**2022
TECHNOLOGY
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Automating Internet2 NGI and the Migration

James Harr
Sr NetDevOps Engineer, Internet2

Ryan Harden
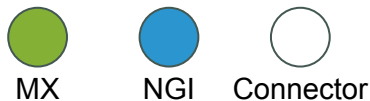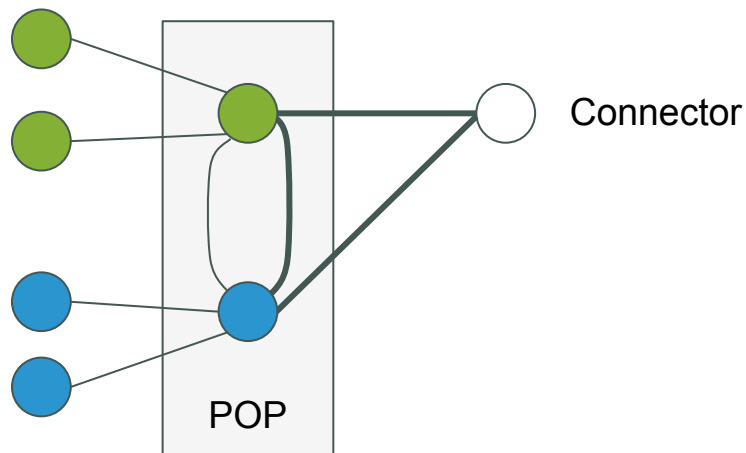Sr Cyberinfrastructure Security Architect, Internet2

Matt Mullins
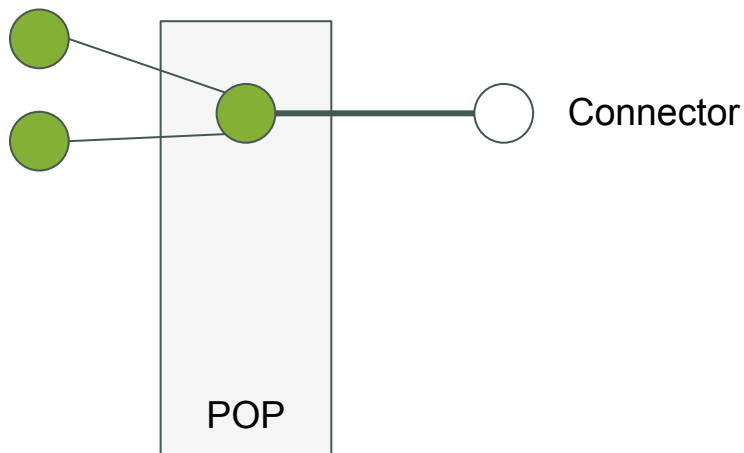Senior Network Engineering Manager, Internet2

INTERNET2

Refresher & Timeline

Connector

POP

MX   NGI   Connector

Packet Timeline
- Packet RFP
  - 2019 Q4 - Packet RFP Begins
  - 2020 Q3 - Packet RFP Award
- Timeline of deployment
  - 2021 Apr - Build Backbone
  - 2021 May - Network Testing
  - 2021 Jun - Shim
  - 2021 Aug-Dec - Service Migrations

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Refresher & Timeline

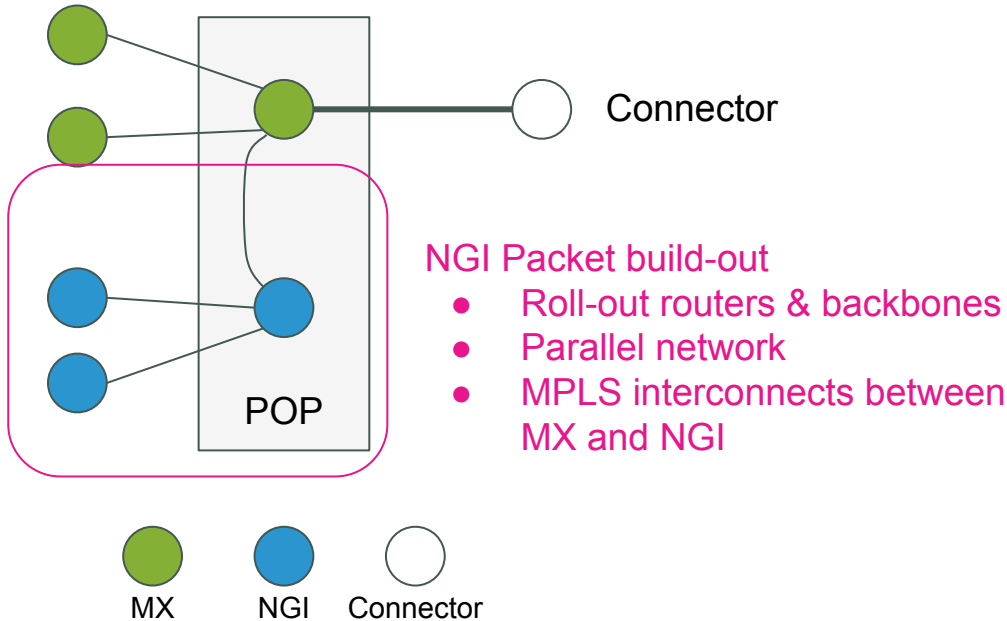Connector

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Refresher & Timeline

NGI Packet build-out
- Roll-out routers & backbones
- Parallel network
- MPLS interconnects between MX and NGI

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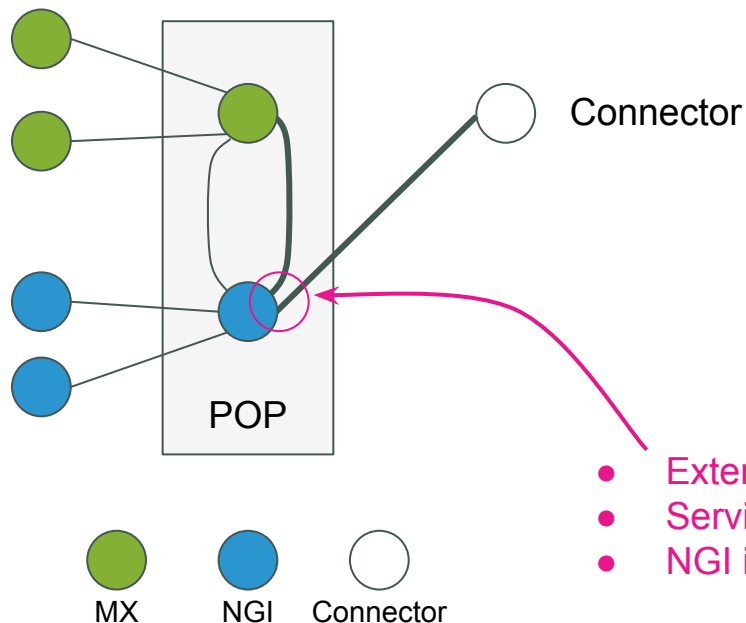 - 2021 Aug-Dec - Service Migrations

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- External connections physically migrated
- Services still handled on MX
- NGI is a "bump-in-the-wire"
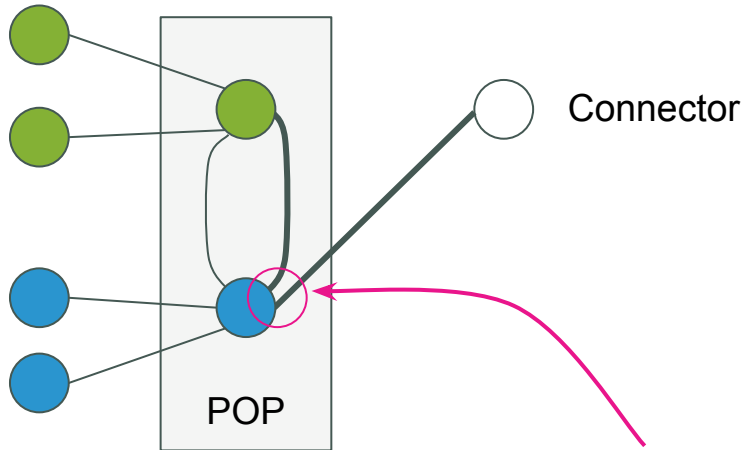
Refresher & Timeline

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Connector

POP

MX   NGI   Connector

Service Migrations
- L2 and L3 services are migrated selectively
- Migration & Rollback are performed remotely
- Migration performed when services are ready
  - L2 functionality was not complete out of the gate

Refresher & Timeline

Connector

POP

Decommissioning MX Network
- Services Stable
- No support tickets
- Leisurely pace to avoid mistakes
- Examine links & routers for traffic prior to taking offline
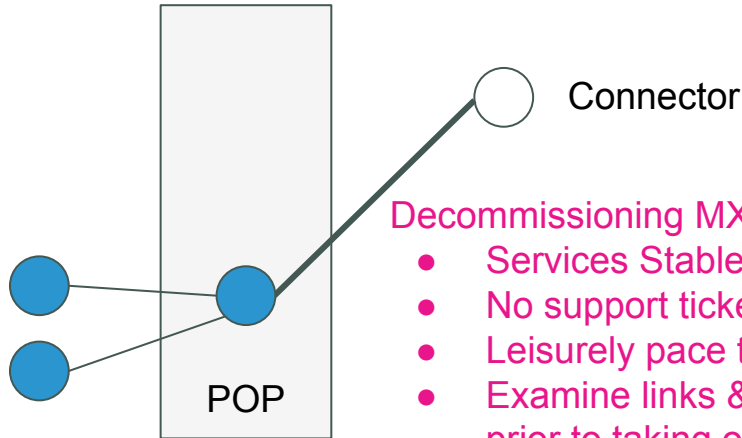
MX NGI Connector

Packet Timeline
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Building the Backbone

Building the Backbone

- Green-field - building parallel backbones
- The interconnects

400G+ COAST TO COAST, COMMUNITY TO CLOUD

Network Infrastructure Topology | March 2022

NETWORK

INTERNET2 2022TECHNOLOGYEXCHANGE
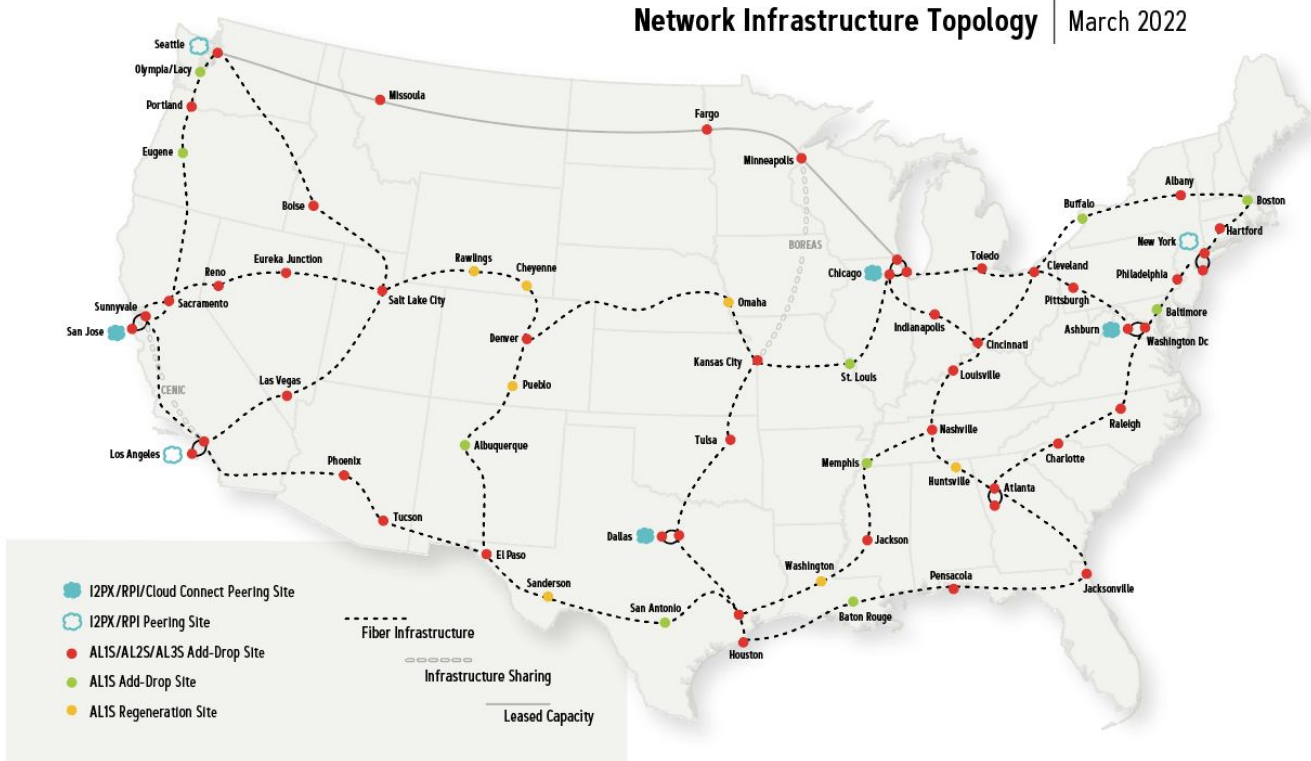
```
> show configuration infrastructure pops route-distance
route-distance ALBA CLEV {
    distance 823;
    srlg      [ 1 ];
}
route-distance ALBA HART2 {
    distance 548;
    srlg      [ 1 ];
}
route-distance ASHB ATLA {
    distance 1330;
    srlg      [ 3 12 ];
}
```

```
> show configuration services backbone BB-DENV-KANS-*
backbone BB-DENV-KANS-1 {
    pdp DENV-BB-KANS-1;
    pdp KANS-BB-DENV-1;
    admin-state in-service;
    circuit-id  193441;
}
backbone BB-DENV-KANS-2 {
    pdp DENV-BB-KANS-2;
    pdp KANS-BB-DENV-2;
    admin-state in-service;
    circuit-id  193445;
}
```

```
> show configuration services pdp DENV-BB-KANS-*
pdp DENV-BB-KANS-1 {
    device        core1.denv;
    admin-state in-service;
    role          backbone;
    ios-xr {
        interfaces {
            FourHundredGigE 0/0/0/1 {
                circuit-id 193187;
            }
        }
    }
}
```

Interconnects

List of interconnect sites?

Test Plans

Screenshot of smartsheet

Cisco NSO

Configuration Orchestration
Why and some Examples

Why NSO?

- Single config tree (CDB)
  - Many devices, single config tree
  - Multi-platform
- Custom service models
  - Custom-defined schema in CDB
  - Translates to device config in CDB
- Why services?
  - Use defaults & conventions relevant to us
  - Can control multiple devices
  - Upgrade config with the model
  - Knows what to remove
- Access CDB with CLI & API

NSO CDB - Remote Devices

IOS-XR

```
#show run interface GigabitEthernet 0/0/0/0
Mon Dec  5 16:38:36.413 UTC
interface GigabitEthernet0/0/0/0
 description BACKBONE: CORE1.EQCH.AA-CORE2.EQCH.AA
 mtu 9184
 lldp
  enable
 !
 carrier-delay up 5000
 load-interval 30
 dampening 4 800 1000 30
```
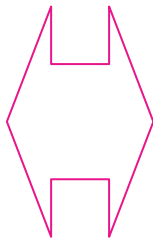
Cisco NSO

```
[edit devices device core1.eqch.aa config interface GigabitE
lab@nsdevlab-nso% show 0/0/0/0*

GigabitEthernet 0/0/0/0 {
  description    "BACKBONE: CORE1.EQCH.AA-CORE2.EQCH.AA";
  mtu            9184;
  lldp {
    enable;
  }
  load-interval 30;
  dampening {
    half-life         4;
    reuse             800;
    suppress          1000;
    max-suppress-time 30;
  }
  carrier-delay {
    up 5000;
  }
}
```

NSO CDB - Services
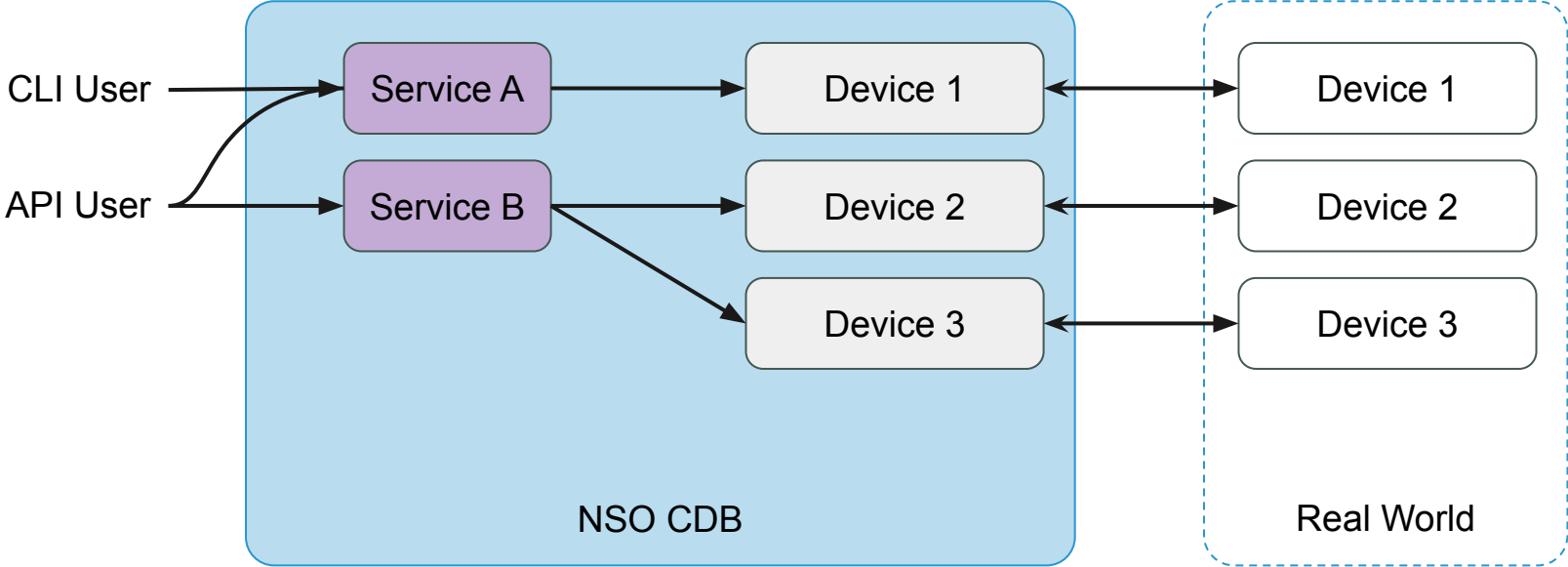
Example Service - PDP

PDP
- Physical Delivery Point
- Largely vendor agnostic
- Single interface or LAG
  - Single PDP regardless
  - Can be converted
- Sane defaults

Referenced by other services:
- RE services
- I2PX services
- OESS Services
- Shim Service
- SimplePW services

```
services {
  pdp POP-CONN-ENTITY-1 {
    device        core1.ashb;
    admin-state   in-service;
    lag-id        13;
    role          edge;
    lag-circuit-id 10001;
    ios-xr {
      interfaces {
        TenGigE 0/0/0/8/1 {
          circuit-id 10002;
        }
        TenGigE 0/0/0/8/2 {
          circuit-id 10003;
        }
      }
    }
  }
}
```

Example Service - I2PX-Cust

i2px-cust
- I2PX service for a Member
- Vendor agnostic

Creates device config:
- sub-interface config
- BGP neighbor
- BGP policy for neighbor
- Prefix-Sets used by policy

Checks
- Address reachability
- Unique encapsulation

```
i2px-cust POP-ENTITY-1 {
    admin-state  in-service;
    entity       ENTITY;

    pdp          POP-CONN-ENTITY-1;
    encapsulation {
        dot1q { vlan-id 1091; }
    }
    address-ipv4 192.0.2.1/30;
    address-ipv6 2001:db8::1/126;

    remote-as    64511;
    neighbor     192.0.2.2;
    neighbor     2001:db8::2;
    password-md5 SecurePassword;
    select-in {
        prefix LEGACY-RIF-64511-CUST-V4-IN;
        prefix LEGACY-RIF-64511-CUST-V6-IN;
    }
}
```

NSO CDB - Config Removal & Service References

```
lab@nsdevlab-nso% show | display service-meta-data

GigabitEthernet 0/0/0/0 {
    /* Refcount: 2 */
    /* Originalvalue: rtr2.eqch:gi0/0/0/0 */
    description    "BACKBONE: CORE1.EQCH.AA-CORE2.EQCH.AA";

    /* Refcount: 2 */
    /* Originalvalue: 9100 */
    mtu            9184;

    /* Refcount: 1 */
    /* Backpointer: [ /ncs:services/pdp:pdp[pdp:name='EQCH-IC-Z-8'] ] */
    lldp {

        /* Refcount: 1 */
        /* Backpointer: [ /ncs:services/pdp:pdp[pdp:name='EQCH-IC-Z-8'] ] */
        enable;
```

NSO - what's the result?

- 7930 lines of YANG
  - Custom schema for our services
- 13,800 lines of XML config templates
  - 7600 lines of XML
  - 2400 lines of Jinja2 expands to 6200 lines
- 5800 lines of Python
- 1500 lines of YAML (VRF config, static route policy)

How'd we get there?
- 632 Merge Requests
- 3234 Commits

Project and Resource References

- NSO-Docker project - https://gitlab.com/nso-developer/nso-docker
  - Puts NSO into a Docker
  - Modular
  - Includes testing hooks
- Kristian Larsson - https://plajjan.github.io/
  - Blogs and talks about YANG, NSO
- NSO Developer Hub Youtube - https://www.youtube.com/@cisconsodeveloperhub492
  - Recorded NSO dev talks
- YANG RFC - https://tools.ietf.org/html/rfc7950
  - JSON encoding of YANG data - https://www.rfc-editor.org/rfc/rfc7951
  - YANG-Patch - https://www.rfc-editor.org/rfc/rfc8072.html
- Robot Testing Framework - https://robotframework.org/
  - Specific framework isn't important, but this produces a really nice trace/log

Extracting Information

From exploration to mining

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Exploring config with XML

- **XML** is your friend
- **XPath** is your best friend
- **Python** and **xml.etree.ElementTree** will help you move to a new house
- but **xmlstarlet** will help you bury a body

```
xmlstarlet sel -t -f -n -m '//routing-instances/instance' -v './name' -n *.xml
        sel -t          "select" sub-command using a cli template (-t)
        -f              Output current file
        -m XPATH        Match this xpath expression, loop over results
        -v XPATH        Output value(s)
        -o "xyz"        Output "xyz", use -o "," to create a CSV
        -c XPATH        Output a copy of the XML matching this
                        Use -B to trim whitespace.
        -n              New line
```

XML Terms

```
<my-tag my-attribute="123">Foo</my-tag>
```
- my-tag   - tag / node
- my-attribute - attribute (inactive & annotation)
- 123   - attribute value
- Foo   - value / tag value / CDATA

```
<interface>
  <name>et-1</name>
  <unit>
    <name>500</name>
  </unit>
  <unit inactive="inactive">
    <name>600</name>
  </unit>
</interface>
```

XPath

```
/foo            - match a <foo> tag at the root of the tree
//foo           - match a <foo> tag, anywhere
.               - match current node / context node
foo or ./foo    - match a child <foo>
foo[x=1]        - match node with direct child <foo><x>1</x></foo>
foo[@x=1]       - match node with an attribute <foo x="1">...</foo>
```

```
<interface>                              /interface    or    /interface[name="et-1"]
  <name>et-1</name>
  <unit>                                 /interface[name="et-1"]/unit[name="500"]
    <name>500</name>
  </unit>
  <unit inactive="inactive">             /interface/unit[inactive="inactive"]
    <name>600</name>
  </unit>
</interface>
```

XPath example

```
<interface>                            /interface or /interface[name="et-1"]
  <name>et-1</name>
  <unit>                               /interface[name="et-1"]/unit[name="500"]
    <name>500</name>
  </unit>
  <unit inactive="inactive">  /interface/unit[inactive="inactive"]
    <name>600</name>
  </unit>
</interface>
```
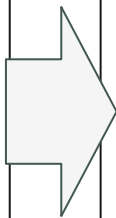
Example - BGP Neighbor Descriptions

```
xmlstarlet sel -t -m '//neighbor' \
       -v description -n \
       *.xml | sort | uniq -c | sort -rn
```

```
<neighbor>
  <name>163.253.34.177</name>
  <description>vrr.wash2 [NO-MONITOR]</..
  <peer-as>11537</peer-as>
  ...
</neighbor>
```

```
71 [RE] Internet2 Route Collector | [NO...
46 vrr.wash2 [NO-MONITOR]
 7 [NETPLUS] Zoom Video Communications ...
 4 [i2pxpeer] Yahoo! - Equinix Dallas [...
 4 [i2pxpeer] Valve - SIX | I2-S191860 ...
 4 [i2pxpeer] Twitch - Equinix Chicago ...
 4 [i2pxpeer] Twitch - Equinix Ashburn ...
```

Example - LACP Options

```
xmlstarlet sel -B -t -f -n \
  -m "//interfaces/interface[starts-with(name,'ae')]/aggregated-ether-options" \
  -v ../name -o ' - ' \
  -c lacp -n *.xml
```

```
<interface>
    <name>ae1</name>
    <aggregated-ether-options>
        <minimum-links>1</minimum-links>
        <link-speed>100g</link-speed>
        <lacp>
            <active/>
        </lacp>
    </aggregated-ether-options>
</interface>
```

```
rtsw2.sanj.net.internet2.edu.xml
ae1 - <lacp><active/></lacp>
ae3 - <lacp><active/></lacp>
ae5 - <lacp><active/><periodic>
            fast</periodic></lacp>
```

Example - Interface MTUs

```
xmlstarlet sel -B -t -m '//interface/unit[not(contains(name,"*"))]' \
  -f -o , \
  -v ../name -o , \
  -v name -o ',"' \
  -v '//interfaces/interface[name=current()/../name]/description' -o '",' \
  -v description -o , \
  -v '//interfaces/interface[name=current()/../name]/mtu' -o , \
  -v family/inet/mtu -o , \
  -v family/inet6/mtu -o , \
  -v family/iso/mtu -o , \
  -v family/mpls/mtu -o , \
  -n *.xml > ~/Downloads/mtu.csv
```

```xml
<interface>
  <name>xe-0/0/1</name>
  <unit>
    <name>301</name>
    <family>
      <inet>
        <mtu>9000</mtu>
      </inet>
    </family>
  </unit>
</interface>
```

XPath Resources

- XPath
  - W3C Schools - XPath Introduction: https://www.w3schools.com/xml/xpath_intro.asp
  - MDN XPath - https://developer.mozilla.org/en-US/docs/Web/XPath
- Python + XML
  - xml.etree docs - https://docs.python.org/3/library/xml.etree.elementtree.html#example
  - lxml - https://lxml.de/
- XMLStarlet
  - User Guide: https://xmlstar.sourceforge.net/doc/UG/xmlstarlet-ug.html
  - XSLT: https://developer.mozilla.org/en-US/docs/Web/XSLT

Extracting data - Getting the data we need

Export for Migration

- ○ Scrape BGP sessions from a router
- ○ Correlate with interface information
- ○ Correlate with BGP policy(prefix-lists)
- ○ Correlate with data in NOC-DB (Service ID, Entity, etc)

CSV export of neighbors for each router

- ○ Interface, Encapsulation, Description
- ○ Addressing
- ○ BGP Neighbor config (Address, ASN, BFD, Password, GTSM, prefix limit)
- ○ BGP Policy (prefix-list names, communities, extra policies)

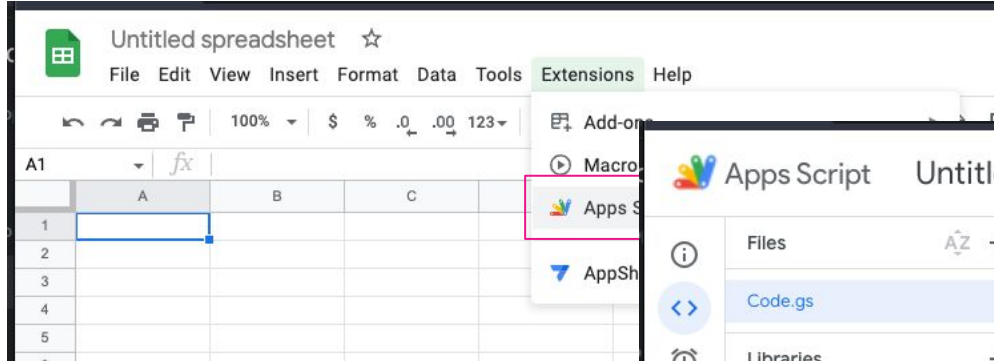Thanks to Molly Balas w/ GlobalNOC for all this

Transforming the Data
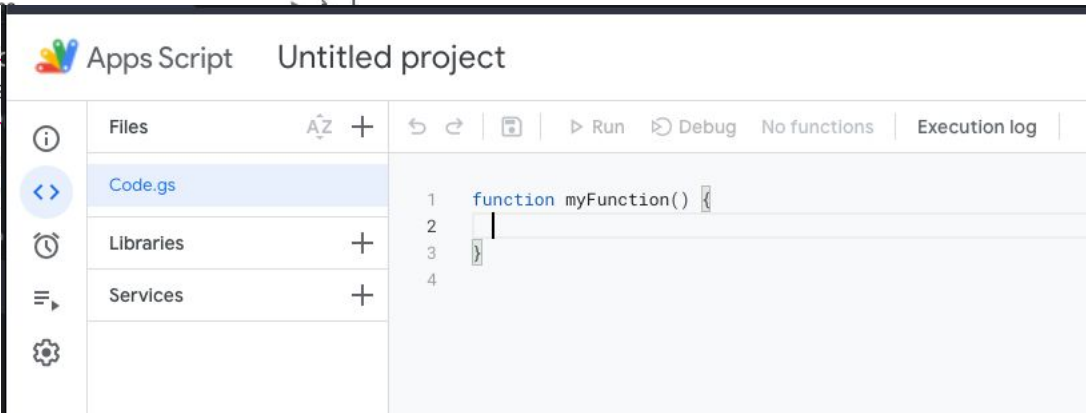
Using Google Sheets for fun and profit
...way more than human kind should

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Google App-Script - A crash course

Google App-Script - First steps

Google App-Script - Reading from a matrix

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Google App-Script - Reading from a matrix

Google App-Script - A crash course

```
60    function return_matrix() {
61      return [
62        ["First line", 1, "Greetings"],
63        ["Second line", 2, "from"],
64        ["Third line", 3, "TechEx"],
65        ["Forth line", 4, "2022"],
66        ["", "", "!!!!"],
67      ]
68    }
```
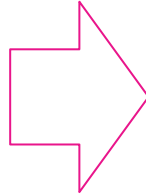
B2		fx	=return_matrix()	
	A	B	C	D
1				
2		First line	1	Greetings
3		Second line	2	from
4		Third line	3	TechEx
5		Forth line	4	2022
6				!!!!
7				

Google App-Script - A crash course

Screenshot: Multiple tabs
- Instructions in first
- Augment Data
- Debug tab (hidden)
- Skipped migrations - place to move things you're not migrating

The Input

- 27 Columns of information
- One neighbor on each line
- Imperfect information

The process of transformation

- Convert a matrix into an object
- Check for missing mandatory fields
- Build an intermediate tree
  - Combine IPv4 and IPv6 information
  - Infer settings/information
  - Note where information came from
  - Reconcile differences
- Generate the report output
  - Some decisions
  - Largely template formatting

Debugging - Intermediate tree

```
Files                    A̧Z  +    ↺  ↻   💾    ▷ Run   🐞 Debug   nso_svc_parse ▼    Execution log

ConfigService.gs             8    /**
                             9     * Debug to spit out data structures
ConfigPDP.gs                10     */
                            11    function nso_svc_parse(input_matrix, pdp_table) {
ConfigBGPCompare.gs         12
                            13        // Transform from COLS/ROWS -> Array of Objects
ConfigJunOS.gs              14        var data = mat2dict_list(input_matrix);
                            15        var interfaces = parse_export(data, pdp_table);
ExportParser.gs             16        var rv = [];
                            17        rv.push("nso_svc_parse output (main data structure for templ
Util.gs                     18        rv.push(... JSON.stringify(interfaces, null, 2).split("\n"))
                            19        return rv;
UtilSubnet.gs               20    }

UtilShim.gs
```

```
A1          ▼   fx   =nso_svc_parse('Sample-Export'!A:AZ, PDP!A:Z)
                                        A
 1   nso_svc_parse output (main data structure for templating)
 2   {
 3     "rtsw.salt.net.internet2.edu,et-4/3/0,701": {
 4       "legacy_router": "rtsw.salt.net.internet2.edu",
 5       "legacy_interface": "et-4/3/0",
 6       "legacy_unit": 701,
 7       "pop": "SALT",
 8       "vrf": "i2px",
 9       "pdp": "POP-CONN-AAA1-1",
10       "_pdp_source": "Existing PDP from shim service SHIM-PO
11       "vlan1": 701,
12       "vlan2": "",
13       "address_ipv4": "192.0.2.0/31",
14       "address_ipv6": "2001:db8::/126",
15       "is_pdp": true,
16       "is_ixp": false,
17       "neighbors": {
18         "64500": [
19           {
20             "_type": "i2px-cust",
21             "_subtype": null,
22             "service_id": "55749",
23             "_service_id_source": "peer description",
24             "remote_as": 64500,
25             "entity": "AAA1",
26             "neighbor": "192.0.2.1",
27             "is_ipv4": true,
28             "is_ipv6": false,
29             "group": "EBGP-CUST-FULL",
30             "bfd_enable": "",
31             "bfd_min_interval": "",
```

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Generating Output

- Loop through interfaces
  - About 700 lines
- Append to output rows
  - Section
  - Config/Commands
  - Info/Error
- Two output forms
  - Collated (by unit)
  - Uncollated (by section)

```
        ↶  ↷    🖫      ▷ Run  ⊗ Debug   nso_svc_config ▾    Execution log

210                }
211
212    if(collate) {
213      cl_collated.unshift(["Service", "Config", "Notes/Debug"]);
214      return cl_collated;
215    } else {
216      var rv = [];
217      rv.push(['Section', 'Config', 'Notes/Debug']);
218
219      rv.push(['- Load Services into NSO']);
220      rv.push([``, `configure`]);
221      rv.push([``, `load merge terminal`]);
222      rv.push([``, `services {`]);
223      for(var pdp_config of Object.values(cl_nso_pdp_config)) {
224        rv.push(... pdp_config);
225      }
226      rv.push(... cl_nso_svc_config);
227      rv.push([``, `}`]);
228      rv.push([``, `ENTER, CTRL-D`]);
229      rv.push([``, `commit dry-run`, 'Also try adding `outformat native` to the end']);
230      rv.push([``, `commit`]);
231      rv.push([]);
232
233      rv.push(['- Set up bgp_compare.py config file']);
234      rv.push(['', "mkdir output", "Only needed once"]);
235      rv.push(['', "! Place this into 2021-08-DD.pop.batch1.yml", "You can split the YAML up to matc
236      rv.push(... cl_bgp_compare);
237      rv.push([]);
238
239      rv.push(['- Capture routes on MX prior to maintenance']);
240      rv.push(['', '/srv/shared/i2-shared/scripts/bgp-comparison/bgp-compare.sh -f 2021-08-DD.pop.ba
241      rv.push([]);
104
                    }
```

Building a MOP

What went into the MOP

- Config to load into NSO
- bgp_compare.py - config
- bgp_compare.py - capture routes on MX
- Perform migration
- Commands to activate services in NSO
- bgp_compare.py - Command to check for routes
- Sample IOS-XR troubleshooting commands

Displaying the report: Formatting tricks
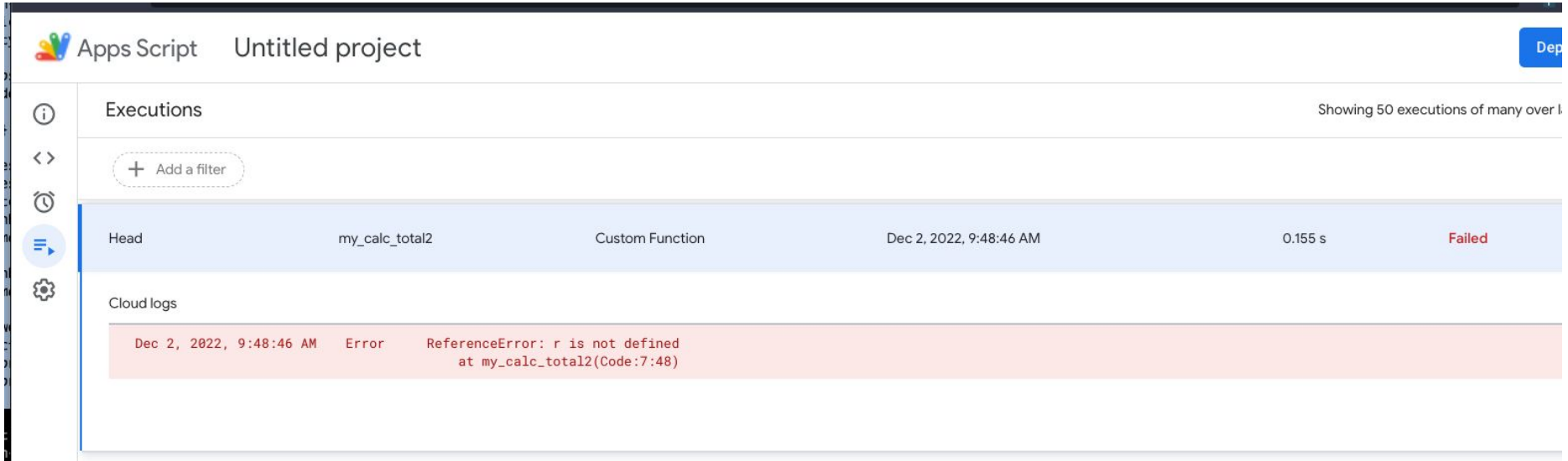
- Single line of config per row
- 3 Columns:
  - Section title (**bold**)
  - Config
  - Notes - Inform NetEng
- Use overflow
  - Lets text in column A run into column B
  - Overflow isn't "copied"
- Use highlighting rules
  - ERROR: Needs addressed
  - WARNING: Needs review
  - TODO/unknown: Something missing

Conditional format rules ×

123   Text contains "ERROR"
A1:C3366

123   Text contains "TODO"
A1:C3366

123   Text contains "unknown"
A1:C3366

123   Text contains "WARNING:"
A1:C3366

+ Add another rule

When something goes wrong

Section	Config	Notes/Debug
	remote-as 64503;	
	neighbor-ipv6 2001:db8::8;	
	select-in {	
		ERROR: Import did not contain any prefix-lists for this,
	}	
	}	
	lhcone-peer NEWY32AOA-DDD4-1 {	AS64503 - [LHCONE] D1 via MANLAN vlan 2001 | l2-:
	entity DDD4;	
	service-id 13547;	
	admin-state no-config;	
	pdp POP-CONN-MANLAN-1;	Existing PDP from shim service SHIM-POP-IX-1
	encapsulation { dot1q { vlan-id 2001; } }	
	address-ipv4 192.0.2.8/31;	
	address-ipv6 2001:db8::8/126;	

When something goes wrong

Google AppScript - Lessons

Stats:
- 1,450 lines of conversion code
- 506 lines of library code (LPM match)
- 19,200 lines of JSON data for lookup

Lessons:
- Cheap user interface
- Copying the spreadsheet worked surprisingly well
- Keep a copy of the AppScript somewhere else (source control)
- Would have skipped the "by Unit" conversion

Docs:
- https://developer.mozilla.org/en-US/docs/Web/JavaScript
- https://developers.google.com/apps-script/reference/spreadsheet/

Validating 100s of BGP Session Migrations

Poorly written python

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Why Automate Review?

- Lots (~1000) of BGP Sessions to Migrate
  - IPv4 and IPv6
  - RE + I2PX VRFs, etc
  - (CloudConnect Excluded)
- Dozens per Late-Night Migration Window
- Up To Hundreds of Prefixes per Session
- Familiarity of Individual Session Details (Lack thereof)
  - (Thank You to Community NetEng for joining calls..)
- Brand new Route Policy Language
  - Did it work as expected?

bgp-compare.py

- Cisco pyATS (Genie Parsers)
  - https://github.com/CiscoTestAutomation/genieparser
  - Community Contributed (incomplete)
- LOTS of trial and error
  - Regex Madness
  - BGP Features
  - IPv6 Support
- Fast and Dirty
  - Throwaway code
  - 777 lines, could be much less
- Contributed back to pyATS

ancker010   #26
28 commits   3,391 ++   1,775 --

50

2017   2020
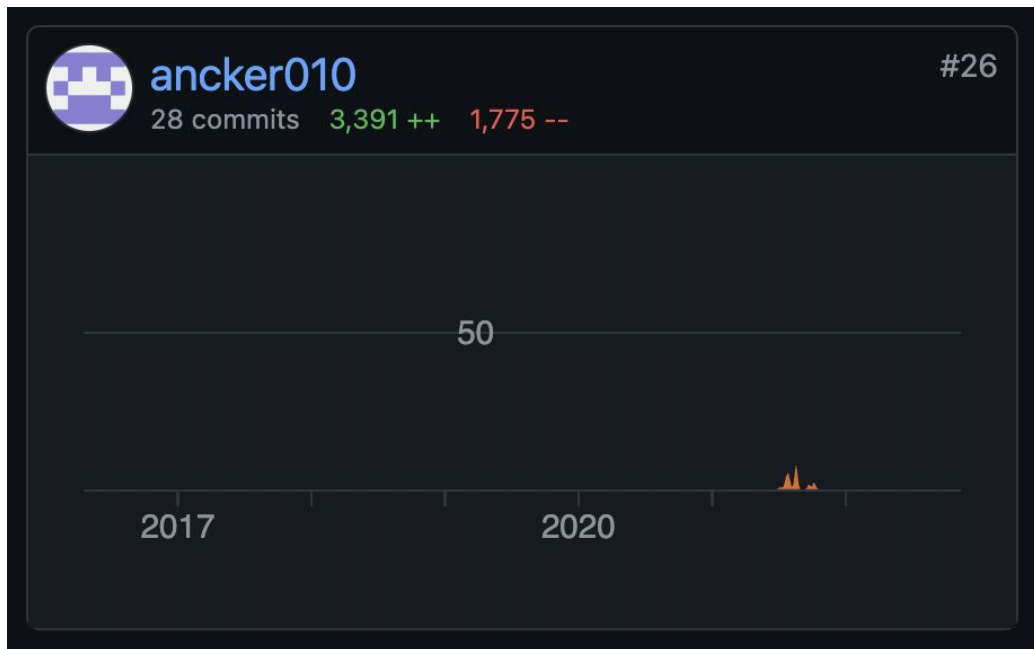
IPv4 Output is Easy

```
* i23.251.252.0/22     163.253.0.26        1000    500     0 16509 14618 i
* i                    163.253.0.27        1000    500     0 16509 14618 i
*>i                    163.253.0.32        1000    500     0 16509 14618 i
* i                    163.253.0.33        1000    500     0 16509 14618 i
* i24.38.86.0/24       163.253.0.43                600     0 62532 1436 55209 i
*>i                    163.253.0.45                600     0 62532 1436 55209 i
*>i24.224.234.0/23     163.253.0.43       30500    500     0 6509 10972 394846 i
*>i24.235.8.0/24       163.253.0.22          50    500     0 2907 59103 36599 i
*>i24.235.9.0/24       163.253.0.22          50    500     0 2907 59103 36599 i
*>i27.96.64.0/22       163.253.0.54           0    500     0 38022 55524 ?
*>i27.125.208.0/20     163.253.0.22         155    500     0 7575 24437 24437 55813 i
*>i31.3.112.0/21       163.253.0.21                500     0 20965 766 2114 i
* i                    163.253.0.43                500     0 20965 766 2114 i
*>i31.14.19.0/24       163.253.0.21                500     0 20965 2614 i
```

IPv6 Output is a Pain

- Sometimes 1…
- Sometimes 2…
- Sometimes 3…

```
2001:4200:7800::/48
                        2001:468:0:2::14
                                     163.253.0.124    11537 20080 2018i
2001:4200:8000::/44
                        2001:468:0:2::14
                                     163.253.0.124    11537 20080 2018i
2001:4310::/32        2001:468:0:2::14
                                     163.253.0.124    11537 20965 199354 30983i
2001:4310::/33        2001:468:0:2::14
                                     163.253.0.124    11537 20965 199354 30983i
2001:4310:f1::/48    2001:468:0:2::14
                                     163.253.0.124    11537 20965 199354 30983i
2001:4310:8000::/33
                        2001:468:0:2::14
                                     163.253.0.124    11537 20965 199354 30983i
```

Script Setup

- James Harr's Google Sheet Wizardry
  - Auto-Generated Input Config per Migration
- Tells the script what to do/where to look
- It's ultimately the required inputs to pyATS, plus VRF info

31	
32	- Config bgp-compare.py
33	"198.71.47.247": {pre: "rtsw.hart2", preip: "162.252.70.242", post: "core1.hart2", postip: "163.253.12.212", prevrf: "i2px", postvrf: "I2PX"}
34	"2001:468:f000:2501::2": {pre: "rtsw.hart2", preip: "162.252.70.242", post: "core1.hart2", postip: "163.253.12.212", prevrf: "i2px", postvrf: "I2PX"}
35	

86	
87	- Config bgp-compare.py
88	"198.71.46.215": {pre: "rtsw.hart2", preip: "162.252.70.242", post: "core1.hart2", postip: "163.253.12.212", prevrf: "default", postvrf: "RE"}
89	"2001:468:2300:6::2": {pre: "rtsw.hart2", preip: "162.252.70.242", post: "core1.hart2", postip: "163.253.12.212", prevrf: "default", postvrf: "RE"}

Gather Accepted Prefixes (Pre: JUNOS)

```
{
    "maint": "CEN-CHG-RE-9aug2021",
    "run": "pre",
    "198.71.46.215": {
        "vrf": "default",
        "router": "rtsw.hart2",
        "received_prefixes": [
            "50.28.128.0/18",
            "64.147.56.0/24",
            "64.147.57.0/24",
            "64.202.80.0/20",
            "64.202.80.0/21",
            "64.251.48.0/20",
            "64.251.48.0/21",
            "64.251.56.0/22",
            "64.251.56.0/24",
            "67.218.80.0/20",
            "67.218.80.0/21",
            "67.218.88.0/21",
            "67.218.89.0/24",
```
```
                ]
        },
        "2001:468:2300:6::2": {
            "vrf": "default",
            "router": "rtsw.hart2",
            "received_prefixes": [
                "2001:468:2650::/48",
                "2604:b200::/32",
                "2620:96:8000::/48",
                "2620:bc:4000::/48"
            ]
        }
}
```

Gather Accepted Prefixes (Post: IOS-XR)

```
{
    "maint": "CEN-CHG-RE-9aug2021",
    "run": "post",
    "198.71.46.215": {
        "vrf": "RE",
        "router": "core1.hart2",
        "received_prefixes": [
            "50.28.128.0/18",
            "64.147.56.0/24",
            "64.147.57.0/24",
            "64.202.80.0/20",
            "64.202.80.0/21",
            "64.251.48.0/20",
            "64.251.48.0/21",
            "64.251.56.0/22",
            "64.251.56.0/24",
            "64.251.60.0/22",
            "67.218.80.0/20",
            "67.218.80.0/21",
            "67.218.88.0/21"
```

```
    },
    "2001:468:2300:6::2": {
        "vrf": "RE",
        "router": "core1.hart2",
        "received_prefixes": [
            "2604:b200::/32",
            "2607:f460::/32",
            "2620:9:6000::/48",
            "2620:96:8000::/48",
            "2620:bc:4000::/48"
        ]
```

Combined JSON Diff

- Not Super Readable
- Hundres of Prefixes

```
{
    "maint": "CEN-CHG-RE-9aug2021",
    "run": "diff",
    "198.71.46.215": {
        "pre_state": "Established",
        "post_state": "established",
        "pre_router": "rtsw.hart2",
        "post_router": "core1.hart2",
        "prevrf": "default",
        "postvrf": "RE",
        "pre_remote_as": 22742,
        "post_remote_as": 22742,
        "pre_description": "N/A JUNOS",
        "post_description": "N/A Cisco",
        "pre_accepted": 221,
        "post_accepted": 221,
        "pre_denied": 0,
        "post_denied": 0,
        "diff": 0.0,
        "prefixes": {
            "0": {
                "pre": "",
                "post": "",
                "same": "128.36.0.0/16"
            },
            "1": {
                "pre": "",
                "post": "",
                "same": "129.133.0.0/17"
            },
            "2": {
                "pre": "",
                "post": "",
```

Condensed Diff Output

```
[malottma@sandbox bgp-comparison]$ /srv/shared/i2-shared/scripts/bgp-comparison/bgp-compare.sh -f 2021-09-14.chic.re1.yml --diff --brief
::Neighbor::              ::NSO Service::     ::ASN::      ::PRE::            ::POST::           ::DIFF %::
                                                          Accepted/Rejected  Accepted/Rejected  Accepted/Rejected
2001:468:ff:241::2        re-participant:CHIC-NCSA-1 1224 (RE)    1 / 0        1 / 0           0.0 / 0.0
64.57.28.2               re-participant:CHIC-NCSA-1 1224 (RE)    1 / 1        1 / 1           0.0 / 0.0
164.113.255.245         re-participant:CHIC-GPN-1 11317 (RE)   593 / 57     593 / 57         0.0 / 0.0           **
192.122.183.45          re-participant:CHIC-MERIT-1 237 (RE)    83 / 19      83 / 19          0.0 / 0.0
2001:48a8:5fff:1c::1    re-participant:CHIC-MERIT-1 237 (RE)    12 / 6       12 / 6           0.0 / 0.0           **
2001:468:1900:16::1     re-participant:CHIC-NLIGHTS-1 57 (RE)    10 / 0       10 / 0           0.0 / 0            **
146.57.253.53           re-participant:CHIC-NLIGHTS-1 57 (RE)   113 / 6      113 / 6          0.0 / 0.0
2607:ea00:0:f::1        re-participant:CHIC-NLIGHTS-2 57 (RE)    10 / 0       10 / 0           0.0 / 0            **
146.57.253.41           re-participant:CHIC-NLIGHTS-2 57 (RE)   113 / 6      113 / 6          0.0 / 0.0
192.5.143.28            re-participant:CHIC-NWU-1 103 (RE)      22 / 0       14 / 8          -36.36 / EXCEPTION   **
198.71.45.157           re-participant:CHIC-PSU-1 3999 (RE)     12 / 0       12 / 0           0.0 / 0
2001:468:2:280::3       re-participant:CHIC-PSU-1 3999 (RE)      1 / 0        1 / 0           0.0 / 0
198.49.182.4            re-participant:CHIC-UIOWA-1 3676 (RE)    52 / 2       52 / 2           0.0 / 0.0
2001:468:ff:2c2::2      re-participant:CHIC-UIOWA-1 3676 (RE)     6 / 0        6 / 0           0.0 / 0.0
2620:0:e10:6013::1      re-participant:CHIC-UIUC-1 40387 (RE)     6 / 0        6 / 0           0.0 / 0
72.36.127.161           re-participant:CHIC-UIUC-1 40387 (RE)    14 / 1       14 / 1           0.0 / 0.0
2607:f388:0:2201::1     re-participant:CHIC-UWMADISON-1 59 (RE)   1 / 0        1 / 0           0.0 / 0
144.92.254.228          re-participant:CHIC-UWMADISON-1 59 (RE)   8 / 1        8 / 1           0.0 / 0.0

WARNING: Manual Troubleshooting of sessions marked with (**) may be required. Counts may be similar, but actual prefixes received or rejected are different.
HINT: /srv/shared/i2-shared/scripts/bgp-comparison/bgp-compare.py -f 2021-09-14.chic.re1.yml --diff -n 164.113.255.245 --stdout
HINT: /srv/shared/i2-shared/scripts/bgp-comparison/bgp-compare.py -f 2021-09-14.chic.re1.yml --diff -n 164.113.255.245 --stdout-denied-only
HINT: /srv/shared/i2-shared/scripts/bgp-comparison/bgp-compare.py -f 2021-09-14.chic.re1.yml --diff -n 2001:48a8:5fff:1c::1 --stdout
HINT: /srv/shared/i2-shared/scripts/bgp-comparison/bgp-compare.py -f 2021-09-14.chic.re1.yml --diff -n 2001:48a8:5fff:1c::1 --stdout-denied-only
HINT: /srv/shared/i2-shared/scripts/bgp-comparison/bgp-compare.py -f 2021-09-14.chic.re1.yml --diff -n 2001:468:1900:16::1 --stdout
HINT: /srv/shared/i2-shared/scripts/bgp-comparison/bgp-compare.py -f 2021-09-14.chic.re1.yml --diff -n 2001:468:1900:16::1 --stdout-denied-only
HINT: /srv/shared/i2-shared/scripts/bgp-comparison/bgp-compare.py -f 2021-09-14.chic.re1.yml --diff -n 2607:ea00:0:f::1 --stdout
HINT: /srv/shared/i2-shared/scripts/bgp-comparison/bgp-compare.py -f 2021-09-14.chic.re1.yml --diff -n 2607:ea00:0:f::1 --stdout-denied-only
HINT: /srv/shared/i2-shared/scripts/bgp-comparison/bgp-compare.py -f 2021-09-14.chic.re1.yml --diff -n 192.5.143.28 --stdout
HINT: /srv/shared/i2-shared/scripts/bgp-comparison/bgp-compare.py -f 2021-09-14.chic.re1.yml --diff -n 192.5.143.28 --stdout-denied-only
```

Verbose Prefix Diff Output

```
=== re-participant CHIC-NWU-1 (192.5.143.28) ===
Neighbor migrated: rtsw.chic -> core2.chic


                              [   PRE   ] [   POST  ]
Prefix                        Recv Accept Recv Accept  INFO/Advice
8.30.248.0/22                  *     *     *           INVESTIGATE - route no longer being accepted
38.124.97.0/24                 *     *     *           INVESTIGATE - route no longer being accepted
192.5.143.0/24                 *     *     *           INVESTIGATE - route no longer being accepted
192.26.86.0/23                 *     *     *           INVESTIGATE - route no longer being accepted
192.31.155.0/24                *     *     *           INVESTIGATE - route no longer being accepted
199.249.165.0/24               *     *     *           INVESTIGATE - route no longer being accepted
199.249.166.0/23               *     *     *           INVESTIGATE - route no longer being accepted
199.249.168.0/23               *     *     *           INVESTIGATE - route no longer being accepted

Skipped 14 routes that did not change
```

(End)
Validating the Results

`diff -u` on steroids

Herding Cats

Managing the Migration

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... outline

Running the Humans (not ordered)
- Dual Engineer Role - DONE
- Pre and Post Migration checks
- Shim Migrations
- Verifications
- Scheduling and Pace - DONE
- Cisco Software Issues Encountered

Why the Shim?

- Limited window between all edge services ready in software and summer 2021

- Can get started on physical migrations before the software is complete

- Able to migrate one service at a time – no flag days required

- Can run separate provisioning systems on both networks

- No protocol interop required for boutique services (L2VPN/OESS)

Timeline

TODAY

Connector 1
Connector 2
Juniper MX

Install Shim

Connector 1
Connector 2
Cisco XR
Juniper MX

Bridge unknown traffic
- local-xconnect
- local-switching

Migrate Services

Connector 1
Connector 2
Cisco XR
Juniper MX

- sub-interface .1h3 activated
- XR terminates traffic locally
- remaining unknown traffic bridged through to MX

Deactivate Juniper

Connector 1
Connector 2
Cisco XR
Juniper MX

Today

Phase 1:
- Install shim at POP
- Physical cabling moves

Phase II:
- Per-service cut-over
- Deactivate a service on JunOS
- Activate on XR

Phase III:
- Juniper ports can be deactivated
- local-xconnect/local-switching can be disabled

The shim

Software Issues Encountered

Encapsulate default bug found during shim testing

We wanted to use encapsulate default on the physical interface to catch every VLAN configured and not worry about missing any services

```
interface hu0/0/0/19
 description "To Awesome Member"
!
interface HundredGigE0/0/0/19.0 l2transport
 description "Every shimmed service"
 encapsulation default
!
```

Encapsulate Default Work Around

- Audit physical interface and build configuration for each subinterface.
- Once bug was fixed, convert to encapsulate default.
- First few shim migrations used this method.

```
interface HundredGigE0/0/0/19
 description "To Awesome Member"
!
interface HundredGigE0/0/0/19.100
 description "Shimmed BGP Service"
 encapsulation dot1q 100
!
.. ->>> insert many vlans here
!
interface HundredGigE0/0/0/19.200
 description "Shimmed AL2S Service"
 encapsulation dot1q 200
```

SHIM Dashboard

Device	Interface	Description	Logical Ints	Shim Required?	Shimmed?	Int Type	Action	Comment
rtsw.alba	et-3/0/0	I2-S54545 NOX | I2-ALBA-ALBA-100GE-54544	goto	Y	Complete		Done	
rtsw.alba	xe-5/2/2	I2-S11606 UVM | I2-ALBA-ALBA-10GE-11617	goto	Y	Complete		Done	
rtsw.alba	xe-5/2/3	I2-S11609 UNH | I2-ALBA-ALBA-10GE-11621	goto	Y	Complete		Done	
rtsw.alba	xe-5/3/0	I2-S11610 DART | I2-ALBA-ALBA-10GE-11619	goto	Y	Complete		Done	
rtsw.alba	xe-5/3/1	I2-S11608 UMS | I2-ALBA-ALBA-10GE-11620	goto	Y	Complete		Done	
rtsw.ashb	ae32	INTERCONNECT: ASHB-ASHB | I2-ASHB-ASHB-LAG-189831	goto	N	n/a		Other Action	Kentik PNI - move to i2px
rtsw.ashb	ae5	URI - ORACLE LAG 1x10G | I2-ASHB-ASHB-LAG-189847	goto	Y	Complete	RPI	Shim Pending	RPI
rtsw.ashb	ae6	Google GCI Zone 1 LAG 1x10G	goto	Y	Complete	CloudConne	Waiting for NCS	CloudConnect - waiting on NCS installation
rtsw.ashb	et-0/1/4	I2-S51435 USDA | I2-ASHB-ASHB-100GE-51434	goto	Y	Complete	Connector	Done	
rtsw.ashb	et-0/1/5	I2-S54391 MAX Gigapop | I2-ASHB-ASHB-100GE-54390	goto	Y	Complete	Connector	Done	
rtsw.ashb	et-0/1/6	I2-S11408 MARIA | I2-ASHB-ASHB-100GE-11409	goto	Y	Complete		Done	
rtsw.ashb	et-0/1/7	I2-S10654 NIH | I2-ASHB-ASHB-100GE-10653	goto	Y	Complete		Done	

I2-S54545 NOX | I2-ALBA-ALBA-100GE-5454	goto	Y	Complete		Done

Device	Interface	Description	Logical Ints	Shim Required?	Shimmed?	Int Type	Action	Comment
rtsw.ashb	xe-0/0/4:2	AWS DirectConnect 10G #4 | I2-ASHB-ASHB-10GE-192178	goto	Y	Complete	CloudConne	Waiting for NCS	CloudConnect - waiting on NCS installation
rtsw.ashb	xe-0/0/4:3	I2-S192552 OSHEAN ExpressRoute Direct Secondary | I2-ASHB-ASHB-10GE-192533	goto	Y	Complete	RPI	Shim Pending	RPI
rtsw.ashb	xe-0/0/5:0	I2-S10847 Smithsonian | I2-ASHB-ASHB-10GE-10846	goto	Y	Complete		Done	
rtsw.ashb	xe-0/0/5:1	I2-S71685 AbbVie | I2-ASHB-ASHB-10GE-71689	goto	Y	Complete		Done	
rtsw.ashb	xe-0/0/5:3	I2-S190211 KINBER Virtual Cloud Router Pilot | I2-ASHB-ASHB-10GE-190024	goto	Y	Complete	RPI	Shim Pending	RPI
rtsw.ashb	xe-0/1/10:0	I2-S54199 | Syngenta | I2-ASHB-ASHB-10GE-54200	goto	Y	Complete			
rtsw.ashb	xe-0/1/10:2	AWS DX Hosted Connection 10GE, LR OPTIC | I2-ASHB-ASHB-10GE-187750	goto	Y	Complete	CloudConne	Waiting for NCS	CloudConnect - waiting on NCS installation
rtsw.ashb	xe-0/1/10:3	Microsoft ExpressRoute Com #3 Primary | I2-ASHB-ASHB-10GE-191910	goto	Y	Complete	CloudConne	Waiting for NCS	CloudConnect - waiting on NCS installation
rtsw.ashb	xe-0/1/11:0	pas-test.ashb em1 | [NO-MONITOR]	goto	N	n/a			
rtsw.ashb	xe-0/1/11:1	Microsoft Express Route Primary | I2-ASHB-ASHB-10GE-184190	goto	Y	Complete	CloudConne	Waiting for NCS	CloudConnect - waiting on NCS installation
rtsw.ashb	xe-0/1/11:2	AWS Direct Connect 10G dxcon-fha89e1l | I2-ASHB-ASHB-10GE-192778	goto	Y	Complete	CloudConne		CloudConnect - waiting on NCS installation
rtsw.ashb	xe-1/0/4:0	ExpressRoute Direct Primary for Jefferson University via KINBER | I2-ASHB-ASHB-10GE-1	goto	Y	Complete	RPI		

Device	Interface	Description	Logical Ints	Shim Required?	Shimmed?	Int Type	Action	Comment
rtsw.ashb	xe-0/1/10:2	AWS DX Hosted Connection 10GE, LR OPTIC | l2-ASHB-ASHB-10GE-187750	goto	Y	Complete	CloudConne ▾	Waiting for NCS ▾	CloudConnect - waiting on NCS installation

Dual Engineer Roles

Migration Role
- Audit BGP sessions to ensure classified appropriately
- Determine sequencing and grouping during the window
- Contact the network owners and respond to any changes requested
- Set up all change tickets with the service desk
- Perform changes on Junipers and NSO
- Handle all communications

Evaluation Role
- Generate migrations scripts
- Assist with determining sequencing and grouping of BGP sessions
- Pre-stage all changes in NSO
- After each batch of migrations, ensure the accuracy of the work.
- Track each change in the BGP session tracker
- Determine if a BGP session needs rolled back

BGP Migration Schedule

Router	Maintenance Date	Window (ET)	Expected Start	# Sessions	Total # of Sessions
rtsw.char.net.internet2.edu	8/17/2021	0001-0400	0001 ET	4	8
rtsw.reno.net.internet2.edu	8/17/2021	0001-0400	0030 ET	4	
rtsw.dall.net.internet2.edu	8/31/2021	0001-0400	0100ET	6	6
rtsw.rale.net.internet2.edu	9/1/2021	0001-0400	0001 ET	7	23
rtsw.salt.net.internet2.edu	9/1/2021	0001-0400	0030 ET	7	
rtsw2.ashb.net.internet2.ed	9/1/2021	0001-0400	0100 ET	4	
rtsw.hous.net.internet2.edu	9/2/2021	0001-0400	0001 ET	8	16
rtsw.lasv.net.internet2.edu	9/2/2021	0001-0400	0030 ET	8	
rtsw.port.net.internet2.edu	9/2/2021	0001-0400	0130ET	4	
rtsw.pitt.net.internet2.edu	9/3/2021	0001-0600	0001 ET	10	37
rtsw.cinc.net.internet2.edu	9/3/2021	0001-0600	0030 ET	13	
rtsw.denv.net.internet2.edu	9/3/2021	0001-0600	0100 ET	8	
rtsw.houh.net.internet2.edu	9/3/2021	0001-0600	0100 ET	6	
rtsw.indi.net.internet2.edu	9/4/2021	0001-0600	0001 ET	15	49
rtsw.tuls.net.internet2.edu	9/4/2021	0001-0600	0030 ET	16	
rtsw.alba.net.internet2.edu	9/4/2021	0001-0600	0100ET	18	
	9/5/2021				
	9/6/2021				
	9/7/2021				
	9/8/2021				
rtsw.kans.net.internet2.edu	9/9/2021	0001-0600	0001 ET	46	50
rtsw.loui.net.internet2.edu	9/9/2021	0001-0600	0100ET	4	
rtsw.ashb.net.internet2.edu	9/10/2021	0001-0600	0001 ET	43	52
rtsw.tucs.net.internet2.edu	9/10/2021	0001-0600	0030 ET	5	
rtsw.char.net.internet2.edu	9/10/2021	0001-0600	0100 ET	4	
rtsw.losa.net.internet2.edu	9/11/2021	0001-0600	0001 ET	58	115

AL2S Circuit Migration

	A	B	C	D	E	F	G	H	I	J	K	L
			10/11		10/12		10/13		10/14		10/15	
	Circuit Type	Total # of Circuits	# Ready	# Blocking	# Ready	# Blocking	# Ready	# Blocking	# Ready	# Blocking	# Ready	# Blocking
	l2vpls	30	18	12	18	12	18	12	18	12	18	12
	l2vpn	720	243	477	243	477	243	477	243	477	243	477
	l3vpn	73	9	64	9	64	9	64	9	64	9	64
	Total	**823**	**270**	**553**	**270**	**553**	**270**	**553**	**270**	**553**	**270**	**553**

Window	Pending Migration	Migrated	Postponed
10/11/21 0001-0800	0	50	0
10/12/21 0001-0800	0	6	0
10/13/21 0001-0800	0	122	0
10/14/21 0001-0800	0	140	0
10/15/21 0001-0800	0	68	0
10/16/21 0001-0800	0	103	0
10/19/21 0001-0800	0	70	0
10/20/21 0001-0800	0	134	0
10/21/21 0001-0800	0	67	0
11/3/21 0001-0800	0	60	0
			0
Not Scheduled	3	around half of these are l2vpls	
	3	820	0	823
	0.4%	99.6%	0.0%	

Lessons

- Automation is Key, even if it's messy
- Get rid of the monotonous bits
- Spread the effort around - 2 engineers
- Flexible migration schedules help a lot (shim)

INTERNET2

2022
TECHNOLOGY
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