CSCI-1680
APIs

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Based partly on lecture notes by Rodrigo Fonseca, Scott Shenker and John Jannotti

Administrivia

TCP officially due tonight (Tuesday, Nov 21)

- Office hours 2-5pm (Me); 5-7pm (Alex); 7-9pm (Rhea)

- Like with IP: you can continue to make *small* bugfixes after the deadline
  - OK: Fixing *small* bugs, README, capture files, code cleanup
  - Not OK: eg. implementing sendfile/recvfile, teardown, submitting untested code

- Grading meetings: after break

Administrivia

Final project is online

- Group registration form: due tomorrow (11/29) by 5pm EST
- Brief proposal: due Friday 12/1, no late days permitted!!
  - We will review all of these over the weekend

- HW4 (probably last HW): out this week, due next week

- TCP grading: end of this week, early next week
  - Look for email today/tomorrow

Project examples

- Make your own iterative DNS resolver
- Build a simple HTTP server
- Make your own web API for something
- Implement Snowcast, etc. using RPCs (more next week)
- Extend your IP/TCP in some way…

These are only a few ideas!

HTTP request: a way to fetch (**GET**) or send (**POST**) some object

- Doesn't need to be a web page
- Doesn't need to be from a browser

⇒ Generic way to ask the server to do something => an API over the network!

How do programs communicate?

Need a protocol! We've seen lots of examples….

IP, TCP, ICMP, RIP, OSPF, BGP, DNS, HTTP, Snowcast …

How do programs communicate?

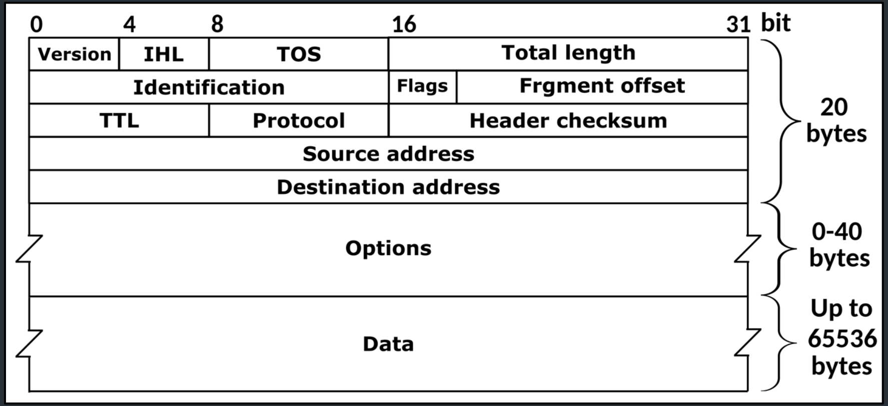
Need a protocol! We've seen lots of examples….

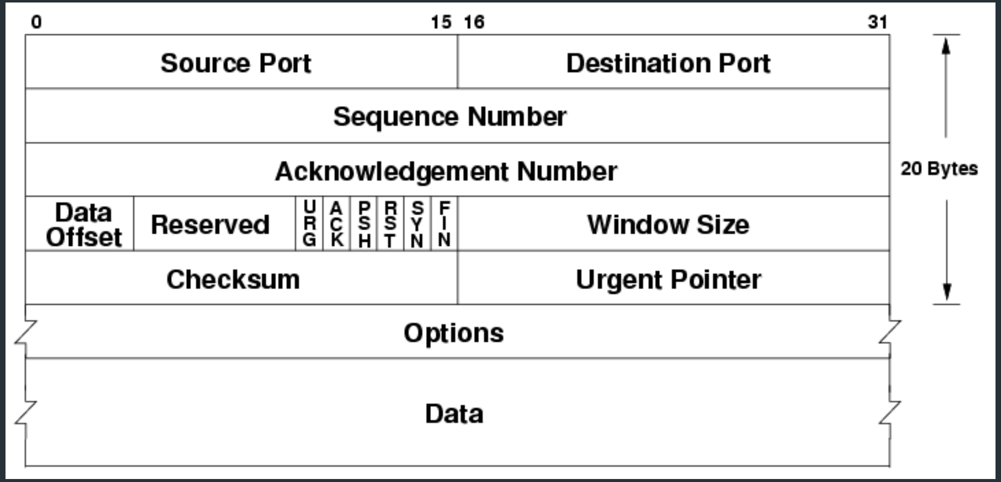
IP, TCP, ICMP, RIP, OSPF, BGP, DNS, HTTP, Snowcast ...

⇒ What do protocols require?

Requirements for protocols

Data representation (headers, packet formats)





Semantics *(when to send each message, how to handle errors)*

```
From: draft-ietf-tcpm-rfc793bis-28                       Internet Standard

Internet Engineering Task Force (IETF)                          W. Eddy, Ed.
STD: 7                                                           MTI Systems
Request for Comments: 9293                                       August 2022
Obsoletes: 793, 879, 2873, 6093, 6429, 6528,
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Updates: 1011, 1122, 5961
Category: Standards Track
ISSN: 2070-1721


                   Transmission Control Protocol (TCP)

Abstract

   This document specifies the Transmission Control Protocol (TCP).  TCP
   is an important transport-layer protocol in the Internet protocol
   stack, and it has continuously evolved over decades of use and growth
   of the Internet.  Over this time, a number of changes have been made
```

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Network Working Group                                        D. Waitzman
Request for Comments: 1149                                       BBN STC
                                                            1 April 1990


   A Standard for the Transmission of IP Datagrams on Avian Carriers

Status of this Memo

   This memo describes an experimental method for the encapsulation of
   IP datagrams in avian carriers.  This specification is primarily
   useful in Metropolitan Area Networks.  This is an experimental, not
   recommended standard.  Distribution of this memo is unlimited.

Overview and Rational

   Avian carriers can provide high delay, low throughput, and low
```

Requirements for protocols

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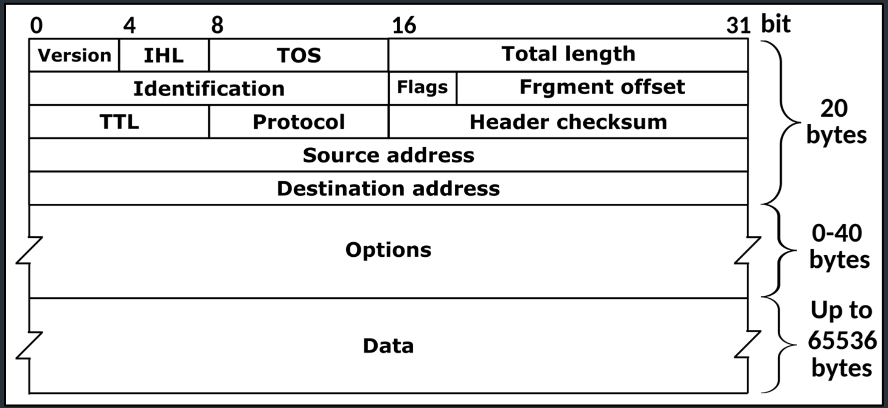

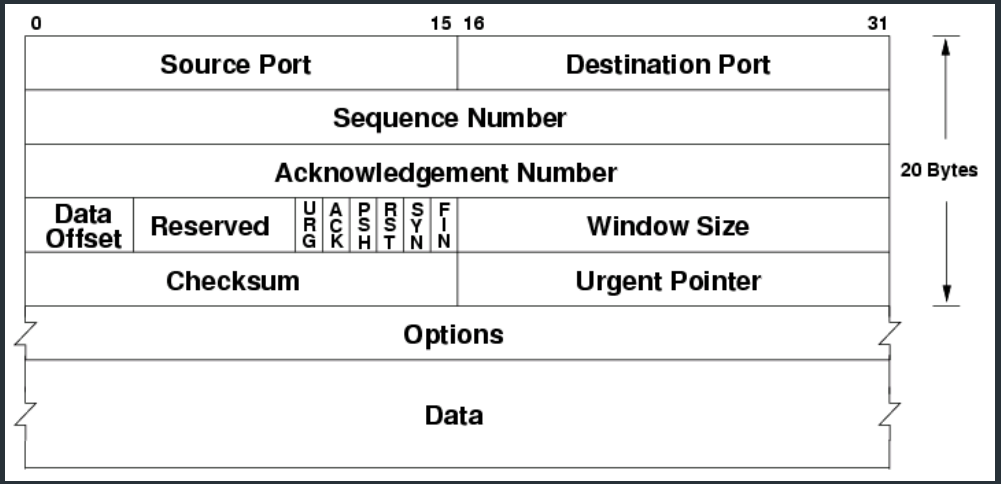

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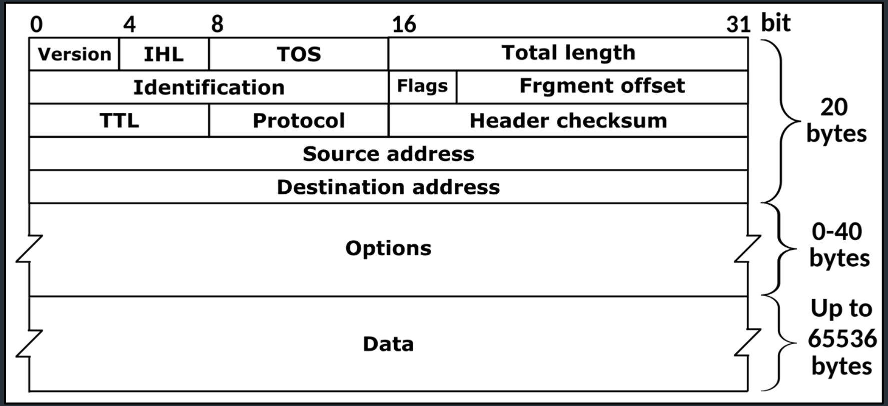

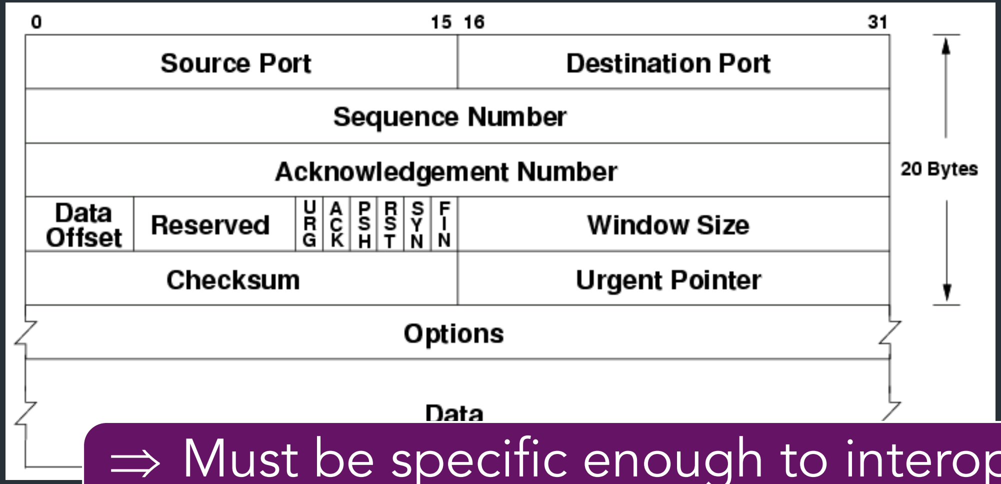

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⇒ Must be specific enough to interoperate
(support multiple architectures, byte orders, languages, locales …)

When you made a custom protocol…

Client to Server Commands

The client sends the server messages called **commands**. There are two commands the client can send the server, in the following format:

```
Hello:
    uint8 commandType = 0;
    uint16 udpPort;

SetStation:
    uint8 commandType = 1;
    uint16 stationNumber;
```

A `uint8` is an unsigned 8-bit integer; a `uint16` is an unsigned 16-bit integer. Your programs `MUST` use **network byte order**. So, to send a `Hello` command, your client would send exactly three bytes to the server: one for the command type and two for the port.

When you made a custom protocol…

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```
// Guessing game example (lecture 3!!)
type struct GuessMessage {
    MessageType uint8
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}

func (m *GuessMessage) Marshal() []byte {
        buf := new(bytes.Buffer)
        err := binary.Write(buf, binary.BigEndian, m.MessageType)
        if err != nil {
                . . .
        }

        err = binary.Write(buf, binary.BigEndian, m.Number)
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        return buf.Bytes()
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```

All the protocols you've made so far (+IP, TCP, RIP, …):
manually packing bytes into buffers

All the protocols you've been writing so far: manually loading bytes into buffers

This is useful for learning:

- How protocols work under the hood
- How fundamental Internet protocols actually work

But if your job is to build applications, is this what you should be doing?

Almost certainly not.

How SHOULD you write a protocol outside this class?

And why?

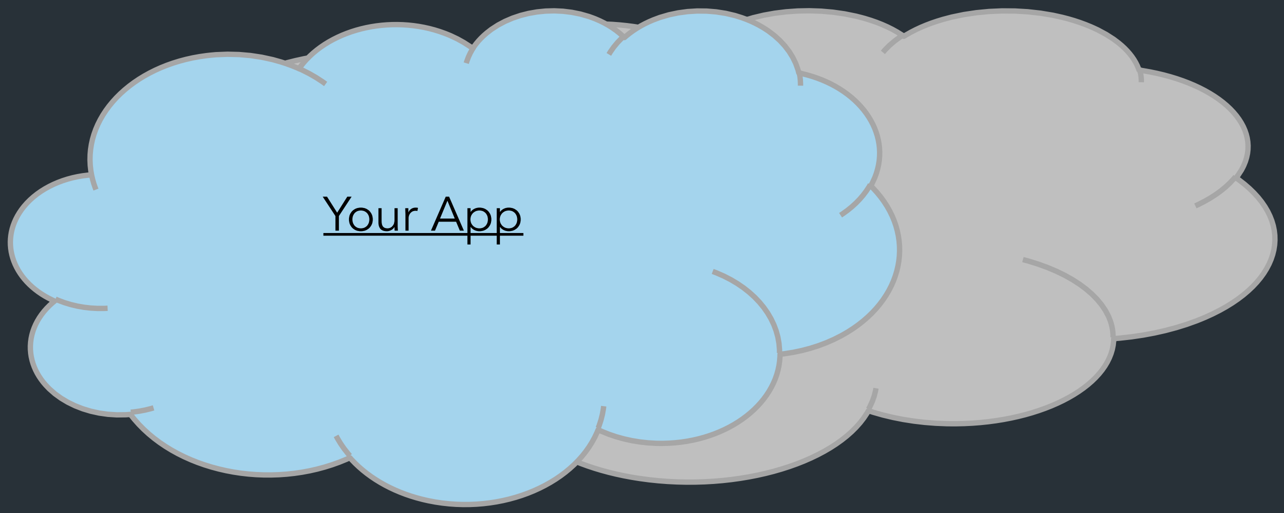
How SHOULD you write a protocol outside this class?

And why?

** At least, how to start thinking about it*

Typical application goal: make an API for something

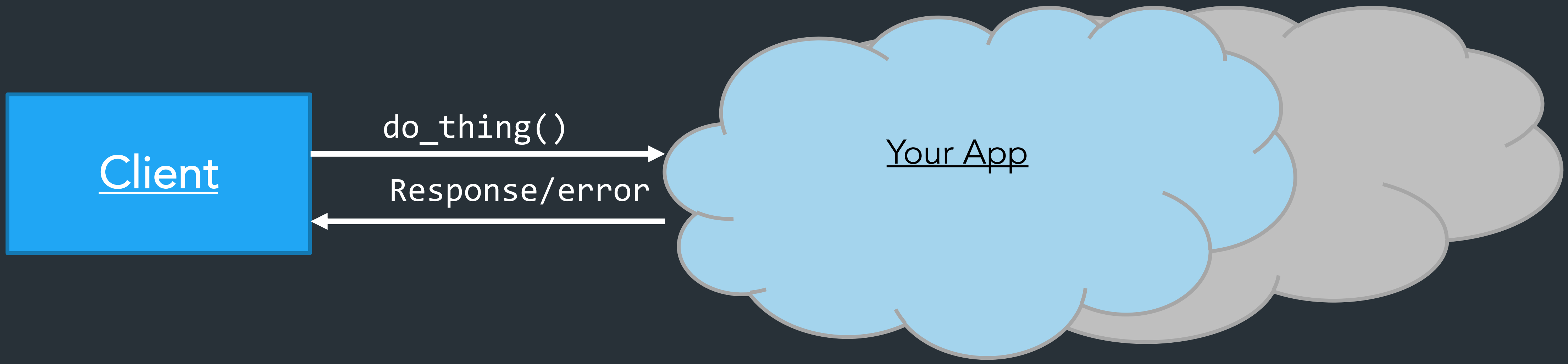
What you have: some servers/services that live somewhere in the cloud

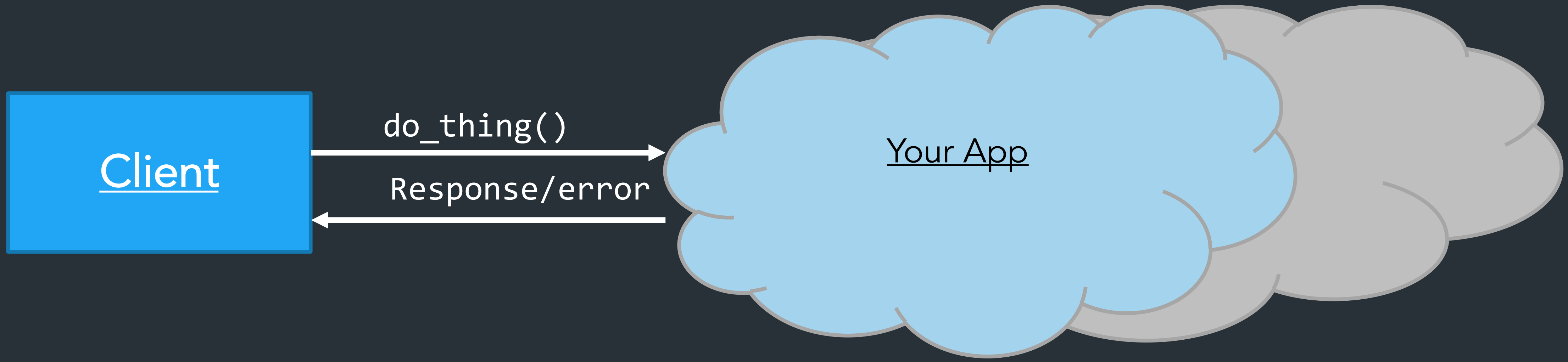


Typical application goal: make an API for something

What you have: some servers/services that live somewhere in the cloud
=> Might be distributed, might not

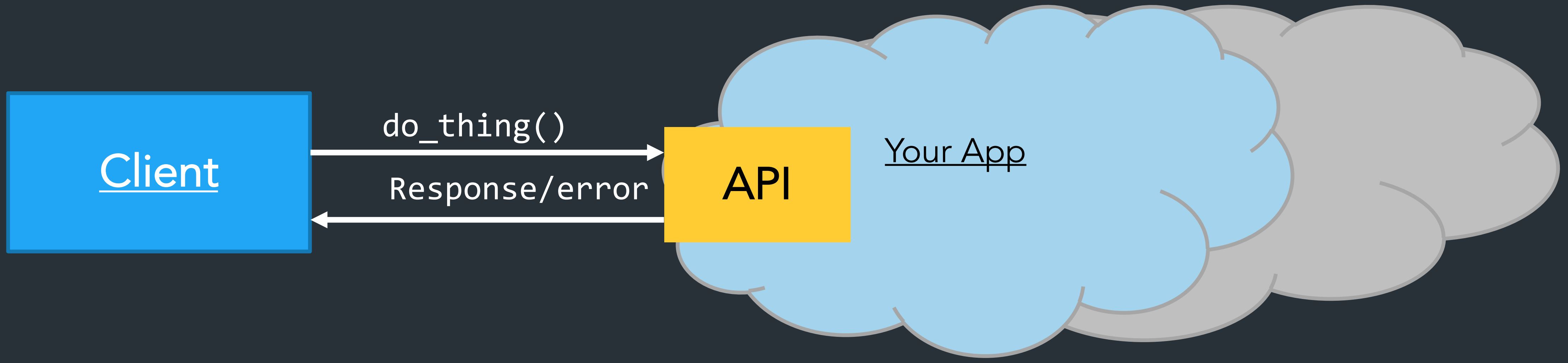
Want: end-user to be able to use your app
- Read data
- Write/upload data





Challenges/Requirements

- Heterogeneous devices (desktop/mobile, different OSes)
- Application will change
- Number of user devices will scale
- Number of services/services will scale too!



Would like to have a generic API for interacting with application services

=> Flexible to changes

=> Easy to scale

=>

Why doesn't this work?

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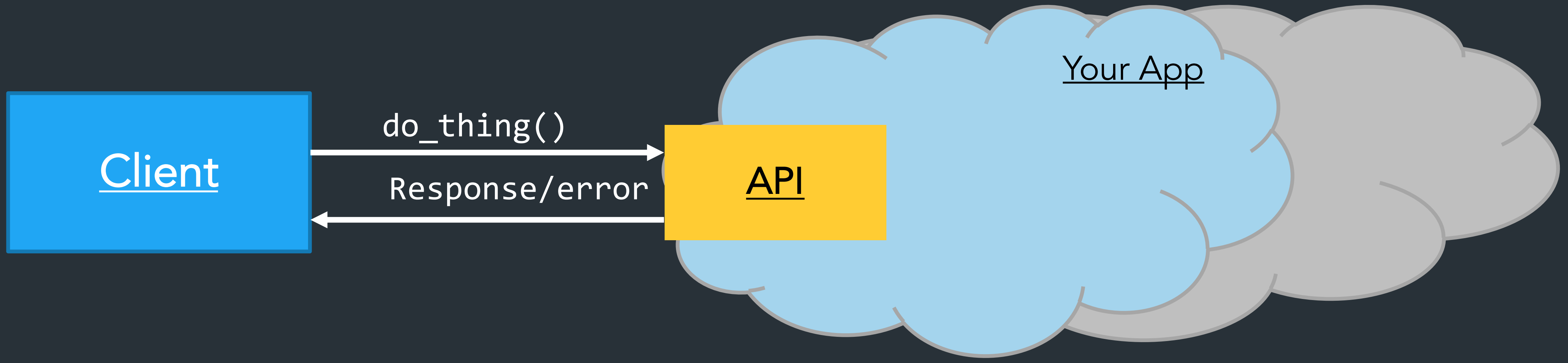
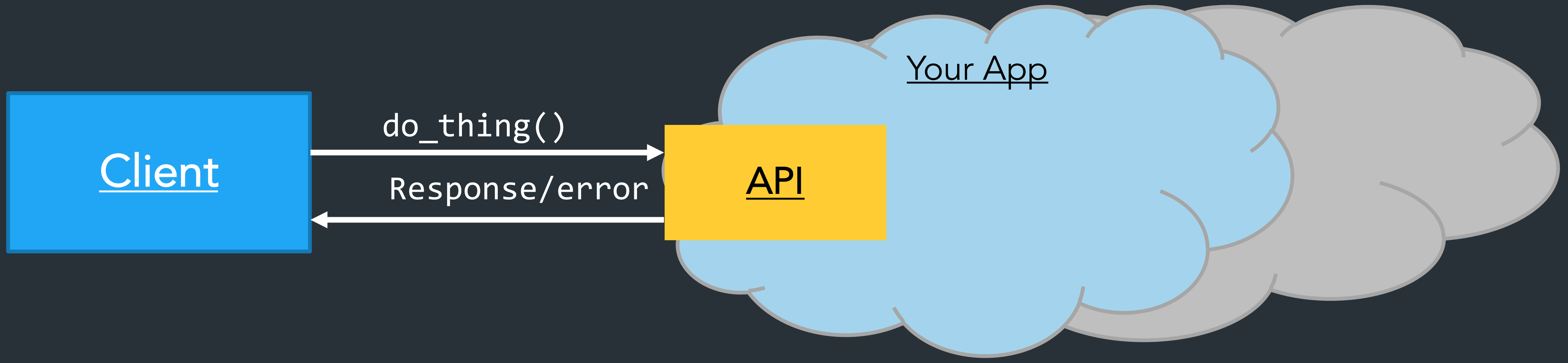


Usually, build on existing tools that can define the API for you



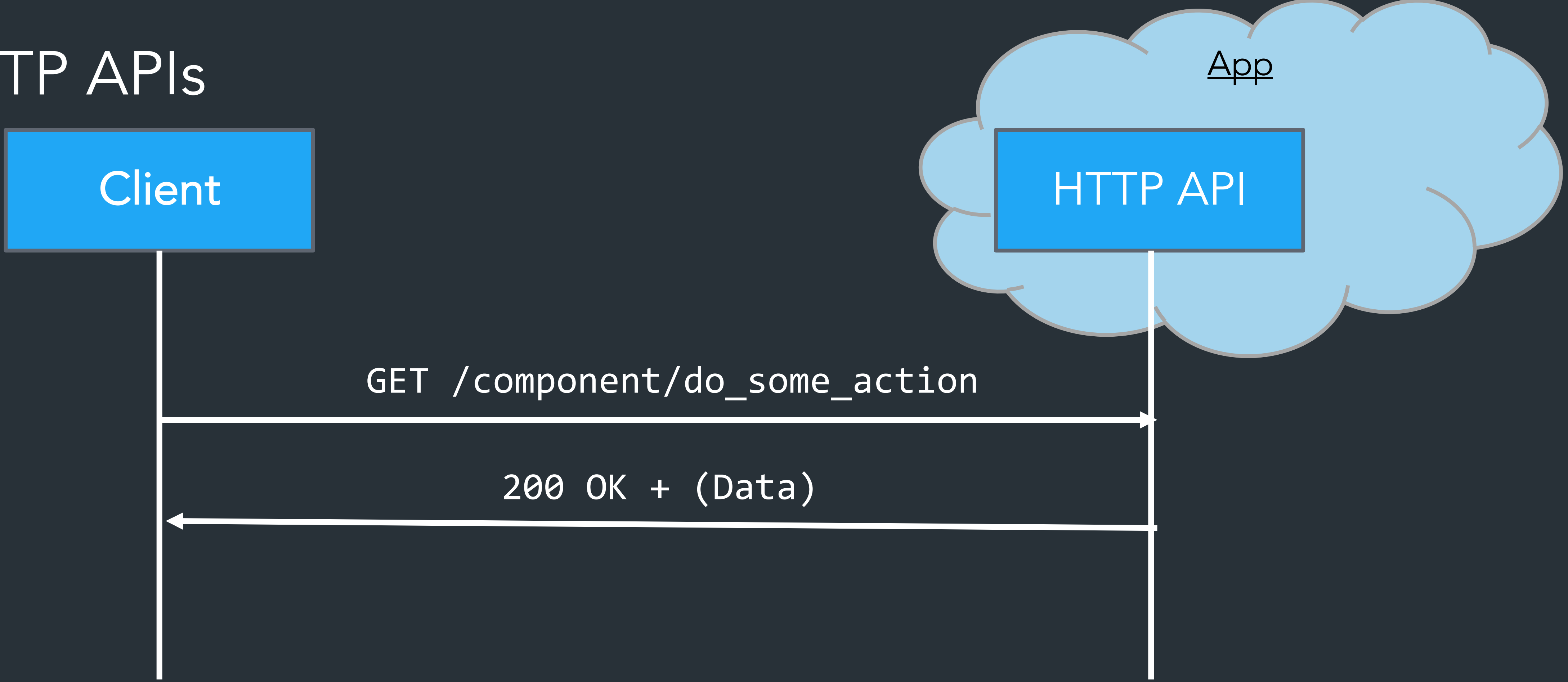
Usually, build on existing tools that can define the API for you
=> Creates endpoints where you write code to perform actions

=> Don't need to worry about serializing/deserializing messages

=> Build on existing protocols to handle scaling
(eg. HTTP proxies, load balancing, caching, etc.)

Concepts: endpoints

HTTP APIs



- Endpoints at various URLs
- Usually: Request data with GET, upload with POST
- Client authenticates/passes inputs data with headers, cookies
- Response normally JSON, XML, or other self-describing format

An example

```
curl -X GET 'https://www.gradescope.com/courses/567871/memberships.csv'
    -H 'User-Agent: Mozilla/5.0 (Macintosh; Intel Mac OS X 10.15; rv:109.0) Gecko/20100101
    Firefox/118.0'
    -H 'Accept: text/html,application/xhtml+xml,application/xml;q=0.9,image/avif,image/webp,*/*;q=0.8'
    -H 'Accept-Language: en-US,en;q=0.5'
    -H 'Accept-Encoding: gzip, deflate, br'
    -H 'Referer: https://www.gradescope.com/courses/567871/memberships'
    -H 'DNT: 1'
    -H 'Connection: keep-alive'
    -H 'Cookie: remember_me=XXXXXXXXXXXXXXXX; __stripe_mid=XXXXXXXXXXXXX;
    signed_token=XXXXXXXXXXXXXXX; _gradescope_session=XXXXXX[. . .]XXXXXXXX; __stripe_sid=XXXXXXXXXXX'
    -H 'Upgrade-Insecure-Requests: 1'
    -H 'Sec-Fetch-Dest: document'
    -H 'Sec-Fetch-Mode: navigate'
    -H 'Sec-Fetch-Site: same-origin'
    -H 'Sec-Fetch-User: ?1'
```

Example: Github public API

```
$ curl https://api.github.com/users/ndemarinis
{
  "login": "ndemarinis",
  "id": 1191319,
  "node_id": "MDQ6VXNlcjExOTEzMTk=",
  "avatar_url": "https://avatars.githubusercontent.com/u/1191319?v=4",
  "gravatar_id": "",
  "url": "https://api.github.com/users/ndemarinis",
  "type": "User",
  "site_admin": false,
  "name": "Nick DeMarinis",
  "blog": "https://vty.sh",
  "twitter_username": null,
  "public_repos": 10,
 . . .
}
```

Why is this useful?

- HTTP is ubiquitous
- Lots of existing tools to scale HTTP
  - Cookies etc. for user authentication
  - Proxies/load balancers

Why use JSON/etc vs. a binary encoding?

HTTP Example

```
> telnet www.cs.brown.edu 80
Trying 128.148.32.110...
Connected to www.cs.brown.edu.
Escape character is '^]'.
GET / HTTP/1.0

HTTP/1.1 200 OK
Date: Thu, 24 Mar 2011 12:58:46 GMT
Server: Apache/2.2.9 (Debian) mod_ssl/2.2.9 OpenSSL/0.9.8g
Last-Modified: Thu, 24 Mar 2011 12:25:27 GMT
ETag: "840a88b-236c-49f3992853bc0"
Accept-Ranges: bytes
Content-Length: 9068
Vary: Accept-Encoding
Connection: close
Content-Type: text/html

<!DOCTYPE html PUBLIC "-//W3C//DTD XHTML 1.0 Strict//EN"
   "http://www.w3.org/TR/xhtml1/DTD/xhtml1-strict.dtd">
<html xmlns="http://www.w3.org/1999/xhtml" xml:lang="en" lang="en”>
...
```

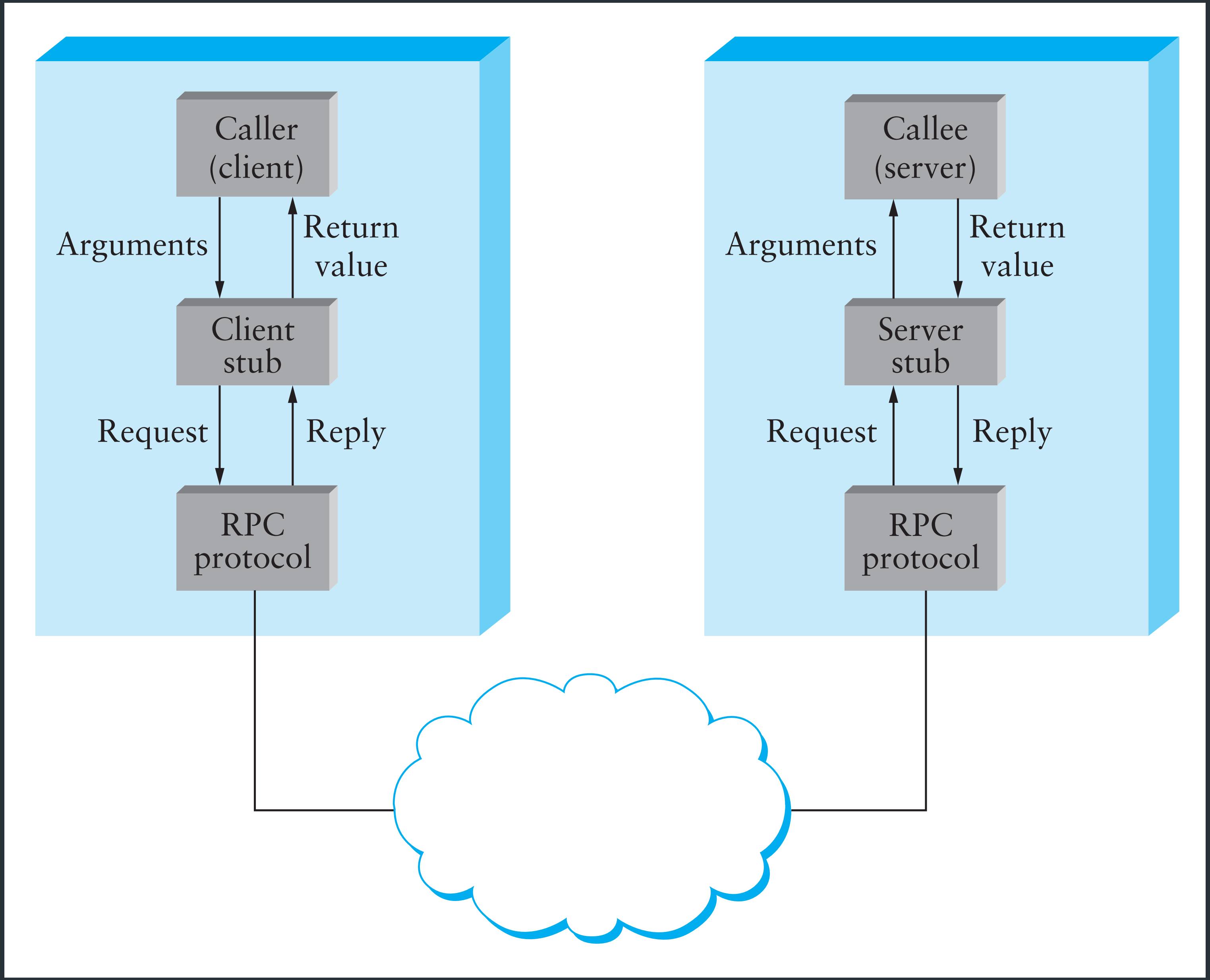
What if you need more flexibility?

Generic view: Remote Procedure Call (RPC)

- Procedure calls are a well understood mechanism
  - Transfer control and data on a single computer
- Idea: make distributed programming look the same
  - Have servers export interfaces that are accessible through local APIs
  - Perform the illusion behind the scenes
- 2 Major Components
  - Protocol to manage messages sent between client and server
  - Language and compiler support
    - Packing, unpacking, calling function, returning value

Stub Functions

- Local stub functions at client and server give appearance of a local function call
- client stub
  - marshalls parameters -> sends to server -> waits
  - unmarshalls results -> returns to client
- server stub
  - creates socket/ports and accepts connections
  - receives message from client stub -> unmarshalls parameters -> calls server function
  - marshalls results -> sends results to client stub


Caller
(client)
Arguments
Return
value
Client
stub
Request
Reply
RPC
protocol
Callee
(server)
Arguments
Return
value
Server
stub
Request
Reply
RPC
protocol

Some examples

- gRPC
- Apache Thrift
- JSON-RPC
- XML-RPC, SOAP
- . . .

Design questions

Describing data

Example: gRPC

- IDL-based, defined by Google
  - Protocol Buffers as IDL
- User specifies services, calls
  - Single and streaming calls
  - Support for timeouts, cancellations, etc
- Transport: based on HTTP/2

```
service HelloService {
  rpc SayHello (HelloRequest)
  returns (HelloResponse);
}


message HelloRequest {
  string greeting = 1;
}
message HelloResponse {
  string reply = 1;
}
```

gRPC

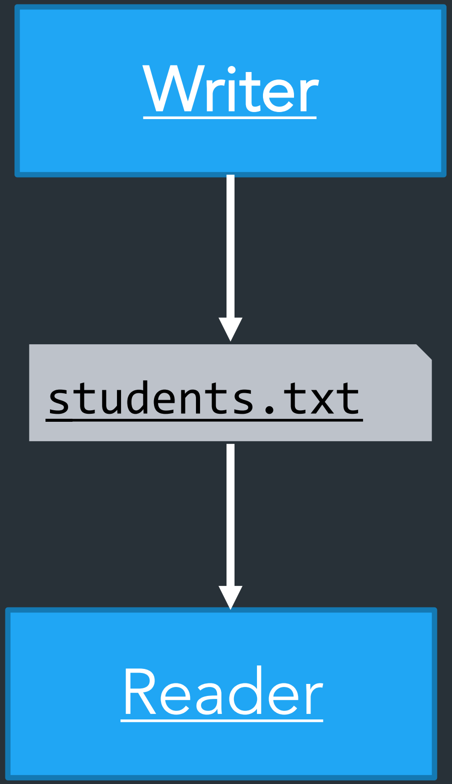
- Generates stubs in many languages
  - C/C++, C#, Node.js, PHP, Ruby, Python, Go, Java
  - These are interoperable
- Transport is http/2

Protocol Buffers

- Defined by Google, released to the public
  - Widely used internally and externally
  - Supports common types, service definitions
  - Natively generates C++/Java/Python/Go code
    - Over 20 other supported by third parties
  - Efficient binary encoding, readable text encoding
- Performance
  - 3 to 10 times smaller than XML
  - 20 to 100 times faster to process

Protocol Buffers Example (for a file)

```
message Student {
  required String name = 1;
  required int32 credits = 2;
}
```




```
Student s;
s.set_name(“Jane”);
s.set_credits(20);
fstream output(“students.txt” , ios:out | ios:binary );
s.SerializeToOstream(&output);
```

```
Student s;
fstream input(“students.txt” , ios:in | ios:binary
  );
s.ParseFromIstream();
```

protobuf: Binary Encoding

- Variable-length integers
  - 7 bits out of 8 to encode integers
  - Msb: more bits to come
  - Multi-byte integers: least significant group first
- Signed integers: zig-zag encoding, then varint
  - 0:0, -1:1, 1:2, -2:3, 2:4, …
  - Advantage: smaller when encoded with varint
- General:
  - Field number, field type (tag), value
- Strings:
  - Varint length, unicode representation

Apache Thrift

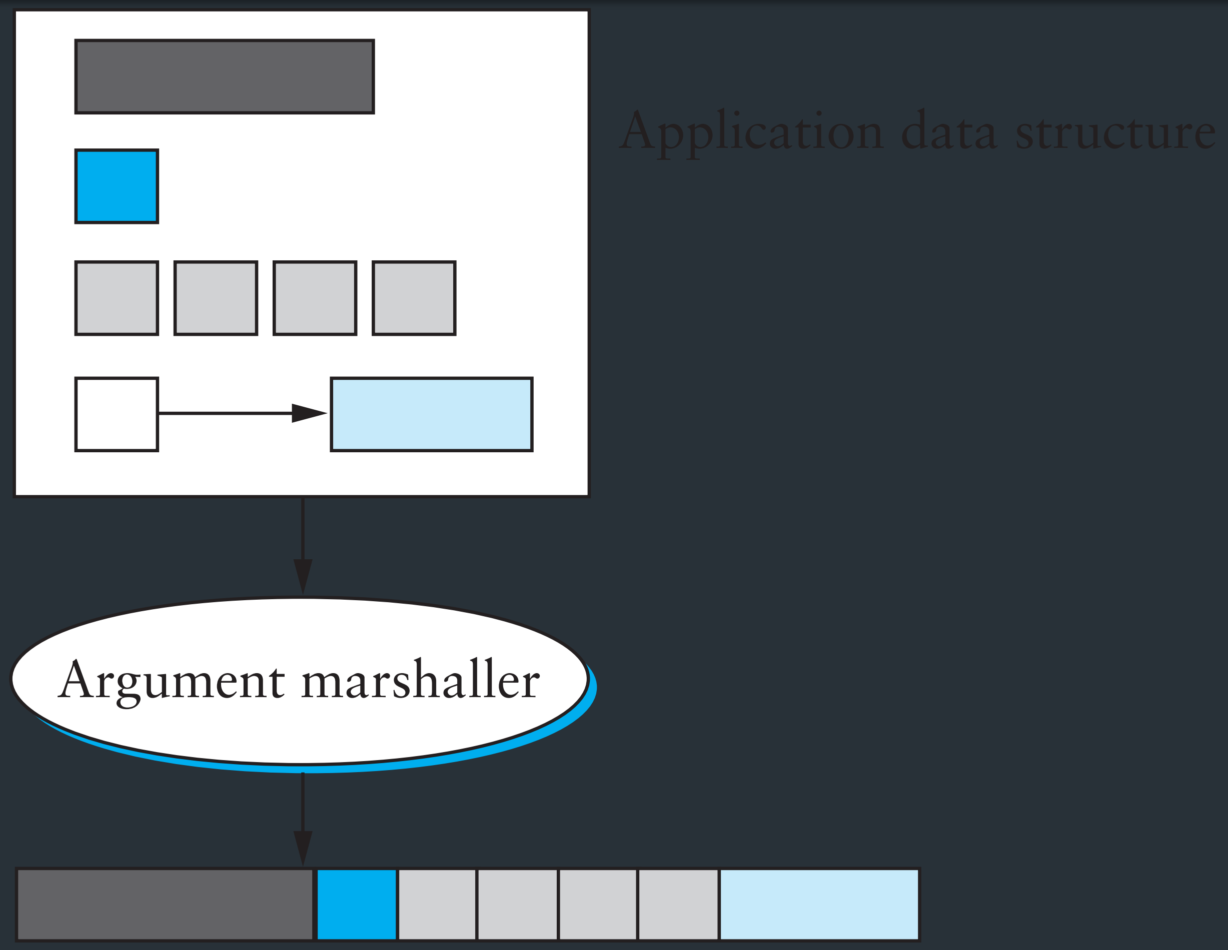
- Originally developed by Facebook
- Used heavily internally
- Supports (at least): C++, Java, Python, PHP, Ruby, Erlang, Perl, Haskell, C#, Cocoa, Smalltalk, and Ocaml
- Types: basic types, list, set, map, exceptions
- Versioning support
- Many encodings (protocols) supported
  - Efficient binary, json encodings

Conclusions

- Unless you *really* want to optimize your protocol for performance, use an IDL
- Parsing code is easy to get (slightly) wrong, hard to make fast—only want to do this once!
- Which one should you use?

Which data types?

- Basic types
  - Integers, floating point, characters
  - Some issues: endianness (ntohs, htons), character encoding, IEEE 754
- Flat types
  - Strings, structures, arrays
  - Some issues: packing of structures, order, variable length
- Complex types
  - Pointers! Must flatten, or serialize data structures


Application data structure
Argument marshaller

Problem

- Two programs want to communicate: must define the protocol
  - We have seen many of these, across all layers
  - E.g., Snowcast packet formats, protocol headers
- Key Problems
  - Semantics of the communication
    - APIs, how to cope with failure
  - Data Representation
  - Scope: should the scheme work across
    - Architectures
    - Languages
    - Compilers…?

Data Schema

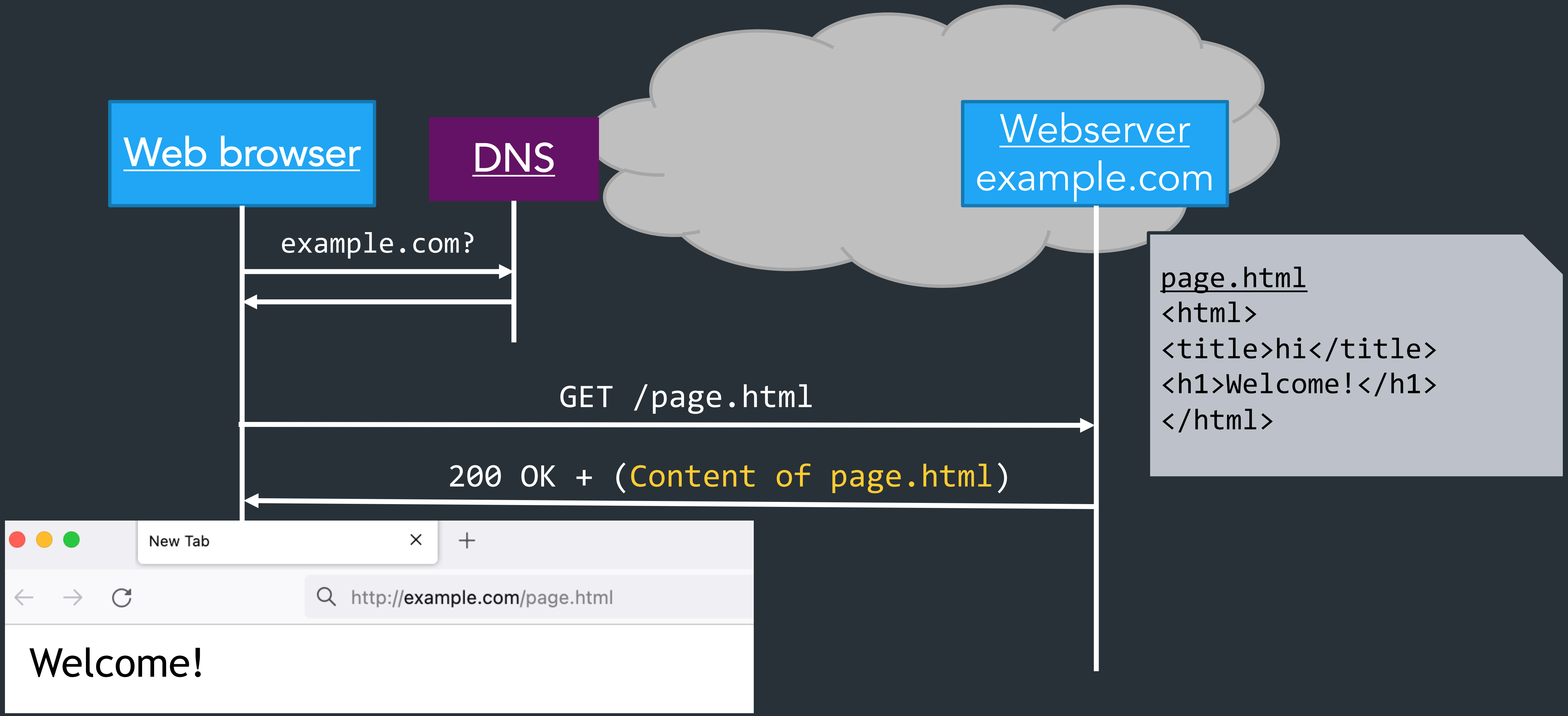
- How to parse the encoded data?
- Two Extremes:
  - Self-describing data: tags
    - Additional information added to message to help in decoding
    - Examples: field name, type, length
  - Implicit: the code at both ends "knows" how to decode the message
    - E.g., your Snowcast implementation
    - Interoperability depends on well defined protocol specification!
    - very difficult to change

Presentation Formatting

- How to represent data?
- Several questions:
  - Which data types do you want to support?
    - Base types, Flat types, Complex types
  - How to encode data into the wire
  - How to decode the data?
    - Self-describing (tags, type-length-value)
    - Implicit description (the ends *know*)
- Several answers:
  - Many frameworks do these things automatically

Stub Generation

- 2 Main ideas:
- Introspection-based
  - E.g., Java RMI
- Independent specification: IDL
  - IDL – Interface Description Language
    - describes an interface in a **language neutral** way
  - Separates logical description of data from
    - Dispatching code
    - Marshalling/unmarshalling code
    - Data wire format



Server returns response (in this case, with HTML)