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
- Research work
Motivation for Virtual Labs

• IT curriculum should emphasize “learning IT core concepts with authentic practice\(^1\)”
  ➢ “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

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1. Information Technology Curricula 2017, ACM/IEEE Joint Committee. Online: [https://tinyurl.com/4nqqwa5m](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
FABRIC

- www.whatisfabric.net
Platform - 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

Introduction to P4 with Tofino
This pod provides P4 training using the Intel Tofino switch
<table>
<thead>
<tr>
<th>Lab Name</th>
<th>Action</th>
</tr>
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<tbody>
<tr>
<td>Lab 1: Introduction to P4 and Tofino</td>
<td></td>
</tr>
<tr>
<td>Lab 2: Introduction to P4 Tofino Software Development Environment (SDE)</td>
<td></td>
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<tr>
<td>Lab 3: Parser Implementation</td>
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<td>Lab 4: Introduction to Match-action Tables</td>
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<tr>
<td>Lab 5: Populating and Managing Match-action Tables at Runtime</td>
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Library on P4 Programmable Data Plane with Tofino
Library on P4 Programmable Data Plane with Tofino

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<td>298</td>
<td>2022-09-17 16:57</td>
<td>Class: P4 Course</td>
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<td></td>
<td>2022-09-17 20:00</td>
<td>Lab: Lab 2: Introduction to P4 Tofino Software Development Environment (SDE)</td>
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<td></td>
<td>2 hrs., 52 mins.</td>
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<td>User: 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
<table>
<thead>
<tr>
<th>Feature</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Allocation of resources</td>
<td>Pod granularity</td>
</tr>
<tr>
<td>2 Custom pods</td>
<td>Easy to create custom pods, including physical (e.g., Tofino switches) and virtual devices</td>
</tr>
<tr>
<td>3 Cost</td>
<td>Cost-effective when used extensively</td>
</tr>
<tr>
<td>4 Presentation layer</td>
<td>Topology is graphically presented to the learner using a regular browser</td>
</tr>
<tr>
<td>5 Time sharing</td>
<td>Easy to implement time-sharing policies</td>
</tr>
<tr>
<td>6 IP addresses</td>
<td>Pods have the same topology / IP addresses (overlapping addresses w/o conflict)</td>
</tr>
<tr>
<td>7 Functional realism</td>
<td>Virtual labs have the same functionality as real IT hardware in a real deployment</td>
</tr>
<tr>
<td>8 Traffic realism</td>
<td>Devices generate/receive real, interactive network traffic to/from the Internet</td>
</tr>
<tr>
<td>9 Management</td>
<td>Devices are managed via out-of-band management connections (i.e., management is not disrupted by experiments)</td>
</tr>
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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)
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”
• “An Exhaustive Survey on P4 Programmable Data Plane Switches: Taxonomy, Applications, Challenges, and Future Trends”
• “A Survey on TCP Enhancements using P4-programmable Devices”
• “A Survey on Security Applications of P4 Programmable Switches and a STRIDE-based Vulnerability Assessment”