Operating Systems

Isfahan University of Technology
Electrical and Computer Engineering Department
1400-1 semester

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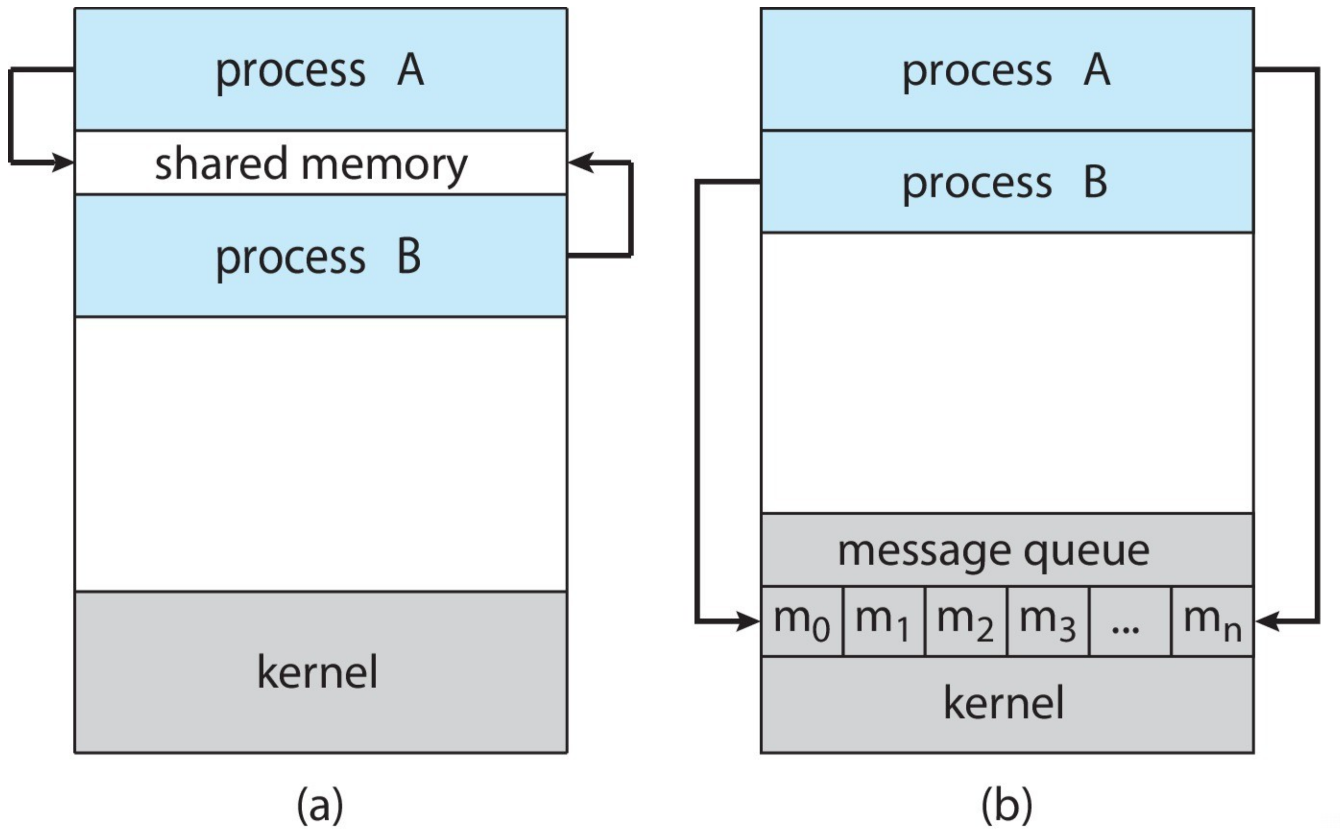
Session 7: Inter Process Communication (IPC)

Interprocess Communication

- Processes within a system may be ***independent*** or ***cooperating***
- Cooperating process can affect or be affected by other processes, including sharing data
- Reasons for cooperating processes:
  - Information sharing
  - Computation speedup
  - Modularity
  - Convenience
- Cooperating processes need **interprocess communication** (**IPC**)
- Two models of IPC
  - **Shared memory**
  - **Message passing (for small amounts of data)**

Communications Models

(a) Shared memory. (b) Message passing.



Producer-Consumer Problem

- Paradigm for cooperating processes:
  - *producer* process produces information that is consumed by a *consumer* process
- Two variations:
  - **unbounded-buffer** places no practical limit on the size of the buffer:
    - Producer never waits
    - Consumer waits if there is no buffer to consume
  - **bounded-buffer** assumes that there is a fixed buffer size
    - Producer must wait if all buffers are full
    - Consumer waits if there is no buffer to consume

Interprocess Communication – Shared Memory

- An area of memory shared among the processes that wish to communicate
- The communication is under the control of the users processes not the operating system.
- **Benefits:**
  - Faster than message passing
- **Disadvantages:**
  - Major issues is to provide mechanism that will allow the user processes to synchronize their actions when they access shared memory.

Bounded-Buffer – Shared-Memory Solution

- Shared data

```
#define BUFFER_SIZE 10
typedef struct {
  . . .
} item;

item buffer[BUFFER_SIZE];
int in = 0;
int out = 0;
```

- Solution is correct, but can only use **BUFFER_SIZE-1** elements

Producer Process – Shared Memory

```
item next_produced;

while (true) {
   /* produce an item in next produced */
   while (((in + 1) % BUFFER_SIZE) == out)
       ; /* do nothing */
   buffer[in] = next_produced;
   in = (in + 1) % BUFFER_SIZE;
}
```

Consumer Process – Shared Memory

```
item next_consumed;

while (true) {
    while (in == out)
        ; /* do nothing */
    next_consumed = buffer[out];
    out = (out + 1) % BUFFER_SIZE;

    /* consume the item in next consumed */
}
```

What about Filling all the Buffers?

- Suppose that we wanted to provide a solution to the consumer-producer problem that fills **all** the buffers.
- We can do so by having an integer **`counter`** that keeps track of the number of full buffers.
- Initially, **`counter`** is set to 0.
- The integer **`counter`** is incremented by the producer after it produces a new buffer.
- The integer **`counter`** is and is decremented by the consumer after it consumes a buffer.

Producer

```
while (true) {
    /* produce an item in next produced */

    while (counter == BUFFER_SIZE)
        ; /* do nothing */
    buffer[in] = next_produced;
    in = (in + 1) % BUFFER_SIZE;
    counter++;
}
```

Consumer

```
while (true) {
    while (counter == 0)
        ; /* do nothing */
    next_consumed = buffer[out];
    out = (out + 1) % BUFFER_SIZE;
        counter--;
    /* consume the item in next consumed */
}
```

Race Condition

- `counter++` could be implemented as

```
register1 = counter
register1 = register1 + 1
counter = register1
```

- `counter--` could be implemented as

```
register2 = counter
register2 = register2 - 1
counter = register2
```

- Consider this execution interleaving with “count = 5” initially:

  S0: producer execute `register1 = counter` {register1 = 5}
  S1: producer execute `register1 = register1 + 1` {register1 = 6}
  S2: consumer execute `register2 = counter` {register2 = 5}
  S3: consumer execute `register2 = register2 – 1` {register2 = 4}
  S4: producer execute `counter = register1` {counter = 6 }
  S5: consumer execute `counter = register2` {counter = 4}

Race Condition (Cont.)

- Question – why was there no race condition in the first solution (where at most N – 1) buffers can be filled?
- More in Chapter 6.

Examples of IPC Systems - POSIX

- POSIX Shared Memory
  - Process first creates shared memory segment
    `shm_fd = shm_open(name, O CREAT | O RDWR, 0666);`
  - Also used to open an existing segment
  - Set the size of the object

    ```
    ftruncate(shm_fd, 4096);
    ```
  - Use `mmap()` to memory-map a file pointer to the shared memory object
  - Reading and writing to shared memory is done by using the pointer returned by `mmap()`.

IPC POSIX Producer

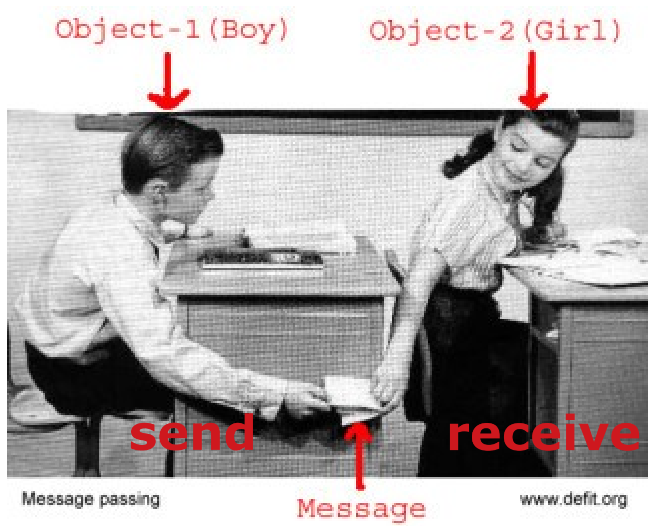
```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <fcntl.h>
#include <sys/shm.h>
#include <sys/stat.h>

int main()
{
/* the size (in bytes) of shared memory object */
const int SIZE = 4096;
/* name of the shared memory object */
const char *name = "OS";
/* strings written to shared memory */
const char *message_0 = "Hello";
const char *message_1 = "World!";

/* shared memory file descriptor */
int shm_fd;
/* pointer to shared memory obect */
void *ptr;

   /* create the shared memory object */
   shm_fd = shm_open(name, O_CREAT | O_RDWR, 0666);

   /* configure the size of the shared memory object */
   ftruncate(shm_fd, SIZE);

   /* memory map the shared memory object */
   ptr = mmap(0, SIZE, PROT_WRITE, MAP_SHARED, shm_fd, 0);

   /* write to the shared memory object */
   sprintf(ptr,"%s",message_0);
   ptr += strlen(message_0);
   sprintf(ptr,"%s",message_1);
   ptr += strlen(message_1);

   return 0;
}
```

IPC POSIX Consumer

```
#include <stdio.h>
#include <stdlib.h>
#include <fcntl.h>
#include <sys/shm.h>
#include <sys/stat.h>

int main()
{
/* the size (in bytes) of shared memory object */
const int SIZE = 4096;
/* name of the shared memory object */
const char *name = "OS";
/* shared memory file descriptor */
int shm_fd;
/* pointer to shared memory obect */
void *ptr;

   /* open the shared memory object */
   shm_fd = shm_open(name, O_RDONLY, 0666);

   /* memory map the shared memory object */
   ptr = mmap(0, SIZE, PROT_READ, MAP_SHARED, shm_fd, 0);

   /* read from the shared memory object */
   printf("%s",(char *)ptr);

   /* remove the shared memory object */
   shm_unlink(name);

   return 0;
}
```

IPC – Message Passing

- Message system – processes communicate with each other without sharing the same address space directly
- IPC facility provides two operations:
  - **`send`**(*message*)
  - **`receive`**(*message*)
- The *message* size is either fixed or variable



Message Passing

- If processes *P* and *Q* wish to communicate, they need to:
  - Establish a ***communication link*** between them
  - Exchange messages via send/receive
- Implementation issues:
  - How are links established?
  - Can a link be associated with more than two processes?
  - How many links can there be between every pair of communicating processes?
  - What is the capacity of a link?
  - Is the size of a message that the link can accommodate fixed or variable?
  - Is a link unidirectional or bi-directional?

Message Passing model

- **Physical link**
  - Shared memory, Hardware bus, Network
- **Logical link**
  - Naming
    - Direct (name the process), indirect (name the mailbox or link)
  - Synchronization
    - Block, Non-block
  - Buffering
    - Zero, bounded, un-bounded

Producer-Consumer: Message Passing

- Producer

```
message next_produced;
while (true) {
 /* produce an item in next_produced */

 send(next_produced);
}
```

- Consumer

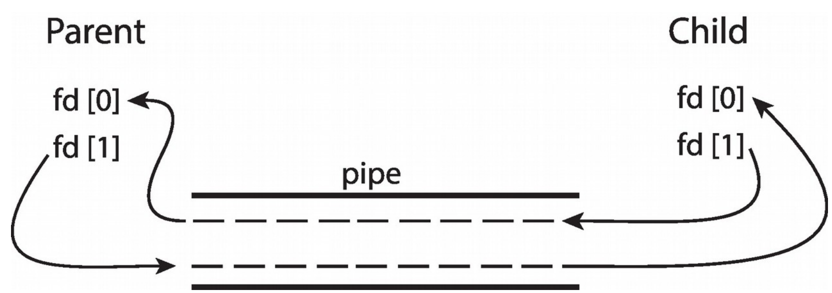
```
message next_consumed;
while (true) {
  receive(next_consumed)

 /* consume the item in next_consumed */
}
```

Pipes

- Acts as a conduit allowing two processes to communicate
- Issues:
  - Is communication unidirectional or bidirectional?
  - In the case of two-way communication, is it half or full-duplex?
  - Must there exist a relationship (i.e., ***parent-child***) between the communicating processes?
  - Can the pipes be used over a network?
- **Ordinary pipes** – cannot be accessed from outside the process that created it. Typically, a parent process creates a pipe and uses it to communicate with a child process that it created.
- **Named pipes** – can be accessed without a parent-child relationship.

Ordinary Pipes

- Ordinary Pipes allow communication in standard producer-consumer style
- Producer writes to one end (the **write-end** of the pipe)
- Consumer reads from the other end (the **read-end** of the pipe)
- Ordinary pipes are therefore unidirectional
- Require parent-child relationship between communicating processes



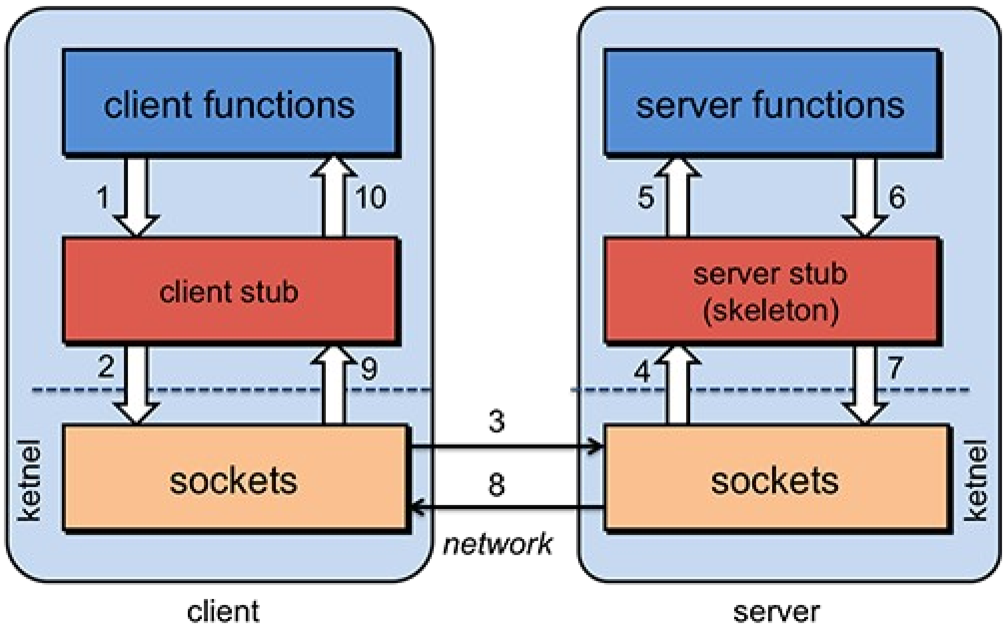
- Windows calls these **anonymous pipes**

Named Pipes

- Named Pipes are more powerful than ordinary pipes
- Communication is bidirectional
- No parent-child relationship is necessary between the communicating processes
- Several processes can use the named pipe for communication
- Provided on both UNIX and Windows systems

Communications in Client-Server Systems

- Sockets
- Remote Procedure Calls (RPC)

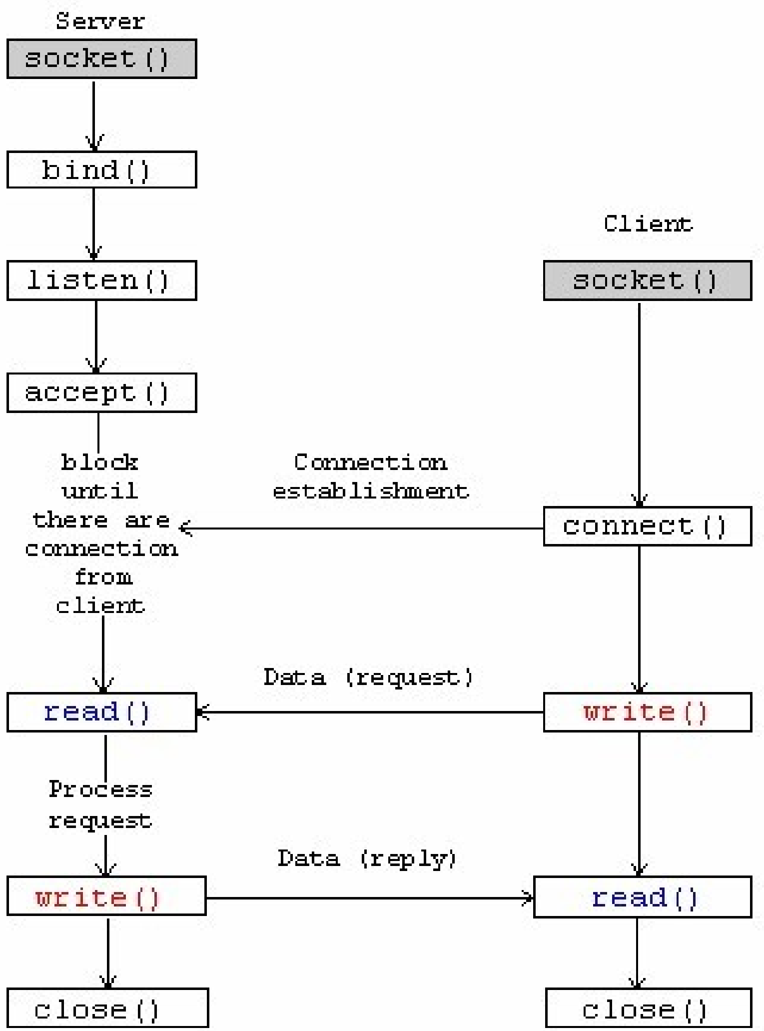


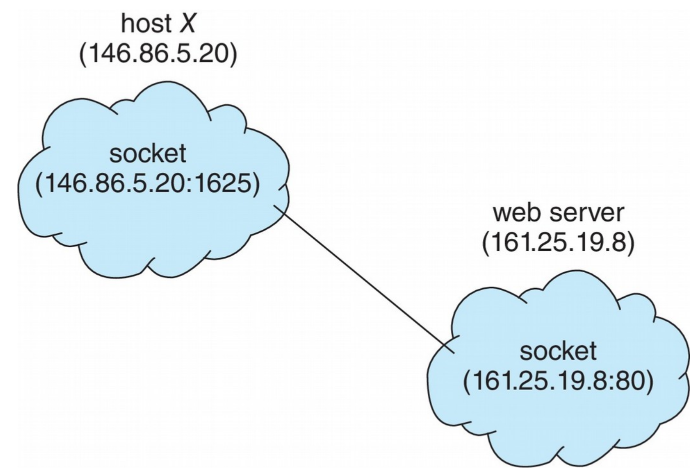
Sockets

- A **socket** is defined as an endpoint for communication
- Concatenation of IP address and **port** – a number included at start of message packet to differentiate network services on a host
- The socket **161.25.19.8:1625** refers to port **1625** on host **161.25.19.8**
- Communication consists between a pair of sockets
- All ports below 1024 are ***well known***, used for standard services
- Special IP address 127.0.0.1 (**loopback**) to refer to system on which process is running

- Three types of sockets
  - **Connection-oriented** (**TCP**)
  - **Connectionless** (**UDP**)
  - `MulticastSocket` class– data can be sent to multiple recipients
- Consider this “Date” server in Java:

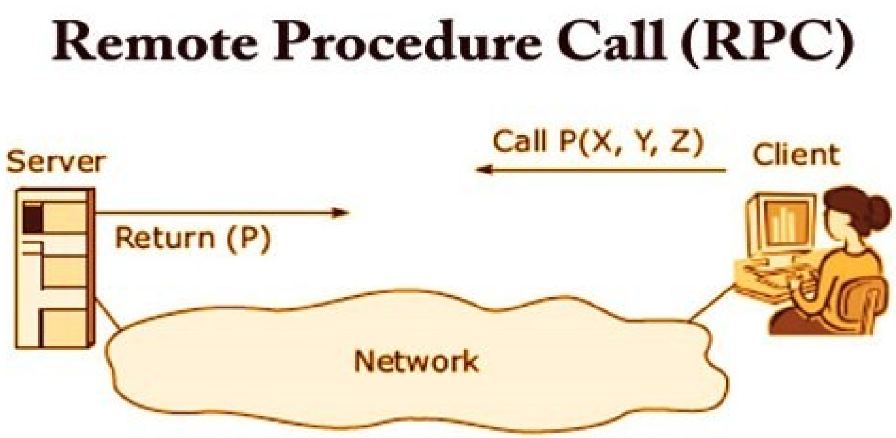
Socket Communication





Remote Procedure Calls

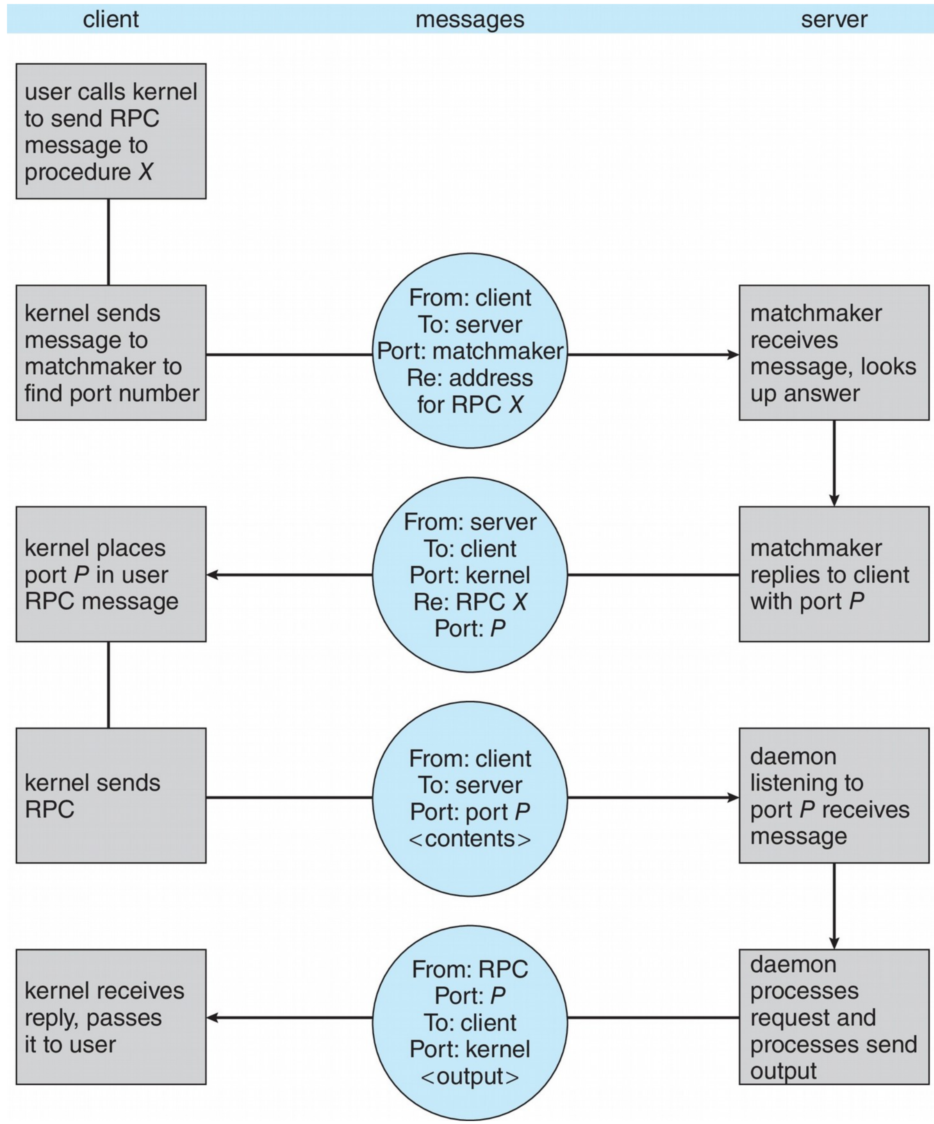
- Remote procedure call (RPC) abstracts procedure calls between processes on networked systems
  - Again uses ports for service differentiation
- **Stubs** – client-side proxy for the actual procedure on the server
- The client-side stub locates the server and **marshalls** the parameters
- The server-side stub receives this message, unpacks the marshalled parameters, and performs the procedure on the server
- On Windows, stub code compile from specification written in **Microsoft Interface Definition Language** (**MIDL**)



Remote Procedure Calls (Cont.)

- Data representation handled via **External Data Representation** (**XDL**) format to account for different architectures
  - **Big-endian** and **little-endian**
- Remote communication has more failure scenarios than local
  - Messages can be delivered ***exactly once*** rather than ***at most once***
- OS typically provides a rendezvous (or **matchmaker**) service to connect client and server

Execution of RPC



Examples of IPC Applications

- X Server and client
  - Unix-domain sockets, named pipes, …
- Piping commands in shell
  - pipe
- Database server
  - Socket, RPC
- Web services
  - Kind of RPC
- …

End of Chapter 3