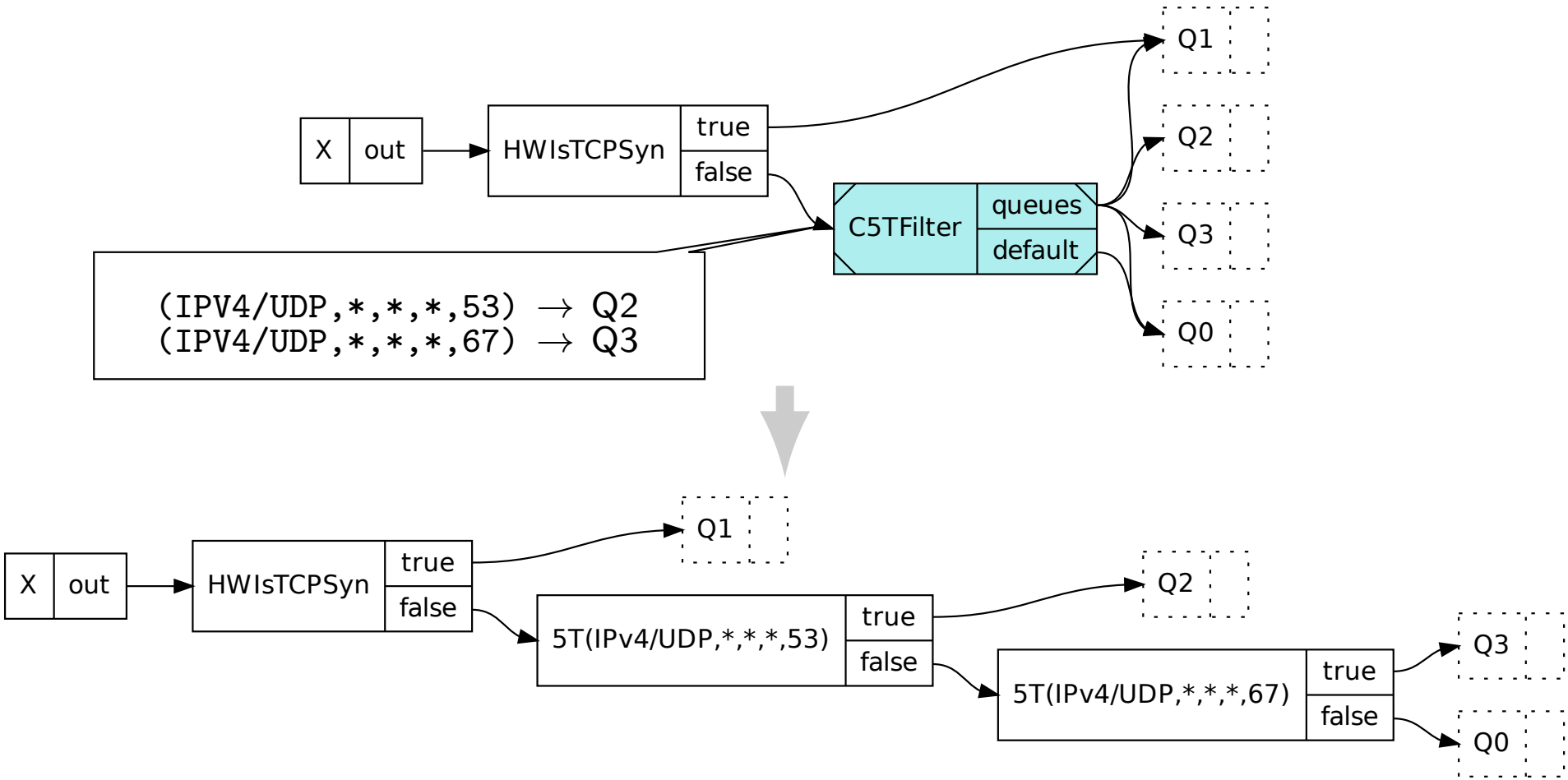

Managing queues

Dragonet provides:

- NIC model (including configuration)
- boolean logic for reasoning

Example Policies:

1. balancing flows across queues (and subsequently cores)
2. providing performance isolation for high-priority flows

Managing queues

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Policies are expressed as cost functions:

- input: How *flows* are mapped into *queues* ($f \rightarrow q$)
- output: cost

Example Policies:

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Specifying policies with cost functions

Load balancing:

- variance of number of flows per queue across queues

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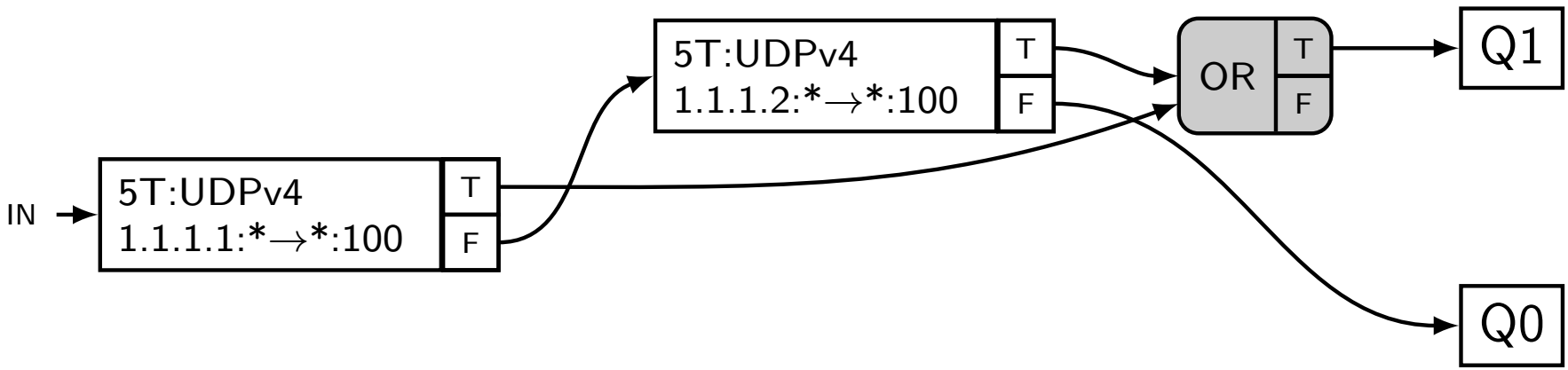
QoS/Performance isolation:

- high-priority (HP) flows, best-effort (BE) flows
- HP flows get N queues, rest to BE flows
- Each class provides its own cost function for its flows (e.g., balancing)
- reject all configurations that assign flows to queues of a different class
- accepted configurations cost: $c = c_{BE} + c_{HP}$
- 20 lines of Haskell code

Computing flow → queue mapping

(cost function input)



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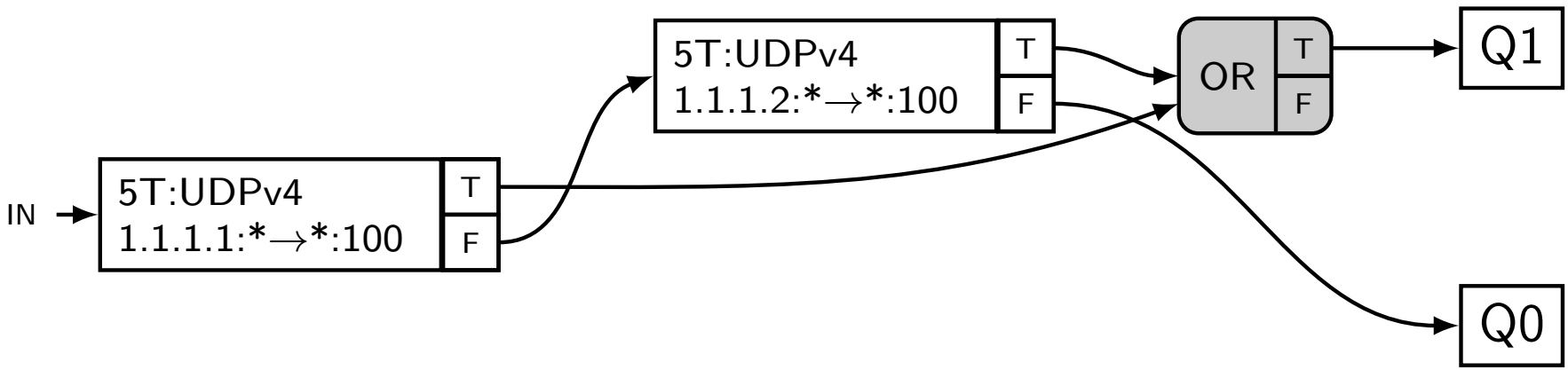

Flow: UDPv4 / 1.1.1.1:9001 → 1.1.1.42:100

predicate:

$$\begin{aligned} & \mathit{EtherType} = \mathit{IPv4} \quad \wedge \mathit{IpProt} = \mathit{UDP} \\ \wedge\ & \mathit{srcIp} = 1.1.1.1 \quad \wedge \mathit{srcPort} = 9001 \\ \wedge\ & \mathit{dstIp} = 1.1.1.42 \quad \wedge \mathit{dstPort} = 100 \end{aligned}$$

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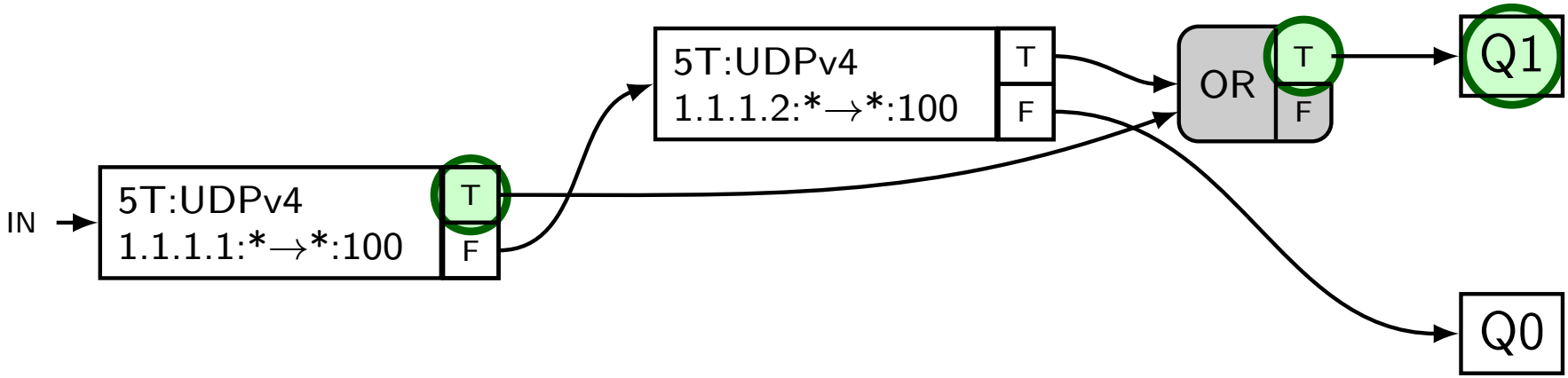

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Searching the configuration space

$$c_o(\text{PRG}, F_{all}) = \arg\min_{c \in C} \text{cost}(\text{qmap}(\text{PRG}(c), F_{all}))$$

Performance concerns:

- full search space is too big

Improving performance:

- reduce space (e.g., NIC-specific heuristics)
- incremental computations (flows added, removed)

Greedy search algorithm

Input : The set of active flows F_{all}
Input : A cost function `cost`
Output : A configuration c

$c \leftarrow C_0$ `// start with an empty configuration`
$F \leftarrow \emptyset$ `// flows already considered`
foreach f *in* F_{all} **do**
    `//` CC_f`:  A set of configuration changes on` f
    `// that incrementally change` c
    $CC_f \leftarrow$ `oracleGetConfChanges(`c, f`)`
    $F \leftarrow F + f$ `// Add` f `to` F
    find $cc \in CC_f$ that minimizes `cost(qmap(PRG(`$c + cc$`),` F`))`
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- oracle: NIC-specific configuration generation

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Efficient flow-to-queue map computation

foreach f *in* F_{all} **do**

...

find $cc \in CC_f$ that minimizes $\texttt{cost}(\texttt{qmap}(\texttt{PRG}(c + cc), F))$

...

naive:

- compute configuration (C) from configuration changes ($[cc]$)
- apply C to PRG
- compute map

Efficient flow-to-queue map computation

foreach f *in* F_{all} **do**

...

find $cc \in CC_f$ that minimizes `cost(qmap(PRG(`$c + cc$`), `F`))`

...

incremental:

- maintain a *partially configured* PRG
- compute flow-to-port mappings for each node
- Applying a *cc* adds new nodes
- propagate mappings

Evaluation

Implementation + Experimental setup

Implementation

- Haskel + C
- SolarFlare SFC9020 (OpenOnload)
- Intel i82599 (DPDK)

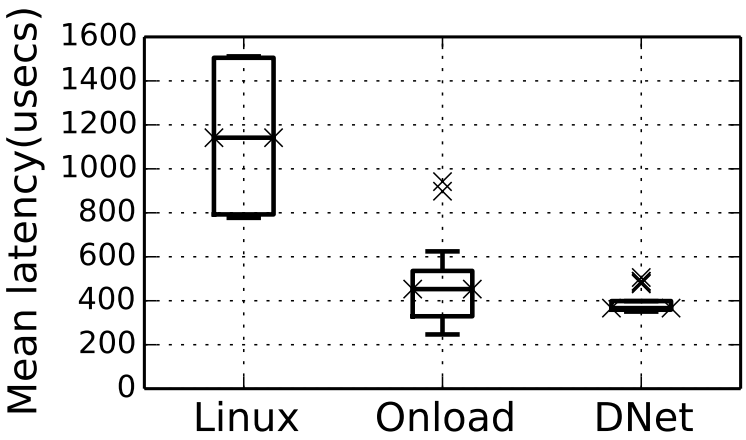
Setup

- 10 client machines for load generation
- 1 server with 20 cores
  - 10 cores to Dragonet, 10 cores to application,
  - 10 queues.

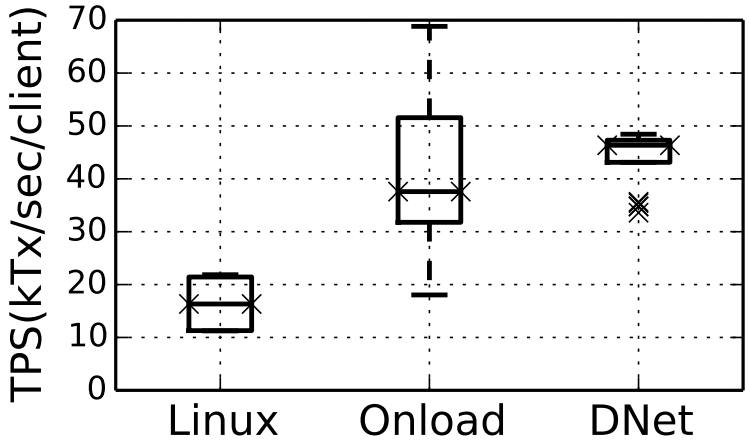
Experiment #1: basic comparison

- **goal**: to show that Dragonet has reasonable performance under the same conditions
- μbench: UDP echo server
- 20 netperf clients, 16 packets in-flight
- Solarflare SFC9020 (vs: Linux stack, OpenOnload user-level stack)
- Dragonet: load balancing cost function, other: RSS

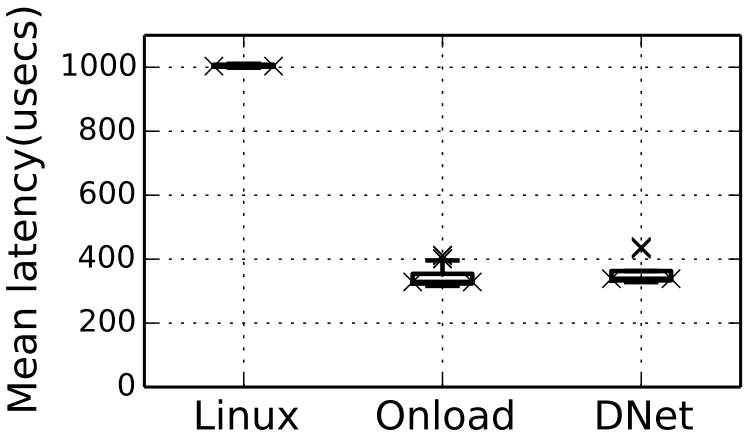
echo server performance on the SFC9020 NIC



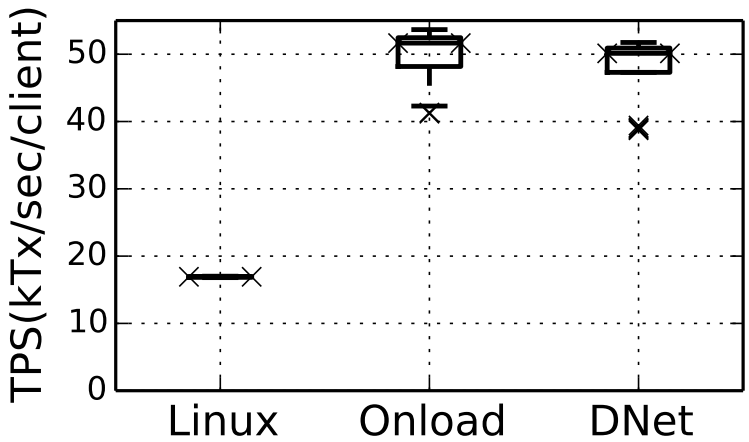
(a) Latency, 1024 bytes



(b) Throughput, 1024 bytes



(c) Latency, 64 bytes



(d) Throughput, 64 bytes

Experiment #2

Performance isolation/Qos

- UDP memcached, memaslap clients
- HP clients: 4 queues, BE clients: 6 queues
- 2 HP clients $\times$16 flows, 18 BE clients $\times$16 flows (320 flows in total) (*stable*)

- we show here results for the Intel i82599
  (similar* results for Solarflare SFC9020 are in the paper)

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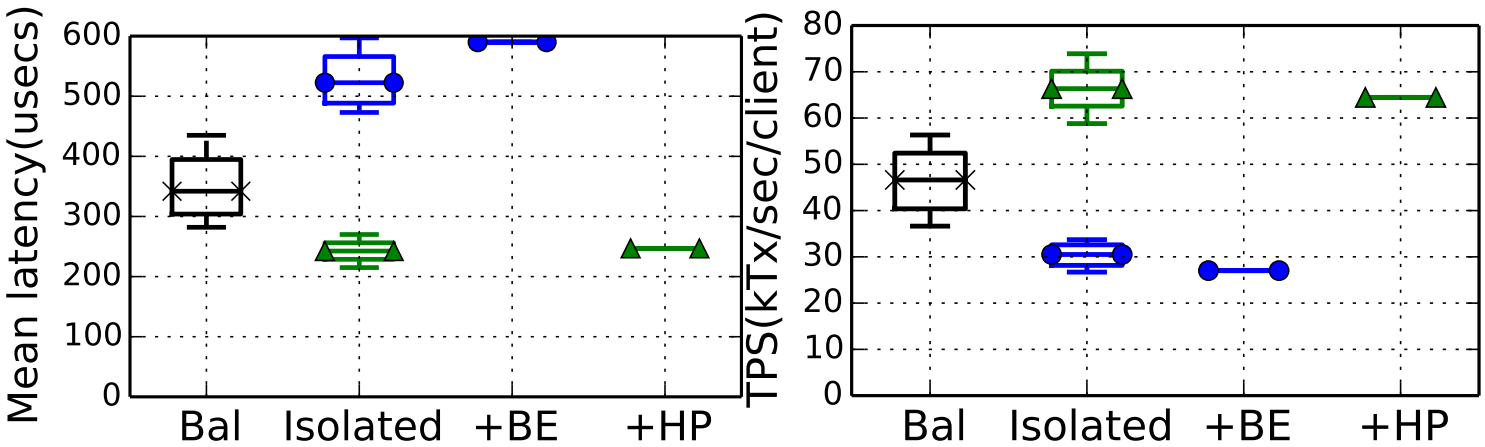
Performance isolation/Qos

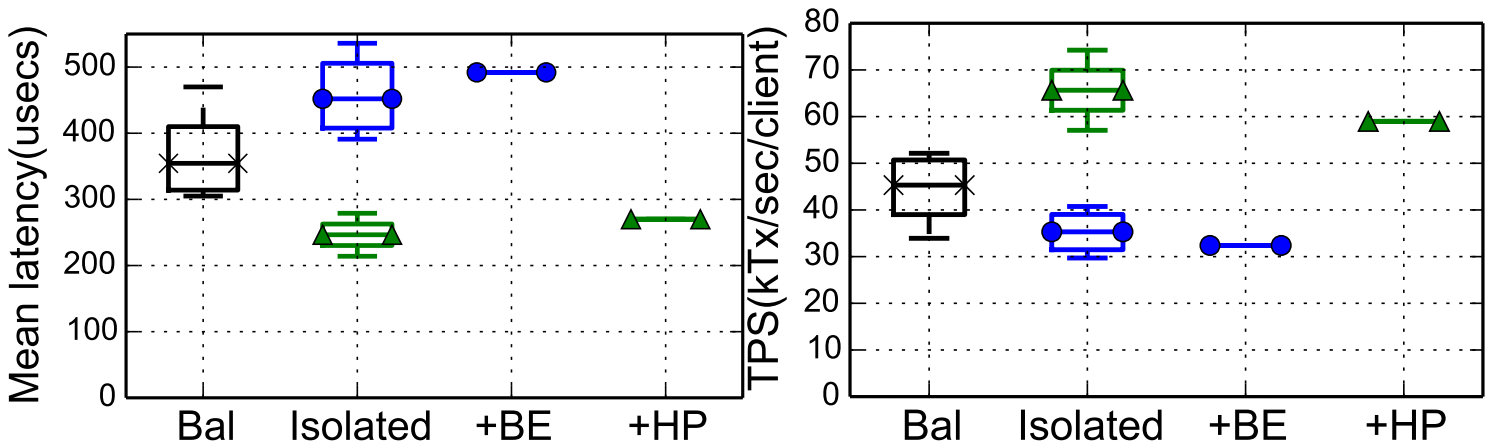
- UDP memcached, memaslap clients
- HP clients: 4 queues, BE clients: 6 queues
- 2 HP clients $\times$16 flows, 18 BE clients $\times$16 flows (320 flows in total) (*stable*)
- after 10secs, we start a new HP client that runs for 50secs
- after new HP is done, we start new BE client
- we show here results for the Intel i82599
  (similar* results for Solarflare SFC9020 are in the paper)

Performance Isolation

(Intel i82599)



(e) Latency, 1024 bytes (f) Throughput, 1024 bytes



(g) Latency, 64 bytes (h) Throughput, 64 bytes

Search cost

(10 queues, i82599 PRG)

	Naive	Incremental				
flows	full	full	+1 fl.	+10 fl.	-1 fl.	-10 fl.
10	11 ms	17 ms	2 ms	22 ms	9 µs	23.7 µs
100	1.2 s	0.6 s	9 ms	94 ms	74 µs	117 µs
250	13 s	4 s	21 ms	219 ms	190 µs	277 µs
500	76 s	17 s	43 ms	484 ms	382 µs	548 µs

Conclusion

- Dragonet offers a systematic approach to managing queues
- Models NIC using a dataflow graph
- Expresses policy via cost-functions
- Incremental computations for improving performance
- Code available at `http://git.barrelfish.org/?p=dragonet`

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