

Network Communication and Remote Procedure Calls (RPCs)

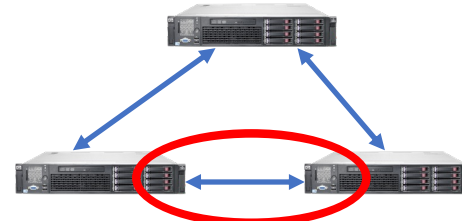


COS 418/518: Distributed Systems
Lecture 2

Jialin Ding, Mike Freedman

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Distributed Systems, What?



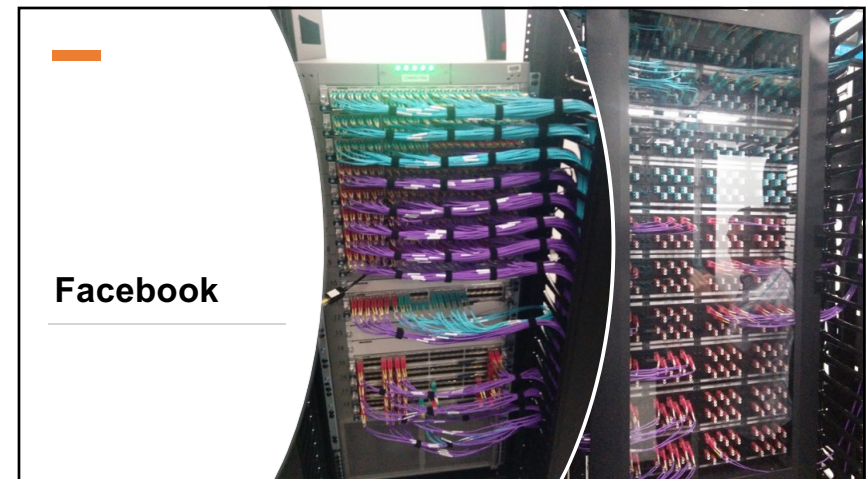
- 1) Multiple computers
- 2) Connected by a network
- 3) Doing something together

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Facebook

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Facebook

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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)

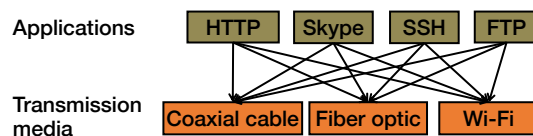
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The problem of communication

- 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?

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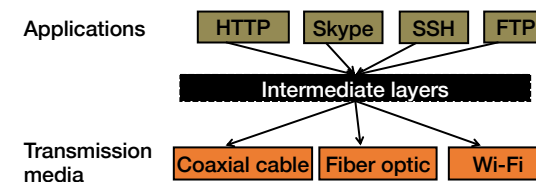
The problem of communication



- 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?

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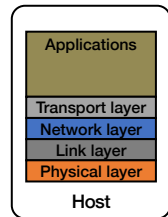
Solution: Layering



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

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Layering in the Internet

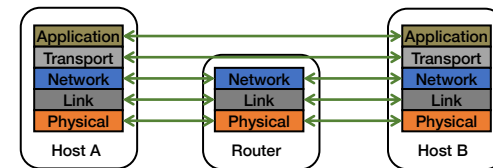


- **Transport:** Provide end-to-end communication between processes on different hosts
- **Network:** Deliver packets to destinations on other (heterogeneous) networks
- **Link:** Enables end hosts to exchange atomic messages with each other
- **Physical:** Moves bits between two hosts connected by a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

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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**

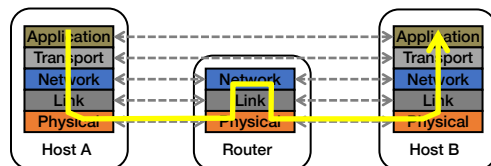


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Physical communication

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

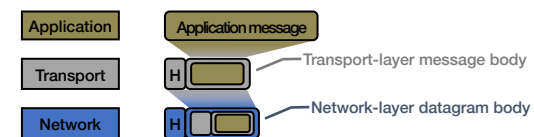


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Communication between peers

- 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

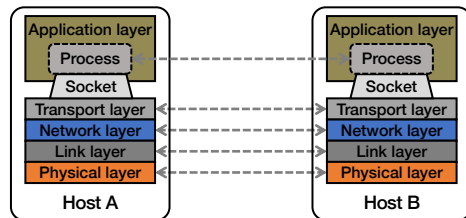


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Network socket-based communication

- **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`



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```
// 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);
```

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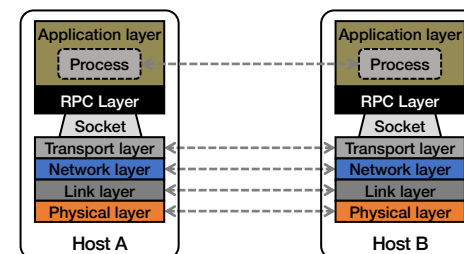
Socket programming: still not great

- 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

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Solution: Another layer!



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Today's outline

1. Network Communication
2. Remote Procedure Call

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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

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Everyone uses RPCs

- COS 418 programming assignments use RPC
- Google gRPC
- Facebook/Apache Thrift
- Apache Avro
- ...

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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...

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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 μ s ($10^3\times$ slower)
 - In the wide area, typically ≈ 10 -100 ms ($10^6\times$ slower)

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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** (e.g., 32 bit vs. 64 bit integers)
 - 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

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Solution: Interface Description Language (IDL)

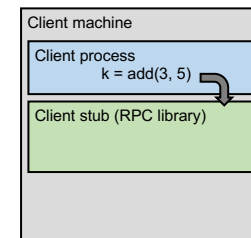
- Mechanism to pass procedure parameters and return values in a machine-independent way
- Programmer may write an **interface description** in the IDL
 - Defines API for procedure calls: names, parameter/return types
- Then runs an **IDL compiler** which generates:
 - Code to **marshal** (convert) native 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

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A day in the life of an RPC

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

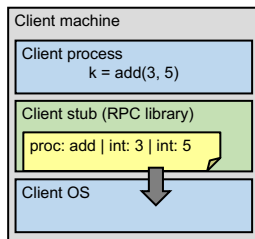


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A day in the life of an RPC

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

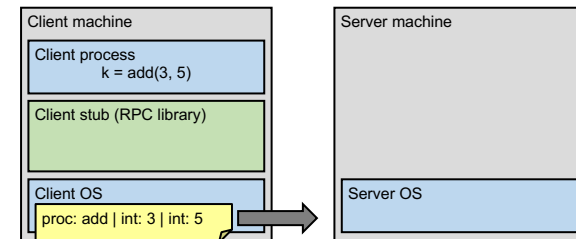


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A day in the life of an RPC

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

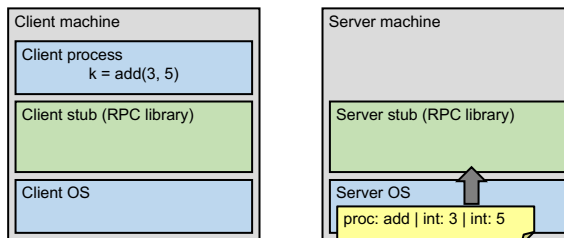


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A day in the life of an RPC

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

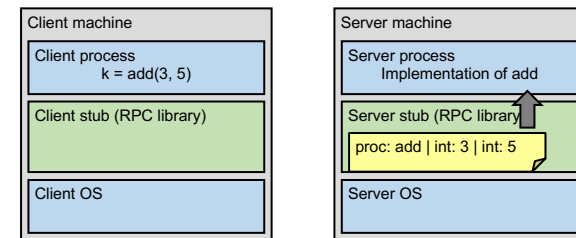


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A day in the life of an RPC

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

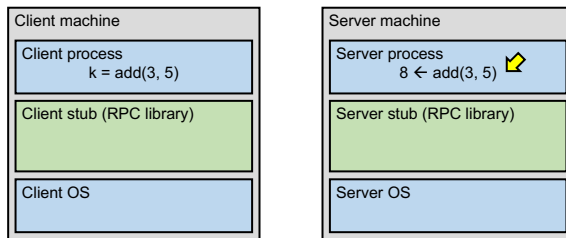


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A day in the life of an RPC

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

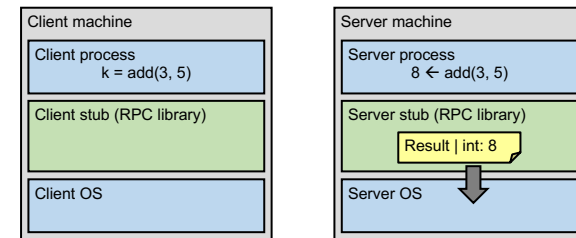


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A day in the life of an RPC

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

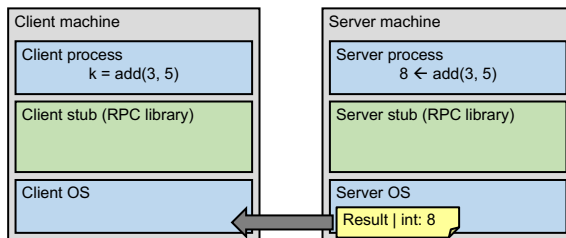


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A day in the life of an RPC

7. Server stub marshals the return value, sends message
8. Server OS sends the reply back across the network

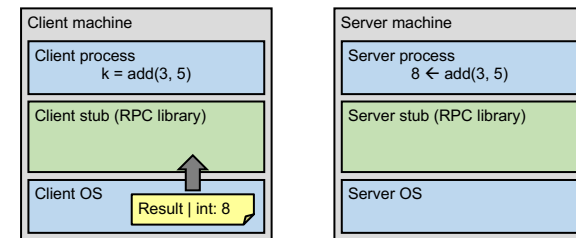


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A day in the life of an RPC

8. Server OS sends the reply back across the network
9. Client OS receives the reply and passes up to stub

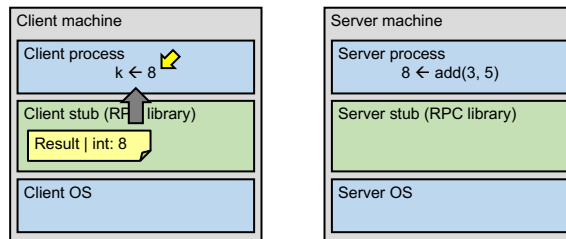


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A day in the life of an RPC

9. Client OS receives the reply and passes up to stub
10. Client stub unmarshals return value, returns to client



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Today's outline

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

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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**

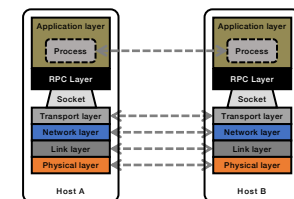
All of these may look the same to the client...

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Summary: RPCs and Network Comm.

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



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