A Cloud System for Teaching and Research on P4 Programmable Data Plane

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Agenda

• Motivation for virtual labs
• Platform
• Libraries
• P4 Tofino Library
• Topologies used by the research community
• Conclusion
Motivation for Virtual Labs

• IT curriculum should emphasize “learning IT core concepts with authentic practice\textsuperscript{1}”
  ➢ “It is not enough to simply attend courses and read books”

• Disadvantages of physical labs
  ➢ Difficult to scale
  ➢ Expensive (space, maintenance, staff)
  ➢ Since COVID-19 emerged, the capacity of labs has been further reduced

\textsuperscript{1} Information Technology Curricula 2017, ACM/IEEE Joint Committee. Online: \url{https://tinyurl.com/4nqqwa5m}. 
Motivation for Virtual Labs

- The University of South Carolina (USC) (SC), the Network Development Group (NDG) (NC), and Stanly Community College (SCC) (NC) have deployed an Academic Cloud
  - Virtual labs on P4, routing, high-speed networks (USC)
  - Remote-access capability to lab equipment via Internet
  - Shared resources (CPU, memory, storage) from four data centers
USC Data Center

- Hosts 1-n store virtual machines (VMs) for virtual labs
- Management server runs vCenter, Management Software (NETLAB+)
- Partnership with Network Development Group (NDG)\(^1\)

\[^1\] Network Development Group (NDG). Online: https://netdevgroup.com
Libraries

- A library consists of between 10-20 lab experiments
- Each lab experiment includes a detailed, step by step manual
- Once a learner completes all experiments, the learner acquires significant knowledge and hands-on expertise, and may earn an academic credential or certificate
- Information about libraries are available at http://ce.sc.edu/cyberinfra/cybertraining.html
Library on Introduction to P4 with BMv2

Experiments
• Lab 1: Introduction to Mininet
• Lab 2: Introduction to P4 and BMv2
• Lab 3: P4 Program Building Blocks
• Lab 4: Parser Implementation
• Lab 5: Introduction to Match-action Tables (Part 1)
• Lab 6: Introduction to Match-action Tables (Part 2)
• Lab 7: Populating / Managing Match-action Tables
• Lab 8: Checksum Recalculation and Deparsing

Exercises
• Exercise 1: Building a Basic Topology
• Exercise 2: Compiling and Testing a P4 Program
• Exercise 3: Parsing UDP and RTP
• Exercise 4: Building a Simplified NAT
• Exercise 5: Configuring Tables at Runtime
• Exercise 6: Building a Packet Reflector
Library on P4 Applications, Stateful Elements, and Custom Packet Processing

Experiments

• Lab 1: Introduction to Mininet
• Lab 2: Introduction to P4 and BMv2
• Lab 3: P4 Program Building Blocks
• Lab 4: Defining and processing custom headers
• Lab 5: Monitoring the Switch’s Queue using Standard Metadata
• Lab 6: Collecting Queueing Statistics using a Header Stack
• Lab 7: Measuring Flow Statistics using Direct and Indirect Counters
• Lab 8: Rerouting Traffic using Meters
• Lab 9: Storing Arbitrary Data using Registers
• Lab 10: Calculating Packets Interarrival Time w/ Hashes and Registers
• Lab 11: Generating Notification Messages from the Data Plane
Library on P4 Programmable Data Plane with Tofino

Experiments

• Lab 1: Introduction to P4 and Tofino
• Lab 2: Introduction to P4 Tofino Software Development Environment
• Lab 3: Parser Implementation
• Lab 4: Introduction to Match-Action Tables
• Lab 5: Populating and Managing Match-Action Tables at Runtime
• Lab 6: Checksum Recalculation and Packet Deparsing
Library on P4 Programmable Data Plane with Tofino

- [https://netlab2.cec.sc.edu/](https://netlab2.cec.sc.edu/)
Library on P4 Programmable Data Plane with Tofino
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Library on P4 Programmable Data Plane with Tofino
## Library on P4 Programmable Data Plane with Tofino

### Lab Reservations

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<td>2022-09-17 16:57 &lt;br&gt; 2022-09-17 20:00 2 hrs., 52 mins.</td>
<td><strong>Class:</strong> P4 Course  &lt;br&gt; <strong>Lab:</strong> Lab 2: Introduction to P4 Tofino Software Development Environment (SDE)  &lt;br&gt; <strong>Type:</strong> Instructor  &lt;br&gt; <strong>User:</strong> Jorge Crichigno</td>
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**Pod:** Tofino_H2_pod4

[Enter Lab]
Library on P4 Programmable Data Plane with Tofino
Library on P4 Programmable Data Plane with Tofino

• Topology complexity
  - 6.4 Tbps Tofino programmable switch
  - Tofino model for debugging (trace execution in the data plane)
  - Servers to send/receive data to/from the switch/other servers
  - Multi-mode fiber
  - QSFP28+ transceivers
  - Open Network Linux (ONL) (control plane)
  - Software Development Environment (SDE) from Intel (control plane)
  - Sample P4 codes for each lab (data plane)
  - Laboratory experiments with step-by-step directions (thousands of development hours)

• Logistic challenges
  - NDA with Intel, lawyers’ agreement
  - Procurement process
  - Physical hardware, rack space, data center, etc.
  - Software tools, SDE, operating system, etc.
Literature Survey: Topologies used for Research

- 293 papers from 2014 to 2022
- Determine the topologies that are commonly used by experimenters
- Determine the devices that are used
Literature Survey: Topologies used for Research

- Number of switches
Literature Survey: Topologies used for Research

• Targets
Literature Survey: Topologies used for Research

- Number of switches and hosts

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Literature Survey: Topologies used for Research

- Papers that use a 2-host, 1-switch topology

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Literature Survey: Topologies used for Research

- 25% of the papers rely on virtualization to add end devices

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Literature Survey: Topologies used for Research

- Topology supported by the current Tofino pod

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USC, UTSA, USF Research Work

- “INC: In-Network Classification of Botnet Propagation at Line Rate”
- “P4DDPI: Securing P4-Programmable Data Plane Networks via DNS Deep Packet Inspection”
- “Dynamic Router's Buffer Sizing using Passive Measurements and P4 Programmable Switches”
- “On Offloading Network Forensic Analytics to Programmable Data Plane Switches”
- “Coarse Estimation of Bottleneck Router's Buffer Size for Heterogeneous TCP Sources”
- “Offloading Media Traffic to Programmable Data Plane Switches”
- “Towards a Unified In-Network DDoS Detection and Mitigation Strategy”
- “Enabling TCP Pacing using Programmable Data Plane Switches”
- “A Survey on TCP Enhancements using P4-programmable Devices”
- “A Survey on Security Applications of P4 Programmable Switches and a STRIDE-based Vulnerability Assessment”
Conclusion

• The primary use is of the platform is for teaching
• The platform is used at USC, UTSA, and USF for research
  ➢ Time to research is shortened
  ➢ Scalable, cost efficient
  ➢ Resources are shared
Conclusion

• Future work includes exploring potential use cases when pods are connected via a wide-area network
  ➢ Visibility
  ➢ Accurate real-time measurements
  ➢ Data plane processing speed
Conclusion

• Demo, as the time permits
• Application examples in the Poster Presentation session

Thank you
## Platform Features

<table>
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<tr>
<th>Feature</th>
<th>Comments</th>
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<tbody>
<tr>
<td>Allocation of resources</td>
<td>Pod granularity</td>
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<tr>
<td>Custom pods</td>
<td>Easy to create custom pods</td>
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<tr>
<td>Cost</td>
<td>Cost-effective when used extensively</td>
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<td>Presentation layer for pedagogy</td>
<td>Topology is graphically presented to the learner using a regular browser</td>
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<td>Time sharing</td>
<td>Easy to implement time-sharing policies</td>
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<tr>
<td>IP addresses</td>
<td>Pods have the same topology / IP addresses (overlapping addresses w/o conflict)</td>
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<td>Functional realism</td>
<td>Virtual labs have the same functionality as real IT hardware in a real deployment</td>
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<td>Traffic realism</td>
<td>Devices generate/receive real, interactive network traffic to/from the Internet</td>
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Motivation for Virtual Labs


• What can be done to reach out those who are yet to be engaged in STEM workforce?
  ➢ “The present research computing and data ecosystems look impenetrable to many…”
  ➢ “Lower barriers to entry…”
  ➢ “Invest in CI and community laboratories at the edge, enabling broader and more diverse participation”
  ➢ “Explore investments in research computing ... that are easily accessible (such as GUIs, ...)

31