CS 168

Designing the Internet

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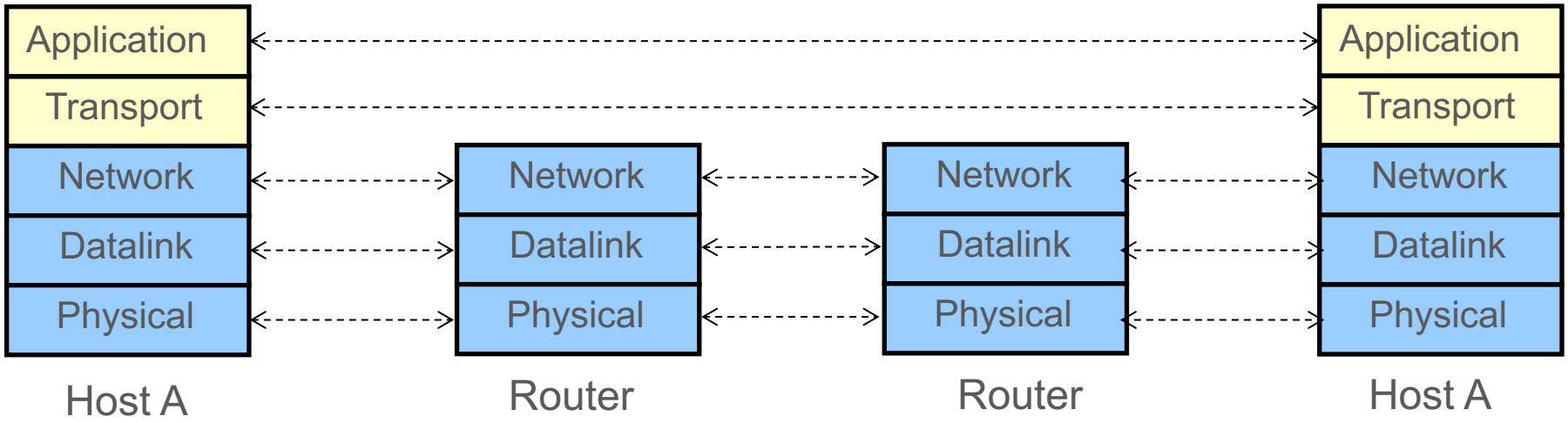
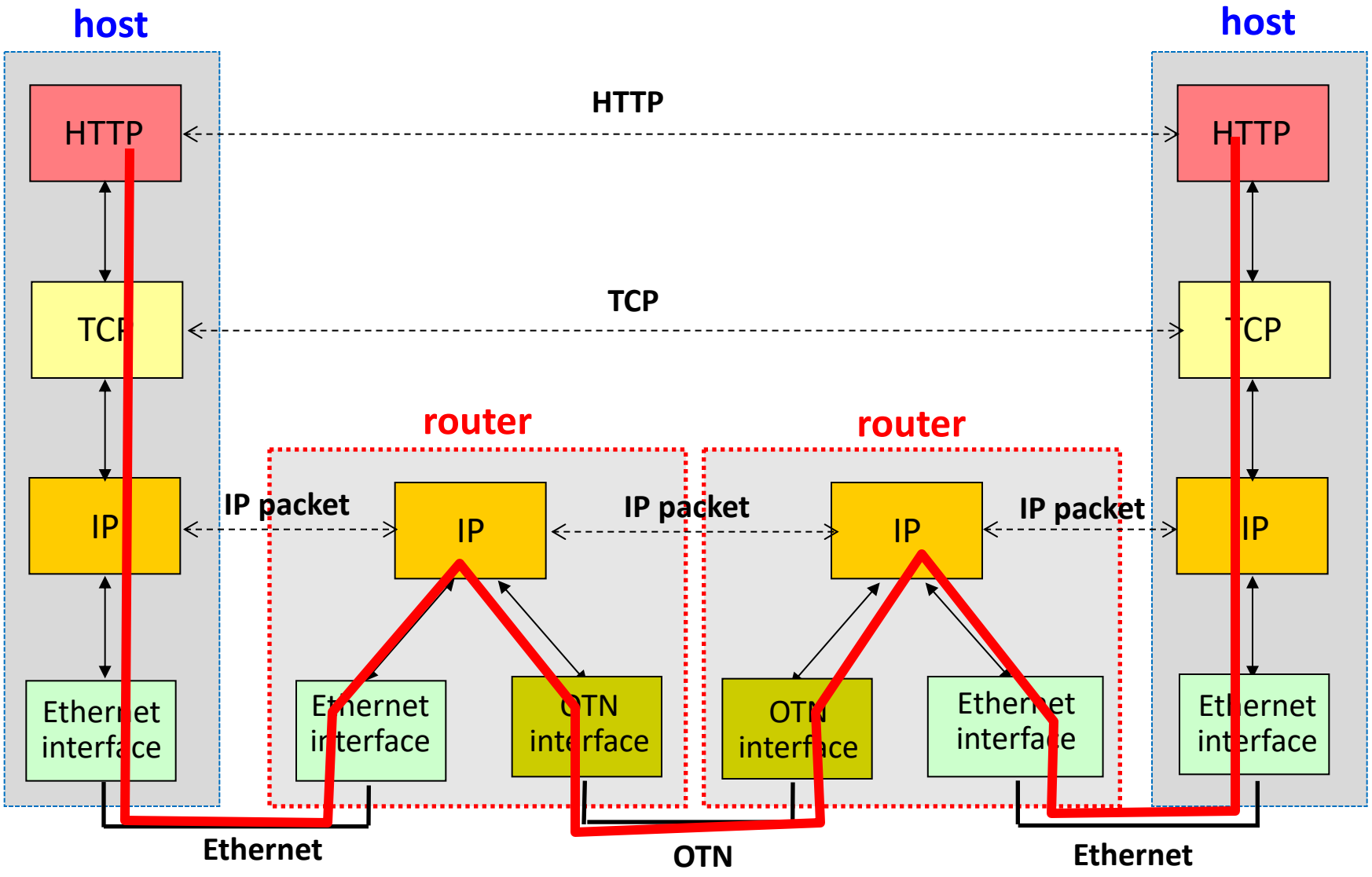
Outline

- Review: layering and the Internet
- The end-to-end argument
- Get started on Ethernet (Rob)

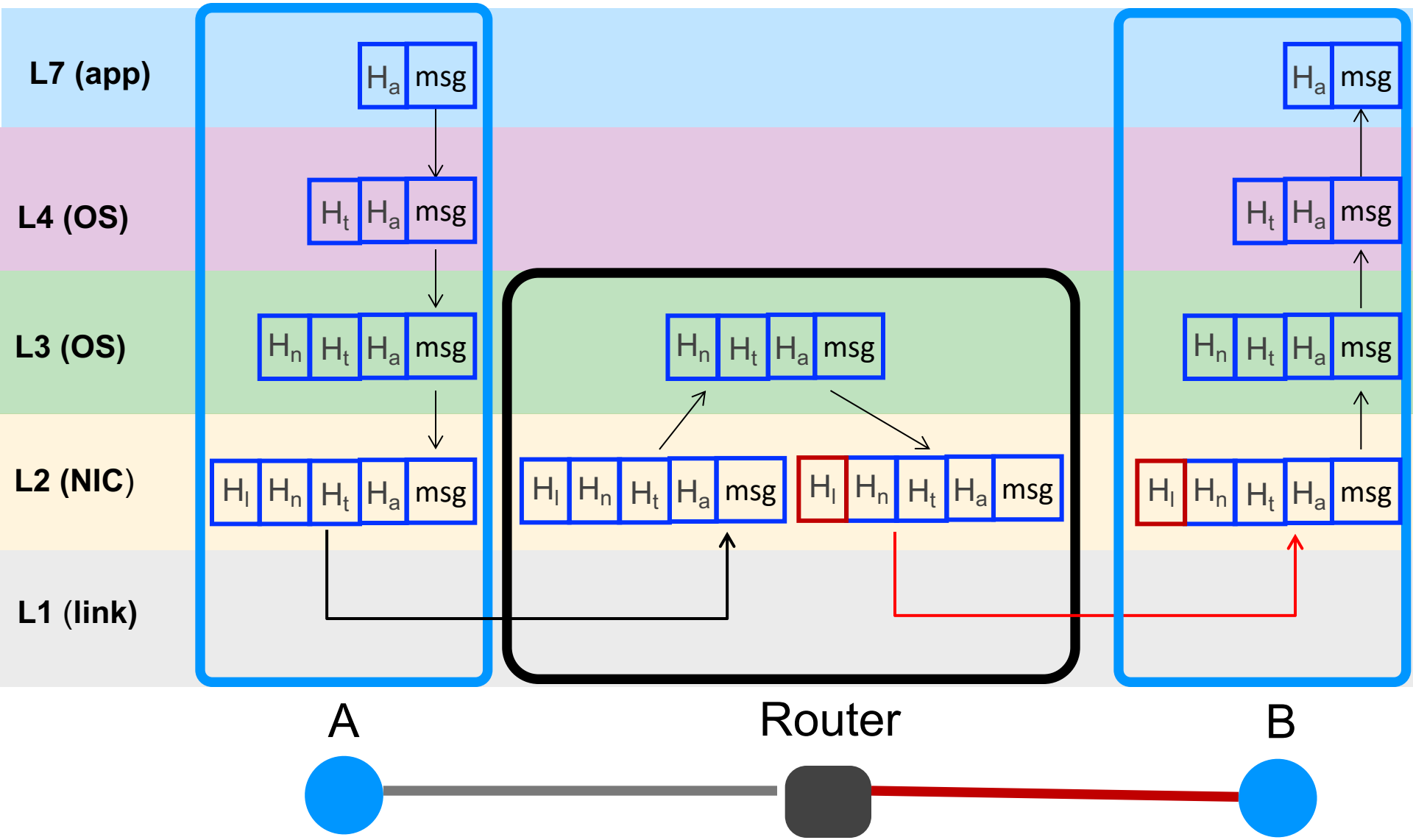
Recall: The Internet's layered architecture



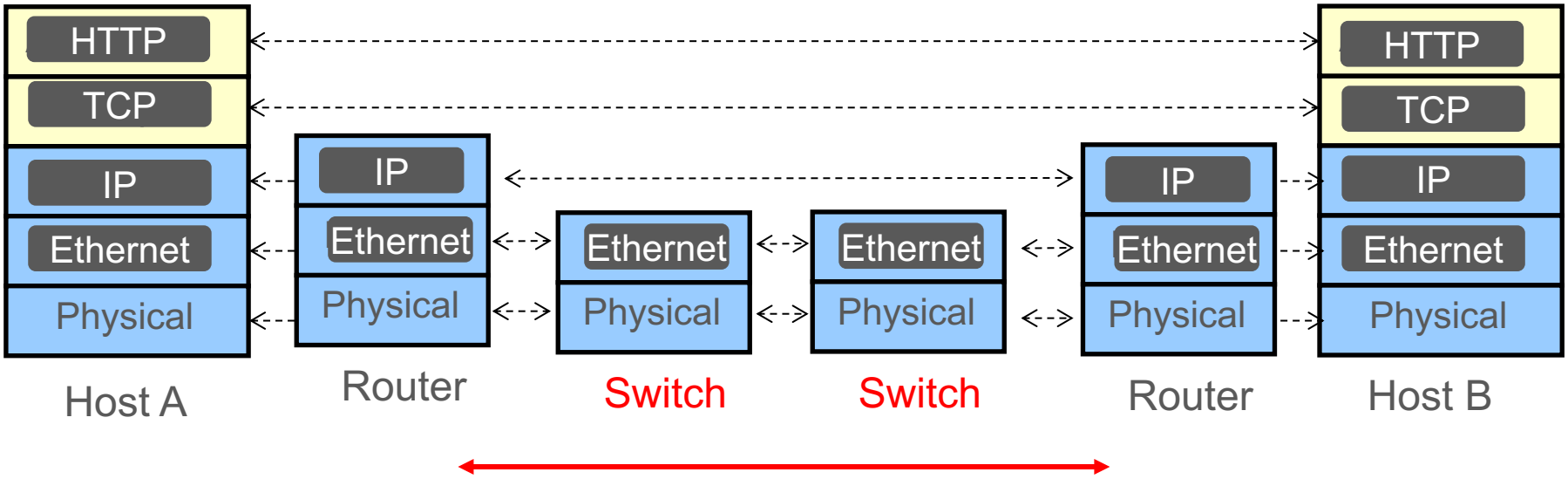
Recall: Example



Recall: Adding/removing headers from a packet as it traverses layers



Where we left off ...



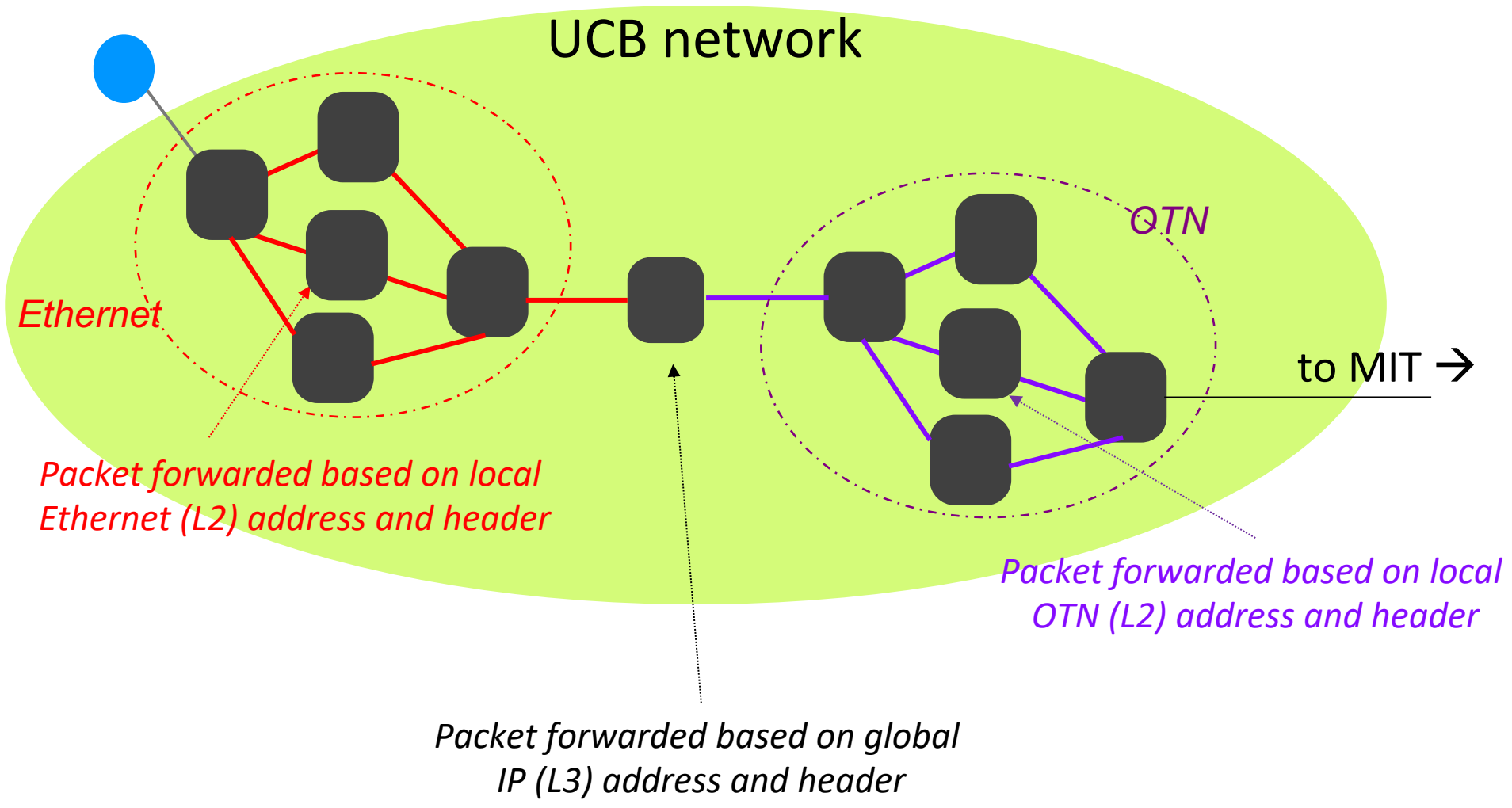
Packet traverses a local Ethernet network;
(i.e., based on its L2 header)

Local vs. Global networking

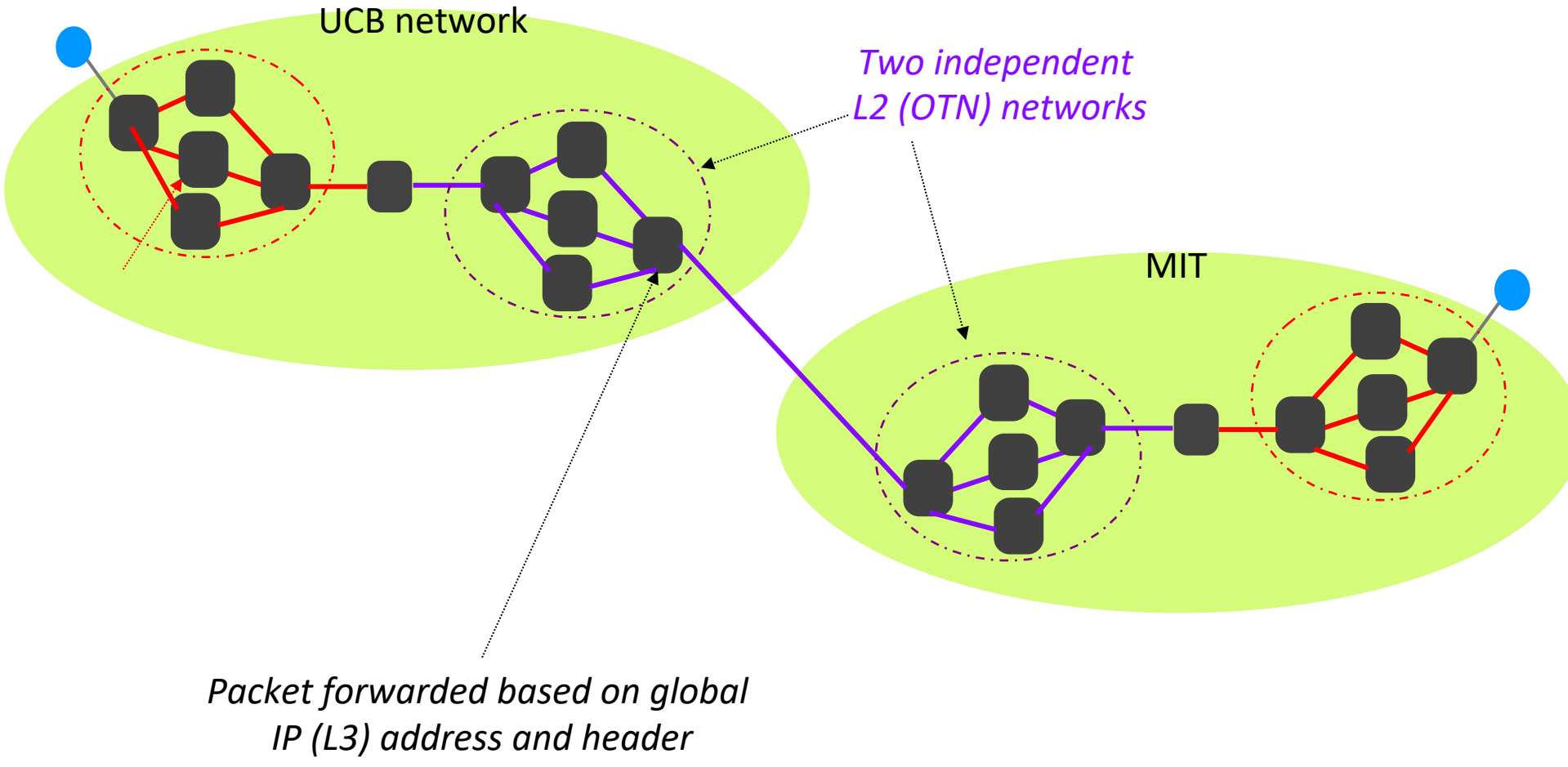
- Recall:
  - Local → relying on L2 headers
  - Global → relying on L3 headers

- So, when do we need L3 to interconnect L2 networks?
  1. When the L2 networks are based on different technologies
  2. When the L2 networks are operated independently (e.g., for administrative or policy reasons)

#1 Using L3 to interconnect different L2 technologies



#2a) Using L3 to interconnect L2 networks in different administrative/policy domains



Local vs. Global networking

- Recall:
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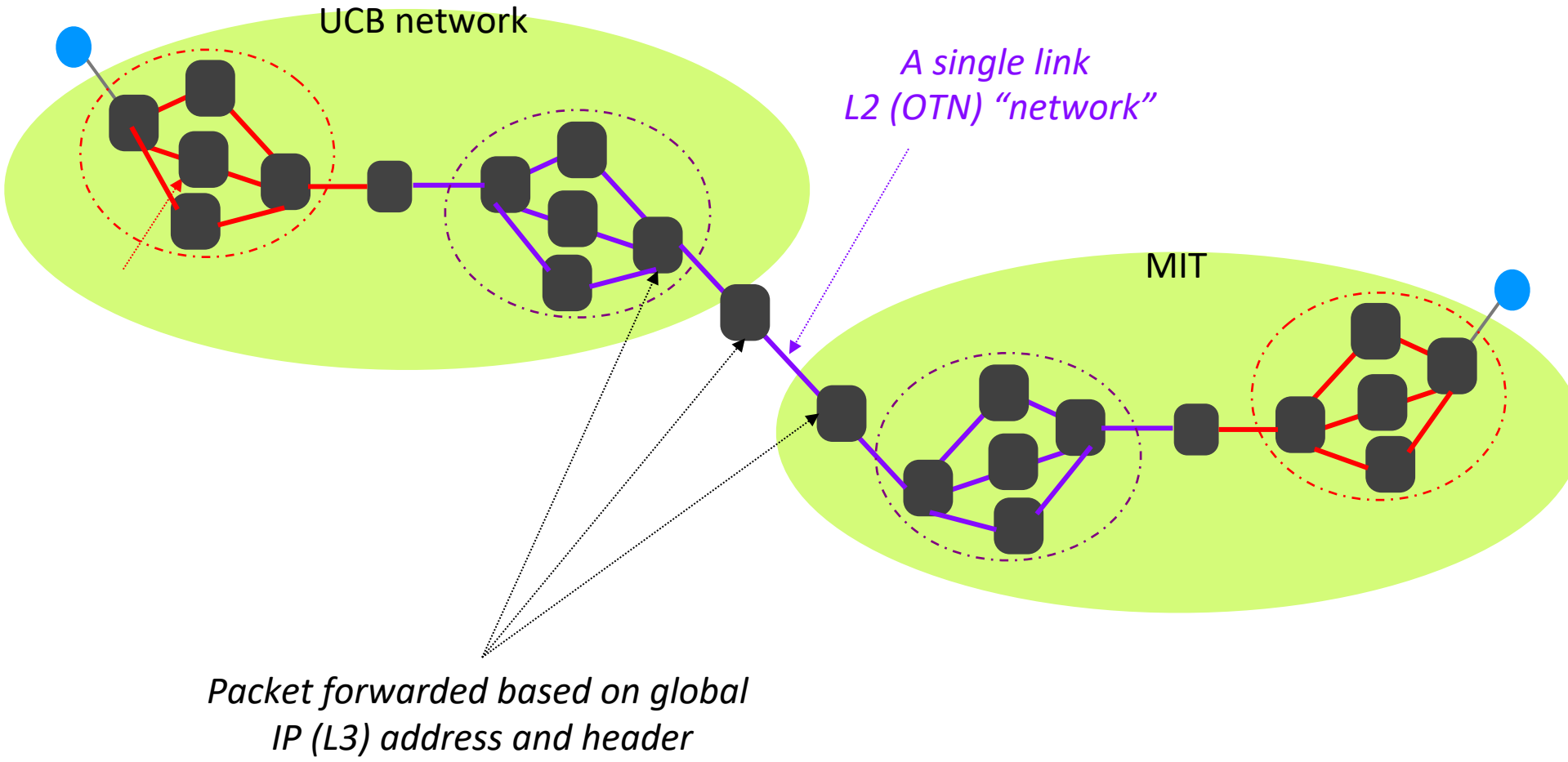
- So, when do we need L3 to interconnect L2 networks?
  1. When the L2 networks are based on different technologies
  2. When the L2 networks are operated independently (admin, policy)

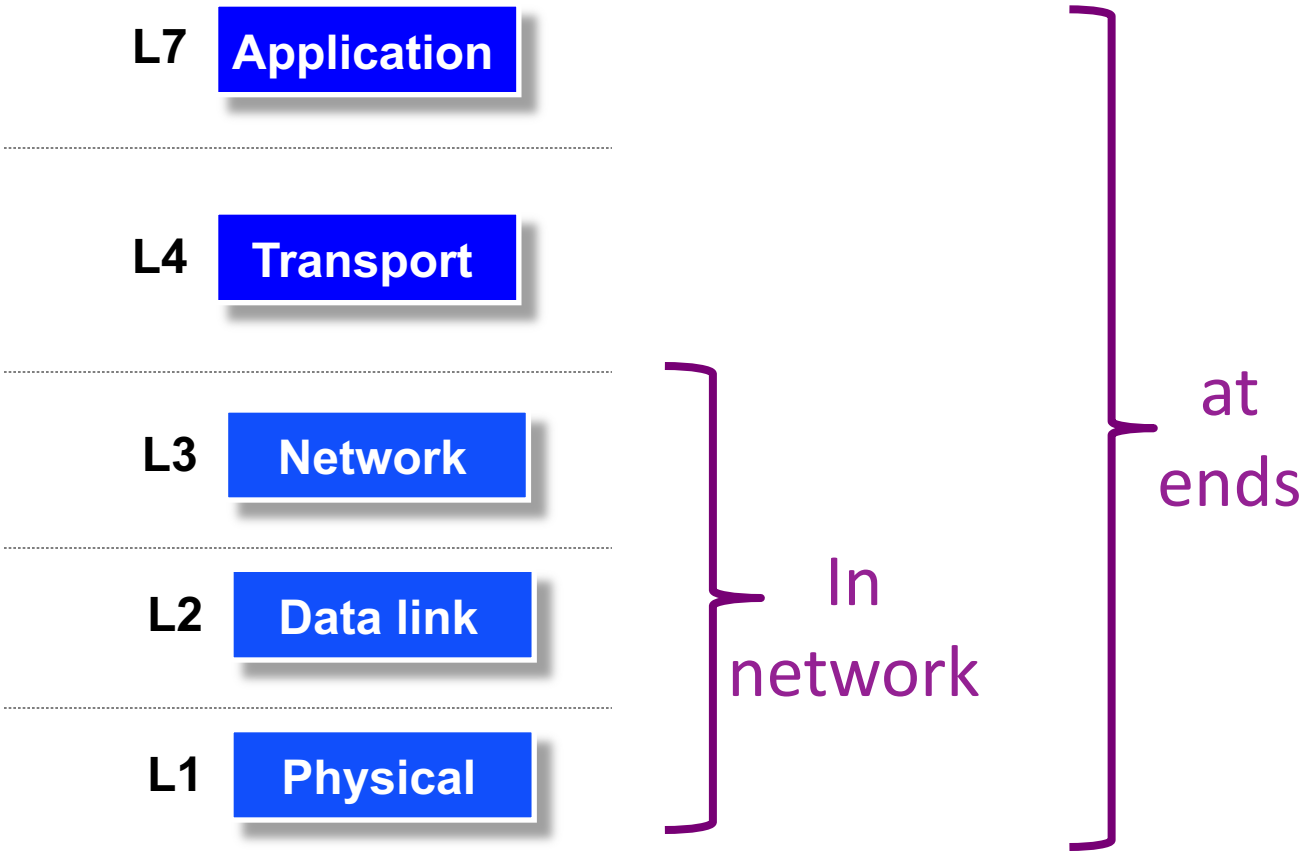
- Can we just interconnect L3 routers directly?
  - Yes! Just a degenerate case of interconnecting L2 networks

#2a) Using L3 to interconnect L2 networks in different administrative/policy domains



Questions?

Rest of this lecture



Why is *this* assignment of tasks good?

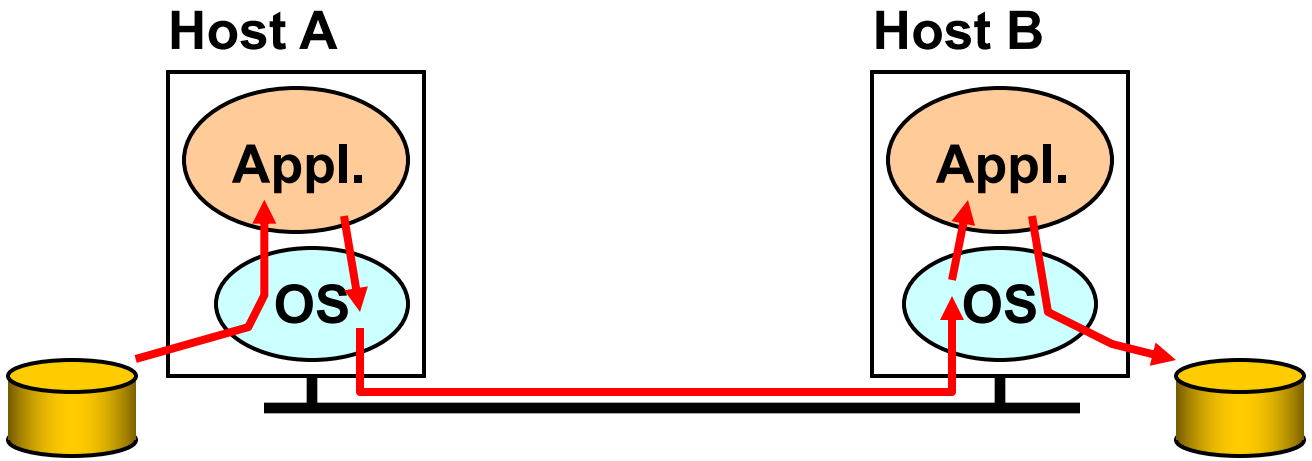
Architectural Wisdom

- David D. Clark
  - Chief protocol architect for the Internet in the 80s
- Co-authored two classics
  - "End-to-End Arguments in System Design" (1981)
  - "The Design Philosophy of the DARPA Internet Protocols" (1988)
- Articulates the rationale underlying the Internet's arch.

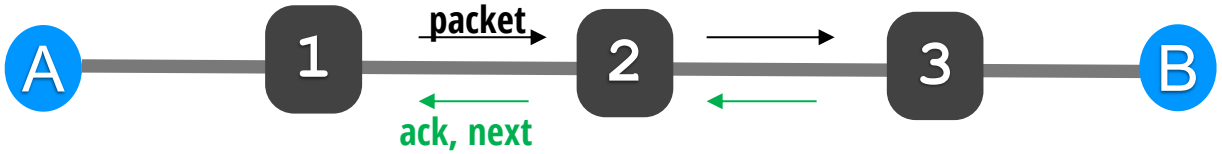
The End-to-End Principle

- Guides the debate about what functionality the network does or doesn't implement
- Everyone believes it, but no one knows what it means …

Example: Reliable File Transfer



- Solution 1: make each step reliable
  (requires network to handle reliability)



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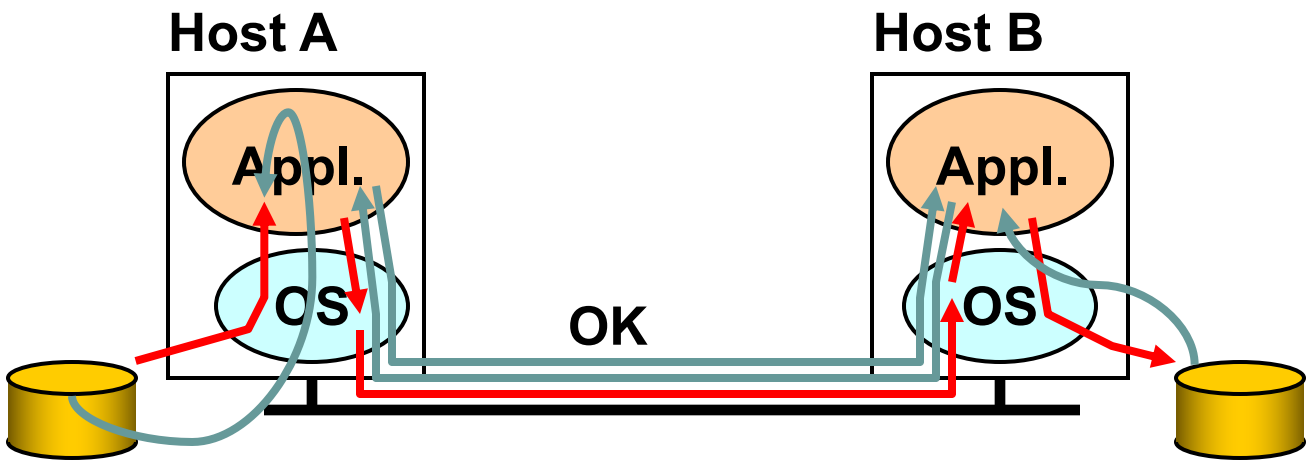


- Solution 1: make each step reliable
  (requires network to handle reliability)
- Solution 2: allow steps to be unreliable, but do end-to-end **check** and try again if necessary
  (do not assume network is reliable)

Discussion

- Solution 1 cannot be made perfectly reliable
  - What happens if a component fails between steps?
  - Receiver has to do the check anyway!
- Solution 2 can also fail, but only if the endhost itself fails (i.e., doesn't follow its own protocol)
  - In which case it doesn't matter….
- Solution 2 only relies on what it can control
  - The endpoint behavior
- Solution 1 requires endpoints trust other elements

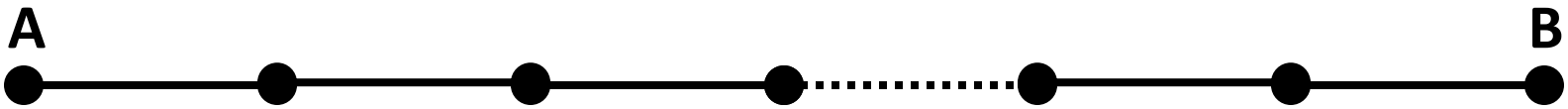
Two Notions of Reliability (Clark)

- The network recovers from failures quickly so that, as long as *some* path exists, two endpoints should be able to communicate.
- Network failures should not interfere with endpoint semantics
- The second requirement implies that we must adopt solution 2 (cannot depend on network).

So...

- Should you ever implement reliability in network?
  - I.e., in addition to doing so in the hosts

Performance



- If each link drops packets 10% of the time, and we have 10 links, then E2E failure rate is ~65%
- What if the link implemented two retransmissions?
  - Per-link drop rate reduced to 0.1%, E2E error rate is ~1%

Performance

- Should you ever implement reliability in network?
  - I.e., in addition to doing so in the hosts
- Perhaps, if needed for reasonable performance
  - Don’t aim for perfect reliability, but ok to reduce error rate

Back to the End-to-End Principle

Implementing reliability in the network:

- Doesn't reduce host implementation complexity
- Does increase network complexity
- Can impose overhead on all applications, *even if they don't need reliability*
- However, implementing in network *can* enhance performance in some cases
  - E.g., very lossy link

The end-to-end argument in Clark's words

"The function in question can completely and correctly be implemented only with the knowledge and help of the application at the end points. Therefore, providing that function as a feature of the communication system itself is not possible. (Sometimes an incomplete version of the function provided by the communication system may be useful as a performance enhancement.)"

The End-to-End Principle

- Everyone believes it, but no one knows what it means…..
- Pretty convincing in the context of reliability but not as clear in other cases
- In general, three interpretations of the end-to-end principle

“Only-if-Sufficient” Interpretation

- Don’t implement a function at the lower levels of the system unless it can be completely implemented at this level

- *Don’t bother unless you can eliminate the burden from hosts*

“Only-if-Necessary” Interpretation

- Don’t implement *anything* in the network that can be implemented correctly by the hosts

- Make network layer absolutely minimal
  - This E2E interpretation trumps performance issues
  - Increases flexibility, since lower layers stay **simple**

"Only-if-Useful" Interpretation

- If hosts can implement functionality correctly, implement it in a lower layer only as a performance enhancement
- But do so only if it does not impose overhead on apps that do not require that functionality
- This criterion typically weighs performance heavily in deciding where to place functionality

What Does This Mean In Practice?

Interpretation	Reliability	QoS (Priority forwarding)	Routing
Sufficient	**No**	**Yes**	**Yes**
Necessary	**No**	**Yes**	**No**
Useful	**Sometimes**	**-**	**Yes**

Reliable Transport: at ends (sometimes network)

Priorities: In network

Routing: In network (in almost all cases)

Summary

- **Where** to implement functionality is non-trivial
  - E2E principle shaped how we reason about tradeoffs!
- Important: remember it's an argument, not a rule
  - Though everyone agrees that reliability should be primarily implemented in the hosts

What Does E2E Principle Ignore?

- There are other stakeholders besides users
  - ISPs care about the operation/security of their network
  - Plus looking for new revenue-generating functions
- These functions more easily done in the network.
  - Think of firewalls…..
- **Easier because this is what the ISPs control!**
  - They don't control hosts, so it doesn't matter if it *could* be implemented in the hosts; it *won't* be
- Led to widespread deployments of "middleboxes"
  - Firewalls, NAT boxes, etc. Will cover later in course…

Characteristics often attributed to the E2E principle

- "Dumb" network and "smart" end systems
- "Fate sharing"

A Cynical View of Distributed Systems

"A distributed system is one in which the failure of a computer you didn't even know existed can render your own computer unusable"

-- Leslie Lamport

Fate Sharing tries to prevent this!

General Principle: *Fate-Sharing*

- When storing state in a distributed system, co-locate it with entities that rely on that state
- Only way failure can cause loss of the critical state is if the entity that cares about it also fails ...
  - … in which case it doesn't matter
- Often argues for keeping *flow state* at end hosts rather than inside routers
  - E.g., packet-switching rather than circuit-switching

Recap: architectural wisdom (the ”how")

- How to decompose system into modules?
  - Layering
- Where are layers implemented?
  - End hosts implement all layers (L1-L7)
  - Network implements only layers (L1-L3)
- One unifying protocol at the network layer
  - Internet Protocol (IP)

Recap: architectural wisdom (the "why")

- **Layering** provided a clean separation of concerns
  - And hence enabled innovation!
- **End-to-end principle** kept unnecessary state and functionality out of the network
  - And hence allowed the Internet to scale!

Questions?

Internet Design Goals

- Clark's 1988 articulates why the Internet turned out as it did
- In particular, it described an ordered list of priorities that informed the design
- What do you think those priorities were?
  - Think about this briefly…. (there are 8 of them!)

Internet Design Goals (Clark '88)

1. **Connect existing networks**
2. Robust in face of failures
3. Support multiple types of applications / services
4. Accommodate a variety of networks
5. Allow distributed management of resources
6. Easy end host attachment
7. Cost effective
8. Allow resource accountability

The paradox of the Internet's design

- The goal is to support many applications
- These applications have different requirements
- So shouldn't the Internet support them all?
  - By meeting the most stringent requirements
  - No application minds getting good service!
- **Instead: built the lowest common denominator service!**
  - Architected for *flexibility*
  - Rejected: reliability, perf guarantees, authentication, diagnostics, ...

Questions to think about….

- What priorities would a commercial design have?
  - Accountability / authentication as top goals
  - Probably focus on high-revenue applications
- What would the resulting design look like?
  - Very likely to be much less flexible and general
- What goals are missing from this list?

Some of the missing issues

- Security
  - Resilience to attacks (denial-of-service)
  - Access control
  - Tracking down misbehaving users
- Privacy
- Performance
- Availability
- ISP-level concerns
  - Imposing policy and internal management
  - Economic issues of interconnection
  - Accounting and resource sharing (fairness, prioritization)

Questions?