Network Communication and Remote Procedure Calls (RPCs)

CSE 513

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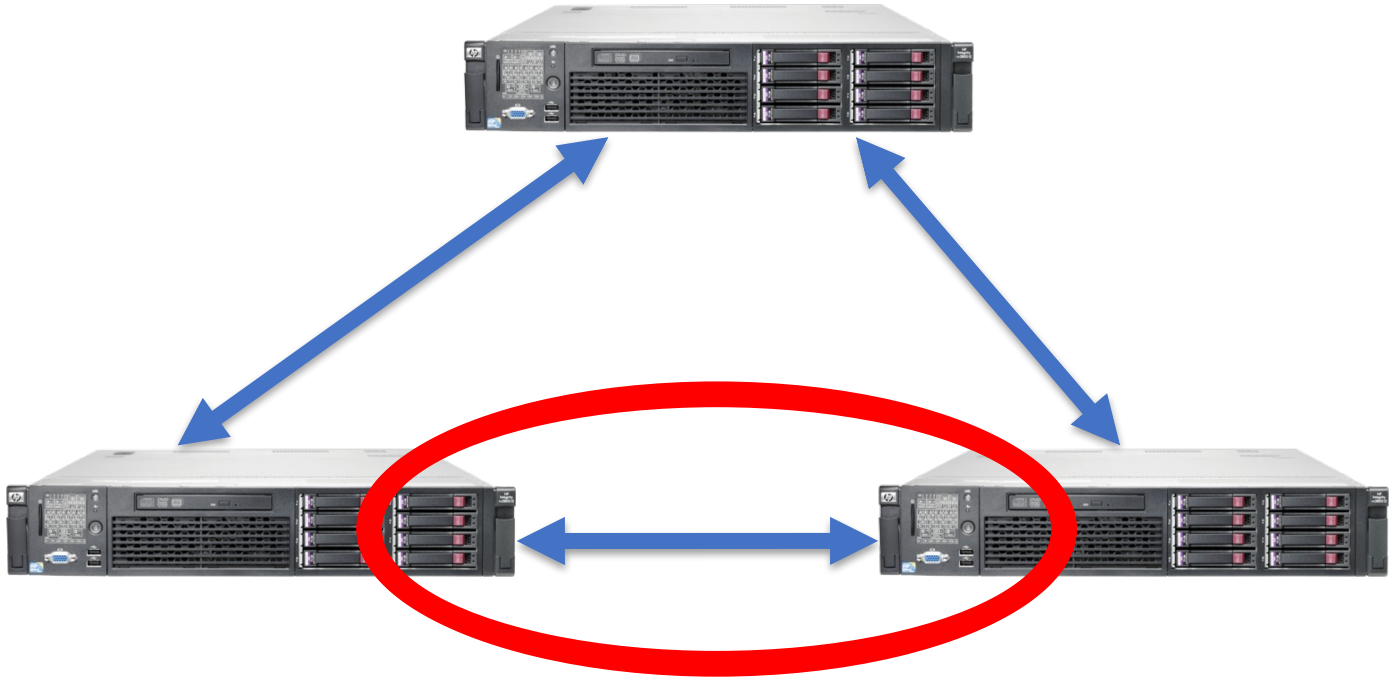
(slides by Mike Freedman @ Princeton)

Distributed Systems, What?

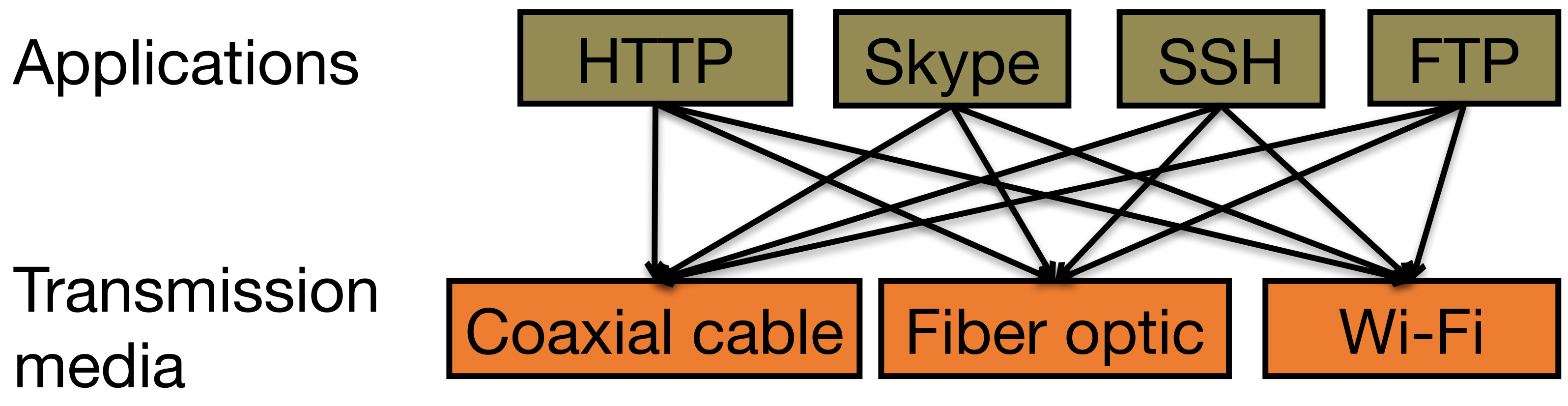


1) Multiple computers
2) Connected by a network
3) Doing something together

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?

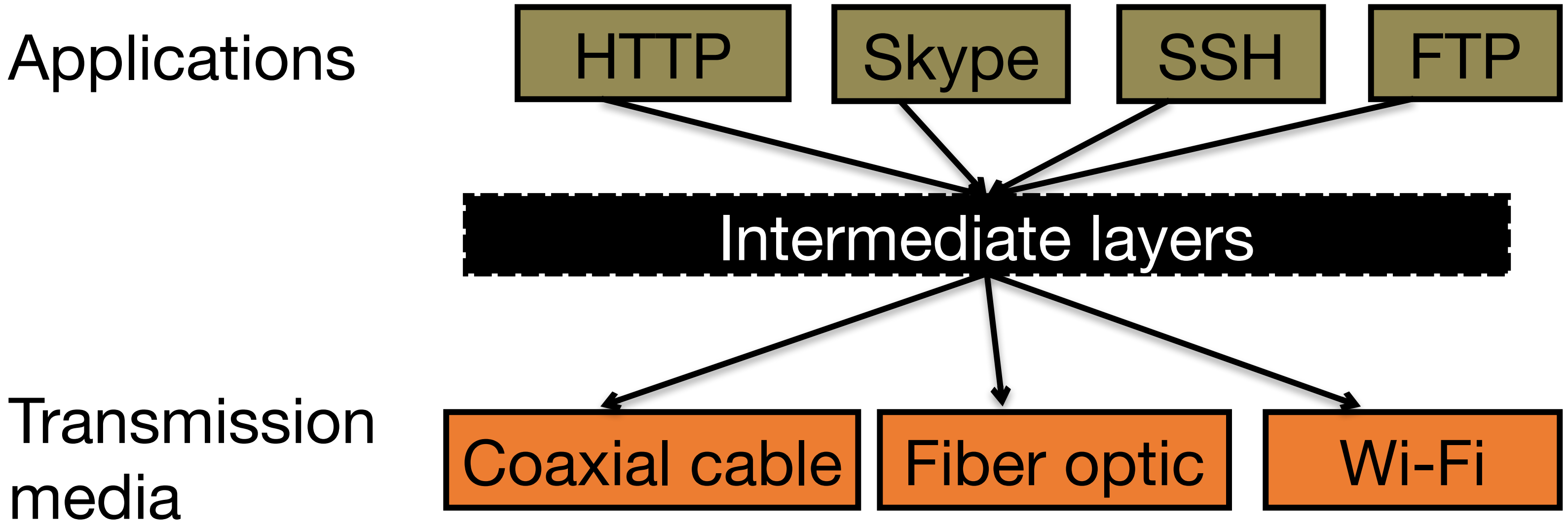
The problem of communication



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

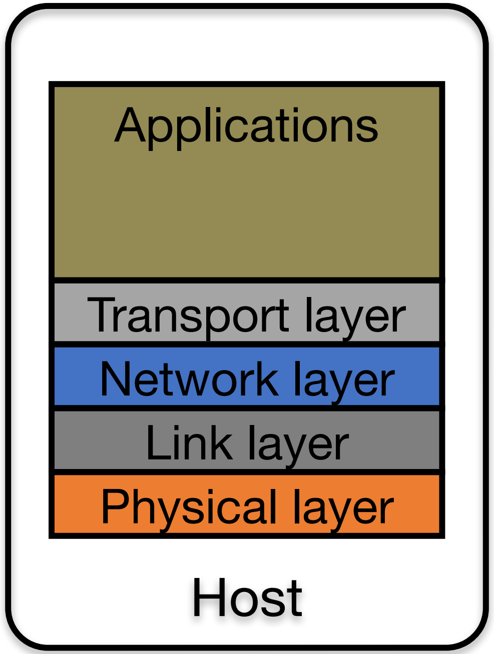
- No! But how does the Internet design avoid this?

Solution: Layering



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

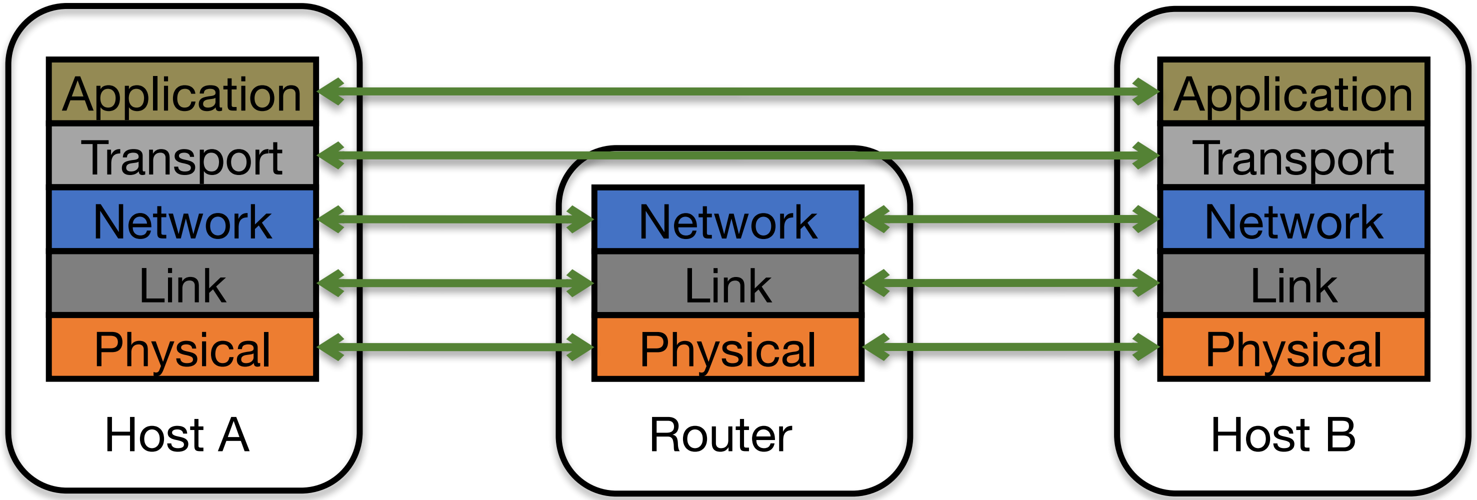
Layering in the Internet



- **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

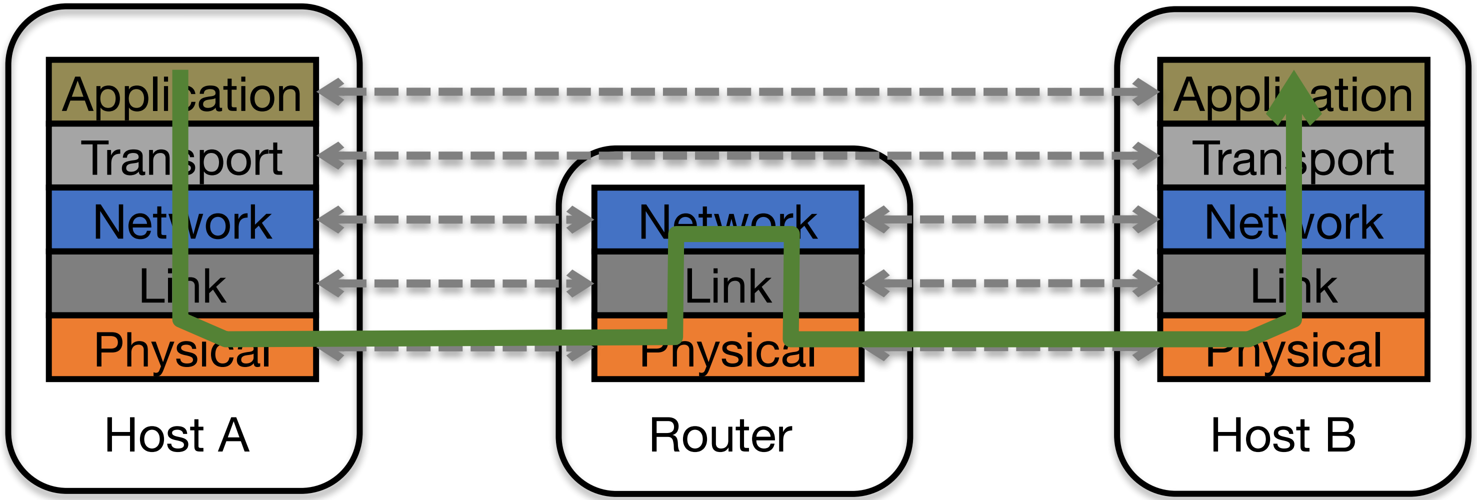
Logical communication between layers

- How to forge agreement on meaning of bits exchanged b/w two hosts?
- **Protocol:** Rules that govern format, contents, and meaning of messages
  - Each layer on a host interacts with its peer host's corresponding layer via the **protocol interface**



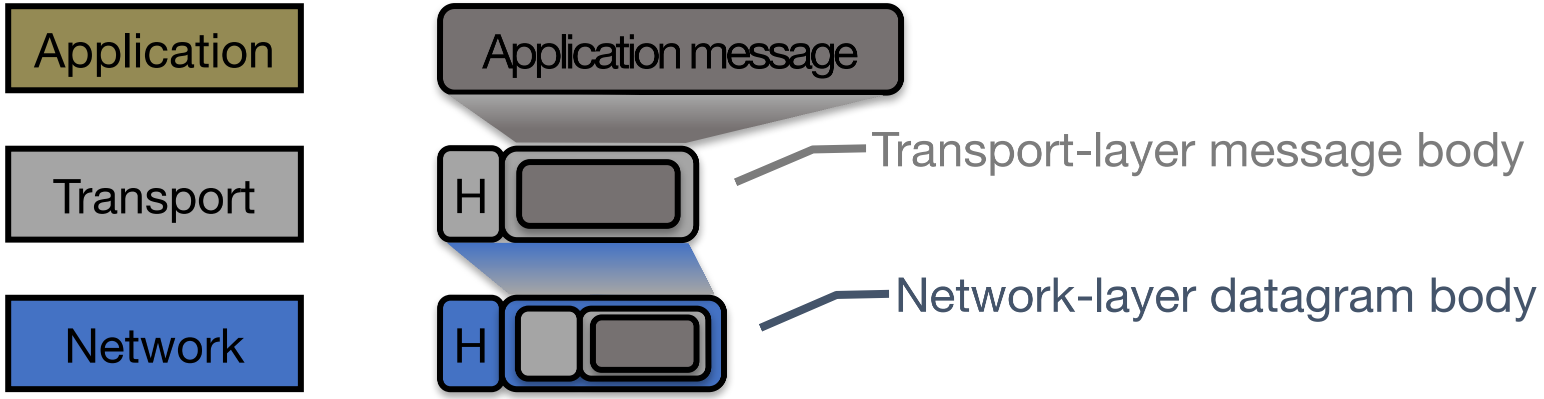
Physical communication

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



Communication between peers

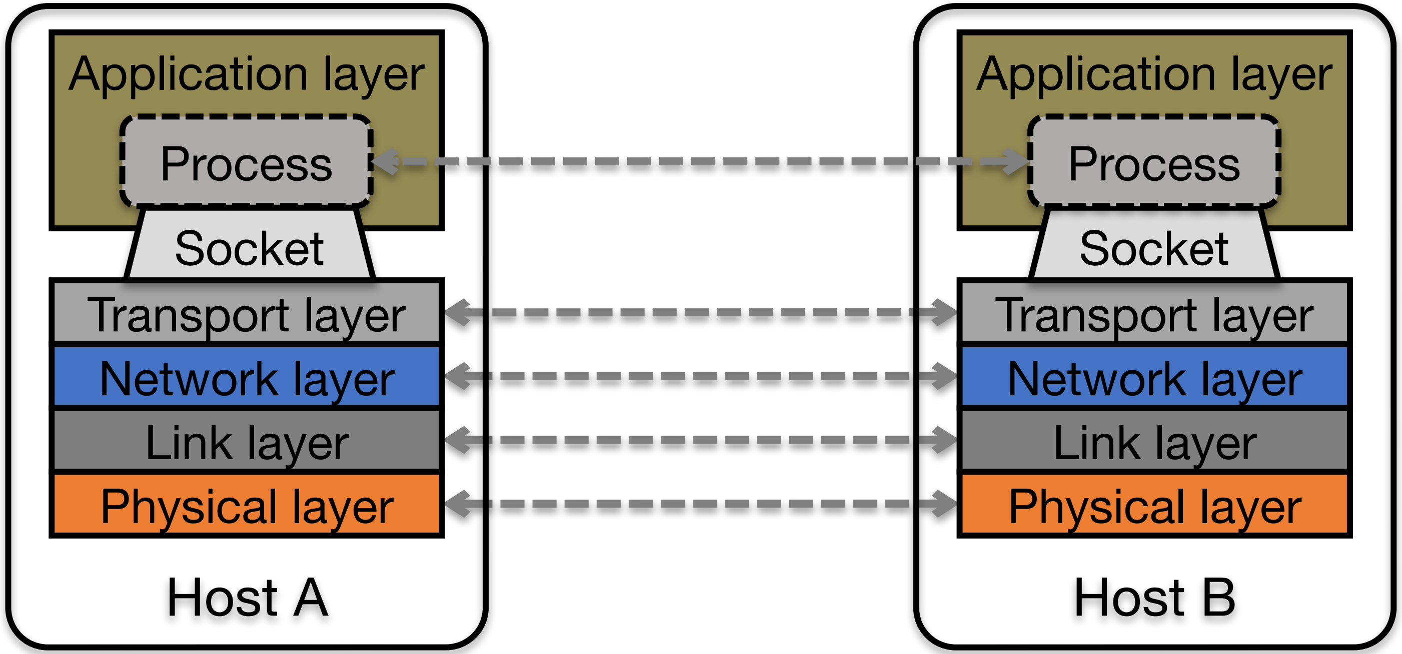
- How do peer protocols coordinate with each other?
- Layer attaches its own header (H) to communicate with peer
  - Higher layers' headers, data encapsulated inside message
  - Lower layers don't generally inspect higher layers' headers



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



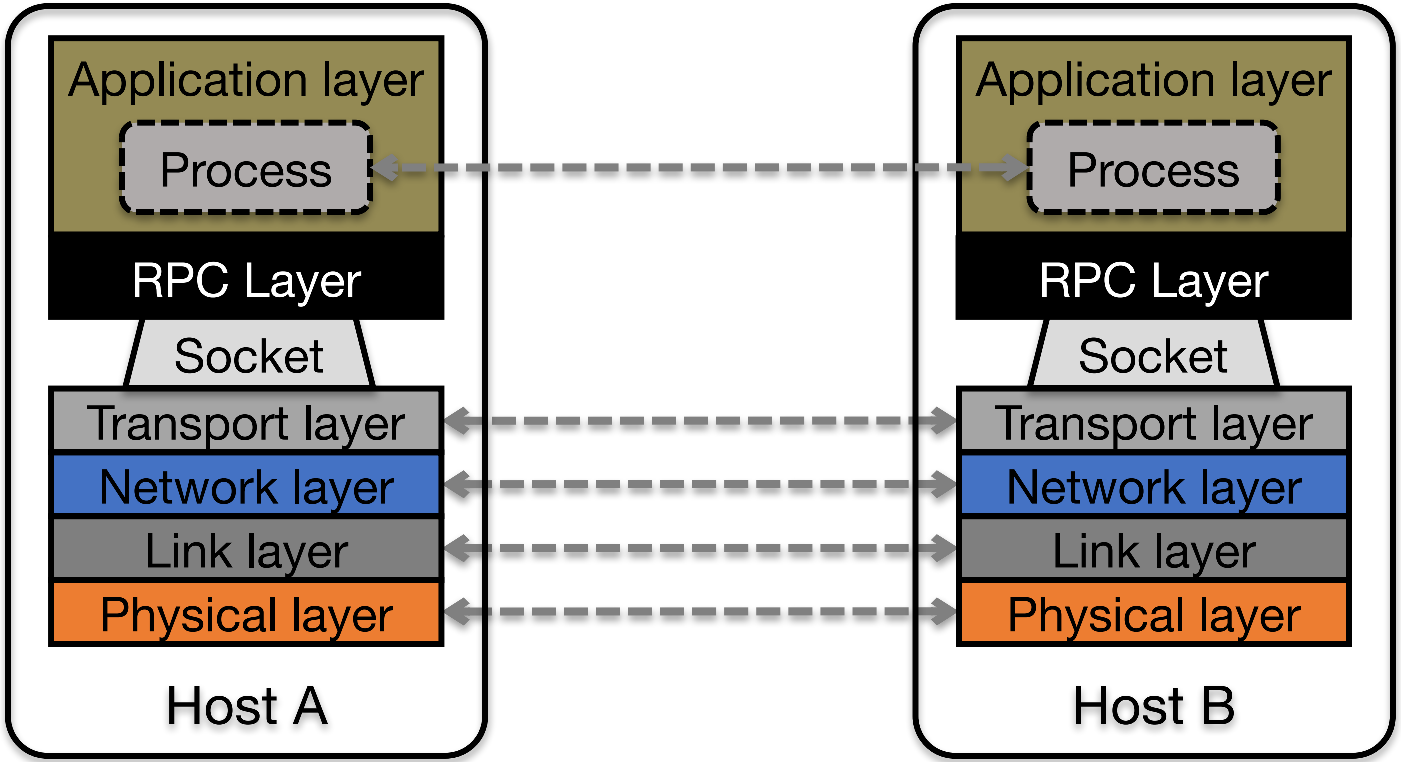
```c
// Create a socket for the client
if ((sockfd = socket (AF_INET, SOCK_STREAM, 0)) < 0) {
  perror(”Socket creation");
  exit(2);
}

// 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!



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 seem transparent
  - Retains the “feel” of writing centralized code
  - Programmer needn’t think (much) about the network

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

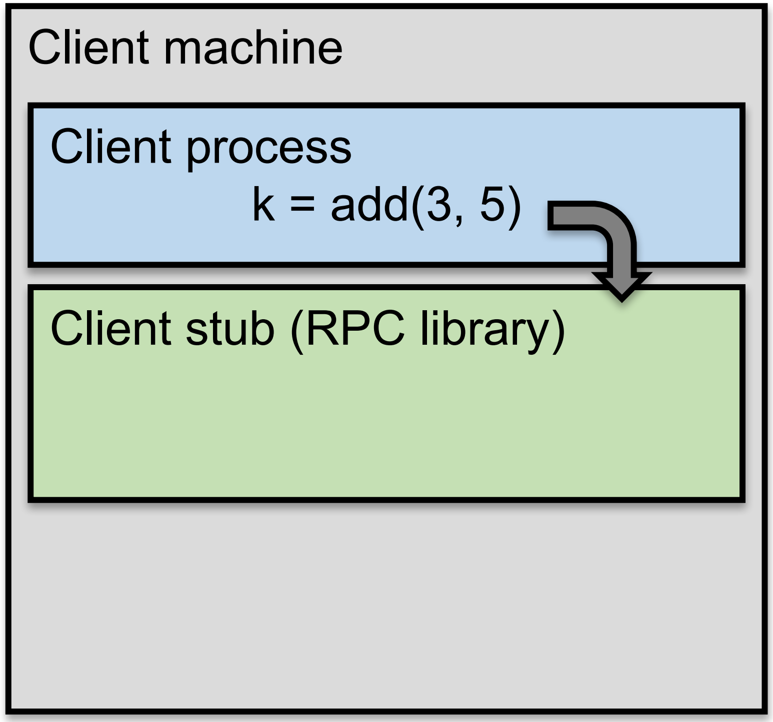
- For a remote procedure call, a remote machine may:
  - Run process written in a different language
  - Represent data types using different sizes
  - Use a different byte ordering (endianness)
  - Represent floating point numbers differently
  - Have different data alignment requirements
    - e.g.,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

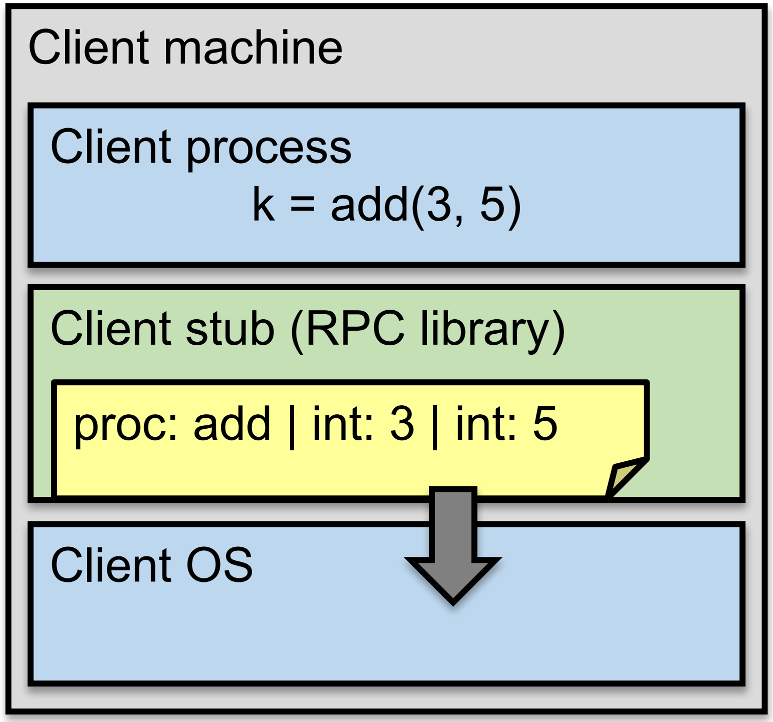
A day in the life of an RPC

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



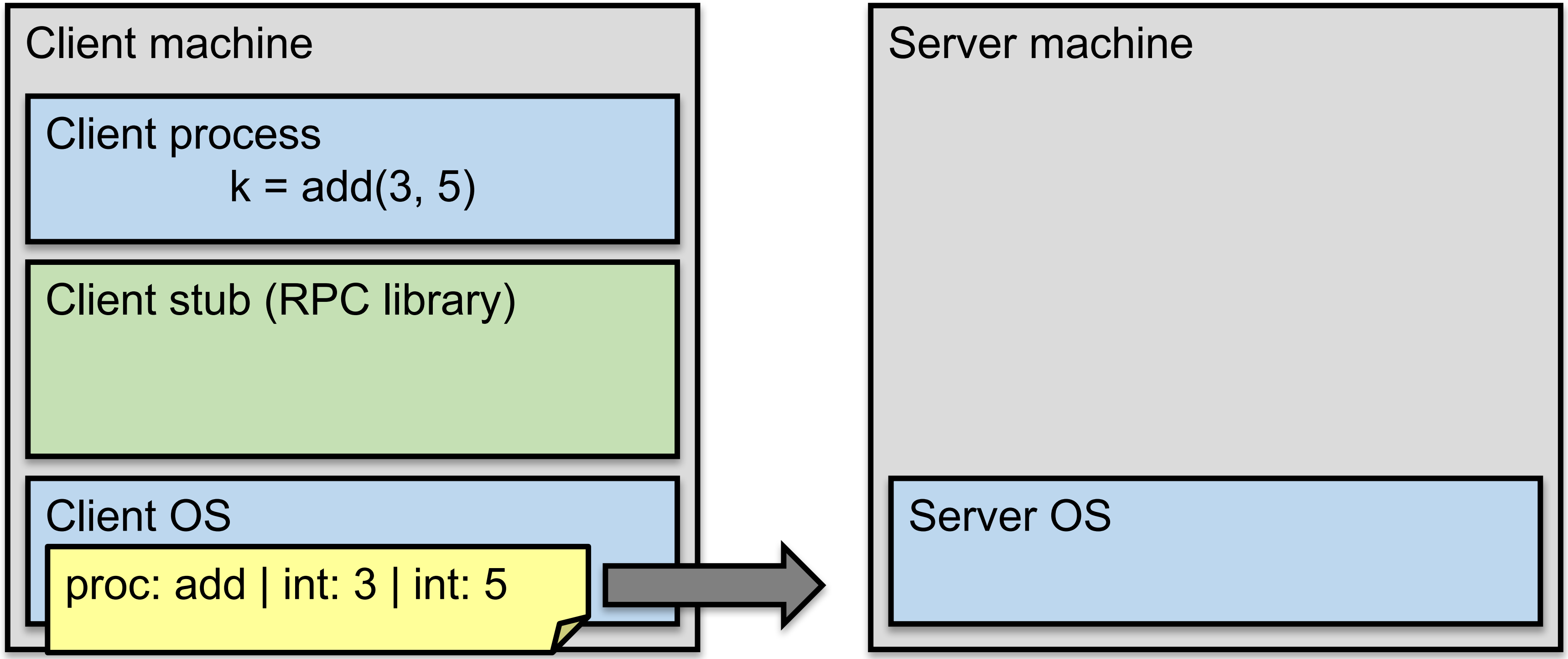
A day in the life of an RPC

1. Client calls stub function (pushes parameters onto stack)
2. Stub marshals parameters to a network message



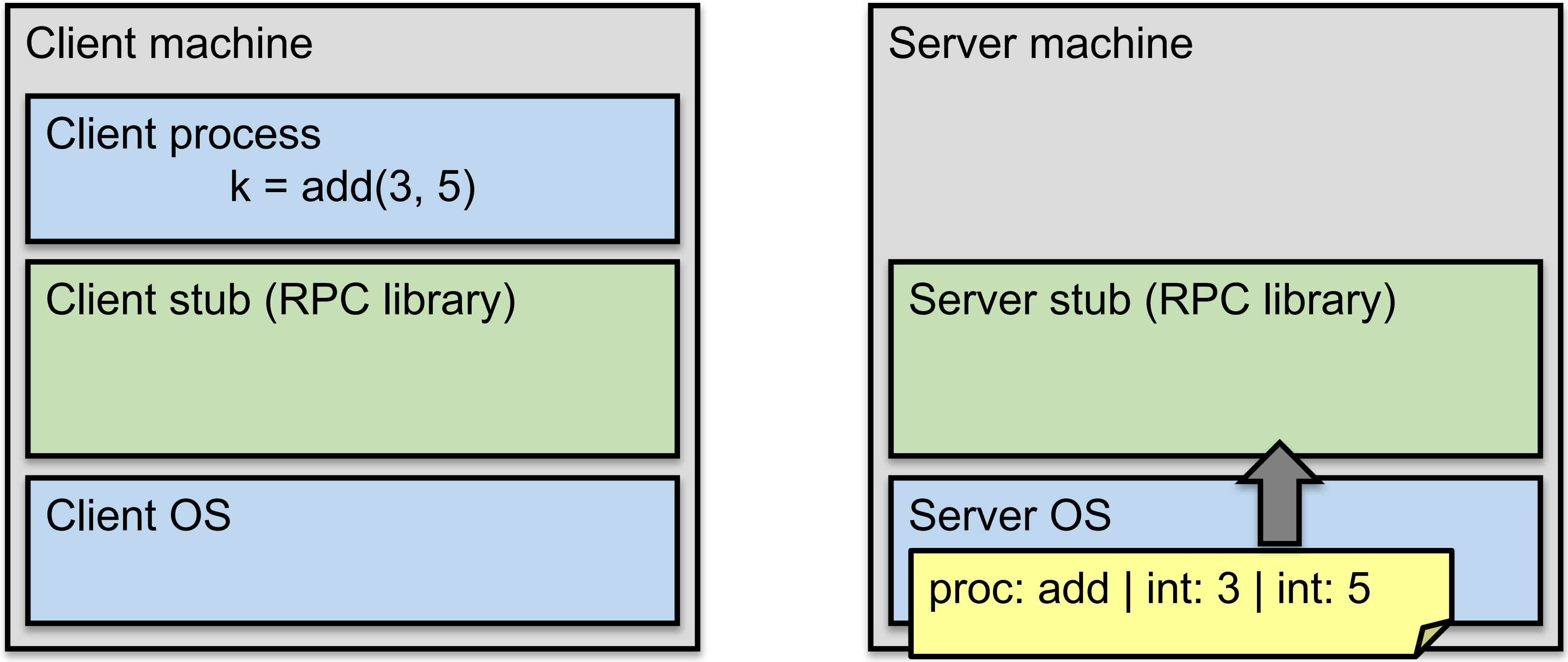
A day in the life of an RPC

2. Stub marshals parameters to a network message
3. OS sends a network message to the server



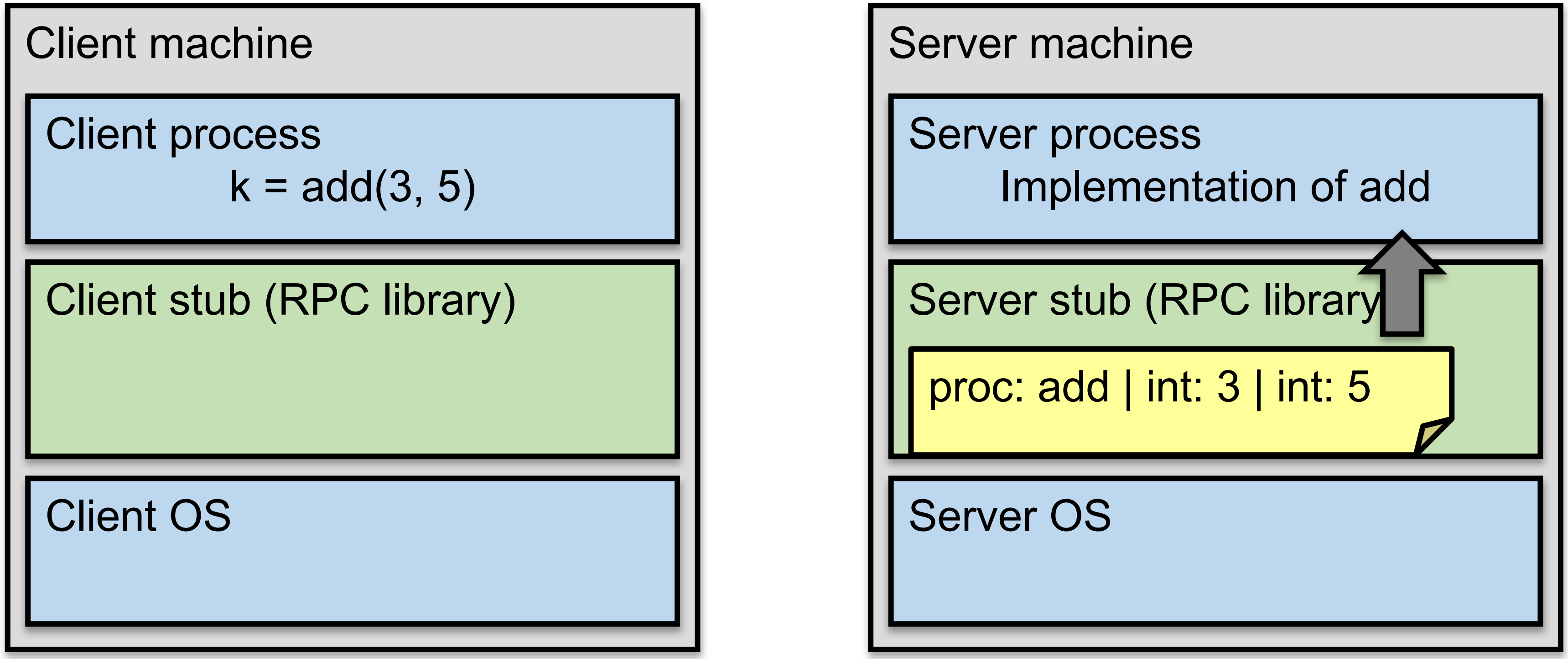
A day in the life of an RPC

3. OS sends a network message to the server
4. Server OS receives message, sends it up to stub



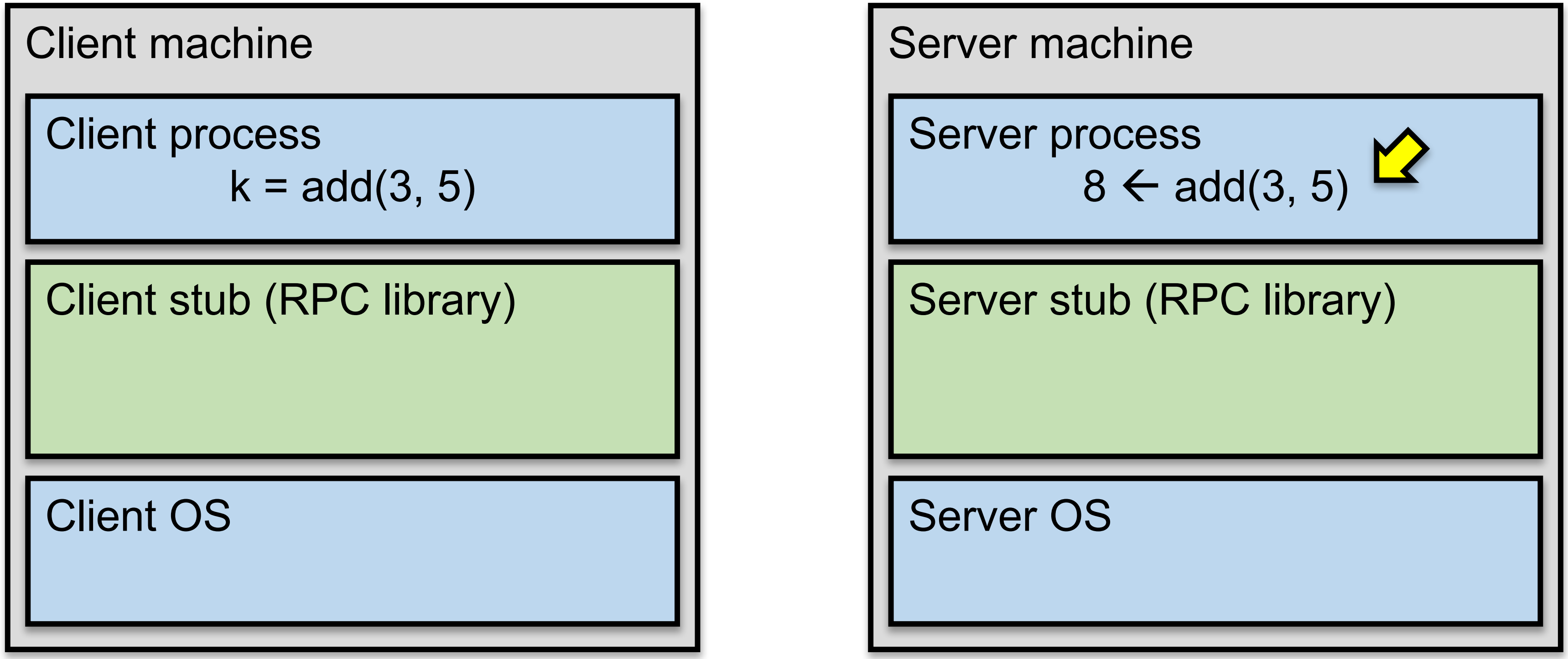
A day in the life of an RPC

4. Server OS receives message, sends it up to stub
5. Server stub unmarshals params, calls server function



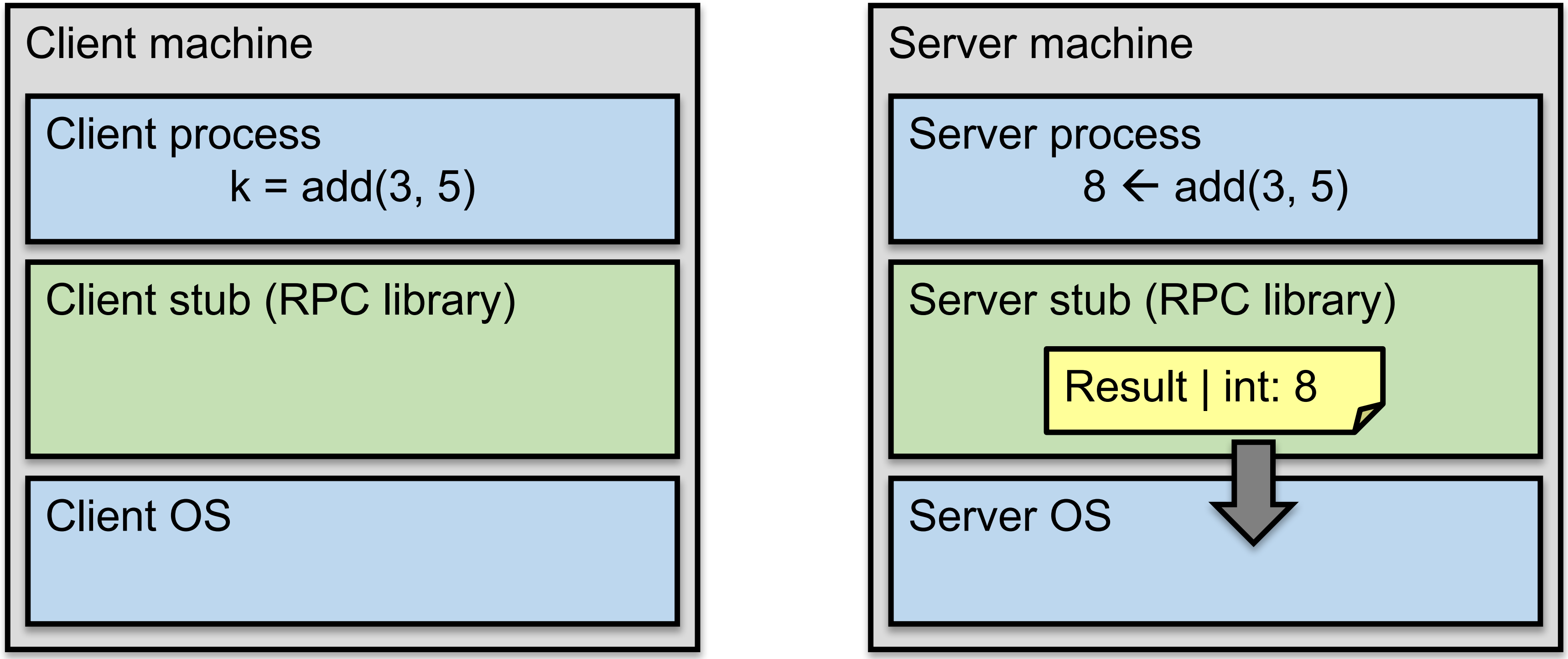
A day in the life of an RPC

5. Server stub unmarshals params, calls server function
6. Server function runs, returns a value



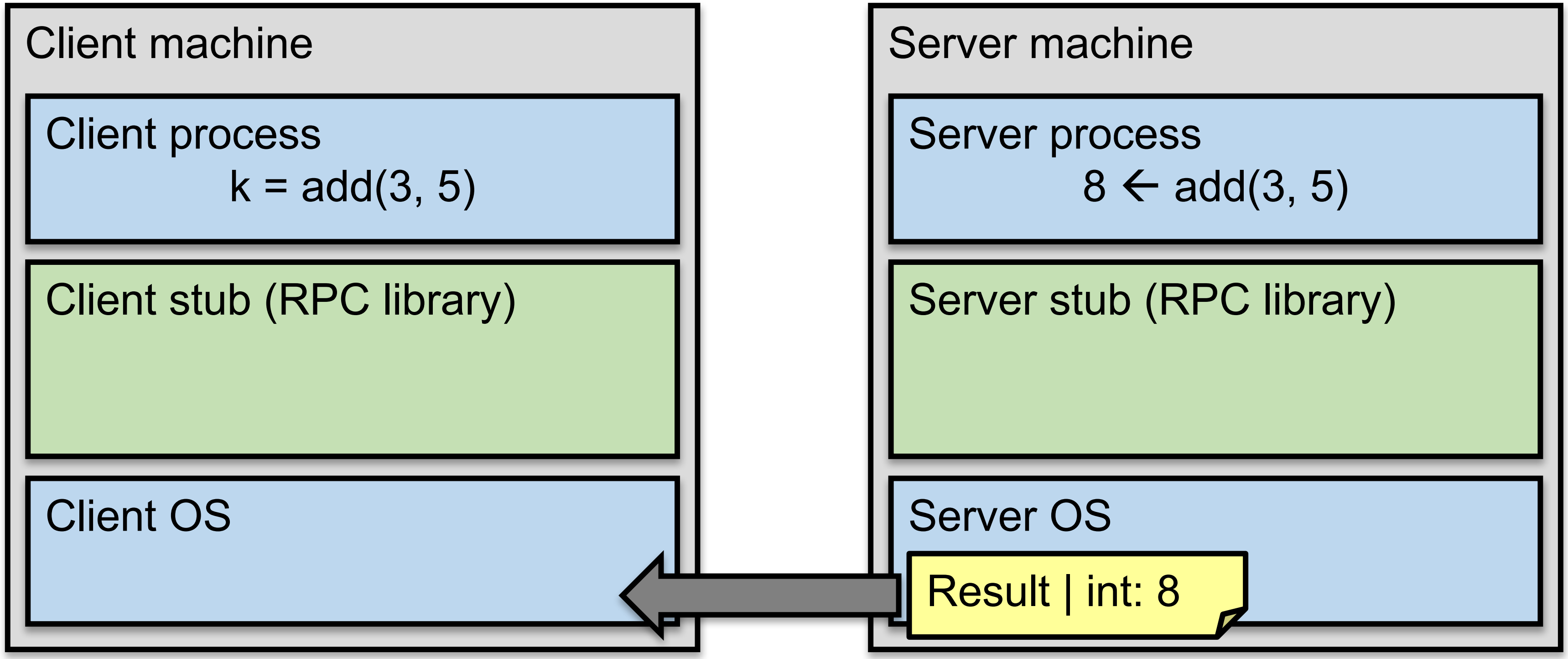
A day in the life of an RPC

6. Server function runs, returns a value
7. Server stub marshals the return value, sends message



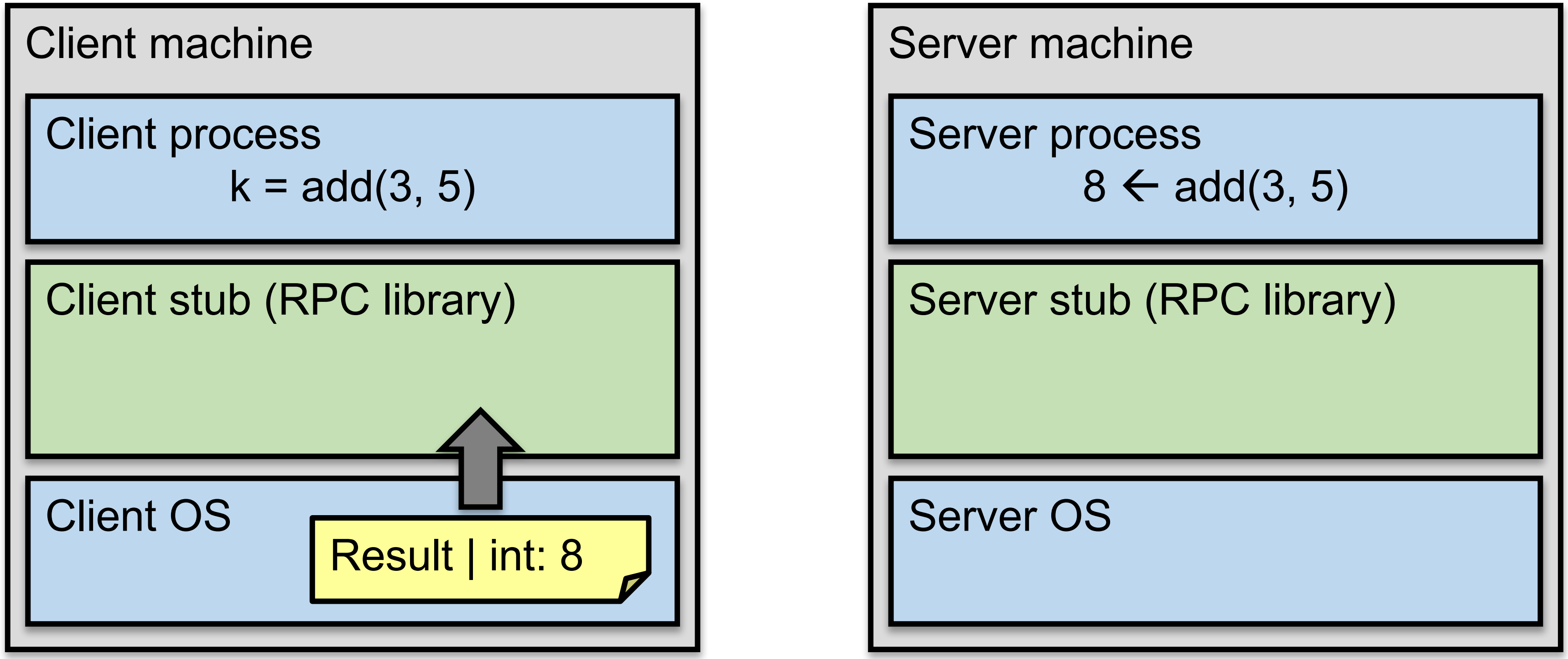
A day in the life of an RPC

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