# Operating Systems

## 18. Remote Procedure Calls

Paul Krzyzanowski

Rutgers University

Spring 2015

# Remote Procedure Calls

# 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

# RPC

1984: Birrell & Nelson

– Mechanism to call procedures on other machines

Remote Procedure Call

RPC is a set of tools and libraries to give the programmer the *illusion* of calling procedures on a remote system.

# Regular procedure calls

The code for generating a normal procedure call is generated by the compiler

You write:

x = f(a, “test”, 5);

The compiler parses this and generates code to:

a. Push the value 5 on the stack
b. Push the address of the string “test” on the stack
c. Push the current value of a on the stack
d. Generate a call to the function f

In compiling *f*, the compiler generates code to:

a. Push registers that will be clobbered on the stack to save the values
b. Adjust the stack to make room for local and temporary variables
c. Before a return, unadjust the stack, put the return data in a register, and issue a return instruction

# Implementing RPC

No architectural support for remote procedure calls

*Simulate it* with tools we have
(local procedure calls)

Simulation makes RPC a
language-level construct

instead of an
operating system construct

The compiler creates code to send messages to invoke remote functions

The OS gives us sockets

# Implementing RPC

The trick:

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

**On the client**

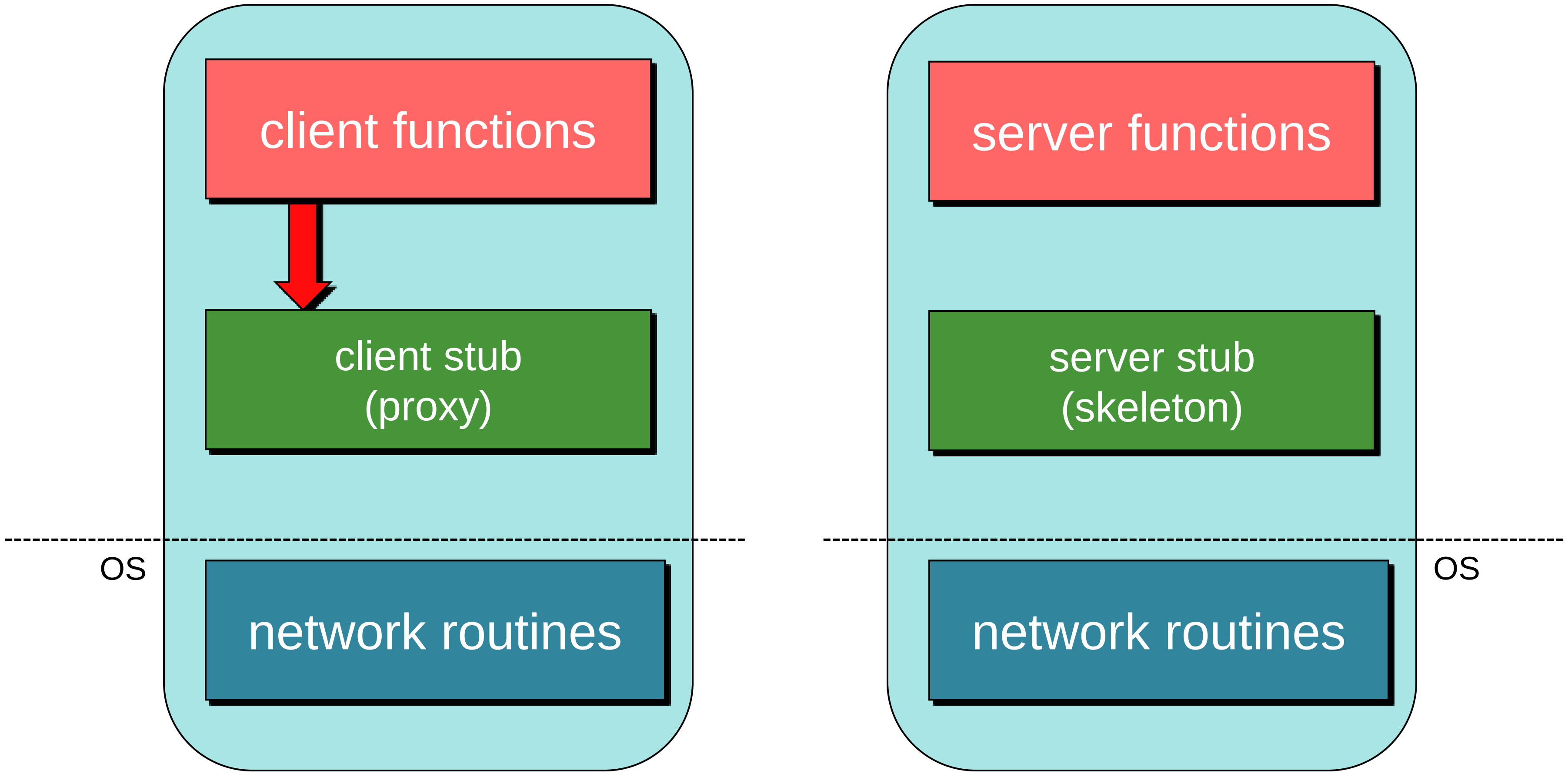
The stub function has the function's interface
Packages parameters and calls the server

**On the server**

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

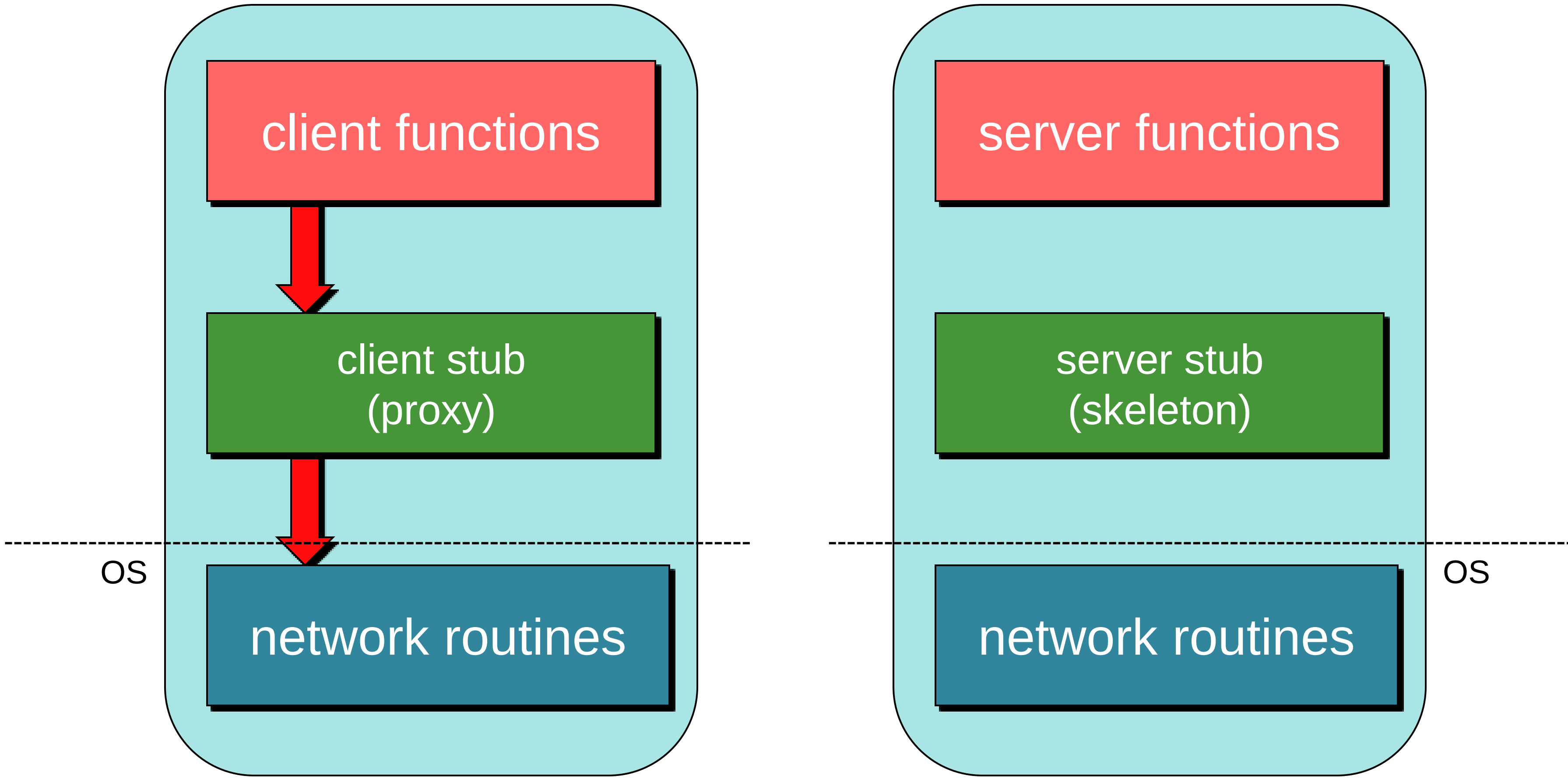
# Stub functions

1. Client calls stub (params on stack)



# Stub functions

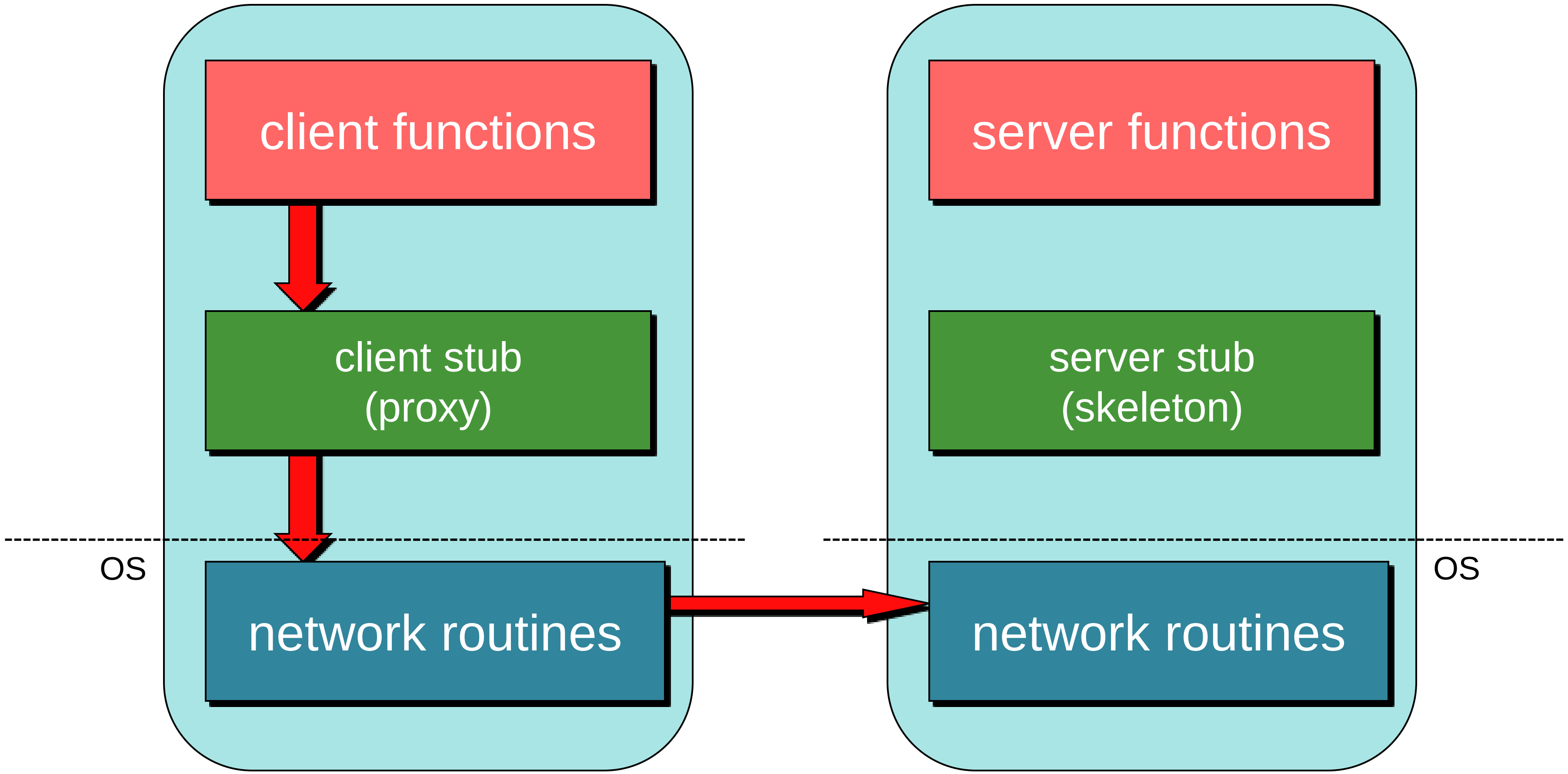
2. Stub marshals params to net message




*Marshaling = put data in a form suitable for transmission over a network (serialized)*

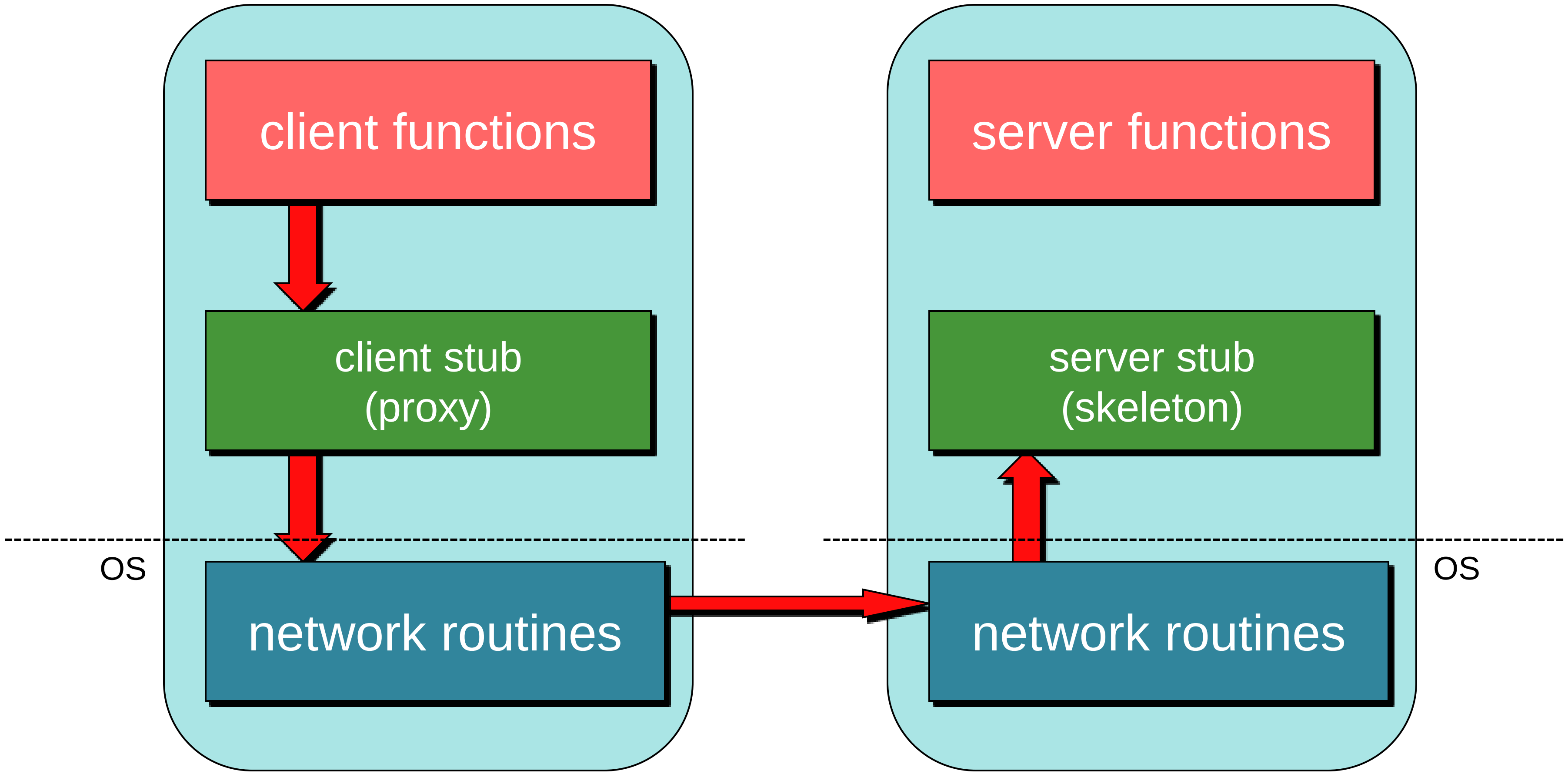
# Stub functions

3. Network message sent to server



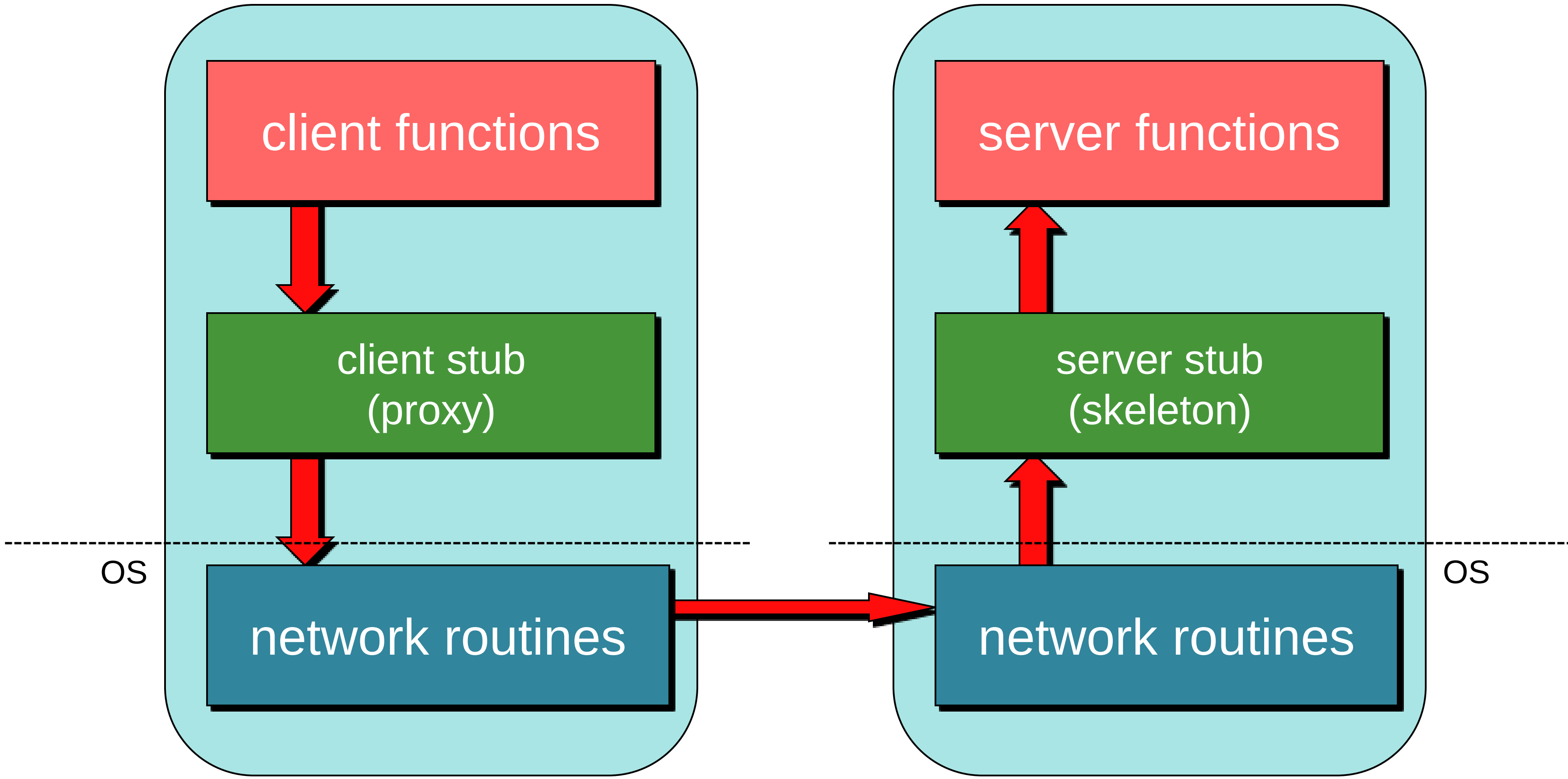
# Stub functions

4. Receive message: send it to server stub



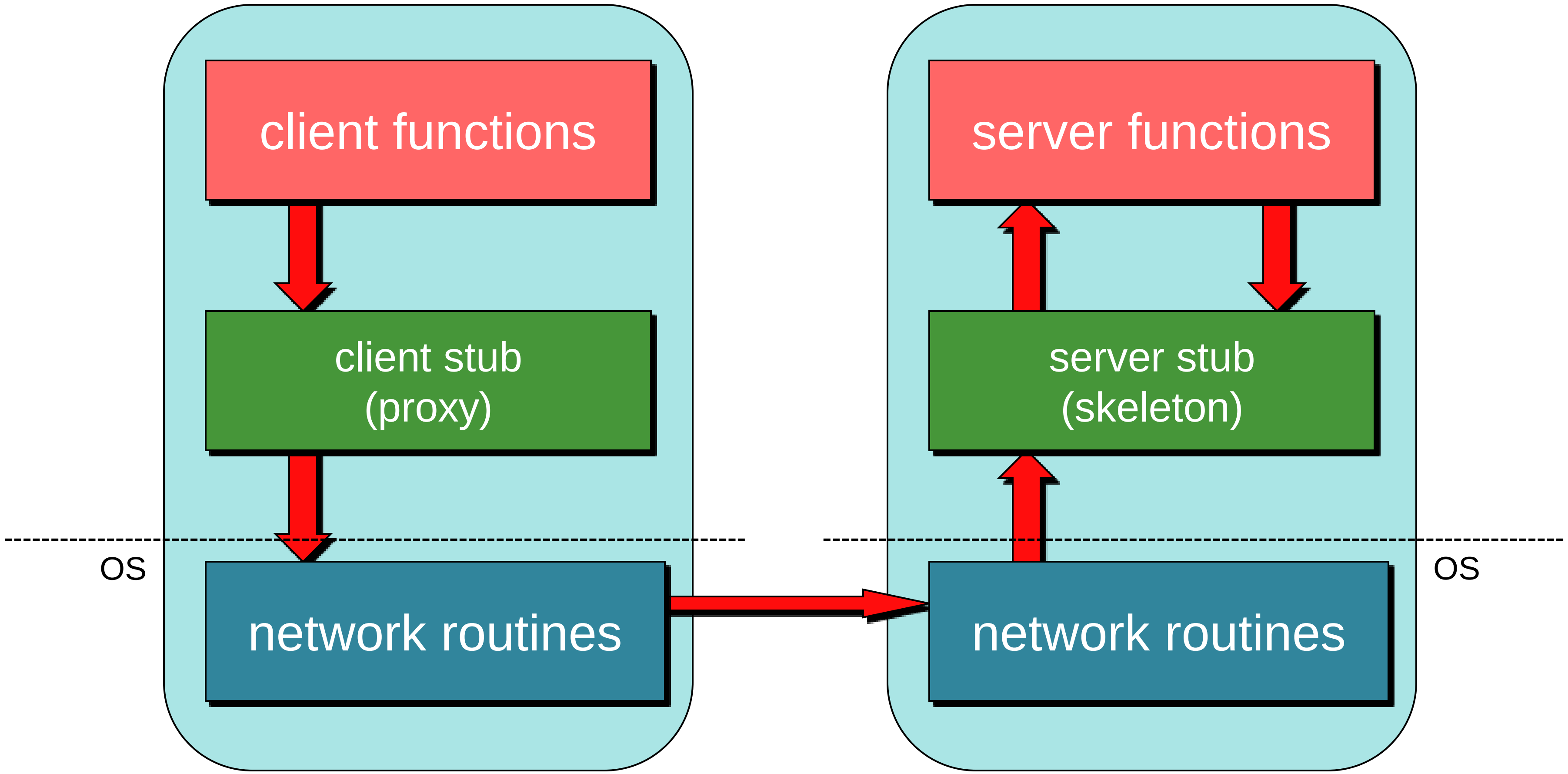
# Stub functions

5. Unmarshal parameters, call server function



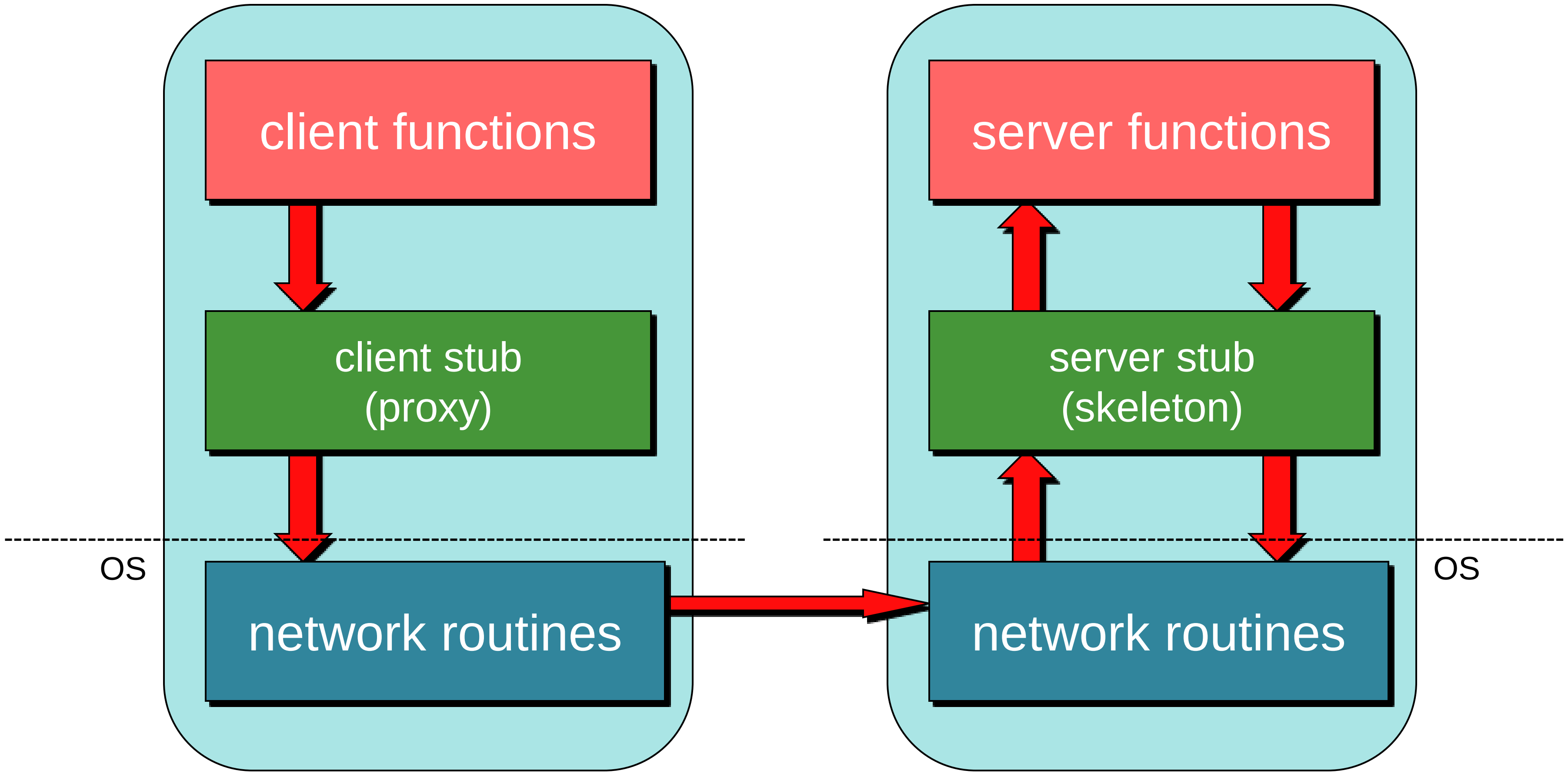
# Stub functions

6. Return from server function



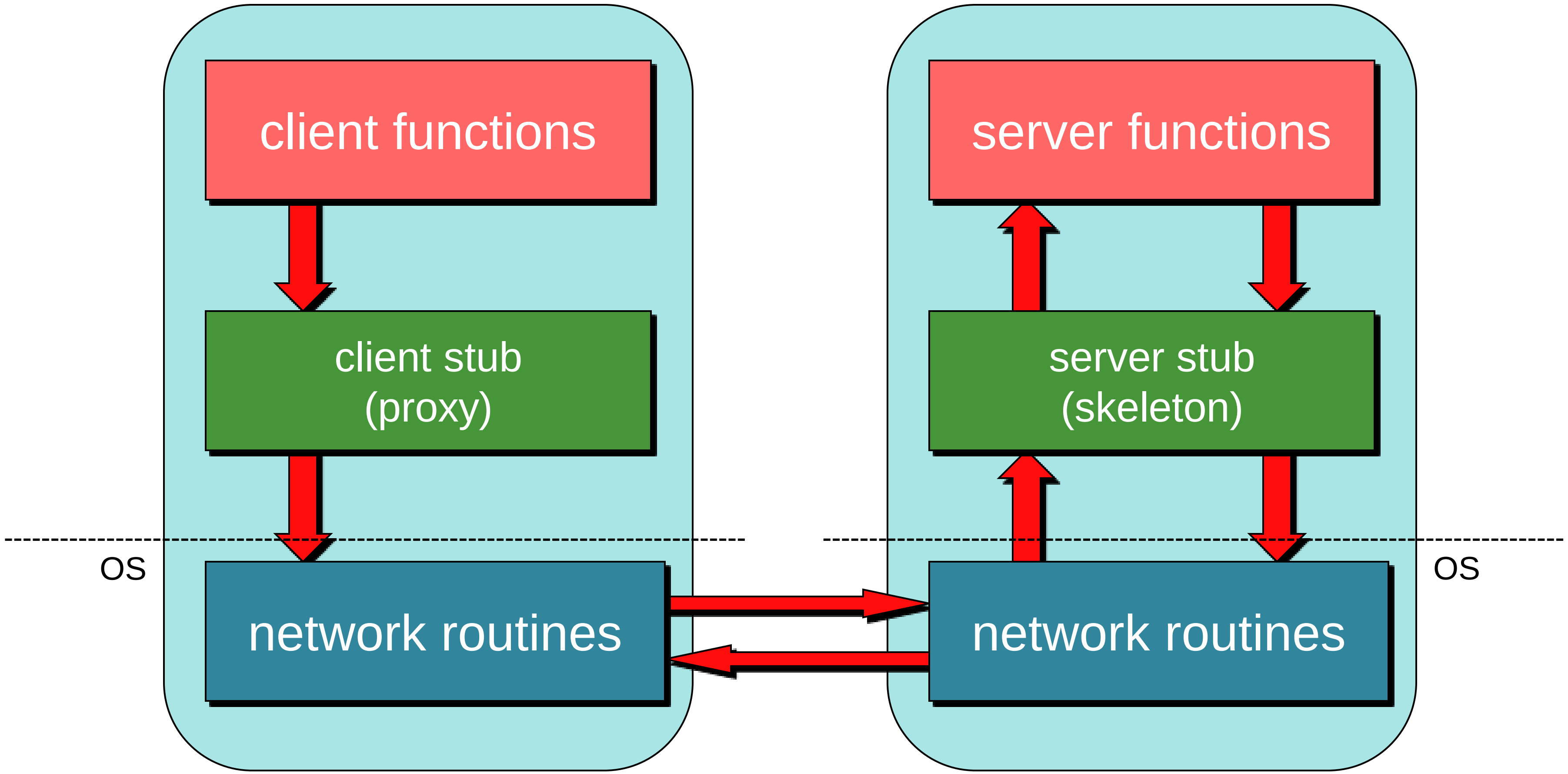
# Stub functions

7. Marshal return value and send message



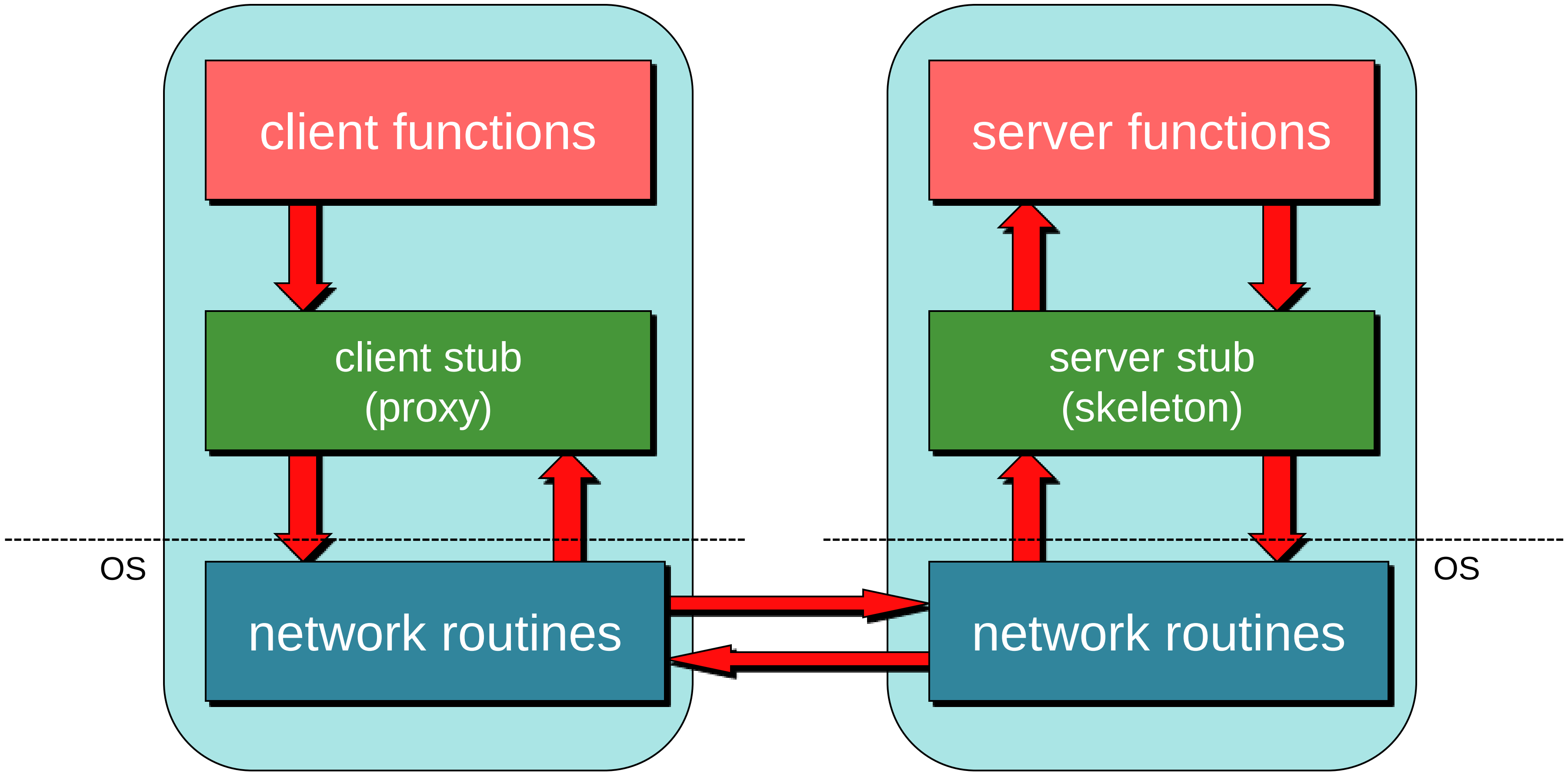
# Stub functions

8. Transfer message over network



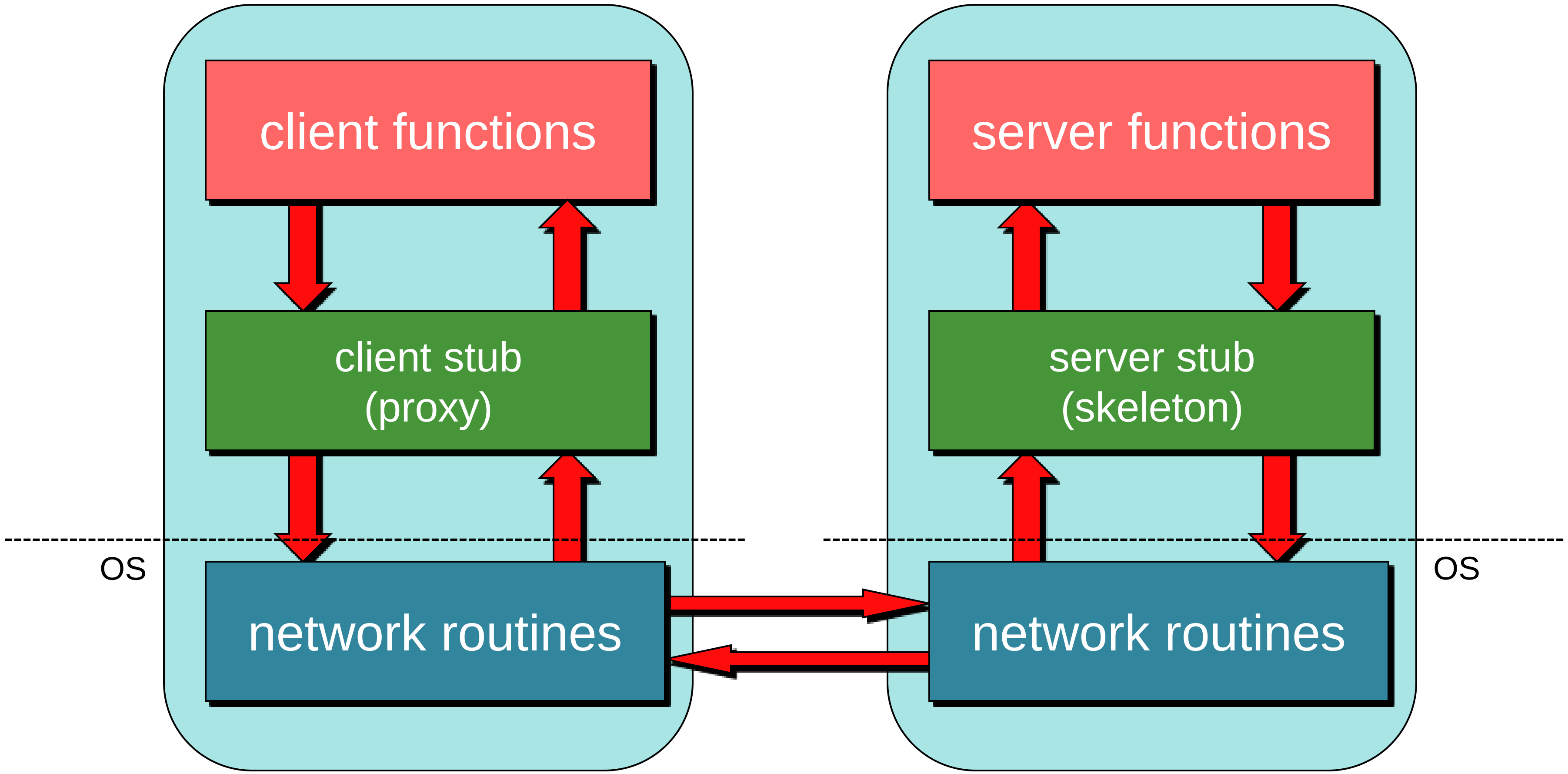
# Stub functions

9. Receive message: client stub is receiver



# Stub functions

10. Unmarshal return value, return to client code



# A 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

# A skeleton is really two parts

- Dispatcher
  - Receives client requests
  - Identifies appropriate function (method)
- Skeleton
  - Unmarshals parameters
  - Calls the <u>local</u> server procedure
  - Marshals the response & sends it back to the dispatcher
- Invisible to the programmer
  - The programmer doesn’t deal with any of this
  - Dispatcher + Skeleton may be integrated
    - Depends on implementation

# 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 or UDP)

# RPC has challenges

# Parameter passing

Pass by value

- Easy: just copy data to network message

Pass by reference

- Makes no sense without shared memory

# Pass by reference?

1. Copy items referenced to message buffer
2. Ship them over
3. Unmarshal data at server
4. Pass *local* pointer to server stub function
5. Send new values back

To support complex structures

- Copy structure into ***pointerless*** representation
- Transmit
- Reconstruct structure with local pointers on server

# 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

# 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:
**44, 33, 22, 11**

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

# 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

# Representing 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

# Where to bind?

Need to locate host and correct server process

# Where to bind? – Solution 1

Maintain a centralized DB that can
locate a host that provides a particular service

*(Birrell & Nelson's 1984 proposal)*

Challenges:

- Who administers this?
- What is the scope of administration?
- What if the same services run on different machines (e.g., file systems)?

# Where to bind? – Solution 2

A server on each host maintains a DB of *locally* provided services

# Transport protocol

TCP or UDP? Which one should we use?

- Some implementations may offer only one (e.g. TCP)
- Most support several
  - Allow programmer (or end user) to choose at runtime

# When things go wrong

- Local procedure calls do not fail
  - If they core dump, entire process dies
- More opportunities for error with RPC
- Transparency breaks here
  - Applications should be prepared to deal with RPC failure

# When things go wrong

- <u>Semantics of remote procedure calls</u>
  - Local procedure call: *exactly once*

- A remote procedure call may be called:
  - 0 times:

    server crashed or server process died before executing server code

  - 1 time:

    everything worked well, as expected

  - 1 or more times: excess latency or lost reply from server and client retransmission

# RPC semantics

- Most RPC systems will offer either:
  - ***at least once*** semantics
  - or ***at most once*** semantics
- Understand application:
  - **idempotent** functions: may be run any number of times without harm
  - **non-idempotent** functions: those with side-effects
- Try to design your application to be idempotent
  - Not always easy!
  - Store transaction IDs, previous return data, etc.

# 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?

# 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 via XML)

## Common solution

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

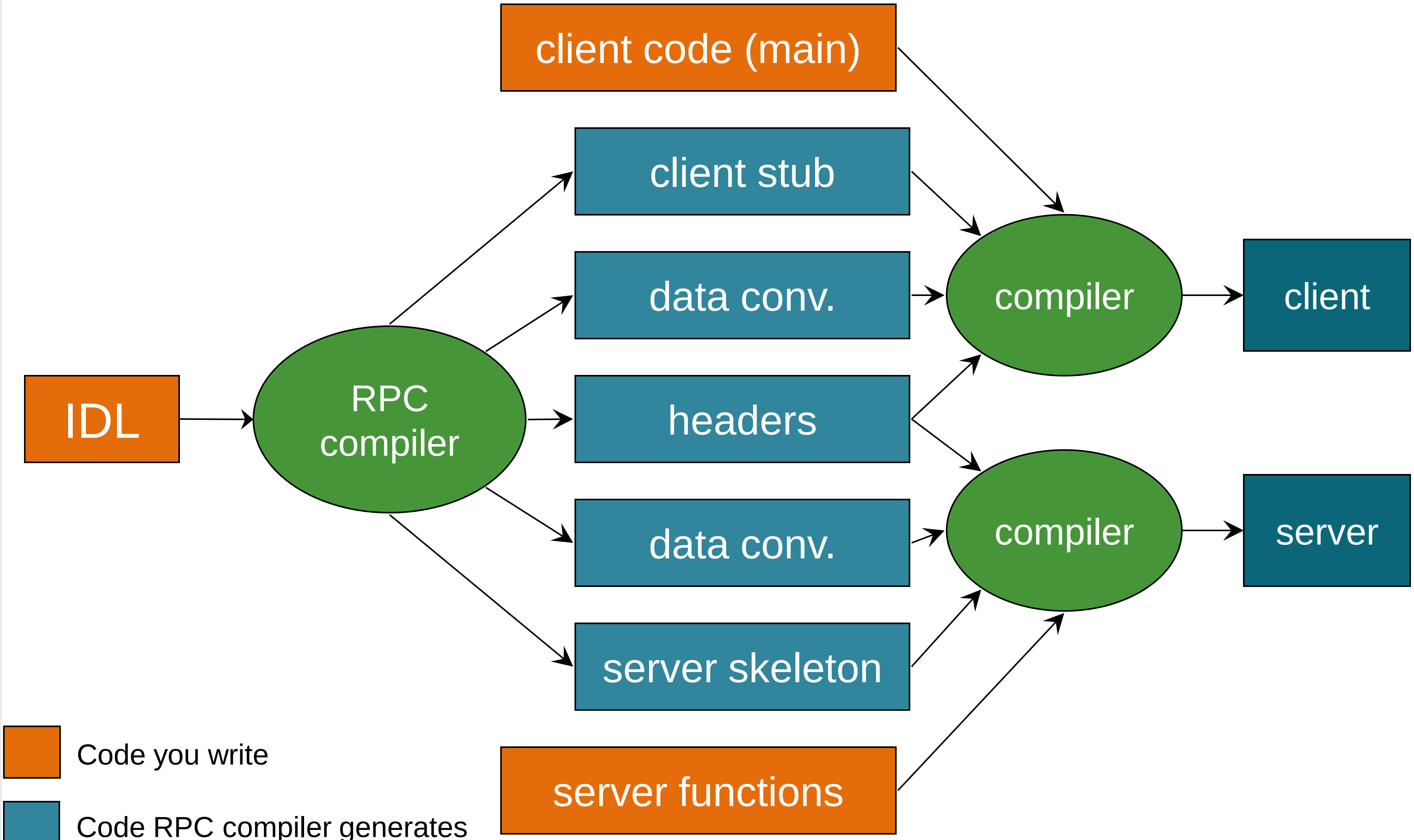
# Interface Definition Language (IDL)

- 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

# RPC compiler



# 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

# The End