Writing Fine-grained Measurements App with P4 Programmable Switches

Overview of P4 and Programmable Data Plane Switches

Jorge Crichigno
University of South Carolina
http://ce.sc.edu/cyberinfra

University of South Carolina (USC)
Energy Sciences Network (ESnet)

September 18, 2023

Workshop Website

- All material is posted on the website of the tutorial

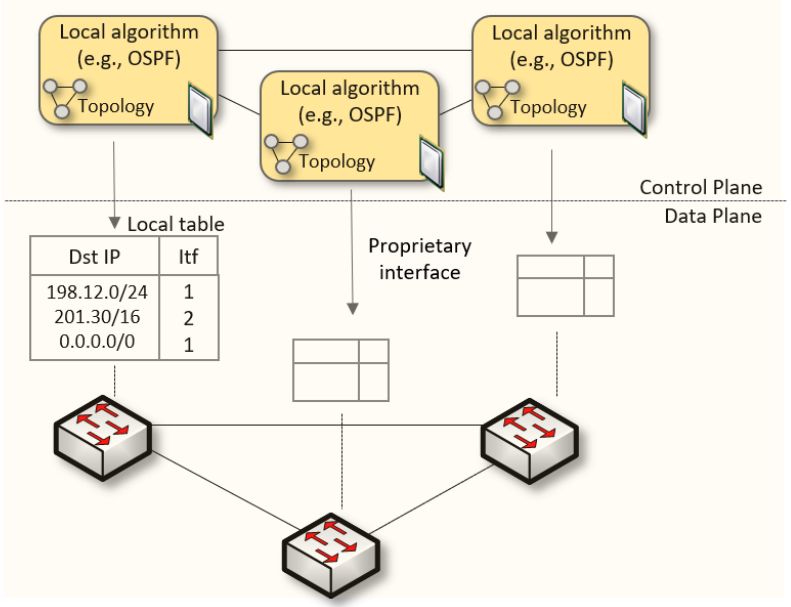
  https://research.cec.sc.edu/cyberinfra/workshop-techex1

Agenda

Time	Topic	Presenter
8:00 - 8:25	Overview of P4 and programmable data plane switches Introduction to packet parsing	Jorge Crichigno
08:25 - 09:00	Hands-on Session 1: Intro to P4 and BMv2, writing a parser, and compiling P4 code	Elie Kfoury
09:00 - 09:15	Break	
09:15 - 09:30	Buffers and queues	Jorge Crichigno
09:30 - 10:15	Hands-on session 2: monitoring queue occupancy on a per-packet basis	Elie Kfoury
10:15 - 10:30	Break	
10:30 - 11:00	Hands-on session 2 (continuation): monitoring queue occupancy on a per-packet basis	Elie Kfoury
11:00 - 11:30	Discussions, applications with P4 switches, Tofino pods	Jorge Crichigno, Elie Kfoury

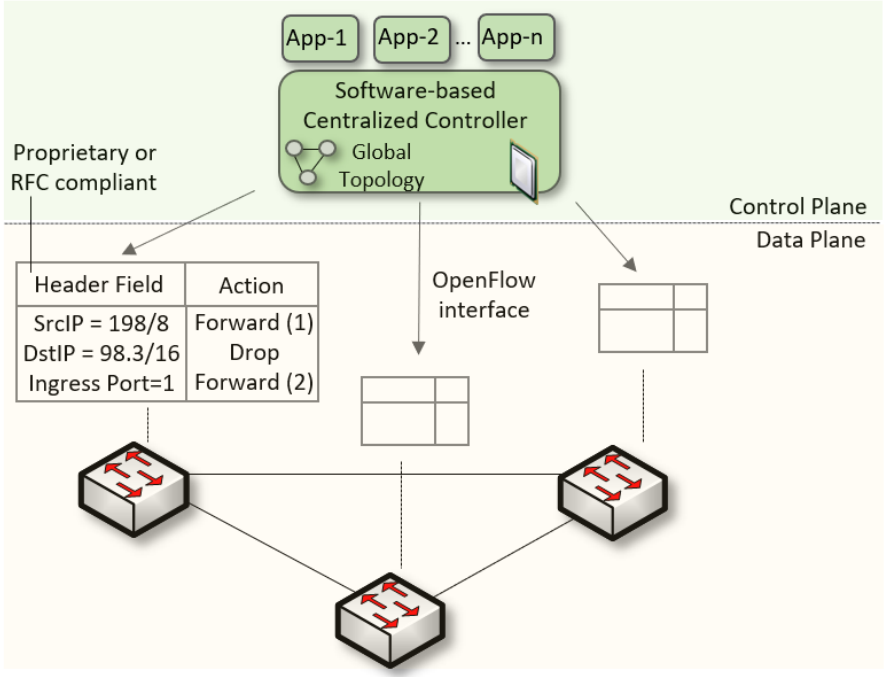
Traditional (Legacy) Networking

- Since the explosive growth of the Internet in the 1990s, the networking industry has been dominated by closed and proprietary hardware and software
- The interface between control and data planes has been historically proprietary
  - Vendor dependence: slow product cycles of vendor equipment, no innovation from network owners
  - A router is a monolithic unit built and internally accessed by the manufacturer only



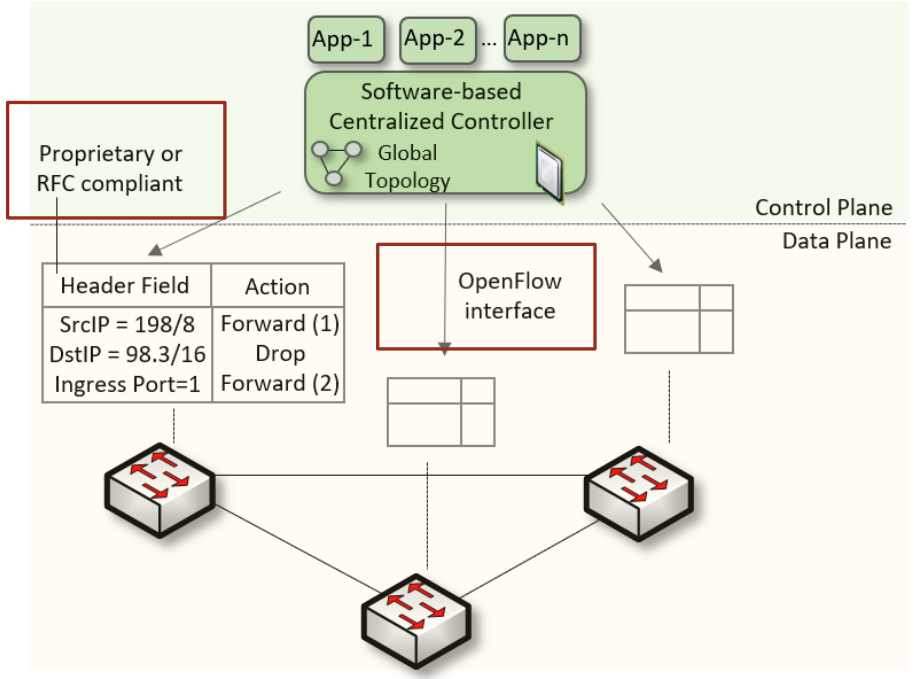
SDN

- Protocol ossification has been challenged first by SDN
- SDN (1) explicitly separates the control and data planes, and (2) enables the control plane intelligence to be implemented as a software outside the switches
- The function of populating the forwarding table is now performed by the controller



SDN Limitation

- SDN is limited to the OpenFlow specifications
  - Forwarding rules are based on a fixed number of protocols / header fields (e.g., IP, Ethernet)
- The data plane is designed with fixed functions (hard-coded)
  - Functions are implemented by the chip designer



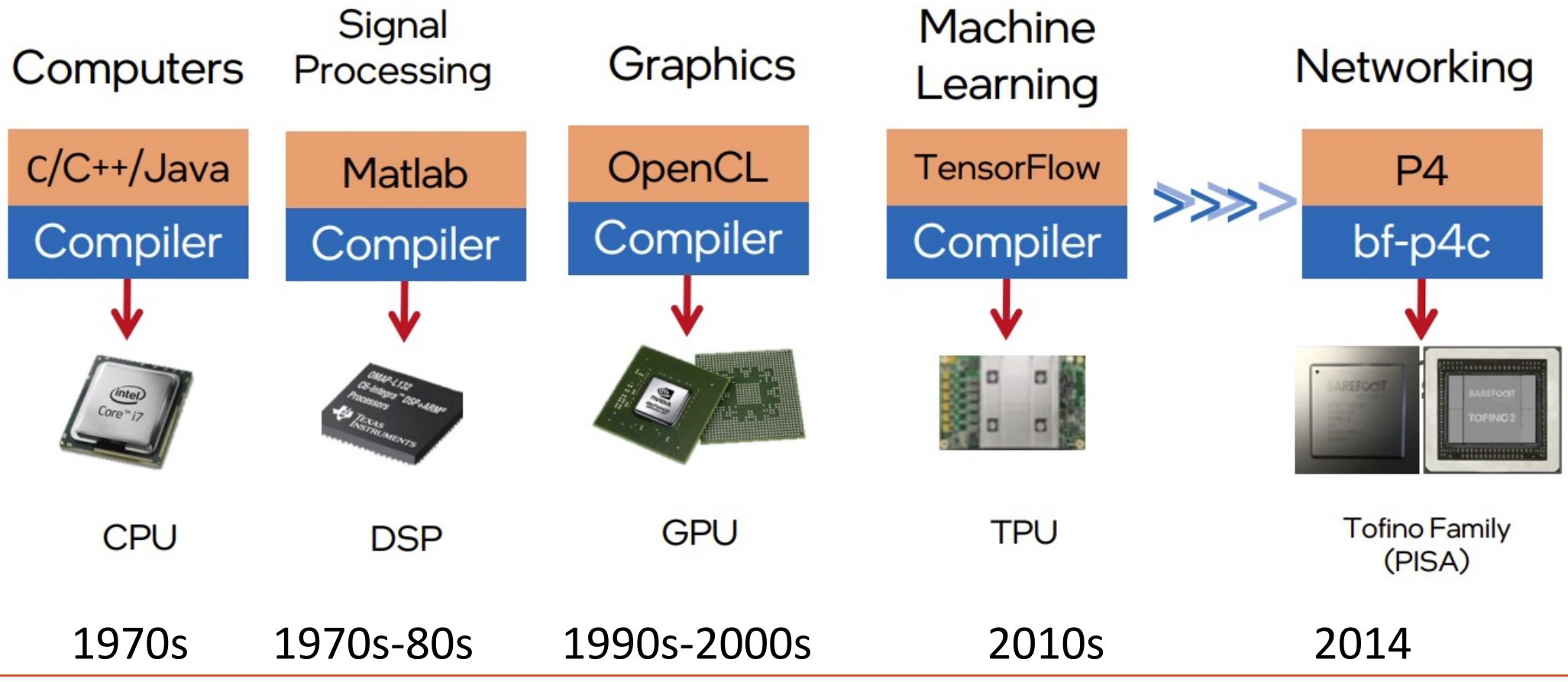
Can the Data Plane be Programmable?

- “Programmable switches are 10-100 times slower than non-programmable ones. They are more expensive and consume more power”[1]

1. Vladimir Gurevich, “Introduction to P4 and Data Plane Programmability,” https://tinyurl.com/2p978tm9.

Can the Data Plane be Programmable?

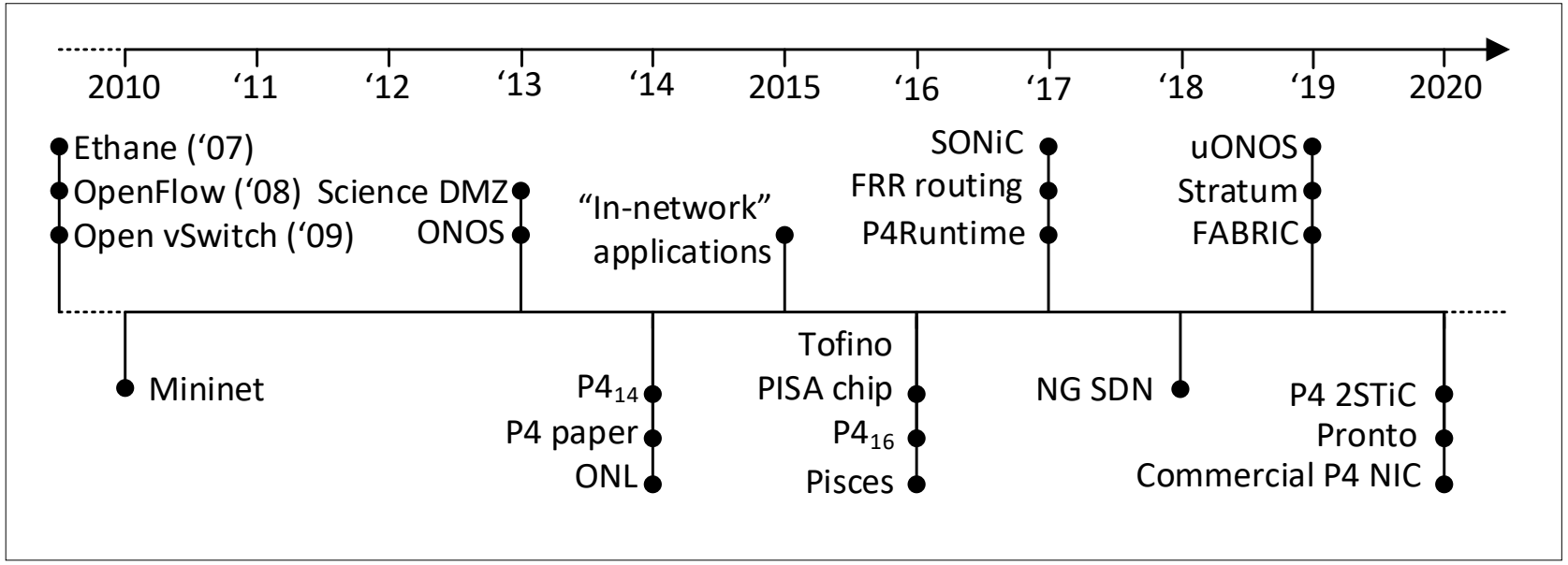
- Evolution of the computing industry



1. Vladimir Gurevich, “Introduction to P4 and Data Plane Programmability,” https://tinyurl.com/2p978tm9.

Can the Data Plane be Programmable?

- "Programmable switches are 10-100 times slower than non-programmable ones. They are more expensive and consume more power"
- The above assumption was challenged by a group of researchers at Stanford and Texas Instruments that led to "Barefoot Networks" in 2013



1. Vladimir Gurevich, "Introduction to P4 and Data Plane Programmability," https://tinyurl.com/2p978tm9.

Can the Data Plane be Programmable?

- Data plane comparison: fixed-function vs P4 programmable

64 x 100GE
Legacy,
Fixed Function ASIC

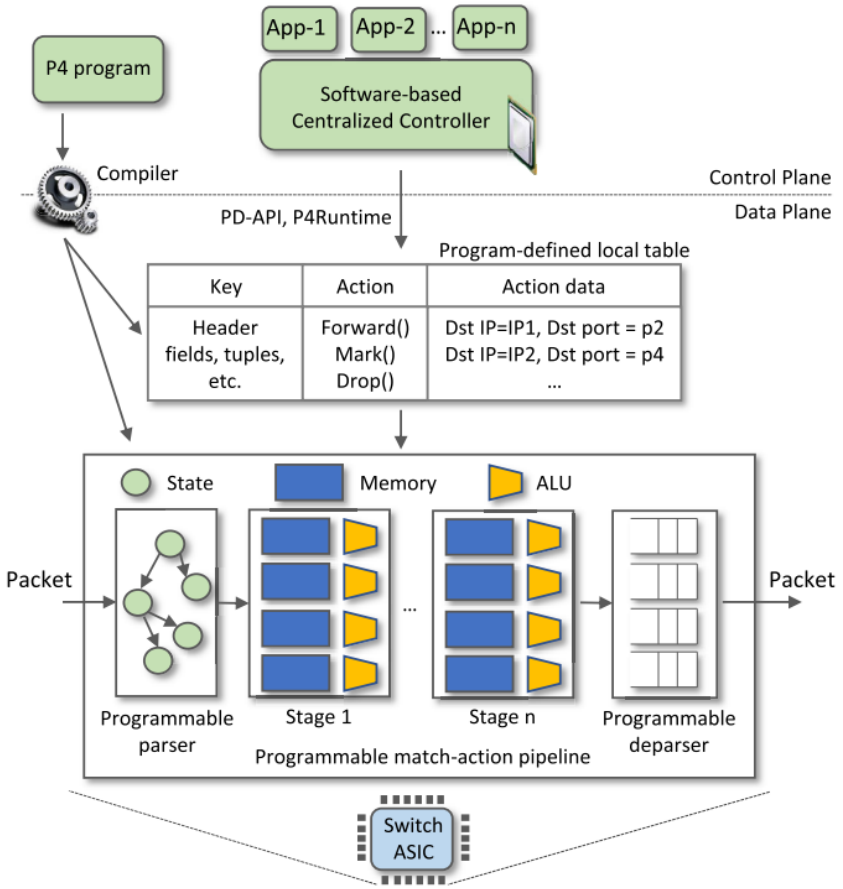
Parameter	Measurement Unit	Comparison
Throughput	Packets/s	21% higher
Power Consumption	Switching Troughput/W (pps/W)	53% lower
Table Scale	ACL, NAT, tunnels	20x
	Routes (IPv4/IPv6)	10x
	ECMP	2x
Non-standard Application Support	Smart Load balancing	∞
	Segment routing	∞
	In-band Telemetry	1000x

64x100GE
Barefoot Tofino

1. Vladimir Gurevich, “Introduction to P4 and Data Plane Programmability,” https://tinyurl.com/2p978tm9.

P4 Programmable Switches

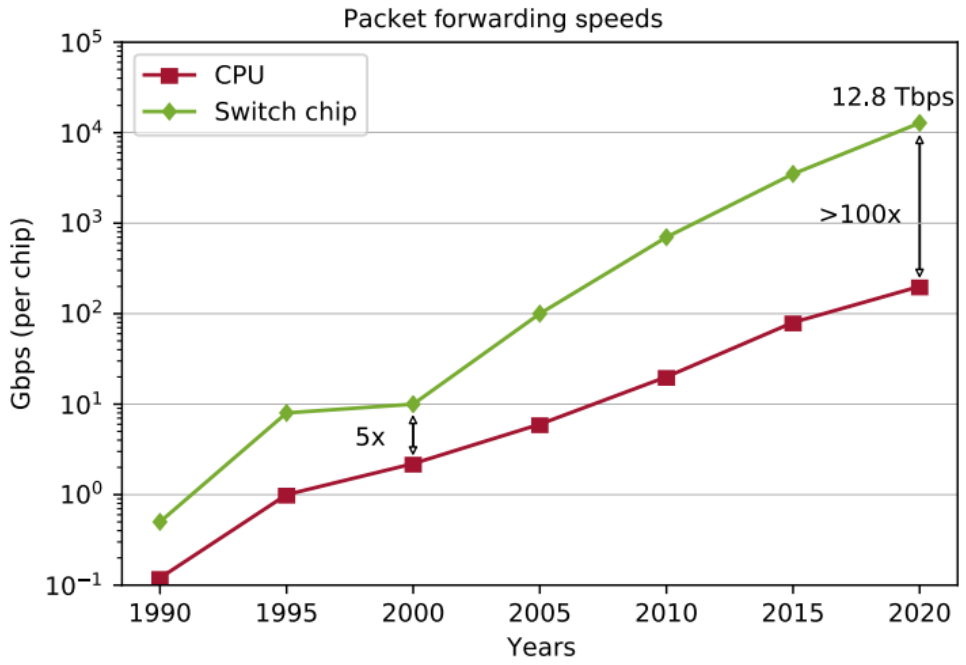
- P4[1] programmable switches permit a programmer to program the data plane
  - Define and parse new protocols
  - Customize packet processing functions
  - Measure events occurring in the data plane with high precision
  - Offload applications to the data plane



1. P4 stands for stands for Programming Protocol-independent Packet Processors

P4 Programmable Switches

- P4[1] programmable switches permit a programmer to program the data plane
  - Define and parse new protocols
  - Customize packet processing functions
  - Measure events occurring in the data plane with high precision
  - Offload applications to the data plane

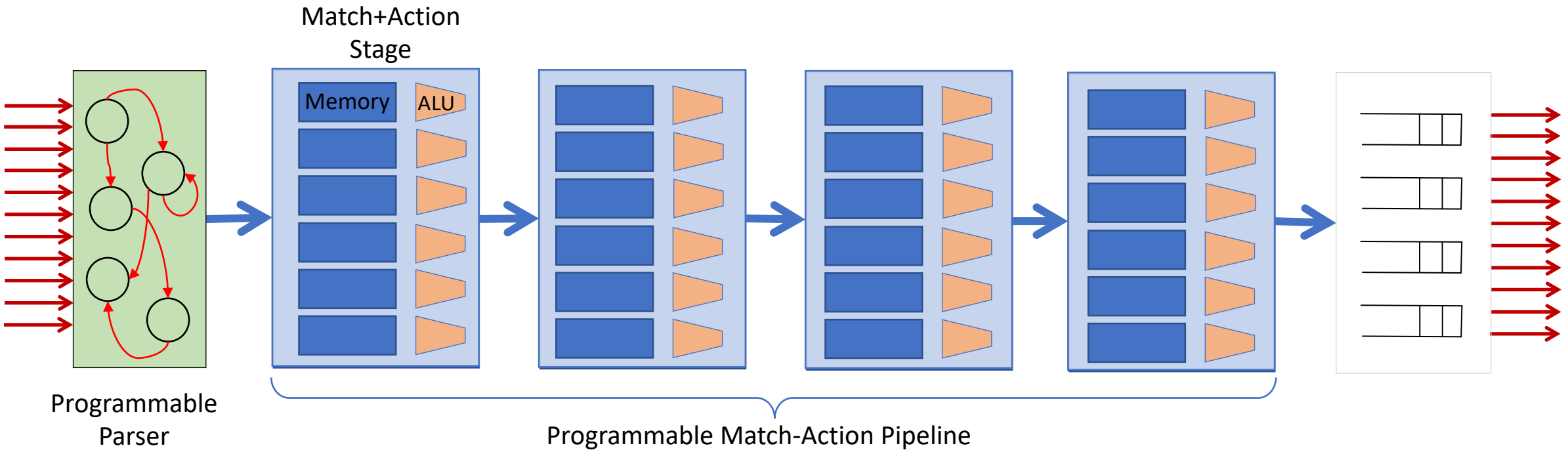


Reproduced from N. McKeown. Creating an End-to-End Programming Model for Packet Forwarding. Available: **https://www.youtube.com/watch?v=fiBuao6YZI0&t=4216s**

Generalized forwarding: Match + Action

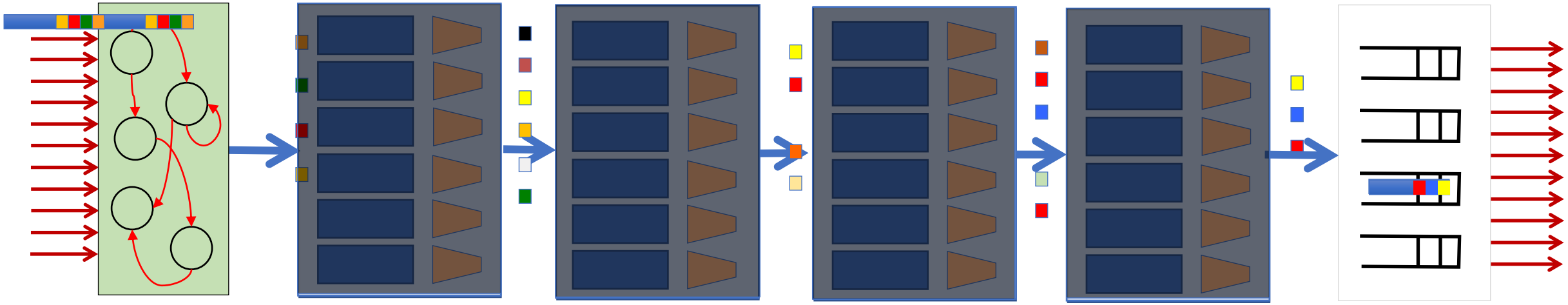
- Each switch contains table/s
  - Match bits in arriving packet (match phase)
  - Take action - Many header fields can determine action (action phase)
    - Drop
    - Copy
    - Modify
    - Log packet
    - Forward out a link (destination-based forwarding is just a particular case)

PISA: Protocol Independent Switch Architecture



Reproduced from N. McKeown. Creating an End-to-End Programming Model for Packet Forwarding. Available: **https://www.youtube.com/watch?v=fiBuao6YZI0&t=4216s**

PISA: Protocol Independent Switch Architecture



Reproduced from N. McKeown. Creating an End-to-End Programming Model for Packet Forwarding. Available: **https://www.youtube.com/watch?v=fiBuao6YZI0&t=4216s**

Example P4 Program

Parser Program

```
parser parse_ethernet {
    extract(ethernet);
    return switch(ethernet.ethertype) {
        0x8100 : parse_vlan_tag;
        0x0800 : parse_ipv4;
        0x8847 : parse_mpls;
        default: ingress;
}
```

Header and Data Declarations

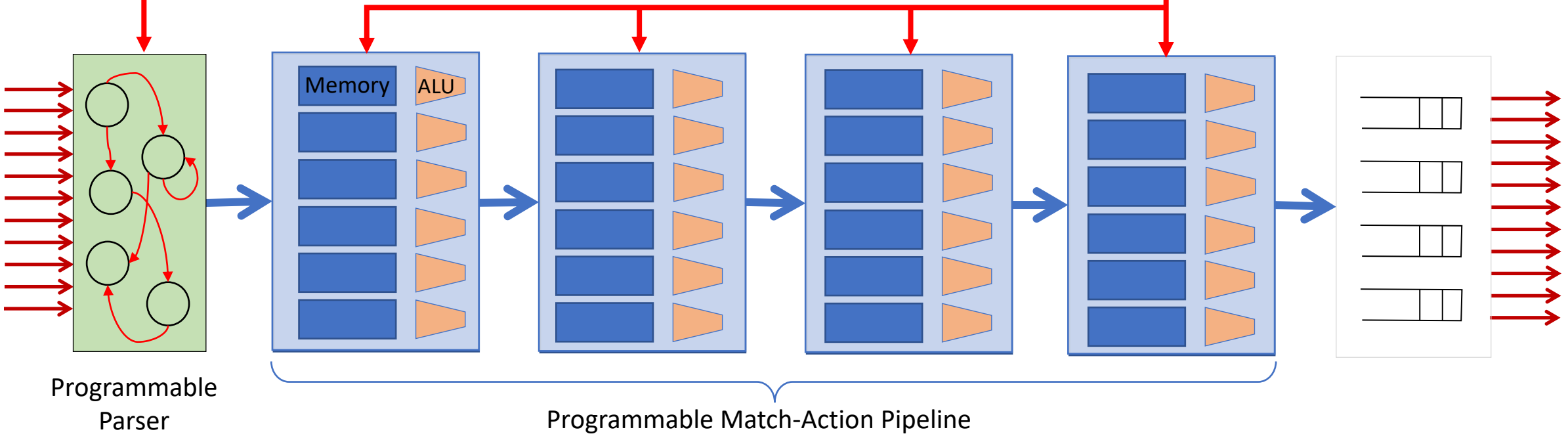
```
header_type  ethernet_t     { … }
header_type  l2_metadata_t  { … }

header     ethernet_t     ethernet;
header     vlan_tag_t
vlan_tag[2];
metadata   l2_metadata_t l2_meta;
```

Tables and Control Flow

```
table port_table { … }

control ingress {
    apply(port_table);
    if (l2_meta.vlan_tags == 0) {
        process_assign_vlan();
    }
}
```



Reproduced from N. McKeown. Creating an End-to-End Programming Model for Packet Forwarding. Available: **https://www.youtube.com/watch?v=fiBuao6YZI0&t=4216s**


1801
UNIVERSITY OF
SOUTH CAROLINA

U.S. Initiatives Related to P4 Programmable Switches

- FABRIC (https://whatisfabric.net/)
  - >$20M investment by the U.S. National Science Foundation (NSF)
  - Analogous to Arpanet (predecessor of the Internet)
  - Adaptable **programmable** research infrastructure, for network research

U.S. Initiatives Related to P4 Programmable Switches

- Pronto Project (https://prontoproject.org)
  - $30M investment by the U.S. Department of Defense (DoD)
  - Project Pronto is building and deploying a beta-production end-to-end 5G connected edge cloud leveraging a fully **programmable** network empowered by unprecedented visibility, verification and closed-loop control