P4 & Named Data Networks

A networking paradigm for the future

May 3, 2017

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PRESENTATION OUTLINE (committed)

§1
- The P4 programming language for networks

§2
- Named data networks (NDN)

§3
- *(tentative)* Express NDN using P4

- *…And a round of NavTalk atendee participation!*

CHAPTER I

The P4 Programming Language

MOTIVATION for P4

- Different reprogrammable technologies (switches, NICs, FPGAs) each have their own **capabilities** and **internal language**.

- The OpenFlow interface started simple, but has been frequently extended to **allow switches to expose their capabilities**, becoming overly complex.

- It would be desirable that future switches **support flexible parsing and header matching**, through a common, open API (a new "OpenFlow 2.0").

ABOUT P4

- P4 is a generic, **high-level language** to describe **target-independent processing** on the forwarding plane.
  1. It becomes possible to **express a packet processing flow** that is **generic**, **flexible**, and **easily changeable**.
  2. Untied to specific protocols.
  3. It is like programming in C with no concern regarding the underlying architecture!

- P4 currently has two versions: P4-14 and P4-16.
  - We'll discuss differences between them later.

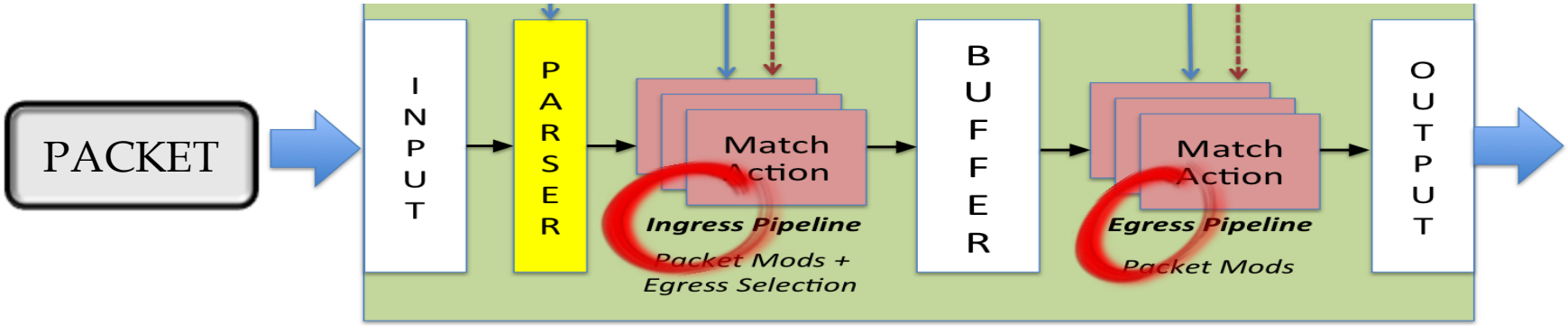
ABOUT P4

- While its motivation stems from SDN and OpenFlow, P4 does not assume:
  - There is an SDN controller overseeing the network.
  - The network is TCP/IP, Ethernet or otherwise.
  - Devices are controlled using OpenFlow.

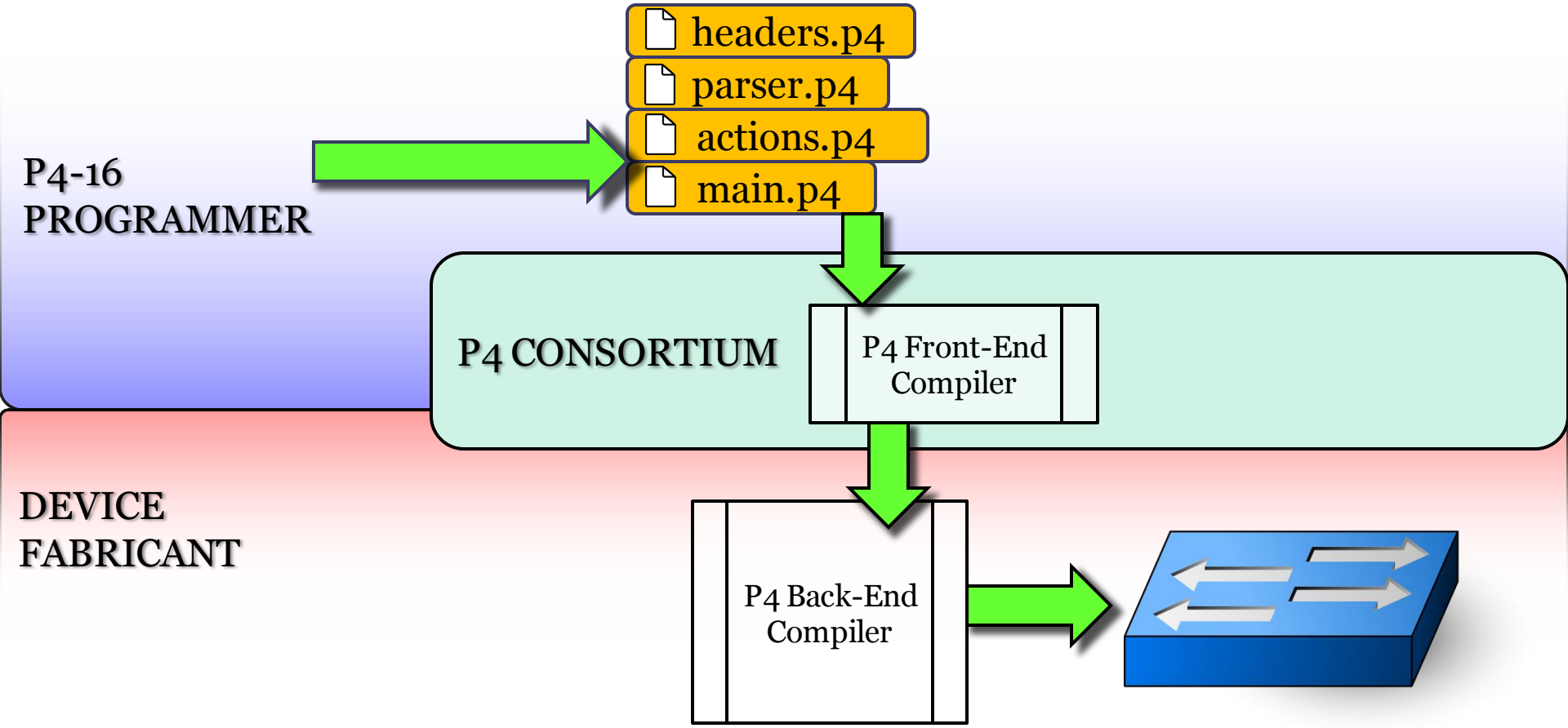
- Assumptions P4 does make:
  - If a device supports P4, then its vendors provide a back-end compiler to translate it to the device's internal language.
  - If two match-action stages are independent, then they **can be performed in parallel**, even if specified imperatively.

ABOUT P4

- We should take a look at another assumption made for the earlier version, P4-14 *(not true for P4-16)*.
  - A P4 compatible device will abide to the following model/architecture:



PROGRAMMING A P4-COMPATIBLE DEVICE



P4 — Learn by example

Defining a whee, simple L2-switch for IP packets

Headers.p4

P4-14

```
header_type ethernet_t {
  fields {
    dstAddr: 48;
    srcAddr: 48;
    ethType: 16;
  }
}
```

P4-16

```
typedef bit<48>
  EthernetAddress;

header ethernet {
   EthernetAddress dstAddr;
   EthernetAddress srcAddr;
   bit<16> etherType;
}

struct Parsed_packet {
  ethernet eth;
}
```

P4 — Learn by example

Defining a whee, simple L2-switch for IP packets

Parser.p4

P4-14

```
parser start {
  return ethernet_st;
}

header ethernet_t ethernet;

parser ethernet_st {
1  extract(ethernet);
2  return select(latest.ethType) {
3    0x800: ingress;
4    default: parse_error e;
5  }
6 }
```

```
parser_exception e {
  parser_drop;
}
```

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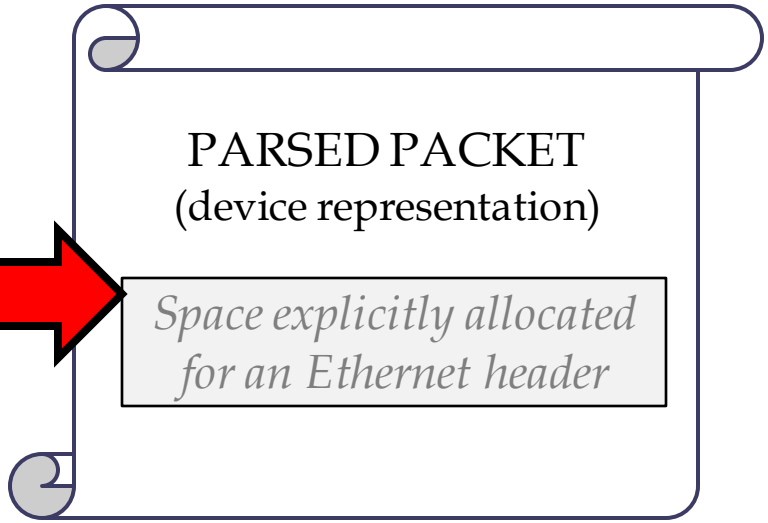

P4 — Learn by example

Defining a whee, simple L2-switch for IP packets

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P4-14

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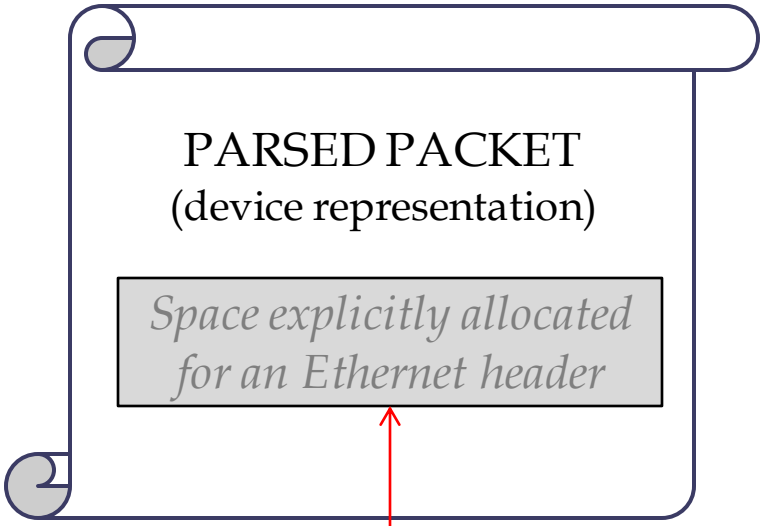

extract()

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Defining a whee, simple L2-switch for IP packets

Parser.p4

P4-14

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  parser_drop;
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```

PARSED PACKET
(device representation)

8:56:27:6f:2b:9c
8:0:20:4:5:6
0x800

0856276f2b9c 08020040506 800 ? ? ? ?
? ? ? ? ? ? ? ? ? ? ?

P4 — Learn by example

Defining a whee, simple L2-switch for IP packets

Parser.p4

P4-14

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   bit<16> etherType;
}

struct Parsed_packet {
  ethernet eth;
}
```

Parser.p4

P4-16

```
parser TopParser(packet_in b,
  out Parsed_packet p) {

  state start {
1   b.extract(p.eth);
2   transition
  select(p.eth.etherType) {
3     0x800: accept;
4     _: reject;
5   }
  }
}
```

P4 — Learn by example

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P4-16

```
parser TopParser(packet_in b,
  Parsed_packet p) {

  state start {
  1   b.extract(p.eth);
  2   transition
  select(p.eth.etherType) {
  3     0x800: accept;
  4     _: reject;
  5   }
  }
}
```

ABOUT P4

Loose note

- Our exercise is giving us a glimpse on how to implement our own protocols in P4.
  - By defining our own headers and writing our own parser, we can program the forwarding device to expect non-standard protocols… or the standard ones we already know and love!
  - This also demonstrates P4 is quite flexible, as it aspired to be.

P4 — Learn by example

Defining a whee, simple L2-switch for IP packets

Main.p4

P4-14

```
action set_output_port (port) {
  modify_field(standard_metadata
  .egress_port, port);
}

table forward {
  reads {
    ethernet.dstAddr: exact;
  }
  actions {
    set_output_port;
    drop;
  }
}

control ingress {
  apply(forward);
}
```

P4 is forbidden from **WRITING** (adding entries) to tables, but it can **READ** from them.

P4 — Learn by example

Defining a whee, simple L2-switch for IP packets

Main.p4

P4-14

```
action set_output_port (port) {
  modify_field(standard_metadata
  .egress_port, port);
}

table forward {
  reads {
    ethernet.dstAddr: exact;
  }
  actions {
    set_output_port;
    drop;
  }
}

control ingress {
  apply(forward);
}
```

There's something awkward here. We are expecting a parameter when *set_output_port()* is invoked, but we are passing none in the table declaration. So how does it know, in execution time, what parameter is being passed?

The official answer is: the control plane decides. For simpler reasoning, we can imagine it is part of the table.

P4 — Learn by example

Defining a whee, simple L2-switch for IP packets

Main.p4

P4-14

```
action set_output_port (port) {
  modify_field(standard_metadata
  .egress_port, port);
}

table forward {
  reads {
    ethernet.dstAddr: exact;
  }
  actions {
    set_output_port;
    drop;
  }
}

control ingress {
  apply(forward);
}
```

DESTINATION MAC	ACTION	PORT
8:56:27:6f:2b:9c	set_output_port	3
8:0:20:4:5:6	set_output_port	1
*	drop	-

P4 — Learn by example

Defining a whee, simple L2-switch for IP packets

Main.p4

P4-14

```
action set_output_port (port) {
  modify_field(standard_metadata
  .egress_spec, port);
}

table forward {
  reads {
    ethernet.dstAddr: exact;
  }
  actions {
    set_output_port;
    drop;
  }
}

control ingress {
  apply(forward);
}
```

P4-16

```
control TopMainIngr(
  inout standard_metadata_t m,
  inout Parsed_packet p) {

  action set_output_port(port)
  { m.egress_spec = port; }

  table forward {
    key = { p.eth.dstAddr: exact;}
    actions = {
        set_output_port;
        Drop;
    }
  }
```

P4 — Learn by example

Defining a whee, simple L2-switch for IP packets

Main.p4

P4-14

```
action set_output_port (port) {
  modify_field(standard_metadata
  .egress_port, port);
}

table forward {
  reads {
    ethernet.dstAddr: exact;
  }
  actions {
    set_output_port;
    drop;
  }
}

control ingress {
  apply(forward);
}
```

P4-16

```
control TopMainIngr(...) {

  action set_output_port(port)
  { m.egress_spec = port; }

  table forward {
    ...
  }

  apply {
    forward.apply();
  }
}
```

P4 — Learn by example

Defining a whee, simple L2-switch for IP packets

Main.p4

P4-14

```
control egress {

}
```

P4-16

```
control TopMainEgr(...) {

  apply { }

}
```

P4 — Learn by example

HYPOTHETICAL L3 ROUTER REWRITING SMAC

Main.p4

P4-14

```
action rewrite_mac(smac) {
  modify_field(ethernet.srcAddr,
  smac); }

table set_egress {
  reads {
   standard_metadata.
      egress_port : exact;
  }
  actions {
    rewrite_macs;
    drop;   }
}

control egress {
  apply(set_egress);
}
```

P4-16

```
control TopMainEgr(...) {

  action set_srcMAC(address)
  { p.eth.srcAddr = address; }

  table set_egress {
    key = { m.egress_port: exact;}
    actions = {
        set_srcMAC;
        Drop;
    }
  }

  apply { set_egress.apply(); }
```

P4 — Learn by example

HYPOTHETICAL L3 ROUTER REWRITING SMAC

Main.p4

P4-14

```
action rewrite_mac(smac) {
  modify_field(ethernet.srcAddr,
  smac); }

table set_egress {
  reads {
   standard_metadata.
      egress_port : e  ct;
  }
  actions {
   re        s;
   drop;   }
}

control egress {
  apply(set_egress);
}
```

P4-16

```
control T  in

apply { set_egress.apply(); }
```

The takeaway of that slide: you can also match on metadata!

P4 — Learn by example

Defining a whee, simple L2-switch for IP packets

Deparser.p4

P4-16 only

```
control TopDeparser (
  packet_out b,
  in Parsed_packet p) {



  apply {
    b.emit(p.eth);
  }

}
```

P4-14 vs P4-16

P4-14

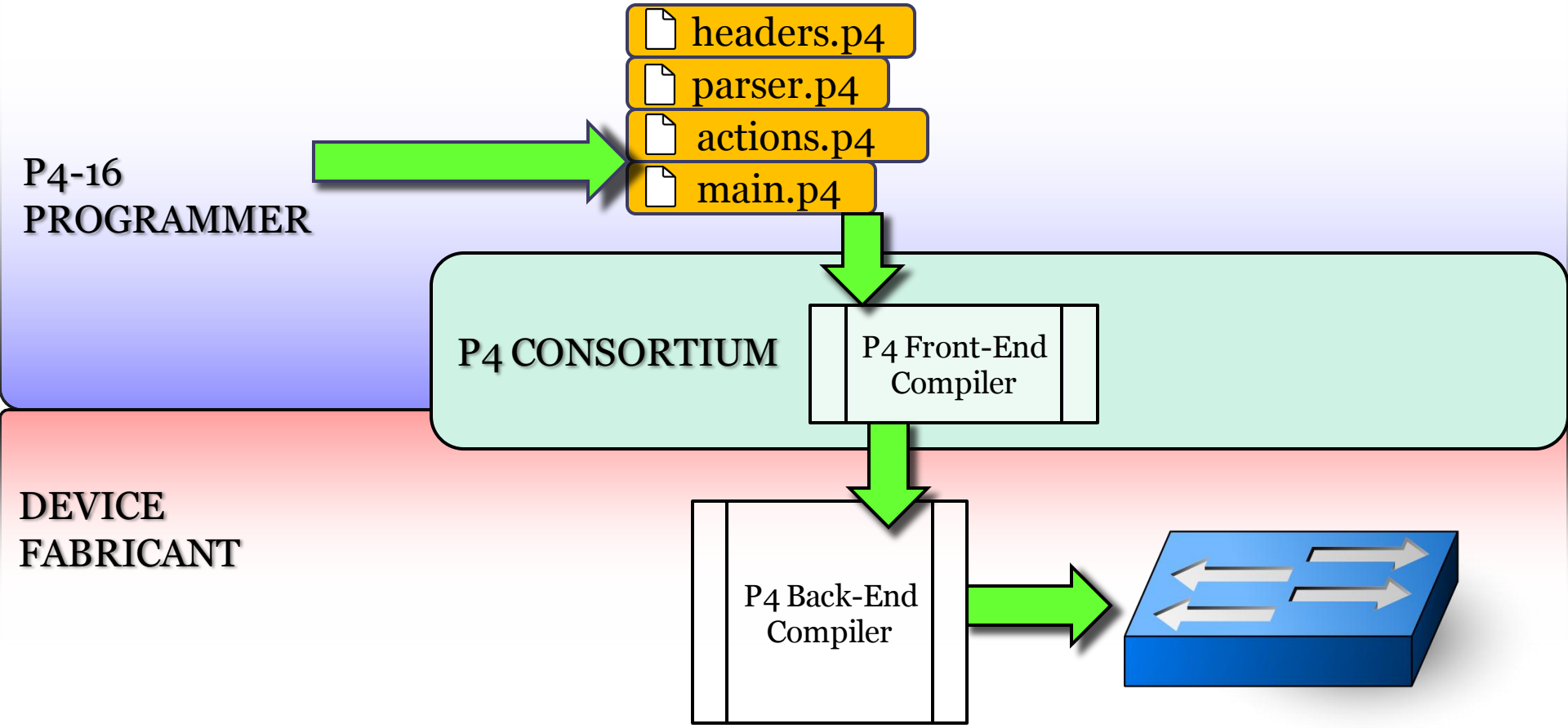
- ✓ Any P4-14 device follows a common model.
  - ✓ PARSER → INGRESS → EGRESS
  - — But is that model fitting for all purposes (e.g. firewalls?)
- ✓ P4-14 defines primitives that compatible devices will implement… most of the time.
  - — Will they?
  - — They may implement extra features but be unable to expose them?

P4-16

- ✓ Very stable core language, updated rarely.
- ✓ Not bound to the assumed P4-14 model/architecture.
  - ✓ Vendors specify, in P4 syntax, an **architecture definition file**.
  - — Software switch users that define new architectures must build their own back-end compiler?
- ✓ Enhanced parameterization features.
  - ✓ You may have noticed earlier.
- ✓ Selective deparser.
- ✓ **Extern** blocks and functions.

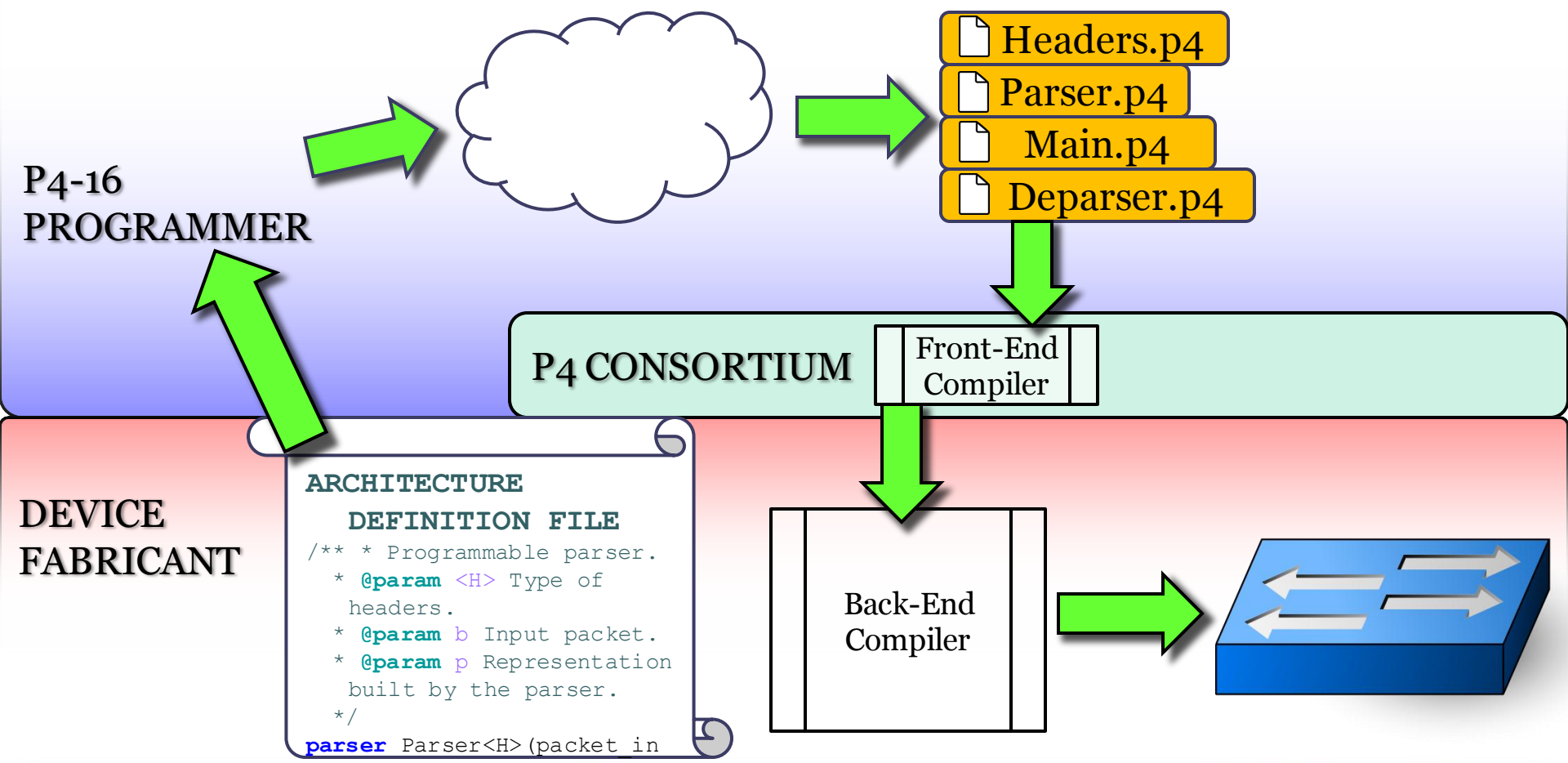
ABOUT P4-16

Our P4-14 workflow



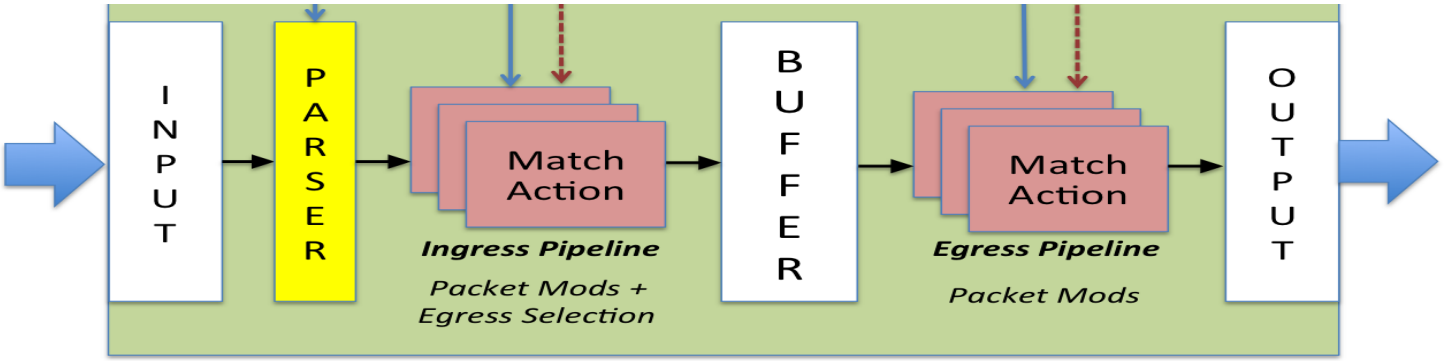
ABOUT P4-16

Our P4-16 workflow



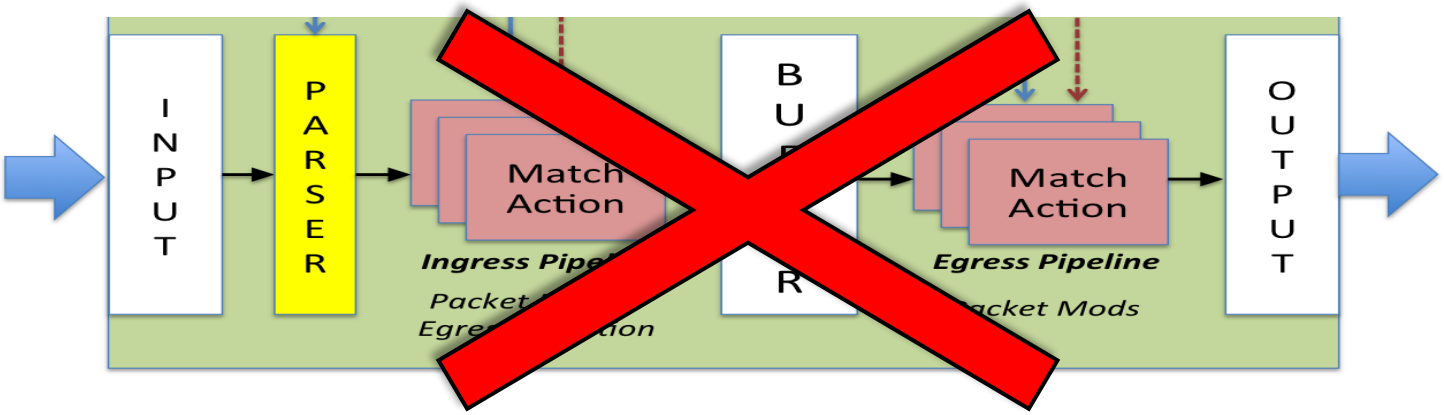
ABOUT P4-16

- The figure is a possible architecture in P4-16, but not the default, mandatory and only architecture, as in in P4-14.



ABOUT P4-16

- The figure is a possible architecture in P4-16, but not the default, mandatory and only architecture, as in in P4-14.
  - P4-16-compatible devices must provide an **architecture definition file** on top of the back-end compiler.



ABOUT P4-16

See how a simple drop can differ across architectures

```
action Drop()
{ ctrl.outPort = DROP_PORT; }
```

ARCHITECTURE A

DROP_PORT is a special port, a **#define** in the architecture definition file.

ABOUT P4-16

See how a simple drop can differ across architectures

```
action Drop()
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```

ARCHITECTURE A

DROP_PORT is a special port, a **#define** in the architecture definition file.

```
action Drop()
{ metadata.dropBit = 1; }
```

ARCHITECTURE B

Drop is performed by setting a metadata bit.

ABOUT P4-16

See how a simple drop can differ across architectures

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action Drop()
{ ctrl.outPort = DROP_PORT; }
```

ARCHITECTURE A

DROP_PORT is a special port, a **#define** in the architecture definition file.

```
action Drop()
{ metadata.dropBit = 1; }
```

ARCHITECTURE B

Drop is performed by setting a metadata bit.

```
action Drop()
{ mark_for_drop(); }
```

ARCHITECTURE C

`mark_for_drop()` is an **extern** function declared in the architecture definition file.

ABOUT P4-16

A sample architecture definition

```
/** * Programmable parser.
  * @param <H> Type of headers.
  * @param b Input packet.
  * @param p Representation built by the parser.
  */
parser Parser<H>(packet_in b, out H p);

struct ctrl_t {
  bit<5> inputPort;
  bit<5> outputPort;
}

/** * Main match-action pipeline.
  * @param <T> Type of headers.
  * @param headers Received from the parser and sent to the deparser.
  * @param ctrl Input and output ports. Input set by control plane.
  */
control Pipe<T>(inout T headers, inout ctrl_t ctrl);
```

ABOUT P4-16

A sample architecture definition

```
/** * Programmable parser.
  * @param <D> Type of headers.
  * @param b Output packet.
  * @param p Representation built by the parser.
  */
control Deparser<D>(inout D outputHeaders, packet_out b);

/** * Top-level package declaration - must be instantiated by user.
  * @param <S> User-defined type of the headers processed.
package VerySimpleSwitch<S>(
  Parser<S> p,
  Pipe<S> map,
  Deparser<S> d);
```

ABOUT P4-16

A sample architecture definition

```
/** * Programmable parser.
  * @param <D> Type of headers.
  * @param b Output packet.
  * @param p Representation built by the parser.
  */
control Deparser<D>(inout D outputHeaders, packet_out b);

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  * @param <S> User-defined type of the headers processed.
package VerySimpleSwitch<S>(
  Parser<S> p,
  Pipe<S> map,
  Deparser<S> d);
```

The programmer instantiates this device in Main.p4, by writing:

```
VerySimpleSwitch(TopParser(), TopPipe(), TopDeparser()) main;
```

(TopParser is the name we gave to our parser in Parser.p4, and so on)

ABOUT P4-16

Extern blocks and functions

- **Extern** blocks/functions are programmed by the device manufacturer and **specified in P4 syntax** on the architecture definition file.
  - They **are all-powerful** as the manufacturer **can program them to do pretty much anything!**

```
extern register<T> {
  register(bit<32> size); // Constructor
  void read(out T result, in bit<32> index);
  void write(in bit<32> index, in T value);
}

extern void recirculate<T>(in T data);
```

ABOUT P4-16

Enhanced parameterization

```
//Extracts a myheader_h header into h.
parser Subparser(packet_in b, out myheader_h h)(bool
  specialField) {

   state start { … }
}

parser TopParser(packet_in b, Parsed_packet p) {

  Subparser(true) s; //Instantiates a Subparser.

  state start {
    s.apply(b, p.someHeader);
    …
  }
}
```

CONCLUSIONS

- P4 is a high-level language for programmable network devices.
  - It is motivated by OpenFlow's rigidity on supporting new protocols.
  - It is a paradigm similar to C programming for an arbitrary underlying processor architecture.
  - Devices must provide a back-end compiler to translate it to its own internal language. Such a device is **P4-compatible**.
  - You run whatever protocols you want... and only those you want!

- On the language.
  - P4-14 is loosely typed and more verbose for some use cases.
  - P4-16 is strongly typed and has more parameterization features.

CONCLUSIONS

- On the trade-off between portability and functionality.
  - P4-14 assumes a common model (parser -> ingress -> egress), which makes programs more portable. However, device manufacturers are constrained on the functionality their switches can provide.
  - P4-16 allows manufacturers to expose more of their device through diverse control blocks, **extern** functions and instantiable blocks, at the cost of portability.

- Use P4-16, as P4-14 is likely to be deprecated ;)

CHAPTER II

Named Data Networks (NDNs)