Interprocess Communication

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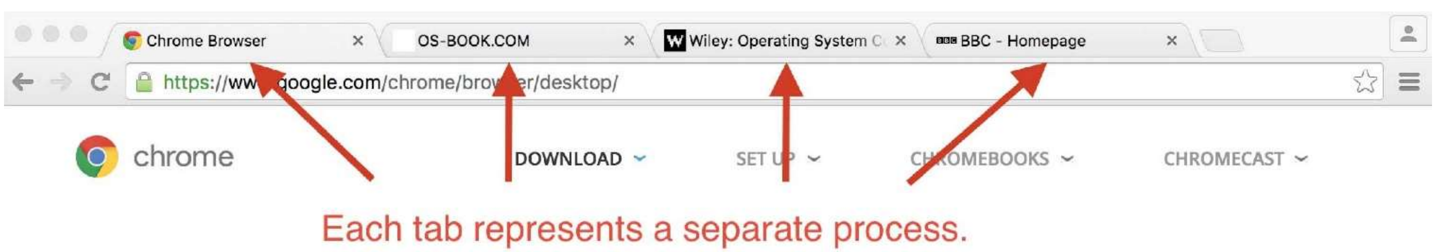
517-312 Operating Systems

Multi-process Architecture: Chrome Browser

- Many web browsers ran as single process (some still do)
  - If one web site causes trouble, entire browser can hang or crash
- Google Chrome Browser is multiprocess with 3 different types of processes:
  - **Browser** process manages user interface, disk and network I/O
  - **Renderer** process renders web pages, deals with HTML, Javascript. A new renderer created for each website opened
    - Runs in **sandbox** restricting disk and network I/O, minimizing effect of security exploits
  - **Plug-in** process for each type of plug-in

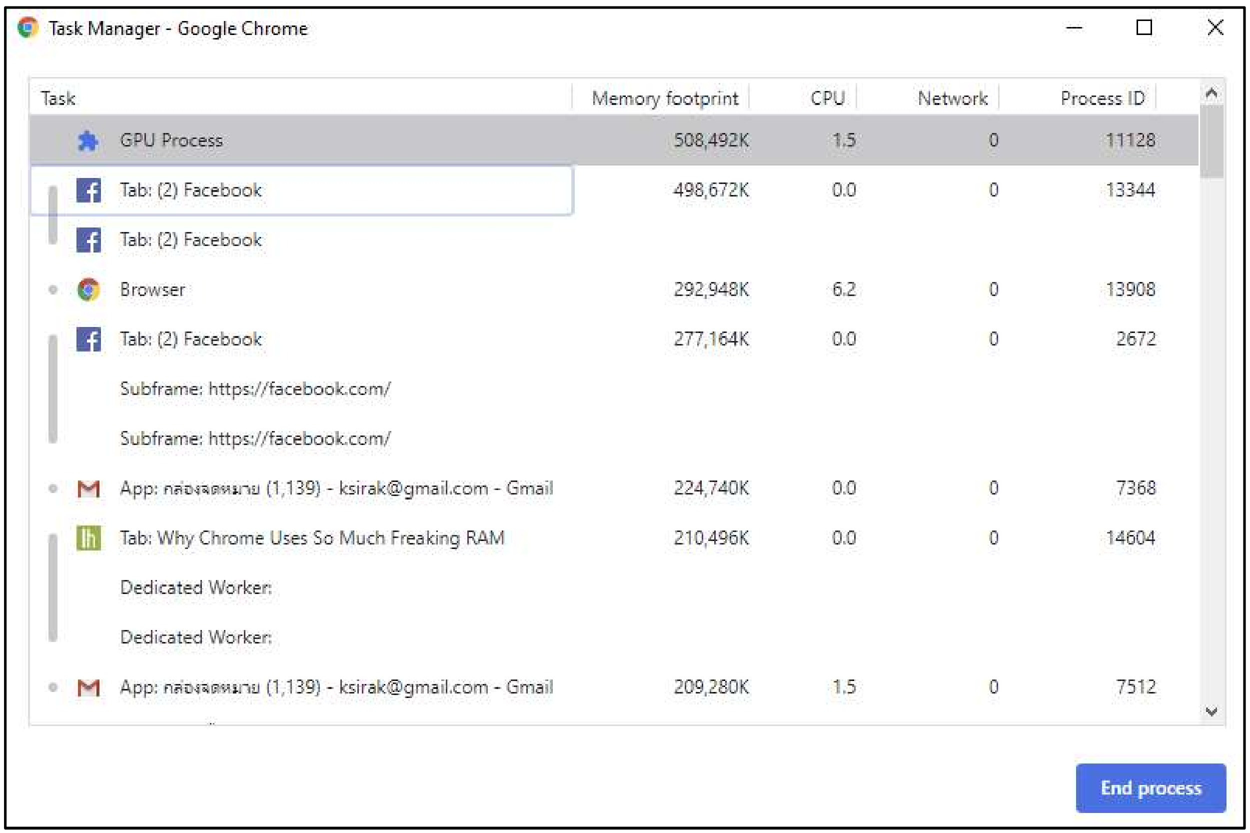


Why Chrome uses so much RAM??

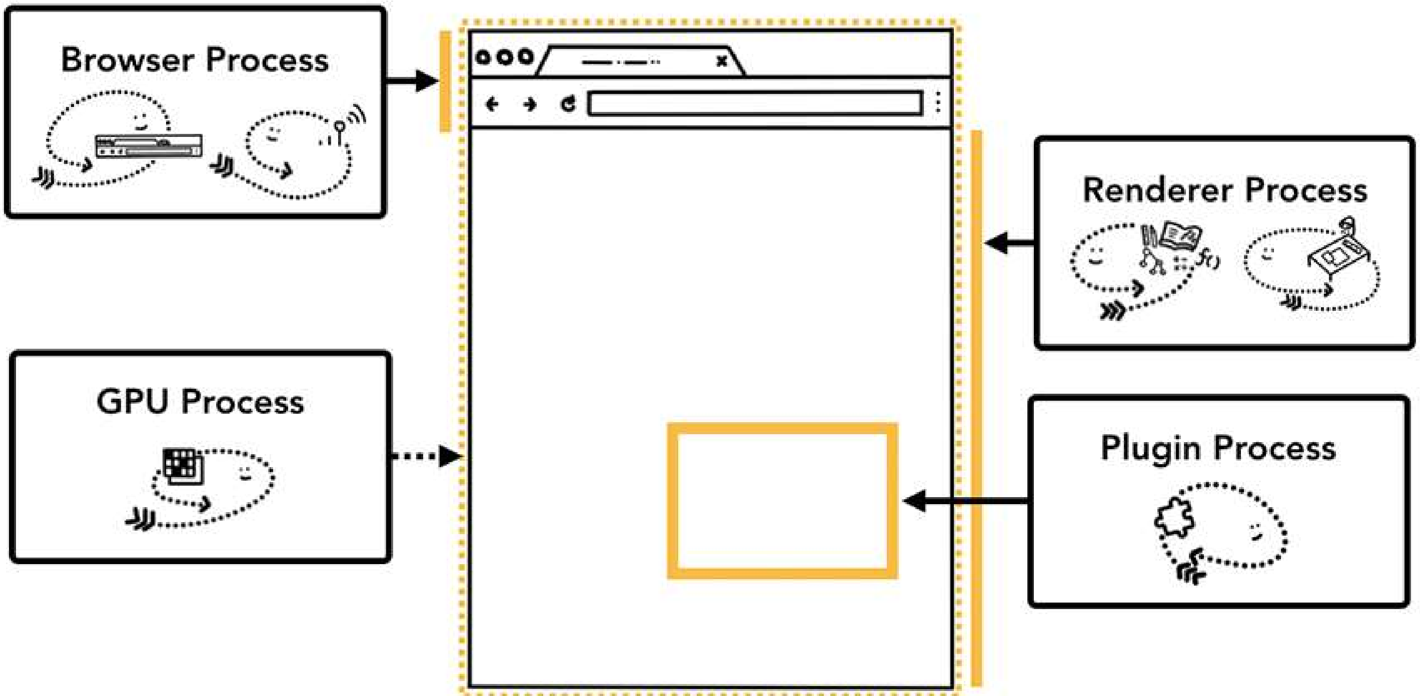
- Chrome splits every tab and extension into its own process
  - It duplicates tasks for every tab, more tab more memory
  - If any process crashes, it does not bring down other tabs
- Chrome has pre-rendering feature, it does not wait until the entire page content arrived. This can cause higher memory usage but makes web pages load faster
- Chrome’s extensions also consume memory

Chrome’s task manager

- Open Chrome and then press Shift+Esc
- Chrome’s task manager gives a more accurate look how much memory each tab or extension is taking up.



Chrome Architecture



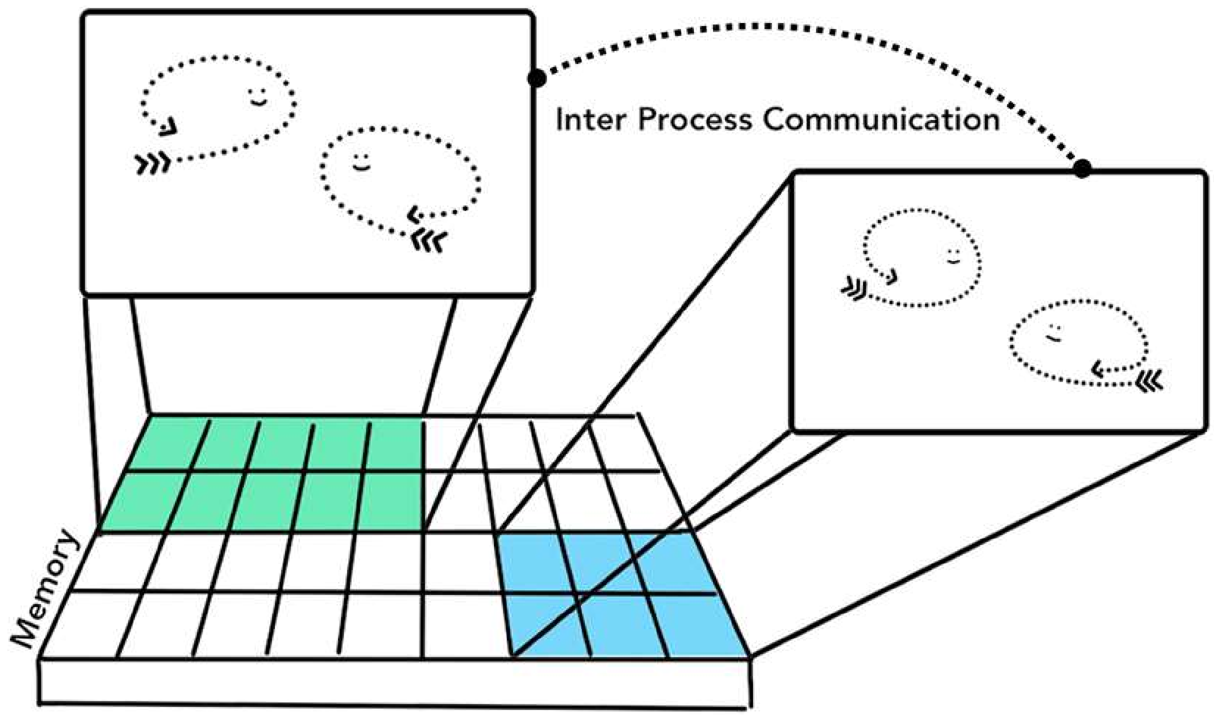
https://developers.google.com/web/updates/2018/09/inside-browser-part1

Chrome’s Process and What it controls

Browser	Controls "chrome" part of the application including address bar, bookmarks, back and forward buttons. Also handles the invisible, privileged parts of a web browser such as network requests and file access.
Renderer	Controls anything inside of the tab where a website is displayed.
Plugin	Controls any plugins used by the website, for example, flash.
GPU	Handles GPU tasks in isolation from other processes. It is separated into different process because GPUs handles requests from multiple apps and draw them in the same surface.

https://developers.google.com/web/updates/2018/09/inside-browser-part1

Inter-process Communication is needed



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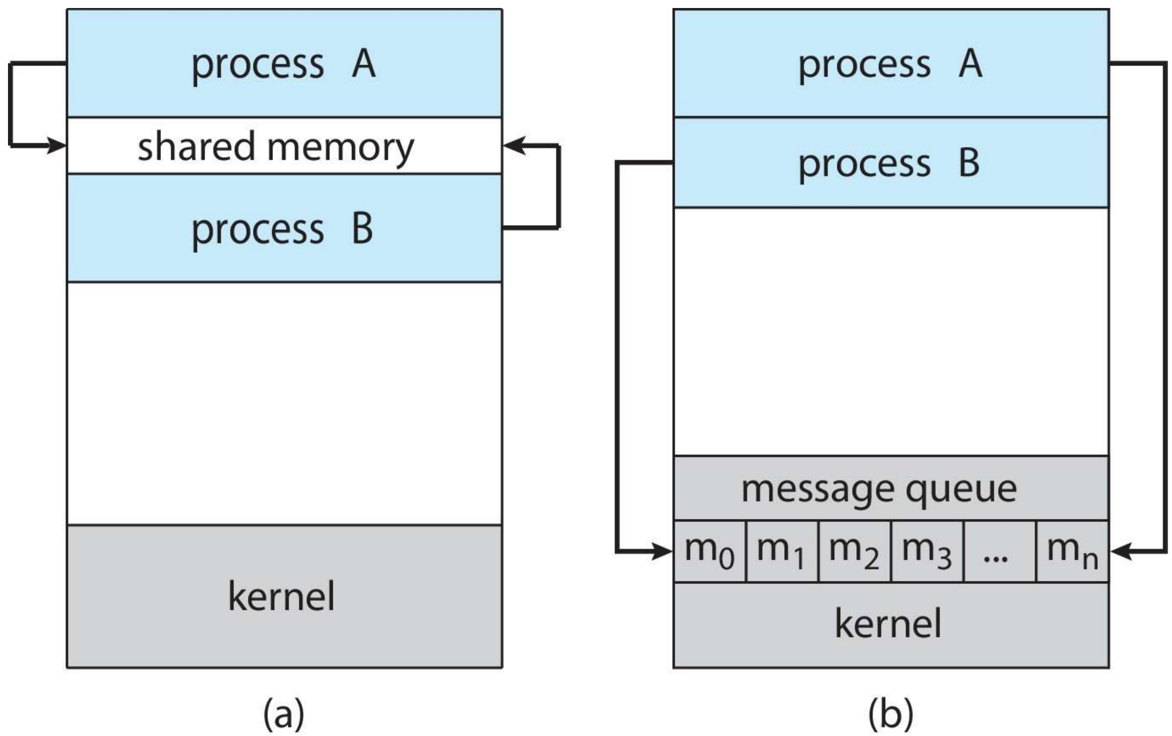
Inter-process Communication

- 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 **inter-process communication** (**IPC**)
- Two models of IPC
  - **Shared memory**
  - **Message passing**

Communications Models

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



Cooperating Processes

- ***Independent*** process cannot affect or be affected by the execution of another process
- ***Cooperating*** process can affect or be affected by the execution of another process
- Advantages of process cooperation
  - Information sharing
  - Computation speed-up
  - Modularity
  - Convenience

Producer-Consumer Problem

- Paradigm for cooperating processes, *producer* process produces information that is consumed by a *consumer* process
- Producer-Consume paradigm is the same as client-server model
- In shared memory with Producer-Consume, buffers are needed for both sides. There are 2 types of buffers
  - **unbounded-buffer** places no practical limit on the size of the buffer
  - **bounded-buffer** assumes that there is a fixed buffer size

IPC : 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
- Major issues is to provide mechanism that will allow the user processes to synchronize their actions when they access shared memory

IPC : Message Passing

- Mechanism for processes to communicate and to synchronize their actions
- Message system – processes communicate with each other without resorting to shared variables
- IPC facility provides two operations:
  - **`send`**(*message*)
  - **`receive`**(*message*)
- The *message* size is either fixed or variable
  - Fixed message size: programmer have to manage message size
  - Variable message size: complex system-level implementation

Message Passing (Cont.)

- 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?
    - The processes need to know each other's identity
  - 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 (Cont.)

- Implementation of communication link
  - Physical:
    - Shared memory
    - Hardware bus
    - Network
  - Logical:
    - Direct or indirect
    - Synchronous or asynchronous
    - Automatic or explicit buffering

Direct Communication

- Processes must name each other explicitly:
  - **`send`** (*P, message*) – send a message to process P
  - **`receive`**(*Q, message*) – receive a message from process Q
- Properties of communication link
  - Links are established automatically
  - A link is associated with exactly one pair of communicating processes
  - Between each pair there exists exactly one link
  - The link may be unidirectional, but is usually bi-directional

Indirect Communication

- Messages are directed and received from mailboxes (also referred to as ports)
  - Each mailbox has a unique id
  - Processes can communicate only if they share a mailbox
- Properties of communication link
  - Link established only if processes share a common mailbox
  - A link may be associated with many processes
  - Each pair of processes may share several communication links
  - Link may be unidirectional or bi-directional

Indirect Communication

- Operations
  - create a new mailbox (port)
  - send and receive messages through mailbox
  - destroy a mailbox
- Primitives are defined as:
  - **`send`**(*A, message*) – send a message to mailbox A
  - **`receive`**(*A, message*) – receive a message from mailbox A

Indirect Communication

- Mailbox sharing
  - P_1, P_2, and P_3 share mailbox A
  - P_1, sends; P_2 and P_3 receive
  - Who gets the message?
- Solutions
  - Allow a link to be associated with at most two processes
  - Allow only one process at a time to execute a receive operation
  - Allow the system to select arbitrarily the receiver. Sender is notified who the receiver was

Synchronization

- Message passing may be either blocking or non-blocking
- Blocking is considered synchronous
  - Blocking send -- the sender is blocked until the message is received
  - Blocking receive -- the receiver is blocked until a message is available
- Non-blocking is considered asynchronous
  - Non-blocking send -- the sender sends the message and continue
  - Non-blocking receive -- the receiver receives:
    - A valid message, or
    - Null message
- Different combinations possible
  - If both send and receive are blocking, we have a rendezvous

Buffering

- Queue of messages attached to the link.
- Implemented in one of three ways
  1. Zero capacity – no messages are queued on a link.
     Sender must wait for receiver (rendezvous)
  2. Bounded capacity – finite length of *n* messages
     Sender must wait if link full
  3. Unbounded capacity – infinite length
     Sender never waits
- The zero capacity is sometimes referred to as a message system with no buffering while the other two are referred as automatic buffering

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;
}
```

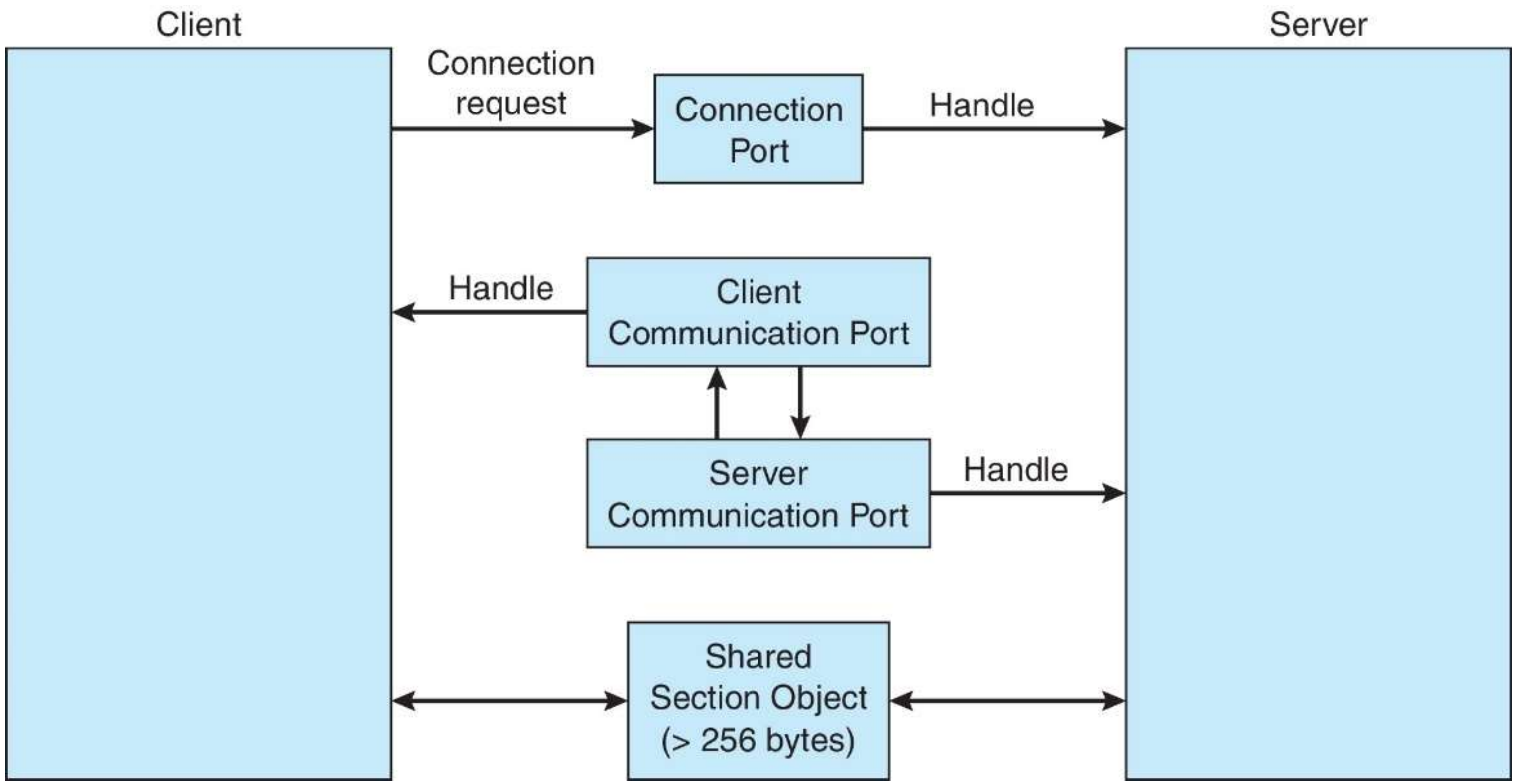
IPC POSIX Consumer

```
#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;
}
```

Examples of IPC Systems – Windows

- Message-passing centric via **advanced local procedure call** **(LPC)** facility
  - Only works between processes on the same system
  - Uses ports (like mailboxes) to establish and maintain communication channels
  - Communication works as follows:
    - The client opens a handle to the subsystem's **connection port** object.
    - The client sends a connection request.
    - The server creates two private **communication ports** and returns the handle to one of them to the client.
    - The client and server use the corresponding port handle to send messages or callbacks and to listen for replies.

Local Procedure Calls in Windows

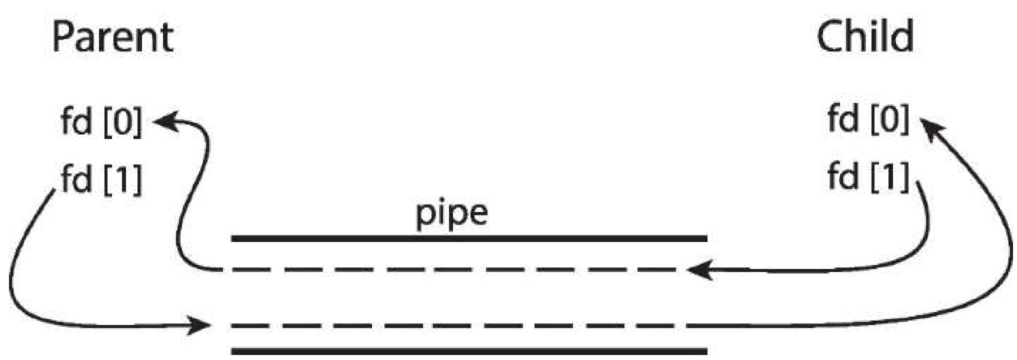


Pipes

- 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**

Example write and read from Parent and Child

```
#include<stdio.h>
#include<unistd.h>

int main() {
  int pipefds[2];
  int returnstatus;
  int pid;
  char writemessages[2][20]={"Hi", "Hello"};
  char readmessage[20];
  returnstatus = pipe(pipefds);
  if (returnstatus == -1) {
    printf("Unable to create pipe\n");
    return 1;
  }
  pid = fork();
```

Example write and read from Parent and Child (Cont)

```
// Child process
  if (pid == 0) {
    read(pipefds[0], readmessage, sizeof(readmessage));
    printf("Child Process – Reading from pipe – Message 1 is %s\n", readmessage);
    read(pipefds[0], readmessage, sizeof(readmessage));
    printf("Child Process – Reading from pipe – Message 2 is %s\n", readmessage);
  } else { //Parent process
    printf("Parent Process –Writing to pipe - Message 1 is %s\n", writemessages[0]);
    write(pipefds[1], writemessages[0], sizeof(writemessages[0]));
    printf("Parent Process - Writing to pipe - Message 2 is %s\n", writemessages[1]);
    write(pipefds[1], writemessages[1], sizeof(writemessages[1]));
  }
  return 0;
}
```

https://www.tutorialspoint.com/inter_process_communication/inter_process_communication_pipes.htm

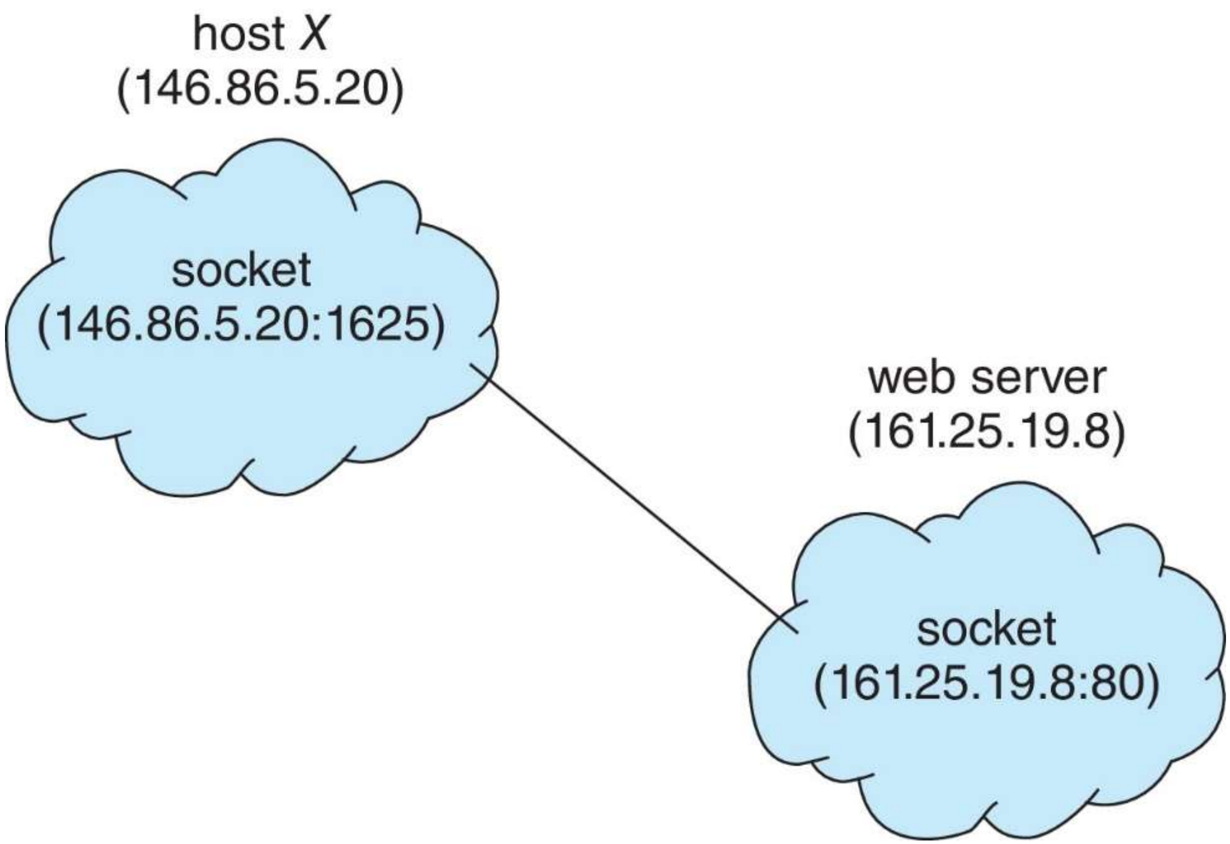
Communications in Client-Server Systems

- Sockets
- Remote Procedure Calls

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

Socket Communication



Sockets in Java

- Three types of sockets
  - **Connection-oriented** (**TCP**)
  - **Connectionless** (**UDP**)
  - **`MulticastSocket`** class– data can be sent to multiple recipients

- Consider this “Date” server in Java:

```
import java.net.*;
import java.io.*;

public class DateServer
{
   public static void main(String[] args) {
      try {
         ServerSocket sock = new ServerSocket(6013);

         /* now listen for connections */
         while (true) {
            Socket client = sock.accept();

            PrintWriter pout = new
             PrintWriter(client.getOutputStream(), true);

            /* write the Date to the socket */
            pout.println(new java.util.Date().toString());

            /* close the socket and resume */
            /* listening for connections */
            client.close();
         }
      }
      catch (IOException ioe) {
         System.err.println(ioe);
      }
   }
}
```

Sockets in Java

- The equivalent Date client

```
import java.net.*;
import java.io.*;

public class DateClient
{
   public static void main(String[] args) {
      try {
         /* make connection to server socket */
         Socket sock = new Socket("127.0.0.1",6013);

         InputStream in = sock.getInputStream();
         BufferedReader bin = new
            BufferedReader(new InputStreamReader(in));

         /* read the date from the socket */
         String line;
         while ( (line = bin.readLine()) != null)
            System.out.println(line);

         /* close the socket connection*/
         sock.close();
      }
      catch (IOException ioe) {
         System.err.println(ioe);
      }
   }
}
```

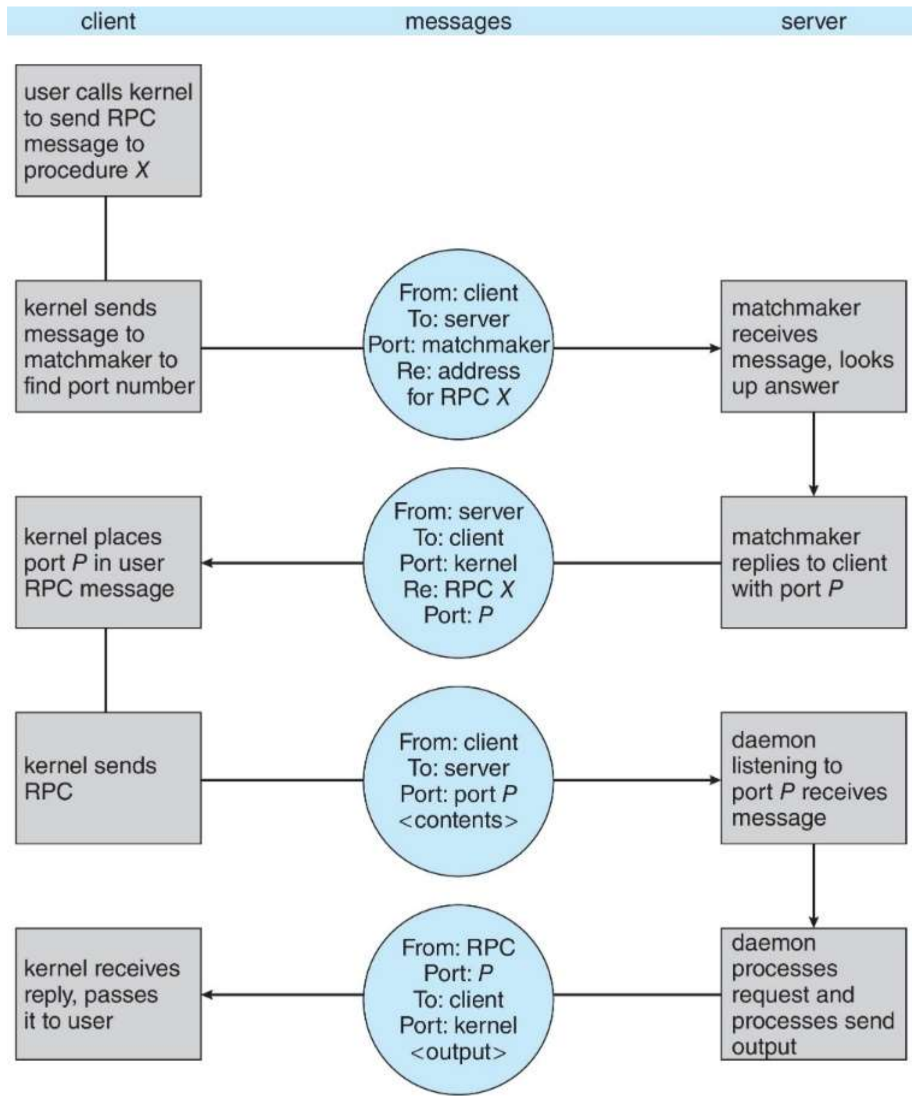
Remote Procedure Calls

- 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



JAVA RMI

- Java remote method invocation (Java RMI) is a Java API that performs remote method invocation, the object-oriented equivalent of remote procedure calls (RPC)
- RMI supports for direct transfer of serialized Java classes and distributed garbage-collection
- In order to support code running in a non-JVM context, CORBA has been used

Essential Characteristics of RMI

- Full integration with object-oriented programming language
  - Ability to exploit objects, class and inheritance
  - Added benefits from exploiting built in (object-oriented) approaches to, for example, exception handling
- From procedure calling to method invocation
- Added expressiveness of supporting object references
- More sophisticated options for parameter passing
    - Pass by (object) reference
    - Pass by value (exploiting serialisation)
- Often integrated with code (object) mobility
  - E.G. Use of class loading in RMI

Homework

- The alternative way of using RPC is REST (Representational State Transfer) API
- What is REST and how it work?
- What is API and is it different from REST?
- What is web service?
- What is SOAP, XML-API, JSON etc.?
- You must know about this because you may use it in the future.
- These will be asked in Midterm Exam.

References

- Almost all slides are from Operating System Concepts 10th book official slides by Abraham Silberschatz, Greg Gagne, Peter B. Galvin
- https://developers.google.com/web/updates/2018/09/inside-browser-part1
- https://www.tutorialspoint.com/inter_process_communication/inter_process_communication_pipes.htm