Performance Interfaces for Network Functions

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EPFL

Semantic Interfaces

connect

```
public void connect(SocketAddress endpoint)
             throws IOException
```

Connects this socket to the server.

Parameters:

`endpoint` - the `SocketAddress`

Throws:

`IOException` - if an error occurs during the connection

`IllegalBlockingModeException` - if this socket has an associated channel, and the channel is in non-blocking mode

`IllegalArgumentException` - if endpoint is null or is a SocketAddress subclass not supported by this socket

Since:

1.4

https://docs.orcale.com/javase/7/docs/api/java/net/Socket.html

Semantic Interfaces

```
int aws_array_list_get_at_ptr(
        const struct aws_array_list* list,
        void **val,
        size_t index)
{
    AWS_PRECONDITION(aws_array_list_is_valid(list));
    AWS_PRECONDITION(val != NULL);
    if (aws_array_list_length(list) > index) {
        *val = (void *)((uint8_t *)list->data +
                        (list->item_size * index));
        AWS_POSTCONDITION(aws_array_list_is_valid(list));
        return AWS_OP_SUCCESS;
    }
    AWS_POSTCONDITION(aws_array_list_is_valid(list));
    return aws_raise_error(AWS_ERROR_INVALID_INDEX);
}
```

Code-Level Model Checking in the Software Development Workflow, Chong et al., ICSE (2020)

An Ideal Interface

- Simple
  - Concise
  - Accessible
- Precise

Can there exist a performance interface?

- Simple
  - Concise
  - Accessible
- Precise

Performance Interfaces for NFs

- Concise: 100-1000x shorter than NF implementations
- Accessible: use similar primitives as semantic specifications
- Precise: predict NF latency with avg. error of 8%

- Simple, precise performance interfaces are useful!
  - NF developers can identify performance regressions/bugs
  - NF operators can identify root cause of performance anomalies

Performance Interfaces for NFs

Performance interfaces summarize NF latency simply and precisely, just like semantic interfaces summarize functionality

Outline

- What do performance interfaces look like?
- What could one do with performance interfaces?
- How to extract performance interfaces from NF code?
- Evaluation

Outline

- **What do performance interfaces look like?**
- What could one do with performance interfaces?
- How to extract performance interfaces from NF code?
- Evaluation

```python
def perf_interface_vignat(pkt):
    # Perf metric: x86 instructions
    # Resolution: 1
    # NF state: flowtable
    # PCVs:
    #   s - flowtable.stale_flows
    #   t - flowtable.bucket_traversals
    #   c - flowtable.hash_collisions

    x = 19*s*t + 40*s*c + 227*s + 123
    if (pkt.port != internal_network):
        if not (pkt.is_IP):
            return x
        else:
            if pkt.is_TCP:
                if flowtable.contains(pkt.flow):
                    return x + 288
                else:
                    return x + 67
            else:
                if not (pkt.is_UDP):
                    return x + 13
                else:
                    if flowtable.contains(pkt.flow):
                        return x + 290
                    else:
                        return x + 69
    else:
        if not (pkt.is_IP):
            return x
        else:
            if pkt.is_TCP:
                if flowtable.contains(pkt.flow):
                    return x + 18*t + 30*c + 394
                else:
                    return x + 31*t + 30*c + 546
            else:
                if not (pkt.is_UDP):
                    return x + 13
                else:
                    if flowtable.contains(pkt.flow):
                        return x + 18*t + 30*c + 396
                    else:
                        return x + 31*t + 30*c + 548
```

The performance interface of a program P is a program S_P

S_P takes the same arguments as P and returns P's performance.

```
def perf_interface_vignat(pkt):
    # Perf metric: x86 instructions
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                    if flowtable.contains(pkt.flow):
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Latency Metrics:

- x86 instructions
- x86 mem-ops
- CPU cycles

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    x = 19*s*t + 40*s*c + 227*s + 123
    if (pkt.port != internal_network):
        if not (pkt.is_IP):
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        else:
            if pkt.is_TCP:
```

PCVs = Performance Critical Variables

PCVs capture the effect of state on NF latency

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        else:
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```

r: S_p's resolution

$\mathcal{P}(P(\mathcal{I}))$:
P's performance given input $\mathcal{I}$

$|S_p(\mathcal{I}) - \mathcal{P}(p_i(\mathcal{I}))| < r$

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                else:
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                    else:
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    else:
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                    if flowtable.contains(pkt.flow):
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                    else:
                        return x + 31*t + 30*c + 548
```

coarser
resolution

```python
def perf_interface_vignat(pkt):
  # Perf metric: x86 instructions
  # Resolution: 10
  # NF state: flowtable
  # PCVs:
  #   s - flowtable.stale_flows
  #   t - flowtable.bucket_traversals
  #   c - flowtable.hash_collisions

  x = 19*s*t + 40*s*c + 227*s + 123

  if not (pkt.is_IP) or not(pkt.is_TCP or pkt.is_UDP):
    return x + 7
  else:
    if pkt.port != internal_network_port:
      if flowtable.contains(pkt.flow):
        return x + 289
      else:
        return x + 68
    else:
      if flowtable.contains(pkt.flow):
        return x + 18*t + 30*c + 395
      else:
        return x + 31*t + 30*c + 547
```

General-case interfaces

```
def perf_interface_vignat(pkt):
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```

General-case interfaces

- Precise ✓

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```

General-case interfaces

- Precise ✓
- Simple
  - Concise ✓

```
def perf_interface_vignat(pkt):
  # Perf metric: x86 instructions
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```

General-case interfaces

- Precise ✓
- Simple
  - Concise ✓
  - Accessible ?

PCVs hard to understand for those who didn't write the code

```
def perf_interface_vignat(pkt):
  # Perf metric: x86 instructions
  # Resolution: 10
  # NF state: flowtable
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        return x + 289
      else:
        return x + 68
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        return x + 18*t + 30*c + 395
      else:
        return x + 31*t + 30*c + 547
```

Deployment-specific interfaces

- get joint PCV distribution from given deployment
- replace PCV formulas with desired statistic

```
def perf_interface_vignat_ds(pkt):
  # Perf metric: x86 instructions
  # Resolution: 10
  # Statistic: 99th percentile
  # NF state: flowtable

  if not (pkt.is_IP) or not(pkt.is_TCP or pkt.is_UDF
   return 492
  else:
    if pkt.port != internal_network_port:
      if flowtable.contains(pkt.flow):
        return 774
      else:
        return 553
    else:
      if flowtable.contains(pkt.flow):
        return 1000
      else:
        return 1117
```

What does a performance interface look like?

- Program with same inputs that returns the latency
- Resolution: granularity at which interface specifies performance

- General-case interfaces express latency as a function of PCVs
- Deployment-specific interfaces express latency as concrete statistics

Outline

- What do performance interfaces look like?
- **What could one do with performance interfaces?**
- How to extract performance interfaces from NF code?
- Evaluation

Developer: Identify latency regressions

Commit ID	Perf before [# of instrns]	Perf after [# of instrns]	Performance regression [%]
Orig commit	-	1771	-
873d0501695c	1765	1896	7.42%
39e58b530a8a	1896	1914	0.95%
458aa0907b68	1914	1933	0.99%
15f81d0e7ec6	1930	1946	0.83%
74c3338c2f7e	1952	1983	1.59%
d0790d3a3823	1983	2030	2.37%
All commits	1771	2030	14.62%

Maximum packet processing latency in Katran

Operator: Root-cause diagnosis

Bug	**Root cause**	**Identified as most-likely cause?**
Spike in median latency of Bridge for uniform random workload	`hash-collisions`	Yes
Spike in tail latency of VigNAT due to high churn	`expired-flows (batched)`	Yes
Spike in median latency of Maglev on a particular x86 server	`active-flowtable-size`	Yes

Outline

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- **How to extract performance interfaces from NF code?**
- Evaluation

Performance Interface eXtractor (PIX)

- Input: NF source code in C. Output: Python performance interfaces
- Limitations:
  - Relies on Exhaustive Symbolic Execution (ESE)
    - Single-threaded, static loop bounds, cleanly separated state
  - Interfaces do not account for performance interference
  - Interfaces do not reason about queueing latency

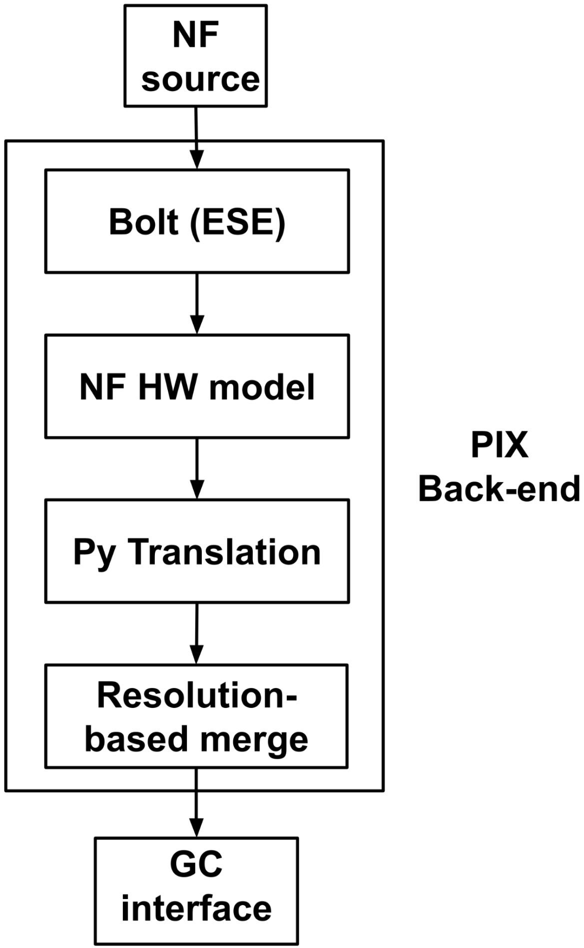
PIX Overview

- Consists of 2 parts: a back-end and front-end

- PIX back-end run by NF developers
  - Input: NF source in C.
  - Output: General-case (GC) interfaces

- PIX front-end run by NF operators
  - Inputs: NF **binary**, GC interface, packet trace.
  - Output: Deployment-specific interfaces

PIX Back-end

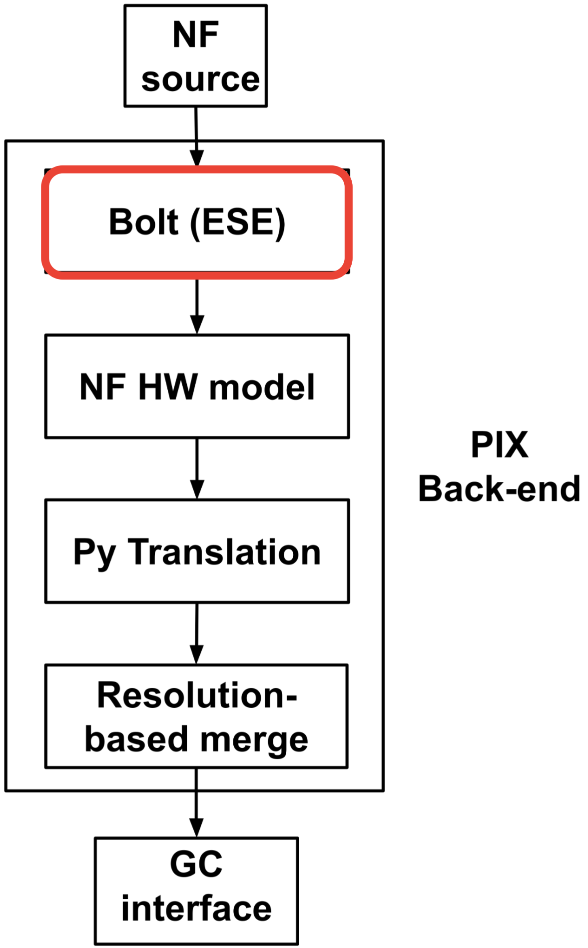


NF source
Bolt (ESE)
NF HW model
Py Translation
Resolution-based merge
GC interface
PIX Back-end

PIX Back-end

Step 1: Bolt

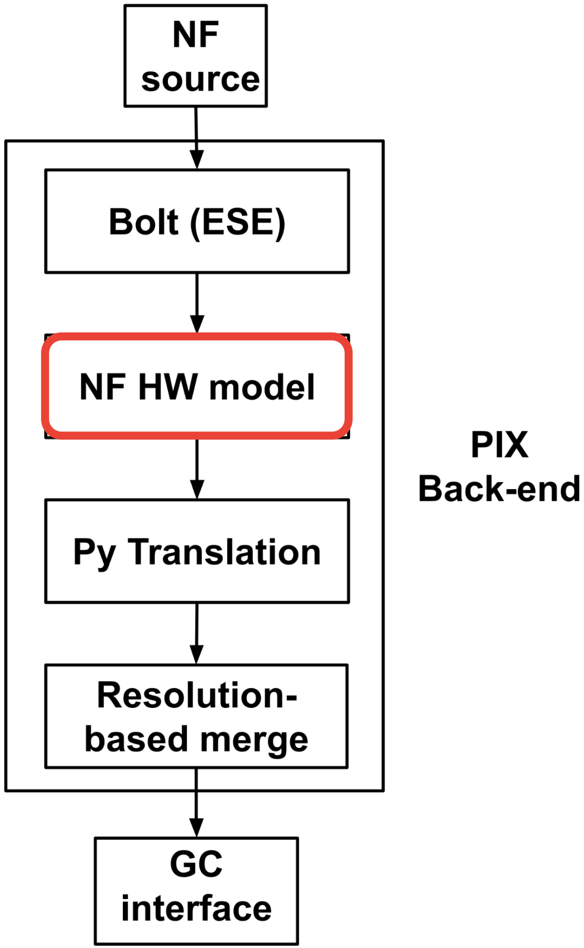
- Exhaustively symbexes the NF code
- Plugs-in contracts for pre-analyzed data structures
- Output:
    - # of x86 instructions, mem-ops per execution path



PIX Back-end

Step 2: NF Hardware Model

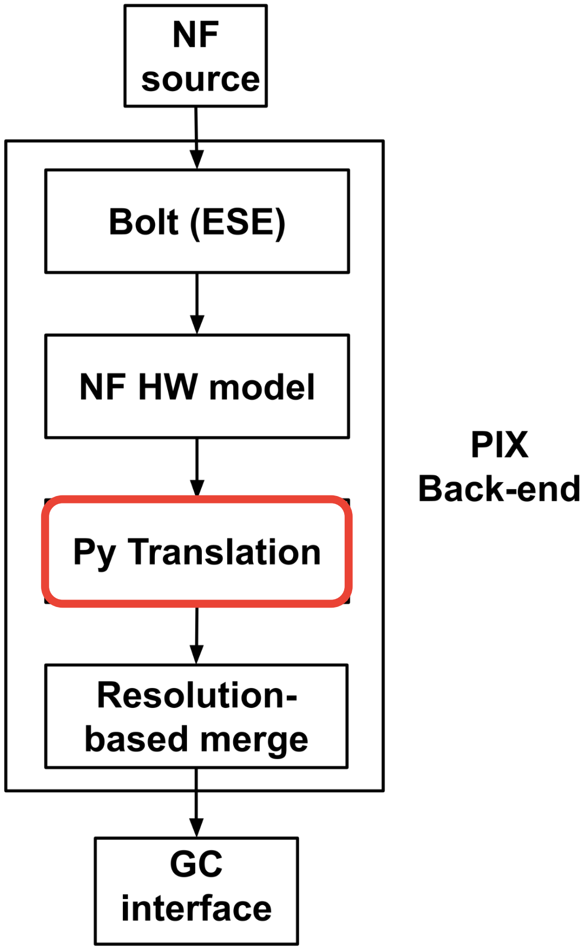
- LLC misses are primary cause of increased latency
- Taint analysis to identify potential miss sites



PIX Back-end

Step 3: Python translation

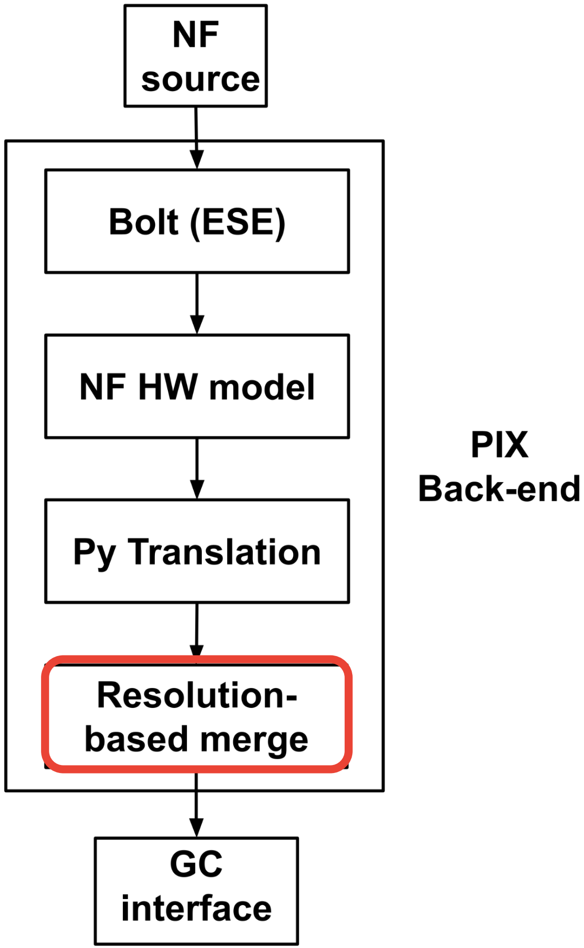
- SMT queries ⟶ human-readable python expressions



PIX Back-end

Step 4: Resolution-based merging

- Eliminates implementation details irrelevant at a given resolution



Outline

- What do performance interfaces look like?
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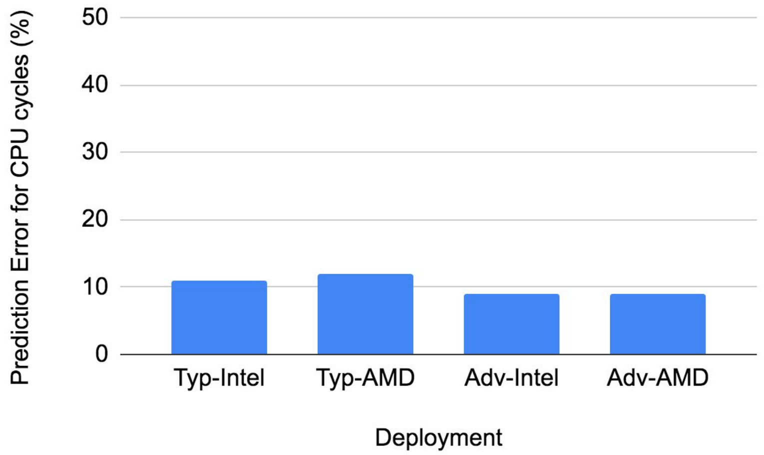
- **Evaluation**

Evaluation

- Extracted interfaces for 12 NFs written using DPDK and eBPF XDP
  - 3 NFs used in production (Katran LB, Natasha NAT, Cilium filter)
- Eval questions:
  - Accuracy of PIX-extracted interfaces
  - Time required to extract interfaces
  - Simplicity of PIX-extracted interfaces
    - 100-1000x simpler than NF implementations

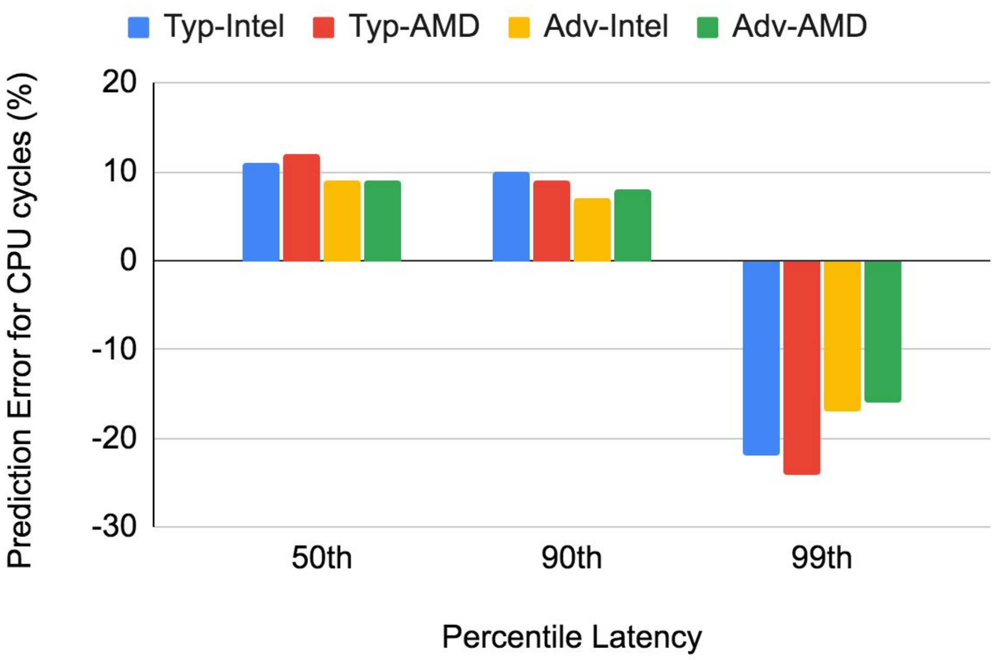
Prediction accuracy across deployments

- Evaluated accuracy for 4 deployments
  - 2 workloads (typical, adversarial) x 2 servers (Intel Sandy Bridge, AMD EPYC)
  - Absolute NF latency varies by up to 3x



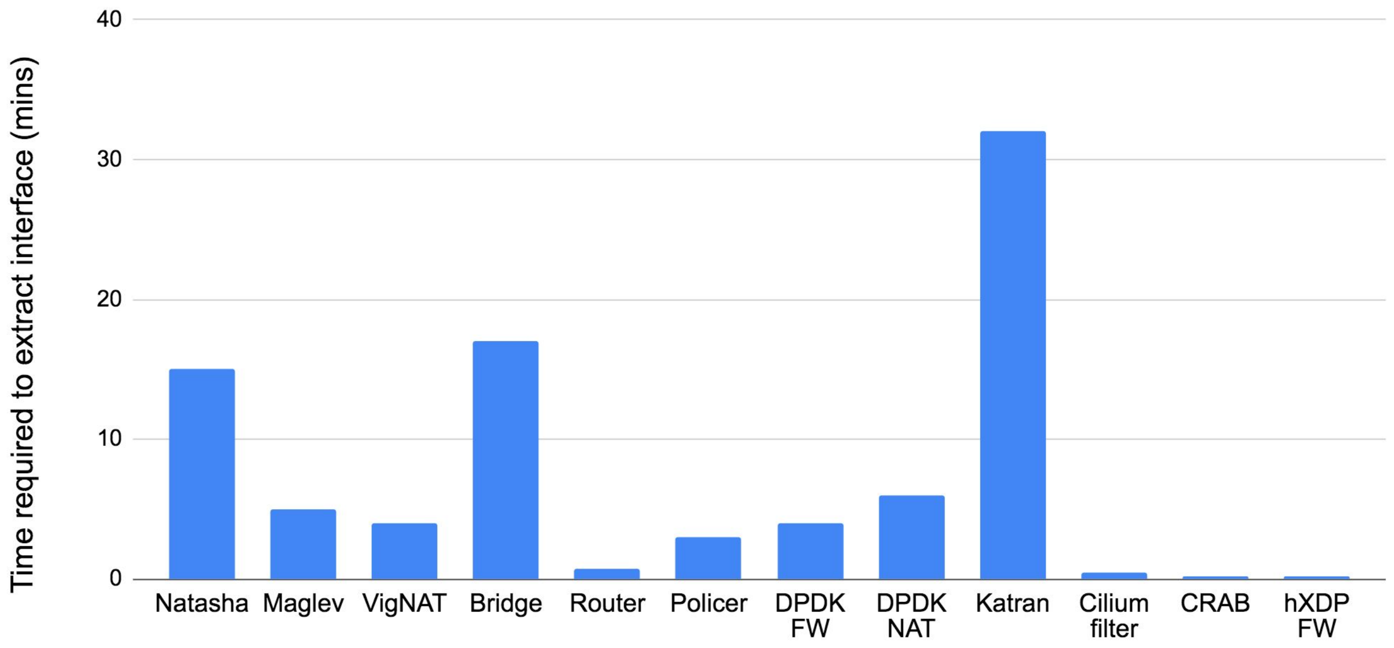
PIX-extracted interfaces correctly adapt to different deployments

Prediction accuracy across latency percentiles



PIX-extracted interfaces are accurate until the 99th percentile

Time required to extract interfaces



Extracting performance interfaces can be part of the regular NF development cycle

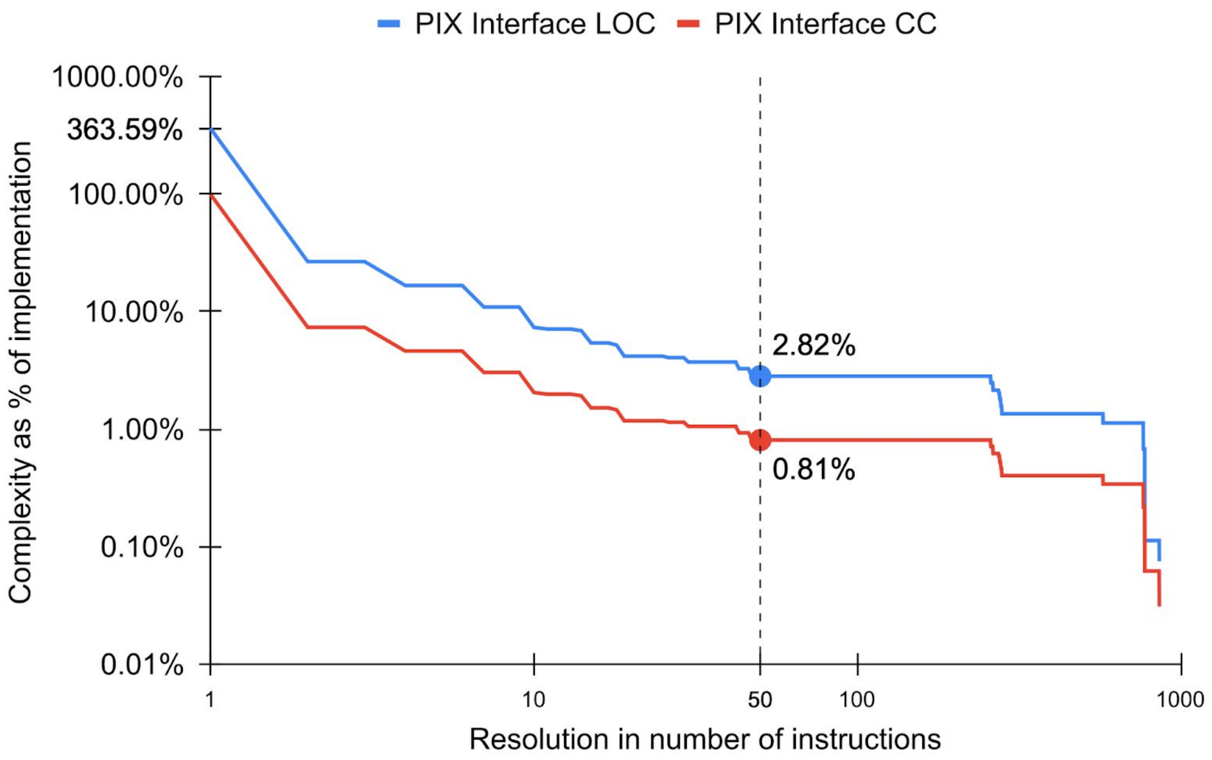
Performance Interfaces for NFs

Performance interfaces summarize NF latency simply and precisely, just like semantic interfaces summarize functionality

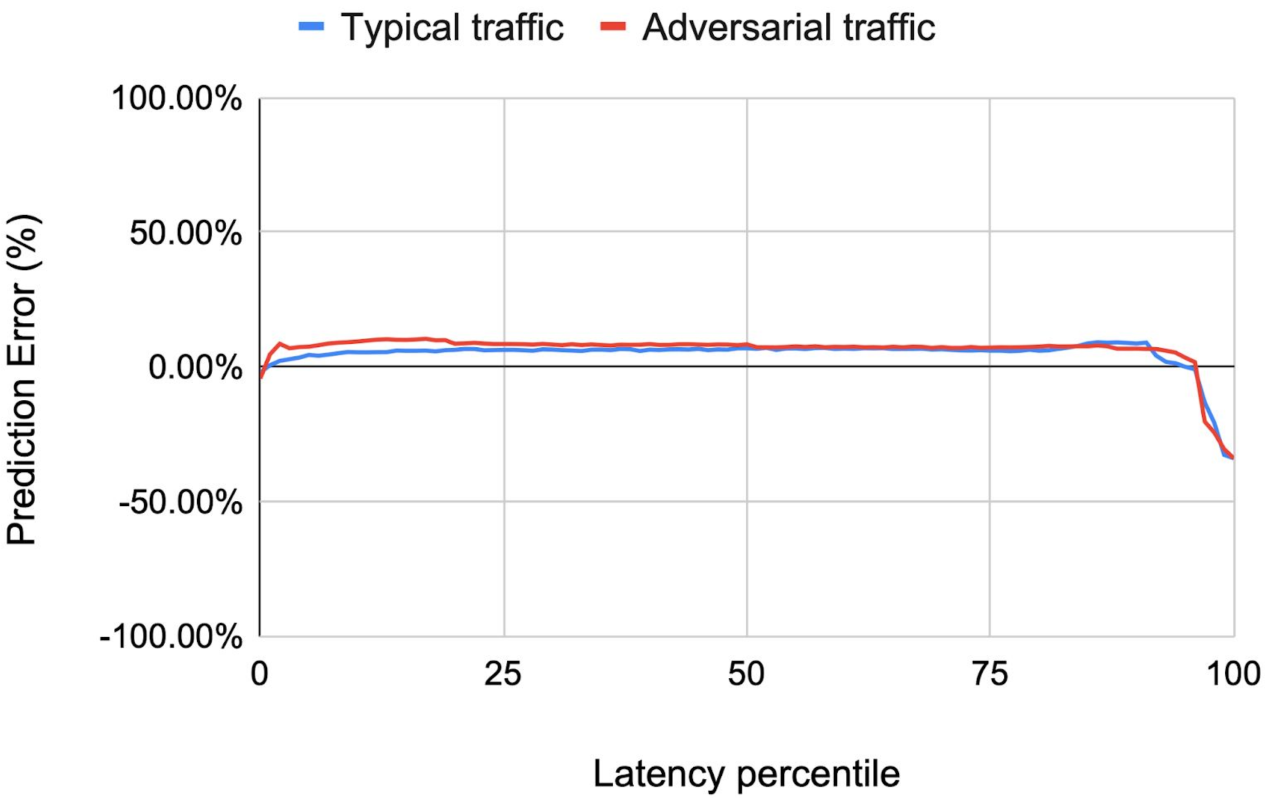
Paper and code available at:
https://dslab.epfl.ch/research/pix

Backup Slides

Backup: Complexity (Katran Load Balancer)



Backup: PIX Prediction error



Backup: Bolt Prediction Error