Operating Systems Design
17. Networking: Remote Procedure Calls

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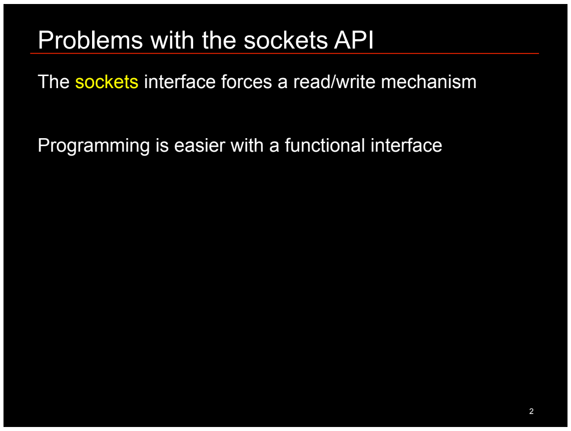
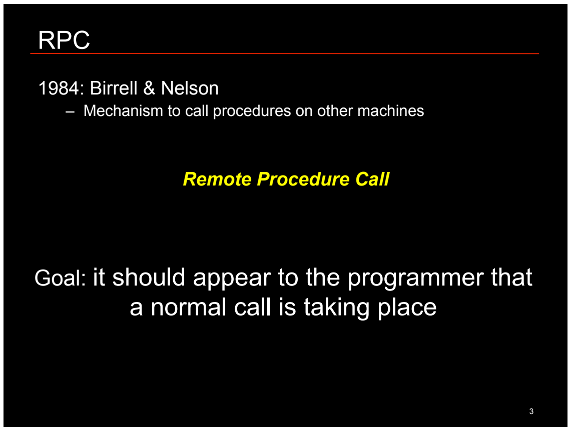


Problems with the sockets API

The sockets interface forces a read/write mechanism

Programming is easier with a functional interface

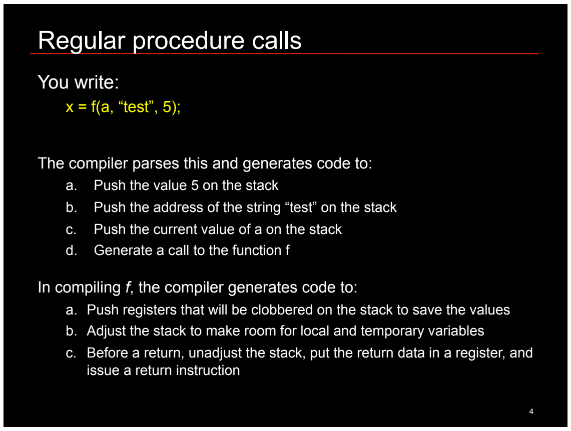


RPC

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



Regular procedure calls

You write:

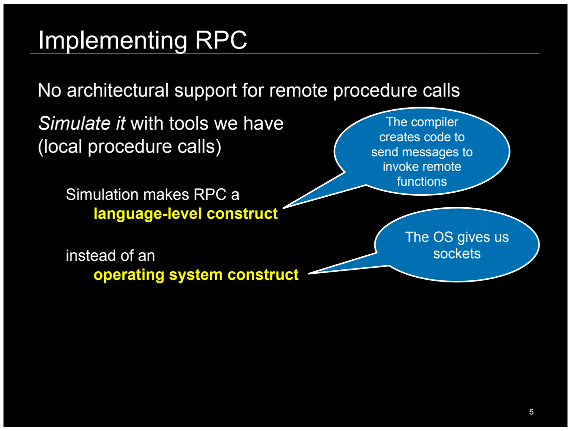
```
x = f(a, “test”, 5);
```

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

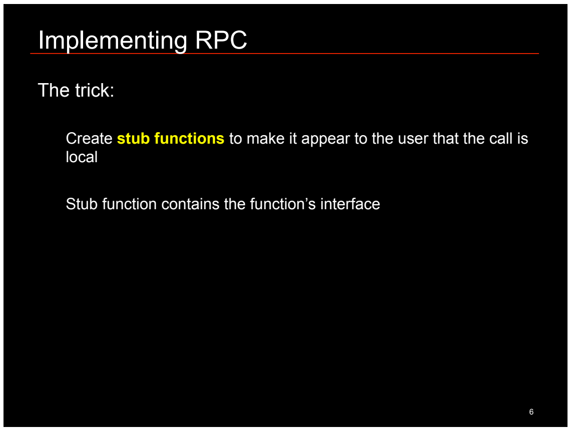
No architectural support for remote procedure calls

Simulate it with tools we have (local procedure calls)

Simulation makes RPC a **language-level construct**

instead of an **operating system construct**

The compiler creates code to send messages to invoke remote functions
The OS gives us sockets

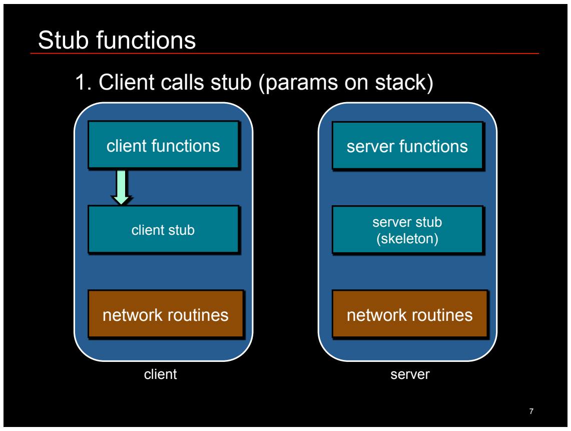


Implementing RPC

The trick:

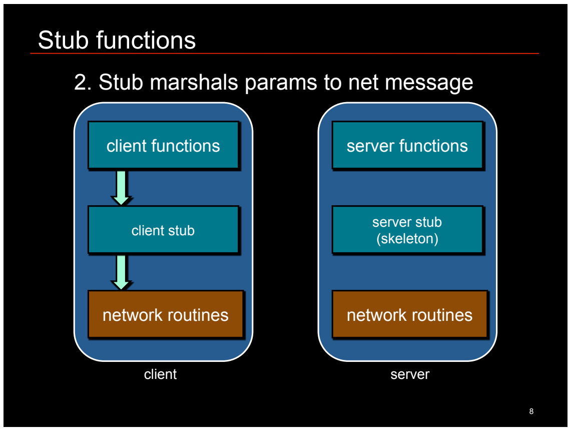
Create **stub functions** to make it appear to the user that the call is local

Stub function contains the function’s interface



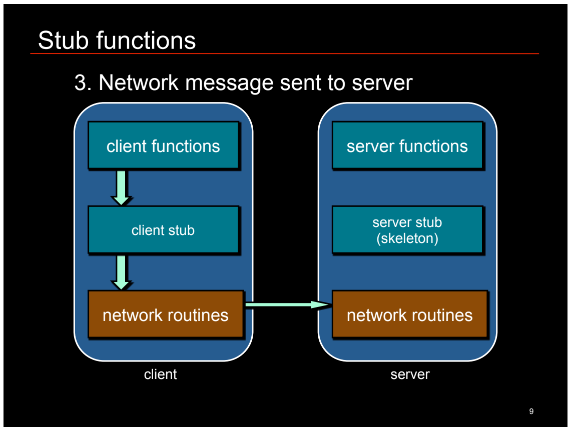
Stub functions

1. Client calls stub (params on stack)



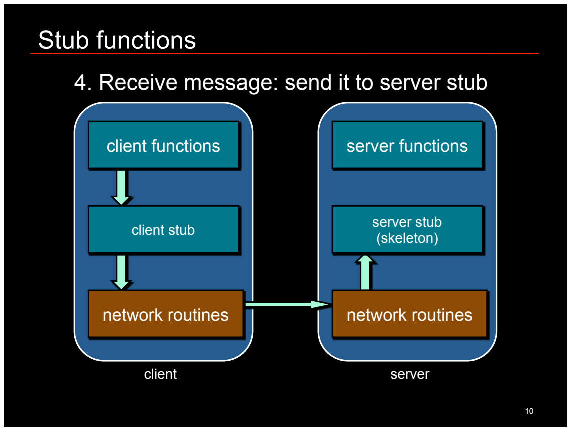
Stub functions

2. Stub marshals params to net message



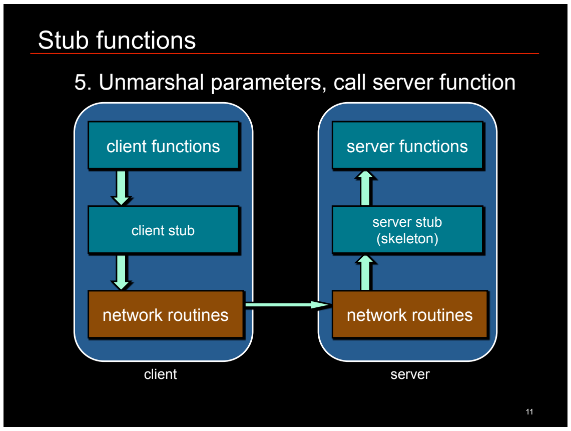
Stub functions

3. Network message sent to server



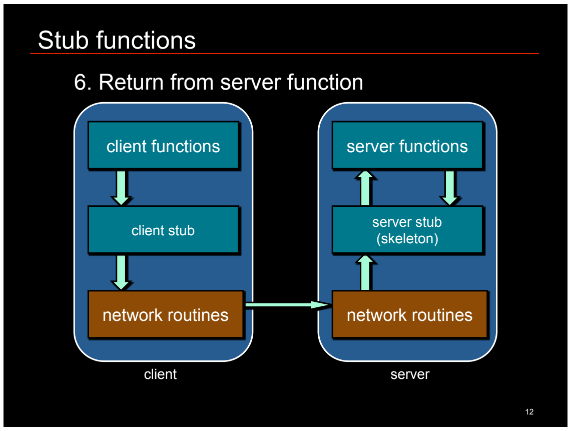
Stub functions

4. Receive message: send it to server stub



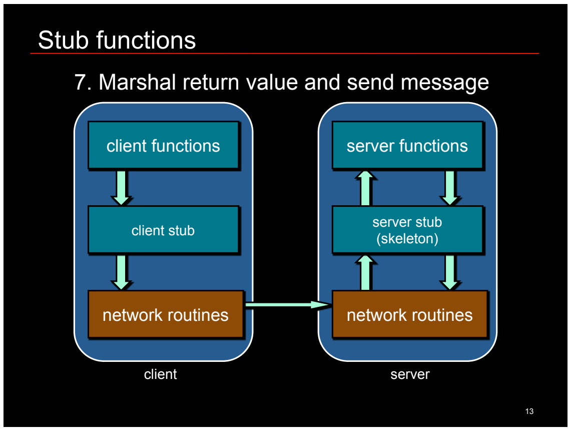
Stub functions

5. Unmarshal parameters, call server function



Stub functions

6. Return from server function



Stub functions

7. Marshal return value and send message

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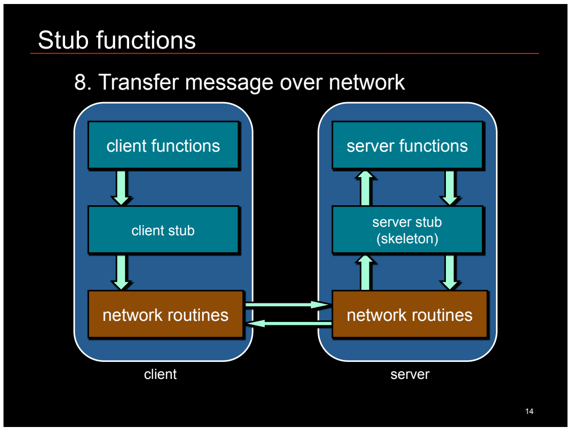

Stub functions

8. Transfer message over network

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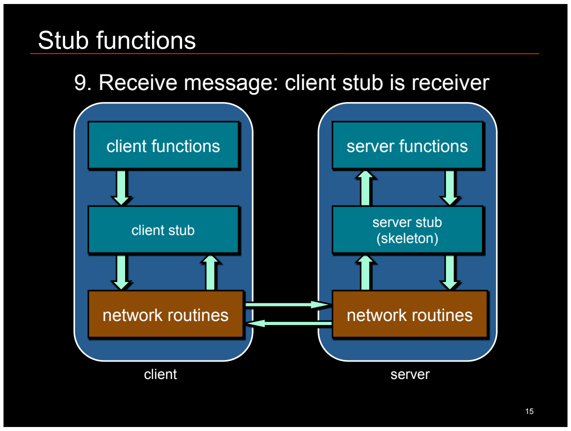

Stub functions

9. Receive message: client stub is receiver

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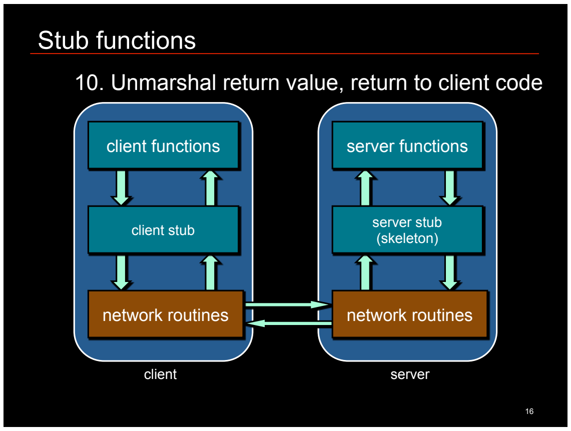

Stub functions

10. Unmarshal return value, return to client code

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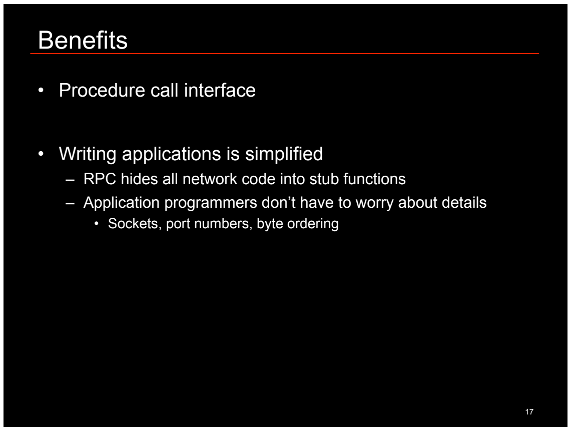

Benefits

- 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

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RPC has issues

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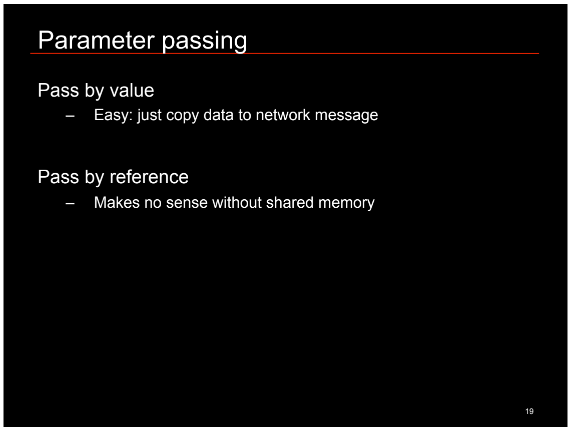


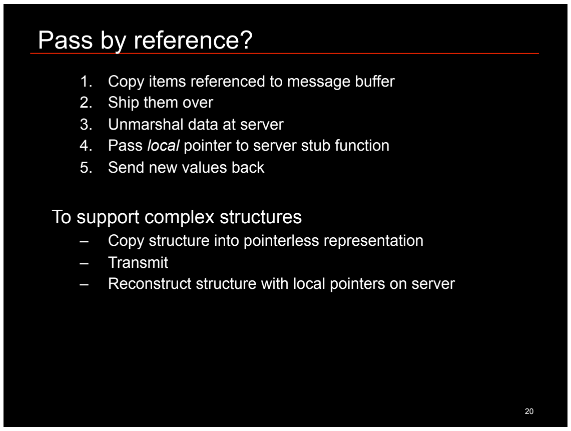
Parameter passing

Pass by value

- Easy: just copy data to network message

Pass by reference

- Makes no sense without shared memory

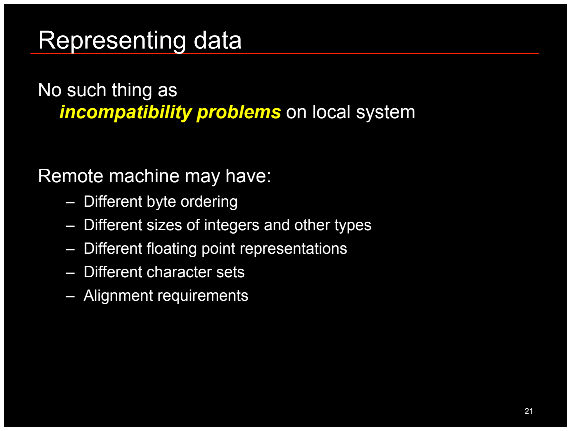


Pass by reference?

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

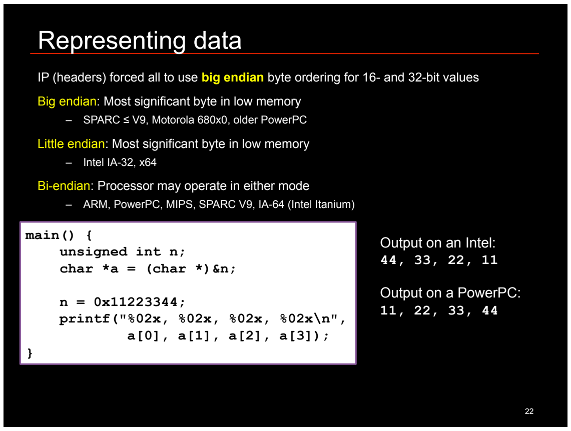


Representing data

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

Little endian: Most significant byte in low memory

- Intel IA-32, x64

Bi-endian: Processor may operate in either mode

- ARM, PowerPC, MIPS, SPARC V9, IA-64 (Intel Itanium)

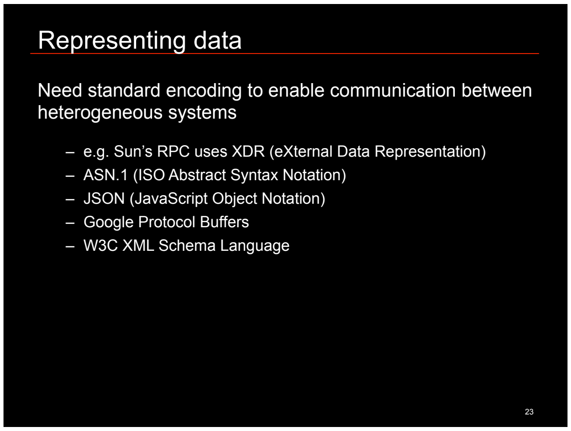
```
main() {
    unsigned int n;
    char *a = (char *)&n;

    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:

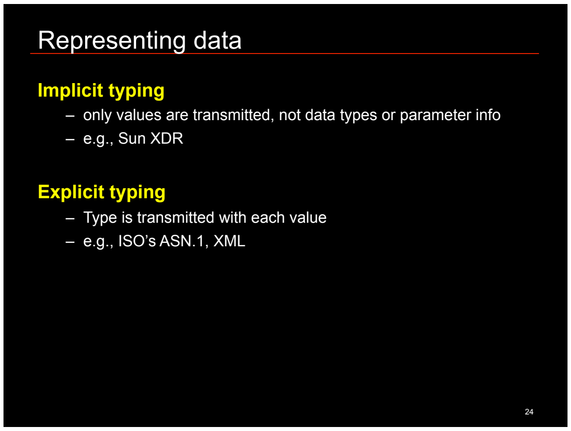
```
11, 22, 33, 44
```



Representing data

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)
- JSON (JavaScript Object Notation)
- Google Protocol Buffers
- W3C XML Schema Language



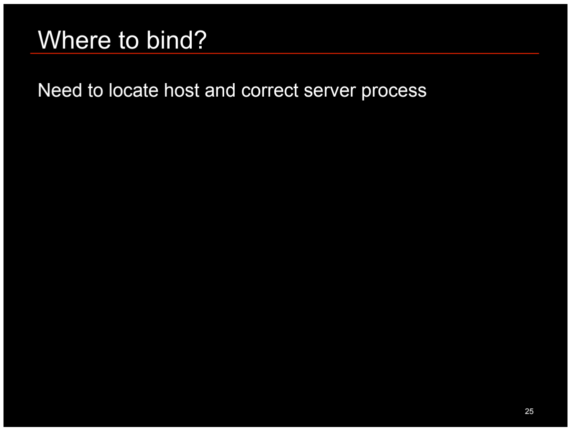
Representing data

Implicit typing

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

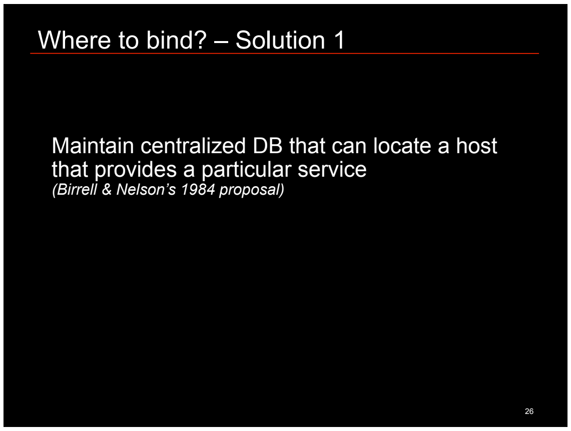
Explicit typing

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



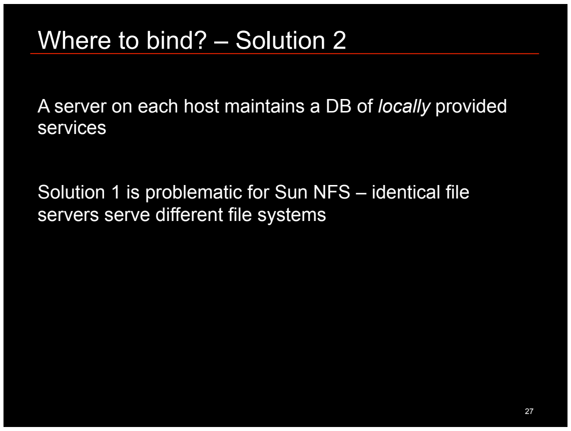
Where to bind?

Need to locate host and correct server process



Where to bind? – Solution 1

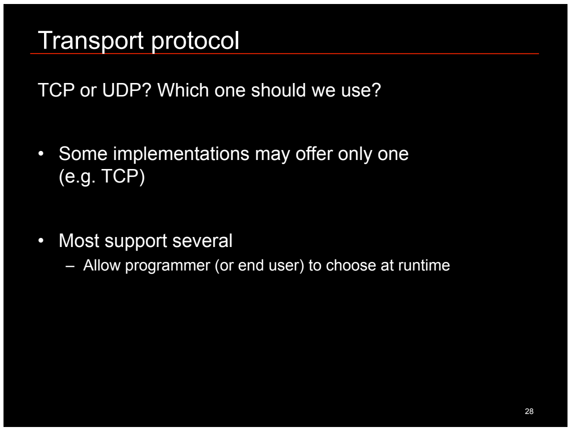
Maintain centralized DB that can locate a host that provides a particular service
(Birrell & Nelson's 1984 proposal)



Where to bind? – Solution 2

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

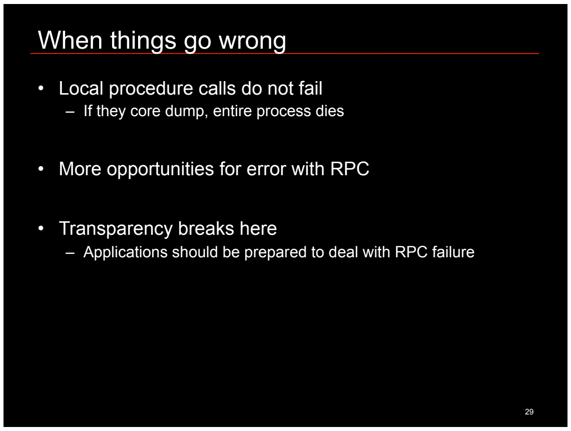
Solution 1 is problematic for Sun NFS – identical file servers serve different file systems



Transport protocol

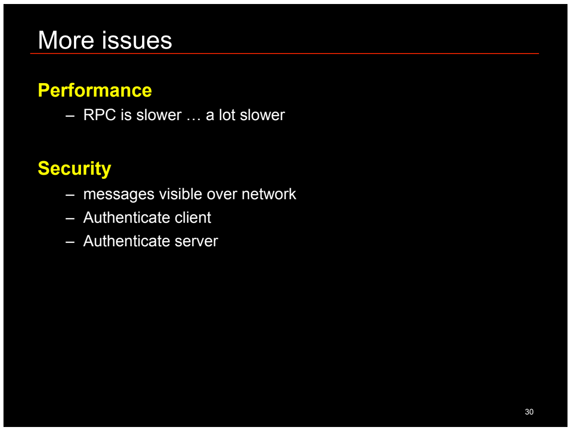
TCP or UDP? Which one should we use?

- 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

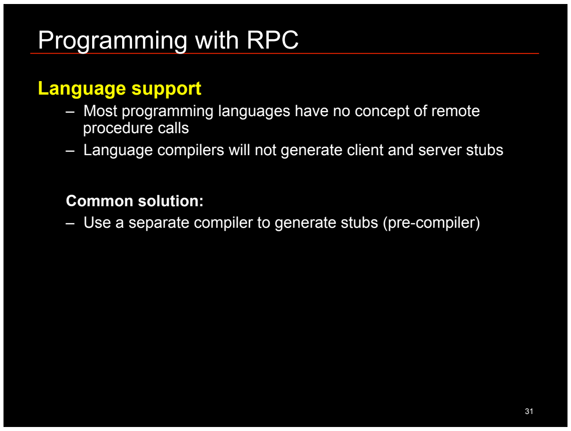
- Local procedure calls do not fail
  - If they core dump, entire process dies
- More opportunities for error with RPC
- Transparency breaks here
  - Applications should be prepared to deal with RPC failure



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 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)

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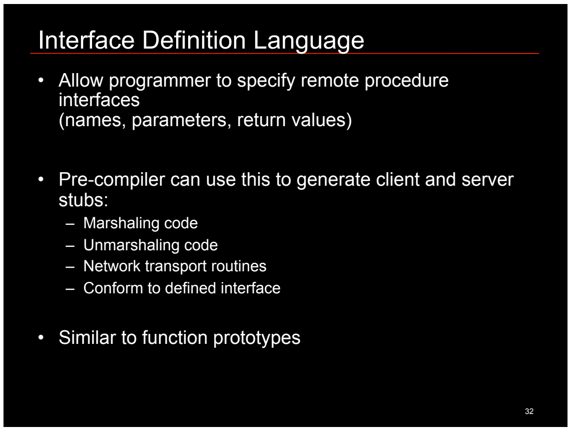

Interface Definition Language

- 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

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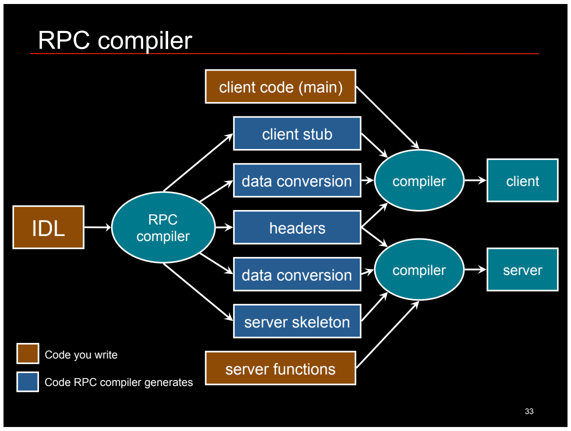

RPC compiler

🟫 Code you write

🟦 Code RPC compiler generates

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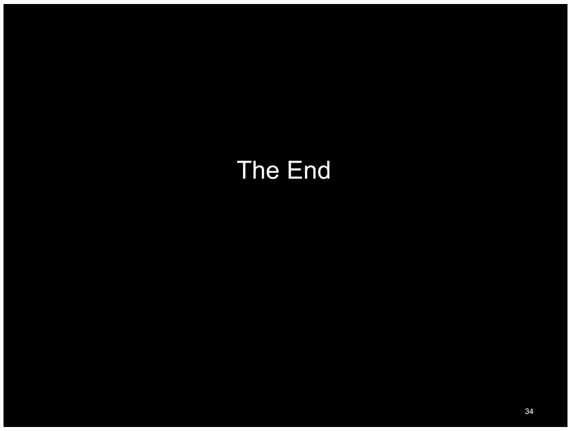

The End

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