



# Computer Networking Beyond Theory

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# Who is Ivan Pepelnjak (@ioshints)

## Past

- Kernel programmer, network OS, and web developer
- Sysadmin, database admin, network engineer, CCIE
- Trainer, course developer, curriculum architect
- Team lead, CTO, business owner
- SDN skeptic and network automation evangelist



## Present

- Network architect, consultant, blogger, **open-source developer**

## Focus

- SDN and network automation
- Large-scale data centers, clouds, and network virtualization
- Scalable application design
- Core IP routing/MPLS, IPv6, VPN



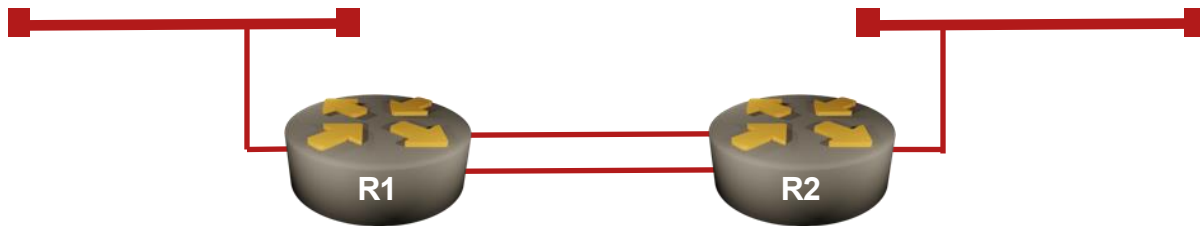
**Also: I built too many labs for one lifetime, and hated that with passion**

# Based on a True Story

**Pär Stolpe** 01 September 2023 12:06

Beware of the fact that having more than one ospf link in between the same two nodes, together with unnumbered interfaces for multipathing purposes would most likely cause troubles. I don't know if any vendor have solved it or if they just recommend using link aggregation instead.

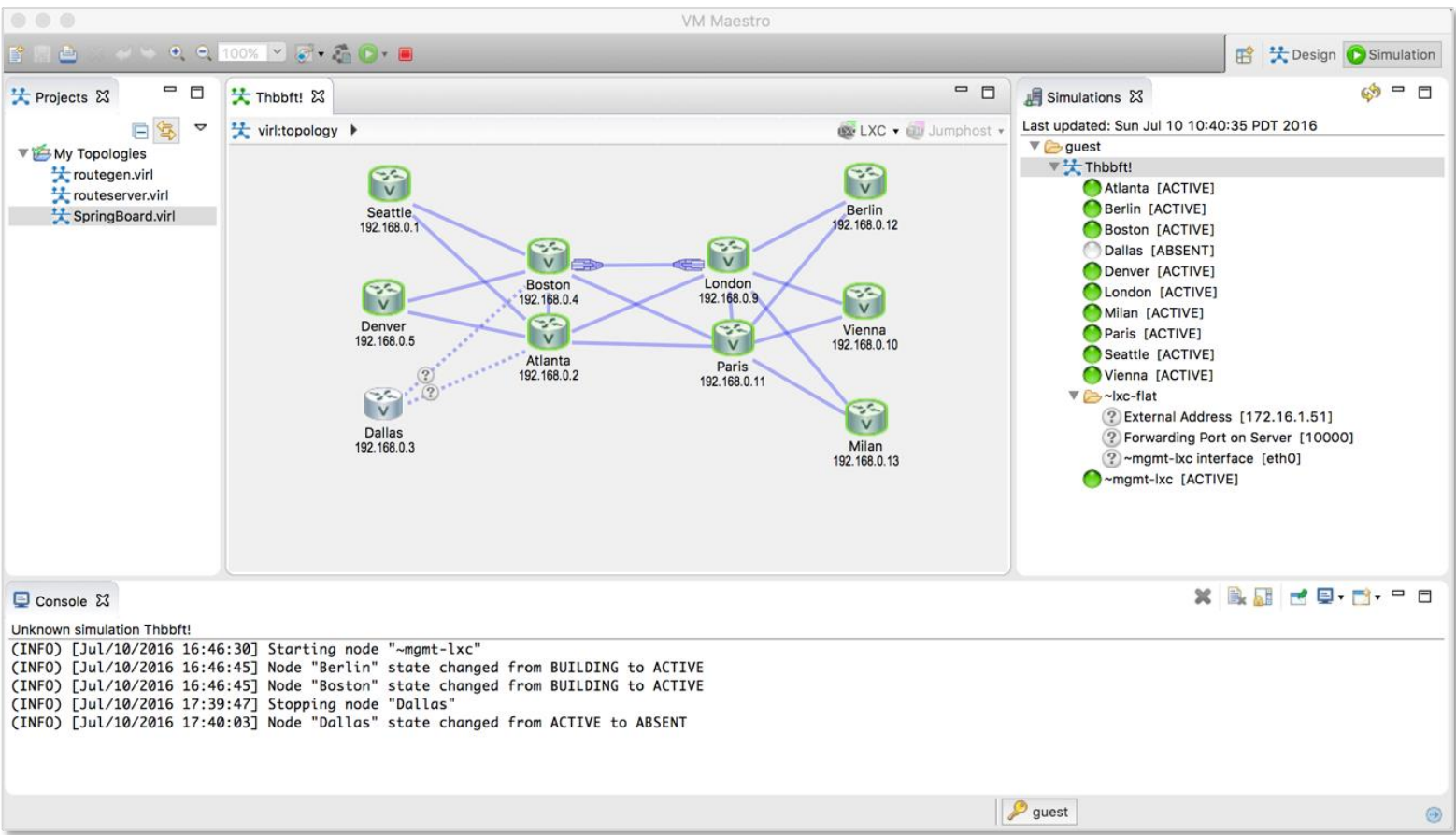
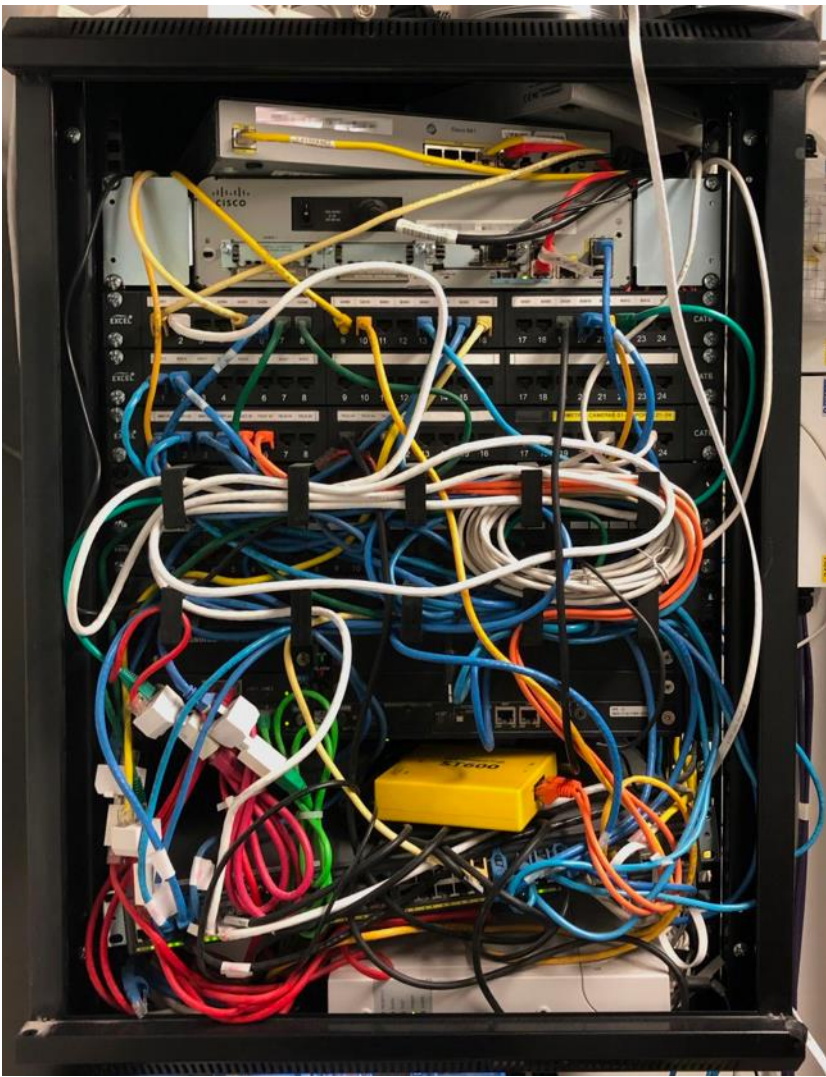
 **reply**



That should be trivial to test in a lab... However, someone has to build that lab...



# The Reality Intervenes...



A man with dark hair and a beard, wearing a dark green button-down shirt, sits at a wooden bar. He is looking out a large window with a multi-paned frame, his head resting on his hand in a pensive or stressed pose. A glass of dark beer with a thick head of foam sits on the bar in front of him. The background is dark and out of focus, showing warm, glowing lights from within the bar.

**NETWORKING IS SO HARD...**





**LET'S ASK CHATGPT**

## ChatGPT Sounds Reasonable

Imagine a network with two routers (R1, R2) that have two parallel links between them. The routers use unnumbered IPv4 interfaces and run OSPF. Would they be able to use both links to reach the other router? Why or why not?



In a network where **two routers (R1 and R2)** are connected by **two parallel links**, and the routers use **unnumbered IPv4 interfaces** while running **OSPF**, they **would not be able** to use **both links simultaneously** to reach each other. Here's why:

# ChatGPT Explains the Details

## Key Concepts

### 1. Unnumbered Interfaces in IPv4:

- These interfaces **do not have their own IP addresses**.
- Instead, they **borrow an IP address** (usually from a loopback or another interface) for OSPF purposes.
- This saves address space and is common in point-to-point links.

### 2. OSPF and Interface Identification:

- OSPF identifies links using **interface IP addresses** and **Router IDs**.
- On **point-to-point links**, OSPF doesn't need a unique subnet per link, but it **still identifies each interface uniquely**.

### 3. Multiple Parallel Links with Unnumbered Interfaces:

- Since unnumbered interfaces share the **same IP address**, OSPF sees **multiple interfaces with the same IP**.
- OSPF cannot **differentiate** the links based on IP because they appear **identical**.
- This leads OSPF to see them as **a single logical link**, or it may **ignore one of them**.

”

Explanations exist; they have existed for all time; there is always a well-known solution to every human problem—neat, plausible, and **wrong**.

H.L. Mencken, *Prejudices: Second Series*, 1920

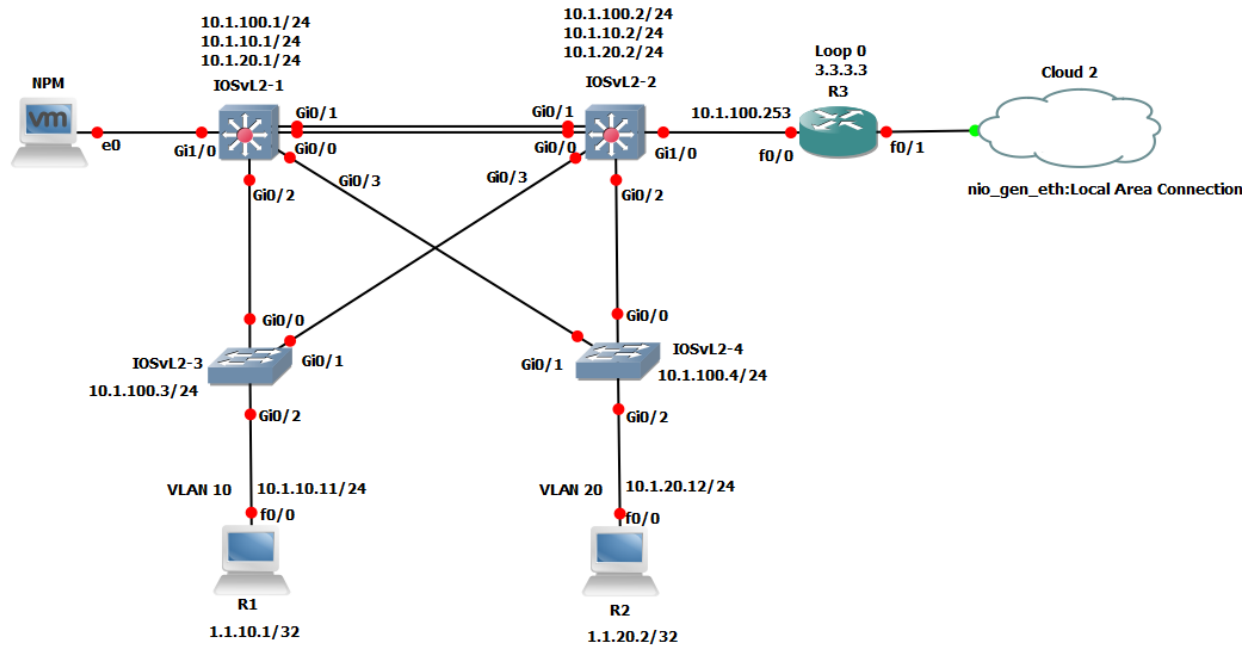




ONE DOES NOT SIMPLY

TRUST CHATGPT

## Next Option: GNS-3 and Friends



### How do they work?

- Network devices are virtual machines or containers

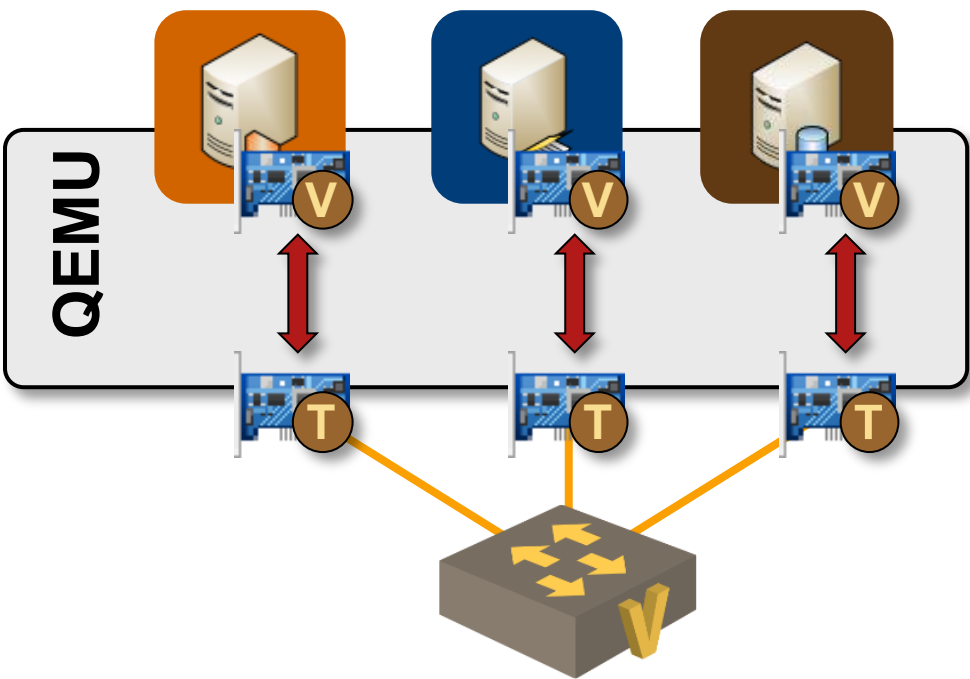
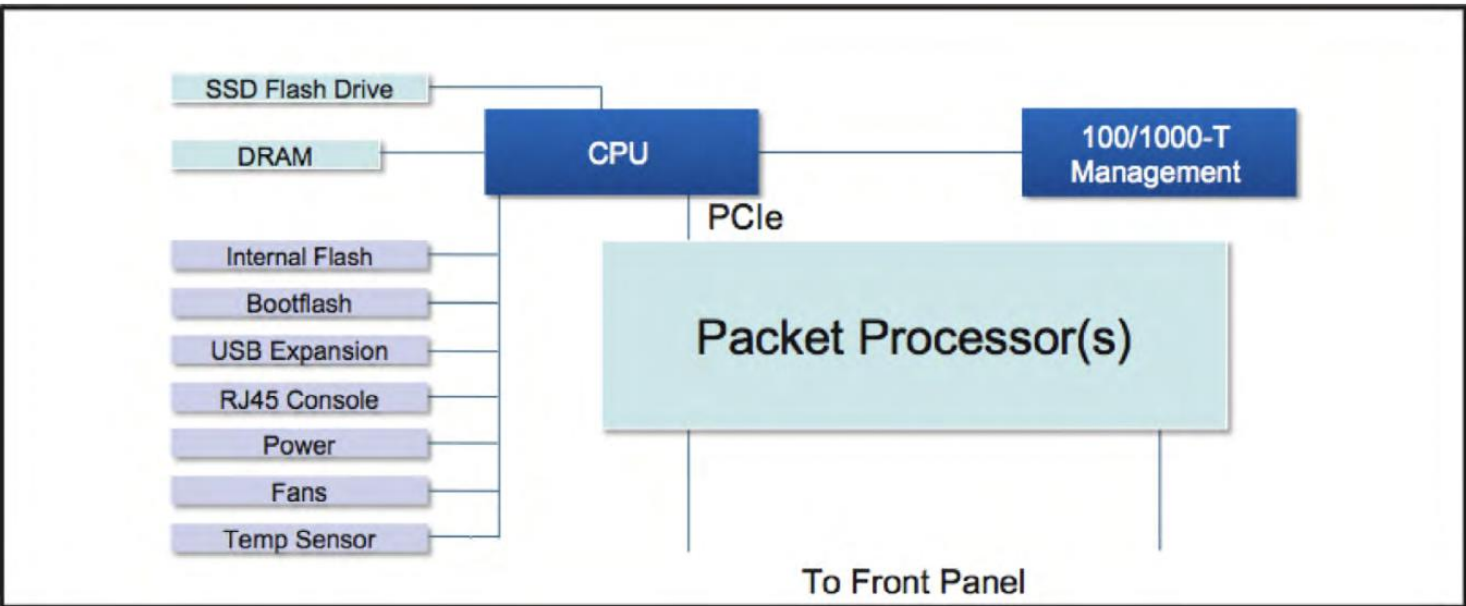
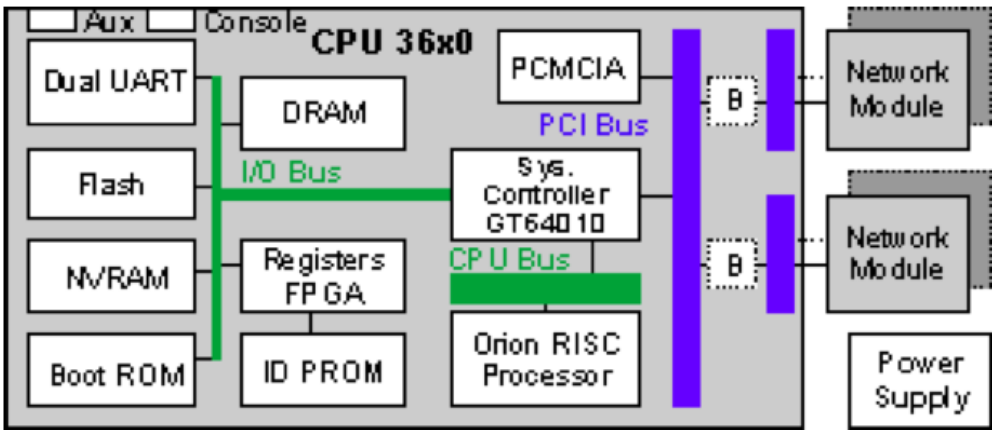
### Can we trust the results?

- Control-plane protocols are usually OK
- Data-plane implementations could be suboptimal
- Beware of the Linux bridge

### Other challenges

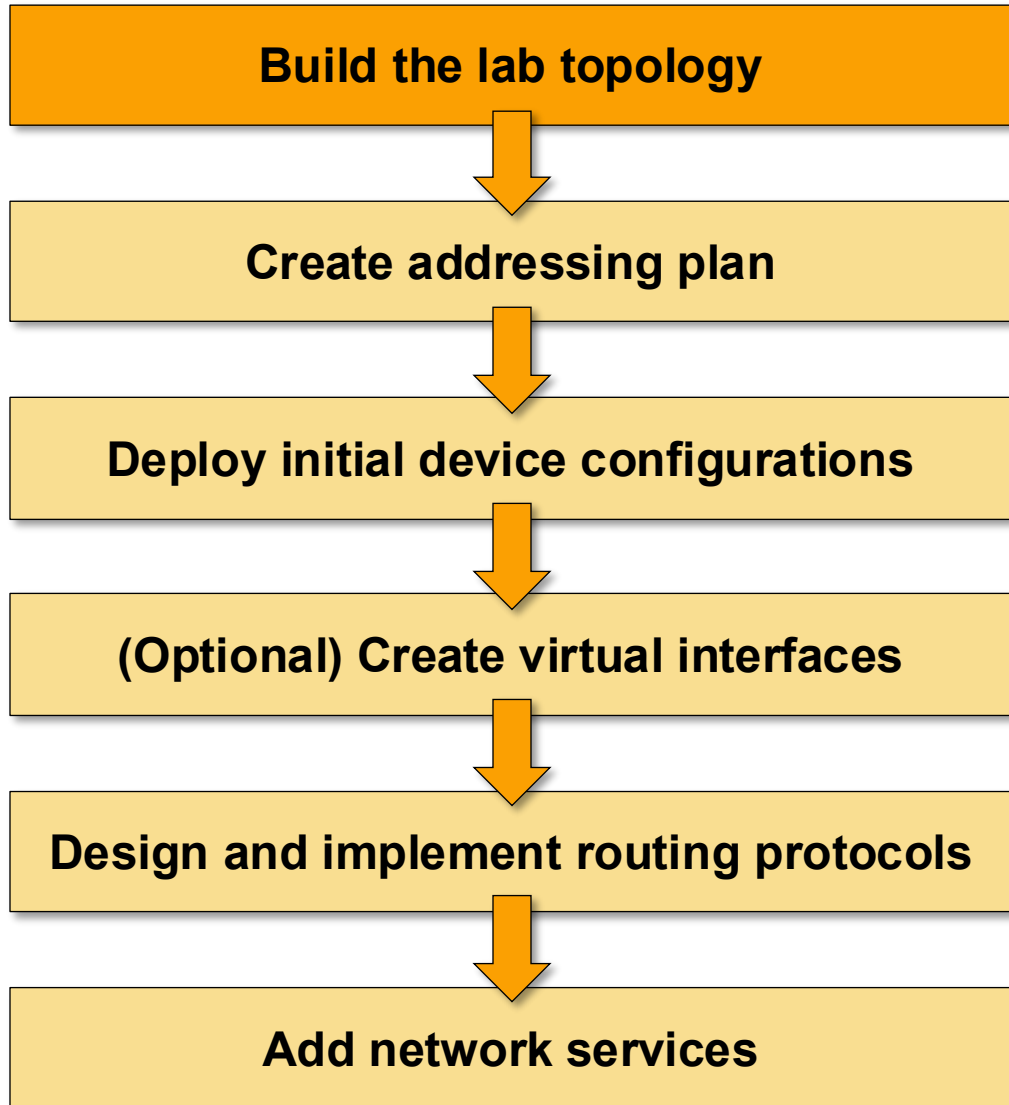
- It takes a long time to build the lab
- Someone has to configure all those boxes

# Reality versus Virtual Implementation





# A Networking Lab Is Much More than Topology





**And now for something  
completely different**



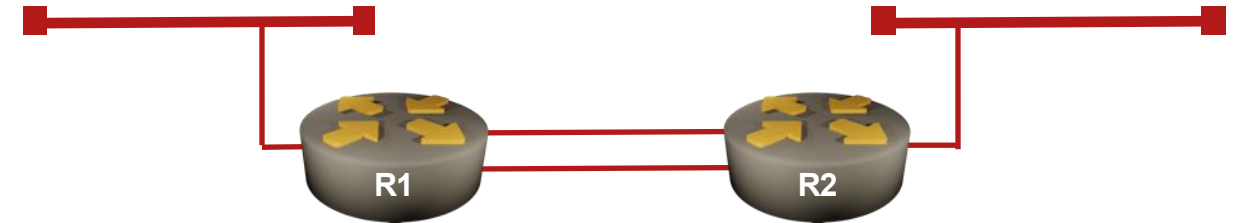
# What Do We Need (in Unicorn Land of Infrastructure-as-Code)

## Create a high-level description of the network

- Two devices: R1 and R2
- Let's make them Arista EOS containers
- They are running OSPF
- We need four links (two of them stub LANs)
- Oh, we're running unnumbered links...

## Next

- Save the file
- Execute **netlab up** and you'll get a running network (including IP addressing and OSPF)



### topology.yml

```
nodes: [ r1, r2 ]

defaults.device: eos
provider: clab

module: [ ospf ]

links: [ r1, r2, r1-r2, r1-r2 ]

addressing.p2p.ipv4: True
```



```
$ netlab up -p clab -d eos parallel.yml █
```

- Create configuration files
- Start the containers
- Start an Ansible playbook
- Initial device configuration
- Configuring OSPF
- Connect to the device
- ... and we have the answer!

# ChatGPT Strikes Again

Hey, I built the network and the routers installed both paths in the IP routing table. Why's that?

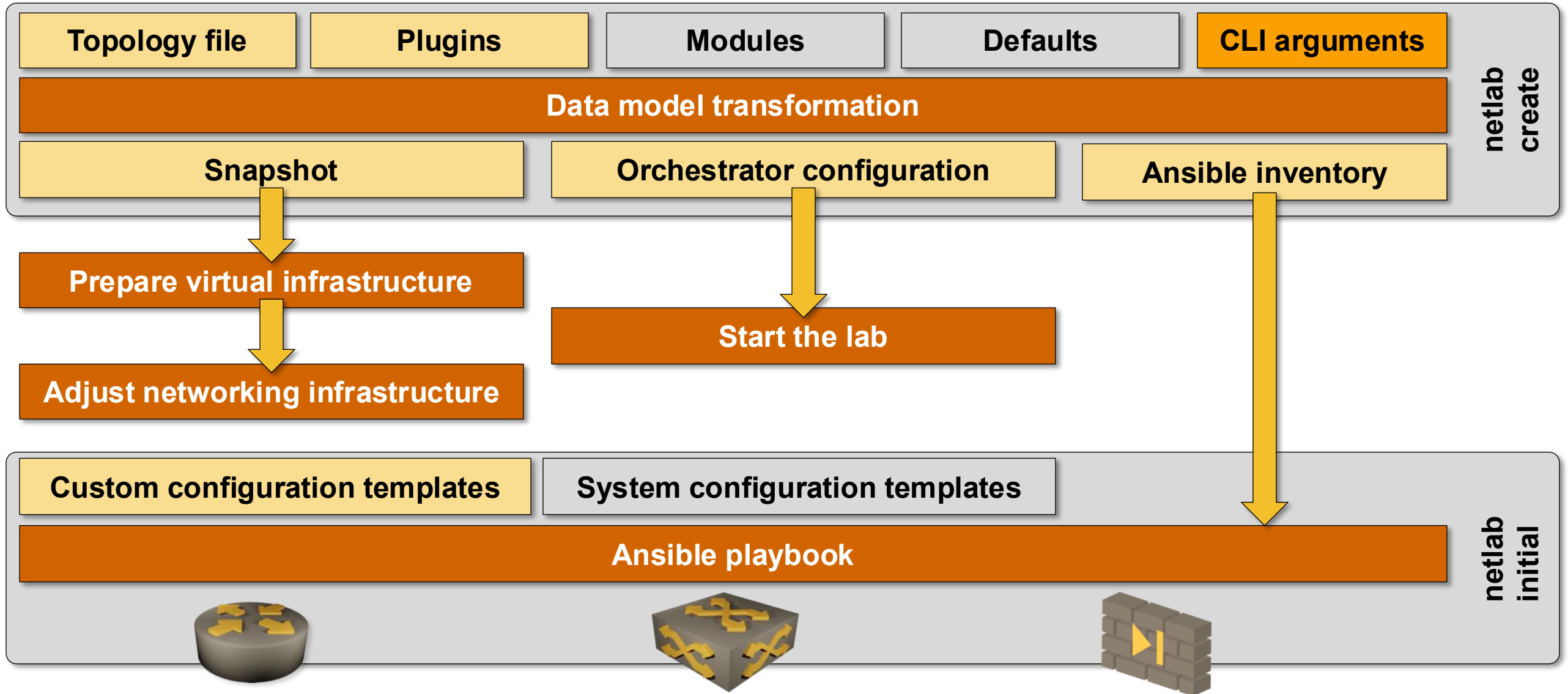
Ah, great observation — and this highlights an important nuance.

You're absolutely right to be surprised: **modern OSPF implementations *can* install multiple parallel unnumbered links** between two routers in the routing table, **if the underlying point-to-point interfaces are treated as distinct links at the OSPF level.**

Let me clarify what's going on and why **both paths appeared in your routing table:**

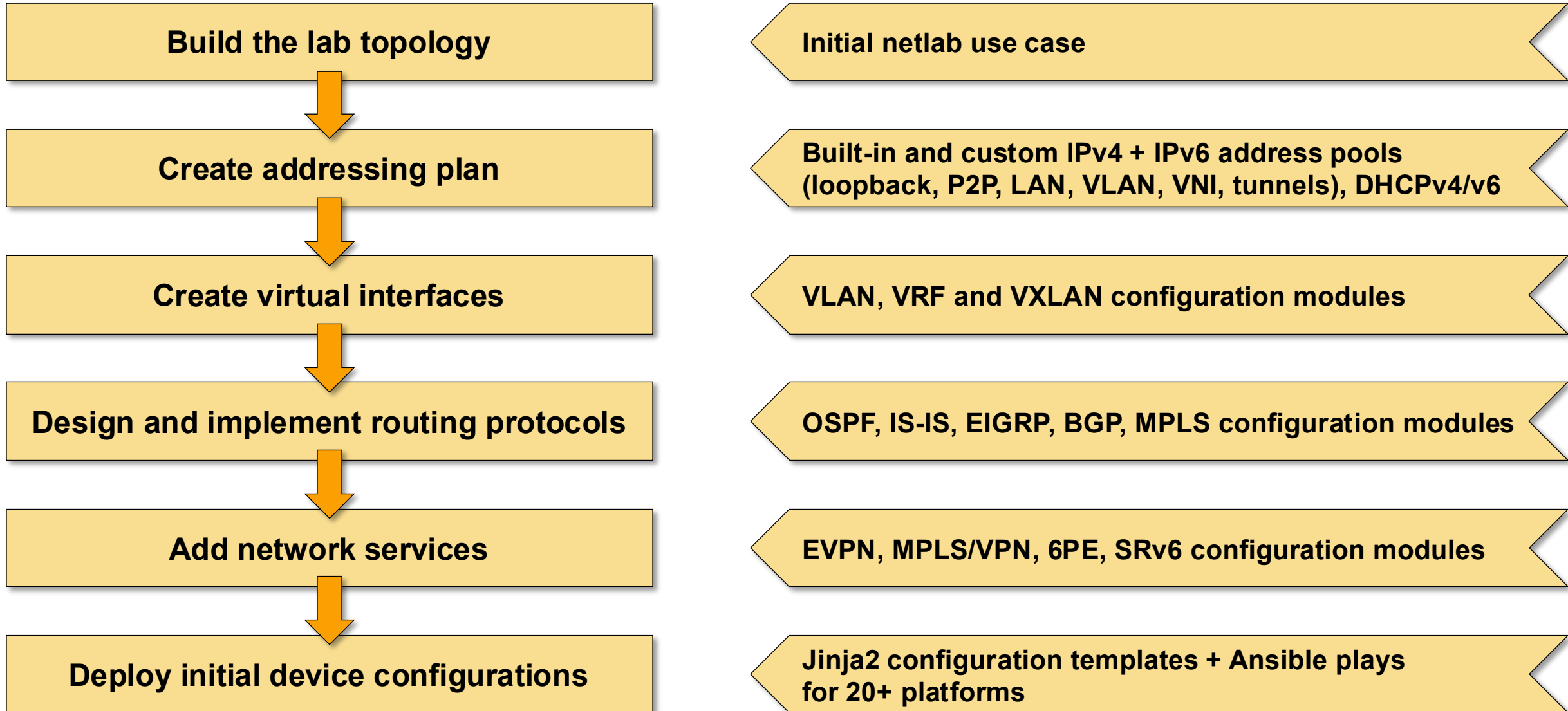
**ChatGPT is an overconfident, sloppy intern. Want to bet your career on it? Be my guest 😊**

# Wait, What Just Happened? netlab up Behind the Scenes





# Building a Networking Lab with netlab



# Current State of netlab (May 2025)

## Network devices

- Arista vEOS/cEOS
- Aruba CX
- Cisco ASAv, IOSv, IOSvL2, IOL, IOLL2, CSR 1000v, Catalyst 8000v, Nexus OS (9300v), IOS XR/XRd
- Cumulus Linux 4.x and 5.x (NVUE)
- Dell OS10
- Fortinet
- FRR
- Juniper vSRX 3.0, vMX, vPTX (vEVO), vJunos-switch, vJunos-router
- Mikrotik RouterOS 6 and 7
- Nokia SR Linux and SR OS
- Sonic
- VyOS 1.4 and 1.5

## Hosts and daemons

- Generic Linux host or container
- BIRD
- dnsmasq

## Virtualization providers

- KVM with libvirt (Vagrant)
- Docker (containerlab)
- Hardware labs (requires extra interface information)
- VirtualBox (Vagrant) (deprecated)

## Multi-provider topologies

- Combine containers and virtual machines in the same lab
- Connect external devices with the virtual lab

# Current State of netlab (May 2025)

## Addressing

- IPv4 + IPv6
- Address pools and named prefixes
- VLAN-wide subnets
- Static subnets and interface addresses
- Unnumbered IPv4 and IPv6 (LLA) interfaces
- Layer-2-only interfaces
- DHCP (clients, servers, relays)

## Data Plane

- VLANs and VRFs
- VXLAN (static ingress replication or EVPN)
- MPLS including SR-MPLS
- SRv6
- Tunnel interfaces

## Routing and Routing Protocols

- OSPFv2, OSPFv3, IS-IS, RIP, EIGRP, BGP
- BFD
- Static routes
- Routing policies
- Route redistribution and default routes
- Prefix filters, AS-path filters, BGP community filters
- VRRP and anycast gateways

## MPLS Control Plane

- LDP, BGP-LU, SR-MPLS (OSPF or IS-IS), SRv6

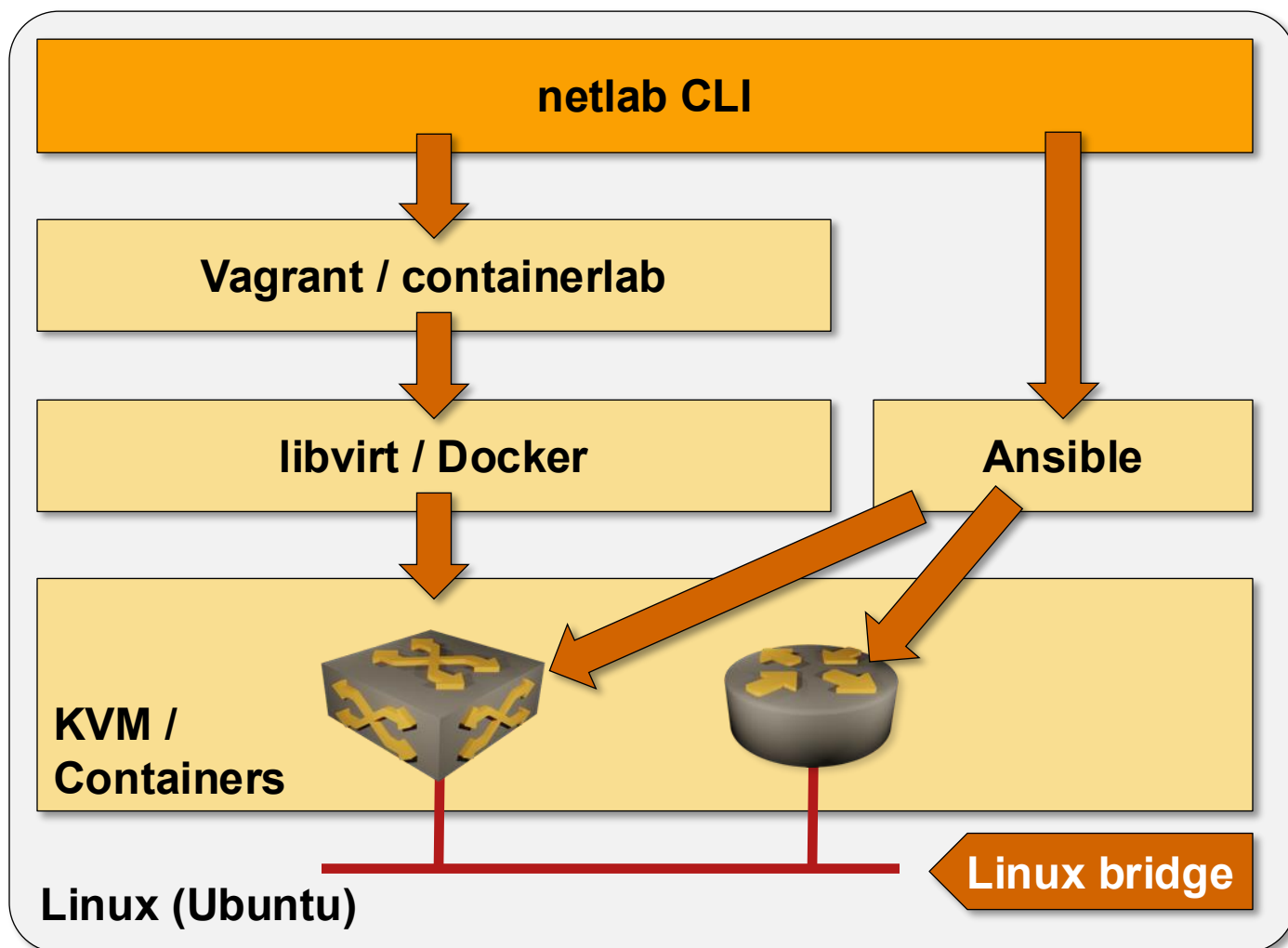
## Network Virtualization

- MPLS L3VPN and 6PE, L3VPN over SRv6
- EVPN (bridging, VLAN bundles, asymmetric and symmetric IRB, most combinations of IGP and BGP)



# Deployment Scenarios

## Recommended: Ubuntu, KVM, libvirt, Docker



### Prerequisite software

- Python3
- Ansible (to configure the devices)

### Devices as virtual machines

- KVM
- libvirt
- Vagrant with vagrant-libvirt plugin

### Containers

- Docker
- Containerlab

## Open-Source BGP Configuration Labs

[Deploy BGP in Your Network](#)

[BGP Routing Policies](#)

[Challenge Labs](#)

[Recent Labs](#)

# Open-Source BGP Configuration Labs

This series of BGP hands-on labs will help you master numerous aspects of EBGp, IBGP, and BGP routing policy configuration on a [platform of your choice](#)<sup>1</sup>, including:

- Arista EOS
- Aruba AOS-CX
- Cisco ASAv, IOSv, IOS XE, IOS XR and Nexus OS
- Cumulus Linux and FRR
- Dell OS10
- Juniper vSRX, vMX and vPTX
- Mikrotik RouterOS
- Nokia SR OS and SR Linux
- Vyatta VyOS

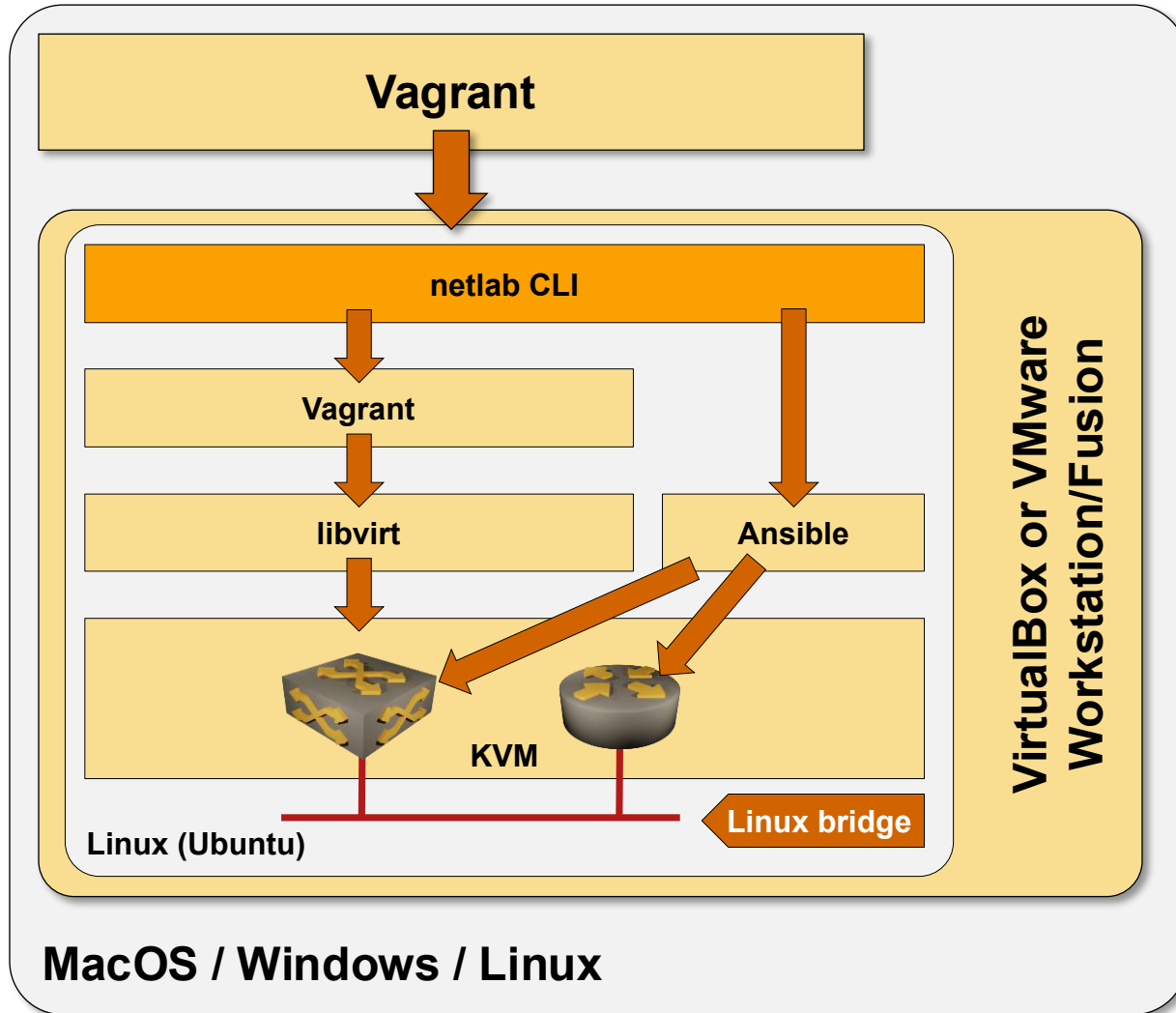
Dozens of labs are already waiting for you (with more [coming soon](#)), but if this is your first visit to this site, you should start with the [Installation and Setup](#) documentation or [run BGP labs in GitHub codespaces](#).

## Deploy BGP in Your Network

In the first set of the BGP labs, you'll master these skills:

- [Configure and monitor routing daemons on Cumulus Linux and FRRouting](#)
- [Configure BGP sessions and advertise IPv4 and IPv6 prefixes](#)
- [Protect BGP sessions](#)
- [Run BGP in networks with more than one BGP router](#)
- [Manipulate BGP AS numbers or AS paths](#) with nerd knobs like **as-override** and **local-as**

# Use Existing x86 Device: Ubuntu VM



## Requirements

- You can run containers with any VM virtualization product
- Nested virtualization is required to run network device VMs

## Virtualization solution with nested virtualization

- Hyper-V (WSL)
- KVM
- VirtualBox
- VMware Workstation/Fusion

## Optional

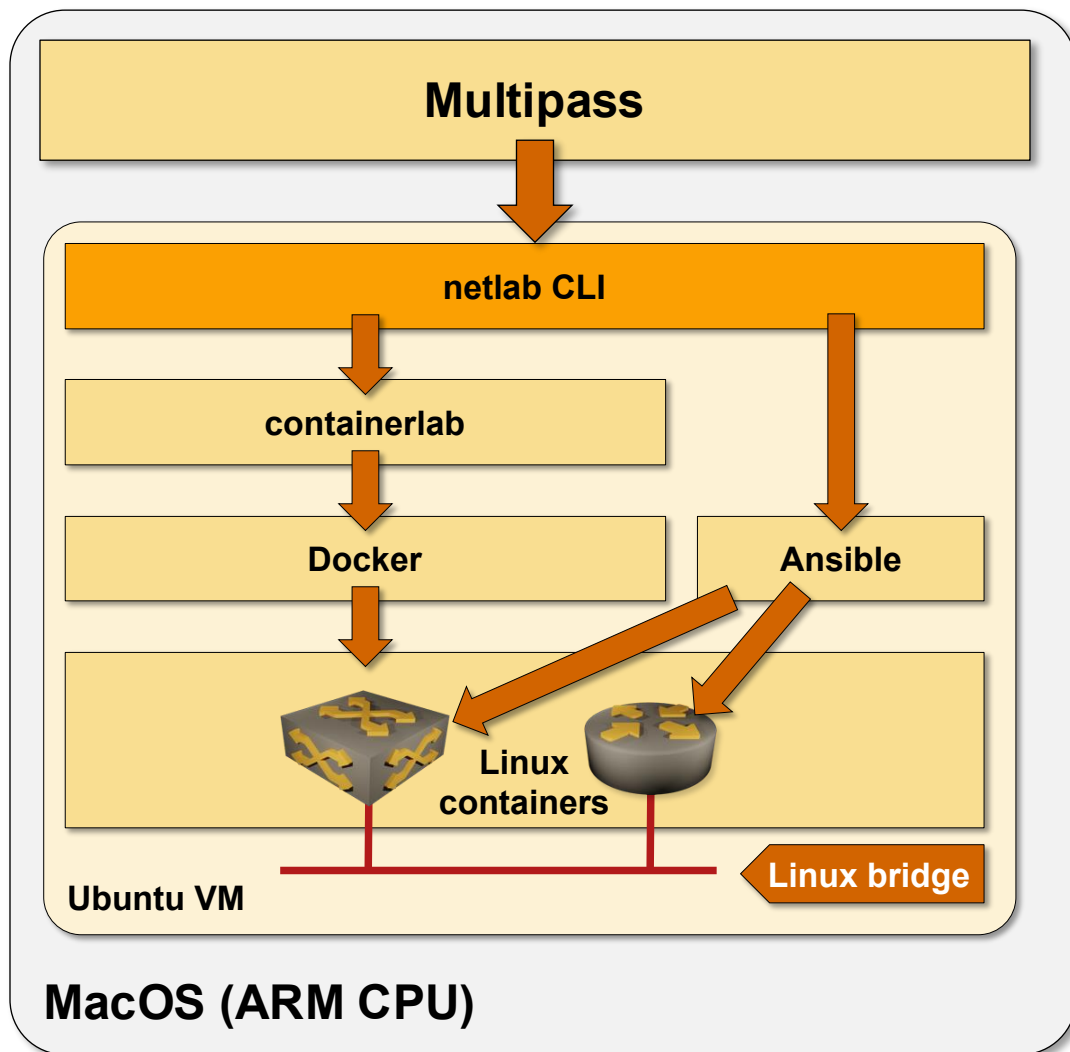
- Start the VM with Vagrant (simplifies the operations)

## Alternative

- Cloud deployment



# Ubuntu VM on Apple Silicon



- **multipass** starts an Ubuntu VM on an ARM CPU
- Nested virtualization is not supported → containers only
- Container images must be built for the ARM CPU → Arista EOS, FRRouting, and SR Linux

## Interesting use cases

- Run BGP, VXLAN, or EVPN labs on your Apple laptop
- FRRouting and Arista configuration syntax are pretty close to the *industry standard CLI*



# Some Assembly Required (Thank You, Vendors)

## Automatically downloadable images and containers

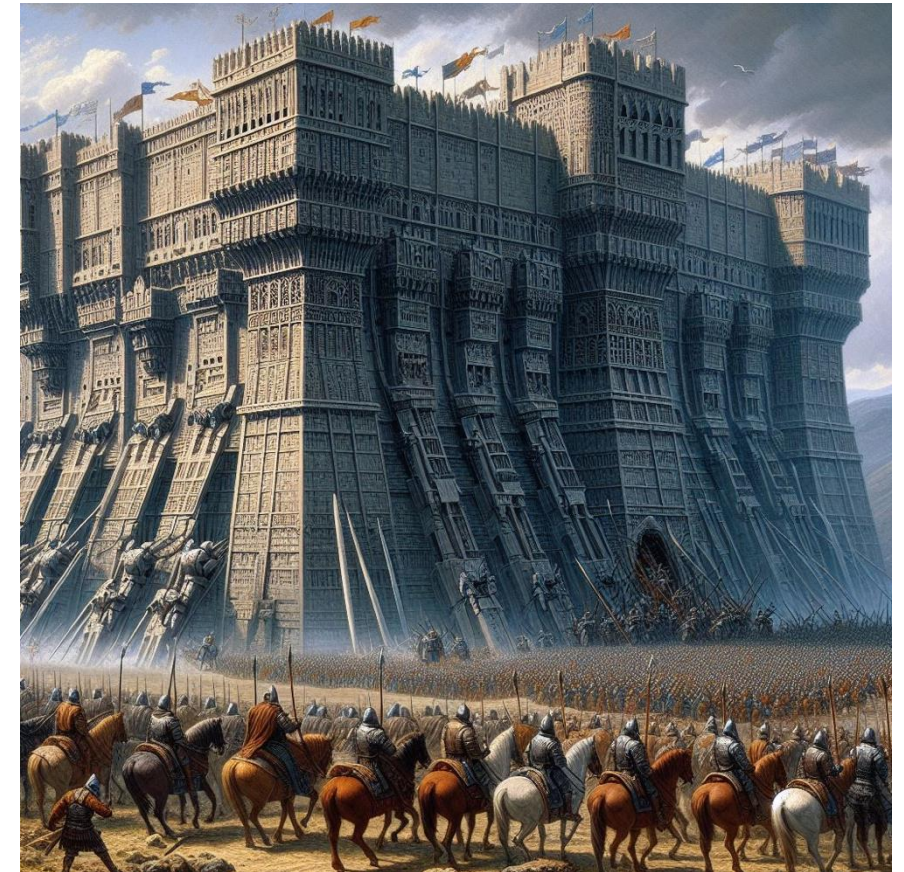
- FRR
- Linux
- Nokia SR Linux
- VyOS

## Easy to download (no registration required)

- Juniper switches and routers, Dell OS10, Mikrotik RouterOS7

## Most everything else (from bad to worse)

- Registration (Arista EOS, Aruba CX, Cisco Nexus OS, Cumulus)
- Download tied to a valid support contract (Cisco CSR)
- Begging your SE
- Available only if you know the right dev person



## But Wait, That's Not All

### After you download a container image (Arista cEOS)

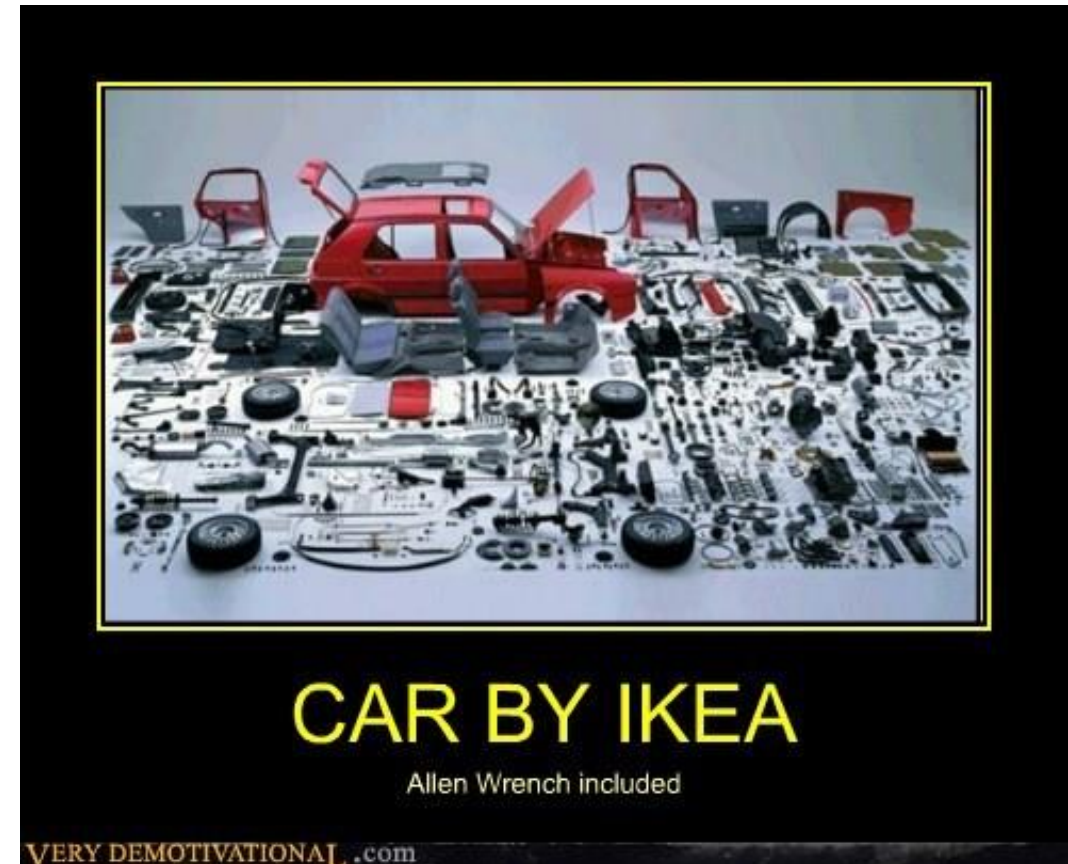
- Unpack and install it (easy)

### Virtual machines are a nightmare

- Download a virtual disk
- It boots without a configuration and expects stuff on serial port
- Exception: Junos and ASA can take configuration from a mounted CD-ROM

### Building a Vagrant box

- What we need to automate lab startup
- Start the VM, answer a dozen questions
- Copy-paste initial configuration
- Save the configuration, shut down the VM
- Package as a Vagrant box, hope it works





A man with dark hair and a beard, wearing a dark green button-down shirt, sits at a wooden bar. He is looking out a large window with a multi-paned frame, his head resting on his hand in a pensive or stressed pose. A glass of dark beer with a thick head of foam sits on the bar in front of him. The background is dark and out of focus, showing warm, glowing lights from within the bar.

**NETWORKING IS SO HARD...**

A man with dark hair, wearing a dark green button-down shirt, is sitting at a dark wooden desk. He is smiling broadly at the camera while holding a pen over a piece of paper. To his right is a tall glass of dark beer with a thick white head of foam. The scene is dimly lit, with warm light coming from a window on the right, which has multiple panes. The background is dark and out of focus, showing a warm light source in the distance.

**BUT NETLAB WITH FRR OR ARISTA MAKES IT EASIER**



## Questions?

Documentation: [netlab.tools](https://netlab.tools)  
Blog posts: [blog.ipspace.net/tag/netlab.html](https://blog.ipspace.net/tag/netlab.html)  
Source code: [github.com/ipspace/netlab](https://github.com/ipspace/netlab)  
Examples: [github.com/ipspace/netlab-examples](https://github.com/ipspace/netlab-examples)  
Sample project: [bgplabs.net](https://bgplabs.net) (BGP labs)  
[isis.bgplabs.net](https://isis.bgplabs.net) (IS-IS labs)

## To reach me

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