# CS168, Lecture 3

# How the Internet Works : overview

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Fall 2024

# Today

- Wrap up our discussion of circuit & packet switching
- Start our top-down overview

# Recall, from last lecture…

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- Reservations via circuit switching
- Best-effort via packet switching

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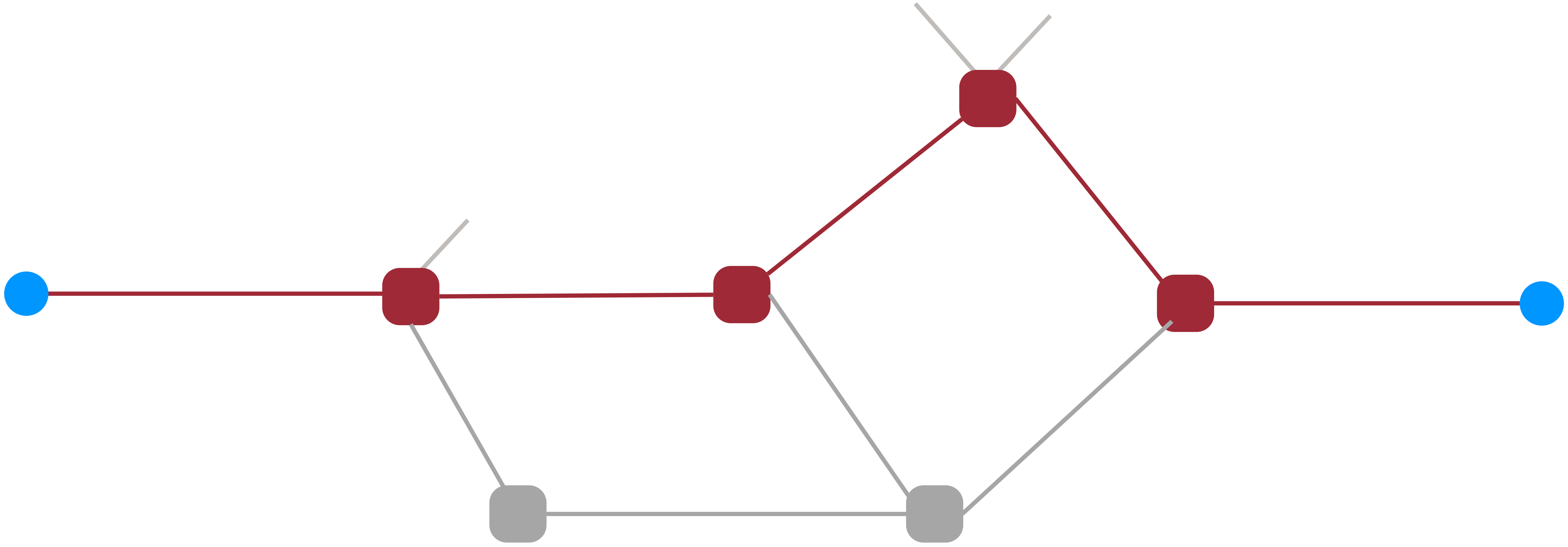

Idea: Reserve network capacity for all packets in a flow

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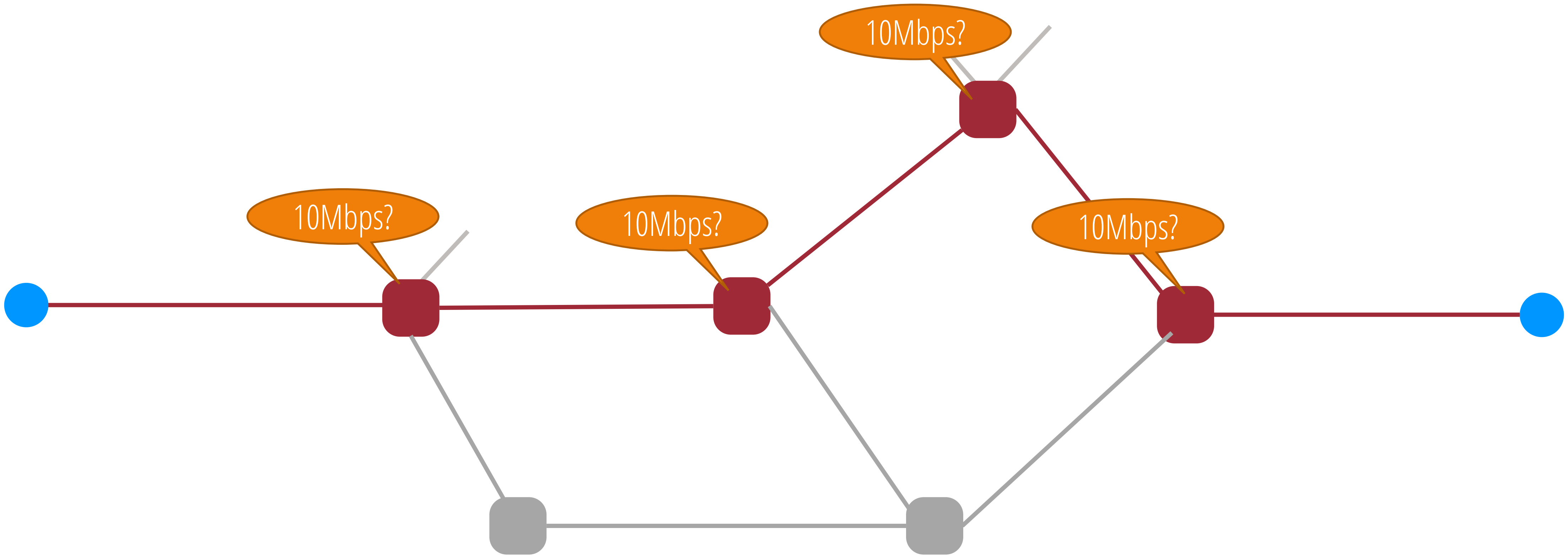


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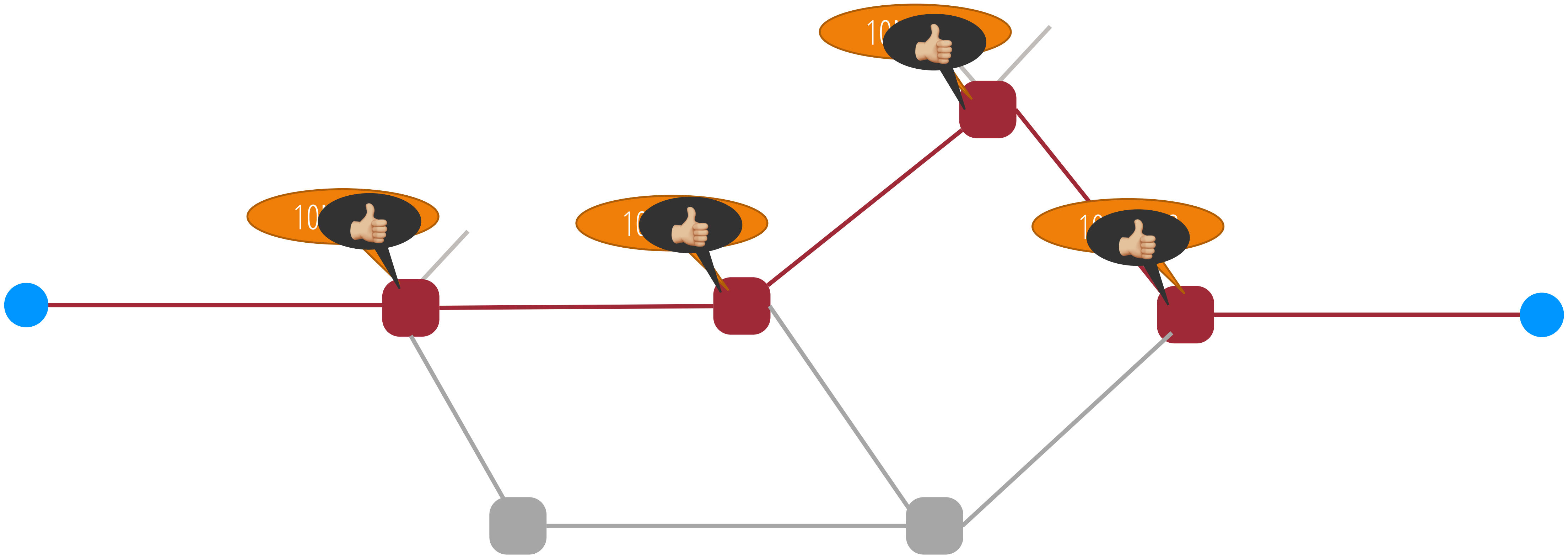

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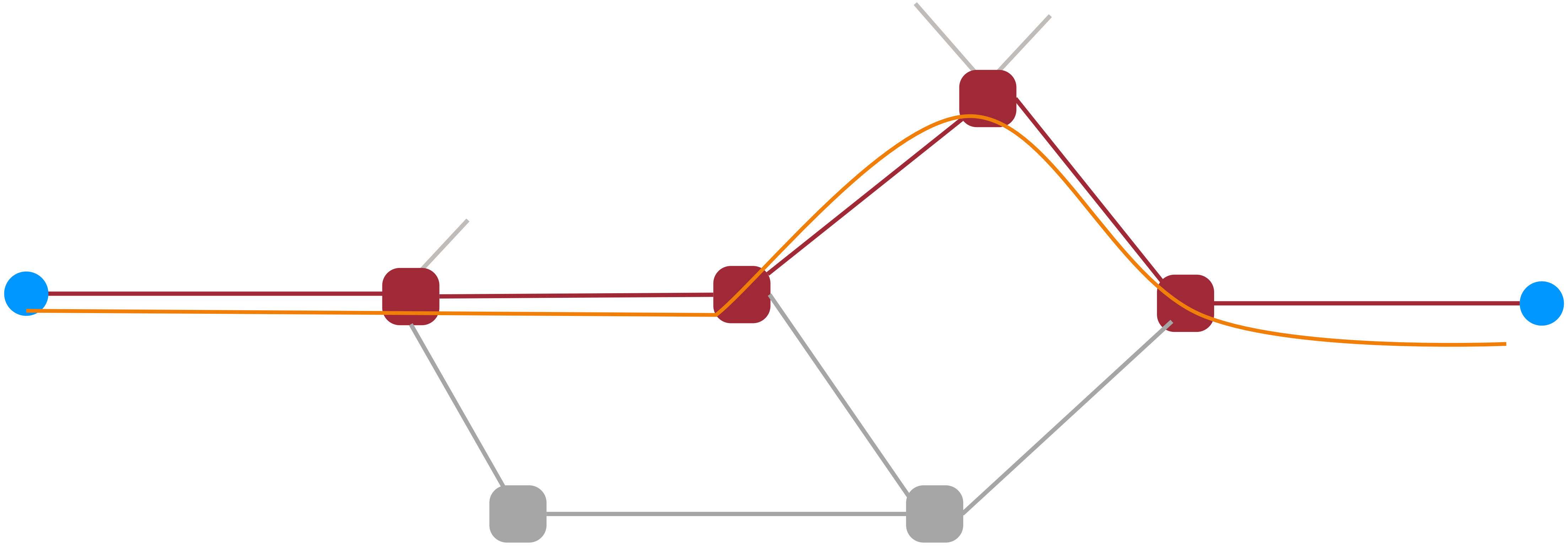

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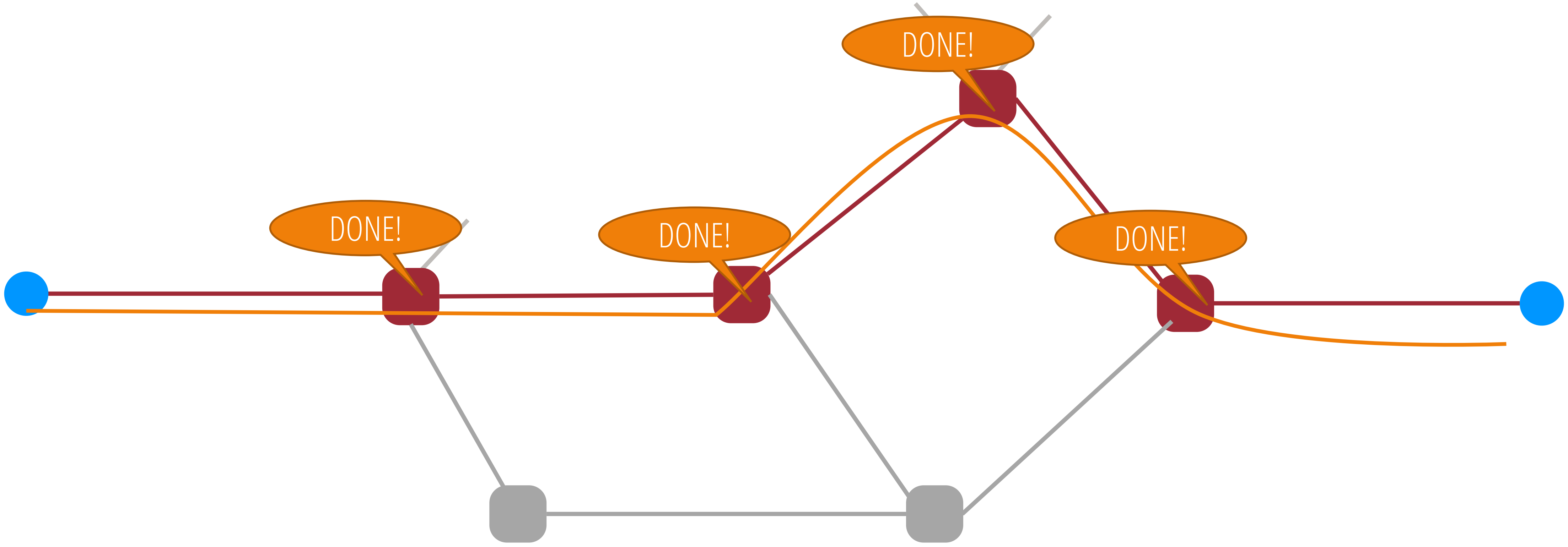


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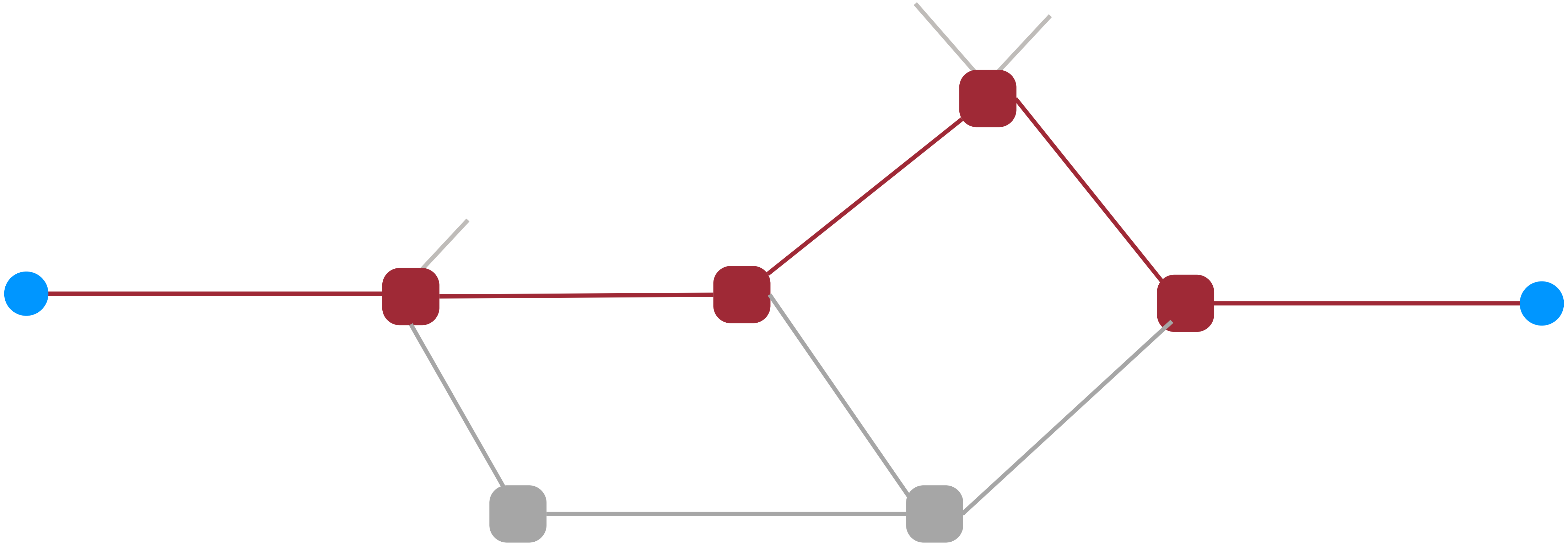

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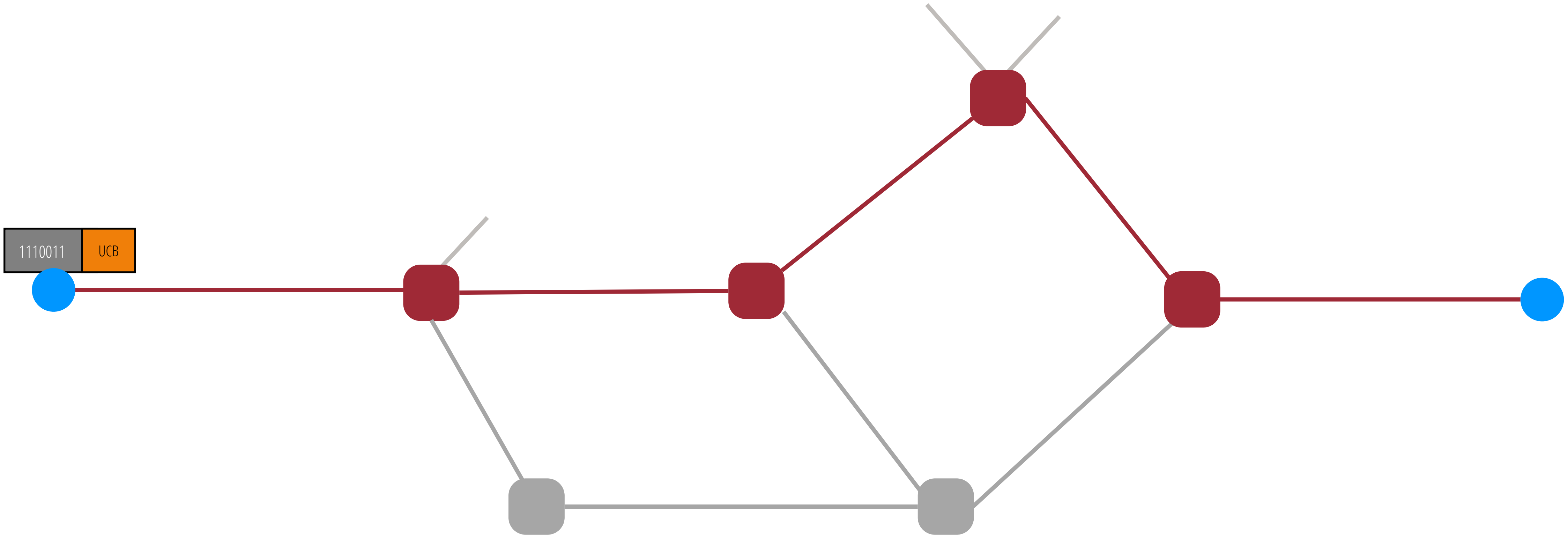


Allocate resources to each packet independently

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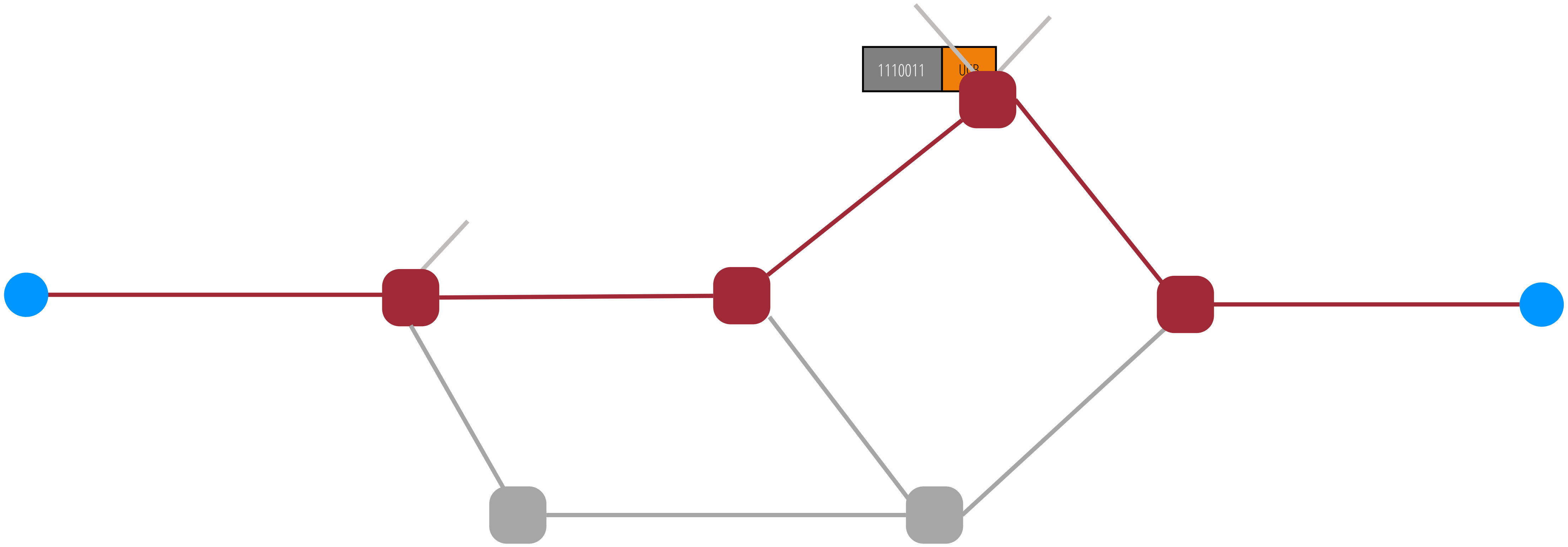


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# Circuit *vs.* Packet switching: which is better?

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  - As an abstraction to applications
  - Efficiency (at scale)
  - Handling failures (at scale)
  - Complexity of implementation (at scale)

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- Also a very intuitive abstraction in support of business models

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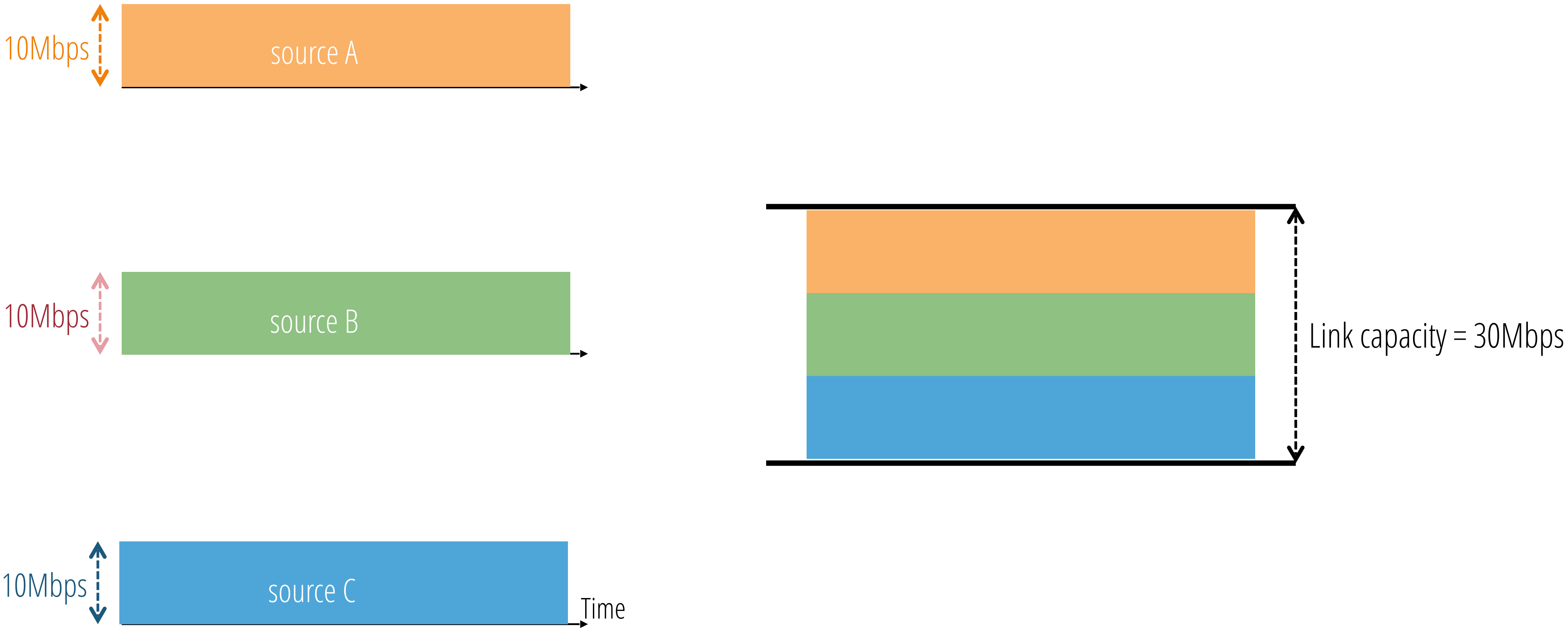
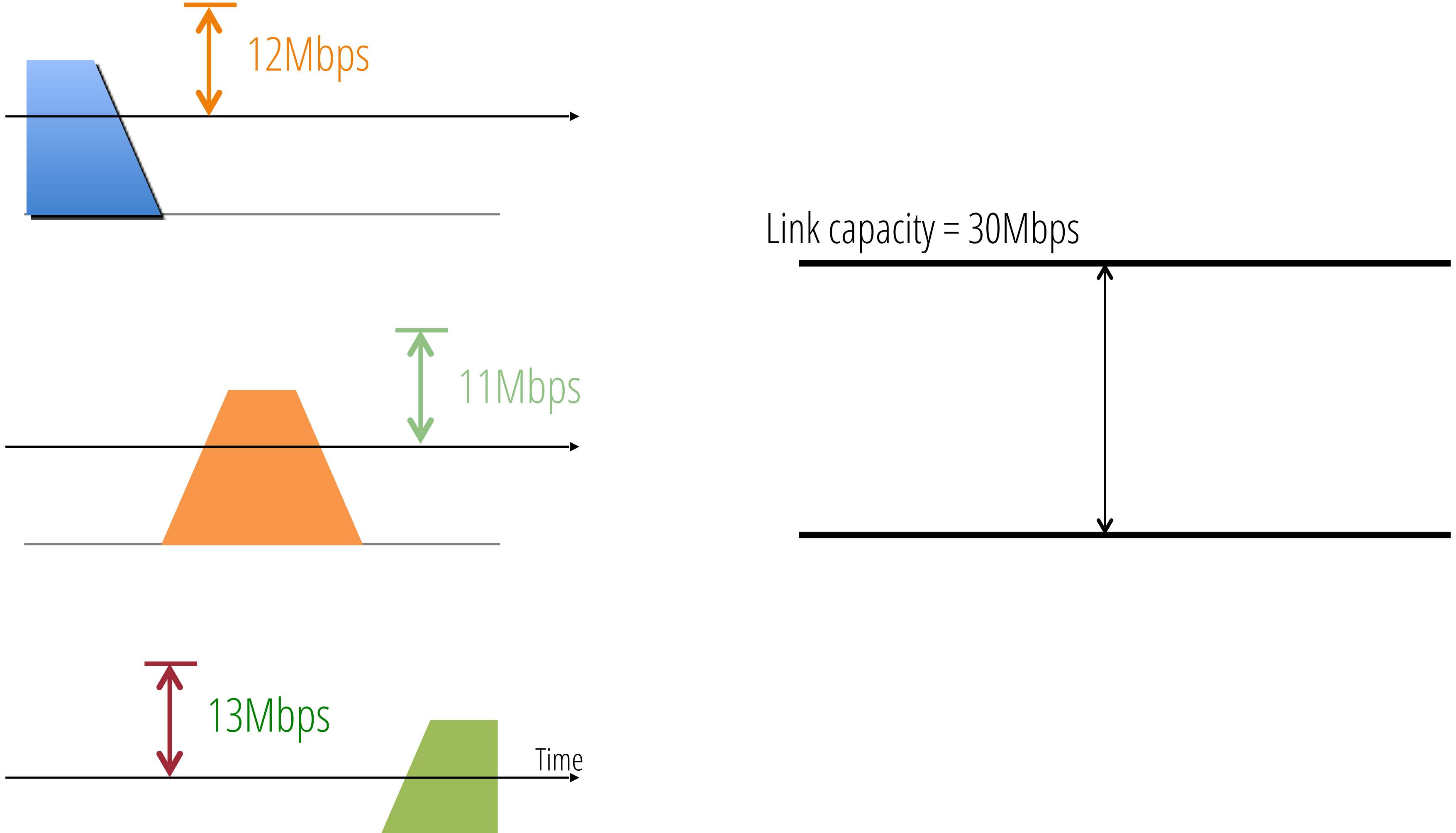
# Example#1: Three constant sources



# Example#2: Three "bursty" sources



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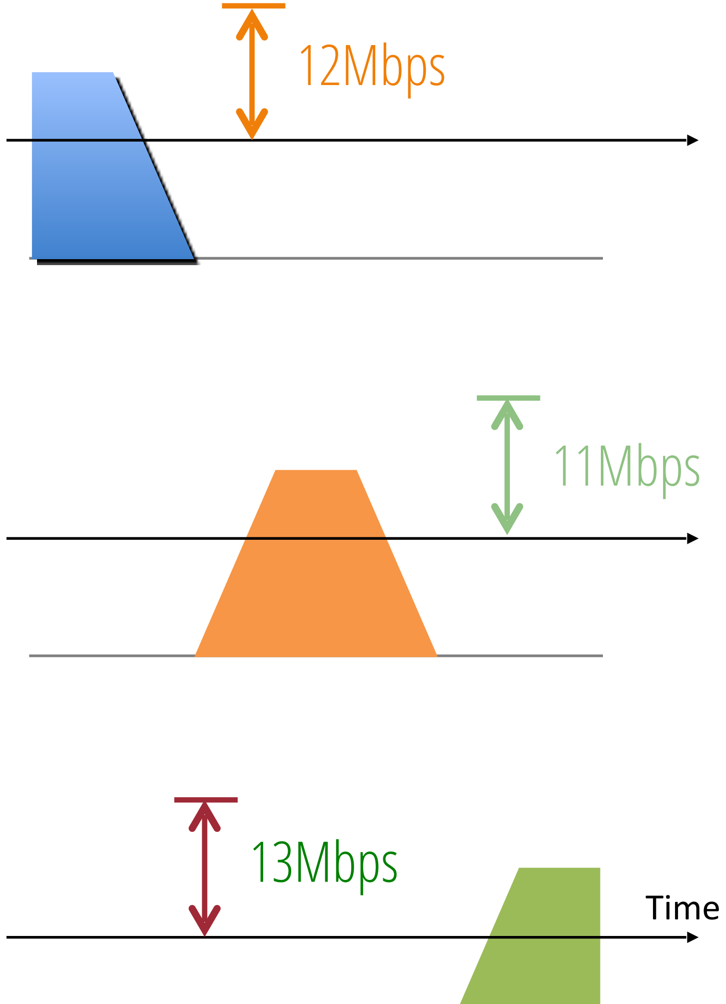
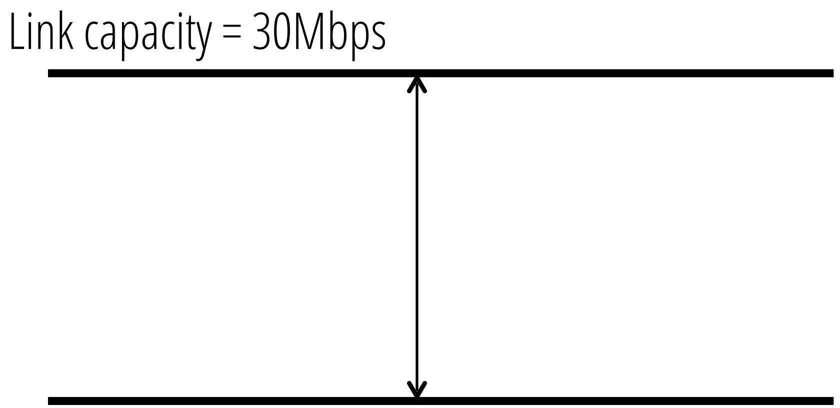
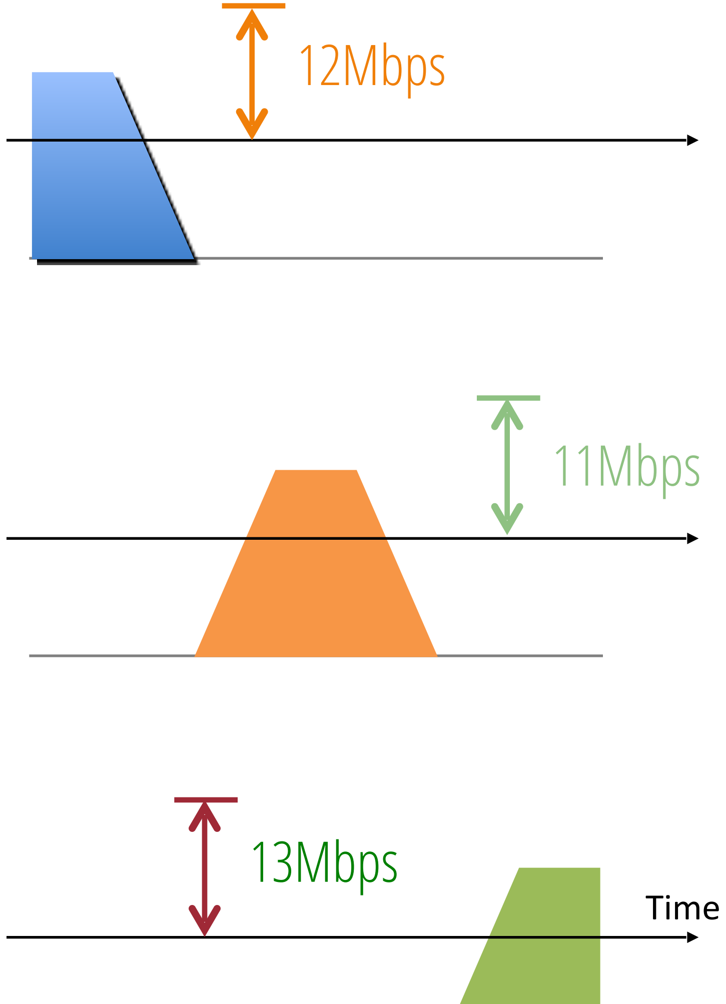
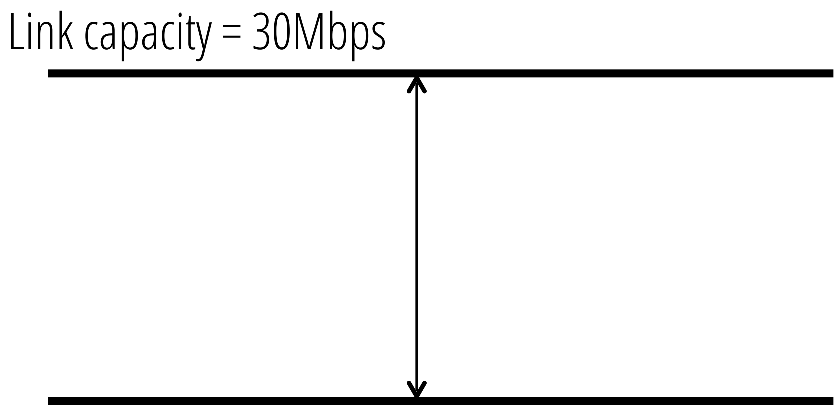


# What happens with reservations?

Allow two flows to reserve peak rate



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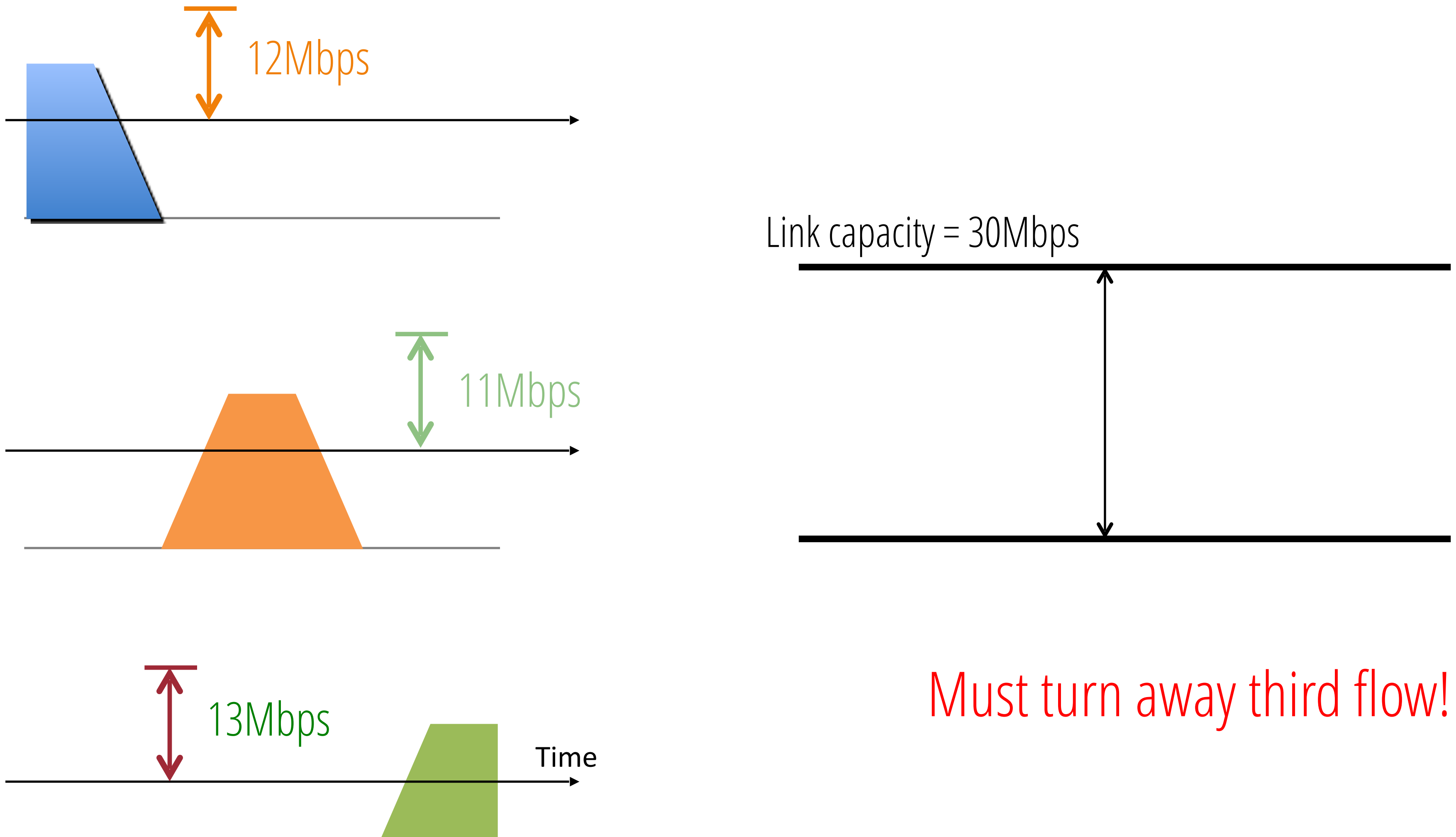


Must turn away third flow!

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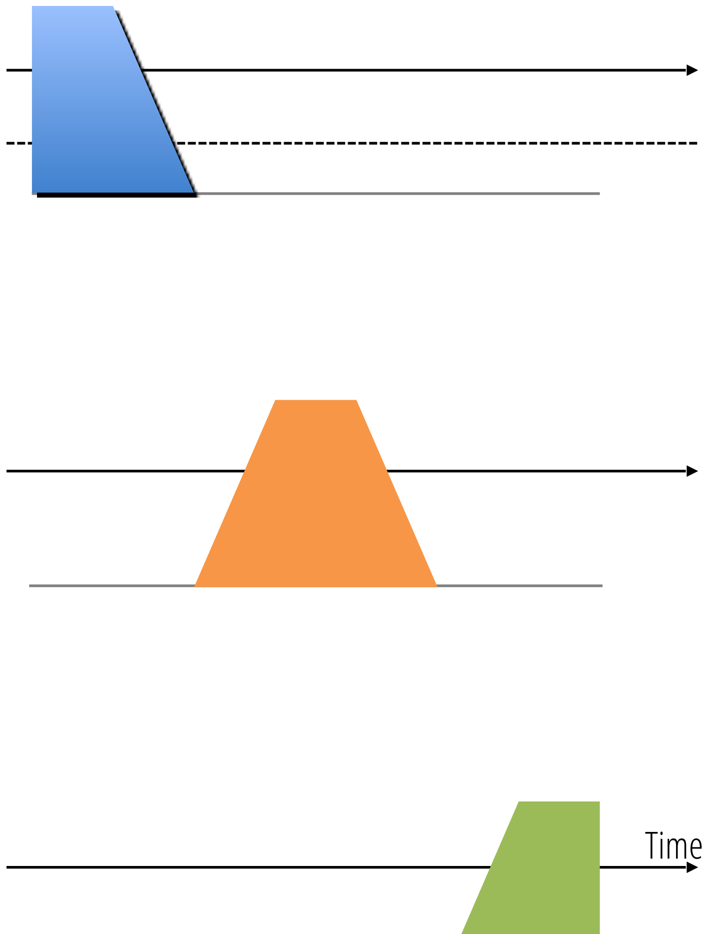


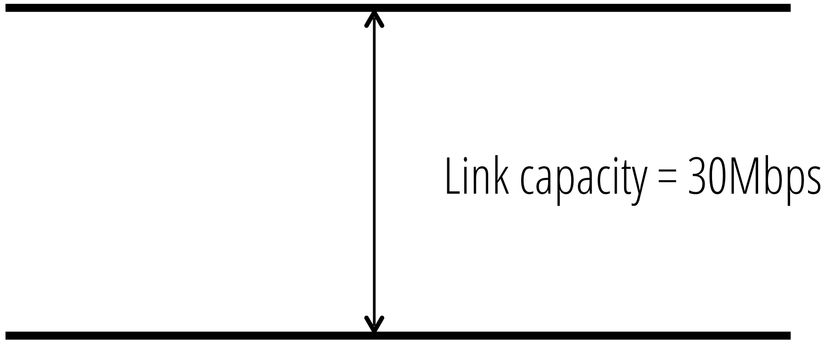

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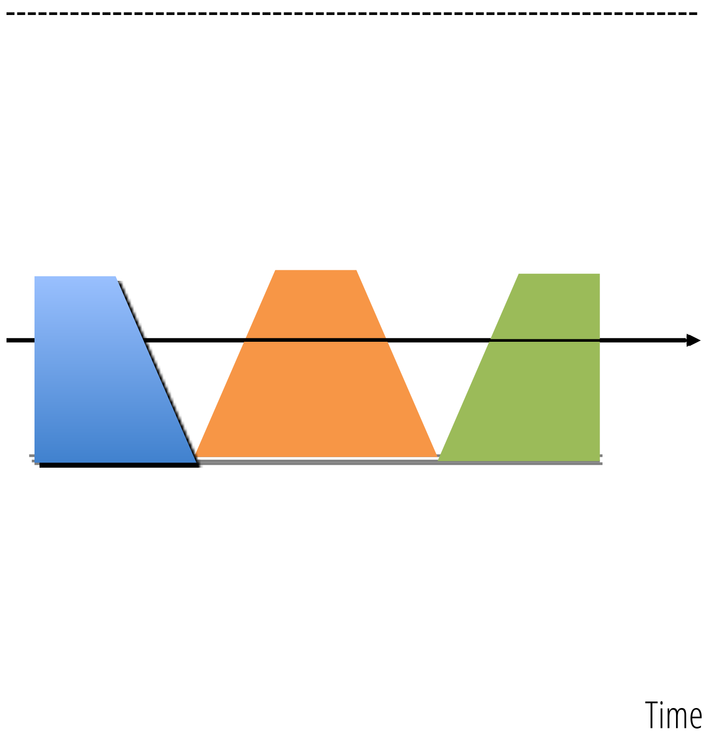


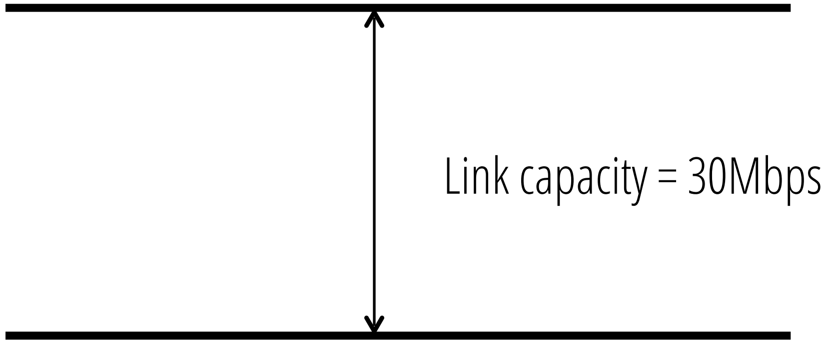

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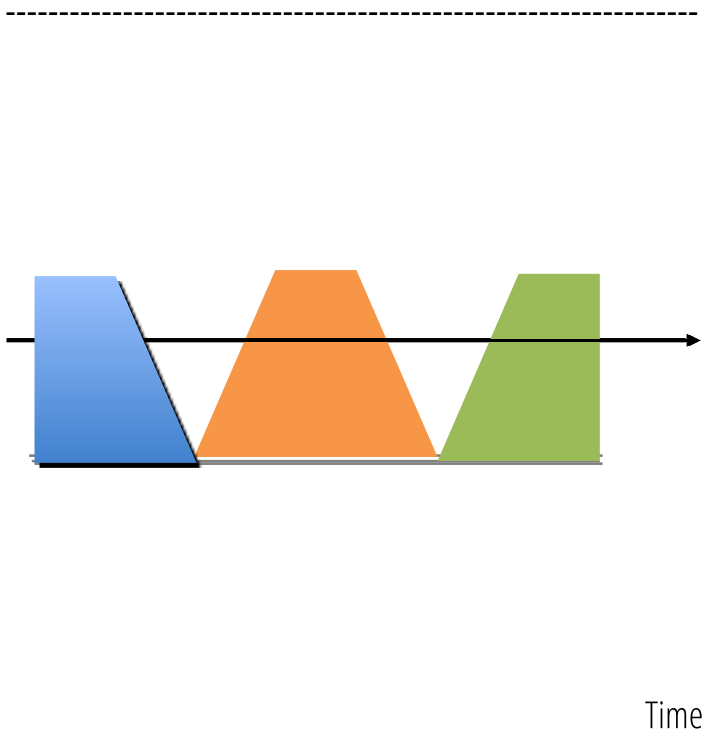
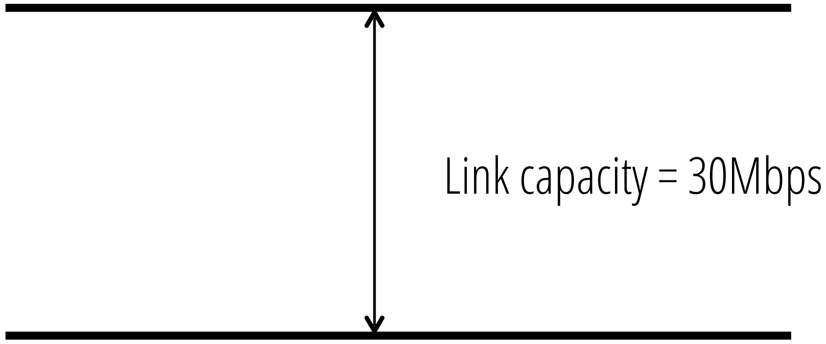
All good! No overloading



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- That's why the phone network used reservations and the Internet does not!

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Answer: Packet switching is typically more efficient

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# Other differences in efficiency?

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- Circuit switching spends some time to setup / teardown circuits
  - Very inefficient when you don’t have much data to send! (short flows)

# Circuit *vs.* Packet switching: which is better?

- What are the dimensions along which we should compare?
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  - Handling failures (at scale)
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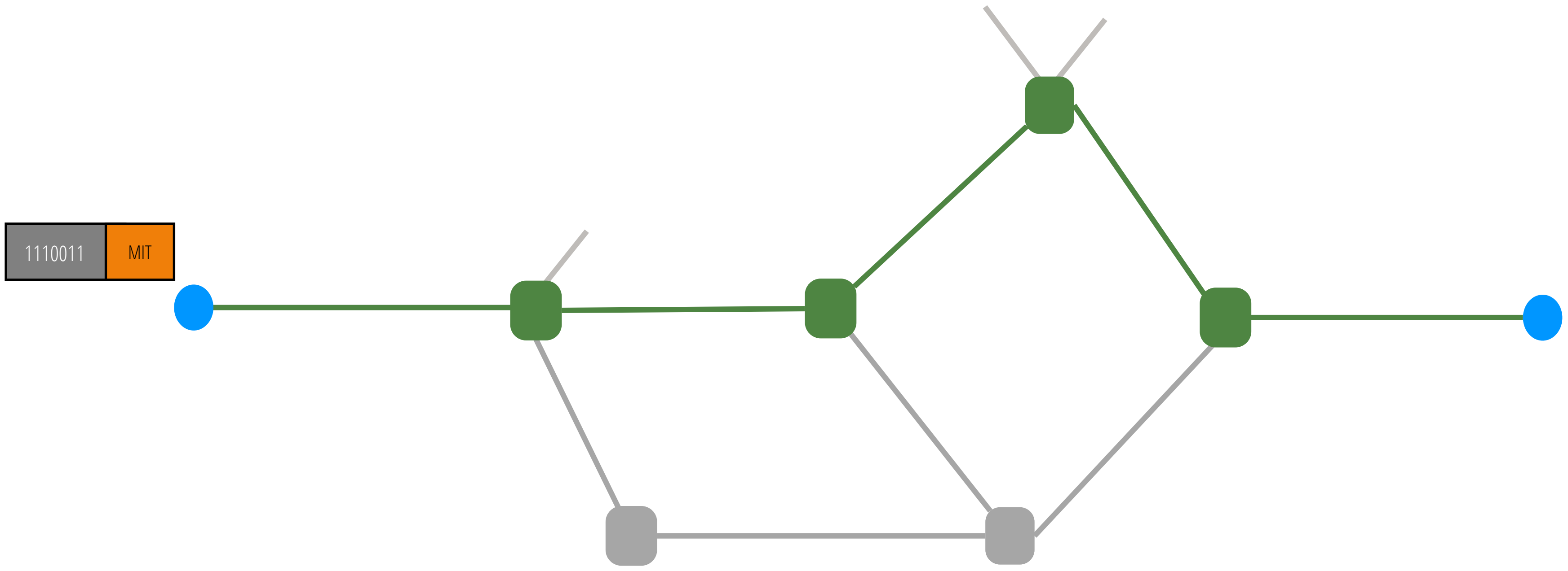

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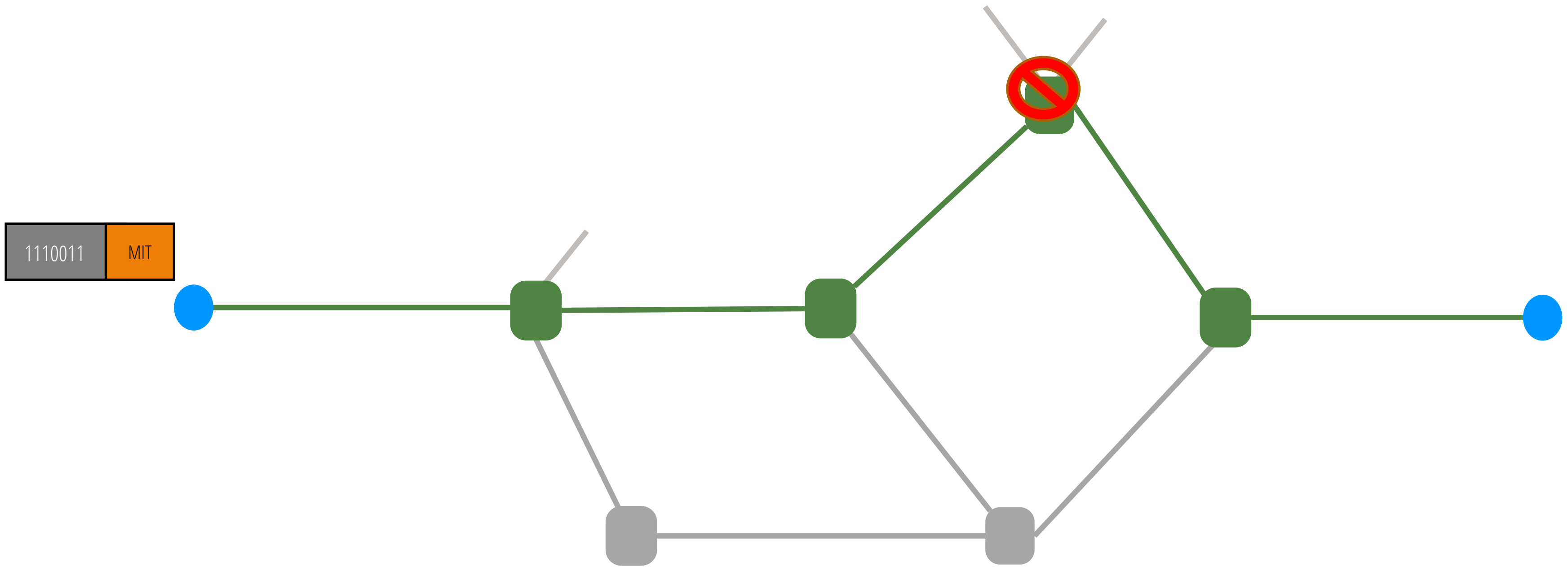

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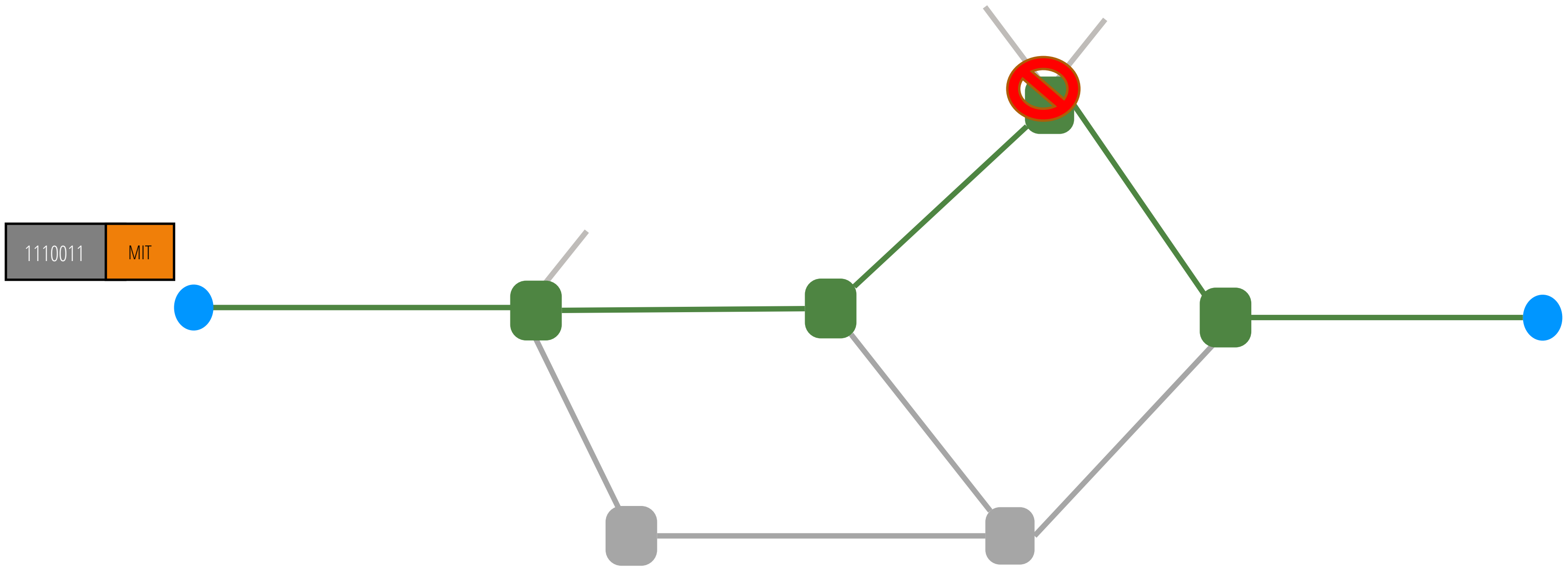


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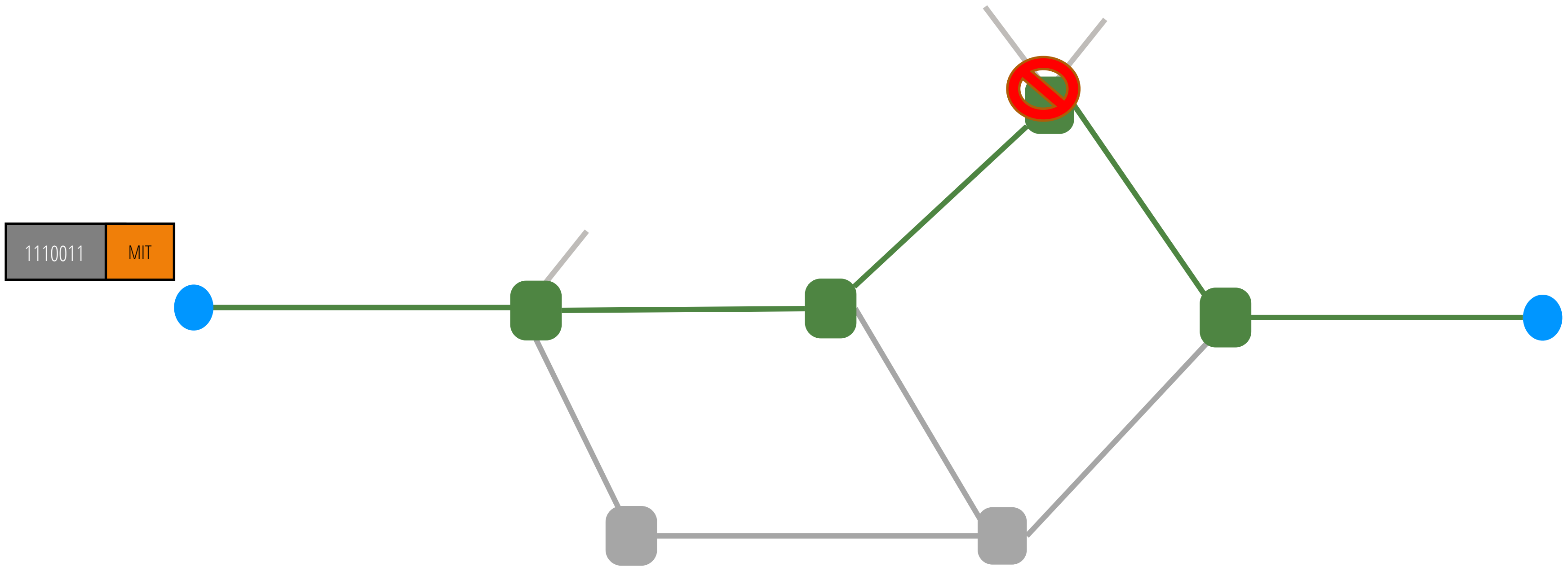


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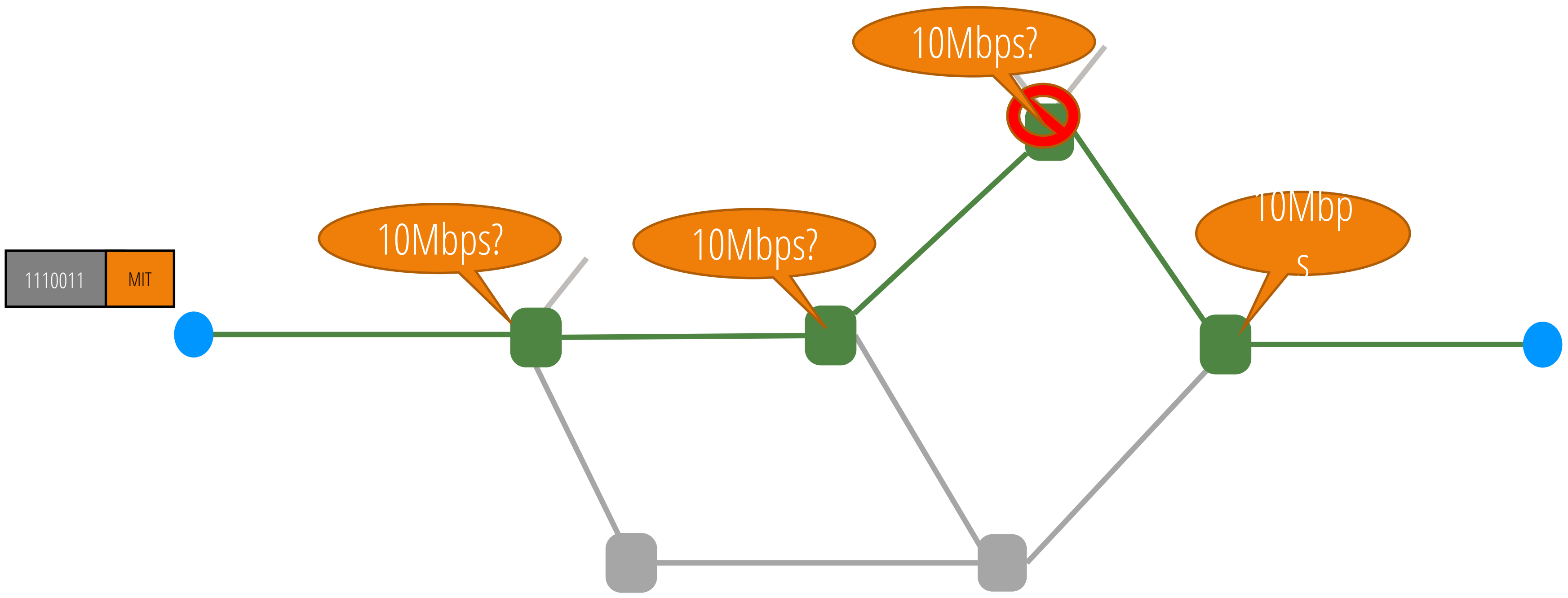


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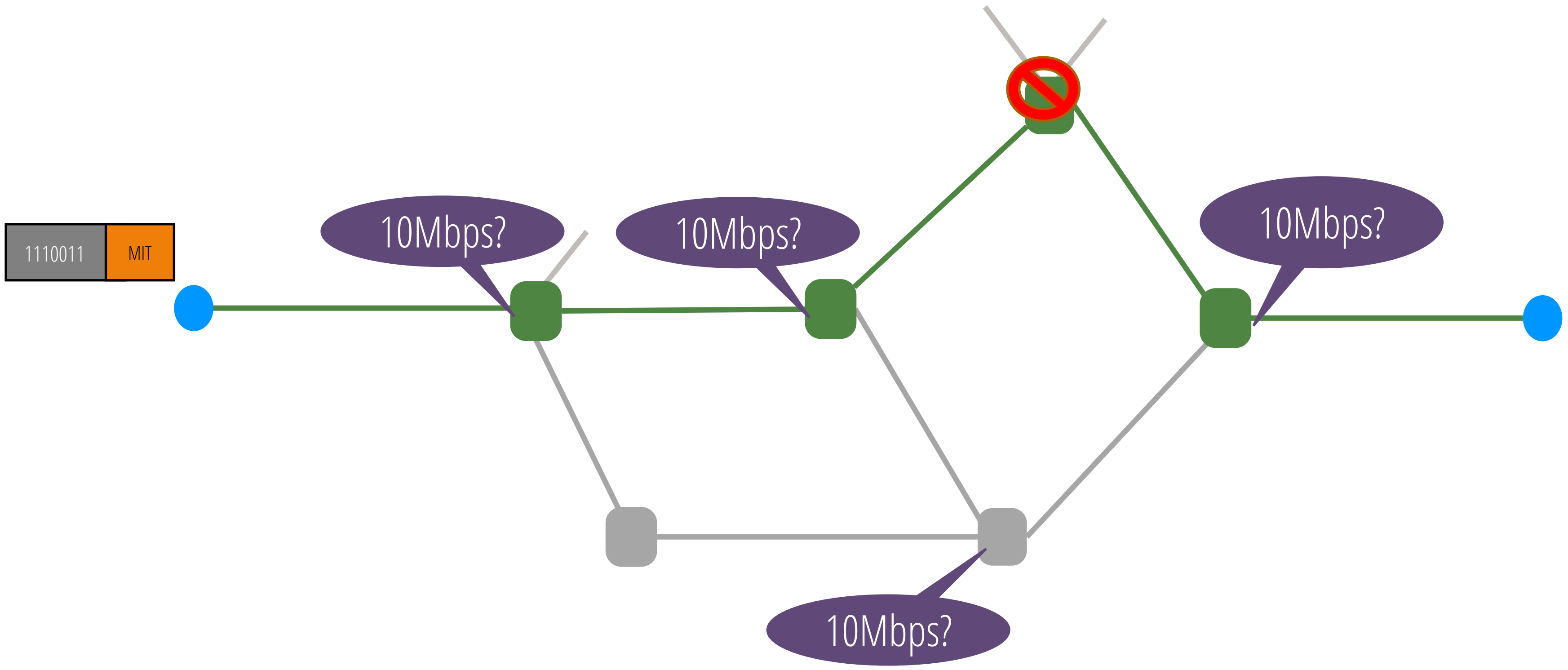


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- Link goes down, then what?
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  - (Job of the routing control plane)
- Endhosts and individual flows do nothing special
  - Except cope with the temporary loss of service

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- All impacted endhosts must do this, for each impacted flow
- If millions of flows were going through a switch, then millions of reservation requests are being simultaneously re-established!

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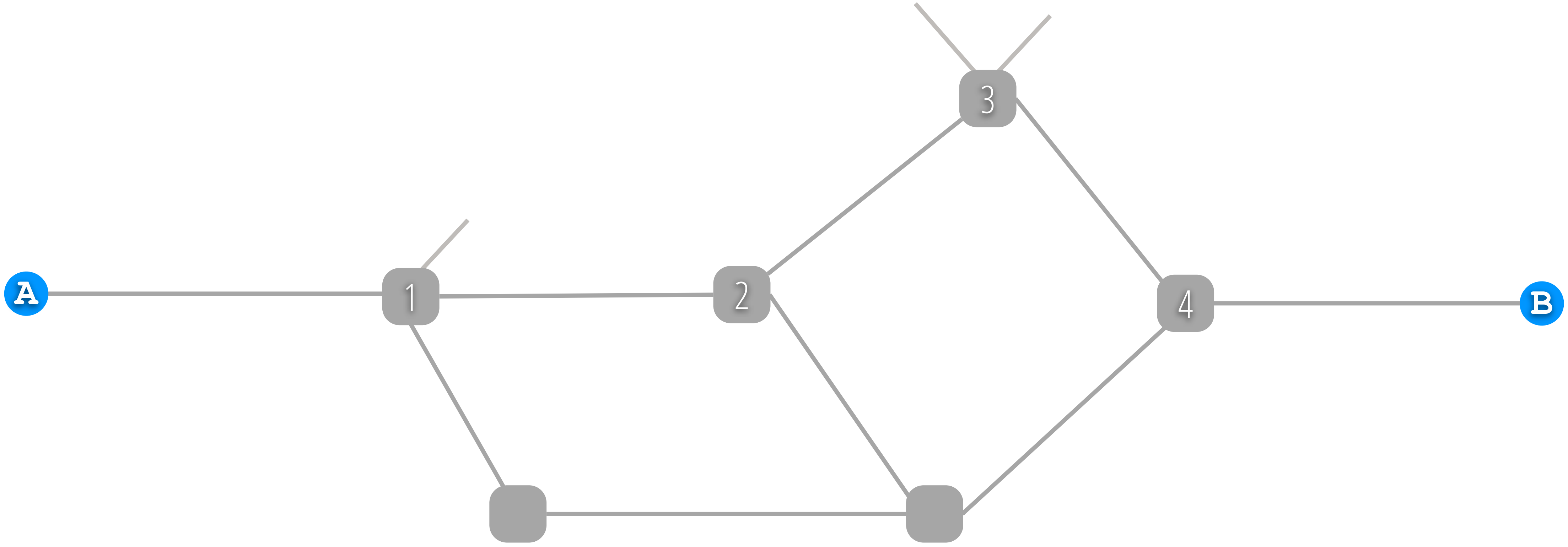

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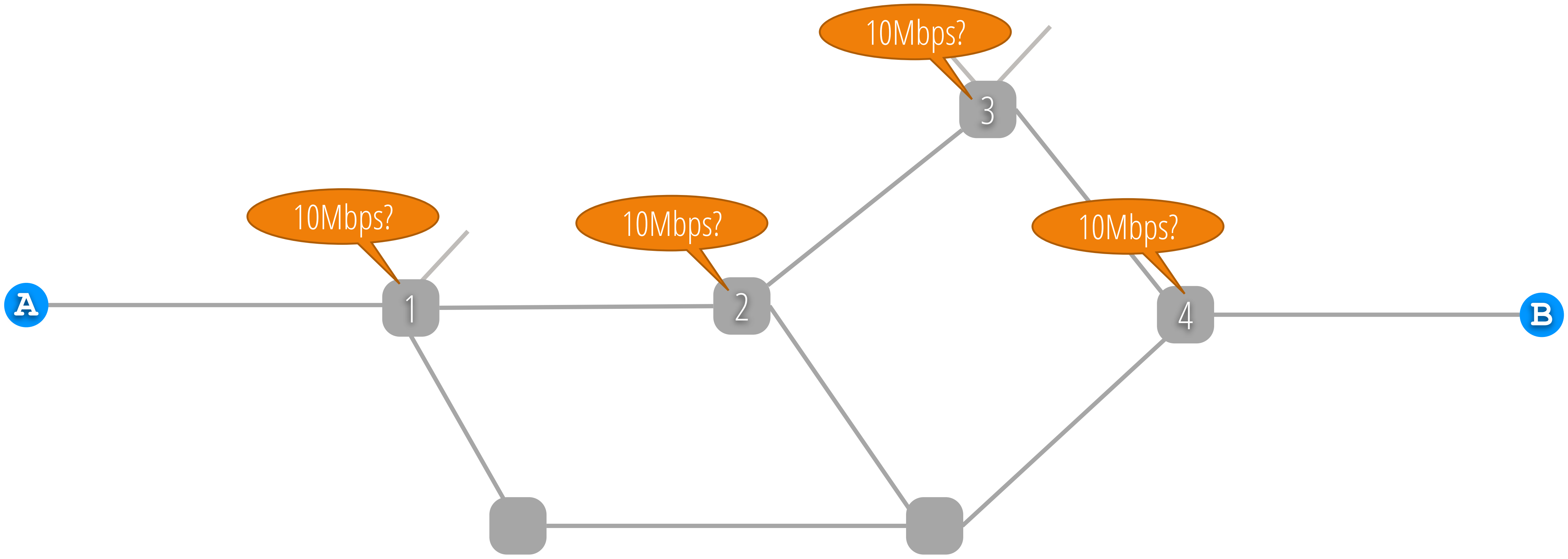

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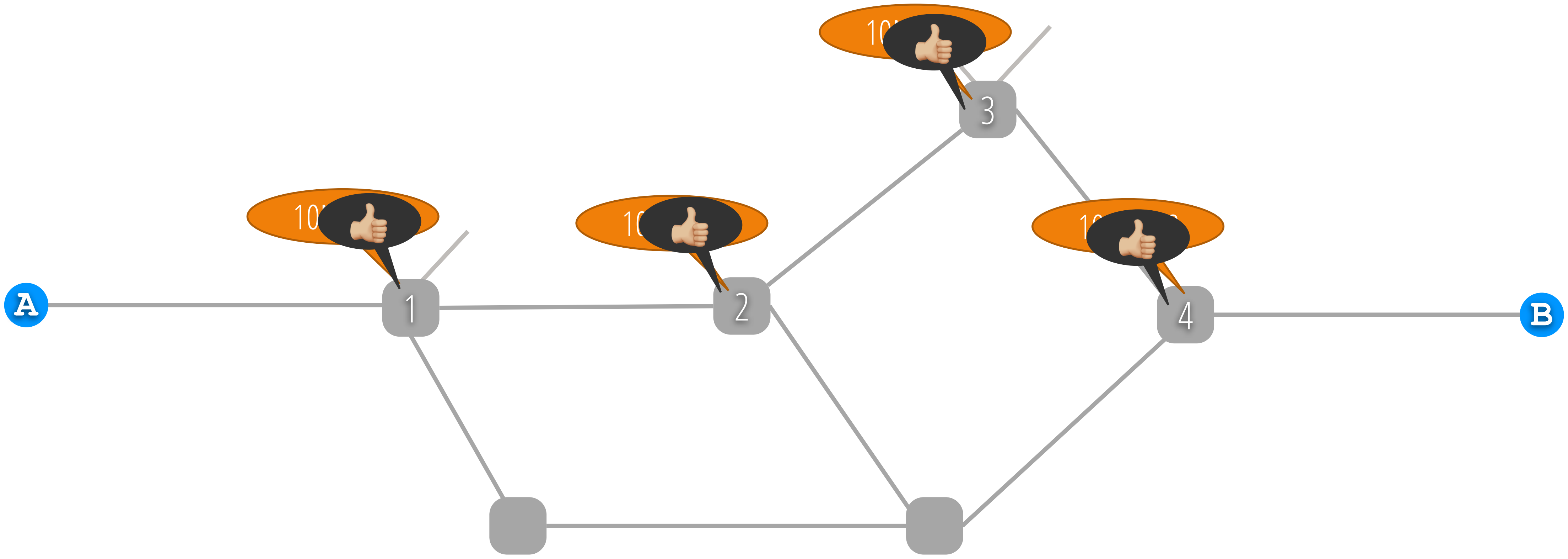

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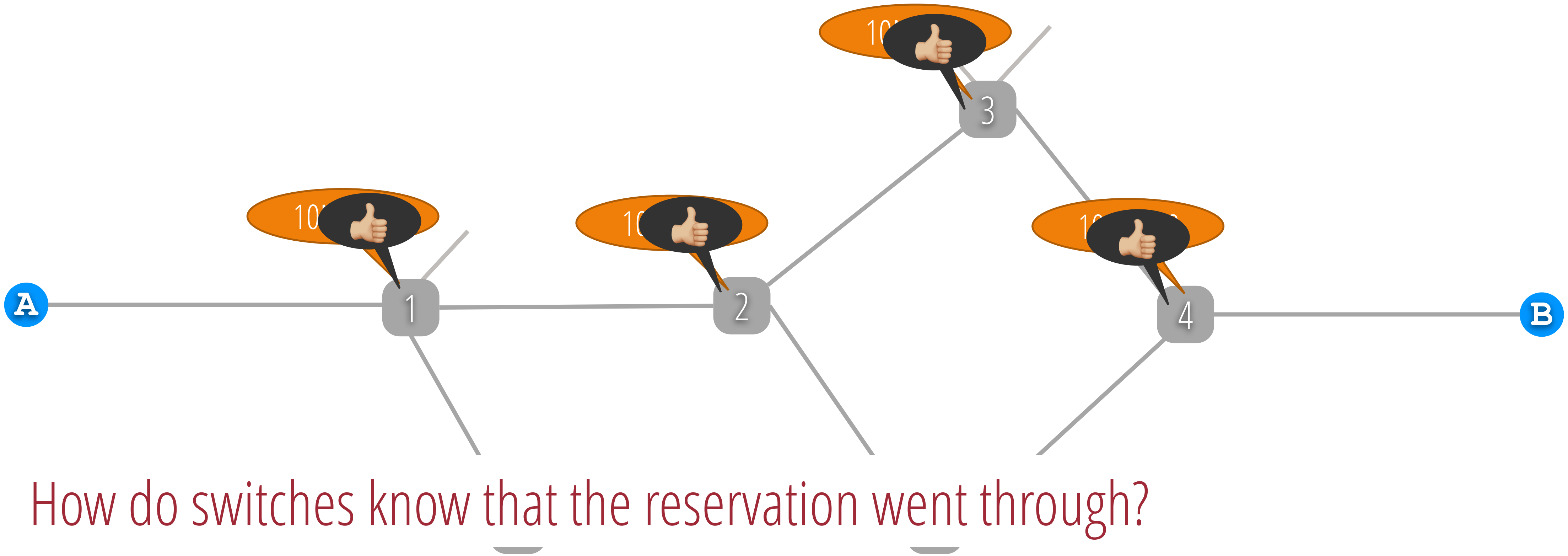


How do switches know that the reservation went through?

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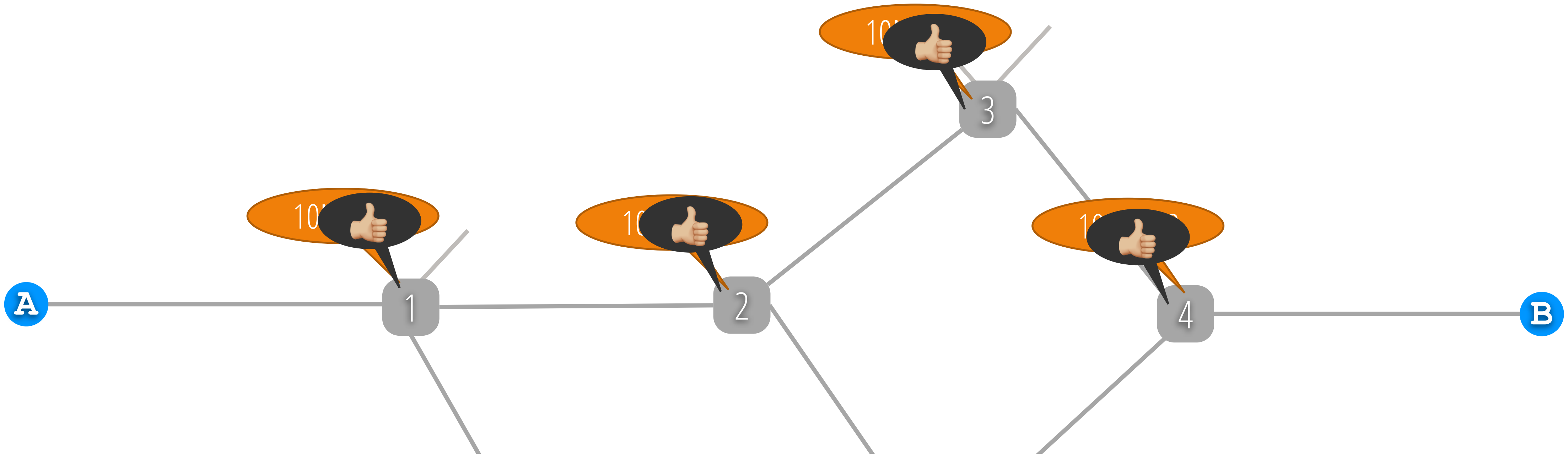


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What happens if the reservation request is lost mid way?

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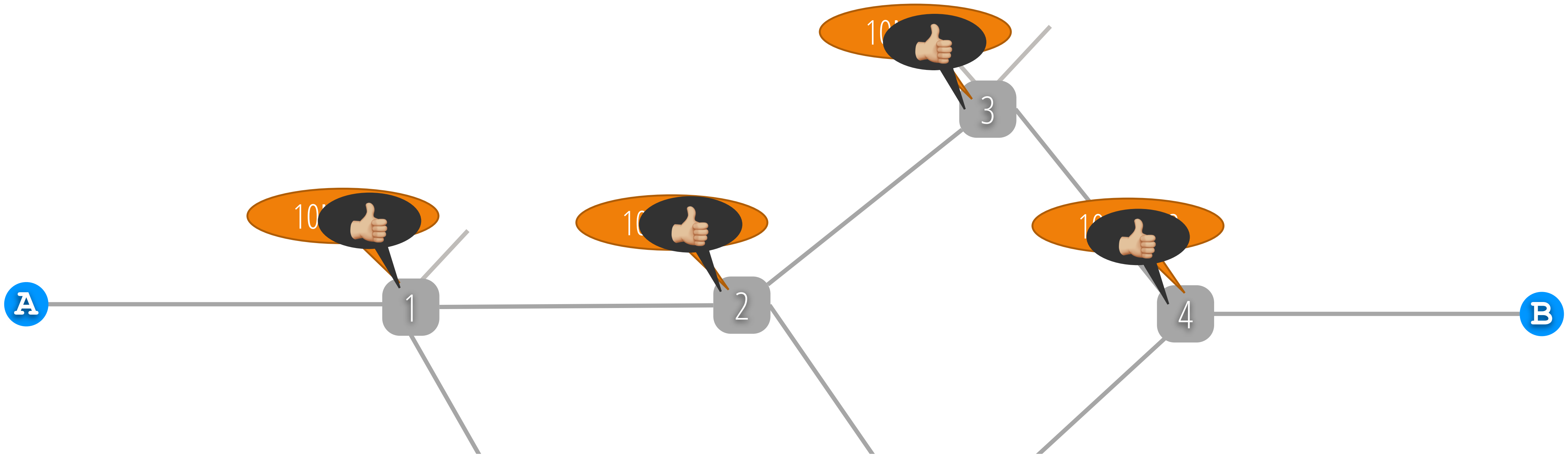


What happens if the confirmation that the reservation made it is lost?

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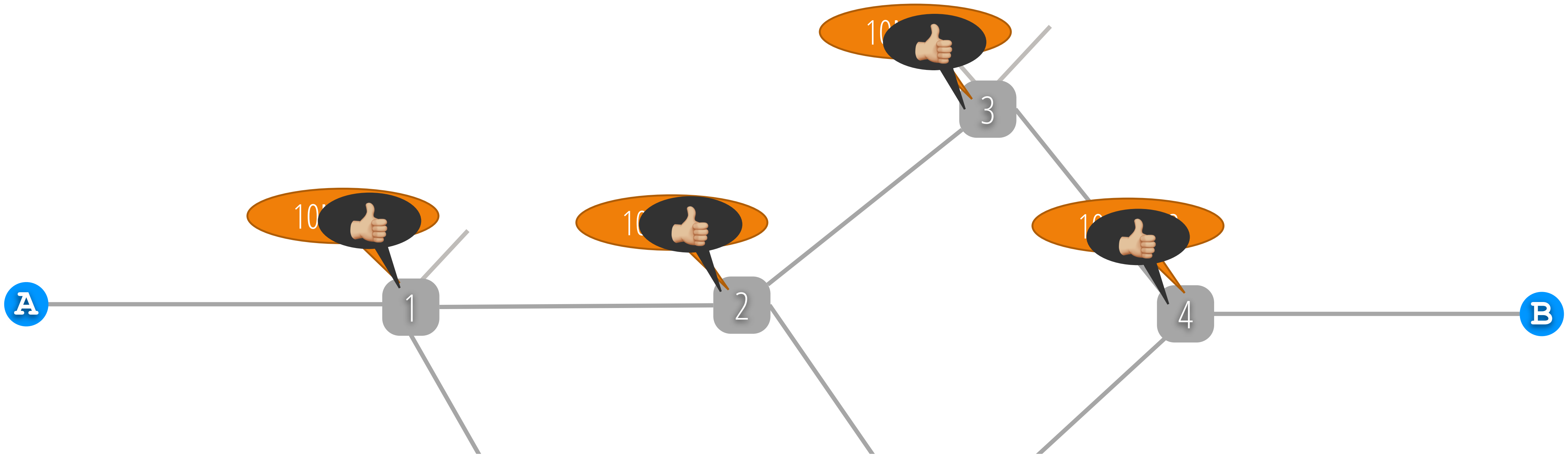


What should the endhost do if the reservation is declined?

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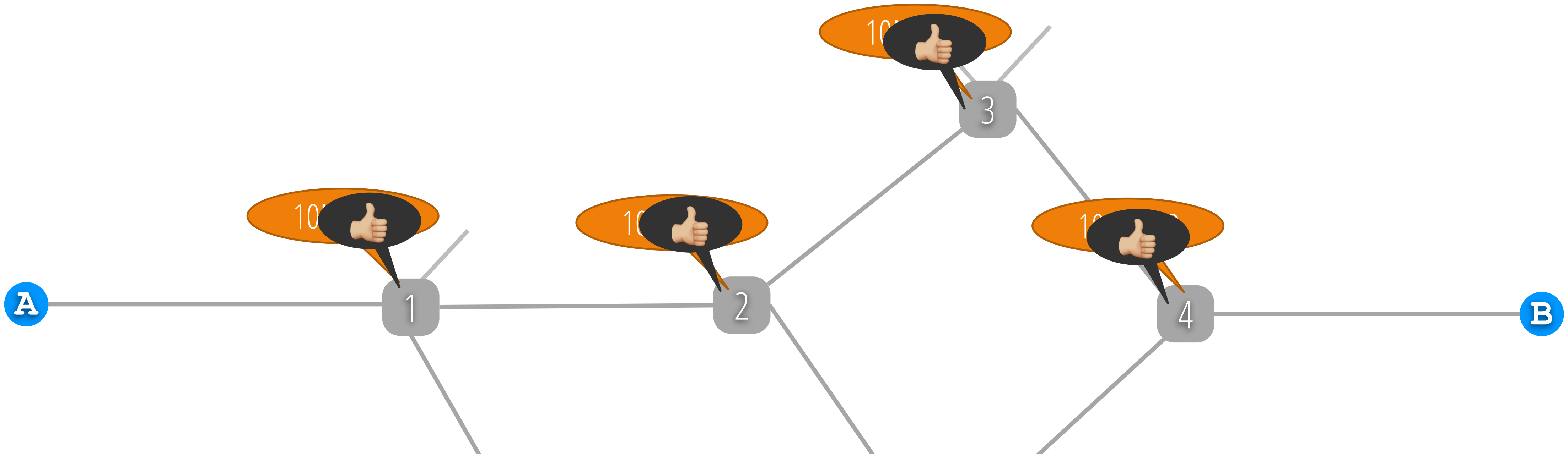


What happens if the underlying route changes?

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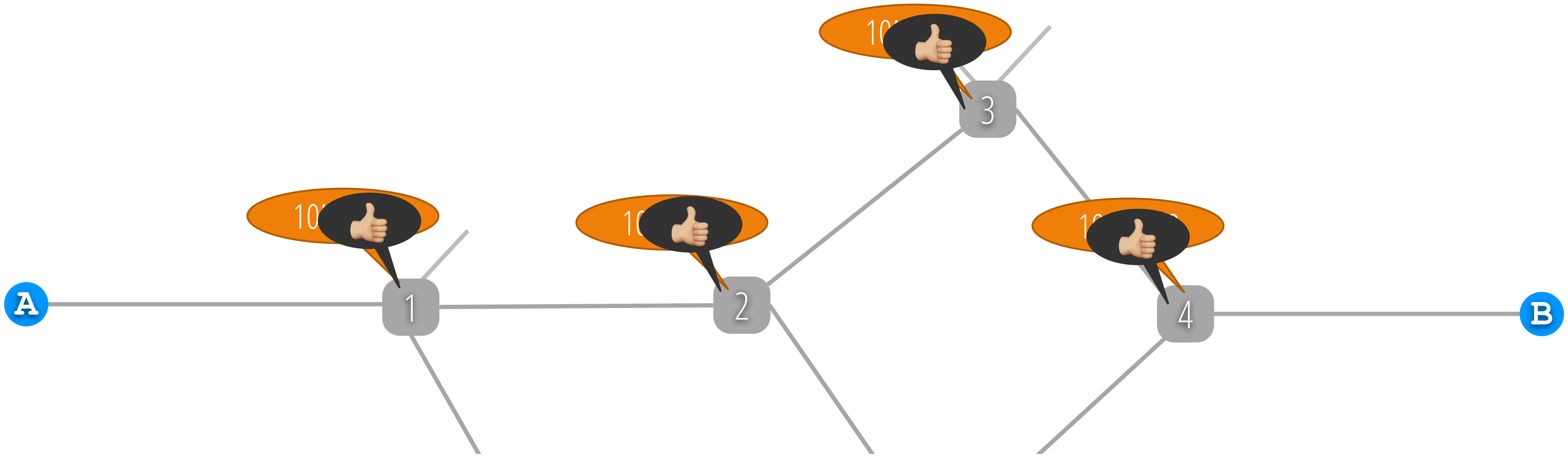


And on and on....

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- Pros for packet switching:
  - Better efficiency
  - Faster startup to first packet delivered
  - Easier recovery from failure
  - Simpler implementation (avoids dynamic per-flow state management in switches)

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  - So, a far cry from the vision of dynamic reservations that we just discussed

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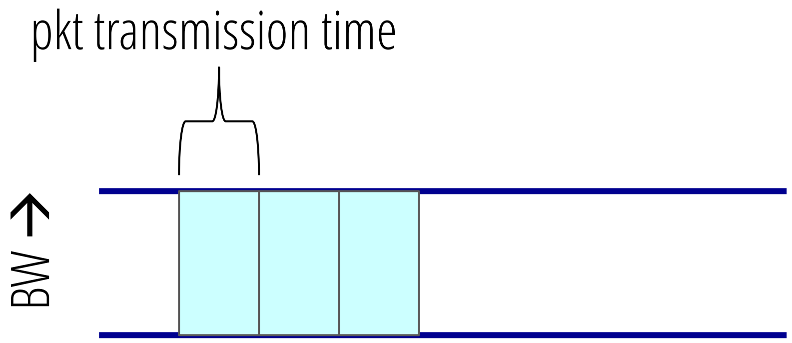
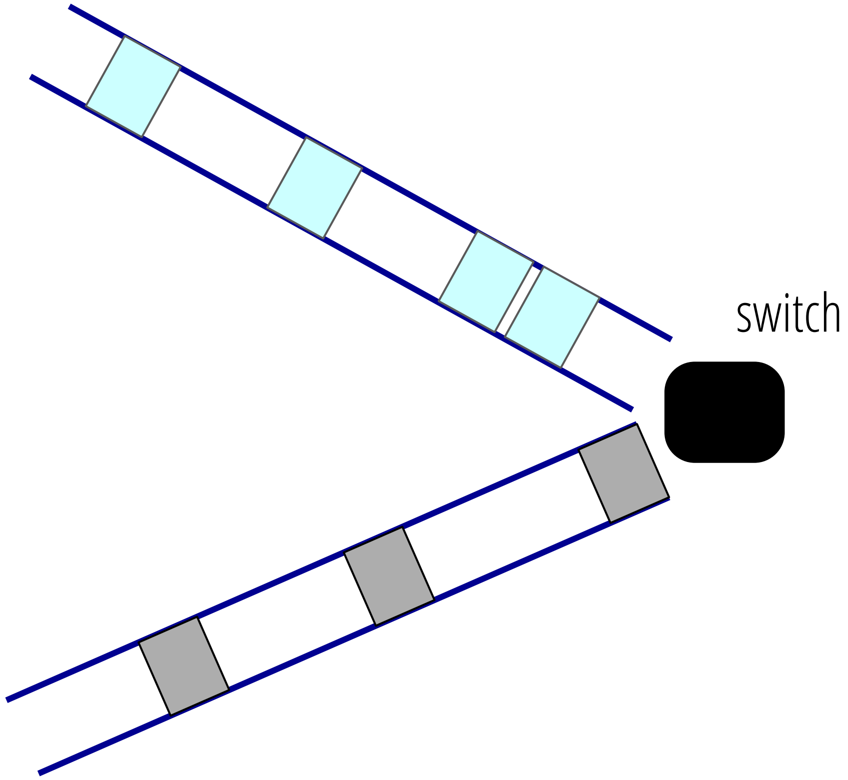
*A lesson in how technology can transform user behavior!*

Let's take a closer look at packet switching ....

# Recall, packets in flight: “pipe” view

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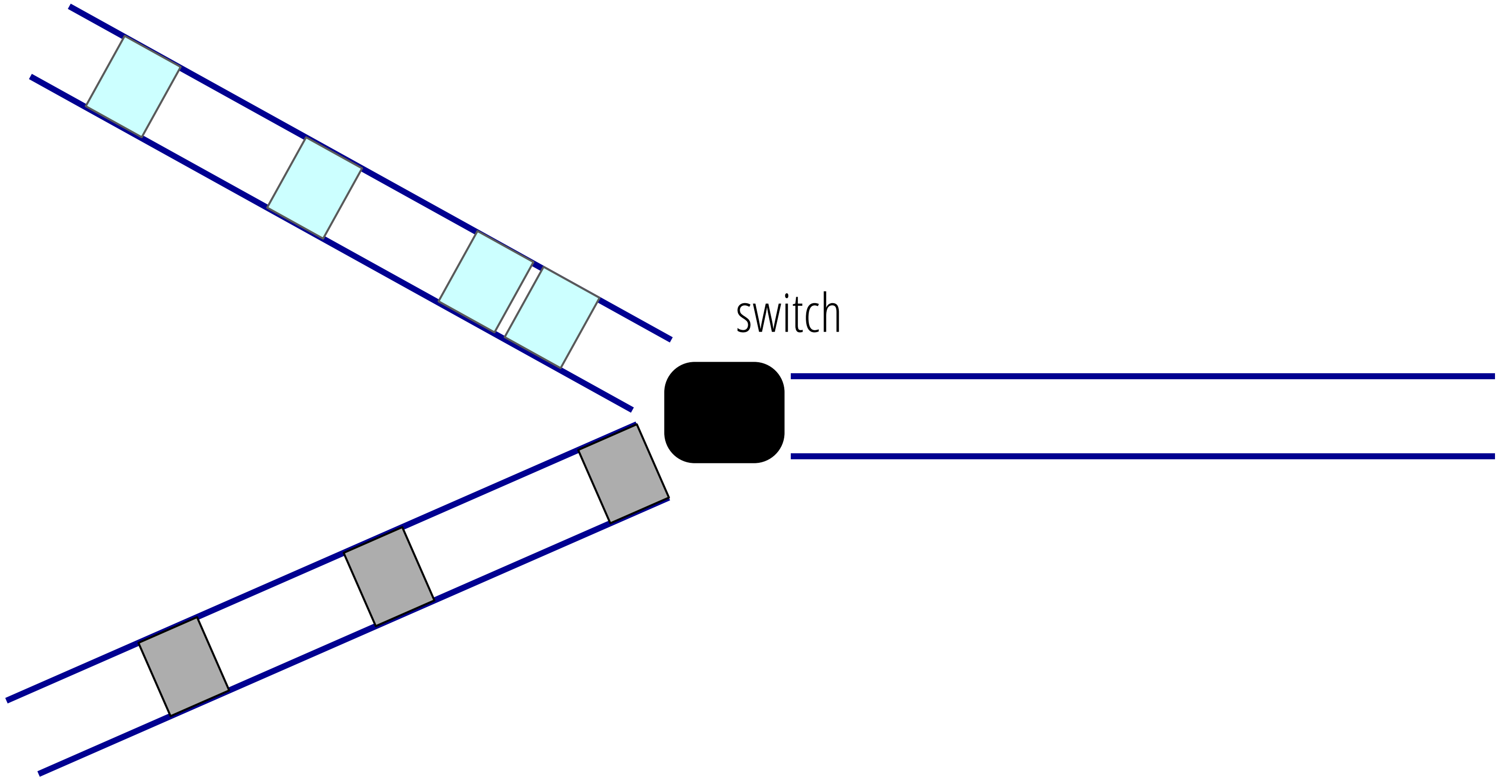
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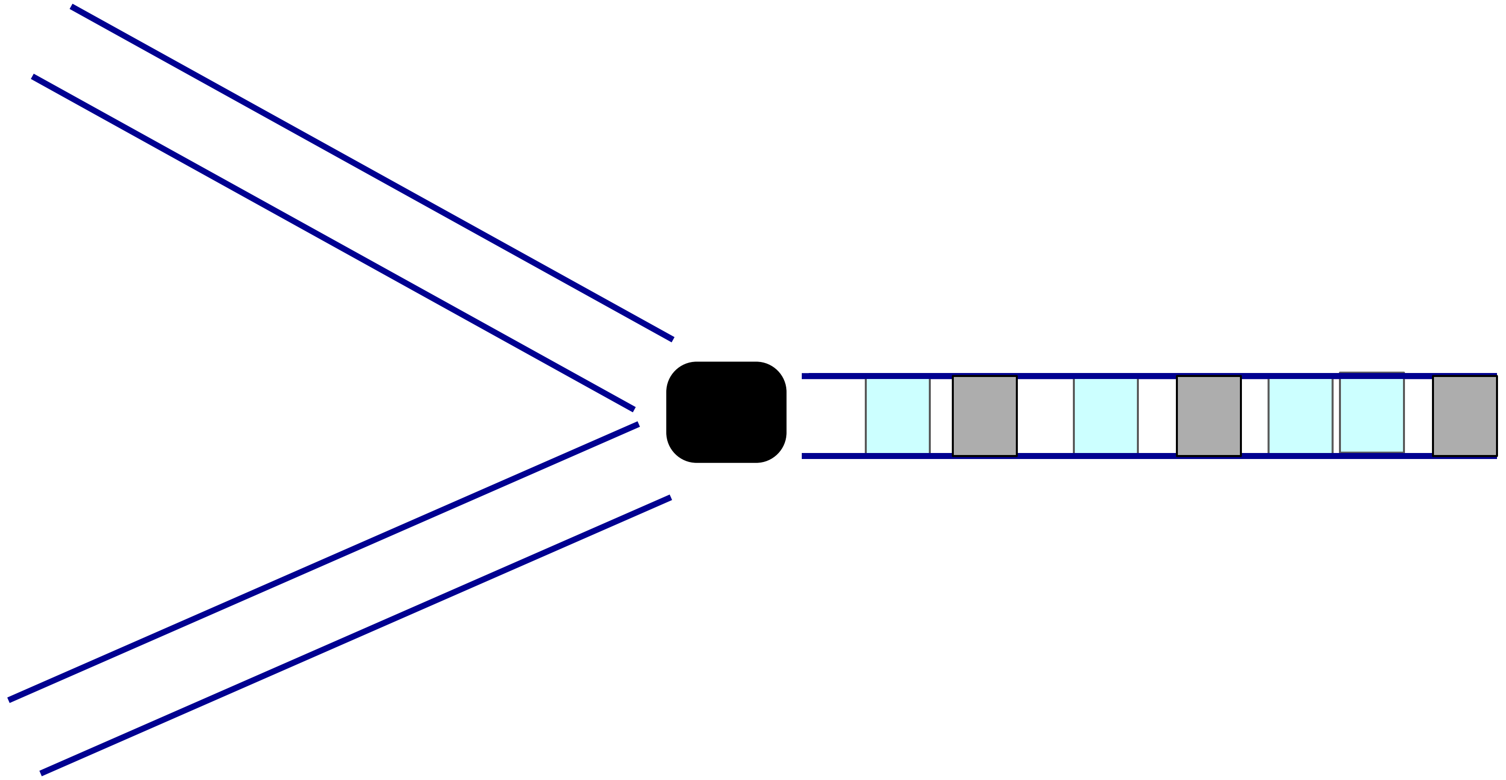
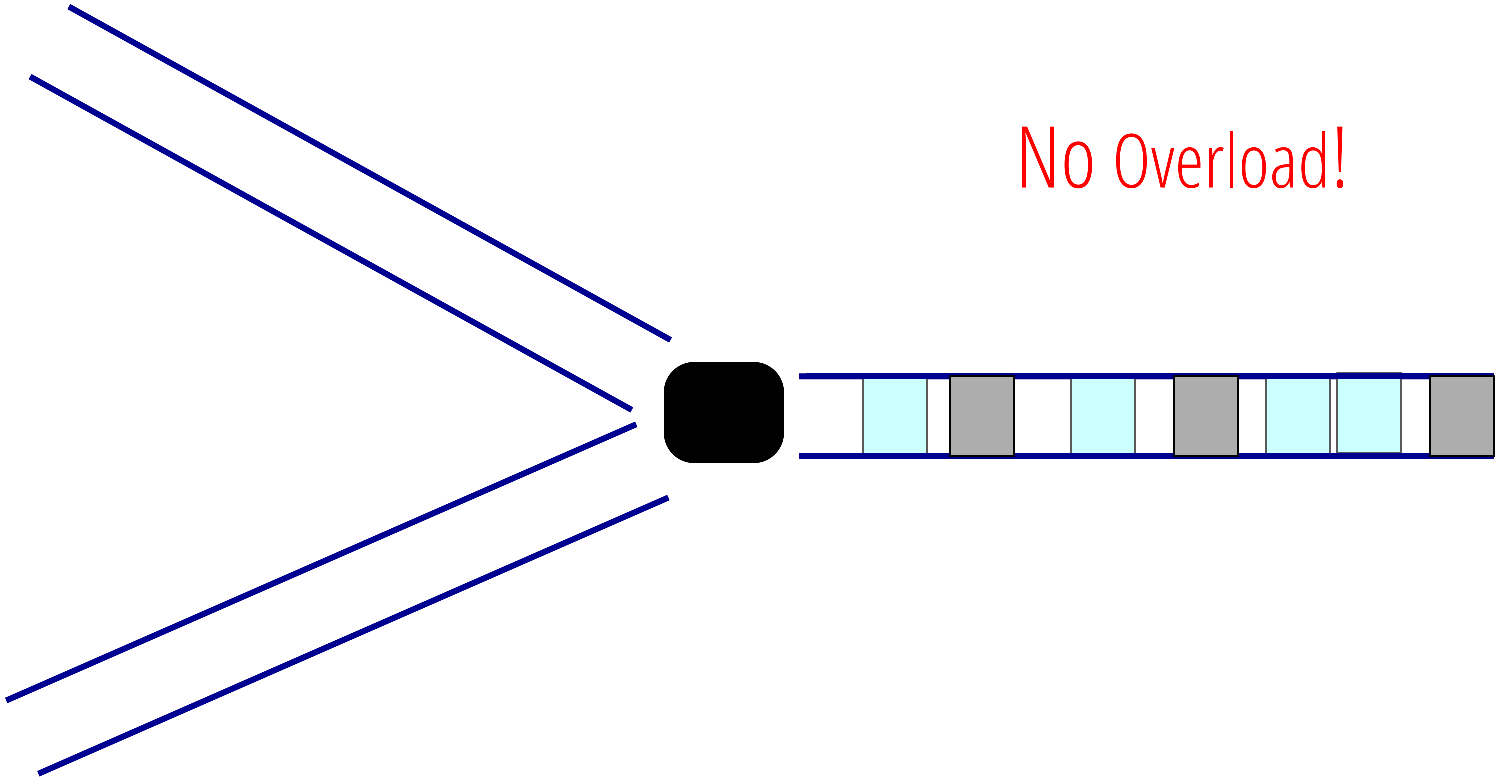
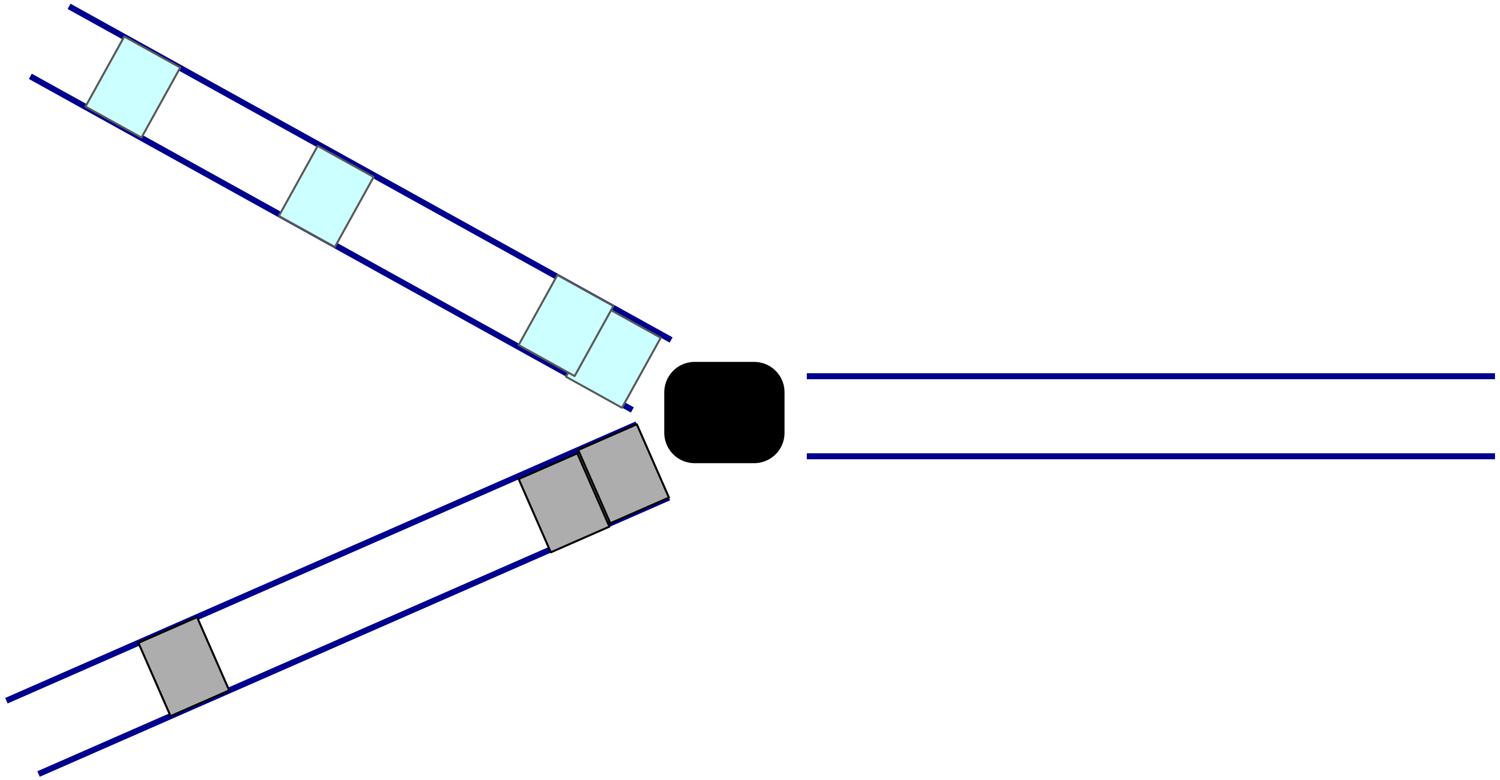
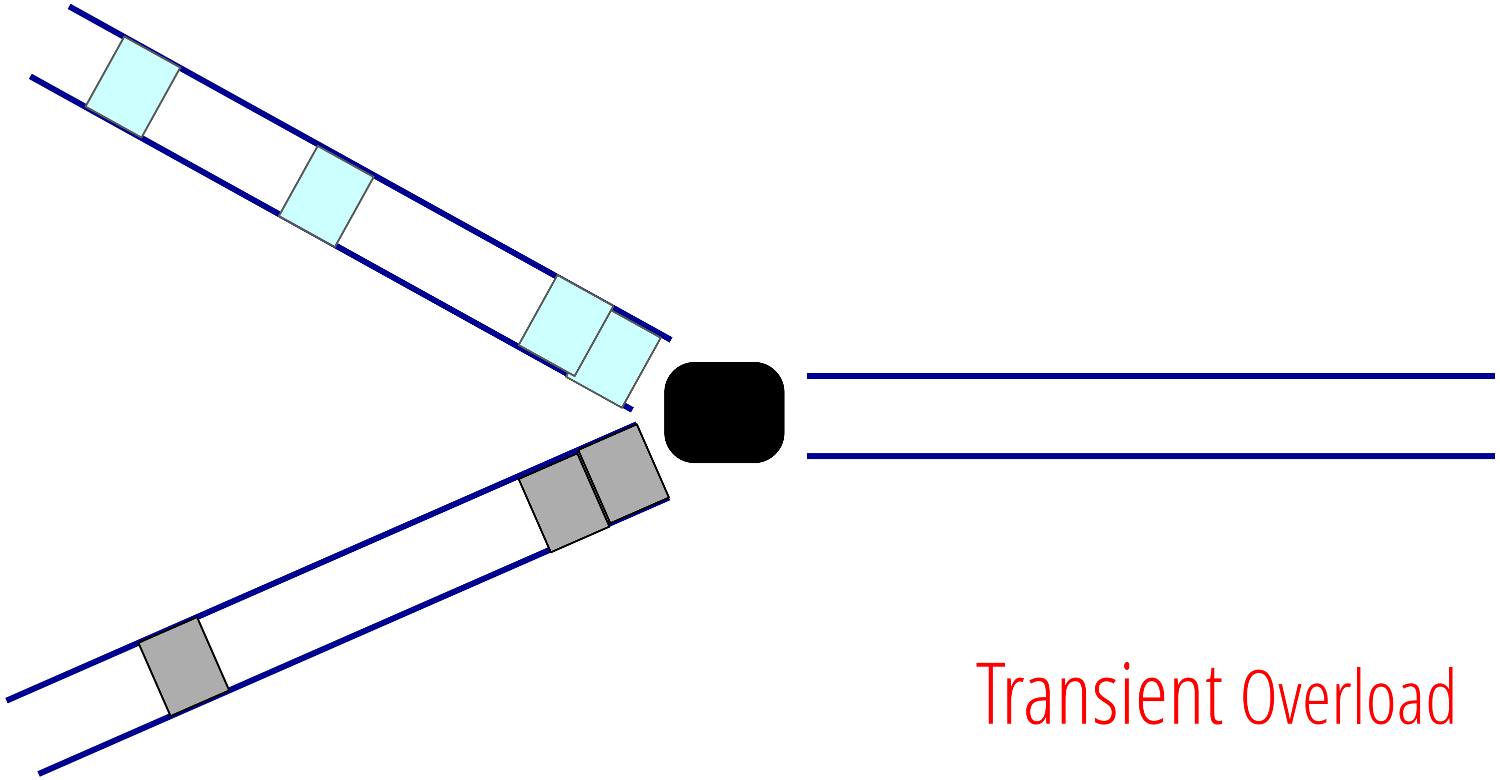
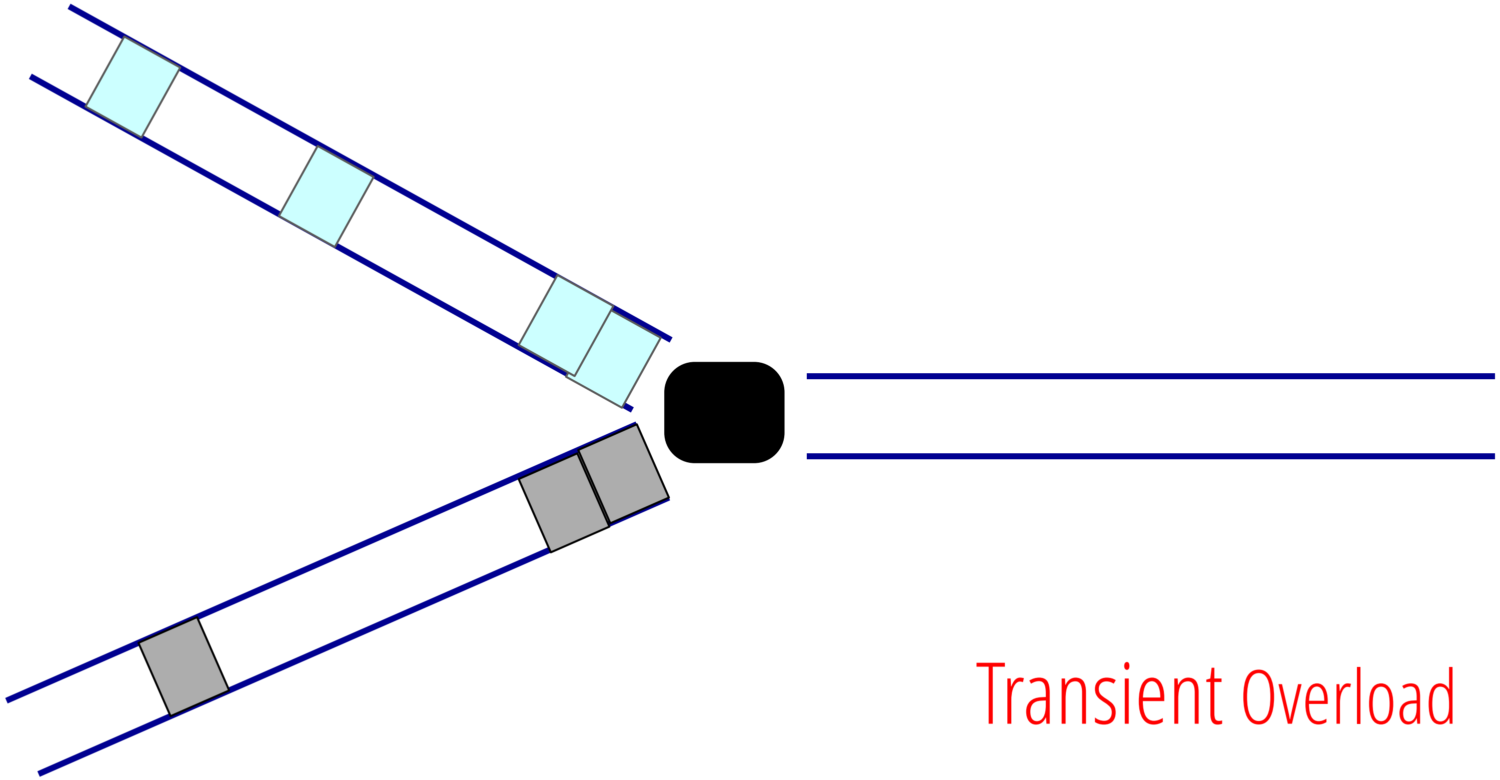



No Overload!



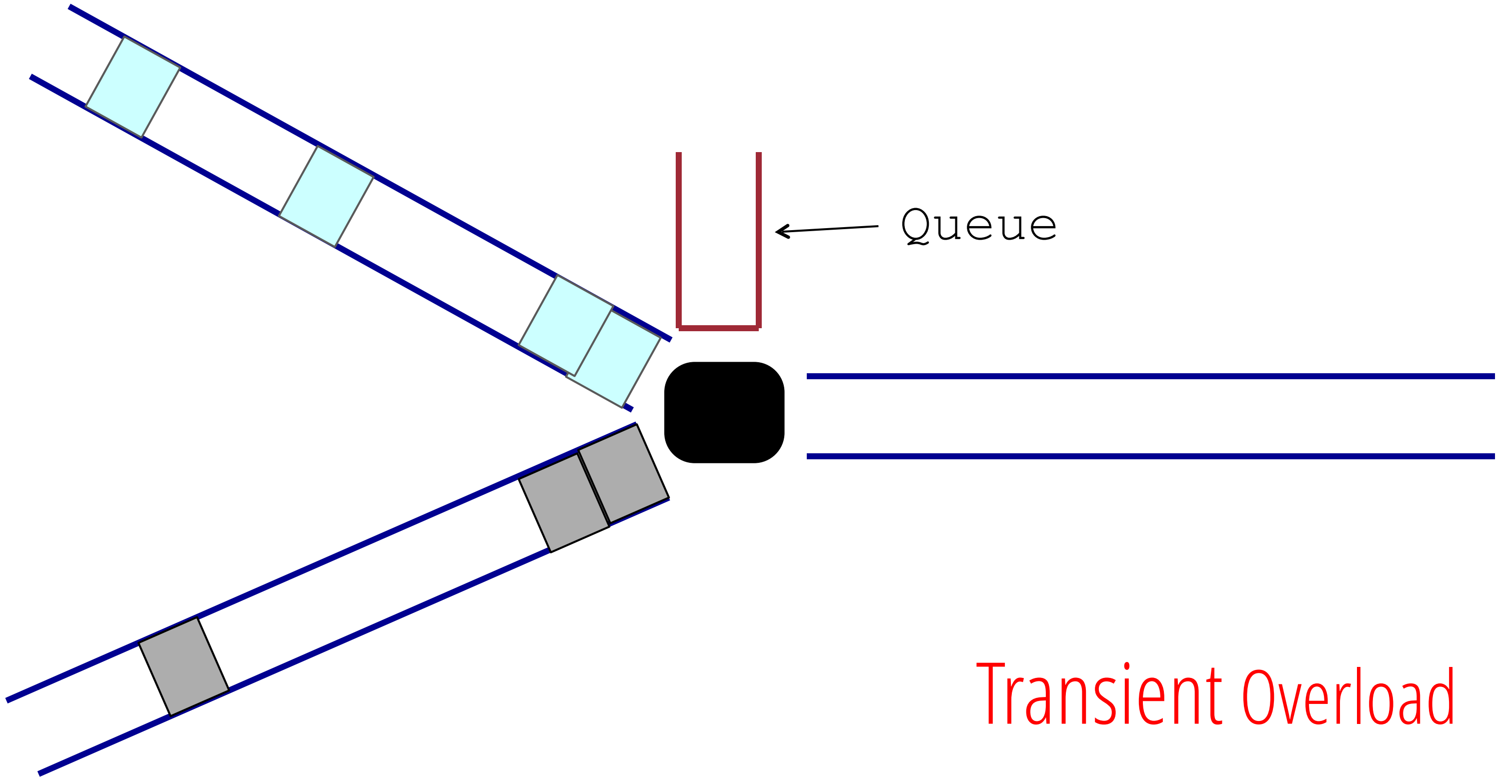


Transient Overload



Transient Overload

Not a rare event!

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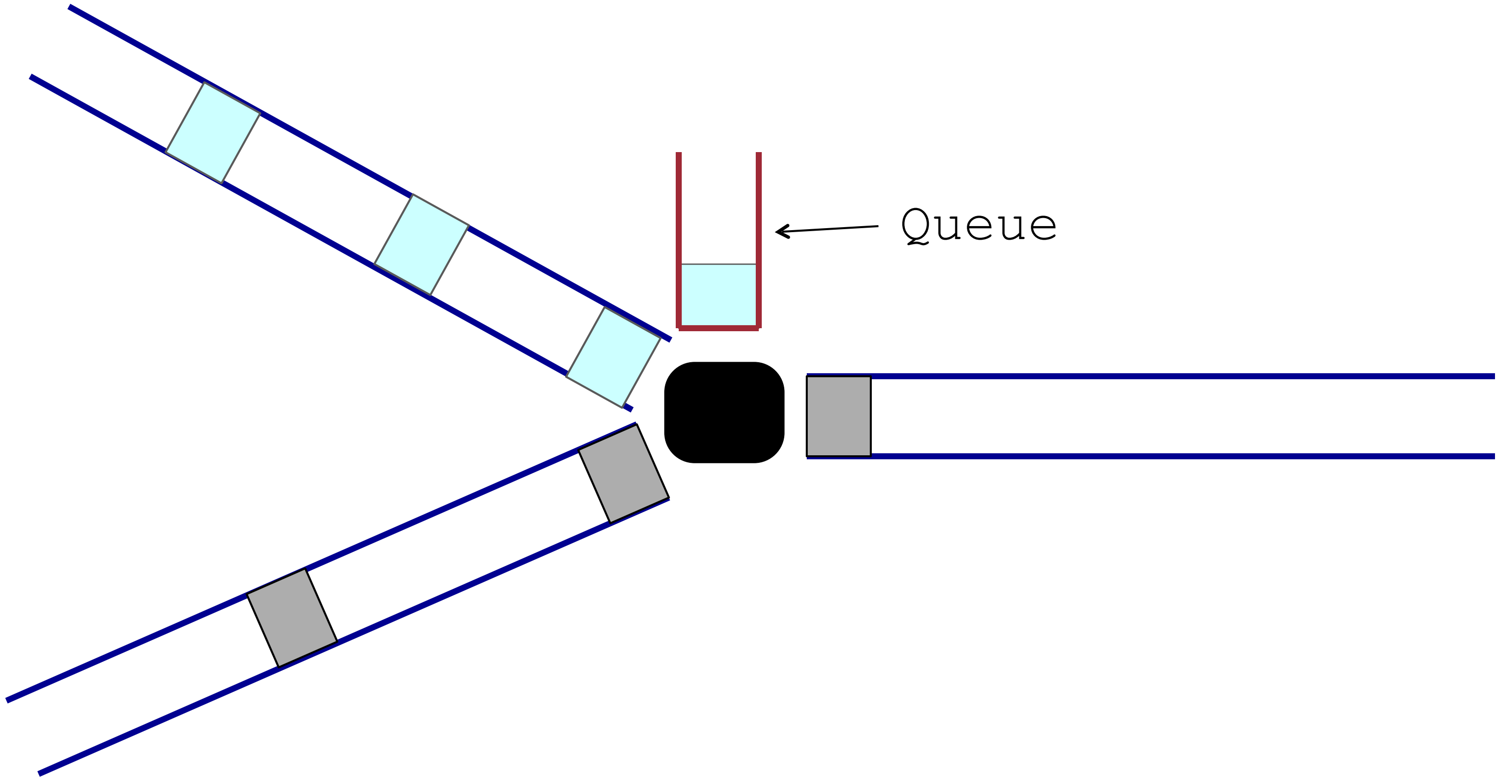
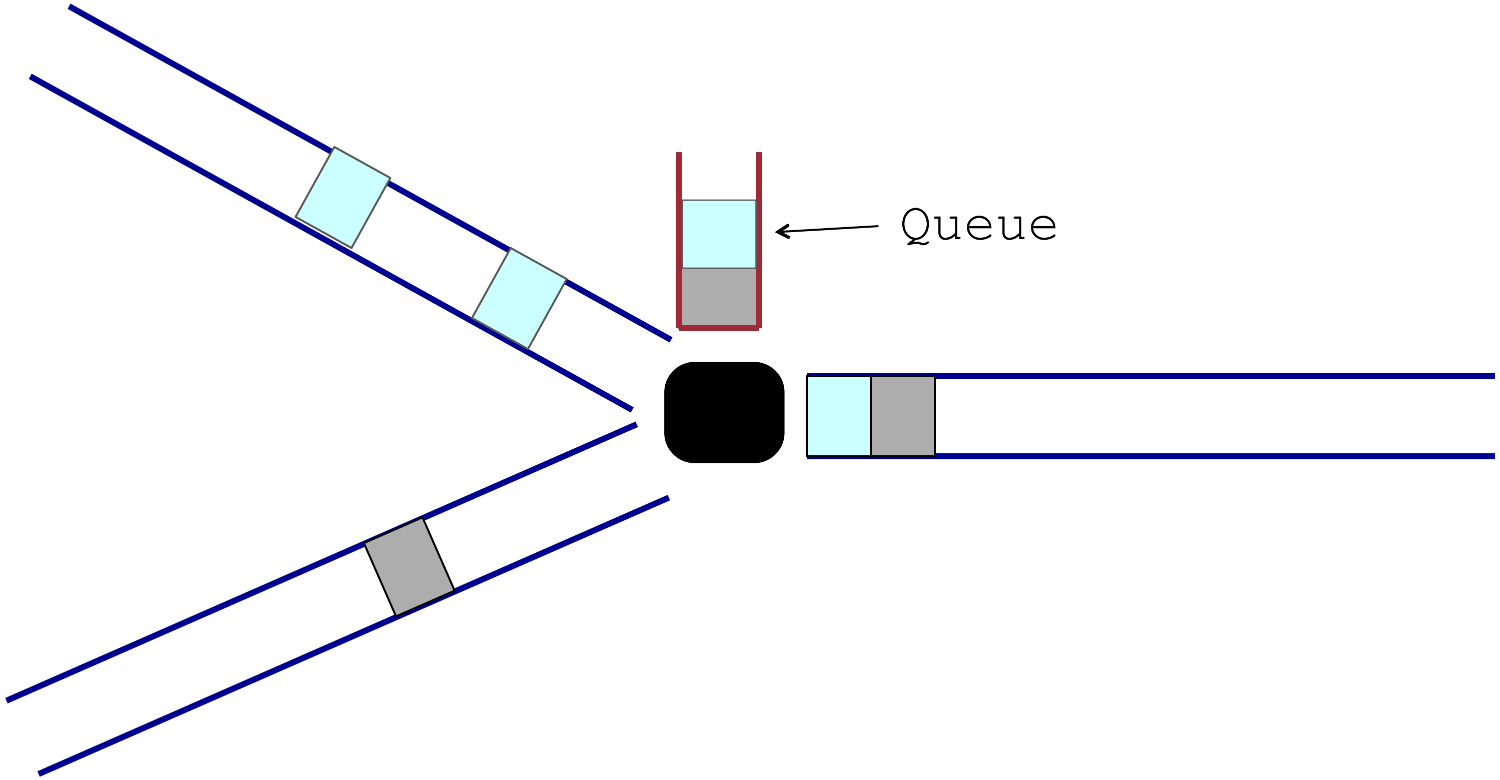

Queue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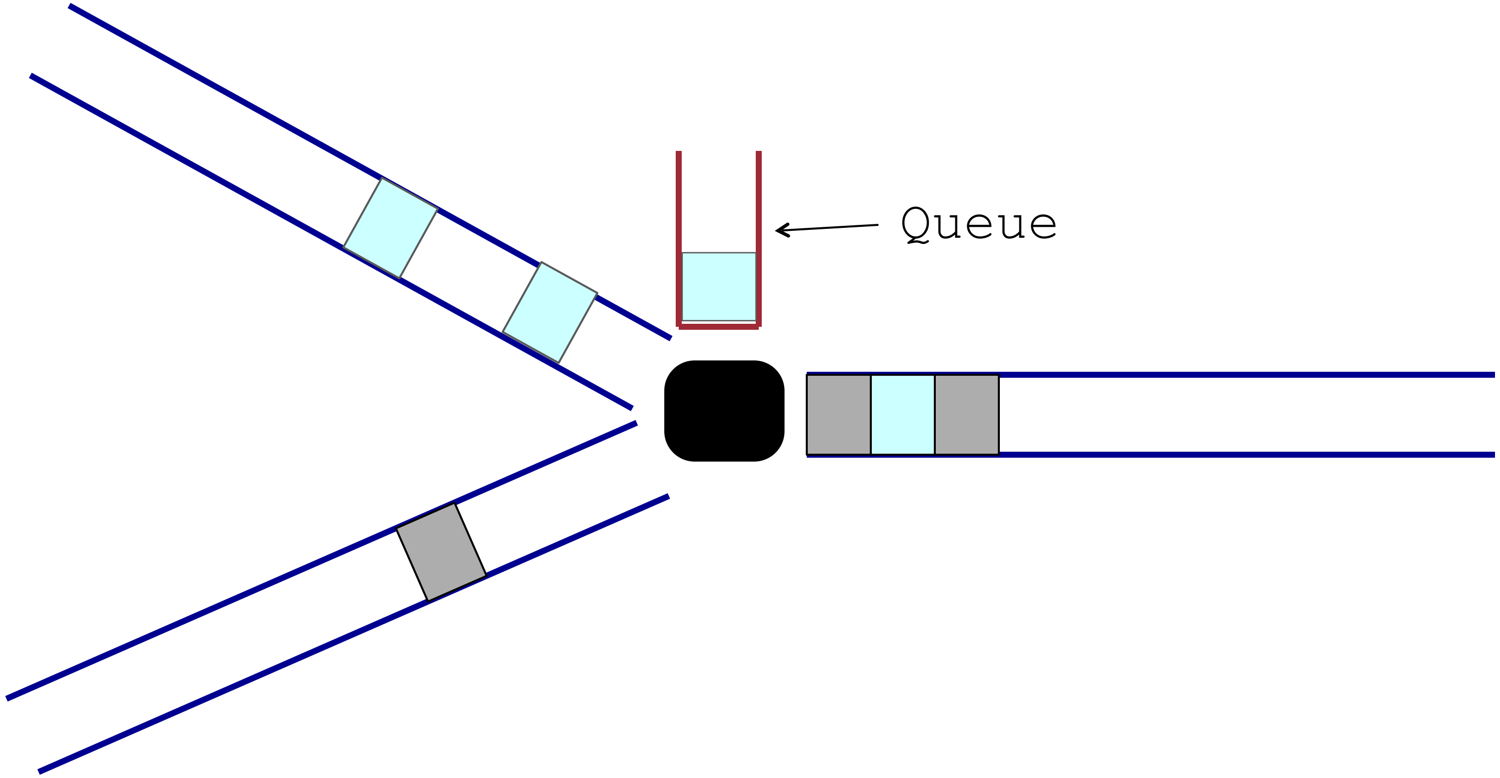
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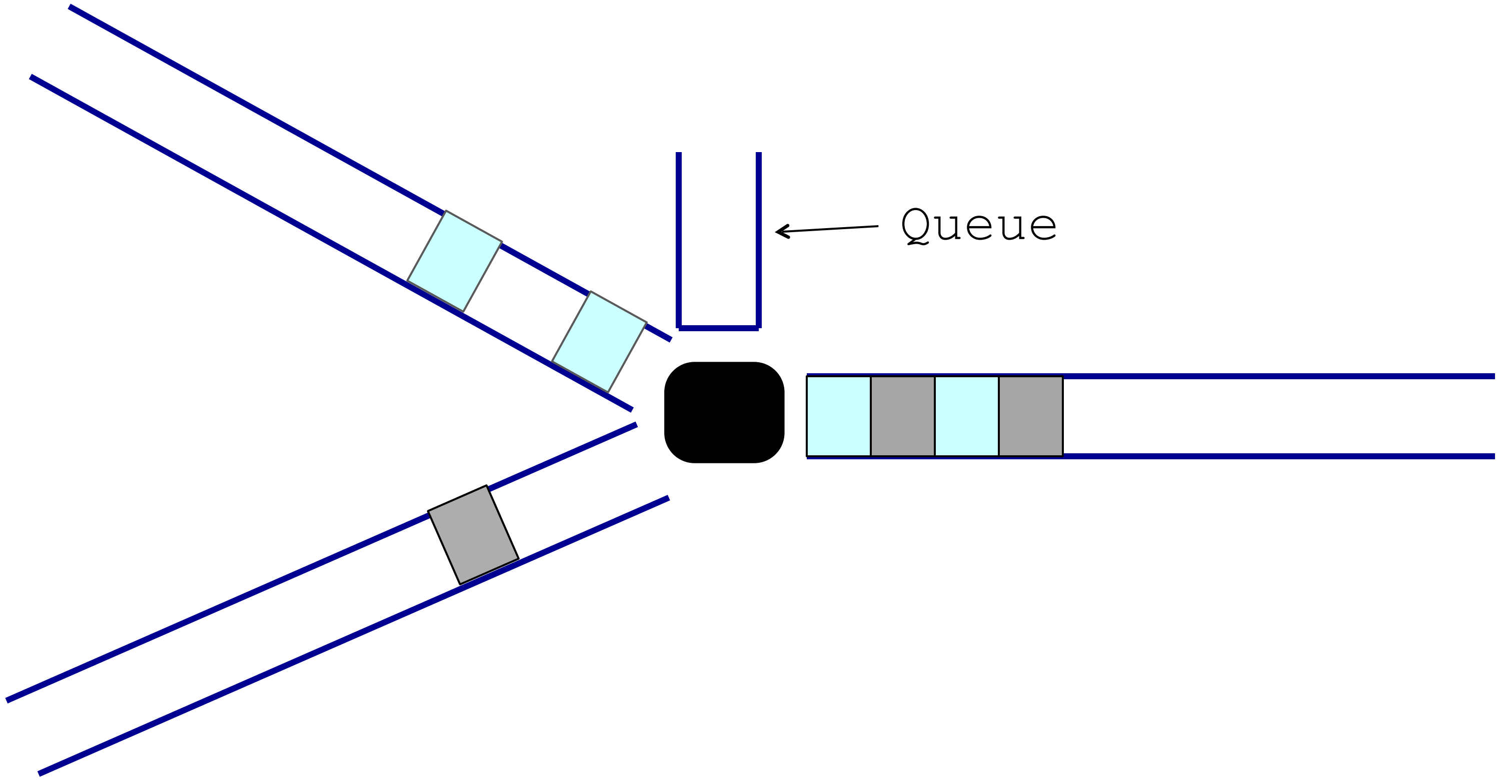
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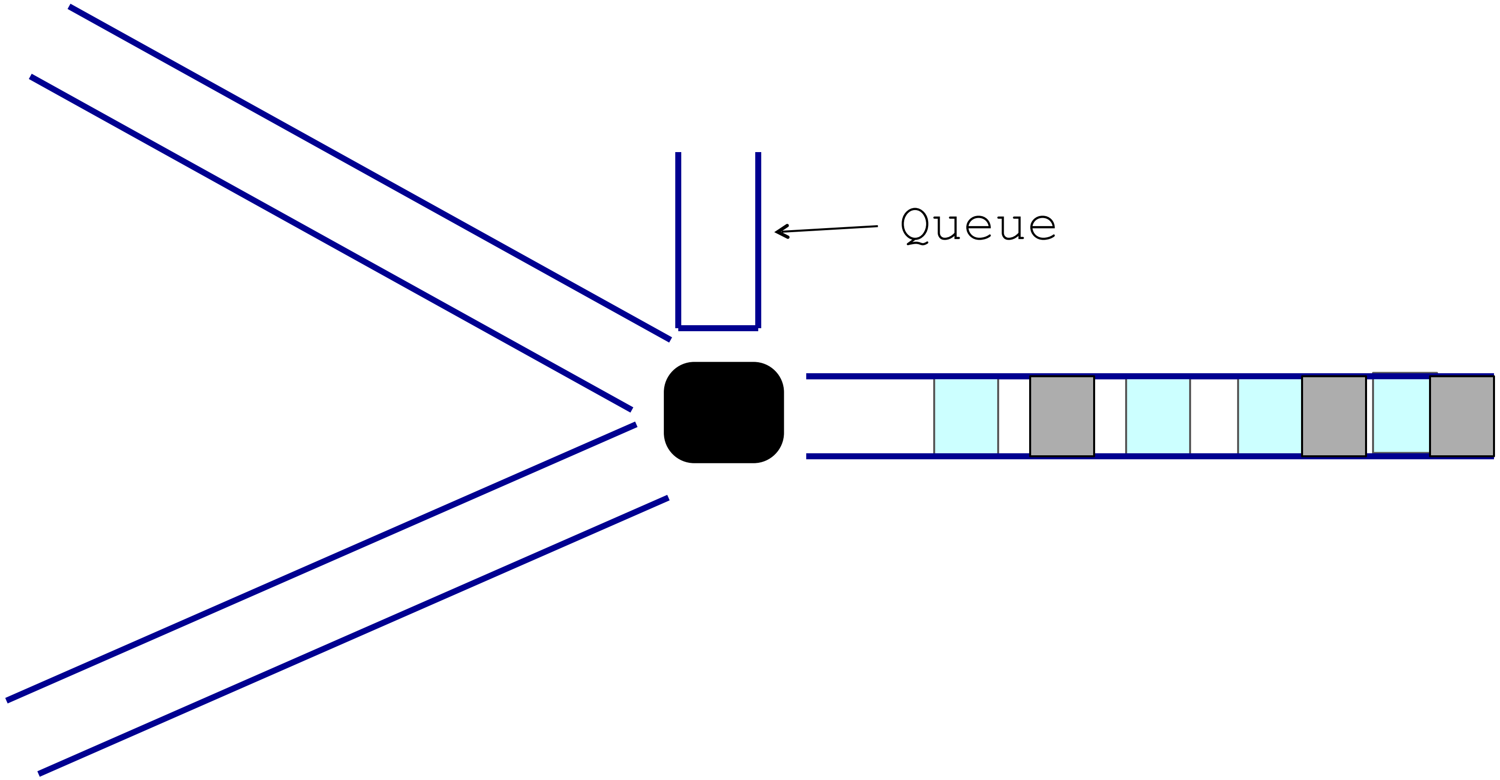
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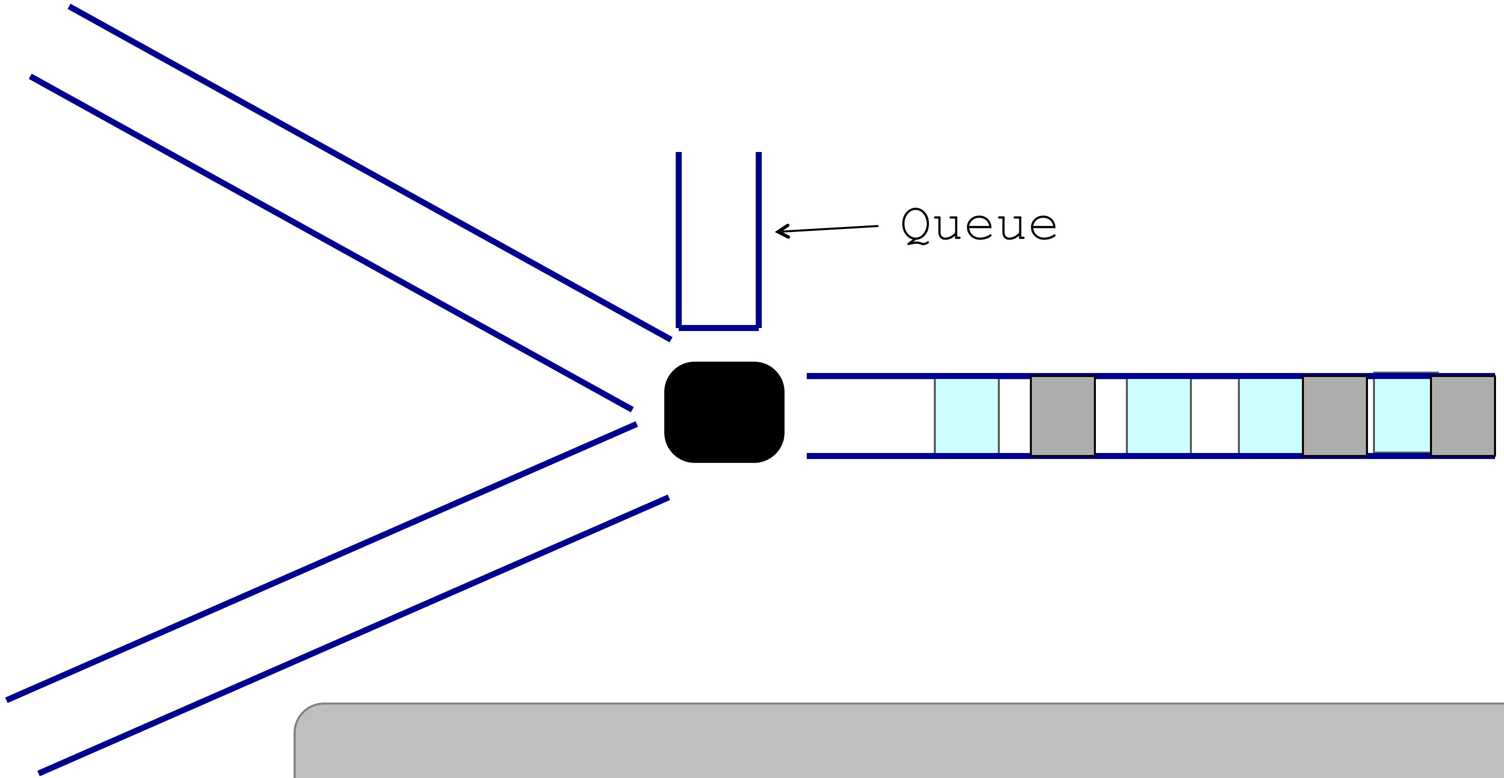
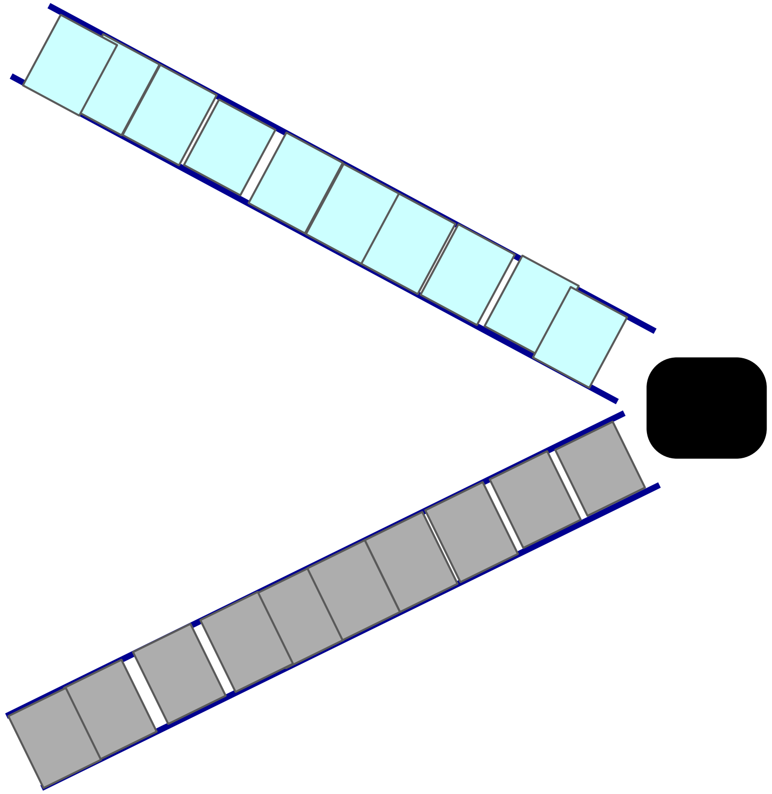
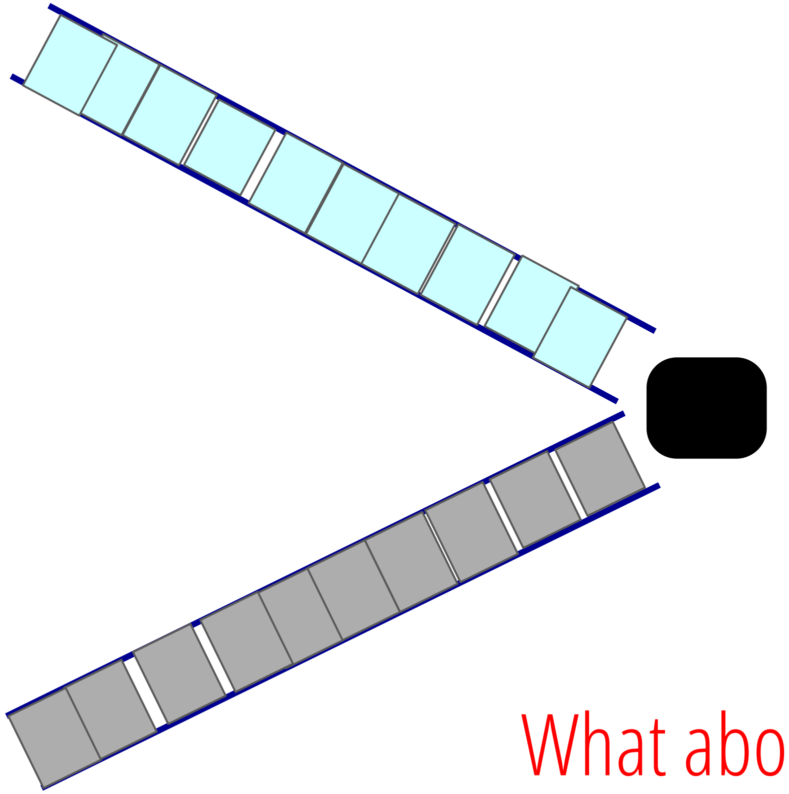
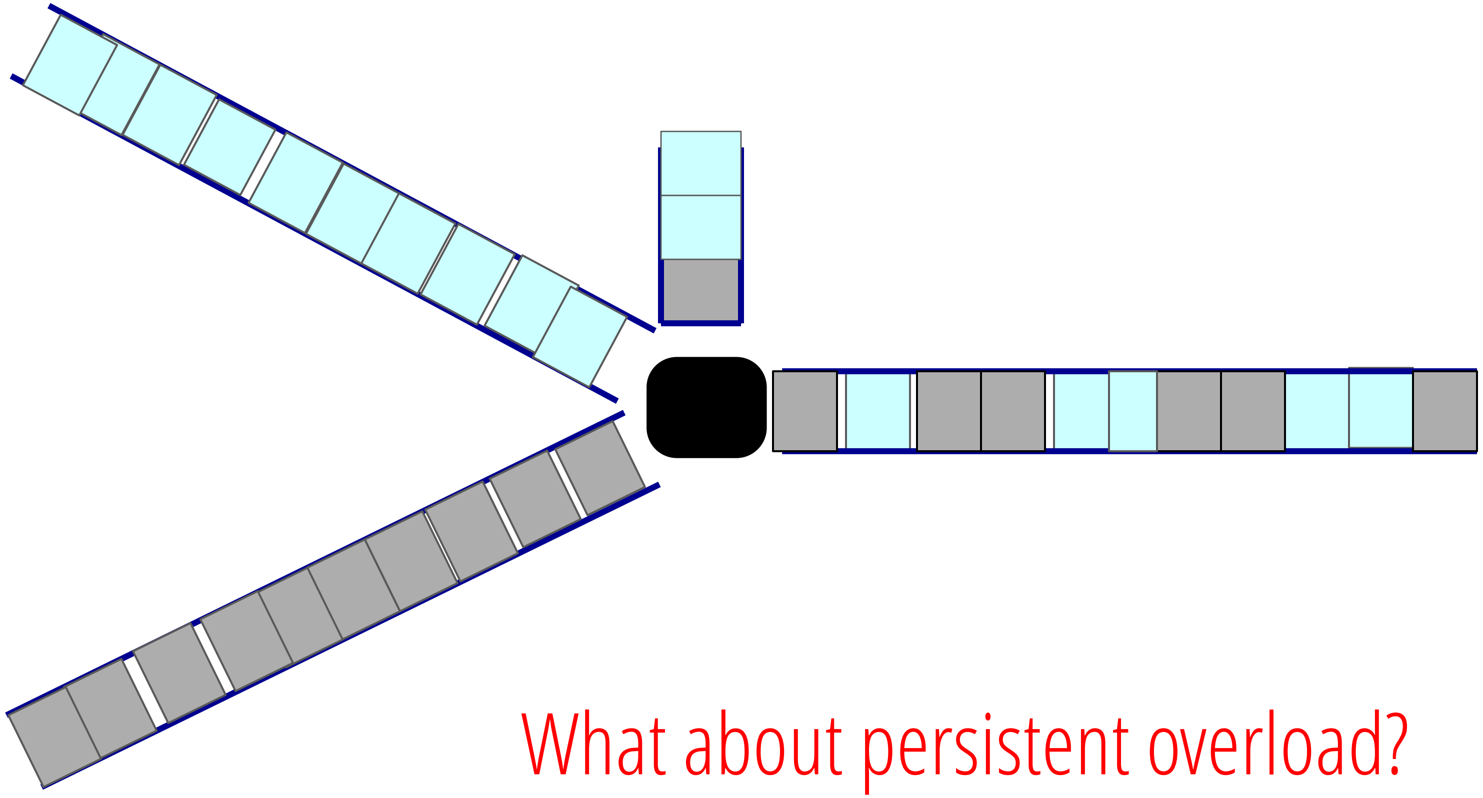



Queues absorb transient bursts!





What about persistent overload?



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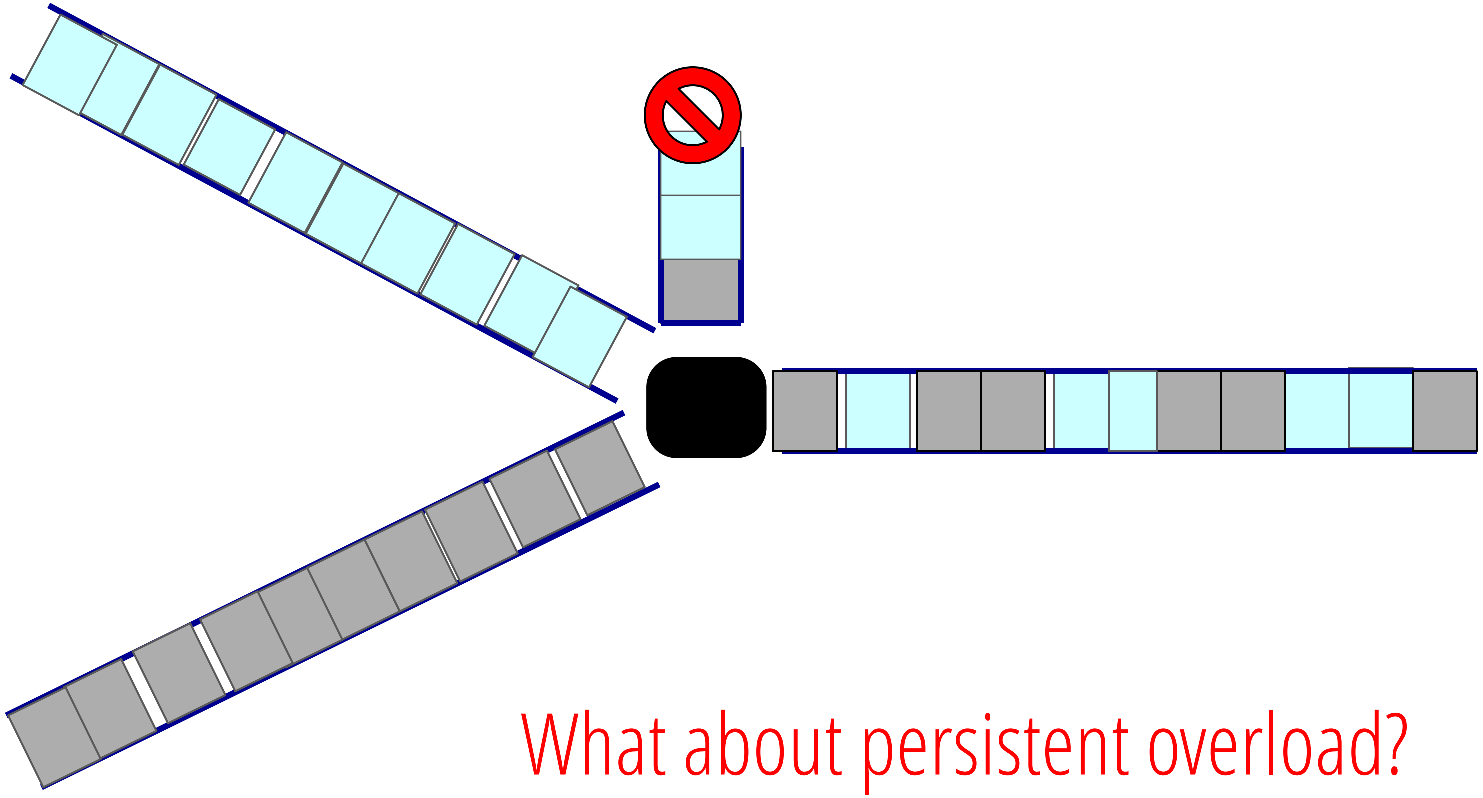

What about persistent overload?

Will eventually drop packets

# Queues introduce queuing delays

- Recall, packet delay = transmission delay + propagation delay
- With queues:  packet delay = transmission delay + propagation delay + queueing delay

# Recall: life of a packet so far…

- Source has some data to send to a destination
- Chunks it up into packets: each packet has a payload and a header
- Packet travels along a link
- Arrives at a switch; switch forwards the packet to its next hop
- And the last step repeats until we reach the destination …

# Recall: life of a packet so far…[updated]

- Source has some data to send to a destination
- Chunks it up into packets: each packet has a payload and a header
- Packet travels along a link
- Arrives at a switch; switch forwards the packet to its next hop
  - switch may buffer, or even drop, the packet
- And the last step repeats until we reach the destination …
  - or the packet is dropped

# Hence, our fundamental topics [updated]

- How do we name endhosts on the Internet? (naming)
- How do we address endhosts? (addressing)
- How do we map names to addresses? (mapping names to addresses)
- How do we compute forwarding tables? (routing control plane → project 1)
- How do we forward packets? (routing data plane)
- How do hosts communicate reliably? (reliable packet delivery → project 2)
- How do sources know at what rate they can send packets? (congestion control)
- Plus advanced topics (the web, SDN, cellular, datacenters, etc.)

# Recap: key takeaways from our bottom-up overview

- What is a packet?
- Approaches to sharing the network – circuit vs. packet switching -- and their tradeoffs
- An overall sense of the life of a packet
    - We'll continue to refine this picture over the course of the semester
- An overall sense of the topics we'll be studying and why they're fundamental

# Questions??

# Changing Perspective

- Designing the Internet: a top-down approach
- In the process, discuss a few enduring ideas:
  - Layering
  - The end-to-end principle
  - Fate sharing

# The Internet's problem definition

- Support the transfer of data between endhosts
- ... across multiple networks
  - The Internet

# How do you solve a problem?

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1. Decompose it (into tasks and abstractions)

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2. Assign tasks to entities (who does what)

# Modularity

***Modularity based on abstraction is the way things are done***

*– Barbara Liskov, Turing lecture*

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- Decomposing systems into smaller units
  - Providing a “separation of concerns”
- Plays a crucial role in computer science…
- The challenge is to find the *right* modularity

# <u>Network</u> Modularity

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  - **And is even more important!**
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- But network implementations are not just distributed across many lines of code…
  - Also distributed across many devices (hosts, routers)
  - … *and* different players (clients, server, ISPs)

How do we decompose the job of transferring data between end-hosts?

# Inspiration…

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- **CEO A writes letter to CEO B**
  - Folds letter and hands it to administrative aide

Dear Sundar,

Your days are numbered.

-- Satya

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  - Puts name and street address on FedEx envelope
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  - Puts name and street address on FedEx envelope
  - Puts package on FedEx delivery truck
- **FedEx delivers to other company**

# The Path of the Letter

CEO

Aide

FedEx

CEO

Aide

FedEx

# The Path of the Letter

CEO

Aide

FedEx

CEO

Aide

FedEx

# The Path of the Letter

CEO

Aide

↓

FedEx

CEO

Aide

FedEx

# The Path of the Letter

| | |
|---|---|
| **CEO** | **CEO** |
| **Aide** | **Aide** |
| **FedEx** → | **FedEx** |

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**CEO**

**Aide**

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| | |
|---|---|
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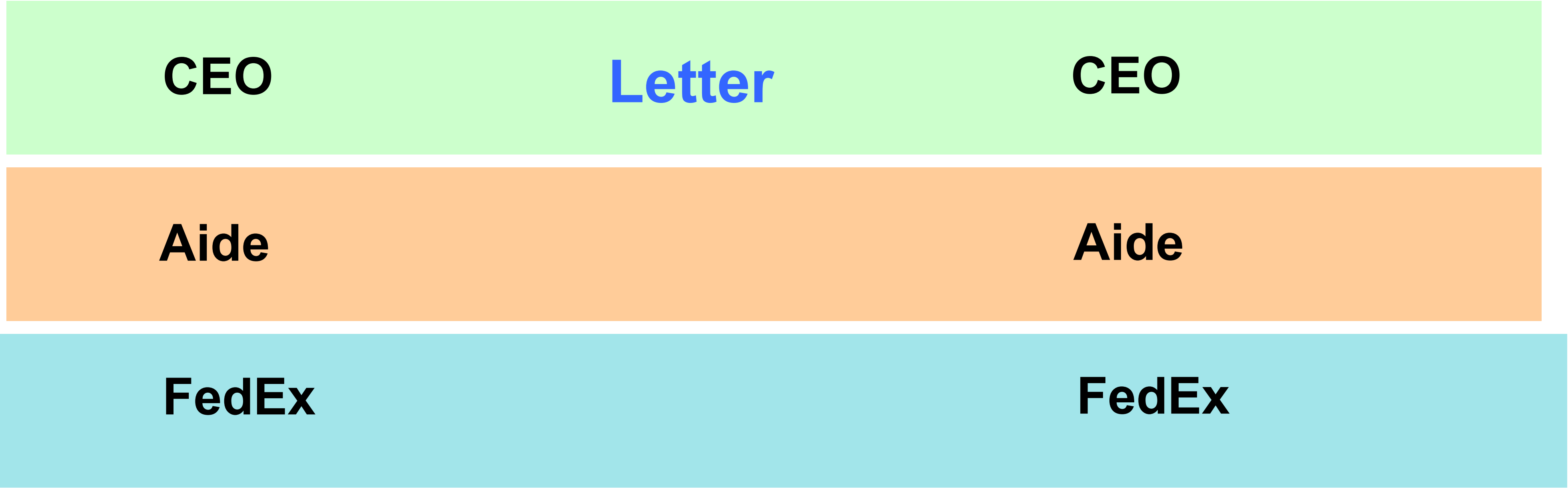
- “Peers” understand the same things



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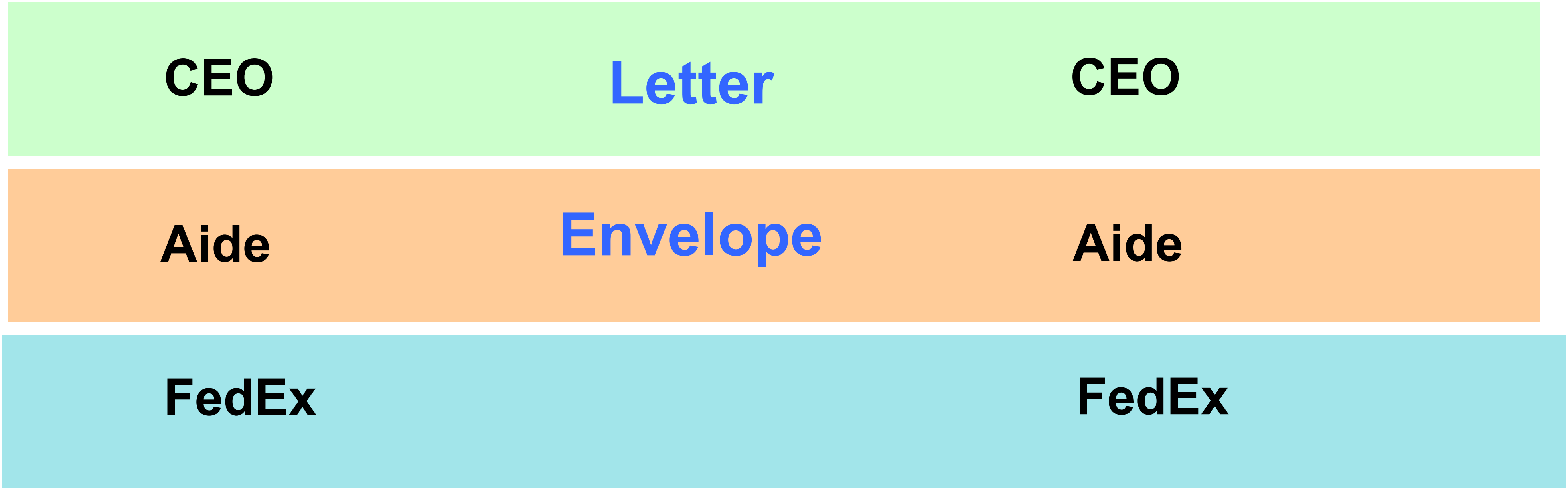

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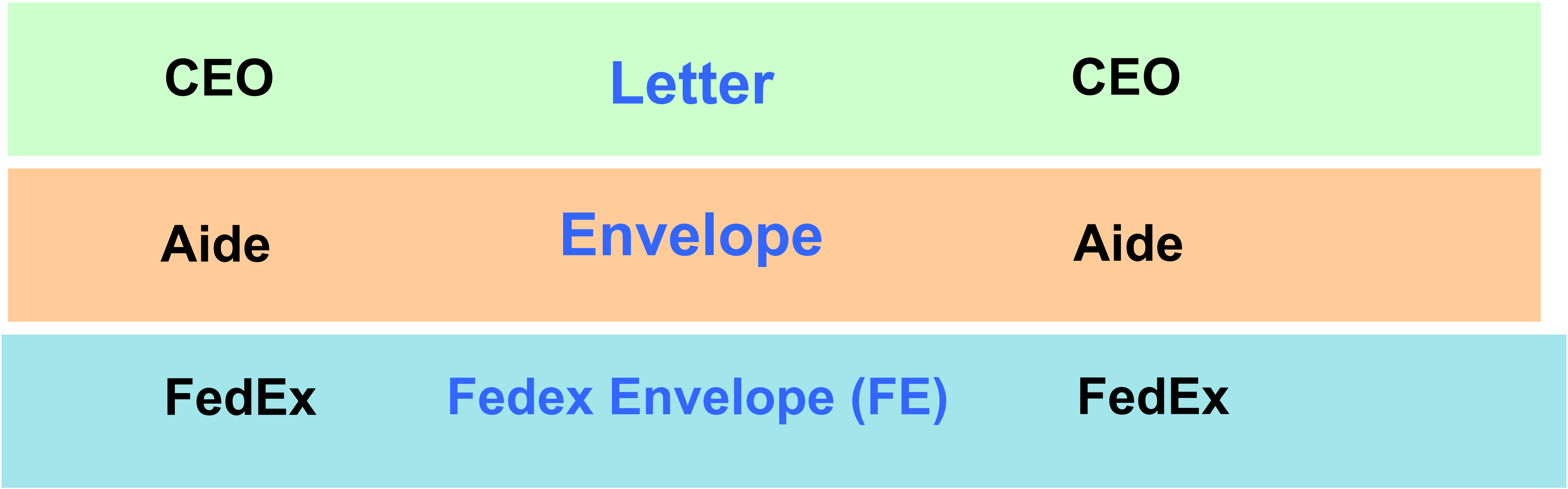


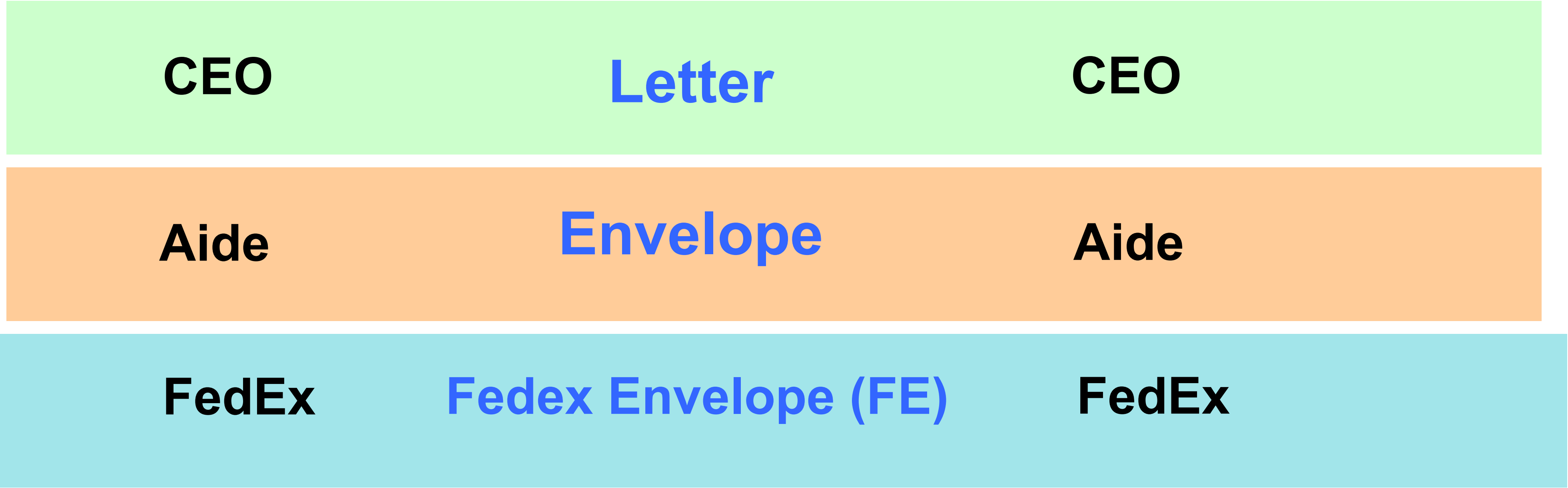
# The Path of the Letter

- “Peers” understand the same things
- No one else needs to

| | | |
|---|---|---|
| CEO | Letter | CEO |
| Aide | Envelope | Aide |
| FedEx | Fedex Envelope (FE) | FedEx |

# The Path of the Letter

- "Peers" understand the same things
- No one else needs to
- Lowest level has most "packaging"



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- How would ***you*** break the Internet into tasks?
- Just focus on what is needed to get packets between processes on different hosts….
- Do not consider application or control tasks
  - Naming, computing forwarding tables, etc.

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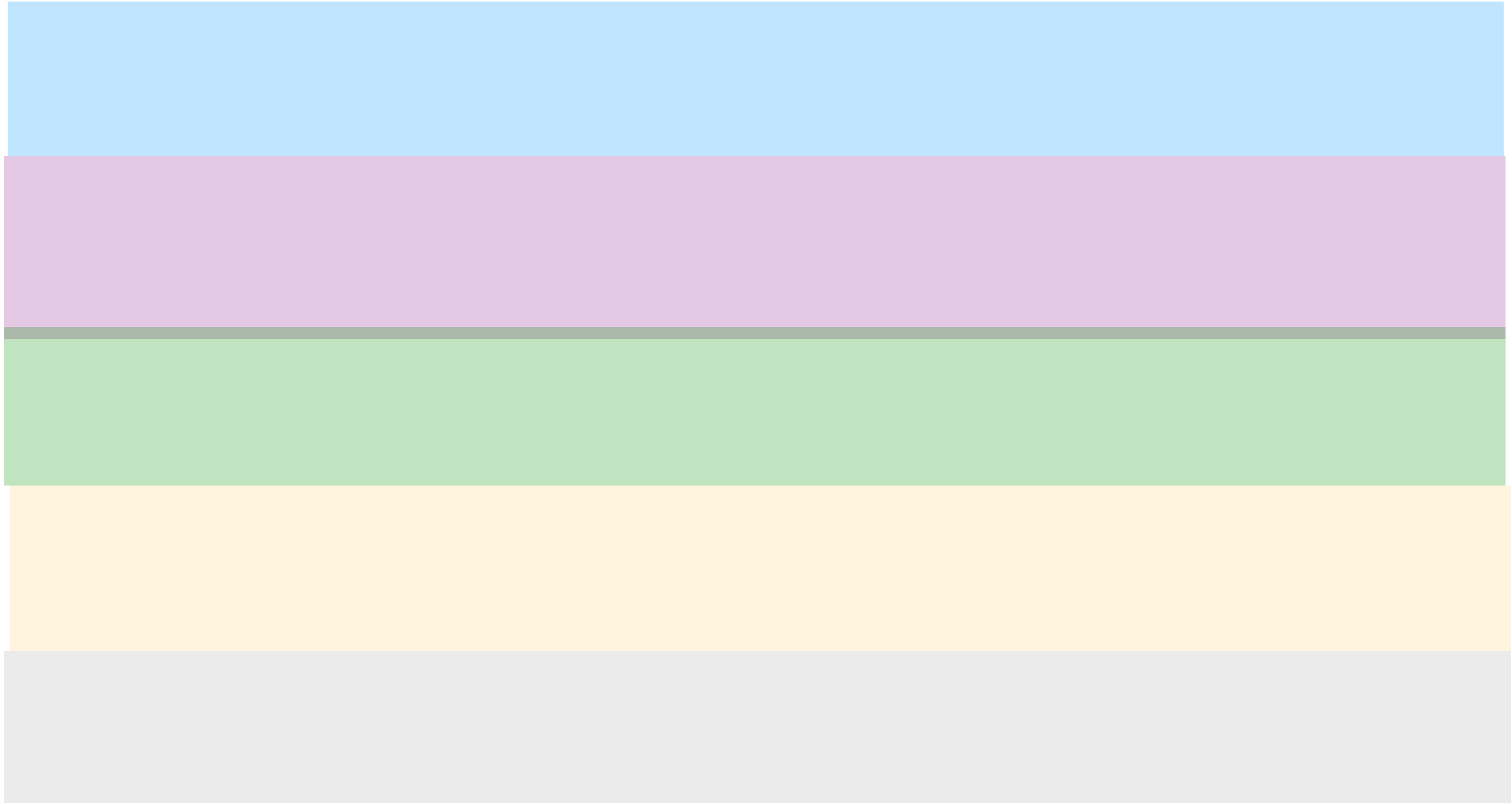
# In the Internet: organization



# In the Internet: organization

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Best-effort local *packet* delivery

Physical transfer of bits

# In the Internet: organization

**Best-effort *global* packet delivery**

**Best-effort local *packet* delivery**

**Physical transfer of bits**

# In the Internet: organization

Reliable (or unreliable) data delivery

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**Applications**

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...built on...

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# A <u>layered</u> architecture

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- **One layer interacts only with layer above and layer below**

- Two layers interact only through the interface between them

# In the Internet: organization

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**Physical transfer of bits**

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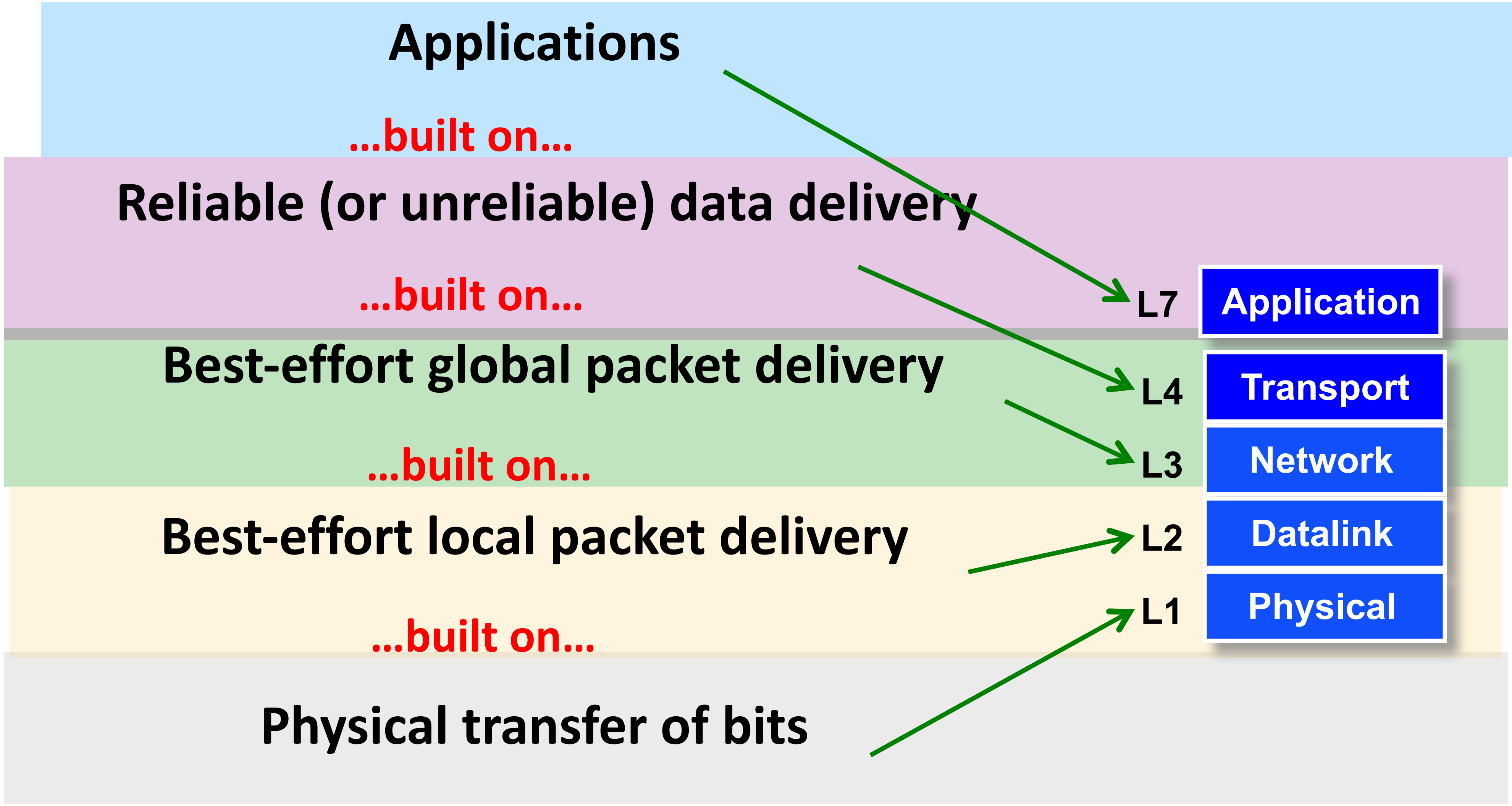

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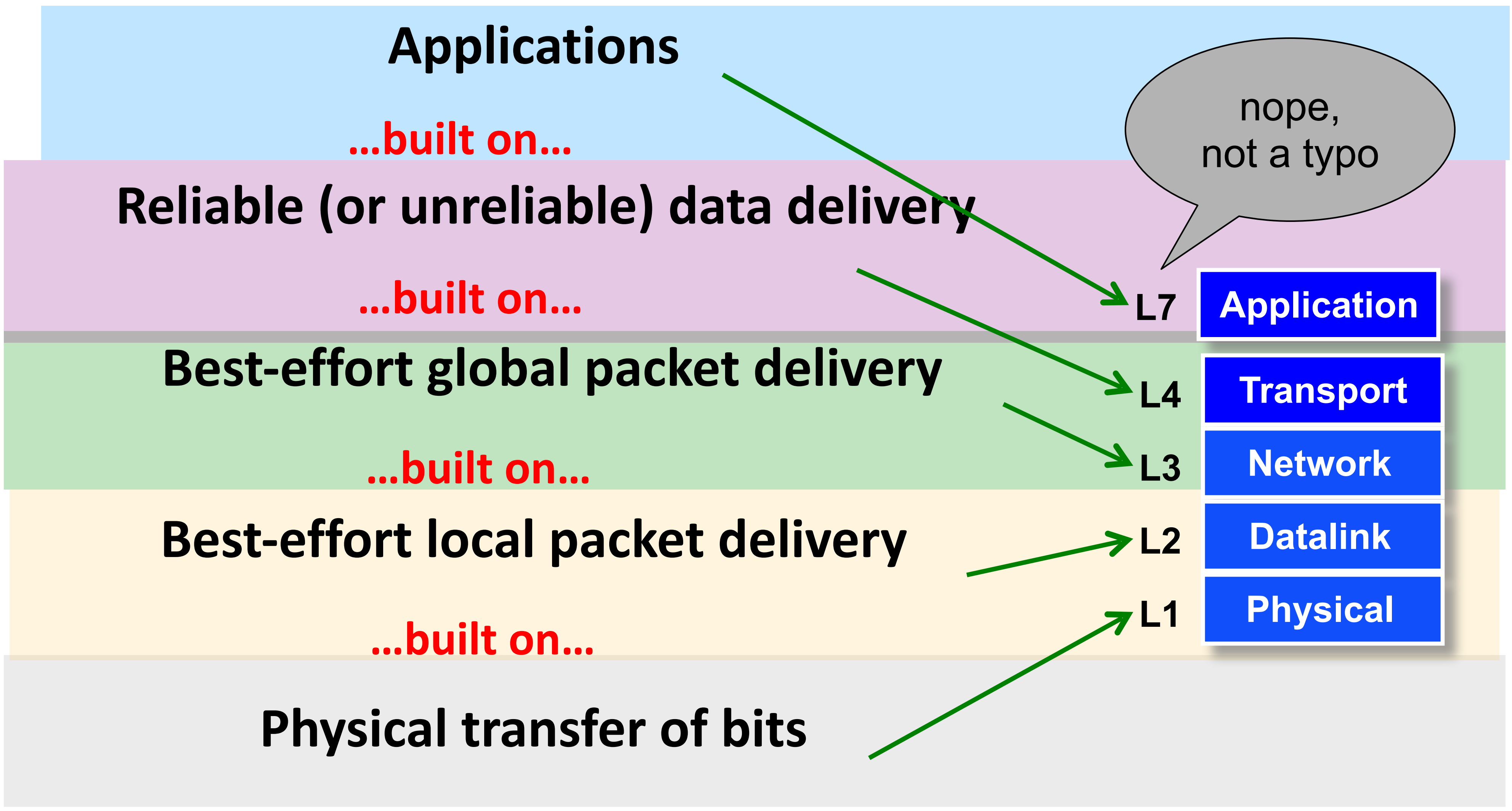
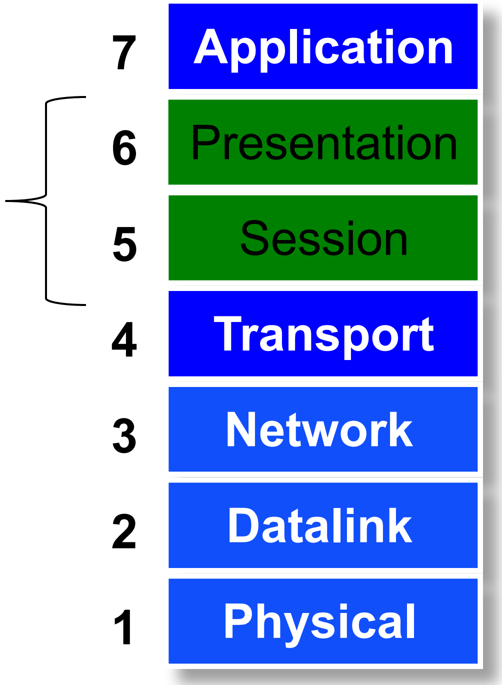


# Ancient history (late 1970s)

The Open Systems Interconnect (OSI) model developed by the International Organization for Standardization (ISO) included two additional layers that are often implemented as part of the application



# Questions?