

# An Radical but Incrementally Deployable Vision for Future Internet Architecture

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# The Internet architecture of today

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- Based on IP
- Spectacularly successful architecture!  
History of handling...
  - Incredible growth
  - New use cases
- But the eternal question...  
*Is the current architecture good enough?*

# Is the current architecture good enough?

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- ~20 years ago
  - Not good enough! We need IPv6.
- Since then, proposals driven by...
  - Content (NDN, Netinf), Mobility (MobilityFirst), Cloud (NEBULA), Economics (ChoiceNet), Flexibility (XIA), Security (SCION), ...
  - And more!
  - NSF: “it is no longer clear that emerging and future needs ... can be met by ... incremental changes to the current Internet”

# Problem statement

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- Can we make the Internet fundamentally more extensible?
  - i.e., actually get good architectural ideas deployed!
  
- We think so.

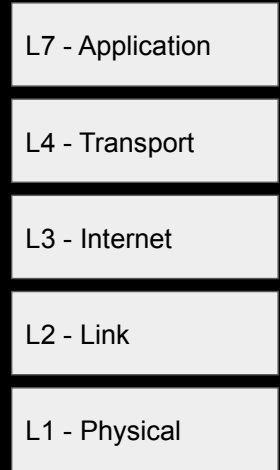
# What *is* an Internet architecture?

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- It's a design in which...
  - data from some endpoint
  - travels through some intermediate nodes
  - which process the data according to architecture's data plane
  - until terminating at one or more endpoints elsewhere
- It must be intended to do this globally
- It is a composition of domains (“ASes” today)

# Digging into the data plane

- Collection of layered protocols
- Internet architecture centers on this one (the lowest global one)
  - Always IP on today's Internet
  - It's a “universal narrow waist”



# The universal narrow waist

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- Often (rightly!) credited for Internet's success
- Single global protocol is easiest way to achieve goal of connecting the world!
- But as we look beyond basic connectivity...  
*universal narrow waist is the single biggest impediment to architectural change*

# The universal narrow waist

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- Universal narrow waist has good cohesion
  - .. a narrow set of related responsibilities
- And has good (loose) coupling with other layers
  - .. can run atop many different protocols at layer below
  - .. and many different protocols can run above it
- This is *great* !
  - ... but ...

# The universal narrow waist

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- On a different axis, IP is *terribly* coupled
  - Enormous number of routers must simultaneously agree on single protocol (or one of two if you count IPv4 and IPv6 separately)
- Like any tightly coupled system, it's tough to change
  - Local changes have nonlocal effects or dependencies
- Coupling crosses every set of stakeholders
  - Makes difficult to align changes with all priorities

# Return to the problem statement

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- Can we make the Internet fundamentally more extensible?

# Return to the problem statement

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- Can we make the Internet fundamentally more extensible?
- Yes. By removing the universal narrow waist.

# Removing the universal narrow waist

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How?

Two steps.

# Step 1: Fix layering

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L7 - Application

L4 - Transport

L3 - Internet

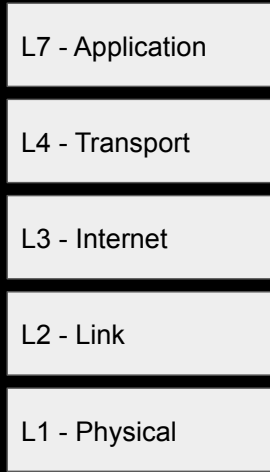
L2 - Link

L1 - Physical

# Step 1: Fix layering

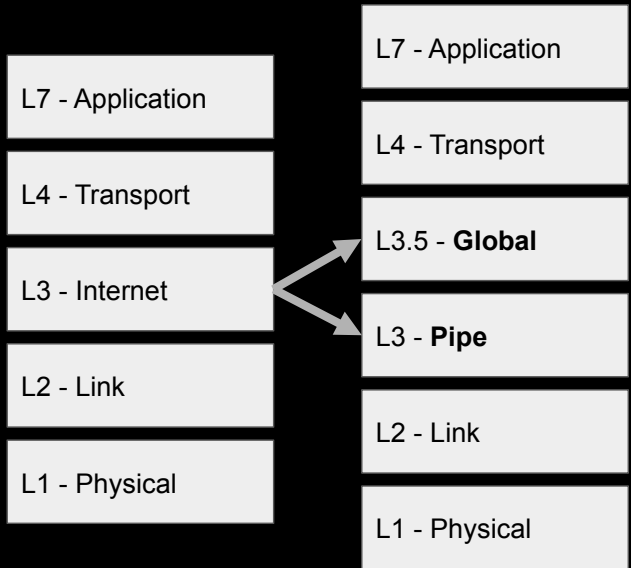
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- We're missing a layer!
- Internet isn't composition of L2 networks... it's a composition of *domains*
- Already encoded in control plane!



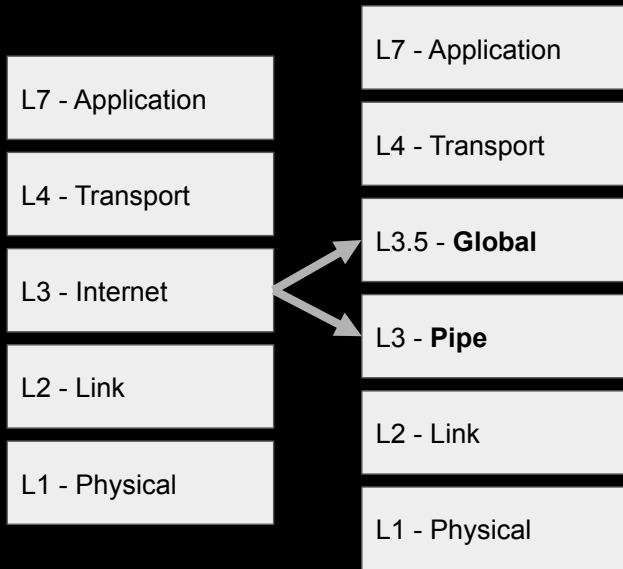
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# Step 1: Fix layering

- We're missing a layer!
- Internet isn't composition of L2 networks... it's a composition of *domains*
- Already encoded in control plane!
- Decouples how data is delivered within/across domain from global protocol
- .. and how one domain delivers internally from how another delivers internally



# Removing the universal narrow waist

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1. Decouple interdomain and intradomain data planes  
(separate global and pipe layers)

# Step 2: Rethink how to add features

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- Traditionally via *upgrade model*
  - Define new version of IP with new features
  - Replace the old version (or *try*, anyway...)
- Even if you don't care about new features...  
you care that what you're using is being obsoleted!

# Step 2: Rethink how to add features

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- We advocate a *coexistence model*
  - Embrace multiple coexisting architectures
- Additive:
  - If new features don't benefit you, ignore it
  - Domains are footing the bill: ability to ignore architectures they don't care about is natural
- Only feasible because we separated internal and external data planes

# Removing the universal narrow waist

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1. Decouple interdomain and intradomain data planes  
(separate global and pipe layers)
2. Embrace multiple coexisting global layer protocols  
instead of upgrading a single one

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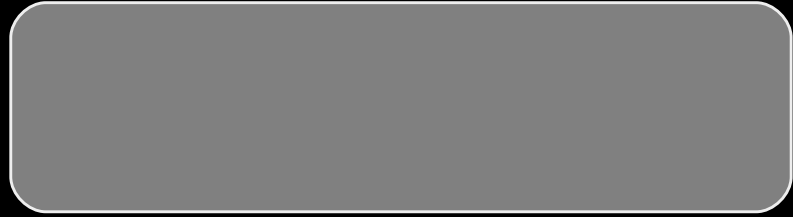
## No more universal narrow waist!

- ♦ Global protocols are *no longer universal*  
(Not on every router or even every domain)
- ♦ It's not narrow  
(Coexisting protocols)

# Inside a domain

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Domain A  
IP+NDN



# Inside a domain

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Domain B  
IP+NDN



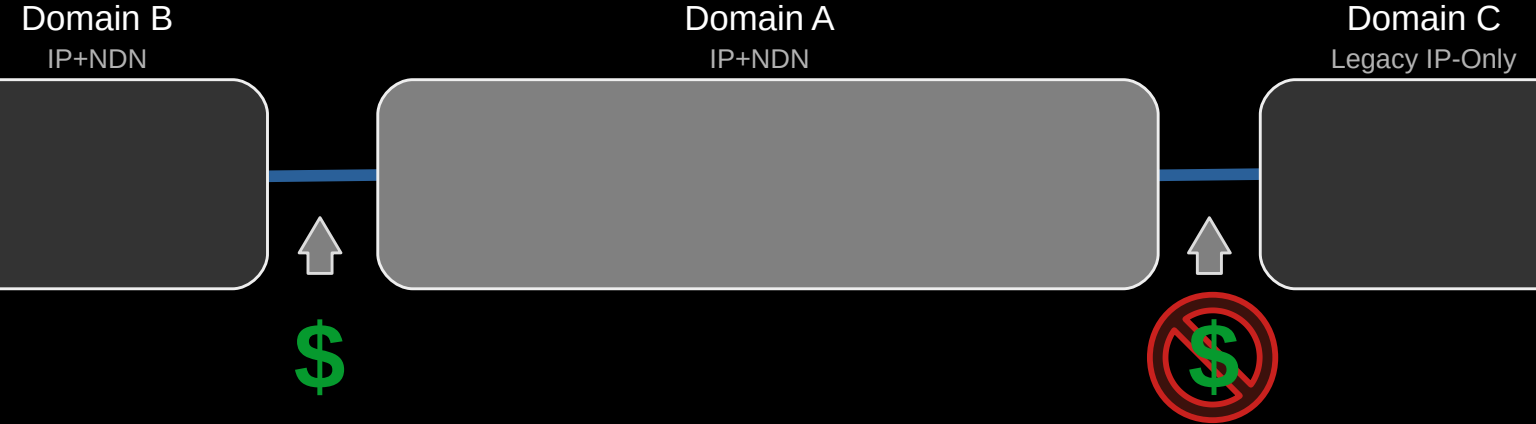
Domain A  
IP+NDN



Domain C  
Legacy IP-Only

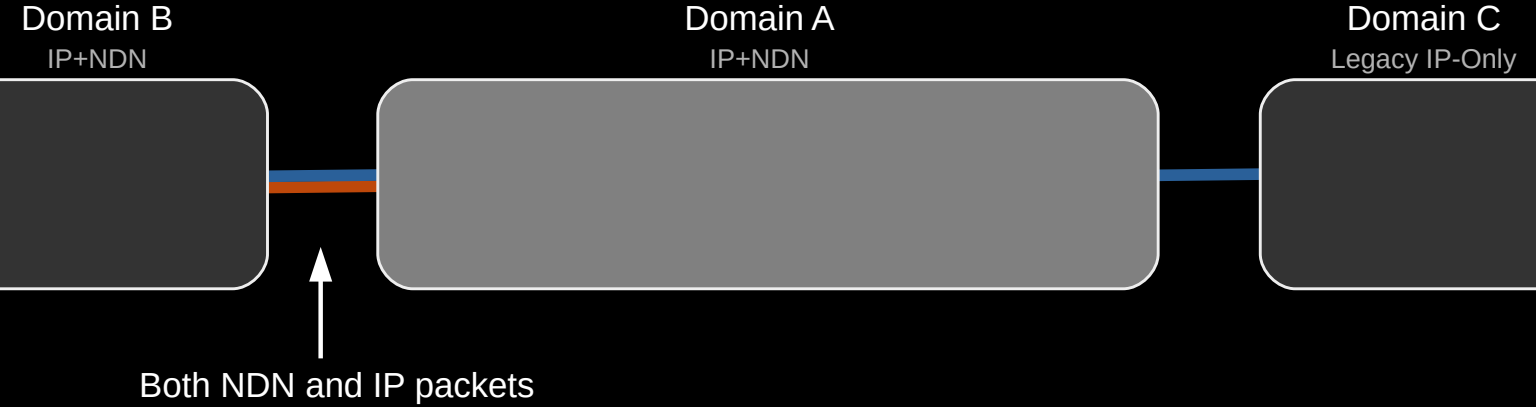


# Inside a domain

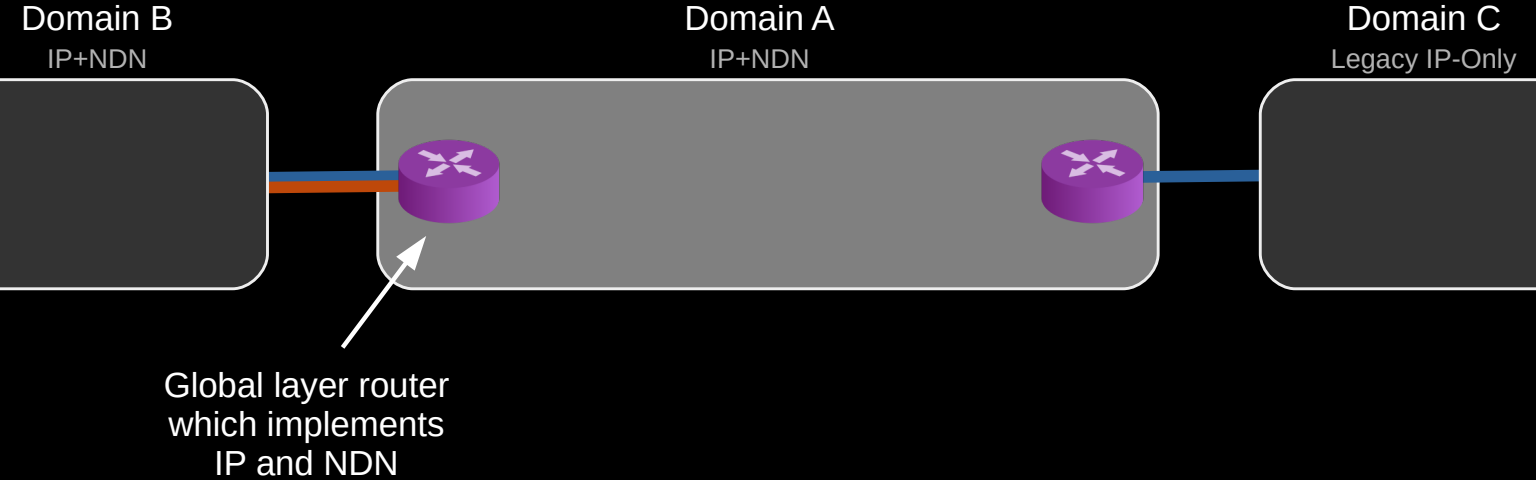


# Inside a domain

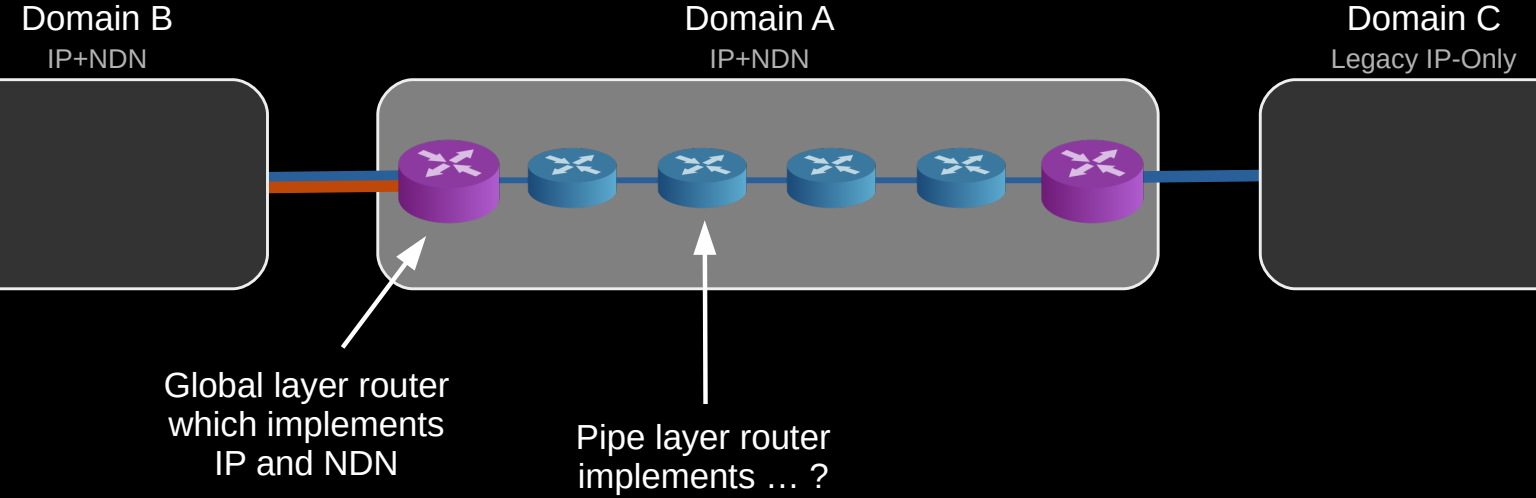
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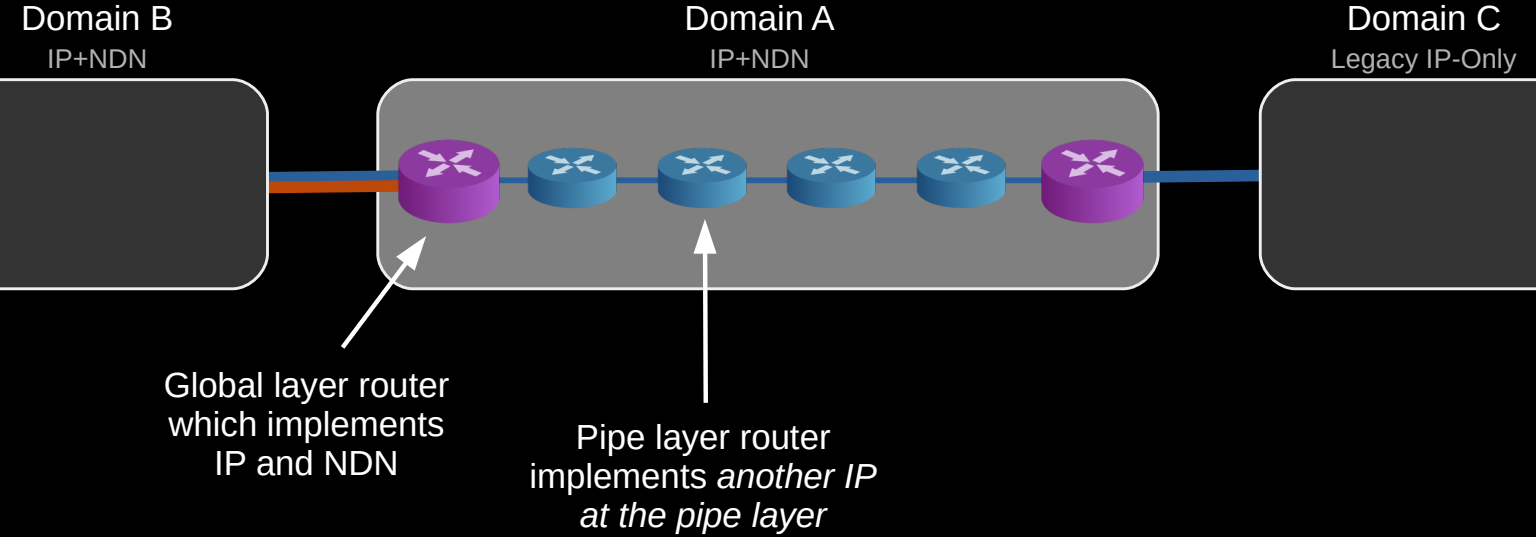
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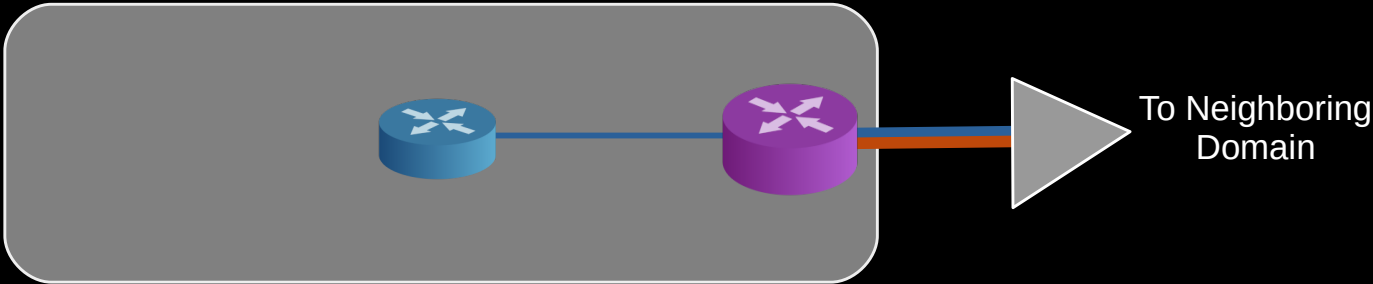
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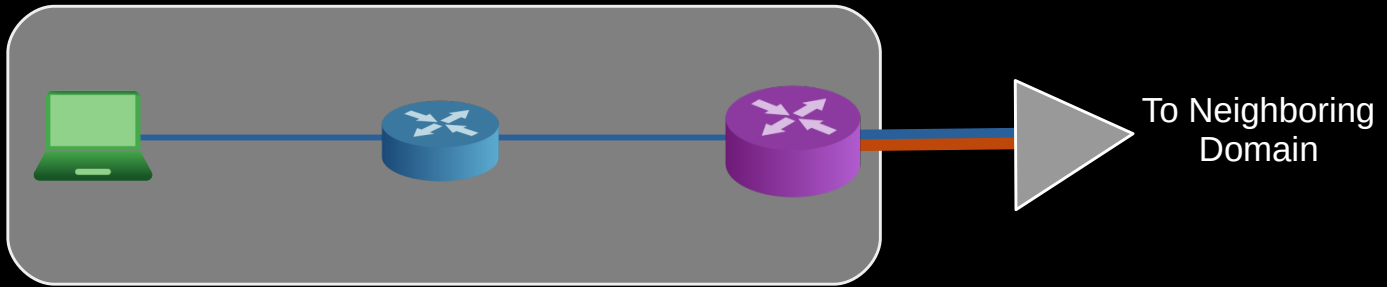


# Host initialization



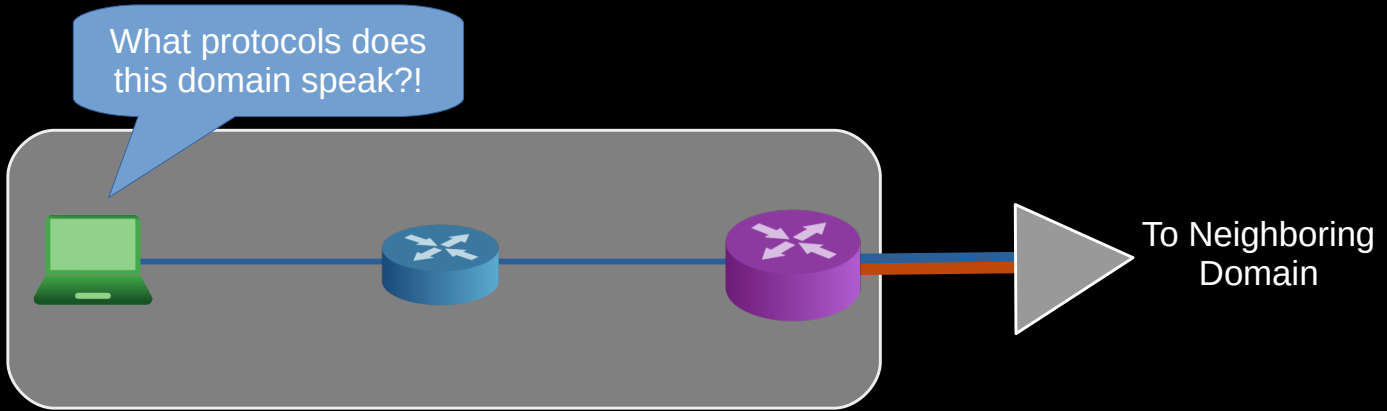
# Host initialization

1. Host arrives



# Host initialization

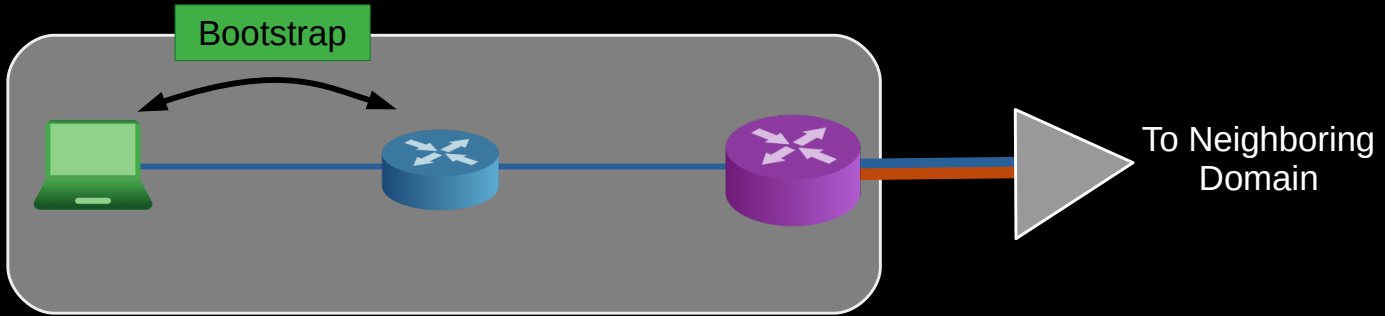
## 1. Host arrives



# Host initialization

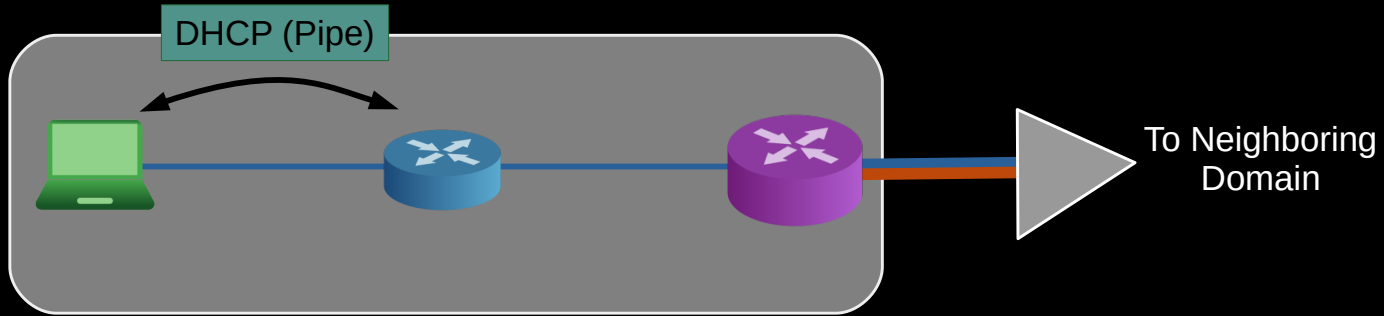
1. Host arrives

2. Bootstrap to learn which pipe and global protocols supported



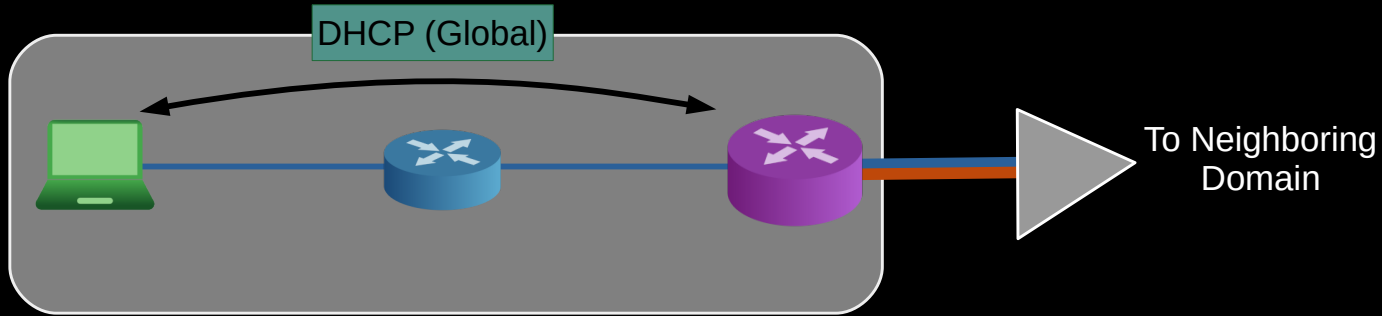
# Host initialization

1. Host arrives
2. Bootstrap to learn which pipe and global protocols supported
3. Configure pipe layer (e.g. DHCP for pipe layer IP address)



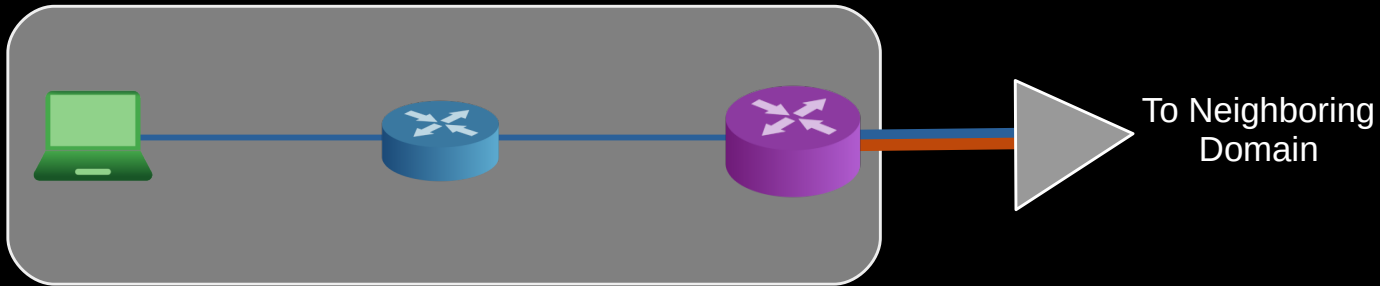
# Host initialization

1. Host arrives
2. Bootstrap to learn which pipe and global protocols supported
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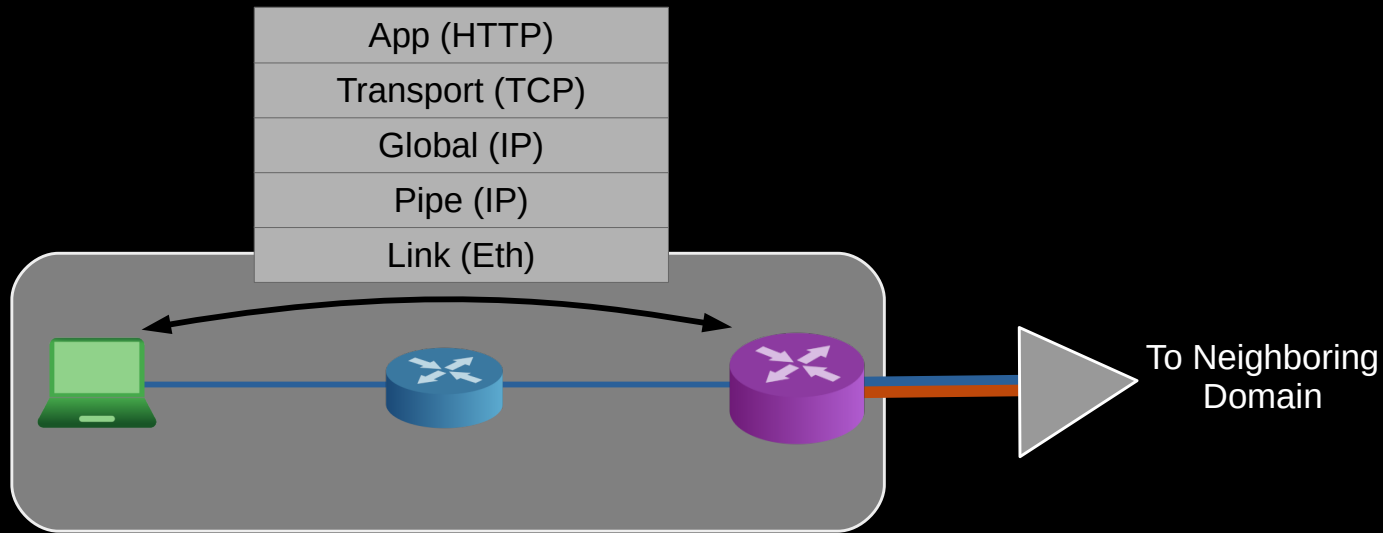
# Host initialization

1. Host arrives
2. Bootstrap to learn which pipe and global protocols supported
3. Configure pipe layer (e.g. DHCP for pipe layer IP address)
4. Configure global layer (e.g., DHCP for global layer IP address)
5. Initialization complete



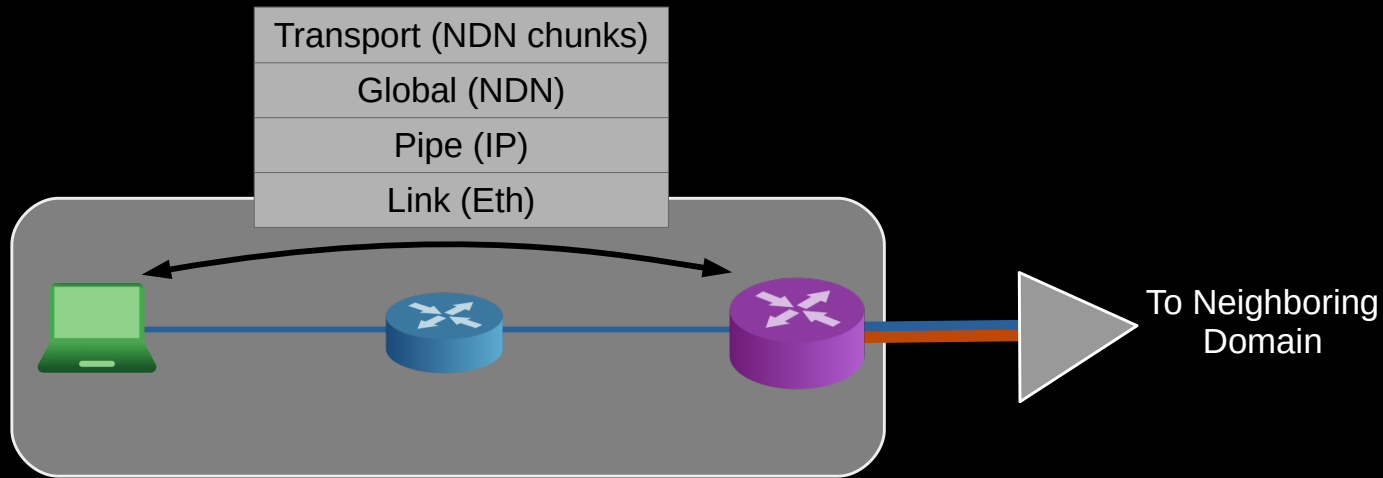
# Multiprotocol web

Downloading web page with *http*: URL



# Multiprotocol web

Downloading resources with *ndnchunks*: URL



# A bit more concretely...

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- Devil is always in the details, but...
- Only two major mechanistic components
  - Pipes to carry global protocols
  - Bootstrap protocol so hosts understand the domain they're attached to
- Together, these form a framework for architectural coexistence

# Our contribution

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- *A framework* that allows incremental, side-by-side deployment of new architectures
- And is itself incrementally deployable

# A little context

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- Approaches to handle heterogeneity (Clark):
  - Conversion
    - Maps between different technologies
  - Overlays (Spanning)
    - Can mean fairly different things
  - Underlays
    - MPLS

# A quick reflection

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- Goal: enable extensibility in Internet architecture
- Problem: the universal narrow waist ( !! )
- Solution: remove it!
  - Decouple intradomain and interdomain data planes
  - Embrace coexistence of interdomain protocols
- Result:
  - An incrementally deployable design
  - .. which can incrementally deploy new architectures

# A quick tangent

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- Internet today relies on specialized data plane HW
  - It's more cost effective
  - Replacing every router with SW on general-purpose HW is out of the question...
  - .. but replacing only global layer routers seems feasible
  - Huge reduction of risk & investment for experimentation

# Conclusion

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- On one hand, this work is *dull*
- On the other, we think it's incredibly exciting
  - An Internet beyond just connectivity
  - A dynamic architectural ecosystem
- An invitation to architects or would-be architects:
  - Let's work together to make this happen

Thank You