Empowering Enterprises for Industry 4.0 Transformation

Verifiable Networks

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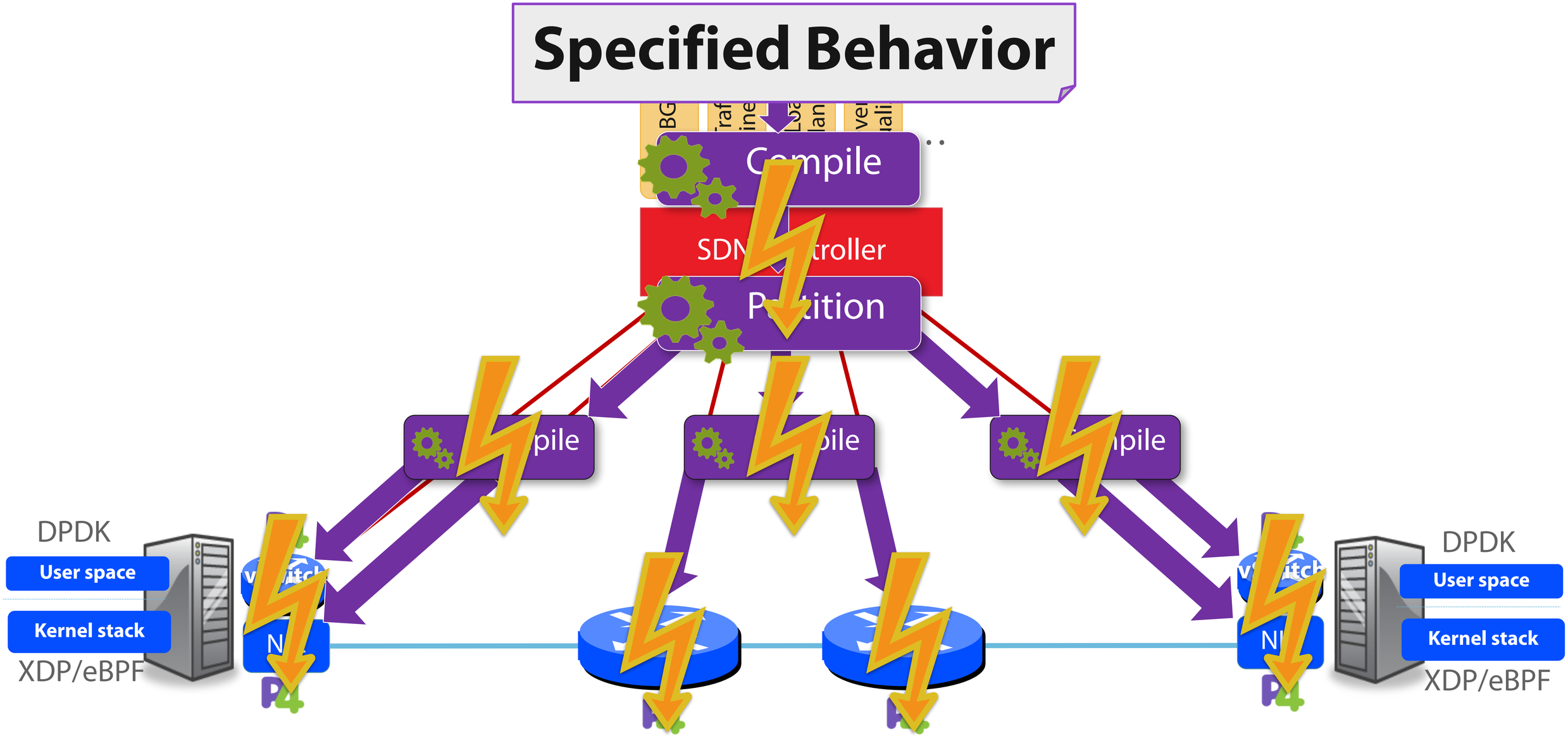
2020

Great Power… Great Responsibility



Fundamental Question

Properties

- Connectivity
- Loop-freedom
- Waypointing
- Resilience
- Isolation

RFC: 791

INTERNET PROTOCOL

DARPA INTERNET PROGRAM

PROTOCOL SPECIFICATION

September 1981

prepared for

Defense Advanced Research Projects Agency
Information Processing Techniques Office
1400 Wilson Boulevard
Arlington, Virginia 22209

by

Information Sciences Institute
University of Southern California
4676 Admiralty Way
Marina del Rey, California 90291

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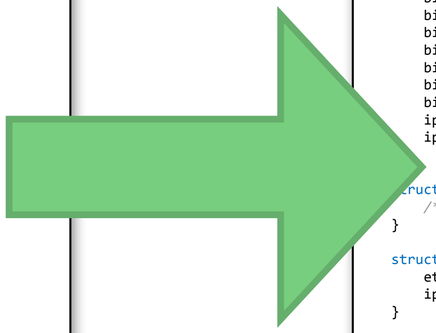



```p4
/* -*- P4_16 -*- */
#include <core.p4>
#include <v1model.p4>

const bit<16> TYPE_IPV4 = 0x800;

/*********************  H E A D E R S  ************************************/

typedef bit<9>  egressSpec_t;
typedef bit<48> macAddr_t;
typedef bit<32> ip4Addr_t;

header ethernet_t {
    macAddr_t dstAddr;
    macAddr_t srcAddr;
    bit<16>   etherType;
}

header ipv4_t {
    bit<4>    version;
    bit<4>    ihl;
    bit<8>    diffserv;
    bit<16>   totalLen;
    bit<16>   identification;
    bit<3>    flags;
    bit<13>   fragOffset;
    bit<8>    ttl;
    bit<8>    protocol;
    bit<16>   hdrChecksum;
    ip4Addr_t srcAddr;
    ip4Addr_t dstAddr;
}

struct metadata {
    /* empty */
}

struct headers {
    ethernet_t   ethernet;
    ipv4_t       ipv4;
}

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

parser MyParser(packet_in packet,
                out headers hdr,
                inout metadata meta,
                inout standard_metadata_t standard_metadata) {

    state start {
        transition parse_ethernet;
    }

    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);
        transition accept;
    }

}
```

Verifiable Networks

Static Approaches

- Use programmability to get precise model
- Check network properties via static analysis

Dynamic Approaches

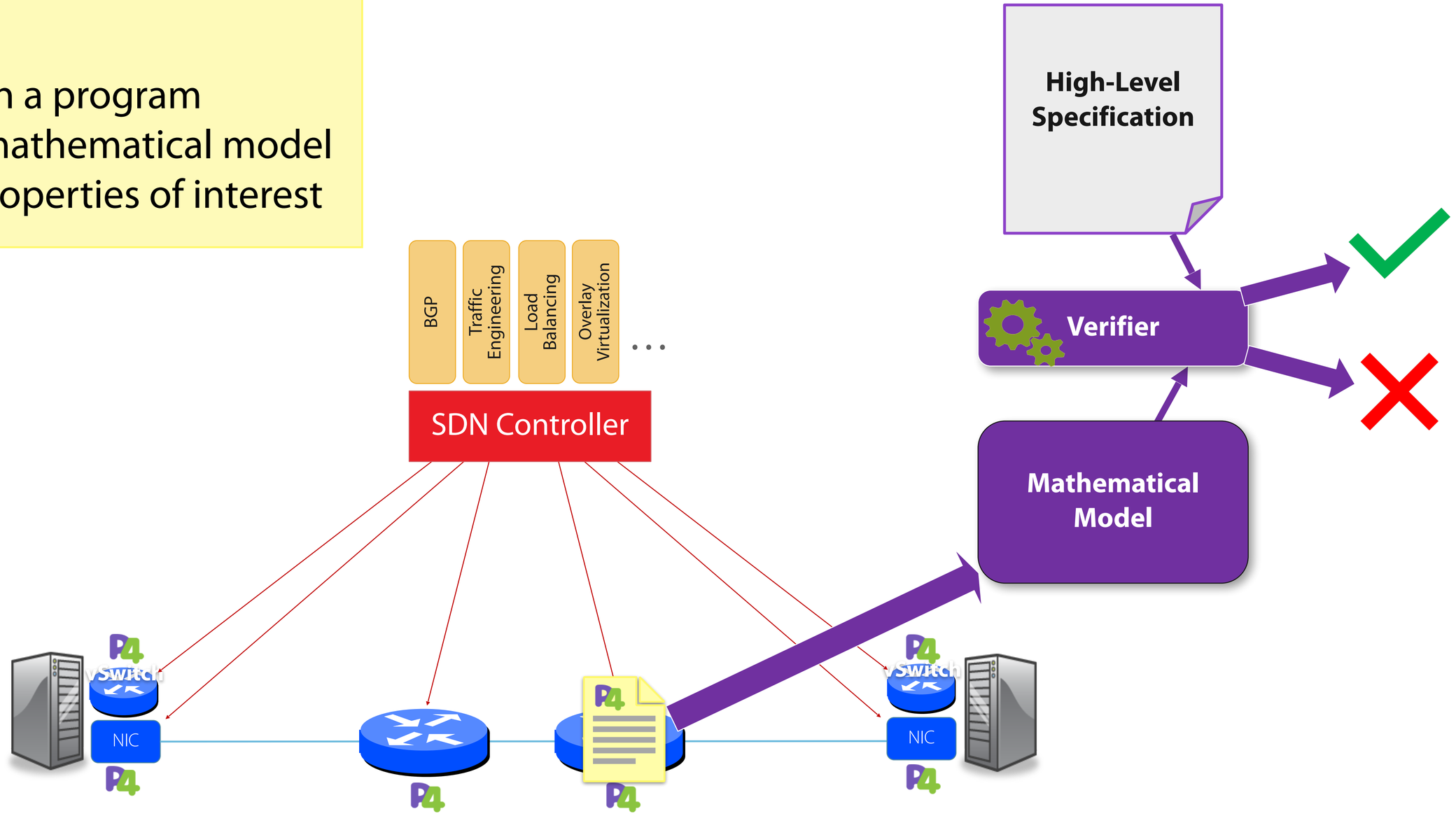
- Use programmability to instrument network
- Check observations against formal specification

Static Verification

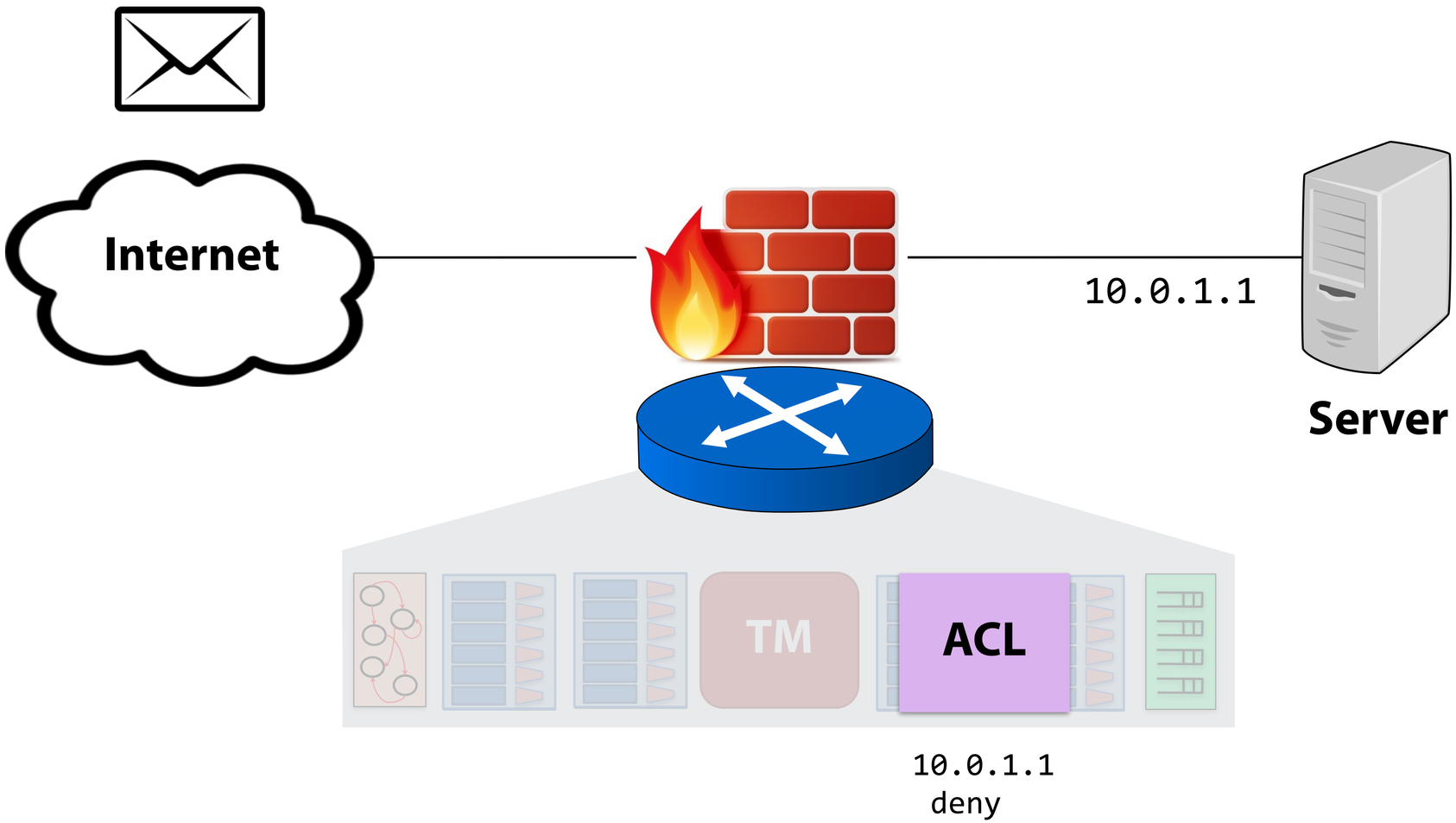
Static Verification

Approach

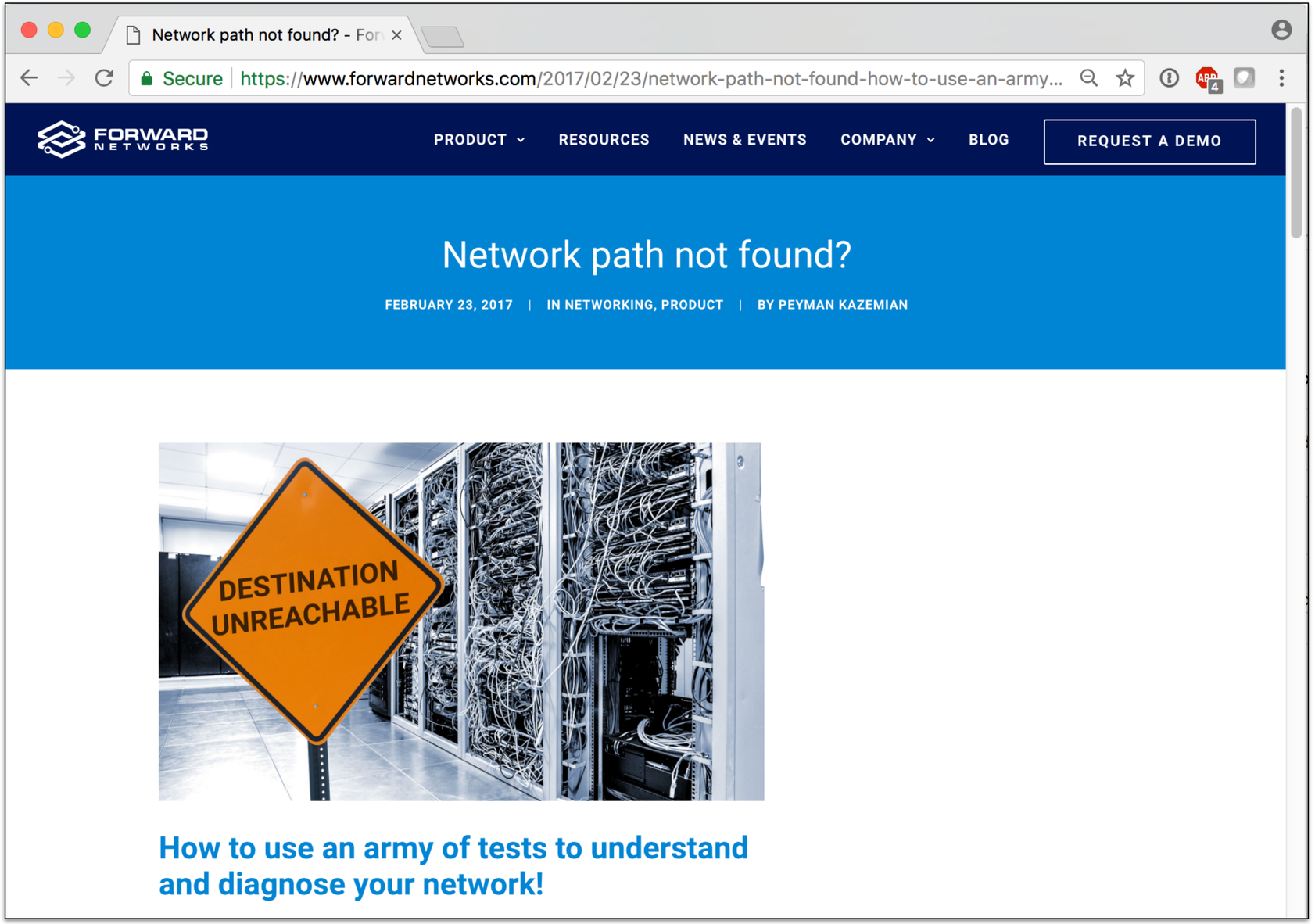
- Start with a program
- Extract mathematical model
- Check properties of interest



Example: ACL

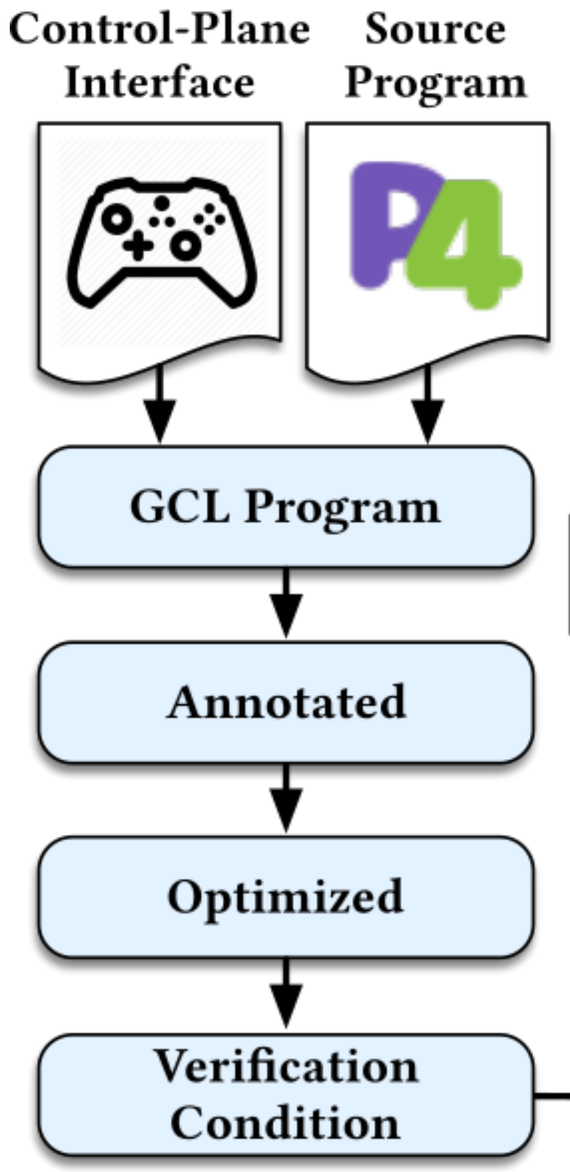


This is not a toy example!



Demo

p4v Architecture




```
[Result] Passed
```

```
[Result] Failed
[Counterexample]
[ Parser ] start
[ Parser ] _parse_ethernet
[ Packet ] ethernet.dst_addr = 0x000000000000
[ Packet ] ethernet.src_addr = 0x000000000000
[ Packet ] ethernet.ether_type = 0xf7ff
[ Assert ] (not (= ipv4.valid 1w0))
```

1. Start with P4 Program
2. Annotate with assertions
3. Translate to imperative code
4. Apply standard optimizations
5. Generate first-order formula
6. Send to theorem prover
7. Success or counterexample
   - Input packet
   - Program trace
   - Violated assertion

Evaluation: `switch.p4`

Statistics

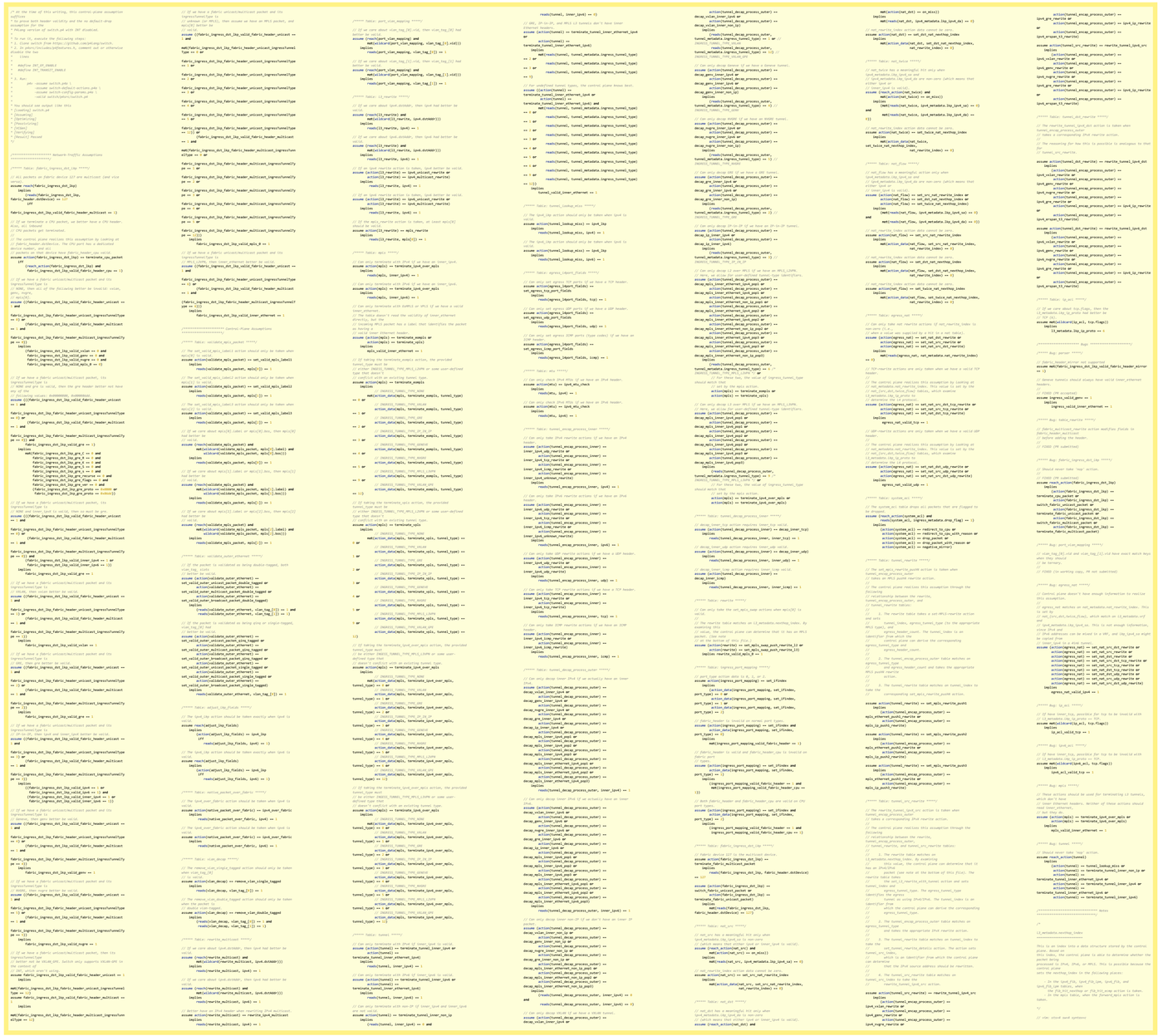
- 5,599 LoC
- 58 parser states
- 120 match–action tables

Control-plane interface

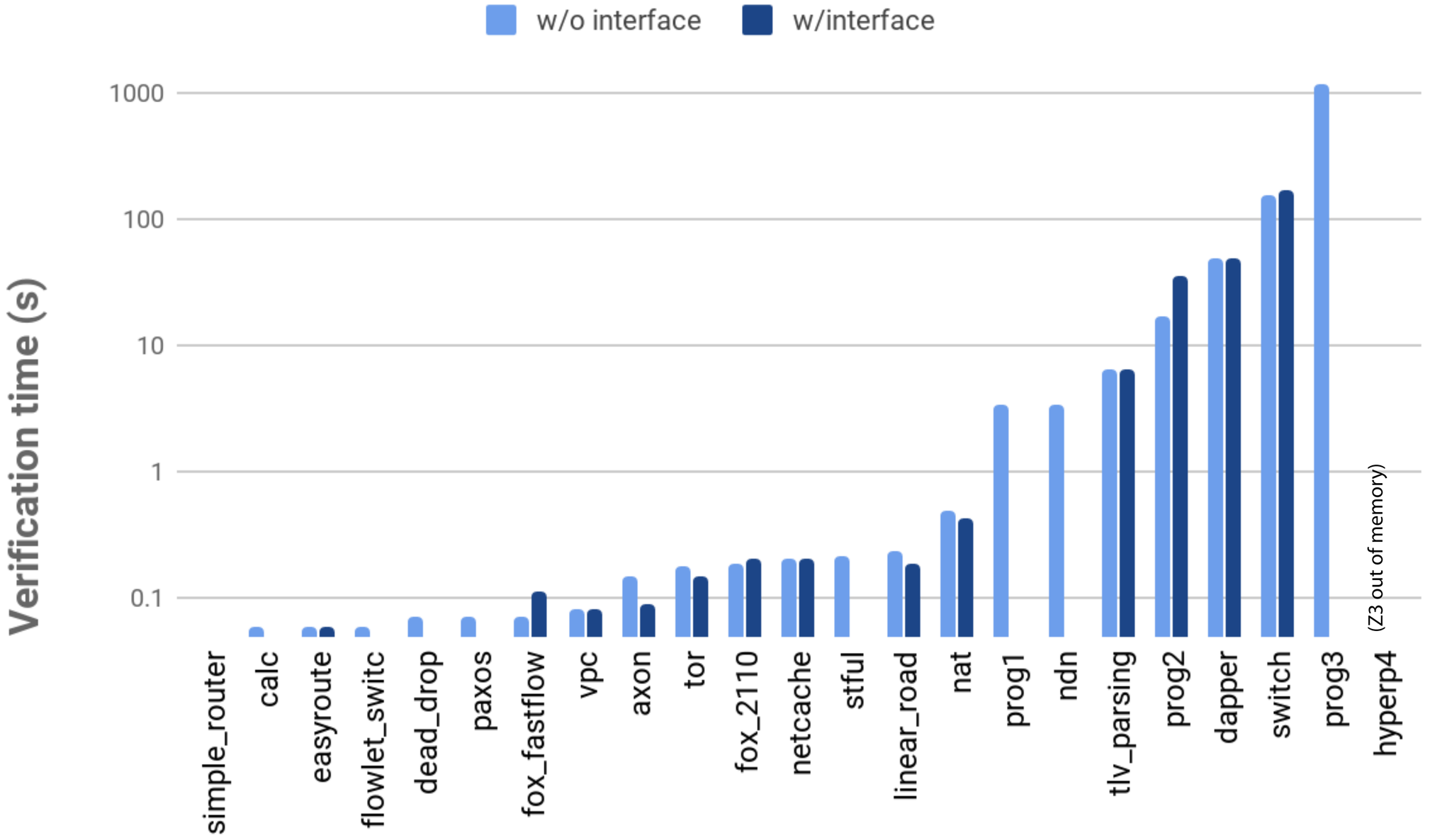
- 758 LoC
- ~2 days' programmer effort
- Default actions (31)
- Fabric wellformedness (14)
- Table actions (66)
- Guarded reads (10)
- Action data (14)

Found 10 bugs

- Parser bugs (2)
- Action flaws (4)
- Infeasible control-plane (3)
- Invalid table read (1)

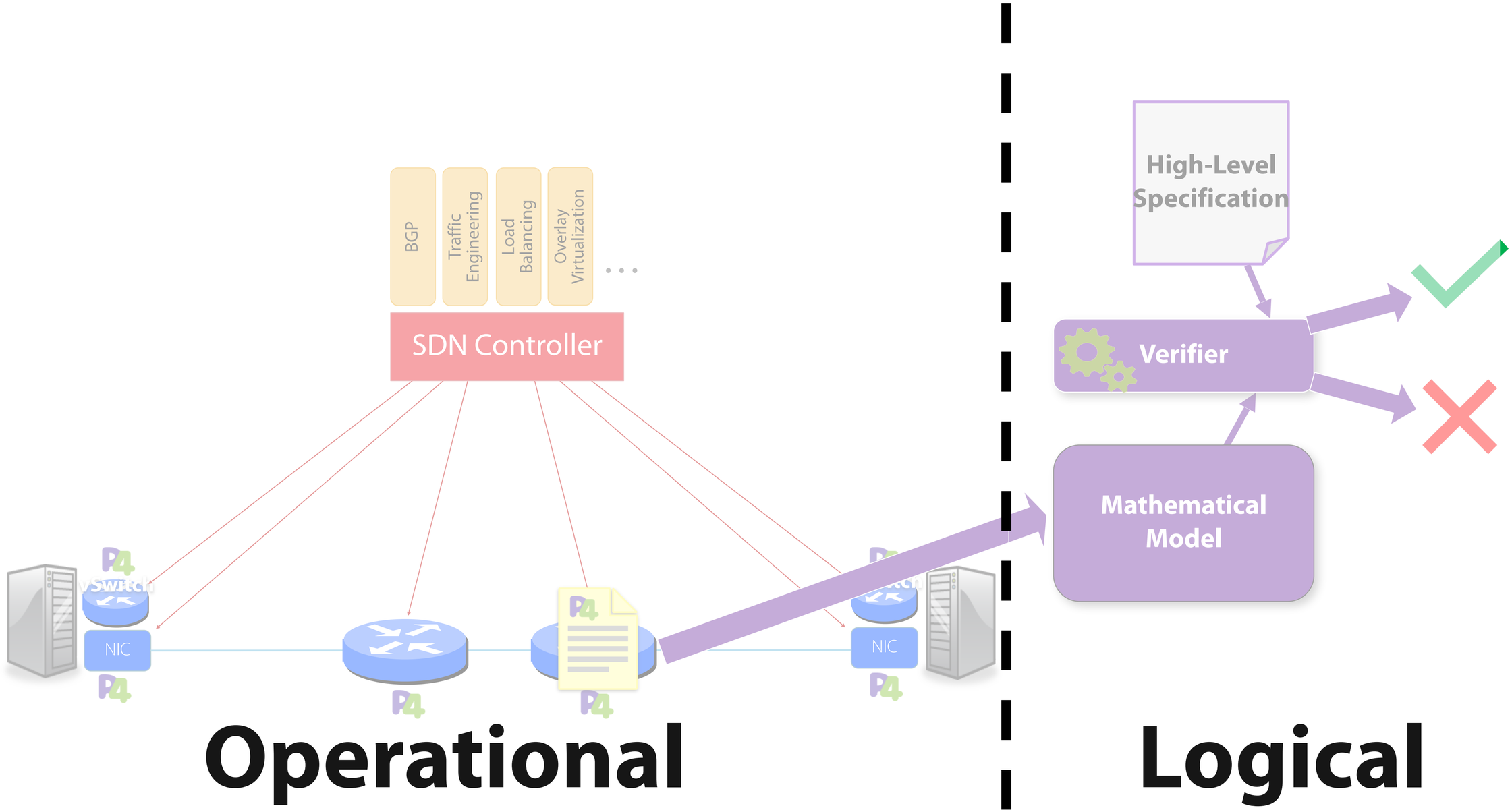


p4v Scalability



Dynamic Verification

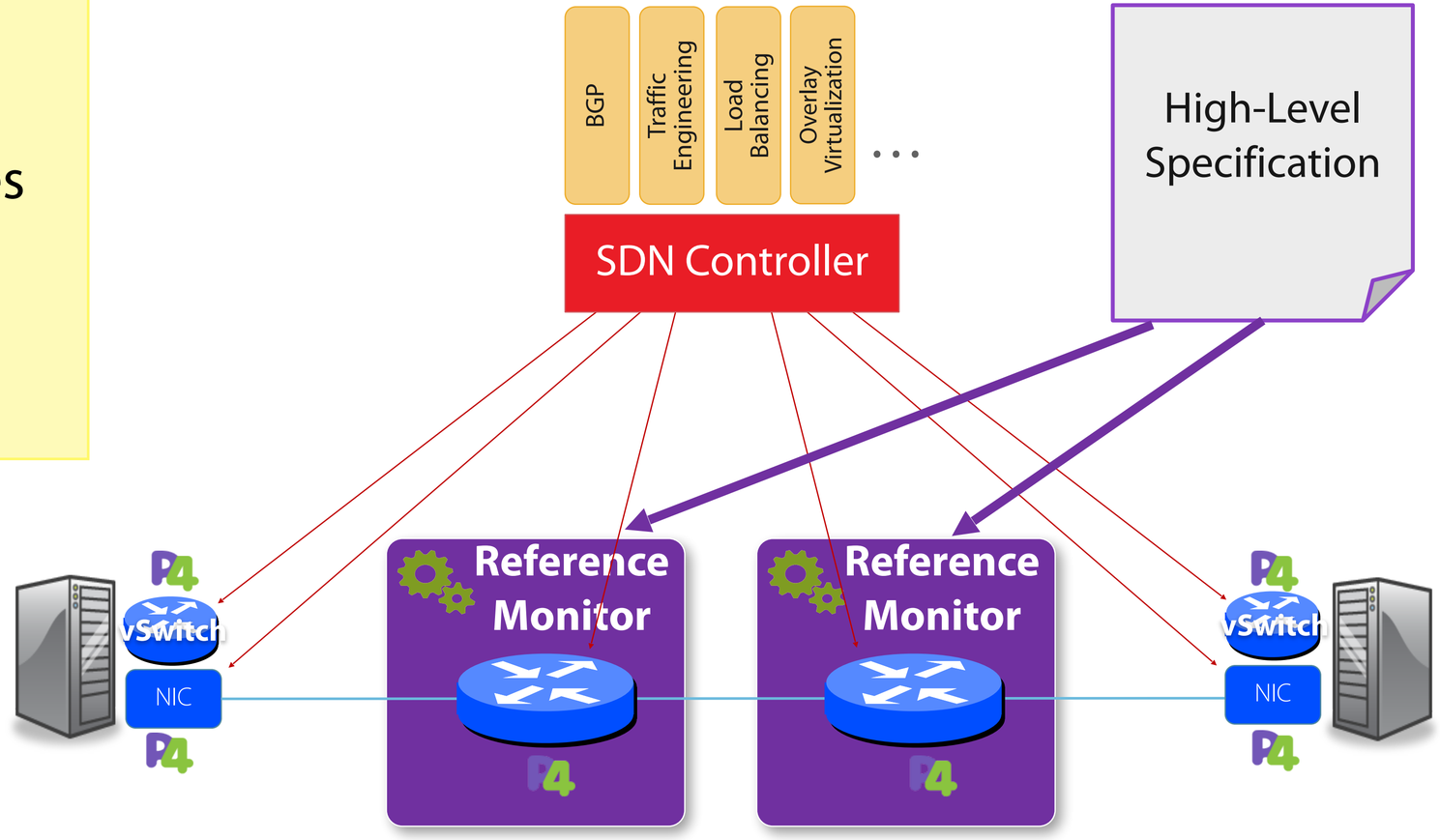
Limits of Static Verification



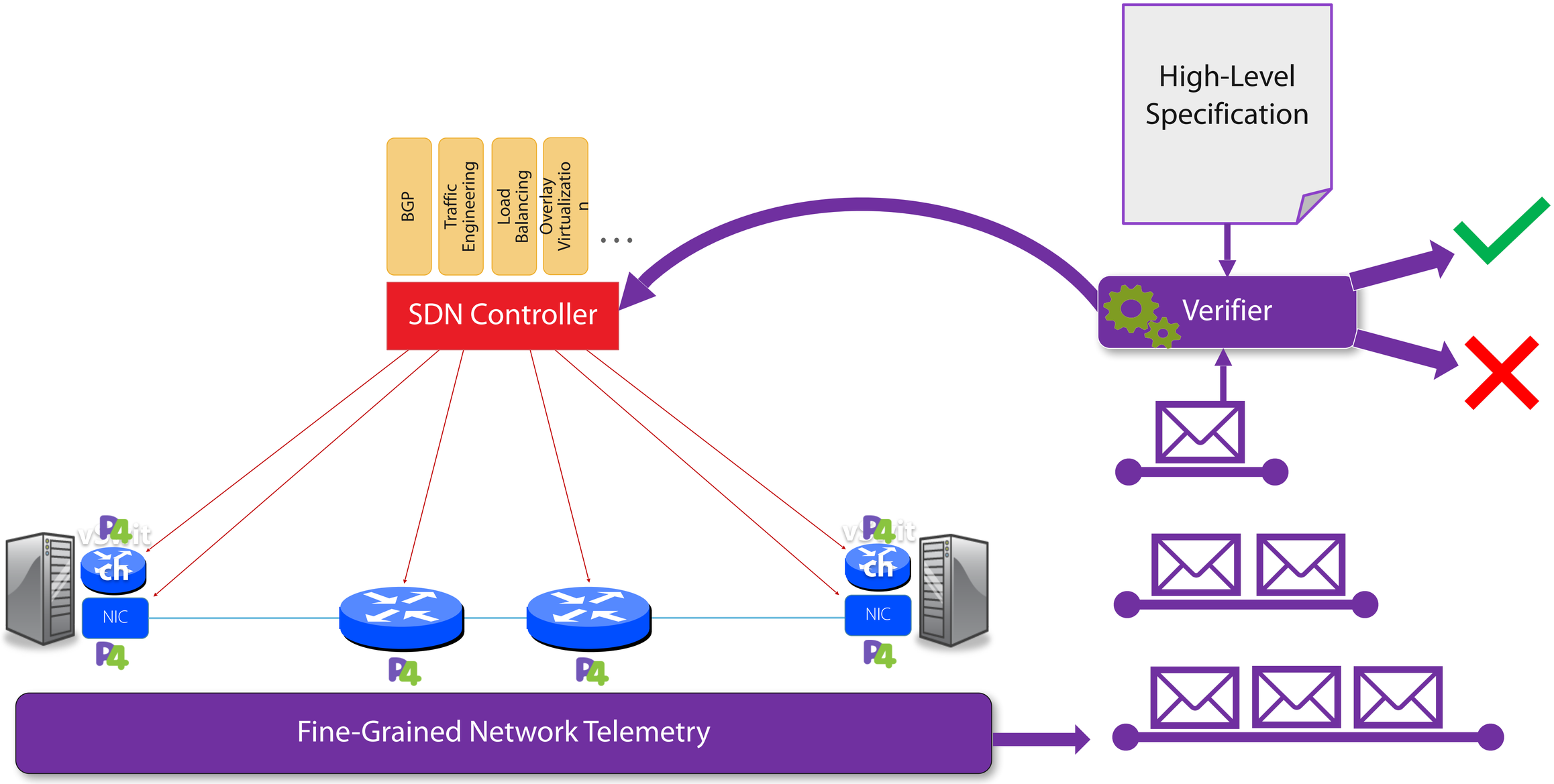
Run-Time Verification

Approach

- Start with a specification
- Compile to local predicates
- Wrap components with a reference monitor that checks for violations



Verifiable Closed-Loop Control



Research Opportunities

- **Efficiency:** can we make collection and analysis of fine-grained telemetry scalable and efficient?

- **Expressiveness:** can we use run-time techniques to verify rich properties (e.g., QoS, causality, etc.)?

- **Trust:** can we trust the network components used to generate and analyze telemetry data?

Thank You!

Collaborators

- Calin Cascaval (Barefoot)
- Bill Hallahan (Yale)
- JK Lee (Barefoot)
- Jed Liu (Barefoot)
- Nick McKeown (Stanford)
- Guru Parulkar (Stanford / ONF)
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