Network Communication and Remote Procedure Calls (RPCs)

COS 418/518: Distributed Systems
Lecture 3

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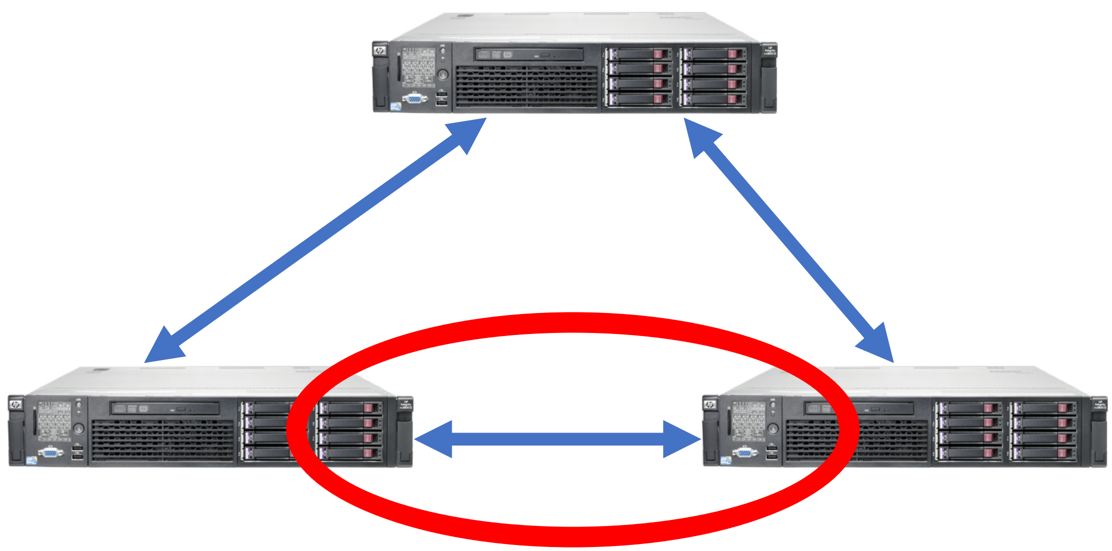
Distributed Systems, What?



1) Multiple computers
2) Connected by a network
3) Doing something together

Today's outline

- How can processes on different cooperating computers communicate with each other over the network?

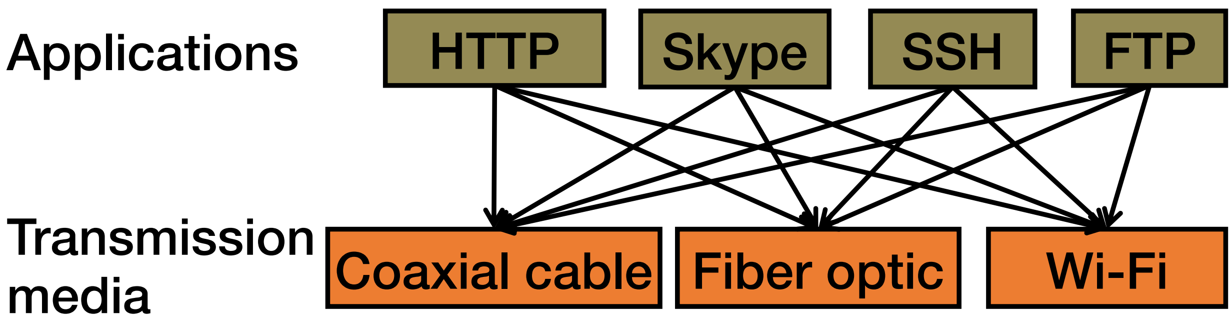
1. Network Communication

2. Remote Procedure Call (RPC)

The problem of communication

- Process on Host A wants to talk to process on Host B
  - A and B must agree on the meaning of the bits being sent and received at many different levels, including:
    - How many volts is a 0 bit, a 1 bit?
    - How does receiver know which is the last bit?
    - How many bits long is a number?

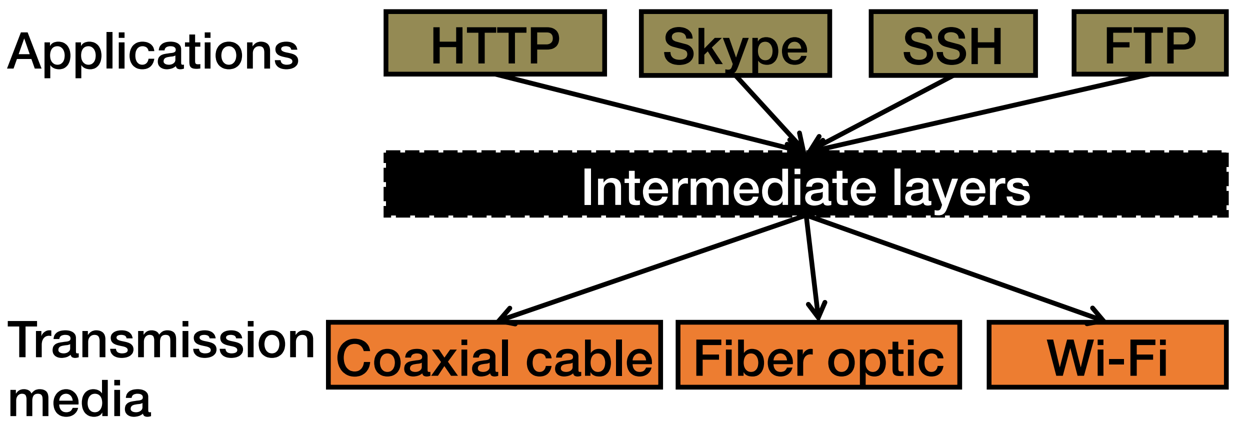
The problem of communication



- Re-implement every application for every new underlying transmission medium?
- Change every application on any change to an underlying transmission medium?

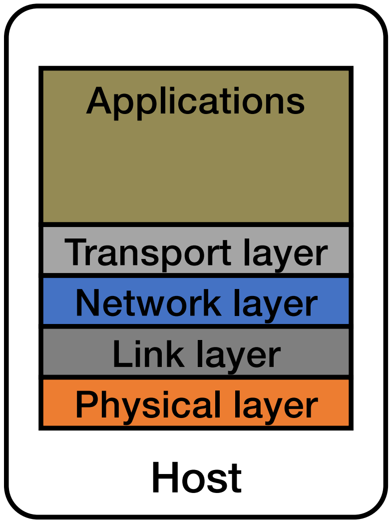
- No! But how does the Internet design avoid this?

Solution: Layering



- Intermediate layers provide a set of abstractions for applications and media
- New applications or media need only implement for intermediate layer's interface

Layering in the Internet

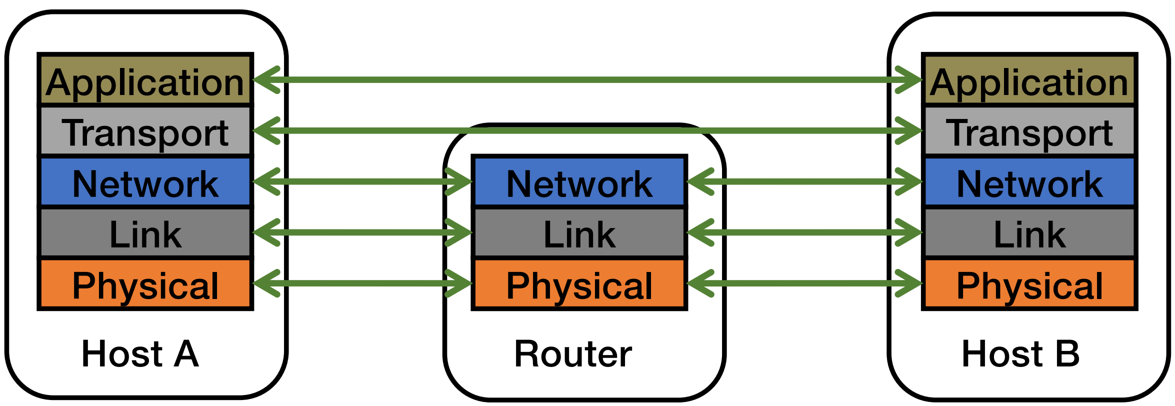


- **Transport:** Provide end-to-end communication between processes on different hosts
- **Network:** Deliver packets to destinations on other (heterogeneous) networks
- **Link:** Enables end hosts to exchange atomic messages with each other
- **Physical:** Moves bits between two hosts connected by a physical link

Logical communication between layers

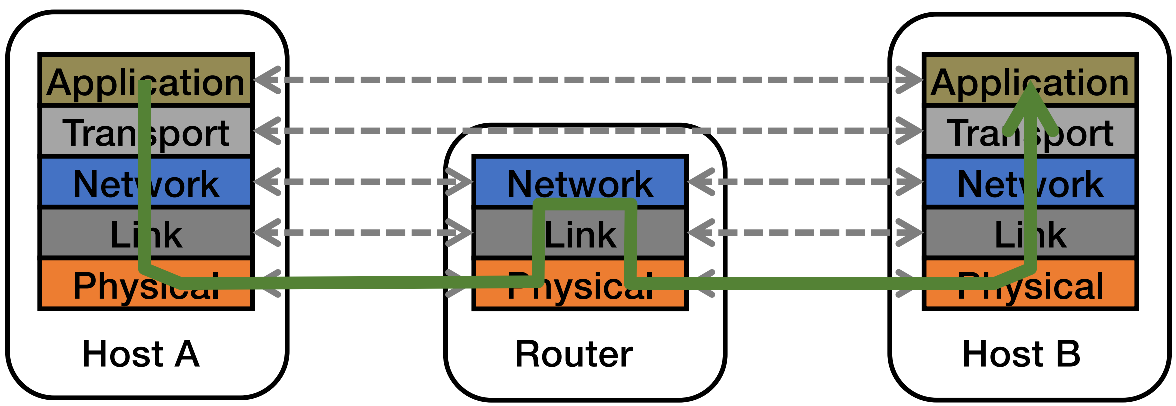
- How to forge agreement on the meaning of the bits exchanged between two hosts?

- **Protocol:** Rules that govern the format, contents, and meaning of messages
  - Each layer on a host interacts with its peer host's corresponding layer via the **protocol interface**



Physical communication

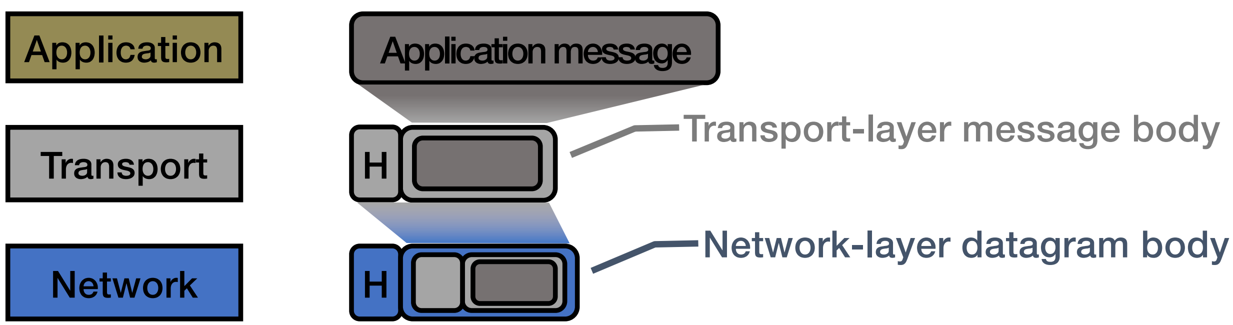
- Communication goes down to the physical network
- Then from network peer to peer
- Then up to the relevant application



Communication between peers

- How do peer protocols coordinate with each other?

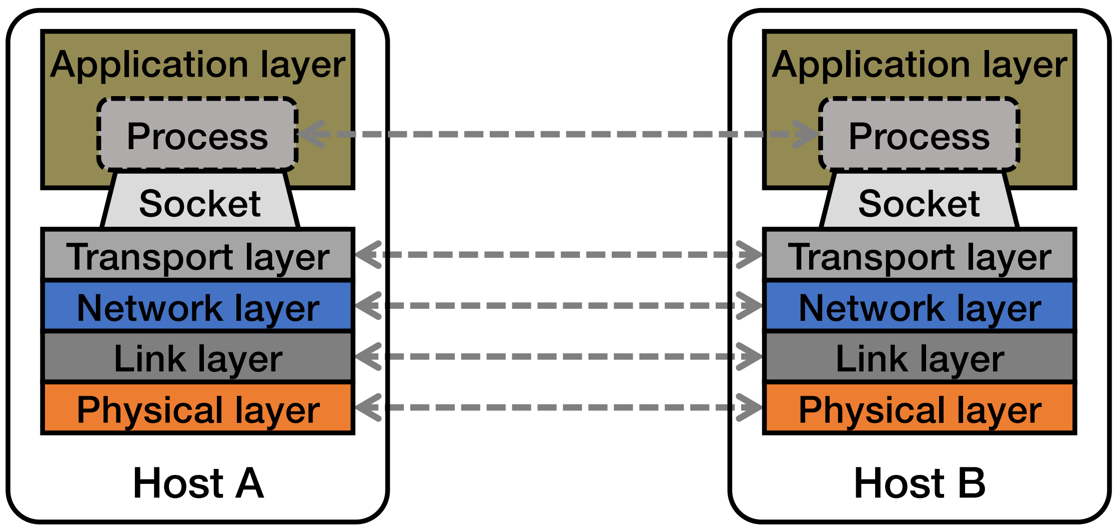
- Layer attaches its own header (H) to communicate with peer
  - Higher layers' headers, data encapsulated inside message
    - Lower layers don't generally inspect higher layers' headers



Network socket-based communication

- Socket: The interface the OS provides to the network
  - Provides inter-process explicit message exchange

- Can build distributed systems atop sockets: send(), recv()
  - e.g.: `put(key,value)` → message

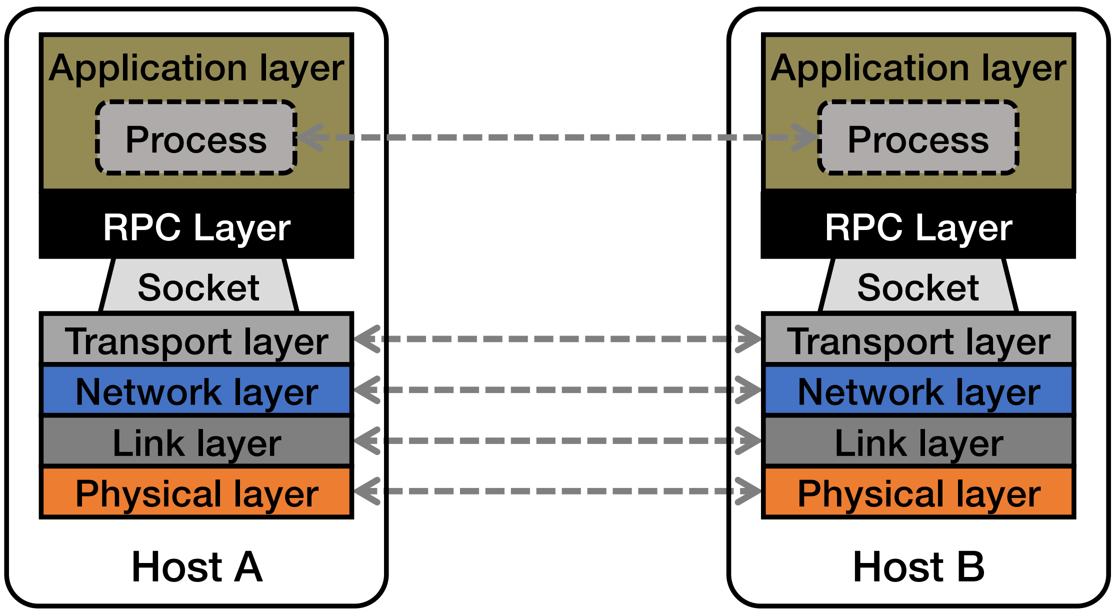


```c
// Create a socket for the client
if ((sockfd = socket (AF_INET, SOCK_STREAM, 0)) < 0) {
  perror("Socket creation");
  exit(2);
}

// Set server address and port
memset(&servaddr, 0, sizeof(servaddr));
servaddr.sin_family = AF_INET;
servaddr.sin_addr.s_addr = inet_addr(argv[1]);
servaddr.sin_port = htons(SERV_PORT); // to big-endian

// Establish TCP connection
if (connect(sockfd, (struct sockaddr *) &servaddr,
           sizeof(servaddr)) < 0) {
  perror("Connect to server");
  exit(3);
}

// Transmit the data over the TCP connection
send(sockfd, buf, strlen(buf), 0);
```

Socket programming: still not great

- Lots for the programmer to deal with every time
    - How to separate different requests on the same connection?
    - How to write bytes to the network / read bytes from the network?
        - What if Host A's process is written in Go and Host B's process is in C++?
    - What to do with those bytes?
- Still pretty painful… have to worry a lot about the network

Solution: Another layer!



Today's outline

1. Network Communication
2. Remote Procedure Call

Why RPC?

- The typical programmer is trained to write single-threaded code that runs in one place

- Goal: Easy-to-program network communication that makes client-server communication transparent
    - Retains the “feel” of writing centralized code
        - Programmer needn’t think about the network

Everyone uses RPCs

- COS 418 programming assignments use RPC

- Google gRPC
- Facebook/Apache Thrift
- Twitter Finagle
- …

What’s the goal of RPC?

- Within a single program, running in a single process, recall the well-known notion of a **procedure call**:
  - **Caller** pushes arguments onto stack,
    - jumps to address of callee function
  - **Callee** reads arguments from stack,
    - executes, puts return value in register,
    - returns to next instruction in caller

RPC’s Goal: make communication appear like a local procedure call: way less painful than sockets…

RPC issues

1. Heterogeneity
    - Client needs to rendezvous with the server
    - Server must dispatch to the required function
        - What if server is different type of machine?

2. Failure
    - What if messages get dropped?
    - What if client, server, or network fails?

3. Performance
    - Procedure call takes ≈ 10 cycles ≈ 3 ns
    - RPC in a data center takes ≈ 10 μs (10^3× slower)
        - In the wide area, typically 10^6× slower

Problem: Differences in data representation

- Not an issue for local procedure calls

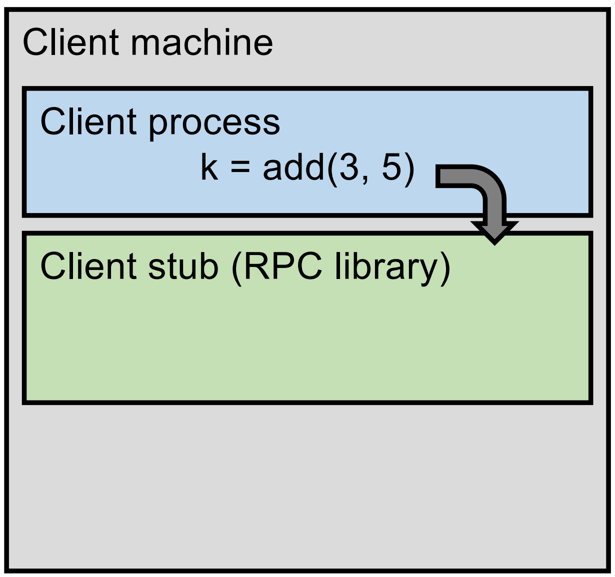
- For a remote procedure call, a remote machine may:
  - Run process written in a different language
  - Represent data types using different sizes
  - Use a different byte ordering (endianness)
  - Represent floating point numbers differently
  - Have different data alignment requirements
    - e.g., 4-byte type begins only on 4-byte memory boundary

Solution: Interface Description Language

- Mechanism to pass procedure parameters and return values in a machine-independent way
- Programmer may write an interface description in the IDL
  - Defines API for procedure calls: names, parameter/return types
- Then runs an IDL compiler which generates:
  - Code to marshal (convert) native data types into machine-independent byte streams
    - And vice-versa, called unmarshaling
  - Client stub: Forwards local procedure call as a request to server
  - Server stub: Dispatches RPC to its implementation

A day in the life of an RPC

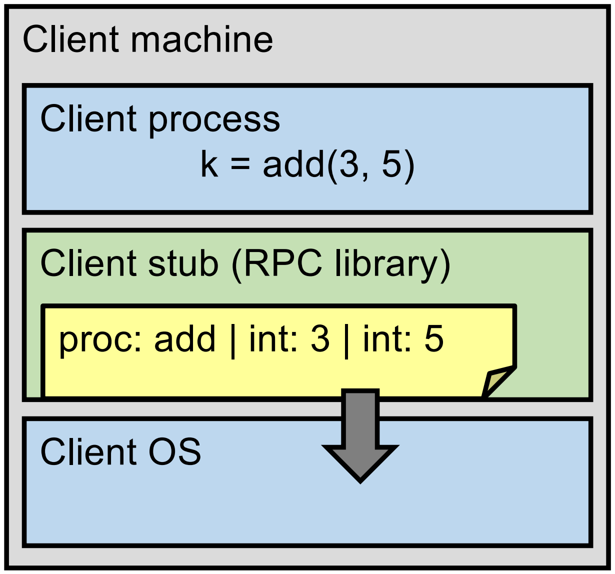
1. Client calls stub function (pushes parameters onto stack)



A day in the life of an RPC

1. Client calls stub function (pushes parameters onto stack)

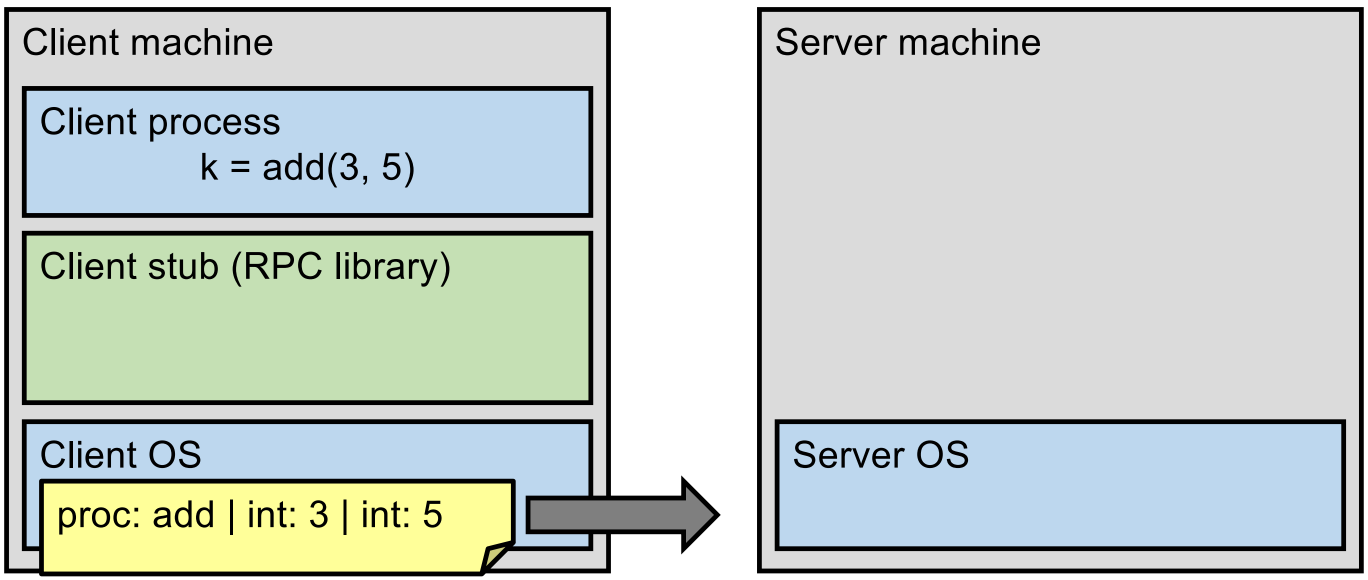
2. **Stub marshals parameters to a network message**



A day in the life of an RPC

2. Stub marshals parameters to a network message

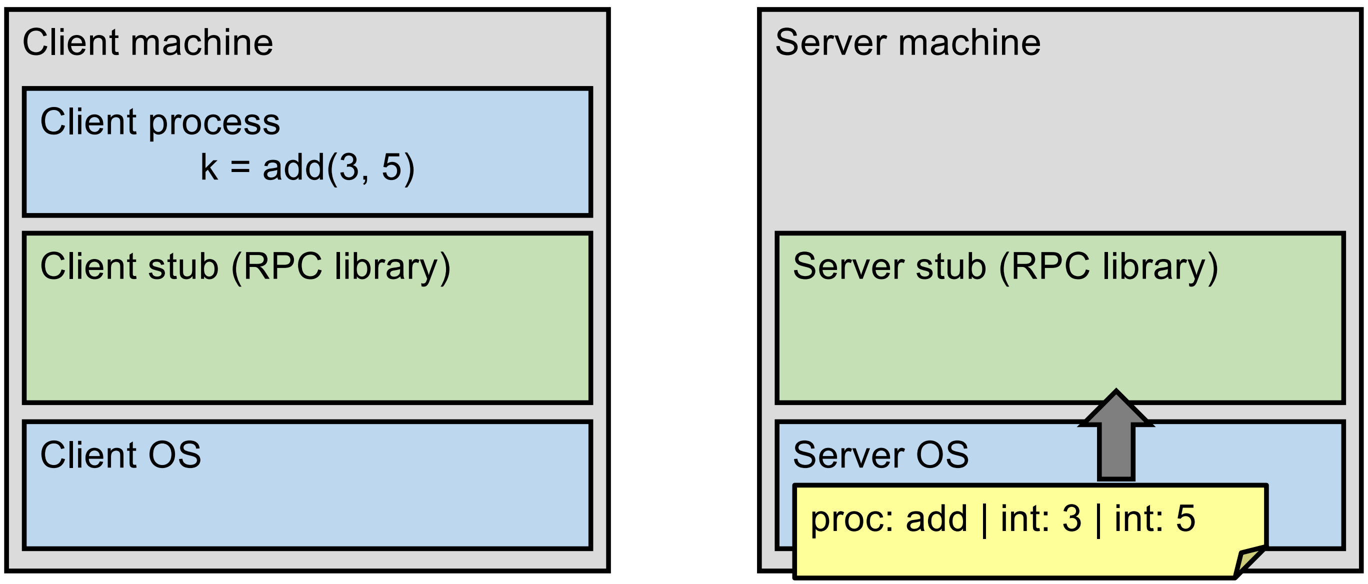
3. **OS sends a network message to the server**



A day in the life of an RPC

3. OS sends a network message to the server

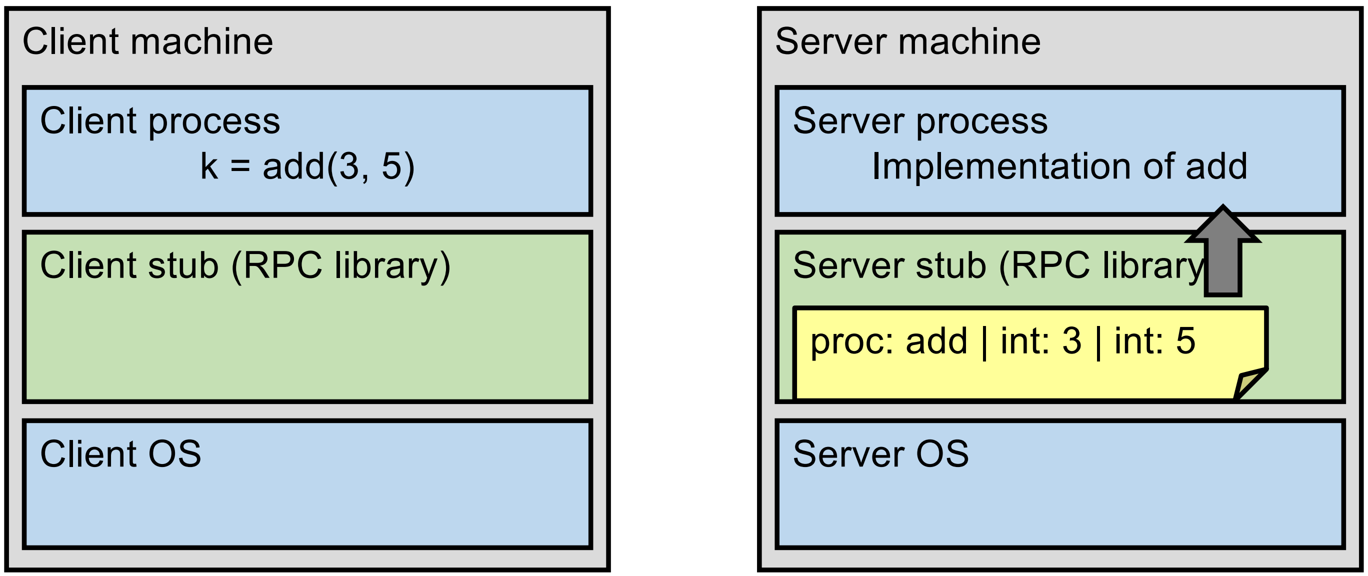
4. **Server OS receives message, sends it up to stub**



A day in the life of an RPC

4. Server OS receives message, sends it up to stub

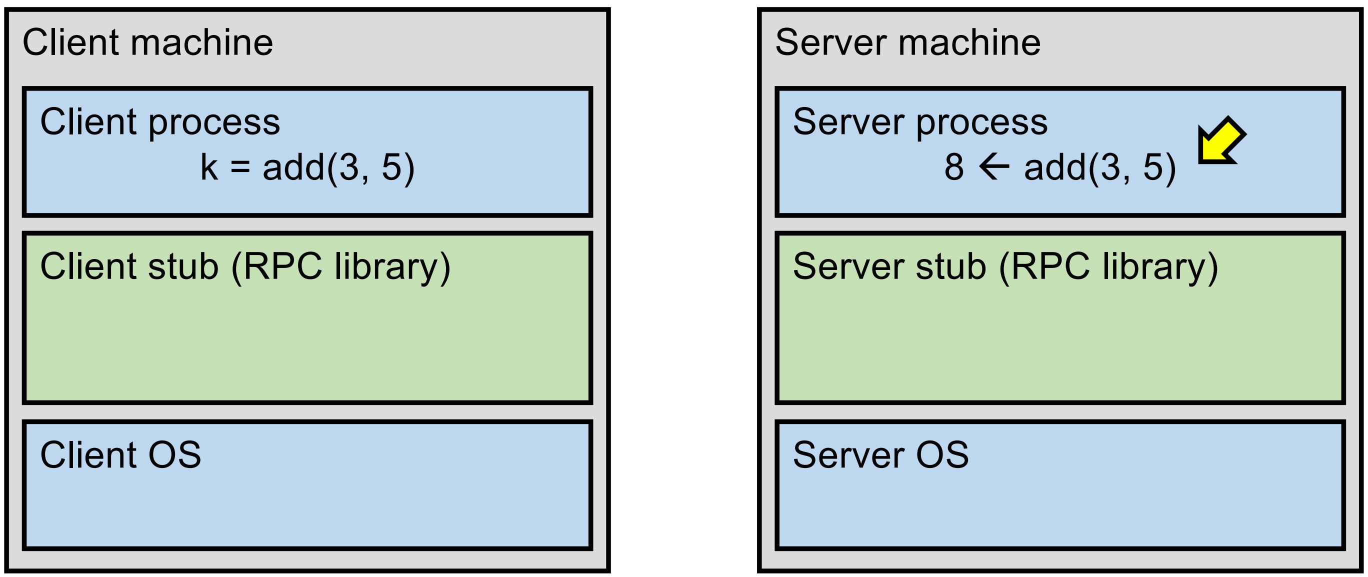
5. **Server stub unmarshals params, calls server function**



A day in the life of an RPC

5. Server stub unmarshals params, calls server function

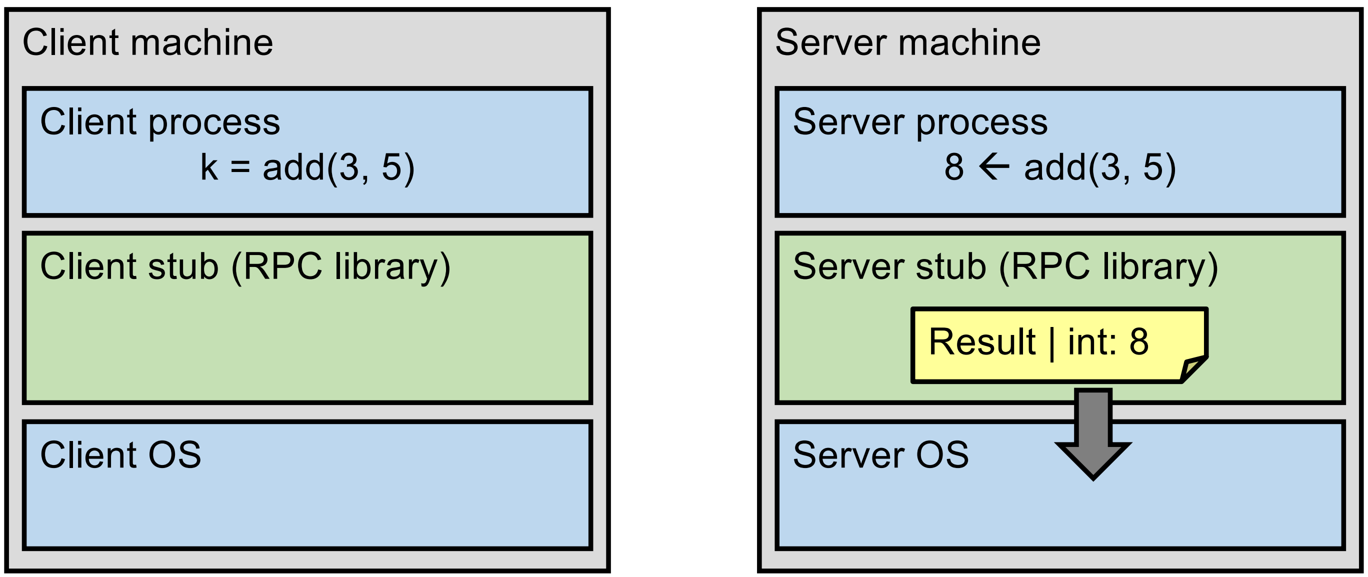
6. **Server function runs, returns a value**



A day in the life of an RPC

6. Server function runs, returns a value

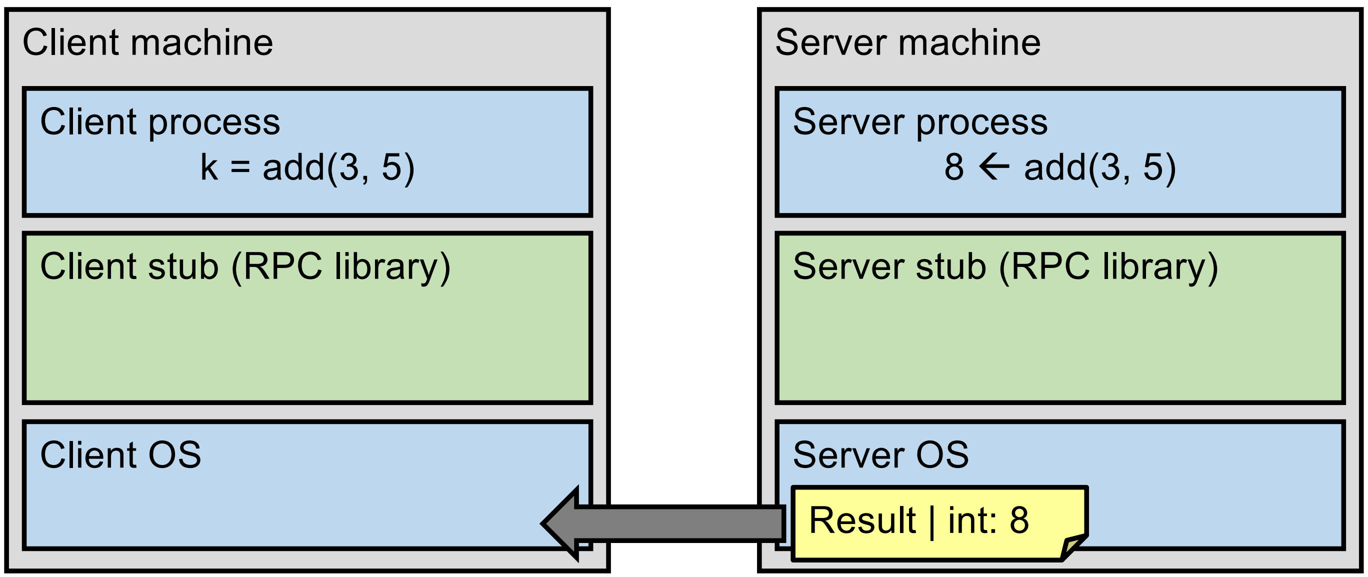
7. **Server stub marshals the return value, sends message**



A day in the life of an RPC

7. Server stub marshals the return value, sends message

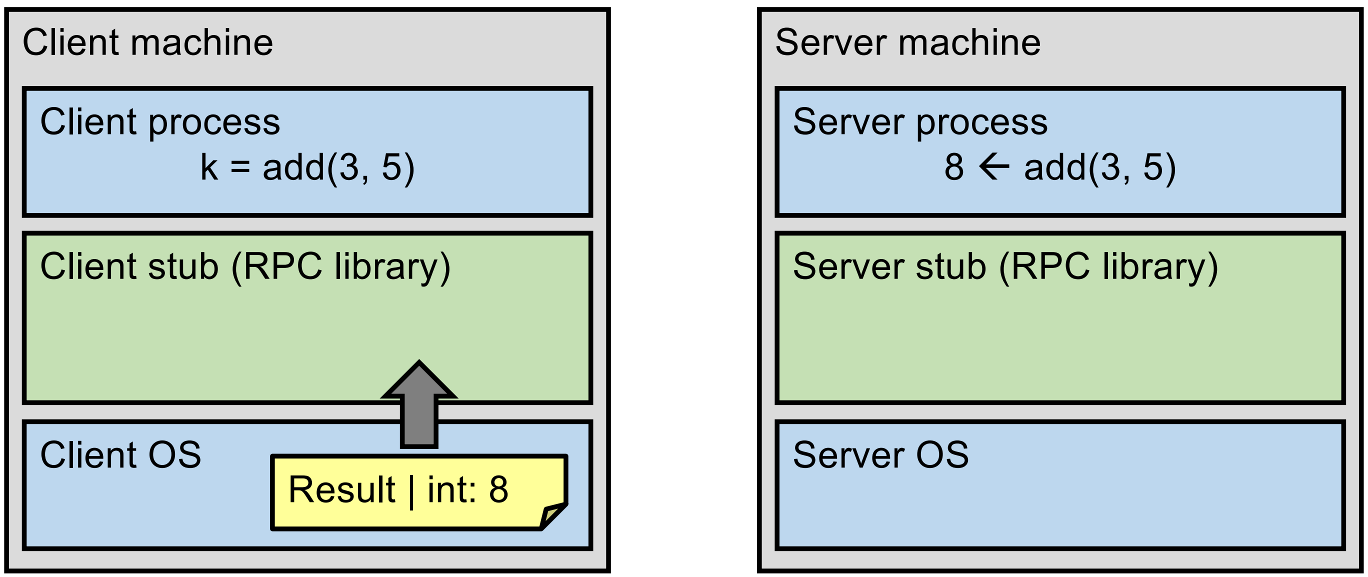
8. **Server OS sends the reply back across the network**



A day in the life of an RPC

8. Server OS sends the reply back across the network

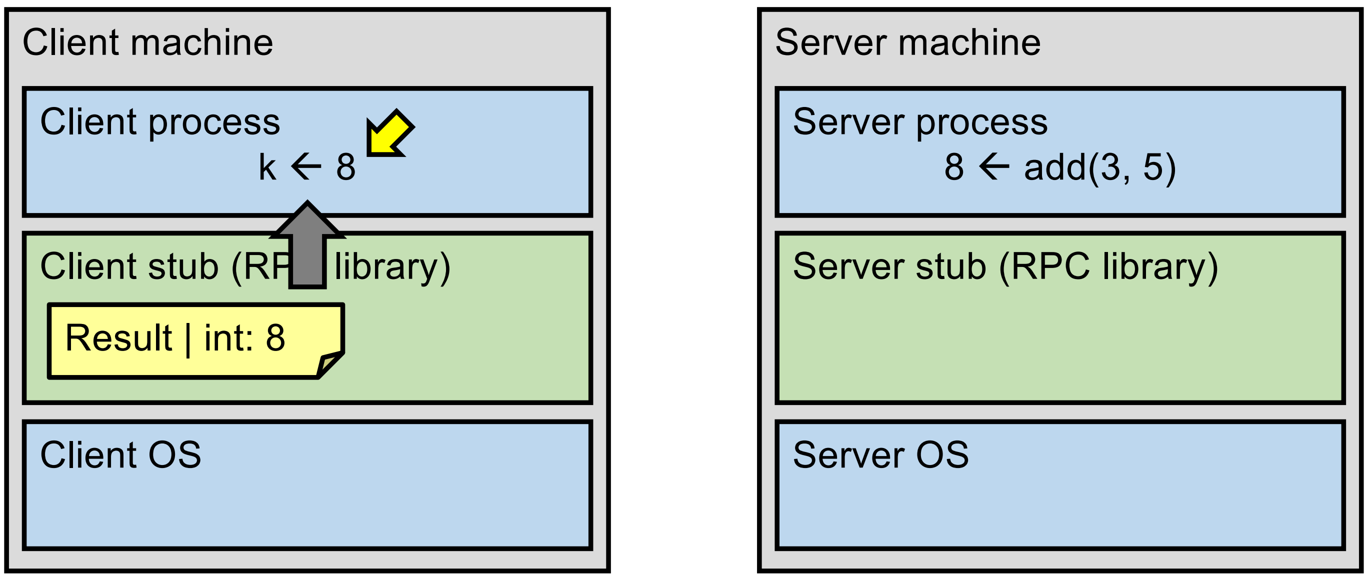
9. **Client OS receives the reply and passes up to stub**



A day in the life of an RPC

9. Client OS receives the reply and passes up to stub

10. **Client stub unmarshals return value, returns to client**



Today's outline

1. Network Communication
2. Remote Procedure Call
   - Heterogeneity – use IDL w/ compiler
   - Failure

What could possibly go wrong?

1. Client may crash and reboot

2. Packets may be dropped
   - Some individual packet loss in the Internet
   - Broken routing results in many lost packets

3. Server may crash and reboot

4. Network or server might just be very slow

All of these may look the same to the client...

Summary: RPCs and Network Comm.

- Layers are our friends!
- RPCs are everywhere
- Necessary issues surrounding machine heterogeneity
- Subtle issues around failures
  - … Next time!!!