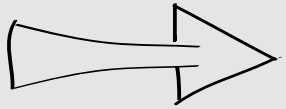
OpenNFP



Software Techniques for Programmable Data Plane Virtualization

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Flux Research Group

Overview

Motivation

Approach

Controller (“Control Plane Hypervisor”)

HyPer4.p4 (“Data Plane Hypervisor”)

Demo

Wrap-up / Questions

Motivation

OpenNFP

Programmable data planes

- How dynamic are they? Can we insert functionality on demand without disrupting important flows?

Multi-tenant environments

Virtualization

- Isolation
- Abstraction
  - Composition
  - Introspection
  - Standard functionality

Approach

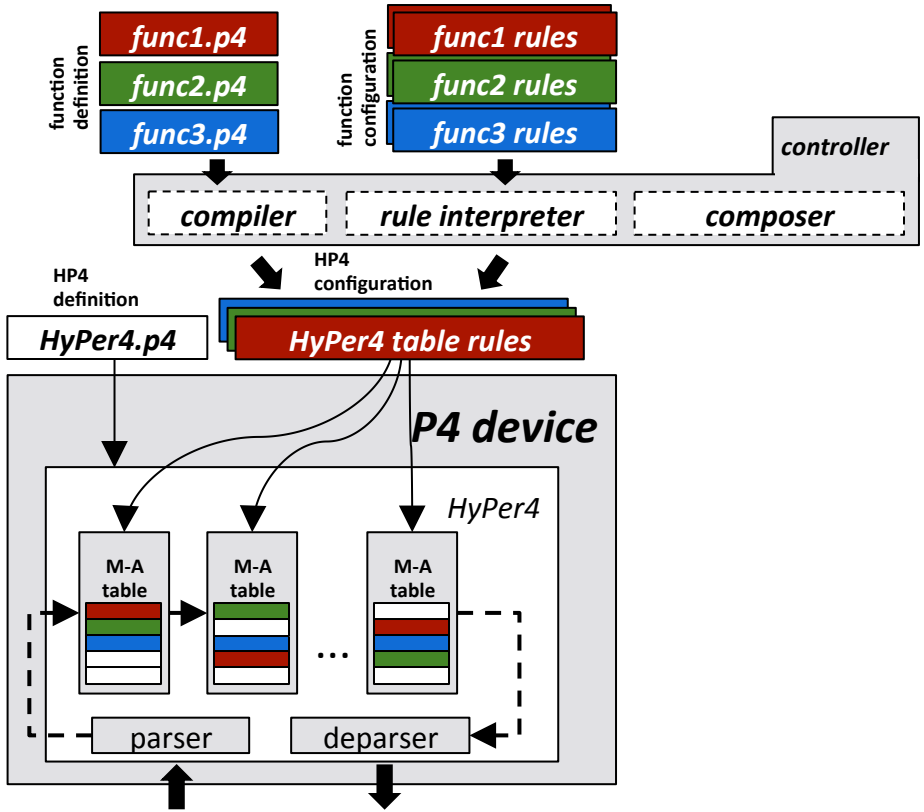
Software approach to expanding PDP device feature set

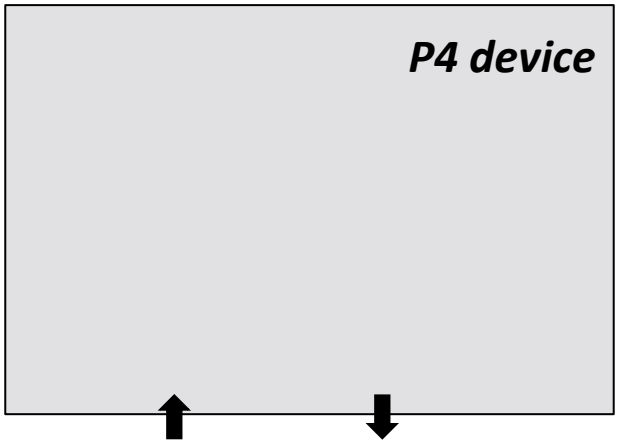
HyPer4.p4: “Data Plane Hypervisor”

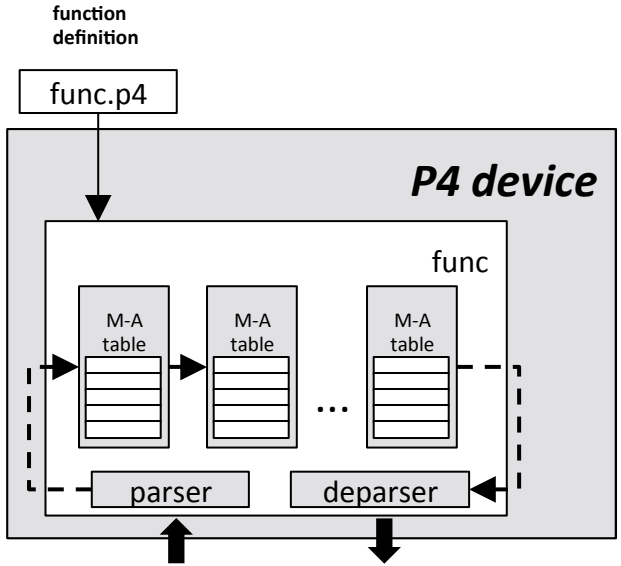
Controller: “Control Plane Hypervisor”

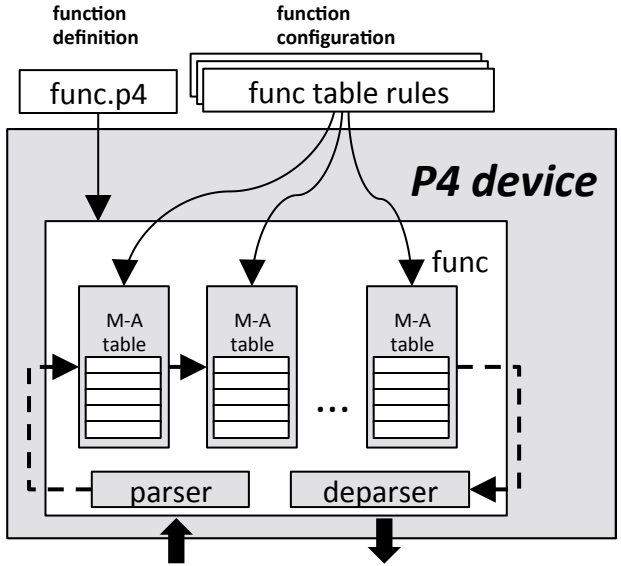
- Slice definition / provisioning
- Slice management
  - Compiler
  - Loader
  - Rule interpreter
  - Composer

HyPer4

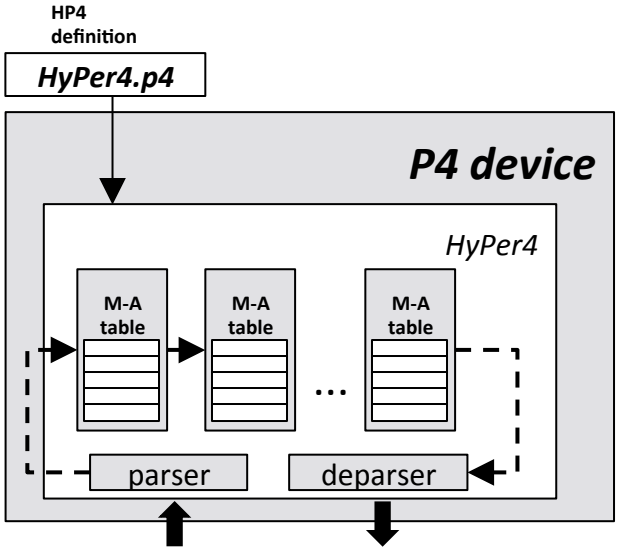




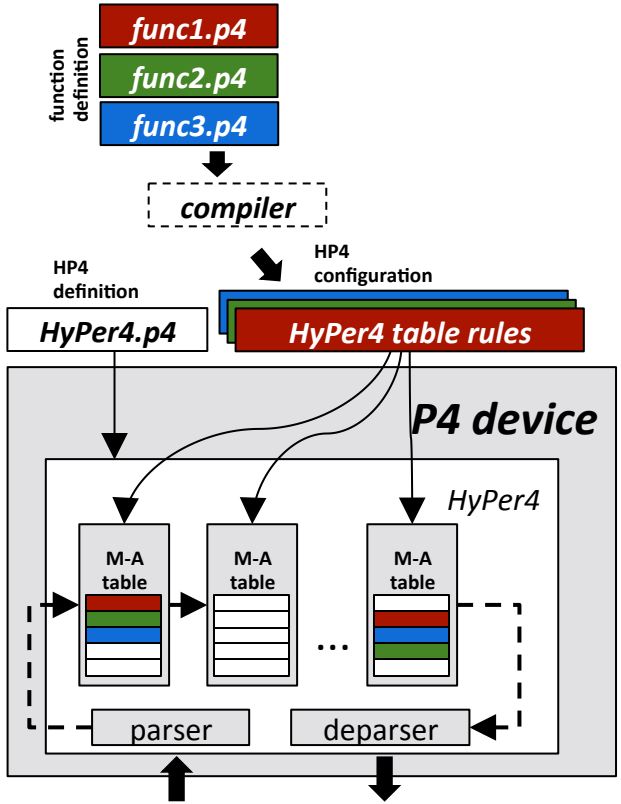




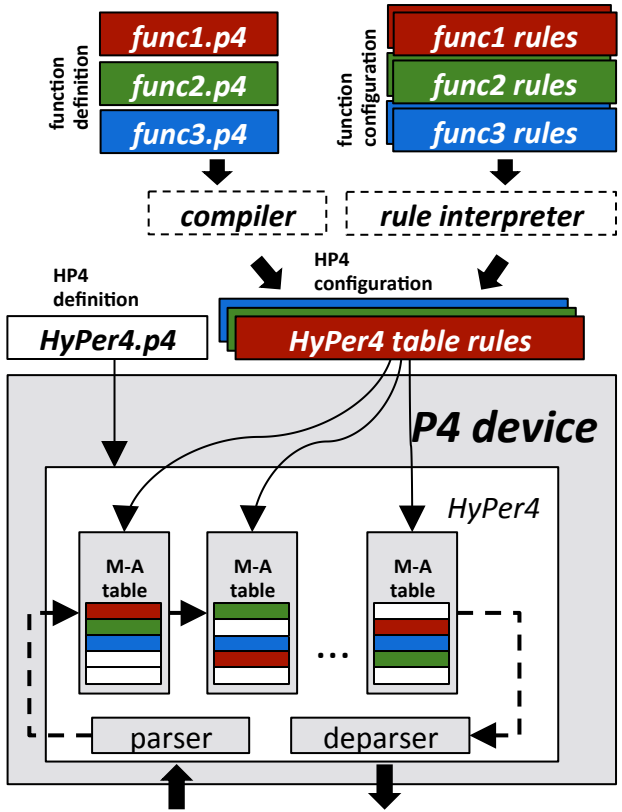
HyPer4



HyPer4


func1.p4
func2.p4
func3.p4
function definition
compiler
HP4 definition
HP4 configuration
HyPer4.p4
HyPer4 table rules
P4 device
HyPer4
M-A table
M-A table
M-A table
parser
deparser

HyPer4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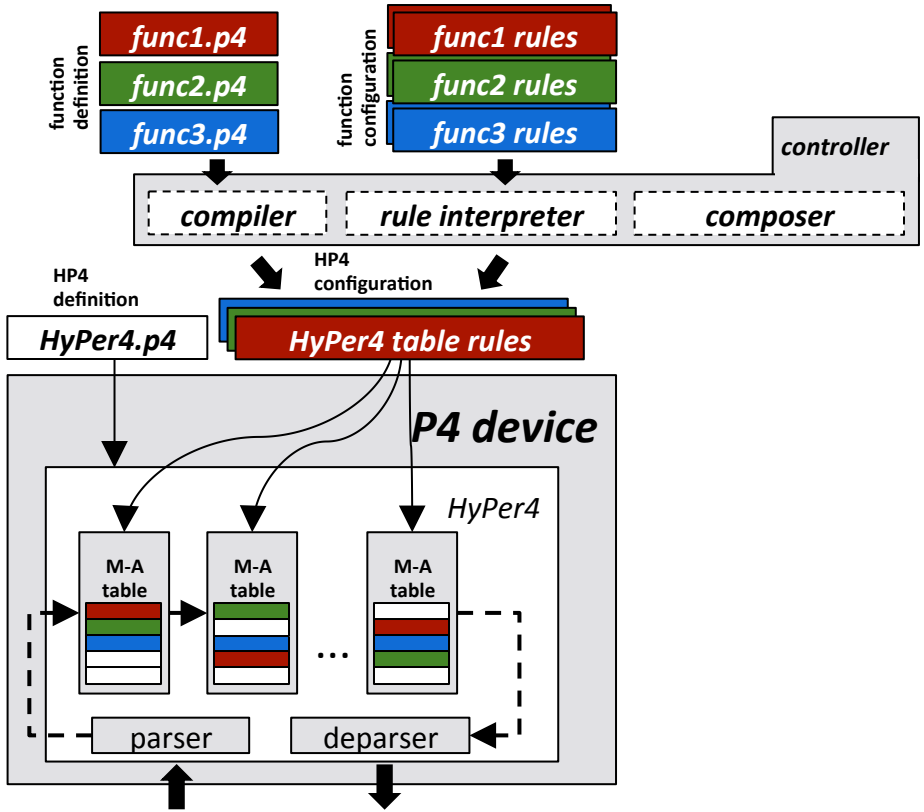
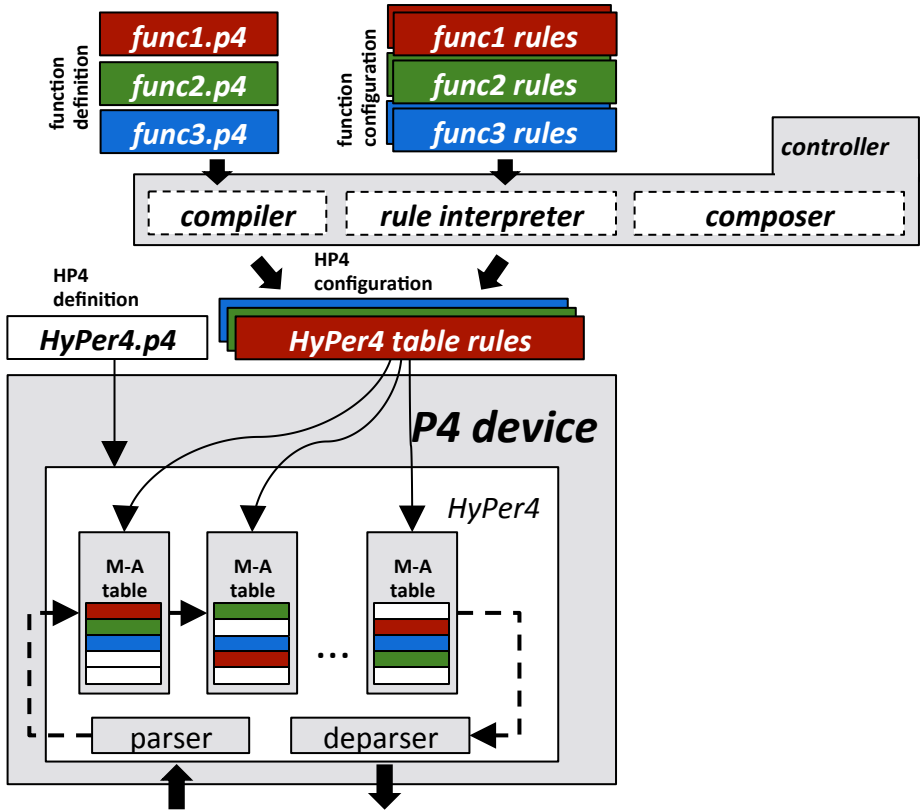
HyPer4



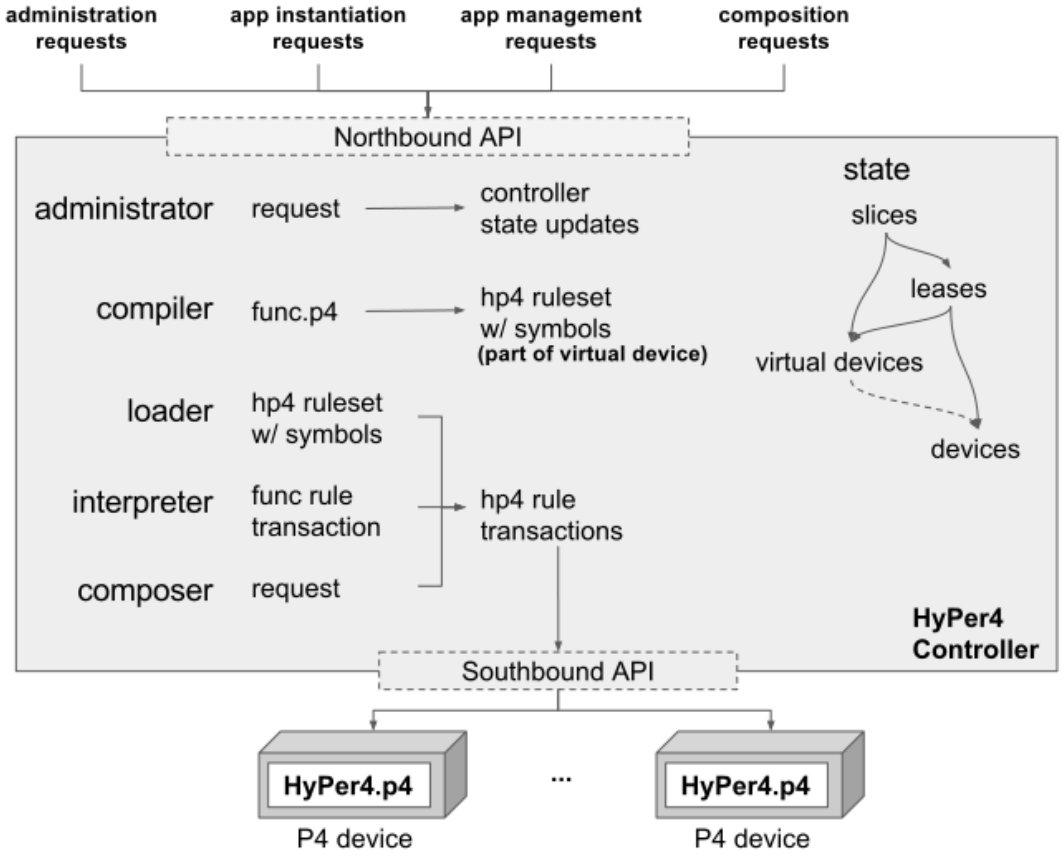
HyPer4.p4: Packet Tagging

```
action a_set_context(vdev_ID, vingress) {
  modify_field(meta.vdev_ID, vdev_ID);
  modify_field(meta.vingress, vingress);
}
table tset_context {
  reads { standard_metadata.ingress_port : exact; }
  actions { a_set_context; }
}
control setup {
  if (meta.vdev_ID == 0) {
    apply(tset_context);
  }
  // …
```

HyPer4



HyPer4 Controller



Northbound API

OpenNFP

Administrator

- create_device <dev name> <ip_addr> <port> \
  <dev_type> <# entries> <ports>
- create_slice <slice name>
- grant_lease <slice name> <dev name> <entry limit> <ports>
- list_devices
- list_slices
- reset_device <dev name>
- revoke_lease <slice name> <dev name>

Northbound API

OpenNFP

Slice Manager

- create_virtual_device <p4 path> <vdev name>
- destroy_virtual_device <vdev name>
- interpret <vdev name> <API style> <command>
- interpret_file <vdev name> <API style> <command> \
  <file>
- lease insert | append | remove | replace <vdev name> [args]
- list_devs
- list_vdev
- list_vdevs

Southbound API

OpenNFP

Device class defines interface

- send_command
  - do_table_add
  - do_table_modify
  - do_table_delete
- various multicast-related methods

Device subclasses implement

- Bmv2-SSwitch
- Agilio

Compiler/Interpreter

Task: P4 programs → “object-code-like” HyPer4 rulesets
→ rule interpreter guidance

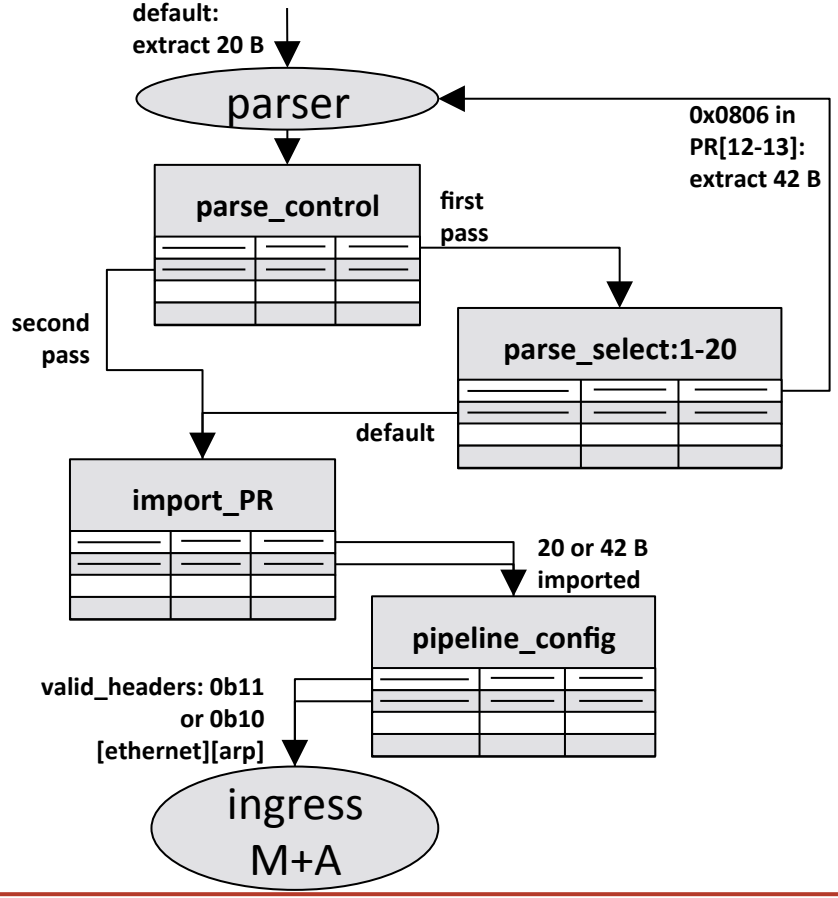
Subtasks:

- metadata field addressing
  - All metadata fields consolidated into HyPer4.p4’s meta.data field
  - Reads/writes done with bitmasks and bitshifts applied to meta.data
- parsing
- matching
- actions
- control flow

Compiler/Interpreter

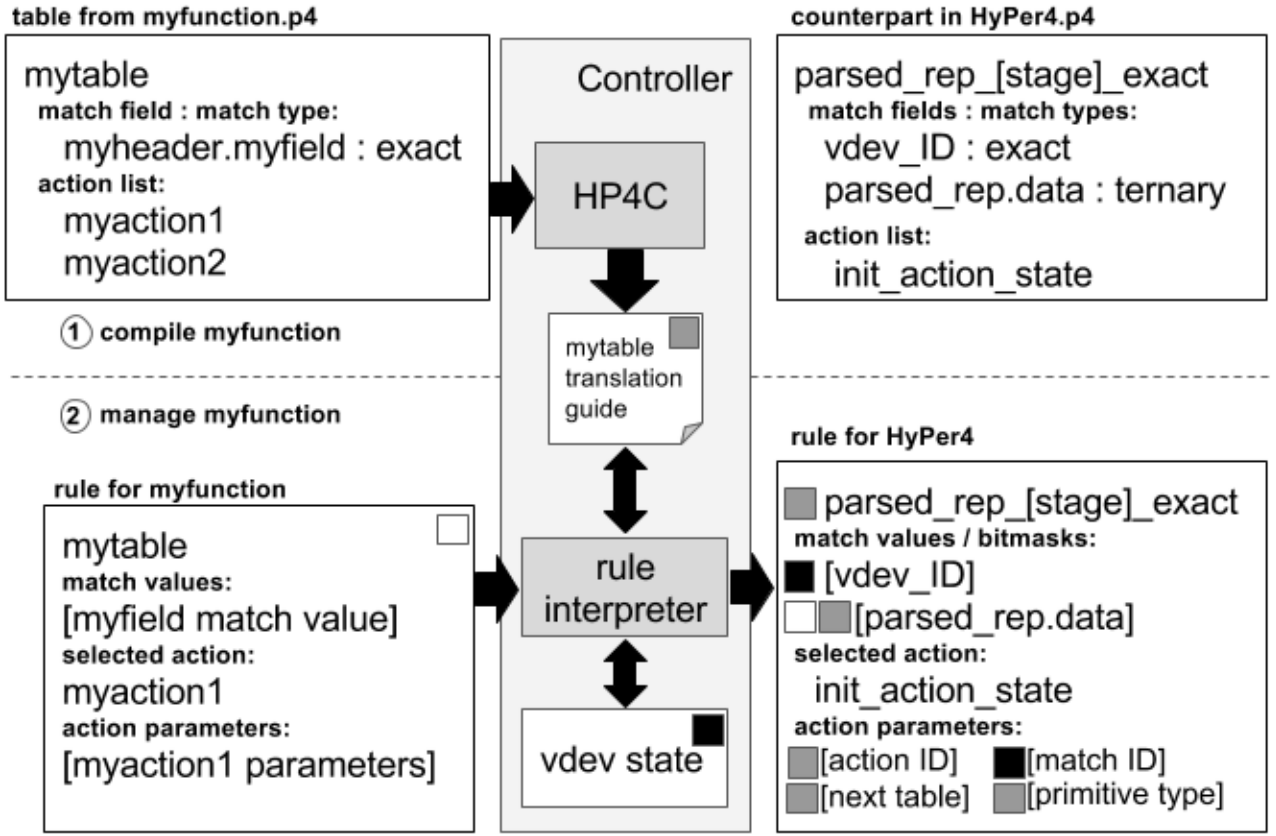
Subtasks: Parsing

```
parser start {
extract(ethernet);
    return select(ethernet.EtherType) {
        0x0806: parse_arp;
        default : ingress;
    }
}
parser parse_arp {
        extract(arp);
        return ingress;
}
```



Compiler/Interpreter

Subtasks: Matching

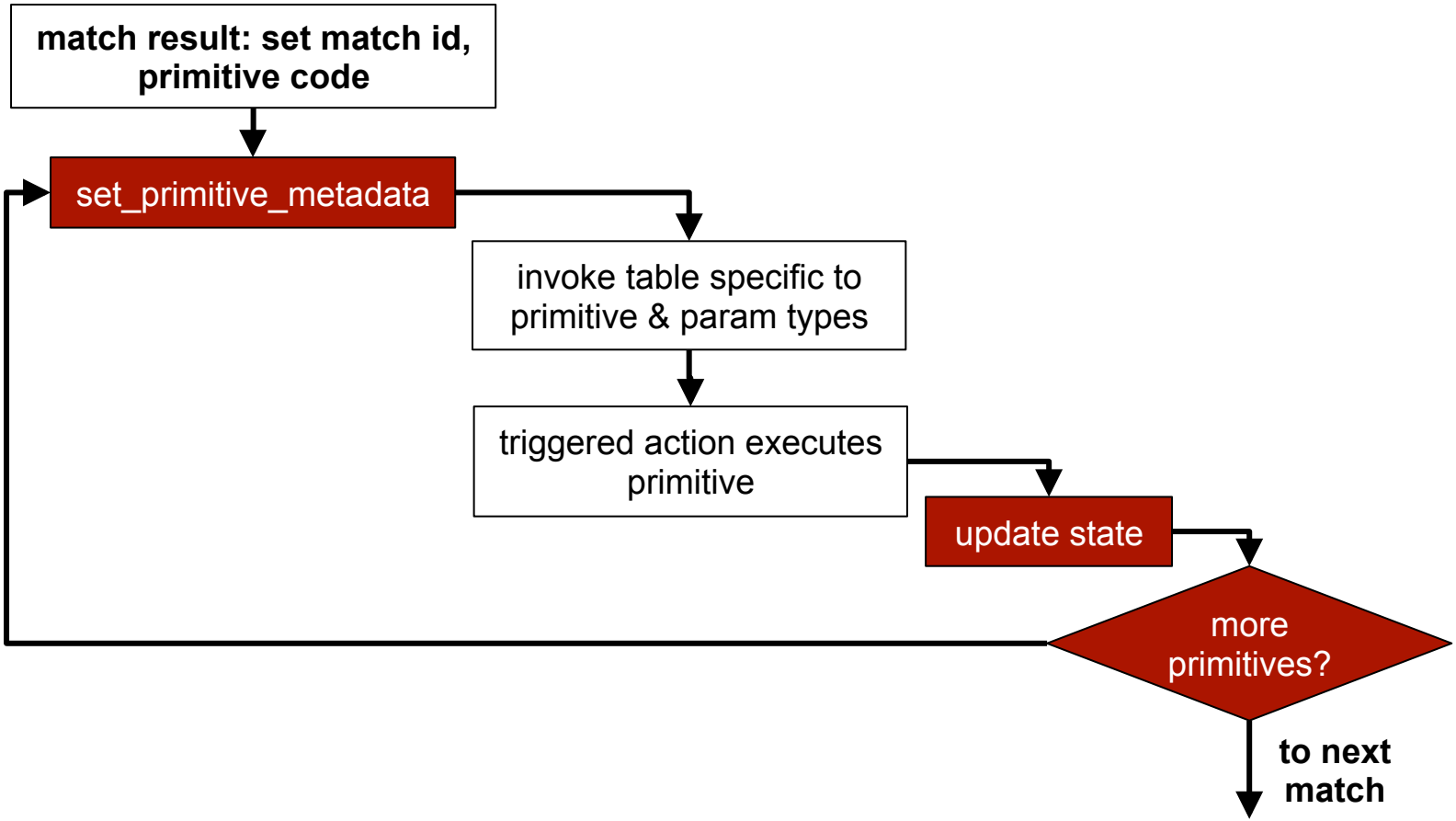


HyPer4.p4: Matching

Exact matching vs arbitrary fields:

- Use ternary matching
  - rules include mask
- Strategy: apply mask to pr.data to isolate relevant bits

HyPer4.p4: Actions



Loader

OpenNFP

"Object code":

```
tset_pipeline_config a_set_pipeline :[vdev ID] 1:
  [STDMETA_INGRESS_PORT_EXACT] 0x80[9x00s] 0



t_mod_41 mod_stdmeta_egressspec_stdmeta_ingressport :
  [vdev ID] 11 4 0&&&0:[MAX PRIORITY]
```

Loader

“Object code”:

table (end of “setup”) action virtualized function ID parse_state

```
tset_pipeline_config a_set_pipeline :[vdev ID] 1:
  [STDMETA_INGRESS_PORT_EXACT] 0x80[9x00s] 0
```

egress handling mode

ID of 1st match table

valid headers bitmap (0b1000…: ethernet only)

```
t_mod_41 mod_stdmeta_egressspec_stdmeta_ingressport :
  [vdev ID] 11 4 0&&&0:[MAX PRIORITY]
```

Loader

OpenNFP

"Object code":

```
tset_pipeline_config a_set_pipeline :[vdev ID] 1:
  [STDMETA_INGRESS_PORT_EXACT] 0x80[9x00s] 0
```

table (modify_field) action

```
t_mod_41 mod_stdmeta_egressspec_stdmeta_ingressport :
[vdev ID]   11      4      0&&&0:[LOWEST PRIORITY]
```

virtualized function ID

prim subtype

action ID

match ID

ternary match priority

Loader

OpenNFP

"Object code":

```
tset_pipeline_config a_set_pipeline :[vdev ID] 1:
  [STDMETA_INGRESS_PORT_EXACT] 0x80[9x00s] 0



t_mod_41 mod_stdmeta_egressspec_stdmeta_ingressport :
  [vdev ID] 11 4 0&&&0:[MAX PRIORITY]
```

Loader

Bmv2-SS API Commands:

```
table_add tset_pipeline_config a_set_pipeline 1 1 =>
  5 0x80000000000000000000 0
```

```
table_add t_mod_41 mod_stdmeta_egressspec_stdmeta_ingressport
  1 11 4 0&&&0 => 2147483646
```

HyPer4.p4: Composition Support

End of ingress

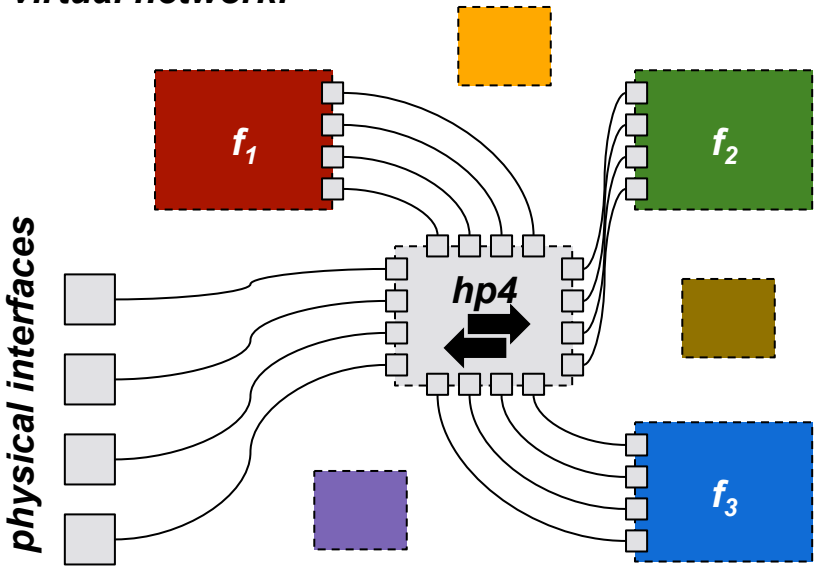
- Match on vegress
- Virtual forwarding? Set egress to ingress port, set virt forwarding flag

Egress

- Virt forwarding flag set?
  - Match on vegress
  - Set next vdev_ID, vingress
  - Recirculate with field list that includes key fields

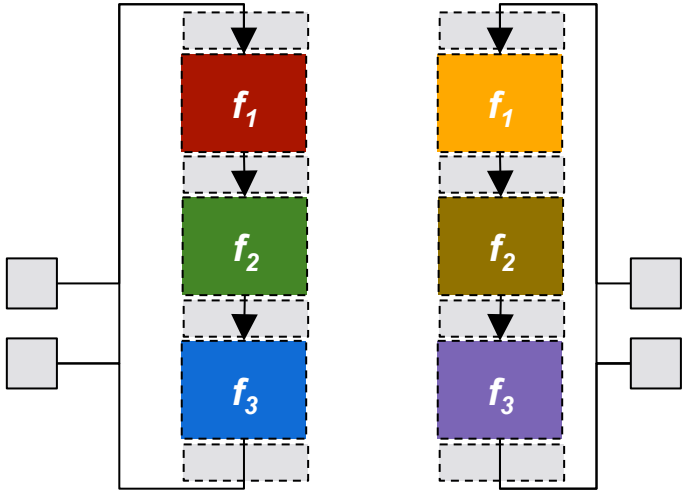
Composition Abstractions

virtual network:



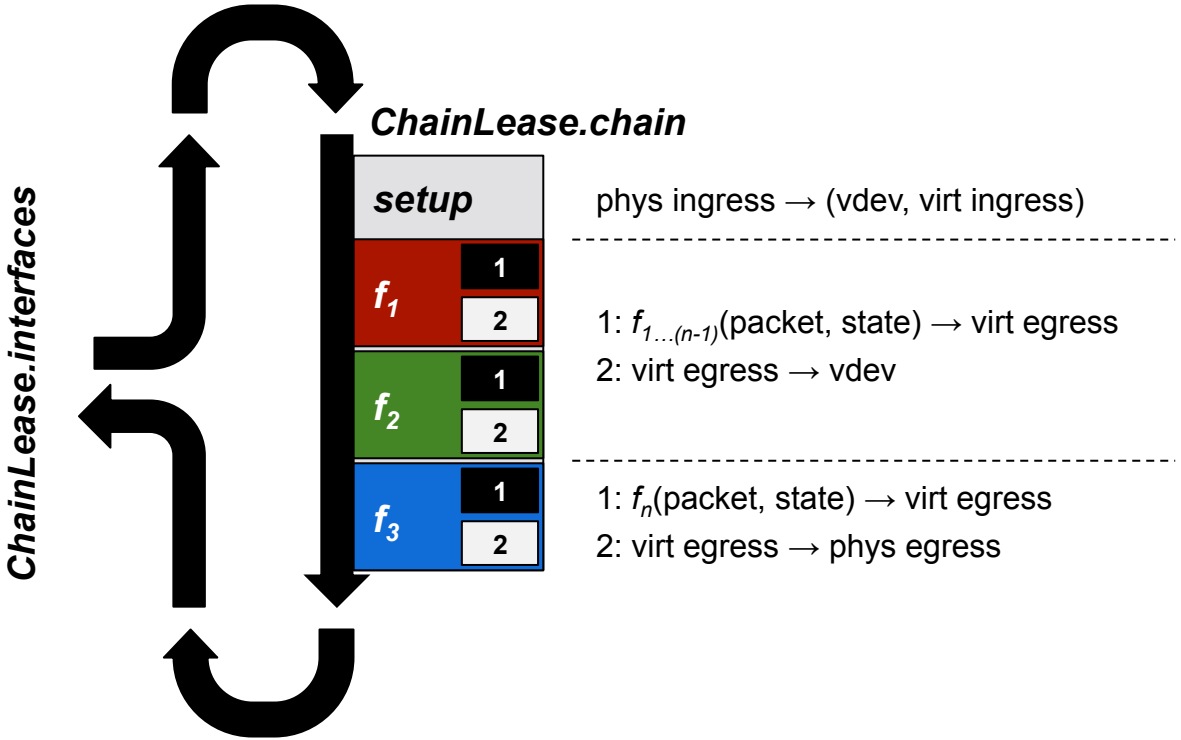
- Very flexible
- Complicated to implement and manage

vdev chains:



- Flexible
- Simpler to implement and manage

Chains


ChainLease.interfaces
ChainLease.chain
setup
f_1
1
2
f_2
1
2
f_3
1
2
phys ingress → (vdev, virt ingress)
1: $f_{1...(n-1)}$(packet, state) → virt egress
2: virt egress → vdev
1: f_n(packet, state) → virt egress
2: virt egress → phys egress

Egress Conflict Resolution

Types of Forwarding Abstractions

- return-to-sender: single port
- bump-in-the-wire [+ return-to-sender]: two ports
- switch: (packet, state) → egress: two+ ports

VDev sequence results in (sometimes unintentional) egress overrides

Resolution:

- ~~Enforce switch at the end~~
- Slice manager indicates preferences with respect to egress modifications for each vdev via controller command option:
  - always write to egress_spec
  - conditionally write to egress_spec (if void)
  - never write to egress_spec

Possibilities

Migration

Cloning

Maintain rulesets separately, attach to compatible vdevs on-demand

Automatically evolving functions

Linked functions (change to one begets [a]symmetrical change to another across the network)

HyPer4.p4: Clean up

Handle virtual networking

Egress filtering (avoid broadcast storms)

Handle checksum (e.g., IPv4)

Resize parsed representation (in case of add_header / remove_header)

Write pr.data back to parsed representation

HyPer4.p4: Code Generation

P4 compiler / target restriction: ONE reference per table

- Want: arbitrary functionality at arbitrary points in the pipeline
- Strategy: many functionally redundant copies, differing in name only
- Want: configurable support for specified # stages, specified # primitives / stage
- Strategy: define .p4 for single stage, single primitive, add tokens directing processing tool to produce desired configuration

HyPer4.p4: Code Generation

```
[+ sloop +]
control stage[+X+] {
  match_[+X+](); // match.p4
  [+ nif +]
  if(meta_ctrl.stage_state != COMPLETE) {
    switch_primitivetype_[+X+][+Y+]();
    apply(tstg[+X+][+Y+]_update_state);
  [+ endnif +]
}
[+ endsloop +]
```

```
control stage1 {
  match_1();
  if(meta_ctrl.stage_state != COMPLETE) {
    switch_primitivetype_11();
    apply(tstg11_update_state);
    if(meta_ctrl.stage_state != COMPLETE) {
      switch_primitivetype_12();
      apply(tstg12_update_state);
      // …
}
control stage2 {
  match_2();
  if(meta_ctrl.stage_state != COMPLETE) {
```

HyPer4.p4: Objections, Rebuttals

Performance Concerns

- May be addressed with custom targets
- May be addressed with more sensible default parsing behavior and streamlined match-action pipeline
- May be addressed by using programmable parser + fixed pipeline, or fixed parser + programmable pipeline
- Should not get in the way of exploring high level abstractions made possible by vPDPs

Demo

Wrap-up

Motivation

Approach

Controller (“Control Plane Hypervisor”)

HyPer4.p4 (“Data Plane Hypervisor”)

- git@gitlab.flux.utah.edu:dhankook/hp4-src.git
- README.md provides commit used for CoNEXT 2016 paper

Demo

Questions

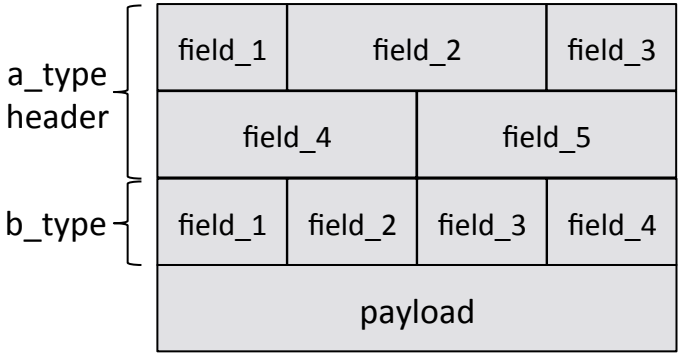
Questions?

HyPer4.p4: Parsing

```
// not shown: header_type definitions
header a_t a;
header b_t b;

parser start {
    extract(a);
    return select(a.field_3) {
        0x01 : parse_b;
        default : ingress;
    }
}
parser parse_b {
    extract(b);
    return ingress;
}
```

parsed representation: a | a, b

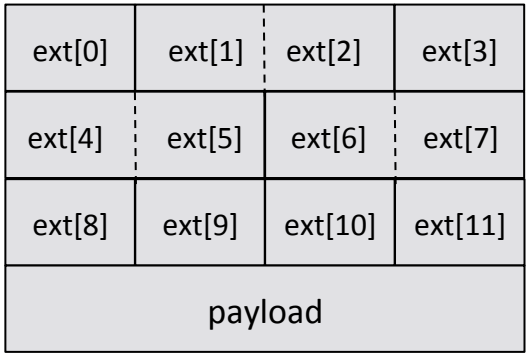


P4 source includes
references to named fields

HyPer4.p4: Parsing

Strategy:

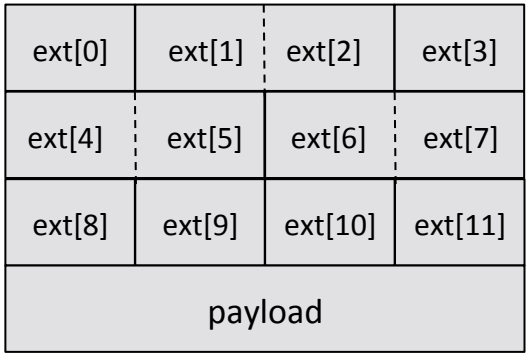
- generic 8-bit header type
- ***ext[100]***: array of such headers



HyPer4.p4: Parsing

Strategy:

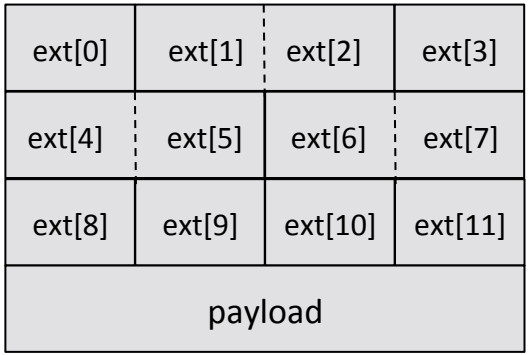
- generic 8-bit header type
- ***ext[100]***: array of such headers
- metadata fields: ***#bytes, parse_state***



HyPer4.p4: Parsing

Strategy:

- generic 8-bit header type
- ***ext[100]***: array of such headers
- metadata fields: ***#bytes, parse_state***
- Parser: extract default -> 100 bytes
  - **#bytes** guides parser



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Strategy:

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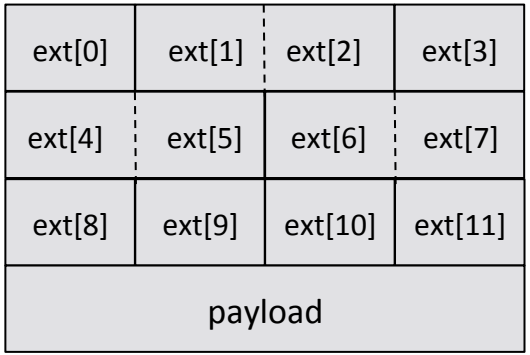
- Complex parsing logic moved to Ingress: **parse_state** may trigger update of **#bytes** + `resubmit`



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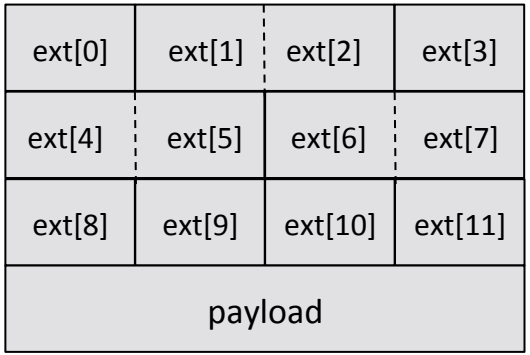
parsed representation: all valid elements of ext

- Inconvenient to work with; copy to single very wide metadata field



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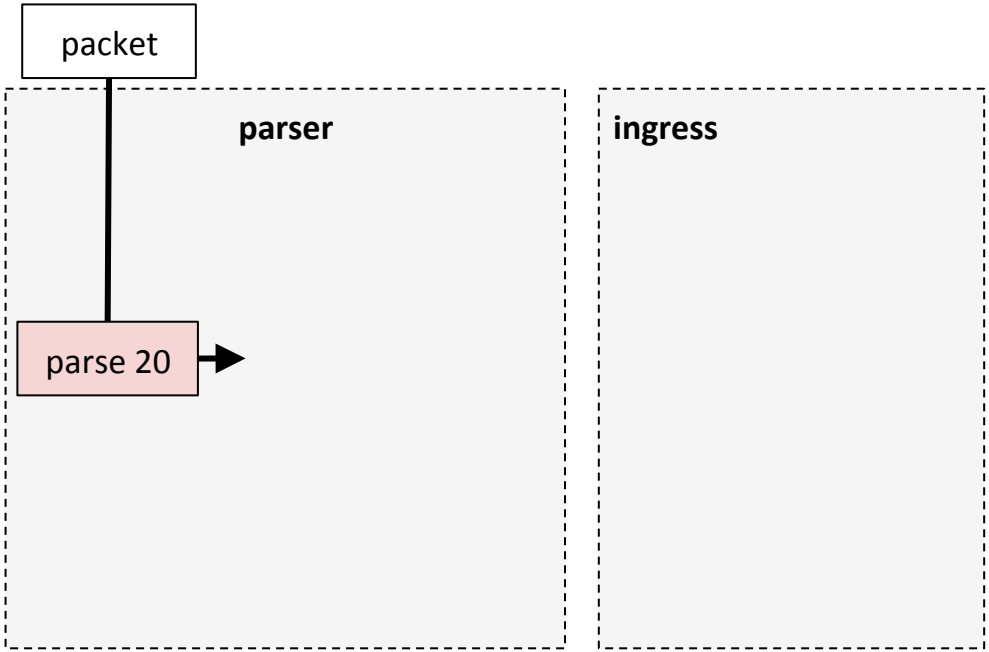

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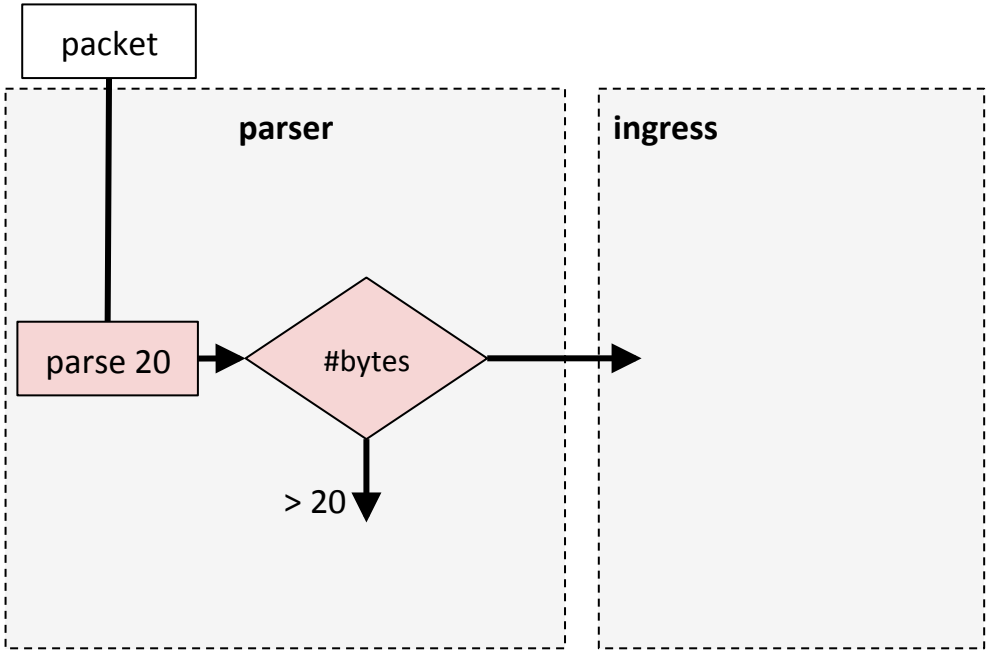

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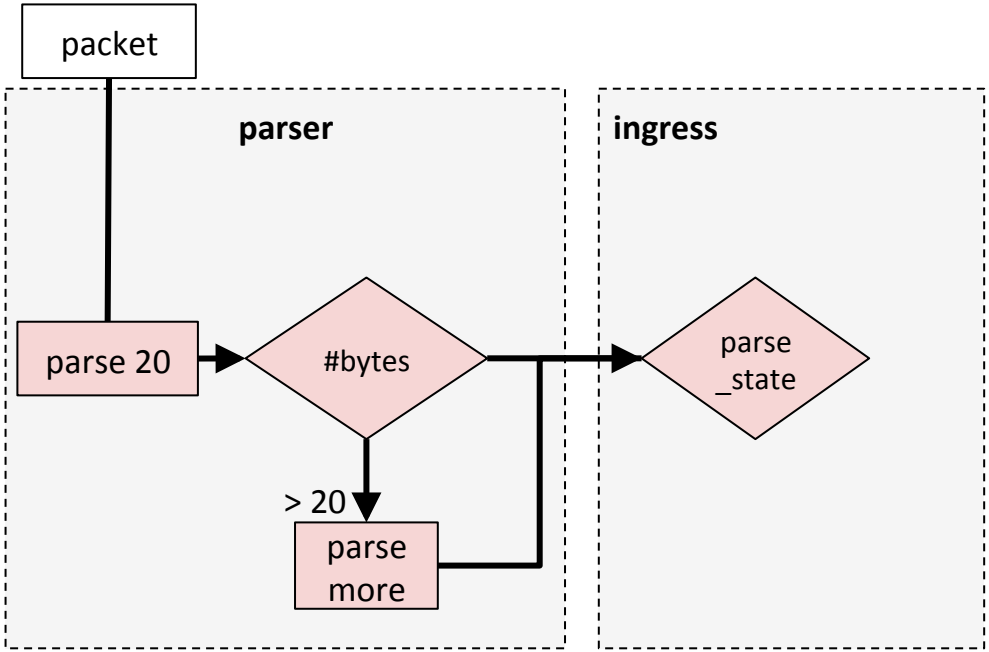
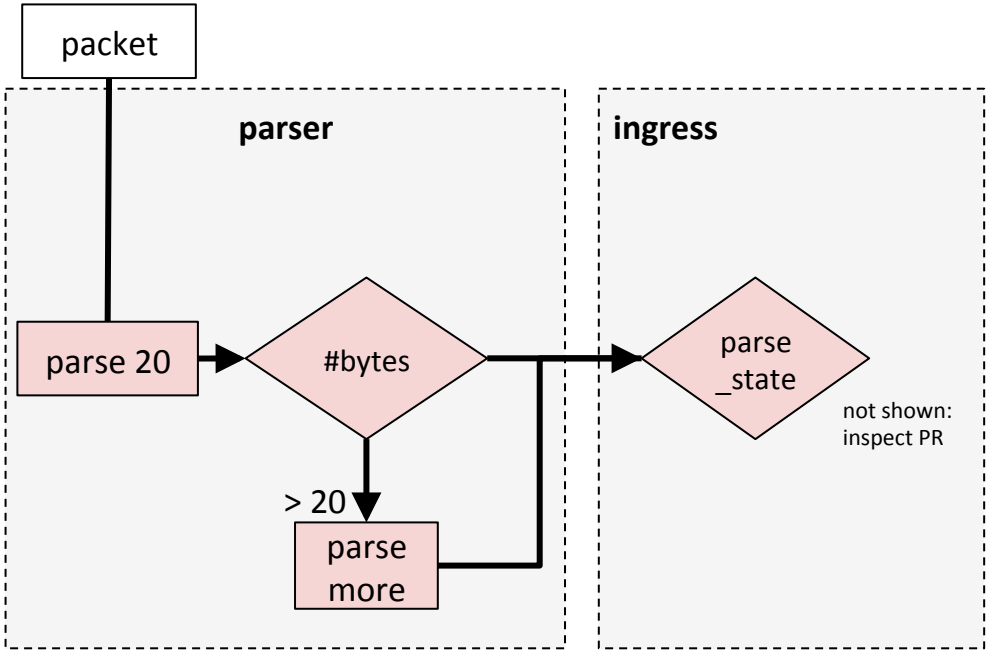


HyPer4.p4: Parsing



HyPer4.p4: Parsing