CS168
Designing the Internet

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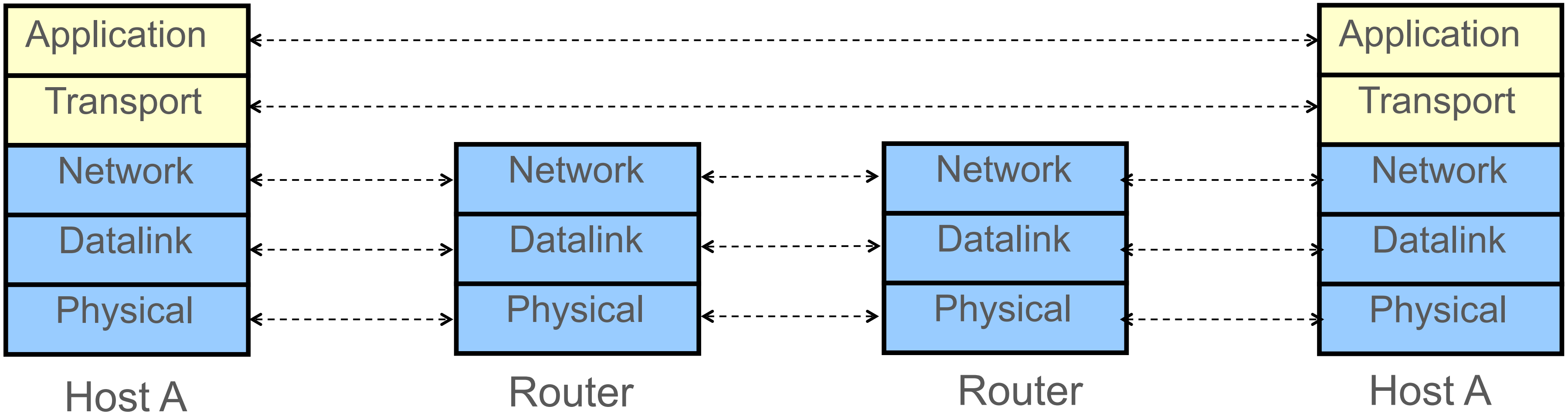
Slide credits: Sylvia Ratnasamy, Rob Shakir, Peyrin Kao

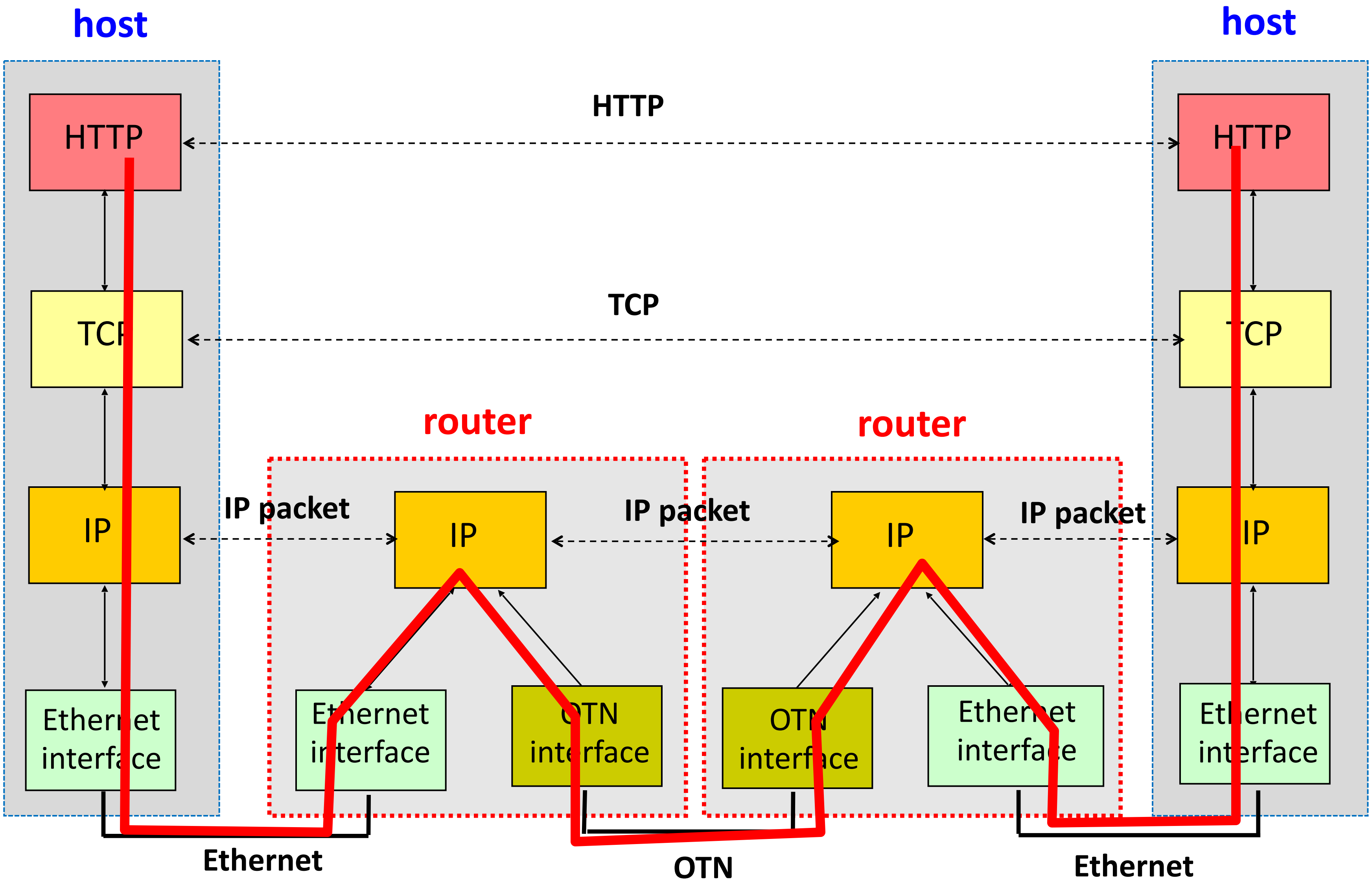
Outline

- Review: layering and the Internet
- The end-to-end argument

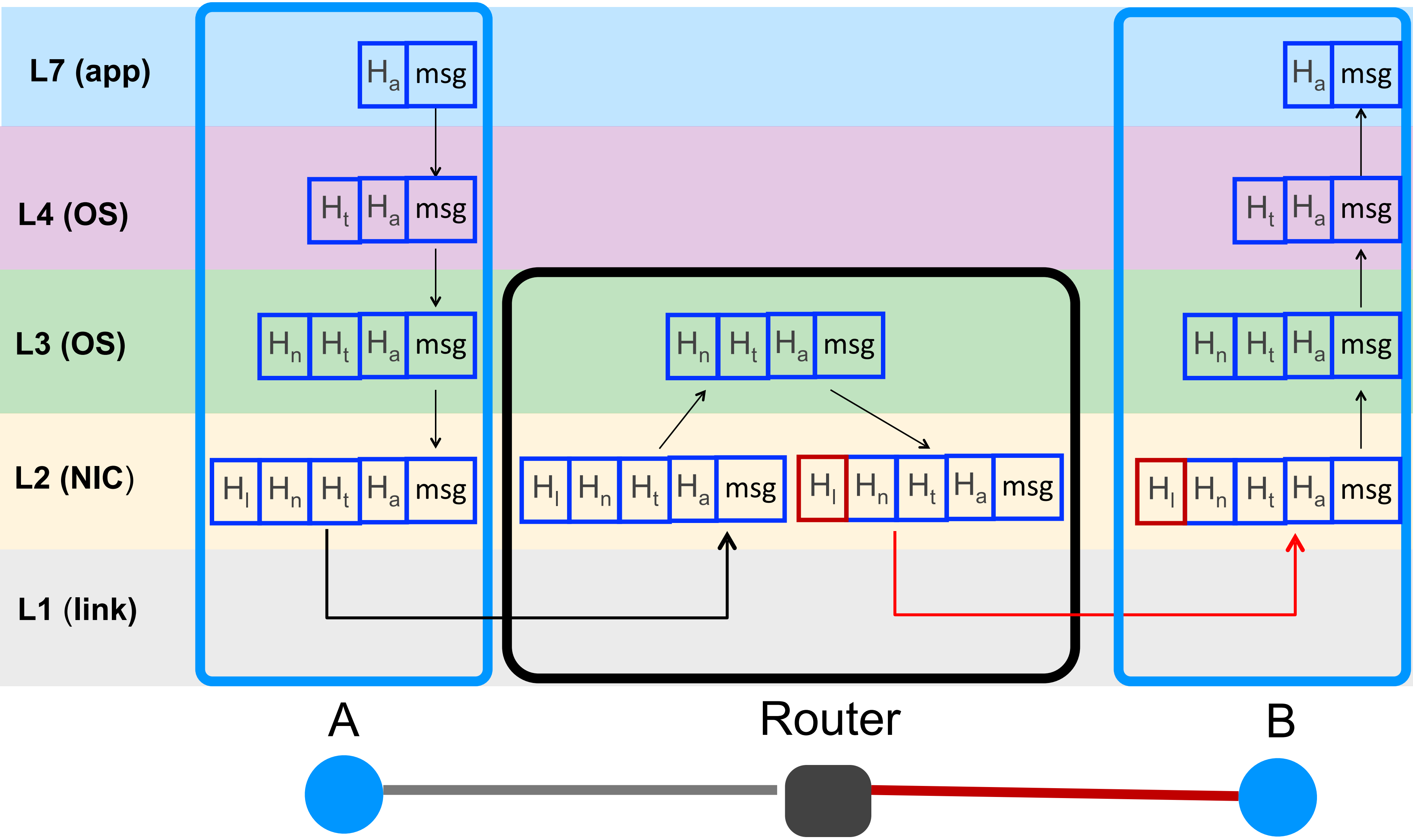
Recall: The Internet's layered architecture



Recall: Example



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



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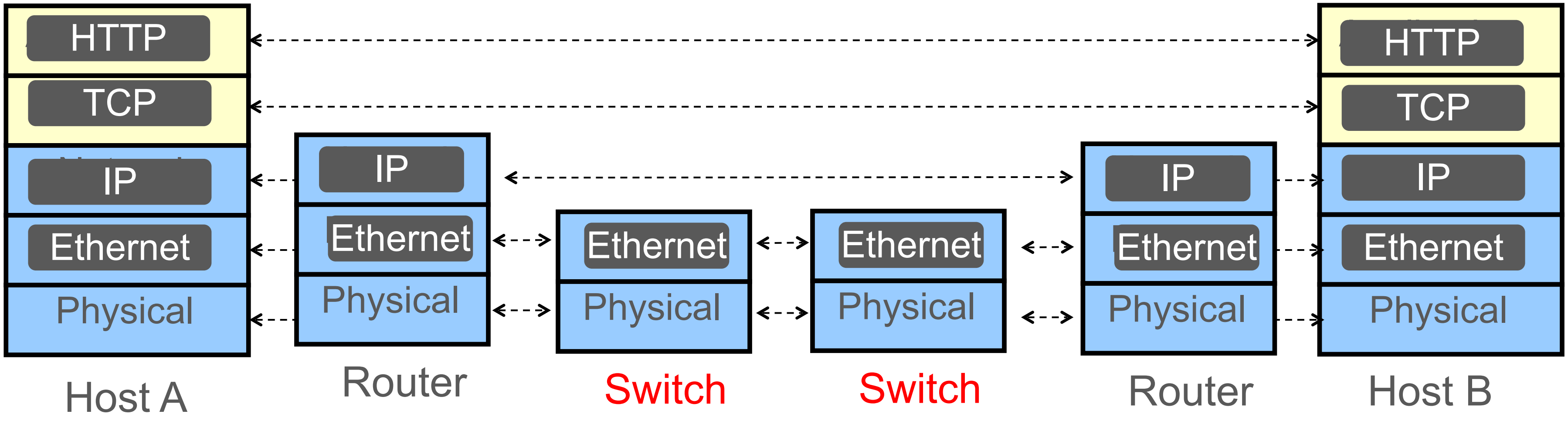

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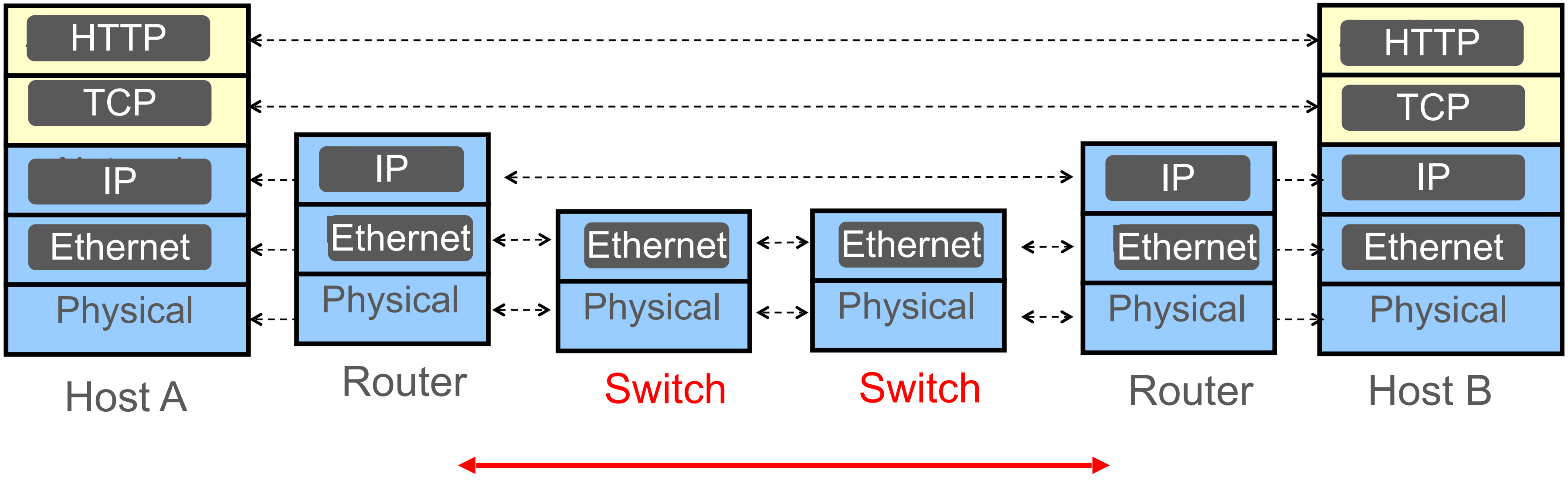

Packet traverses a local Ethernet network;
(i.e., based on its L2 header)

Local vs. Global networking

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- Recall:
  - Local → relying on L2 headers (and local addresses)
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- So, when do we need L3 to interconnect L2 networks?
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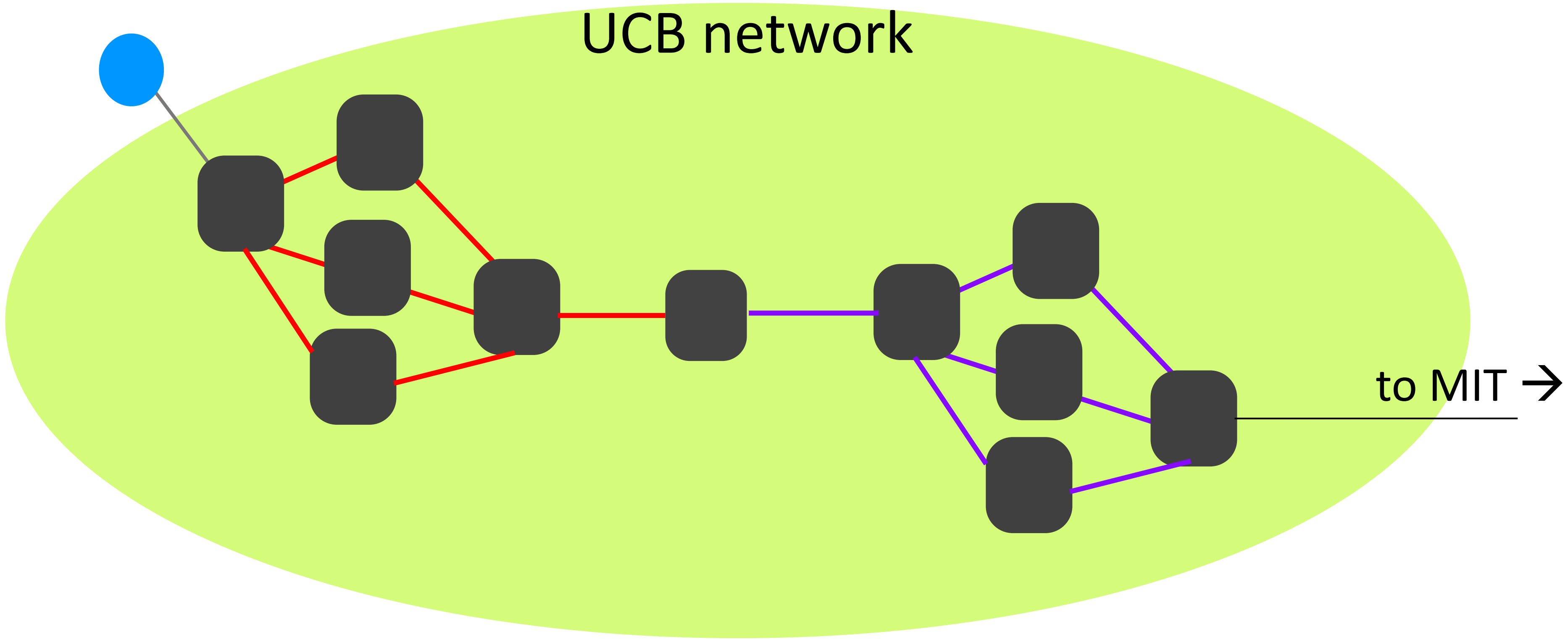
  2. When the L2 networks are operated independently (e.g., for administrative, policy, or scalability reasons)

#1 Using L3 to interconnect different L2 technologies



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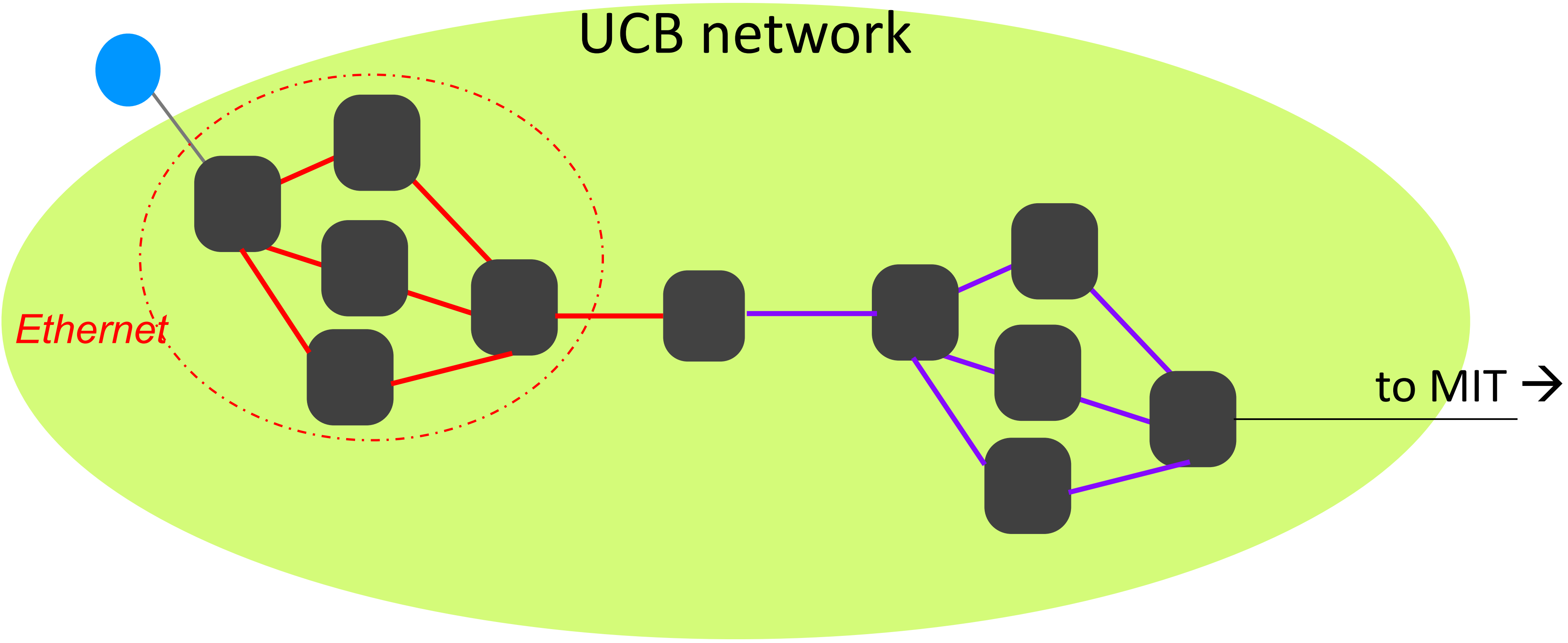

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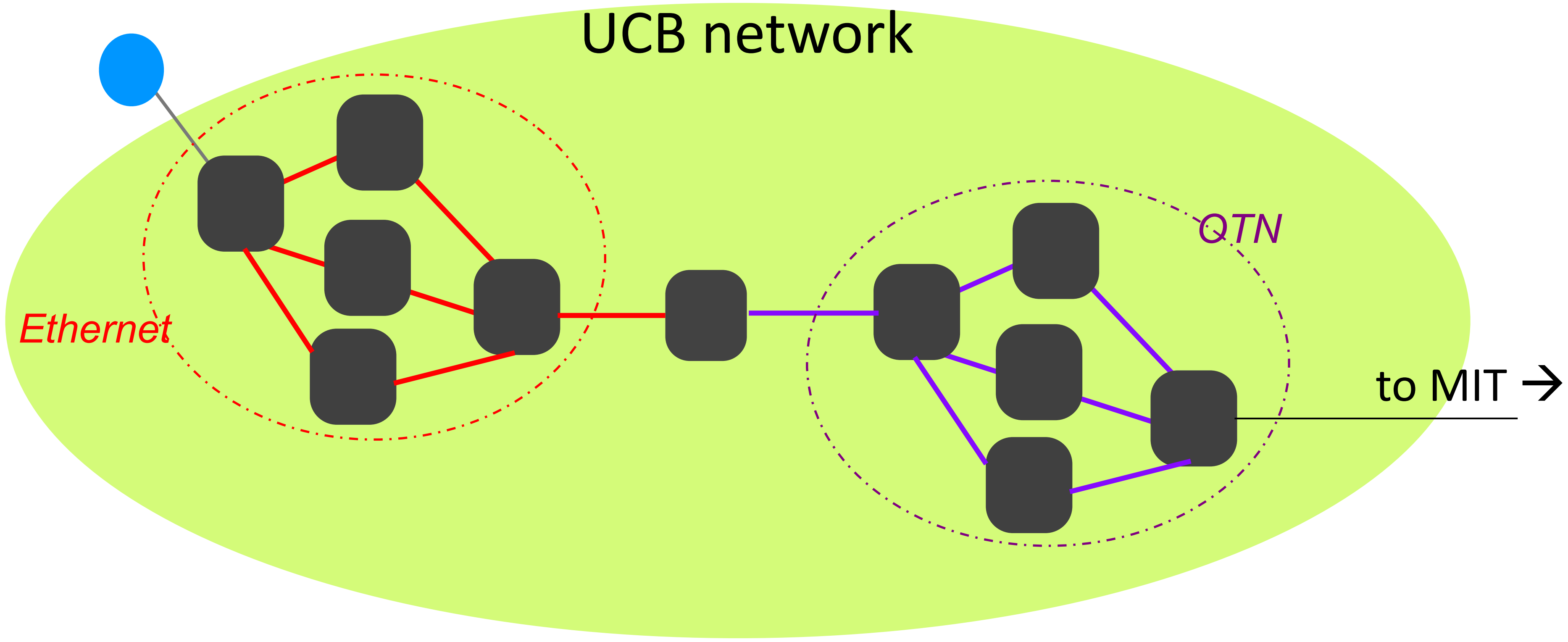

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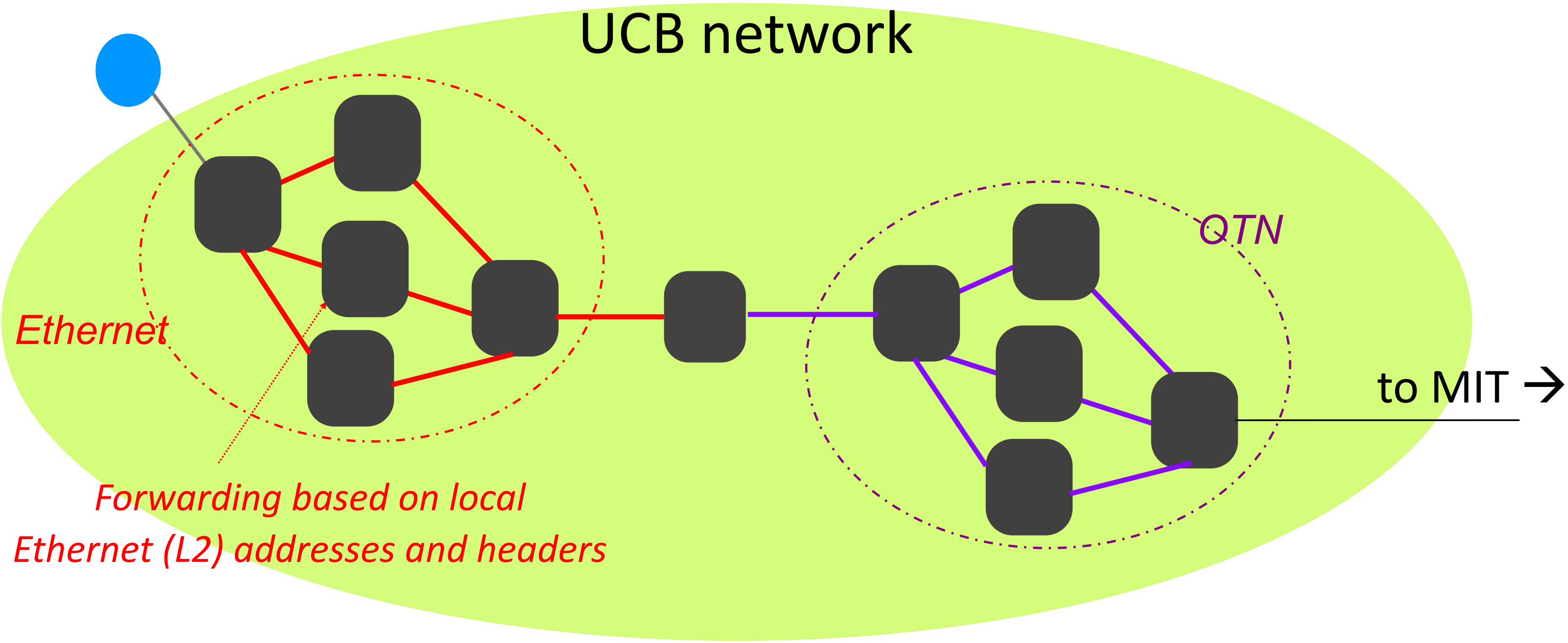

Forwarding based on local Ethernet (L2) addresses and headers

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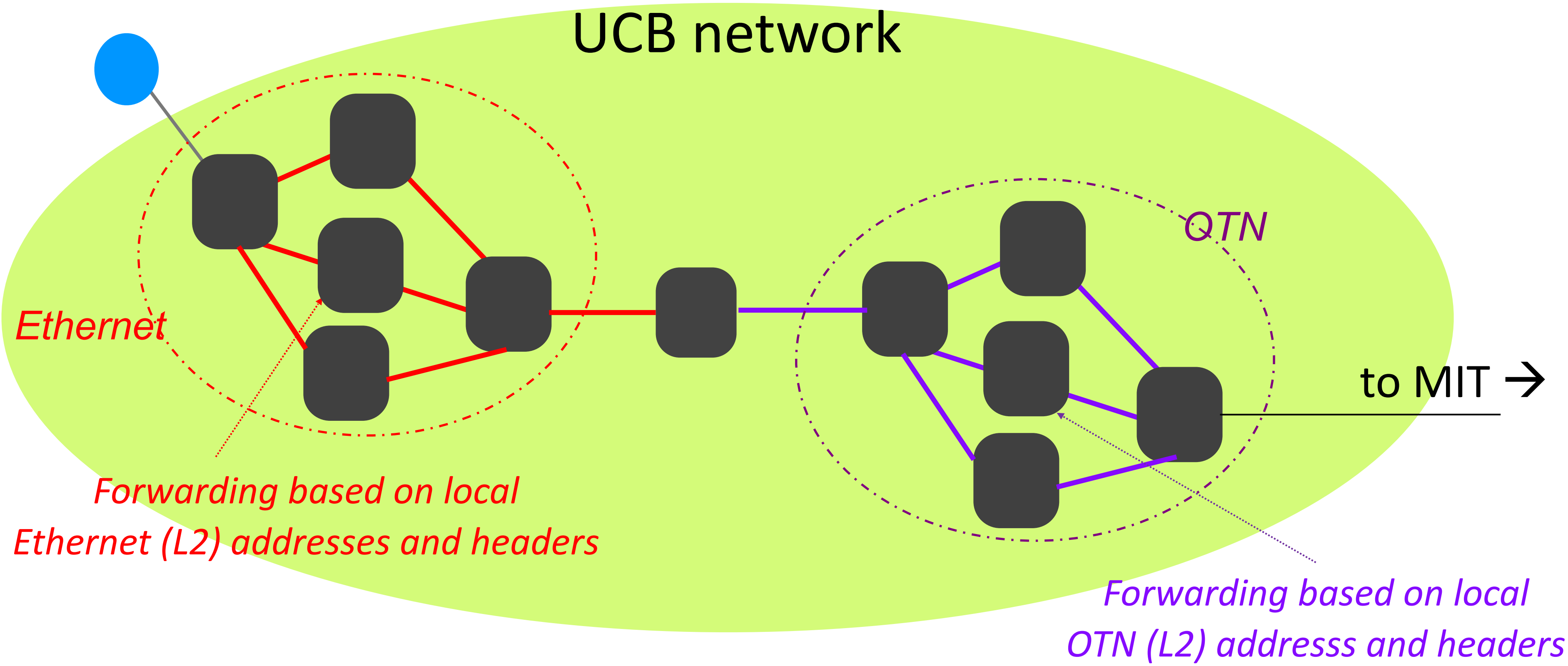

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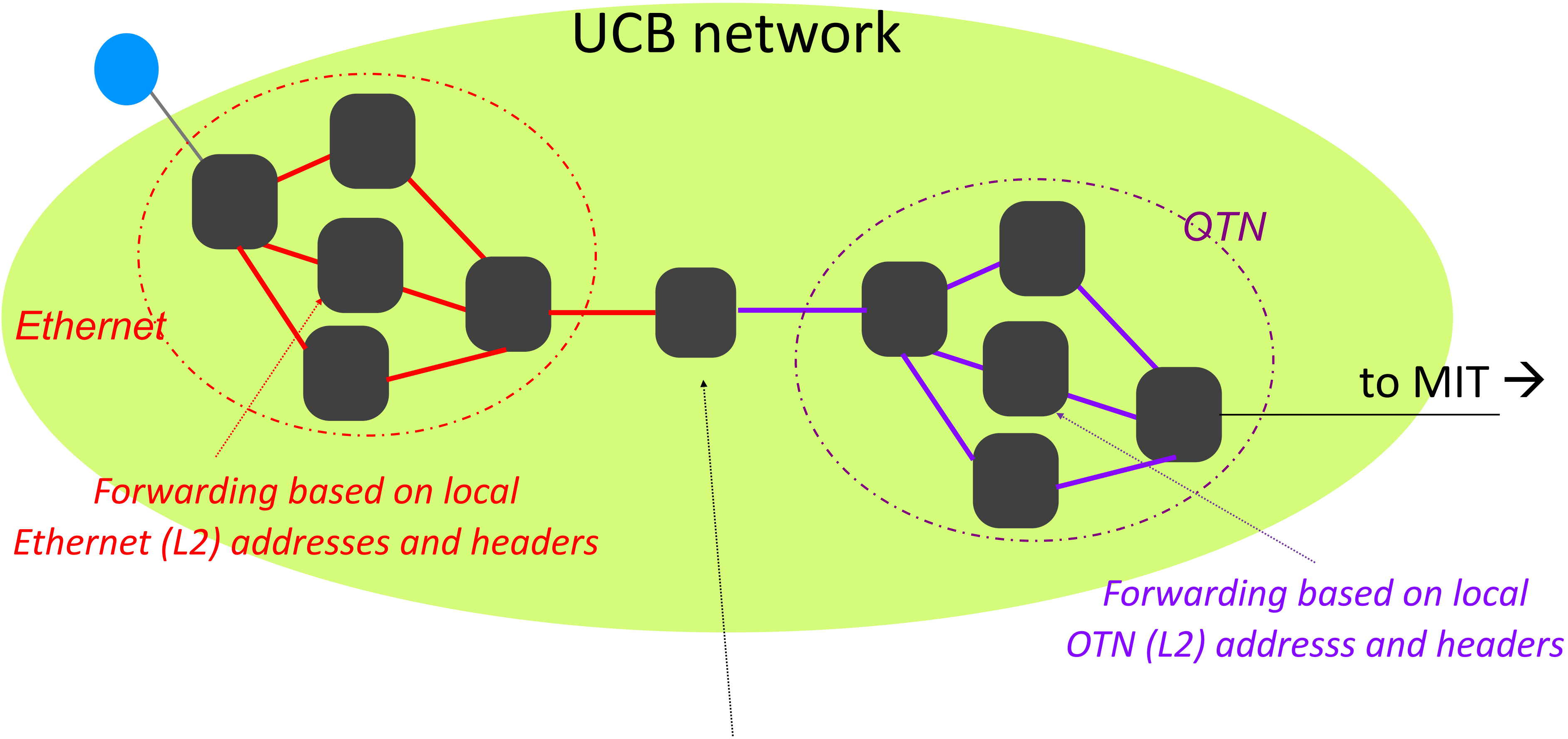

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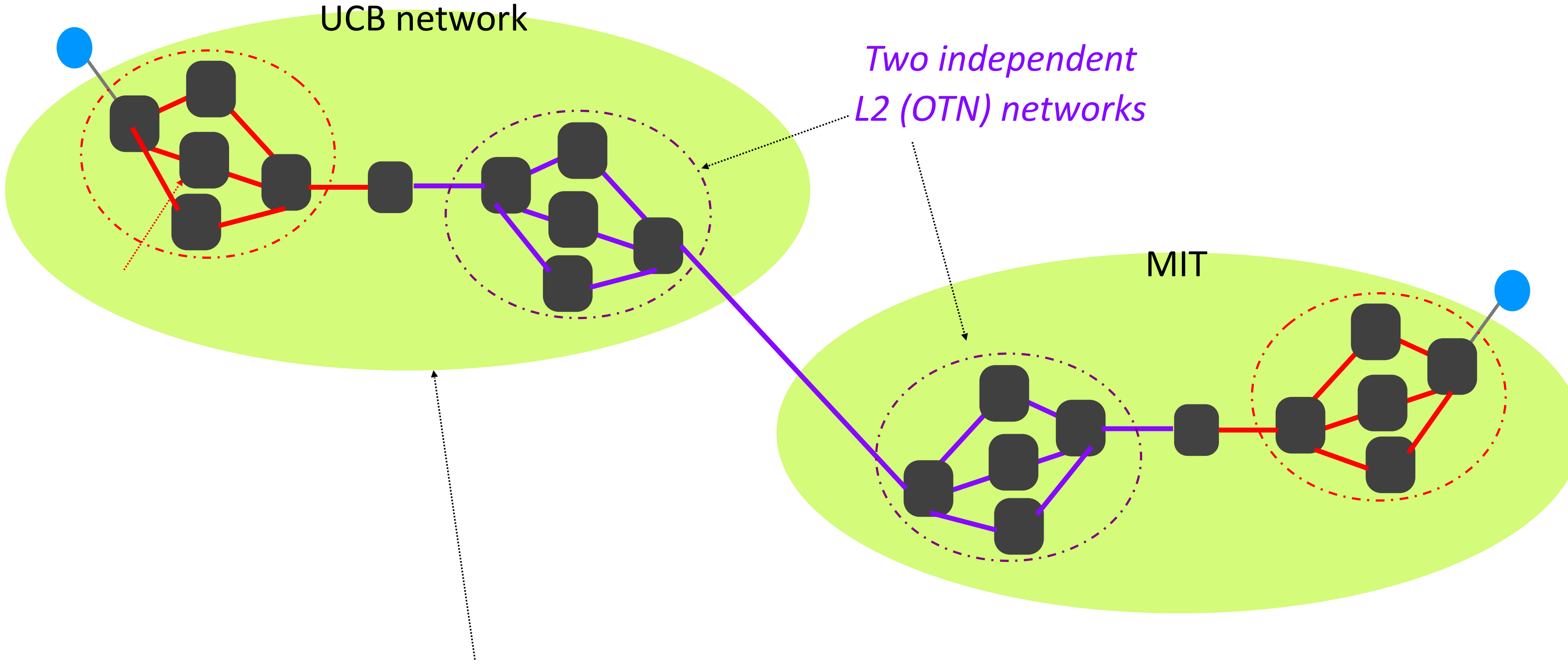
Forwarding based on global IP (L3) addresses and headers

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



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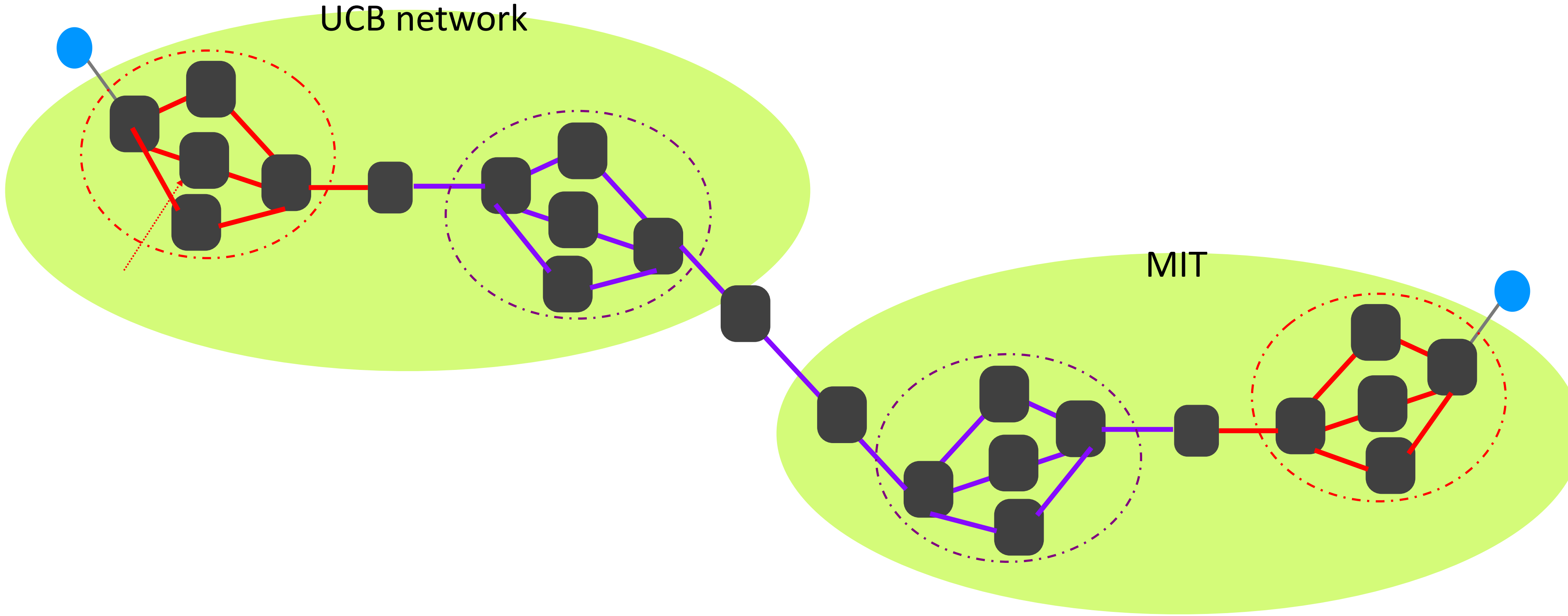
- Can we just interconnect L3 routers directly?
  - Yes! Just a degenerate case of interconnecting L2 networks

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



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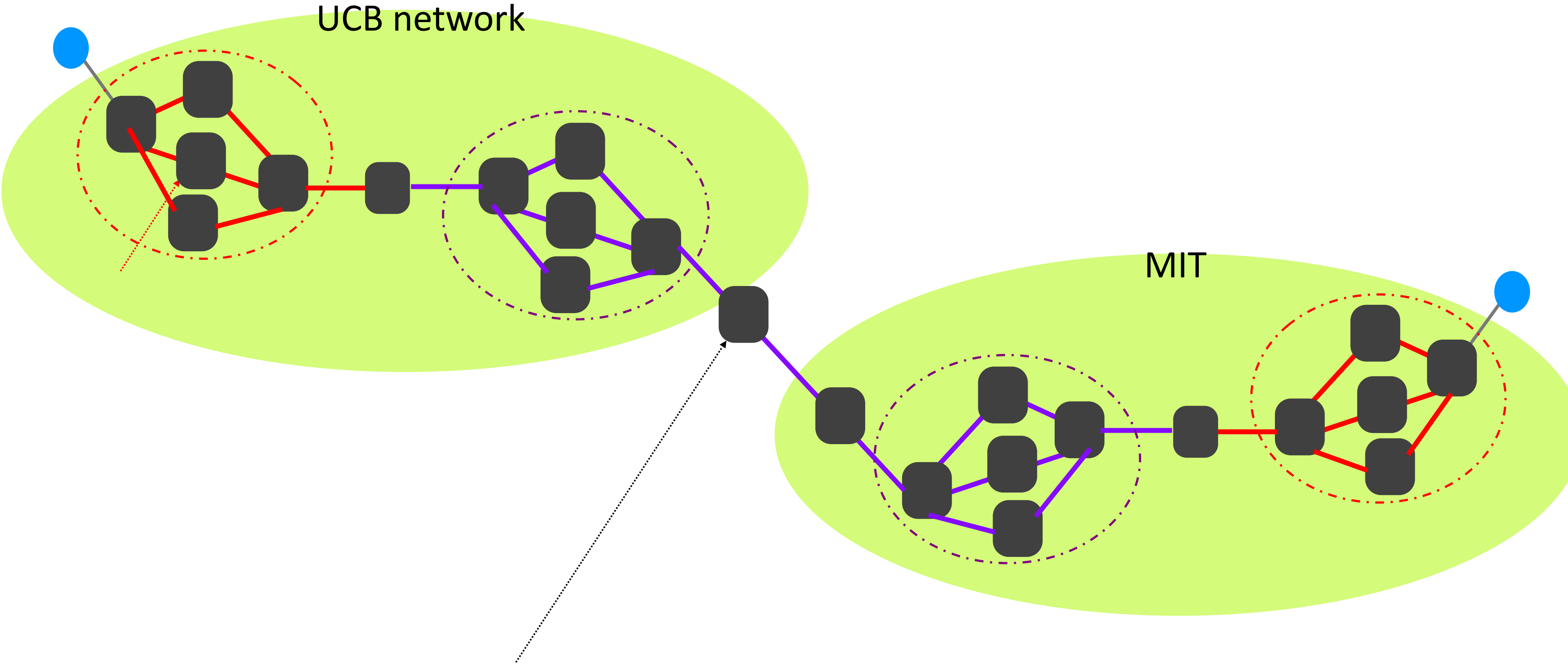

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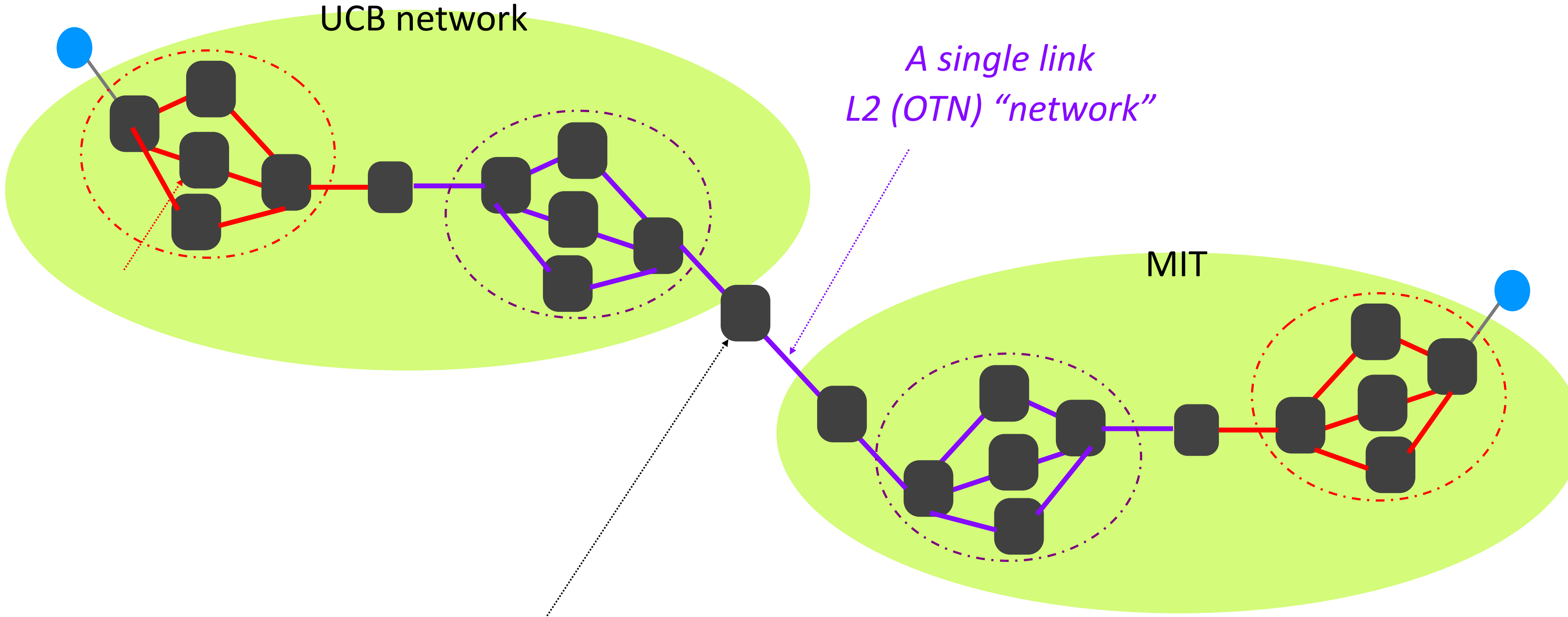
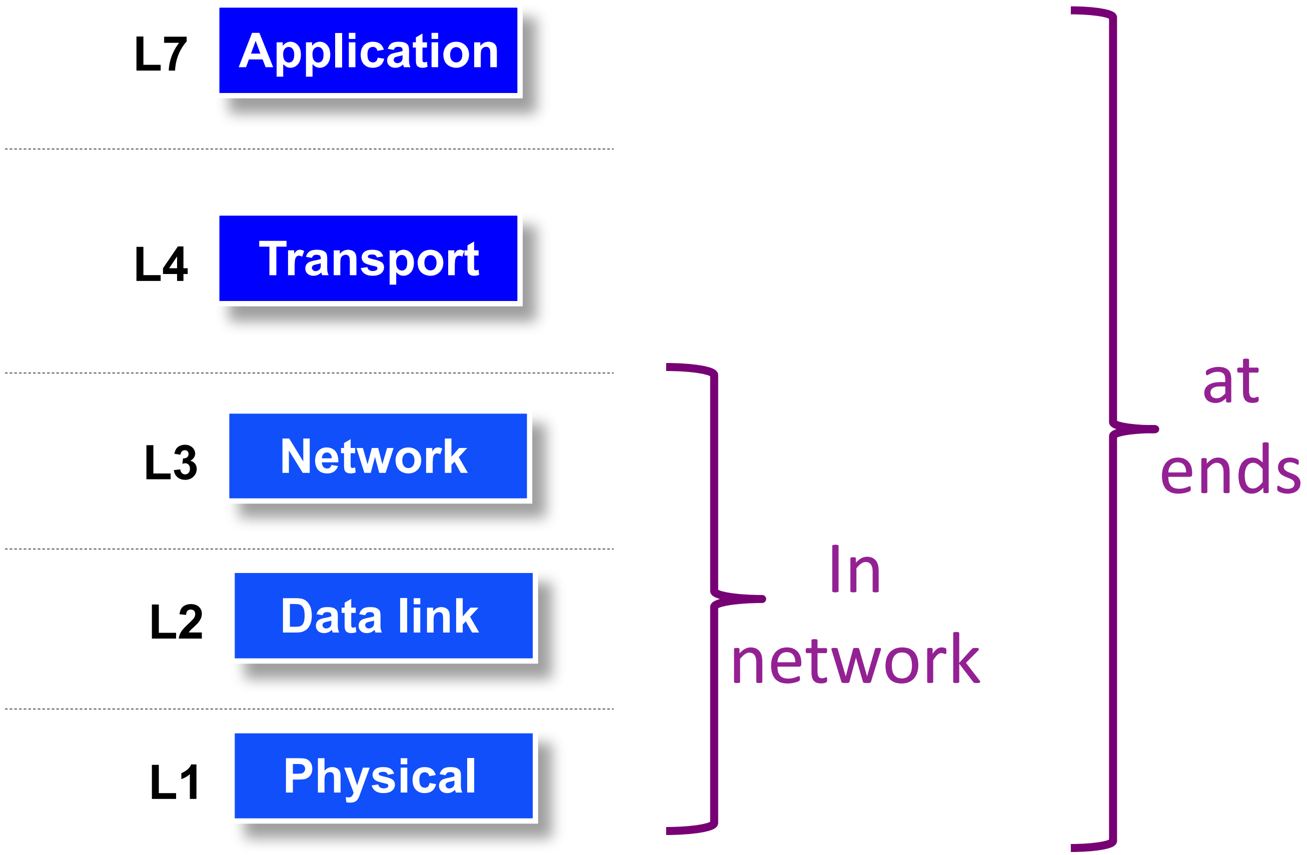


A single link L2 (OTN) "network"

Packet forwarded based on global IP (L3) address and header

Questions?

Rest of this lecture



Why is *this* assignment of tasks good?

Architectural Wisdom

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- 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.

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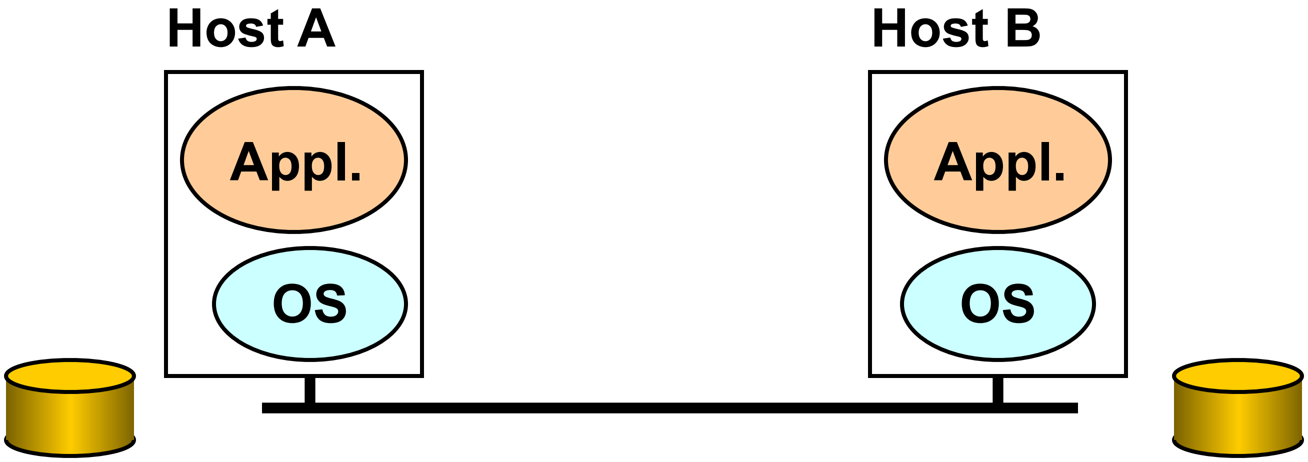
Example: Reliable File Transfer



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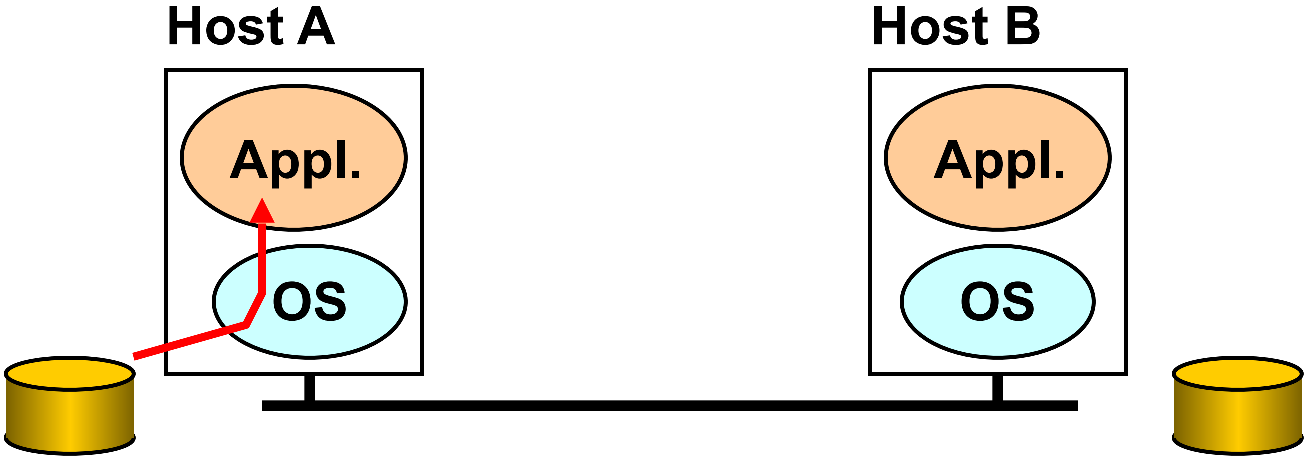

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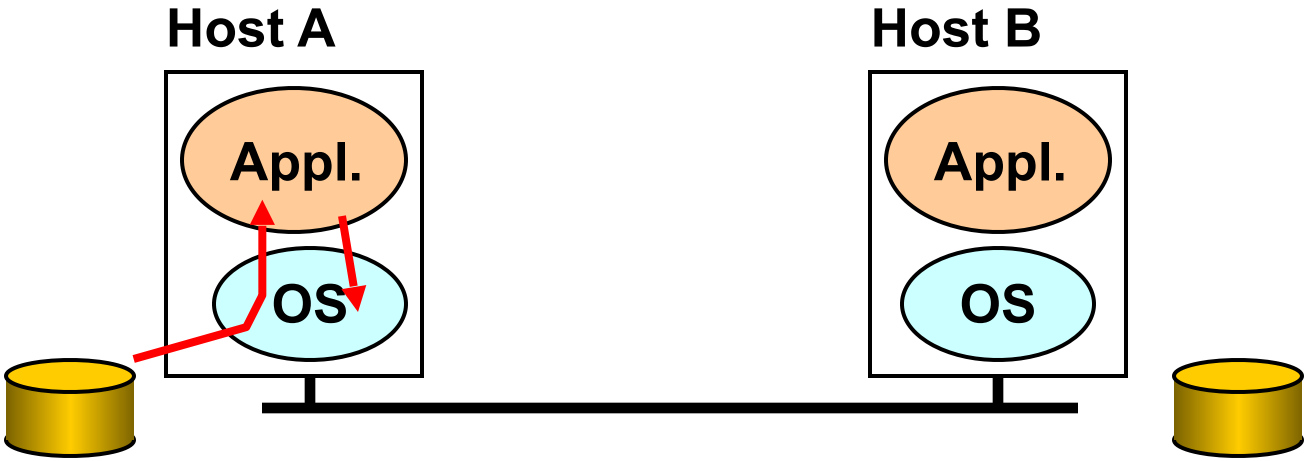

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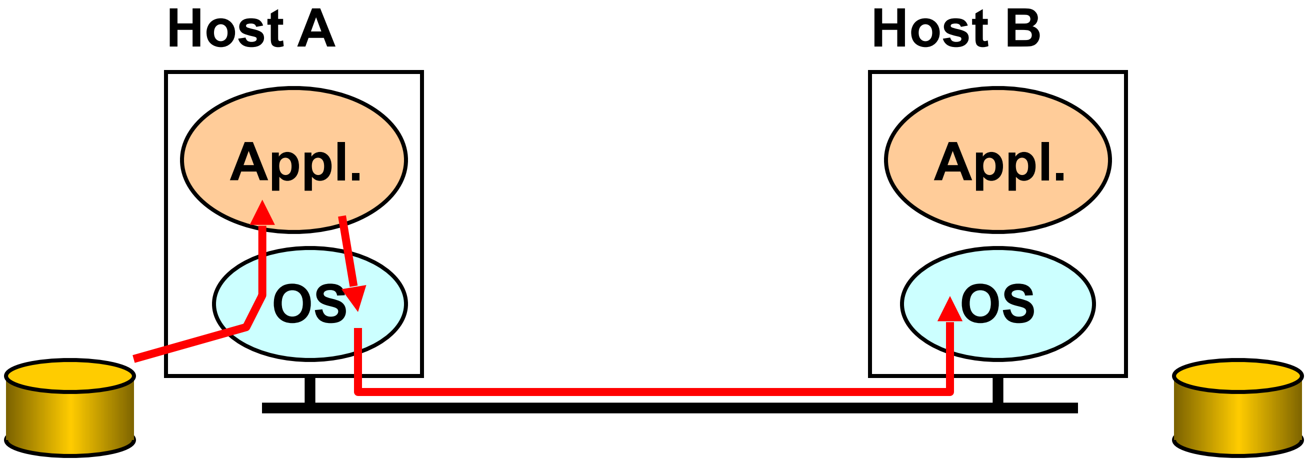

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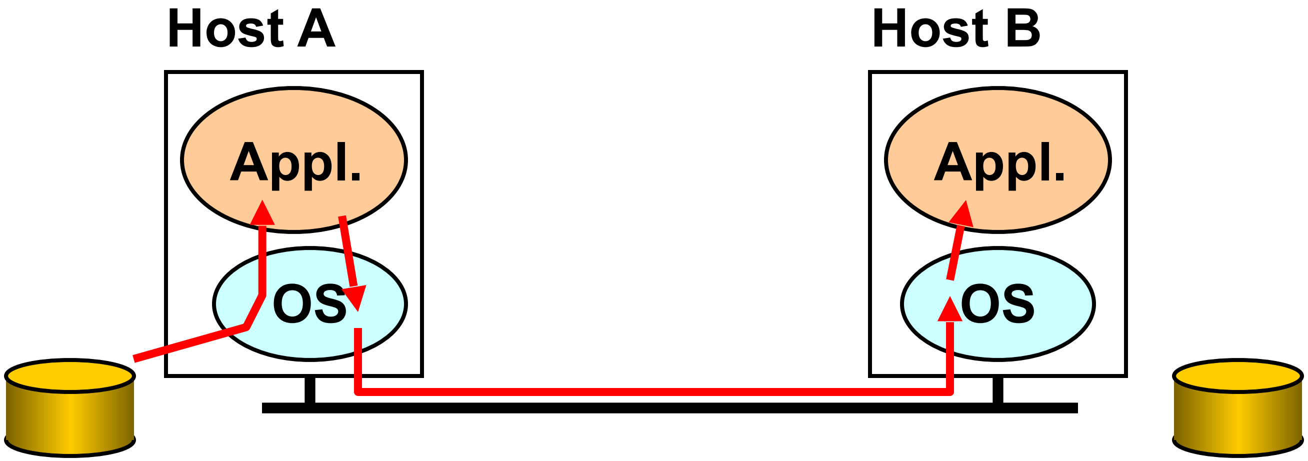

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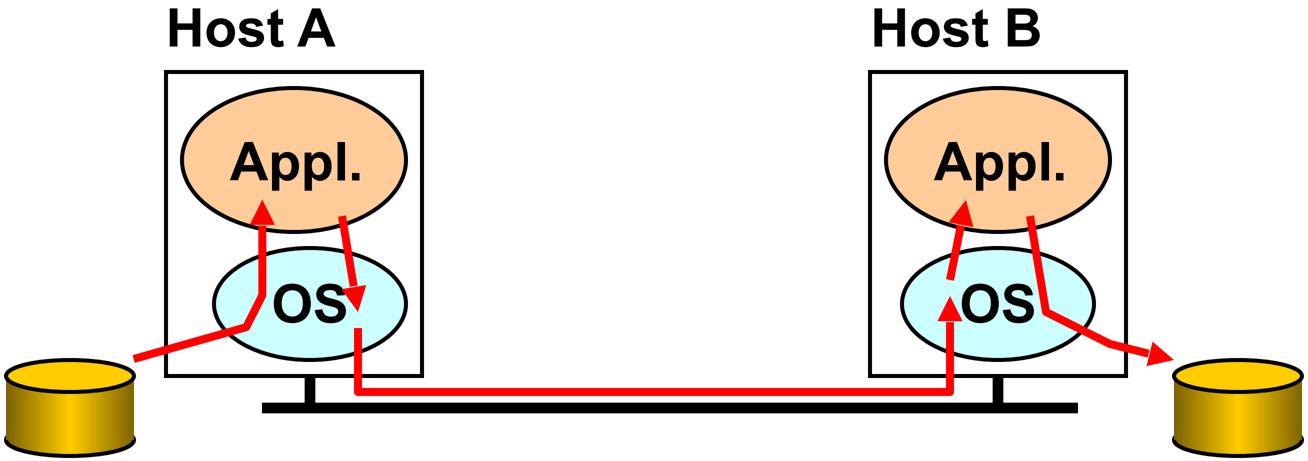

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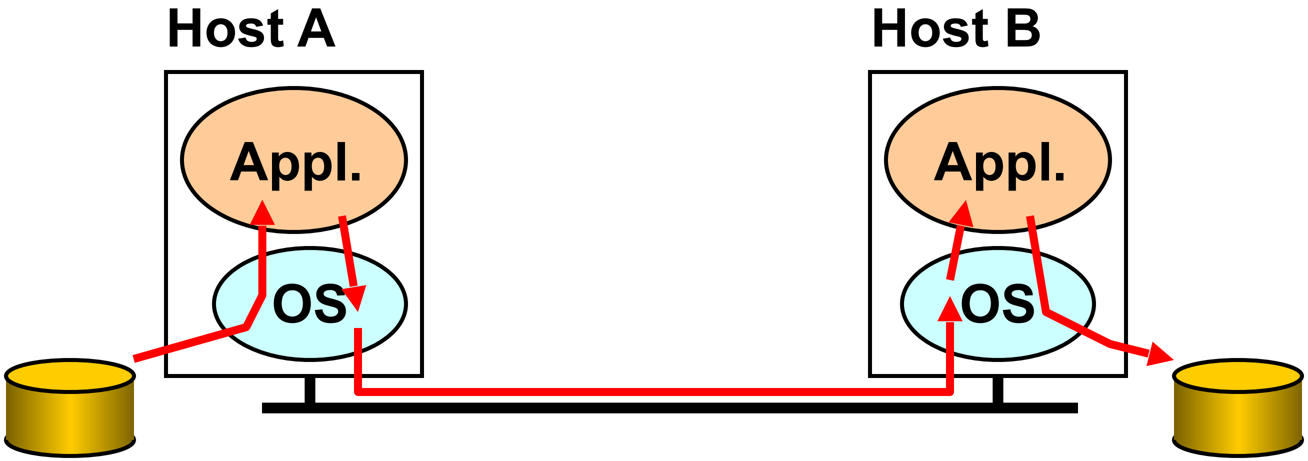

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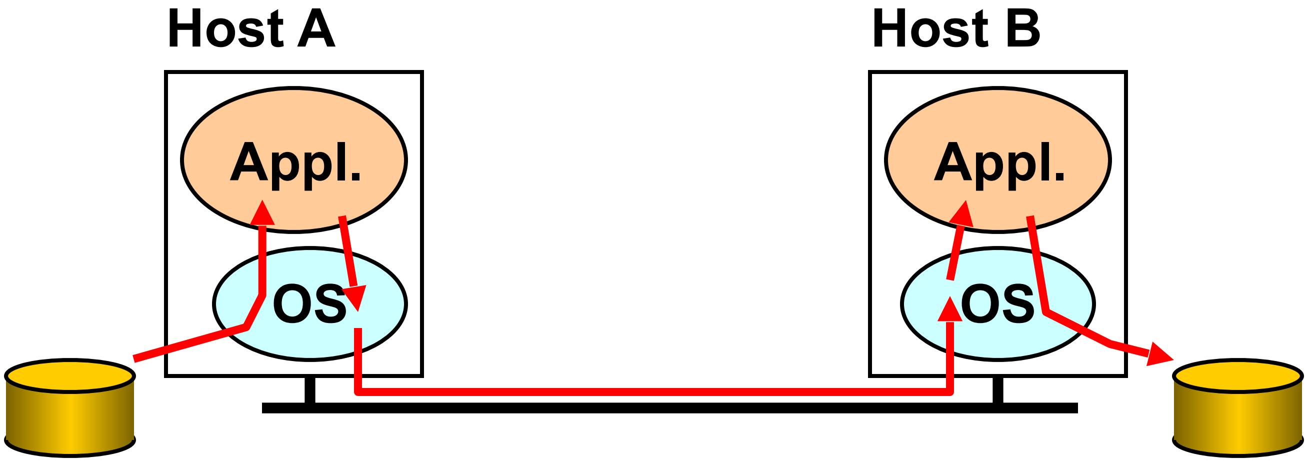

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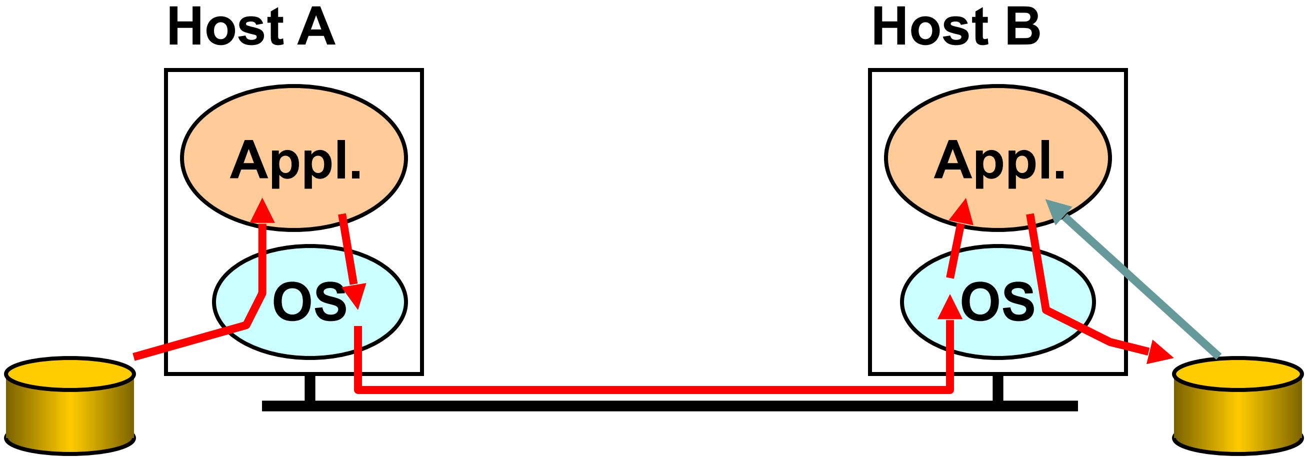

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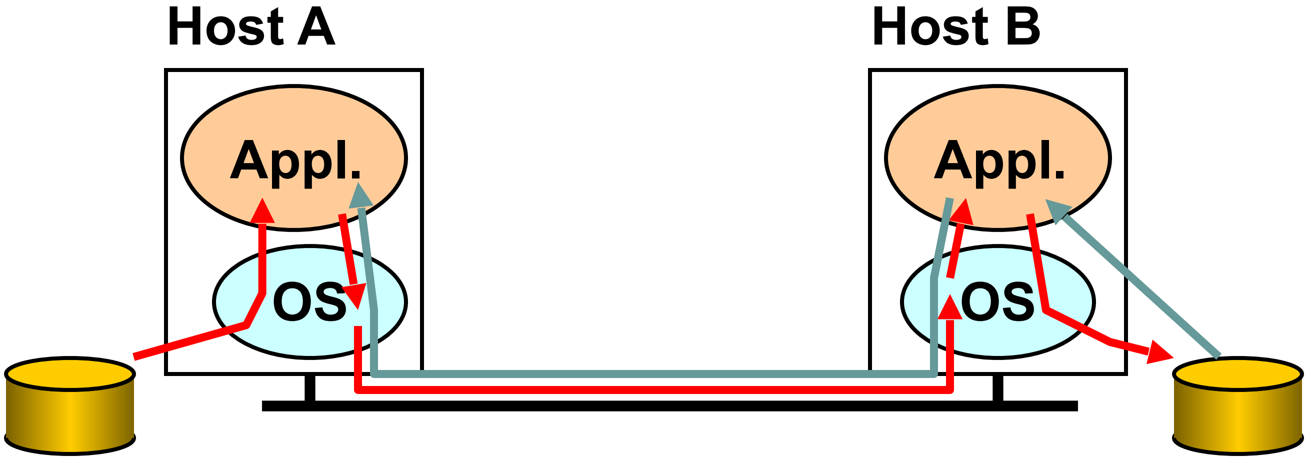

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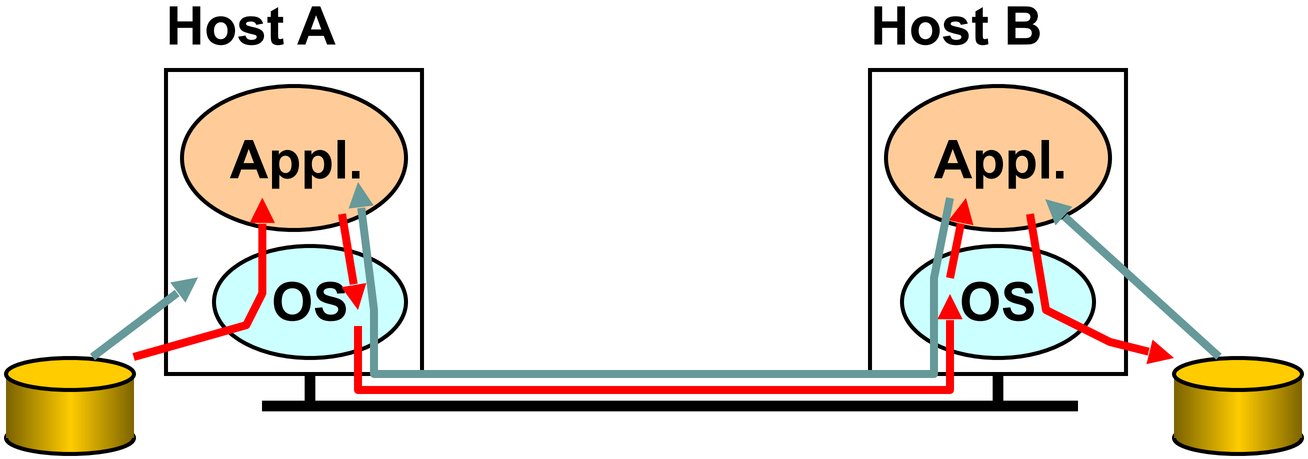

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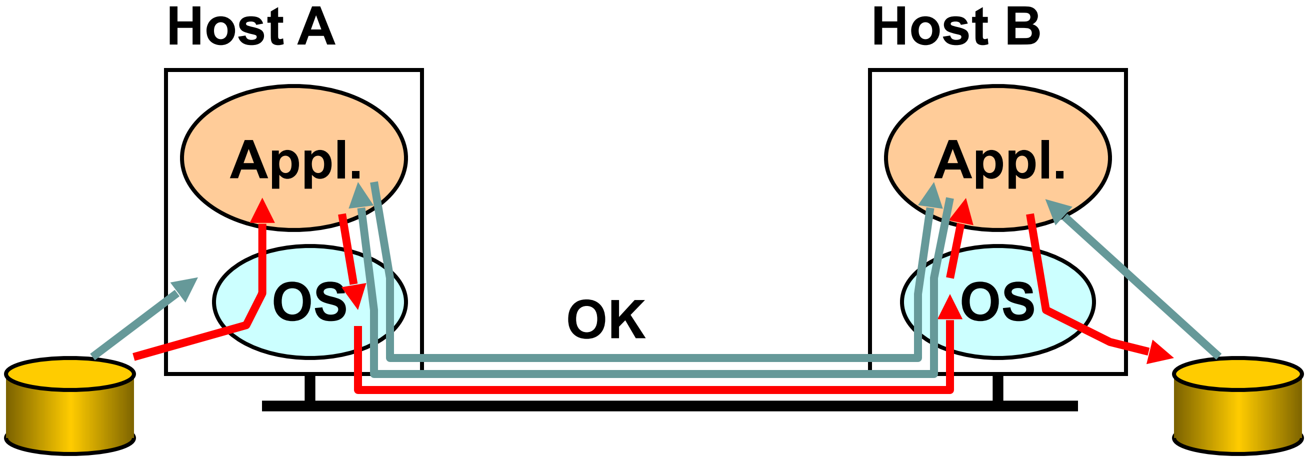

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- Solution 2 only relies on what it can control
  - The endpoint behavior
- Solution 1 requires endpoints trust other elements

Recap

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Making the network reliable:

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Making the network reliable:

- Doesn’t reduce host implementation complexity
- Does increase network complexity
- Can impose overhead on all applications, *even if they don’t need reliability*

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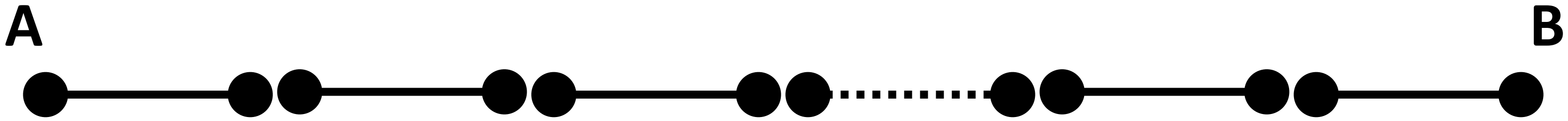
- Network failures should not interfere with endpoint *semantics*
- The second requirement implies that we must adopt solution 2 (cannot depend on network).

So...

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

Performance



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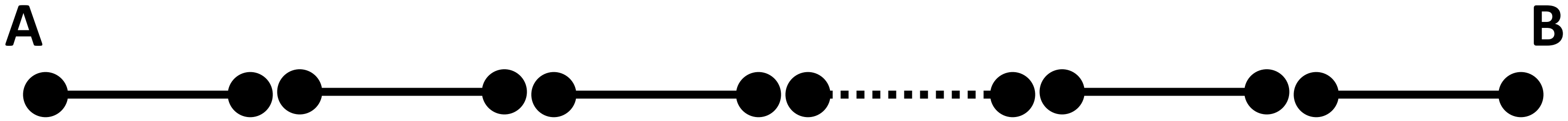

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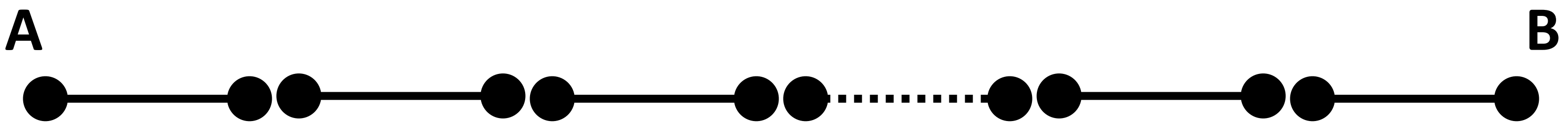

- If each link drops packets 10% of the time, and we have 10 links, then E2E failure rate is ~65%

- What if the link implemented two retransmissions?
  - Per-link drop rate reduced to 0.1%, E2E error rate is ~1%

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- Perhaps, if needed for reasonable performance
  - Don’t aim for perfect reliability, but ok to reduce error rate

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.)”

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- 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	?	?
Necessary	No	?	?
Useful	Sometimes	-	?

- Reliable Transport: at ends (sometimes network)

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- Priorities: In network
- Routing: In network (in almost all cases)

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  - 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

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- “Dumb” network and “smart” end systems
- “Fate sharing”

A Cynical View of Distributed Systems

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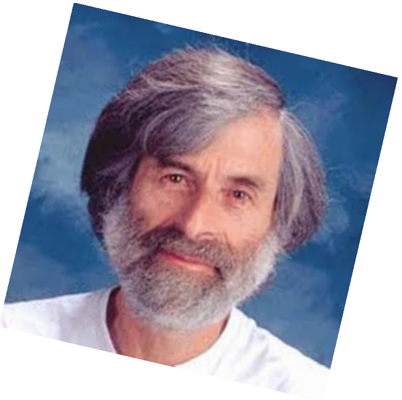

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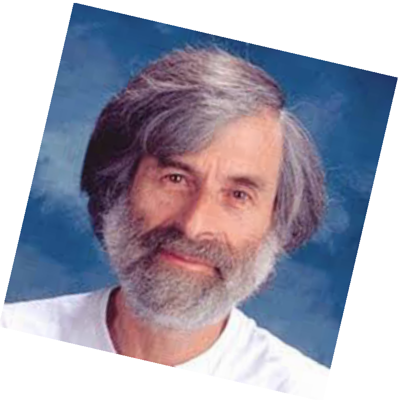

Fate Sharing tries to prevent this!

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- Often argues for keeping *flow state* at end hosts rather than inside routers
  - E.g., packet-switching rather than circuit-switching

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- **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, proxies, NAT, etc. Will cover later in course…

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- One unifying protocol at the network layer
  - Internet Protocol (IP)

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- **End-to-end principle** kept unnecessary state and functionality out of the network
  - And hence allowed the Internet to scale!