Distributed Systems

03. Remote Procedure Calls

Paul Krzyzanowski
Rutgers University
Spring 2020

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Socket-based communication

- Socket API: all we get from the OS to access the network
- Socket = distinct end-to-end communication channels
- Read/write model
- Line-oriented, text-based protocols common
  - Not efficient but easy to debug & use

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Sample SMTP Interaction

SMTP = Simple Mail Transfer Protocol

```
$ telnet porthos.rutgers.edu 25
Trying 128.6.25.90...
Connected to porthos.rutgers.edu.
Escape character is '^]'.
220 porthos.cs.rutgers.edu ESMTP Postfix
HELO cs.rutgers.edu
250 porthos.cs.rutgers.edu
MAIL FROM: <pxk@cs.rutgers.edu>
250 2.1.0 Ok
RCPT TO: <p@pk.org>
250 2.1.5 Ok
DATA
354 End data with <CR><LF>.<CR><LF>
From: Paul Krzyzanowski <pxk@cs.rutgers.edu>
Subject: test message
Date: Mon, 17 Feb 2020 17:00:16 -0500
To: Whomever <testuser@pk.org>

Hi,
This is a test
.
250 2.0.0 Ok: queued as AC37C3000175
quit
221 2.0.0 Bye
Connection closed by foreign host.
```

This is the message body. Headers may define the structure of the message but are ignored for delivery.

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Sample HTTP Interaction

HTTP = Hypertext Transfer Protocol

```
$ telnet www.google.com 80
Trying 172.217.12.164...
Connected to www.google.com.
Escape character is '^]'.
GET /index.html HTTP/1.1
HOST: www.google.com
Accept: image/gif, image/jpeg, */*
Accept-Language: en-us
User-Agent: Mozilla/4.0

HTTP/1.1 200 OK
Date: Mon, 03 Feb 2020 18:31:59 GMT
Expires: -1
Cache-Control: private, max-age=0
Content-Type: text/html; charset=ISO-8859-1
...
Transfer-Encoding: chunked

73c5
<!doctype html><html itemscope=""
itemtype="http://schema.org/WebPage" lang="en"><head>
...
...
```

First part of the response – HTTP headers

Second part of the response – HTTP content

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Problems with the sockets API

The sockets interface forces a read/write mechanism

Programming is often easier with a functional interface

To make distributed computing look more like centralized computing, I/O (read/write) is not the way to go

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RPC

1984: Birrell & Nelson
- Mechanism to call procedures on other machines

Remote Procedure Call

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Implementing RPC

No architectural support for remote procedure calls

Simulate it with tools we have (local procedure calls)

The compiler creates code to send messages to invoke remote functions

Simulation makes RPC a language-level construct

instead of an operating system construct

The OS gives us sockets

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Implementing RPC

The trick:

Create stub functions
to make it appear to the user that the call is local

On the client
The stub function (proxy) has the function's interface
Packages parameters and calls the server

On the server
The stub function (skeleton) receives the request and calls the local function

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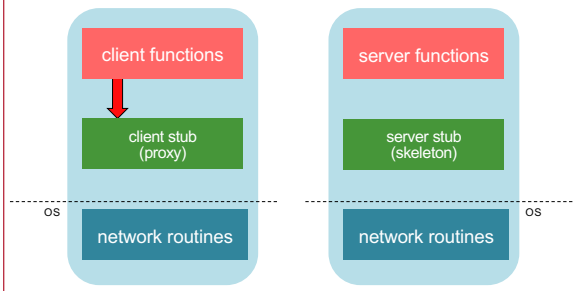
Stub functions

1. Client calls stub (params on stack)



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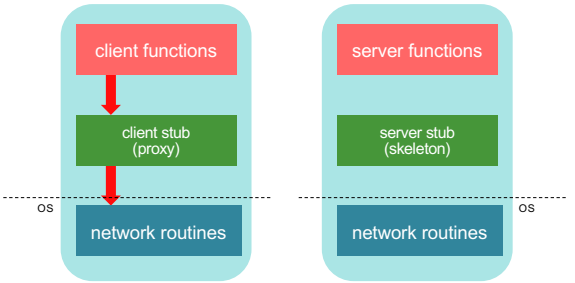
Stub functions

2. Stub marshals params to network message



Marshalling = put parameters in a form suitable for transmission over a network (serialized)

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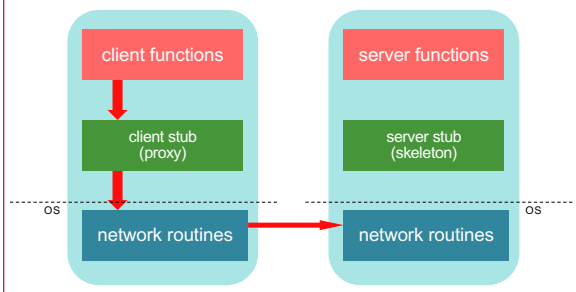
Stub functions

3. Network message sent to server



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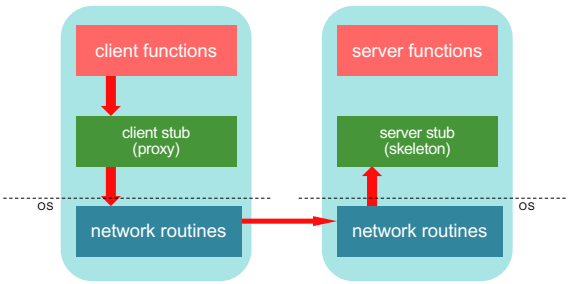
Stub functions

4. Receive message: send it to server stub



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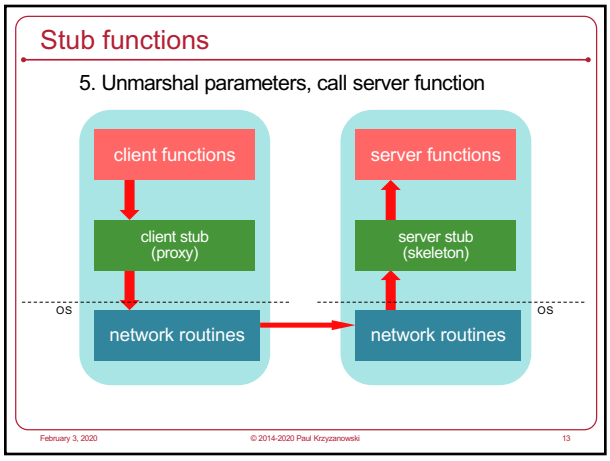

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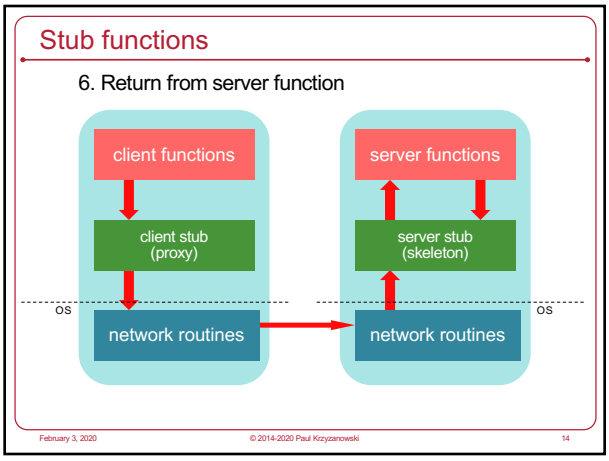

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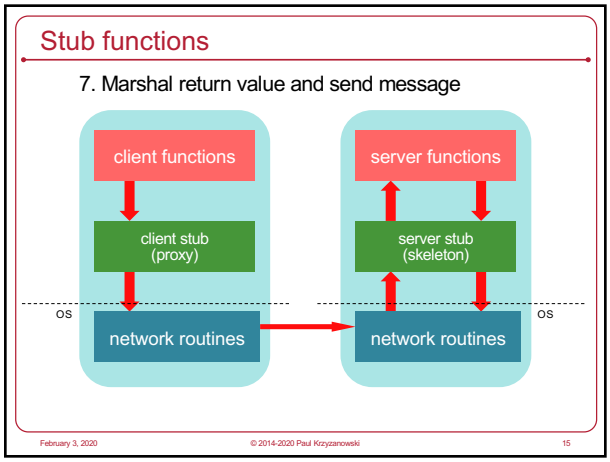

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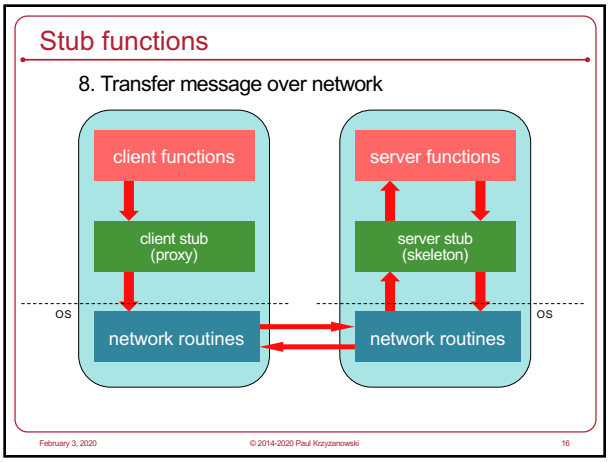

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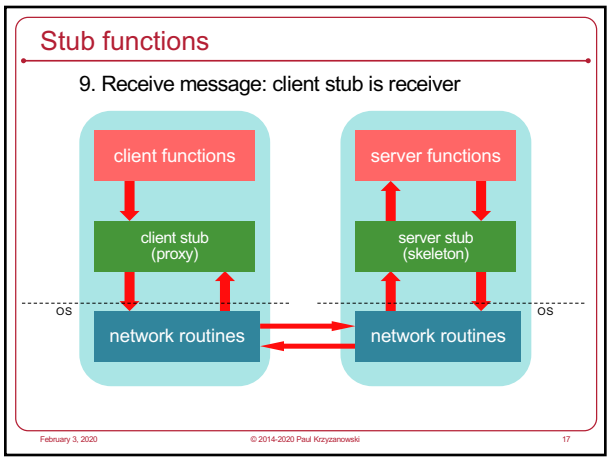

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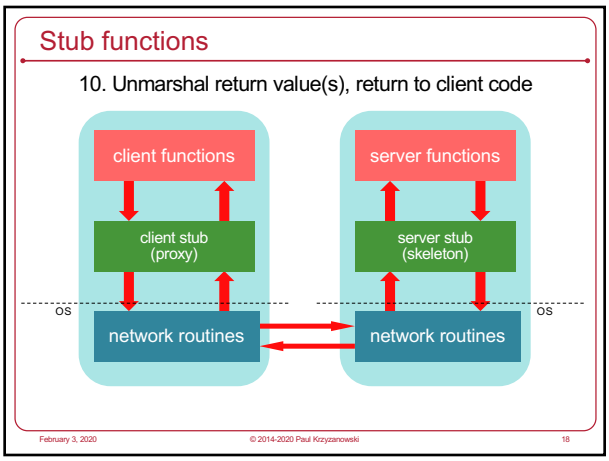

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A client proxy looks like the remote function

- Client stub has the same interface as the remote function
- Looks & feels like the remote function to the programmer
  - But its function is to
    - Marshal parameters
    - Send the message
    - Wait for a response from the server
    - Unmarshal the response & return the appropriate data
    - Generate exceptions if problems arise

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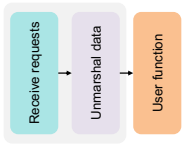
A server stub contains two parts

1. Dispatcher – *the listener*
   - Receives client requests
   - Identifies appropriate function (method)
2. Skeleton – *the unmarshaller & caller*
   - Unmarshals parameters
   - Calls the local server procedure
   - Marshals the response & sends it back to the dispatcher



All this is invisible to the programmer

- The programmer doesn't deal with any of this
- Dispatcher + Skeleton may be integrated
  - Depends on implementation

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RPC Benefits

- RPC gives us a procedure call interface
- Writing applications is simplified
  - RPC hides all network code into stub functions
  - Application programmers don't have to worry about details
    - Sockets, port numbers, byte ordering
- Where is RPC in the OSI model?
  - Layer 5: Session layer: Connection management
  - Layer 6: Presentation: Marshaling/data representation
  - Uses the transport layer (4) for communication (TCP/UDP)

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RPC has challenges

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RPC Issues

- Parameter passing
  - *Pass by value* or *pass by reference*?
  - Pointerless representation
- Service binding. How do we locate the server endpoint?
  - Central DB
  - DB of services per host
- Transport protocol
  - TCP? UDP? Both?
- When things go wrong
  - Opportunities for failure

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When things go wrong

- Semantics of remote procedure calls
  - Local procedure call: *exactly once*
- Most RPC systems will offer either
  - ***at least once*** semantics
  - or ***at most once*** semantics
- Decide based on application
  - **idempotent** functions: may be run any number of times without harm
  - **non-idempotent** functions: those with side-effects
- Ideally – design your application to be idempotent
  - … and stateless
  - Not always easy!
  - Store transaction IDs, previous return data, etc.

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More issues

Performance

– RPC is slower … a lot slower (why?)

Security

– messages may be visible over network – do we need to hide them?
– Authenticate client?
– Authenticate server?

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Programming with RPC

Language support

– Many programming languages have no language-level concept of remote procedure calls
(C, C++, Java <J2SE 5.0, …)
  • These compilers will not automatically generate client and server stubs
– Some languages have support that enables RPC
(Java, Python, Haskell, Go, Erlang)
  • But we may need to deal with heterogeneous environments (e.g., Java communicating with a Python service)

Common solution

– Interface Definition Language (IDL): describes remote procedures
– Separate compiler that generate stubs (pre-compiler)

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Interface Definition Language (IDL)

• Allow programmer to specify remote procedure interfaces (names, parameters, return values)

• Pre-compiler can use this to generate client and server stubs
  – Marshaling code
  – Unmarshaling code
  – Network transport routines
  – Conform to defined interface

• An IDL looks similar to function prototypes

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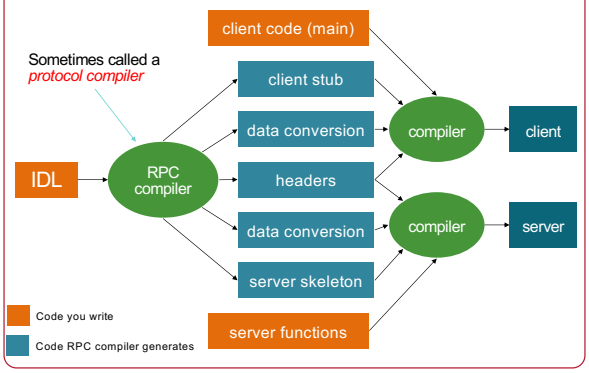
RPC compiler



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Writing the program

• Client code has to be modified
  – Initialize RPC-related options
    • Identify transport type
    • Locate server/service
  – Handle failure of remote procedure calls

• Server functions
  – Generally need little or no modification

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Sending data over the network

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Stream of bytes

```
struct item {
    char name[64];
    unsigned long id;
    int number_in_stock;
    float rating;
    double price;
} scratcher = {
    "Bear Claw Black Telescopic Back Scratcher",
    00120,
    332,
    4.6,
    5.99
}
```

Is stored in memory as:

```
42 65 61 72 20 43 6c 61 77 20 42 6c 61 63 6b 20 54 ...
```


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Representing data

No such thing as
incompatibility problems on local system

Remote machine may have:

- Different byte ordering
- Different sizes of integers and other types
- Different floating point representations
- Different character sets
- Alignment requirements

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Representing data

IP (headers) forced all to use **big endian** byte ordering for 16- and 32-bit values

Big endian: Most significant byte in low memory
- SPARC < V9, Motorola 680x0, older PowerPC

IP headers use big endian

Little endian: Most significant byte in high memory
- Intel/AMD IA-32, x64

Bi-endian: Processor may operate in either mode
- ARM, PowerPC, MIPS, SPARC V9, IA-64 (Intel Itanium)

```
main() {
    unsigned int n;
    char *a = (char *)&n;

    n = 0x11223344;
    printf("%02x, %02x, %02x, %02x\n",
           a[0], a[1], a[2], a[3]);
}
```

Output on an Intel CPU:
`44, 33, 22, 11`

Output on a PowerPC:
`11, 22, 33, 44`

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Representing data: serialization

Need standard encoding to enable communication between heterogeneous systems

- Serialization
  - Convert data into a pointerless format: *an array of bytes*

- Examples
  - XDR (eXternal Data Representation), used by ONC RPC
  - JSON (JavaScript Object Notation)
  - W3C XML Schema Language
  - ASN.1 (ISO Abstract Syntax Notation)
  - Google Protocol Buffers

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Serializing data

Implicit typing

- only values are transmitted, not data types or parameter info
- e.g., ONC XDR (RFC 4506)

Explicit typing

- Type is transmitted with each value
- e.g., ISO's ASN.1, XML, protocol buffers, JSON

Marshaling vs. serialization – almost synonymous:

Serialization: converting an object into a sequence of bytes that can be sent over a network

Marshaling: bundling parameters into a form that can be reconstructed (unmarshaled) by another process. May include object ID or other state. Marshaling uses serialization.

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XML: eXtensible Markup Language

```
<ShoppingCart>
    <Items>
        <Item>
            <ItemID> 00120 </ItemID>
            <Item> Bear Claw Black Telescopic Back Scratcher </Item>
            <Price> 5.99 </Price>
        </Item>
        <item>
            <ItemID> 00121 </ItemID>
            <Item> Scalp Massager </Item>
            <Price> 5.95 </Price>
        </Item>
    </Items>
</ShoppingCart>
```

Benefits:
- Human-readable
- Human-editable
- Interleaves structure with text (data)

Problems:
- Verbose: transmit more data than needed
- Longer parsing time
- Data conversion always required for numbers

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JSON: JavaScript Object Notation

- Lightweight (relatively efficient) data interchange format
  - Introduced as the "*fat-free alternative to XML*"
  - Based on JavaScript
- Human writeable and readable
- Self-describing (explicitly typed)
- Language independent
- Easy to parse
- Currently converters for 50+ languages
- Includes support for RPC invocation via JSON-RPC

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JSON Example

```
{"menu": {
  "id": "file",
  "value": "File",
  "popup": {
    "menuitem": [
      {"value": "New", "onclick": "CreateNewDoc()"},
      {"value": "Open", "onclick": "OpenDoc()"},
      {"value": "Close", "onclick": "CloseDoc()"}
    ]
  }
}}
```

from json.org/example.html

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Google Protocol Buffers

- Efficient mechanism for serializing structured data
  - Much simpler, smaller, and faster than XML
- Language independent
- Define messages
  - Each message is a set of names and types
- Compile the messages to generate data access classes for your language
- Used extensively within Google. Currently over 48,000 different message types defined.
  - Used both for RPC and for persistent storage

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Example (from the Developer Guide)

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

  enum PhoneType {
    MOBILE = 0;
    HOME = 1;
    WORK = 2;
  }

  message PhoneNumber {
    required string number = 1;
    optional PhoneType type = 2 [default = HOME];
  }

  repeated PhoneNumber phone = 4;
}
```


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Example (from the Developer Guide)

```
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);
```


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Efficiency example (from the Developer Guide)

```
<person>
    <name>John Doe</name>
    <email>jdoe@example.com</email>
</person>
```

XML version

```
person {
    name: "John Doe"
    email: "jdoe@example.com"
}
```

Text (uncompiled) protocol buffer

- Binary encoded message: ~28 bytes long, 100-200 ns to parse
- XML version: ≥69 bytes, 5,000-10,000 ns to parse
- In general,
  - 3-10x smaller data
  - 20-100 times faster to marshal/unmarshal
  - Easier to use programmatically

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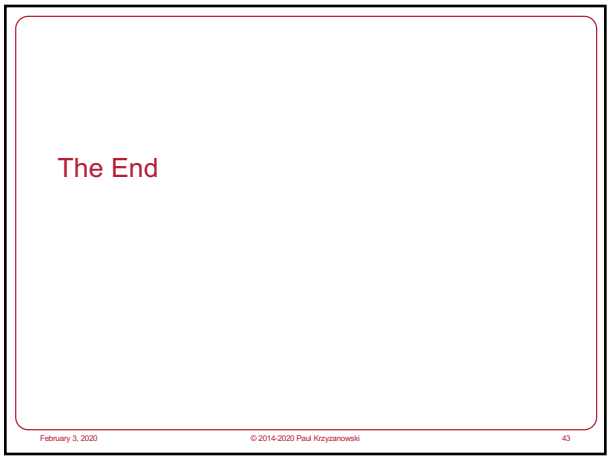

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