Security Apps with P4 Programmable Switches

Motivation for Data Plane Programmability and In-network Defenses

Elie Kfoury, 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

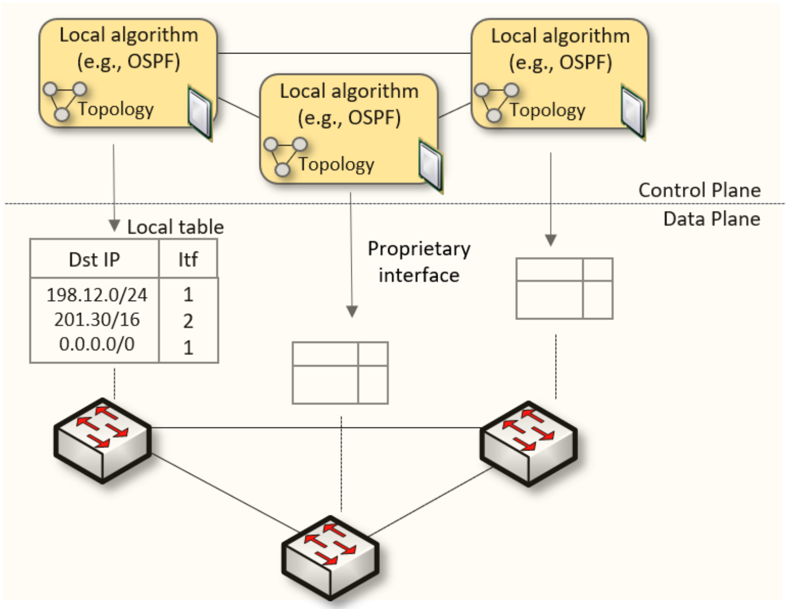
  https://research.cec.sc.edu/cyberinfra/workshop-techex3

Agenda

Time	Topic	Presenter
1:00 - 1:30	Motivation for data plane programmability and in-network defenses Introduction to packet parsing	Elie Kfoury
1:30 – 2:00	Hands-on Session 1: Intro to P4 and BMv2, writing a parser, and compiling P4 code	Elie Kfoury
02:00 - 02:15	Break	
02:15 - 02:45	Stateful packet filters in the data plane	Ali AlSabeh
02:45 - 3:45	Hands-on session 2: implementing a stateful packet filter for the TCP protocol	Ali AlSabeh
3:45 – 4:00	Break	
4:00 – 4:30	Discussions, applications with P4 switches, Tofino pods	Jose Gomez, Ali AlSabeh

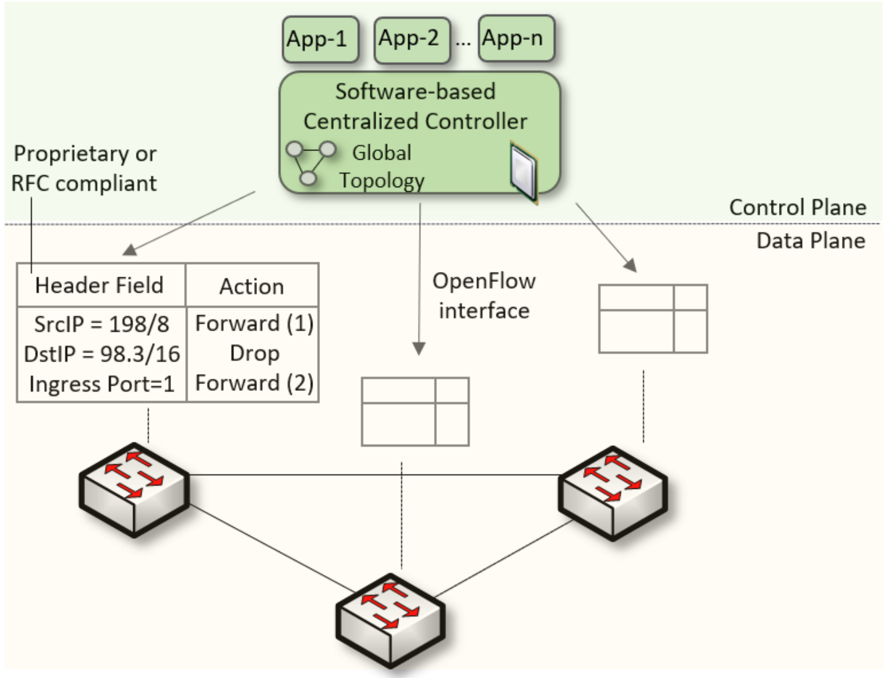
Traditional (Legacy) Networking

- 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



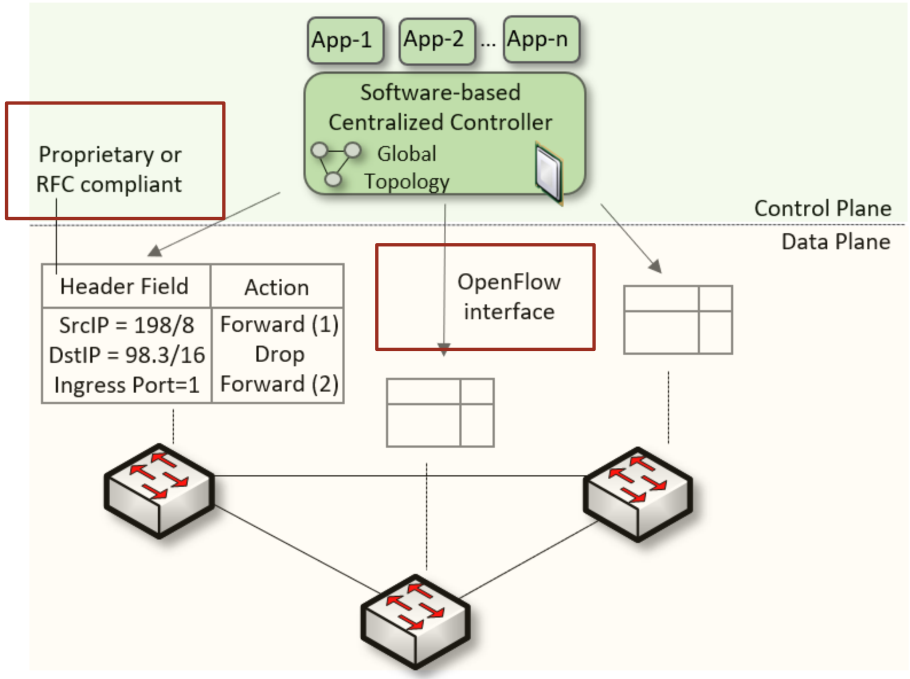
SDN

- 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



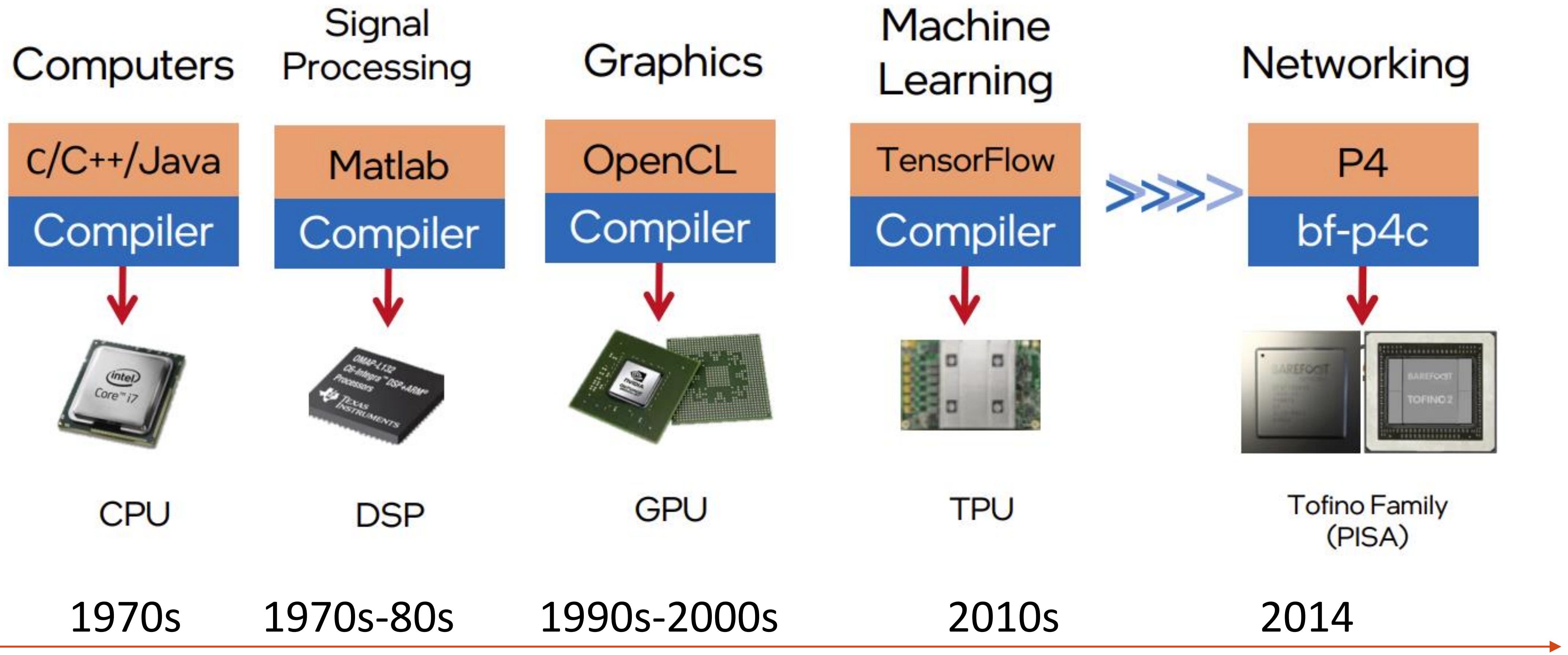
Can the Data Plane be Programmable?

- “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?

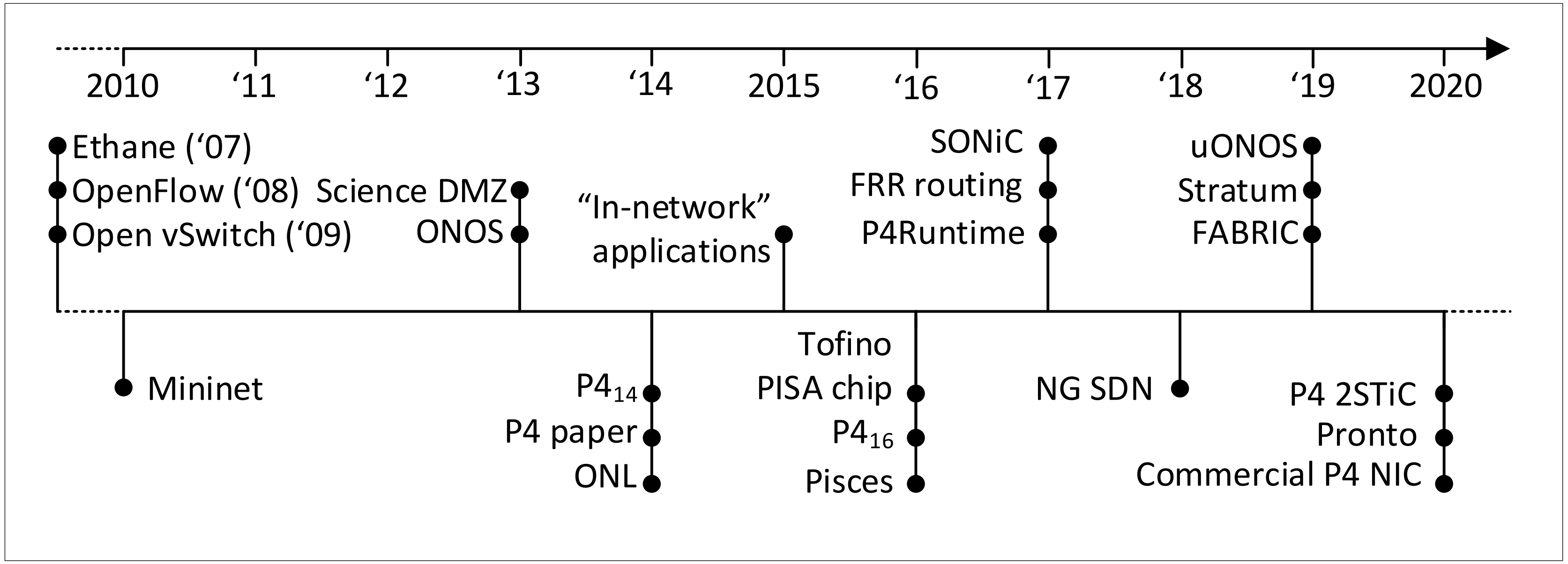
- Evolution of the computing industry



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

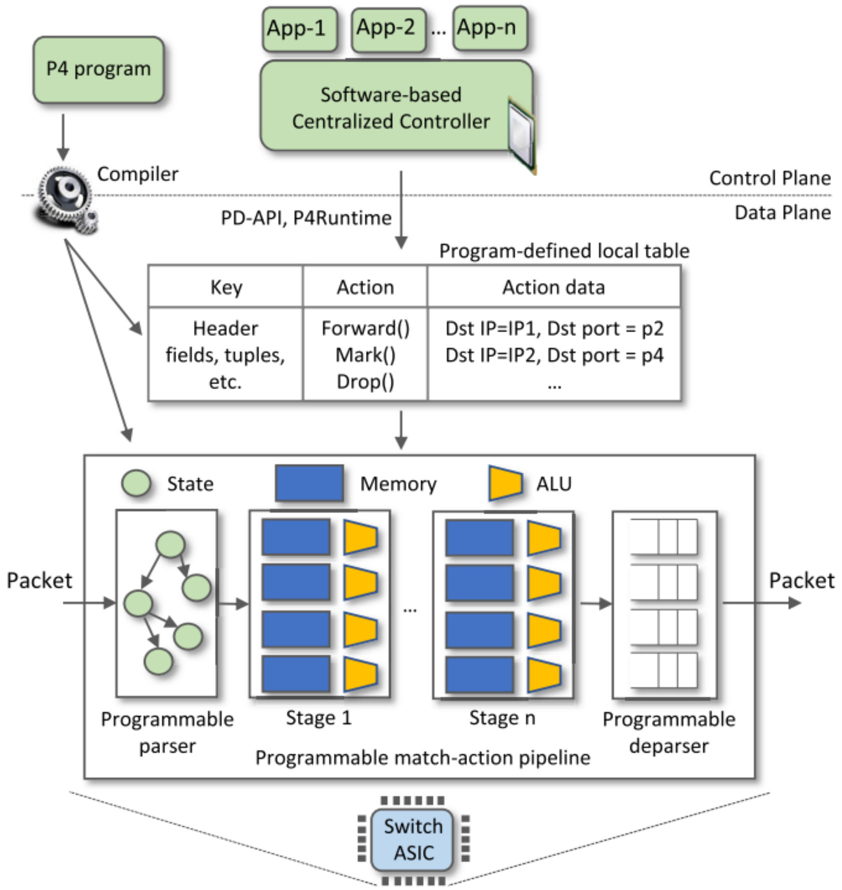
Parameter	Measurement Unit	Comparison
Throughput	Packets/s	21% higher
Power Consumption	Switching Troughput/W (pps/W)	53% lower
Table Scale	ACL, NAT, tunnels	20x
	Routes (IPv4/IPv6)	10x
	ECMP	2x
Non-standard Application Support	Smart Load balancing	∞
	Segment routing	∞
	In-band Telemetry	1000x

64x100GE
Barefoot Tofino

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

P4 Programmable Switches

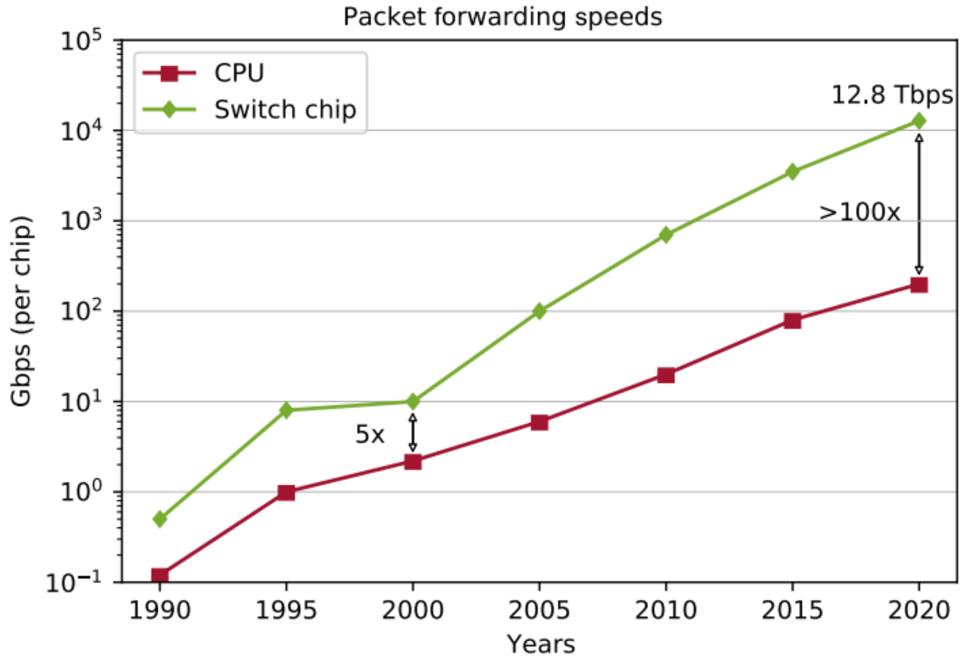
- P4[1] programmable switches permit a programmer to program the data plane
  - Define and parse new protocols
  - Customize packet processing functions
  - Measure events occurring in the data plane with high precision
  - Offload applications to the data plane



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

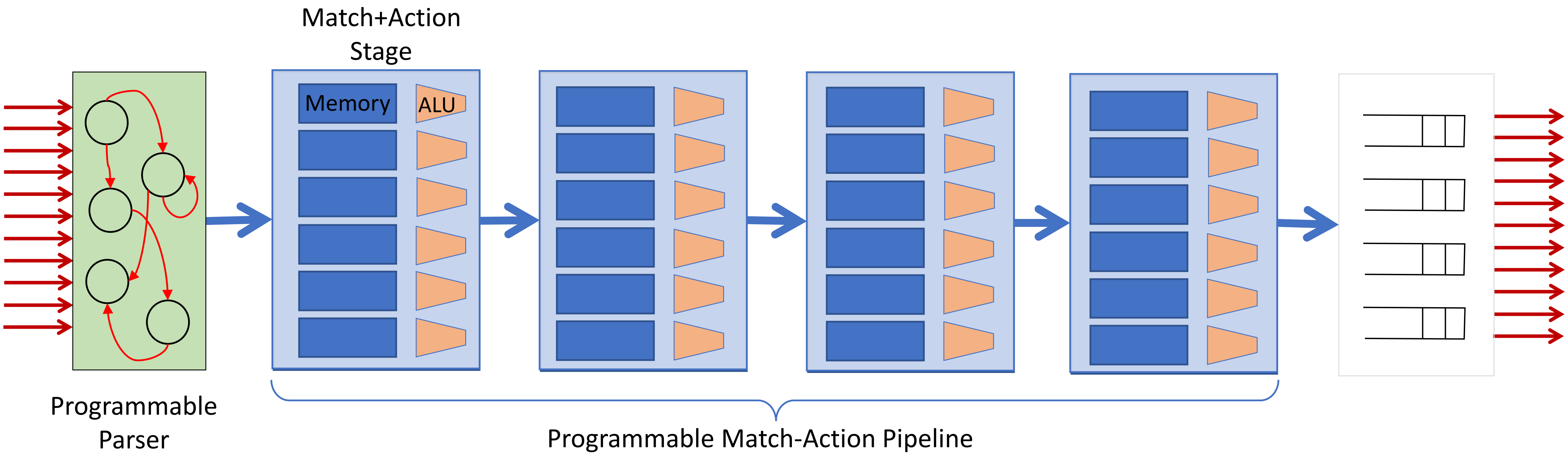


Reproduced from N. McKeown. Creating an End-to-End Programming Model for Packet Forwarding. Available: **https://www.youtube.com/watch?v=fiBuao6YZl0&t=4216s**

Generalized forwarding: Match + Action

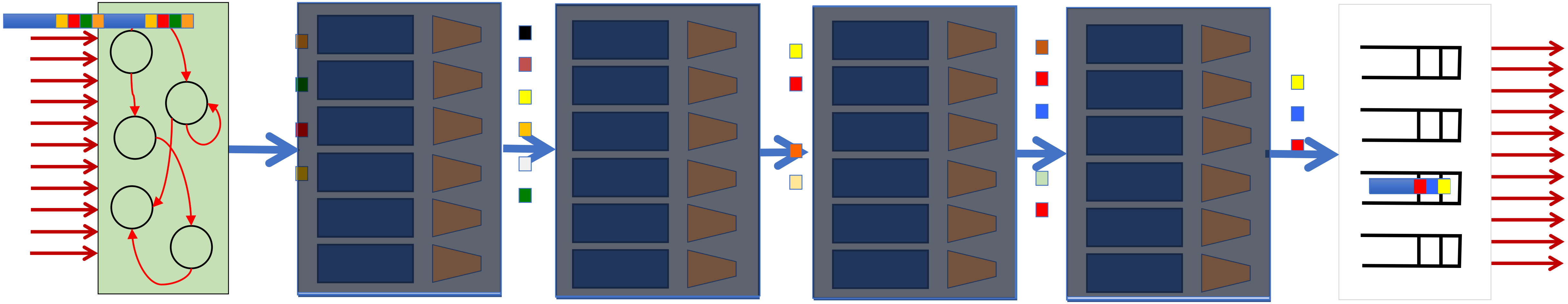
- Each switch contains table/s
  - Match bits in arriving packet (match phase)
  - Take action - Many header fields can determine action (action phase)
    - Drop
    - Copy
    - Modify
    - Log packet
    - Forward out a link (destination-based forwarding is just a particular case)

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=fiBuao6YZl0&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=fiBuao6YZl0&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

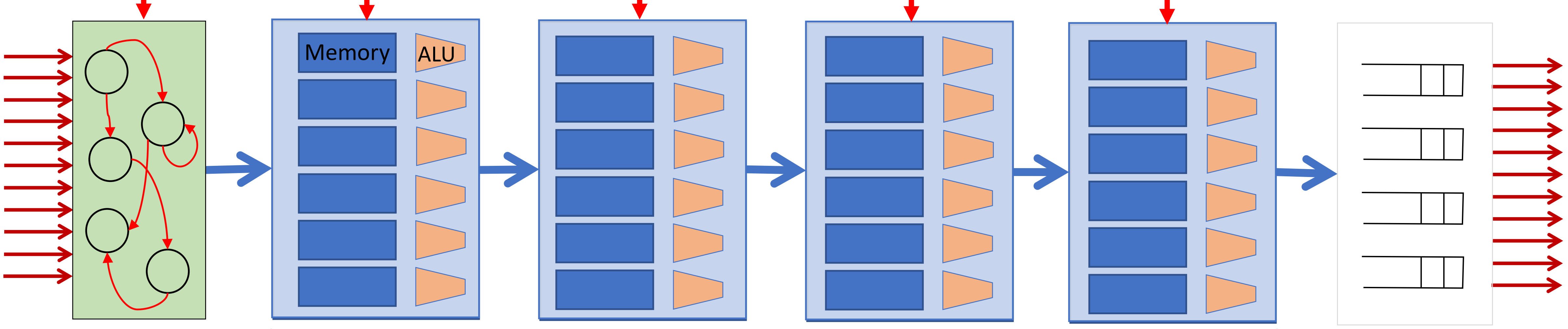
```
header_type  ethernet_t    { … }
header_type  l2_metadata_t { … }

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();
    }
}
```



Programmable Parser

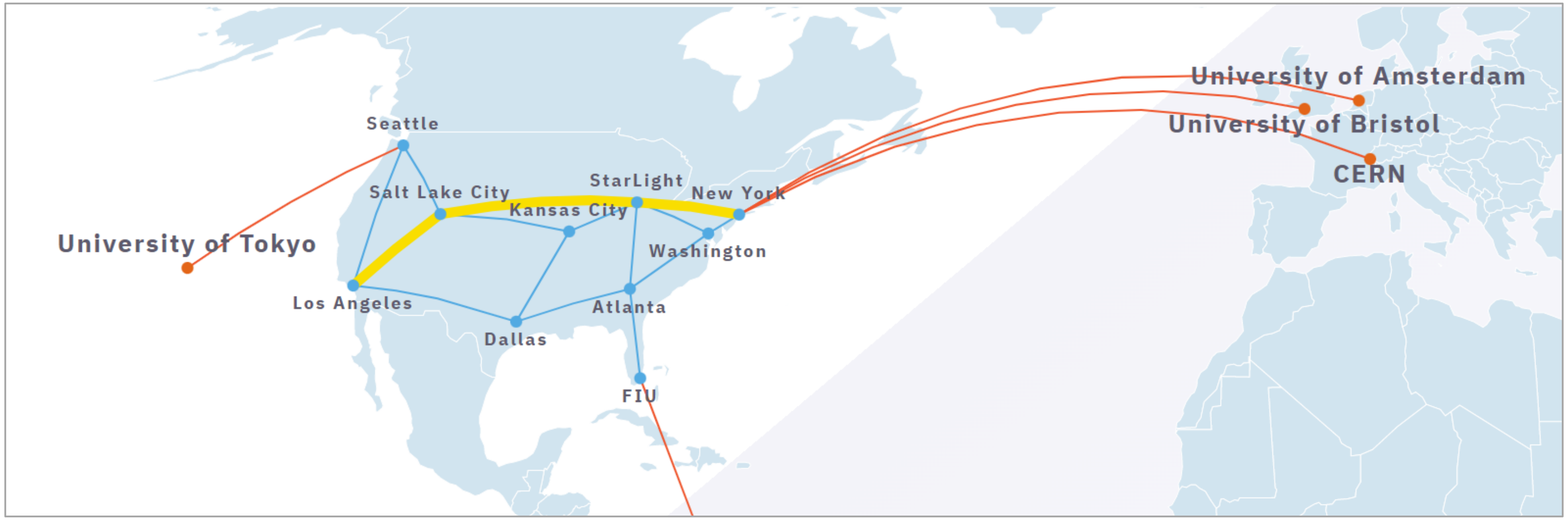
Programmable Match-Action Pipeline

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

UNIVERSITY OF
SOUTH CAROLINA

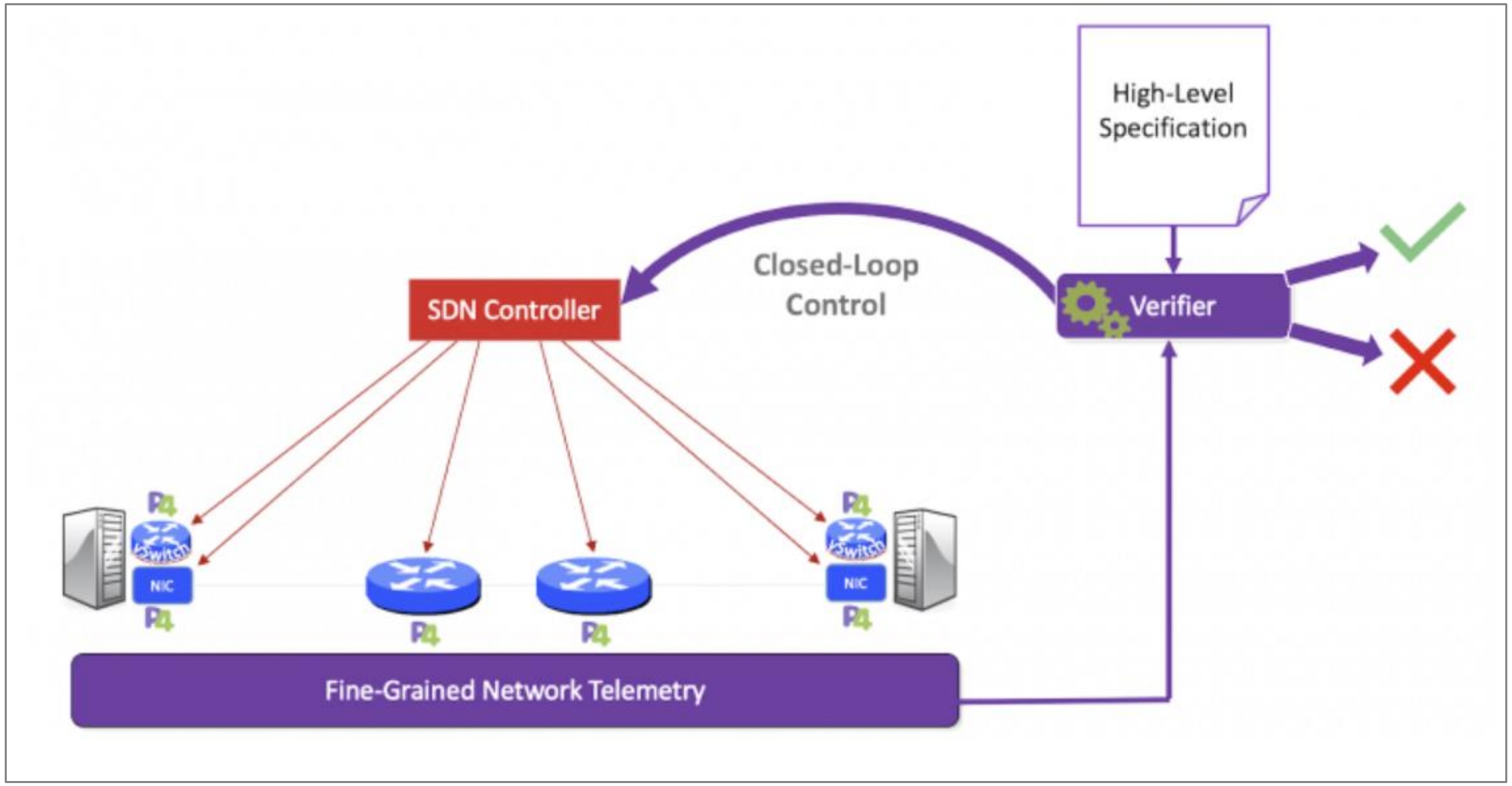
U.S. Initiatives Related to P4 Programmable Switches

- 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



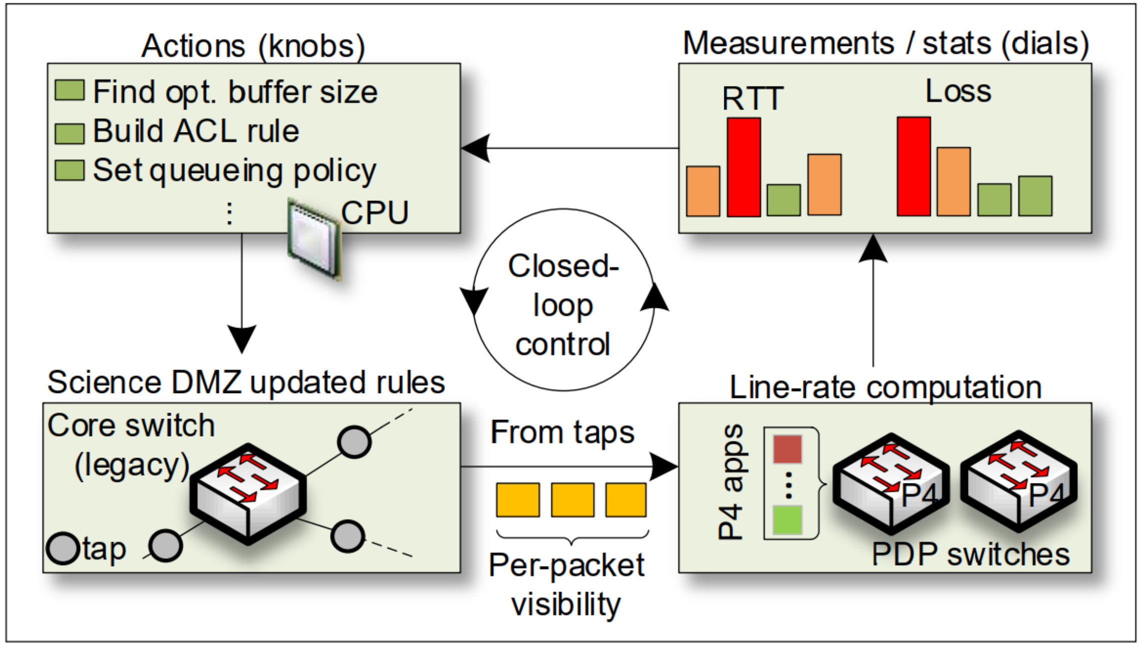
U.S. Initiatives Related to P4 Programmable Switches

- 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



Projects – Cyberinfrastructure Lab at USC

- Track flows in the data plane, fine-grained network measurements
- Project funded by a business ($150,000)



Closed-loop control system