ECE 158A: Lecture 2

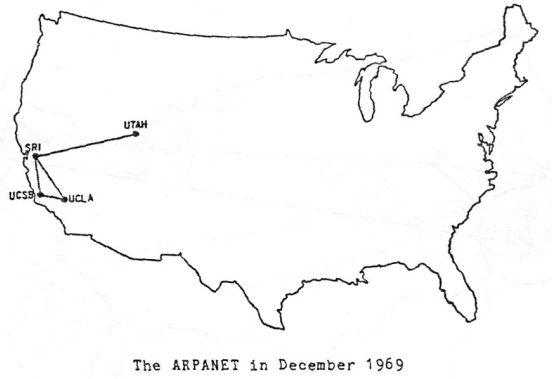
Fall 2014

Outline

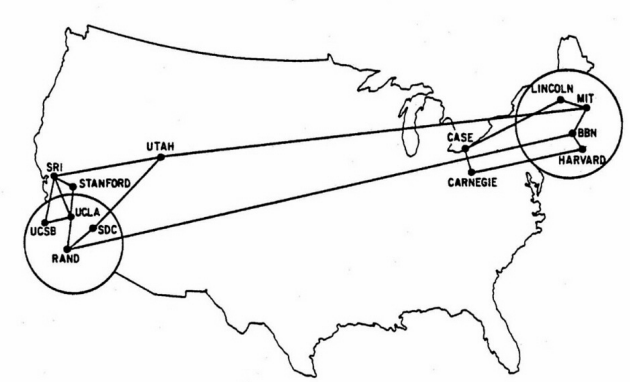
- A brief history of the Internet
- Communication channels:
  - Capacity
  - Latency
- Circuit switch
- Packet switch
- Statistical Multiplexing

Internet: A Brief History

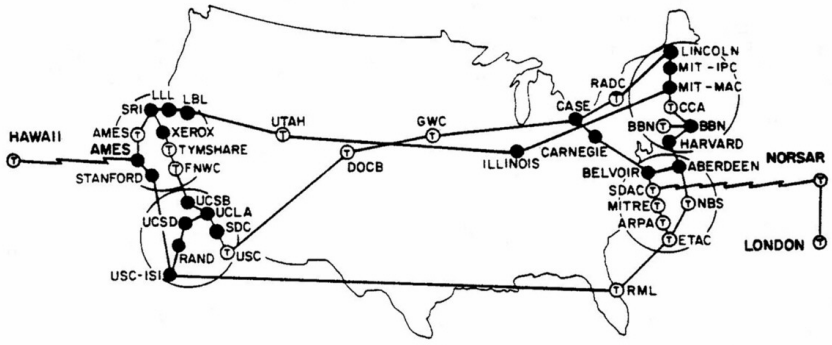
- Maps from http://www.vox.com/a/internet-maps



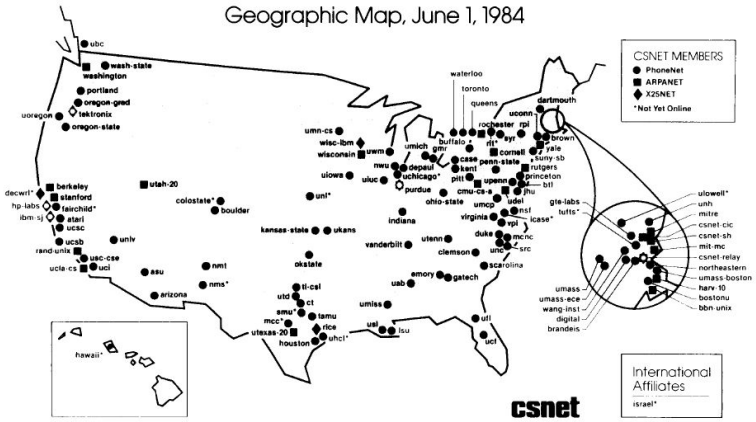
1963: ARPANET



1970: ARPANET expands

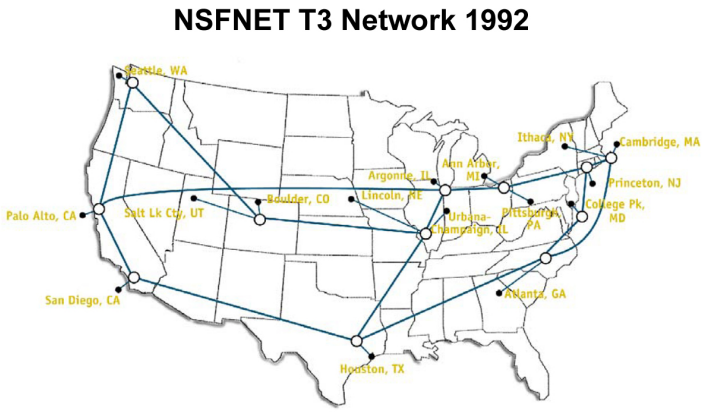


1973: ARPANET goes international

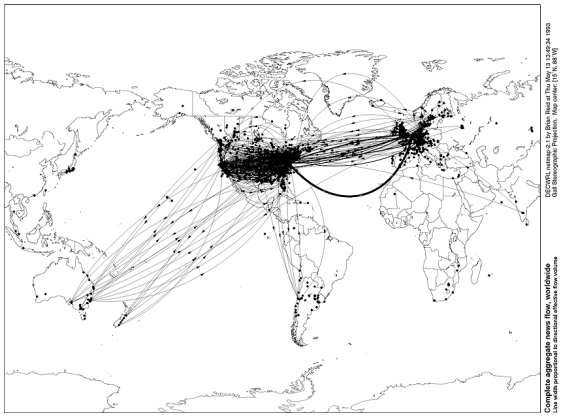


1984: ARPANET becomes Internet

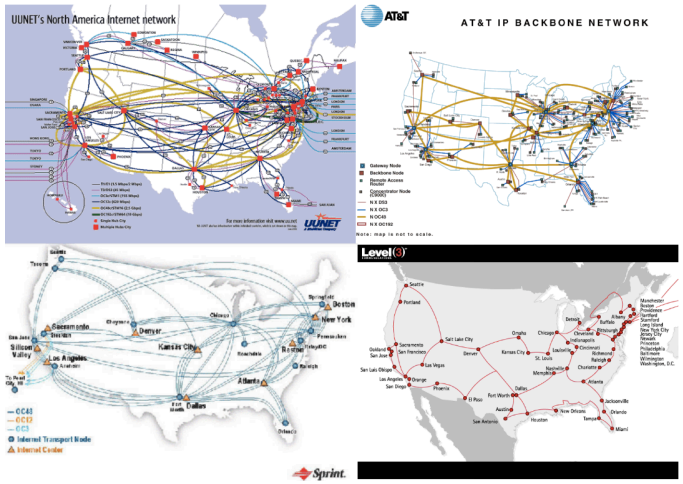
Internet: A Brief History



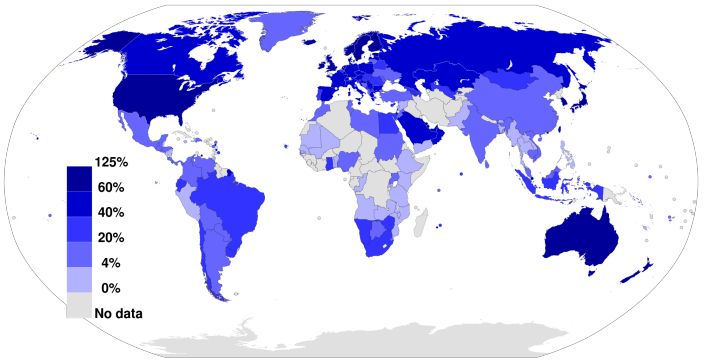
1992: NSFNET (backbone)



1993: The internet is global



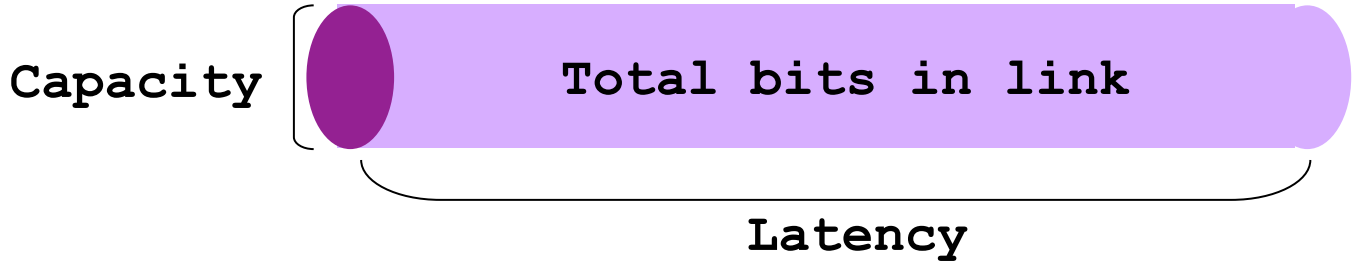
1994: Privatization backbone



2012: Broadband penetration

Properties of Links

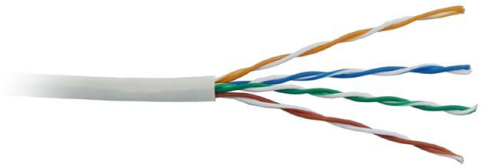
- Capacity: “width” of the link
  - number of bits sent (or received) per unit time (bits/sec or bps)
- Latency (delay): “length” of the link
  - propagation time for data to travel along the link (seconds)



- Link rate: Peak achievable rates in practice

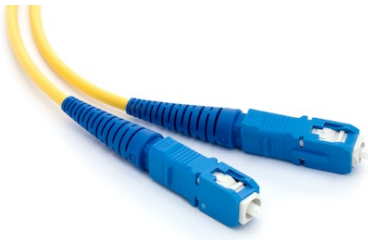
Example of Communication Media

- Unshielded Twisted Pair (UTP)
  - Medium used in telephone line
  - Seven categories of increasing quality
  - Data rates from 0.1Mbps (CAT1) to 600Mbps (CAT6)



- Coaxial cable
  - Audio/TV connectors
  - More resilient to external disturbances than UTP but more expensive, short distances
  - Data rates up to hundreds of Mbps

- Fiber optic cable
  - Internet backbones
  - No external disturbance, small and inexpensive
  - Difficult interconnections, limited curvature
  - Data rates up to 10Gbps



Examples of Capacity-Delay

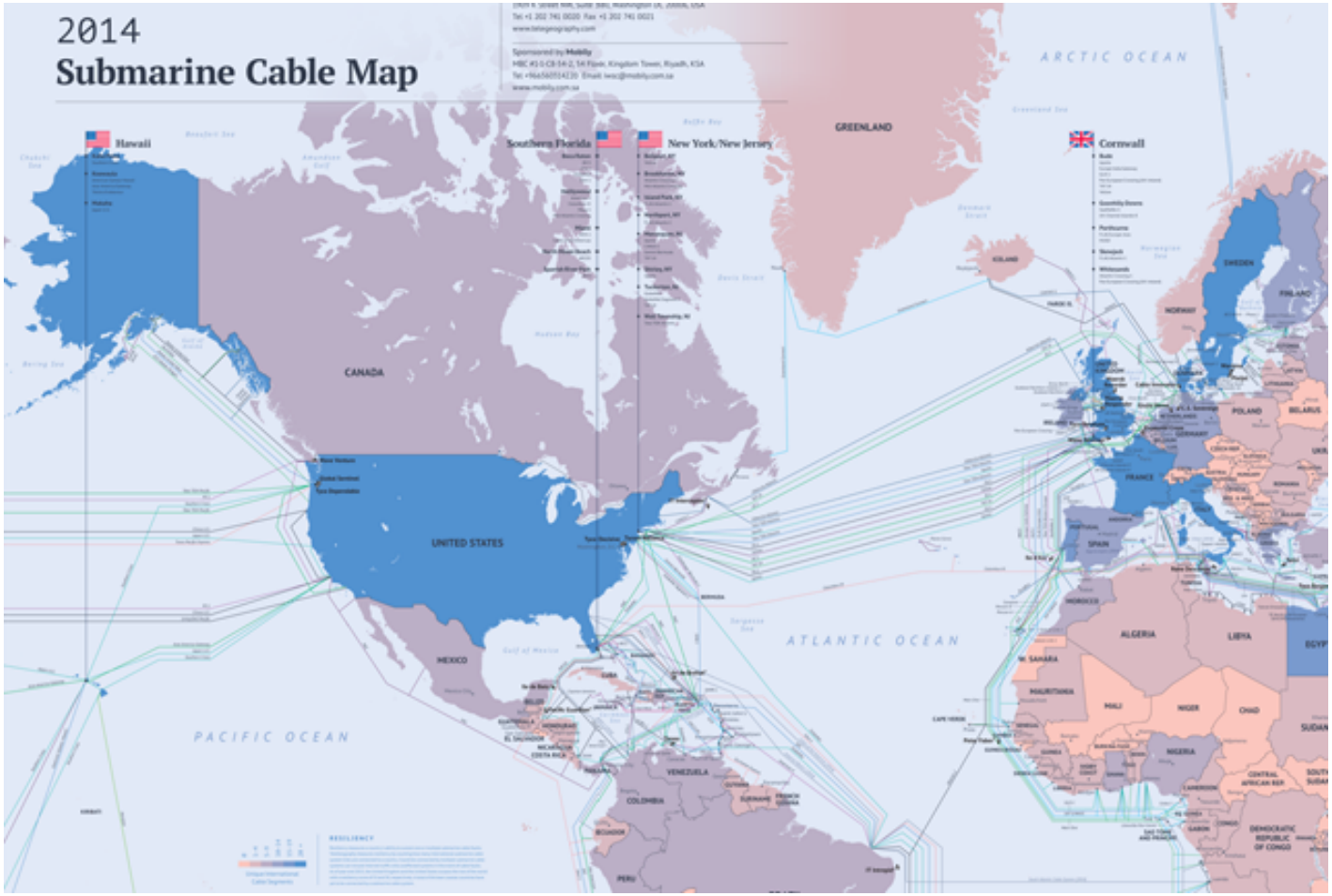
- Propagation speed varies on the material, but it is roughly between 0.5 to 0.8 times the speed of light c, i.e., ~ 1.5×10^8 msec

- Same city over UTP:
  - Capacity~100Mbps
  - Latency~0.1msec (~15Km)
  - Total bits in link ~ 10,000bits ~ 1.25KBytes

- Cross-country over fiber optic cable:
  - Capacity~10Gbps
  - Latency~10msec (~1500Km)
  - Total bits in link ~ 10^8bits ~ 12.5GBytes

Internet Submarines Cables

- More maps at http://www.submarinecablemap.com/



Internet Submarine cables

https://www.youtube.com/watch?feature=player_embedded&v=1ex7uTQf4bQ

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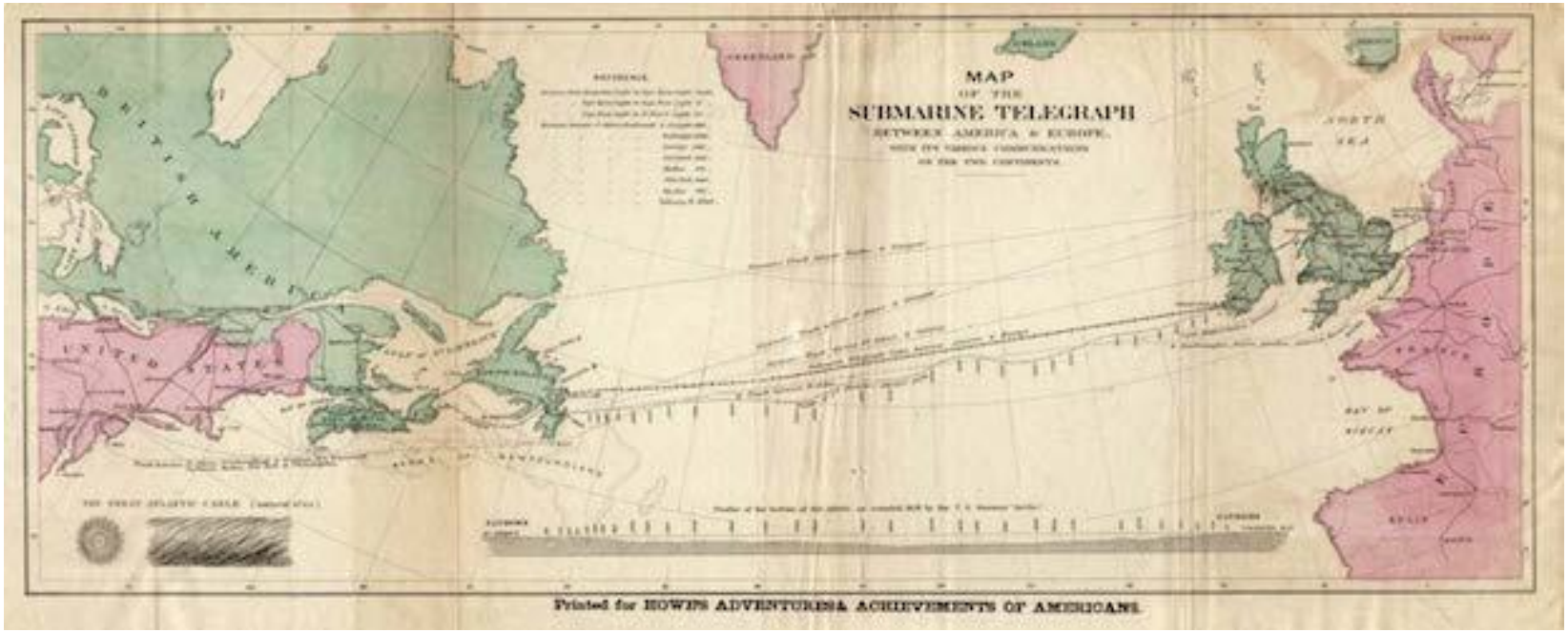
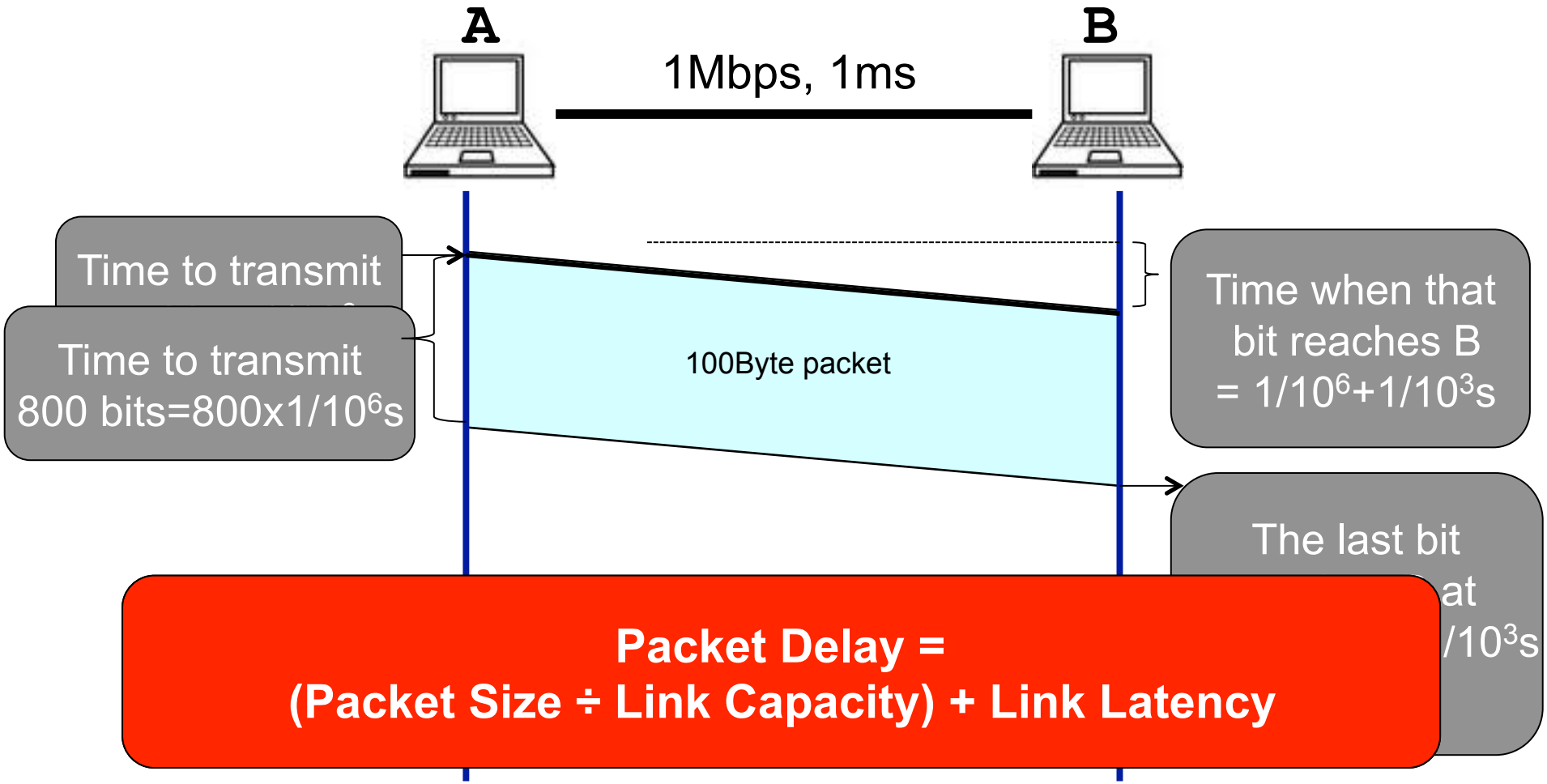

MAP
OF THE
SUBMARINE TELEGRAPH
BETWEEN AMERICA & EUROPE,
BRITISH AMERICA
UNITED STATES
NORTH SEA
BAY OF BISCAY
Printed for HOWES ADVENTURES& ACHIEVEMENTS OF AMERICANS

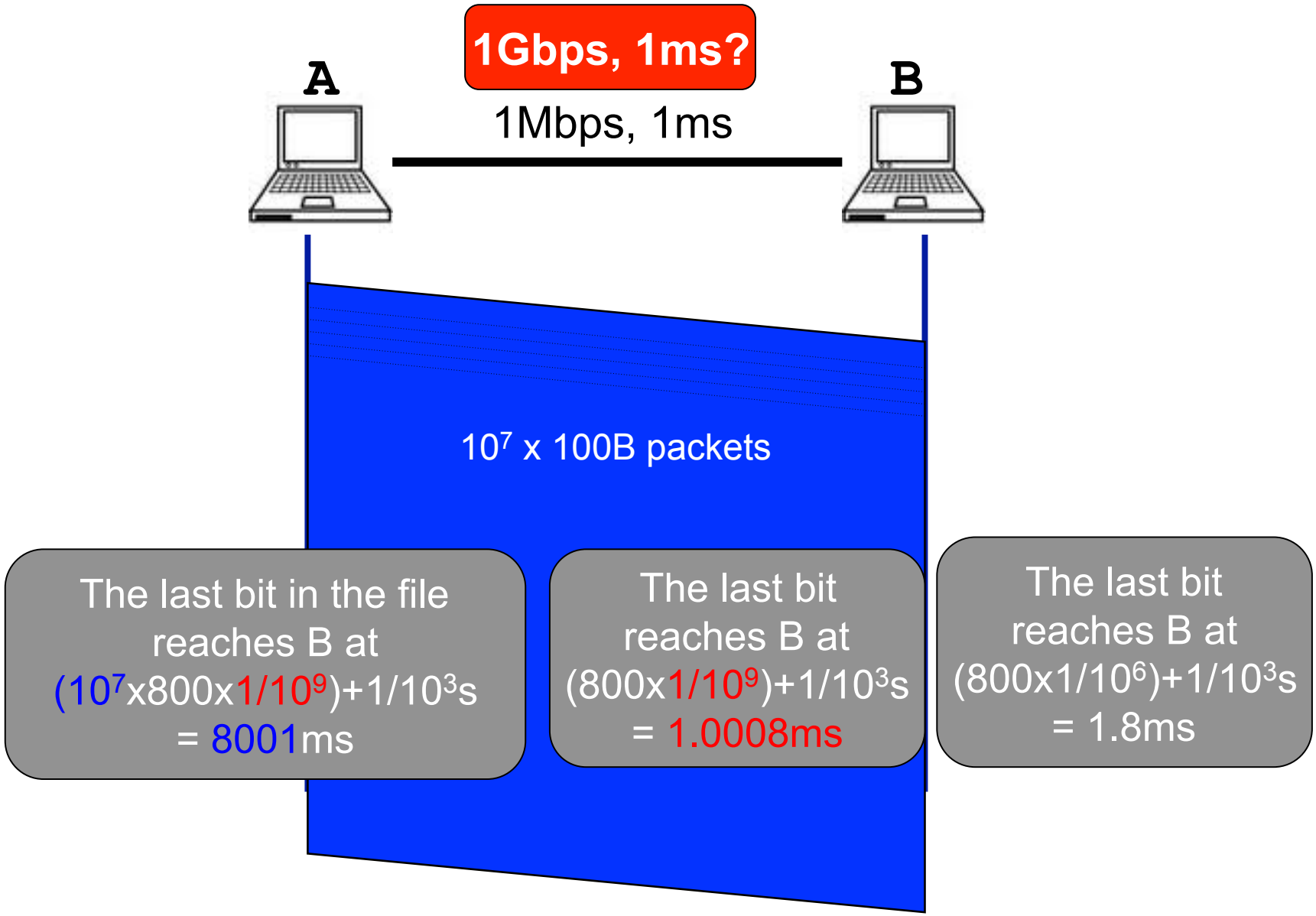
Packet Delay
Sending a 100B packet from A to B?



1GB file in 100B packets

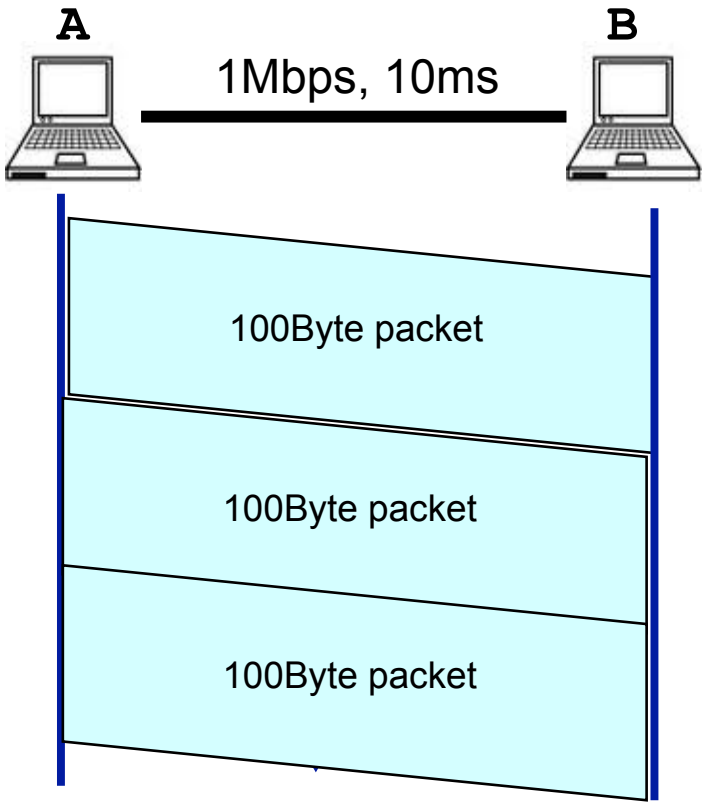
ay

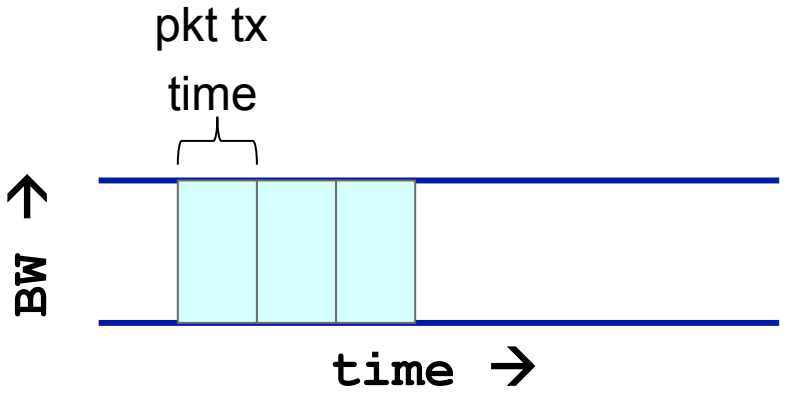
Sending a 100B packet from A to B?



Packet Delay: The "pipe" view

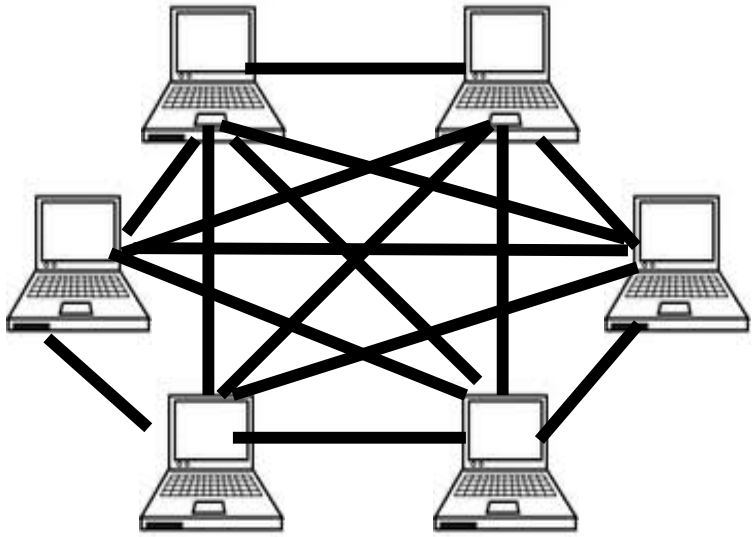
Sending 100B packets from A to B?





What if we have more nodes?

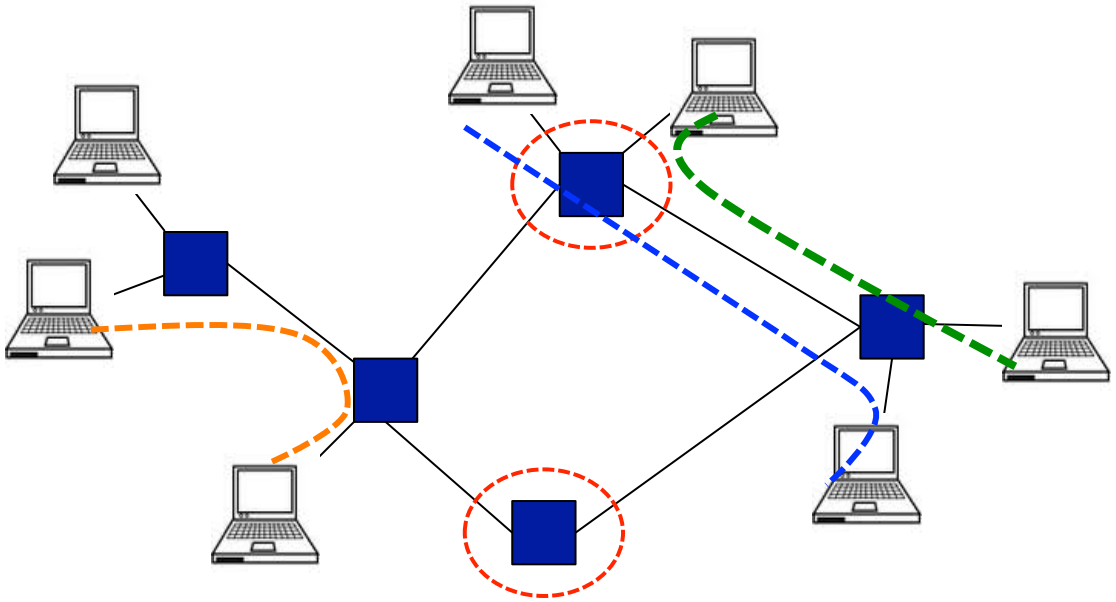
One link for every node?



Need a scalable way to interconnect nodes

Solution: A switched network

Nodes share network link resources

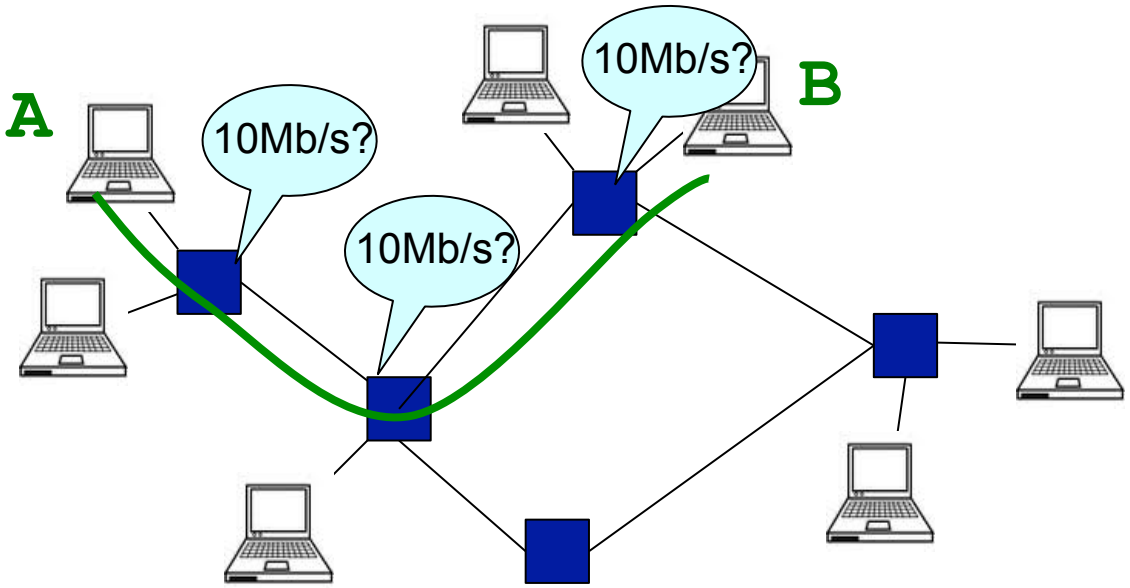


How is this sharing implemented?

Circuit Switching

Circuit switching

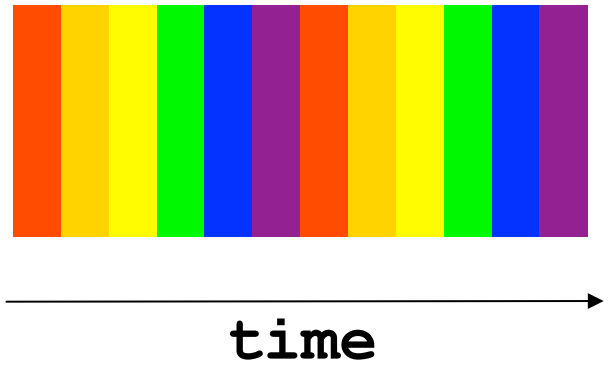
Idea: source reserves network capacity along a path



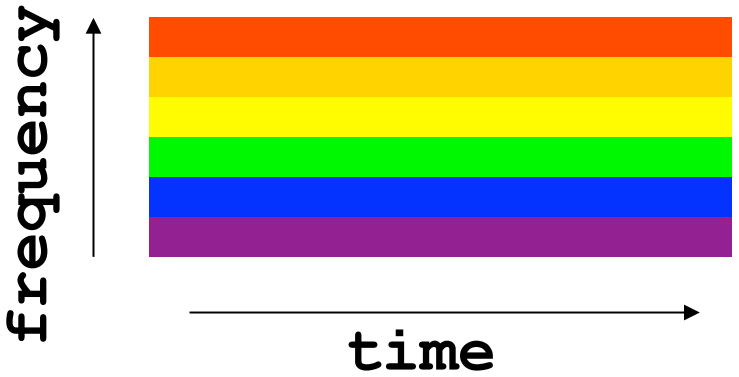
(1) Node A sends a reservation request
(2) Interior switches establish a connection -- i.e., “circuit”
(3) A starts sending data
(4) A sends a “teardown circuit” message

Circuit Switching: Sharing a Link

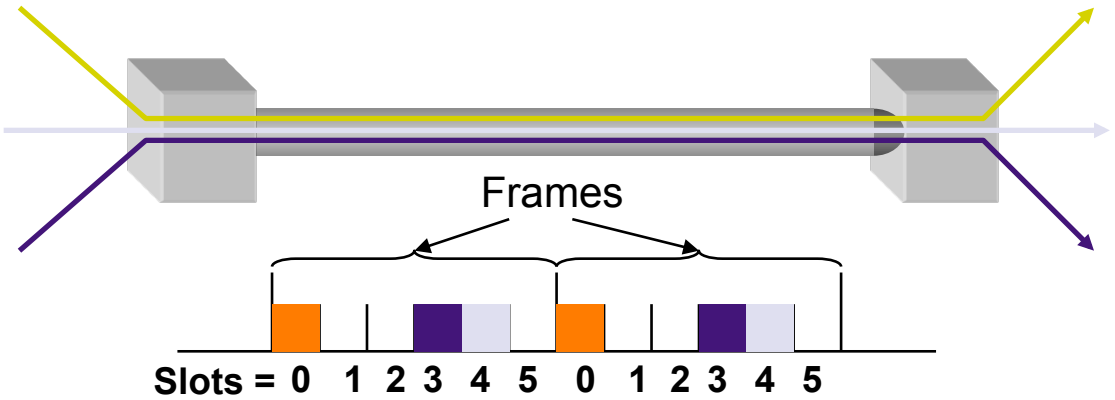
- Time-division
  - Each circuit allocated certain time slots



- Frequency-division
  - Each circuit allocated certain frequencies

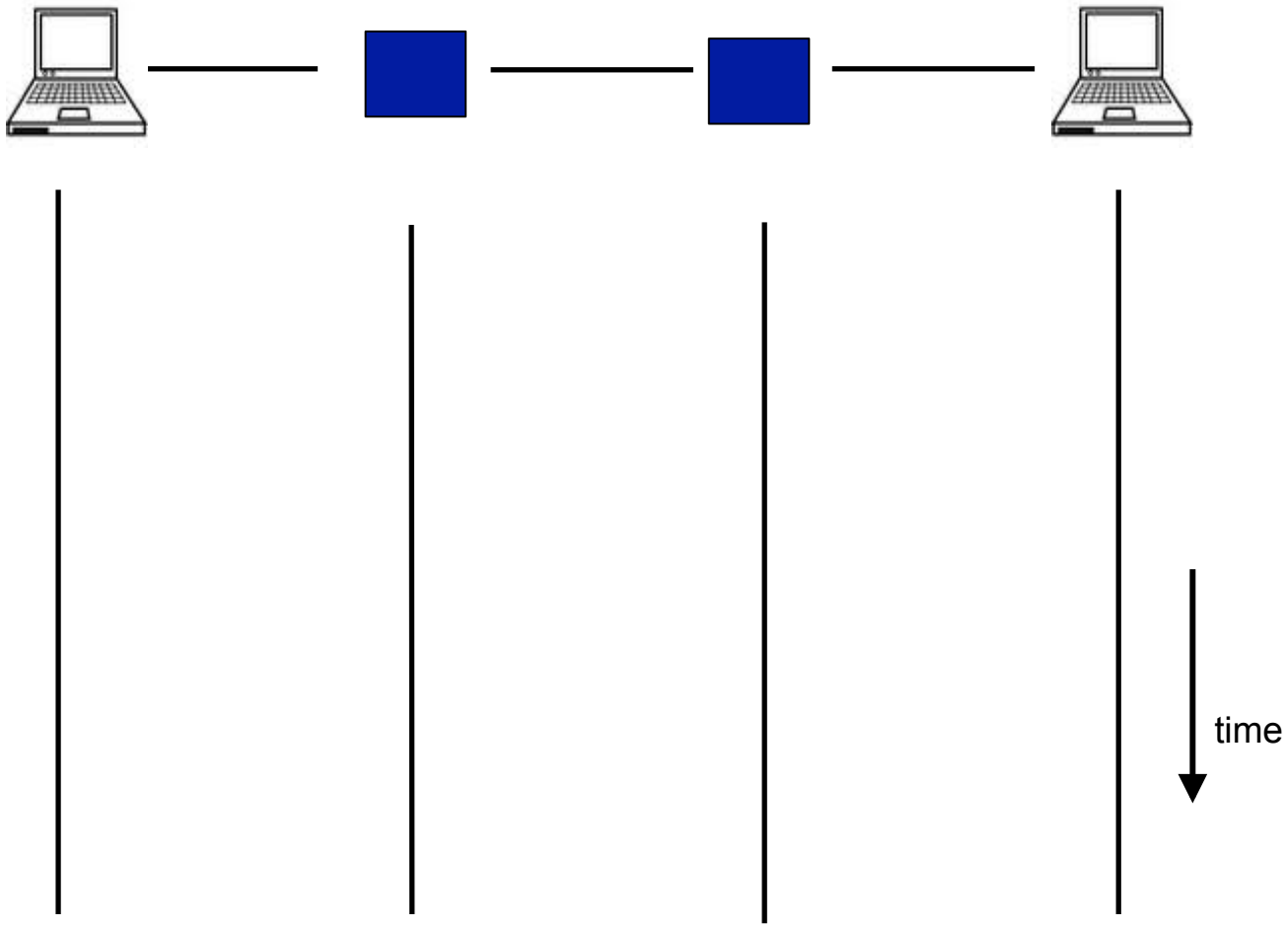


Time-Division Multiplexing



- Time divided into frames; frames into slots
- Relative slot position inside a frame determines to which conversation data belongs
  - e.g., slot 0 belongs to orange conversation
- Slots are reserved (released) during circuit setup (teardown)
- If a conversation does not use its circuit **capacity is lost!**

Timing in Circuit Switching



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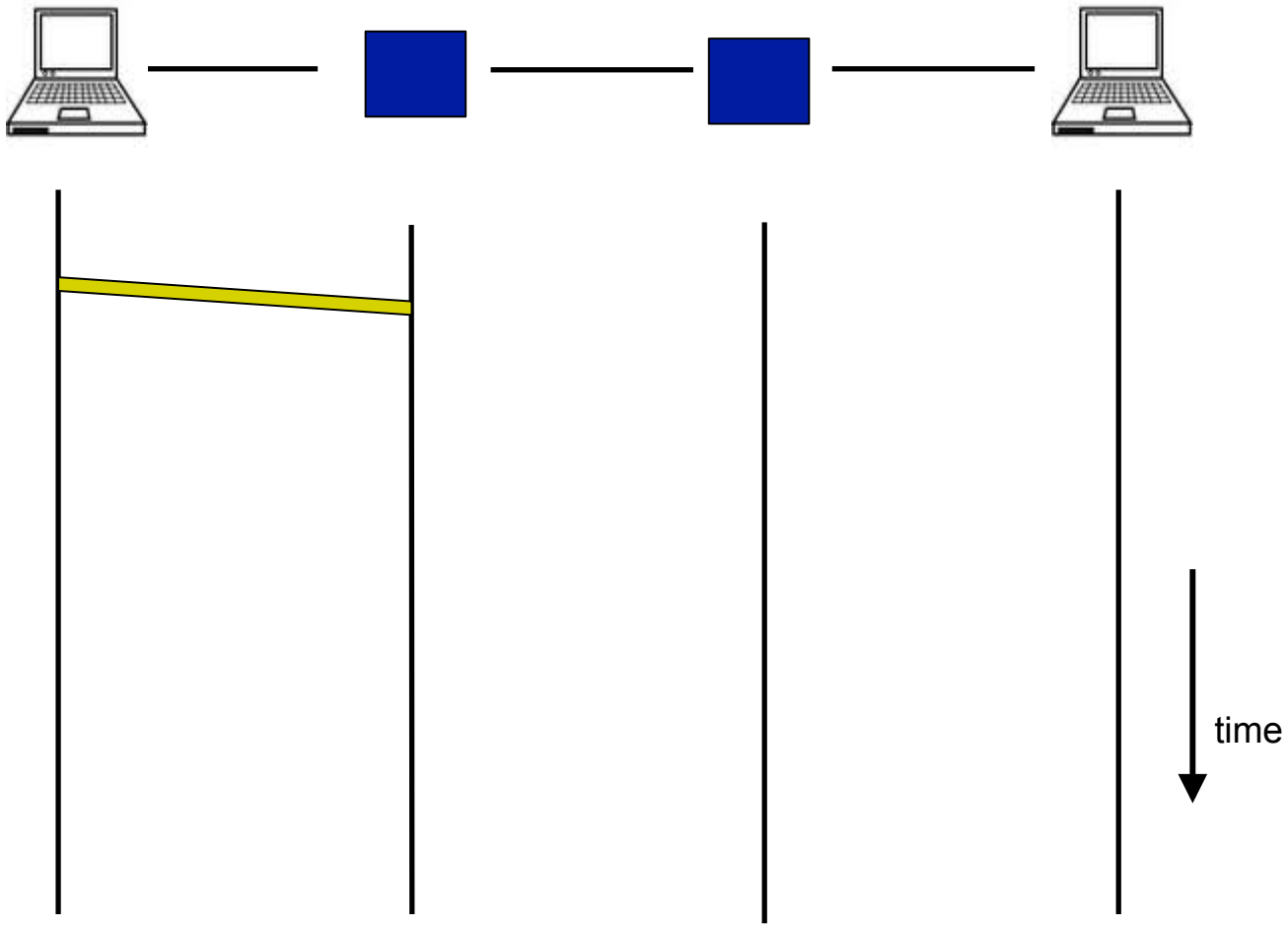

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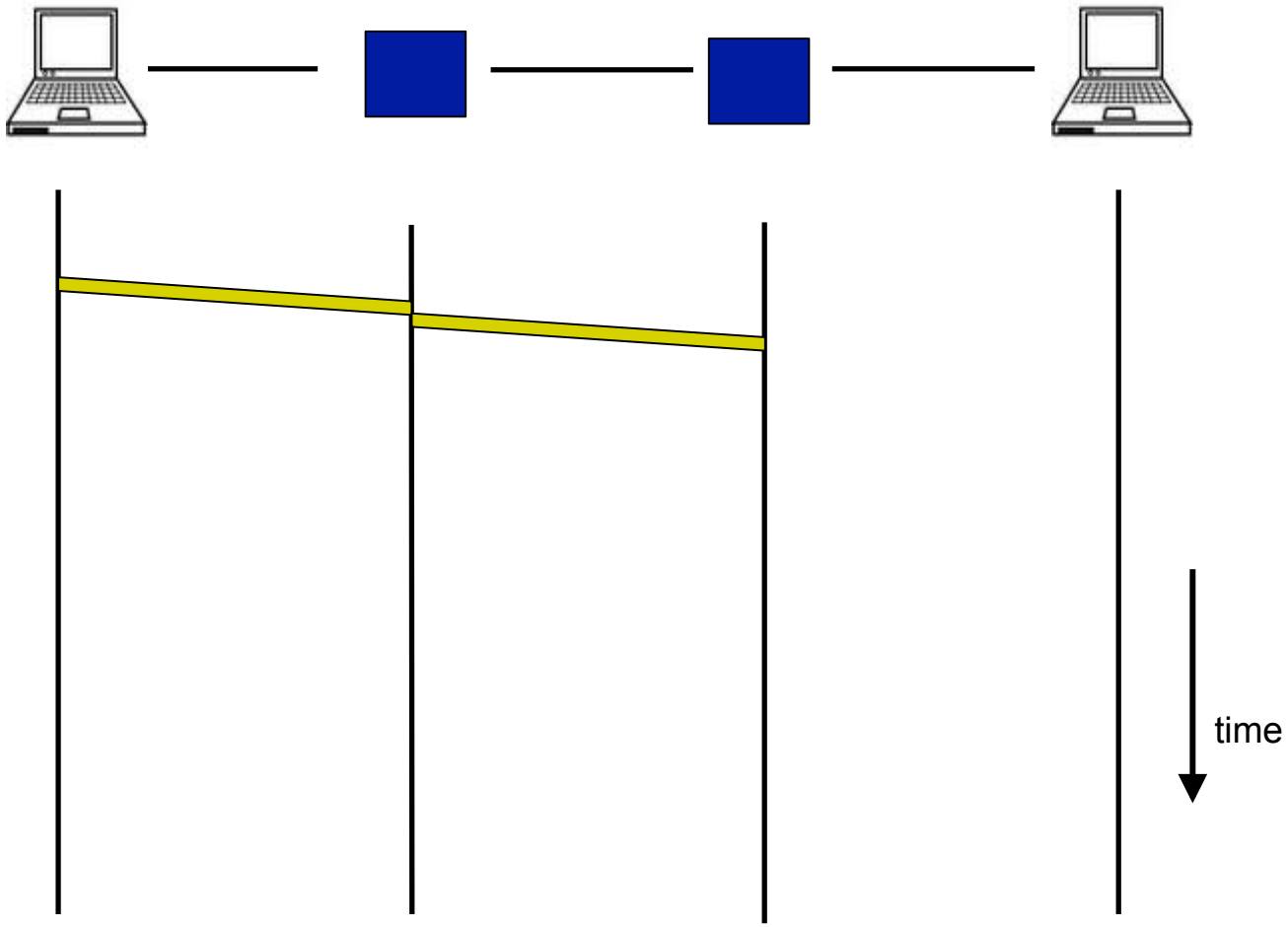

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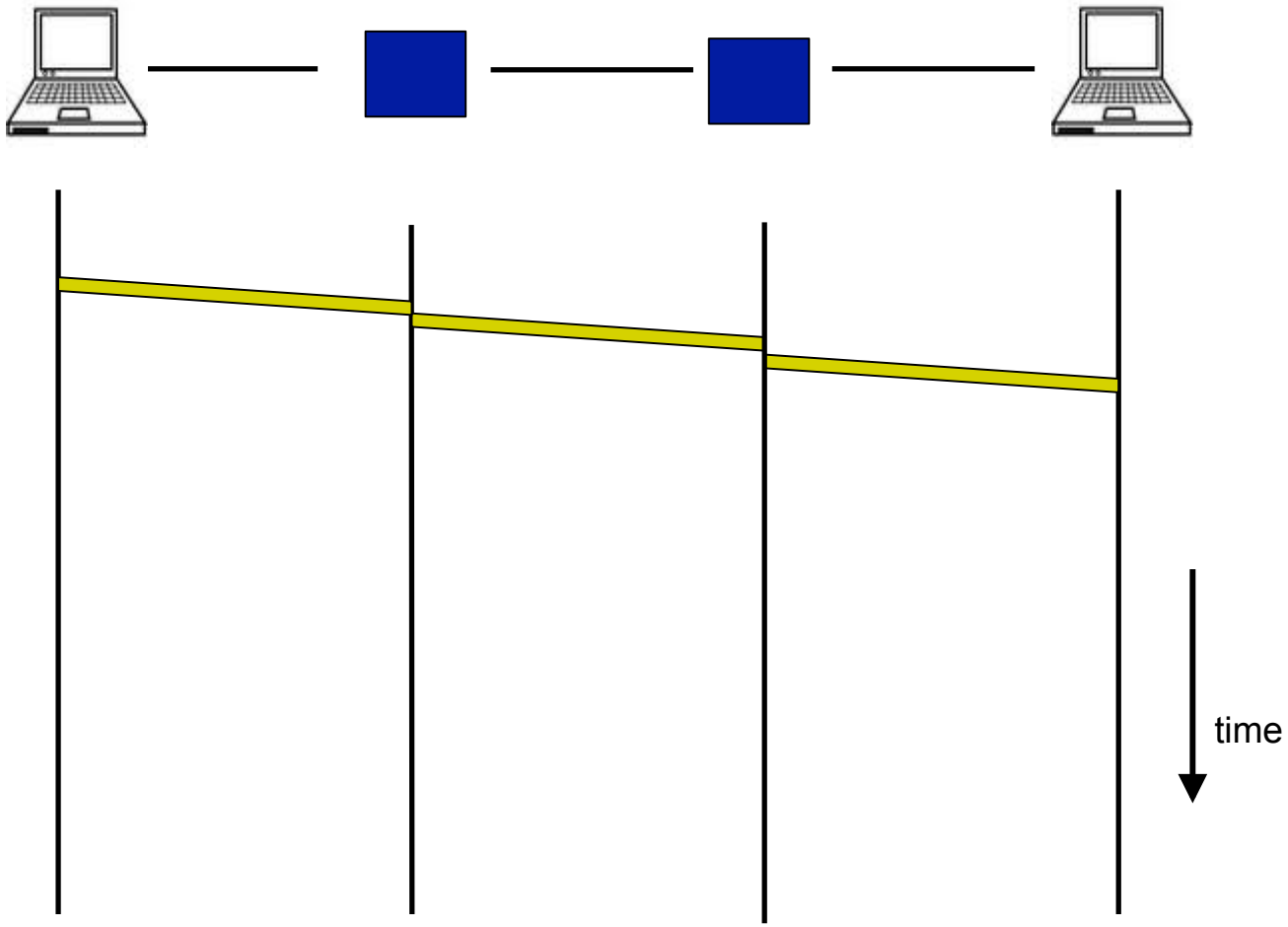

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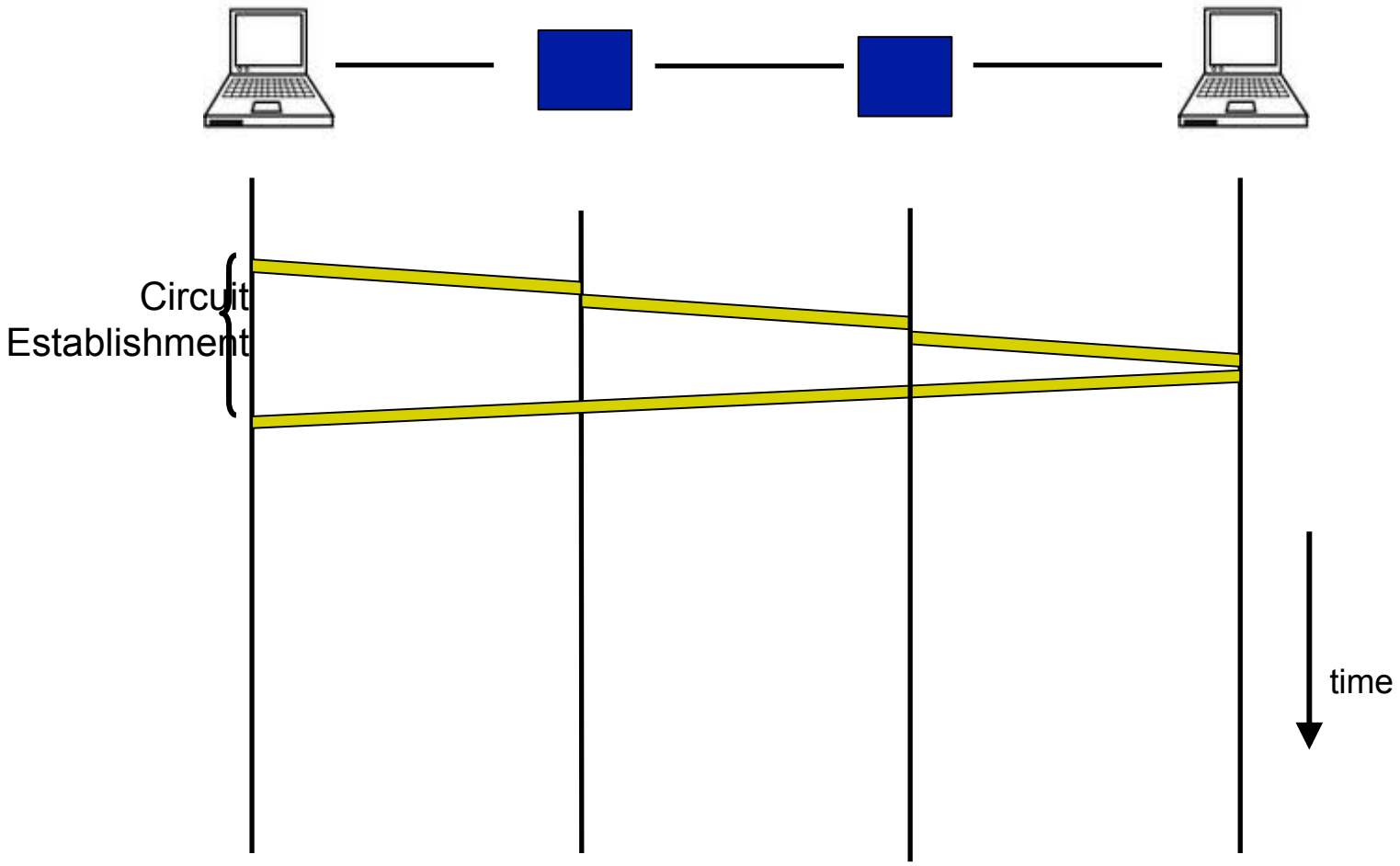

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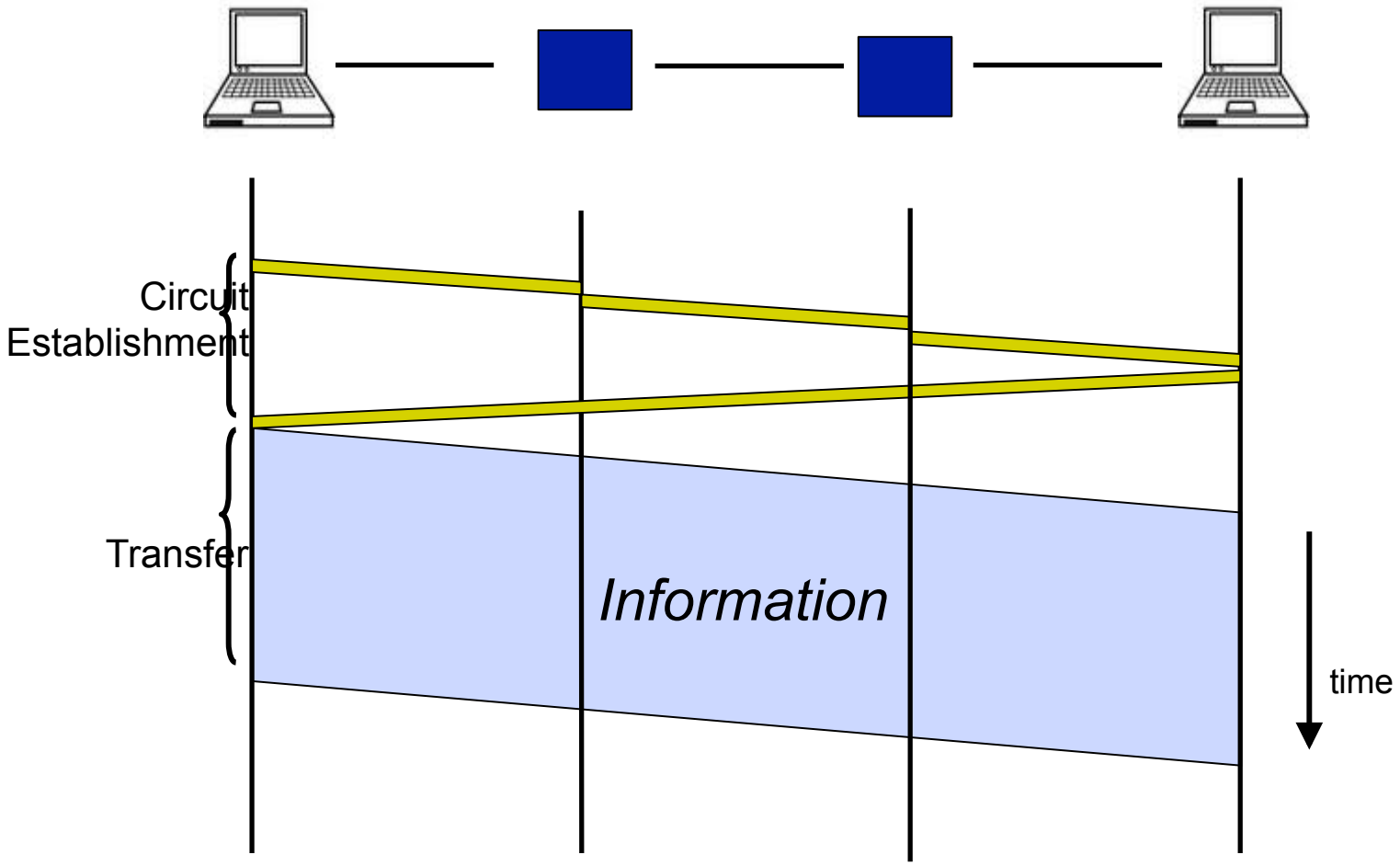
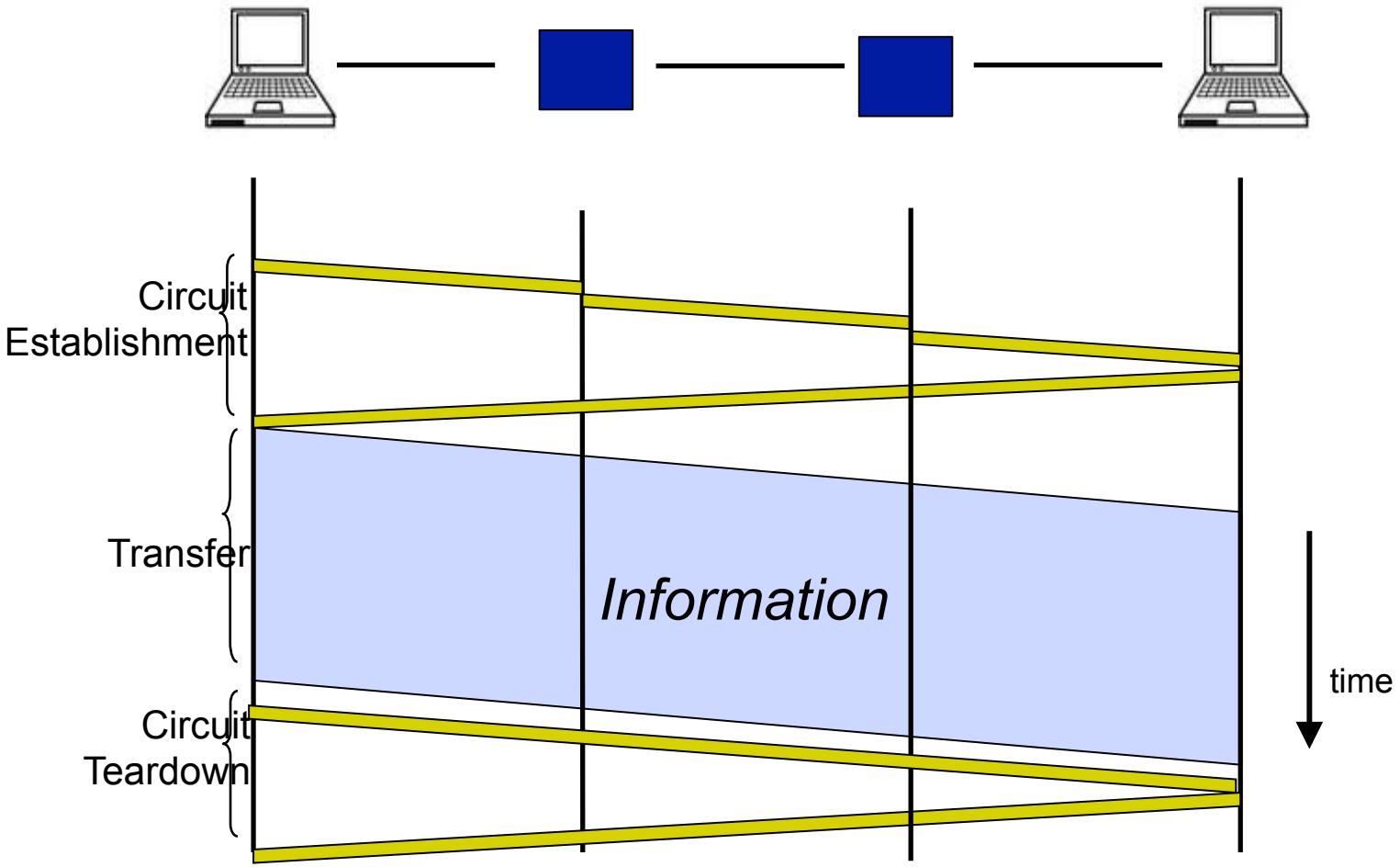


Timing in Circuit Switching

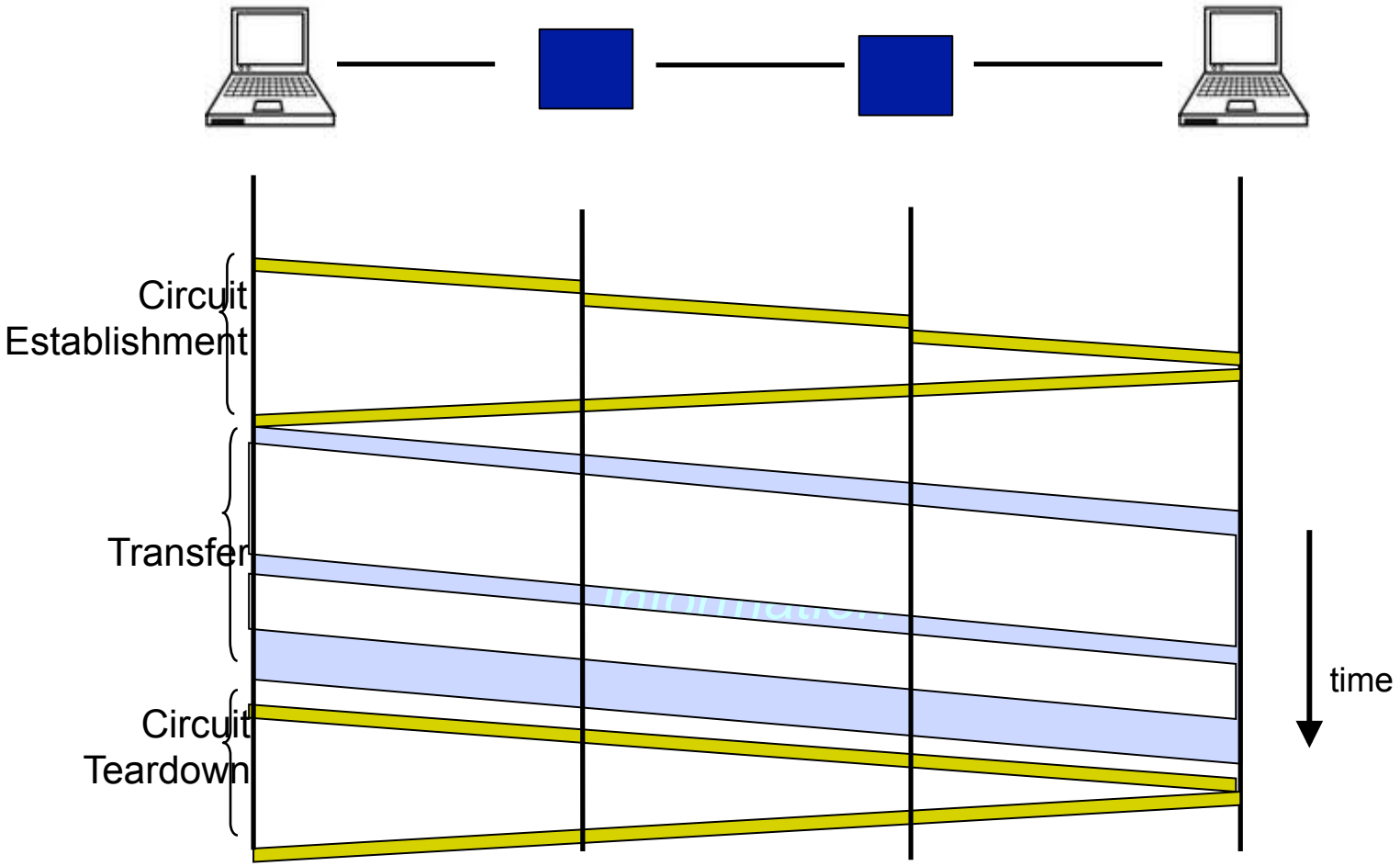


Circuit switching: pros and cons

- Pros
  - guaranteed performance
  - fast transfer (once circuit is established)

- Cons

Timing in Circuit Switching



Circuit switching: pros and cons

- Pros
  - guaranteed performance
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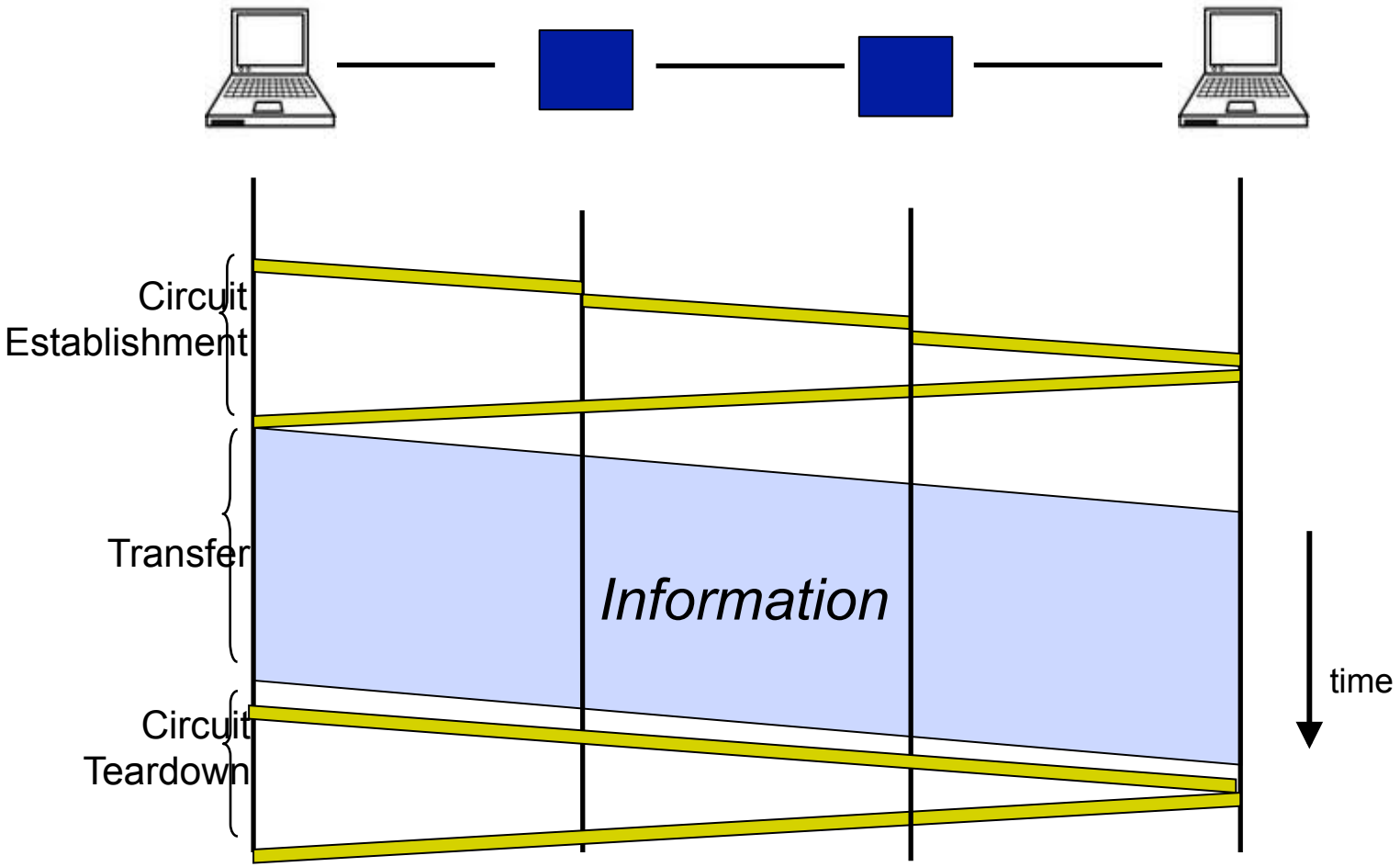
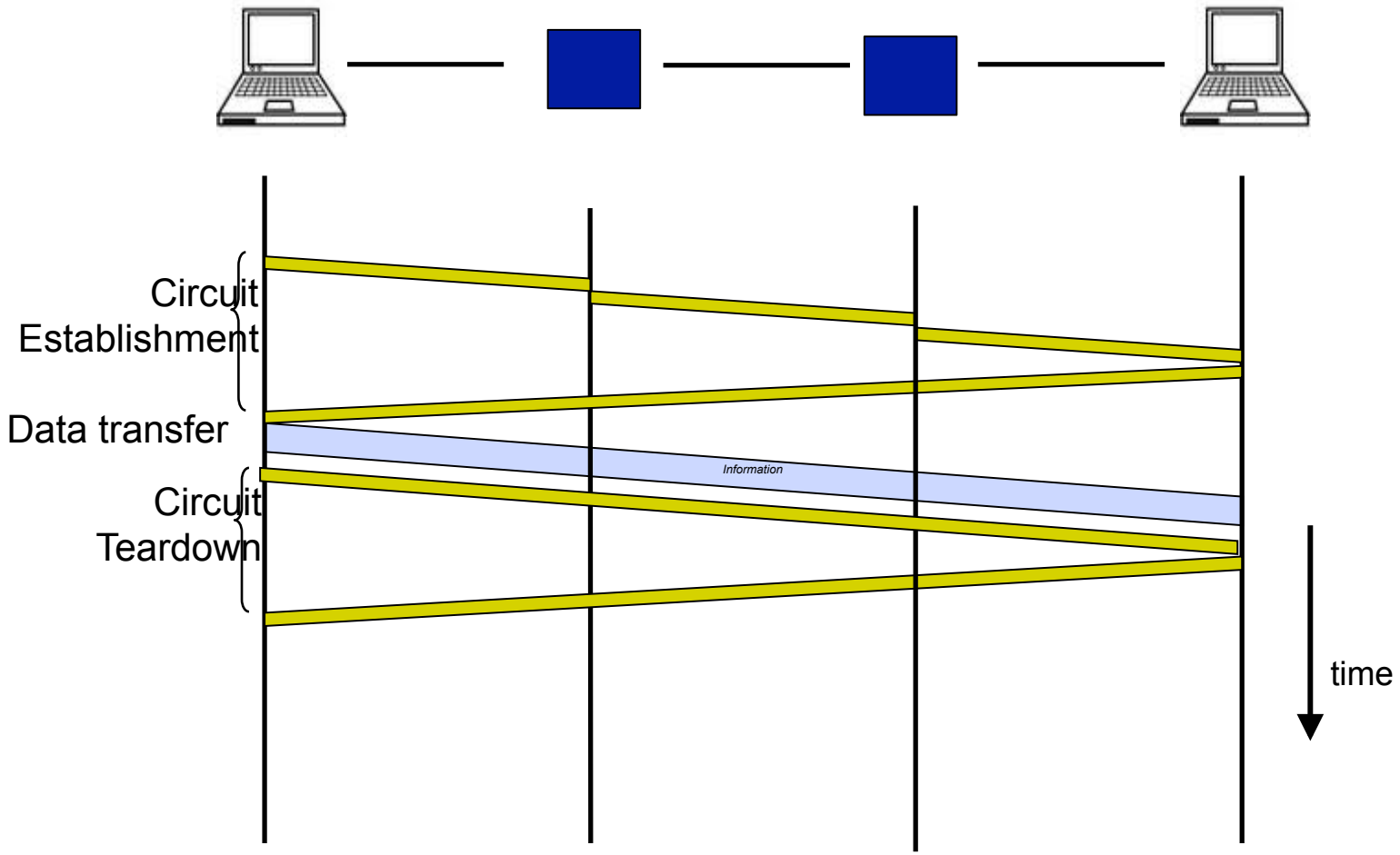
  - **wastes capacity if traffic is “bursty”**

Timing in Circuit Switching



Timing in Circuit Switching

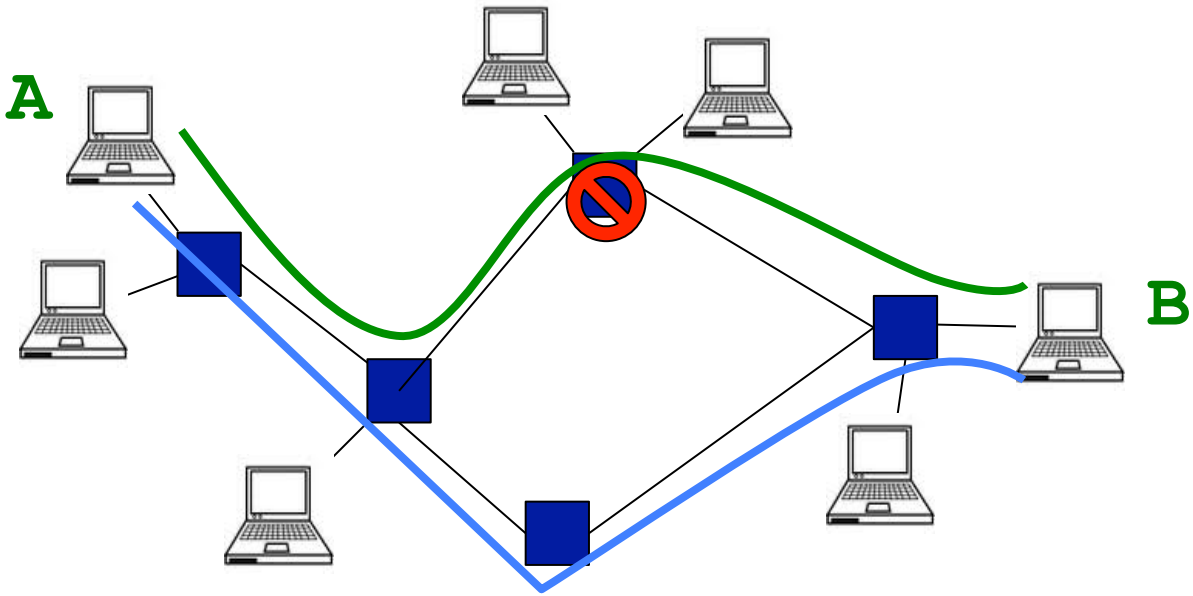


Circuit switching: pros and cons

- Pros
  - guaranteed performance
  - fast transfers (once circuit is established)

- Cons
  - wastes capacity if traffic is “bursty”
  - **connection setup time is overhead**

Circuit switching



Circuit switching doesn't "route around trouble"

Circuit switching: pros and cons

- Pros
  - guaranteed performance
  - fast transfers (once circuit is established)

- Cons
  - wastes capacity if traffic is “bursty”
  - connection setup time is overhead
  - **recovery from failure is slow**

Circuit switching: pros and cons

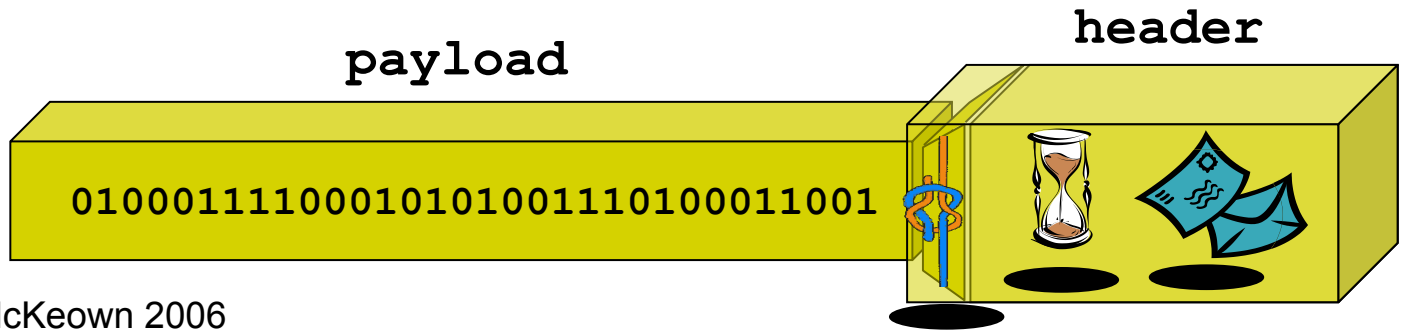
- Pros
  - guaranteed performance
  - fast transfers (once circuit is established)

- Cons
  - wastes capacity if traffic is “bursty”
  - connection setup adds delay
  - recovery from failure is slow
  - [in the telephone network] designed for a specific app

Packet switching

Packet Switching

- Data is sent as chunks of formatted bits (Packets)
- Packets consist of a "header" and "payload"
  - Data is sent as chunks of formatted bits (Packets)
  - Packets consist of a "header" and "payload"
- Switches "forward" packets based on their headers
- Each packet travels independently
  - no notion of packets belonging to a "circuit"
- No link resources are reserved in advance. Instead packet switching leverages statistical multiplexing



Inventors of Packet Switching

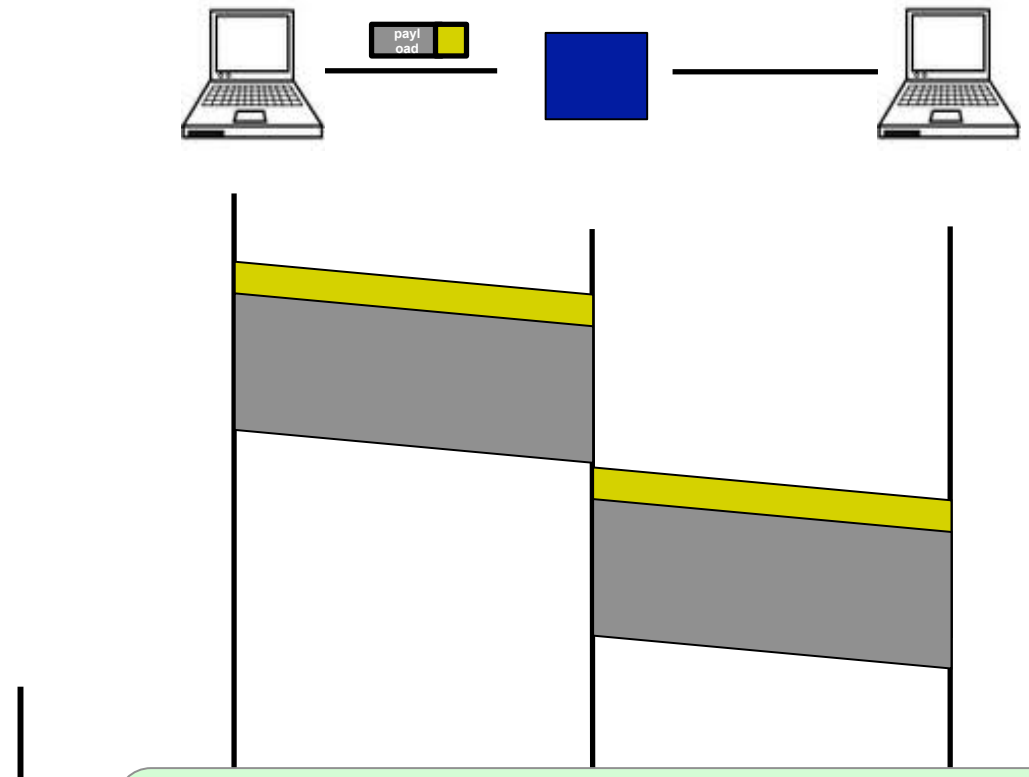
Paul Baran

Donald Davies

Leonard Kleinrock

- Watch the following interview with Prof. Kleinrock for a historical perspective:
- **https://www.youtube.com/watch?v=qsgrtrwydjw**

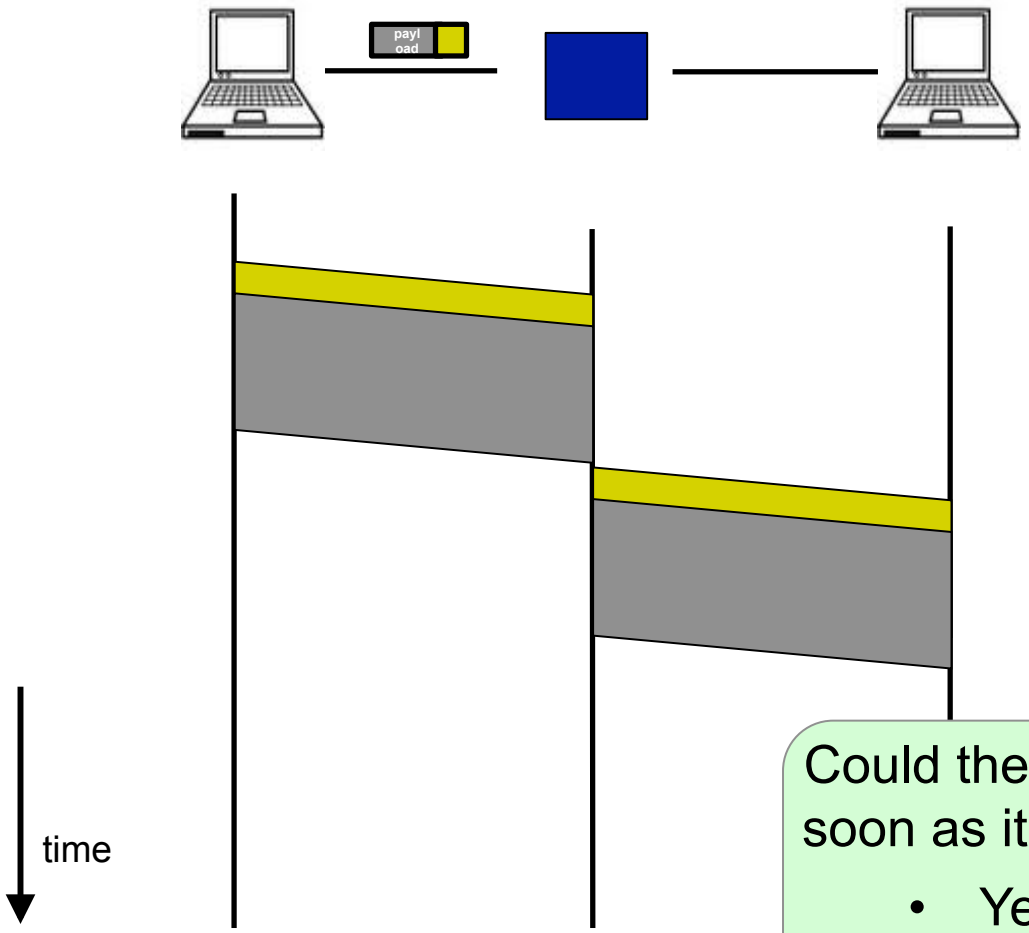
Timing in Packet Switching



What about the time to process the packet at the switch?

- We'll assume it's relatively negligible (mostly true)

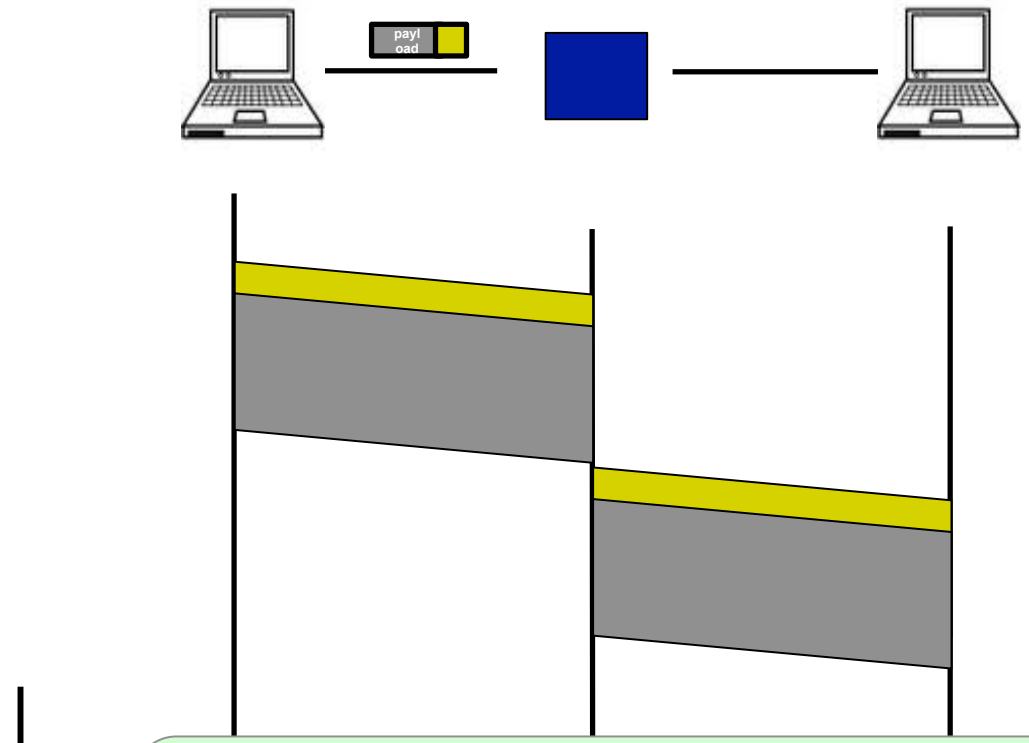
Timing in Packet Switching



Could the switch start transmitting as soon as it has processed the header?

- Yes! This would be called a “cut through” switch

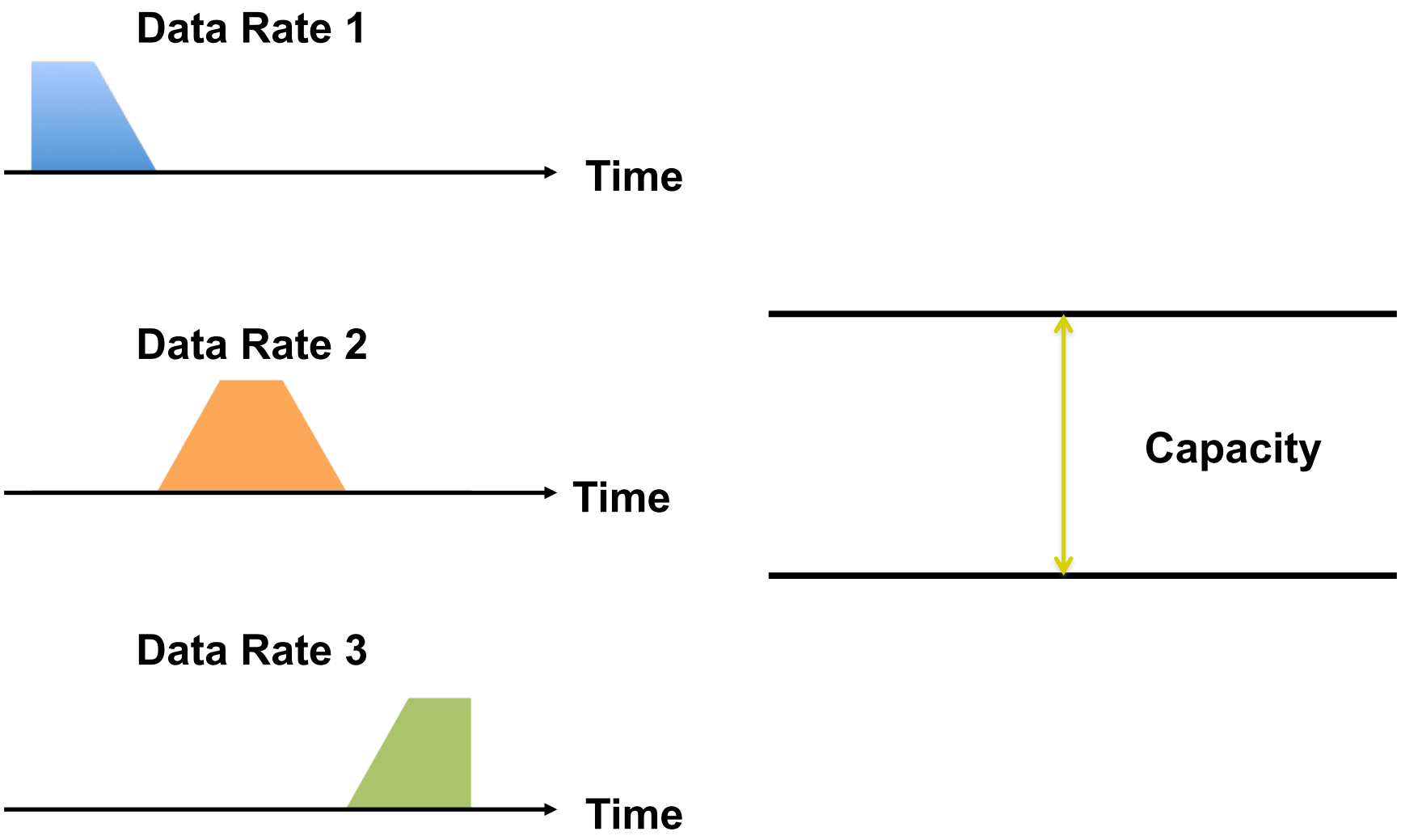
Timing in Packet Switching



We will always assume a switch processes/forwards a packet after it has received it entirely.
This is called “store and forward” switching

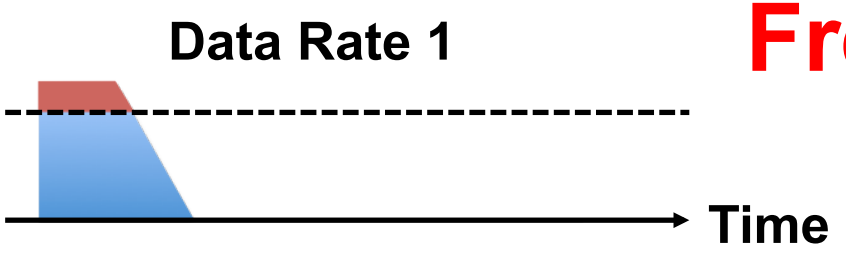
Statistical Multiplexing

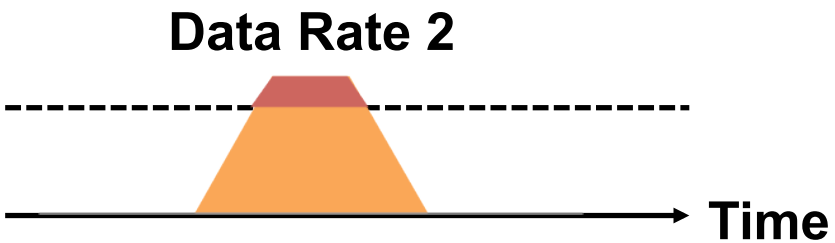
Three Flows with Bursty Traffic

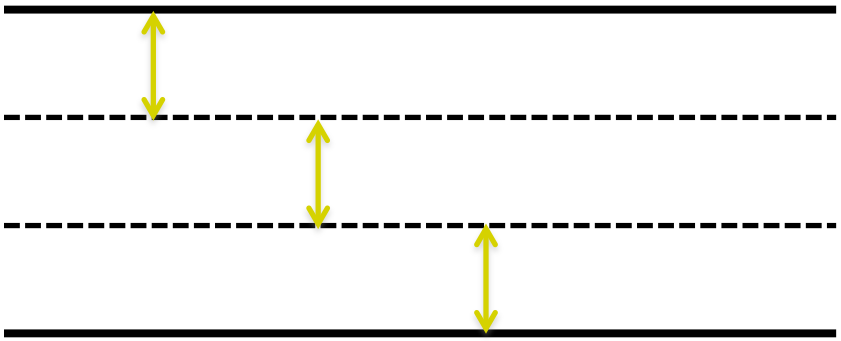


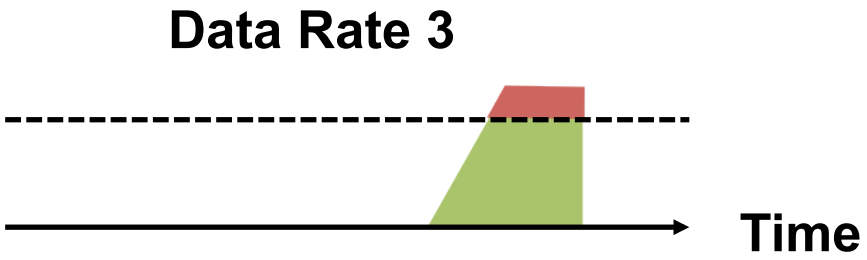
When Each Flow Gets 1/3rd of Capacity

Frequent Overloading

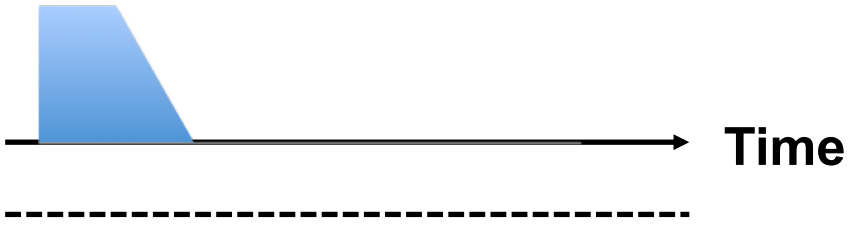


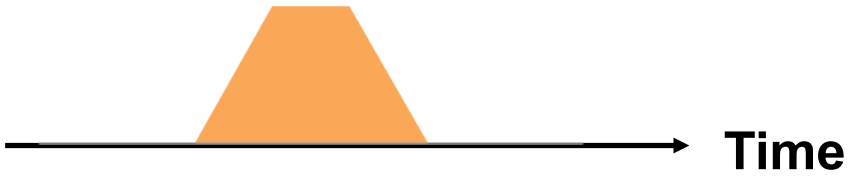






When Flows Share Total Capacity



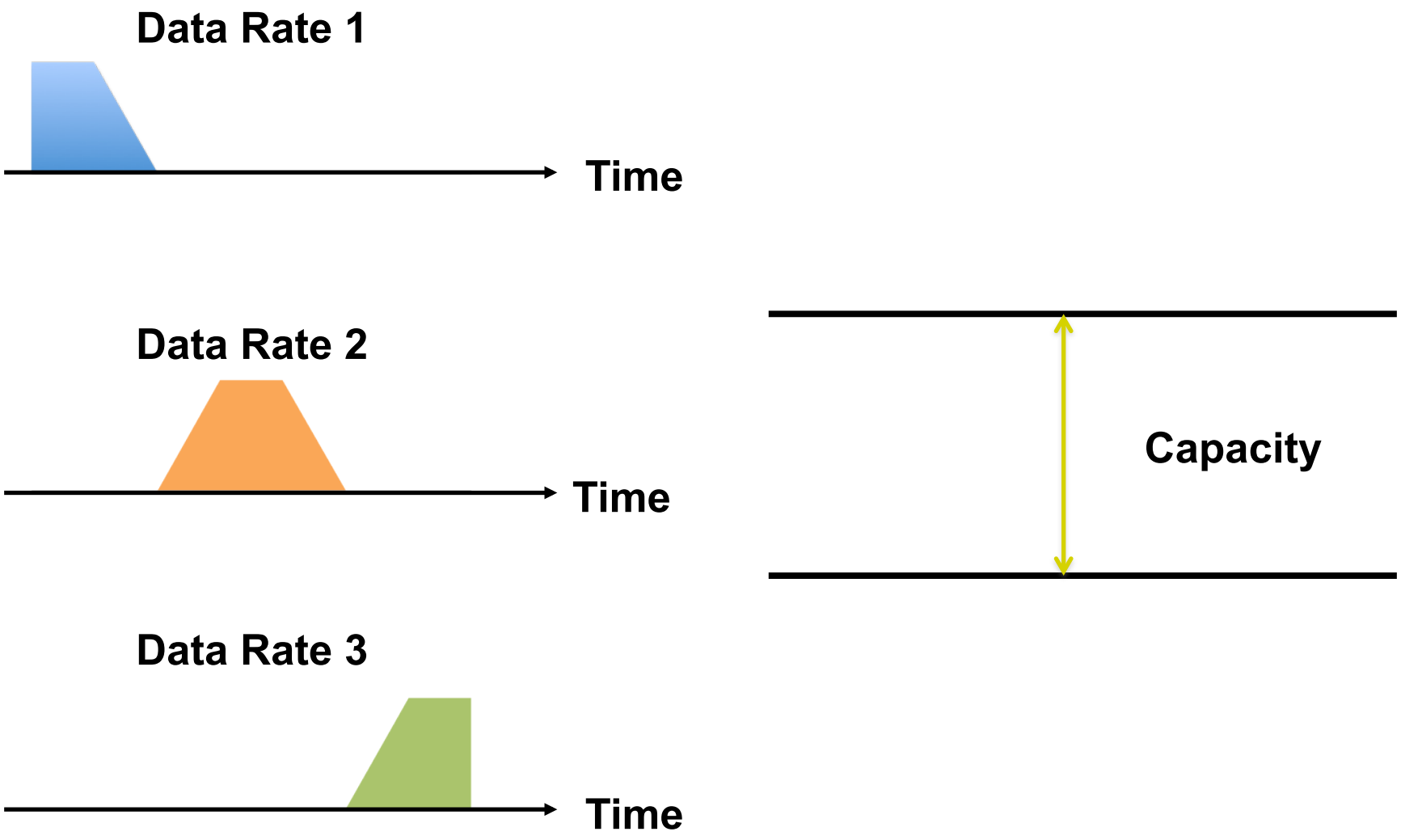


No Overloading

Statistical multiplexing relies on the assumption that not all flows burst at the same time.

Very similar to insurance, and has same failure case

Three Flows with Bursty Traffic



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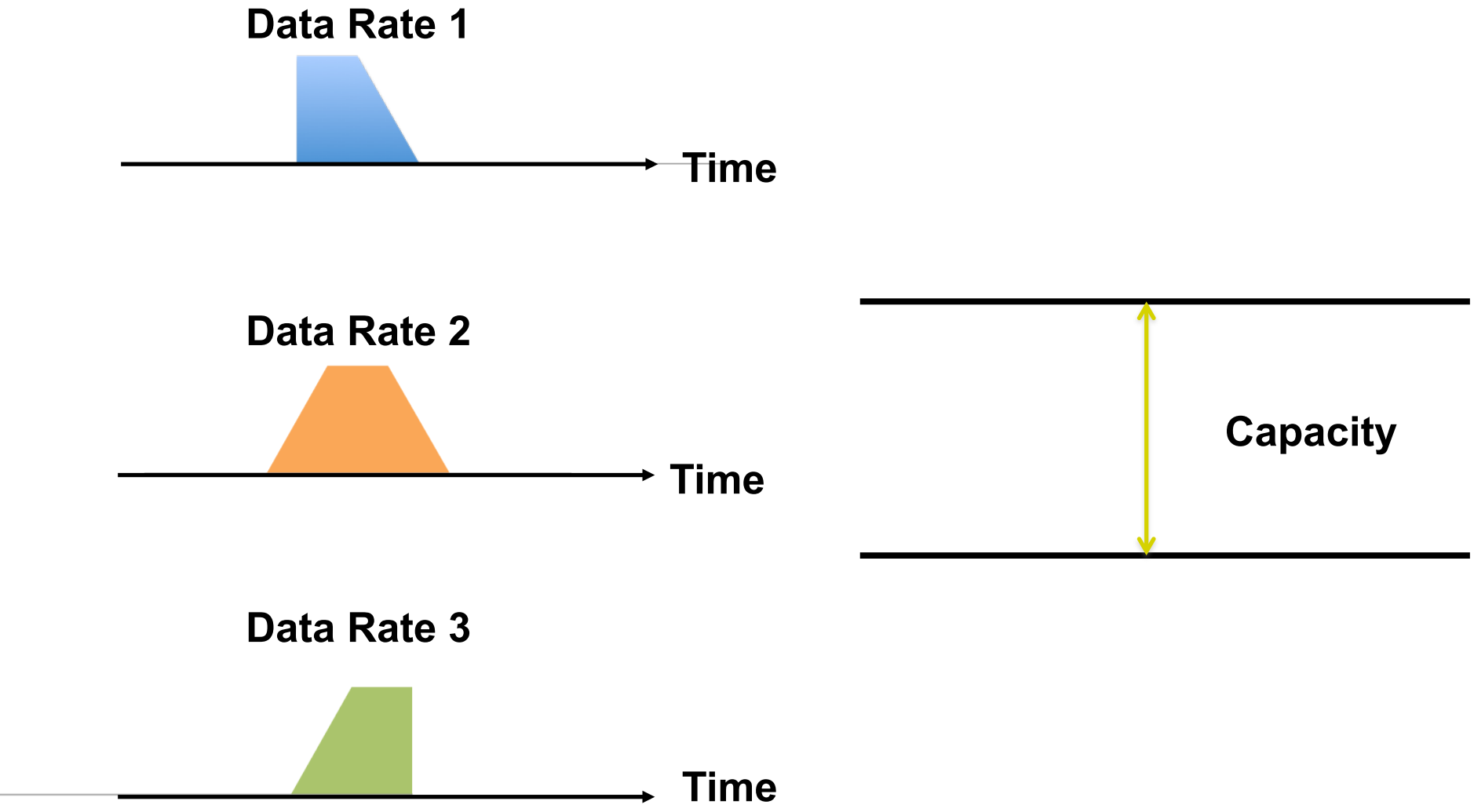
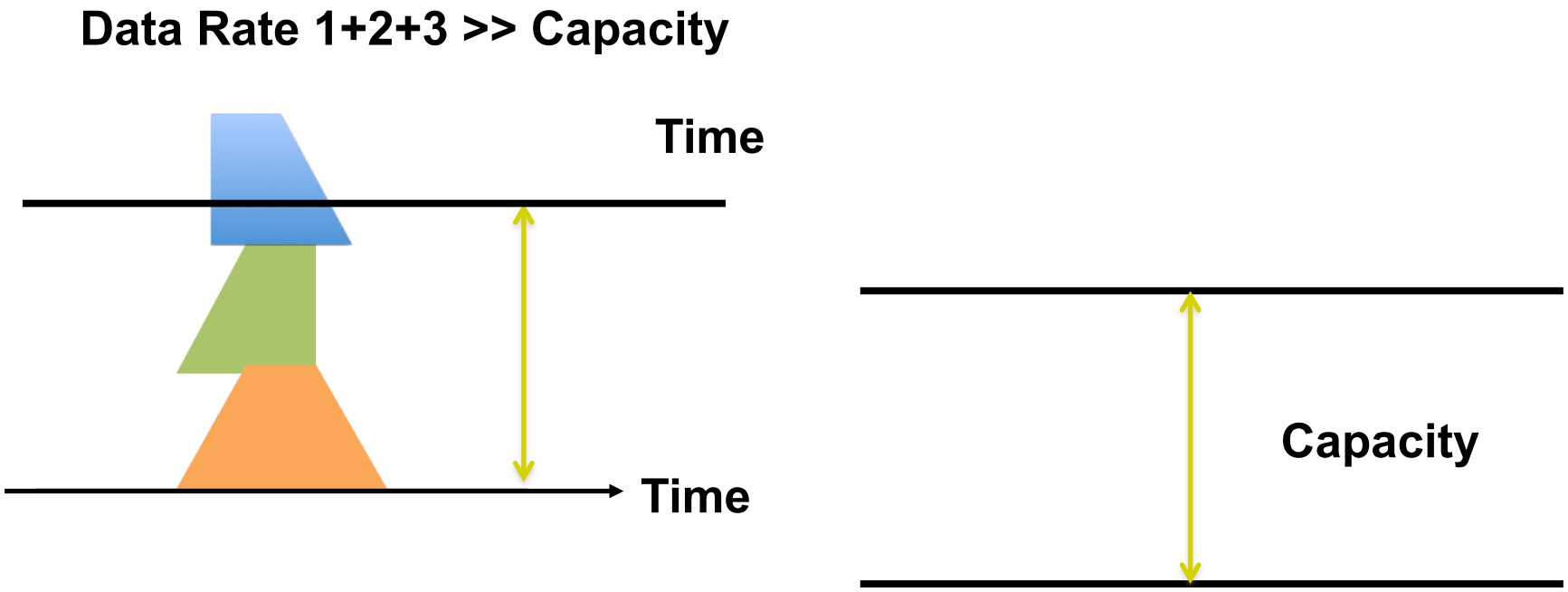
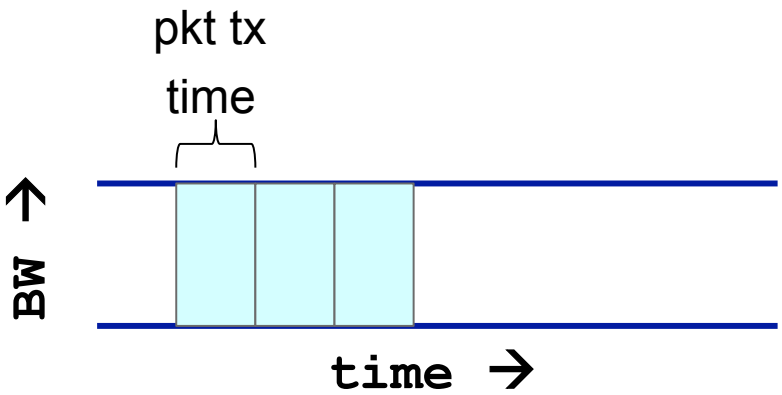


Three Flows with Bursty Traffic

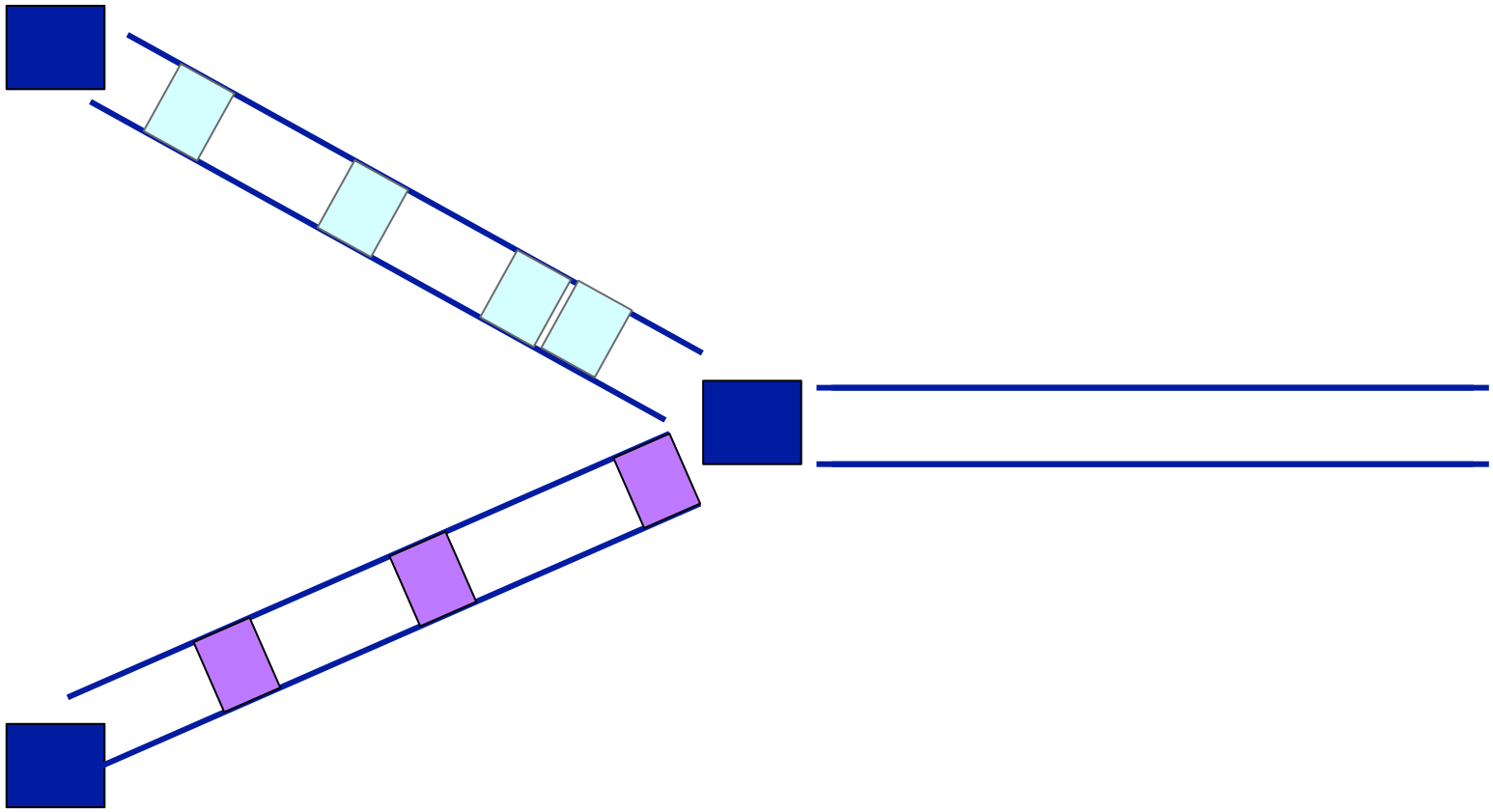


What do we do under overload?

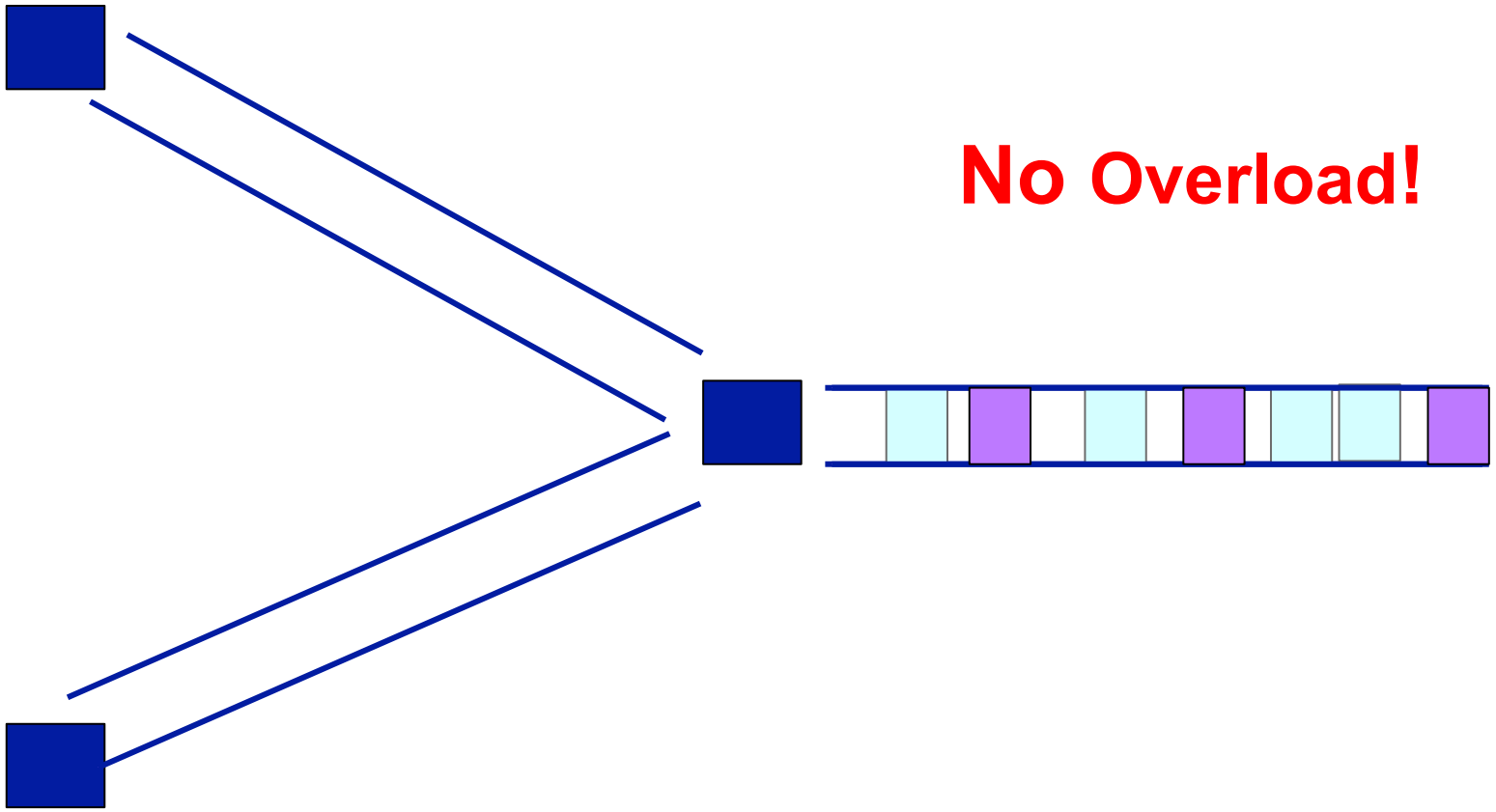
Statistical multiplexing: pipe view



Statistical multiplexing: pipe view

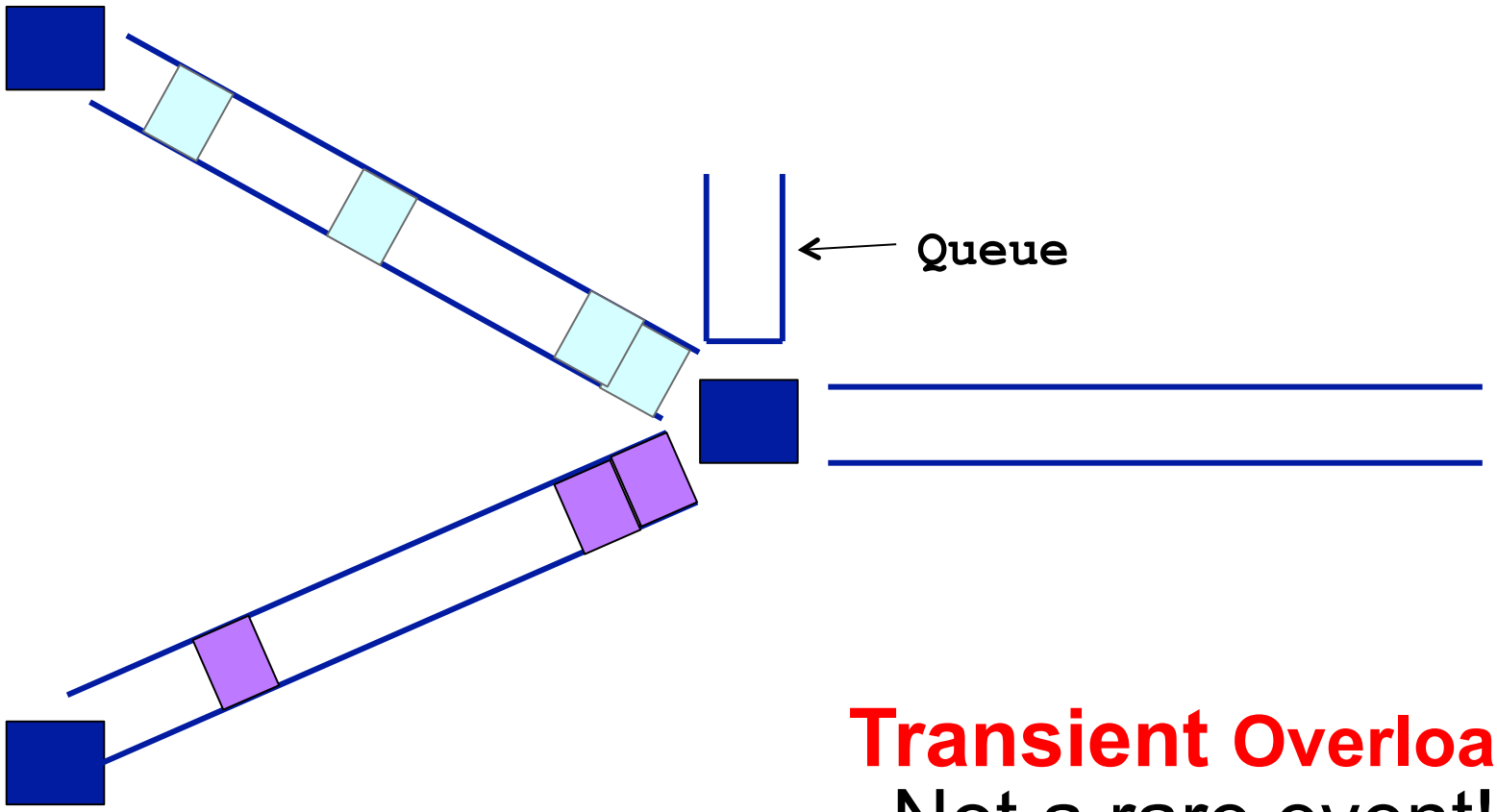


Statistical multiplexing: pipe view



No Overload!

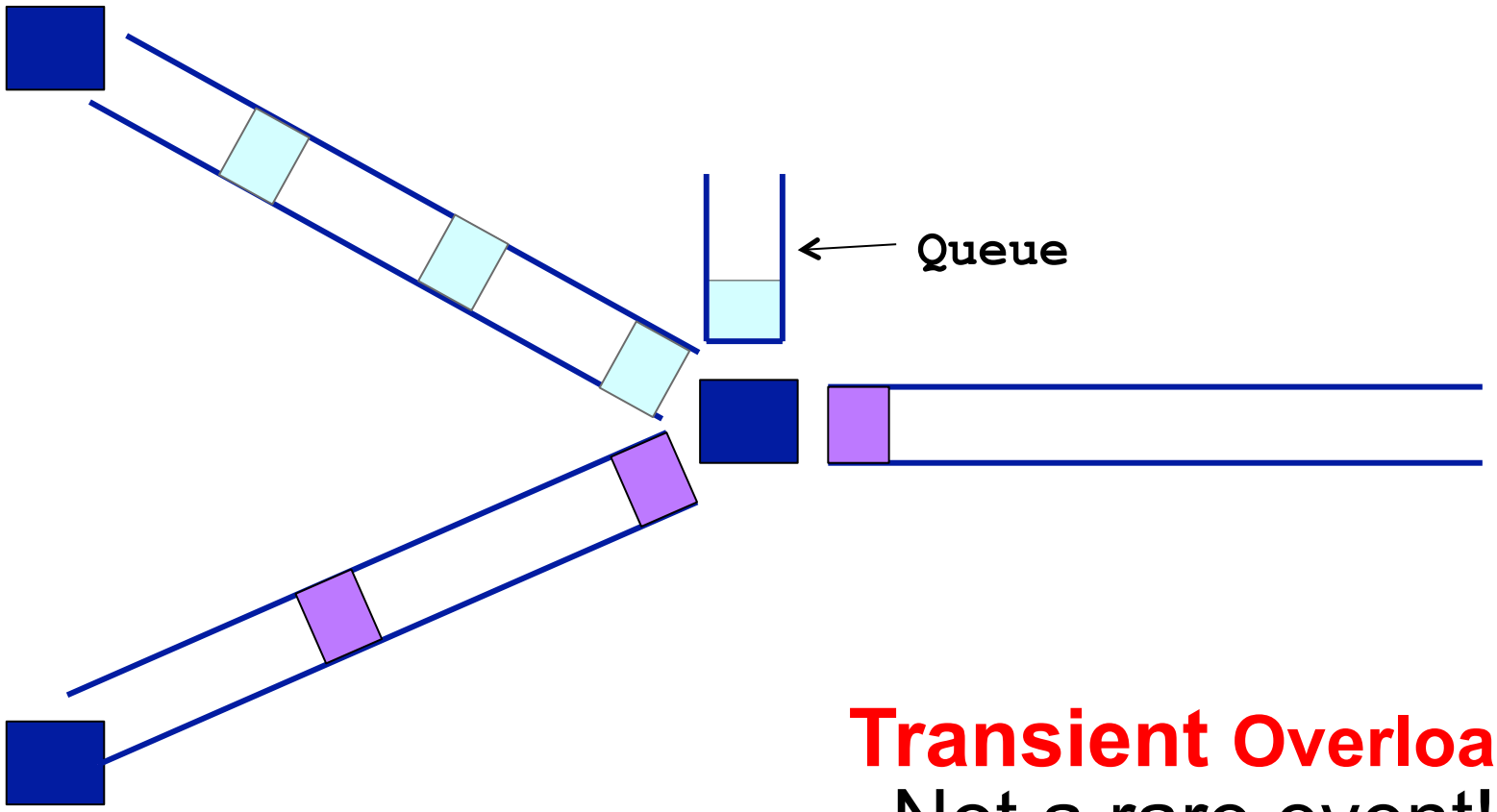
Statistical multiplexing: pipe view



Transient Overload

Not a rare event!

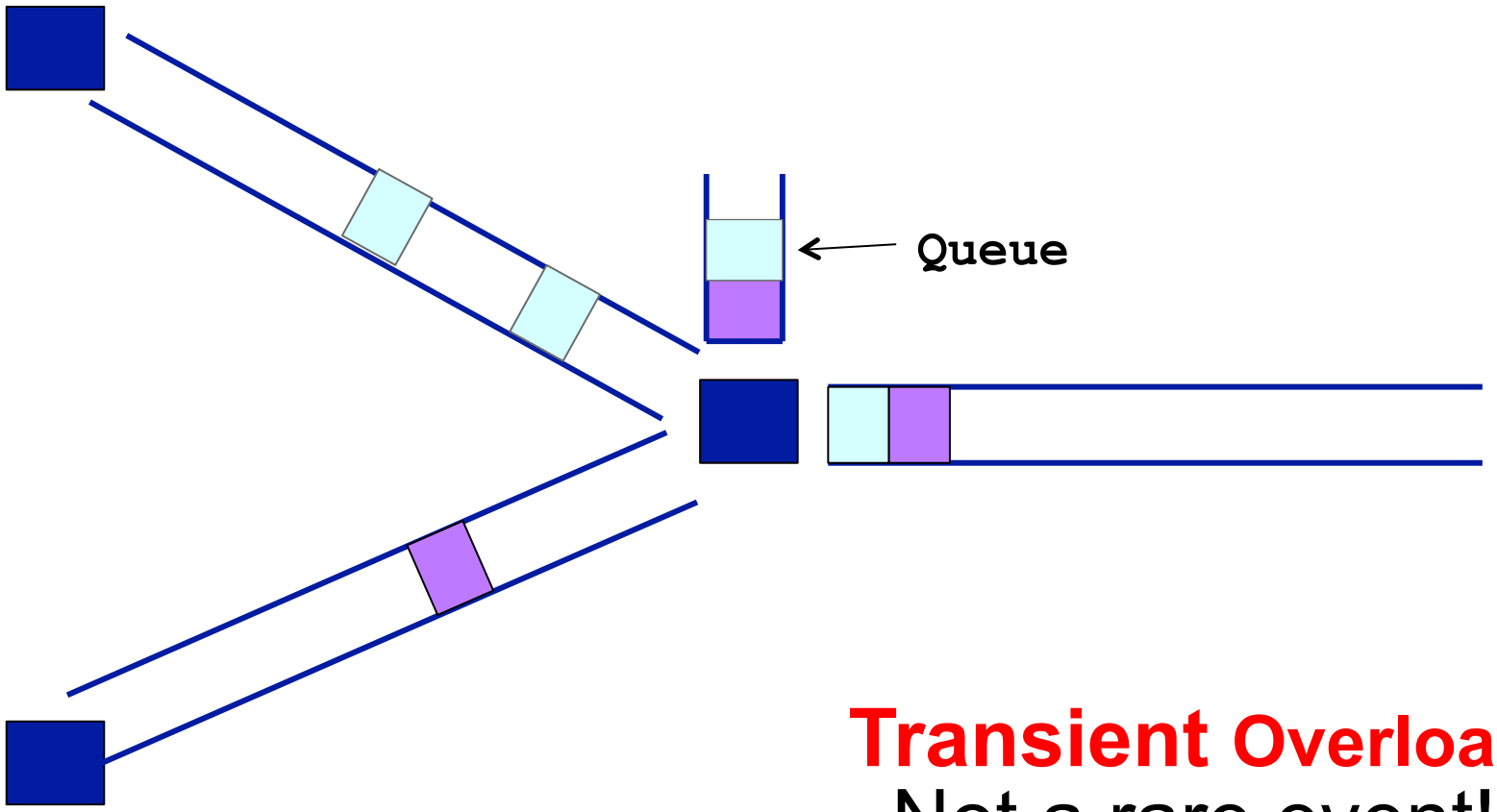
Statistical multiplexing: pipe view



Transient Overload

Not a rare event!

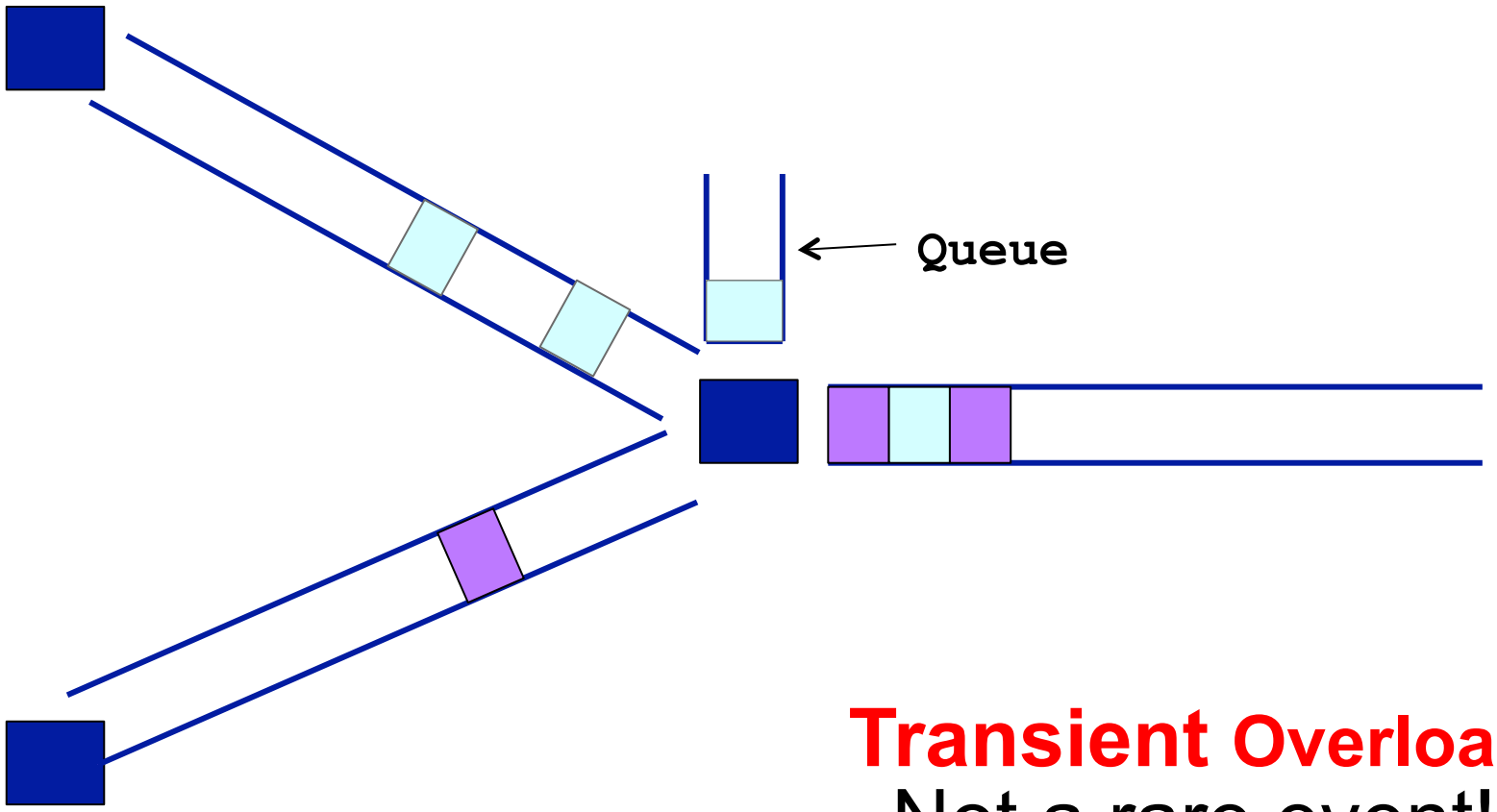
Statistical multiplexing: pipe view



Transient Overload

Not a rare event!

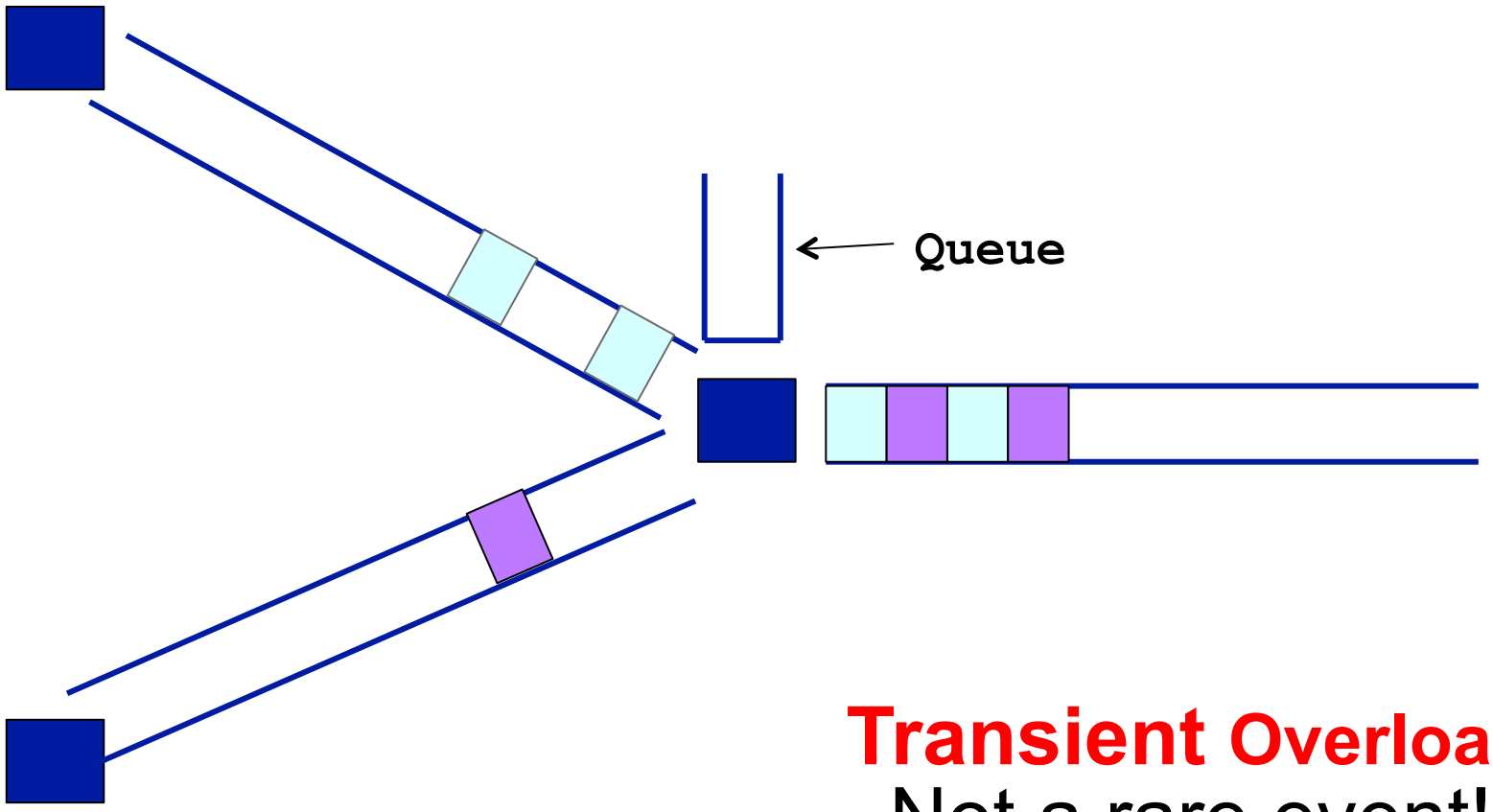
Statistical multiplexing: pipe view



Transient Overload

Not a rare event!

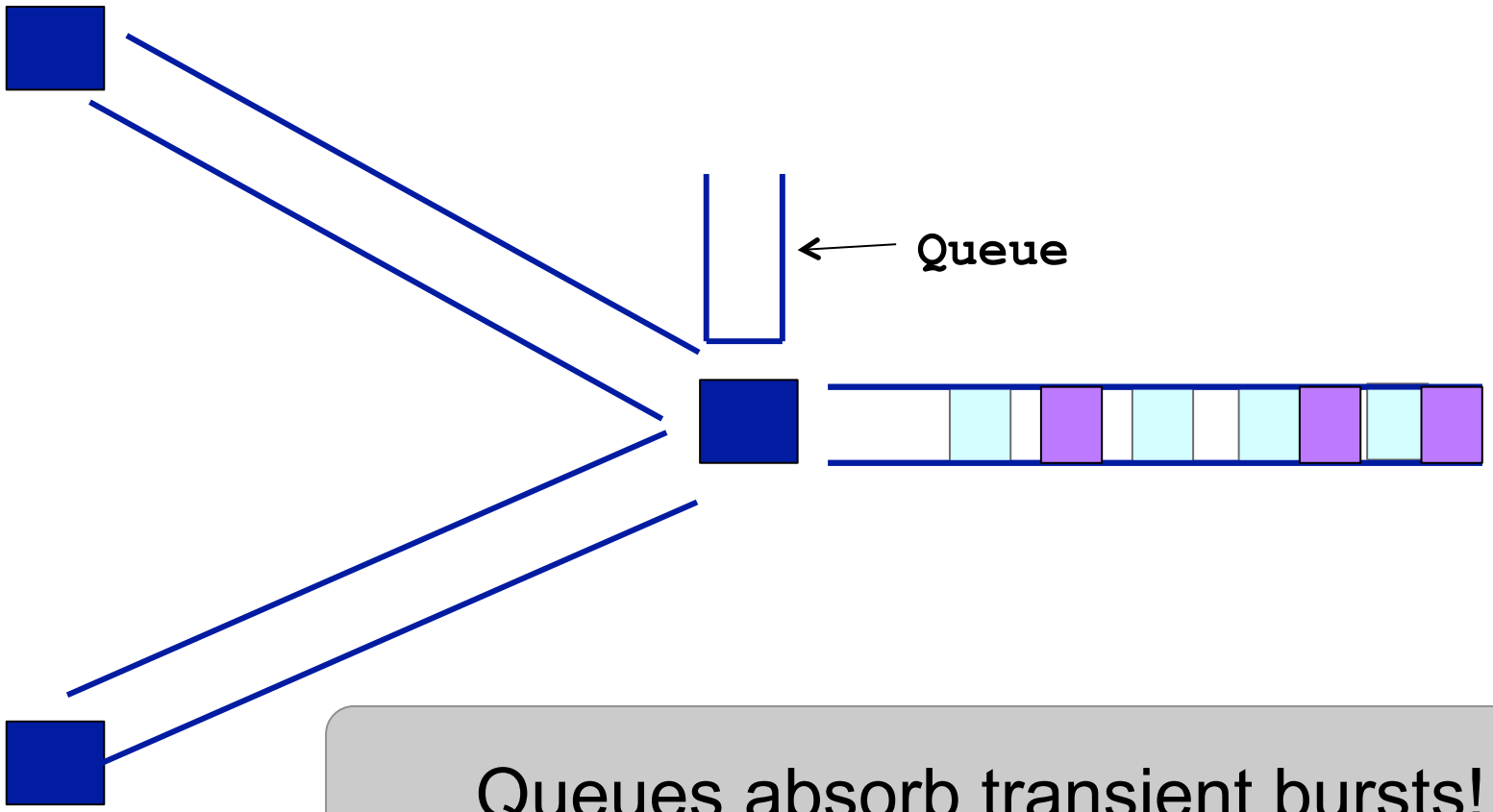
Statistical multiplexing: pipe view



Transient Overload

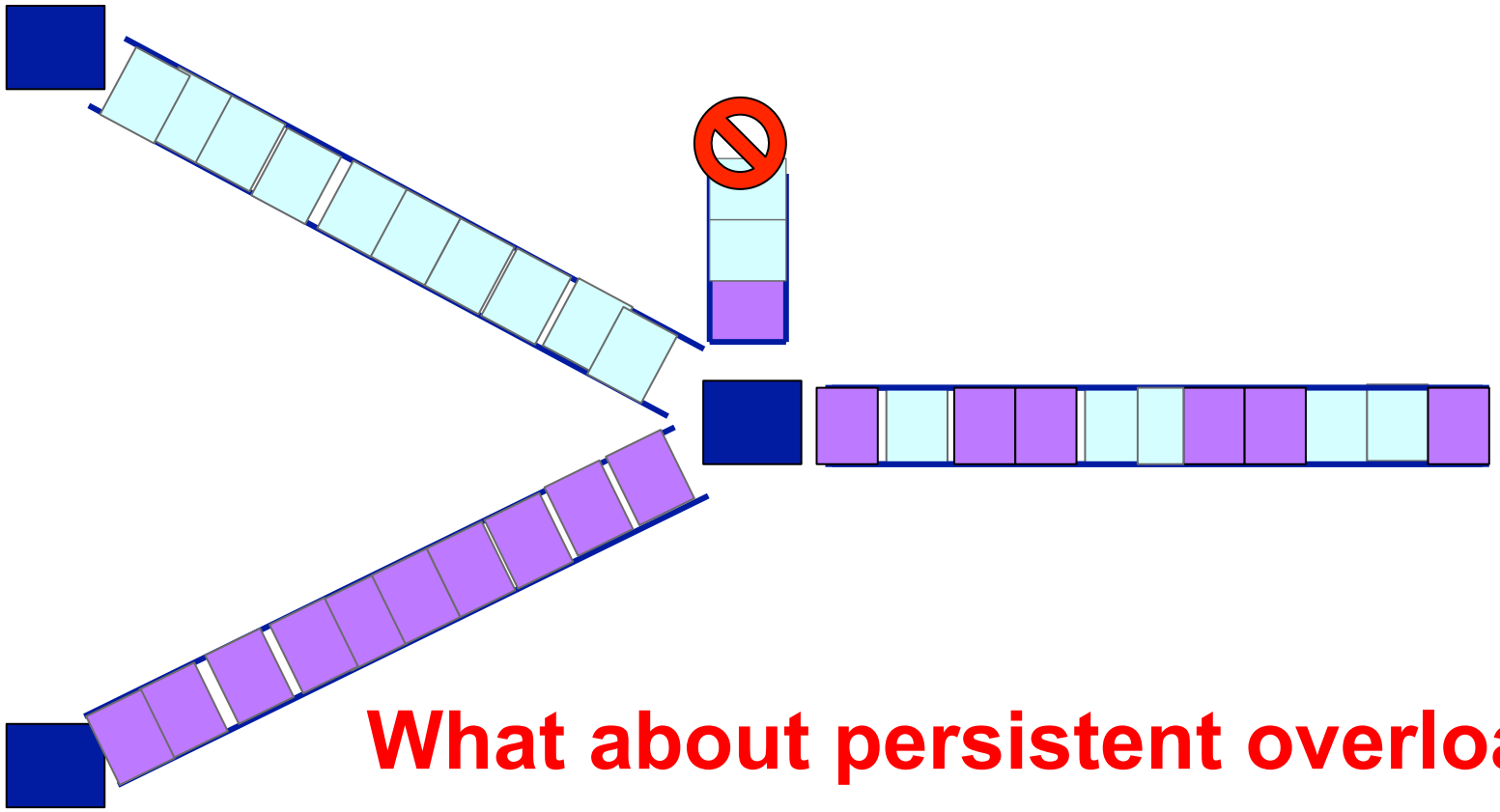
Not a rare event!

Statistical multiplexing: pipe view



Queues absorb transient bursts!

Statistical multiplexing: pipe view



What about persistent overload?

Will eventually drop packets

Queues introduce queuing delays

- Recall, packet delay = tx delay + prop delay
- With queues (stat. muxing)
  - packet delay = tx delay + prop delay + queuing delay
- Queuing delay caused by “packet interference”
- Made worse at high load
  - less “idle time” to absorb bursts
  - think about traffic jams at rush hour

Circuit switching: pros and cons

- Pros
  - guaranteed performance
  - fast transfers (once circuit is established)

- Cons
  - wastes capacity if traffic is “bursty”
  - connection setup adds delay
  - recovery from failure is slow

Packet switching: pros and cons

- Cons
  - no guaranteed performance
  - header overhead per packet
  - queues and queuing delays

- Pros
  - efficient use of capacity (stat. muxing)
  - no overhead due to connection setup
  - resilient -- can `route around trouble'