Programming
The Network Data Plane in P4

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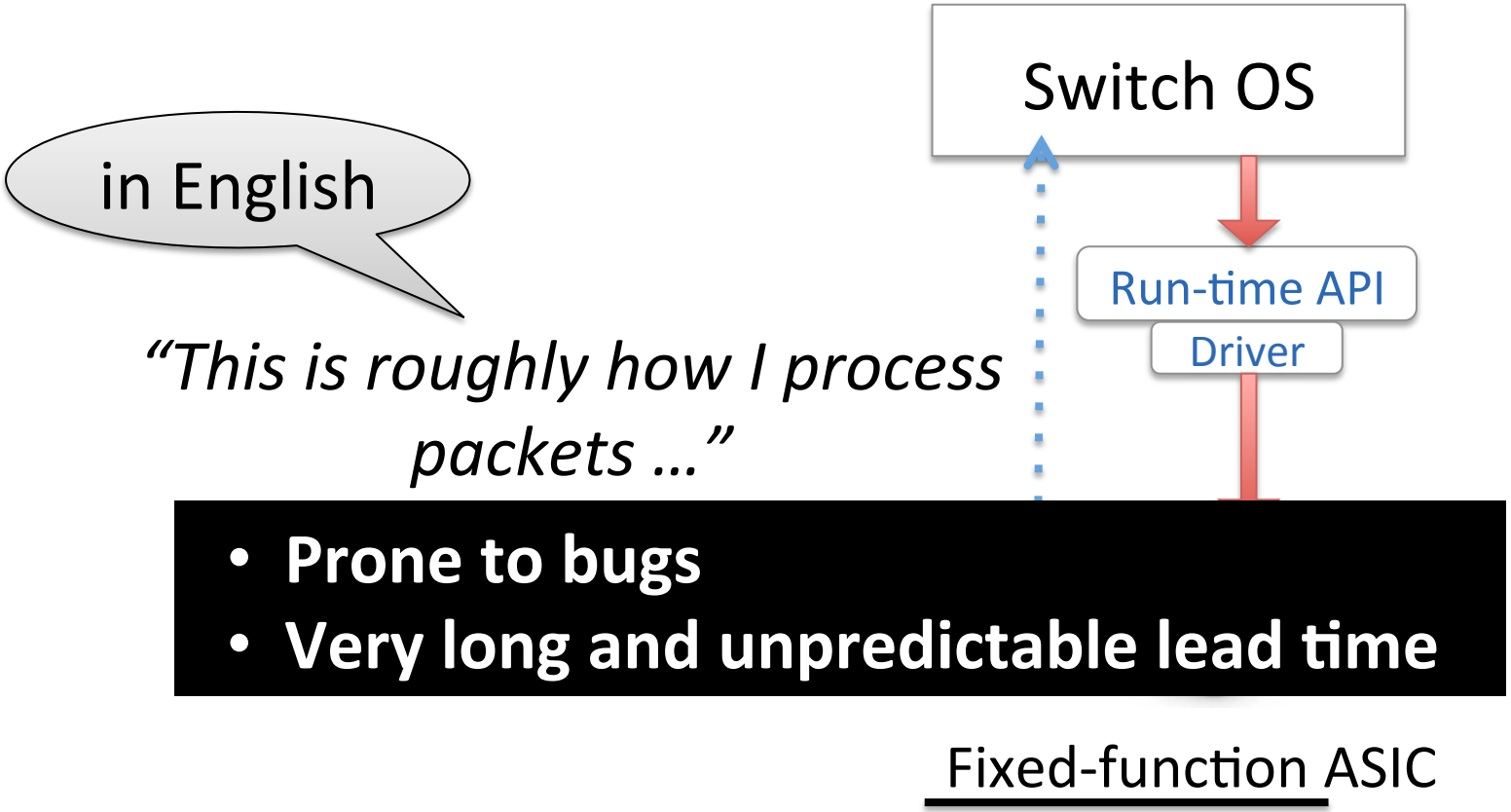
P4 Language Consortium – www.p4.org

Status quo


Switch OS
in English
Run-time API
Driver
"This is roughly how I process packets …"
• Prone to bugs
• Very long and unpredictable lead time
Fixed-function ASIC

Protocols evolve …
more rapidly than we wish they would

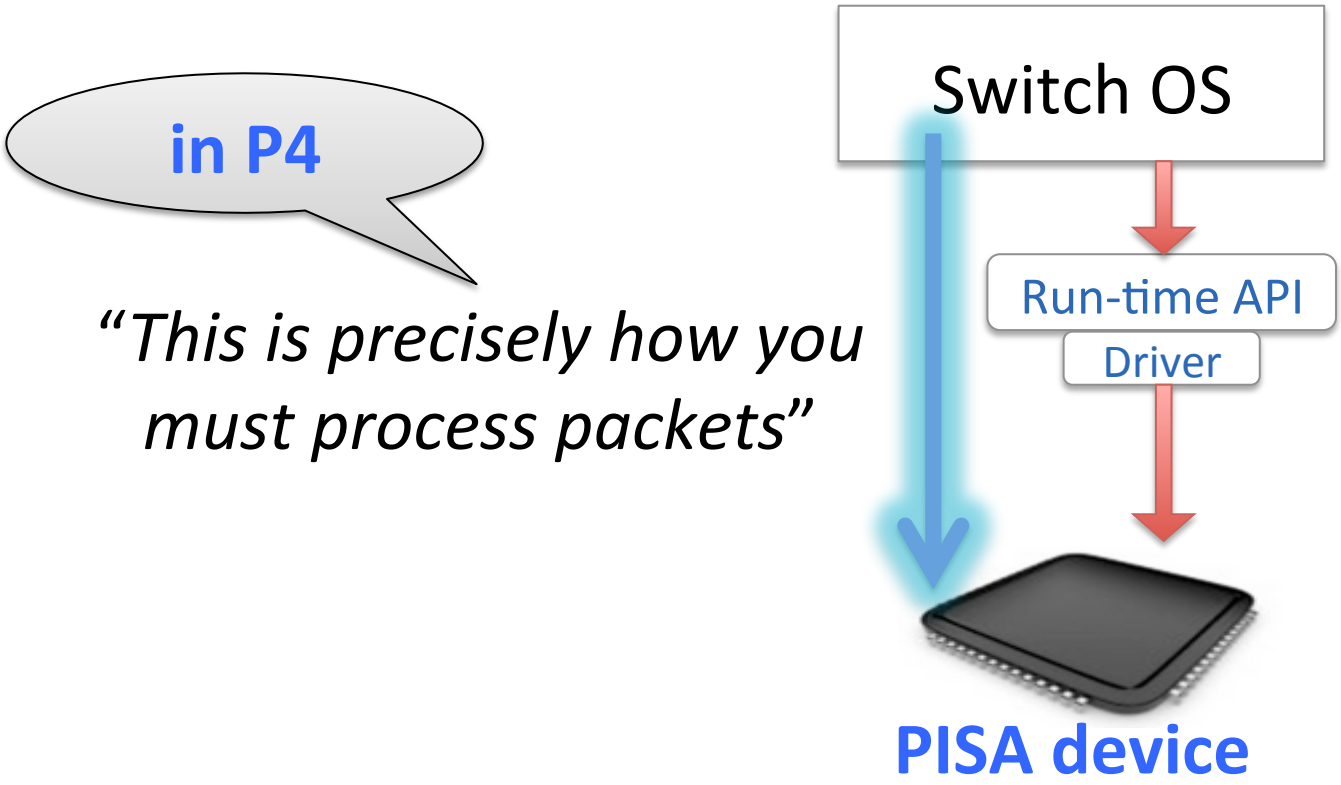
- Encapsulation protocols for network virtualization
  - 1st gen (~2010): VXLAN, NVGRE
  - 2nd gen (~2012): STT, VXLAN-GPE
  - 3rd gen (~2014): NSH, Geneve
- OpenFlow
  - OF 1.0 (Dec 2009): 12 fields (Ethernet, TCP, IPv4)
  - OF 1.1 (Feb 2011): 15 fields (MPLS, inter-table metadata)
  - OF 1.2 (Dec 2011): 36 fields (ARP, ICMP, IPv6)

Everybody has opinions!
Can't we just let them build their own protocols?

Programmable network devices

- Some devices are or will be more programmable than fixed-function ASICs
- CPUs: 10s of Gb/s
- FPGAs, NPUs: 100s of Gb/s
- Protocol-independent switch ASICs: a few Tb/s
  - RMT [SIGCOMM'13] and a few emerging solutions
  - Merchant silicon with fully programmable parser and generic match-action logic
  - In next few years this kind of silicon will dominate

Turning the tables



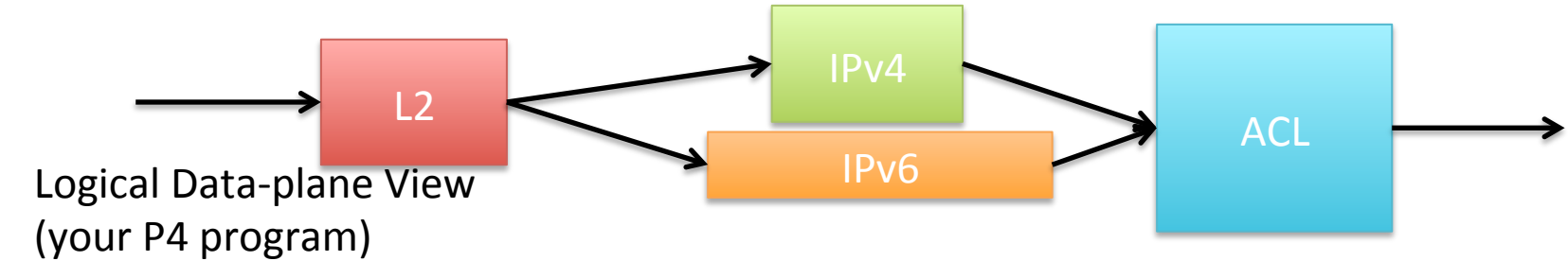
"This is precisely how you must process packets"

What does this mean?

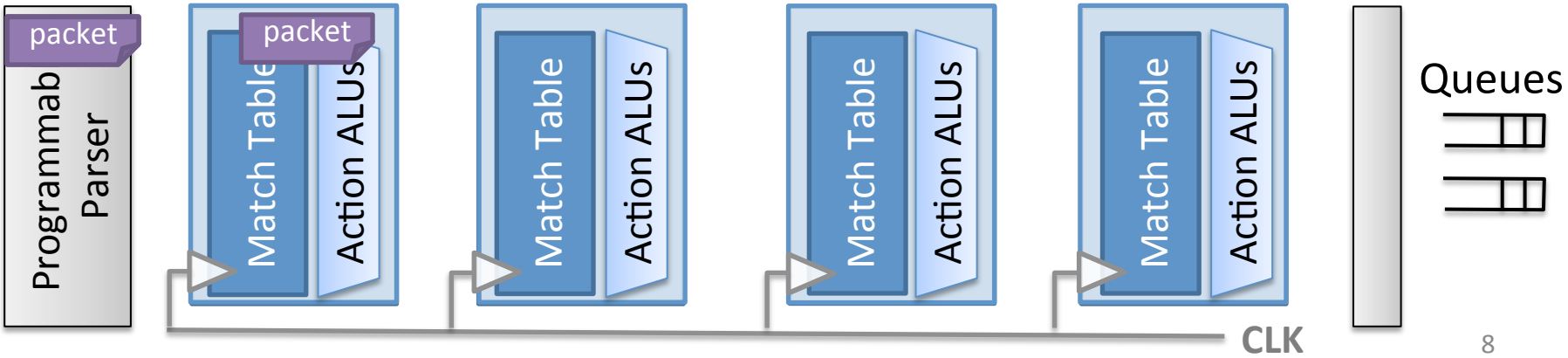
- To network device vendors
  - S/W programming practices and tools used in every phase
  - Extremely fast iteration and feature release
  - Differentiation in capabilities and performance
  - Can fix even data-plane bugs in the field
- To large on-line service providers
  - No more “black boxes” in the “white boxes”
  - Your devs can program, test, and debug your network devices all the way down
  - You keep your own ideas

Why we call it protocol-independent packet processing

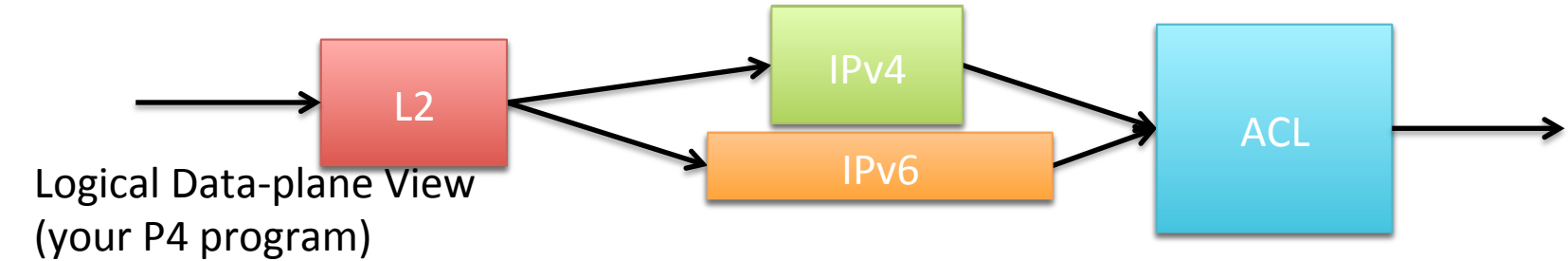
Device does not understand any protocols until it gets programmed



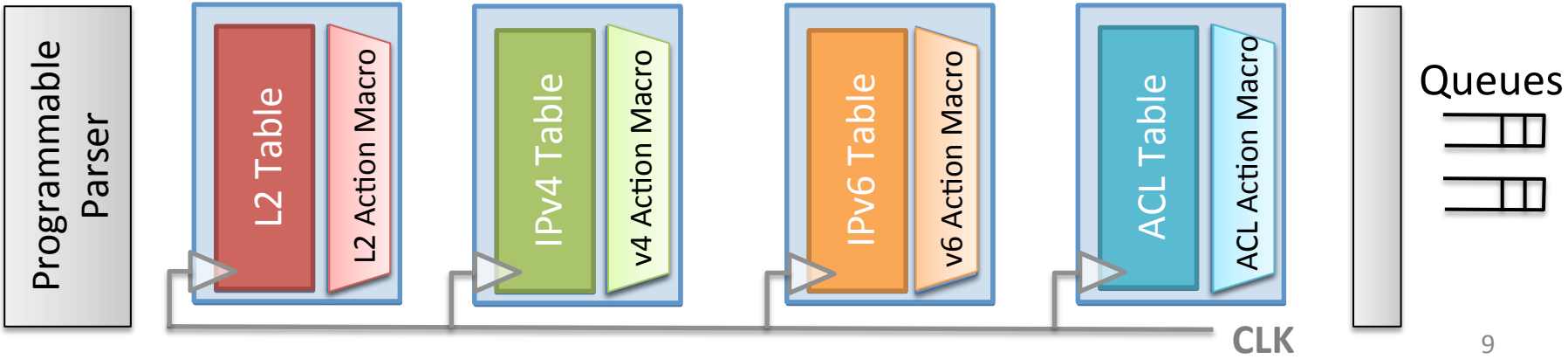
Switch Pipeline



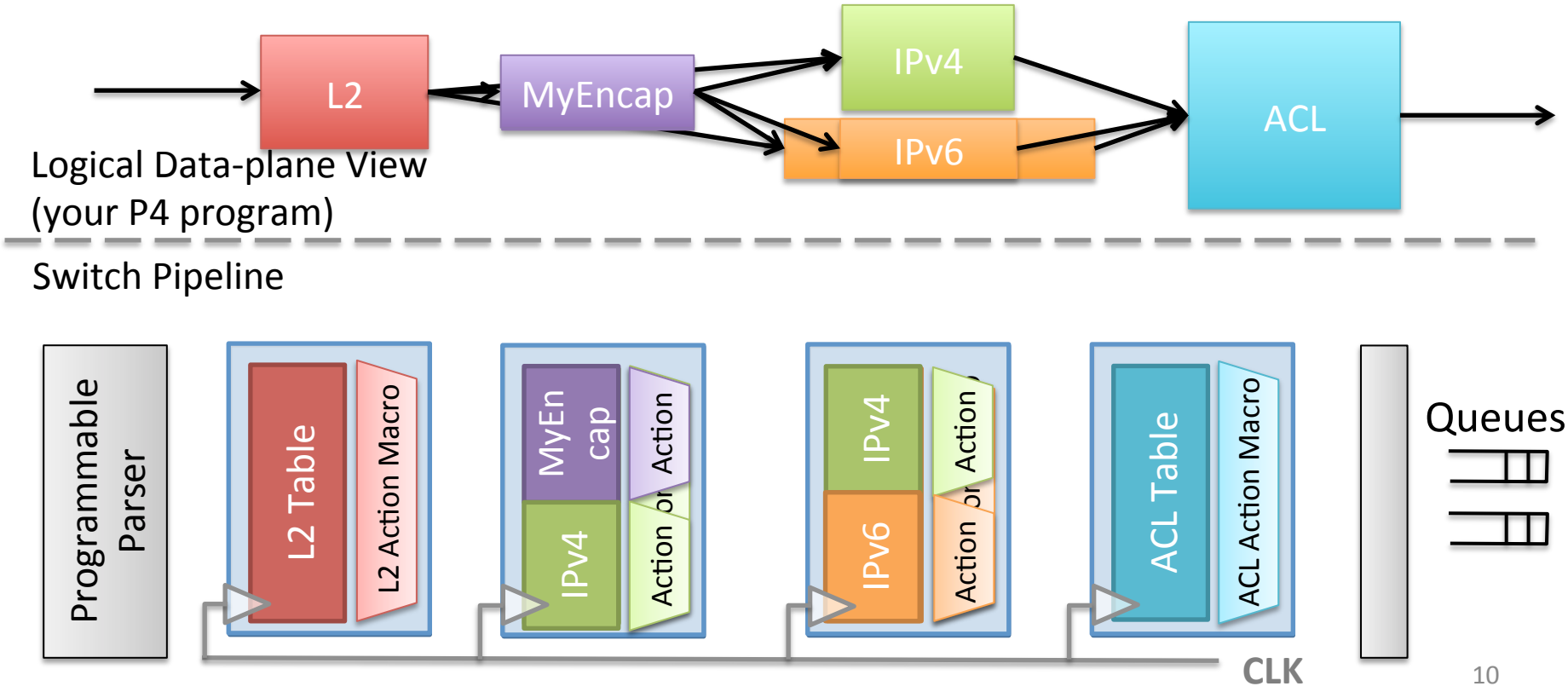
Mapping logical data-plane design to physical resources



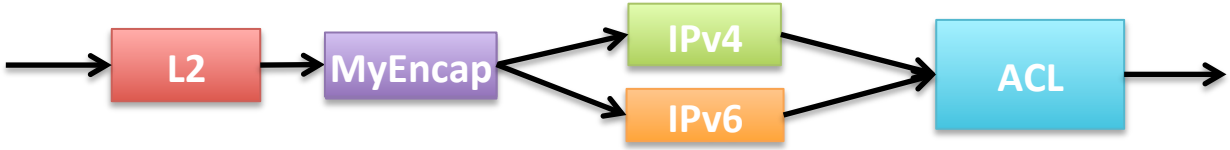
Switch Pipeline

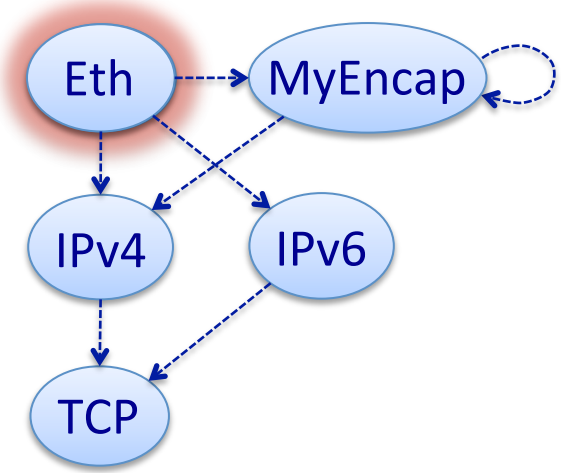


Re-configurability



What does a P4 program look like?

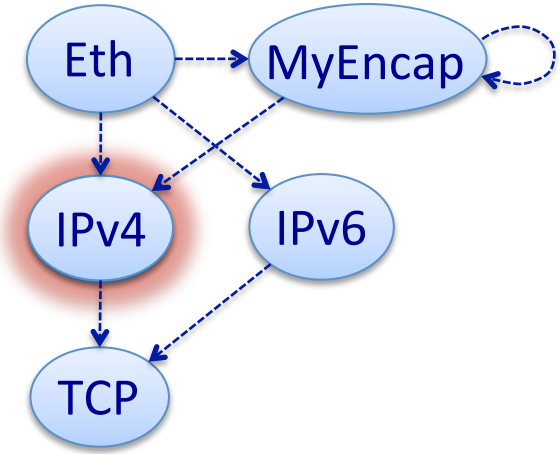





```
header_type ethernet_t {
     fields {
          dstAddr : 48;
          srcAddr : 48;
     }
}
parser parse_ethernet {
     extract(ethernet);
     return select(latest.etherType) {
          0x8100 : parse_vlan;
```

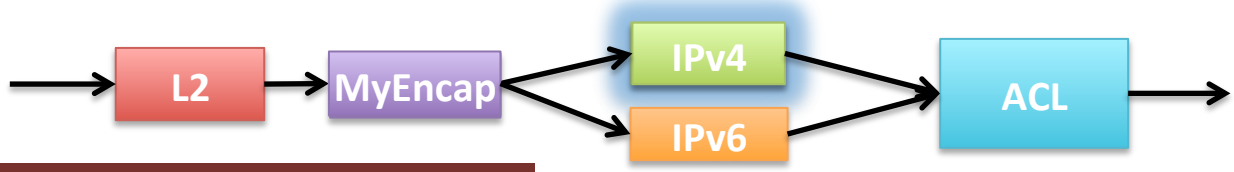
```
header_type my_encap_t {
     fields {
          foo : 12;
          bar : 8;
          baz : 4;
          qux : 4;
          next_protocol : 4;
     }
}
```

What does a P4 program look like?




```
header_type ipv4_t {
    fields {
        version         : 4;
        ihl             : 4;
        diffserv        : 8;
        totalLen        : 16;
        identification  : 16;
        flags           : 3;
        fragOffset      : 13;
        ttl             : 8;
        protocol        : 8;
        hdrChecksum     : 16;
        srcAddr         : 32;
        dstAddr         : 32;
        options         : *;
    }
    length      : (ihl << 2);
    max_length  : 60;
}
```

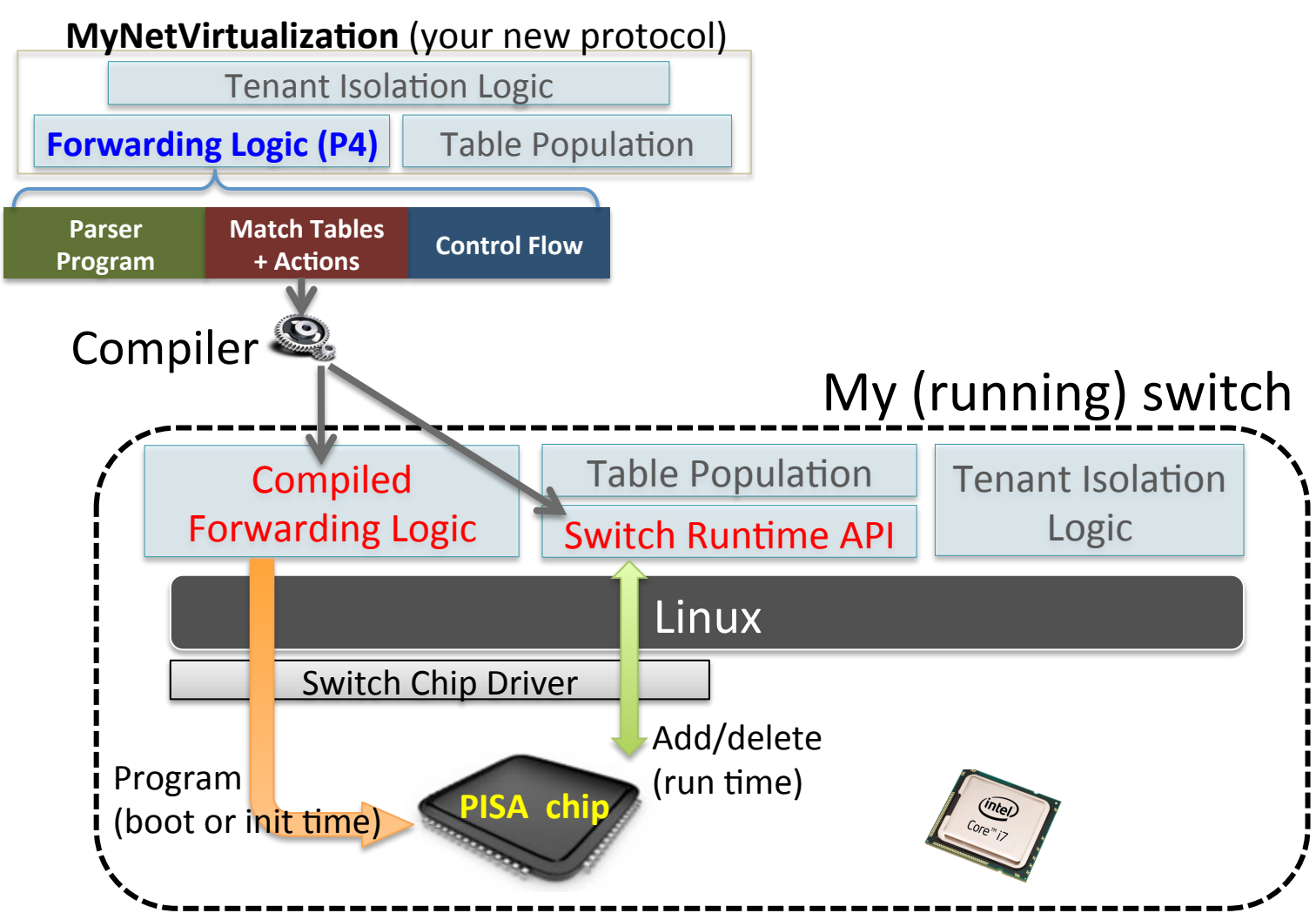
What does a P4 program look like?




```
table ipv4_lpm
{
    reads {
        ipv4.dstA
    }
    actions {
        set_next_
    }
}
```

```
control ingress
{
    apply(l2);
    apply(my_encap);
    if (valid(ipv4) {
        apply(ipv4_lpm);
    } else {
        apply(ipv6_lpm);
    }
    apply(acl);
}
```

```
action set_next_hop(n
{
    modify_field(meta                    ddr);
    modify_field(stan                    ;
    add_to_field(ipv4.ttl, -1);
}
```


MyNetVirtualization (your new protocol)
Tenant Isolation Logic
Forwarding Logic (P4)
Table Population
Parser Program
Match Tables + Actions
Control Flow
Compiler
My (running) switch
Compiled Forwarding Logic
Table Population
Switch Runtime API
Tenant Isolation Logic
Linux
Switch Chip Driver
Add/delete (run time)
Program (boot or init time)
PISA chip
intel
Core i7

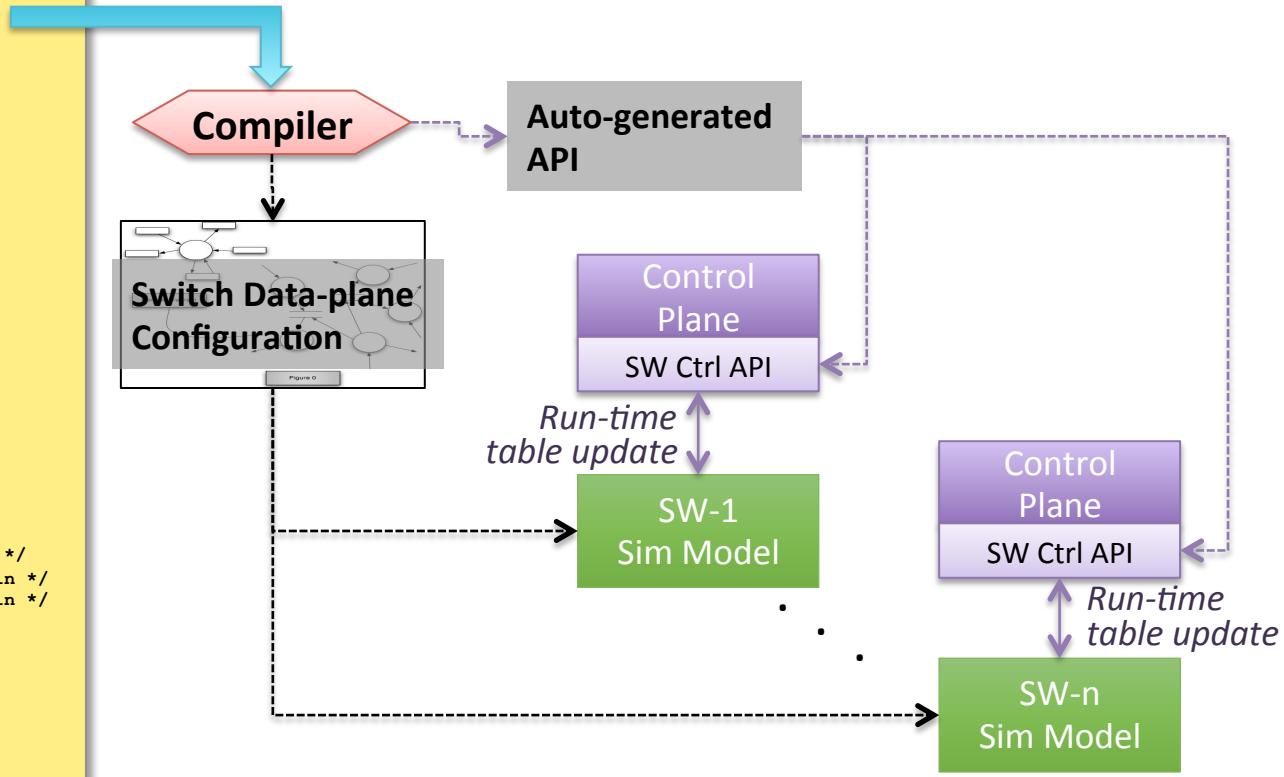
DEMO!

In-band Network Telemetry (INT)

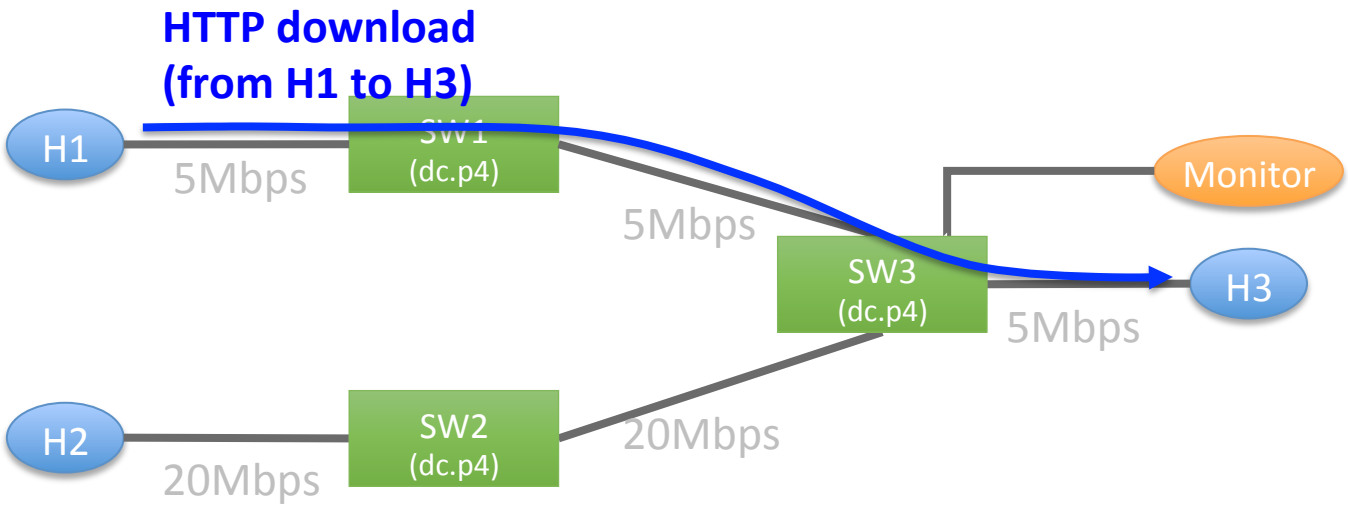
http://p4.org/p4/inband-network-telemetry/

Demo Setup

```
/*  Reference p4 program
    switch.p4
*/

#include "includes/headers.p4"
#include "includes/parser.p4"

/*******************************/
/* Device Personality Selection */
/*******************************/

// #define P_MINIMAL
#define P_BASE
//#define P_MSDC_SPINE
//#define P_MSDC_TOR
//#define P_MSDC_BL
//#define P_INTERNET_ROUTER
...

// Flexible Tables
#define LPM_TABLE_SIZE 16384
#define IPV6_LPM_TABLE_SIZE 4096
#define HOST_TABLE_SIZE 131072
#define IPV6_HOST_TABLE_SIZE 32768
...
header_type routing_metadata_t {
    fields {
        bd : BD_BIT_WIDTH; /* bridge domain */
       vrf : VRF_BIT_WIDTH; /* routing domain */
    v6_vrf : VRF_BIT_WIDTH; /* routing domain */
...

table bridge_domain {
    reads {
        routing_metadata.bd : exact;
    }
    actions {
        nop;    // Not used
     bd_set;
…
```



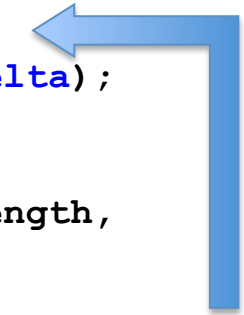
Scenario: Debugging Long Latency Tail



In-band Network Telemetry in P4

```
table int_table {
  reads {
    ip.protocol;
  }
  actions {
    export_queue_latency;
  }
}
```

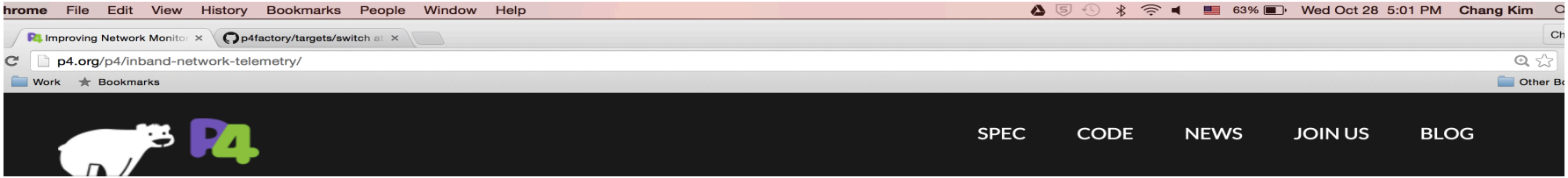
```
action export_queue_latency (sw_id) {
  add_header(int_header);
  modify_field(int_header.kind, TCP_OPTION_INT);
  modify_field(int_header.len, TCP_OPTION_INT_LEN);
  modify_field(int_header.sw_id, sw_id);
  modify_field(int_header.q_latency,
               intrinsic_metadata.deq_timedelta);
  add_to_field(tcp.dataOffset, 2);
  add_to_field(ipv4.totalLen, 8);
  subtract_from_field(ingress_metadata.tcpLength,
                      12);
}
```



Add TCP Options &
copy switch ID and queue latency
Into the options

INT Open-source and Spec

- http://p4.org/p4/inband-network-telemetry/



Improving Network Monitoring and Management with Programmable Data Planes

By Mukesh Hira & LJ Wobker

Quicklinks : The INT specification – – – INT GitHub repository – – – INT demo video

Compute virtualiz ion and the widespread depl ment of virtual machines ha led to an extension of the network into the hypervisor. Ne k virtualization solutions h merged that enable rapid pro ning of network services — logical switches, lancers, irtual ma network interfaces. VMware alization be decou al network so as to enable deployment of virtual services over any physical network infrastructure, the only requirement from the physical network being IP connectivity between the hypervisors.

Spec Ref P4 code Demo

While the decoupling of physical and virtual topologies has advantages, it is important to have some interaction between the physical and virtual switches to allow for end-to-end monitoring of the entire physical + virtual network from a "single pane of glass" and to help in troubleshooting and fault isolation in complex physical + virtual topologies.

We propose methods for various network elements to collect and report their state in real-time, allowing for improved cooperation between the virtual and physical layers without requiring intermediate layers such as CPU driven control planes. The general term we have applied to these methods is INT: Inband Network Telemetry.

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Improving Network Monitoring and Management with Programmable Data Planes

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P4 language evolution

P4 and Open vSwitch

1st P4 Workshop on June 4, 2015

Archives

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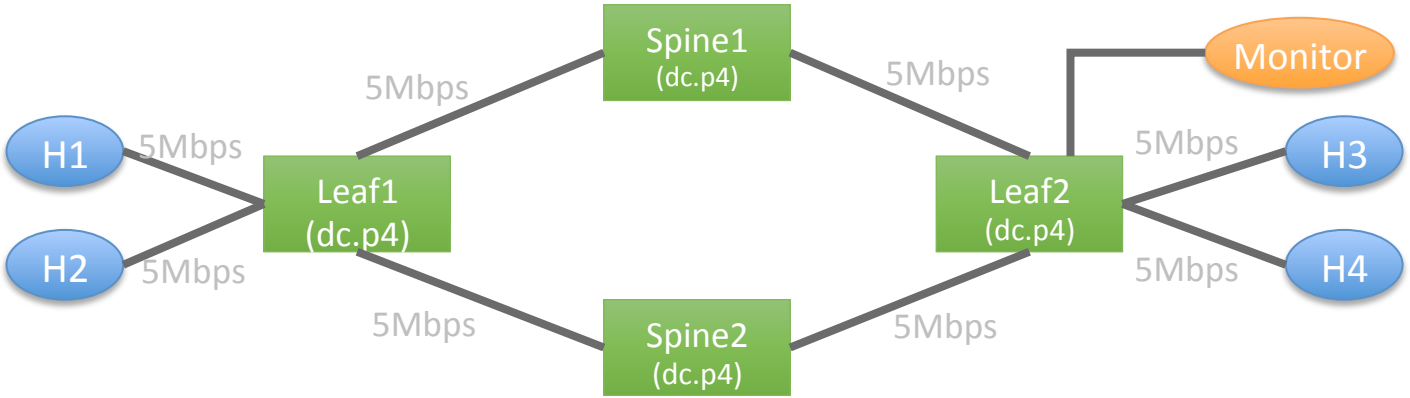
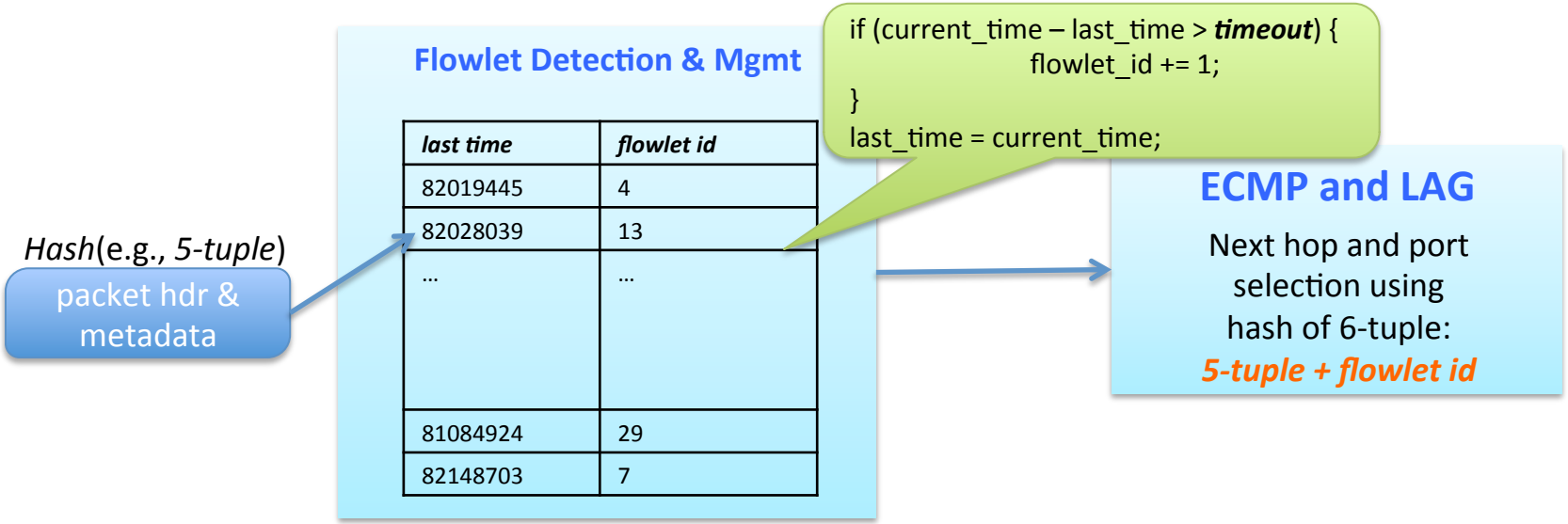
Scenario: Resolving Traffic Split Problem



Traffic Demand

H1 → H3	TCP
H2 → H4	TCP

Simple Flowlet Switching



- Hash collisions are infrequent
  - Flowlets are very short, and hence # of active flowlets is only up to tens of thousands
- Hash collisions are inconsequential
  - Flowlets are very small; sub-optimality caused by collisions is negligible
- Time out is configurable
  - Range can be as low ~1 us to ~100ms; a few hundred usec seems most suitable for DCs

Flowlet Switching in P4

```
field_list_calculation flowlet_map_hash {
   input {
      l3_hash_fields;
   }
   algorithm : crc16;
   output_width : FLOWLET_MAP_SIZE;
}

register flowlet_lasttime {
   width : 32;
   instance_count : 8192;
}

register flowlet_id {
   width : 16;
   instance_count : 8192;
}

action lookup_flowlet_map() {
   modify_field_with_hash_based_offset(ingress_metadata.flowlet_map_index, 0,
                              flowlet_map_hash, FLOWLET_MAP_SIZE);

   register_read(ingress_metadata.flowlet_id,
            flowlet_id, ingress_metadata.flowlet_map_index);

   modify_field(ingress_metadata.flow_ipg, intrinsic_metadata.ingress_global_timestamp);
   register_read(ingress_metadata.flowlet_lasttime,
            flowlet_lasttime, ingress_metadata.flowlet_map_index);
   subtract_from_field(ingress_metadata.flow_ipg, ingress_metadata.flowlet_lasttime);

   register_write(flowlet_lasttime, ingress_metadata.flowlet_map_index,
             intrinsic_metadata.ingress_global_timestamp);
}

table flowlet {
   actions {
      lookup_flowlet_map;
   }
}
```

~ 100 lines of P4 code

```
field_list flowlet_l3_hash_fields {
   ingress_metadata.lkp_ipv4_sa;
   ingress_metadata.lkp_ipv4_da;
   ingress_metadata.lkp_ip_proto;
   ingress_metadata.lkp_l4_sport;
   ingress_metadata.lkp_l4_dport;
   ingress_metadata.flowlet_id;
}

field_list_calculation flowlet_ecmp_hash {
   input {
      flowlet_l3_hash_fields;
   }
   algorithm : crc16;
   output_width : ECMP_SELECT_WIDTH;
}

action set_ecmp_select(ecmp_base, ecmp_count) {
   modify_field_with_hash_based_offset(ingress_metadata.ecmp_offset, ecmp_base,
                              ecmp_hash, ecmp_count);
}

action set_flowlet_ecmp_select(ecmp_base, ecmp_count) {
   modify_field_with_hash_based_offset(ingress_metadata.ecmp_offset, ecmp_base,
                              flowlet_ecmp_hash, ecmp_count);
}

table ecmp_group {
   reads {
      ingress_metadata.ecmp_index : exact;
   }
   actions {
      set_ecmp_select;
      set_flowlet_ecmp_select;
   }
   size : ECMP_GROUP_TABLE_SIZE;
}
```

This will accelerate innovations

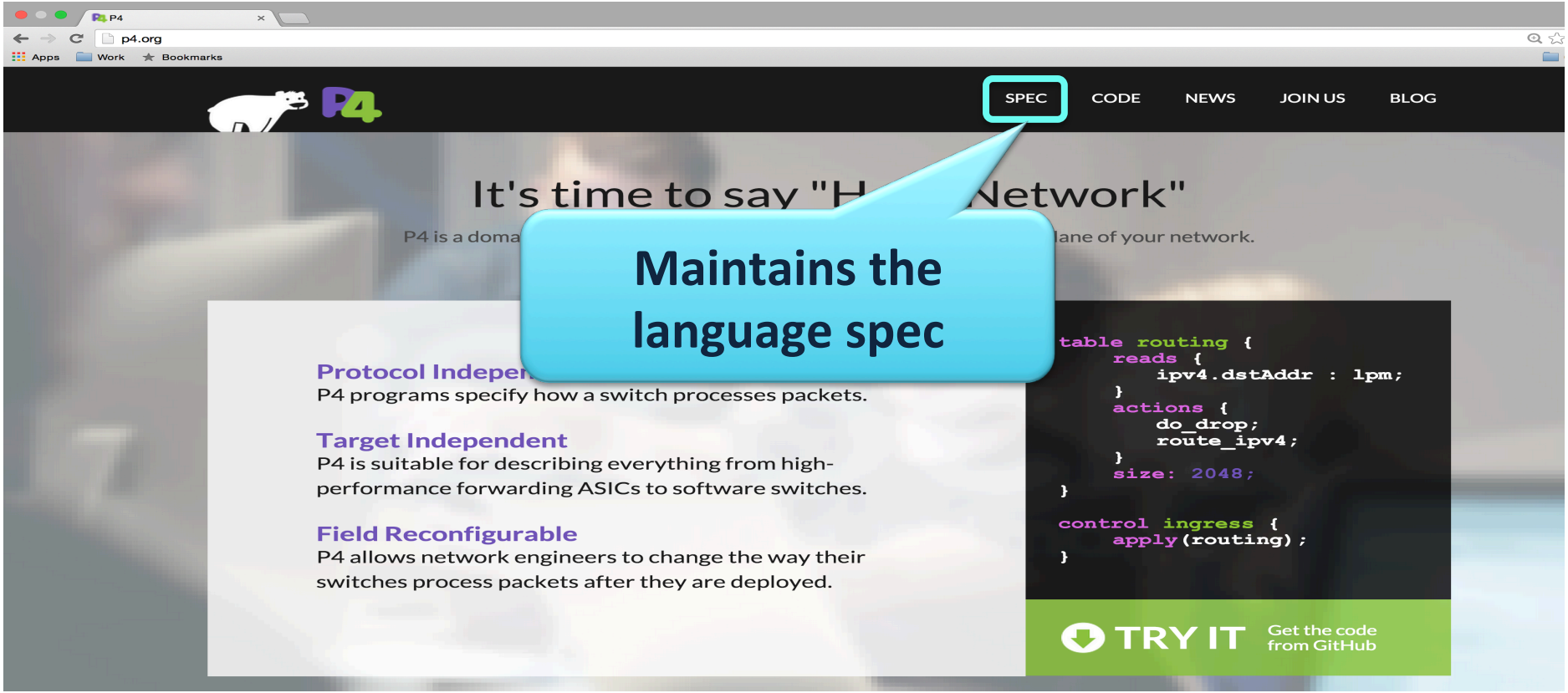
- Areas of innovation (just to name a few)
  - Reducing feature set → "*biggest bang for buck*"
  - Network monitoring, analysis, and diagnostics
  - Tunnel-splicing gateways
  - Load balancing
  - Attack detection and mitigation
  - Host-stack offloading

- Across various types of network devices
  - Hardware and software devices (OVS, eBPF, etc.)
  - Switches, NICs, middle-boxes, etc.

This will create lots of significant R&D opportunities

- Novel network and protocol designs
  - Take advantage of unprecedented amount of visibility and control into the network
  - Joint design and optimization between hosts and network
- Development tools
  - Compilers, debuggers, static analyzers, profilers, etc.
  - P4-programming assistance tools
- Network verification, test, and simulation
- Many more …

P4.org – P4 Language Consortium



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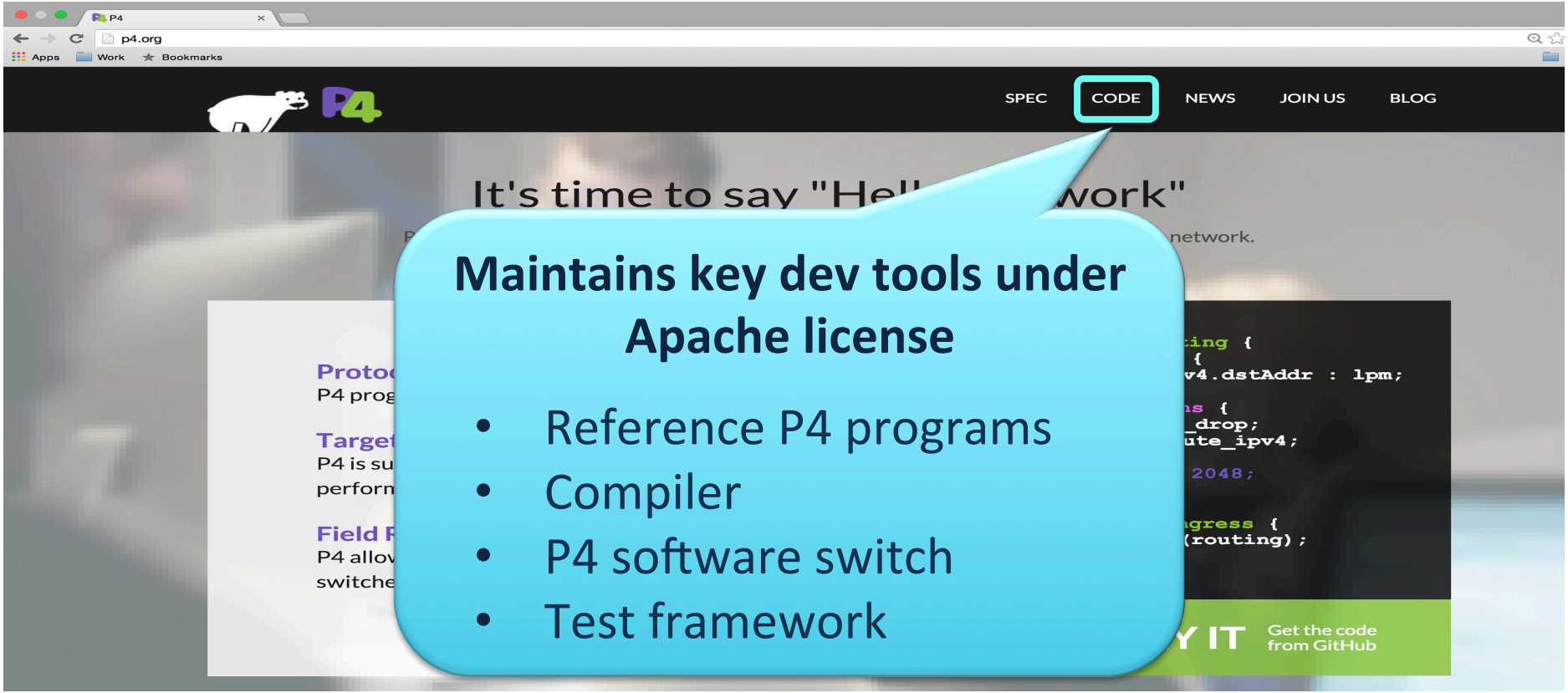

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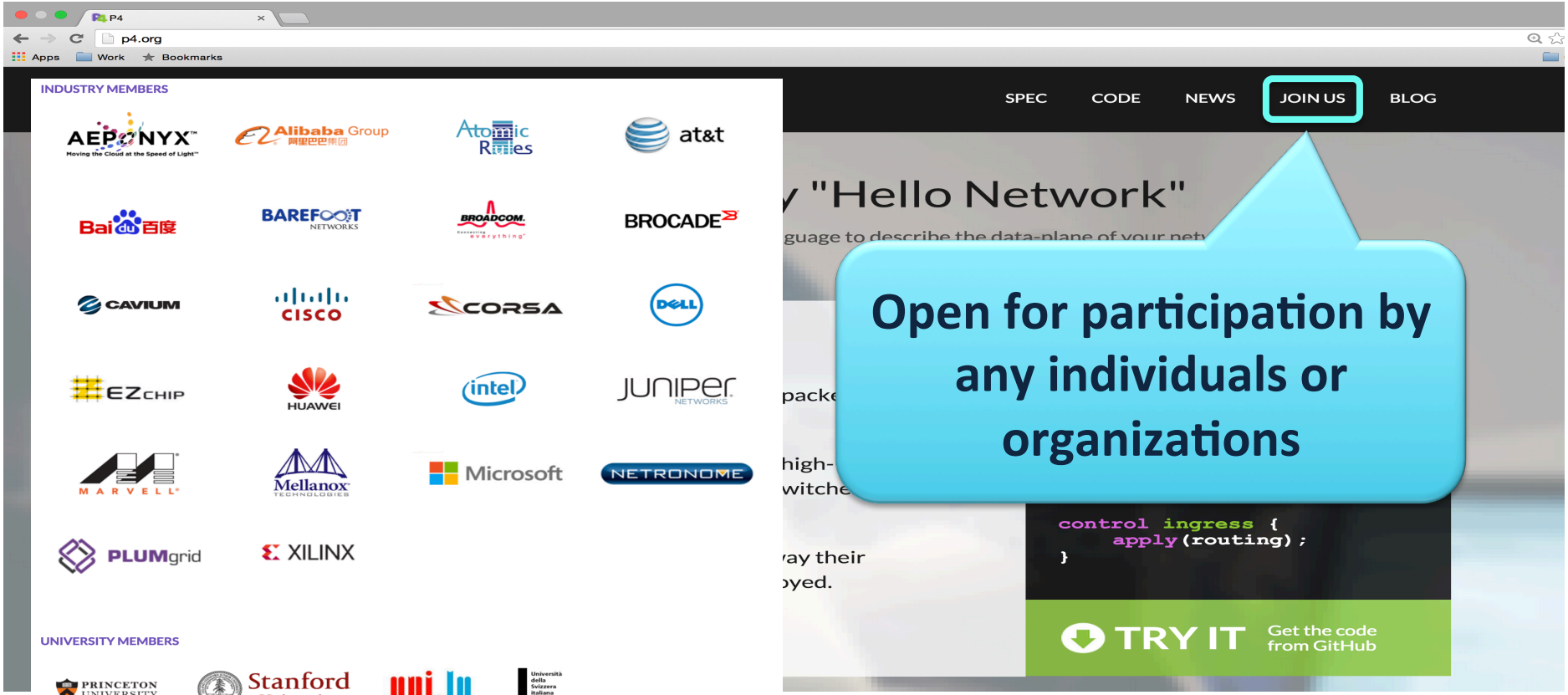

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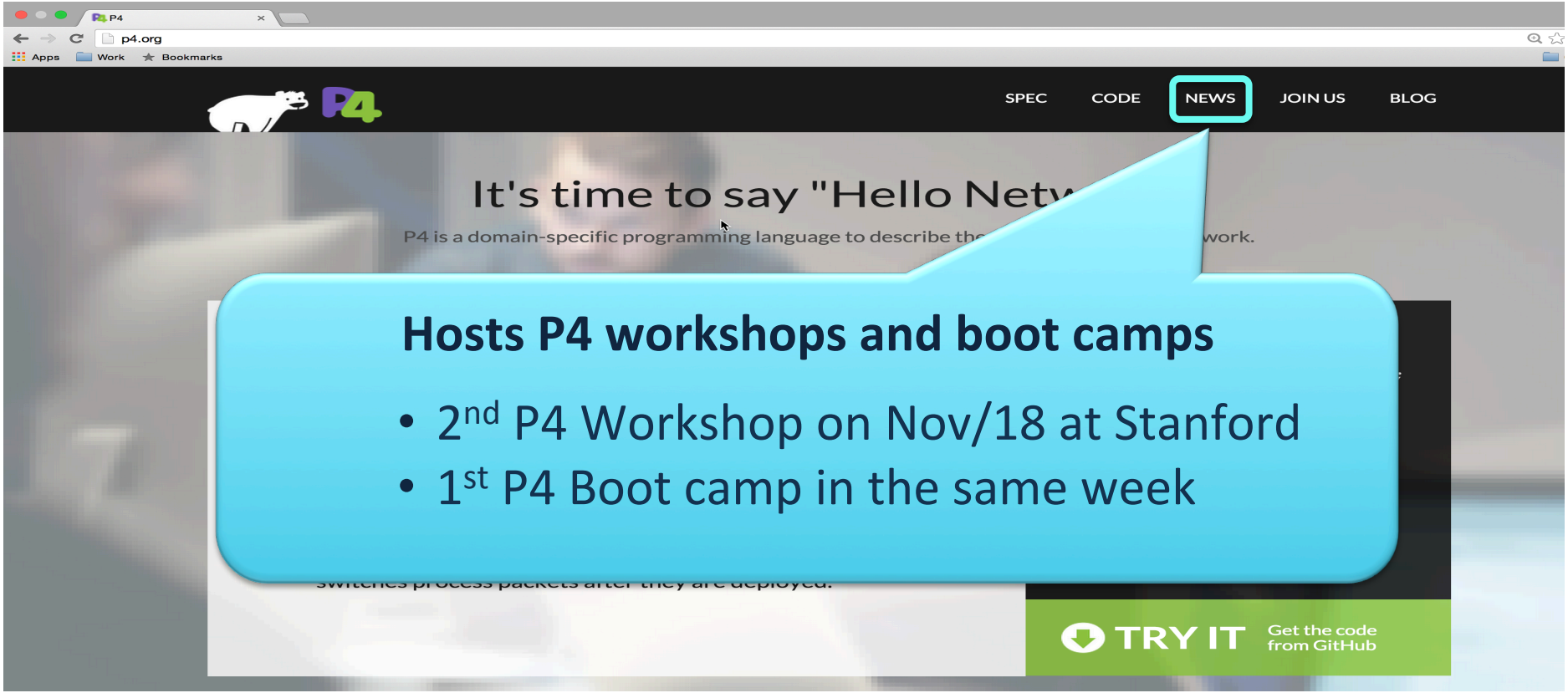

Hosts P4 workshops and boot camps

- 2nd P4 Workshop on Nov/18 at Stanford
- 1st P4 Boot camp in the same week

Switch.p4: A typical L2/L3 switch in P4

- Feature set
  - Basic L2 switching: MAC learning, VLAN, flooding, and STP
  - Basic L3 routing: IPv4 and IPv4 routing with VRF
  - LAG and ECMP
  - Tunneling: VXLAN, NVGRE, Geneve, and GRE
  - Basic ACL: MAC and IP ACLs
  - Unicast RPF
  - MPLS: LER, LSR, IPVPN, VPLS, and L2VPN
  - Host interface
  - Mirroring: Ingress and egress mirroring with ERSPAN
  - Counters/Statistics
- More features coming soon
  - IP Multicast, NAT, QoS, Ingress policing, etc.

Summary

- In next few years **data-plane programmability** will quickly become commonplace
- This will accelerate innovations in networking
- No more “black boxes” in “white boxes”
- As **the common industry-wide forwarding language, P4** will play crucial roles
- Lots of R&D and business opportunities opening up – join and contribute!