Chair of Communication Networks
Department of Electrical and Computer Engineering
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Toward Consistent State Management of Adaptive Programmable Networks Based on P4

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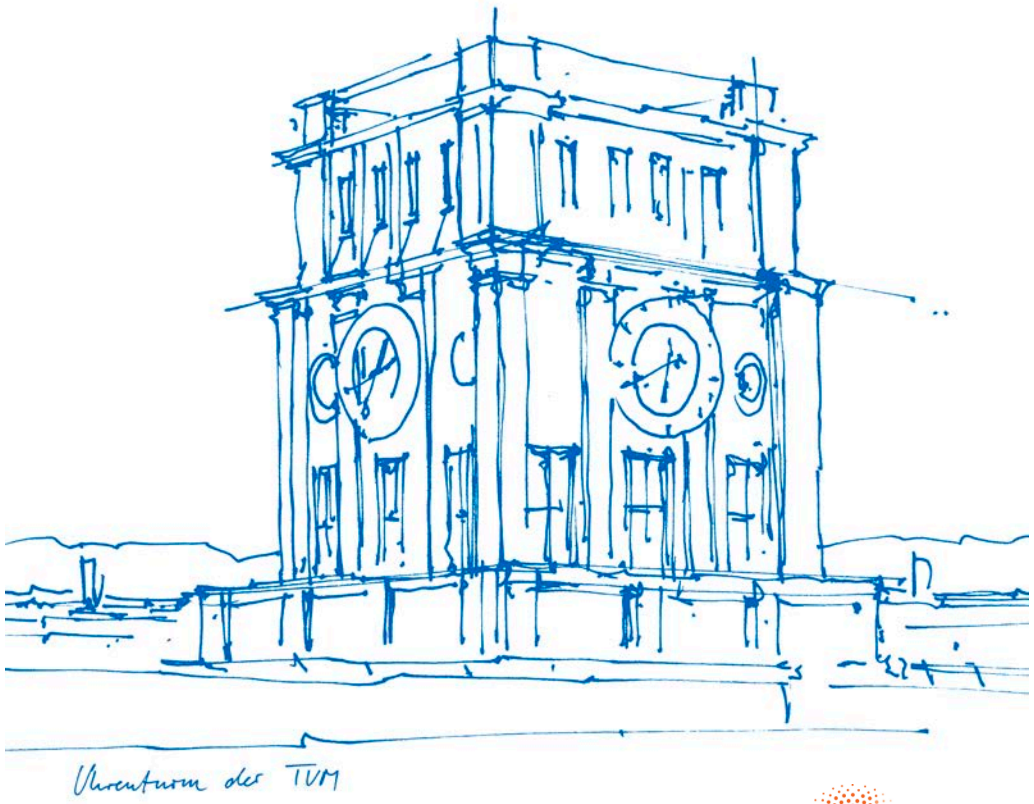

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New Applications and Technologies

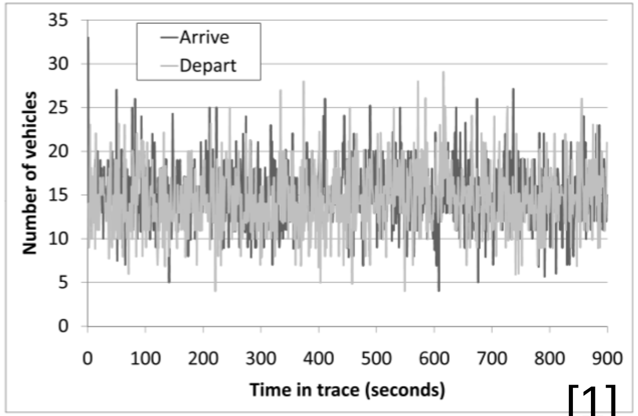
Augmented
Reality

Virtual
Reality

Tactile

Vehicular
Networks

Require ...oughput,
latency, pr ...omizability!



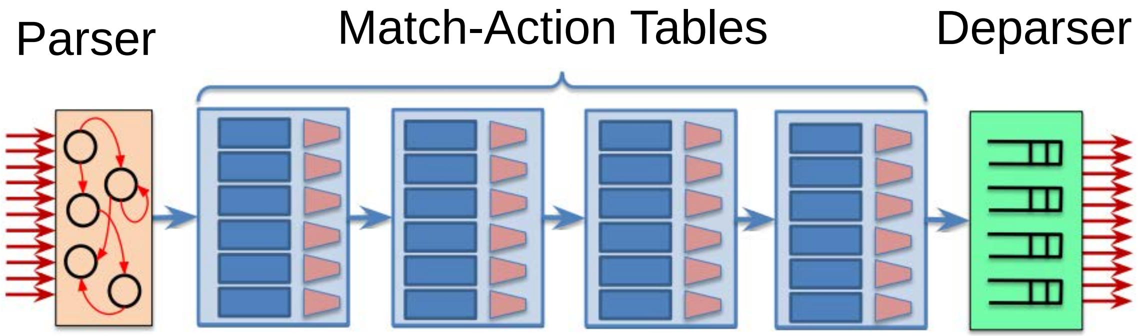
[1]

[1] Rowstron A, Pau G. Characteristics of a vehicular network[J]. University of California Los Angeles, Computer Science Department, Tech. Rep, 2009: 09-0017.

Programable Networks with P4

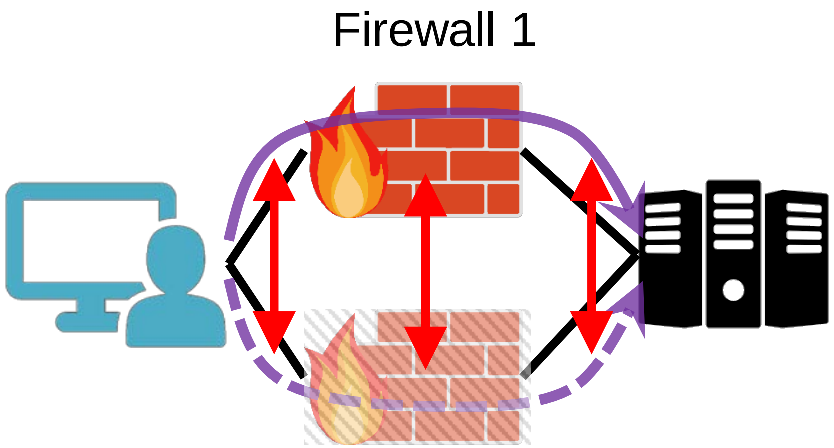
- Program your own data plane [1]
  - Protocol independent
  - Target independent
  - Field reconfigurable

- Advantages in many use cases
  - In-band network telemetry [2]
  - Flow monitoring [3]
  - Load balancing [4]
  - High throughput data center [5]

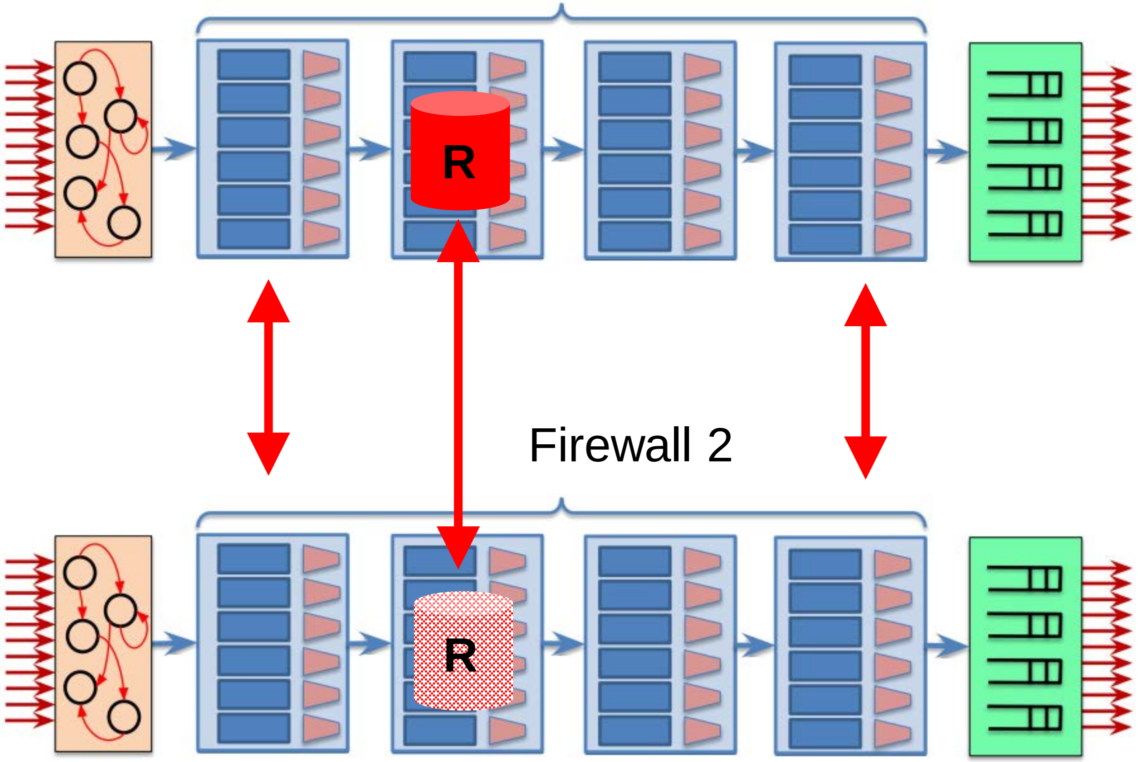


[1] Bosshart, Pat, et al. "P4: Programming protocol-independent packet processors." ACM SIGCOMM Computer Communication Review 44.3 (2014): 87-95.
[2] Gupta, Arpit, et al. "Sonata: Query-driven streaming network telemetry." SIGCOMM. ACM, 2018.
[3] Liu, Zaoxing, et al. "One sketch to rule them all: Rethinking network flow monitoring with univmon." SIGCOMM. ACM, 2016.
[4] Miao, Rui, et al. "Silkroad: Making stateful layer-4 load balancing fast and cheap using switching asics." SIGCOMM. ACM, 2017.
[5] Handley, Mark, et al. "Re-architecting datacenter networks and stacks for low latency and high performance." SIGCOMM. ACM, 2017.

Reconfiguration is needed!



NF Scaling



Field reconfigurability + Data plane states

How to manage them?

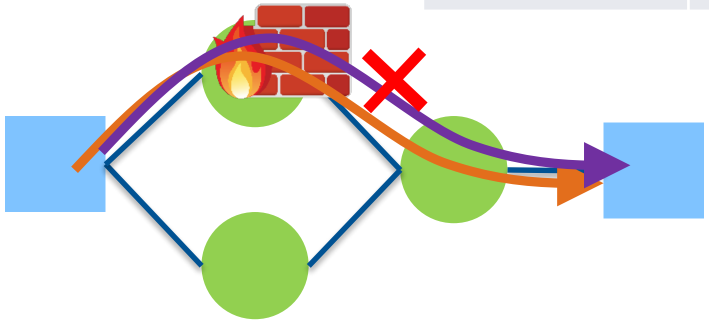
State Consistency during Network Reconfiguration

- Stateful firewall based on packet counts (More than 100)
- State: # packets per flow

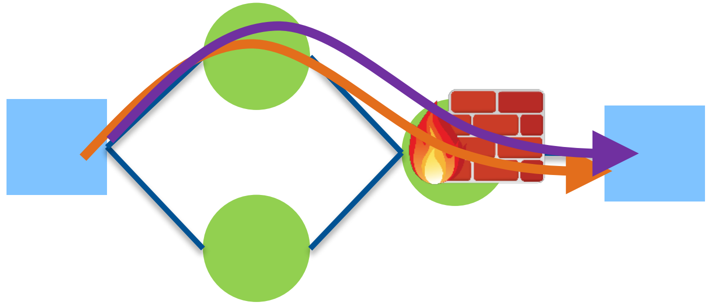
Flow	# PKT
1	200
2	5

Incomplete Copy

Flow	# PKT
1	0
2	5



RECONFIG



New Requirements

Completeness

All necessary state variables

Updated version

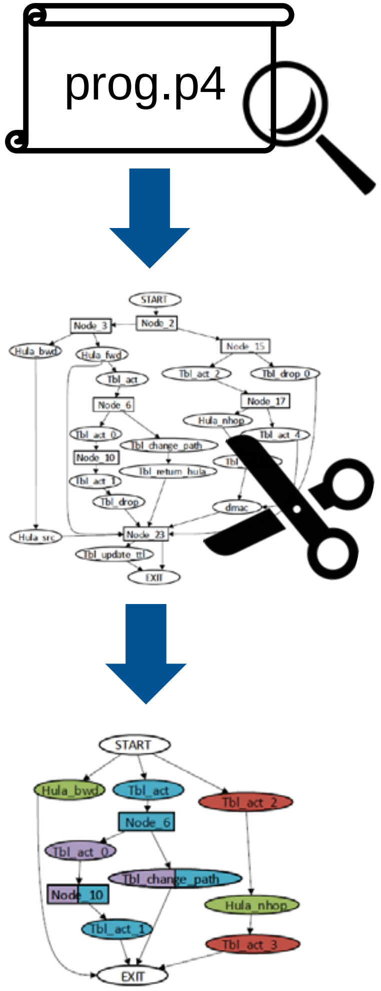
Rapidness

Finish as fast as possible

Agility of data plane

Our Proposal: P4State Analyzer

- States identification
  - Collect all state usage
  - Bind states to tables and if-conditionals
- Control Flow Graph (CFG) construction
  - Abstract match + action pipeline
- Control Flow Graph pruning
  - Delete stateless nodes
- Path and role identification



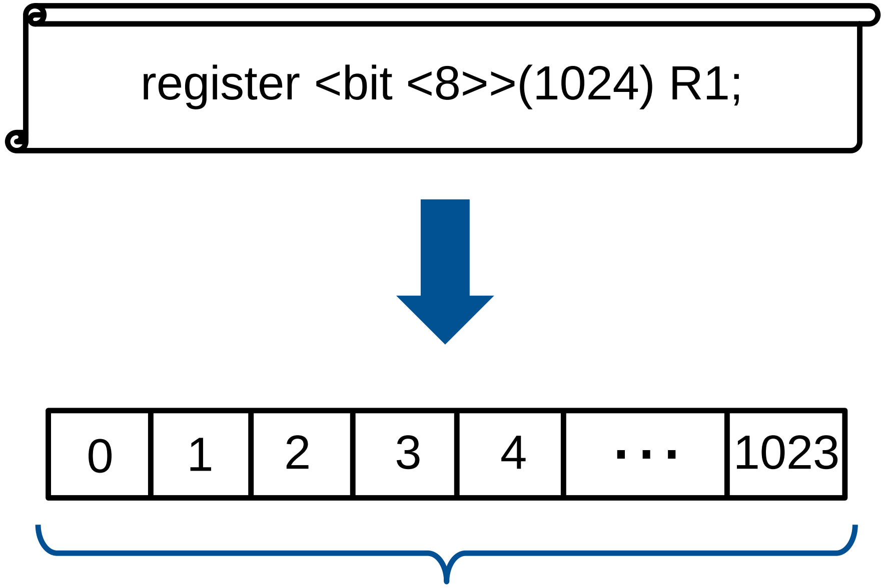
State Variables in P4: Taxonomy

- Various types of states in P4 context
  - Table entries ← control plane
  - Temporary metadata: local information while processing each packet
  - **Stateful variables**: **register**

- Persistent beyond the packet processing loop, e.g.,
  - Packet counter
  - Port status
  - Pipeline control flag

State Variables in P4: Taxonomy

- Register = An array with values
  - Register type
  - Register entry
- Flow-based registers
  - Information per-flow (different granularity)
  - Large number of entries
  - Migrated through data plane or control plane
- Device-based registers
  - Device and pipeline information
  - Migrated through control plane

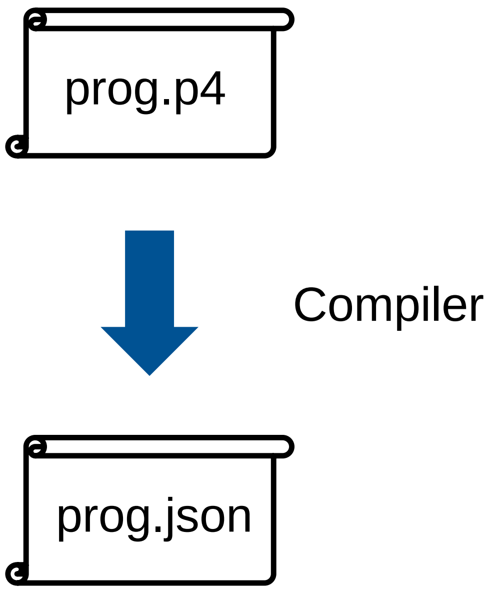


R1 with 1024 entries, each of 8 bits

States Identification

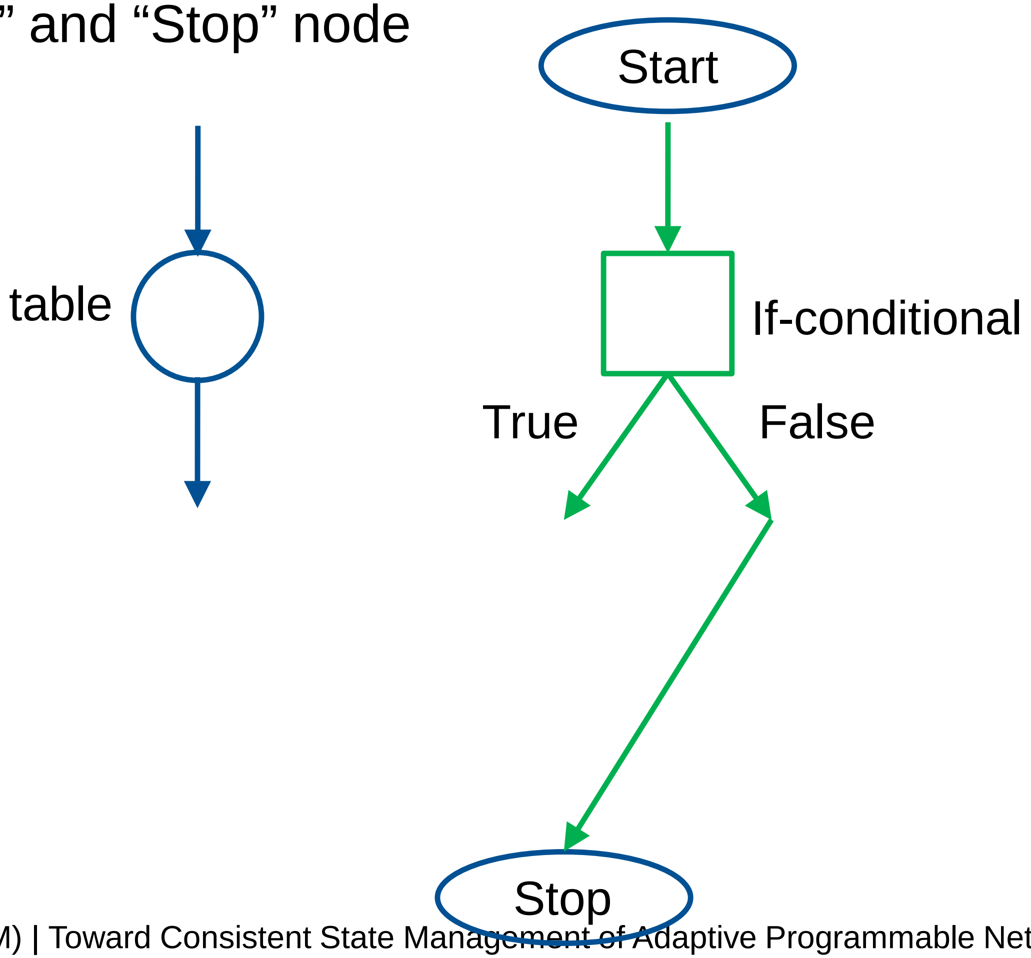
- Input: P4 program
- Output: Set of tables and if-conditionals with register access

- Compile the program to a JSON file
  - Consists definitions of all pipeline components
- Parse JSON file
  - Collect all register definitions
  - Collect all header, action, table, if-conditional definitions
  - Associate registers to tables and if-conditionals



Control Flow Graph (CFG)

- Describes the packet processing pipeline
- Composed of ***tables*** and ***if-conditionals***
- “Start” and “Stop” node

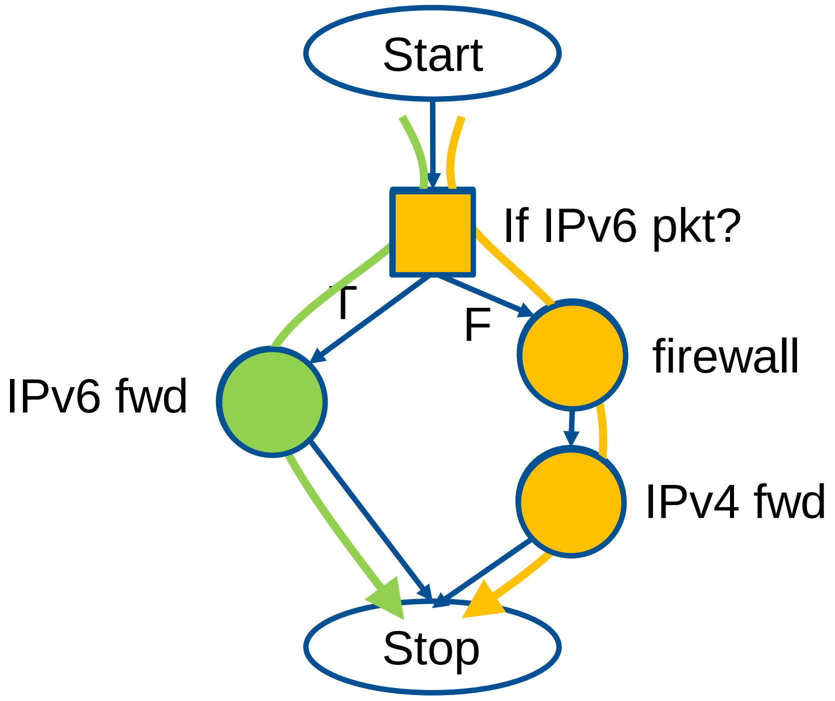



```
table ipv4_lpm {
        key = {
            hdr.ipv4.dstAddr: lpm;
        }
        actions = {
            ipv4_forward;
            drop;
        }
        size = 1024;
}

    apply {
        if (hdr.ipv4.isValid()) {
            ipv4_lpm.apply();
        }
    }
```

Stateful CFG Construction

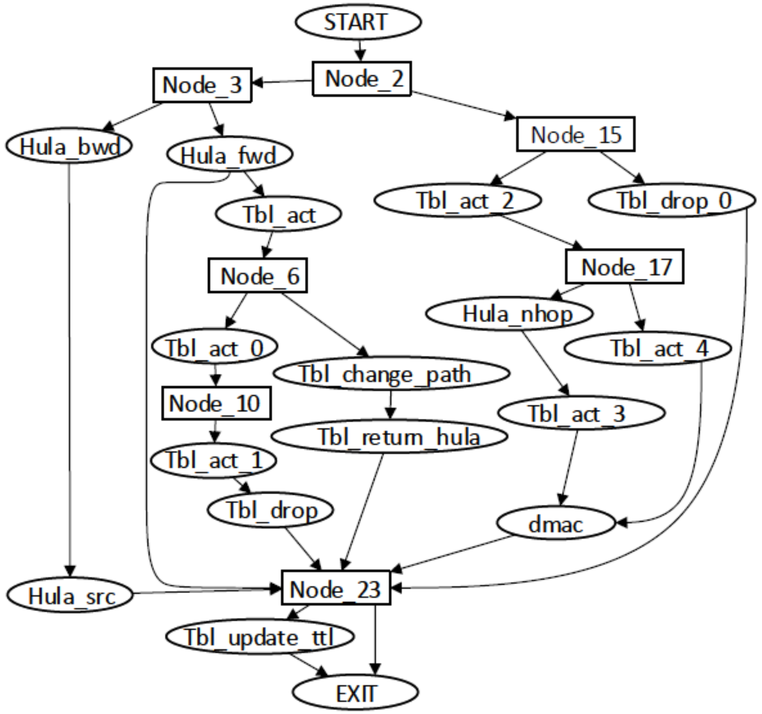
- From “Start”, recursively explore the child nodes of each node, until “Stop” is reached → Find a path
- Merge the common parts of all paths



CFG Pruning

- Why pruning?
  - Original CFG is hard to digest
  - Stateless nodes in CFG have no effect

- Inspired by Thin Slicing [1]
- Two steps
  - 1. Remove all nodes without state access
  - 2. Merge consecutive tables with same state access on a single path



[1] Sridharan, Manu, Stephen J. Fink, and Rastislav Bodik. "Thin slicing." ACM SIGPLAN Notices. Vol. 42. No. 6. ACM, 2007.

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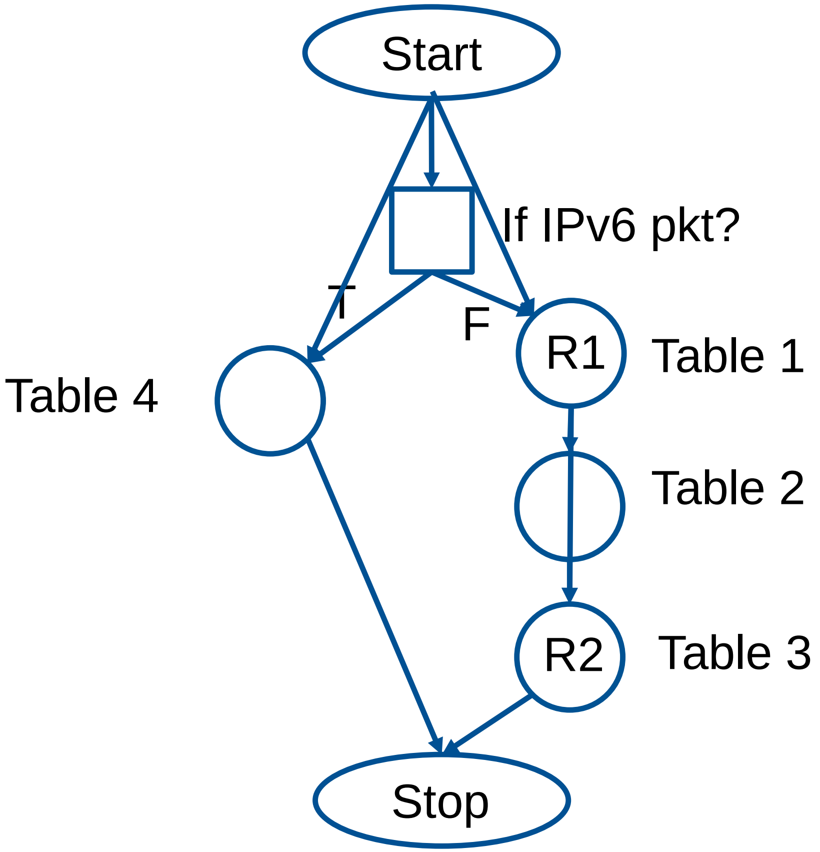
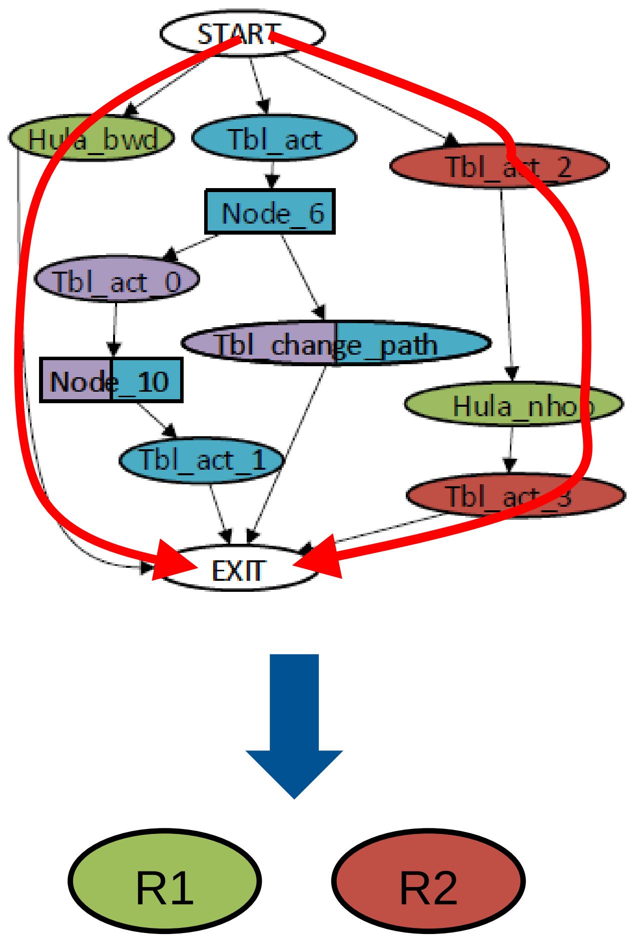


[1] Sridharan, Manu, Stephen J. Fink, and Rastislav Bodik. "Thin slicing." ACM SIGPLAN Notices. Vol. 42. No. 6. ACM, 2007.

Path & Role Identification

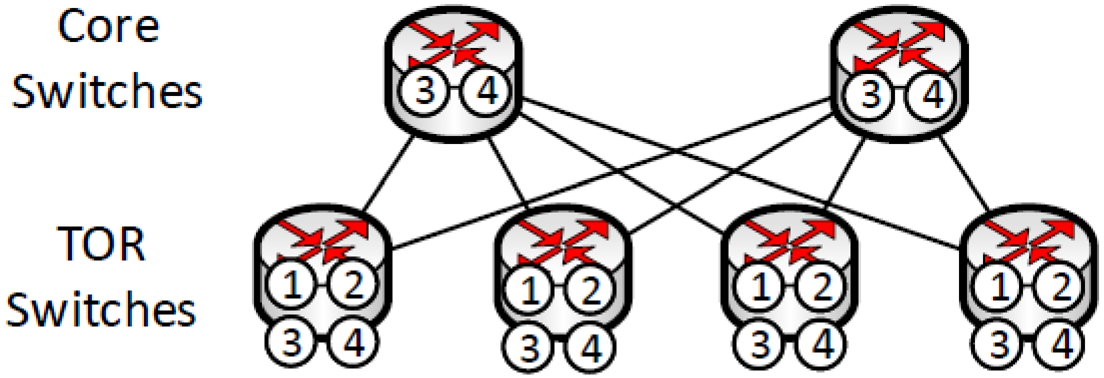
- Why identification?
  - Single P4 program consists of multiple functions
  - Different functions enabled on different P4 switches
- Input
  - Pruned CFG
  - Table entries during data plane initialization
  - Domain knowledge
  - (Human intervention)
- Output
  - States that need to be migrated for a certain P4 switch
  - (Migration schedule)



Evaluation on HULA

- Traffic engineering in data center networks [1]
- Probing
  - Maintain the current best paths between TOR switches considering queue length
- Forwarding
  - Send traffic on the best paths

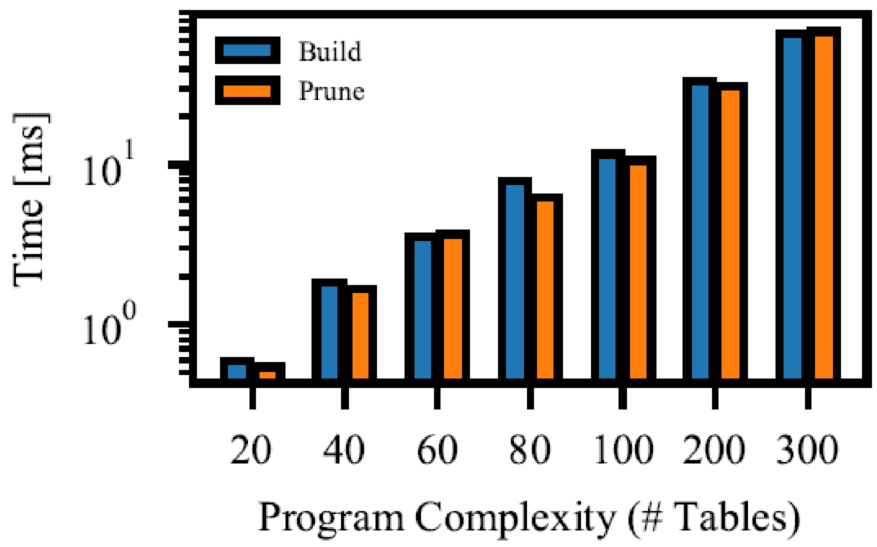
- Probing: R3, R4
- Forwarding: R1, R2
- TOR switches: Probing + Forwarding
- Core switches: Forwarding



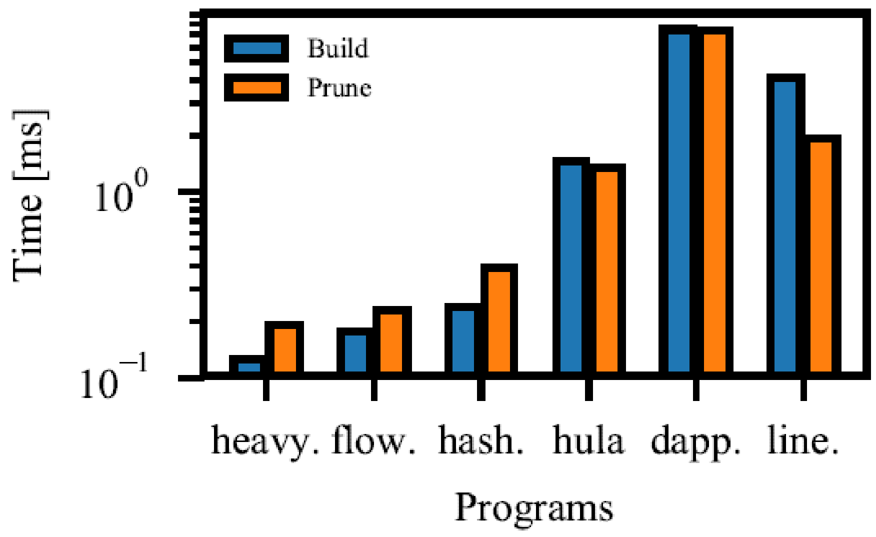
[1] Katta N, et al. Hula: Scalable load balancing using programmable data planes[C]//Proceedings of the Symposium on SDN Research. ACM, 2016: 10.

General Performance: Algorithm Runtime

Synthetic Programs



Real Programs



- Comparable CFG construction time and CFG pruning time
- Synthetic: scales with # tables, less than 100 ms
- Real: depends on pipeline structure (LinearRoad has higher LoC, but Dapper has more branches)

Conclusion and Future Work

- P4State analyzer can **quickly** and **successfully** recognize the register types that need migration during data plane reconfiguration
  - Avoid unnecessary register migration
  - Output CFG with states that allows human intervention

- Next steps
  - Only migrate valid register entries
  - Scheduling of register migrations

Program	LoC	Types of Reg.	# Reg. Entries
Flowlet	203	2	16384
netpaxos	210	6	256002

Thank you! &

Questions?