RPCS AND GOOGLE RPC (GRPC)

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ATTRIBUTION

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Outline

1. RPC fundamentals
2. Protocol Buffers demo
3. gRPC demo (in the weekly TA session)

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

REMOTE PROCEDURE CALL (RPC)

- Distributed programming is challenging
  - Need common primitives/abstraction to hide complexity
  - E.g., file system abstraction to hide block layout, process abstraction for scheduling/fault isolation
- In early 1980's, researchers at PARC noticed most distributed programming took form of *remote procedure call*

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: To make communication appear like a local procedure call: transparency for procedure calls

RPC EXAMPLE

Local computing

```
X = 3 * 10;

print(X)

> 30
```

Remote computing

```
server = connectToServer(S);

Try:

  X = server.mult(3,10);

  print(X)

Except e:

  print "Error!"

> 30

or

> Error
```

RPC ISSUES

- Heterogeneity
  - Client needs to **rendezvous** with the server
  - Server must **dispatch** to the required function
    - What if server is **different** type of machine?
- Failure
  - What if messages get dropped?
  - What if client, server, or network fails?
- 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 call
- For a remote procedure call, a **remote machine may:**
  - 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

BYTE ORDER

- x86-64 is a ***little endian*** architecture
  - **Least** significant byte of multi-byte entity at **lowest** memory address
    - "Little end goes first"
- Some other systems use ***big endian***
  - **Most** significant byte of multi-byte entity at **lowest** memory address
    - "Big end goes first"

int 5 at address 0x1000:

0x1000:	0000 0101
0x1001:	0000 0000
0x1002:	0000 0000
0x1003:	0000 0000

int 5 at address 0x1000:

0x1000:	0000 0000
0x1001:	0000 0000
0x1002:	0000 0000
0x1003:	0000 0101

PROBLEM: DIFFERENCES IN PROGRAMMING SUPPORT

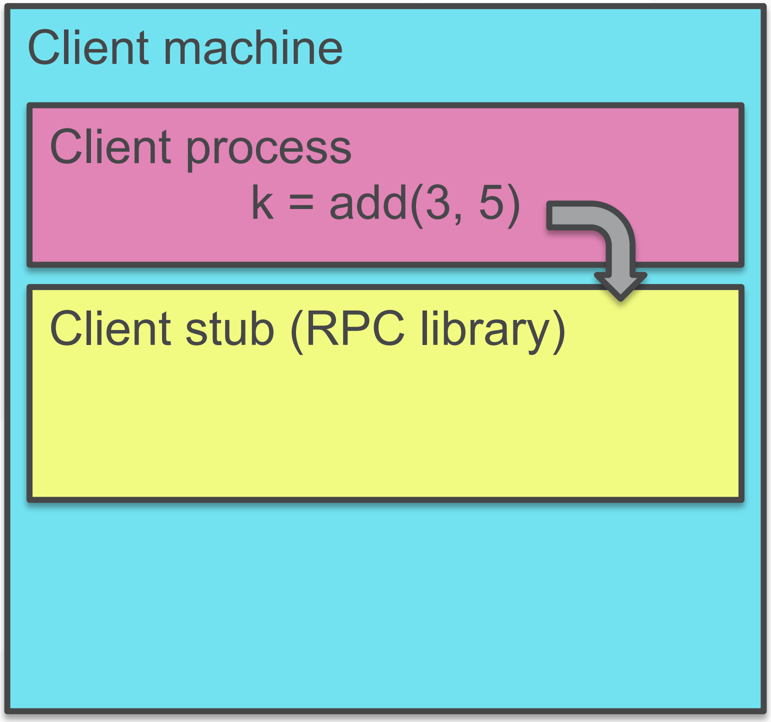
- Language support **varies:**
  - Many programming languages have **no inbuilt concept** of remote procedure calls
    - *e.g.,* C, C++, earlier Java
  - Some languages have **support that enables RPC**
    - *e.g.,* Python, Haskell, Go

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

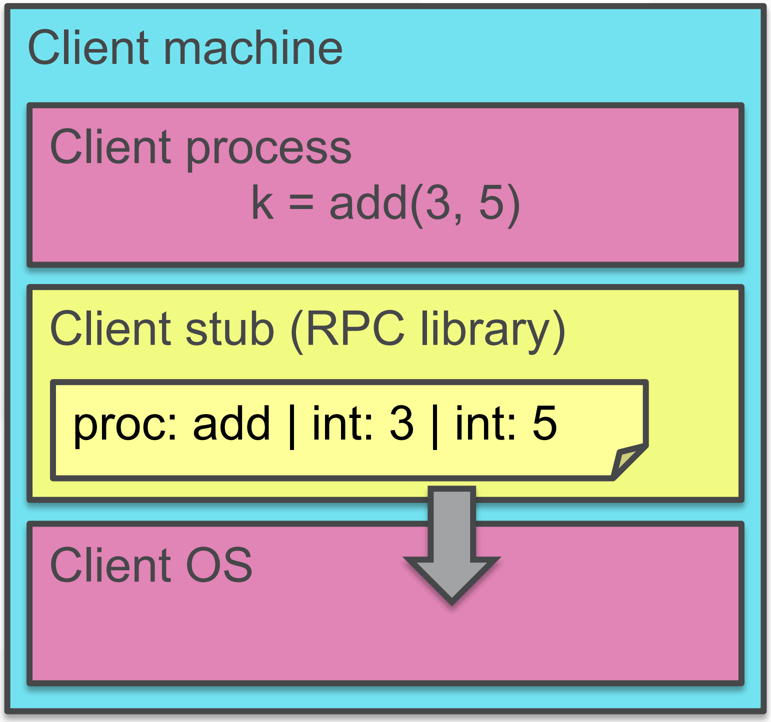
A DAY IN THE LIFE OF AN RPC

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



A DAY IN THE LIFE OF AN RPC

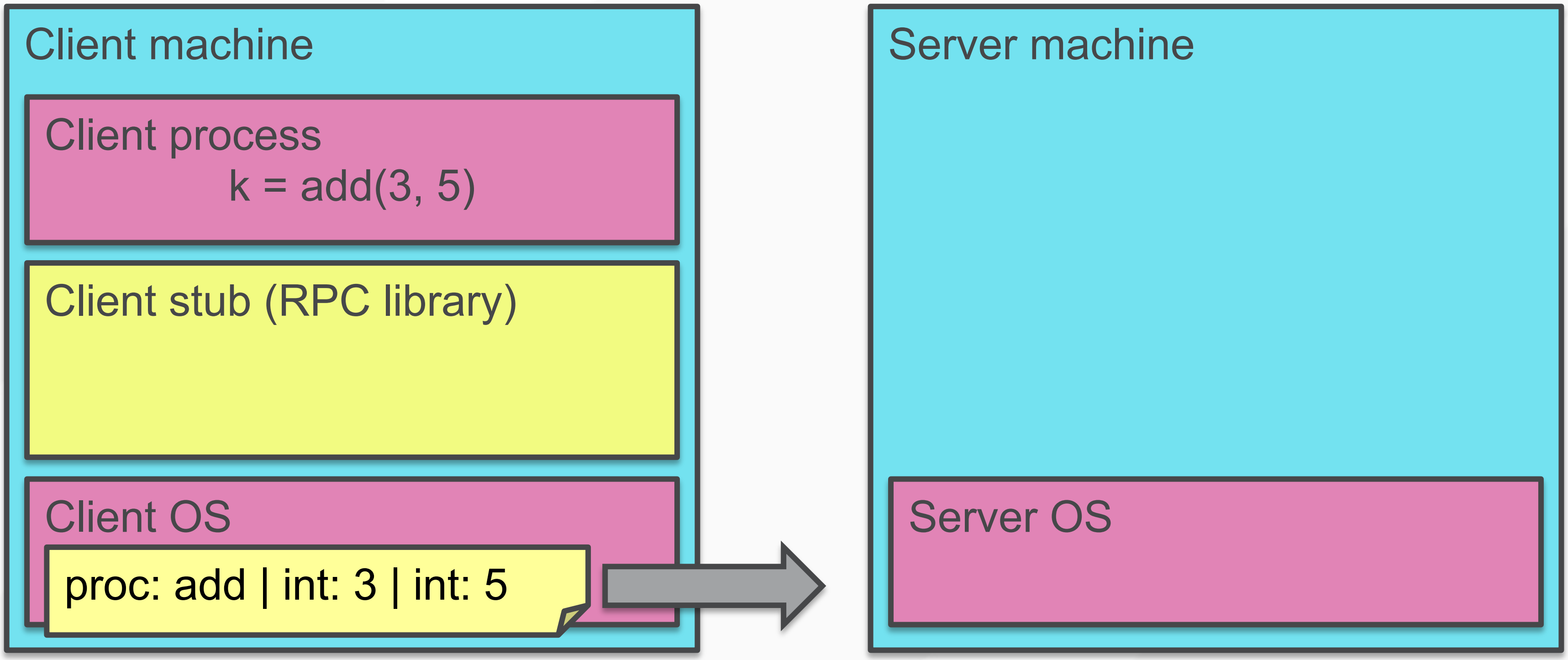
1. Client calls stub function (pushes params onto stack)
2. **Stub marshals parameters to a network message**



A DAY IN THE LIFE OF AN RPC

2. Stub marshals parameters to a network message

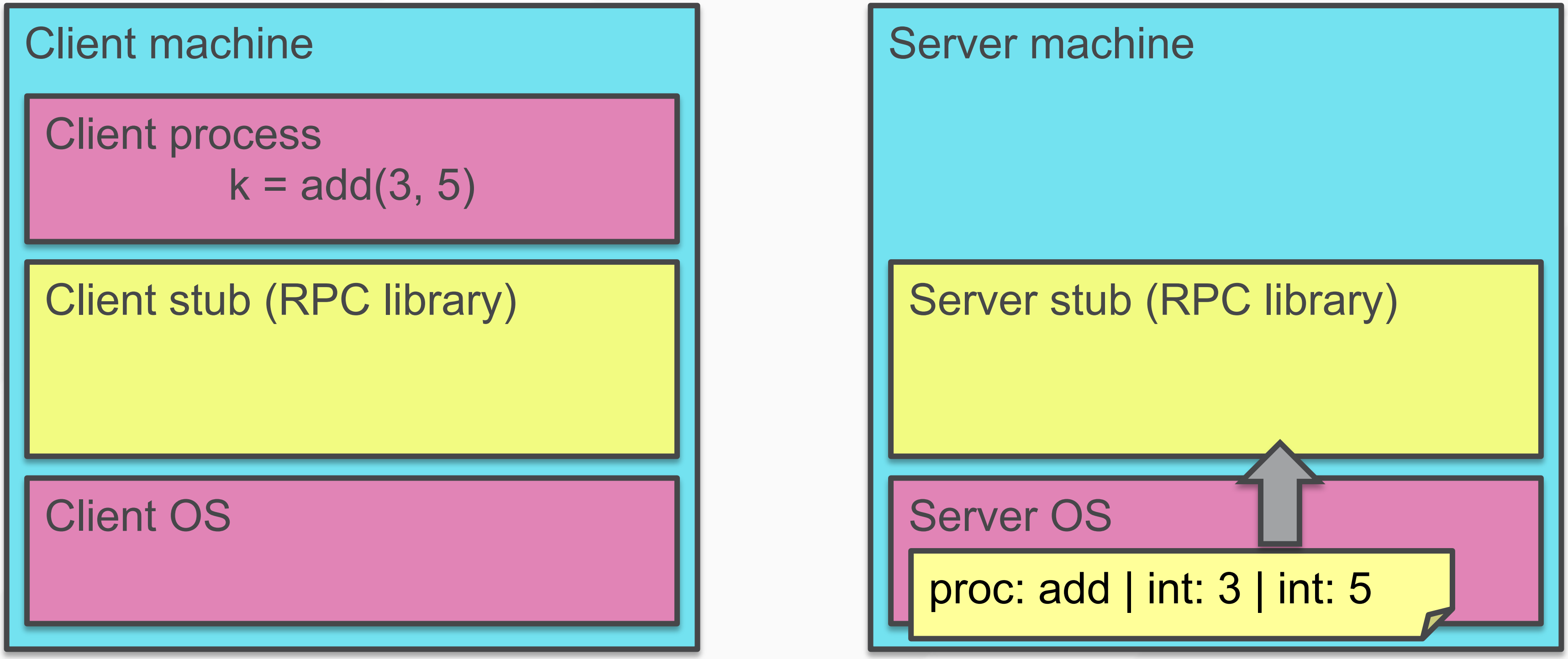
3. **OS sends a network message to the server**



A DAY IN THE LIFE OF AN RPC

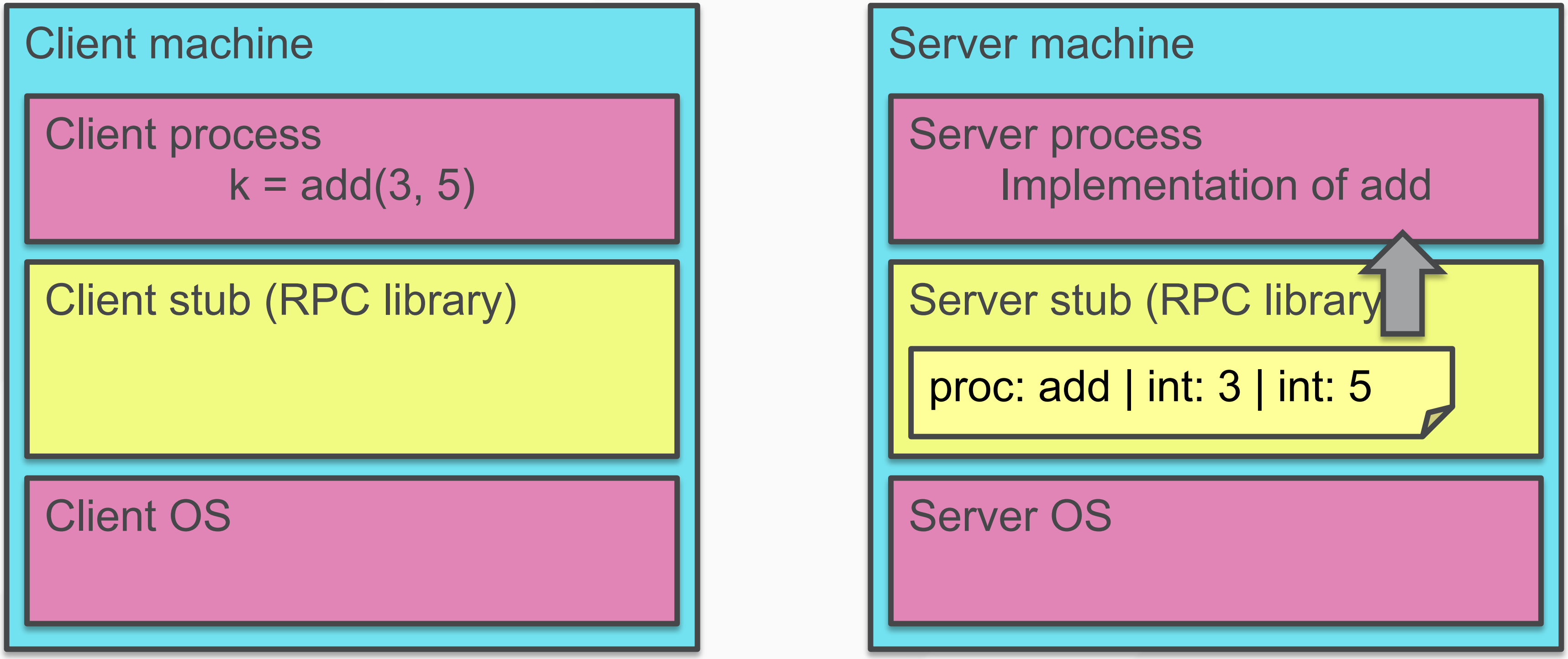
3. OS sends a network message to the server

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



A DAY IN THE LIFE OF AN RPC

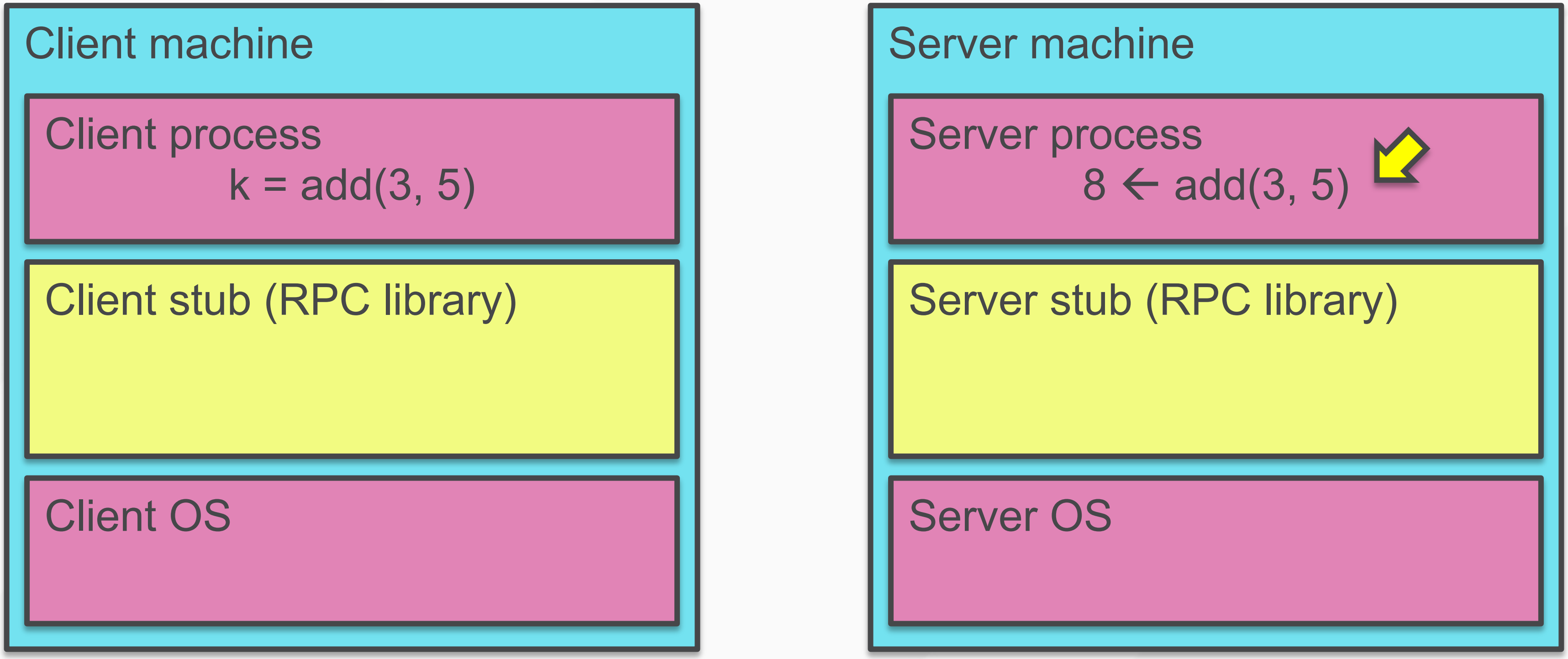
4. Server OS receives message, sends it up to stub
5. **Server stub unmarshals params, calls server function**



A DAY IN THE LIFE OF AN RPC

5. Server stub unmarshals params, calls server function

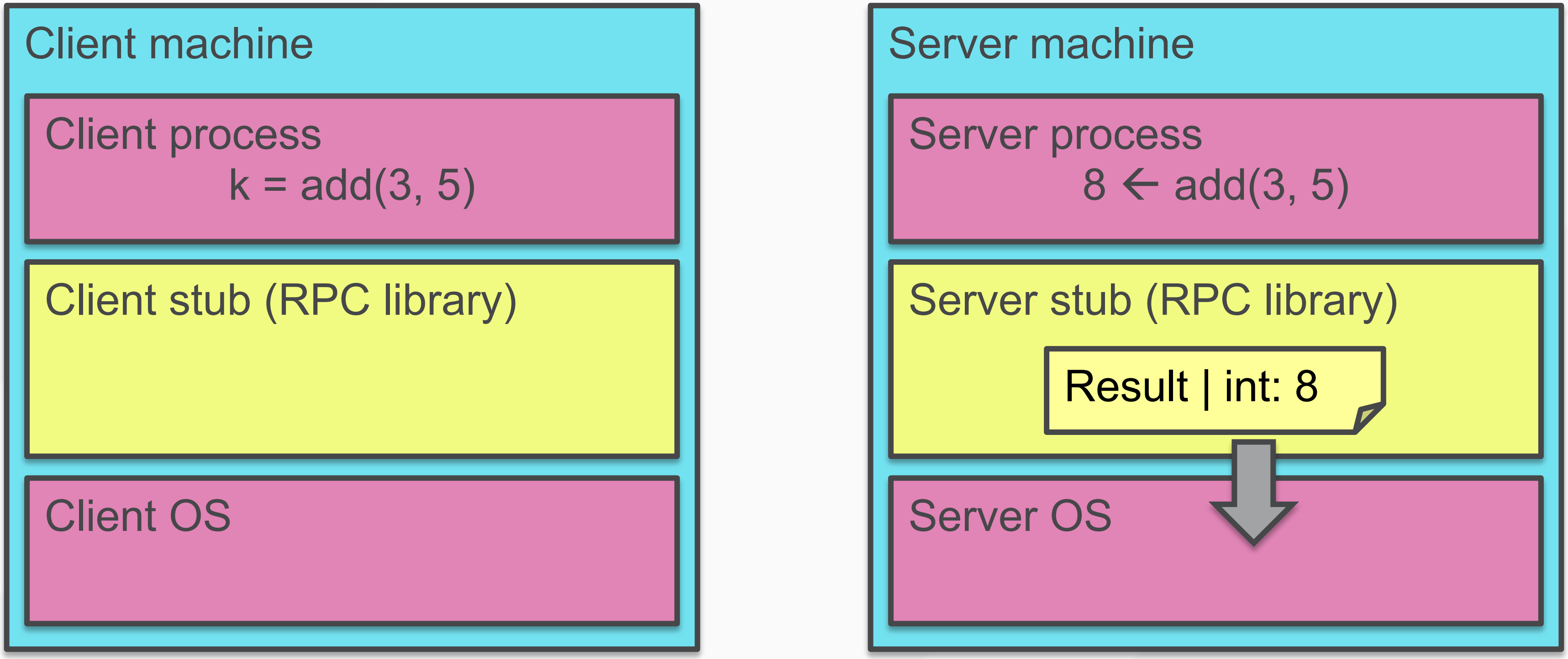
6. **Server function runs, returns a value**



A DAY IN THE LIFE OF AN RPC

6. Server function runs, returns a value

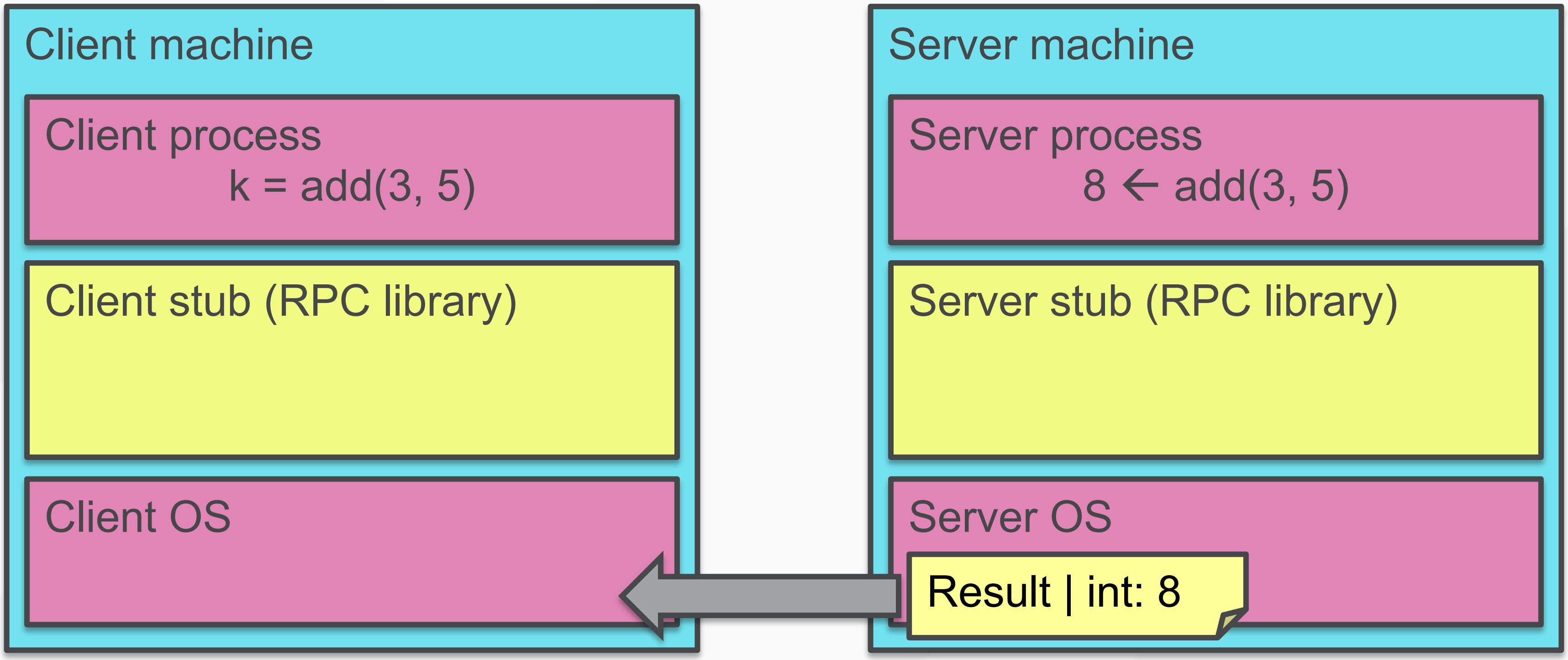
7. **Server stub marshals the return value, sends msg**



A DAY IN THE LIFE OF AN RPC

7. Server stub marshals the return value, sends msg

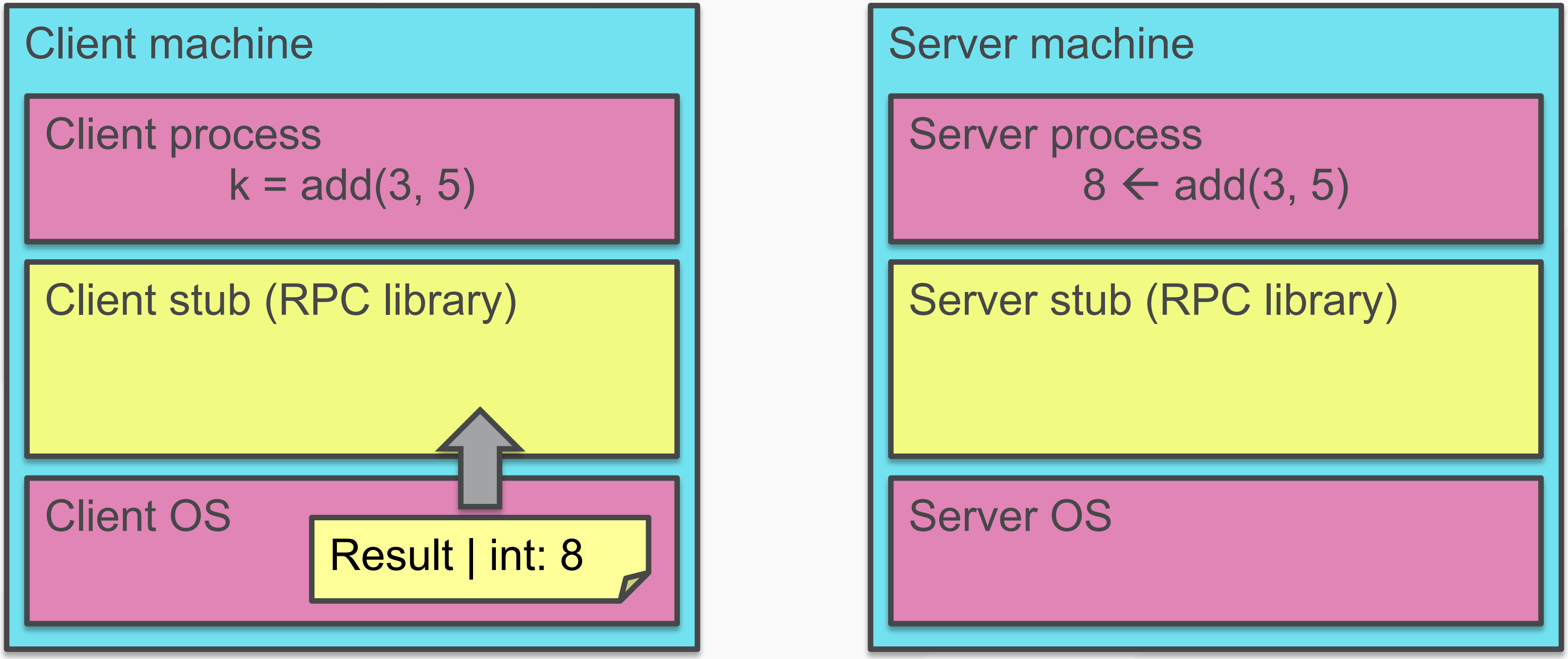
8. **Server OS sends the reply back across the network**



A DAY IN THE LIFE OF AN RPC

8. Server OS sends the reply back across the network

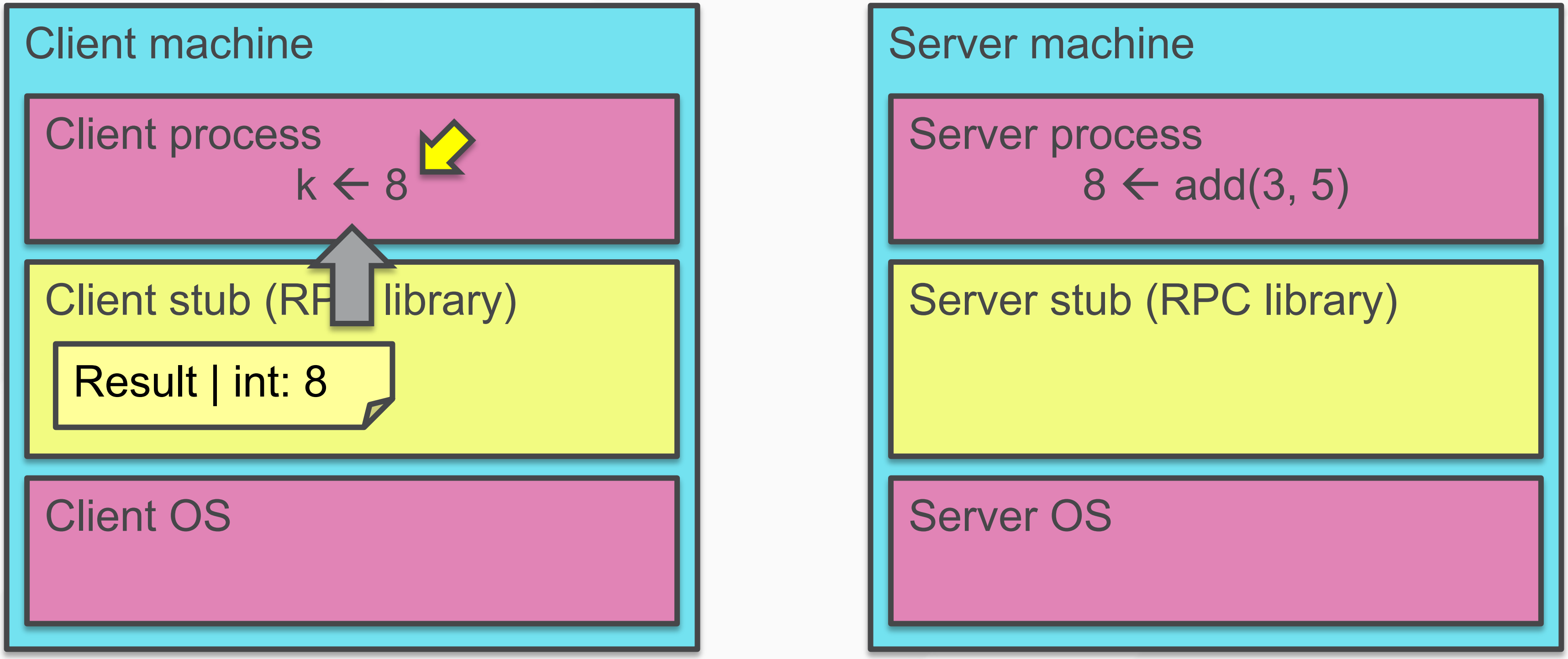
9. **Client OS receives the reply and passes up to stub**



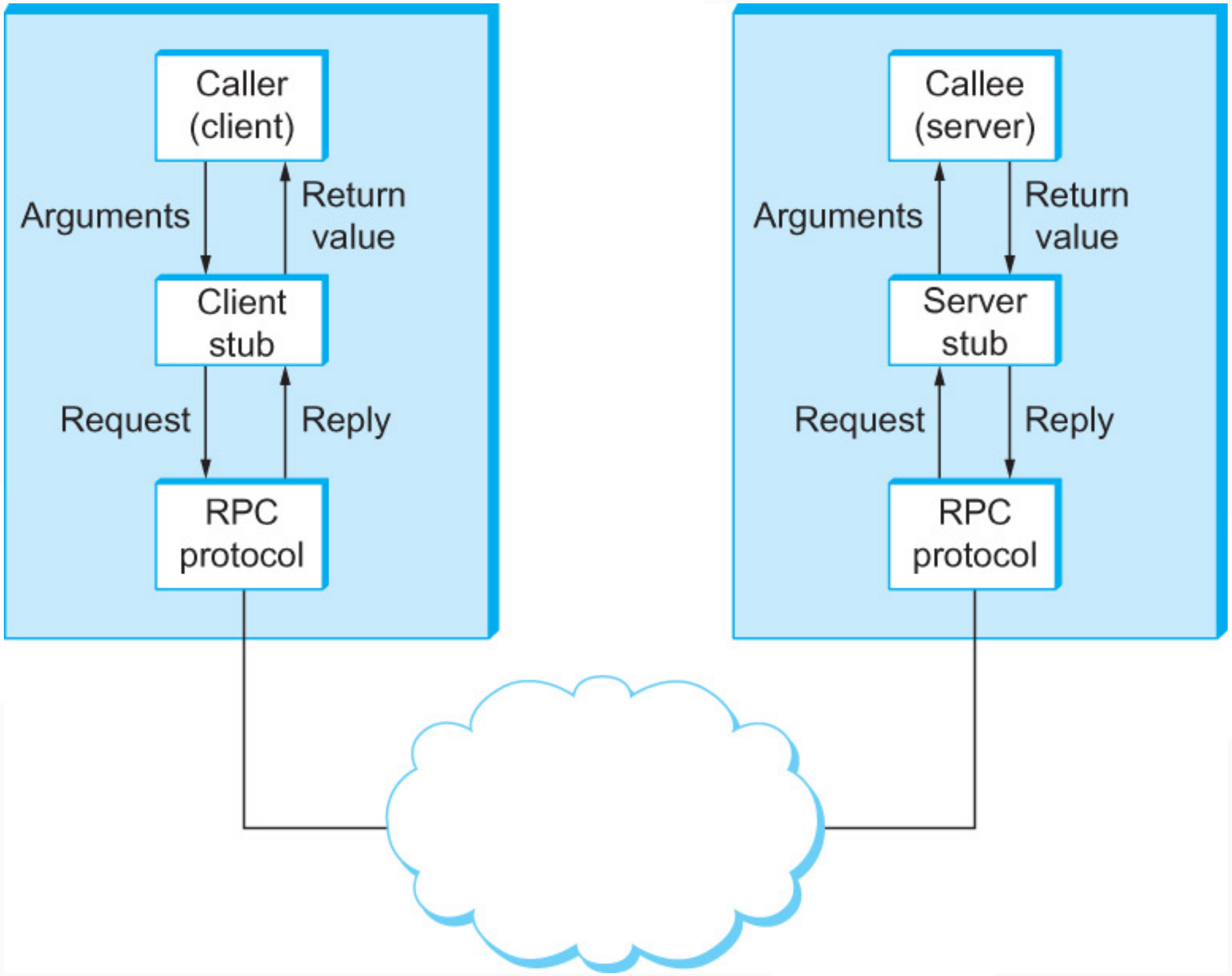
A DAY IN THE LIFE OF AN RPC

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

10. Client stub unmarshals return value, returns to client



PETERSON AND DAVIE VIEW



THE SERVER STUB IS REALLY TWO PARTS

- ***Dispatcher***
  - Receives a client’s RPC request
    - **Identifies** appropriate server-side method to invoke
- ***Skeleton***
  - **Unmarshals** parameters to server-native types
  - **Calls** the local server procedure
  - **Marshals** the response, sends it back to the dispatcher
- **All this is hidden from the programmer**
  - Dispatcher and skeleton may be integrated
    - Depends on implementation

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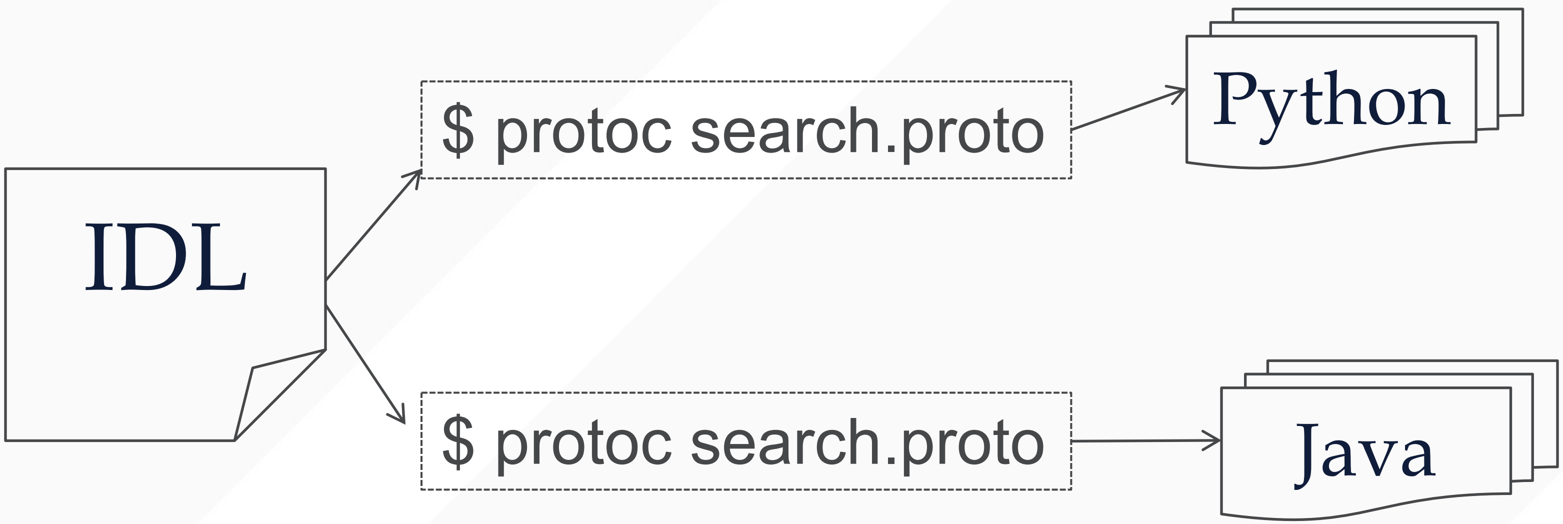
GOOGLE RPC (GRPC)

- Cross-platform RPC toolkit developed by Google
- Languages:
  - C++, Java, Python, Go, Ruby, C#, Node.js, Android, Obj-C, PHP
- Defines *services*
  - Collection of RPC calls

```
service Search {
 rpc searchWeb(SearchRequest) returns (SearchResult) {}
}
```

IDL: INTERFACE DEFINITION LANGUAGE



- Language-neutral way of specifying:
  - Data structures (called Messages)
  - Services, consisting of procedures/methods
- Stub compiler
  - Compiles IDL into Python, Java, etc.

IDL LANGUAGE: PROTOCOL BUFFERS

- Defines Messages (i.e., data structures)

We're using version 3 of protocol buffers

Field 1: query
Type: String

Name of the message

Field 2:
page_number
Type: 32-bit
signed int

```
syntax = "proto3";

message SearchRequest {
  string query = 1;
  int32 page_number = 2;
  int32 result_per_page = 3;
}
```

Field 3:
results_per_page
Type: 32-bit
signed int

PROTOCOL BUFFERS: BASE TYPES

- protobuf IDL:
  - double, float
  - int32, int64
  - uint32, uint64
  - bool
  - string
  - bytes
- Python:
  - float, float
  - int, int/long
  - int, int/long
  - bool
  - str
  - str
- Java:
  - double, float
  - int, long
  - int, long
  - Boolean
  - String
  - ByteString
- C++:
  - double, float
  - int32, int64
  - uint32, uint64
  - bool
  - string
  - string

IDL POSITIONAL ARGUMENTS

- Why do we label the fields with numbers?
- So we can change "signature" of the message later and still be compatible with legacy code

```
syntax = "proto3";

message SearchRequest {
  string query = 1;
  int32 page_number = 2;
  int32 result_per_page = 3;
}
```

```
syntax = "proto3";

message SearchRequest {
  string query = 1;
  int32 page_number = 2;
  int32 shard_num = 4;
}
```

MAKING SERVICES *EVOLVABLE*

- No way to “stop everything” and upgrade
- Clients/servers/services must co-exist
- For newly added fields, old services use defaults:
  - String: “”
  - bytes: []
  - bools: false
  - numeric: 0
  - …

PROTOCOL BUFFERS: MAP TYPE

- map<key_type, value_type> map_field = N;

- Example:
    - map<string, Project> projects = 3;

IMPLEMENTING IN DIFFERENT LANGUAGES

IDL

```
message Person {
  required string name = 1;
  required int32 id = 2;
  optional string email = 3;
}
```

C++: reading from a file

```
Person john;
fstream input(argv[1],
    ios::in | ios::binary);
john.ParseFromIstream(&input);
id = john.id();
name = john.name();
email = john.email();
```

Java: writing to a file

```
Person john = Person.newBuilder()
    .setId(1234)
    .setName("John Doe")
    .setEmail("jdoe@example.com")
    .build();
output = new FileOutputStream(args[0]);
john.writeTo(output);
```

A C++ EXAMPLE

```
Person person;
person.set_name("John Doe");
person.set_id(1234);
person.set_email("jdoe@example.com");
fstream output("myfile", ios::out | ios::binary);
person.SerializeToOstream(&output);
```

```
fstream input("myfile", ios::in | ios::binary);
Person person;
person.ParseFromIstream(&input);
cout << "Name: " << person.name() << endl;
cout << "E-mail: " << person.email() << endl;
```

- Can read/write protobuf Message objects to files/stream/raw sockets
- In particular, gRPC service RPCs
  - Take Message as argument, return Message as response

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