Modeling NICs with Unicorn

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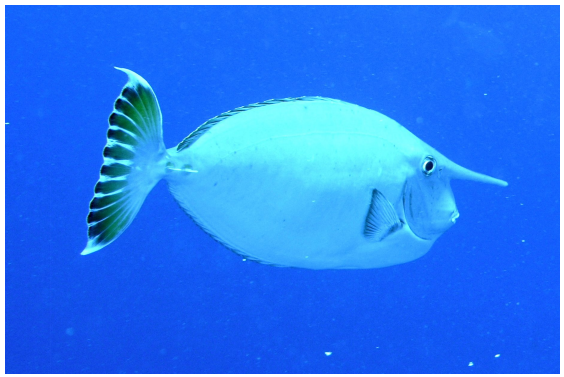


PLOS/Nov. 3 2013

[we thank Microsoft for their financial support]

We need to talk about NICs

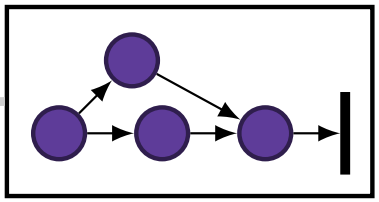
[Shinde et al. HotOS 13]

- increasing complexity/diversity/functionality
  - checksum / segmentation offload, lots of hardware queues, hw filtering, virtualization, direct cache access, ...
- cores are not getting faster, but networks are
- current OSes fail to utilize NIC hardware resources

The Dragonet stack: talking about NICs

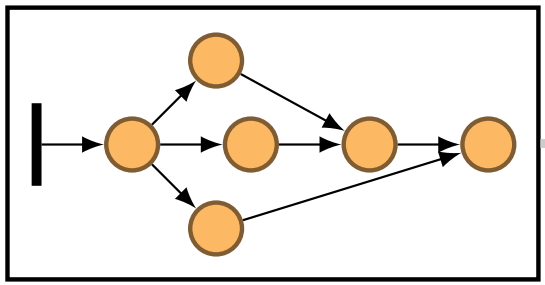
idea: model NIC and net stack as dataflow graphs (c.f. x-kernel, click)

Physical Resource Graph



PRG:
- hw functions
- configuration

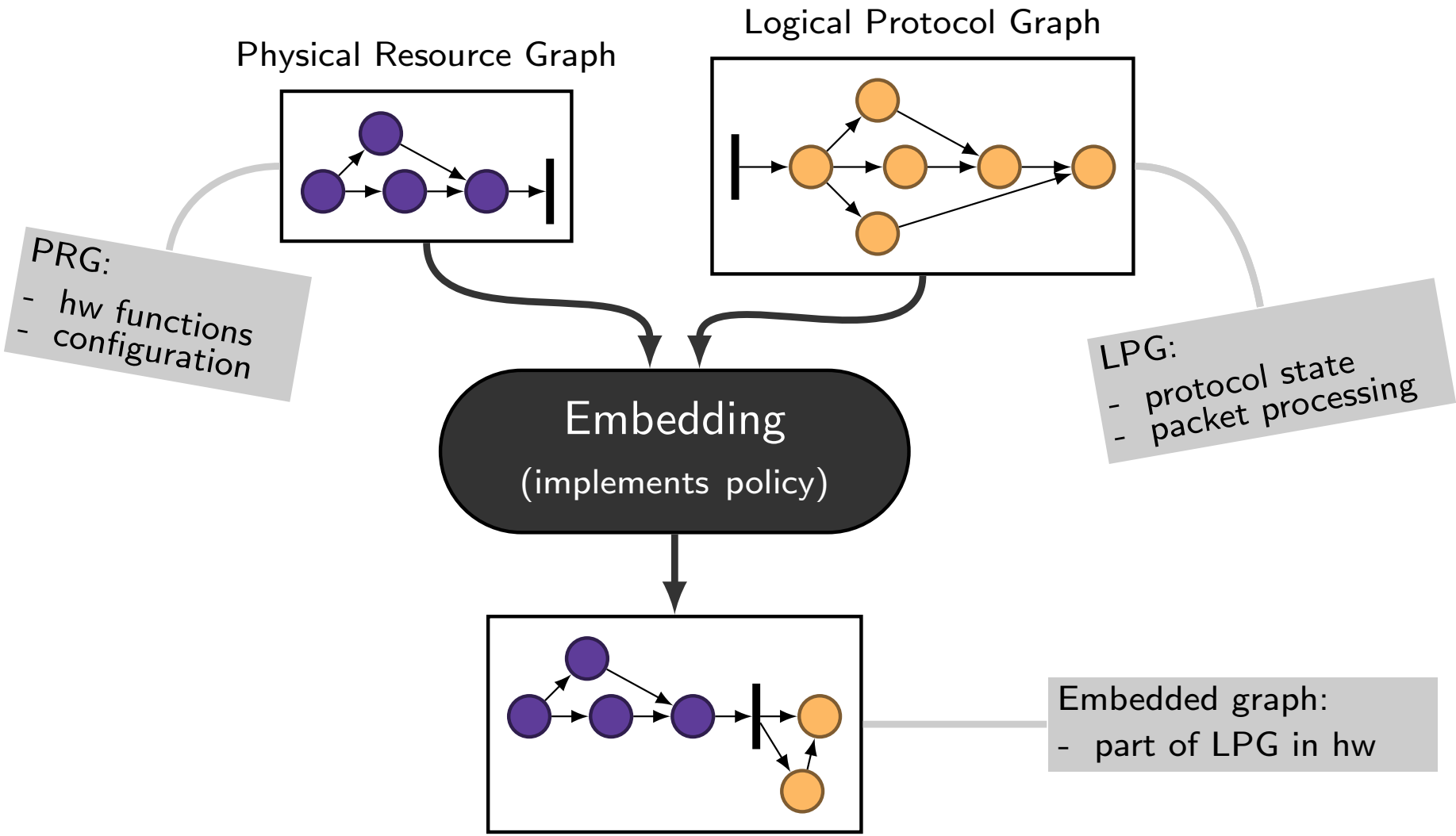
Logical Protocol Graph



LPG:
- protocol state
- packet processing

The Dragonet stack: talking about NICs

idea: model NIC and net stack as dataflow graphs (c.f. x-kernel, click)



The Dragonet stack: talking about NICs

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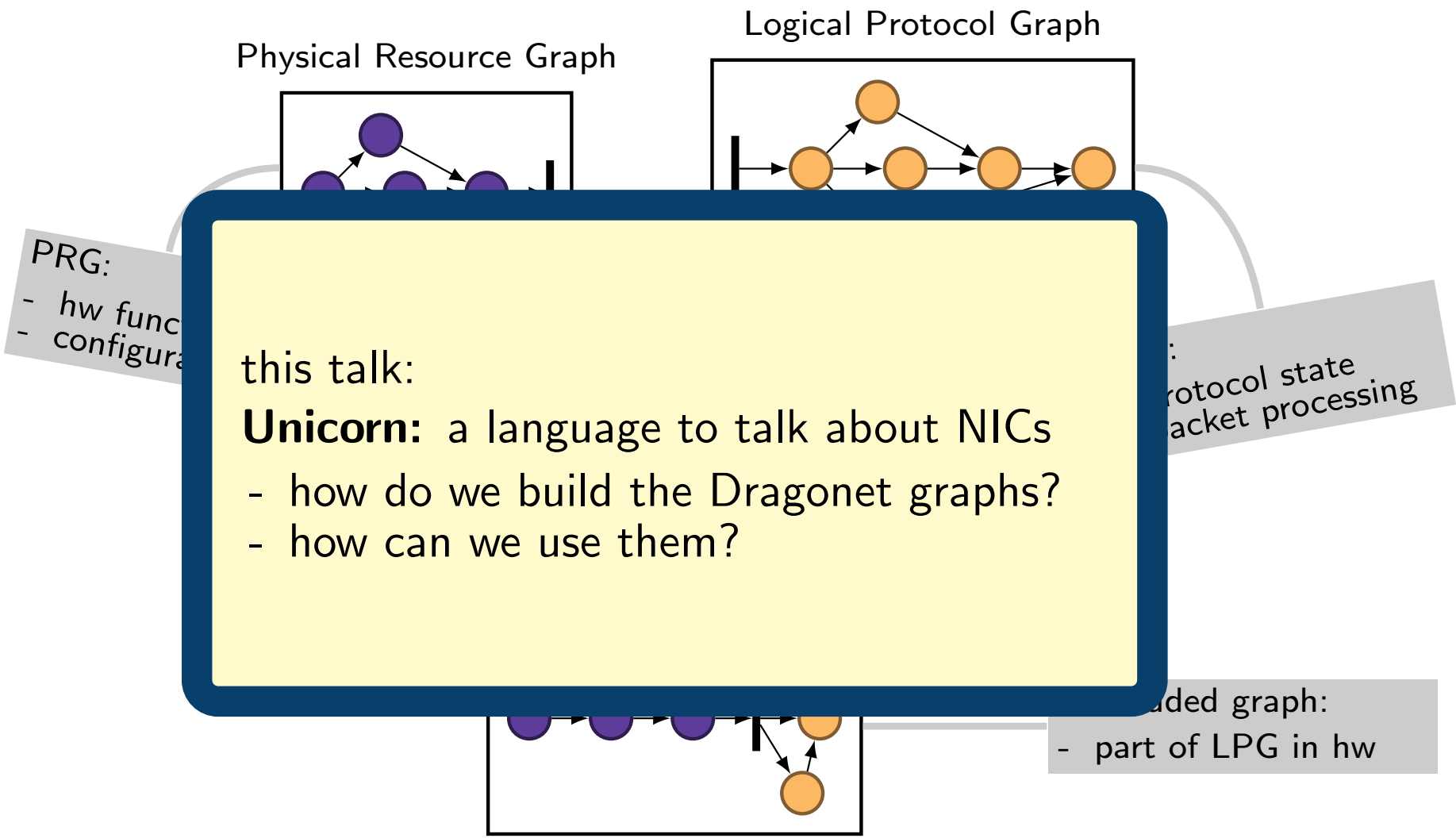
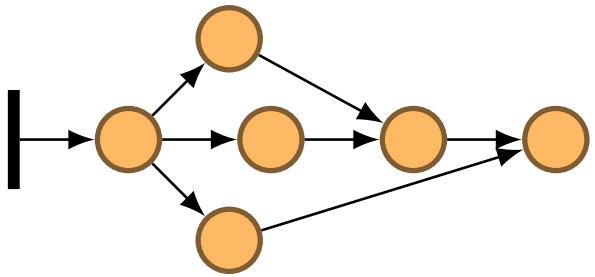
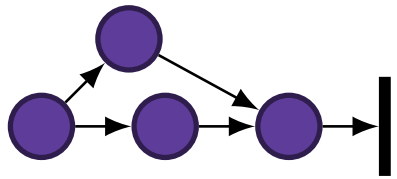


Unicorn: A language to talk about NICs

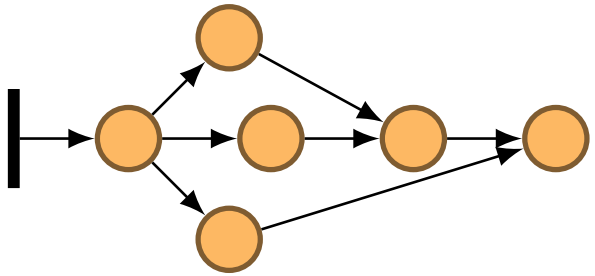
- a syntax for writing PRGs/LPGs
- a *common* abstract model for:
  - protocol state
  - NIC hardware functionality

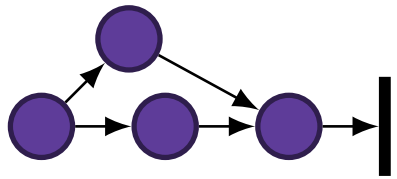




Unicorn: A language to talk about NICs

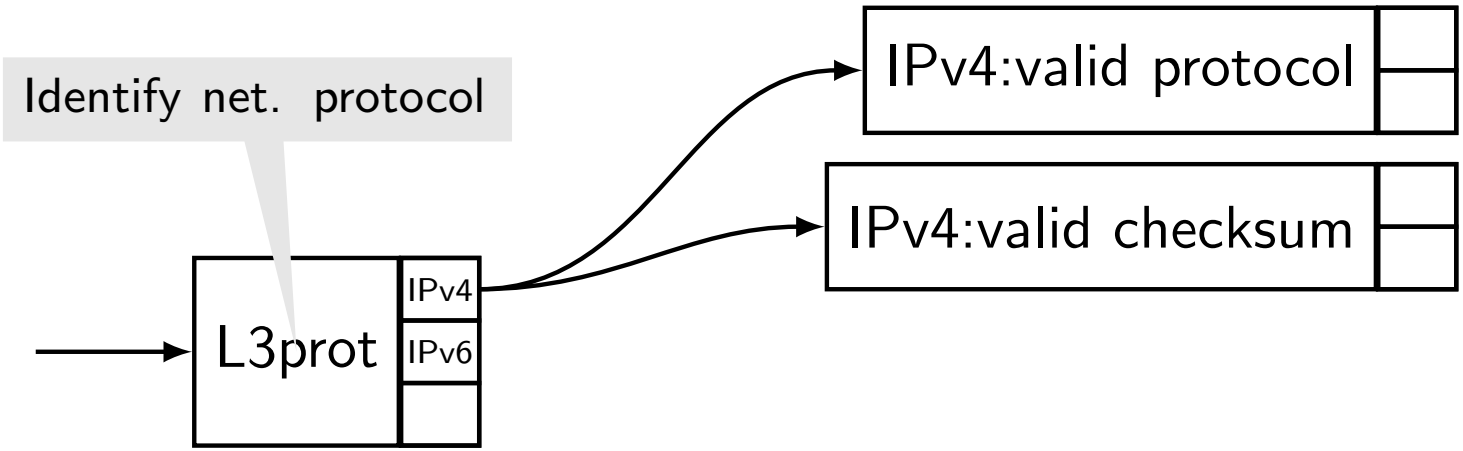
- a syntax for writing PRGs/LPGs
- a *common* abstract model for:
  - protocol state
  - NIC hardware functionality
- basic building blocks:
  - Function nodes (F-nodes)
  - Operators
  - Configuration nodes (C-nodes)





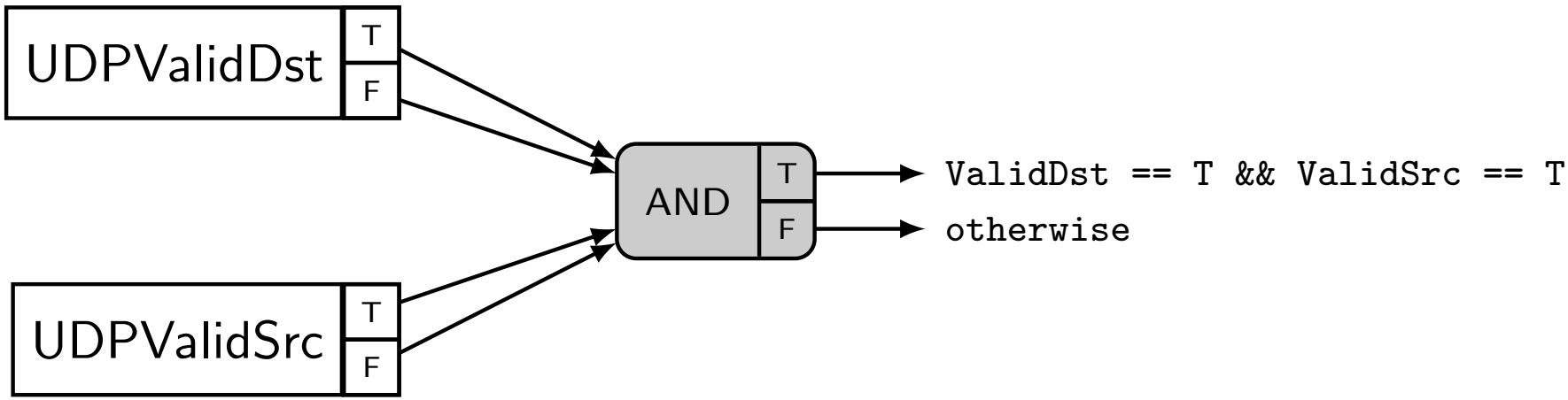
Function nodes

(F-nodes)



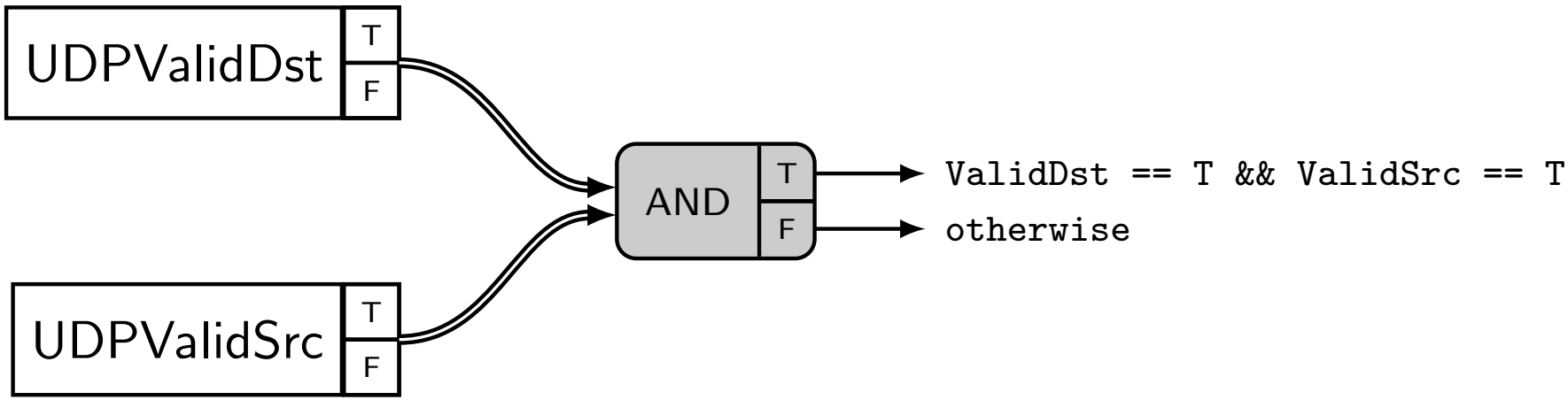
- a single computation
- single input
- ports, each with (possibly) multiple outputs
  - when computation is done, one port is activated
  - subsequently, nodes connected to that port are activated

Operator Nodes



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

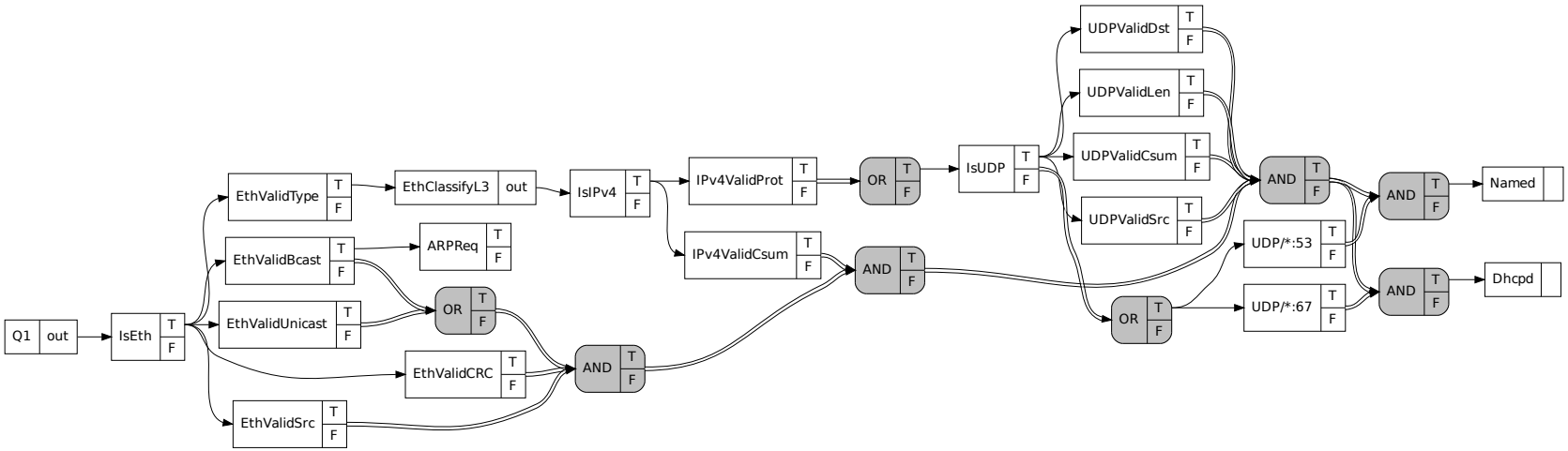
Operator Nodes



- multiple inputs: $\{T, F\} \times$ operands
- can be short-circuited
- "representation sugar": double-line edges

LPG example

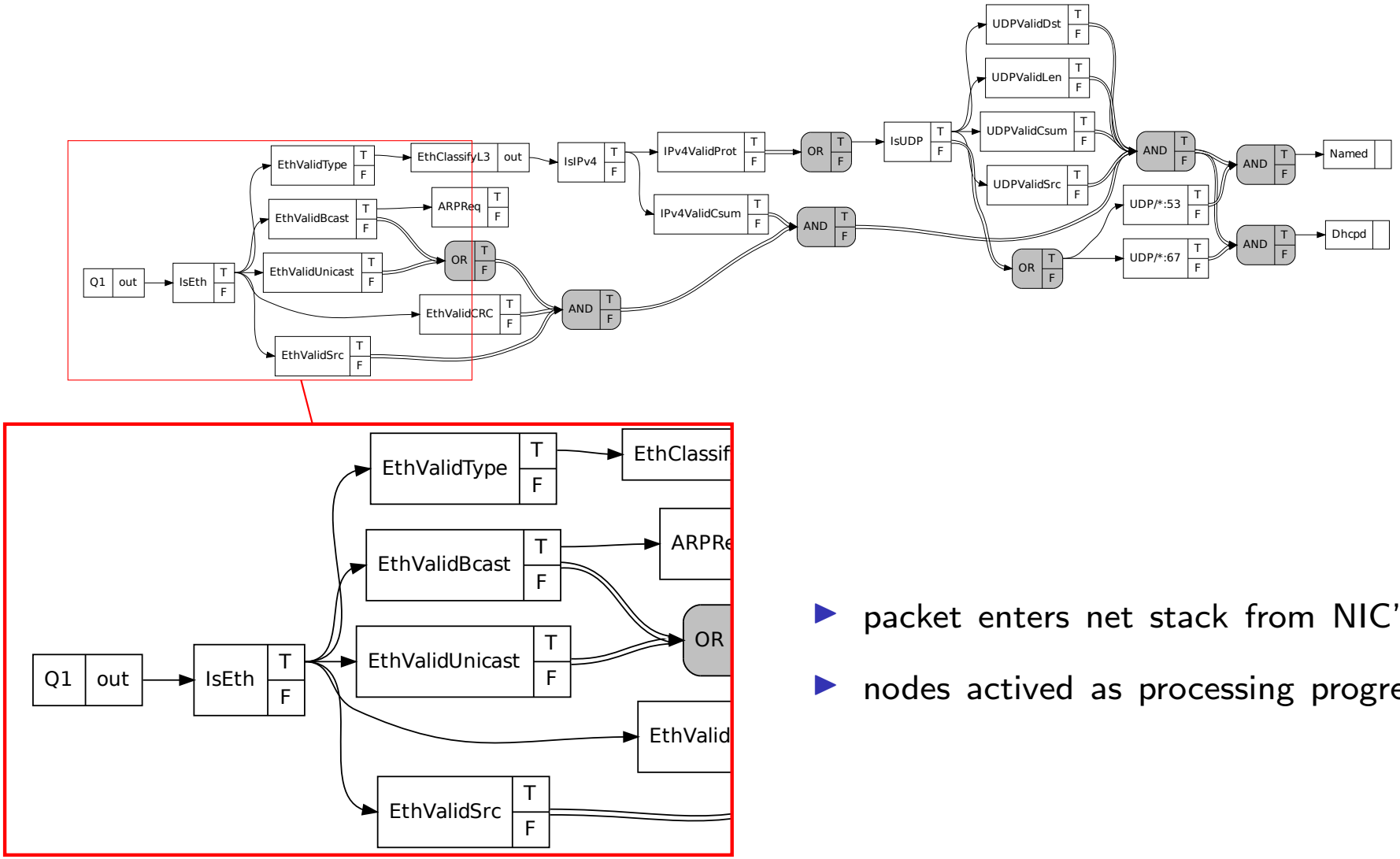
(rx side)



- receive side
- simplified
- Ethernet/IP/UDP
- `named` ← UDP packets at port 53
- `dhcpd` ← UDP packets at port 67

LPG example

(rx side)



- packet enters net stack from NIC's `Q1`
- nodes actived as processing progresses

LPG example

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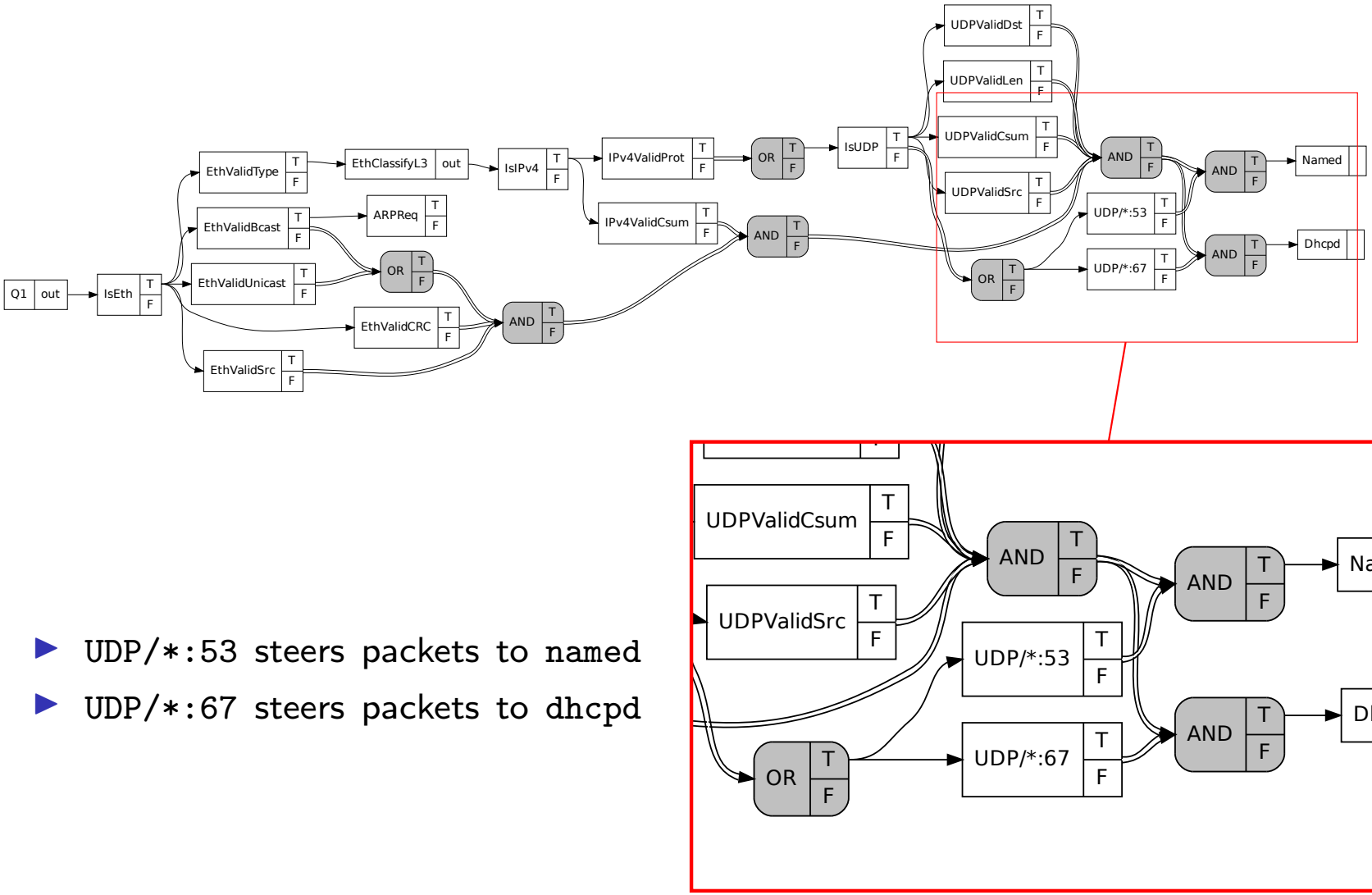
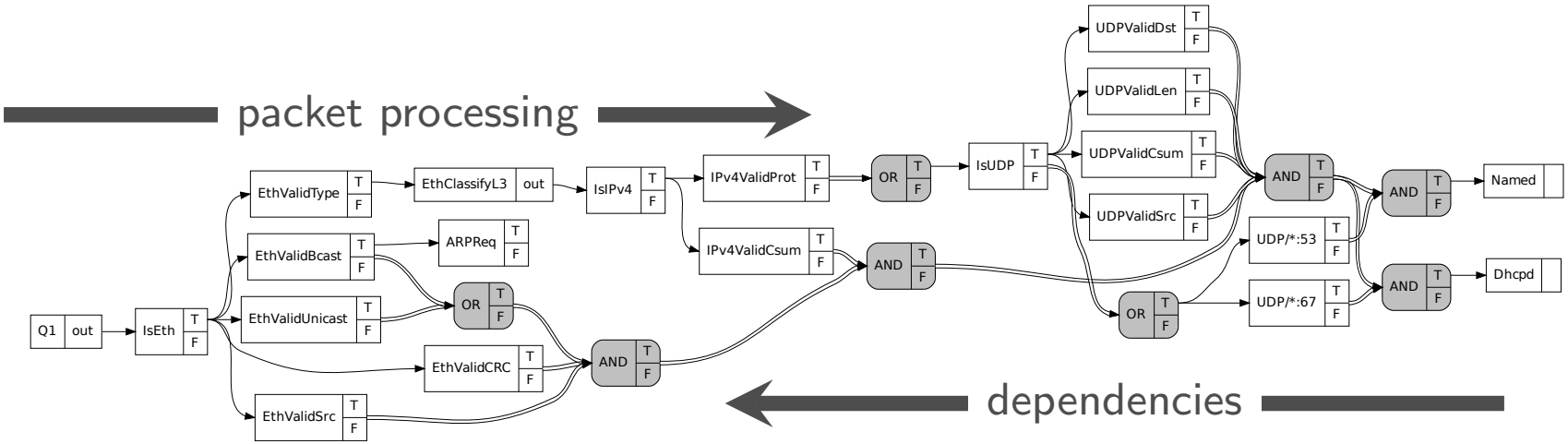


- `UDP/*:53` steers packets to `named`
- `UDP/*:67` steers packets to `dhcpd`

LPG example

(rx side)



- forward: packet processing
- reverse: dependencies
- dependencies "view" used in embedding

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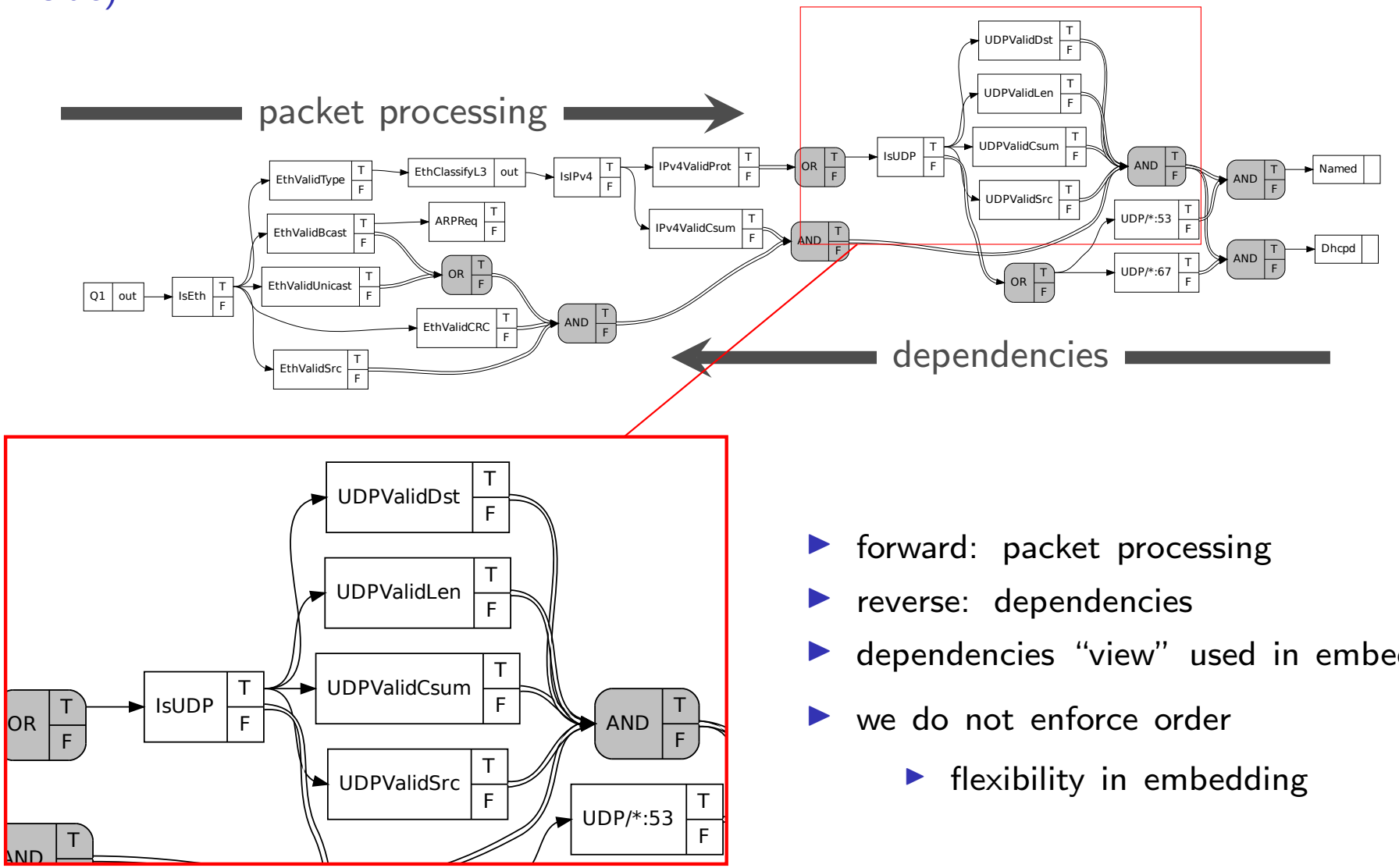
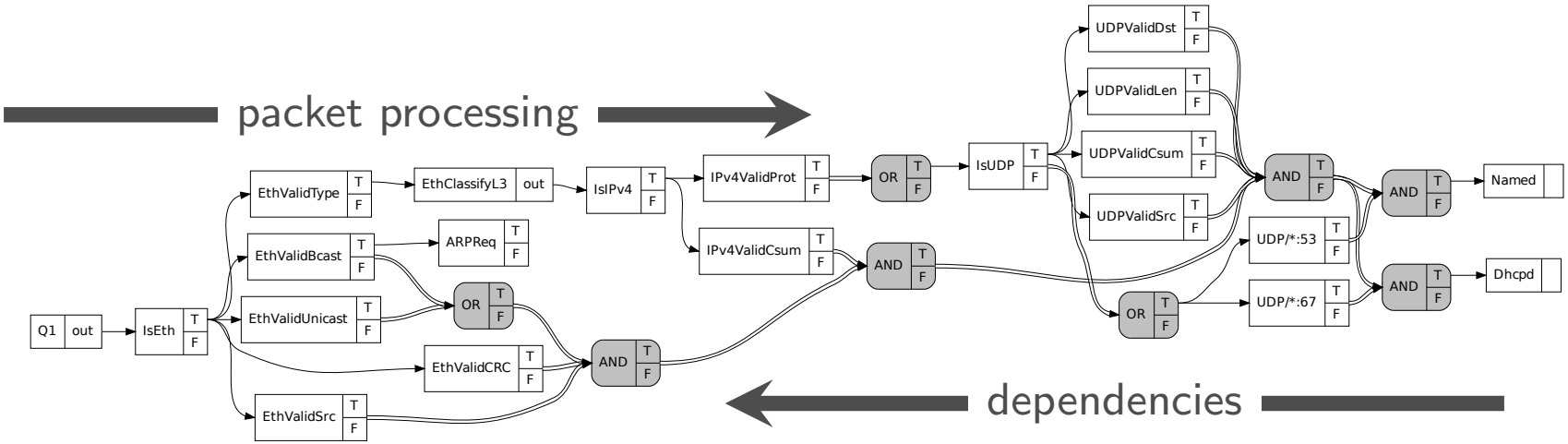


- forward: packet processing
- reverse: dependencies
- dependencies "view" used in embedding
- we do not enforce order
  - flexibility in embedding

LPG example

(rx side)



- PRGs use the same abstractions
- **but...**

Modeling NIC Configuration

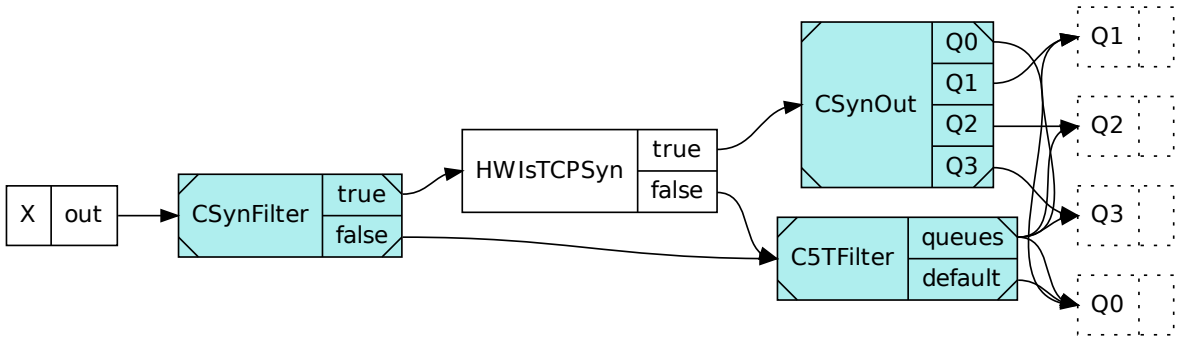
- modern NICS offer rich configuration options
- drastically modify behaviour of NIC
- configuration should be considered in embedding

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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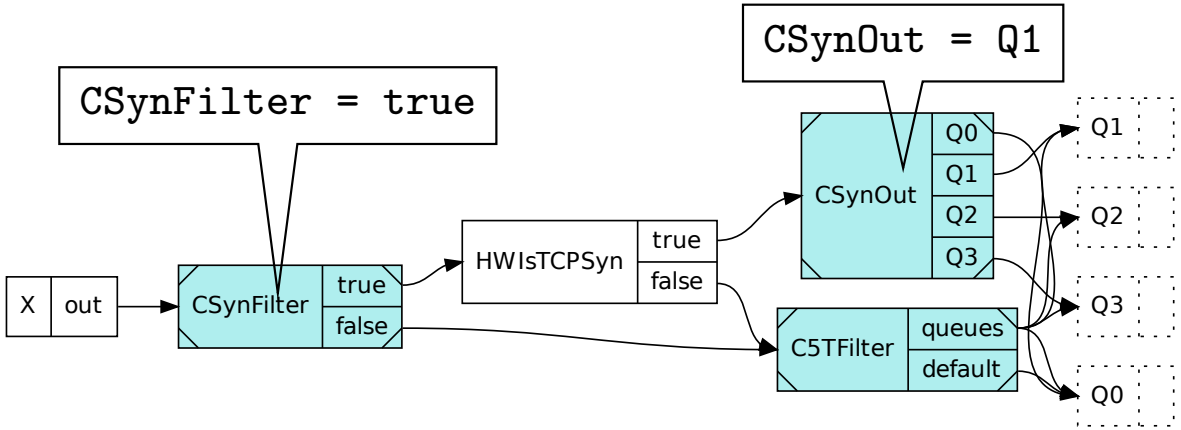

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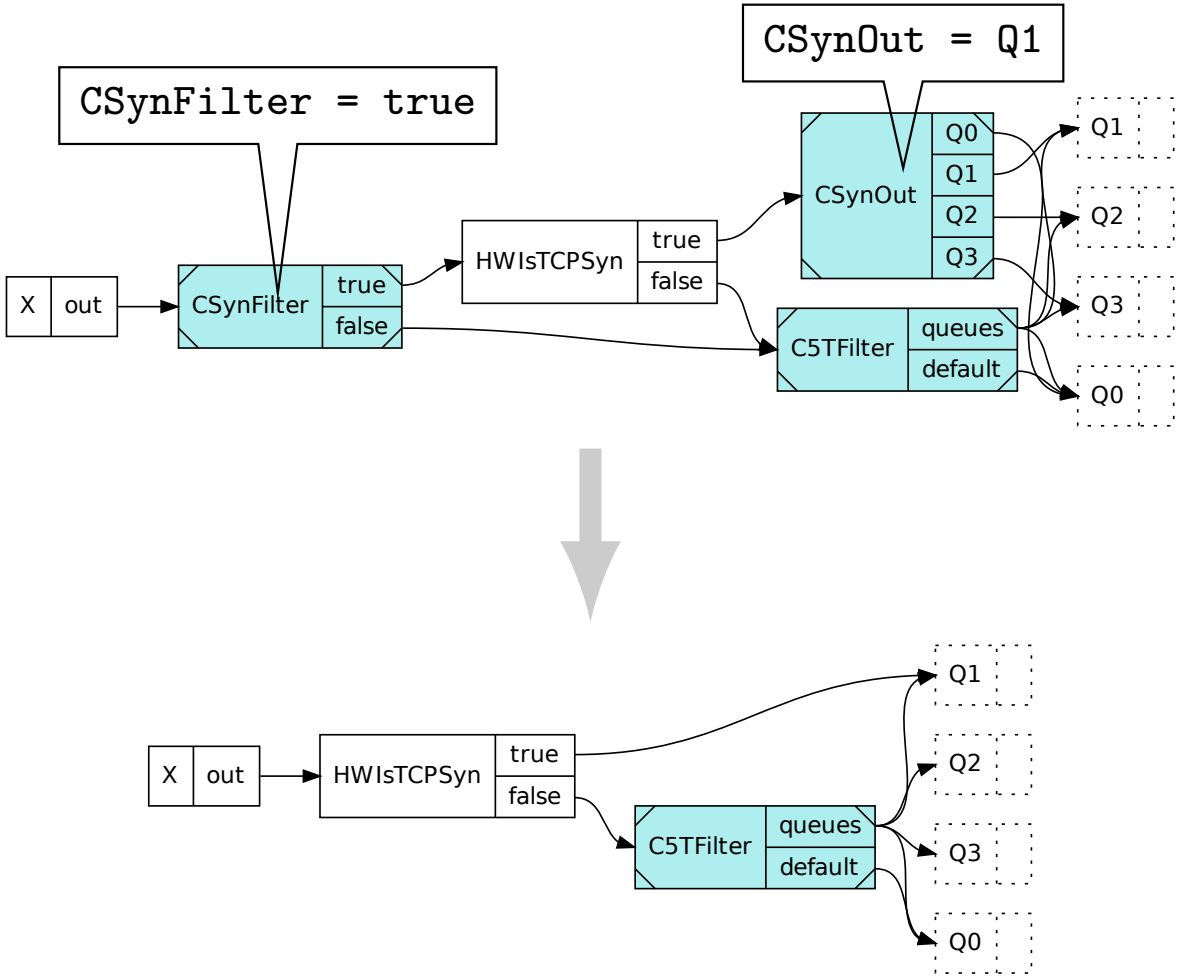

PRG configuration example (cont'd)

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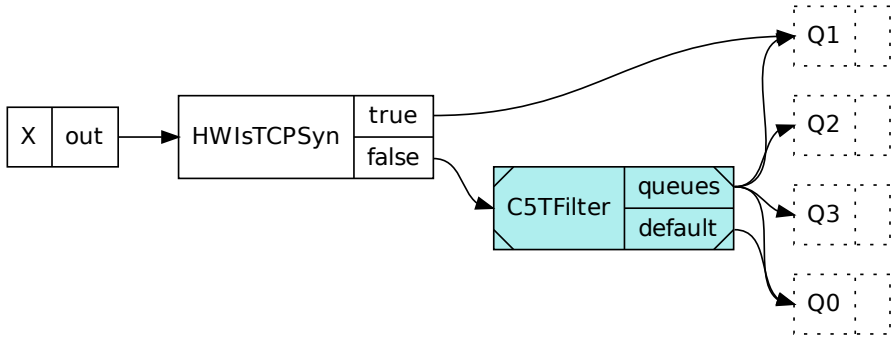

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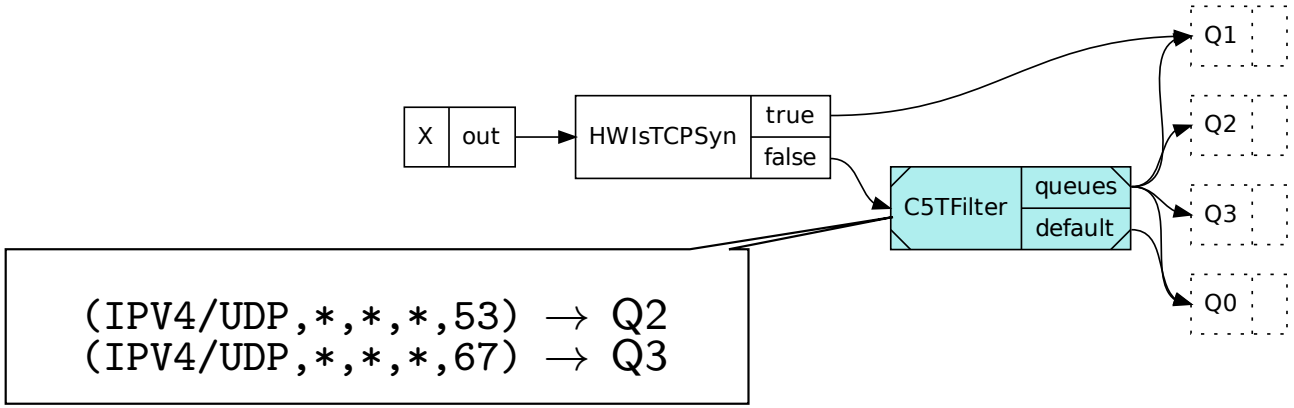

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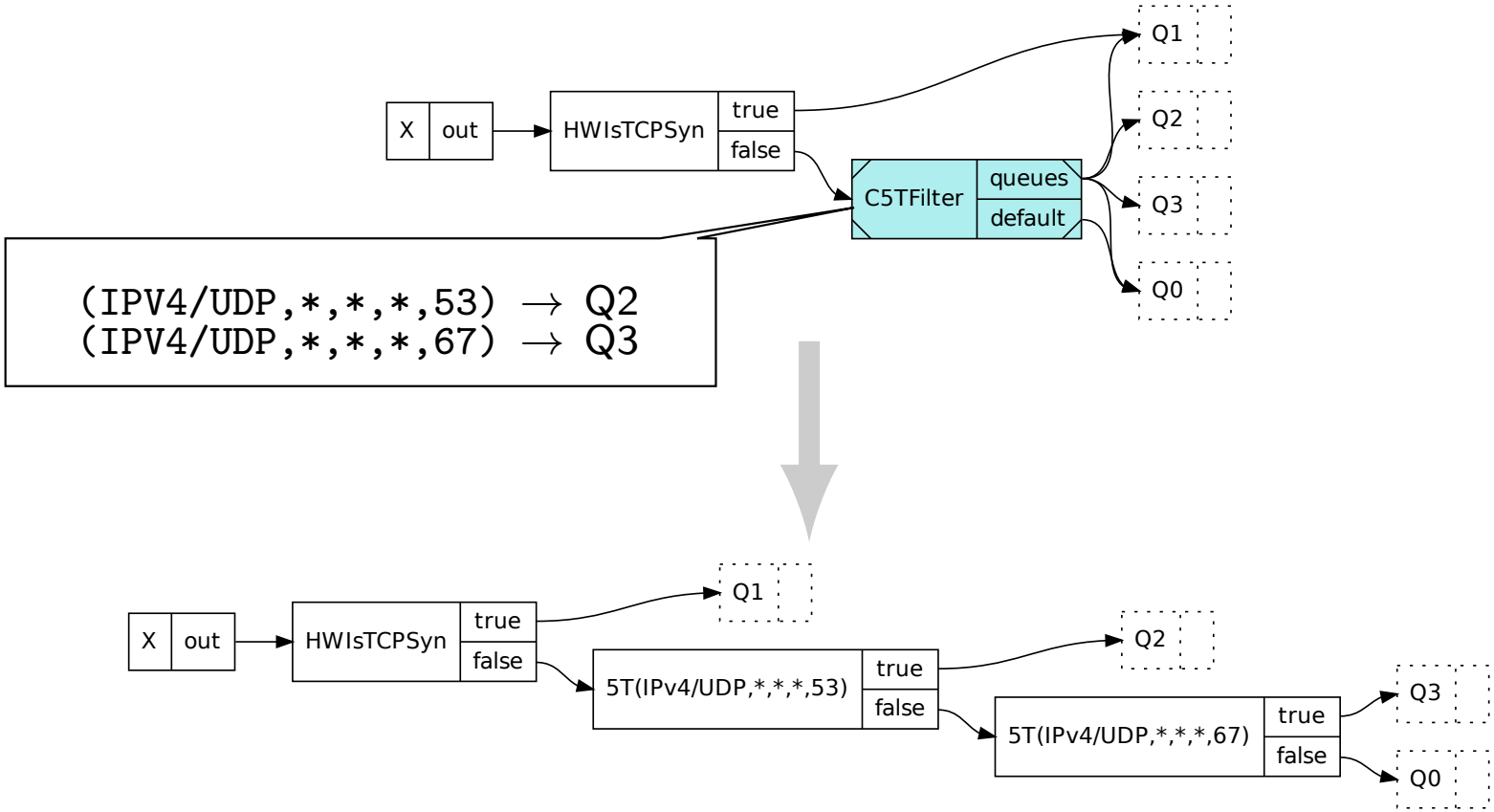


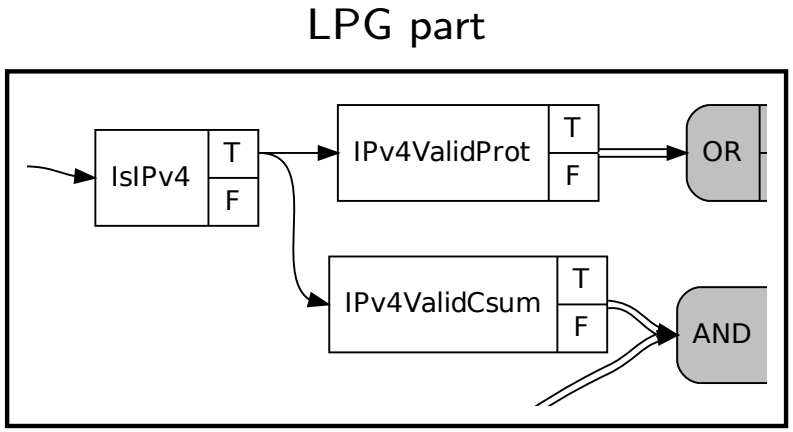
Node attributes

- F-nodes, operators → processing structure / dependencies
- C-nodes → configuration

annotate nodes with attributes for additional information

- modeling performance
  - annotate each node with perf. metrics (e.g., cpu utilization, latency)
  - reason about network stack performance
- implementation attribute

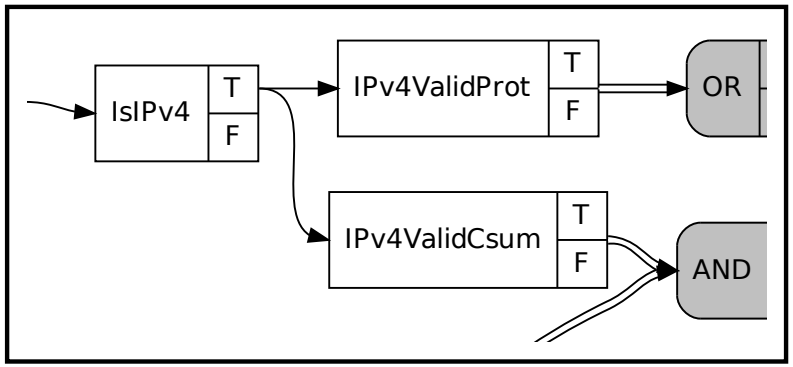
Implementation attribute for PRG software nodes



- hw (i82599) supports:
  - verifying the IPv4 checksum
- result passed in descriptors
  - needs to be checked in sw

Implementation attribute for PRG software nodes

LPG part



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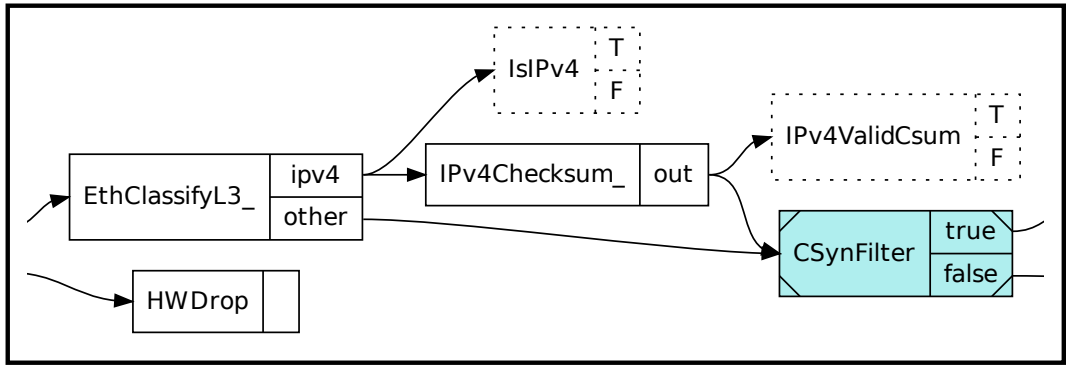

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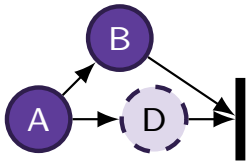
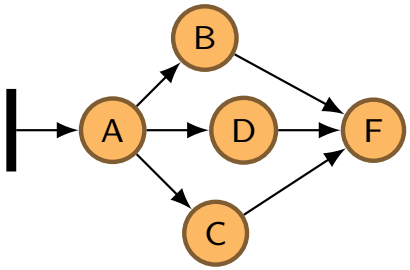
→ PRG software nodes

Embedding a configured PRG

(policy: maximize hw use)





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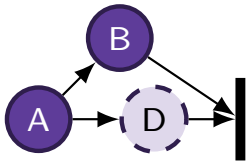

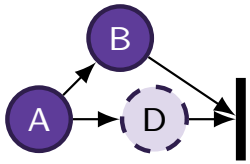

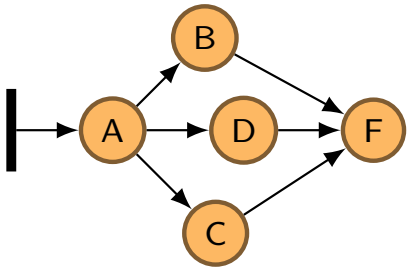

- add the NIC queue and its dependencies
  (as much of the PRG as possible)

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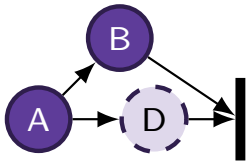

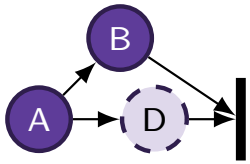

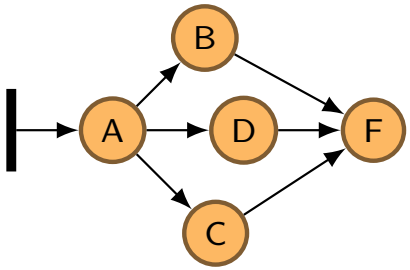

- add the NIC queue and its dependencies
  (as much of the PRG as possible)
- pick not-embedded LPG node with all its dependencies embedded
  (If LPG is acyclic, all nodes embedded or a node exists)
- repeat until all nodes embedded

Embedding a configured PRG

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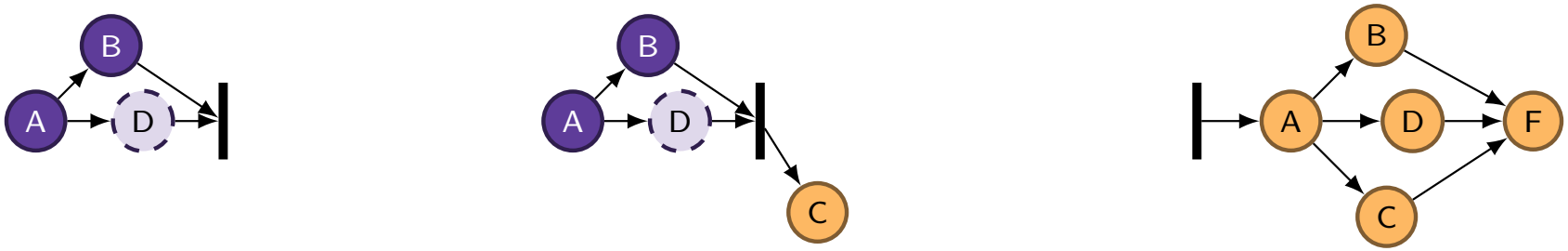

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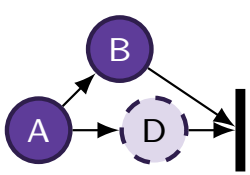

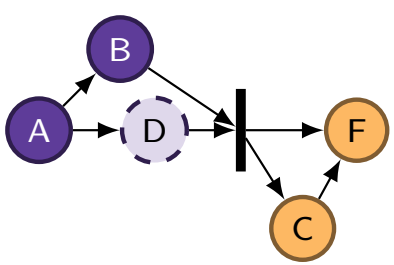

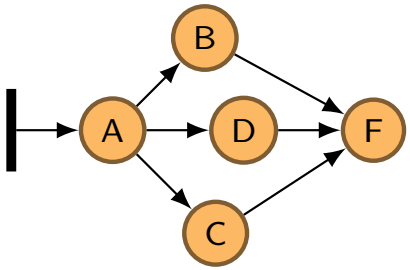

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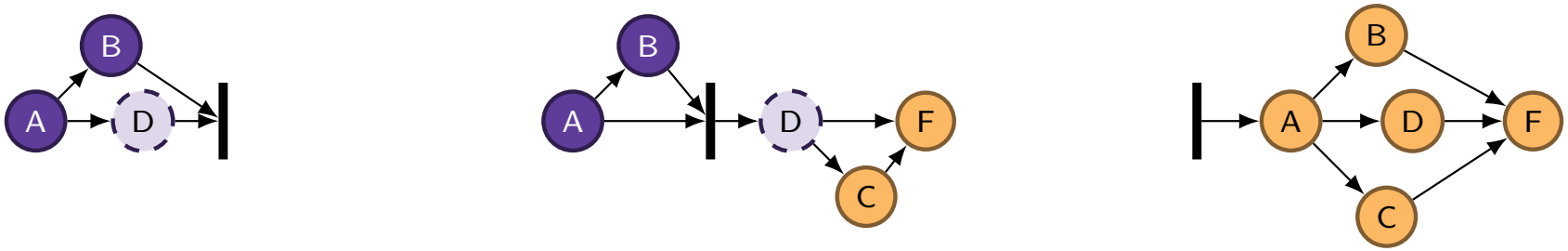

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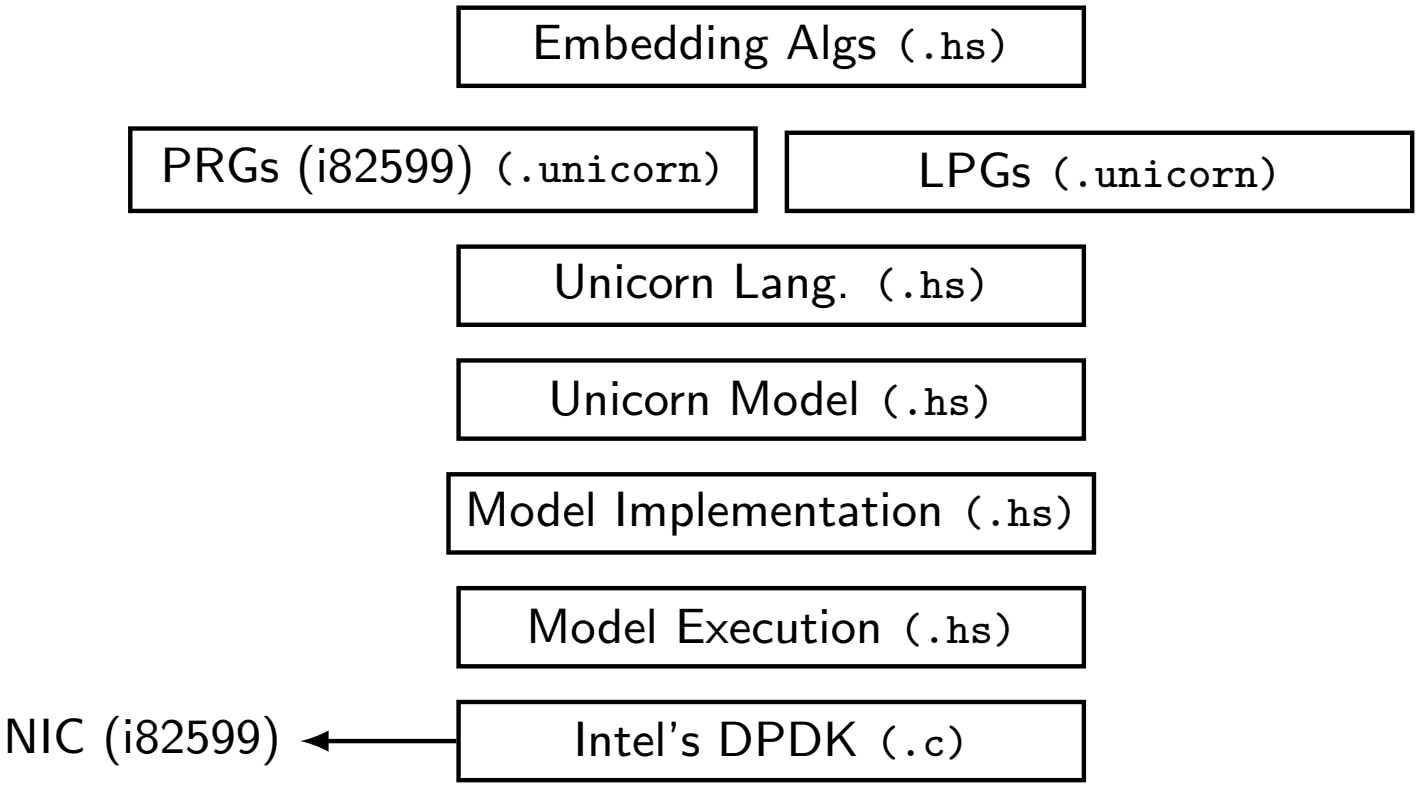
- repeat until all nodes embedded
- move PRG sw nodes beyond hw/sw boundary respecting dependencies

Current status:

(WiP)



- stack responds to pings

Conclusions and Future work

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- Unicorn: a language to "talk" about NICs
  - used to model NIC functionality and network protocol
- F-nodes, operators, C-nodes, attributes

Future Work

- enrich our models / NICs / policies / embedding algorithms
- incremental embedding algorithms $\rightarrow$ reacting to LPG changes
  - e.g., balancing flows across hw queues
- implementation for performance
  - separate fast- and slow-changing LPG parts

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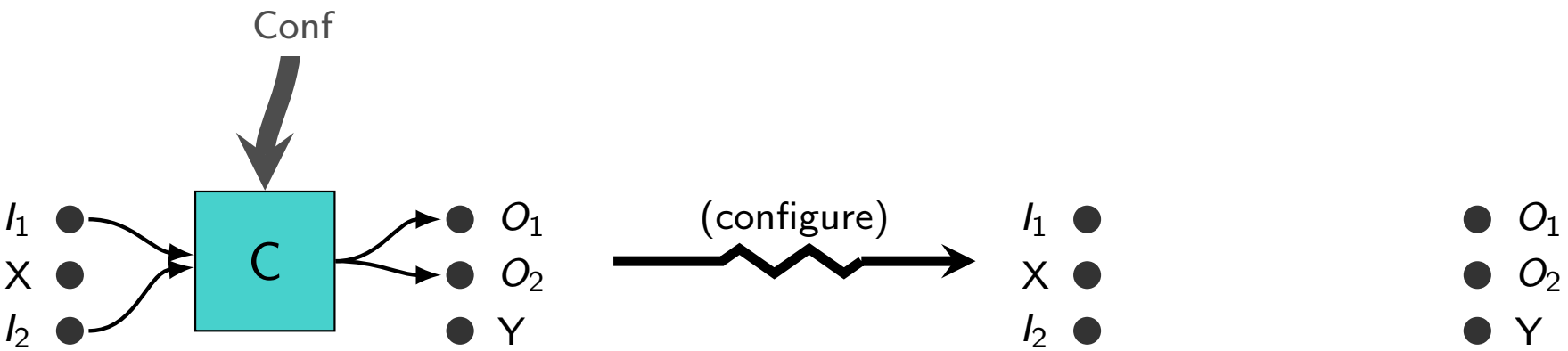
- applications as graphs

Configuration nodes

(C-nodes)



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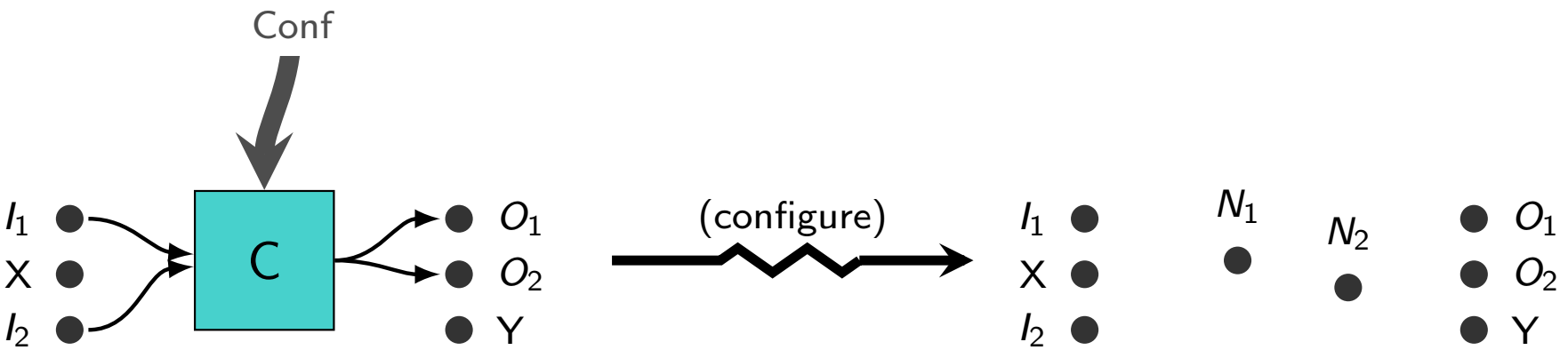

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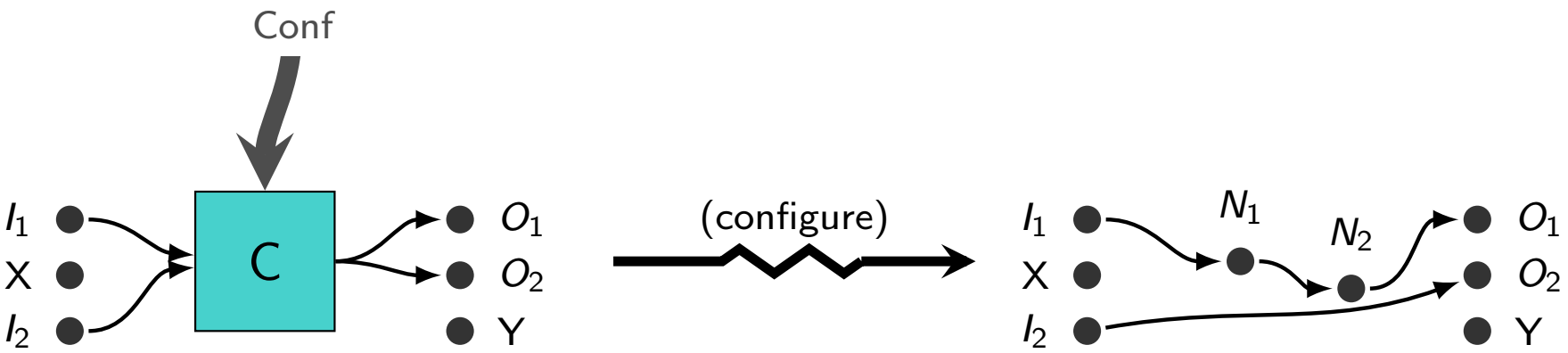

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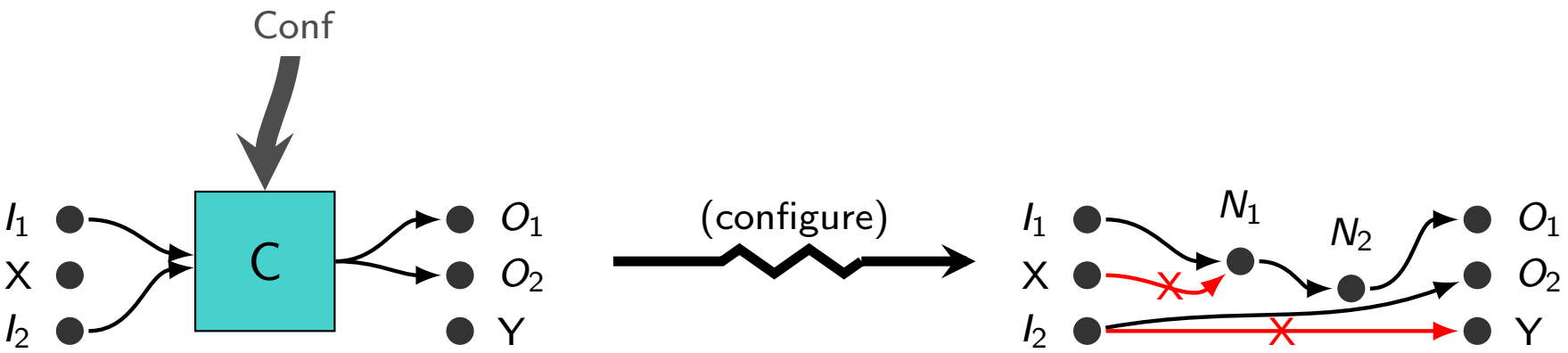
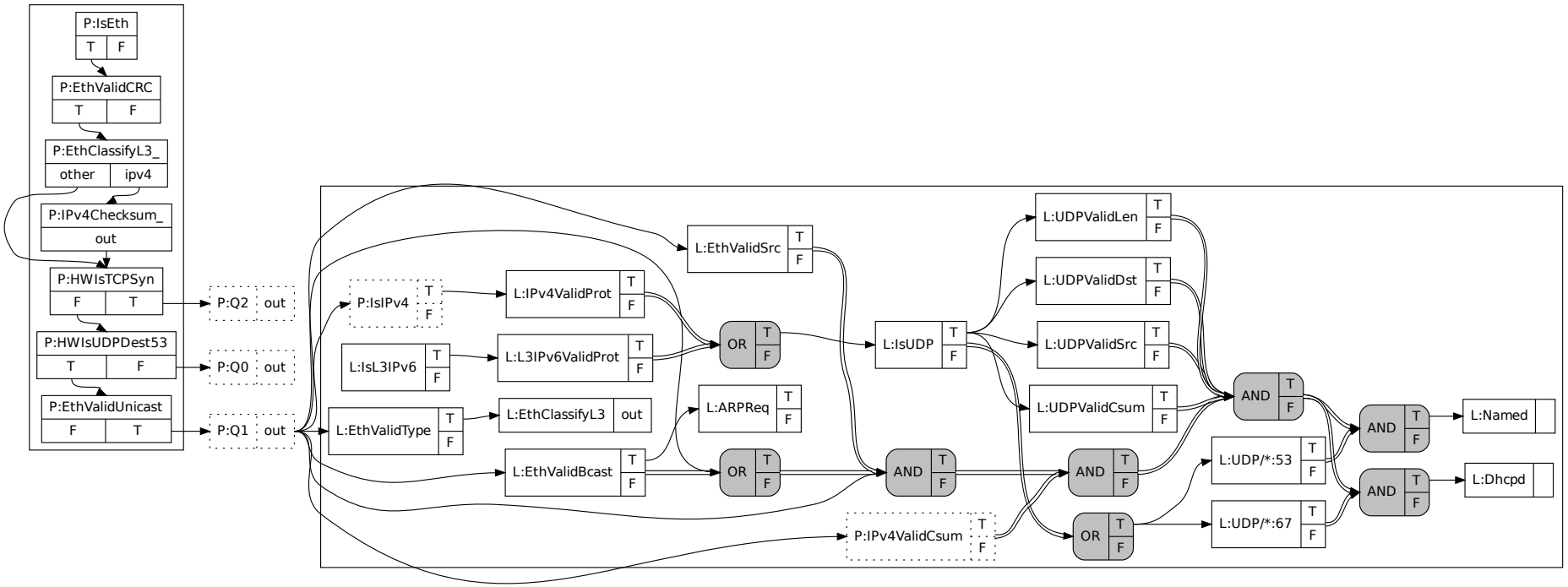


Specializing the network stack



- in general, all network flows can end up in all queues
  - in many scenarios they do not (e.g., isolation)
- reasoning about how flows are assigned to queues
  - PRG filters → LPG state
- specialized net stack per queue

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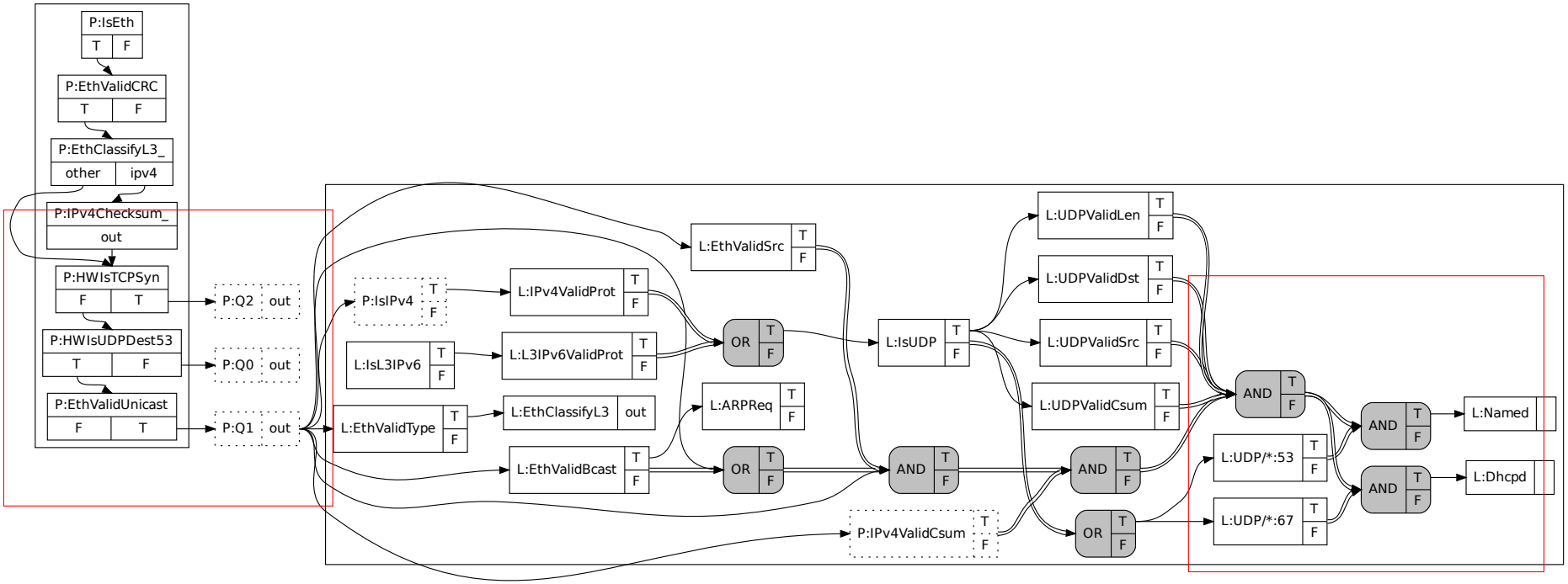

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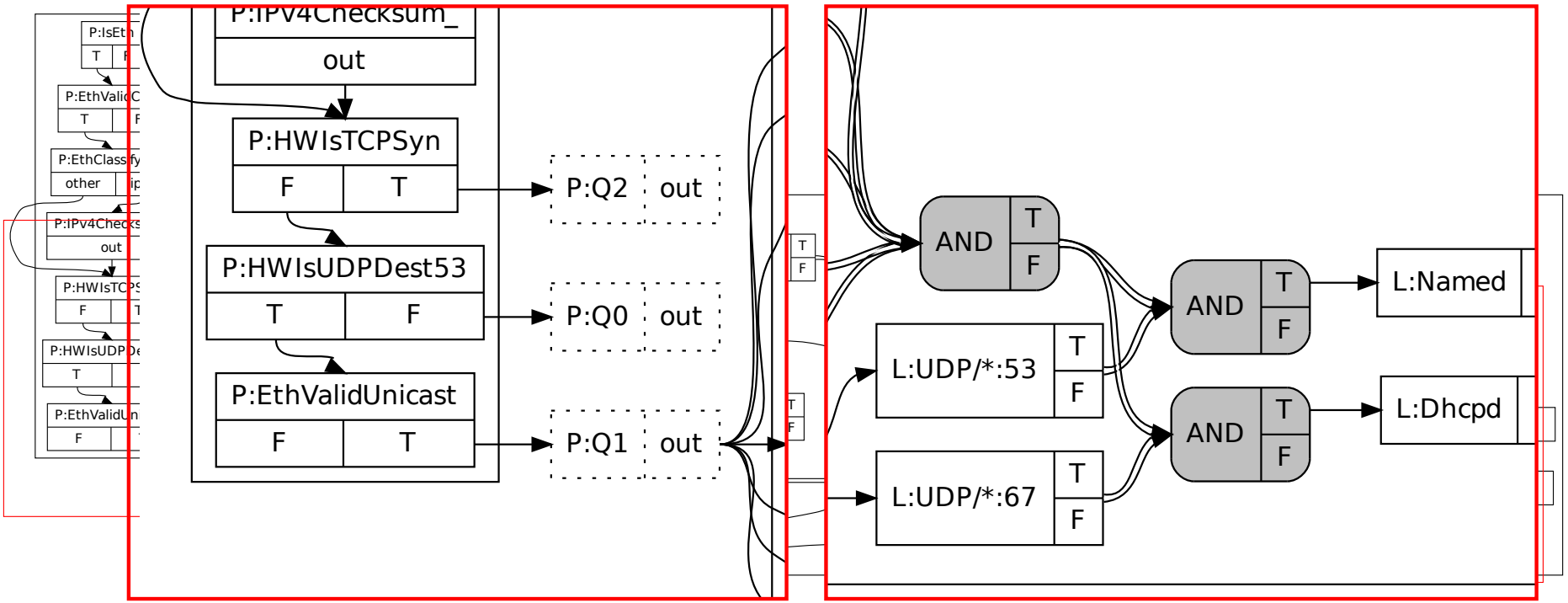
- specialized net stack per queue

Specializing the network stack



- in general, all network flows can end up in all queues
  - in many scenarios they do not (e.g., isolation)
- reasoning about how flows are assigned to queues
  - PRG filters → LPG state
- specialized net stack per queue