Poll Everywhere

pollev.com/cse333j

About how long did Exercise 13 take you?

A. [0, 2) hours
B. [2, 4) hours
C. [4, 6) hours
D. [6, 8) hours
E. 8+ Hours
F. I didn’t submit / I prefer not to say

Systems Programming
Networks Introduction

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Relevant Course Information

- Bit of a break from exercises – Exercises 15 & 16 released on Friday
- Homework 3 is due Thursday (2/23)
  - Debug using small custom test directories
  - Make use of the solution binaries to double-check your work
- Rest of the quarter: networking, concurrency, processes

Lecture Outline (1/4)

- **C++ Inheritance (finish)**
  - **Constructors and Destructors**
  - **Assignment**
- C++ Casting
- C++ Conversions
- Networks Introduction

- Reference: *C++ Primer* §4.11.3, 19.2.1

Assignment and Inheritance

- C++ allows you to assign the value of a derived class to an instance of a base class
  - Known as object slicing
    - It's legal since b = d passes type checking rules
    - But b doesn't have space for any extra fields in d

slicing.cc

```
class Base {
 public:
  Base(int xi) : x(xi) { }
  int x;        b | x[1] |
};

class Der1 : public Base {
 public:
  Der1(int yi) : Base(16), y(yi) { }
  int y;       d | | x[16] | y[2] |
};

void Foo() {
  Base b(1);
  Der1 d(2);

  d = b;   // compiler error - not enough info
  b = d;   // OK, but what happens to y?
}
```

STL and Inheritance (1/2)

- Recall: STL containers store **copies of values**
  - What happens when we want to store mixes of object types in a single container? (*e.g.*, `Stock` and `DividendStock`)
  - You get sliced ☹

```
#include <list>
#include "Stock.h"
#include "DividendStock.h"

int main(int argc, char** argv) {
  Stock s;
  DividendStock ds;
  list<Stock> li;

  li.push_back(s);    // OK
  li.push_back(ds);   // OUCH!

  return EXIT_SUCCESS;
}
```

STL and Inheritance (2/2)

- Instead, store **pointers to heap-allocated objects** in STL containers vector<Stock*>

$$\begin{tikzcd} & \text{vector<Stock*>} \arrow[dl] \arrow[dr] & \\ \text{Stock} & & \text{DividendStock} \end{tikzcd}$$

  - No slicing! ☺
  - `sort()` does the wrong thing ☹ – sorts on addresses by default
  - You have to remember to `delete` your objects before destroying the container ☹
    - Unless you use smart pointers! e.g., vector<shared_ptr<Stock>>

Lecture Outline (2/4)

- C++ Inheritance (finish)
  - Constructors and Destructors
  - Assignment
- **C++ Casting**
- C++ Conversions
- Networks Introduction

- Reference: *C++ Primer* §4.11.3, 19.2.1

Explicit Casting in C

- Simple syntax: `lhs = (new_type) rhs;`
- Used to:
  - Convert between pointers of arbitrary type (void *) my_ptr
    - Doesn't change the data, but treats it differently
  - Forcibly convert a primitive type to another (float) my_int
    - Actually changes the representation

- You *can* still use C-style casting in C++, but sometimes the intent is not clear
  - You *should not* use C-style casting in C++.

Casting in C++

STYLE TIP

- C++ provides an alternative casting style that is more informative:
  - `static_cast<to_type>(expression)`
  - `dynamic_cast<to_type>(expression)`
  - `const_cast<to_type>(expression)`
  - `reinterpret_cast<to_type>(expression)`

- Always use these in C++ code
  - Intent is clearer
  - Easier to find in code via searching

staticcast.cc

static_cast

- static_cast can convert: any well-defined conversion
  - Pointers to classes **of related type**
    - Compiler error if classes are not related
    - Dangerous to cast *down* a class hierarchy
  - Casting between void* and T*
  - Non-pointer conversion
    - *e.g.*, float to int
- static_cast is checked at compile time

static_cast can change the data representation!

```
class A {
 public:
  int x;
};

class B {
 public:
  float x;
};

class C : public B {
 public:
  char x;
};
```

A

B → C

```
void Foo() {
  B b; C c;

  // compiler error (unrelated)
  A* aptr = static_cast<A*>(&b);
  // OK (would have been done implicitly)
  B* bptr = static_cast<B*>(&c);
  // compiles, but dangerous
  C* cptr = static_cast<C*>(&b);
}
```

dynamiccast.cc

dynamic_cast

- `dynamic_cast` can convert:
  - Pointers to classes **of related type**
  - References to classes **of related type**
- `dynamic_cast` is checked at both <u>compile time</u> and <u>run time</u>
  - Casts between unrelated classes fail at compile time
  - Casts from base to derived <u>fail</u> at run time if the pointed-to object is not the derived type

return nullptr

```
class Base {
 public:
  virtual void Foo() { }
  float x;
};

class Der1 : public Base {
 public:
  char x;
};
```

```
void Bar() {
  Base b; Der1 d;

  // OK (run-time check passes)
  Base* bptr = dynamic_cast<Base*>(&d);
  assert(bptr != nullptr);

  // OK (run-time check passes)
  Der1* dptr = dynamic_cast<Der1*>(bptr);
  assert(dptr != nullptr);

  // Run-time check fails, returns nullptr
  bptr = &b;
  dptr = dynamic_cast<Der1*>(bptr);
  assert(dptr != nullptr);
}
```

const_cast

- `const_cast` adds or strips const-ness
  - Dangerous (!)

```
void Foo(int* x) {
  *x++;
}

void Bar(const int* x) {
  Foo(x);                          // compiler error
  Foo(const_cast<int*>(x));  // succeeds
}

int main(int argc, char** argv) {
  int x = 7;
  Bar(&x);
  return EXIT_SUCCESS;
}
```

`reinterpret_cast`

- `reinterpret_cast` casts between *incompatible* types
  - Low-level reinterpretation of the bit pattern
  - *e.g.*, storing a pointer in an `int`, or vice-versa
    - Works as long as the integral type is "wide" enough
  - Converting between incompatible pointers
    - Dangerous (!)
    - This is used (carefully) in hw3
  - Use any other C++ cast if you can!

reinterpret_cast cannot change the data representation

Casting Style Considerations

STYLE TIP

- From the "Casting" and "Run-Time Type Information (RTTI)" sections of the Google C++ Style Guide:
  - When the logic of a program guarantees that a given instance of a base class is, in fact, an instance of a particular derived class, then a `dynamic_cast` may be used freely on the object.
    - Usually one can use a `static_cast` as an alternative in such situations
  - Only use `reinterpret_cast` if you know what you are doing and you understand the aliasing issues
    - For *unsafe conversions* of pointer types to and from integer and other pointer types, including `void*`

Lecture Outline (3/4)

- C++ Inheritance (finish)
  - Constructors and Destructors
  - Assignment
- C++ Casting
- **C++ Conversions**
- Networks Introduction

- Reference: *C++ Primer* §4.11.3, 19.2.1

Implicit Conversion

- The compiler tries to infer some kinds of conversions
  - When types are not equal and you don't specify an explicit cast, the compiler looks for an acceptable implicit conversion

```
void Bar(std::string x);

void Foo() {
  int x = 5.7;  // conversion, float -> int
  char c = x;   // conversion, int -> char
  Bar("hi");    // conversion, (const char*) -> string
}
```

Sneaky Implicit Conversions

- (`const char*`) to `string` conversion?
  - If a class has a constructor with a single parameter, the compiler will exploit it to perform implicit conversions
  - At most, one user-defined implicit conversion will happen
    - Can do `int` → `Foo`, but not `int` → `Foo` → `Baz`

```
class Foo {
 public:
  Foo(int xi) : x(xi) { }
  int x;
};

int Bar(Foo f) {
  return f.x;
}

int main(int argc, char** argv) {
  return Bar(5);  // equivalent to return Bar(Foo(5));
}
```

constructor implicitly invoked

Avoiding Sneaky Implicits

STYLE TIP

- Declare one-argument constructors as `explicit` if you want to disable them from being used as an implicit conversion path
  - Usually a good idea

```
class Foo {
 public:
  explicit Foo(int xi) : x(xi) { }
  int x;
};

int Bar(Foo f) {
  return f.x;
}

int main(int argc, char** argv) {
  return Bar(5);  // compiler error – no longer allowed, but could
}                                     still do Bar(Foo(5)) instead
```

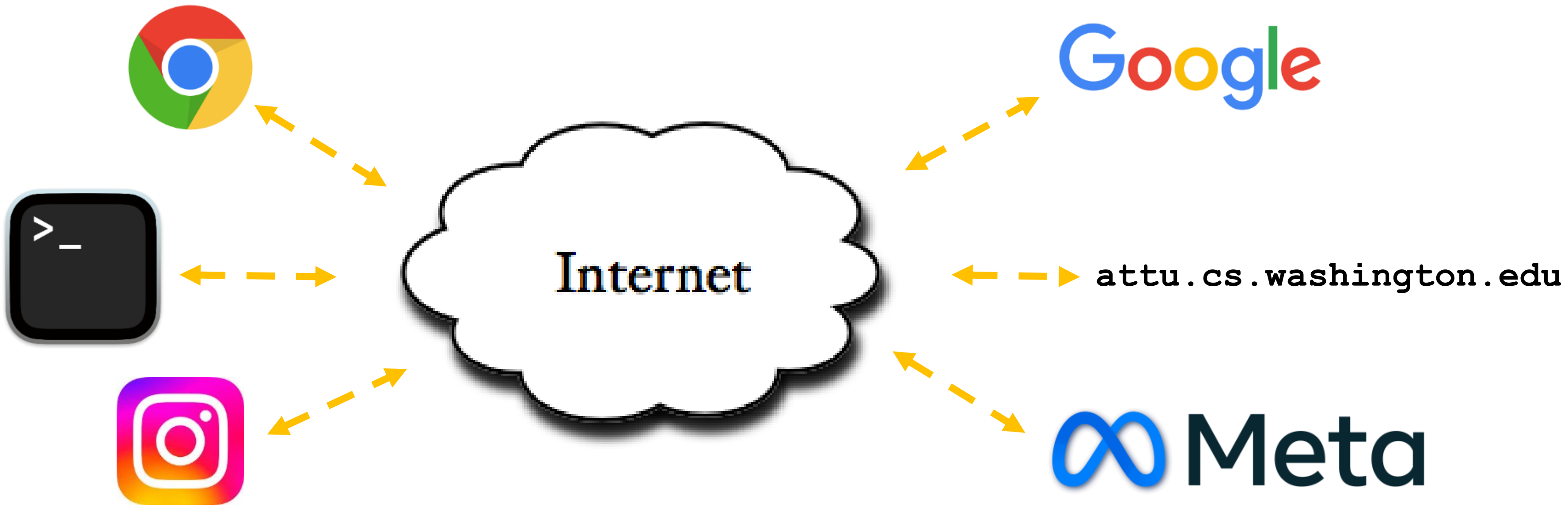
Lecture Outline (4/4)

- C++ Inheritance (finish)
  - Constructors and Destructors
  - Assignment
- C++ Casting
- C++ Conversions
- **Networks Introduction**

Today’s Goals

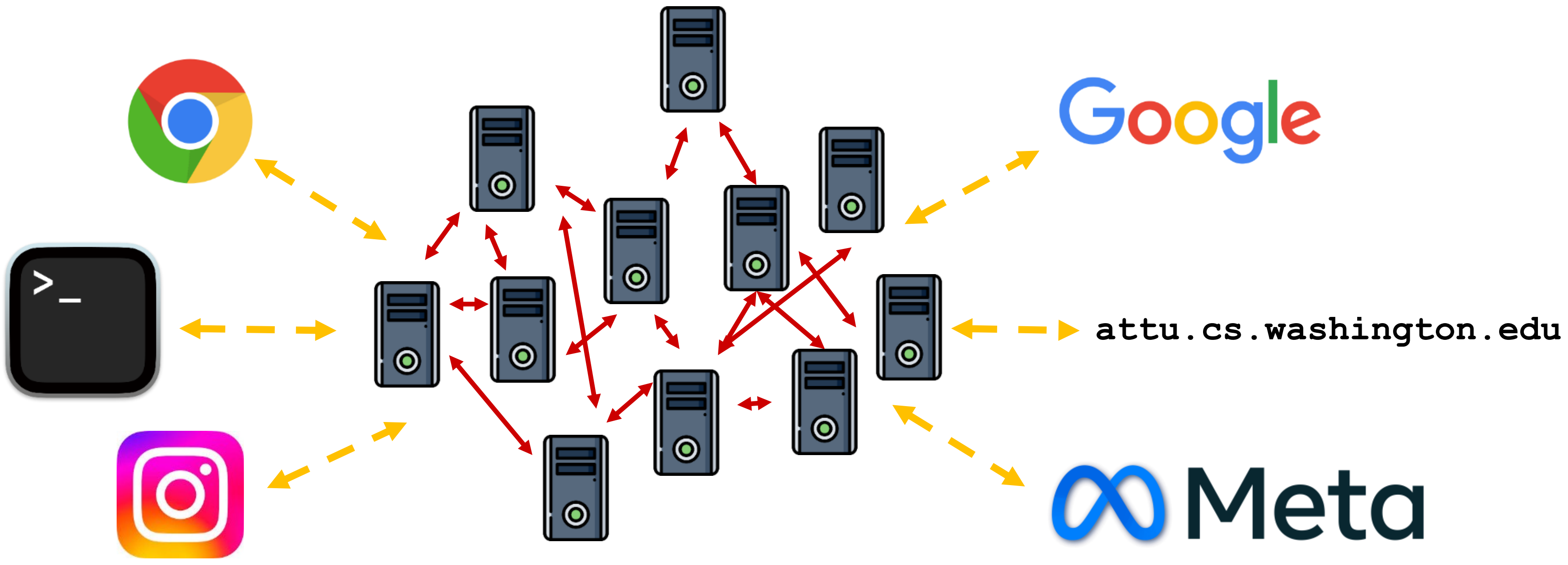
- Networking is a very common programming feature
  - You will likely have to create a program that will read/write over the network at some point in your career
- We want to give you a basic, high-level understanding of how networks work before you use them
  - Lecture will be more “story-like;” we will purposefully skip over most of the details, but hopefully you will learn something new about the Internet today!
  - Take CSE 461 if you want to know more about the implementations of networks (the course is pretty cool ☺)

Networks From 10,000 ft



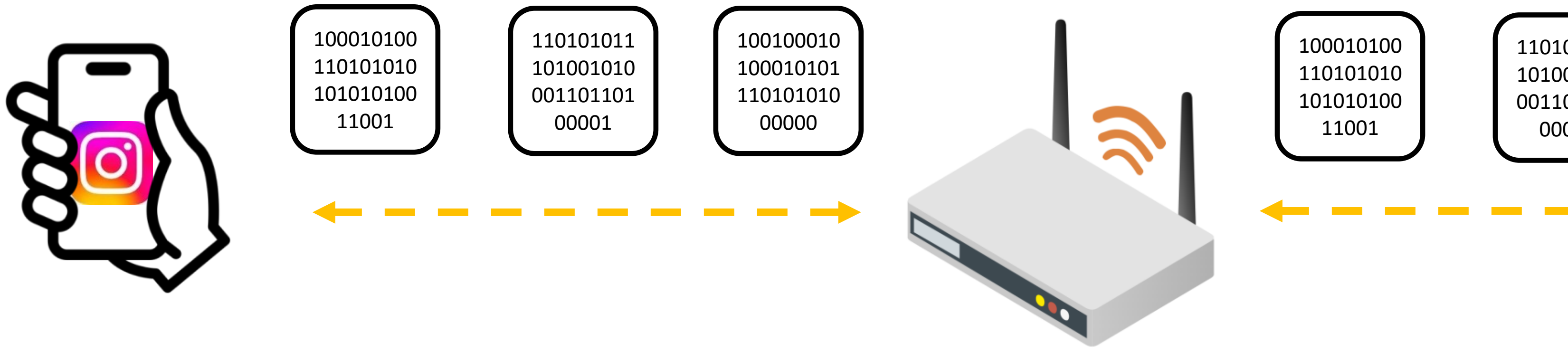
clients servers

Networks From 1,000 ft



clients network backbone servers

Networks From 10 ft



We send data from one software system to another by packaging it into **data packets** and then asking the **operating system** to transport them for us.

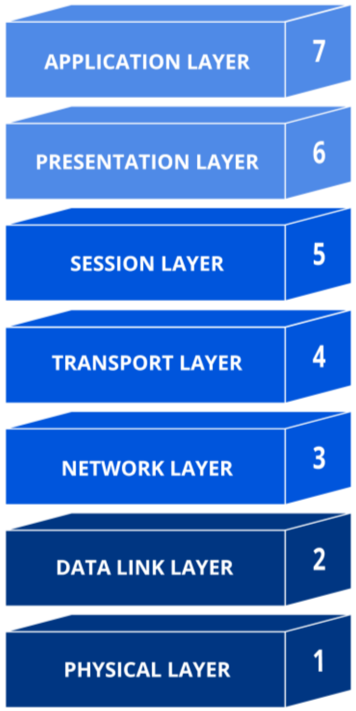
Packet Contents

- Layers…
  - Upon layers…
    - Upon layers…
      - upon layers…
        - upon layers…
          - upon layers…
            - …upon layers!

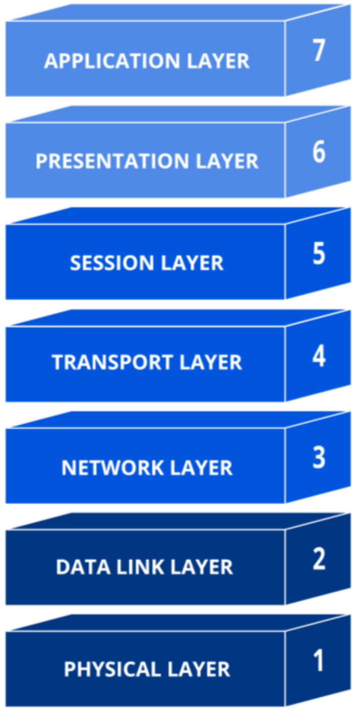
The OSI Model

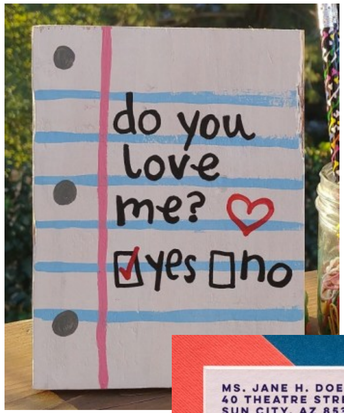
- *Conceptual* reference model for components of a communication system

- The software (and hardware) that gets your packets from one side of the internet to the other is organized into "**layers**"
  - At each step of the way, each layer is present and doing some work to get your bytes to the next hop



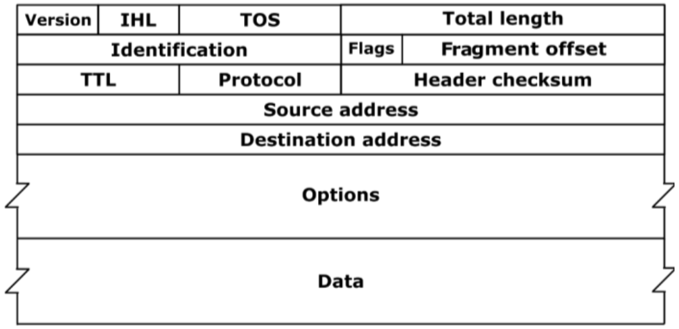
The OSI Model Analogy





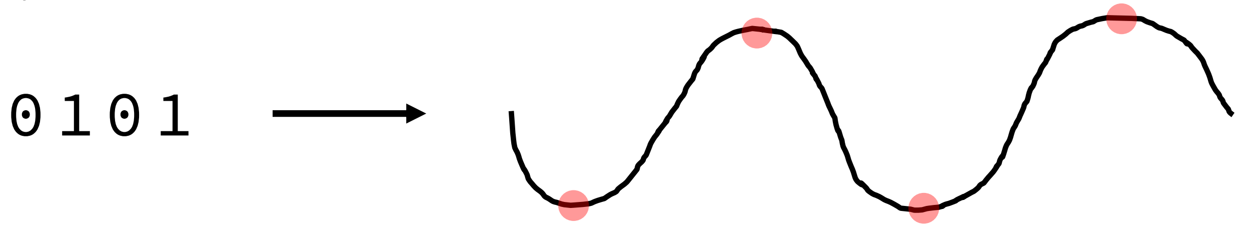
Protocols and Headers

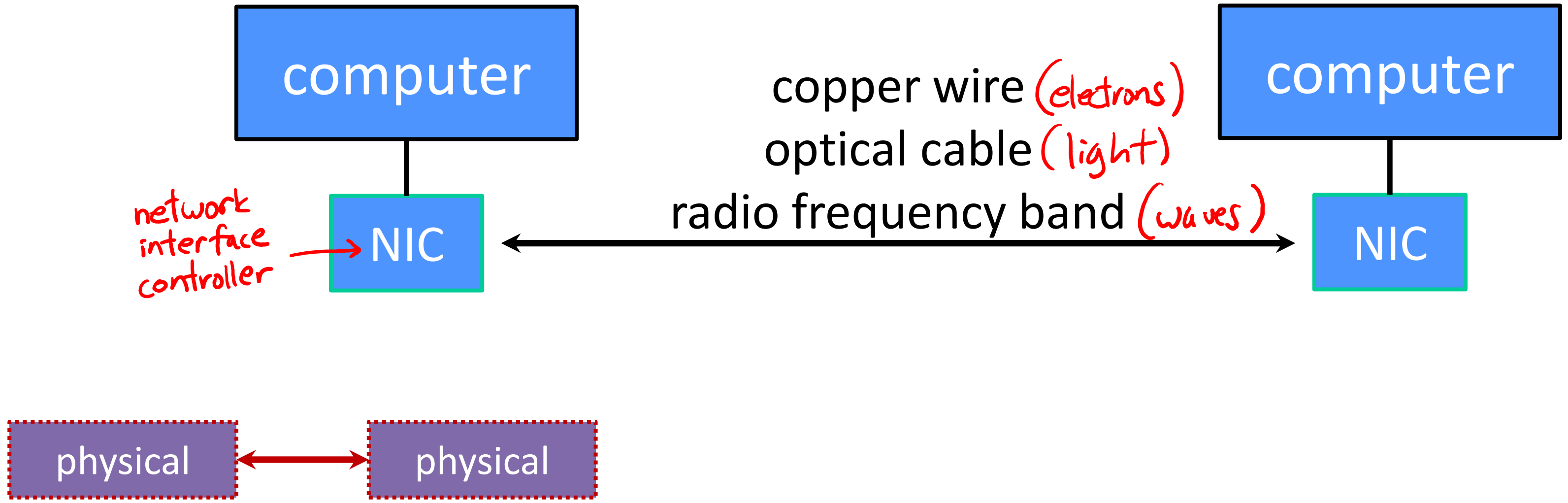
- Your data packet includes some metadata bytes (**packet headers**) for each layer so the next computer will know what to do with it
- We **standardize** those headers, and the behavior of the software reading them, in things called **network protocols**



The Physical Layer

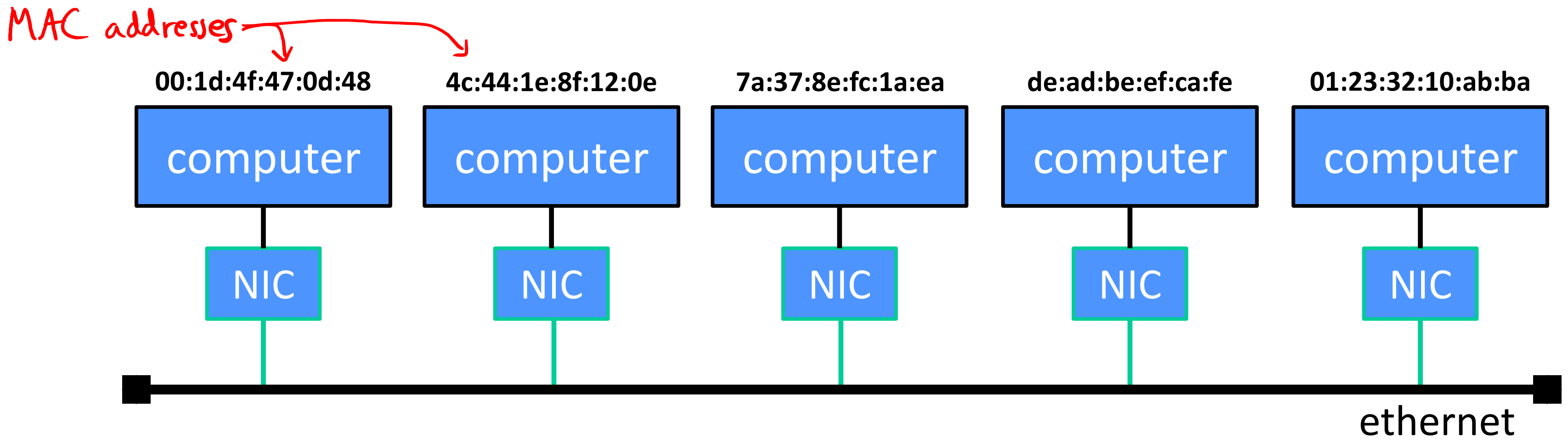
- Individual bits are transmitted over a physical medium
  - Physical layer specifies how bits are encoded at a signal level
  - Many choices, *e.g.*, encode “1” as +1v, “0” as -0v; or “0”=+1v, “1”=-1v, …

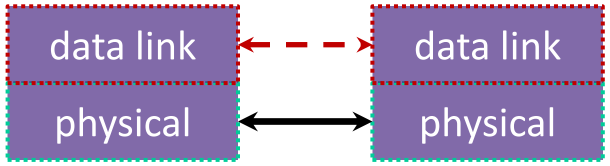


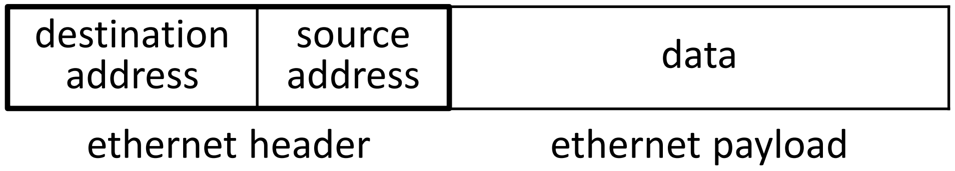


The Data Link Layer

- Multiple computers on a LAN contend for the medium
  - Media access control (MAC) specifies how computers cooperate
  - Link layer also specifies how bits are "packetized" and network interface controllers (NICs) are addressed

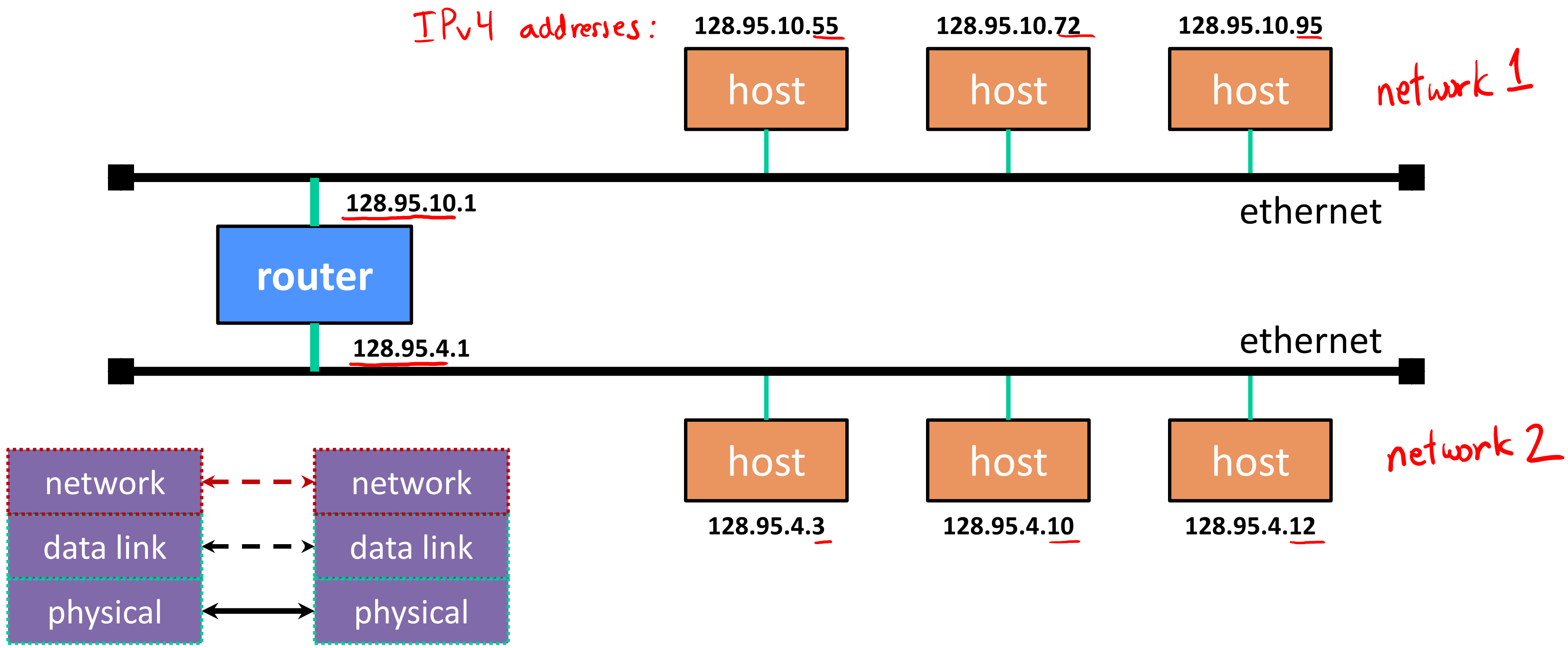






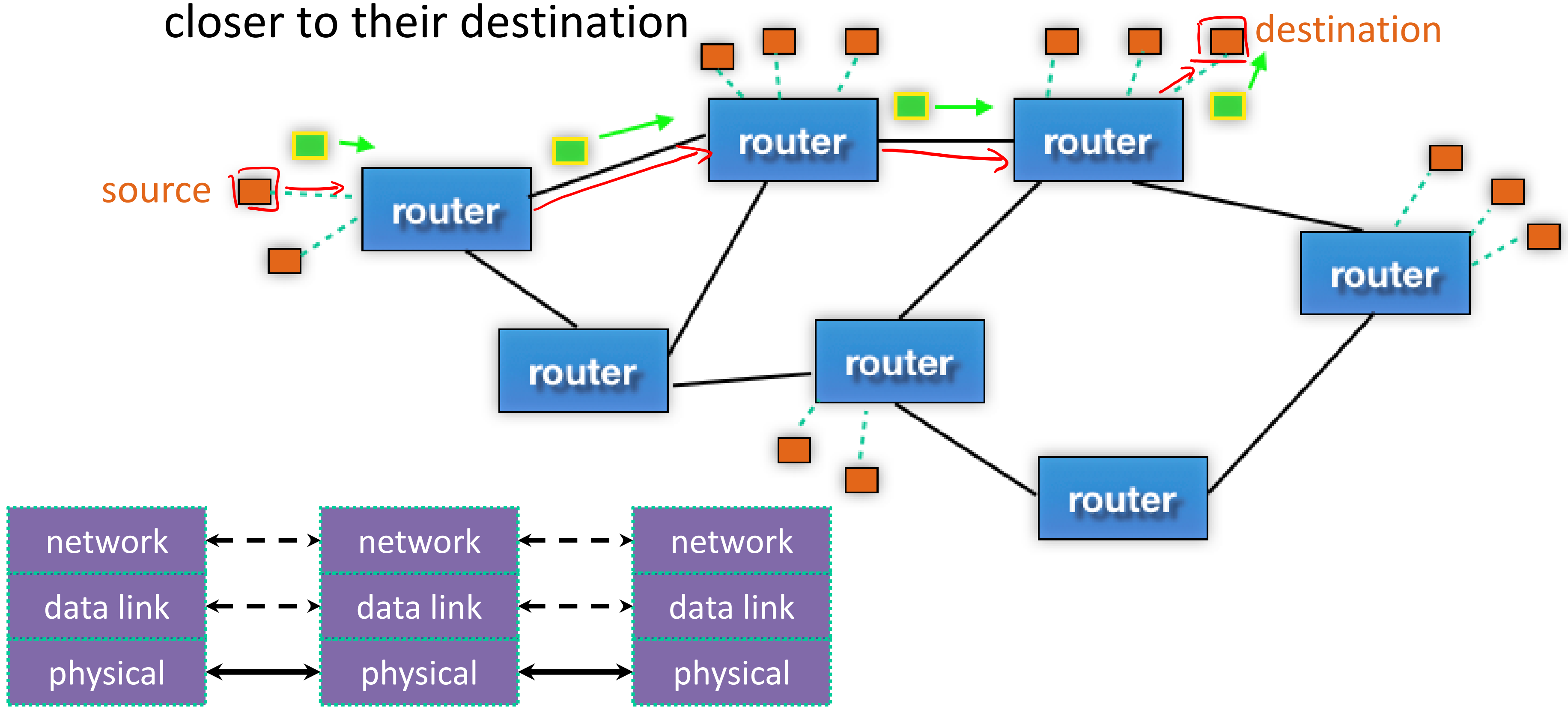
The Network Layer (IP)

- Internet Protocol routes packets across multiple networks
  - Every computer has a unique IP address
  - Individual networks are connected by routers that span networks



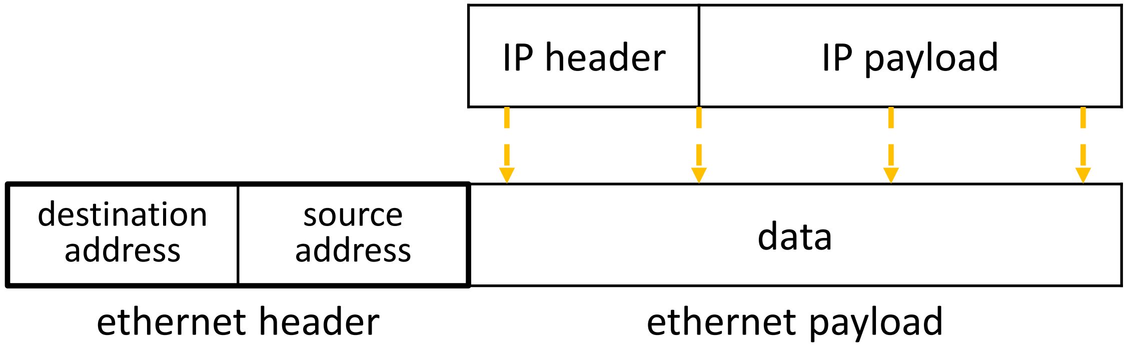
The Network Layer (IP): Routing

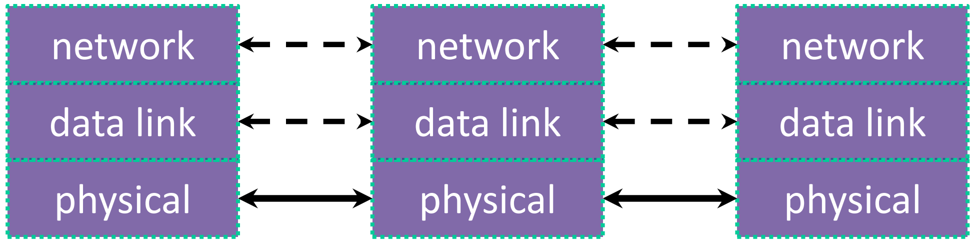
- There are protocols to:
  - Let a host map an IP to MAC address on the same network
  - Let a router learn about other routers to get IP packets one step closer to their destination



The Network Layer (IP): Packets

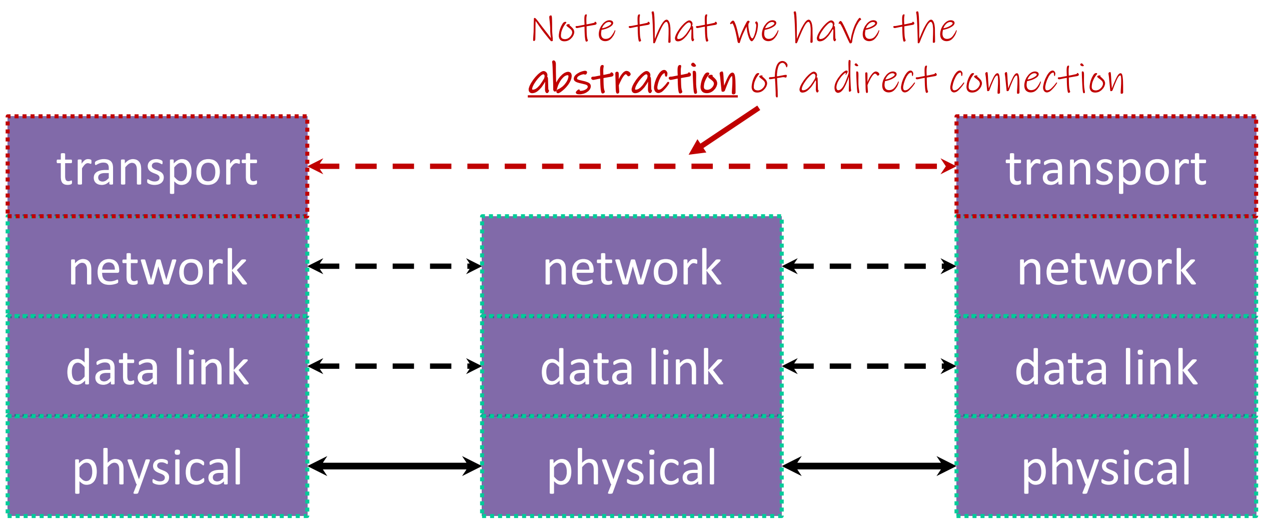
- Packet encapsulation:
  - An IP packet is encapsulated as the payload of an Ethernet frame
  - As IP packets traverse networks, routers pull out the IP packet from an Ethernet frame and plunk it into a new one on the next network





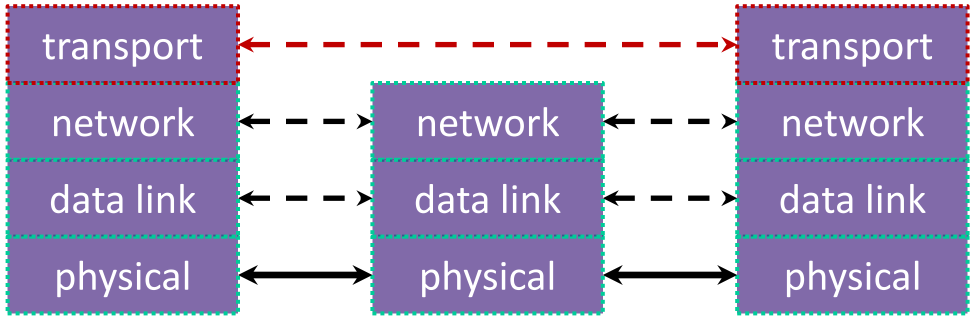
The Transport Layer

- Provides interface to treat the network as a **data stream**
- Provides different *protocols* to interface between source and destination:
  - *e.g.*, Transmission Control Protocol (TCP), User Datagram Protocol (UDP)
  - These protocols still work with packets, but manage their order, reliability, multiple applications using the network…



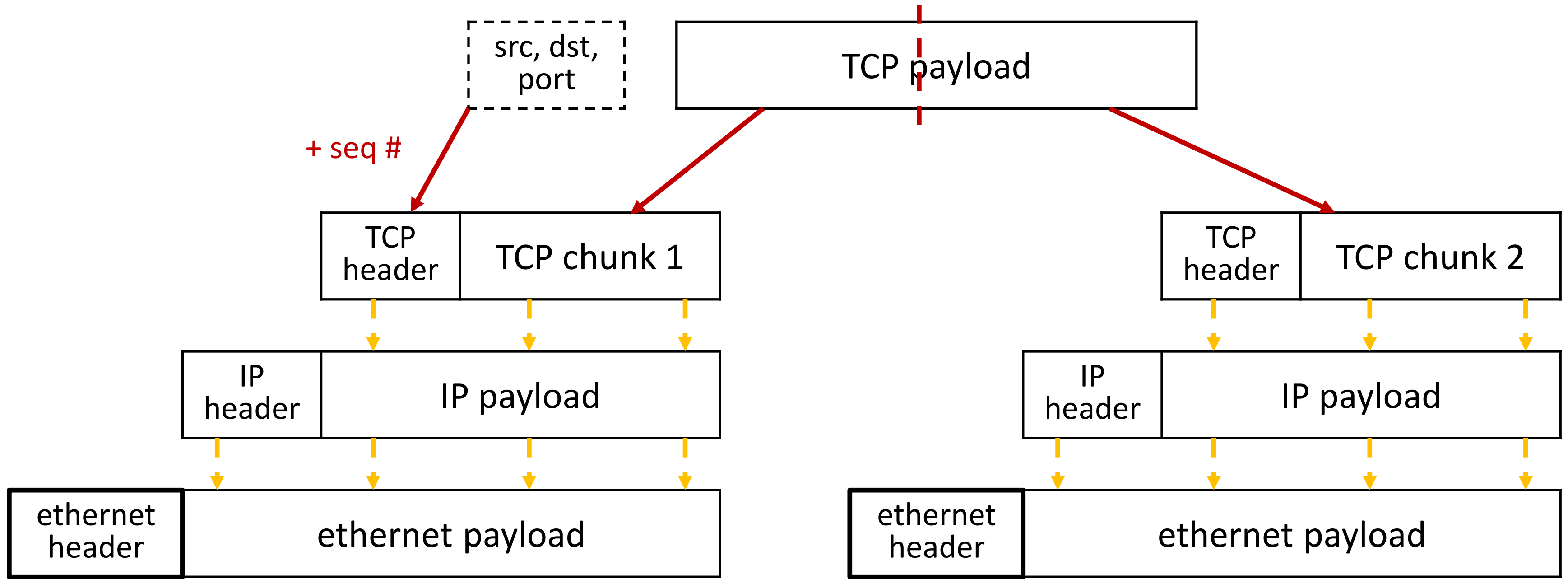
The Transport Layer: TCP

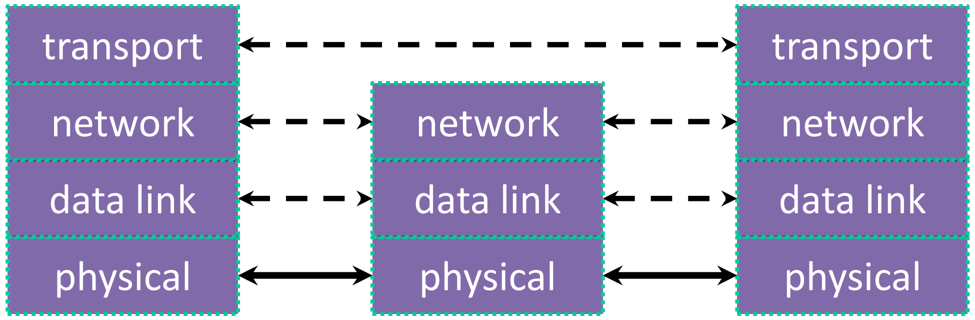
- Transmission Control Protocol (TCP):
  - Provides applications with reliable, ordered, congestion-controlled byte $\boxed{\text{streams}}$
    - Sends stream data as multiple IP packets (differentiated by sequence numbers) and retransmits them as necessary
    - When receiving, puts packets back in order and detects missing packets
  - A single host (IP address) can have up to 216 = 65,535 "ports"
    - Kind of like an apartment number at a postal address (your applications are the residents who get mail sent to an apt. #)



The Transport Layer: TCP Packets

- Packet encapsulation – one more nested layer!

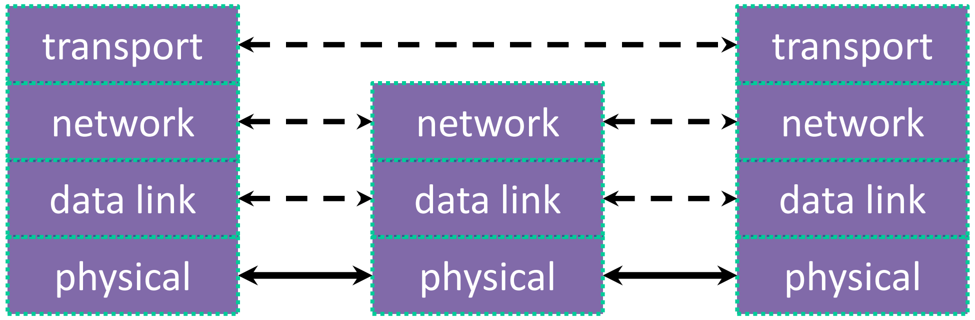




The Transport Layer: TCP API

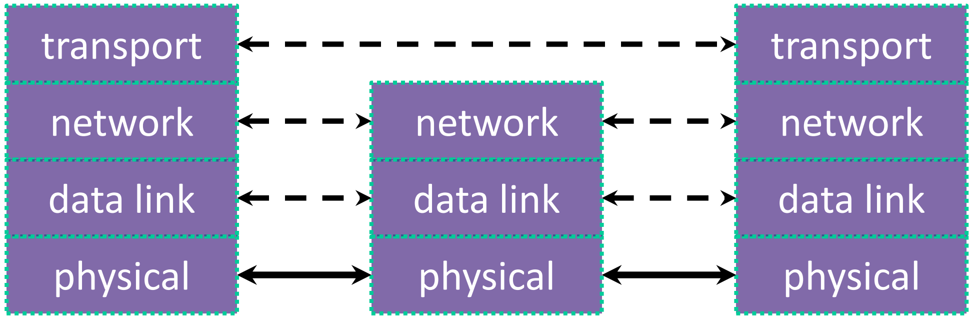
- Applications use OS services to establish TCP streams:
  - The "Berkeley sockets" API
    - A set of OS system calls (part of POSIX for Linux)
  - Clients **`connect()`** to a server IP address + application port number
  - Servers **`listen()`** for and **`accept()`** client connections
  - Clients and servers **`read()`** and **`write()`** data to each other

same as for file I/O



The Transport Layer: UDP

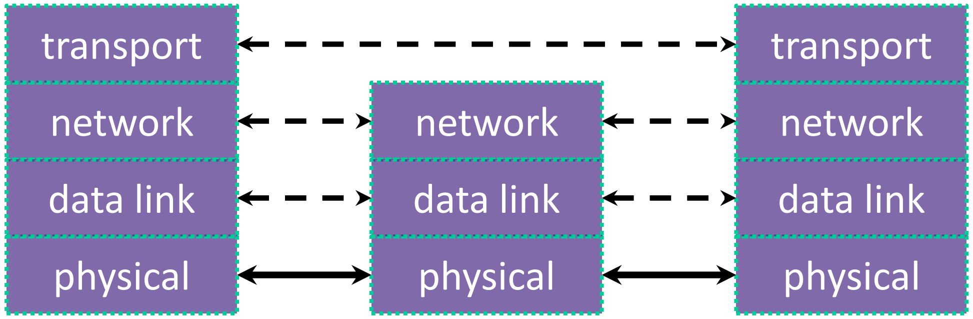
- User Datagram Protocol (UDP):
  - Provides applications with *unreliable* packet delivery ok for things like video streaming
  - UDP is a really thin, simple layer on top of IP
    - Datagrams still are fragmented into multiple IP packets



The Transport Layer: Comparison

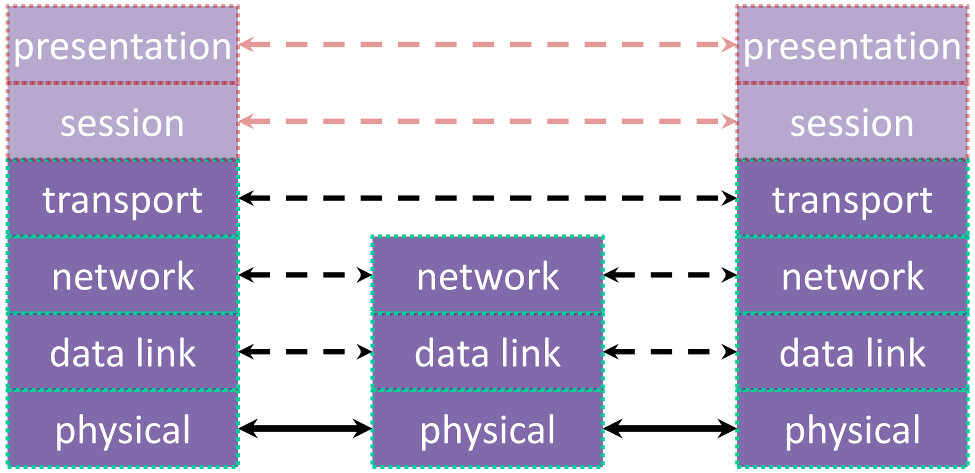
TCP:

UDP:



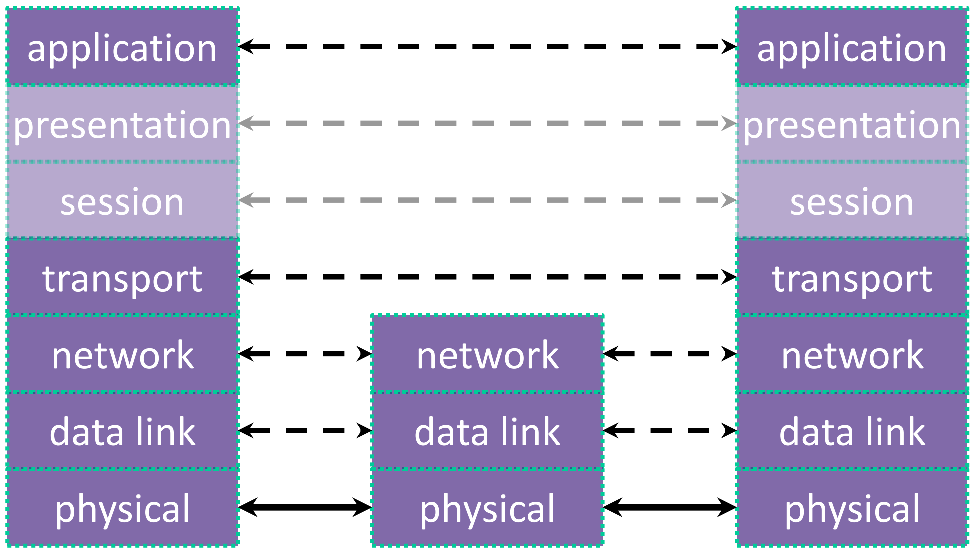
The (Mostly Missing) Layers 5 & 6

- Layer 5: Session Layer
  - Would handle establishing & terminating application sessions
  - Remote Procedure Call (RPC) kind of fits in here
- Layer 6: Presentation Layer
  - Would map application-specific data units into a more network-neutral representation
  - Encryption (SSL) kind of fits in here



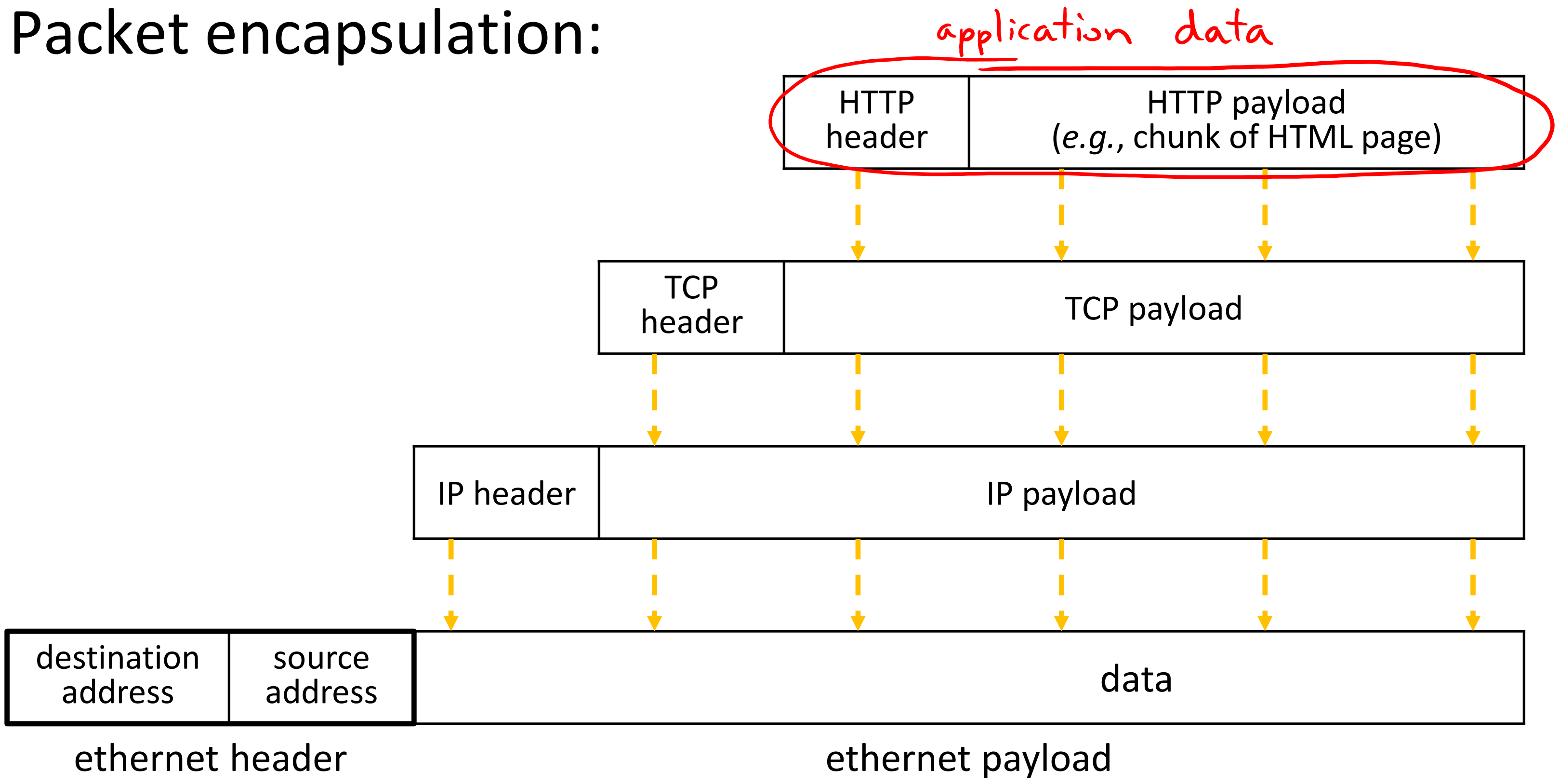
The Application Layer

- Application protocols
  - The format and meaning of messages between application entities
  - *e.g.*, HTTP is an application-level protocol that dictates how web browsers and web servers communicate
    - HTTP is implemented *on top of* TCP streams



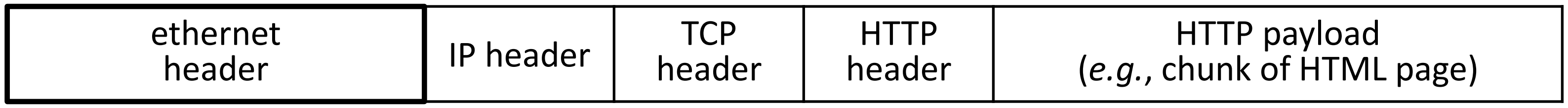
The Application Layer: Packets (1/2)

- Packet encapsulation:



The Application Layer: Packets (2/2)

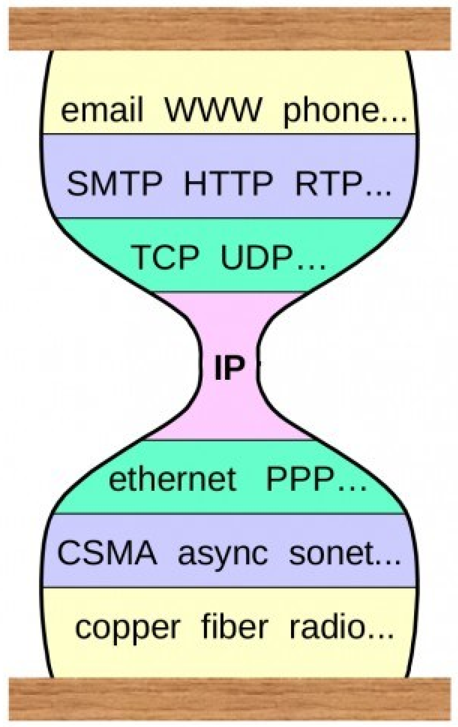
- Packet encapsulation:



The Application Layer

- Popular application-level protocols:
  - **DNS:** translates a domain name (e.g., www.google.com) into one or more IP addresses (e.g., 74.125.197.106)
    - Domain Name System
    - An hierarchy of DNS servers cooperate to do this
  - **HTTP:** web protocols
    - Hypertext Transfer Protocol
  - **SMTP, IMAP, POP:** mail delivery and access protocols
    - Secure Mail Transfer Protocol, Internet Message Access Protocol, Post Office Protocol
  - **SSH:** secure remote login protocol
    - Secure Shell
  - **bittorrent:** peer-to-peer, swarming file sharing protocol

The “Narrow Waist”



- Hahah that’s a lot of protocols. How are we gonna do this 🫠 …
- The bulk of the machinery running the internet **only deals with IP, TCP and UDP** (“TCP/IP”)
  - How is the link layer handled? That’s a **driver** problem
  - How does Instagram work? That’s an **application** problem.
- This is called “**the narrow waist**” of the internet

netcat demo (if time)

- netcat (`nc`) is "a computer networking utility for reading from and writing to network connections using TCP or UDP"
  - https://en.wikipedia.org/wiki/Netcat

  - Listen on port: `nc -l <port>`
  - Connect: `nc <IPaddr> <port>`
    - Local host: `127.0.0.1`