Distributed Systems

Remote Procedure Calls

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Problems with sockets

Sockets interface is straightforward

- [connect]
- read/write
- [disconnect]

BUT … it forces read/write mechanism

- We usually use a procedure call

To make distributed computing look more like centralized:

- I/O is not the way to go

RPC

1984: Birrell & Nelson

- Mechanism to call procedures on other machines

Remote Procedure Call

Goal: it should appear to the programmer that a normal call is taking place

How do regular procedure calls work in programming languages?

Regular procedure calls

Machine instructions for call & return but the compiler really makes the procedure call abstraction work:

- Parameter passing
- Local variables
- Return data

Regular procedure calls

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

Implementing RPC

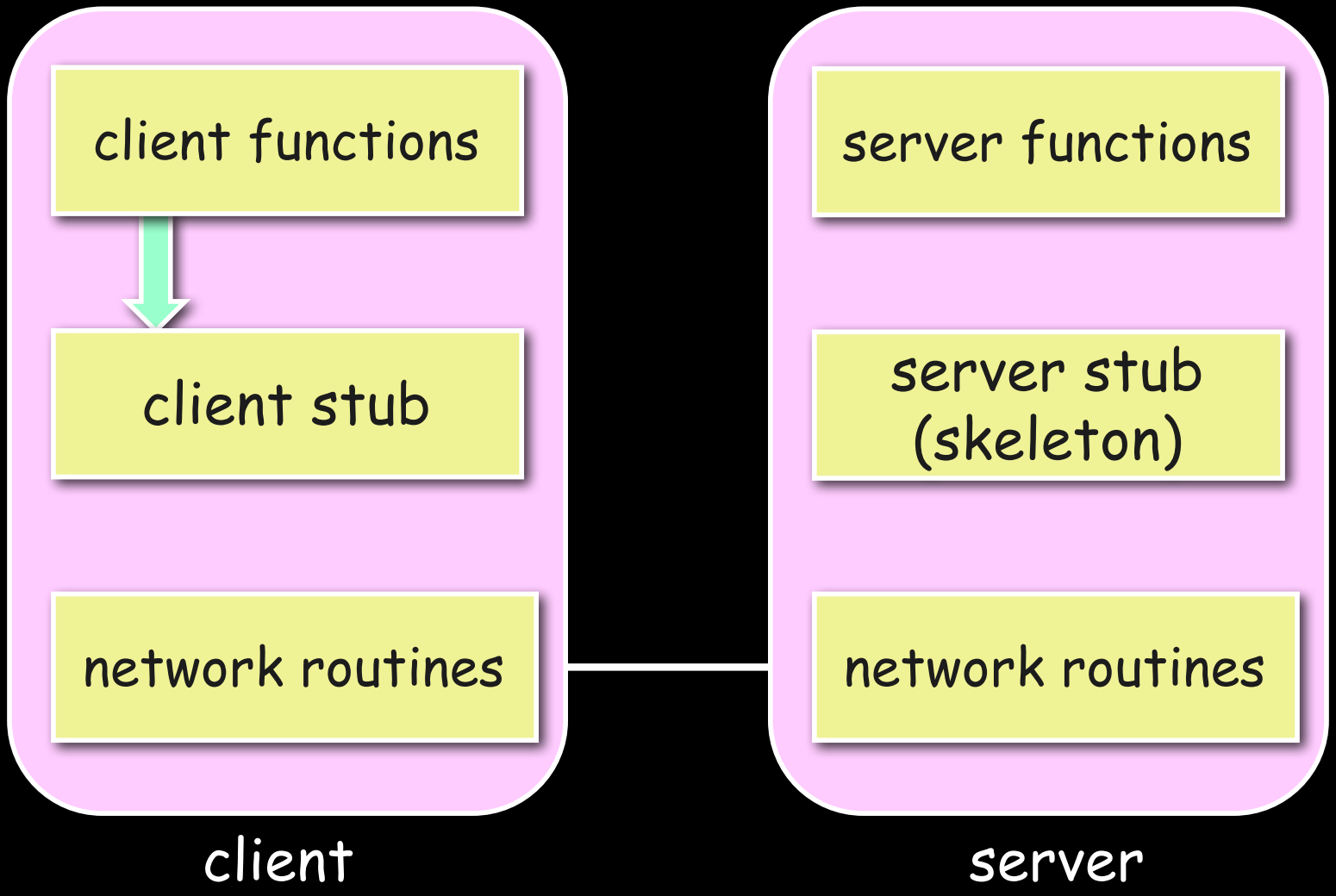
The trick:

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

Stub function contains the function's interface

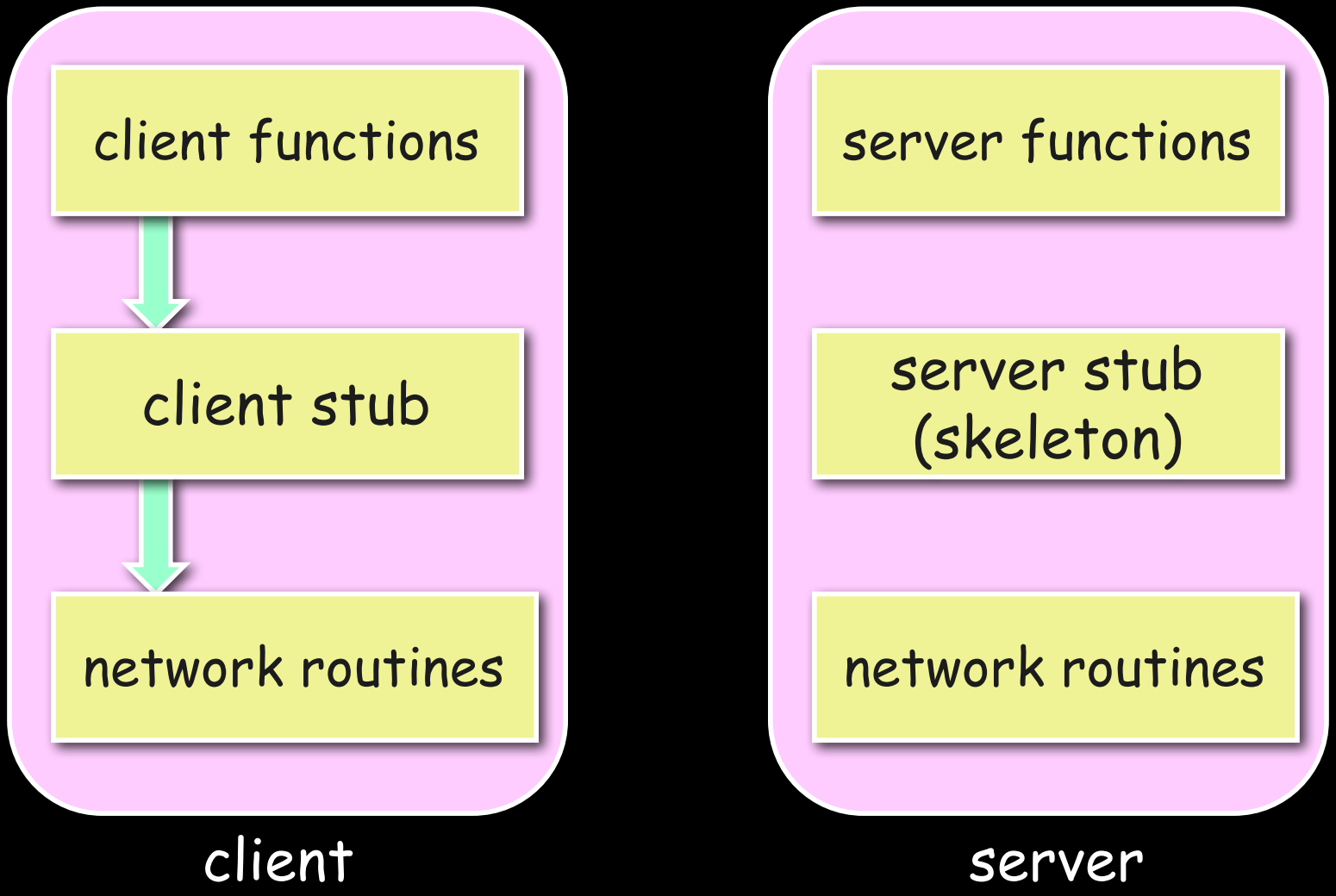
Stub functions

1. Client calls stub (params on stack)



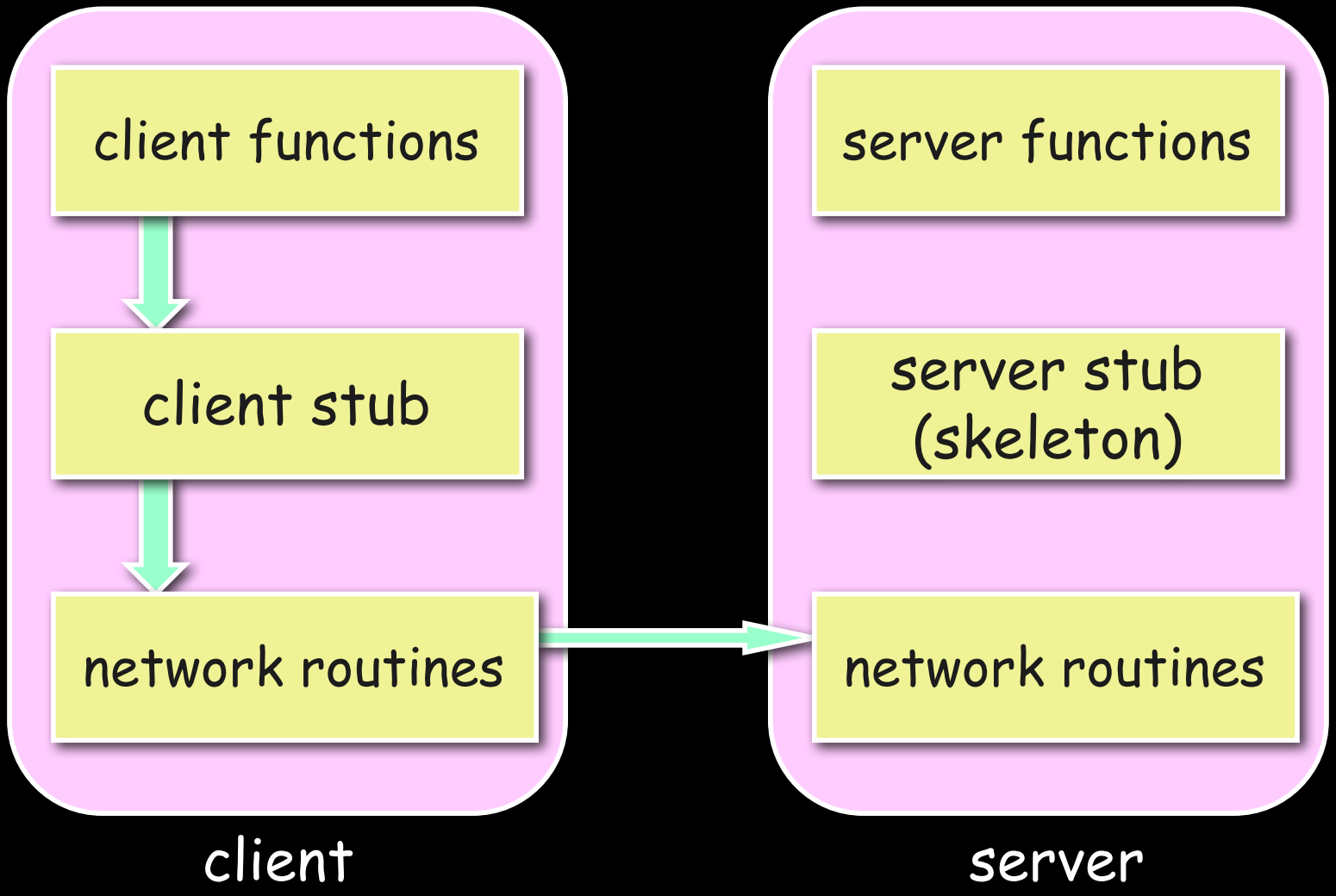
Stub functions

2. Stub marshals params to net message



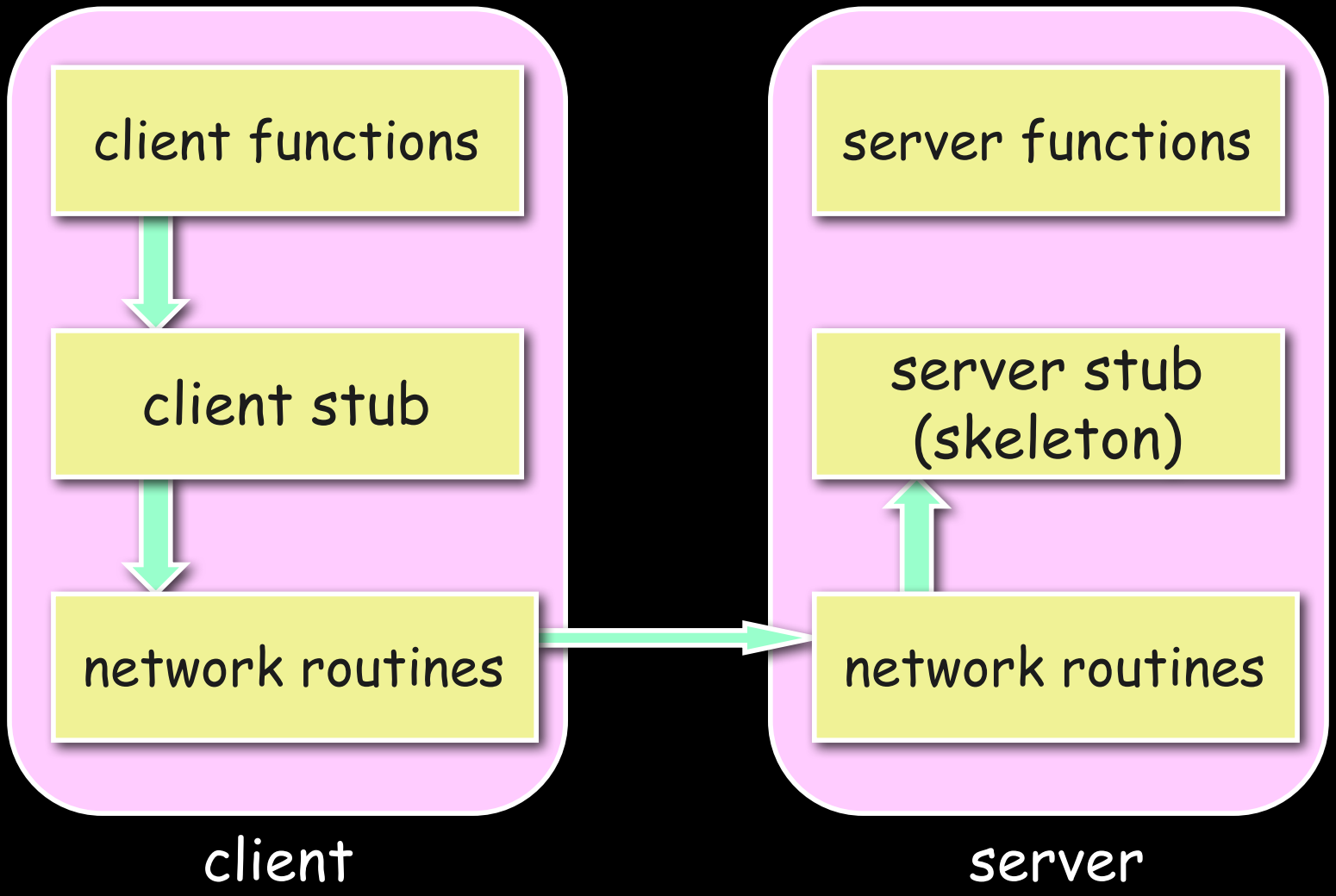
Stub functions

3. Network message sent to server



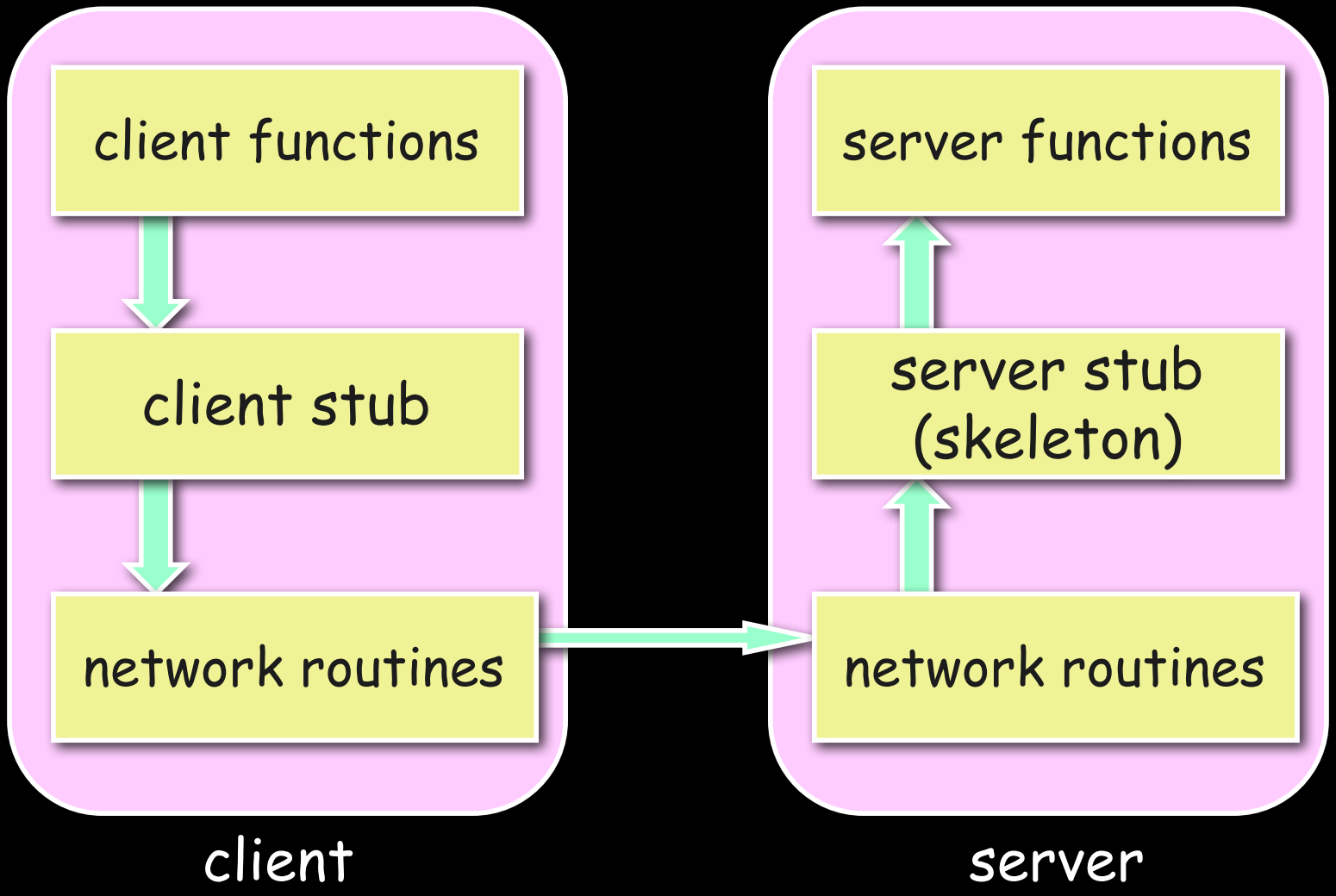
Stub functions

4. Receive message: send to stub



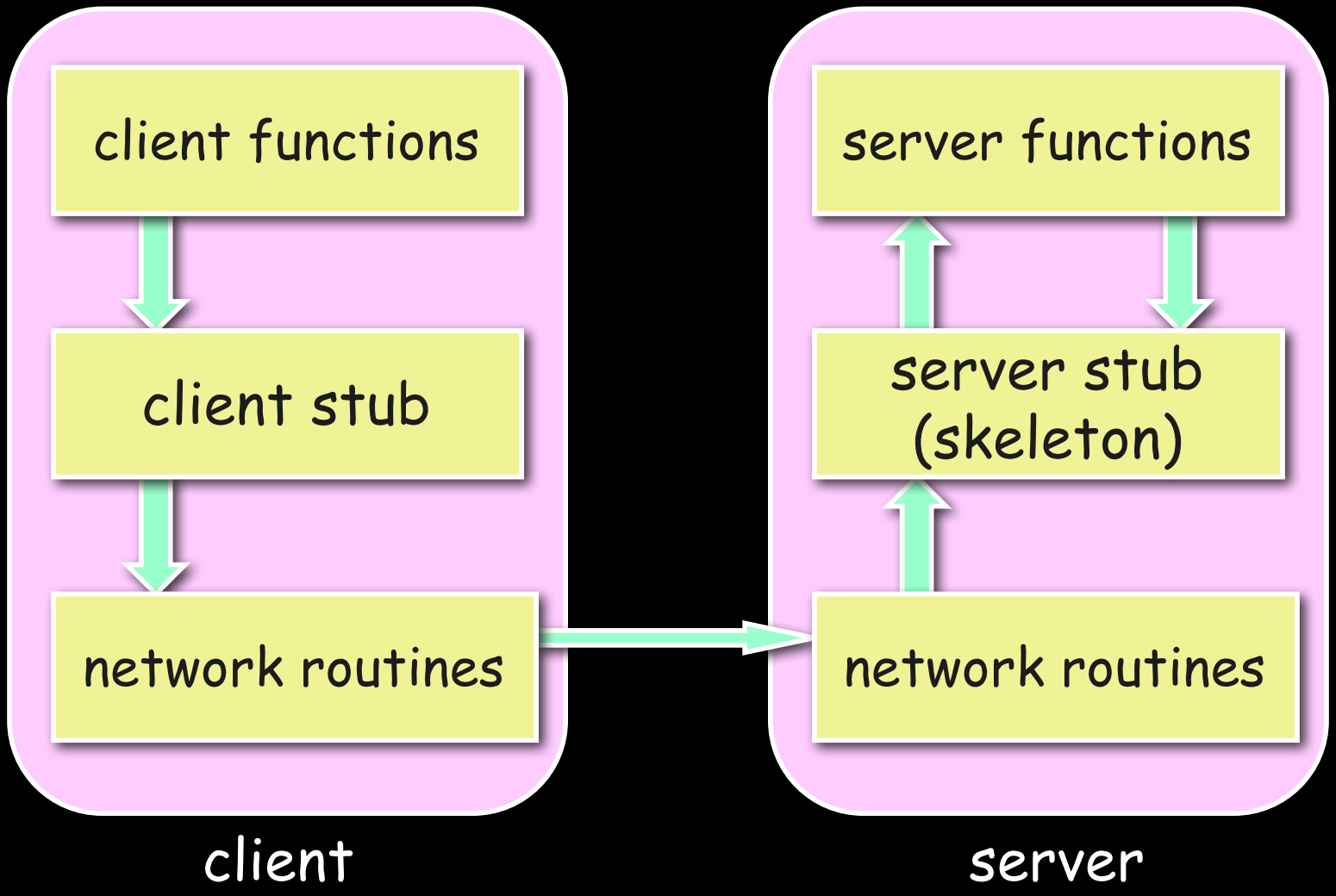
Stub functions

5. Unmarshal parameters, call server func



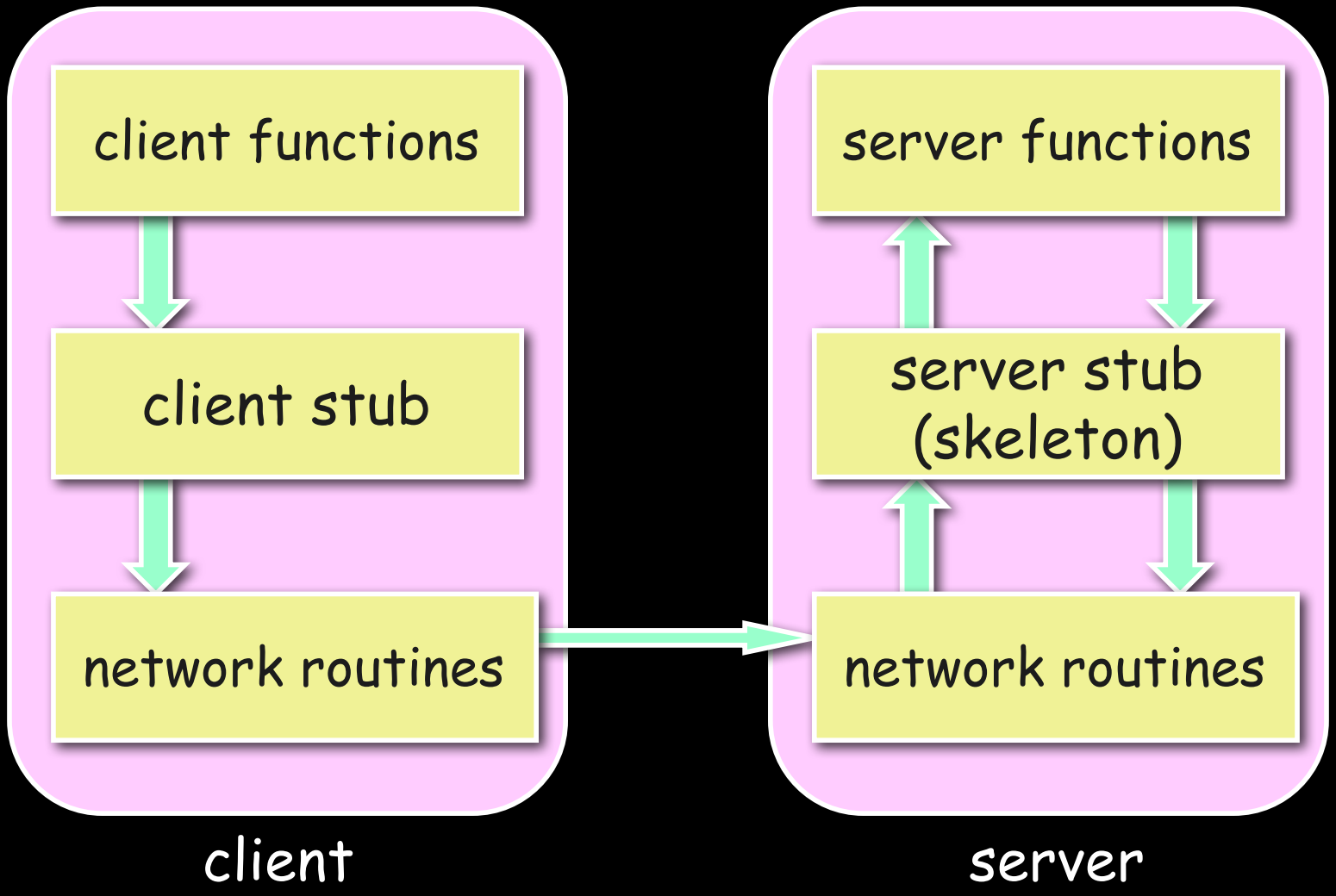
Stub functions

6. Return from server function



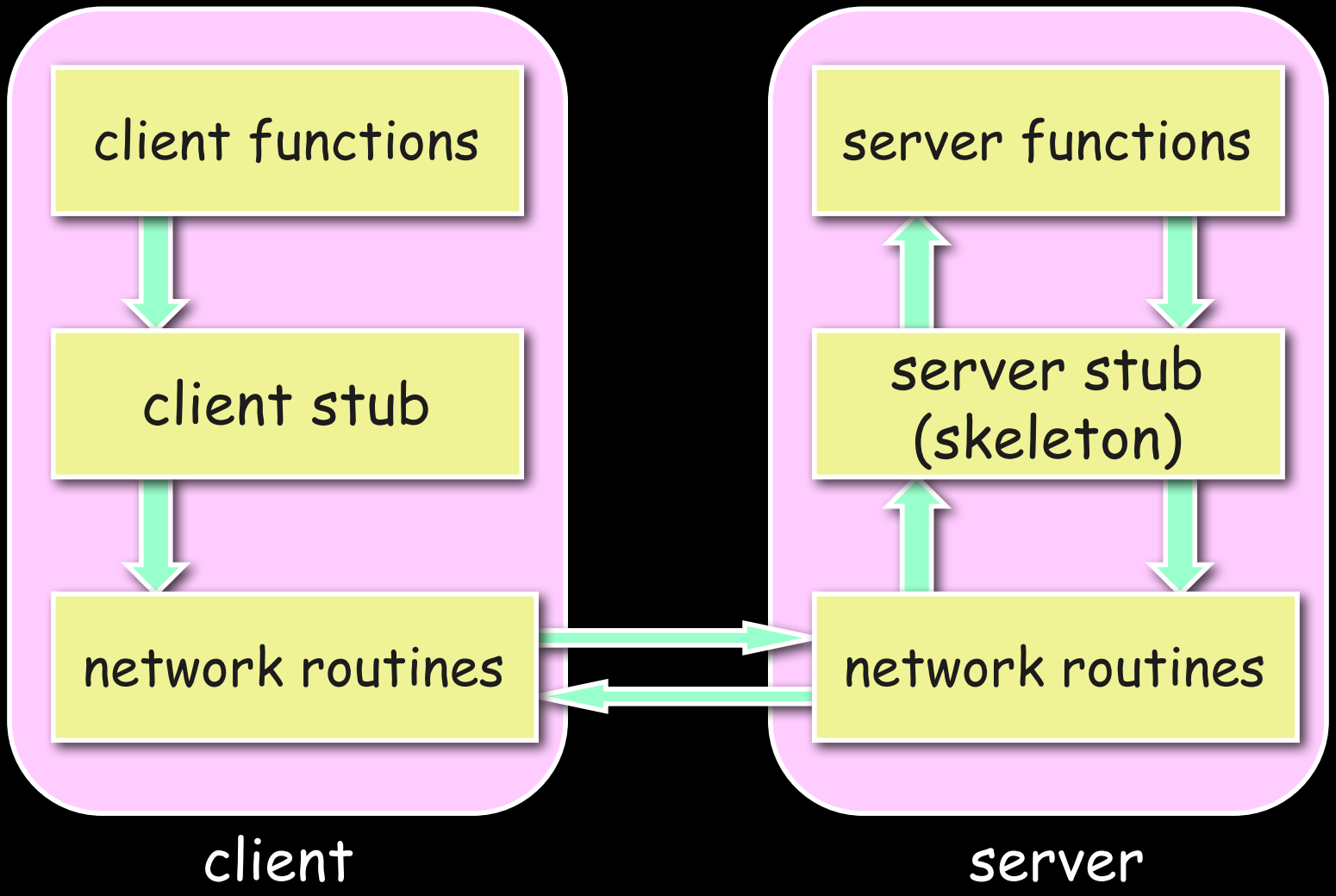
Stub functions

7. Marshal return value and send message



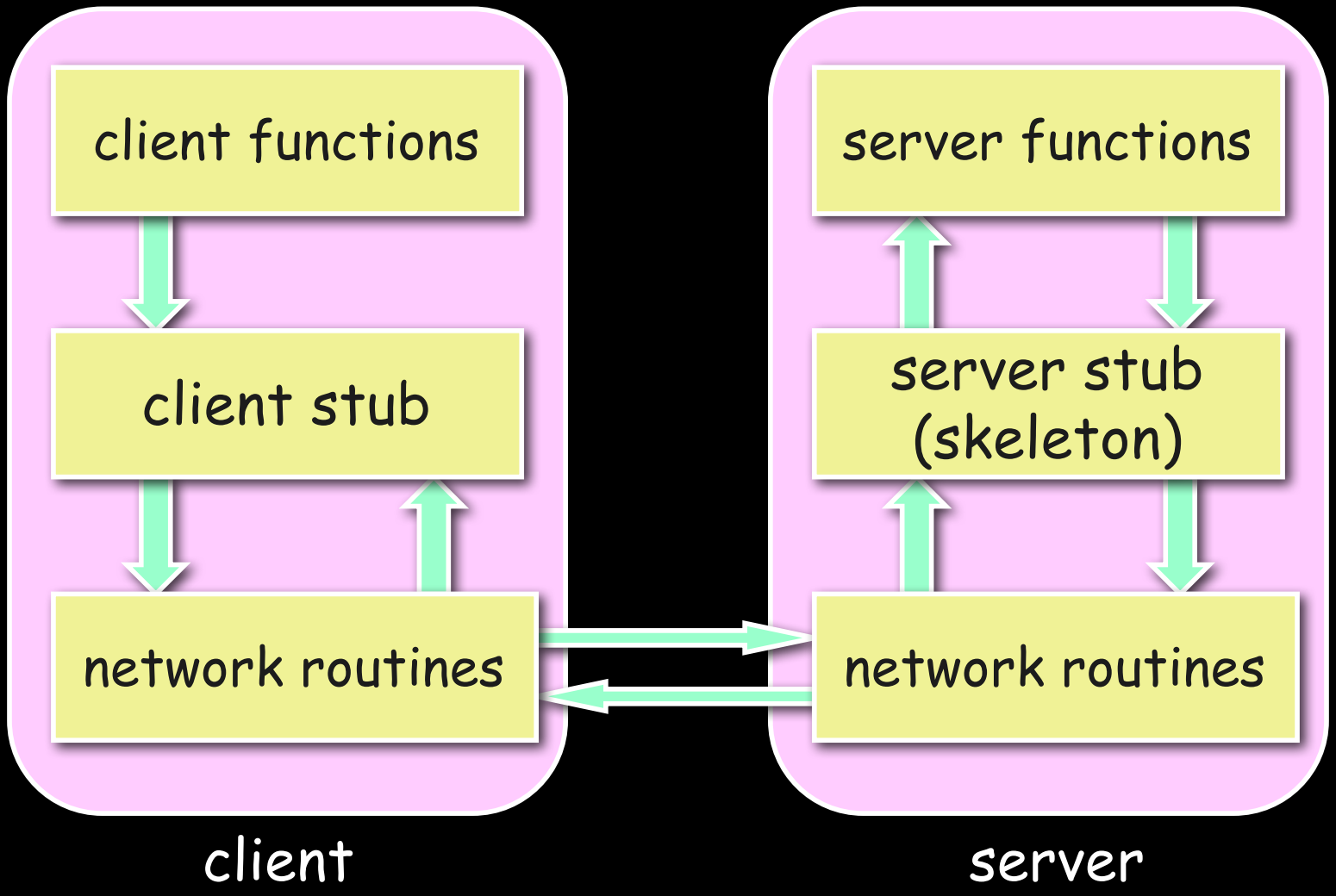
Stub functions

8. Transfer message over network



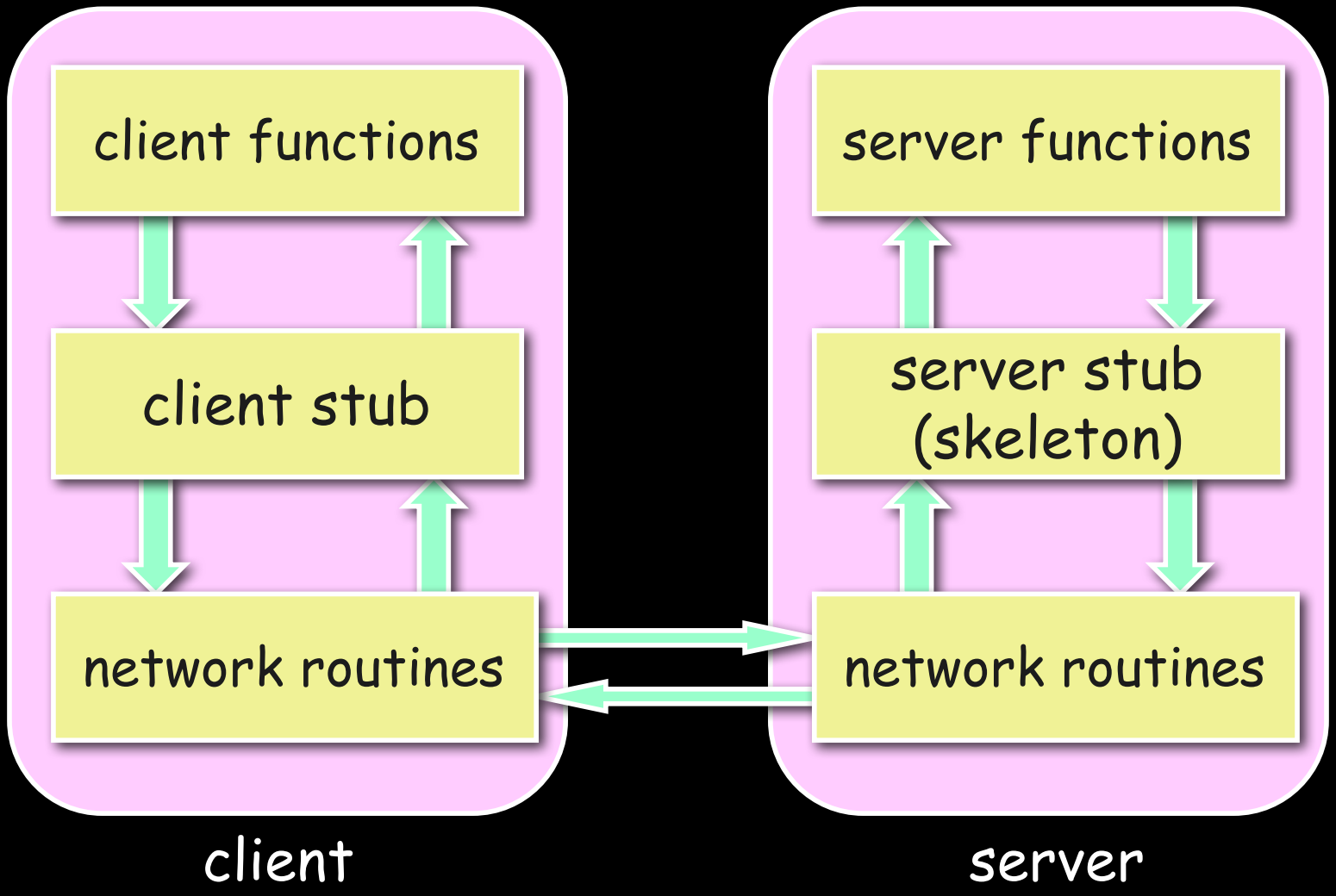
Stub functions

9. Receive message: direct to stub



Stub functions

10. Unmarshal return, return to client code



Benefits

- 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
- RPC: presentation layer in OSI model

RPC has issues

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

- Most significant byte in low memory
  - Sparc, 680x0, MIPS, PowerPC G5
  - x86/Pentiums use little endian

```
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 a Pentium:
`44, 33, 22, 11`

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

Representing data

Need standard encoding to enable communication between heterogeneous systems

- e.g. Sun's RPC uses XDR (eXternal Data Representation)
- ASN.1 (ISO Abstract Syntax Notation)

Representing data

Implicit typing

- only values are transmitted, not data types or parameter info
- e.g., Sun XDR

Explicit typing

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

Where to bind?

Need to locate host and correct server process

Where to bind? – Solution 1

Maintain centralized DB that can locate a host that provides a particular service
(Birrell & Nelson's 1984 proposal)

Where to bind? – Solution 2

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

Solution 1 is problematic for Sun NFS – identical file servers serve different file systems

Transport protocol

Which one?

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

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

- Semantics of remote procedure calls
  - 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
  - 1 or more: 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: side-effects

More issues

Performance

- RPC is slower … a lot slower

Security

- messages visible over network
- Authenticate client
- Authenticate server

Programming with RPC

Language support

- Most programming languages (C, C++, Java, …) have no concept of remote procedure calls
- Language compilers will not generate client and server stubs

Common solution:

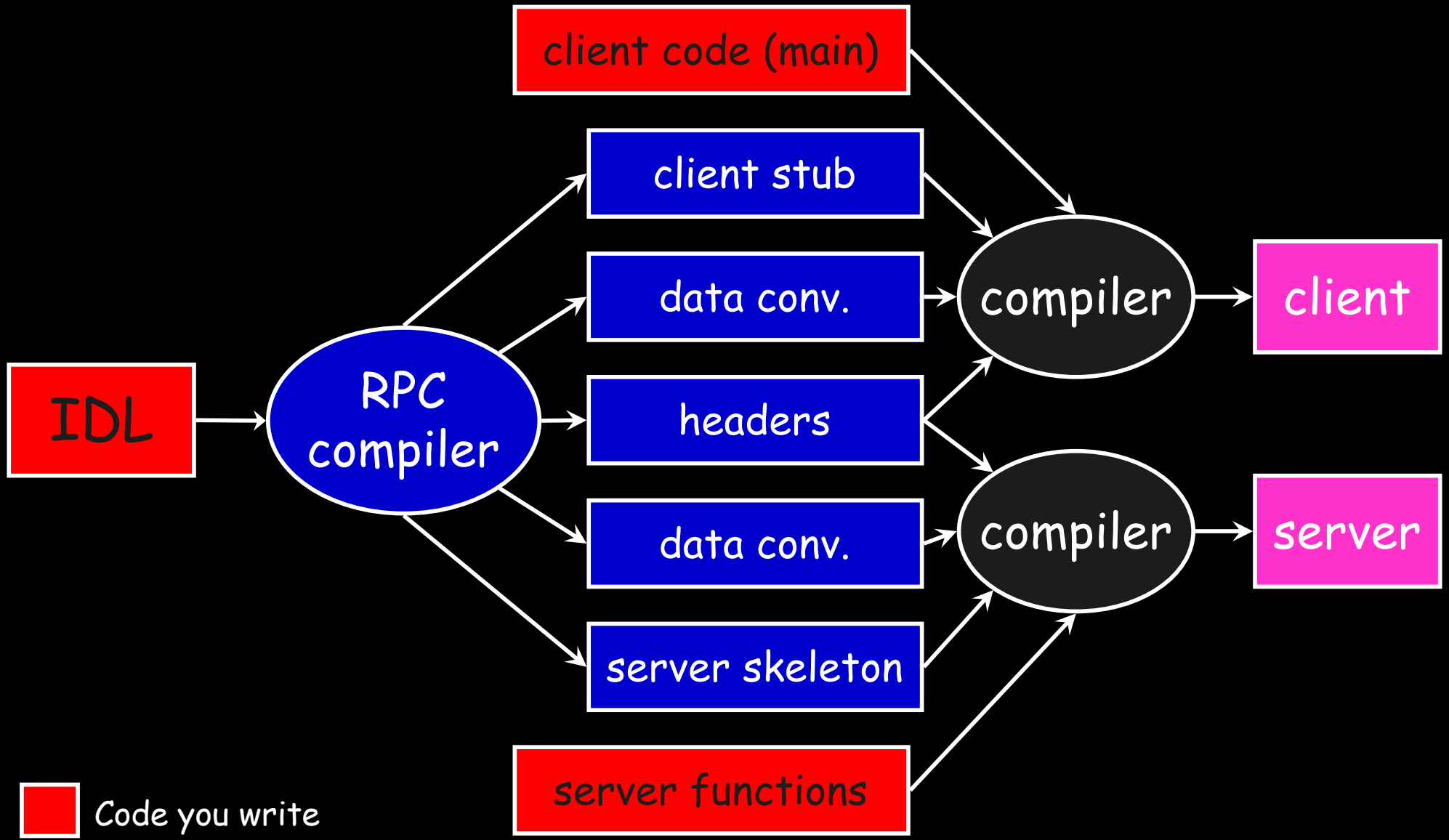
- Use a separate compiler to generate stubs (pre-compiler)

Interface Definition Language

- 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
- Similar to function prototypes

RPC compiler



Writing the program

- Client code has to be modified
  - Initialize RPC-related options
    - Transport type
    - Locate server/service
  - Handle failure of remote procedure call
- Server functions
  - Generally need little or no modification

RPC API

What kind of services does an RPC system need?

- Name service operations
  - Export/lookup binding information (ports, machines)
  - Support dynamic ports
- Binding operations
  - Establish client/server communications using appropriate protocol (establish endpoints)
- Endpoint operations
  - Listen for requests, export endpoint to name server

RPC API

What kind of services does an RPC system need?

- Security operations
  - Authenticate client/server
- Internationalization operations
- Marshaling/data conversion operations
- Stub memory management
  - Dealing with "reference" data, temporary buffers
- Program ID operations
  - Allow applications to access IDs of RPC interfaces