CSCI-1680
RPC and Data Representation

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Today

- **Defining Protocols**
  - RPC
  - IDL

Problem

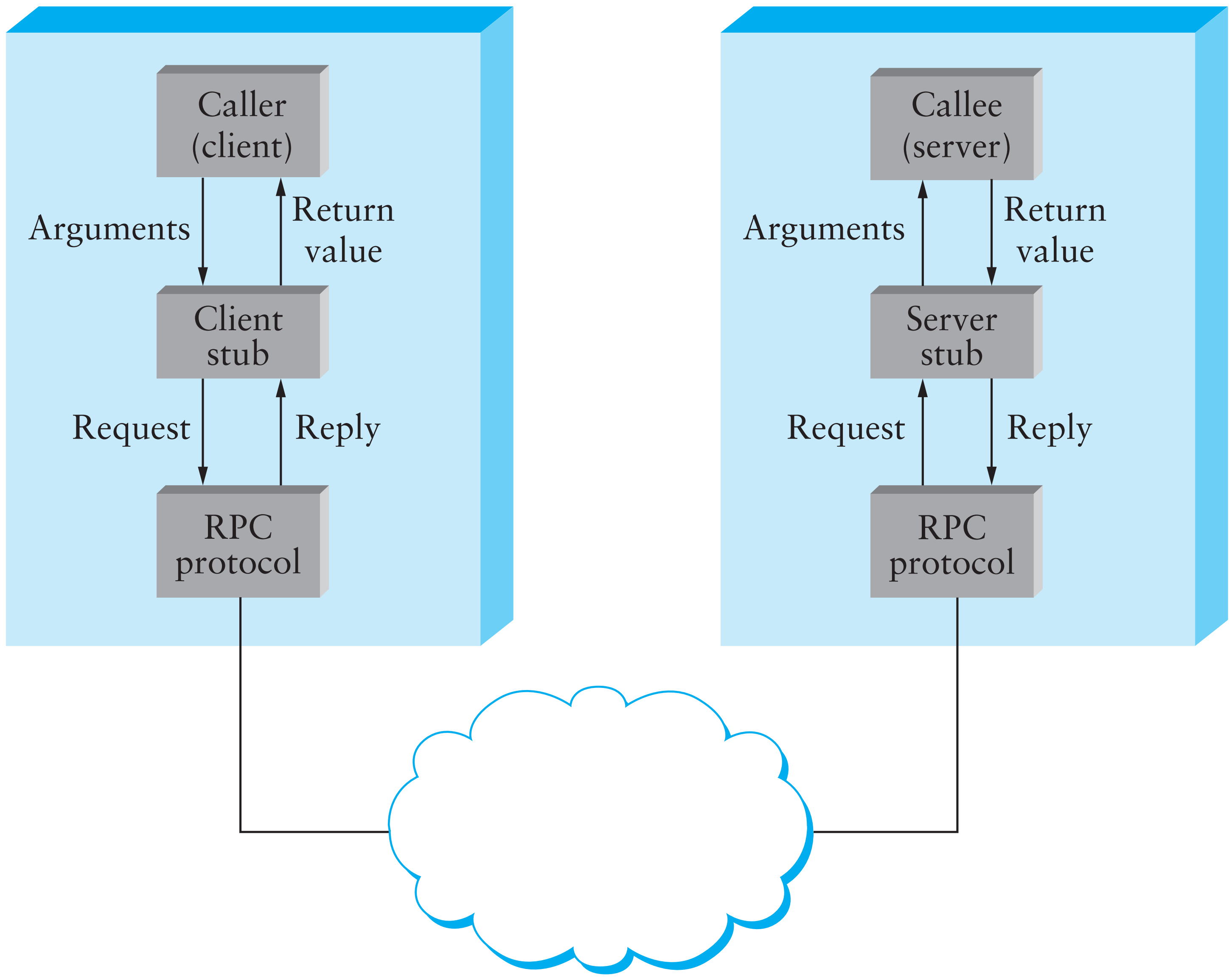
- **Two programs want to communicate: must define the protocol**
  - We have seen many of these, across all layers
  - E.g., Snowcast packet formats, protocol headers
- **Key Problems**
  - Semantics of the communication
    - APIs, how to cope with failure
  - Data Representation
  - Scope: should the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

RPC – Remote Procedure Call

- **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

Can we maintain the same semantics?

- **Mostly…**
- **Why not?**
  - New failure modes: nodes, network
- **Possible outcomes of failure**
  - Procedure did not execute
  - Procedure executed once
  - Procedure executed multiple times
  - Procedure partially executed
- **Desired: at-most-once semantics**

Implementing at-most-once semantics

- **Problem: request message lost**
  - Client must retransmit requests when it gets no reply
- **Problem: reply message lost**
  - Client may retransmit previously executed request
  - OK if operation is *idempotent*
  - Server must keep "replay cache" to reply to already executed requests
- **Problem: server takes too long executing**
  - Client will retransmit request already in progress
  - Server must recognize duplicate – could reply "in progress"

Server Crashes

- **Problem: server crashes and reply lost**
  - Can make replay cache persistent – slow
  - Can hope reboot takes long enough for all clients to fail
- **Problem: server crashes during execution**
  - Can log enough to restart partial execution – slow and hard
  - Can hope reboot takes long enough for all clients to fail
- **Can use "cookies" to inform clients of crashes**
  - Server gives client cookie, which is f(time of boot)
  - Client includes cookie with RPC
  - After server crash, server will reject invalid cookie

RPC Components

- **Stub Compiler**
  - Creates stub methods
  - Creates functions for marshalling and unmarshalling
- **Dispatcher**
  - Demultiplexes programs running on a machine
  - Calls the stub server function
- **Protocol**
  - At-most-once semantics (or not)
  - Reliability, replay caching, version matching
  - Fragmentation, Framing (depending on underlying protocols)

Examples of RPC Systems

- **SunRPC (now ONC RPC)**
  - The first popular system
  - Used by NFS
  - Not popular for the wide area (security, convenience)
- **Java RMI**
  - Popular with Java
  - Only works among JVMs
- **DCE**
  - Used in ActiveX and DCOM, CORBA
  - Stronger semantics than SunRPC, much more complex

…even more examples

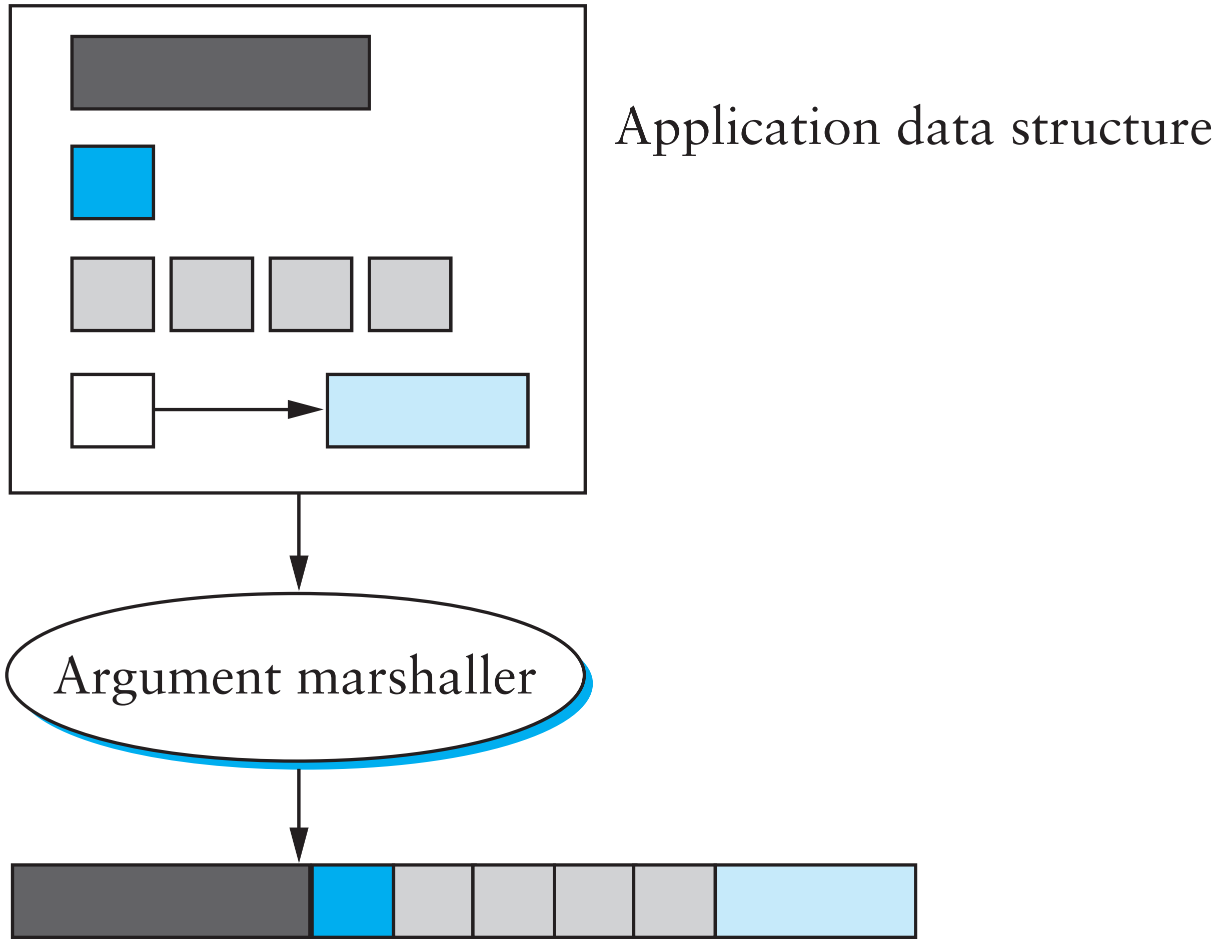
- Apache Thrift
- Google gRPC
- XML-RPC, SOAP
- Json-RPC

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

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

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

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

Example: gRPC

- **IDL-based, defined by Google**
  - Protocol Buffers as IDL
- **User specifies services, calls**
  - Unary and streaming calls
  - Synchronous and Asynchronous
  - Timeouts
  - Cancellations

```
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 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

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

(…compile with proto)

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

(…somebody else reading the file)

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

Binary Encoding

- **Integers: varints**
  - 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**
- **Full RPC system**
  - Support for C++, Java, Python, PHP, Ruby, Erlang, Perl, Haskell, C#, Cocoa, Smalltalk, and Ocaml
- **Many types**
  - Base types, list, set, map, exceptions
- **Versioning support**
- **Many encodings (protocols) supported**
  - Efficient binary, json encodings

Apache Avro

- **Yet another newcomer**
- **Likely to be used for Hadoop data representation**
- **Encoding:**
  - Compact binary with schema included in file
  - Amortized self-descriptive
- **Why not just create a new encoding for Thrift?**
  - I don't know…

Conclusions

- **RPC is good way to structure many distributed programs**
  - Have to pay attention to different semantics, though!
- **Data: tradeoff between self-description, portability, and efficiency**
- **Unless you really want to bit pack your protocol, and it won't change much, use one of the IDLs**
- **Parsing code is easy to get (slightly) wrong, hard to get fast**
  - Should only do this once, for all protocols
- **Which one should you use?**