Network Security
Research at the University of South Carolina

Jorge Crichigno
College of Engineering and Computing
University of South Carolina
http://ce.sc.edu/cyberinfra/

VICEROY Workshop
Friday February 10, 2023
Online

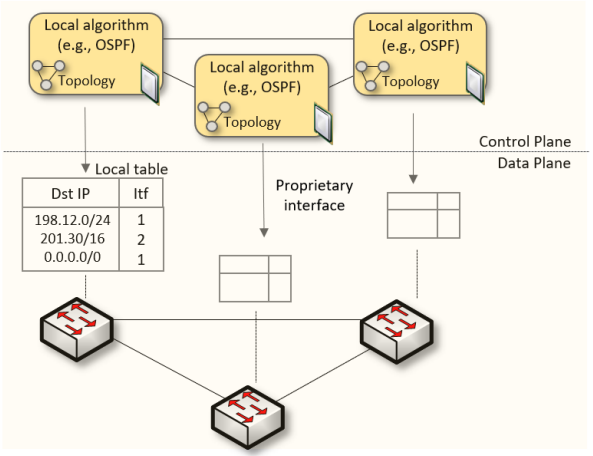
South Carolina

Agenda

- Motivation – Limitations of traditional devices
- Data plane programmability – Evolution
- Essentials of P4 programmable switches
- Applications
- New national infrastructures

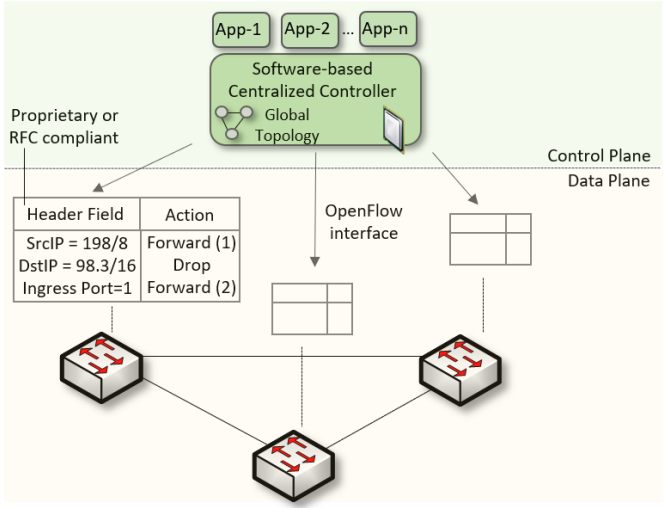
Traditional (Legacy) Networking

- 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



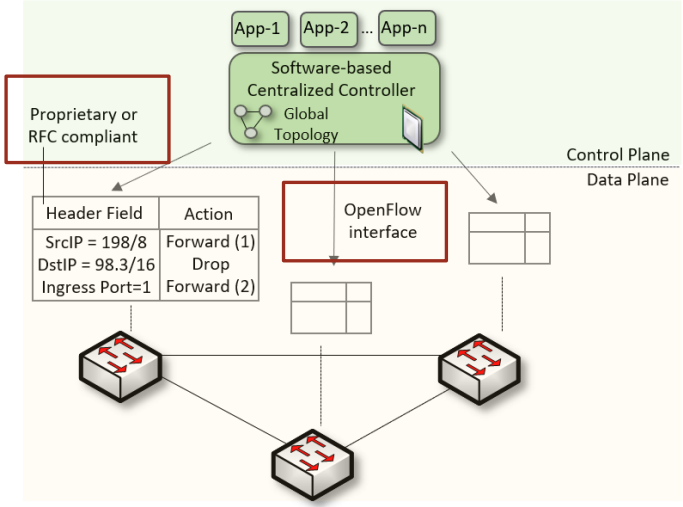
SDN

- 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



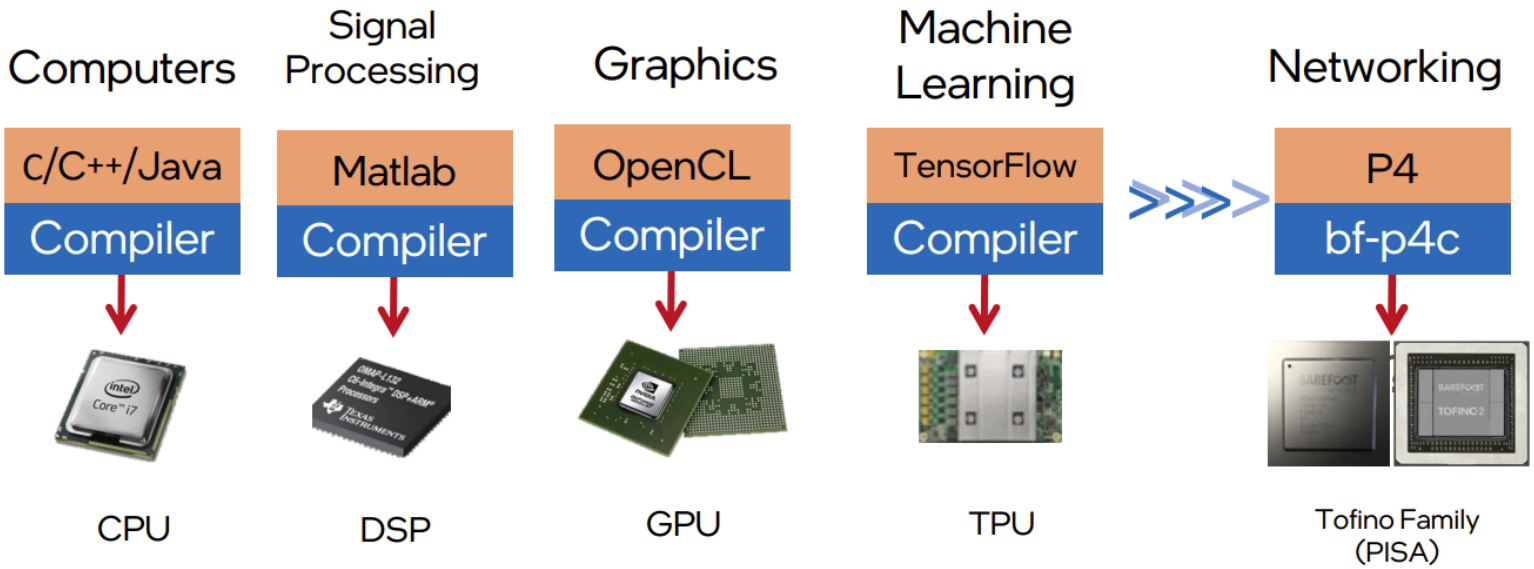
Can the Data Plane be Programmable?

- “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



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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

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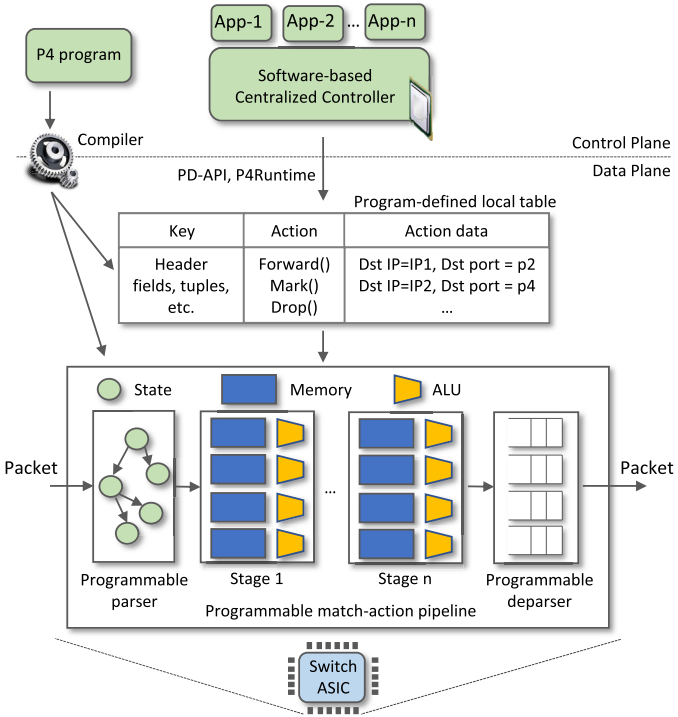
P4 Programmable Switches

- 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

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Programmable chip

```
/*************************************************************************
********************** P A R S E R  ******************************
*************************************************************************/

    state parse_ethernet {
        packet.extract(hdr.ethernet);
        transition select(hdr.ethernet.etherType) {
            TYPE_IPV4: parse_ipv4;
            default: accept;
        }
    }

    state parse_ipv4 {
        packet.extract(hdr.ipv4);
        verify(hdr.ipv4.ihl >= 5, error.IPHeaderTooShort);
        transition select(hdr.ipv4.ihl) {
            5             : accept;
            default       : parse_ipv4_option;
        }
    }
```

P4 code

P4 Programmable Switches

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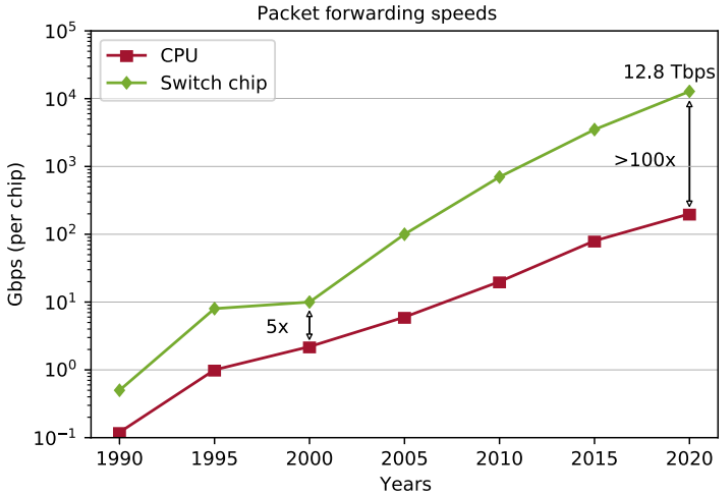
  - **If the P4 program compiles, it runs on the chip at line rate**

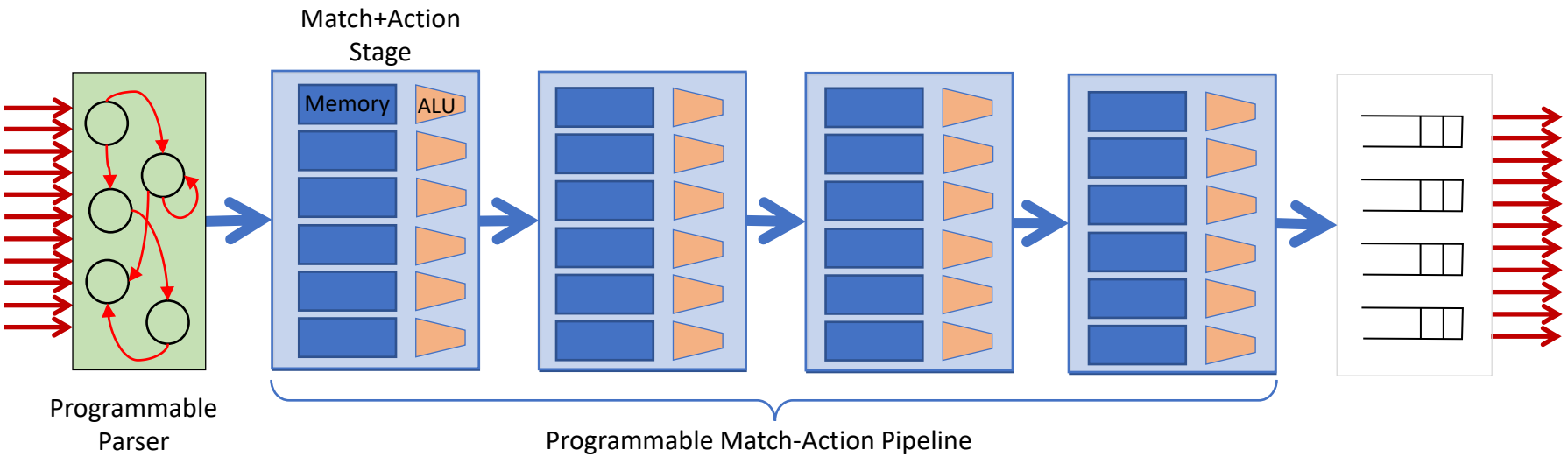


Reproduced from N. McKeown. Creating an End-to-End Programming Model for Packet Forwarding. Available: **https://www.youtube.com/watch?v=fiBuao6YZI0&t=4216s**

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



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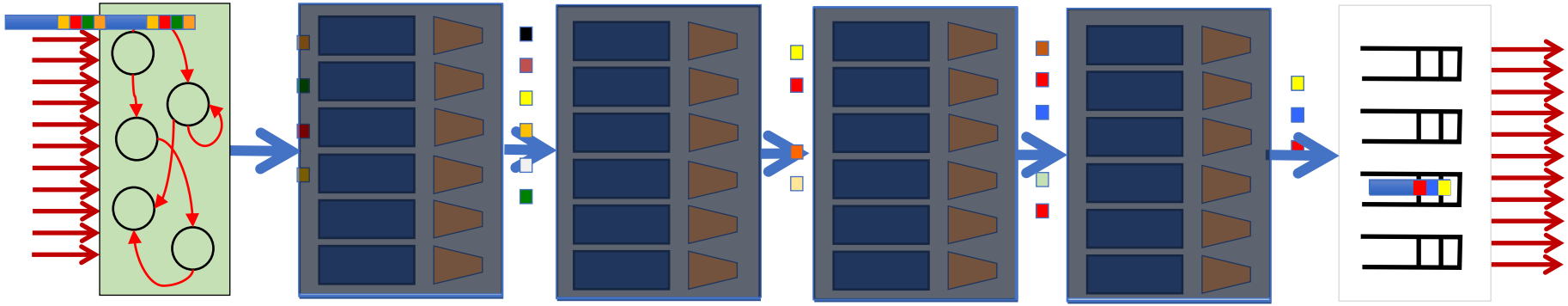

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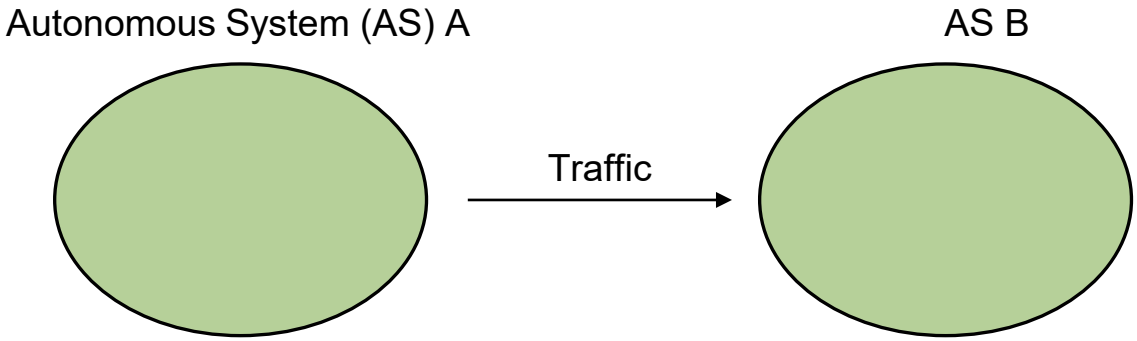
Examples of Applications

Real Time RTT Calculation

- Detecting hijacking attacks, reflected on larger round-trip times (RTTs)



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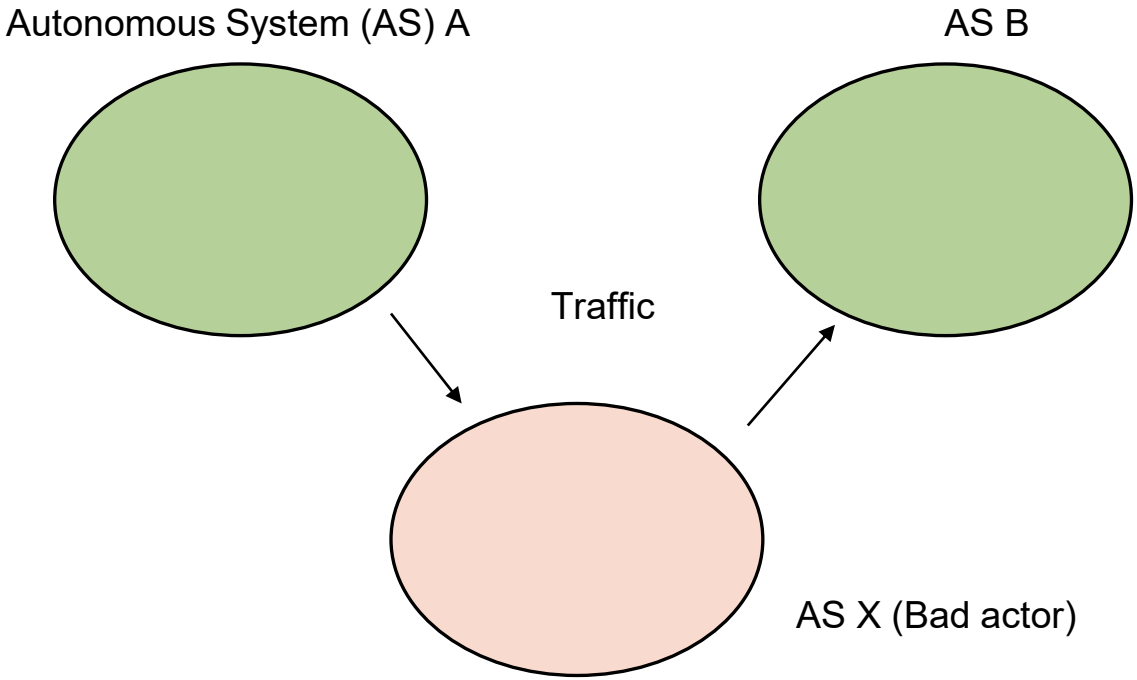


Real Time RTT Calculation

- Detecting hijacking attacks, reflected in larger round-trip times (RTTs)

Cybernews

Why would Russia redirect Apple's traffic

Nation states and financially motivated attackers can exploit the trusting nature of world wide web data router the Border Gateway Protocol (BGP) to gather...

Aug 10, 2022

Cybernews

Apple network traffic went through Russia for 12 hours

While neither Apple nor Russian authorities shed any light on the event, data indicates Apple traffic did go through Russia's leading telecom company.

Aug 9, 2022

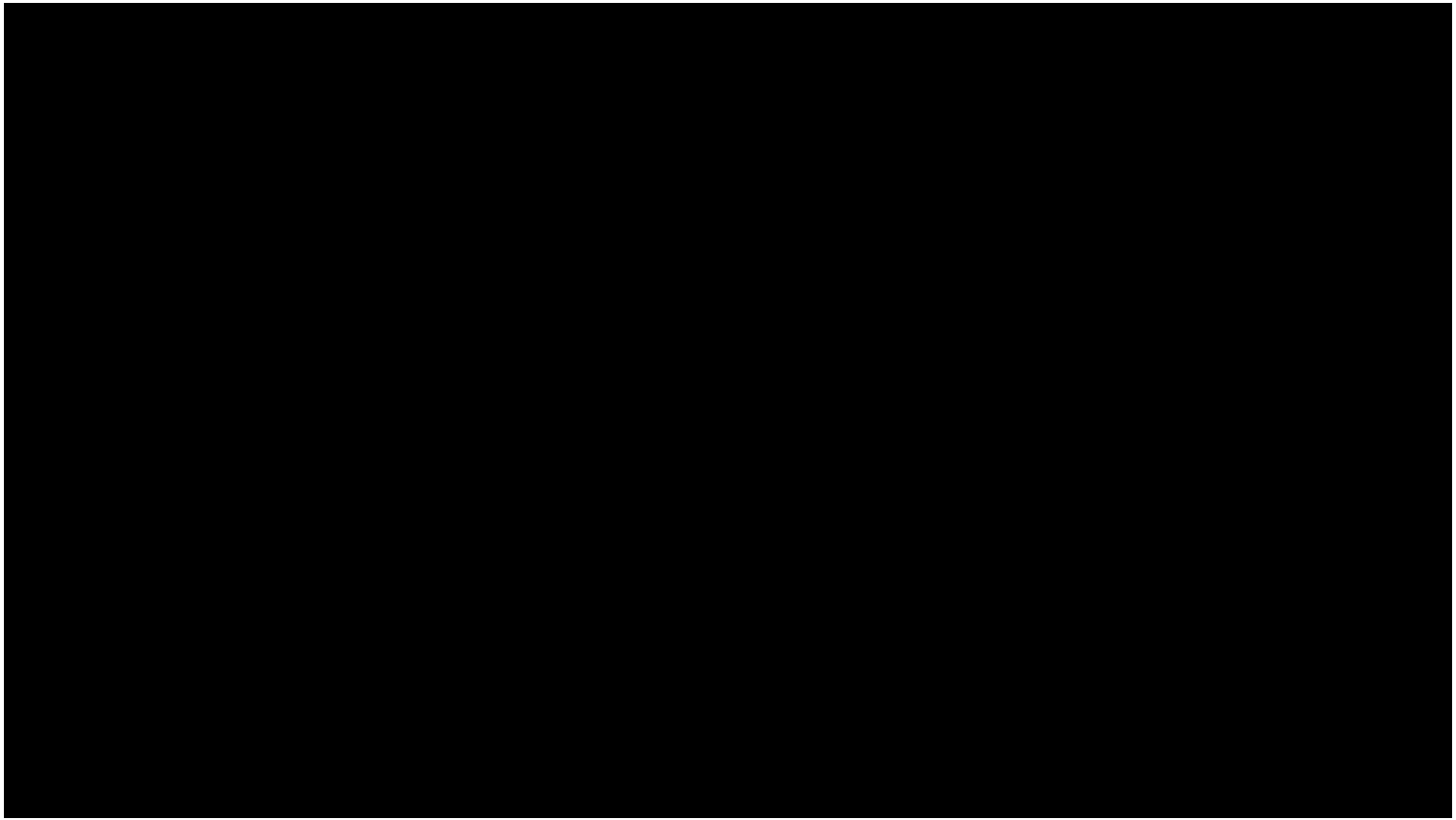
iTnews

Apple Engineering staves off attempted network route hijack

Apple has come away successful from a battle with Russian telco Rostelecom, after the latter sent out false route announcements to redirect traffic meant...

Jul 29, 2022

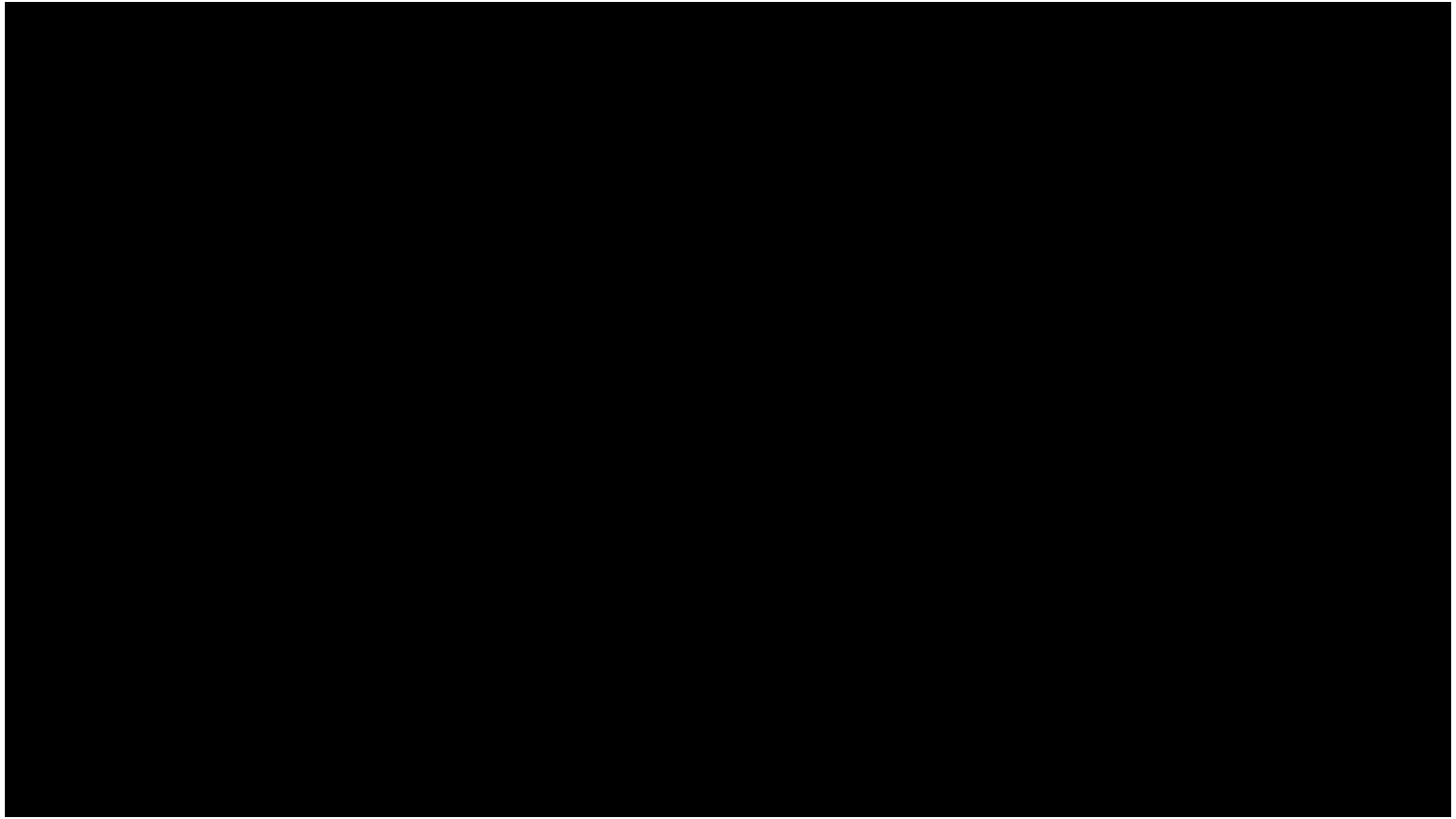
Real Time RTT Calculation



Customized Firewall

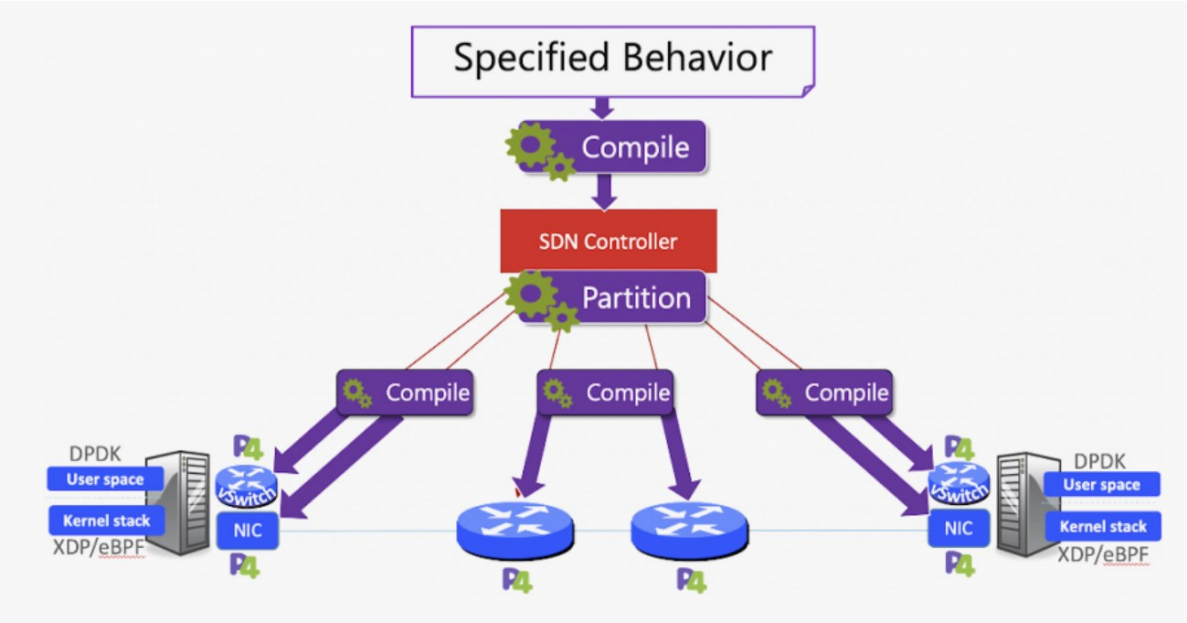
- Customized firewall, without adding any additional middle boxes
- NOTE: legacy CPU-based appliances (e.g., firewalls, Intrusion Detection Systems) cannot process packets fast enough when flows are large

Customized Firewall



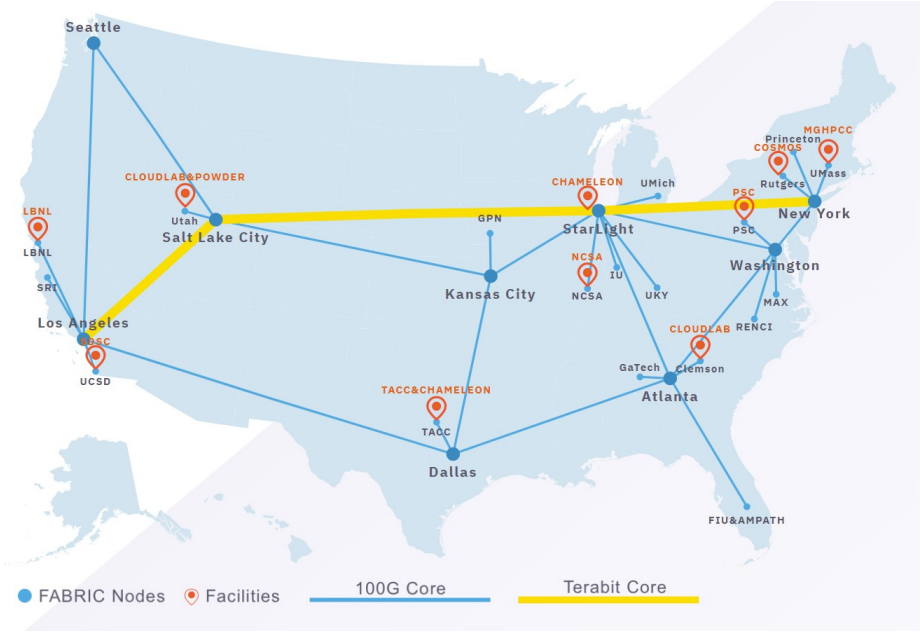
DOD's Pronto Project

- https://prontoproject.org/
- Project Pronto is building and deploying a beta-production end-to-end 5G connected edge cloud leveraging a fully programmable network…



NSF's FABRIC Project

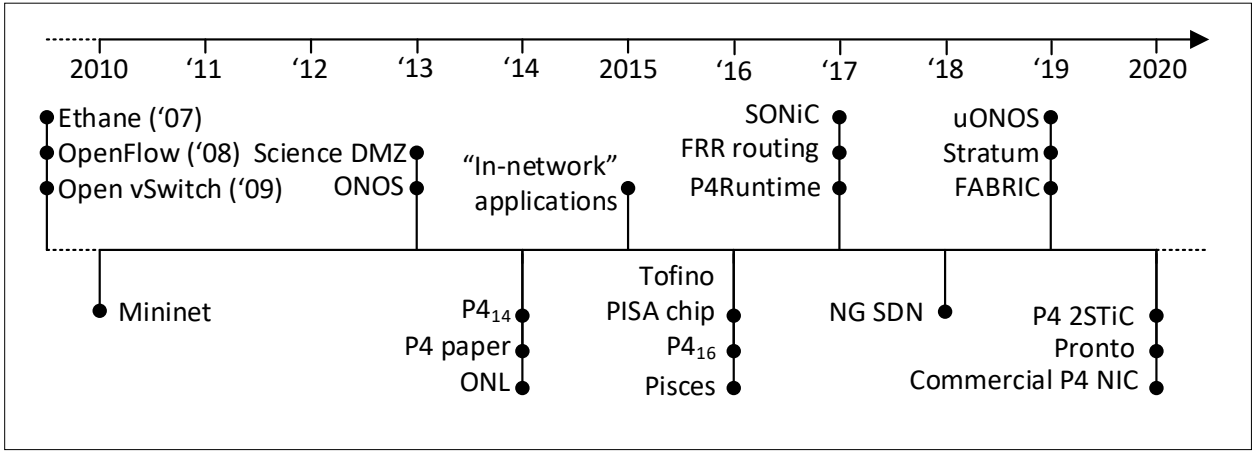
- https://whatisfabric.net/
- FABRIC is an International infrastructure that enables cutting-edge experimentation and research…



UNIVERSITY OF
SOUTH CAROLINA

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



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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

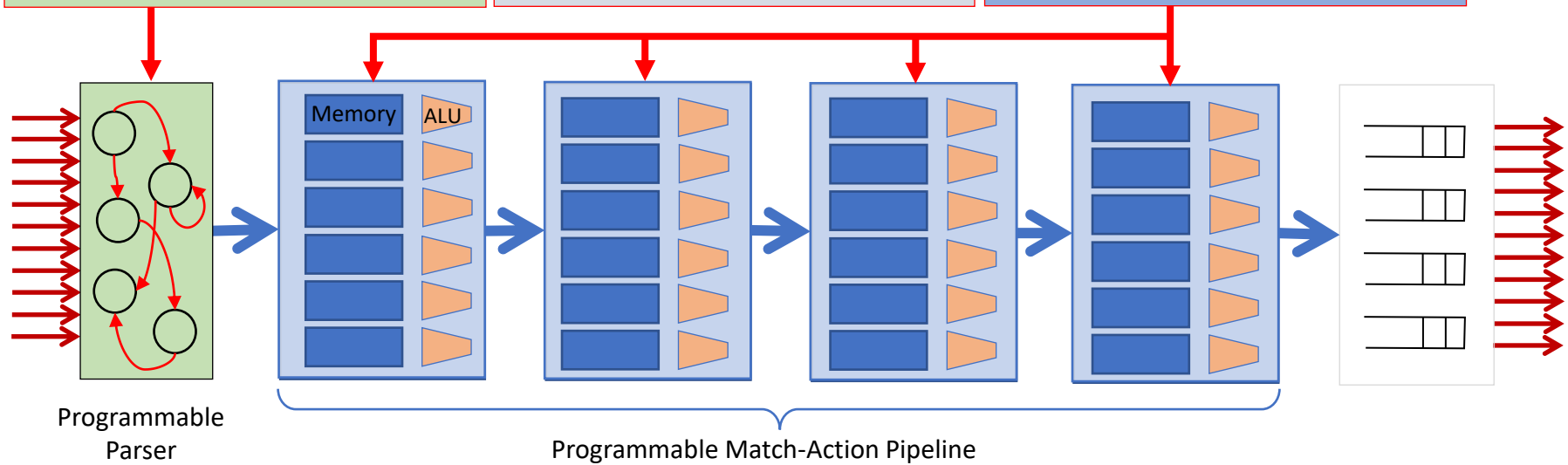
```
header_type  ethernet_t     { … }
header_type  l2_metadata_t  { … }

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();
    }
}
```



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