EECS 482
Introduction to Operating Systems

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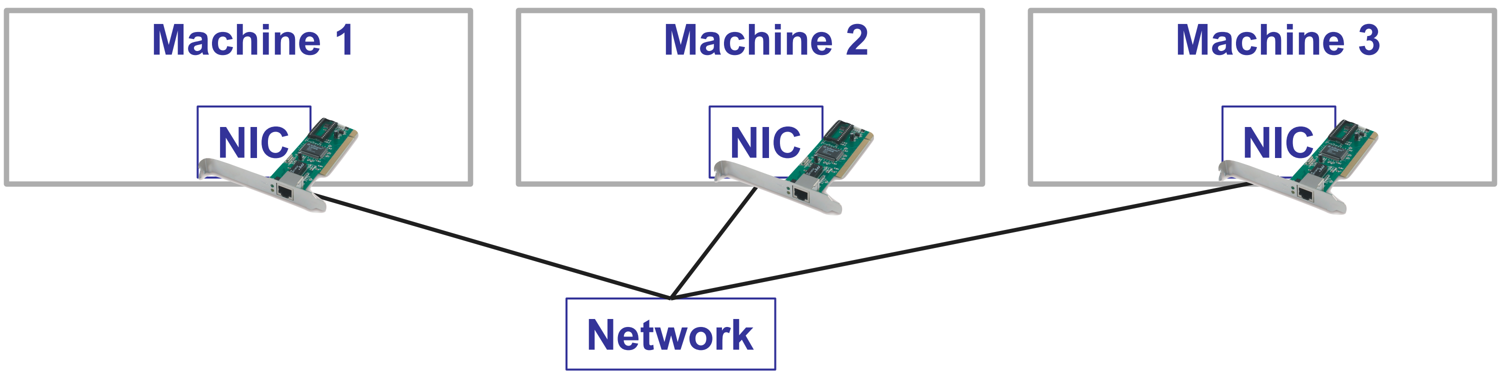
OS abstraction of network

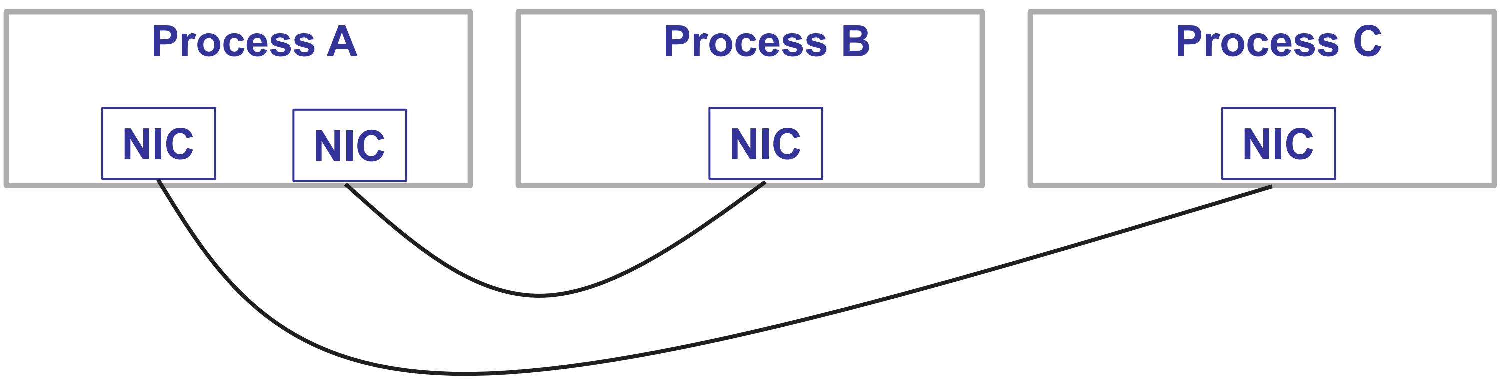
Hardware reality	Abstraction
Multiple computers connected via a network	Single computer
Machine-to-machine communication	Process-to-process communication
Unreliable and unordered delivery of finite messages	Reliable and ordered delivery of byte stream

OS abstraction of network

- Hardware reality



- OS abstraction

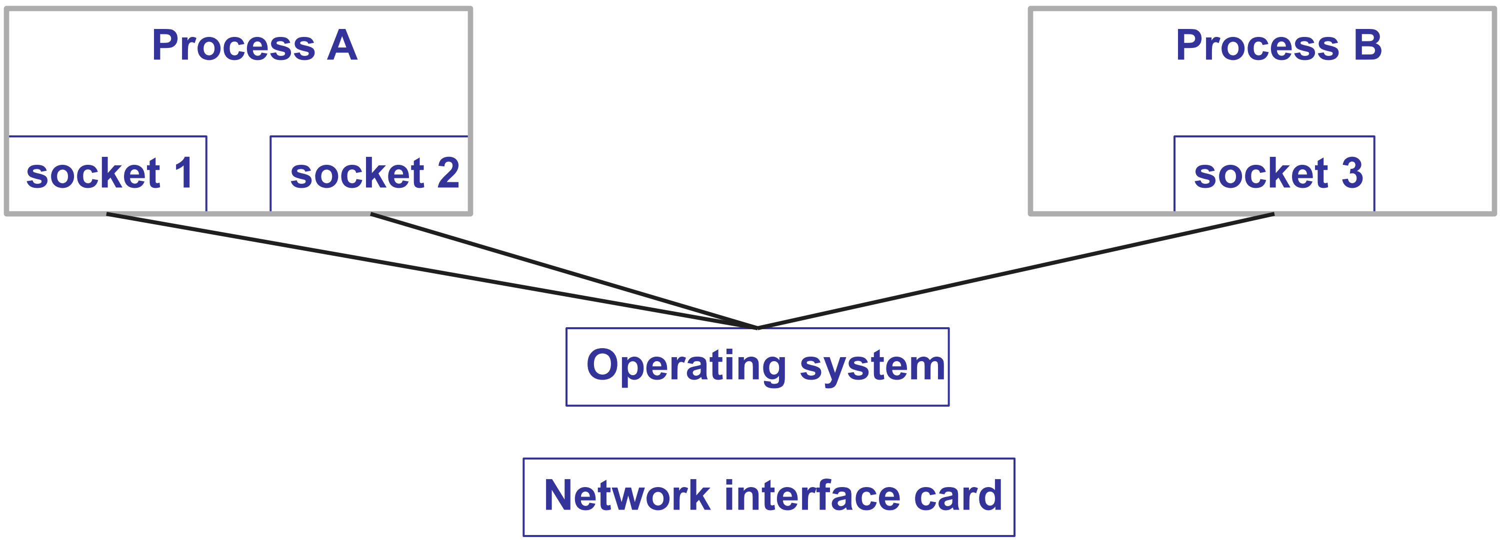


Changing communication from inter-machine to inter-process

- Every process thinks it has its own:
  - Multiprocessor (threads)
  - Memory (address space)
  - Network interface cards (sockets)

- Socket
  - Virtual network interface card
  - Endpoint for communication
  - NIC named by MAC address; socket named by "port number" (via bind)
  - Programming interface: BSD sockets

OS multiplexes multiple sockets onto a single NIC



- UDP (user datagram protocol): IP + sockets
- TCP (transmission control protocol): IP + sockets + reliable, ordered streams

Ordered messages

- Hardware interface: Messages can be re-ordered by IP
  - Sender: A, B
  - Receiver: B, A
- Application interface: Messages received in order sent

- How to provide ordered messages?
  - Assign sequence numbers

- Ordering of messages per-"connection"
  - TCP: process opens connection (via `connect`), sends sequence of messages, then closes connection
  - Sequence number specific to a socket-to-socket connection

Ordered messages

- Example:
  - Sender sends 0, 1, 2, 3, 4, …
  - Receiver receives 0, 1, 3, 2, 4, …
- How should receiver deal with reordering?
  - Drop 3, Deliver 2, Deliver 4
  - Deliver 3, Drop 2, Deliver 4
  - Save 3, Deliver 2, Deliver 3, Deliver 4

Reliable messages

- Hardware interface: Messages can be dropped, duplicated, or corrupted
- Application interface: Each message is delivered exactly once without corruption

- How to fix a dropped message?
  - Have the sender re-send it
- How does sender know message was dropped?
  - Have receiver ACK messages; resend after timeout
- Does timing out mean the message was dropped?

Reliable messages

- How to deal with duplicate messages?
  - Detect by sequence number and drop duplicates
- How to deal with corrupted messages?
  - Add redundant information (e.g., checksum)
  - Fix by dropping corrupted message
- Transform:
  - Corrupted messages → dropped messages
  - Potential dropped messages → potential duplicates
- Solve duplicates by dropping duplicate messages

Byte streams

- Hardware interface: Send/receive messages
- Application interface: Abstraction of data stream

- TCP: Sender sends messages of arbitrary size, which are combined into a single stream
- Implementation
  - Break up stream into fragments
  - Sends fragments as distinct messages
  - Reassembles fragments at destination

Message boundaries

- TCP has no message boundaries (unlike UDP)
  - Example: Sender sends 100 bytes, then 50 bytes; Receiver could receive 1-150 bytes
- Receiver must loop until all bytes received
- How to know # of bytes to receive?
  - Convention (e.g., specified by protocol)
  - Specified in header
  - End-of-message delimiter
  - Sender closes connection

Project 4

- Use assertions to catch errors early
  - No. of free disk blocks matches file system contents?
  - Are you unlocking a lock that you hold?
  - Verify initial file system is not malformed
- Use showfs to verify that contents of file system match your expectations
- There are no boundaries in TCP byte streams
- **A char* is not a string!**

Client-server

- Common way to structure a distributed application:
  - Server provides some centralized service
  - Client makes request to server, then waits for response
- Example: Web server
  - Server stores and returns web pages
  - Clients run web browsers, which make GET/POST requests
- Example: Producer-consumer
  - Server manages state associated with coke machine
  - Clients call `client_produce()` or `client_consume()`, which send request to the server and return when done
  - Client requests block at the server until they are satisfied

Producer-consumer in client-server paradigm

```
client_produce() {
      send produce request to server
      wait for response
}

server() {
      receive request
      if (produce request) {
            add coke to machine
      } else {
            take coke out of machine
      }
      send response
}
```

Problems?

How to fix?

Producer-consumer in client-server paradigm

```
client_produce() {
        send produce request to server
        wait for response
}

server() {
        receive request
        if (produce request) {
                while(machine is full) { wait }
                add coke to machine
        } else {
                take coke out of machine
        }
        send response
}
```

Producer-consumer in client-server paradigm

```
server() {
        receive request
        if (produce request) {
                create thread that calls server_produce()
        } else {
                create thread that calls server_consume()
        }
}

server_produce() {
        lock
        while (machine is full) {
                wait
        }
        put coke in machine
        unlock
        send response
}
```

Producer-consumer in client-server paradigm

- How to lower overhead of creating threads?
  - Maintain pool of worker threads
- There are other ways to structure the server
  - Basic goal: Account for "slow" operations
- Examples:
  - Polling (via `select`)
  - Threads + Signals

Producer-consumer in client-server paradigm

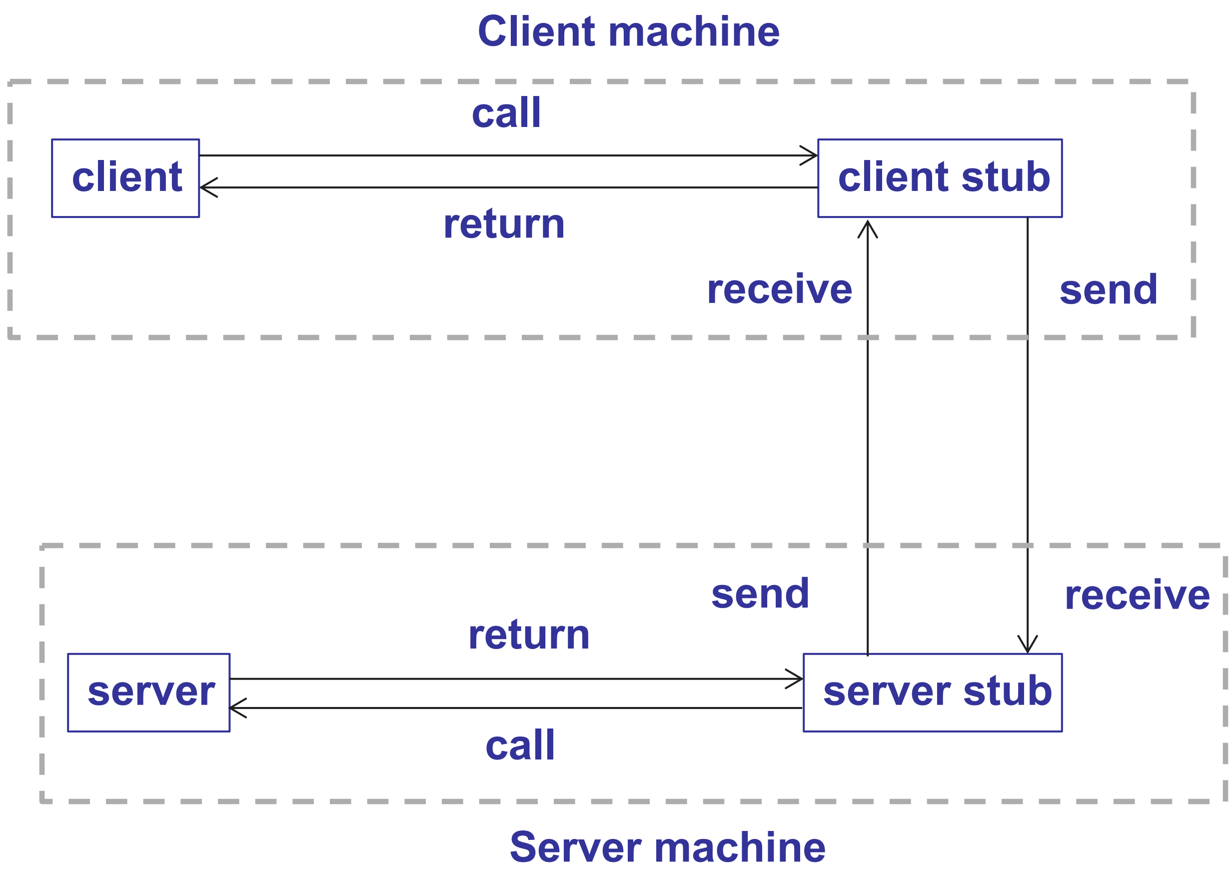
```
client_produce() {
        send produce request to server
        wait for response
}

server() {
        receive request
        if (produce request) {
                thread(server_produce())
        } else {
                thread(server_consume())
        }
        send response
}
```

Remote Procedure Call

- Hide complexity of message-based communication from developers
- Procedure calls more natural for inter-process communication
- Goals of RPC:
  - Client sending request → function call
  - Client receiving response → returning from function
  - Server receiving request → function invocation
  - Server sending response → returning to caller

RPC abstraction via stub functions on client and server

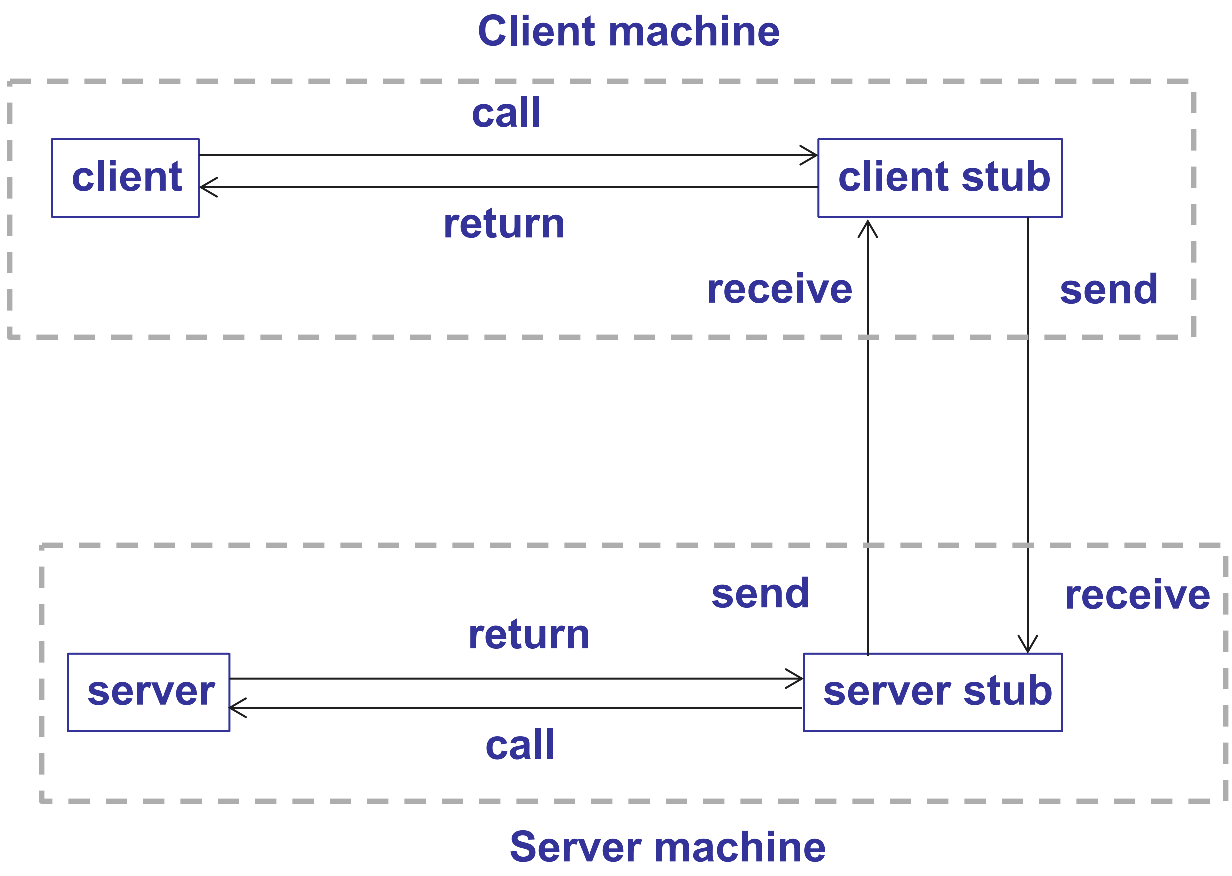


RPC stubs

- Client stub:
  - Constructs message with function name and parameters
  - Sends request message to server
  - Receives response from server
  - Returns response to client

- Server stub:
  - Receives request message
  - Invokes correct function with specified parameterss
  - Constructs response message with return value
  - Sends response to client stub

RPC abstraction via stub functions on client and server



Producer-consumer using RPC

- Client stub

```
int produce (int n) {
    int status;
→   send (sock, &n, sizeof(n));
→   recv (sock, &status, sizeof(status));
→   return(status);
}
```

- Server stub

```
void produce_stub () {
    int n;
    int status;
→   recv (sock, &n, sizeof(n));
→   status = produce(n);
→   send (sock, &status, sizeof(status));
}
```

Generation of stubs

- Stubs can be generated automatically
- What do we need to know to do this?

- Interface description:
  - Types of arguments and return value

- e.g. rpcgen on Linux

RPC Transparency

- RPC makes remote communication look like local procedure calls
  - Basis of CORBA, Thrift, SOAP, Java RMI, …
  - Examples in this class?
- What factors break illusion?
  - Failures – remote nodes/networks can fail
  - Performance – remote communication is inherently slower
  - Service discovery – client stub needs to bind to server stub on appropriate machine

RPC Arguments

- Can I have pointers as arguments?
- How to pass a pointer as argument?
  - Client stub transfers data at the pointer
  - Server stub stores received data and passes pointer
- Challenge:
  - Data representation should be same on either end
  - Example: I want to send a 4-byte integer:
    - » 0xDE AD BE EF
    - » Send byte 0, then byte 1, byte 2, byte 3
    - » What is byte 0?

Endianness

- int x = 0xDE AD BE EF
- Little endian:
  - Byte 0 is 0xEF
- Big endian:
  - Byte 0 is 0xDE

- If a little endian machine sends to a big endian:
  - 0xDE AD BE EF will become 0xEF BE AD DE