Leveraging FABRIC's Hardware Resources for Programmable Networking

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ILLINOIS TECH

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Goals for today

1. Examples of using FABRIC's programmable network hardware.

2. A "starter kit" for your own work.

Background

- Programmable networking

- Applications:
  - Cybersecurity
  - Research network infrastructure


sudo!
sudo!

Integrated computation

Operand 1: 3

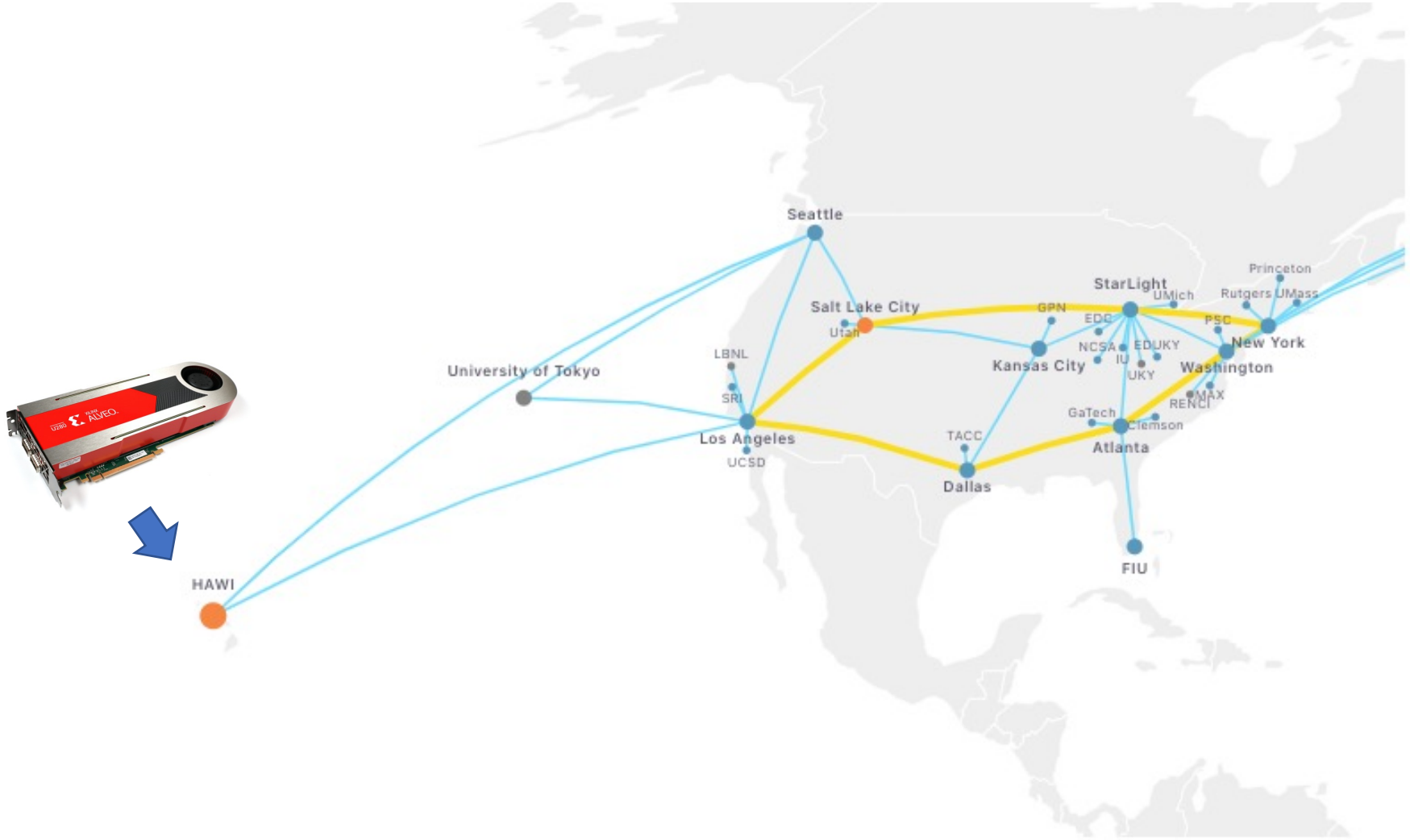
Operand 2: 5

Add

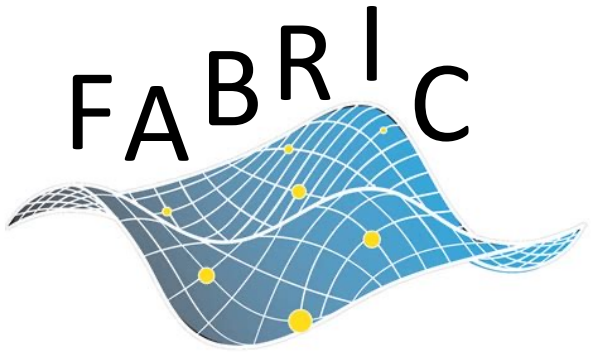
(Expand)

[ ]:


U280
XILINX
ALVEO

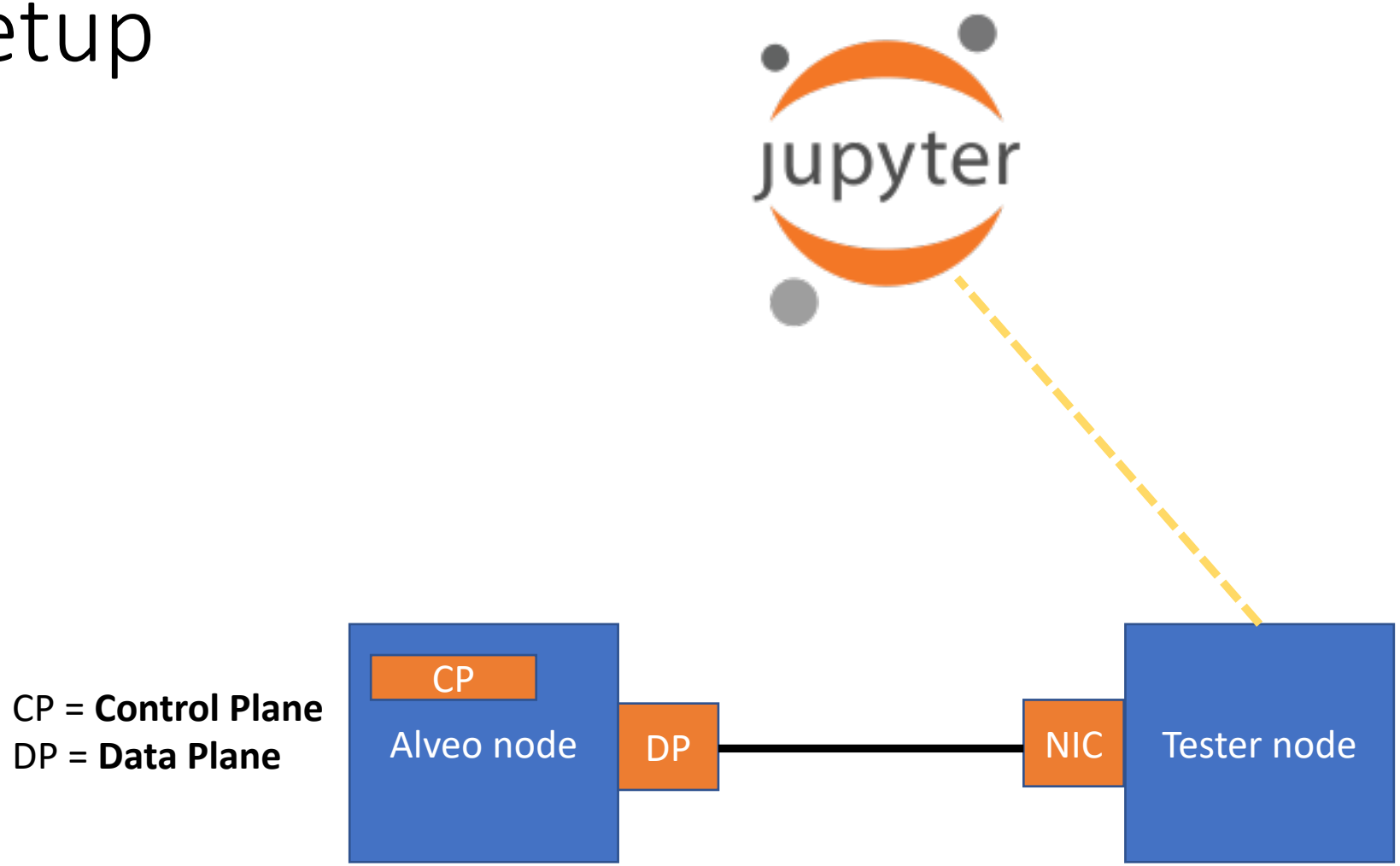

Seattle
Salt Lake City
Utah
University of Tokyo
LBNL
SRI
Los Angeles
UCSD
HAWI
GPN
StarLight
UMich
EDC
NCSA
IU
Kansas City
TACC
Dallas
Princeton
Rutgers
UMass
PSC
New York
EDUKY
UKY
Washington
MAX
RENCI
GaTech
Clemson
Atlanta
FIU

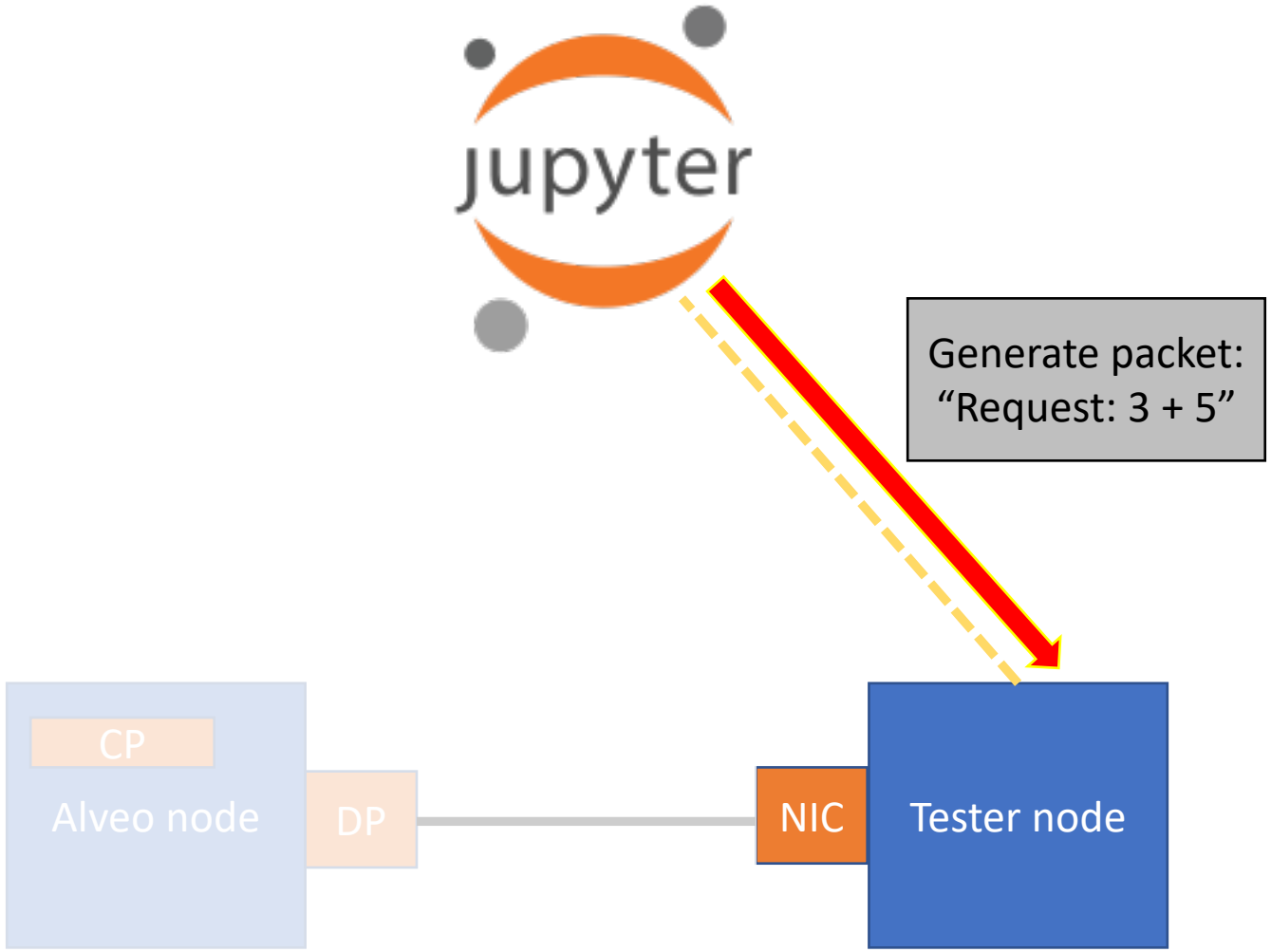
Many Alveos on FABRIC

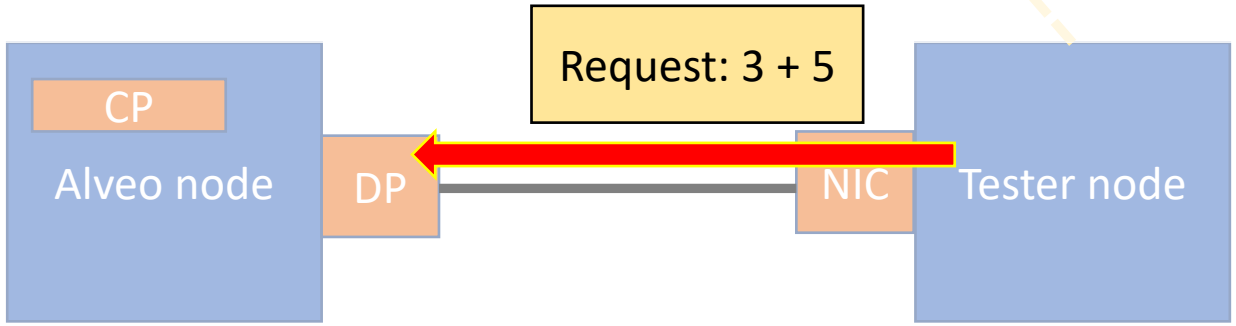


- Large geographic span
- Resource for the research community
- Non-networking and non-research applications
- High performance
- Convenient access/interface – including authn and authz, notebooks and SSH

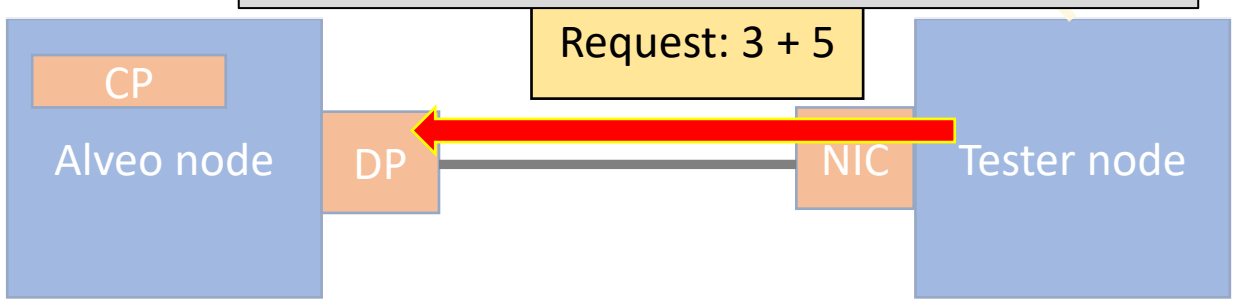
Setup

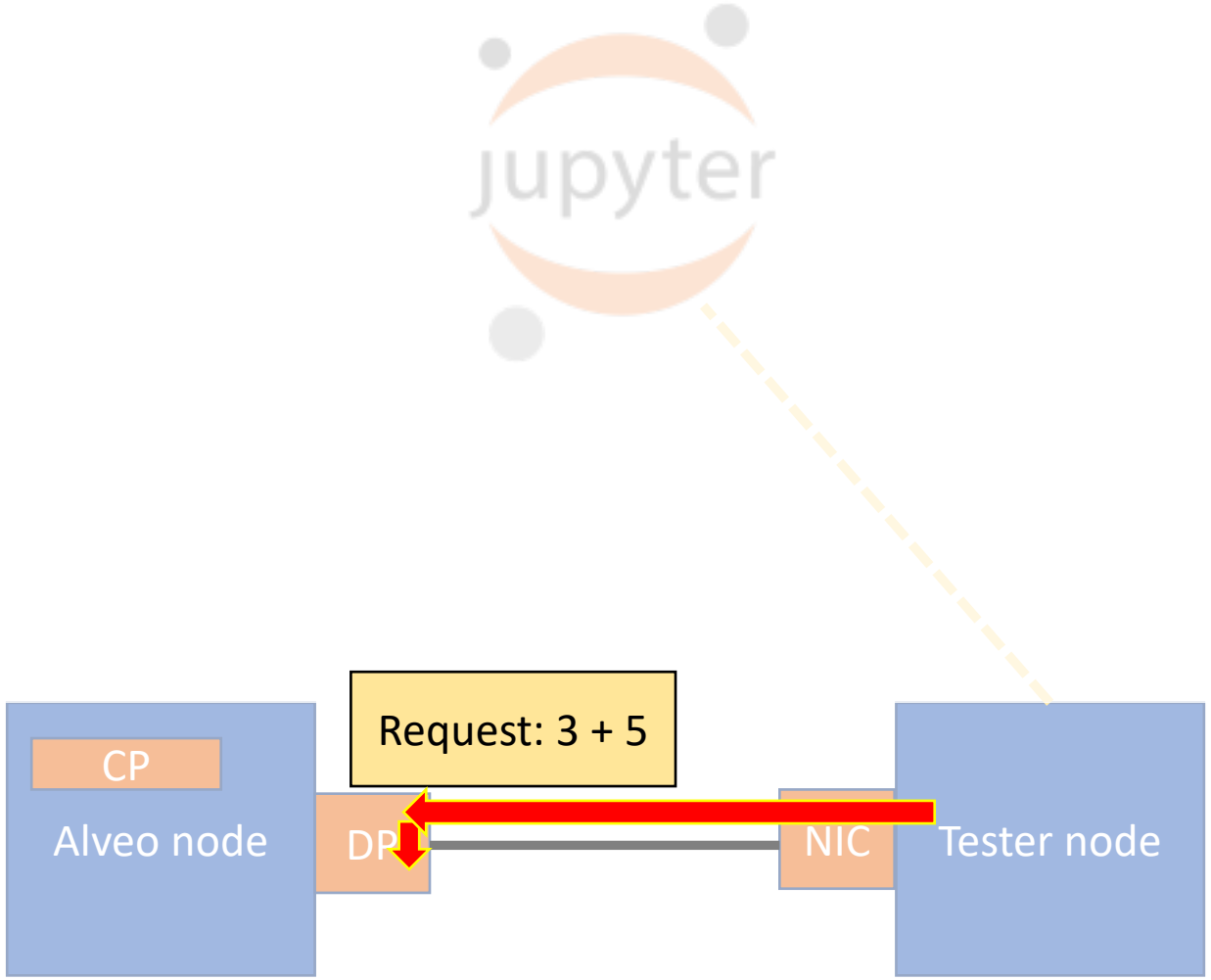

jupyter
CP = **Control Plane**
DP = **Data Plane**
CP
Alveo node
DP
NIC
Tester node

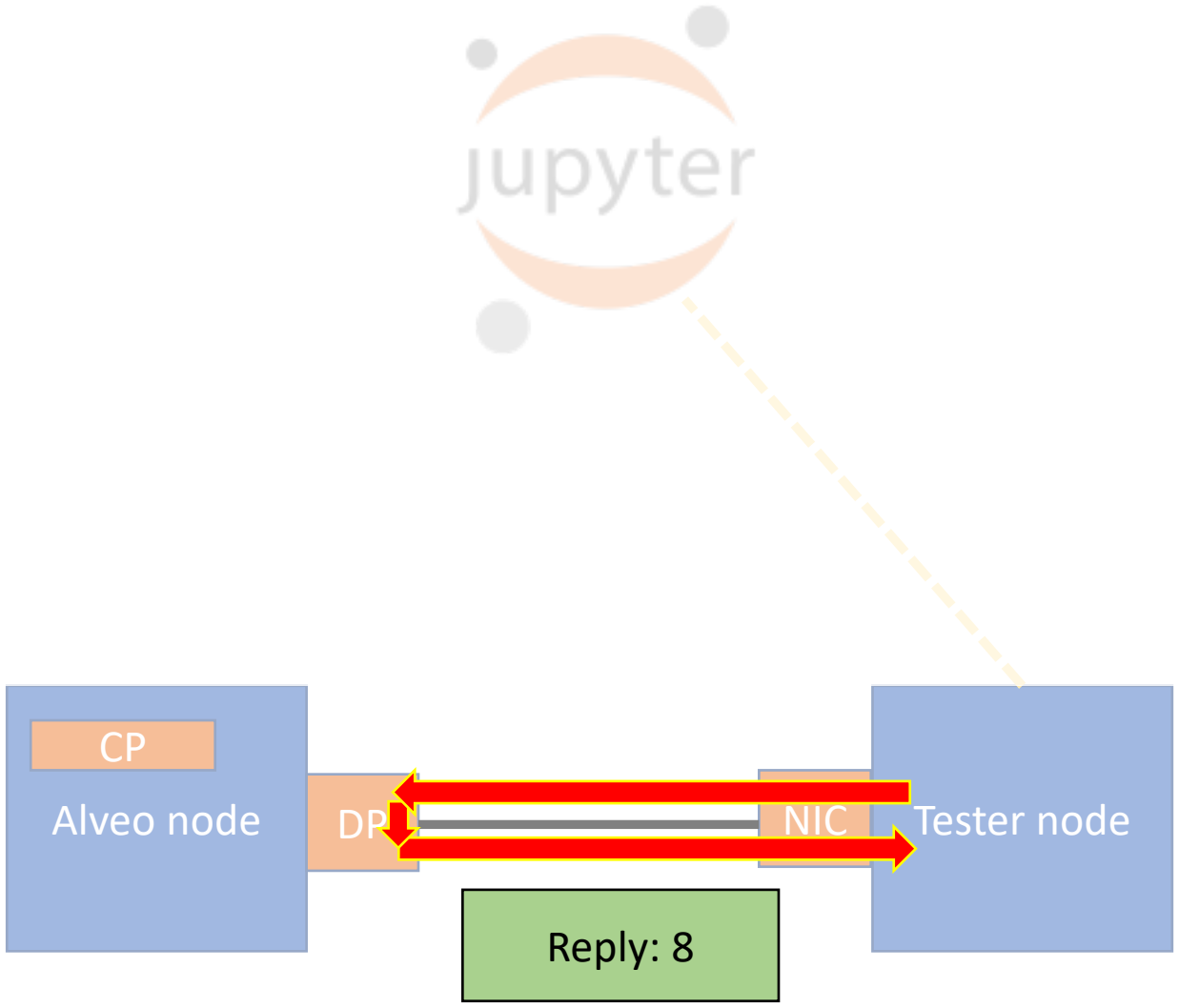

jupyter
Generate packet:
“Request: 3 + 5”
CP
Alveo node
DP
NIC
Tester node


Request: 3 + 5
CP
Alveo node
DP
NIC
Tester node

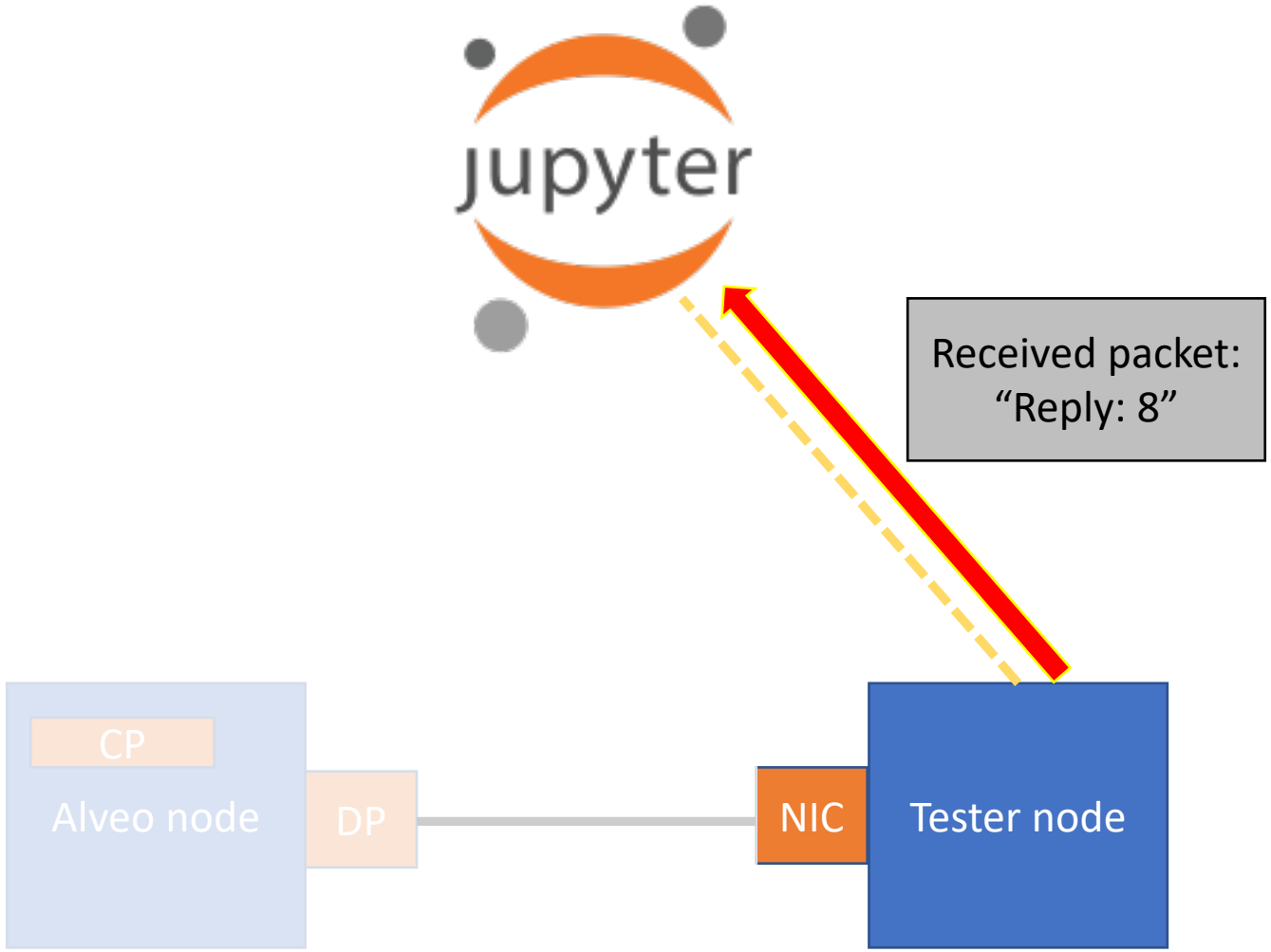
```
###[ Ethernet ]###
  dst       = 06:e4:2c:4e:db:c2
  src       = e8:eb:d3:24:b1:23
  type      = 0x1234
###[ P4calc ]###
     P         = 'P'
     Four      = '4'
     ignore    = 0x0
     version   = 0x1
     op        = 43
     operand_a = 3
     operand_b = 5
     result    = 3405695742
###[ Raw ]###
        load      = ' '
```

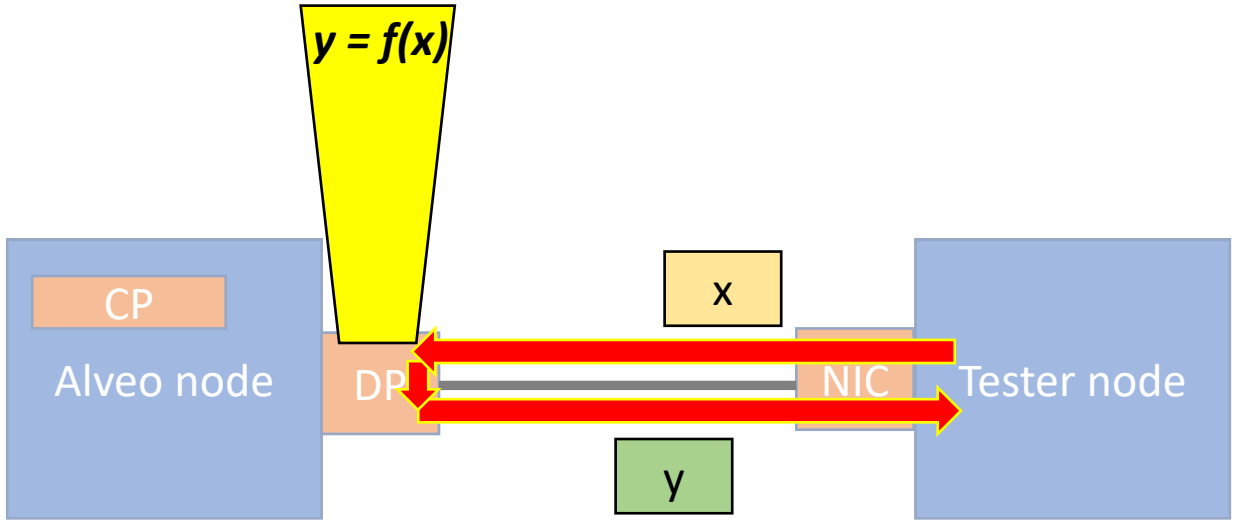


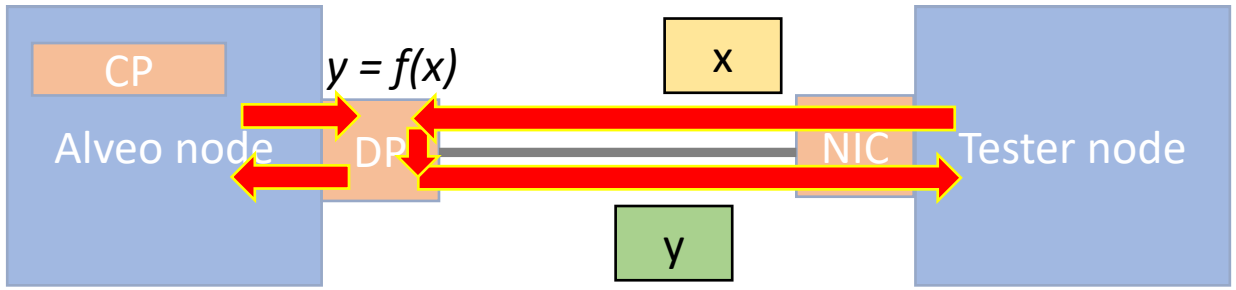

jupyter
Request: 3 + 5
CP
Alveo node
DP
NIC
Tester node


jupyter
CP
Alveo node
DP
NIC
Tester node
Reply: 8

```
###[ Ethernet ]###
  dst       = e8:eb:d3:24:b1:23
  src       = 06:e4:2c:4e:db:c2
  type      = 0x1234
###[ P4calc ]###
     P         = 'P'
     Four      = '4'
     ignore    = 0x0
     version   = 0x1
     op        = 43
     operand_a = 3
     operand_b = 5
     result    = 8
###[ Raw ]###
        load      = ' '
```

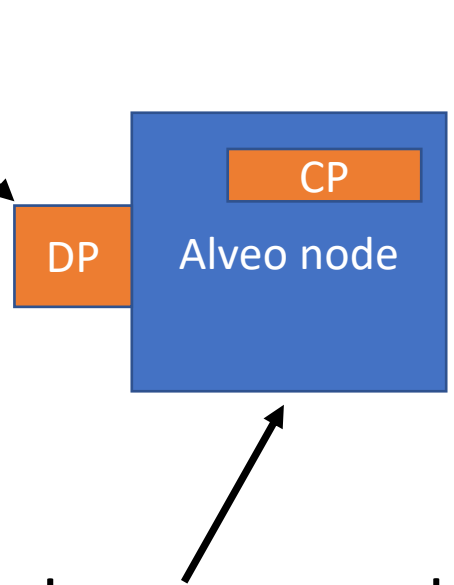

jupyter
Received packet:
“Reply: 8”
CP
Alveo node
DP
NIC
Tester node


y = f(x)
CP
Alveo node
DP
x
NIC
Tester node
y


CP
y = f(x)
x
Alveo node
DP
NIC
Tester node
y

Programmable Networking

- (Limited) computation in the **data plane**



- Rather than confine programmability to edge or control.

Programmable Networking

- (Limited) computation in the data plane

Less Expressiveness
Better Performance

- Rather than confine programmability to edge or control.

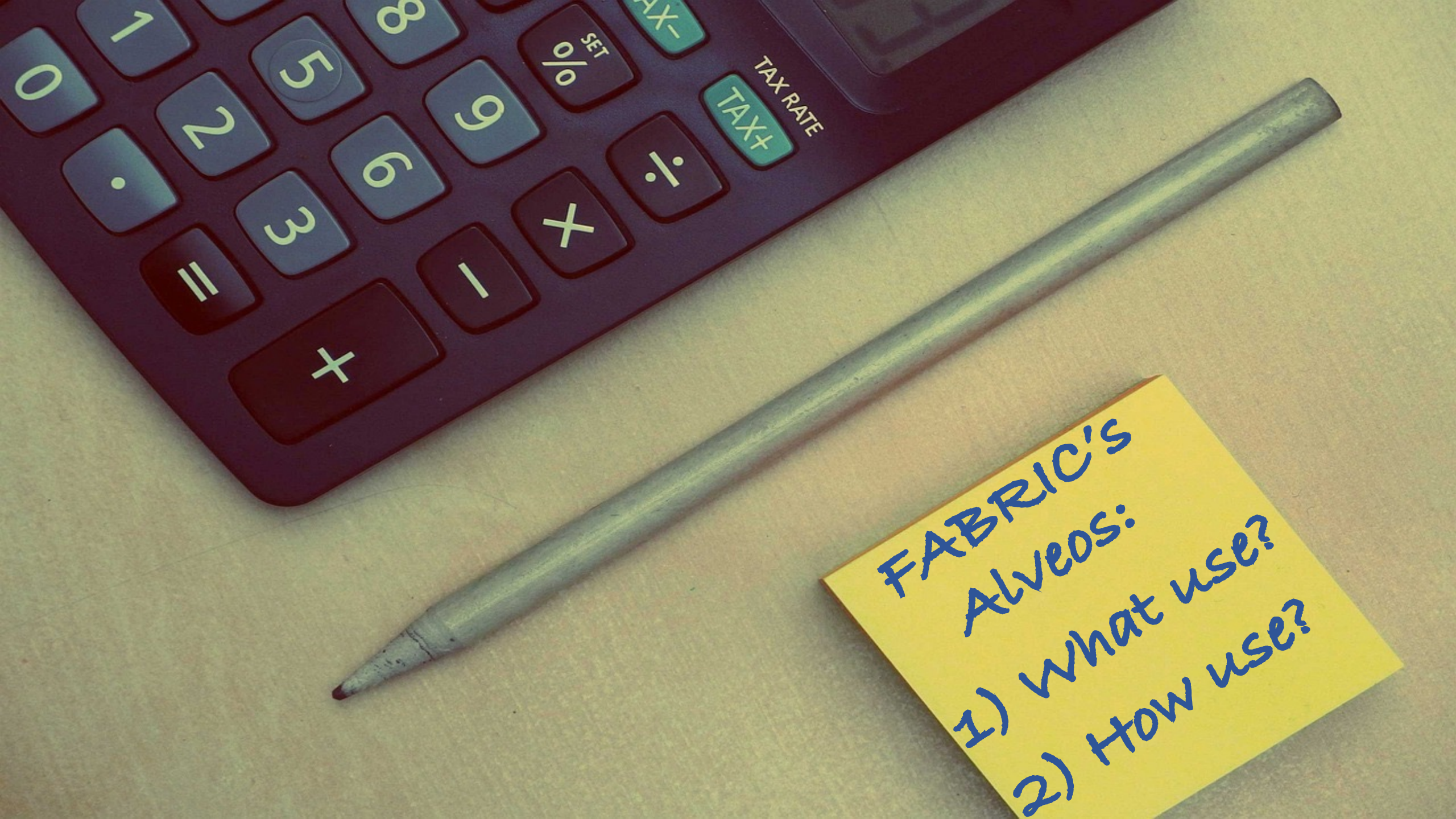
Programmable Networking in FABRIC

- BMv2 and DPDK-based: see examples from **Uni. of South Carolina**.
- FPGAs including Alveo's: **Northeastern + UMass**.
- Alveo-based: 

(this talk)

SmartNIC framework

- Origins: performance requirements of large-scale and high-performance DoE networks.
- Supports P4: doesn’t require hardware-engineering skills.
- Extensible and open-source.
- Streamlined, modular workflow based on using containers.
- Builds on AMD/Xilinx toolchain.
  (See University Program.)


TAX RATE
TAX+
SET
%
FABRIC's
Alveos:
1) What use?
2) How use?

What can we use Alveos for?

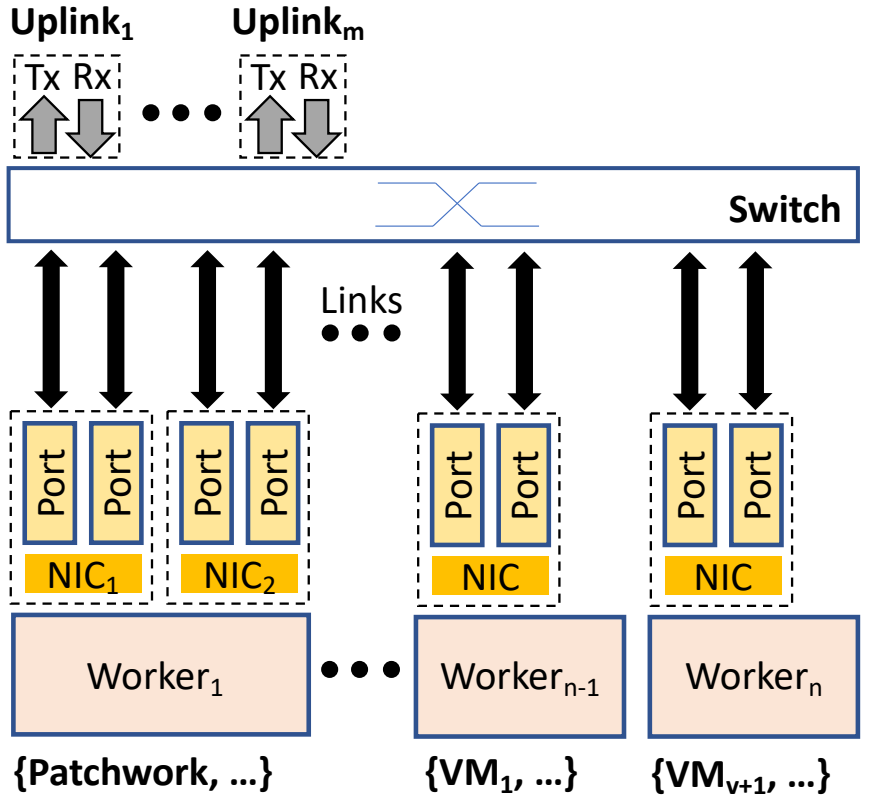
- Ongoing research
  - Network monitoring
  - Cybersecurity

- IIT Courses:
  CS595 (**Applications of Programmable Networking**) :
  http://www.cs.iit.edu/~nsultana1/teaching/F23CS595/

  CS542 (**Computer Networking**) :
  http://www.cs.iit.edu/~nsultana1/teaching/S24CS542/

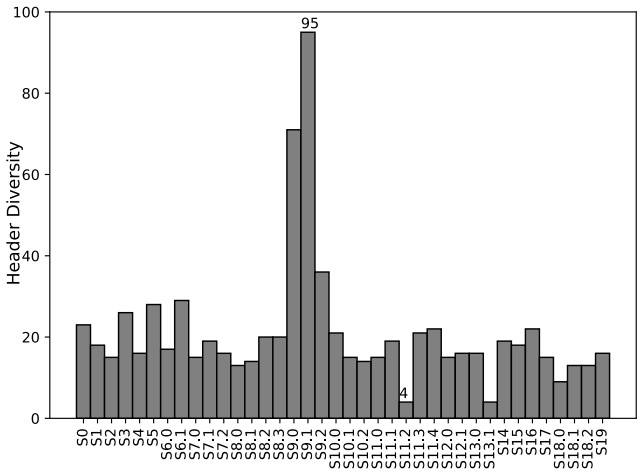
Using FABRIC's Alveos: Network Profiling

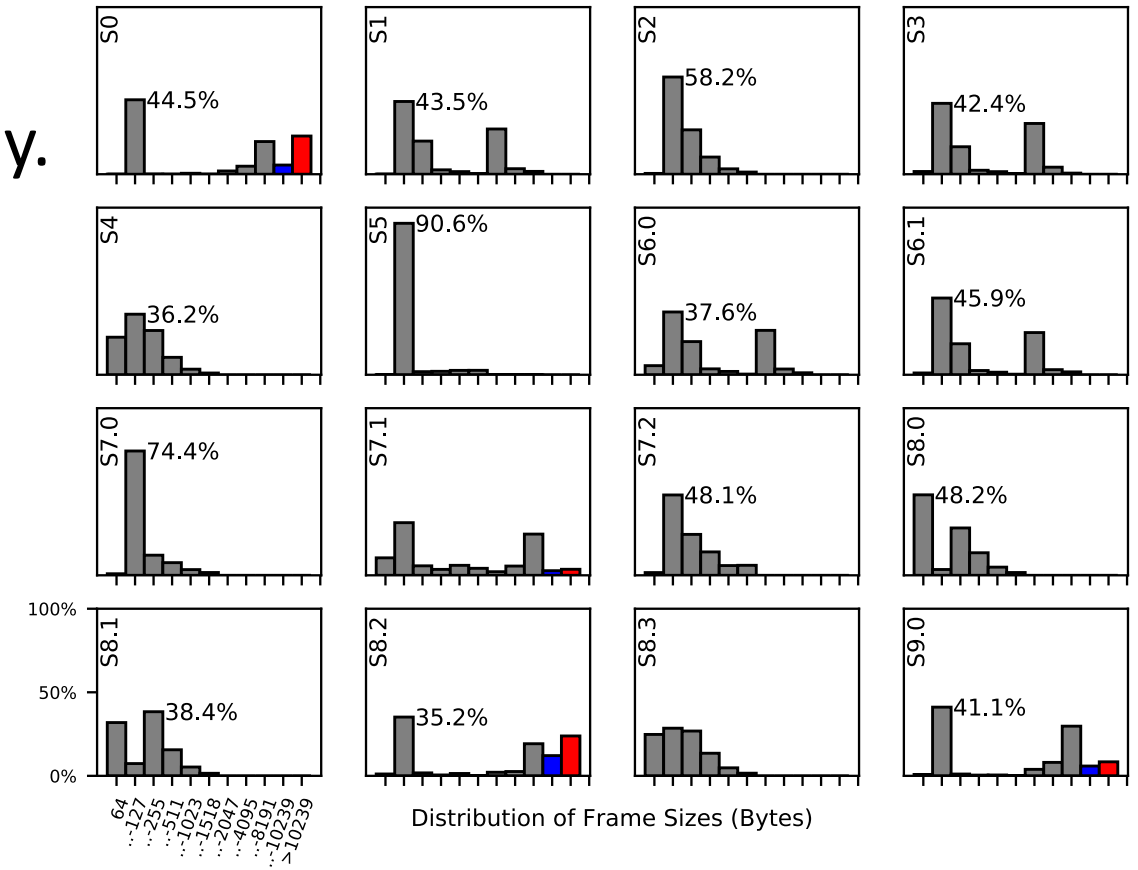
- **Goal:** Understanding the traffic composition and characteristics of FABRIC experiments. Sharing this data + mechanism with the community of testbed users.
- **Motivation:** Provide data and insight for research projects on "sui generis" network. (Unliked datacenter, telecom, etc).
- **How:** Profiler is *itself* a FABRIC experiment.



Using FABRIC's Alveos: Network Profiling

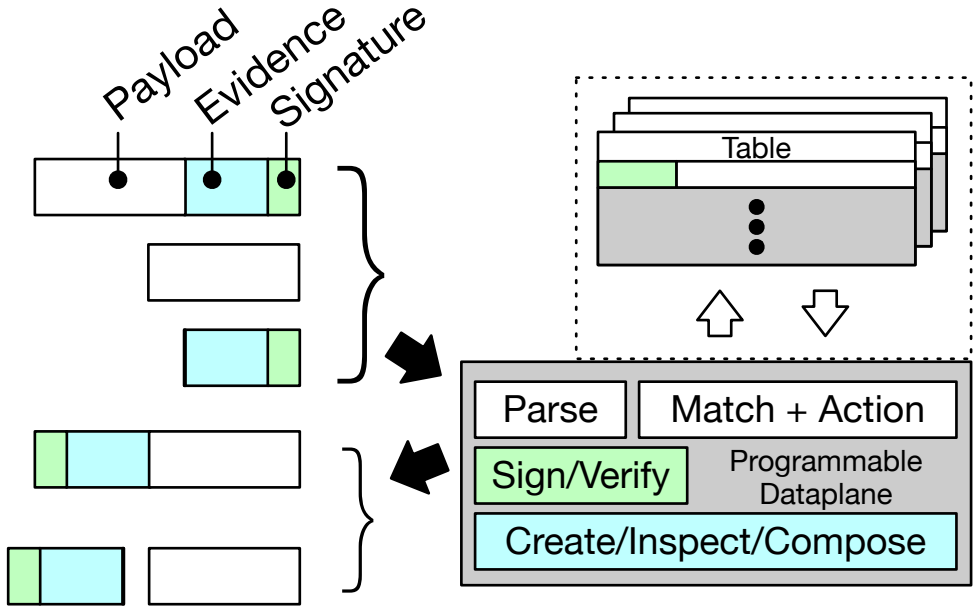
- **Findings:** a lot to digest!
  Speak to **Nishanth** and **Prajwal**
  if you missed their demos on Tuesday.
- **Role of Alveos:** offloading sampling, filtering, truncation, and blinding to the Smart NIC from the host.





Using FABRIC's Alveos: Cybersecurity Research

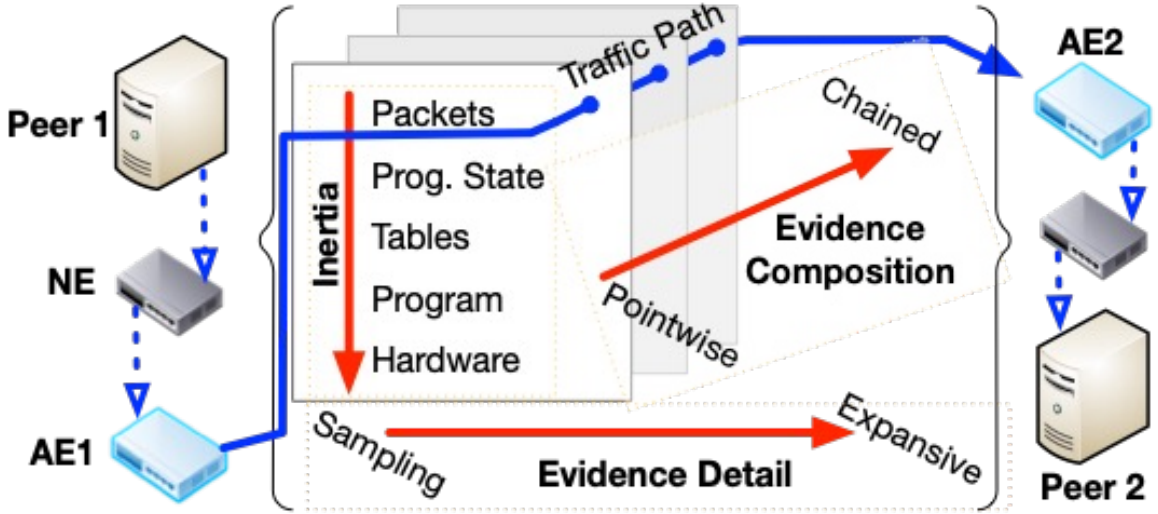
- **Goal:** Adapting "Remote Attestation" to network dataplanes.
- **Motivation:** Early detection of misconfigurations and APTs, mitigating attack surface from programmability.
- **How:** In-band carrying of verifiable evidence about network element state.



Using FABRIC's Alveos: Cybersecurity Research

- **Prototypes and Security Properties:** Speak to **Alexander** and **Hyunsuk** if you missed their demos on Tuesday.

- **<u>Role of Alveos:</u>** "sandwiching" black box, distrusted, third-party network elements. Provide visibility of those elements' behavior, and serializing and verifying evidence.



How do we use FABRIC's Alveos?

- Development done *outside* FABRIC,
  Experiment done *inside* FABRIC.

- **Development**:
  - The programming language(s)
  - The toolchain(s)

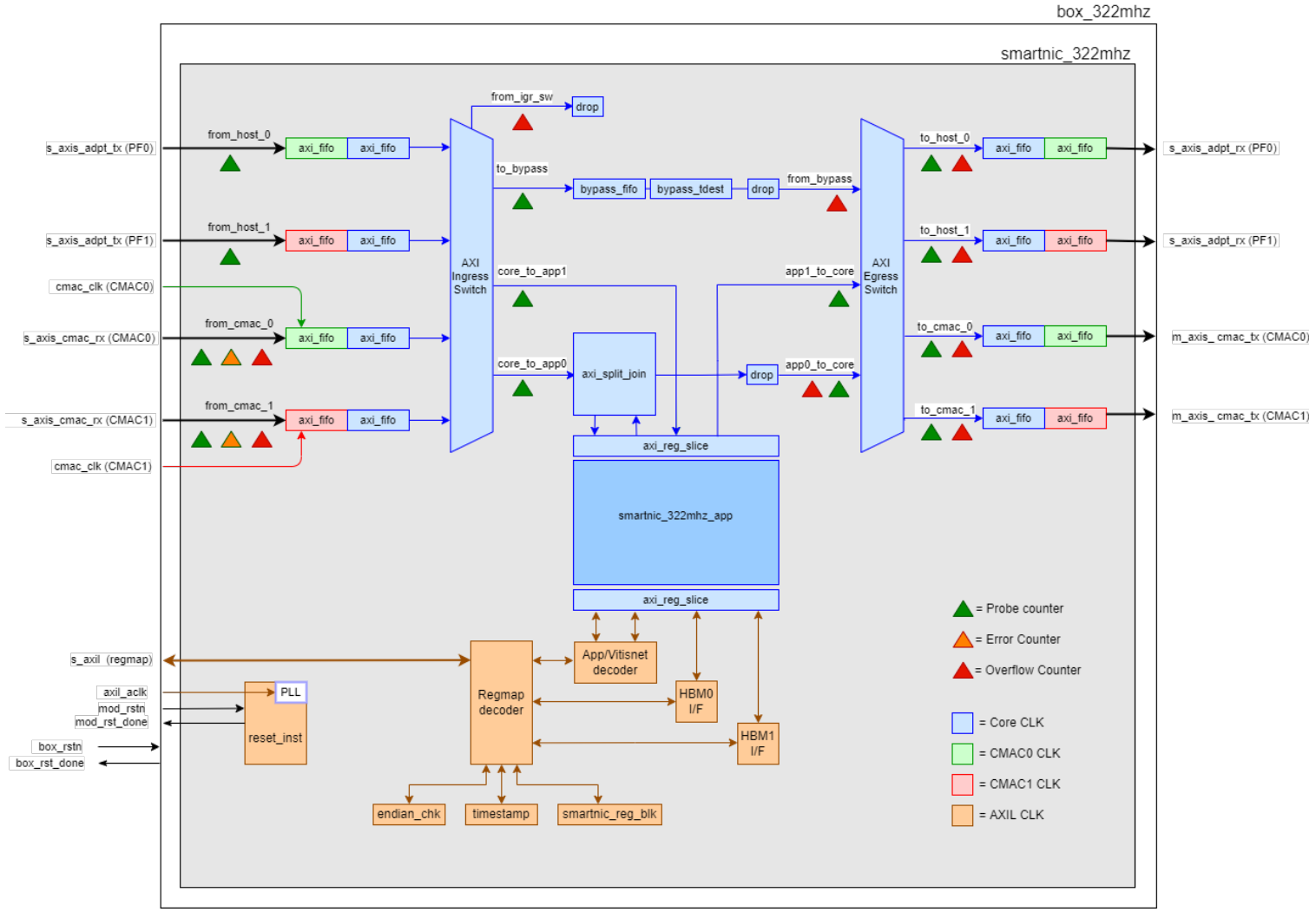
- **Experiment**: allocating and using Alveos on FABRIC.

Plan

1. The development process using ESnet's SmartNIC framework.
2. Allocating the necessary resources on FABRIC, including an Alveo.
3. How to deploy a program on an Alveo (that's in FABRIC).
4. Running and testing the program.
5. Diagnosis.

What we won't see: Recompiling the program running in the FPGA.
(The compilation takes too long for this session.)

SmartNIC framework



Programming

- Header specification and *parsing*.
- Specification of program logic.
- Specification of *tables* and *actions*.

Programming

1. Header specification and *parsing*.

```
header p4calc_t {
  bit<8> p;
  bit<8> four;
  bit<6> ver;
  bit<10> op;
  bit<32> operand_a;
  bit<32> operand_b;
  bit<32> res;
}
```

```
struct headers {
  ethernet_t ethernet;
  p4calc_t p4calc;
}
```

Programming

2. Specification of program logic.

```
header p4calc_t {
  bit<8> p;
  bit<8> four;
  bit<6> ver;
  bit<10> op;
  bit<32> operand_a;
  bit<32> operand_b;
  bit<32> res;
}
```

```
const bit<16> P4CALC_ETYPE = 0x1234;
const bit<8> P4CALC_P = 0x50; // 'P'
const bit<8> P4CALC_4 = 0x34; // '4'
const bit<16> P4CALC_VER = 0x0001; // v0.1
const bit<8> P4CALC_PLUS = 0x2b; // '+'
const bit<8> P4CALC_MINUS = 0x2d; // '-'
const bit<8> P4CALC_AND = 0x26; // '&'
const bit<8> P4CALC_OR = 0x7c; // '|'
const bit<8> P4CALC_CARET = 0x5e; // '^'
```

```
struct headers {
  ethernet_t ethernet;
  p4calc_t p4calc;
}
```

```
if (hdr.p4calc.isValid()) {
  if (hdr.p4calc.p == P4CALC_P &&
      hdr.p4calc.four == P4CALC_4 &&
      hdr.p4calc.ver == P4CALC_VER)
    calculate.apply();
} else operation_drop();
```

Programming

3. Specification of *tables* and *actions*.

```
table calculate {
 key = { hdr.p4calc.op : exact; }
 actions = { operation_add;
   operation_sub;
   operation_and;
   operation_or;
   operation_xor;
   operation_drop;
 } size = 1024;
 default_action = operation_drop();
}
```

Programming

3. Specification of *tables* and *actions*.

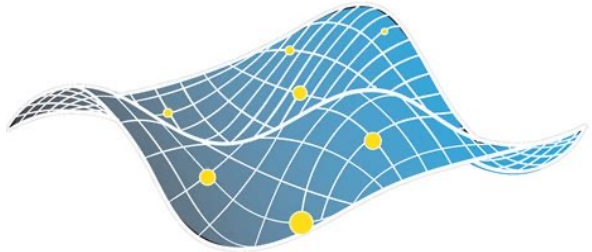
```
table calculate {
 key = { hdr.p4calc.op : exact; }
 actions = { operation_add;
   operation_sub;
   operation_and;
   operation_or;
   operation_xor;
   operation_drop;
 } size = 1024;
 default_action = operation_drop();
}
```

```
action operation_add() {
 send_back(hdr.p4calc.operand_a + hdr.p4calc.operand_b);
}
```

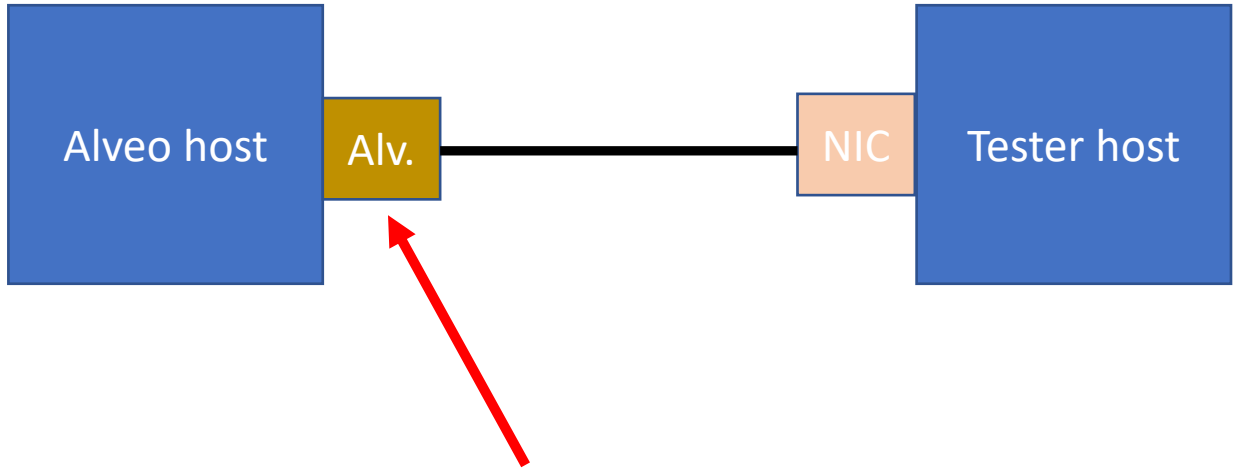
```
action send_back(bit<32> result) {
 bit<48> tmp;
 hdr.p4calc.res = result;
 tmp = hdr.ethernet.dstAddr;
 hdr.ethernet.dstAddr = hdr.ethernet.srcAddr;
 hdr.ethernet.srcAddr = tmp;
 sn_meta.egress_port = sn_meta.ingress_port;
}
```

Running Alveo experiments

- Need “Component.FPGA” permission.
- Creating a FABRIC slice as normal.
- Configuring:
  - Hosts
  - Alveo card
  - Program’s tables

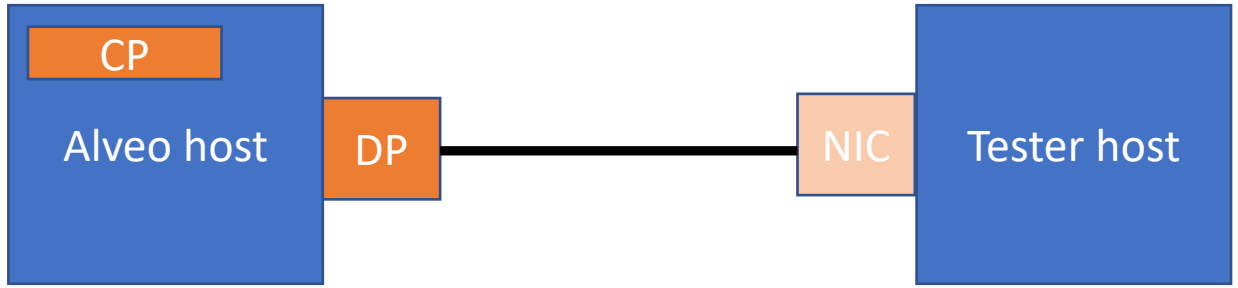


Creating a slice



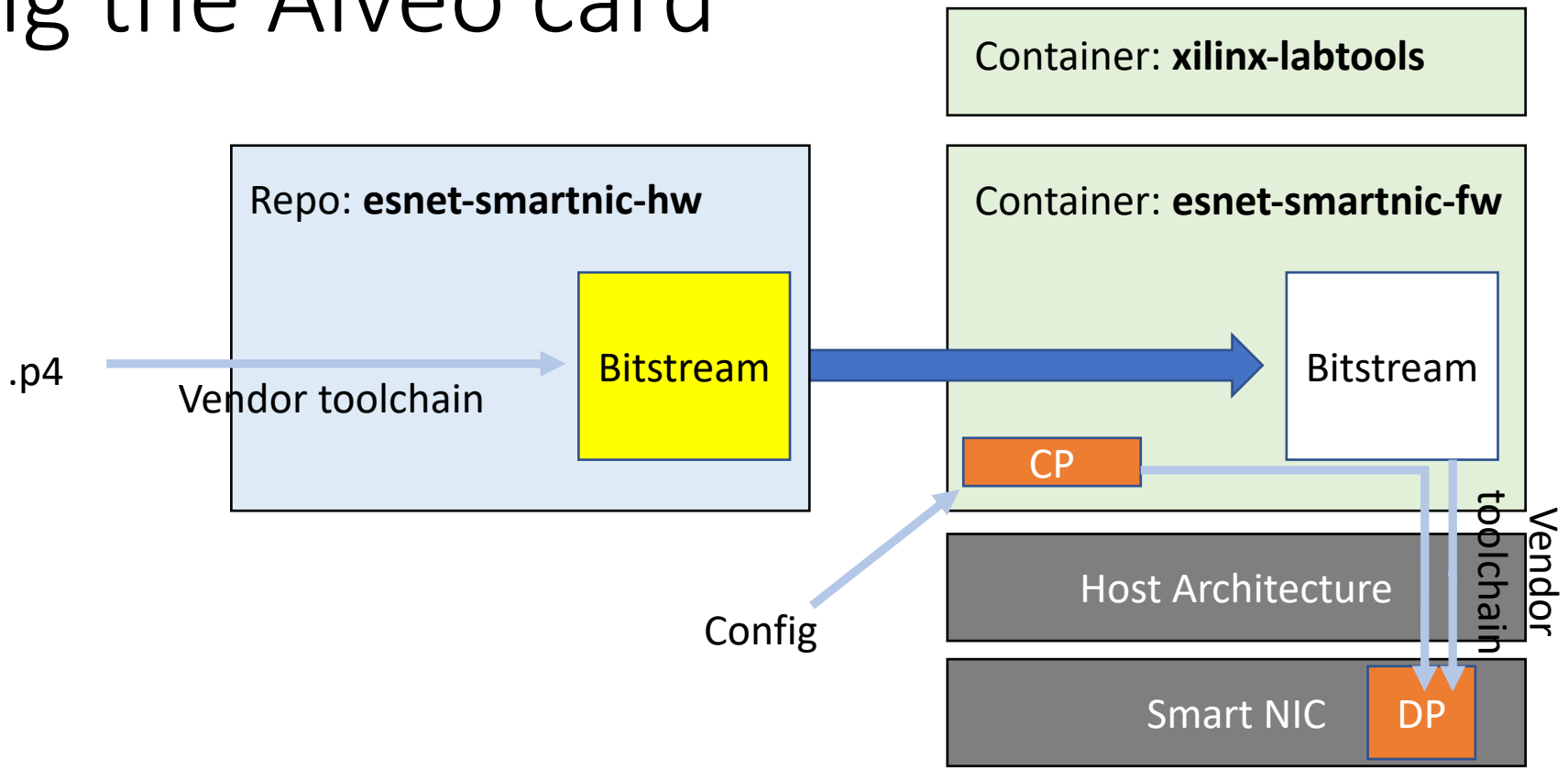
Include a ‘FPGA_Xilinx_U280’ *component* as part of a *node* in your *slice*.

Configuring the hosts



1. Setting up host and software dependencies.
2. Obtaining container images used by ESnet's framework.
3. Uploading scripts that support this experiment.

Configuring the Alveo card



1. Creating the configuration container
2. Configuration through "`sn-cli`" tool: sw, qdma, cmac

Configuring the program's tables

- The `sn-p4-cli` tool.
- Adding, removing, clearing rules – cannot *inspect* rules.
- By changing table entries we'll swap *addition* and *xor*.

Clearing the table

```
ubuntu@nic-node:~$ sudo python3 calc.py '3 + 1'
```

Clearing the table

```
ubuntu@nic-node:~$ sudo python3 calc.py '3 + 1'
4
ubuntu@nic-node:~$ sudo python3 calc.py '3 - 1'
2
ubuntu@nic-node:~$ sudo python3 calc.py '3 ^ 1'
2
ubuntu@nic-node:~$ sudo python3 calc.py '3 & 1'
1
ubuntu@nic-node:~$ sudo python3 calc.py '3 | 1'
3
ubuntu@nic-node:~$ sudo python3 calc.py '3 | 1'
Didn't receive response
ubuntu@nic-node:~$ sudo python3 calc.py '3 & 1'
Didn't receive response
ubuntu@nic-node:~$ sudo python3 calc.py '3 & 1'
Didn't receive response
ubuntu@nic-node:~$
```

Swapping rules

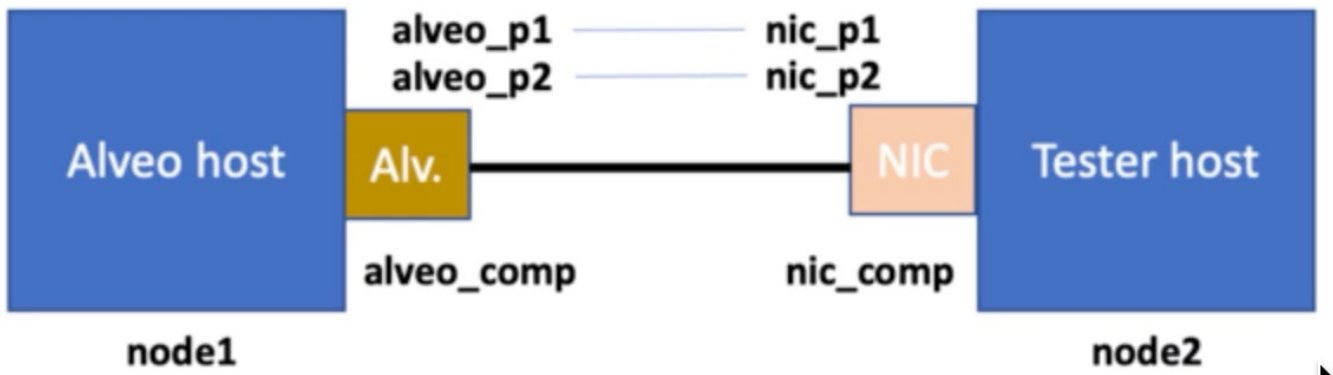
```
ubuntu@nic-node:~$ sudo python3 calc.py '3 + 1'
4
ubuntu@nic-node:~$ sudo python3 calc.py '3 - 1'
2
ubuntu@nic-node:~$ sudo python3 calc.py '3 ^ 1'
2
ubuntu@nic-node:~$ sudo python3 calc.py '3 & 1'
1
ubuntu@nic-node:~$ sudo python3 calc.py '3 | 1'
3
ubuntu@nic-node:~$ sudo python3 calc.py '3 | 1'
Didn't receive response
ubuntu@nic-node:~$ sudo python3 calc.py '3 & 1'
Didn't receive response
ubuntu@nic-node:~$ sudo python3 calc.py '3 & 1'
Didn't receive response
ubuntu@nic-node:~$ sudo python3 calc.py '3 + 1'
4
ubuntu@nic-node:~$ sudo python3 calc.py '3 ^ 1'
Didn't receive response
ubuntu@nic-node:~$ sudo python3 calc.py '3 ^ 1'
4
ubuntu@nic-node:~$ sudo python3 calc.py '3 ^ 1'
Didn't receive response
ubuntu@nic-node:~$ sudo python3 calc.py '3 + 1'
Didn't receive response
ubuntu@nic-node:~$ sudo python3 calc.py '3 - 1'
Didn't receive response
ubuntu@nic-node:~$
```

[ ]:
```
from fabrictestbed_extensions.fablib.fablib import FablibManager as fablib_manager
fablib = fablib_manager()
```

First we set some parameters for the slice, such as node names and where we want to site the slice.

[ ]:
```
alveo_node_name='alveo-node'
nic_node_name='nic-node'

site = <e.g., 'HAWI'>

slice_name=f'P4 calculator on {site}'

esnet_smartnic_dpdk_docker = "wget -q http://.../esnet_smartnic-dpdk-docker.tgz"
esnet_xilinx_labtools_docker = "wget -q http://.../esnet_xilinx-labtools-docker.tgz"

artifact_origin = "http://.../artifacts.au280.p4_only.0.zip_CALC"
```

The site will have two nodes. One node controls an Alveo card. The other node is used to send traffic to the Alveo.



[ ]:
```
slice = fablib.new_slice(name=slice_name)
```

Plan

1. ~~The development process using ESnet's SmartNIC framework.~~
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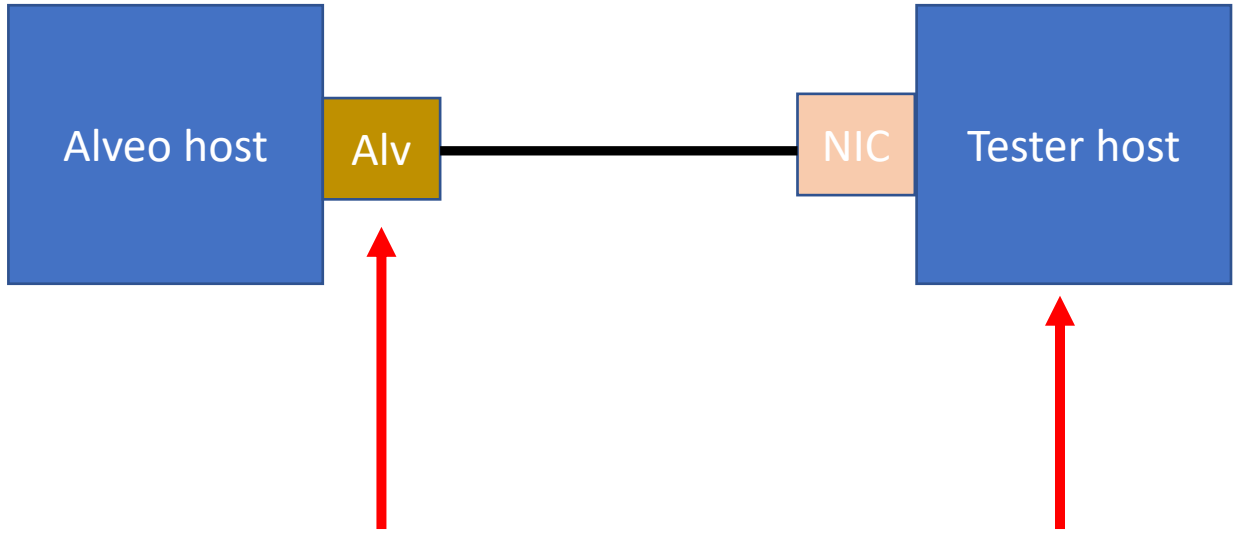
3. ~~How to deploy a program on an Alveo (that's in FABRIC).~~
4. Running and testing the program.
5. Diagnosis.

What we won't see: Recompiling the program running in the FPGA.
(The compilation takes too long for this session.)

Running+Testing the program



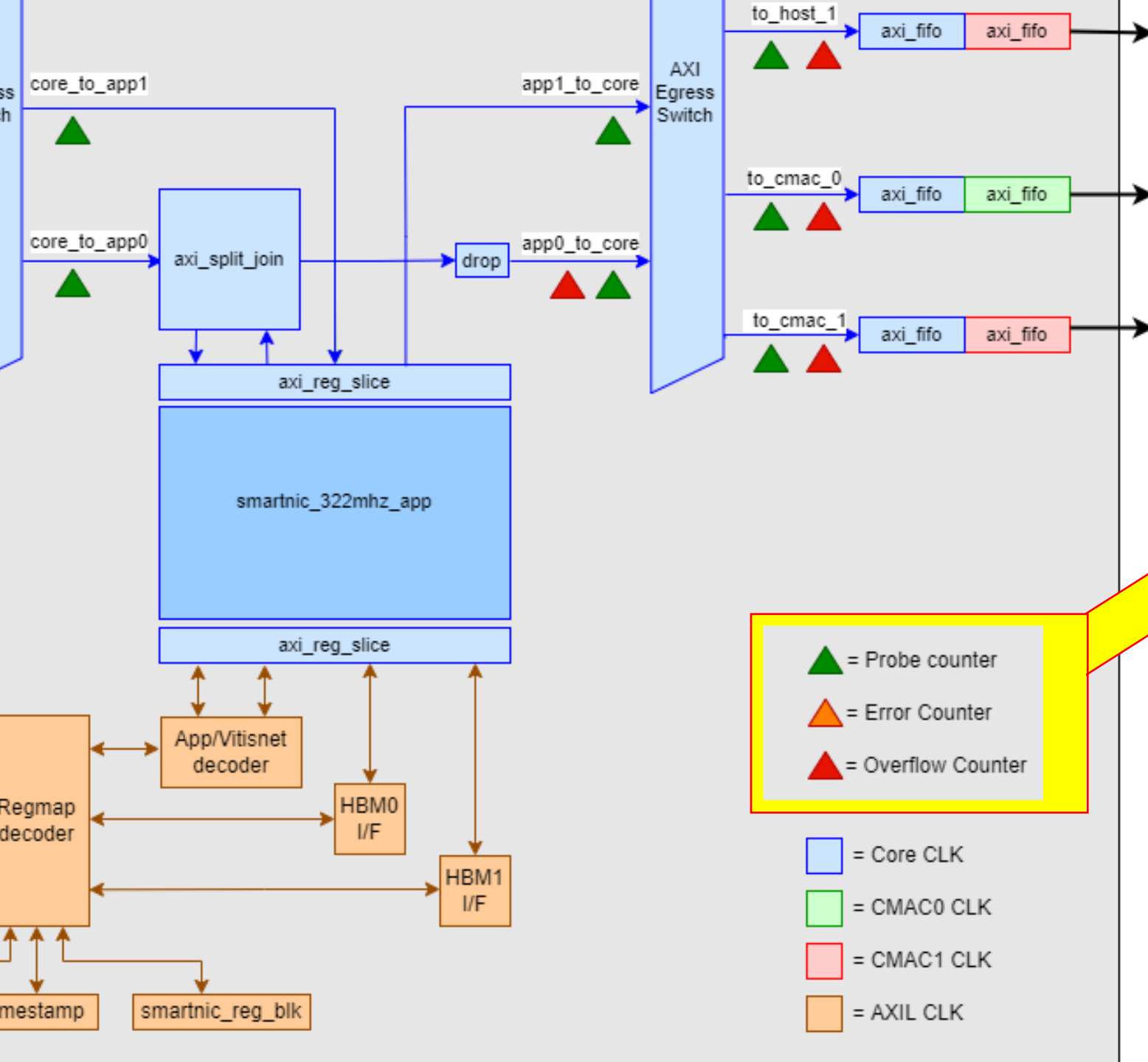
The program is already running.

Testing: let's examine the script that *produces* and *interprets* experiment traffic.

Test script


```
class P4calc(Packet):
  name = "P4calc"
  fields_desc = [StrFixedLenField("P", "P", length=1),
                 StrFixedLenField("Four", "4", length=1),
                 XByteField("version", 0x01),
                 StrFixedLenField("op", "+", length=1),
                 IntField("operand_a", 0),
                 IntField("operand_b", 0),
                 IntField("result", 0xCAFECAFE)
```

```
pkt = Ether(dst='00:04:00:00:00:00', type=0x1234) / P4calc(op=ts[1].value,
                                                operand_a=int(ts[0].value),
                                                operand_b=int(ts[2].value))
```



Diagnosis

- Using `sn-cli` to read counter values.
- Counters provide insight about internal packet loss.

```
ubuntu@alveo-node:~$
```

Thank you


Group (at Nov/Dec 2023)

- **Researchers who use(d) FABRIC at Illinois Tech**:
  Hyunsuk Bang, Sean Cummings, Pilar Fernandez Gayol, Shivam Patel, Vaneshi Ramdhony, Nishanth Shyamkumar, Mohammad Firas Sada, Laura Serrano Velazquez, Prajwal Somendyapanahalli Venkateshmurthy, Alexander Wolosewicz.
- **Community**:
  Ilya Baldin (JLAB), Peter Bengough (ESnet), Gordon Brebner (AMD), Dale Carder (ESnet), Mert Cevik (RENCI), Zongming Fei (UKY), Jim Griffioen (UKY), Yatish Kumar (ESnet), Tom Lehman (Virnao), Inder Monga (ESnet), Chris Neely (AMD), Anita Nikolich (UIUC), Phil Porras (SRI), Paul Ruth (RENCI), Stacey Sheldon (ESnet), Komal Thareja (RENCI), Xi Yang (ESnet), Vinod Yegneswaran (SRI), and the P4 community.

ILLINOIS TECH

How to get started

- FABRIC Forums: https://learn.fabric-testbed.net/forums/forum/all-about-fpgas/

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- This tutorial's "starter kit" has been added to our documentation site: http://packetfilters.cs.iit.edu/esnet-smartnic-tutorial/