# An Open Platform to Teach How the Internet Practically Works

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Joint work with Tobias Bühler,
Tino Rellstab, and
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# How do we traditionally teach how the Internet works?

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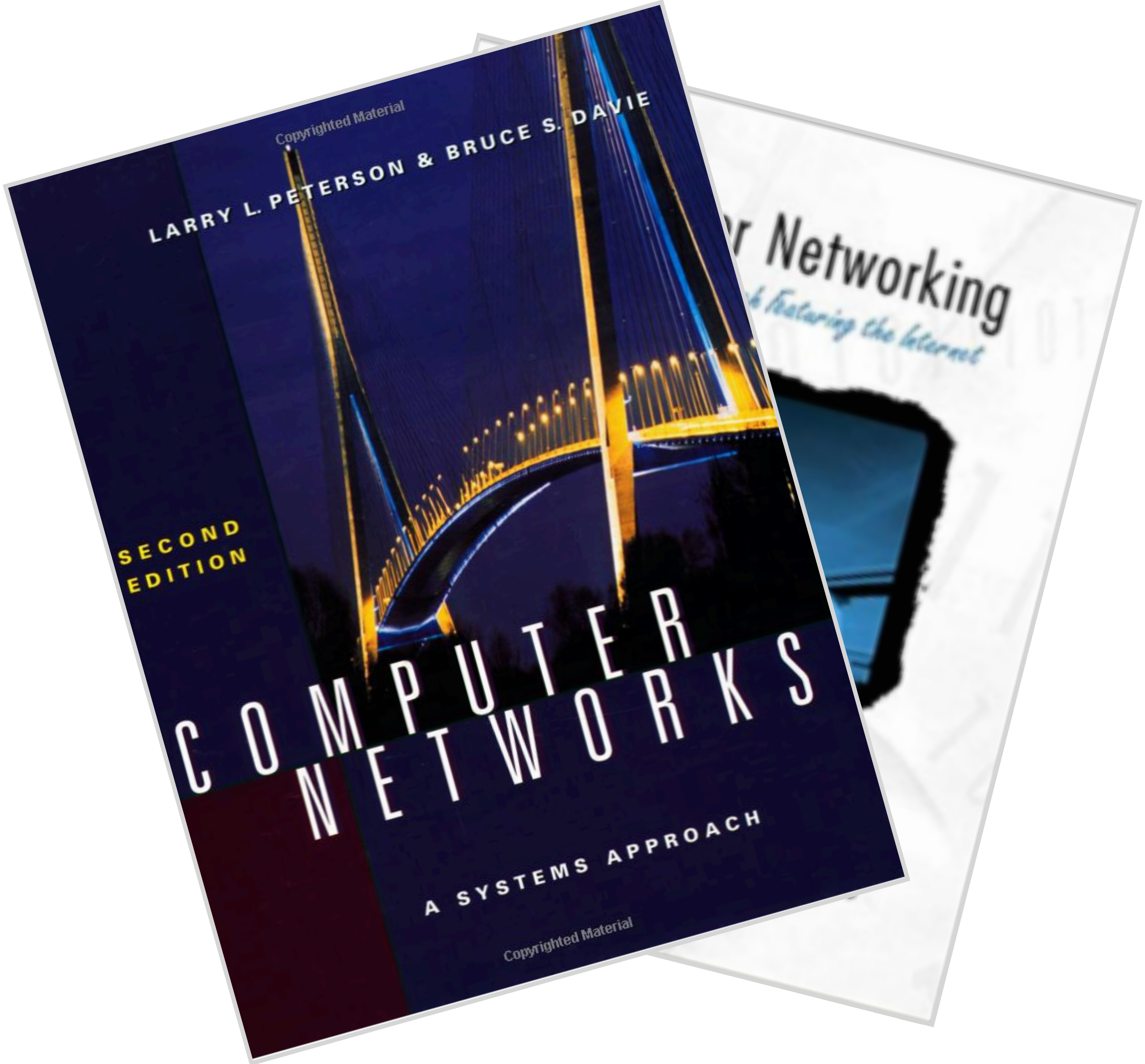
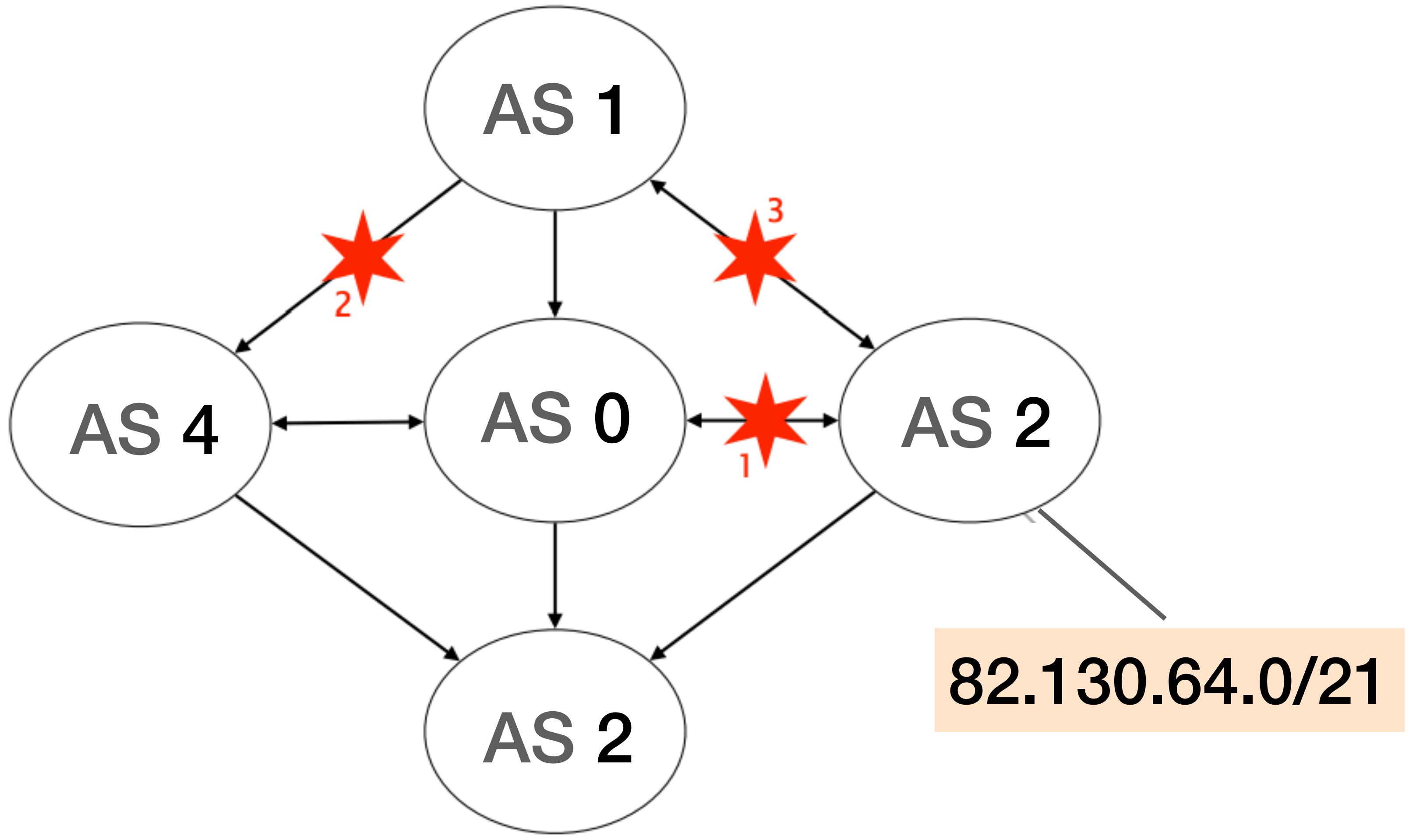
## theory




## exercises




Which messages are exchanged?

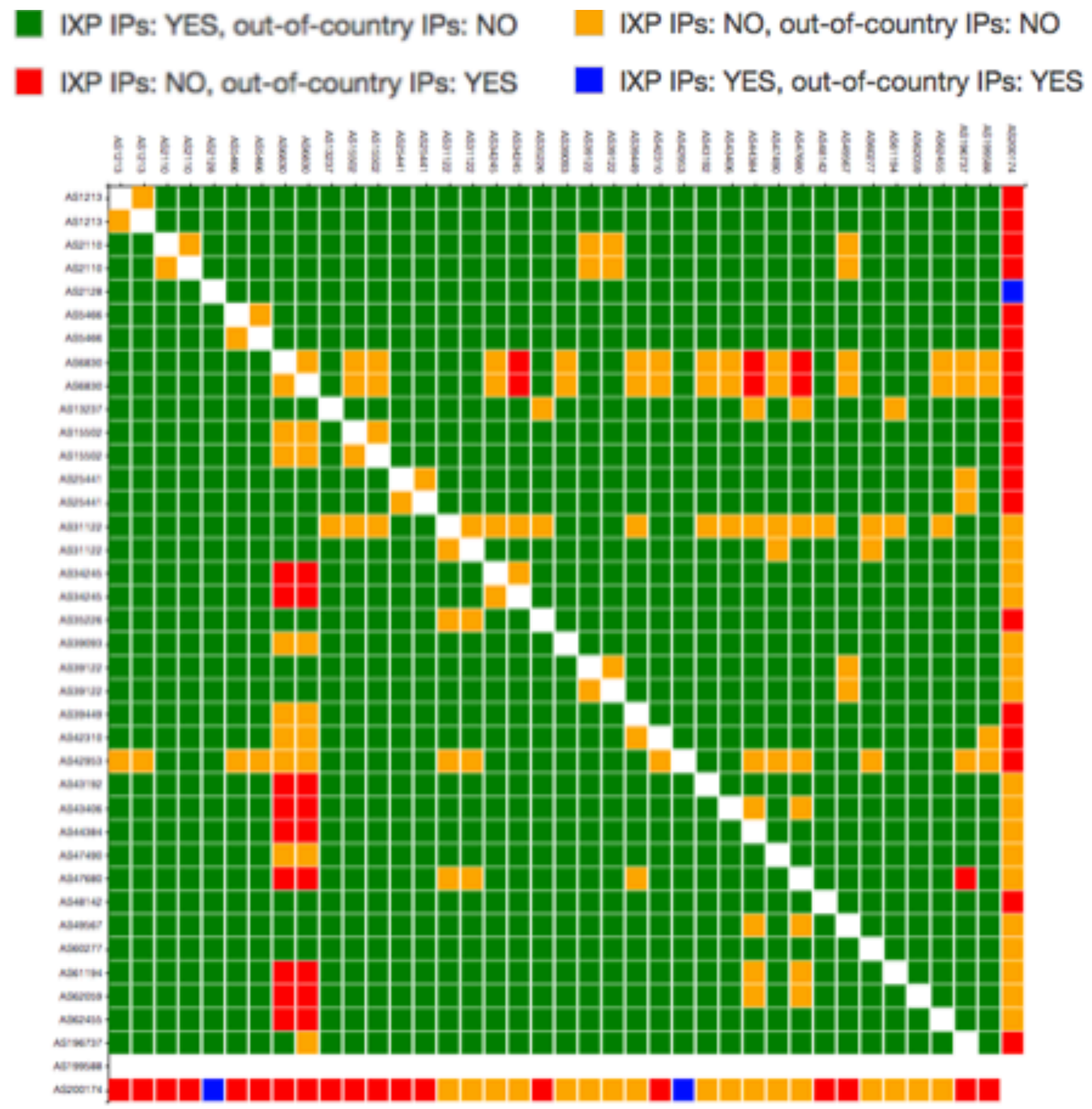
## labs

These concepts are not sufficient to understand how the Internet *practically* works

# In practice, operating a network in the Internet requires…

## Making agreements

## Network-wide monitoring




## Debugging problems

At ETH Zurich, we let the students operate their own mini-Internet, altogether, like if they were the network operators

ETH students working on the mini-Internet

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### ABSTRACT

Each year at ETH Zurich, around 100 students build and operate their very own Internet infrastructure composed of hundreds of routers and dozens of Autonomous Systems (ASes). Their goal? Enabling Internet-wide connectivity.

We find this class-wide project to be invaluable in teaching our students how the Internet *practically* works. Our students have gained a *much* deeper understanding of the various Internet mechanisms alongside with their pitfalls. Besides students tend to love the project: clearly the fact that all of them need to cooperate for the entire Internet to work is empowering.

In this paper, we describe the overall design of our teaching platform, how we use it, and interesting lessons we have learnt over the years. We also make our platform openly available [8].

### 1 INTRODUCTION

Most undergraduate networking courses, including ours [23], aim at teaching "how the Internet works". For the instructor, this typically means painstakingly going through the TCP/IP protocol stack, one layer at a time, following a bottom-up [18] or top-down approach [13]. At the end of the lecture, students (hopefully) have learned concepts such as switching, routing, and reliable transport; together with the corresponding protocols.

Learning these concepts is not sufficient to understand how the Internet *really* works though or, alternatively, why it does *not* work: for this, we think one also needs to understand the ins and outs of how the Internet is operated which includes topics such as network design, network configuration, network monitoring, and... network debugging. Understanding these topics is important as Internet operations have a *huge* impact on its behavior. Among others, most of the Internet downtime are due to human-induced errors [17]. Yet, undergraduate networking courses seldom include these topics, most likely because they are so few principles governing them.

operators: enabling Internet-wide connectivity, between any pair of IP prefixes, by transiting IP traffic across multiple student networks. As they quickly realize though, achieving this goal is challenging and requires a truly collective effort. We found this to be empowering. The fact that all networks need to work for the Internet as a whole to work really helps to bring together the entire classroom.

Over the years, the mini-Internet project has become a flagship piece of our networking lecture, one that the new students look forward to. Thus far, the feedback we received from the students has been extremely positive, with comments such as: *"It really allows us to apply the theoretical concepts"*; *"I am quite confident about many things on the Internet now"*; and *"It is a unique project"*.

Besides gaining a *much* deeper understanding of the various Internet mechanisms, having students build and maintain their own Internet infrastructure enables them to quickly realize the pitfalls and shortcomings behind Internet operations. Students quickly realize: *(i)* how fragile the Internet infrastructure is and how dependent they are on their neighbors' connectivity; *(ii)* how hard it is to troubleshoot Internet-wide problems; and *(iii)* how difficult it is to coordinate with each other to fix remote problems. Each year, several groups of students come up with proposals (sometimes, even implementations!) to improve Internet operations. These proposals often directly relate to research topics active in our community (such as configuration verification/synthesis or active probing). Perhaps candidly, we believe that encountering operational problems early on in their networking curriculum can also help the next-generation of network designers avoid repeating the mistakes made in the past.

***An open platform.*** Given the success of our project, we have open sourced the entire platform [8] and hope that other institutions will start using it. We built our platform with three key goals in mind.

First, we aimed at faithfully emulating the real Internet infrastructure. To do so, we rely on (open-source) switching and routing software implementing the most well-known protocols (e.g., STP,

# Outline

1. How the mini-Internet mimics the real one
2. How we use the mini-Internet to turn the students into network operators
3. How we implemented the mini-Internet

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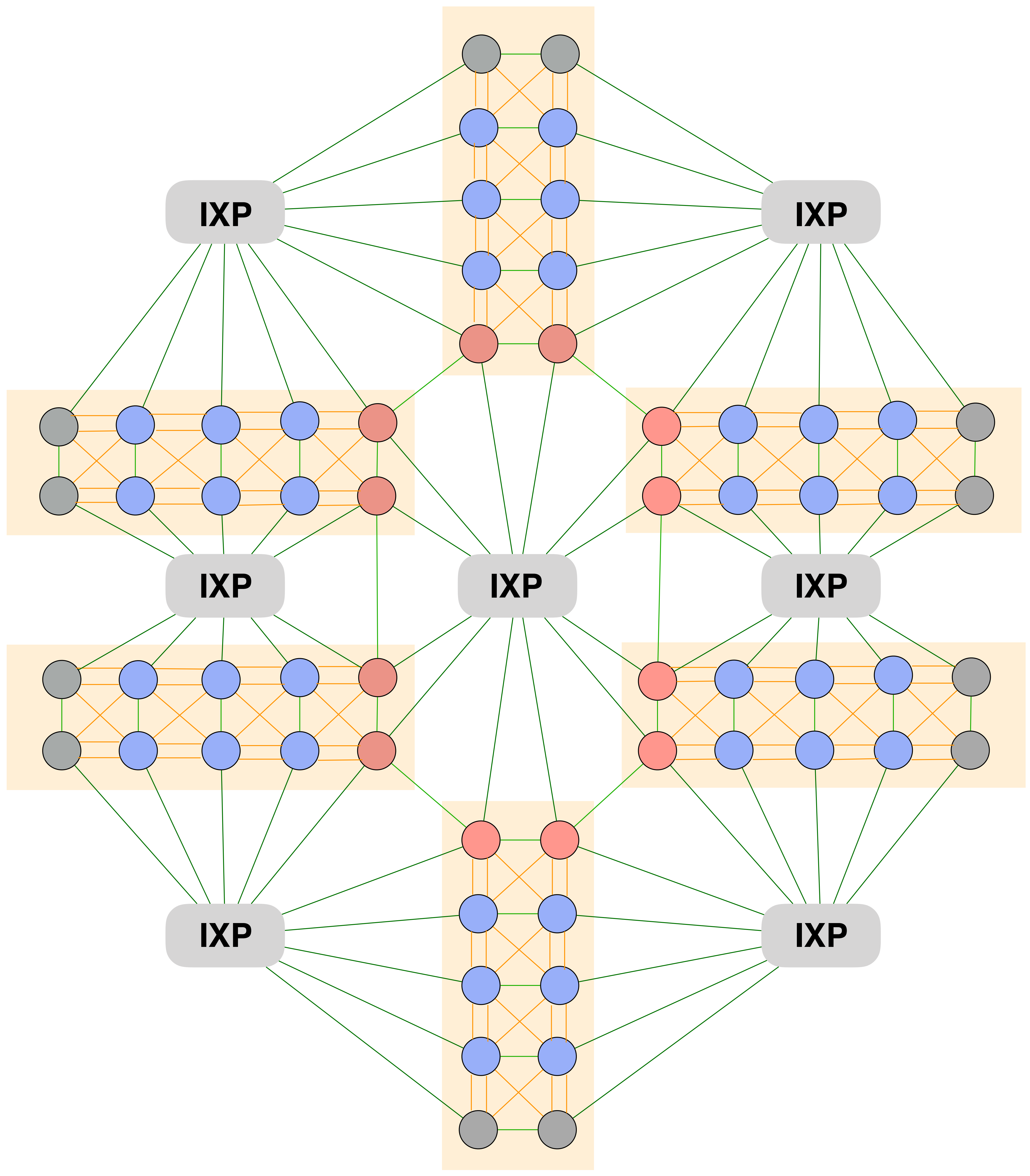
# The AS-level topology of the mini-Internet

There are 60 ASes, divided in six regions

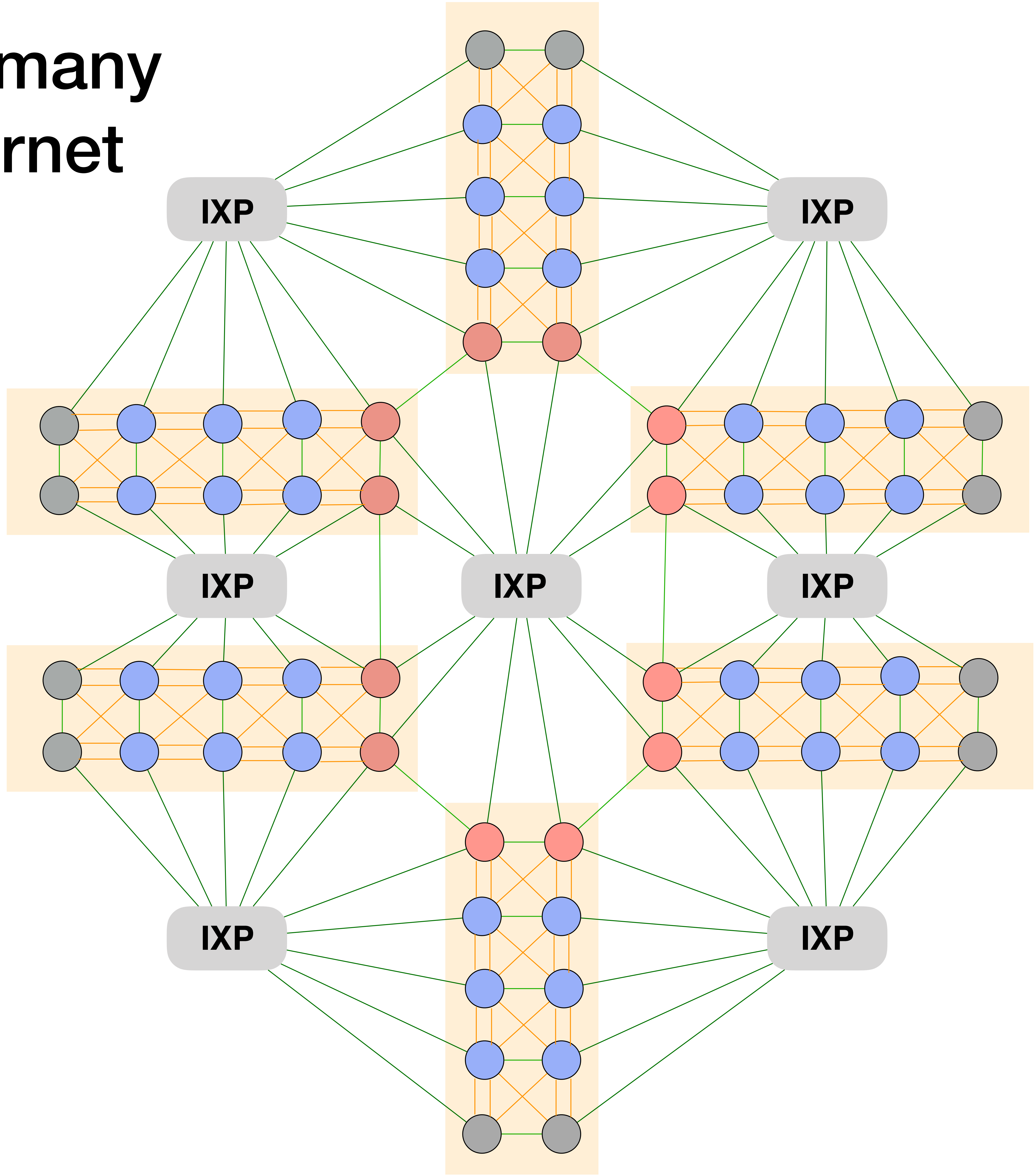


# The AS-level topology exhibits many properties found in the real Internet

There are Tier1 ( ), Stub ( ) and Transit ( ) ASes

There are peer-2-peer ( ) and customer-provider links ( )

There are IXPs ( IXP )



# We build internal topologies
# with the technologies used in practice

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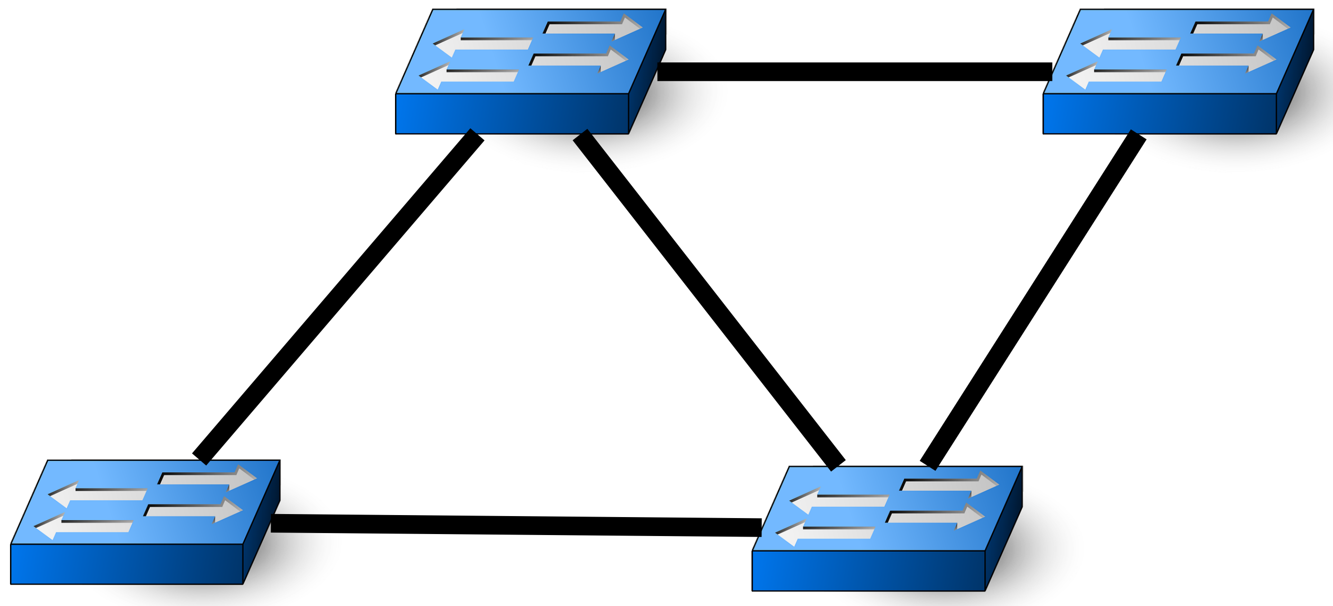
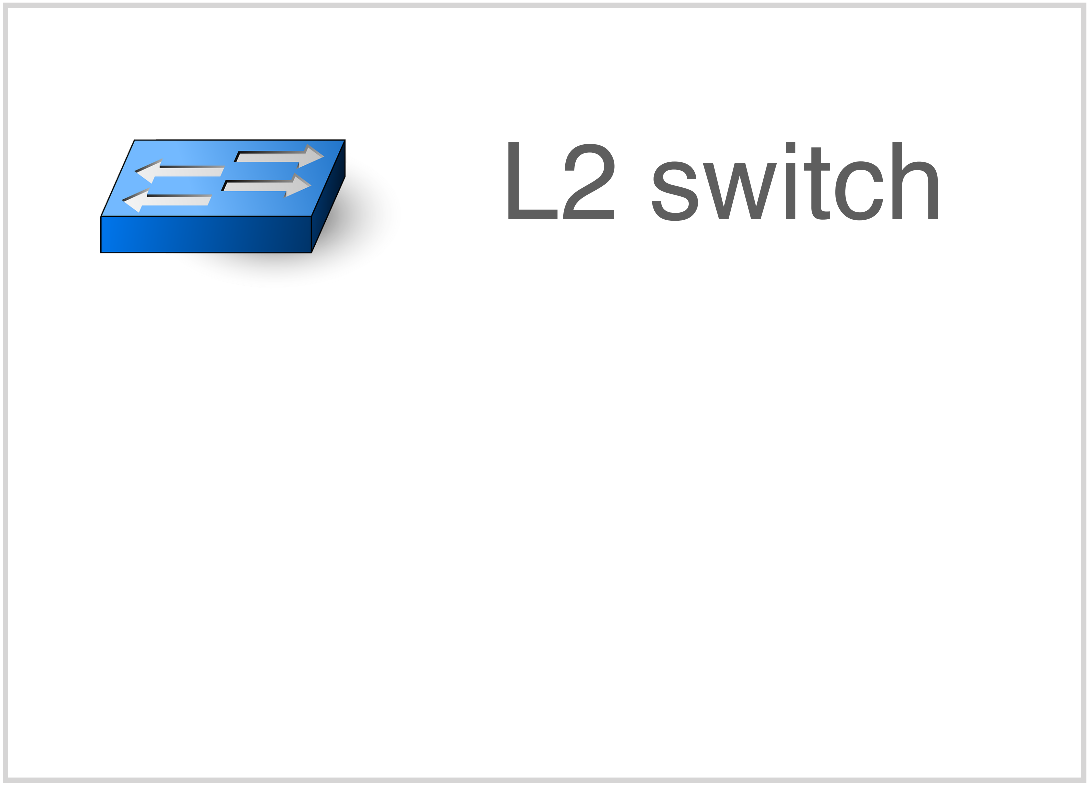
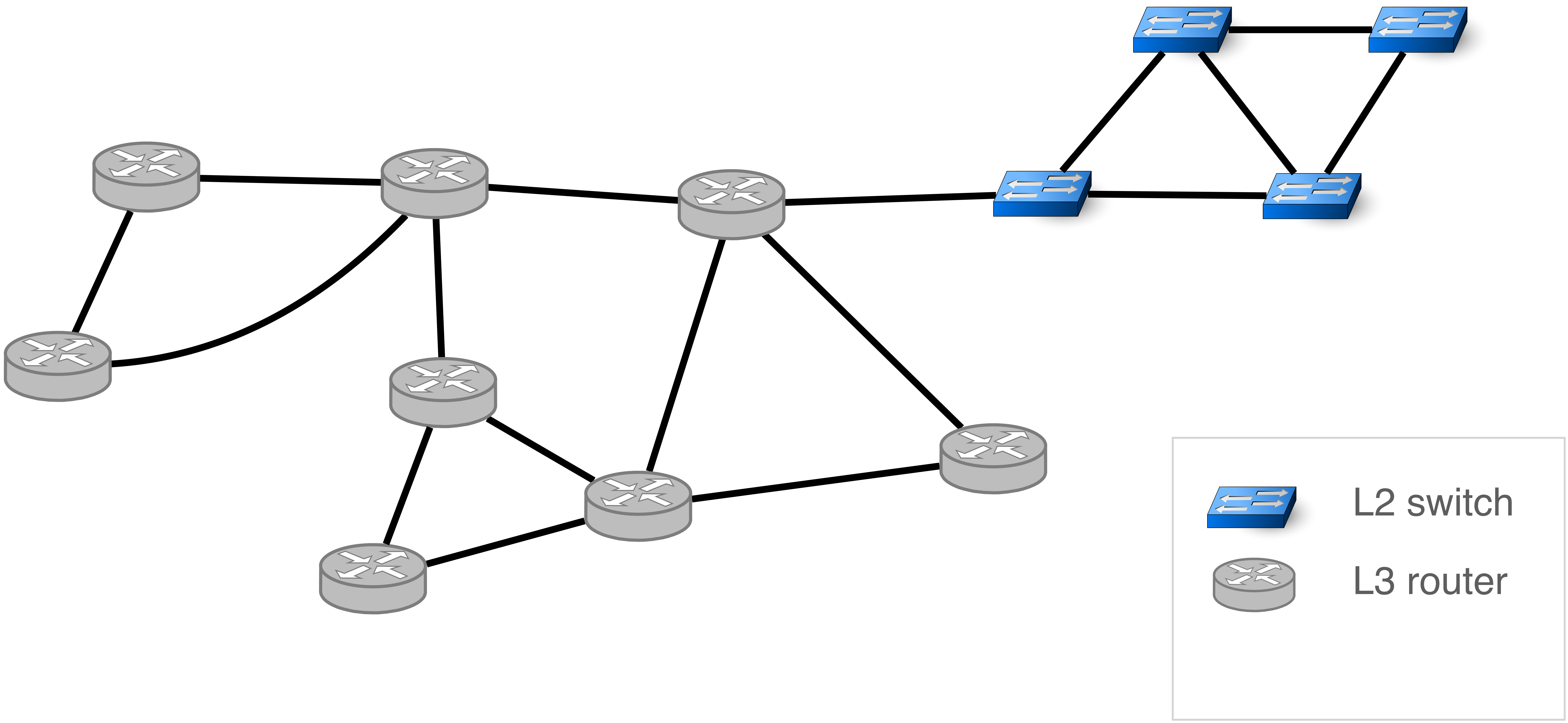




# We build internal topologies with the technologies used in practice



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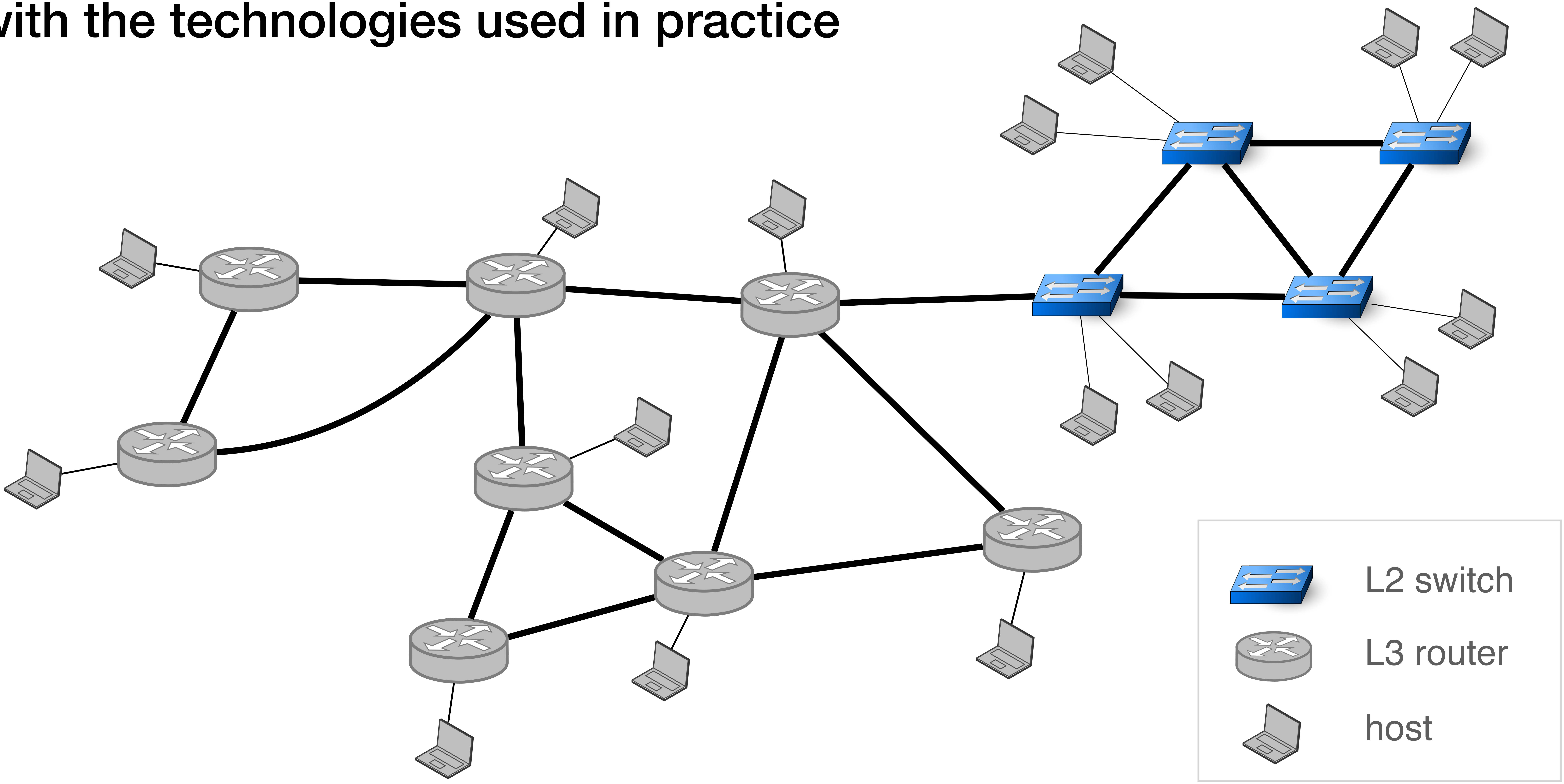


# Outline

1. How the mini-Internet mimics the real one
2. How we use the mini-Internet to turn the students into network operators
3. How we implemented the mini-Internet

We give one transit AS and one IP prefix to each group of students

Goal: enabling Internet-wide connectivity

## First, the students have to enable internal connectivity and configure some traffic engineering

In the L2 network, the students configure the
Spanning tree protocol and VLANs

In the L3 network, the students configure
IP addresses, OSPF and load-balancing

Second, we organise a Hackathon where students gather to configure BGP sessions


mini-Internet Hackathon, April 19, 2018

# Third, students have to implement external routing policies

**Following business agreements**
e.g., local-preference and exportation rules

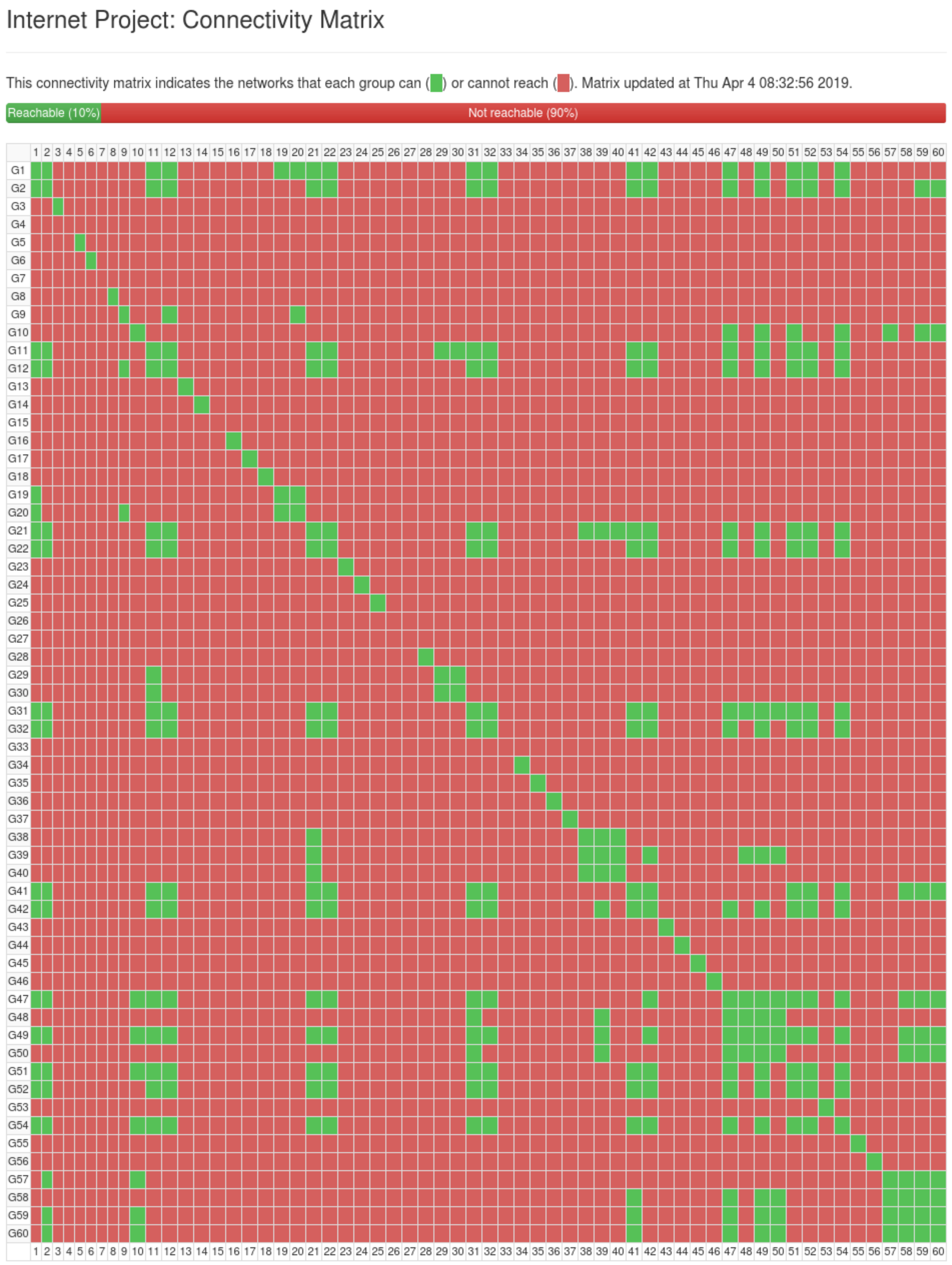
**Following preferences**
e.g., one provider is preferred

# We provide the students with monitoring tools that are similar to ones used in practice

**Looking glass:** the routing table of every router is available on a web interface

**Active probing:** the students can run ping and traceroute between any pair of ASes to test connectivity

# Last year, up to 96% of the ASes were connected to each other



# What the students learn goes beyond just configuring some protocols

**They realise that the Internet is the result of a collective effort**
Students often gather to configure the network together

**They realise that the Internet is fragile**
A small mistake may affect the overall connectivity

**They realise that the Internet can be configured more efficiently**
Students often come up with automation tools

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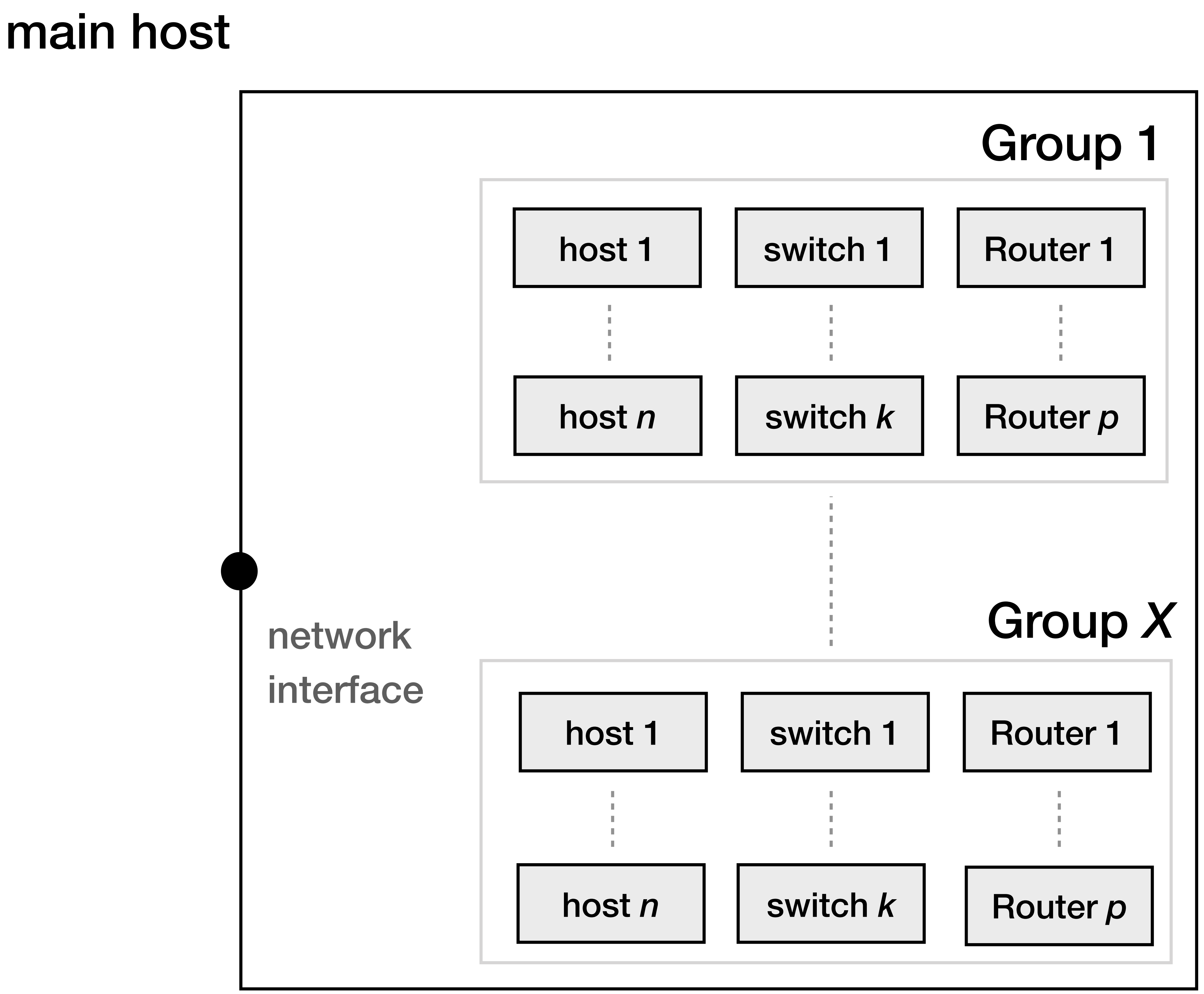
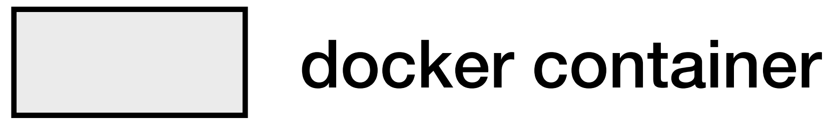
# We rely on docker containers to isolate the different components of the mini-Internet (hosts, switches and routers)




Containers are connected with virtual links



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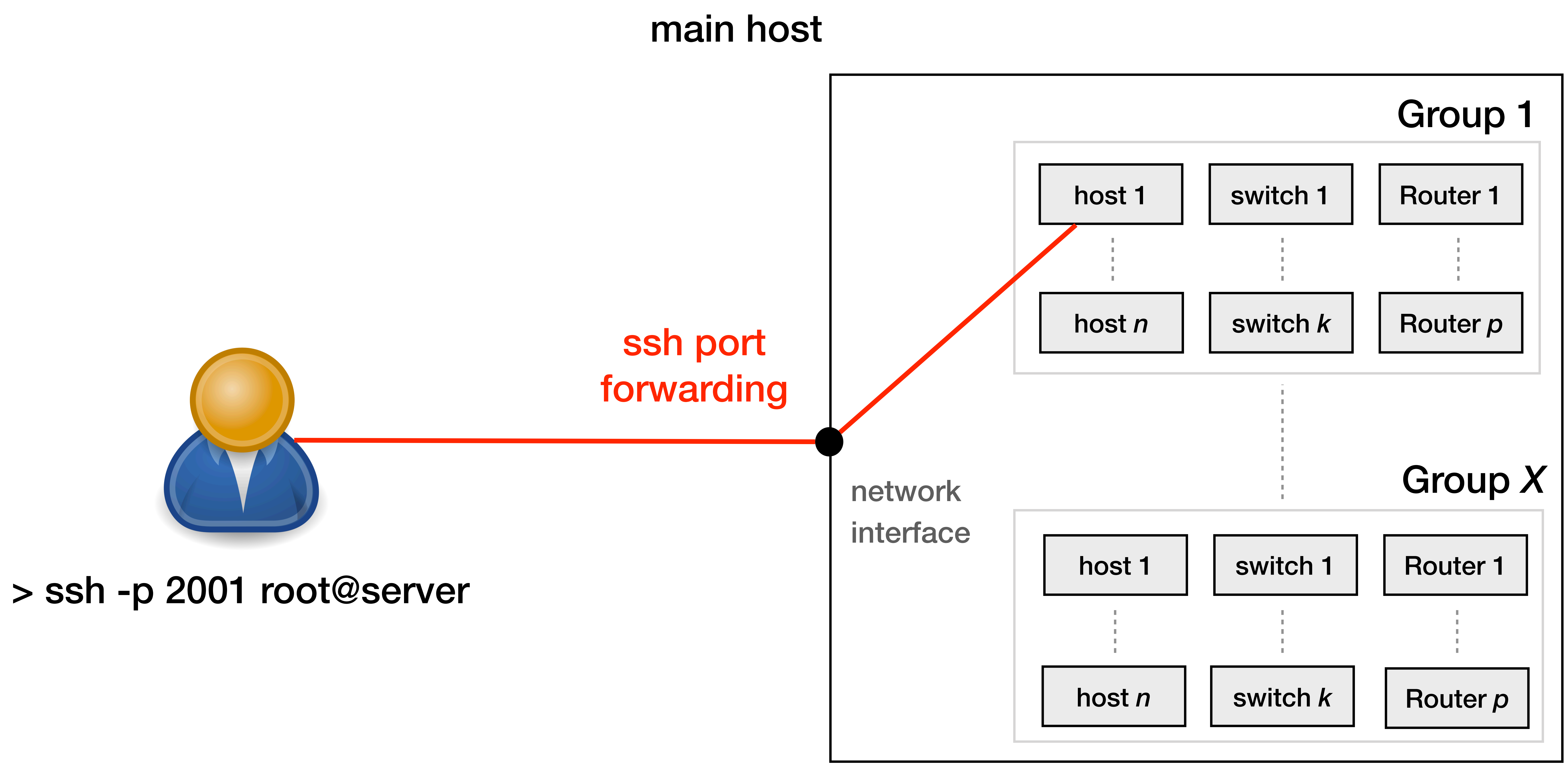



Containers are connected with virtual links

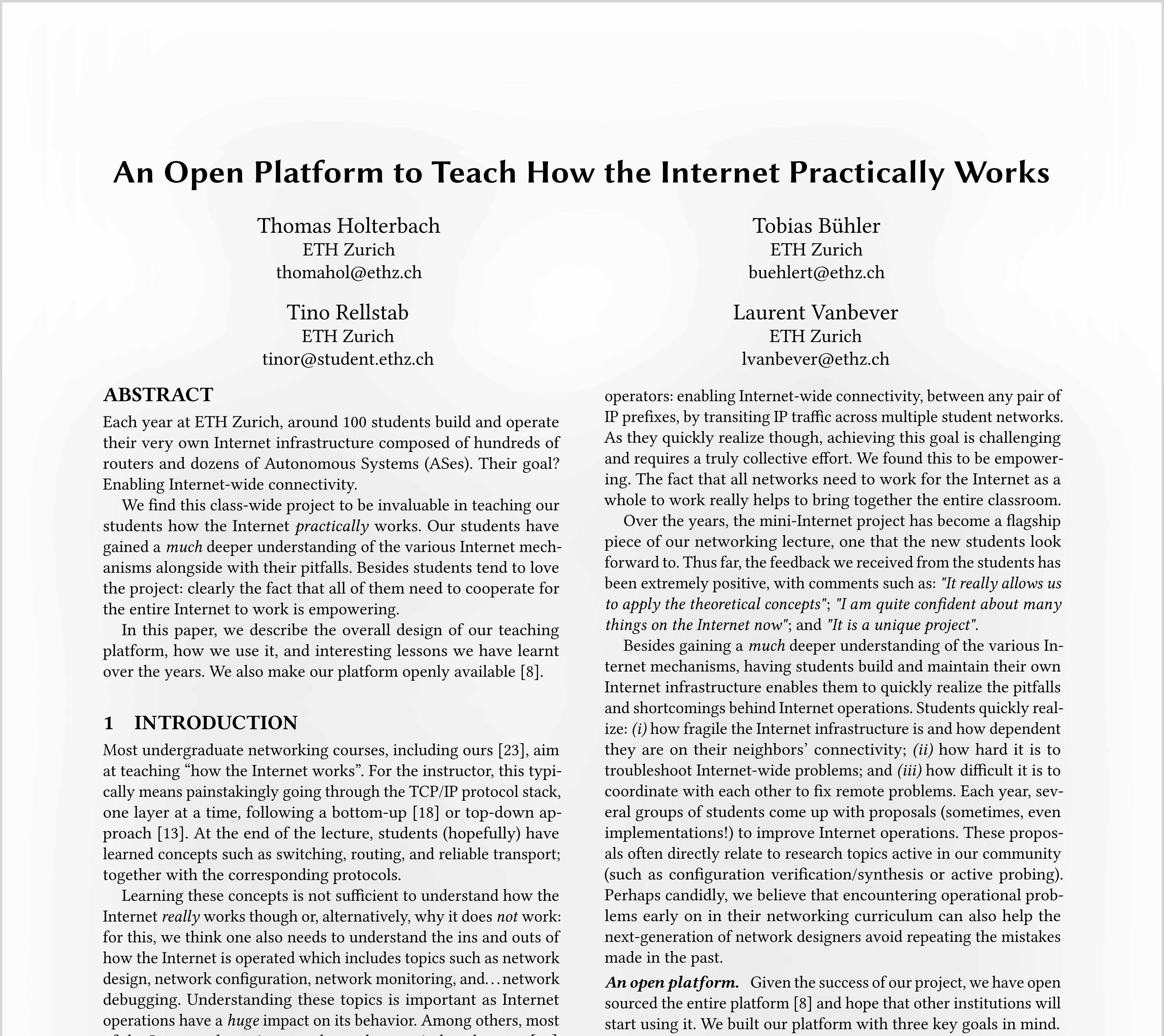
We use the state of the art software suites for the switches and routers

OvS Open vSwitch

FRROUTING

# For further information

## Technical report



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## 30 min presentation at NANOG 78

# How to run your own mini-Internet?

1. Pull from our GitHub page

   github.com/nsg-ethz/mini_internet_project

2. Follow the documentation

3. Define your topologies

4. Run it on your server