UNIVERSITY OF WATERLOO

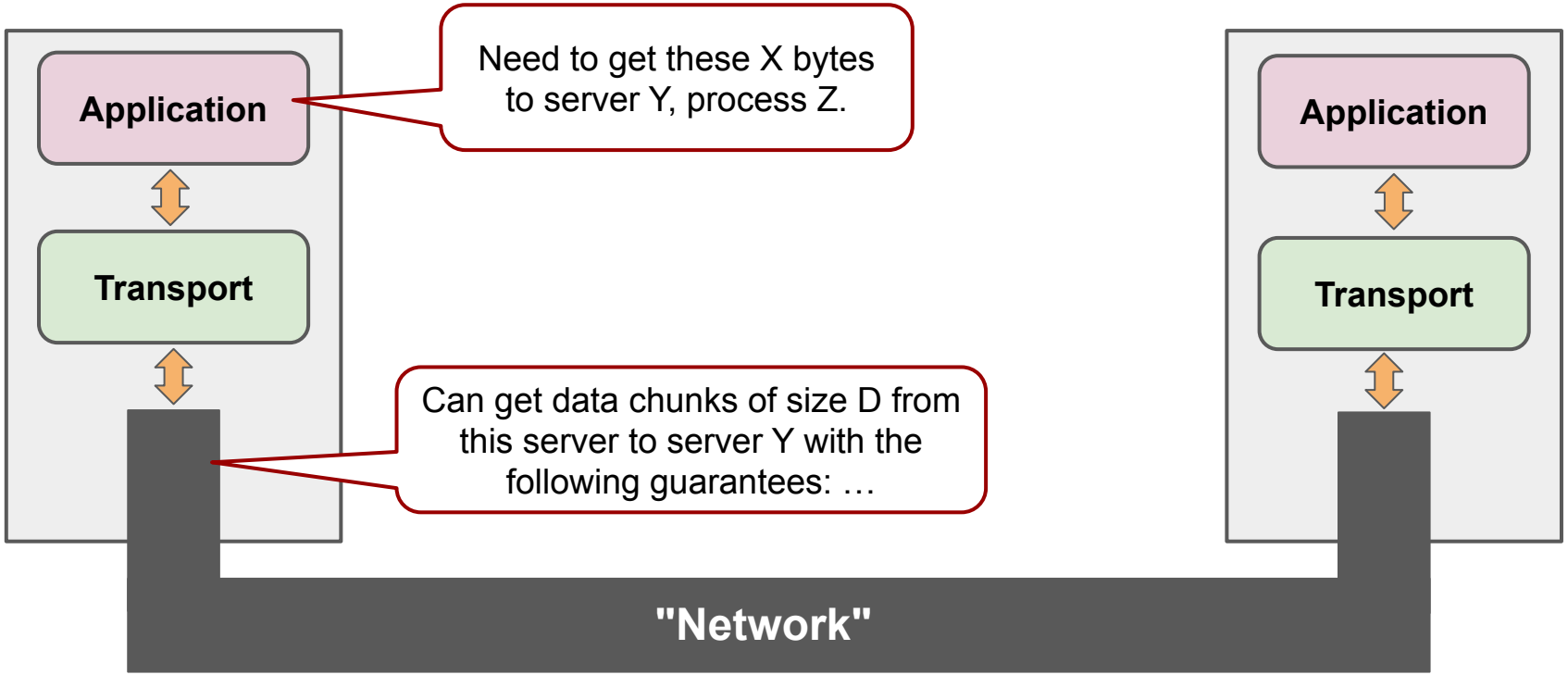
CS 856: Network Transport Protocols

Modeling, Analysis, Performance Exploration

Winter 2026

Part 1

What is a network transport protocol?



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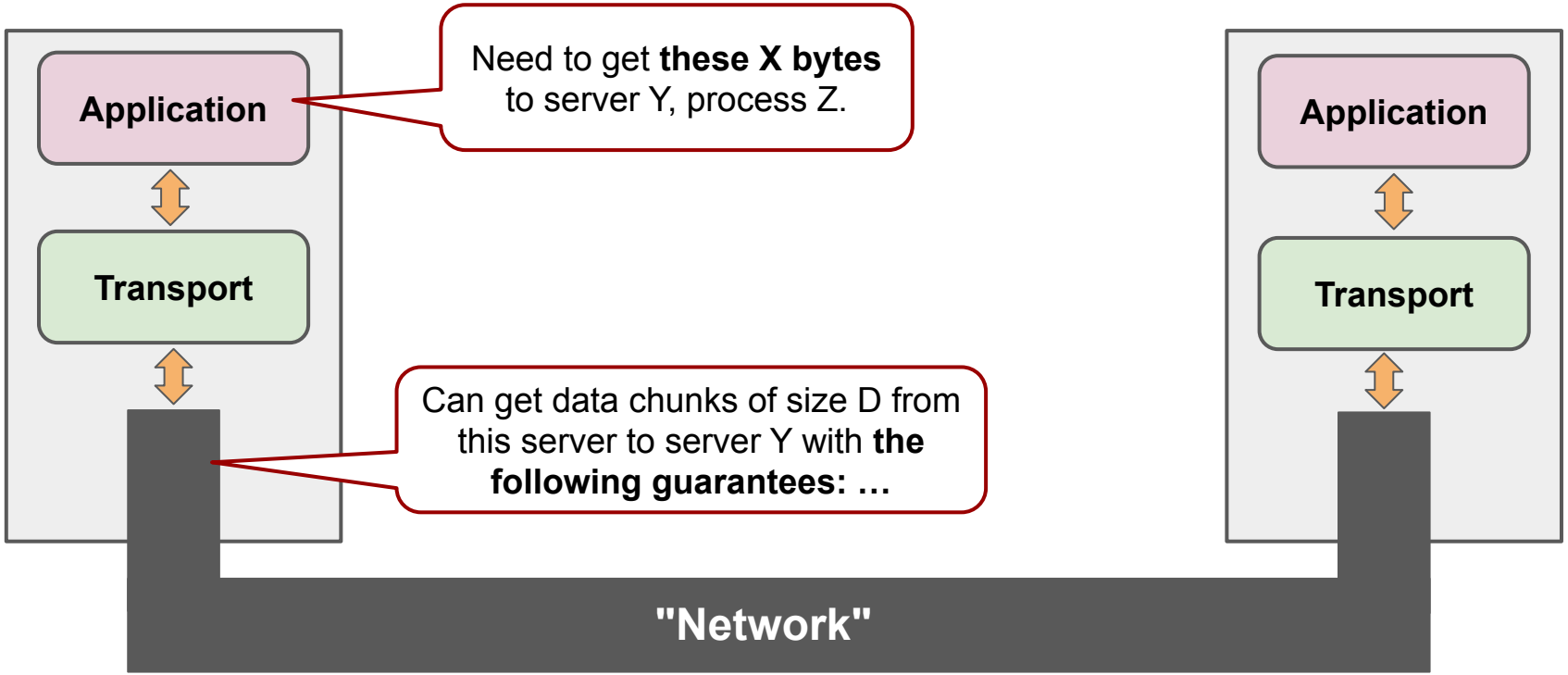


Network transport is closed-loop

- The decisions each individual endpoint makes impacts the pattern of traffic entering the network.
- Traffic interactions in the network impacts the way endpoints perceive the network state
  - Did I receive an ack?
  - How long is the round-trip-time?
  - …
- That impacts subsequent decisions by individual endpoints.
- ...

Network transport is complex

Which transport mechanisms are best depends on:

1. Application communication patterns
    - steady and long, short and bursty, …
2. Application requirements
    - High throughput? Low latency? low jitter? …
3. Network guarantees
    - Can packets get lost?
    - Can packets get re-ordered?
    - Is there a bandwidth guarantee?
    - Is there a latency guarantee?
    - …

Network transport is complex - cont.

4. How much visibility the end point has into the network state
    - Does it know exact congestion levels (e.g., queue lengths) at bottleneck links?
    - Does it know what kind of traffic it is sharing bottlenecks with?
    - Does it have to guess available capacity?
    - Can it make assumptions about how the state of "the pipe" is going to change
    - …

Network transport is complex - cont.

5. What knobs are available to the end point to control the treatment of traffic in the network
    - Does the network support setting priorities?
    - Can it specify the path the traffic should take?
    - …
6. Where is it going to run?
    - Kernel? User space? the NIC?
7. …

Example 1. "Perfect" pipe

- The application wants to send one large file
- The network
  - does not lose/corrupt/re-order packets
  - guarantees an exclusive "slice" to the communication between the sender and the receiver
  - So there is no congestion, fixed guaranteed bandwidth and delay
- The transport protocol can be relatively simple:
  - Chop up data into packets
  - Adjusts rate based on receiver capacity (flow control)
- Transport for RDMA over InfiniBand networks is conceptually similar
  - Just conceptually, there are several differences…

Example 2. Best-effort Internet

- The application wants to send one large file
- The network
  - loses, corrupts, and re-orders packets
  - has no performance guarantees
  - does not provide direct feedback about congestion
  - does not support traffic priorities
- The transport protocol can get quite complicated
  - Chop up data into packets
  - Adjusts rate based on receiver capacity (flow control)
  - Infer available network capacity and adjust rate accordingly (e2e congestion control)
- TCP, QUIC, …

Example 3. Data Center Networks

- The application wants to send multiple independent short messages
- The network and endpoint are controlled by the same entity. So, there is opportunity for more network features and co-design
- The network still loses, corrupts, and re-orders packets
- But, it can potentially
  - provide direct feedback about congestion
  - support traffic priorities
  - allow applications to specify desired paths
  - …
- pFabric, NDP, Homa, dcPIM, …

Example 4. Application interface and multiple requests

- How should the transport layer handle multiple requests from the same application?
  - Concurrently? Sequentially in a stream? a mix?
- How should it handle requests from multiple applications on the same sender?
  - Round robin? Priority?
  - What is a reasonable "scheduling" granularity?

Example 5. Execution environment

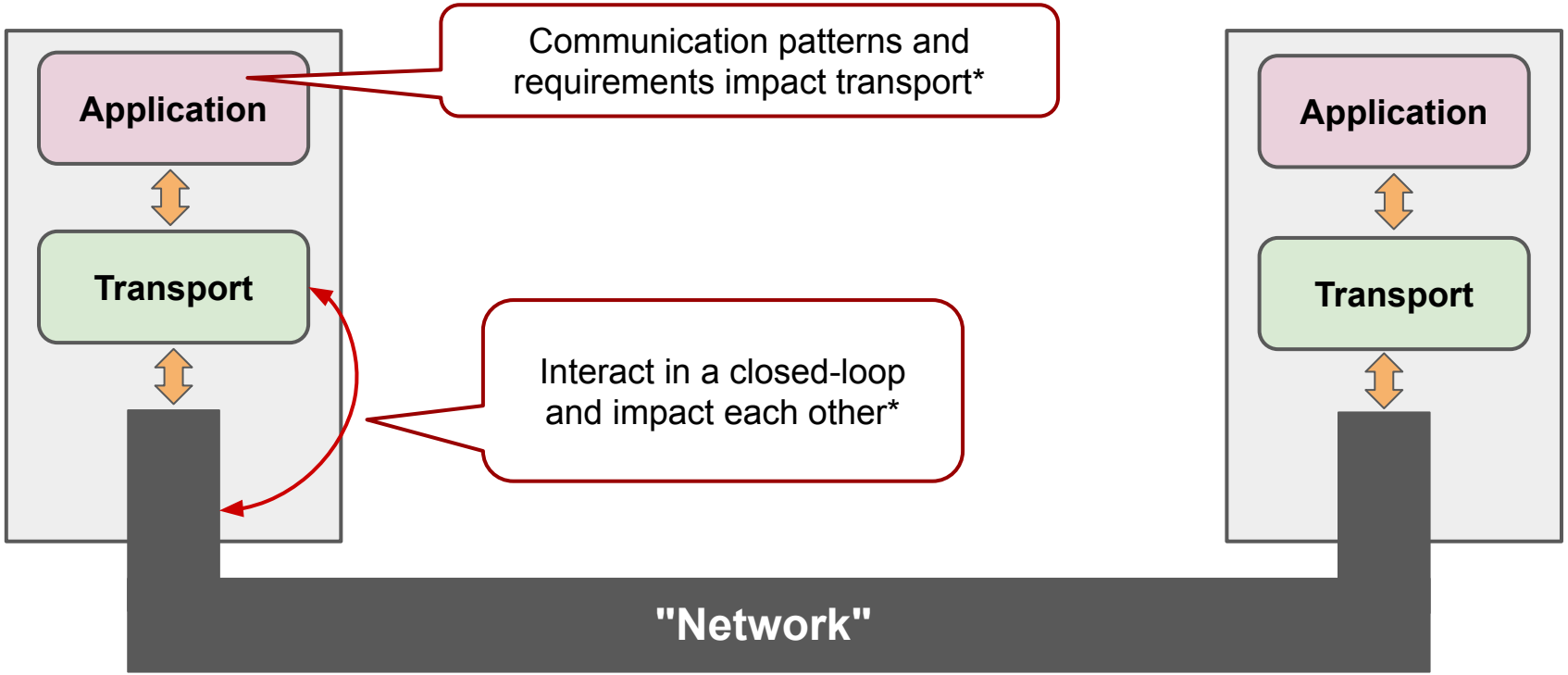
- How do you factor in implementation efficiency in all these decisions?
  - Data structures
  - Memory access patterns
  - caching
  - context switches
  - batching (including ack coalescing)
  - …

In-class discussion

- Say you are creating a data center network
- Would you use regular TCP for your transport? Why or why not?
- What do people do today?

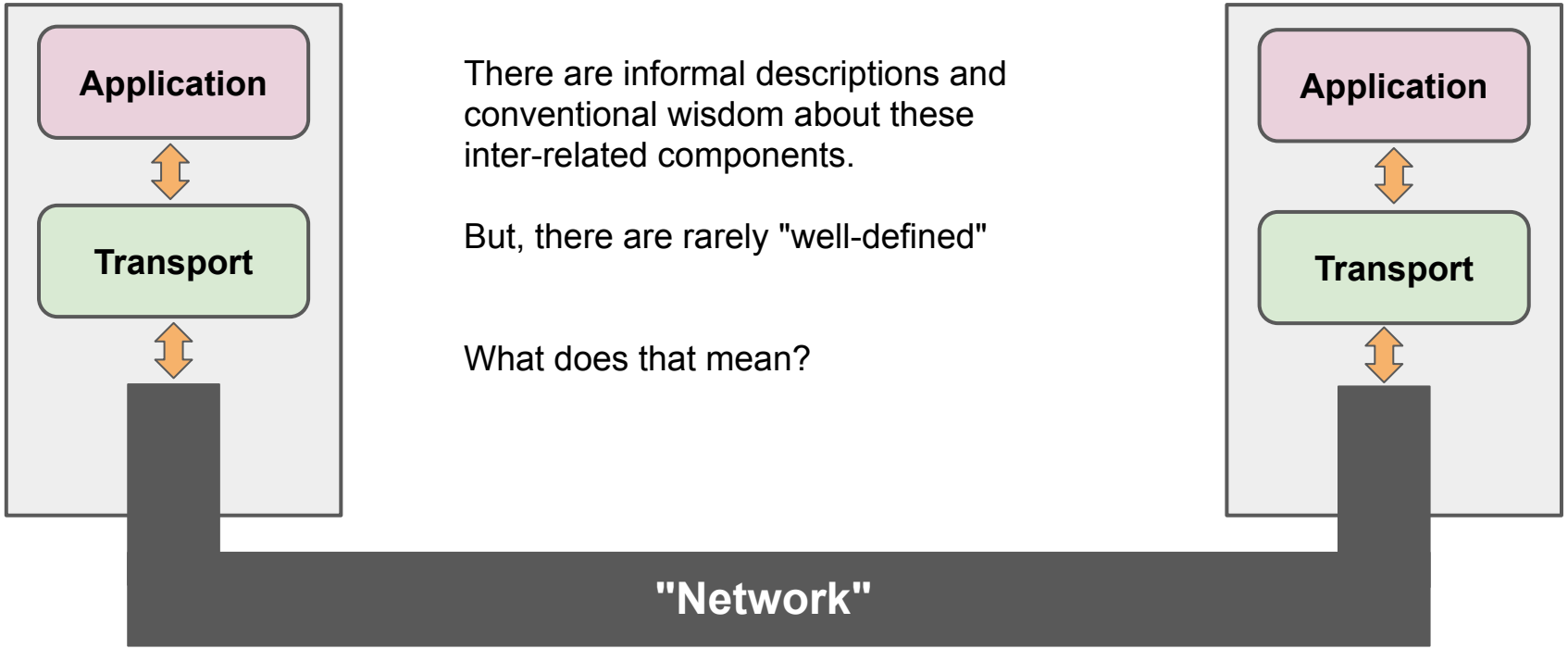
Part 2

Let's look at this picture again



* Technically, the application can be "involved" in the closed-loop as well

The network transport system is not "well-defined"

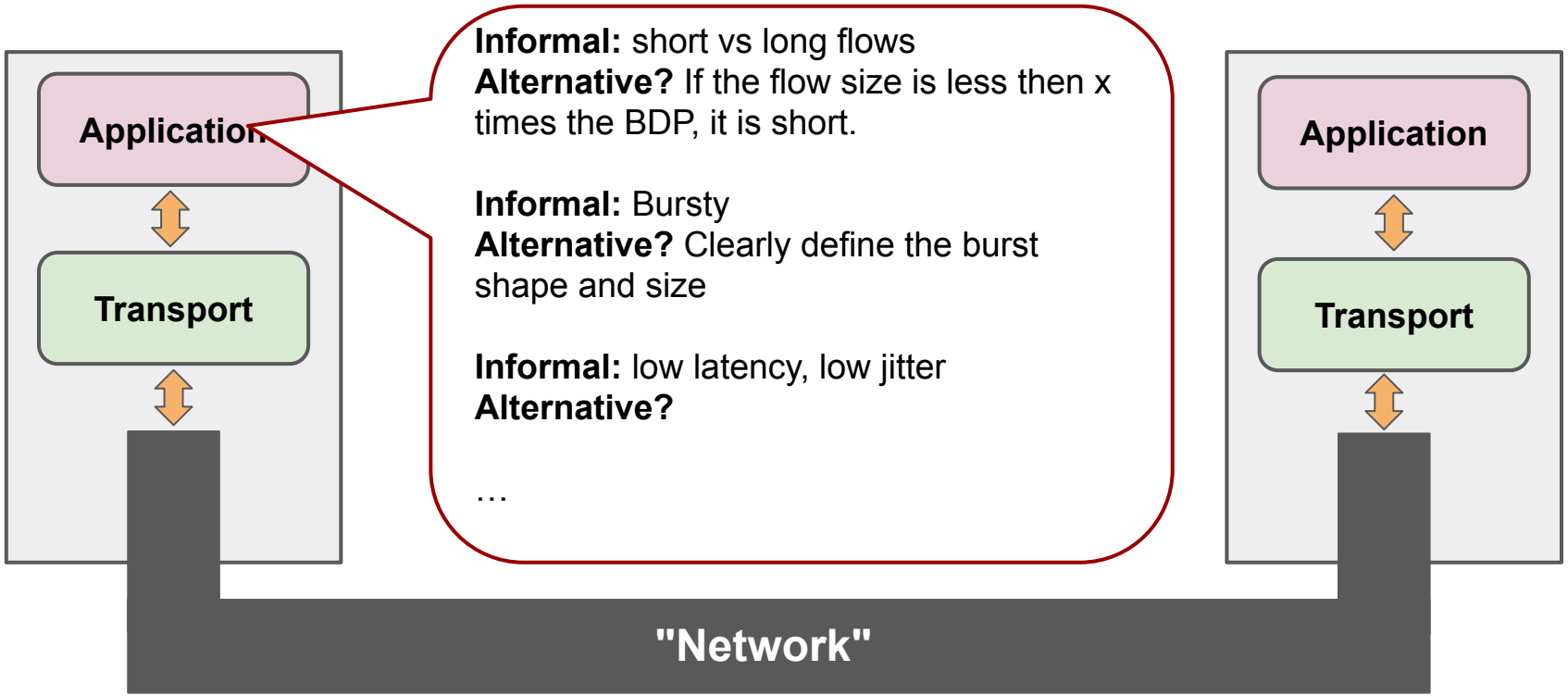


There are informal descriptions and conventional wisdom about these inter-related components.

But, there are rarely "well-defined"

What does that mean?

The network transport system is not "well-defined"



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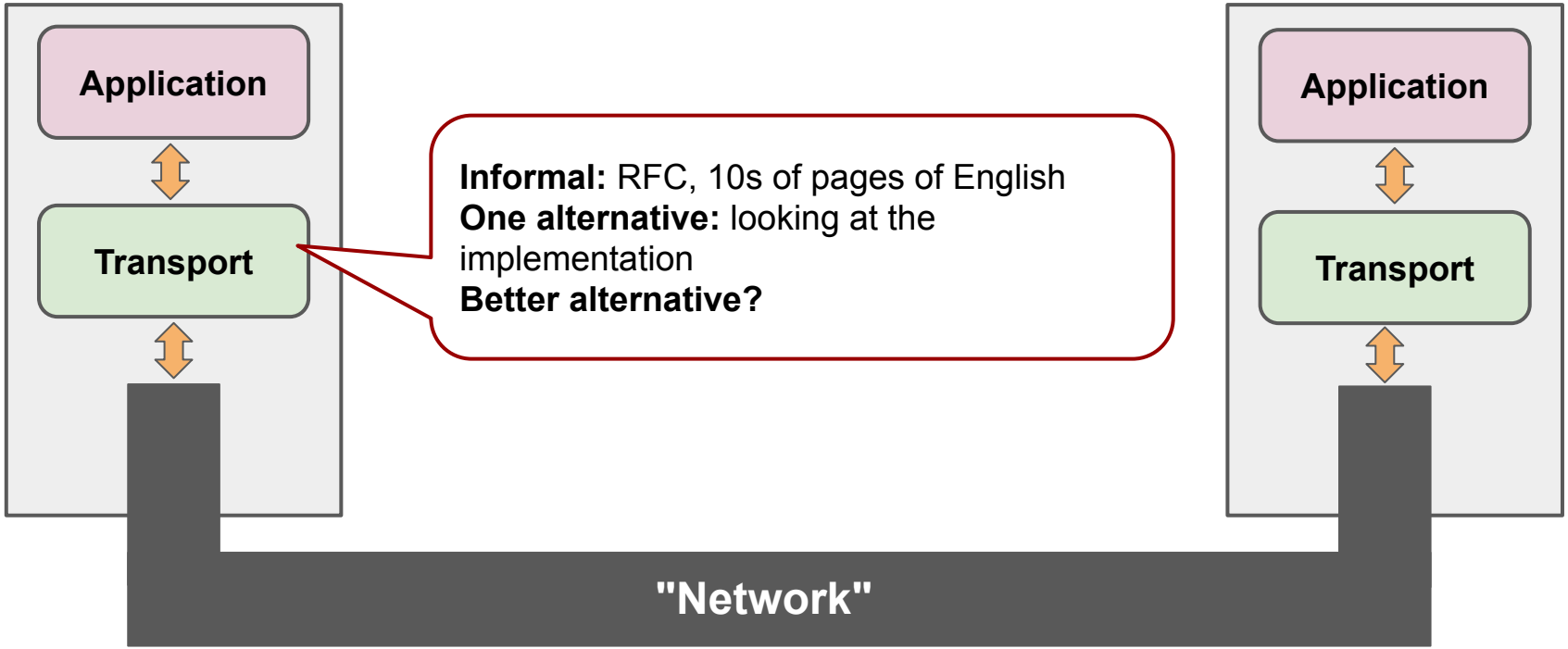

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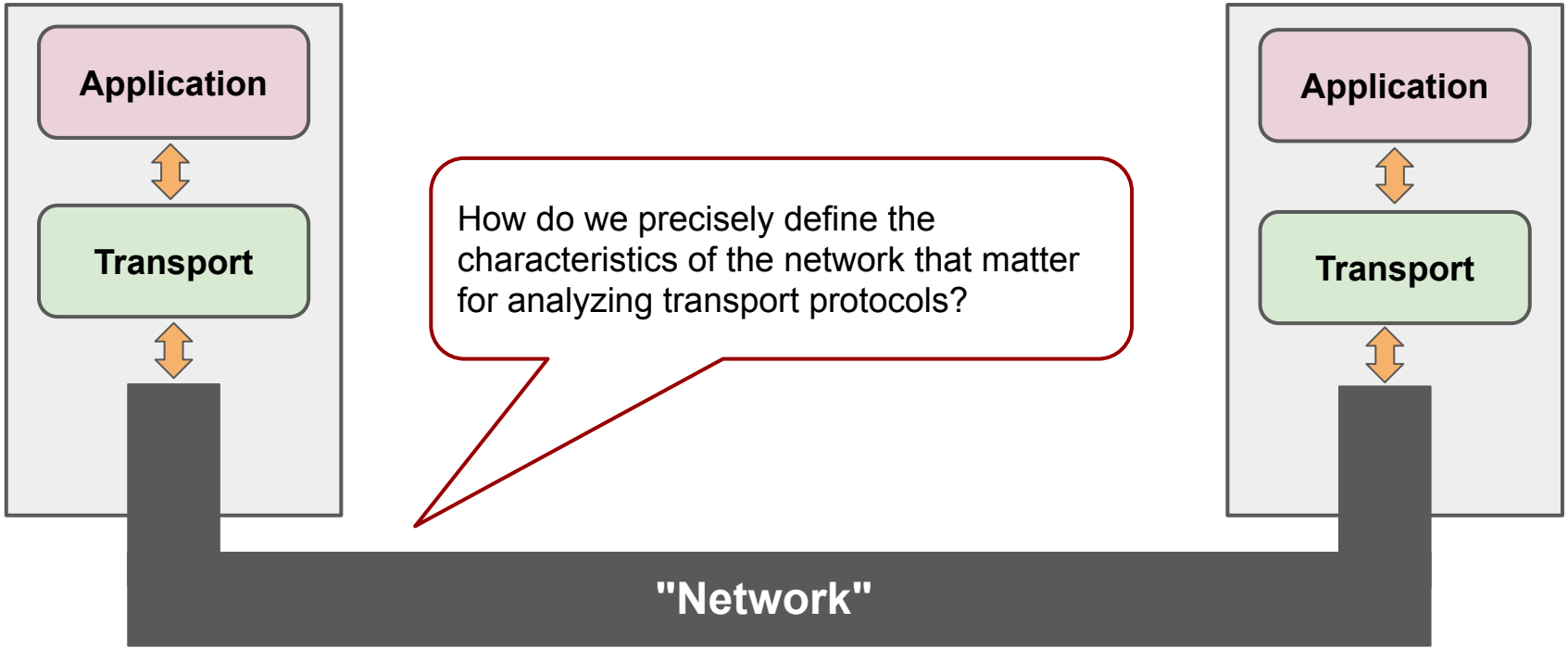

This course

- Understand the precise requirements and assumptions around transport protocols and their decision making process
  - One protocol at a time!
- Explore if protocols work as expected within those assumptions
- Through that, we will learn
  - The intricacies of the transport protocols
  - What transport mechanisms works best for what applications and what networks
  - Particularly important as we more towards more customization in systems and networks

Logistics

- Class is Mondays 3-6pm.
- Instructor is me! Email me for any questions and to request office hours
  - prefix the email with [CS856] for a timely reply
- We will use Piazza for announcements, questions, and discussions.
- Grades will be announced through LEARN.

Course Structure

- Reviews? Presentations? Project? Not quite.
- We will learn through working on research projects together
- How would that work?

Course Structure

- Lectures on week 1 and 2.
- In the first week, each student will pick a transport protocol and a network setting to dive into this term
- For the first half (~until reading week)
  - Each student will learn and teach others about their protocol and network setting
    - Presentation
    - Modeling the protocol in a DSL (more on that next week)
    - Clearly specifying assumptions and properties of the application and the network
  - Start reproducing the paper's results
    - So that you have an experimental setup

Course Structure - cont.

- For the second half, we will explore the effectiveness of the chosen protocols
  - Based on the assumptions specified in the paper, what are the workloads and settings should the paper be evaluated on?
  - What is the protocol evaluated against? What workloads? What network settings?
  - What is missing? Is there any setup under which the protocol will behave undesirably?
- There is a 6-page final report due at the end of the term (April 23)

Alternative project option (ideally a group of 2 students)

Build a unified network simulation environment for evaluating transport protocols (using NS3)

- Instead of the first presentation, this group will use one session to demo the simulator and have other students use it
- For the second half of the course:
  - Work on improving the simulator (e.g., looking at features supported by other transport simulation/emulation frameworks)
  - Provide support to other students using it
- Write the 6-page project report

How do presentations work?

- One week before your presentation, send me your presentation plan
- Plan for first presentation:
  - The specific protocol you want to focus on.
  - The paper(s) you are going to present
    - The main paper for that protocol, and any follow up, adjacent work
- Be prepared to lead a discussion for one session (75 minutes)
  - You are the one deep diving on this protocol/topic
  - Make sure you understand it thoroughly
  - Come up with discussion points before hand
    - I'm happy to provide feedback

How do presentations work?

- Most importantly, remember that the purpose is for us to learn together.
- So, approach your presentation with the goal of teaching others something you have studied in depth.

How do I find related papers?

- Conference proceedings
  - SIGCOMM, NSDI are our go-to conferences
  - Depending on the topic, OSDI, SOSP, ASPLOS, SIGMETRICS, and others could be relevant too.
  - If you need help/pointers, don't hesitate to reach out.
- References "Chasing"
  - Backwards: look at the related work section of a paper, find related citations
  - Forwards: Use academic search engines like Google Scholar to find relevant papers that have cited a specific paper.
- Ask :)
  - I'll be more than happy to provide some initial pointers.

Difference compared to the "traditional" format

- No paper reviews
- No written proposal or progress reports
  - Your presentations will basically serve that purpose
- No assignments
- Presentations and in-class discussions are weighted more heavily.
- No changes to the final project report, but hopefully it is easier to write after all the discussions we will have throughout the term.

Grading

- Presentations: 35%
- Participation in discussions: 15%
- Final project report: 50%

Final Remarks

- Seminar courses are only as good as the discussions we have.
- Be active, ask questions, and voice your opinion.
- There are no bad ideas, and I mean it 🙂
- If you have a hard time speaking up, let me know and I'll make sure to provide space for you to voice your opinion.
- Be mindful of others in discussions.