SymPerf:
Predicting Network Function Performance

European Research Council
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The Need for Predictability

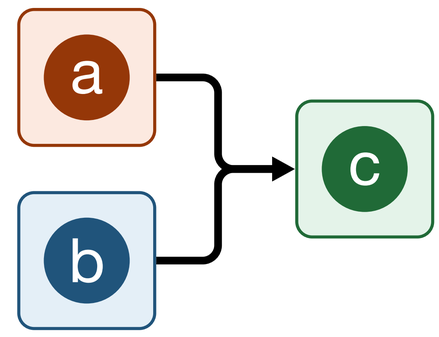
- Software-based on-path Network Functions
  - Would be very nice to have!
  - But operators fear uncertainty of code execution
    - Performance degradation
    - Buggy behavior
    - Interference with other flows/services
    - Generation of unwanted traffic
- To gain trust in software-based NFs, we need to:
  - Predict, assess, analyze, …, know!
  - The behavior and performance impact of a network function before deploying it
  - Ideally: a rigorous, precise and automated tool

High Level Overview

a Symbolic Analysis of NF Code
- Rigorous analysis of all feasible execution paths
- Set of all possible instruction chains
- Detect bugs, e.g., buffer-overflows

b Per-Platform Calibration
- Instruction cost and execution model

c Performance Prediction
- Predicts required computational effort of the NF
- For a given traffic pattern, best/worst case, equal distribution…
- Predicts impact on network ressources



SymPerf

Per Function

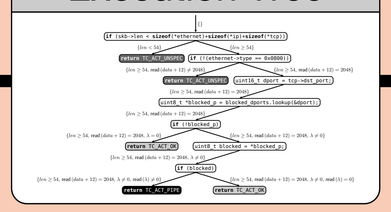
Network Function

```c
#include <bcc/proto.h>
#include <linux/pkt_cls.h>
#include <net/sock.h>
BPF_TABLE("hash", uint16_t, uint8_t, blocked_dports, 4096);

int act_main(struct __sk_buff *skb) {
    u8 *cursor = 0;
    struct ethernet_t *ethernet;
    struct ip_t *ip;
    struct tcp_t *tcp;
    if (skb->len < sizeof(*ethernet)+sizeof(*ip)+sizeof(*tcp)) return TC_ACT_UNSPEC;

    ethernet = cursor_advance(cursor, sizeof(*ethernet));
    if (!(ethernet->type == 0x0800)) return TC_ACT_UNSPEC;
    ip = cursor_advance(cursor, sizeof(*ip));
    if (ip->nextp != 0x06) return TC_ACT_UNSPEC;

    tcp = cursor_advance(cursor, sizeof(*tcp));
    uint16_t dport = tcp->dst_port;
    uint8_t *blocked_p = blocked_dports.lookup(&dport);
    if (!blocked_p) return TC_ACT_OK;
    uint8_t blocked = *blocked_p;
    if (blocked) return TC_ACT_PIPE;
    else return TC_ACT_OK;
}
```

1 Symbolically analyze the NF
- Generate Execution Tree
- All feasible paths

2 If bugs are found, fix NF

Execution Tree



3 Walk the Execution Tree
- Each Path corresponds to exactly one Instruction Chain
- Extract finegrained information

Instruction Chains

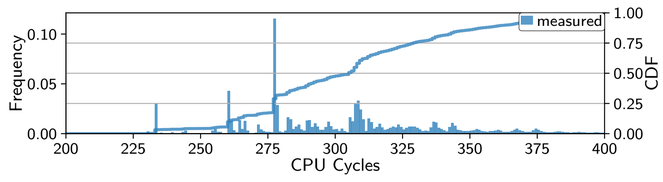
```
1 alloca
2 getelementptr
3 load
4 icmp
5 br
6 bpf_load_half
7 icmp
8 br
```

…

```
1 alloca
2 getelementptr
3 load
4 icmp
5 br
6 bpf_load_half
7 icmp
8 br
9 bpf_load_byte
10 icmp
11 br
12 bpf_load_half
13 trunc
14 store
15 bpf_pseudo
16 bpf_map_lookup
17 hash(2, 1)
18 icmp
19 br
20 load
21 icmp
22 br
```

Per Platform

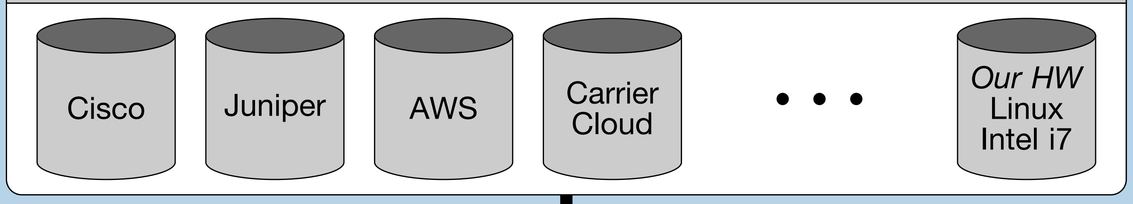
4 Calibrate the Platform
- Each platform has different performance characteristics
- Perform a series of microbenchmarks
- *Once* per platform
- Is done *offline* and can be *shared*
- **No testbed required!**



Offline Calibration

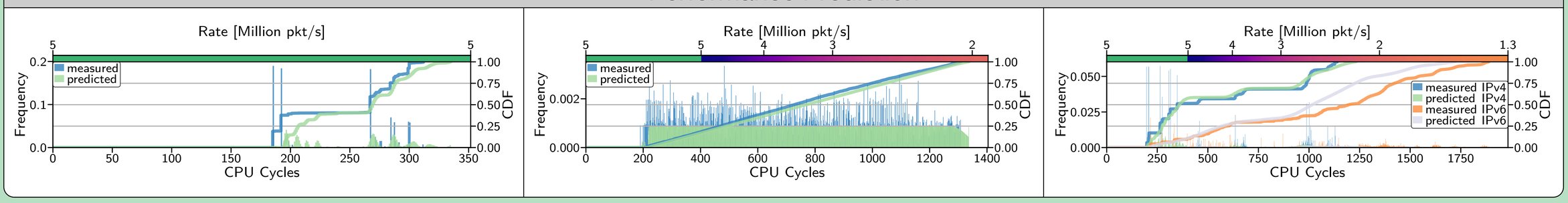
Measure instruction costs on target platform, e.g., CPU cycles needed for an `add` instruction on our hardware (i7-870)

Per Platform Instruction Cost Databases



Performance Prediction

Performance Prediction



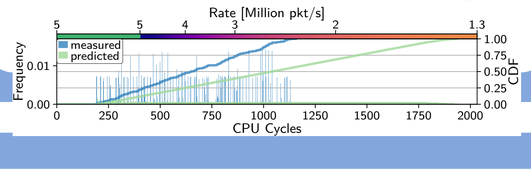
5 Predict the performance of a Network Function
- Convolute the costs for each instruction in a chain
- Combine path predictions by traffic pattern (e.g., from `.pcap` traces)
- Predict average case or worst case

6 Improve the performance of a Network Function
- Create test cases to assist the NF engineer with…
- … increasing packet rate
- … reducing latency
- … hardening against attacks

Opportunities

CPU Effects

- Thoroughly analyze CPU effects
  - Caching probably has little impact
  - Branch prediction on the other hand…



System Interactions

- Which packet rate is actually achievable for a certain NF?
- How do multiple NFs interact with one another?
  - When used serially on the same packets, or …
  - … independently on different flows
- How does the persistent state influence behavior?
  - Can invariants be proven?
  - … in the presence of race conditions?

Symbolic Analysis

- Symbolic Execution is prone to path explosion, even when bounded
  - How far can we push it in this specific area?
- SMT solvers, while impressive, still have to solve NP-hard problems
  - How well can cryptographic functions be emulated?
- How can interactions between multiple NFs be modeled?
  - On the same system, or…
  - … over the network

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SYMBIOSYS

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https://www.comsys.rwth-aachen.de/research/projects/symbiosys/

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