

工業技術研究院

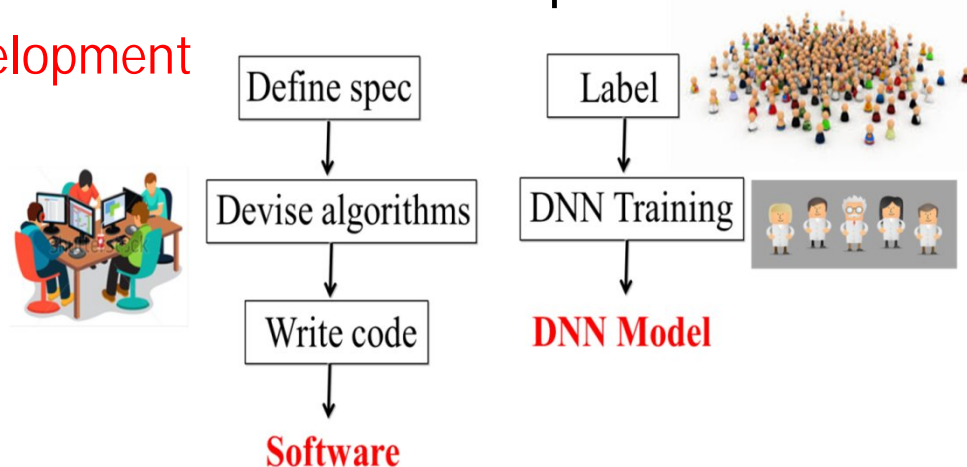
Industrial Technology
Research Institute

DNN Training As a Service



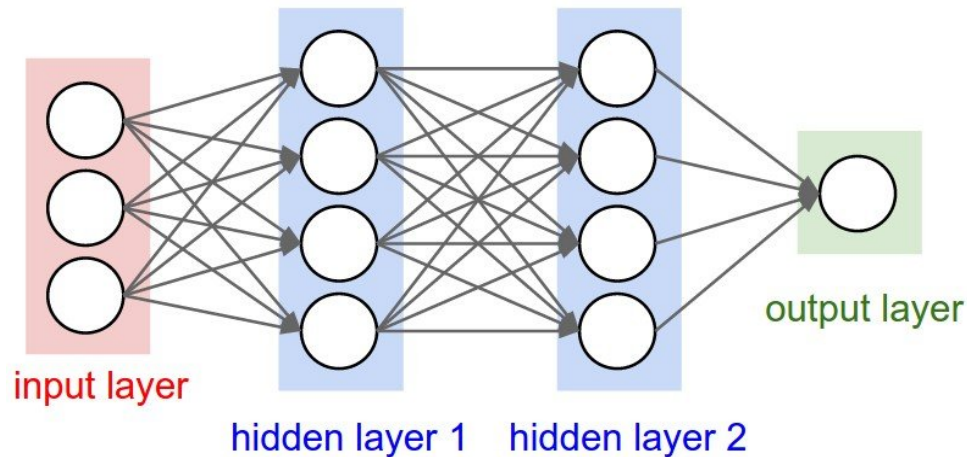
Introduction to Deep Neural Network

- AI ~ **Deep Neural Network** (DNN)-based Machine Learning
 - Algorithmic breakthrough that enables training of deep neural network
- **AI system**: a system with analysis and synthesis capabilities powered by DNN-based machine learning or Deep Learning
 - Autonomous driving vehicle, drone, robot, personal virtual assistant, etc.
- **Machine learning**: a universal algorithm for building a functional mapping between sample inputs and associated outputs
 - **A new paradigm of software development**
 - Learn from many normal people
vs. Design with few gifted experts

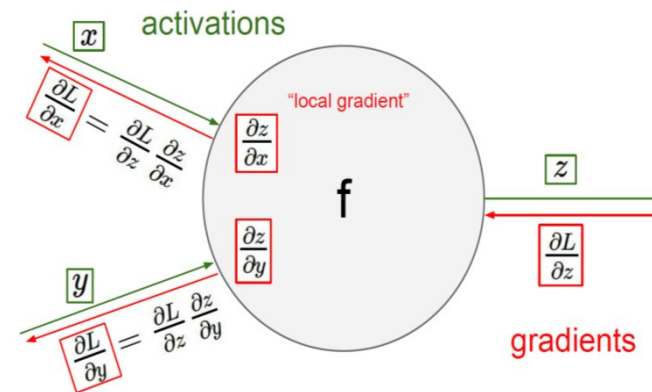
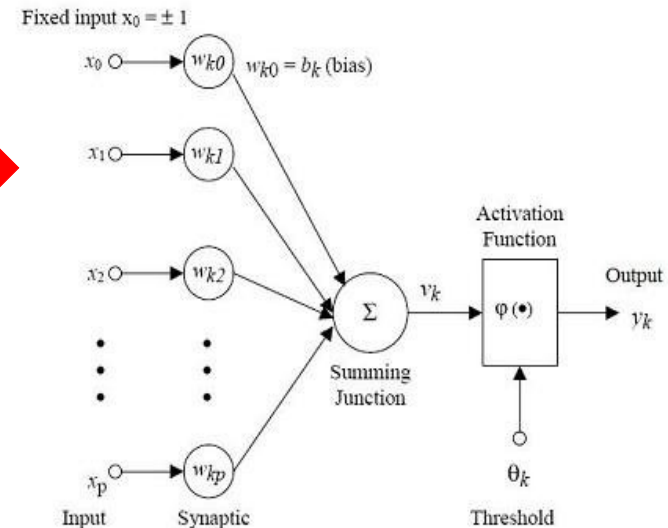


Training and Inference in DNN

Training: Forward/Backward Propagation \leftrightarrow



Inference: Forward Propagation \rightarrow



Key Challenges in DNN Systems

- Training of DNN model
 - **Quality**: how to acquire high-quality training data set
 - Label correctness and diversity
 - Semi-automatic training data collection and labeling
 - **Speed**:
 - Reduce the number of rounds required in the training process
 - Round → Epoch → Batch
 - Reduce the computation overhead associated with each training round
- Speed and power consumption of applying DNN model (inference)
 - Real-time: autonomous driving
 - Embedded system: low power and low cost
- Explainability of learned DNN models

NVIDIA DGX-1 Appliance

DGX-1 with P100 at **USD\$129,000***

DGX-1 with V100 at **USD\$149,000***

* Manufacturer's Suggested Retail Price (MSRP) as established by NVIDIA.
Taxes, shipping and other fees not included. Support plan is required and must be purchased separately. All pricing is subject to change without notice.



SYSTEM SPECIFICATIONS

GPUs	8X Tesla V100	8X Tesla P100
TFLOPS (GPU FP16)	960	170
GPU Memory	128 GB total system	
CPU	Dual 20-Core Intel Xeon E5-2698 v4 2.2 GHz	
NVIDIA CUDA® Cores	40,960	28,672
NVIDIA Tensor Cores (on V100 based systems)	5,120	N/A
Maximum Power Requirements	3,200 W	
System Memory	512 GB 2,133 MHz DDR4 LRDIMM	
Storage	4X 1.92 TB SSD RAID 0	
Network	Dual 10 GbE, 4 IB EDR	
Software	Ubuntu Linux Host OS See Software Stack for Details	
System Weight	134 lbs	
System Dimensions	866 D x 444 W x 131 H (mm)	
Packing Dimensions	1,180 D x 730 W x 284 H (mm)	
Operating Temperature Range	10–35 °C	

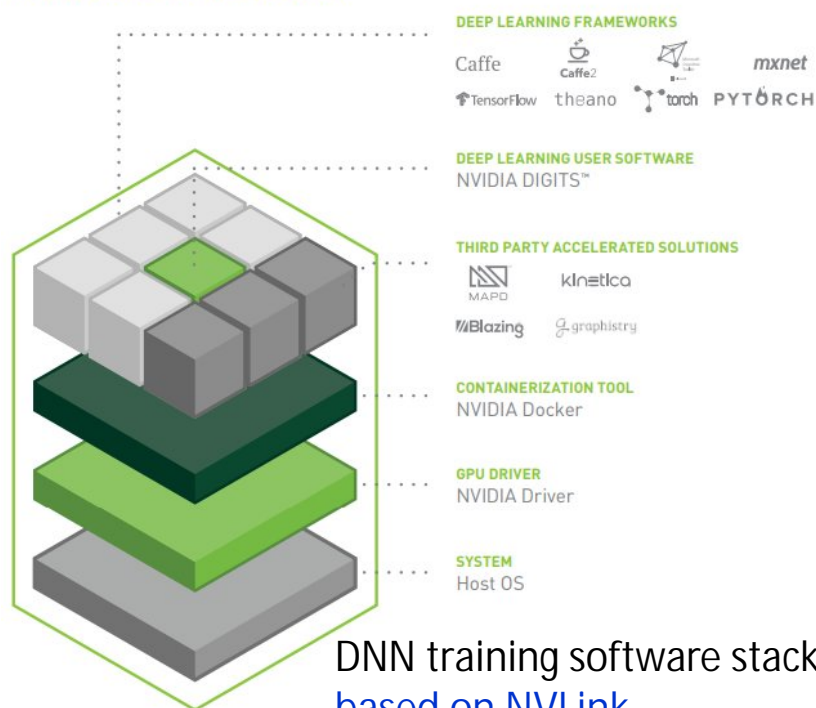
<https://blogs.nvidia.com/blog/2016/08/15/first-ai-supercomputer-openai-elon-musk-deep-learning/>
<https://www.nvidia.com/content/dam/en-zz/Solutions/Data-Center/dgx-1/dgx-1-ai-supercomputer-datasheet-v4.pdf>

DGX-1's System Architecture

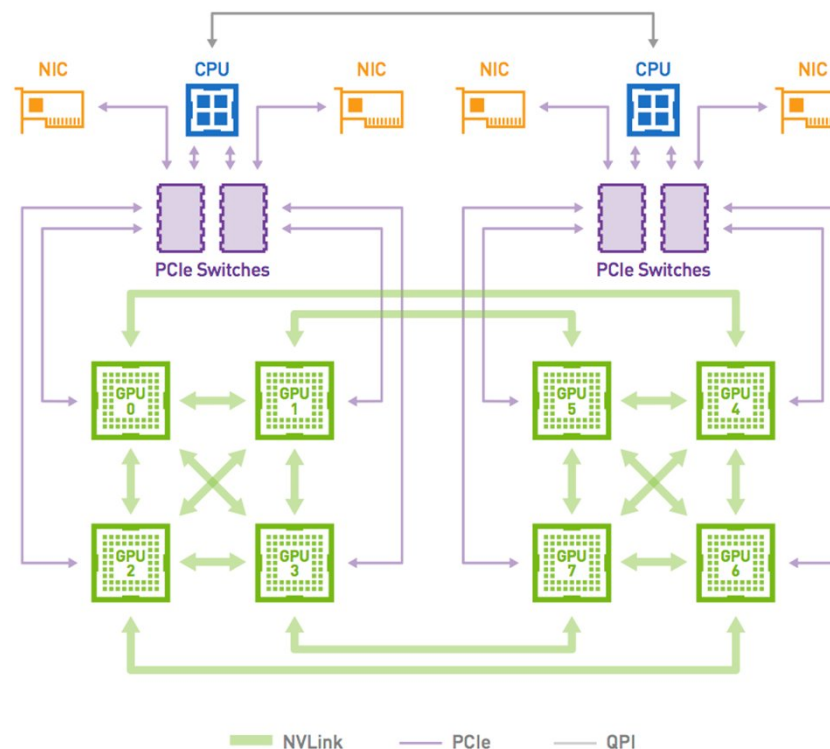


NVIDIA Tesla P100 GPU SXM2(for NVLink)
NVIDIA Tesla V100 GPU SXM2(for NVLink)

NVIDIA DGX Software Stack



DNN training software stack
based on NVLink



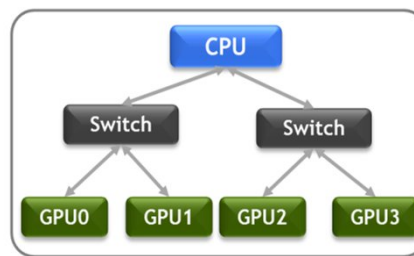
NVLink

Extraordinary bandwidth for multi-GPU connectivity

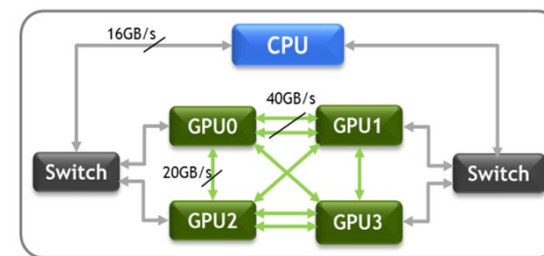
	PCIe 3.0 x16	NVLink 1.0	NVLink 2.0
Sub-Link Data Rate (per data direction)	16 GB/s	20 GB/s	25 GB/s

ITRI DNN Training Appliance

- Objective: 3/4 of the sustained performance at 1/3 of the price
- Hardware configuration
 - Processor Type:
 - Nvidia's Tesla P100 and V100 (12GB, 4.7TFLOPs, \$5899)
 - Nvidia's GeForce GTX 1080Ti (11GB, 11.3TFLOPs of FP32, \$699)
 - AMD's Radeon RX-500 and RX Vega
 - Intel's Knights Mill (KNM)
 - FPGA
 - Number of "GPU"s: 16+
 - System Interconnect:
 - Sufficient cross-section bandwidth
 - Meshed PCIe network
 - Cooling



4 GPUs with PCIe



4 GPUs with NVLink

Software for ITRI DNN Training Appliance

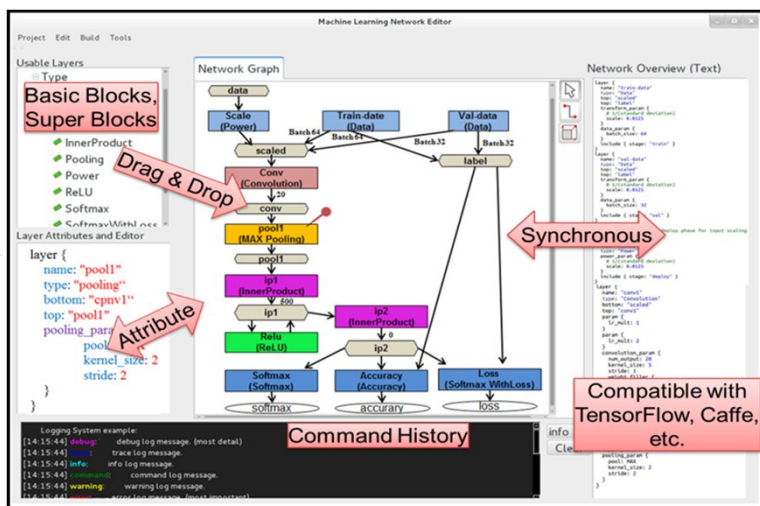
- Supported graphics driver APIs
 - CUDA and OpenCL
- Supported DNN training frameworks
 - Caffe, NVCaffe, Caffe2 and TensorFlow
- Performance Optimizations
 - How to minimize the performance impacts of absence of NVlink
 - Glitch-less data movement from storage, via main memory, to GPU memory
 - Using larger mini-batch size to reduce inter-CPU synchronization overhead
 - Cache memory access optimization via tiling and blocking
 - Amplify the effective memory size of a GPU card via transparent compression/decompression for data stored in GPU memory
- DNN Integrated Development Environment (IDE)
- DNN model compression

Integrated Development Environment for DNN Training

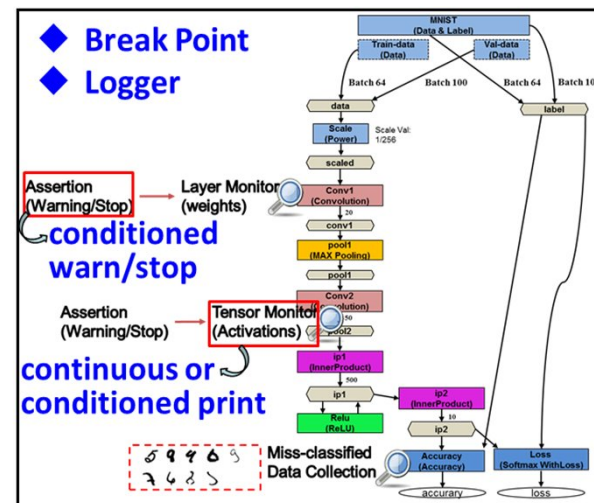
- Coding vs. Training
 - Caters to pattern recognition/classification programs
- Transfer learning of existing DNN models: library function reuse
 - How to enable a user to describe/characterize his DNN training problem so that the system could choose a model in the Model Zoo as a starting point?
 - What transformations should be made to the starting-point model?
- Automated/guided hyper-parameter tuning
 - Human-in-the-loop **pruning** and **steering** of a large number of concurrent training rounds, each corresponding to a distinct hyper-parameter combination
 - Automatic tuning of critical hyper-parameters such as learning rate, regularization constant, dropout probability, network depth/breadth, etc.
- Debugging support for weakness analysis of current DNN model
 - Development of **informed intermediate metrics and their visualization** that reflect a DNN model's overall effectiveness
 - Analysis and categorization of training samples on which predictions are incorrect: mislabeled, noise, difficult/easy to classify, etc.

DeepMAD: Monitor, Analysis and Debug

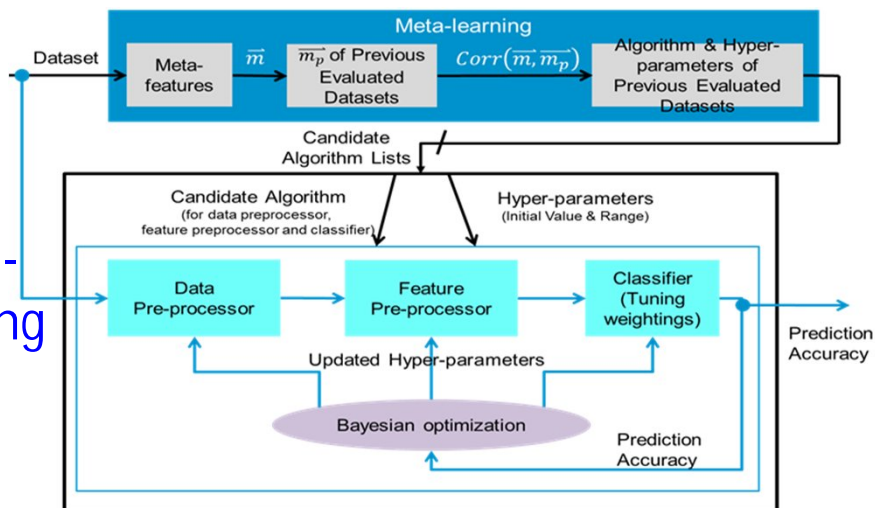
Neural
Network
Editor



Debugger

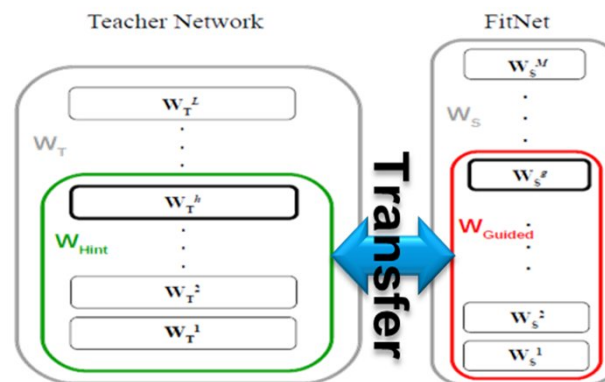


Meta-
Learning



Transfer
Learning

- FitNet knowledge transfer
- Net2Net network expanding



Hardware As a Service (HaaS)

Introduction to HaaS

- HaaS focuses on **leasing of physical machines**
 - Each tenant gets a **physical data center instance (PDCI)**, which consists of a set of physical servers, a physical network connecting them, and a set of local/remote storage volumes accessible to the servers.
 - User could **remotely** configure, monitor, and install OS and applications on servers in its PDCI.
- Why HaaS?
 - Big data/DNN training/HPC: efficient utilization of HW resources is critical
 - Container-based virtualization is sufficient.
- Comparison among service models:

Model	Rental Unit	IT HW Ownership	HW Management
IaaS	Virtual machine	Service provider	Service provider
HaaS	Physical machine	Service provider	User
Colocation	Rack space	User	user

Technical Building Blocks for ITRI HaaS

- Deployment time
 - Server provisioning: Bare Metal Provisioning from ITRI
 - Storage provisioning: local storage vs. shared storage
 - Network provisioning:
 - Agentless and scalable multi-tenancy network isolation: One HaaS tenant's virtual network is isolated from other HaaS tenants
 - Support up to hundreds of thousands of IP subnets
 - Multi-resolution tenancy-aware network traffic analysis
 - Physical link → Tenant → host-pair → Network connection
 - Load balancing among physical network links
- Run time
 - IT hardware inventory and maintenance: HaaS provider
 - System monitoring and administration: HaaS provider and HaaS tenant

BAMPI: Bare-Metal Provisioning from ITRI

- Problem: setting up hardware, network, firmware and first OS on fresh servers correctly is a pain point
- Vision: The only thing a HW vendor needs to do is setting MAC addresses for each server's (BMC/work) NICs, and automates the rest:
 - Extract the physical connectivity between hosts and switches
 - Configure the IP addresses for the work NICs according to a user-specified policy, e.g. machine 13 connected to slot 14 of switch 2 has IP address X
 - Configure the BMC and upgrade its firmware
 - Configure the BIOS and upgrade its firmware
 - Configure NIC and RAID card, and upgrade their firmware
 - Install a local OS (VMware, KVM, Linux) on each server and configure this OS
 - Scalable to thousands of machines residing in multiple L3 subnets
 - DHCP relay + ARP proxy + IP multicast
- Benefits: reduced errors, lower cost and speedier deployment

User View of BAMPI

Physical Server
Provisioning Service Portal
for users



User#1 Login

User#1's
BIOS/BMC Configuration
Parameters Sheet

User#1's
Server List

1. 01:1A:92:2B:70:B6
2. 00:0E:35:E4:FF:74
...
N. 1E:28:33:D1:CE:AA

User#1's
OS Configuration
Parameters Sheet

1. ACPI - Auto
2. USB - Legacy
...
N. VGA Buf. - 256MB



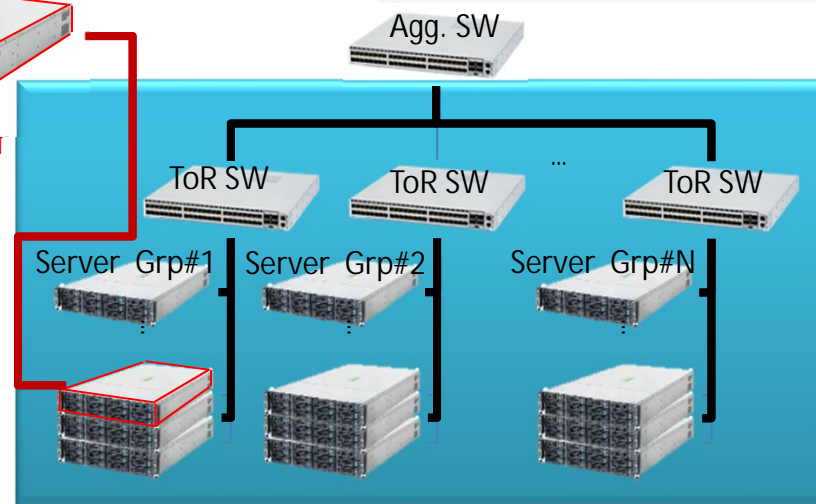
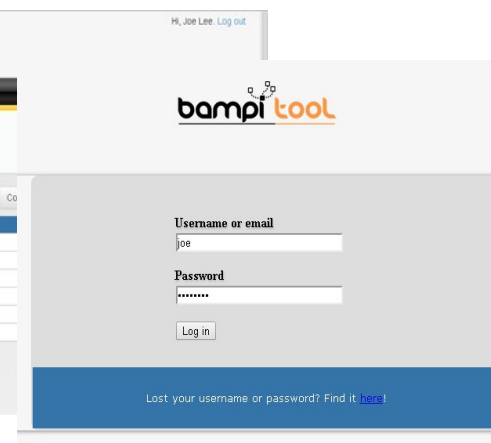
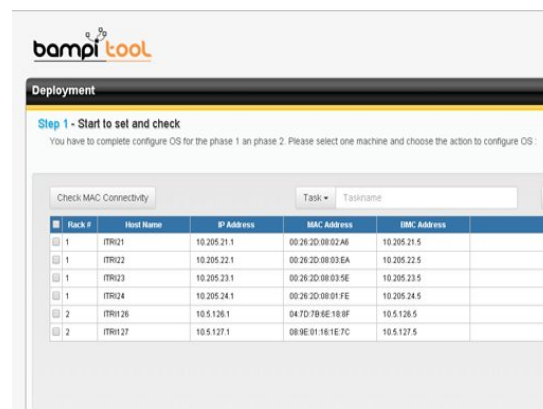
Disk Image Pool

Chose Disk Image
for Provisioning

1. IP: 192.168.20.4
2. Host:
Mail_Server
...
N. Datastor name



BAMPI Server



Physical Server Pool

- Web-based UI for provisioning progress monitor and management
- Every provisioning step and its results are logged
- Robust error handling: cancel, clear, and retry
- Remote bare-meta provisioning

Peregrine: HaaS Network Provisioning

- Physical network connectivity discovery
- VLAN-based inter-tenant network isolation
 - VLAN tree calculation for [physical network load balancing](#)
 - Spread the VLANs' underlying stress across the physical network as much as possible
 - VLAN configuration on Cisco, HP, Dell and Edgecore switches
 - [Scale up the number of VLANs beyond 4096](#)
 - On-demand VxLAN creation
 - VLAN ID reuse
- [Tenant-aware multi-resolution network traffic analysis](#)
- Packaged into a Neutron plugin for OpenStack
- Integration with OpenStack's Ironi API is on-going.

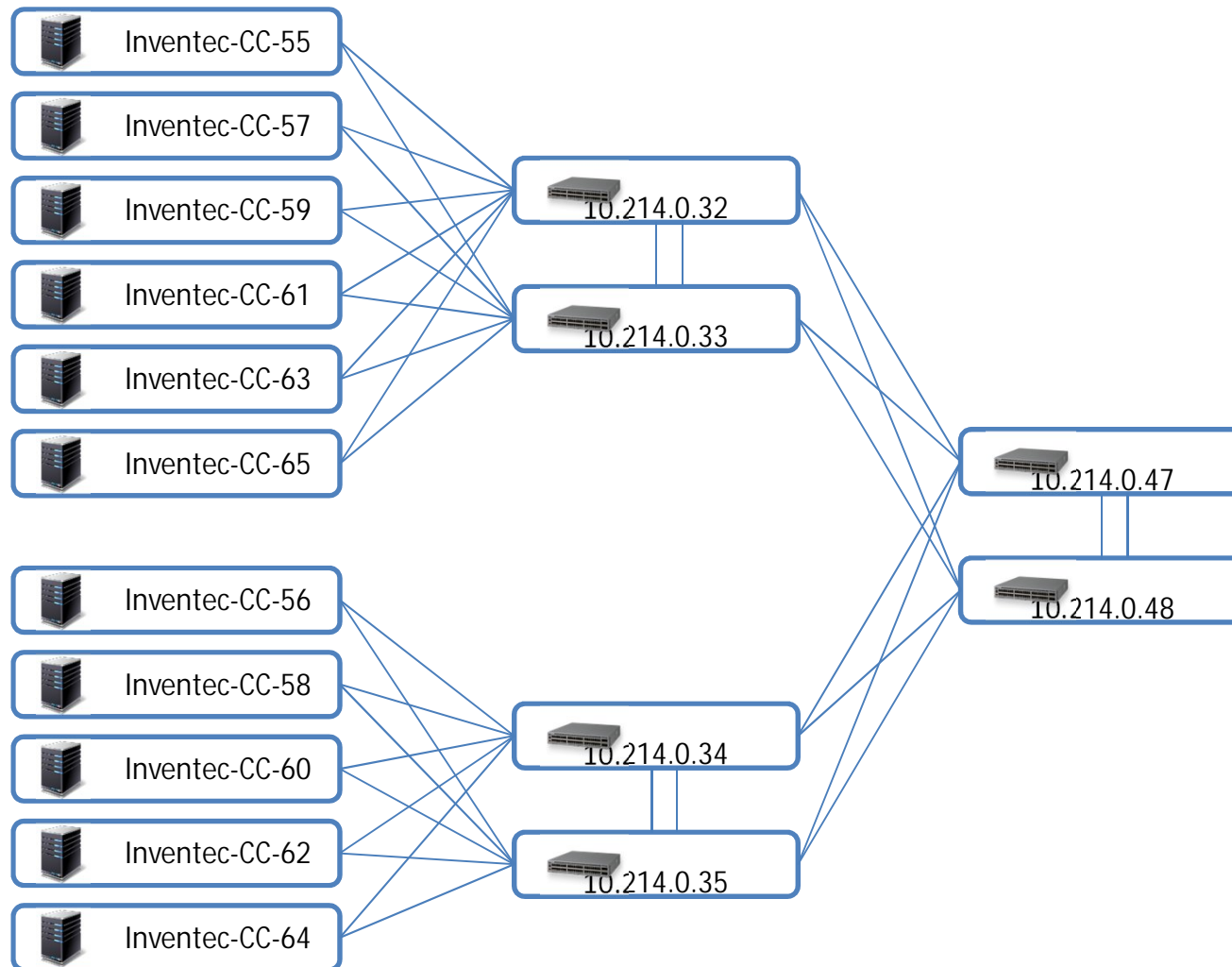
Physical Connectivity Discovery

- Pain point: How to physically identify a problematic NIC on a physical server for maintenance purpose?
 - No apparent ordering of physical NICs on a server
- Assumptions:
 - A physical server has multiple NICs, each of which has a MAC address and is abstracted into an Eth_x interface
 - A physical server is connected to multiple switches via its NICs
- Technology:
 - Eth_x interface \leftrightarrow MAC address \leftrightarrow <switch, port>
- Results:
 - Locate a NIC based on the <switch, port> to which it is connected
 - Assign an IP address to a NIC according to its physical connectivity

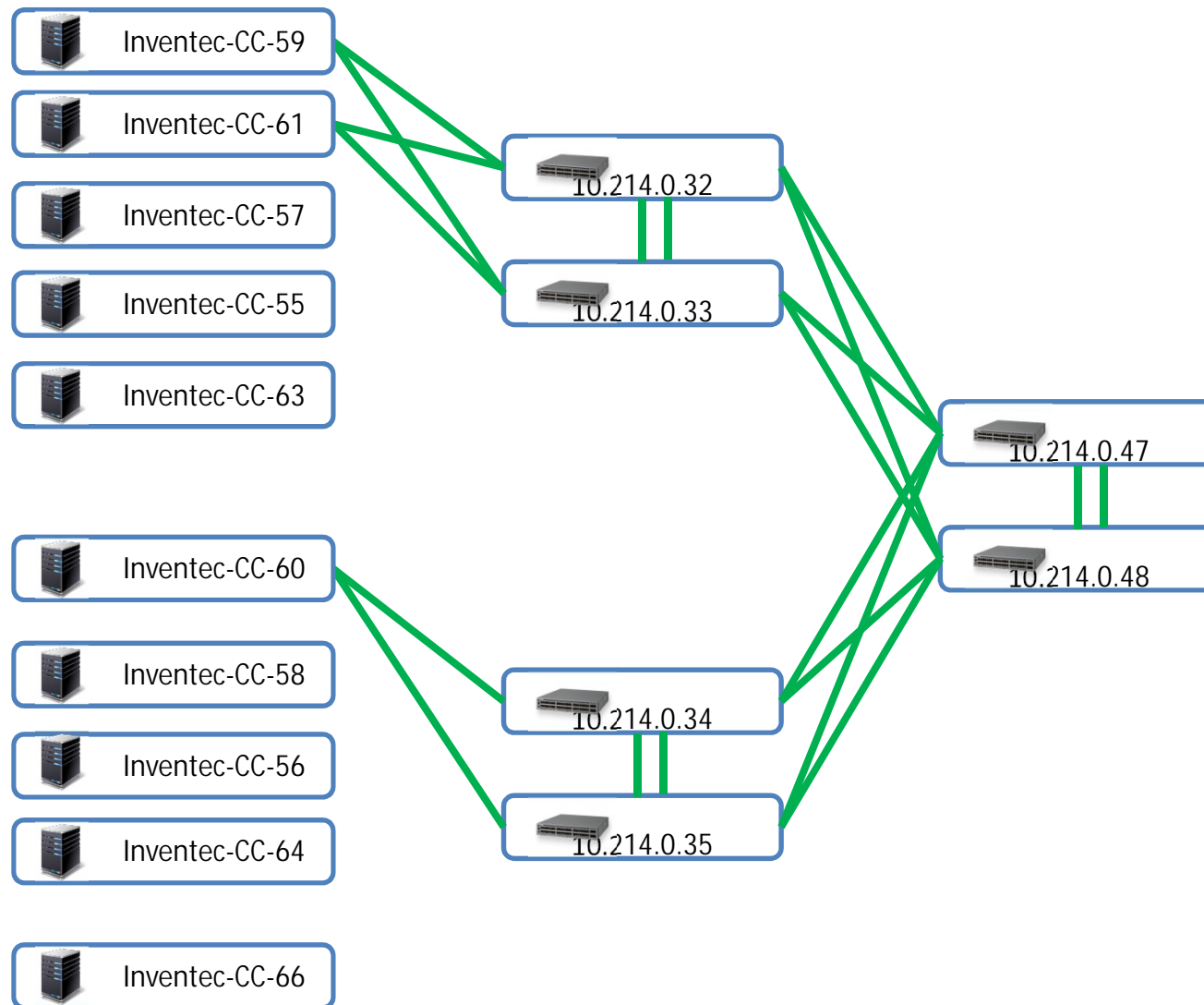
Tenant-Aware Network Traffic Analysis

- Use case: A HaaS tenant calls to complain that the performance of its virtual network is slow, and the HaaS operator is supposed to find out the root cause, fix it, and get back to the tenant within 30 minutes.
- How?
 - Virtual to physical network mapping
 - Health monitoring of physical network devices
 - Multi-resolution network resource usage attribution
 - Which physical network links?
 - Which VLANs?
 - Which server pairs?
 - Which network connections?
 - What do these network connections do?

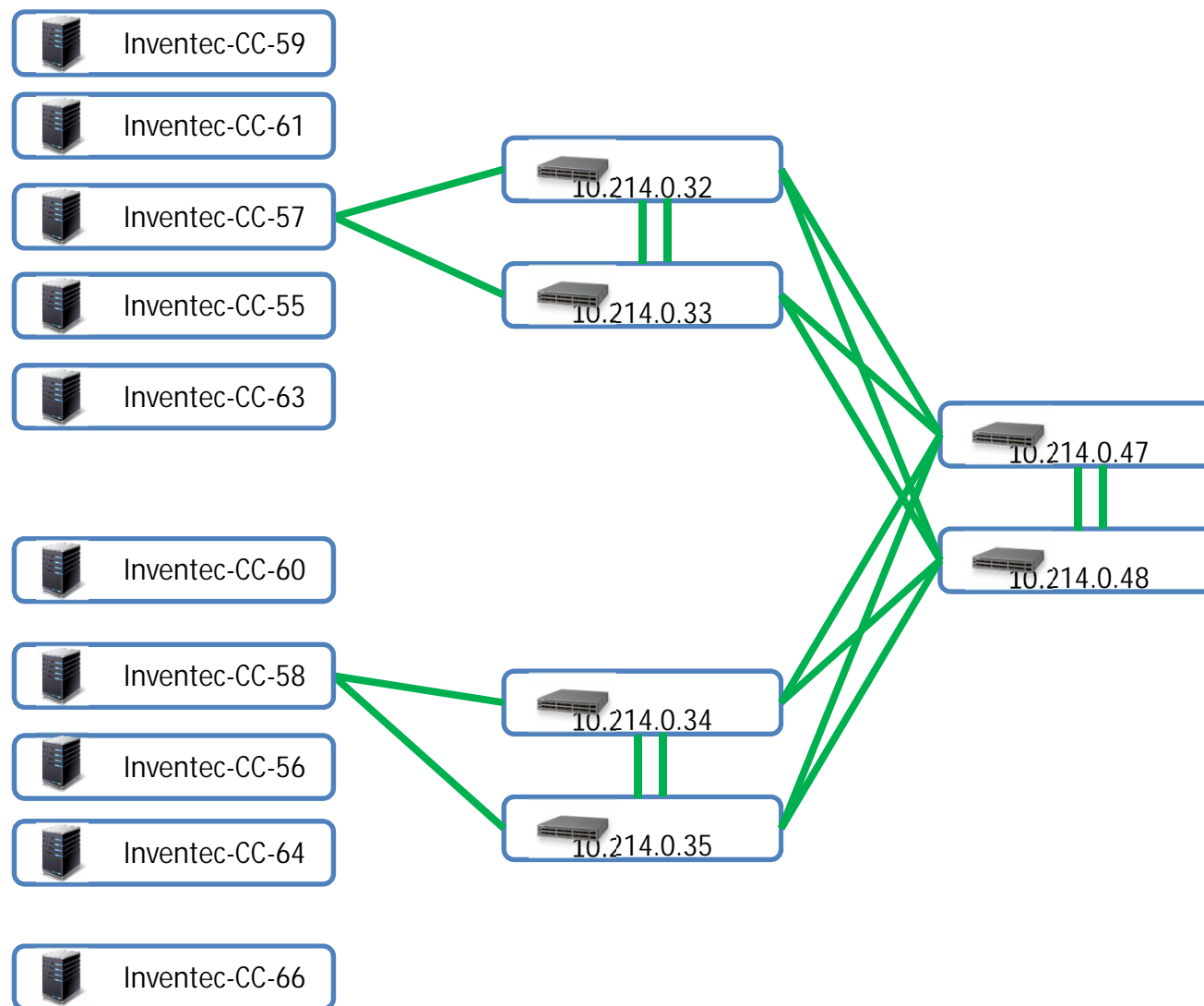
Underlying Physical Network Topology



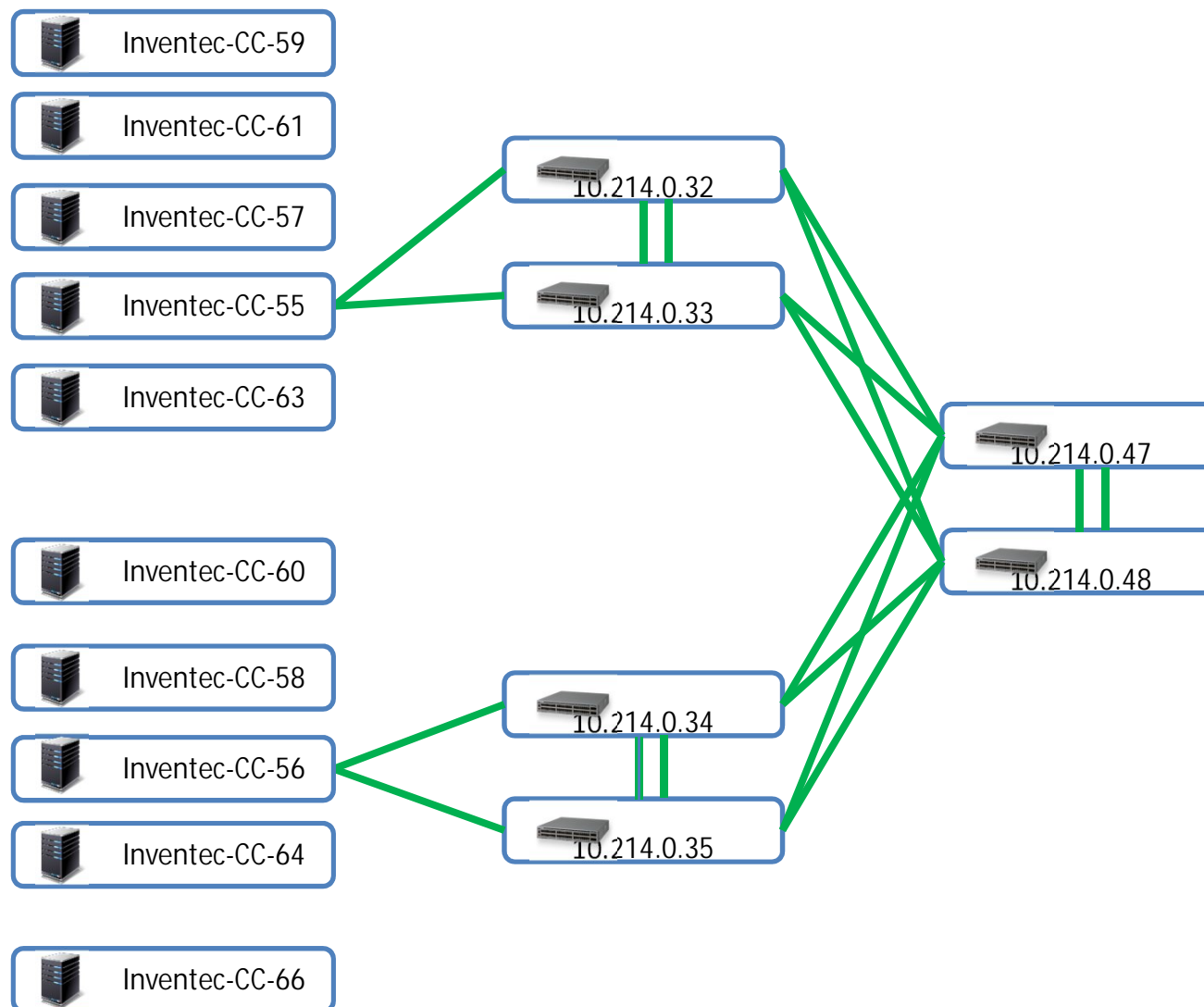
Topology for Tenant A's Virtual Network



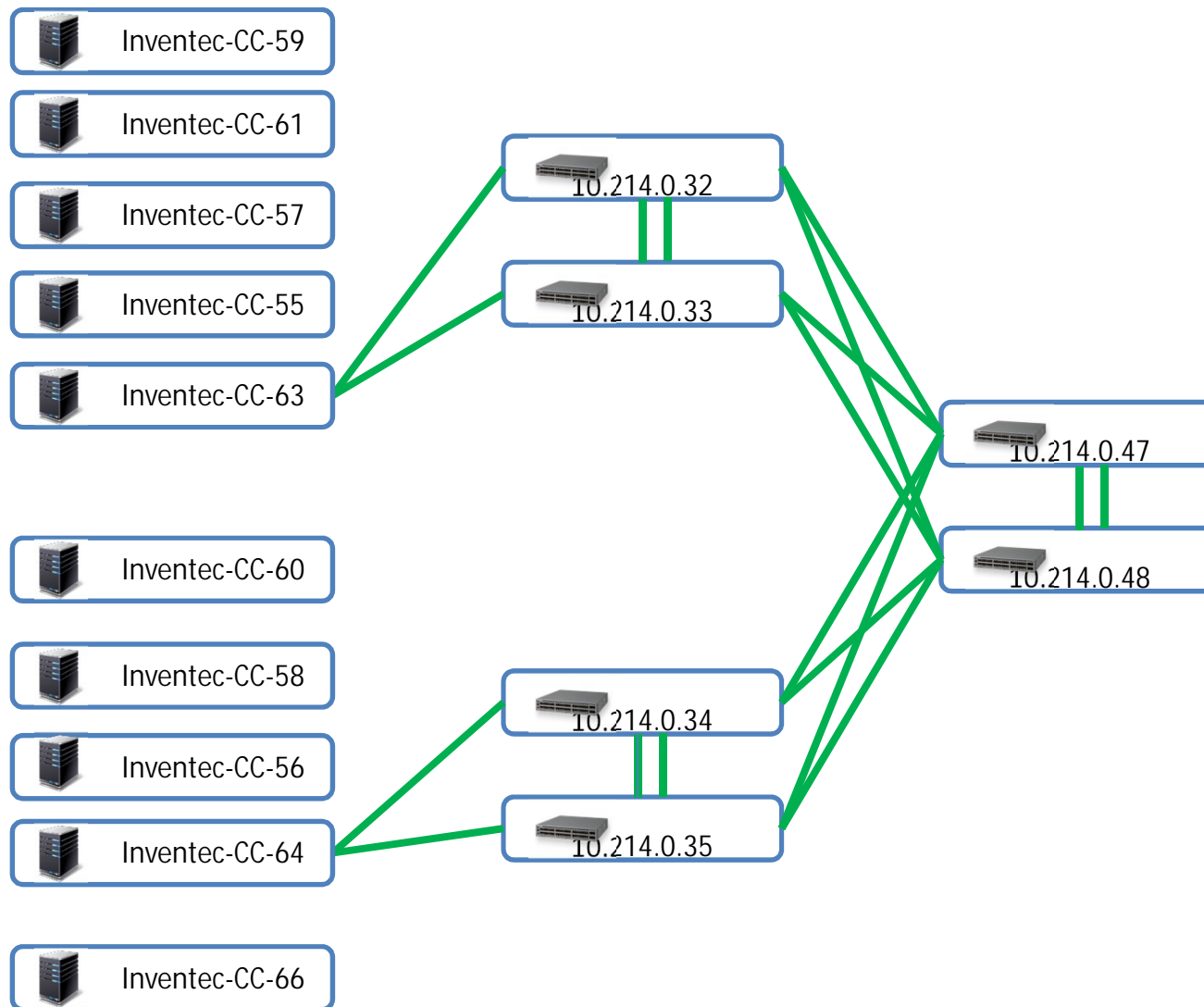
Topology for Tenant B's Virtual Network



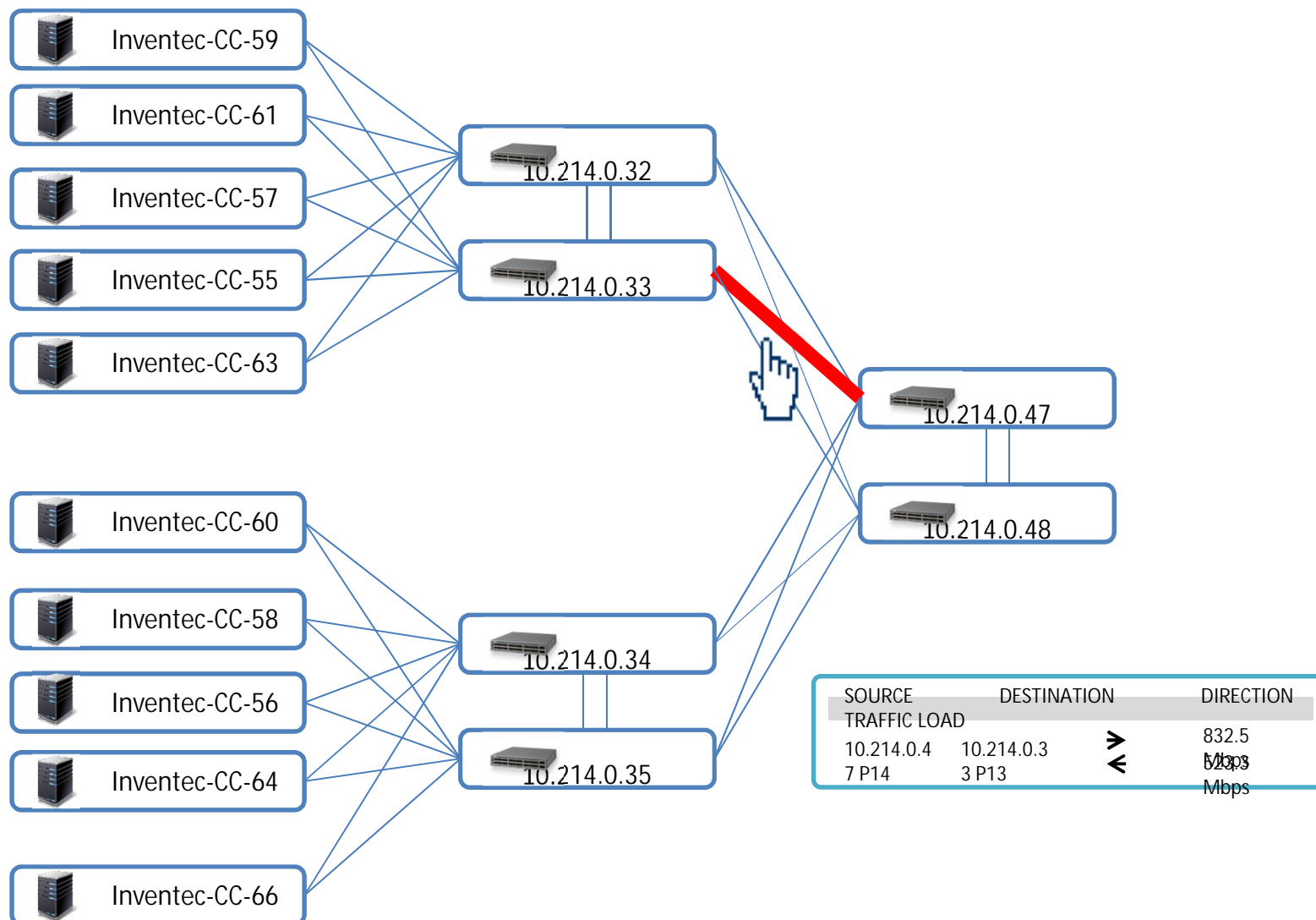
Topology for Tenant C's Virtual Network



Topology for Tenant D's Virtual Network




When an Alert Is Raised



Identify the Problematic Physical Link



Physical Links		Choose this physical link
10.214.0.48 P17 – 10.214.0.34 P17	832.5 Mbps	
10.214.0.34 P17 – 10.214.0.48 P17	523.2 Mbps	

Identify the Problematic Virtual Link



Physical Links	Tenants
10.214.0.48 P17 – 10.214.0.34 P17 832.5 Mbps	Tenant A 413.5 Mbps
10.214.0.34 P17 – 10.214.0.48 P17 523.2 Mbps	Tenant B 236.3 Mbps
	Tenant C 182.7 Mbps

Choose this Tenant

Identify the Problematic VLAN




Tenants		VLANs	
Tenant A	413.5 Mbps	VLAN 1301	367.8 Mbps
Tenant B	236.3 Mbps	VLAN 1305	25.9 Mbps
Tenant C	182.7 Mbps	VLAN 1358	19.8 Mbps

Choose this VLAN ID

Identify the Problematic Host Pair



VLANs		PM Pairs	
VLAN 1301	367.8 Mbps	192.168.10.5 – 192.168.10.3	296.3 Mbps
VLAN 1305	25.9 Mbps	192.168.10.5 – 192.168.10.10	43.2 Mbps
VLAN 1358	19.8 Mbps	192.168.10.5 – 192.168.10.11	28.3 Mbps

 Choose this PM Pair

Identify the Problematic Network Flow



PM Pairs		Flows	Choose this Flow
192.168.10.5 – 192.168.10.3	296.3 Mbps	192.168.10.5:12358 – 192.168.10.3:5001	200.5 Mbps
192.168.10.5 – 192.168.10.10	43.2 Mbps	192.168.10.5:23541 – 192.168.10.3:80	56.8 Mbps
192.168.10.5 – 192.168.10.11	28.3 Mbps	192.168.10.5:13245 – 192.168.10.3:22	39.0 Mbps

Zoom into Problematic Network Flow

The image shows a Wireshark 1.12.1 window titled "Capturing from br-mon [Wireshark 1.12.1 (Git Rev Unknown from unknown)]". The interface includes a menu bar, a toolbar, a filter bar, and a packet list pane. The packet list pane shows a series of TCP packets from 192.168.20.1 to 192.168.20.2. Packet 1532661 is highlighted in blue and contains a red error message: "[Reassembly error, protocol TCP: New fragment overlaps old data (retransmission?)]". The packet details pane shows the structure of the packet: Ethernet II, 802.1Q Virtual LAN, Internet Protocol Version 4, and Transmission Control Protocol. The packet bytes pane shows the raw data in hexadecimal and ASCII.

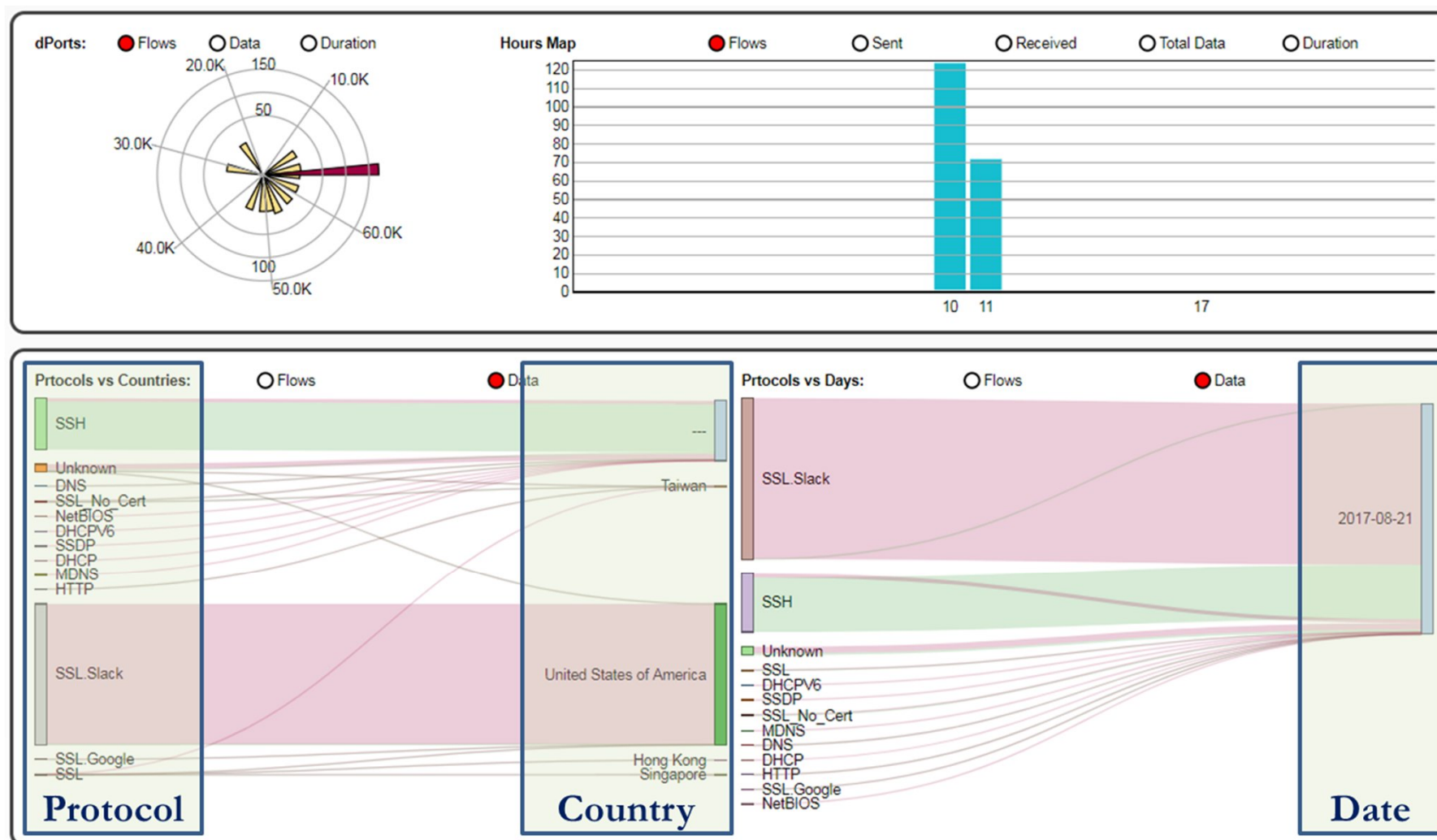
No.	Time	Source	Destination	Protocol	Length	Info
1532652	460.35388700	192.168.20.1	192.168.20.2	TCP	23238	5201->42339 [ACK] Seq=2495852985 Ack=1 Win=227 Len=23168 TSval=519125279 TSr=519125280
1532653	460.35407800	192.168.20.1	192.168.20.2	TCP	13102	5201->42339 [ACK] Seq=2495876153 Ack=1 Win=227 Len=13032 TSval=519125279 TSr=519125280
1532654	460.35408400	192.168.20.1	192.168.20.2	TCP	10206	5201->42339 [ACK] Seq=2495889185 Ack=1 Win=227 Len=10136 TSval=519125280 TSr=519125280
1532655	460.35427100	192.168.20.1	192.168.20.2	TCP	21790	5201->42339 [ACK] Seq=2495899321 Ack=1 Win=227 Len=21720 TSval=519125280 TSr=519125280
1532656	460.35445300	192.168.20.1	192.168.20.2	TCP	23238	5201->42339 [ACK] Seq=2495921041 Ack=1 Win=227 Len=23168 TSval=519125280 TSr=519125280
1532657	460.35465400	192.168.20.1	192.168.20.2	TCP	21790	5201->42339 [ACK] Seq=2495944209 Ack=1 Win=227 Len=21720 TSval=519125280 TSr=519125280
1532658	460.35484800	192.168.20.1	192.168.20.2	TCP	23238	5201->42339 [ACK] Seq=2495965929 Ack=1 Win=227 Len=23168 TSval=519125280 TSr=519125280
1532659	460.35504000	192.168.20.1	192.168.20.2	TCP	21790	5201->42339 [ACK] Seq=2495989097 Ack=1 Win=227 Len=21720 TSval=519125280 TSr=519125280
1532660	460.35523100	192.168.20.1	192.168.20.2	TCP	23238	5201->42339 [ACK] Seq=2496010817 Ack=1 Win=227 Len=23168 TSval=519125280 TSr=519125280
1532661	460.35542300	192.168.20.1	192.168.20.2	TCP	21790	5201->42339 [ACK] Seq=2496033985 Ack=1 Win=227 Len=21720 TSval=519125280 TSr=519125280
1532662	460.35561500	192.168.20.1	192.168.20.2	TCP	23238	5201->42339 [ACK] Seq=2496055705 Ack=1 Win=227 Len=23168 TSval=519125280 TSr=519125280
1532663	460.35580600	192.168.20.1	192.168.20.2	TCP	21790	5201->42339 [ACK] Seq=2496078873 Ack=1 Win=227 Len=21720 TSval=519125280 TSr=519125280
1532664	460.35600000	192.168.20.1	192.168.20.2	TCP	23238	5201->42339 [ACK] Seq=2496100593 Ack=1 Win=227 Len=23168 TSval=519125280 TSr=519125280

Frame 1532661: 21790 bytes on wire (174320 bits), 21790 bytes captured (174320 bits) on interface 0
Ethernet II, Src: Inventec_ea:44:2e (00:a0:d1:ea:44:2e), Dst: Inventec_ea:3e:fb (00:a0:d1:ea:3e:fb)
802.1Q Virtual LAN, PFI: 0, CFI: 0, ID: 4093
Internet Protocol Version 4, Src: 192.168.20.1 (192.168.20.1), Dst: 192.168.20.2 (192.168.20.2)
Transmission Control Protocol, Src Port: 5201 (5201), Dst Port: 42339 (42339), Seq: 2496033985, Ack: 1, Len: 21720
[Reassembly error, protocol TCP: New fragment overlaps old data (retransmission?)]

0000 00 a0 c1 ea 3e fb 00 c0 d1 ea 44 2e 81 00 0f fd>... ..D....
0010 08 00 45 00 55 0c 9b 3a 40 00 40 06 a1 5c c0 a8 ..F.U...: @.@....
0020 14 01 c0 a8 14 02 14 51 a5 63 4a 39 73 9e 22 bfQ .cJ9s.."
0030 c1 05 00 10 00 e3 fe 52 00 00 01 01 00 0e 1e f1R
.....

br-mon: <live capture in progres... Packets: 1532664 · Displayed: 1532664 (100.0%) Profile: Default

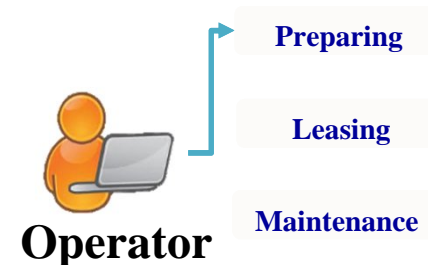
Apply Deep Packet Inspection



Operational Support for HaaS

HW Preparation

- A hardware usage portal for a **HaaS provider operator**
 - Maintenance of server HW specifications
 - Entry of hardware asset inventory list



HaaS Operation

- A service portal for a **HaaS provider operator**
 - Hardware asset health status monitoring
 - Hardware asset usage by each HaaS tenant
 - How to isolate PDCIs used by multiple tenants
 - Images, packages and archived data volumes are made accessible to authorized tenants
 - PDCI preparation when released to users, and clean-up upon return
 - Root cause diagnostics of reported or detected HW problems: Alerts → Problematic HW assets
 - Lest disruptive server HW replacement: replace the problematic hardware and automatically re-do the associated provisioning

Comparison

Metric	ITRI HaaS	IBM Softlayer	OpenStack Ironic
Network Isolation	Y	Y	Y
Network Traffic Analysis	Y	N	N
Physical Network Load Balancing	Y	N	N
Agentless Implementation	Y	Y	Y
Interoperability with multiple switch types	Y	Unknown	N
Compatibility with OpenStack	Y	N	Y

Summary

- DNN is expected to play a critical role in the emerging AI revolution across a wide range of industry segments.
- DNN training will become a major workload on future private and public cloud computing systems.
- DNN training appliance is a key enabling building block for corporations to apply DNN to make sense of their data and/or improve their businesses.
- DNN training as a service = DNN training appliance + HaaS

Thank You!

Questions and Comments?

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