VeriFlow: Verifying Network-Wide Invariants in Real Time

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Outline

- Motivation
- Design
- Evaluation
- Example
- Conclusion

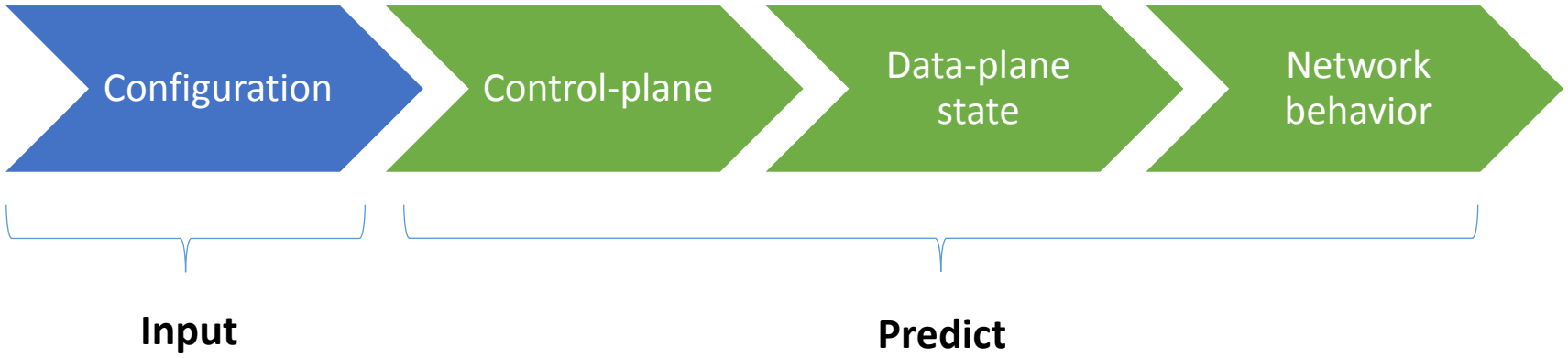
Motivation

- Networks are complex
  - Ensure network's correctness and security
- SDN increases software complexity
  - Multiple applications program the physical network simultaneously
- Check network-wide invariants as network evolves
- Prevent bugs as they arise

Bugs Effect

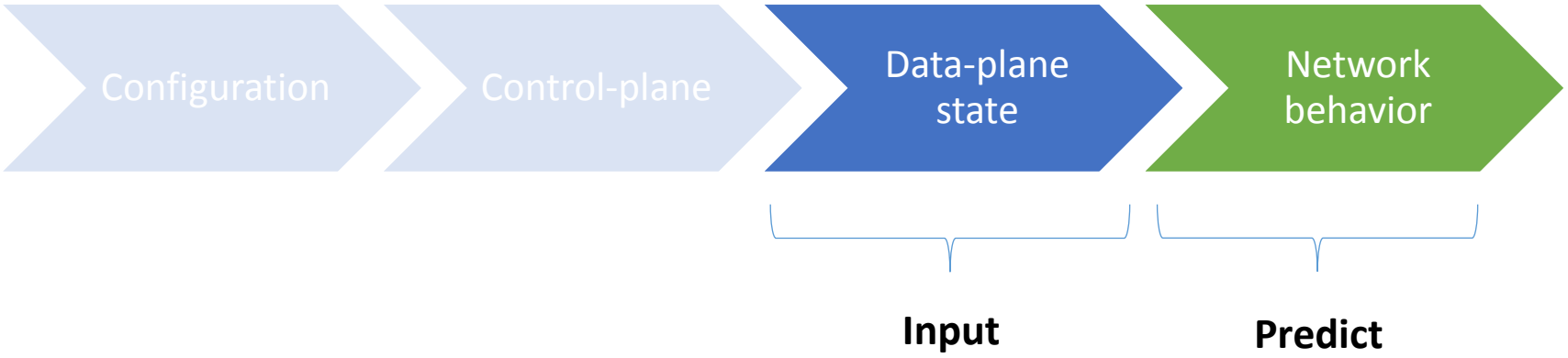
- Allow unauthorized packets to enter a secured zone in a network
- Make services and the infrastructure prone to attacks
- Make critical services unavailable
- Affect network performance

Configuration Verification (Offline)



- Problems:
  - Prediction is difficult
    - Various configuration languages
    - Dynamic distributed protocols
  - Miss control-plane implementation bugs

VeriFlow approach: Data-plane Verification

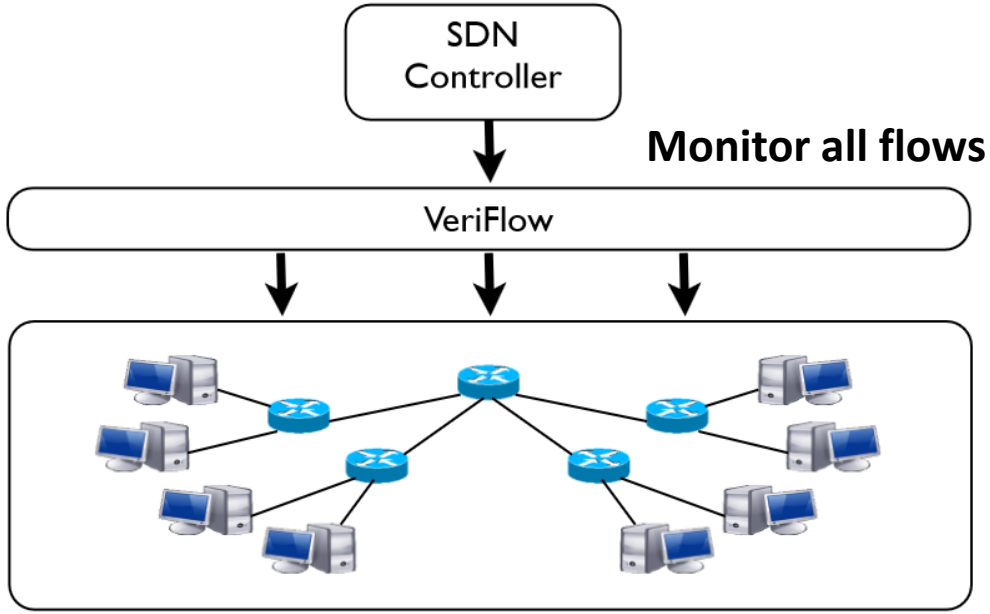


- Advantages:
  - Less prediction
  - Closer to actual network behavior
  - Unified analysis for multiple control-plane protocols
  - Catch control-plane implementation bugs

Challenges

- Obtaining real time view of the network
  - Interpose between controller and network elements
  - Utilize the centralized data-plane view available in an SDN (Software-Defined Network)

- Verification speed

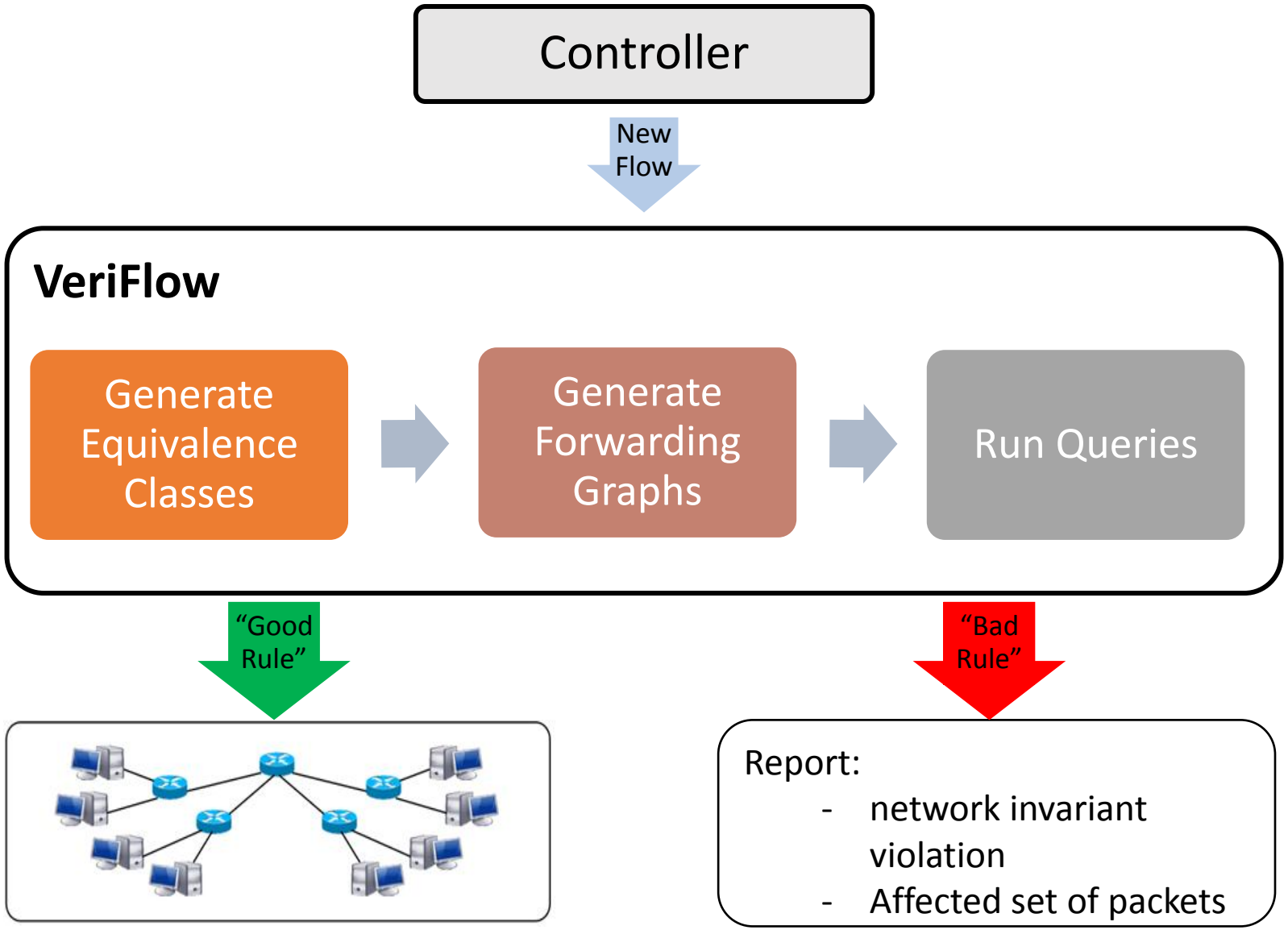


The Tool: VeriFlow

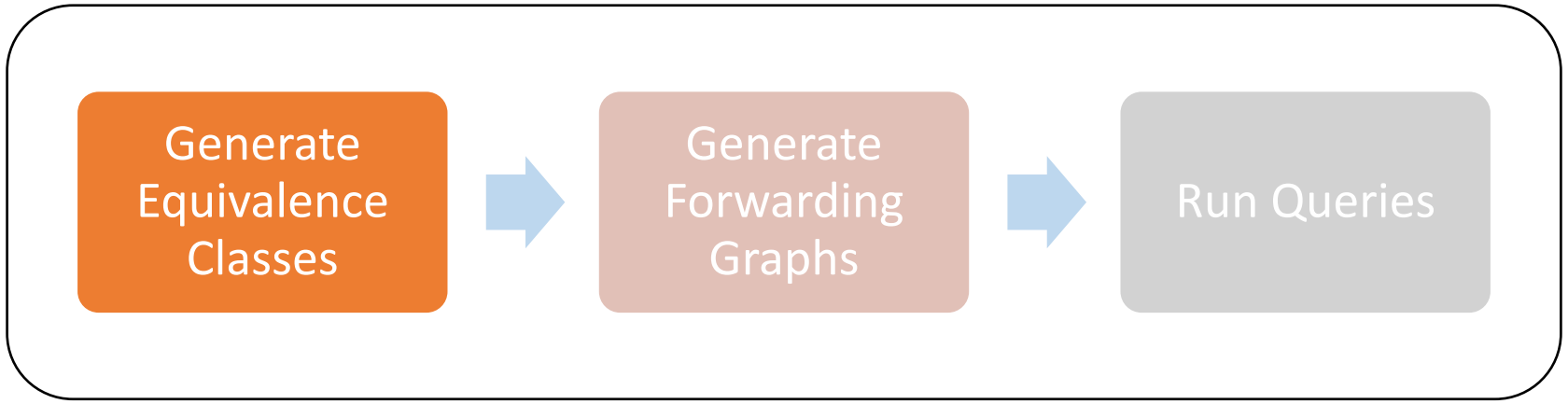
- Checks network-wide invariants in real time using data-plane state
  - Absence of routing loops, black holes, access control violations, etc.

- Functions by
  - Monitoring dynamic changes in the network
  - Constructing a model of the network behavior
  - Using custom algorithms to automatically derive whether the network contains errors

VeriFlow Overview

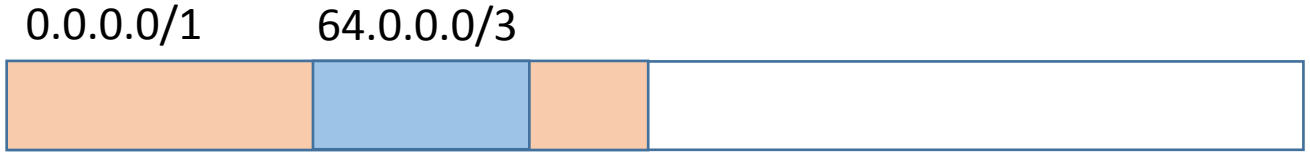


Limit the search space



- **Equivalence class:** Packets experiencing the same forwarding actions throughout the network

- Fw Rules:

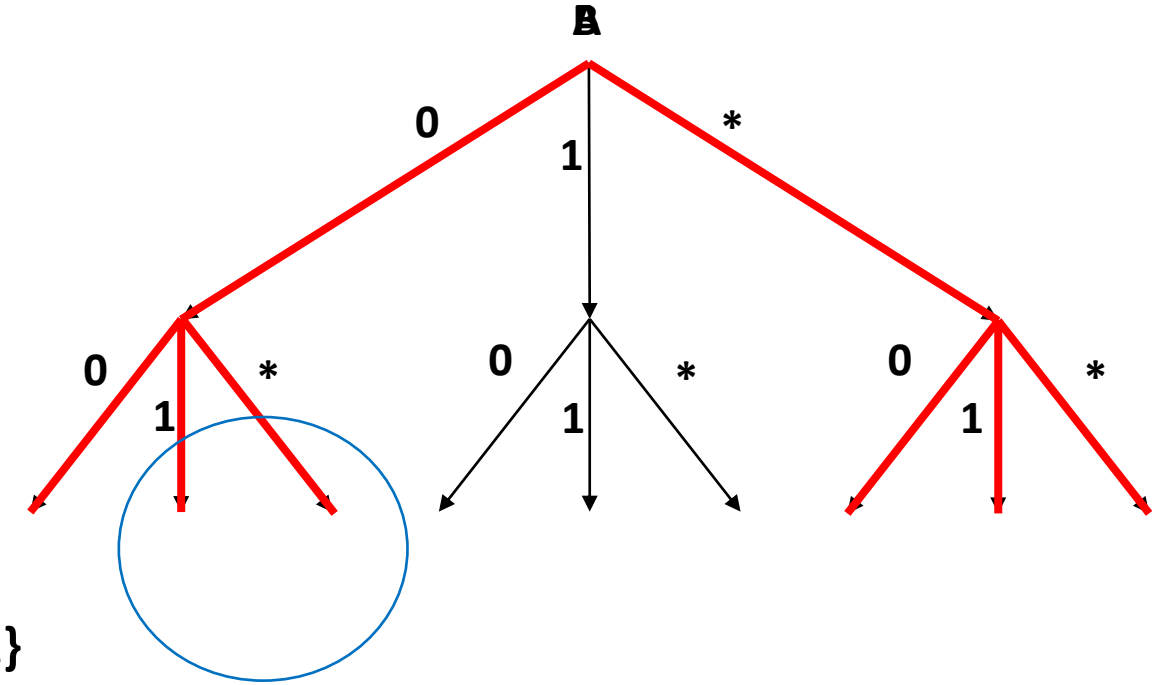


- Eq. classes: 1 2 3 4

Computing Equivalence Classes

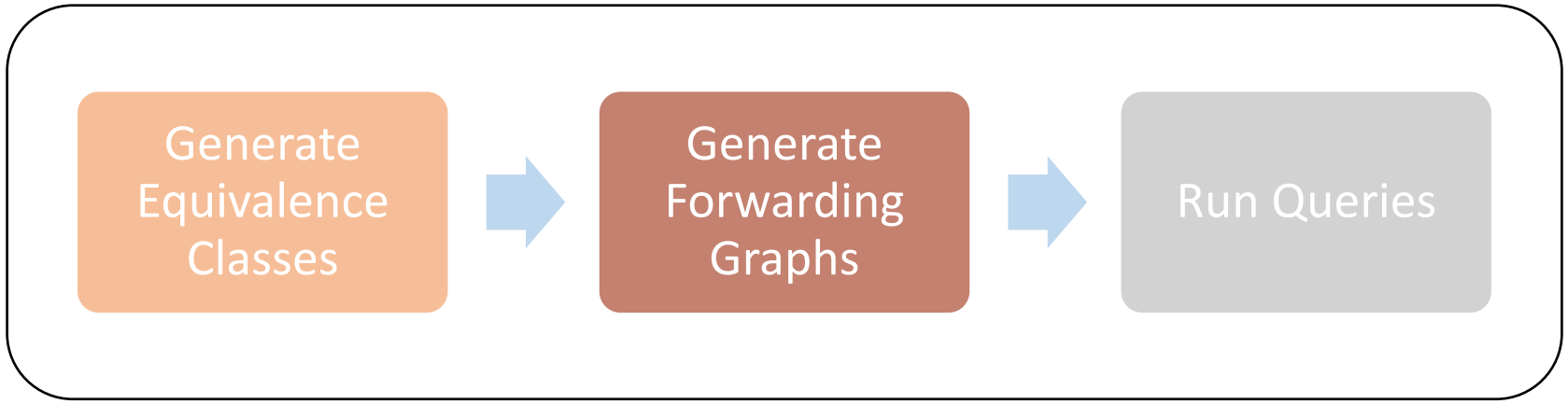
A = (Match =0.1, Action, device)

B = (Match =0.*, Action, device)



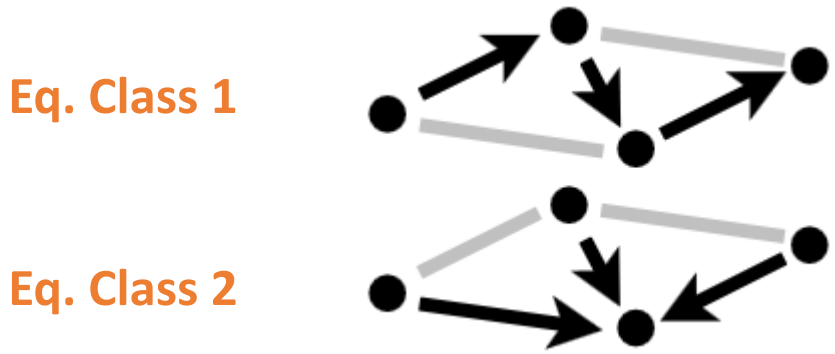
Eq. Classes – {0.0}, {0.1}

Represent Forwarding Rules

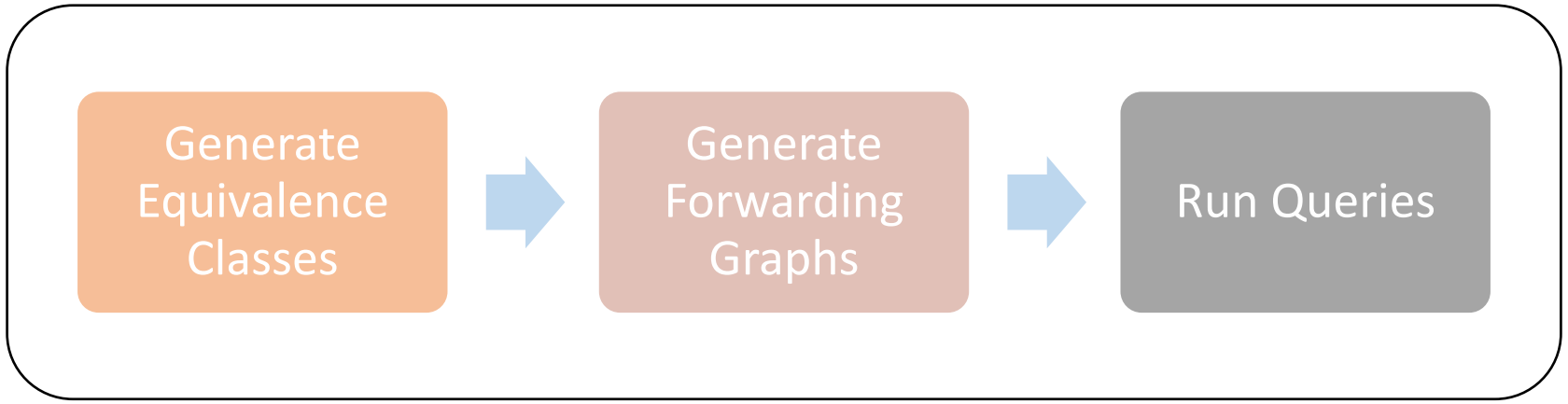


- **Forwarding graphs:**
  - Nodes representing network devices
  - Edges representing forwarding rules

- All the information to answer queries



Check Invariants



- **Queries:**
  - Black holes
  - Routing loops
  - VLANs Isolation
  - Access control policies

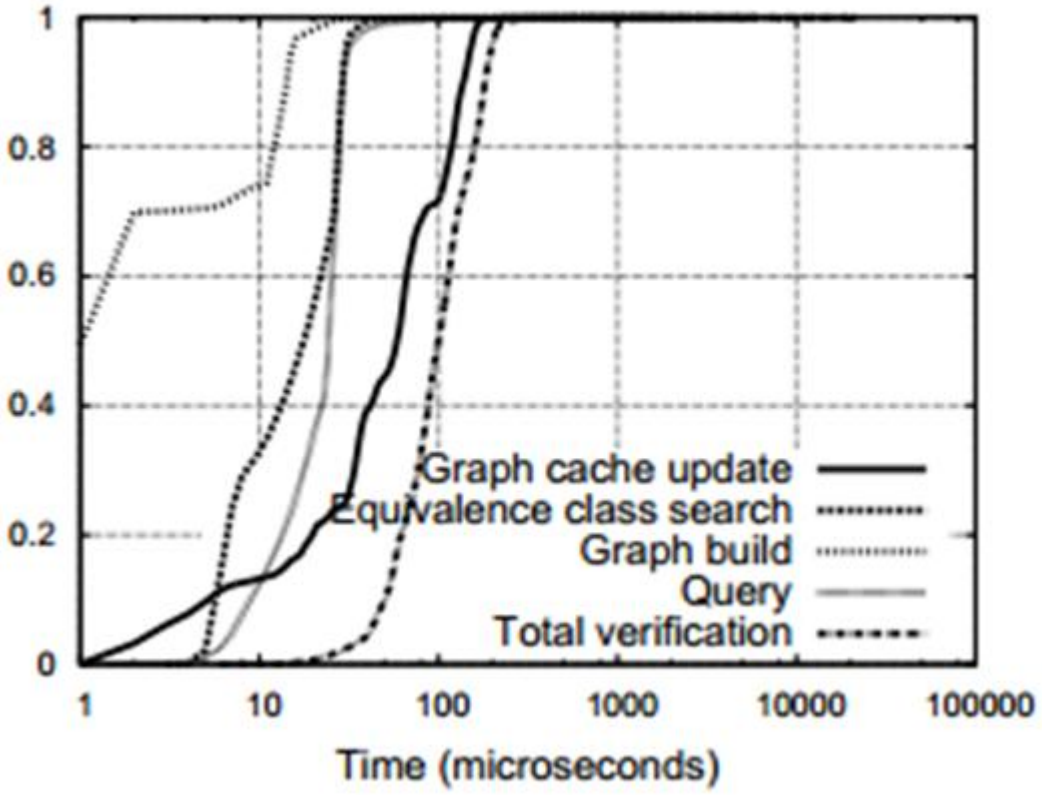
- **Response**:
  - Good Rules → Send flow to network element
  - Bad Rules → Report: invariant violated, affected set of packets

Evaluation #1 – Microbenchmarking VeriFlow run time

- **Goal:** Observe VeriFlow's different phases contribution to the overall run time

- Simulated an IP network
  - 172 routers

- Replayed BGP traces
  - 5 million RIB entries
  - 90K BGP updates



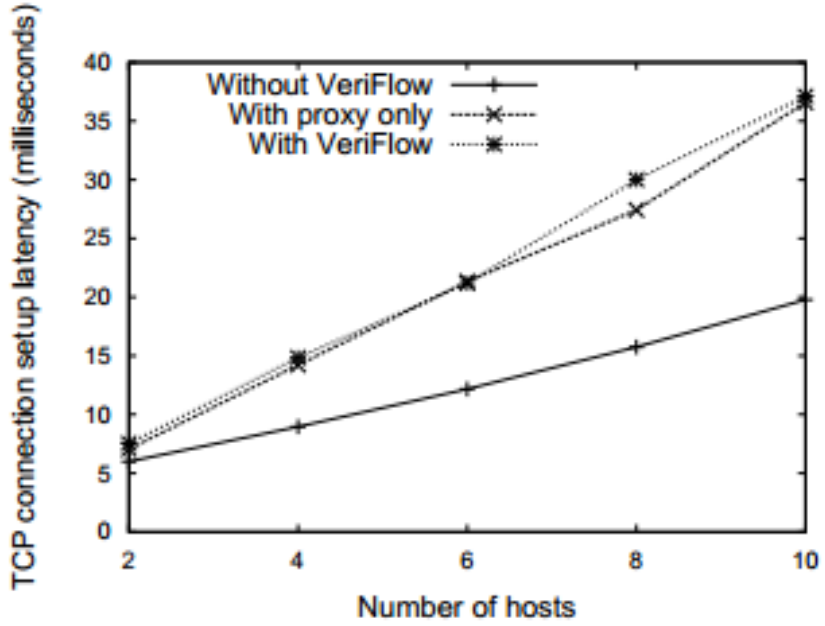
Evaluation #2 – Effect on TCP connection setup latency

- Experiment #2 – Impact of VeriFlow on TCP connection setup latency

- Mininet OpenFlow network
  - 10 switches arranged in chain-like topology
  - A host connected to every switch

- NOX controller running “learning switch” app

- TCP connections between random pairs of hosts



Future Work

- Handling packet transformations
- Deciding when to check (transactions)
- Handling queries other than reachability
- Dealing with multiple controllers

Demo application

```
hosts = {<ip: (device, port)>}
switches = {(sw1, sw2): port}

def packet_in(pkt, in_port, device):
        if (GARP == pkt.proto):
                if (hosts.has_key(pkt.src_ip)):
                        (d,i) = hosts[pkt.src_ip]
                        delete_flow(match=pkt.src_ip, d)
                hosts[pkt.src_ip] = (device, in_port)
                install_flow(match=pkt.src_ip, out=in_port, device)

        else if (hosts.has_key(pkt.dst_ip)):
                (d,i) = hosts[pkt.dst_ip]
                install_flow(match=pkt.dst_ip, out=switches[(device,d)], device)
                send_packet(pkt, switches[(device,d)], device)
```

Conclusion

- VeriFlow achieves real-time verification:
  - A layer between SDN controller & network elements
  - Find faulty flows issued by SDN applications
  - Verify network-wide invariants as each flow is inserted

- Can prevent a flow from reaching the network