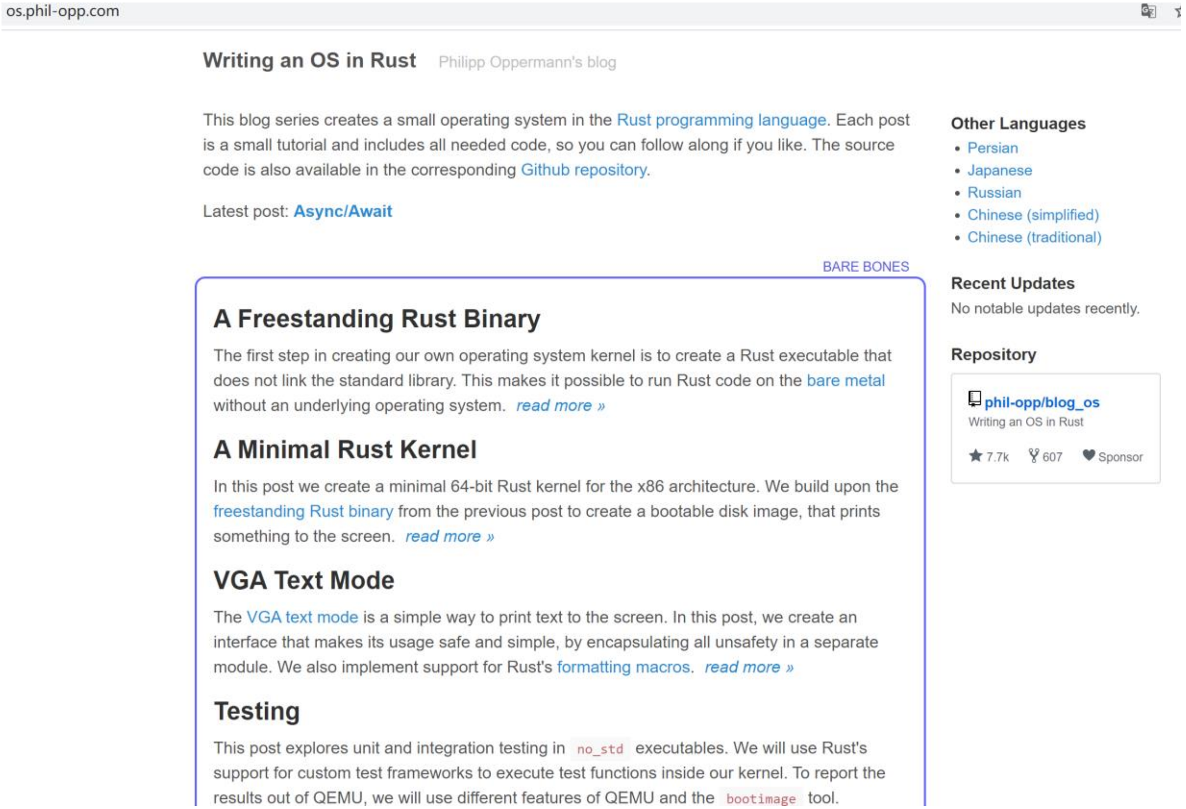
Writing OS

- **Writing an OS in Rust**

https://os.phil-opp.com/



os.phil-opp.com

Writing an OS in Rust Philipp Oppermann's blog

This blog series creates a small operating system in the Rust programming language. Each post is a small tutorial and includes all needed code, so you can follow along if you like. The source code is also available in the corresponding Github repository.

Latest post: **Async/Await**

BARE BONES

A Freestanding Rust Binary

The first step in creating our own operating system kernel is to create a Rust executable that does not link the standard library. This makes it possible to run Rust code on the bare metal without an underlying operating system. *read more »*

A Minimal Rust Kernel

In this post we create a minimal 64-bit Rust kernel for the x86 architecture. We build upon the freestanding Rust binary from the previous post to create a bootable disk image, that prints something to the screen. *read more »*

VGA Text Mode

The VGA text mode is a simple way to print text to the screen. In this post, we create an interface that makes its usage safe and simple, by encapsulating all unsafety in a separate module. We also implement support for Rust's formatting macros. *read more »*

Testing

This post explores unit and integration testing in `no_std` executables. We will use Rust's support for custom test frameworks to execute test functions inside our kernel. To report the results out of QEMU, we will use different features of QEMU and the `bootimage` tool.

Other Languages

- Persian
- Japanese
- Russian
- Chinese (simplified)
- Chinese (traditional)

Recent Updates

No notable updates recently.

Repository

phil-opp/blog_os
Writing an OS in Rust
7.7k 607 Sponsor

Writing OS

- **Write operating system from scratch**

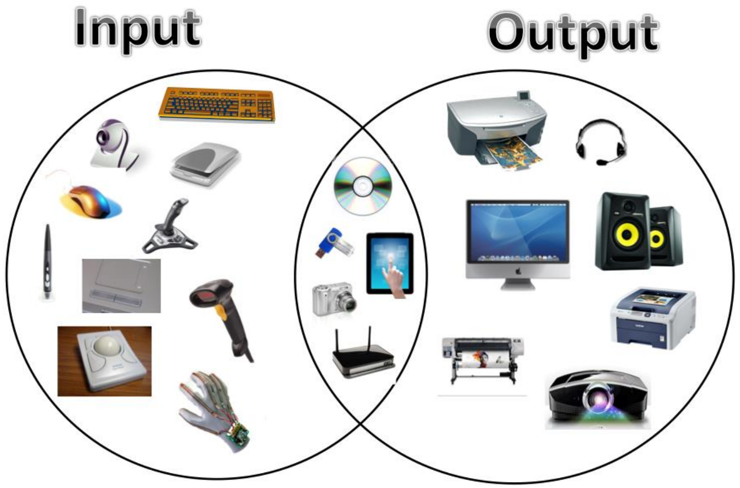
  https://learningos.github.io/rcore_step_by_step_webdoc/

Course Review

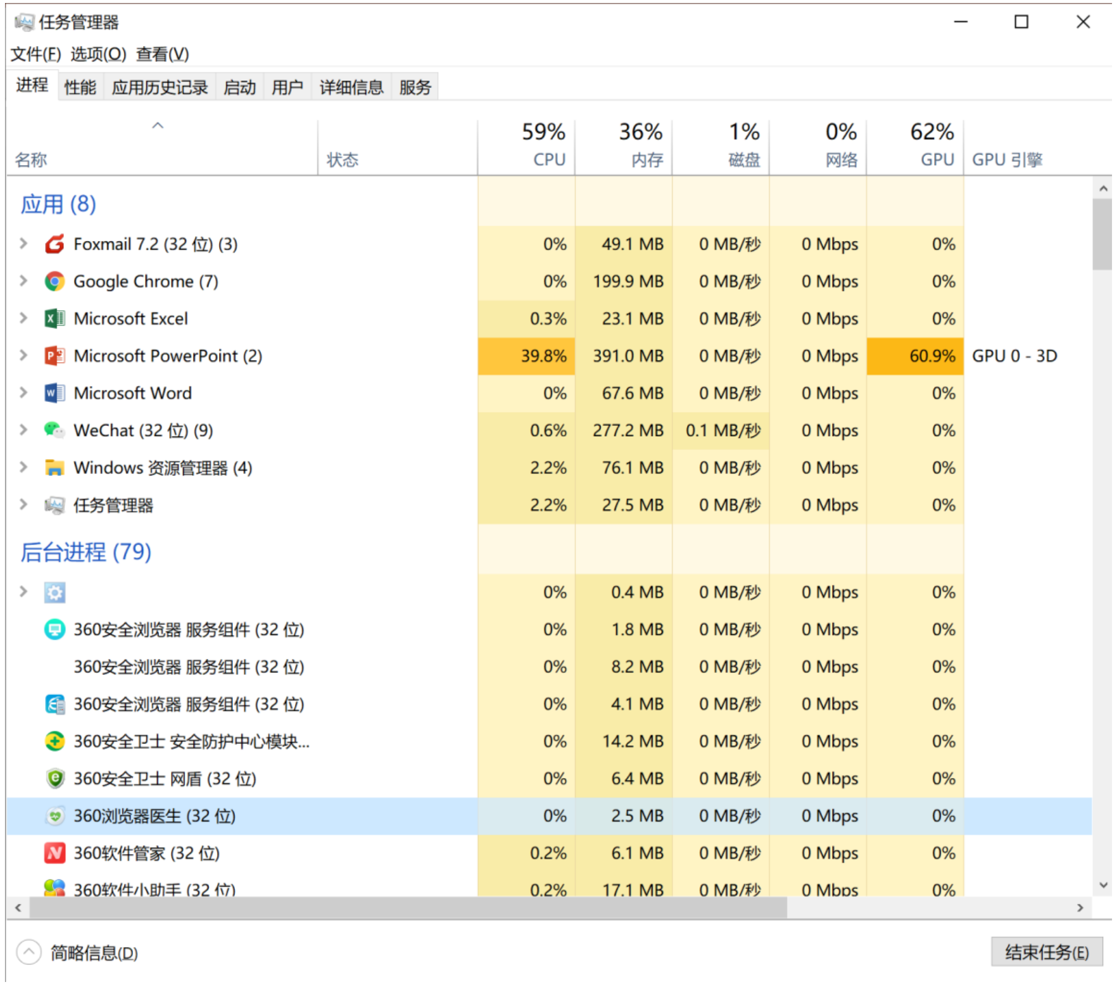
- What is OS ?
- OS components
- OS services
- OS design goals
- OS characteristics
- Early OSs

Manage Execution of Applications

- Resources are made available to multiple applications
- Processor is switched among multiple applications
- The processor and I/O devices can be used efficiently




Windows 任务管理器
文件(F) 选项(O) 查看(V) 关机(U) 帮助(H)
应用程序 进程 性能 联网 用户
映像名称 用户名 CPU 内存使用
AcroRd32Info.exe Formal 00 7,548 K
alg.exe LOCAL SERVICE 00 3,928 K
ati2evxx.exe SYSTEM 00 4,196 K
ati2evxx.exe SYSTEM 00 4,692 K
ArtecTribe.exe Formal 00 82,792 K
CCC.exe Formal 00 7,624 K
Com4QLBEx.exe SYSTEM 00 3,604 K
csrss.exe SYSTEM 01 10,600 K
ctfmon.exe Formal 00 3,816 K
explorer.exe Formal 00 16,596 K
hpqwmiex.exe SYSTEM 00 4,296 K
lsass.exe SYSTEM 00 1,188 K
MDM.EXE SYSTEM 00 3,248 K
MOM.exe Formal 00 6,432 K
POWERPNT.EXE Formal 00 43,844 K
QLBCTRL.exe Formal 00 5,928 K
RavMonD.exe SYSTEM 00 8,192 K
rfwmain.exe Formal 00 12,796 K
显示所有用户的进程(S)
结束进程(E)
进程数: 41 CPU 使用: 2% 提交更改: 777M / 3935M


任务管理器
文件(F) 选项(O) 查看(V)
进程 性能 应用历史记录 启动 用户 详细信息 服务
名称 状态 59% CPU 36% 内存 1% 磁盘 0% 网络 62% GPU GPU 引擎
应用 (8)
Foxmail 7.2 (32 位) (3) 0% 49.1 MB 0 MB/秒 0 Mbps 0%
Google Chrome (7) 0% 199.9 MB 0 MB/秒 0 Mbps 0%
Microsoft Excel 0.3% 23.1 MB 0 MB/秒 0 Mbps 0%
Microsoft PowerPoint (2) 39.8% 391.0 MB 0 MB/秒 0 Mbps 60.9% GPU 0 - 3D
Microsoft Word 0% 67.6 MB 0 MB/秒 0 Mbps 0%
WeChat (32 位) (9) 0.6% 277.2 MB 0.1 MB/秒 0 Mbps 0%
Windows 资源管理器 (4) 2.2% 76.1 MB 0 MB/秒 0 Mbps 0%
任务管理器 2.2% 27.5 MB 0 MB/秒 0 Mbps 0%
后台进程 (79)
0% 0.4 MB 0 MB/秒 0 Mbps 0%
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360安全浏览器 服务组件 (32 位) 0% 4.1 MB 0 MB/秒 0 Mbps 0%
360安全卫士 安全防护中心模块... 0% 14.2 MB 0 MB/秒 0 Mbps 0%
360安全卫士 网盾 (32 位) 0% 6.4 MB 0 MB/秒 0 Mbps 0%
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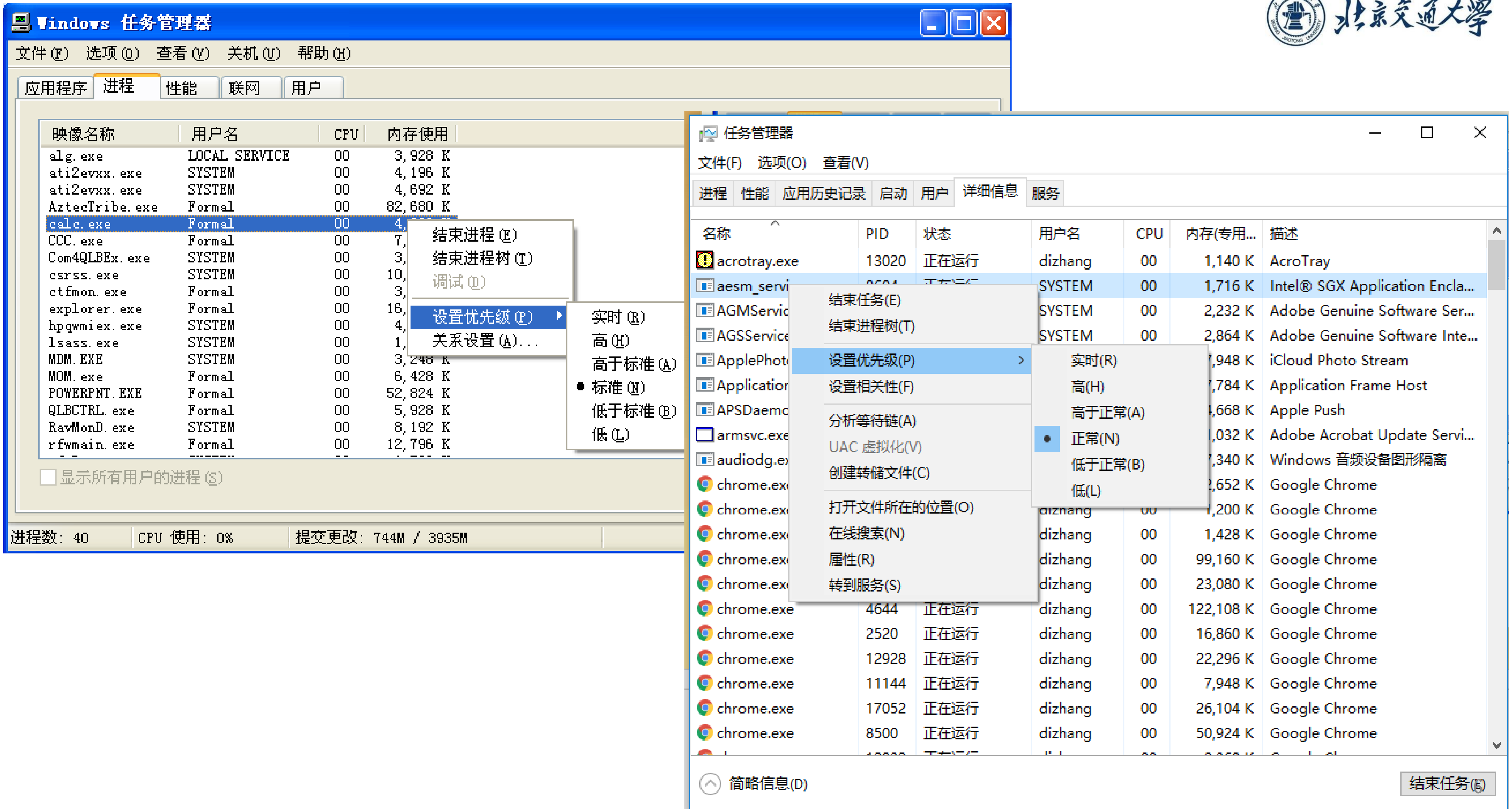
360软件小助手 (32 位) 0.2% 17.1 MB 0 MB/秒 0 Mbps 0%
简略信息(D)
结束任务(E)


Windows 任务管理器
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hpqwmiex.exe SYSTEM 00
lsass.exe SYSTEM 00
MDM.EXE SYSTEM 00
MOM.exe Formal 00 6,428 K
POWERPNT.EXE Formal 00 52,824 K
QLBCTRL.exe Formal 00 5,928 K
RavMonD.exe SYSTEM 00 8,192 K
rfwmain.exe Formal 00 12,796 K
结束进程(E)
结束进程树(T)
调试(D)
设置优先级(P)
关系设置(A)...
实时(R)
高(H)
高于标准(A)
标准(N)
低于标准(B)
低(L)
显示所有用户的进程(S)
进程数: 40
CPU 使用: 0%
提交更改: 744M / 3935M
任务管理器
文件(F) 选项(O) 查看(V)
进程 性能 应用历史记录 启动 用户 详细信息 服务
名称 PID 状态 用户名 CPU 内存(专用... 描述
acrotray.exe 13020 正在运行 dizhang 00 1,140 K AcroTray
aesm_servi SYSTEM 00 1,716 K Intel® SGX Application Encla...
AGMServic SYSTEM 00 2,232 K Adobe Genuine Software Ser...
AGSService SYSTEM 00 2,864 K Adobe Genuine Software Inte...
ApplePhot iCloud Photo Stream
Application Application Frame Host
APSDaemo Apple Push
armsvc.exe Adobe Acrobat Update Servi...
audiodg.ex Windows 音频设备图形隔离
chrome.exe Google Chrome
chrome.exe dizhang 00 1,428 K Google Chrome
chrome.exe dizhang 00 99,160 K Google Chrome
chrome.exe dizhang 00 23,080 K Google Chrome
chrome.exe 4644 正在运行 dizhang 00 122,108 K Google Chrome
chrome.exe 2520 正在运行 dizhang 00 16,860 K Google Chrome
chrome.exe 12928 正在运行 dizhang 00 22,296 K Google Chrome
chrome.exe 11144 正在运行 dizhang 00 7,948 K Google Chrome
chrome.exe 17052 正在运行 dizhang 00 26,104 K Google Chrome
chrome.exe 8500 正在运行 dizhang 00 50,924 K Google Chrome
结束任务(E)
结束进程树(T)
设置优先级(P)
设置相关性(F)
分析等待链(A)
UAC 虚拟化(V)
创建转储文件(C)
打开文件所在的位置(O)
在线搜索(N)
属性(R)
转到服务(S)
实时(R)
高(H)
高于正常(A)
正常(N)
低于正常(B)
低(L)
简略信息(D)
结束任务(E)

Processes

Outline

- Process Concept
- Process Scheduling
- Operations on Processes
- Interprocess Communication
- Communication in Client-Server Systems

What is a Process?

How to describe a Process?

Process Concept

What is a process?

- One program which has an independent function works on certain data set dynamically and allocates resources dynamically
- **Process** is a program in execution
- **An instance** of a **program** running on a computer

Difference Between Process & Program

- A program is a passive entity but a process is an active entity
- Process is dynamic, and the program is static
- Process is temporary, the program is permanent
- The elements of process and program is different
  - Process: **P**rocess **C**ontrol **B**lock
  - Program: Code and Data
- Two processes may be associated with the same program, they are considered as separate execution sequences

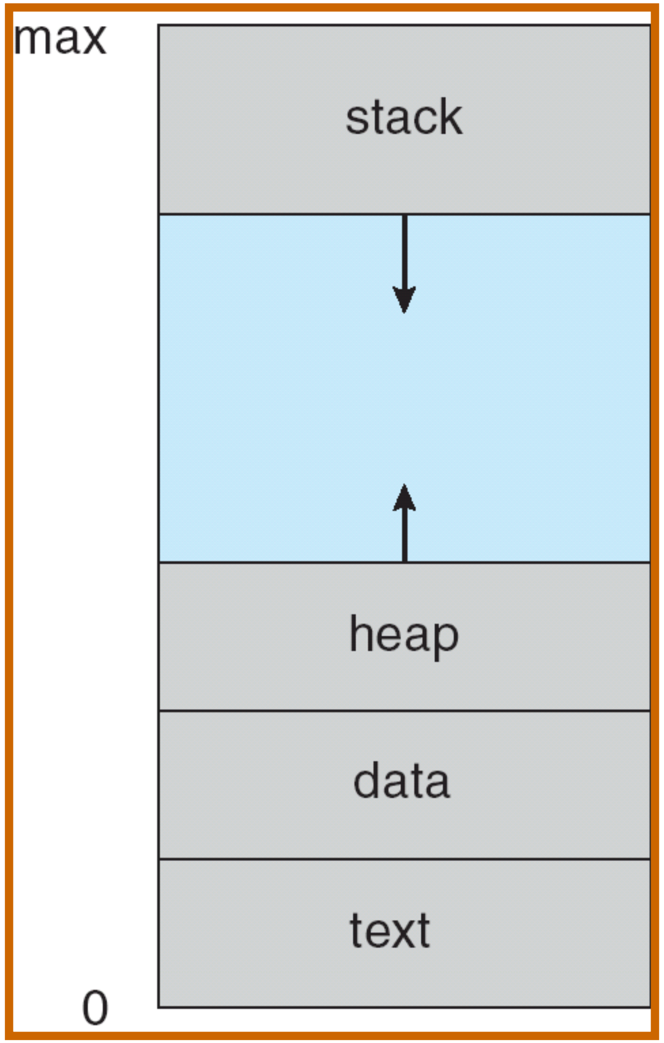
Processes

- A system therefore consists of a collection of processes:
  - Operating system processes execute system code, *and*
  - User processes execute user code.

System Process

& User Process

Process Structure in Memory



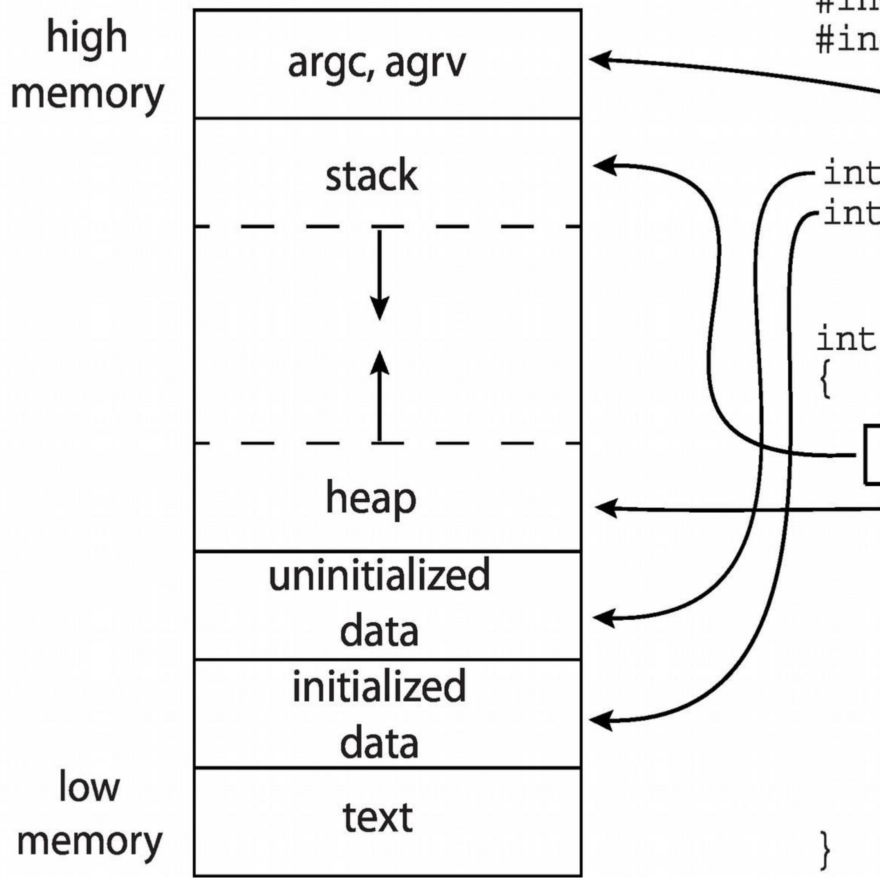
Temporary data
(function parameters, return addresses, local variables)

Dynamically allocated memory at runtime

Global variables

Value of program counter;
Contents of processor's registers

Memory Layout of a C Program

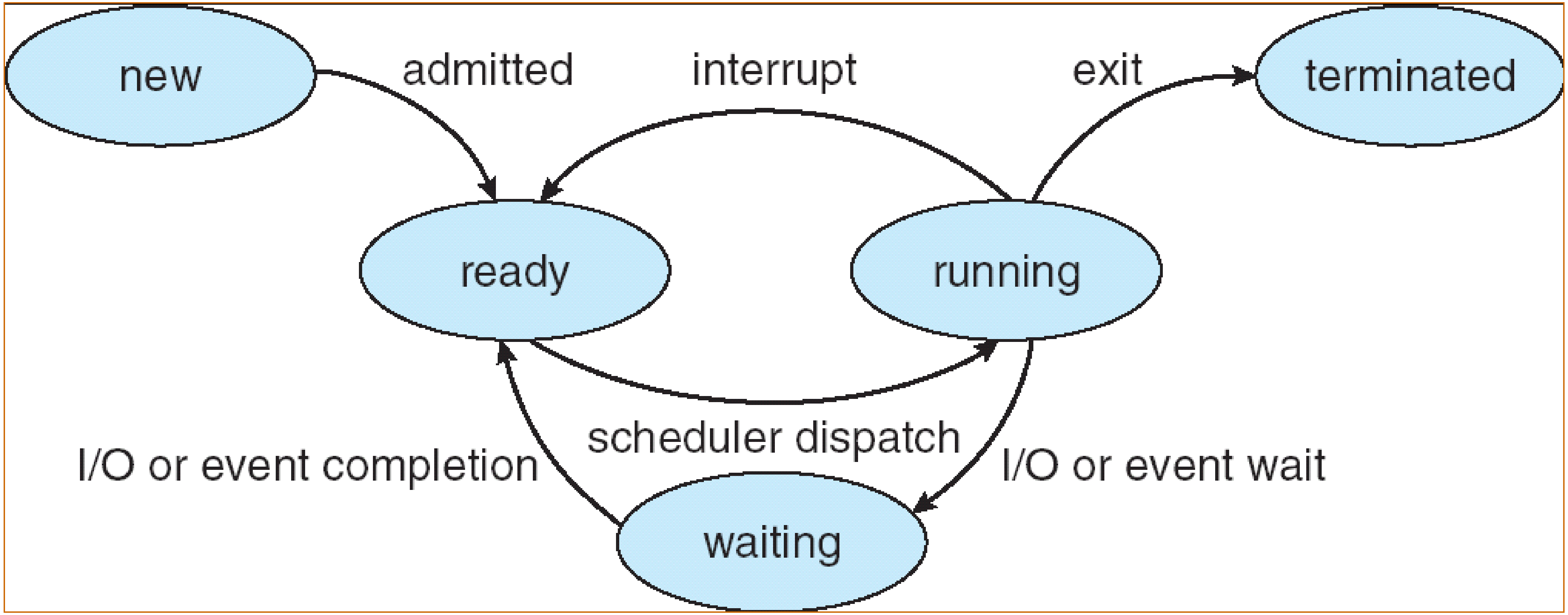



```c
#include <stdio.h>
#include <stdlib.h>

int x;
int y = 15;

int main(int argc, char *argv[])
{
    int *values;
    int i;

    values = (int *)malloc(sizeof(int)*5);

    for(i = 0; i < 5; i++)
        values[i] = i;

    return 0;
}
```

Process State

- Process state
  - **new**: the process is being created
  - **running**: instructions are being executed
  - **waiting**: the process is waiting for some event to occur (such as an I/O completion or reception of a signal)
  - **ready**: the process is waiting to be assigned to a processor
  - **terminated**: the process has finished execution
- As a process executes, it changes state
- **Only one** process is running on one processor at any instant. However, many processes may be ready or waiting

Diagram of Process State

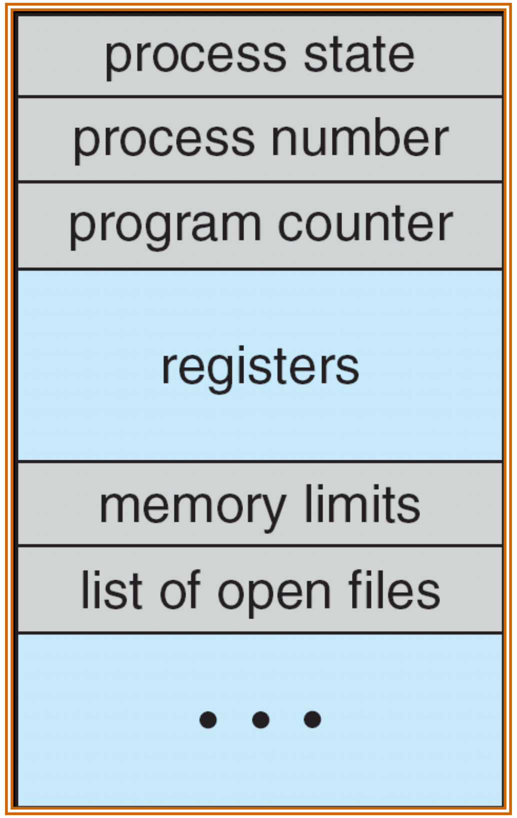


Process Control Block (PCB)

- Information associated with **each** process
  - Identifier
  - Process state
  - CPU scheduling information (e.g., priority)
  - Program counter: next instruction to be executed
  - CPU registers
  - Memory-management information (e.g., base/limit register, page or segment tables)
  - Accounting information
  - I/O status information

Process Control Block (PCB)

- The current state of process is held in a process control block (PCB):
  - This is a “snapshot” of the execution and protection environment
  - Only one PCB is active at a time
- Created and managed by the operating system



Process Control Block

Implementation of Processes

- OS creates process, allocates memory, I/O devices, files, and so on to user program.
- Create the PCB
    - the number is limited

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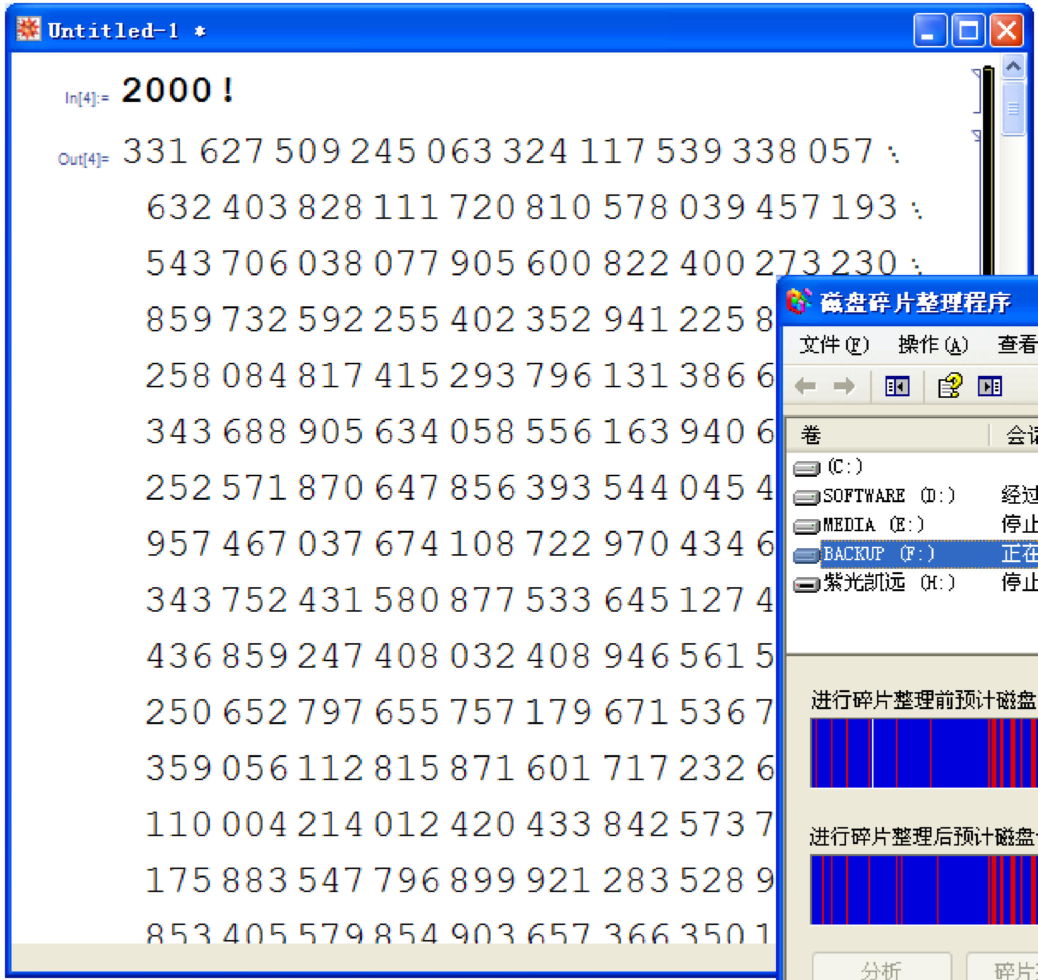
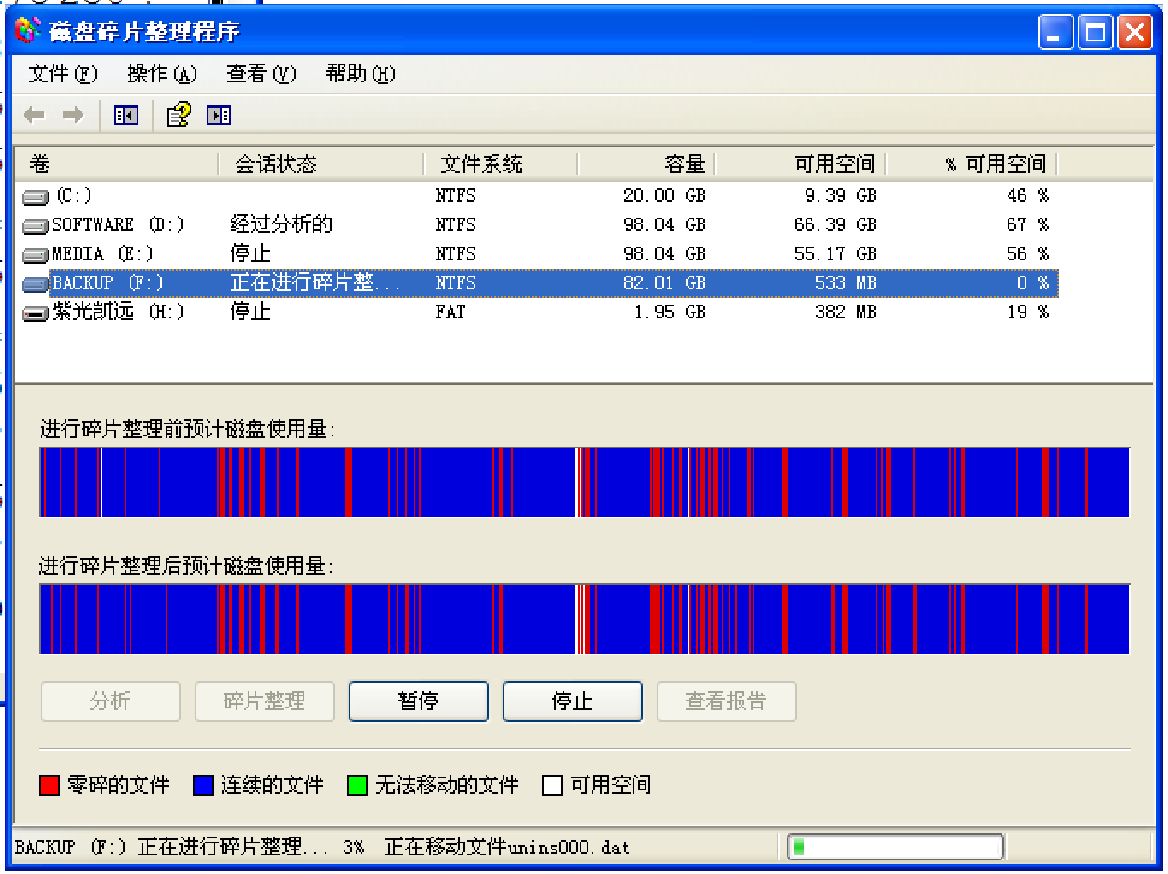
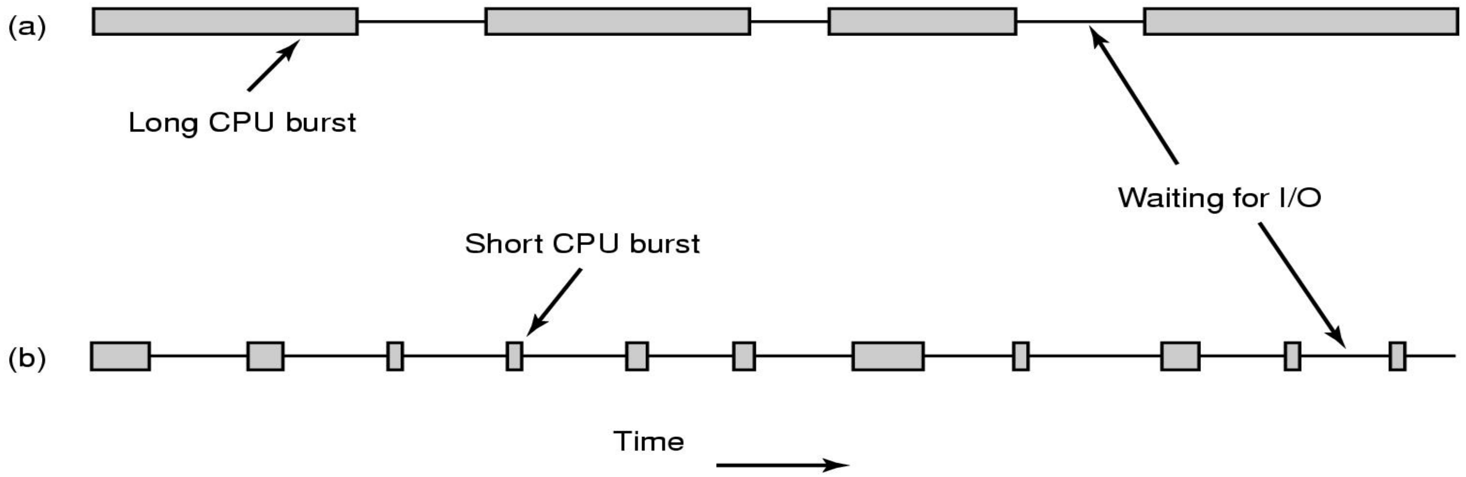
Process Scheduling


Untitled-1 *
In[4]:= 2000 !
Out[4]= 331 627 509 245 063 324 117 539 338 057
632 403 828 111 720 810 578 039 457 193
543 706 038 077 905 600 822 400 273 230
859 732 592 255 402 352 941 225 8
258 084 817 415 293 796 131 386 6
343 688 905 634 058 556 163 940 6
252 571 870 647 856 393 544 045 4
957 467 037 674 108 722 970 434 6
343 752 431 580 877 533 645 127 4
436 859 247 408 032 408 946 561 5
250 652 797 655 757 179 671 536 7
359 056 112 815 871 601 717 232 6
110 004 214 012 420 433 842 573 7
175 883 547 796 899 921 283 528 9


磁盘碎片整理程序
文件(F) 操作(A) 查看(V) 帮助(H)
卷 会话状态 文件系统 容量 可用空间 % 可用空间
(C:) NTFS 20.00 GB 9.39 GB 46 %
SOFTWARE (D:) 经过分析的 NTFS 98.04 GB 66.39 GB 67 %
MEDIA (E:) 停止 NTFS 98.04 GB 55.17 GB 56 %
BACKUP (F:) 正在进行碎片整... NTFS 82.01 GB 533 MB 0 %
紫光凯远 (H:) 停止 FAT 1.95 GB 382 MB 19 %
进行碎片整理前预计磁盘使用量:
进行碎片整理后预计磁盘使用量:
分析
碎片整理
暂停
停止
查看报告
零碎的文件
连续的文件
无法移动的文件
可用空间
BACKUP (F:) 正在进行碎片整理... 3% 正在移动文件unins000.dat

Introduction to Scheduling

- Bursts of CPU usage alternate with periods of I/O wait
- Processes can be described as either:
  - I/O-bound process – spends more time doing I/O than computations, many short CPU bursts
  - CPU-bound process – spends more time doing computations; many long CPU bursts



Introduction to Scheduling

- Why Scheduling?
- For a uni-processor system, there is only one running process. The rest should wait until CPU free and is rescheduled

Process Scheduling Queues

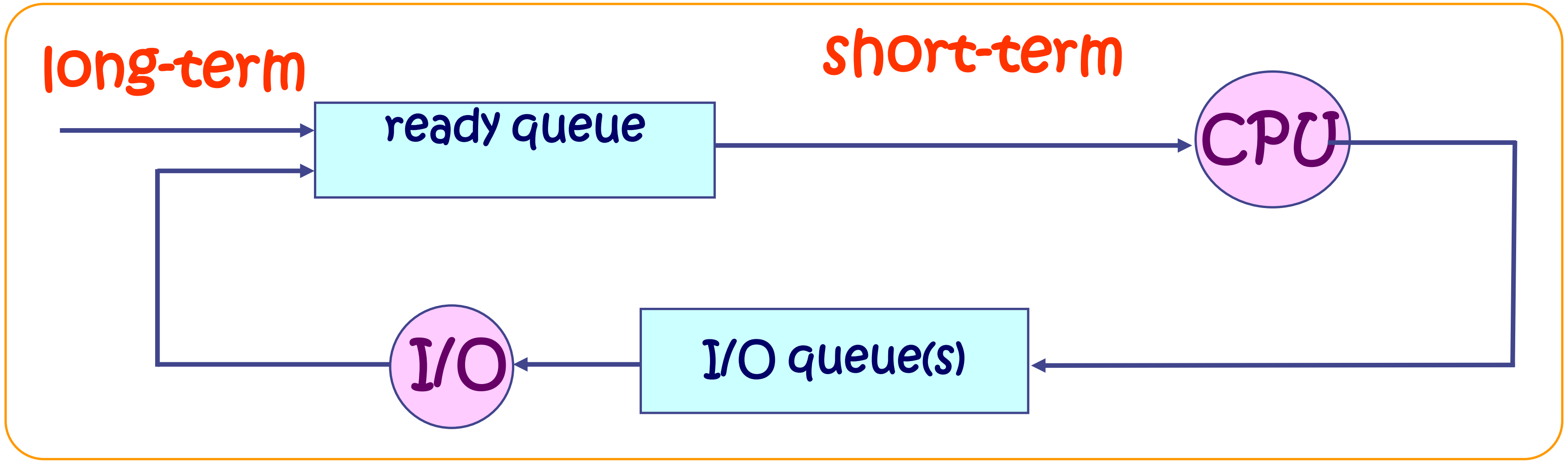
- Job queue
  - set of all processes in the system
- Ready queue
  - set of all processes residing in main memory, ready and waiting to execute
- Device queues
  - set of processes waiting for an I/O device
- Processes migrate among the various queues

Schedulers

- **Long-term scheduler** (or job scheduler) – selects which processes should be brought into the ready queue
  - Execute less frequently (e.g., once several minutes)
  - Control the degree of multiprogramming
  - Select a good process mix of I/O-bound processes and CPU-bound processes

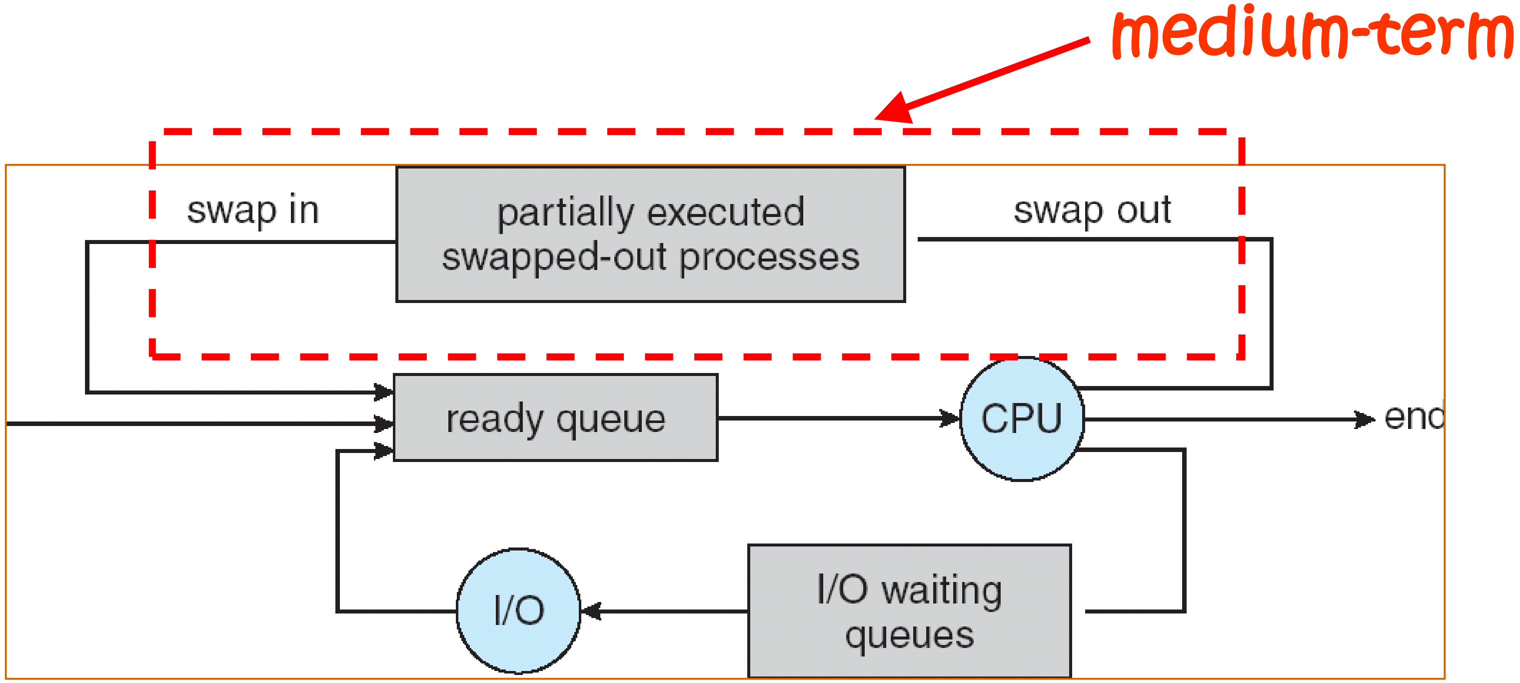
Schedulers

- **Short-term scheduler** (or CPU scheduler) – selects which process should be executed next and allocates CPU
  - Execute quite frequently (e.g., once per 100ms)
  - Must be very fast
    - e.g., if it takes 10 ms, then 10/(100+10) percent of CPU is wasted.

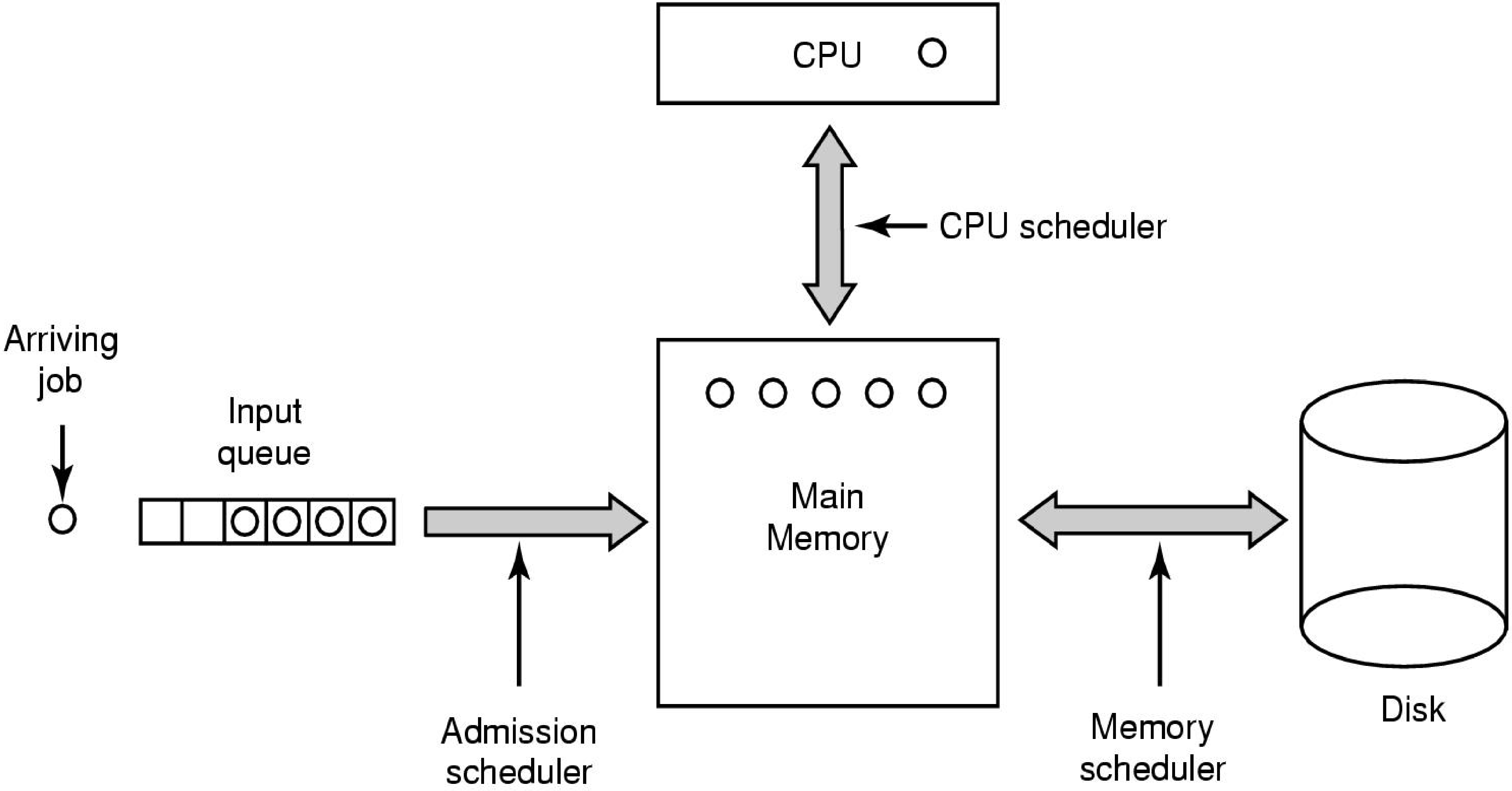


Schedulers

- **Medium-term Scheduler** (Swapping)
  - swap out: removing processes from memory to reduce the degree of multiprogramming.
  - swap in: reintroducing swap-out processes into memory



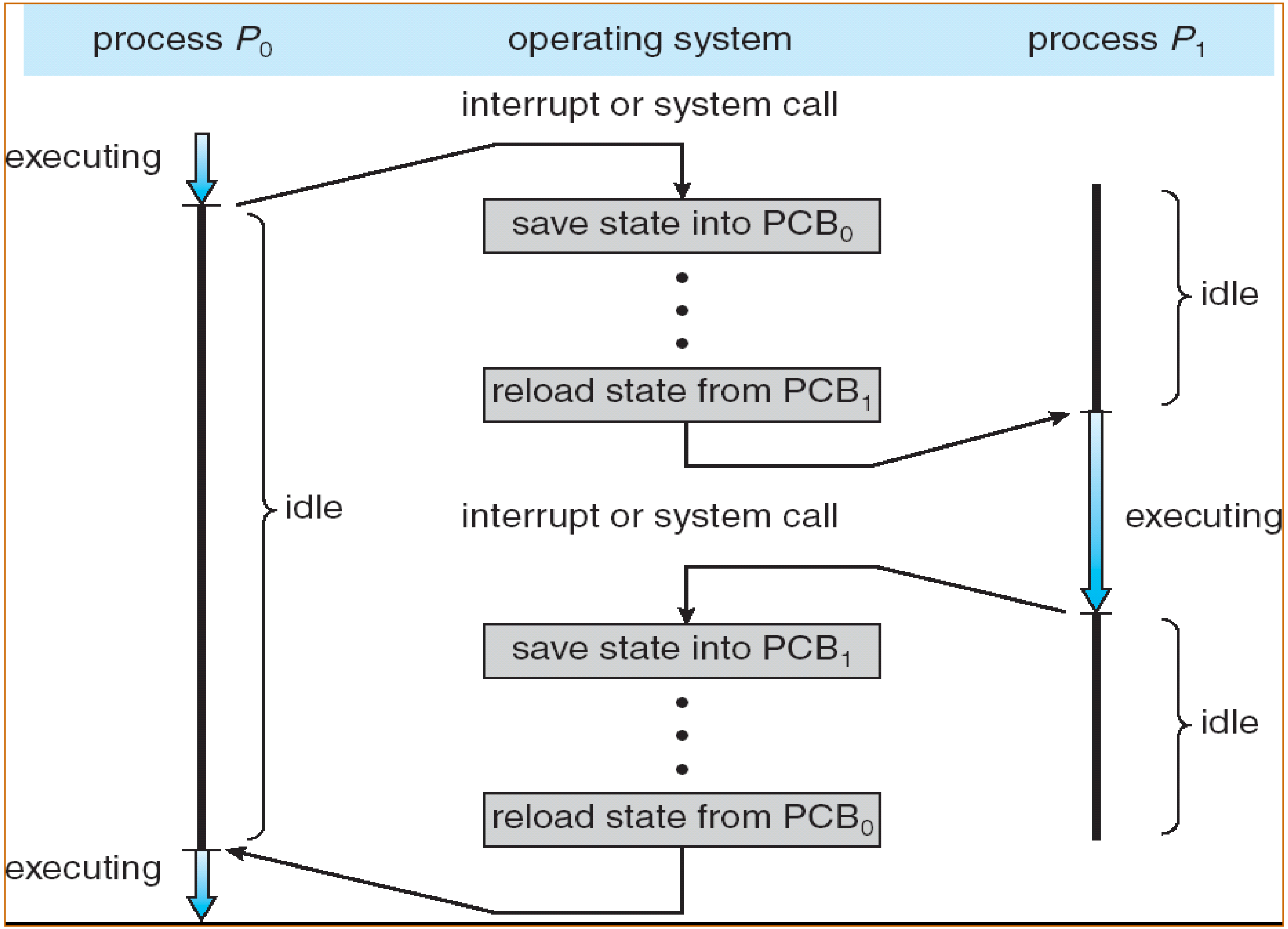
Schedulers


CPU
CPU scheduler
Arriving job
Input queue
Main Memory
Disk
Admission scheduler
Memory scheduler

Differences between These Schedulers

- **Long-term scheduling** - job scheduling, select job from external storage to memory and create a process
  - invoked very infrequently (seconds, minutes) $\Rightarrow$ (may be slow)
- **Short-term scheduling** - process scheduling, select the ready process to run on the processor
  - invoked very frequently (milliseconds) $\Rightarrow$ (must be fast)
- **Medium-term scheduling** - solves the problem of insufficient memory, using secondary storage to alleviate (controls the degree of multiprogramming)

CPU Switch from Process to Process



Context Switch

- When CPU switches to another process, the system must save the state of the old process and load the saved state for the new process
- This is also called a “**context switch**“
- Context-switch time is **overhead**; the system does no useful work while switching

Operations on Processes

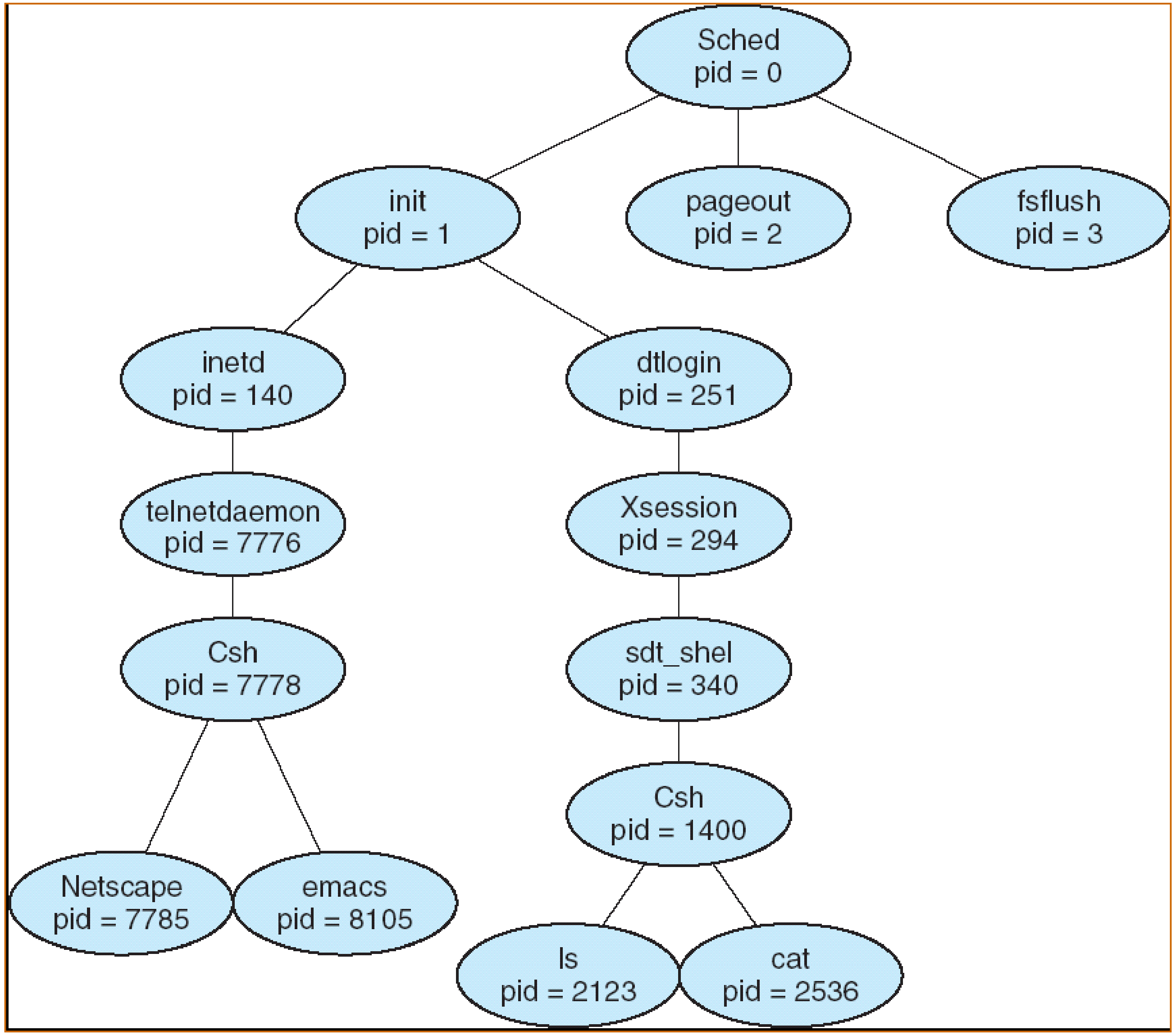
Operations on Processes

- Five major activities of an operating system in regard to process management
  - The creation and deletion of both user and system processes
  - The suspension and resumption of processes
  - The provision of mechanisms for process synchronization
  - The provision of mechanisms for process communication
  - The provision of mechanisms for deadlock handling

Process

- A process may spawn many processes as it runs
- Parent process create children processes, which, in turn create other processes, forming a tree of processes
- Forms a hierarchy
  - UNIX calls this a “ process group"
- Windows has no concept of process hierarchy
  - all processes are created equally (by using handle)

A tree of processes on a typical Solaris



Process Creation

- Parent process create children processes, thus forming a tree of processes
- Resource sharing
  - Parent and children share all resources
  - Children share subset of parent's resources
  - Parent and child share no resources
- Execution
  - Parent and children execute concurrently
  - Parent waits until children terminate

Process Termination

- Conditions which terminate processes
  - Normal exit (voluntary)
  - Error exit (voluntary)
  - Fatal error (involuntary)
  - Killed by another process (involuntary)

CreateProcessA

BOOL CreateProcessA()

CreateProcessA function

12/05/2018 • 12 minutes to read

Creates a new process and its primary thread. The new process runs in the security context of the calling process.

If the calling process is impersonating another user, the new process uses the token for the calling process, not the impersonation token. To run the new process in the security context of the user represented by the impersonation token, use the CreateProcessAsUser or CreateProcessWithLogonW function.

Syntax

C++ Copy

```
BOOL CreateProcessA(
  LPCSTR                lpApplicationName,
  LPSTR                 lpCommandLine,
  LPSECURITY_ATTRIBUTES lpProcessAttributes,
  LPSECURITY_ATTRIBUTES lpThreadAttributes,
  BOOL                  bInheritHandles,
  DWORD                 dwCreationFlags,
  LPVOID                lpEnvironment,
  LPCSTR                lpCurrentDirectory,
  LPSTARTUPINFOA        lpStartupInfo,
  LPPROCESS_INFORMATION lpProcessInformation
);
```

https://docs.microsoft.com/en-us/windows/win32/api/processthreadsapi/nf-processthreadsapi-createprocessa

ExitProcess

void ExitProcess(UINT uExitCode);

ExitProcess function

12/05/2018 • 2 minutes to read

Ends the calling process and all its threads.

Syntax

C++ Copy

```cpp
void ExitProcess(
  UINT uExitCode
);
```

Parameters

`uExitCode`

The exit code for the process and all threads.

Return Value

This function does not return a value.

https://docs.microsoft.com/en-us/windows/win32/api/processthreadsapi/nf-processthreadsapi-exitprocess

TerminateProcess

- BOOL TerminateProcess(HANDLE hProcess,UINT uExitCode);
  - GetCurrentProcess()

TerminateProcess function

12/05/2018 • 2 minutes to read

Terminates the specified process and all of its threads.

Syntax

C++ Copy

```cpp
BOOL TerminateProcess(
  HANDLE hProcess,
  UINT   uExitCode
);
```

Parameters

`hProcess`

A handle to the process to be terminated.

The handle must have the **PROCESS_TERMINATE** access right. For more information, see Process Security and Access Rights.

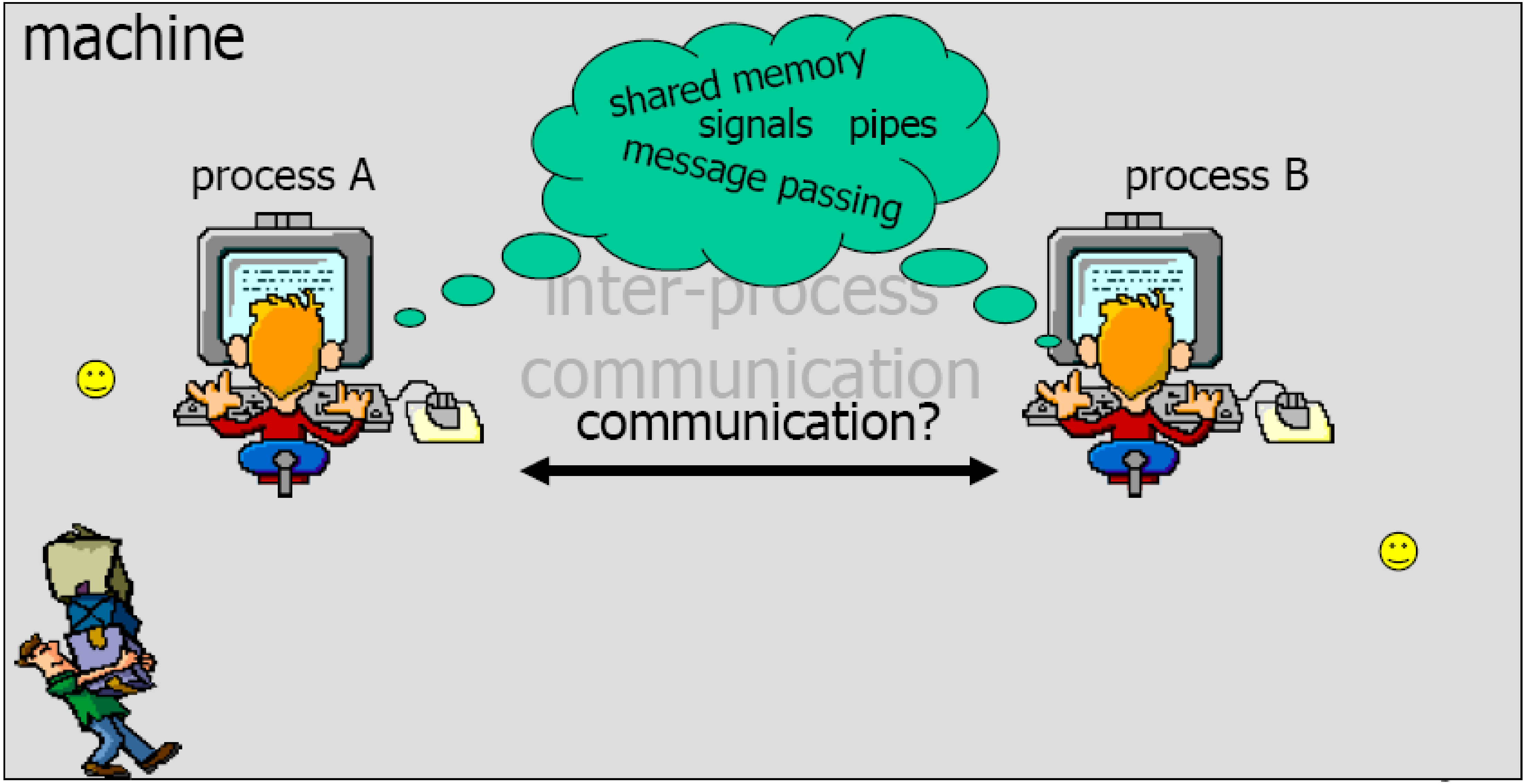
`uExitCode`

The exit code to be used by the process and threads terminated as a result of this call. Use the GetExitCodeProcess function to retrieve a process's exit value. Use the GetExitCodeThread function to retrieve a thread's exit value.

https://docs.microsoft.com/en-us/windows/win32/api/processthreadsapi/nf-processthreadsapi-terminateprocess

Interprocess Communication

Cooperating Processes

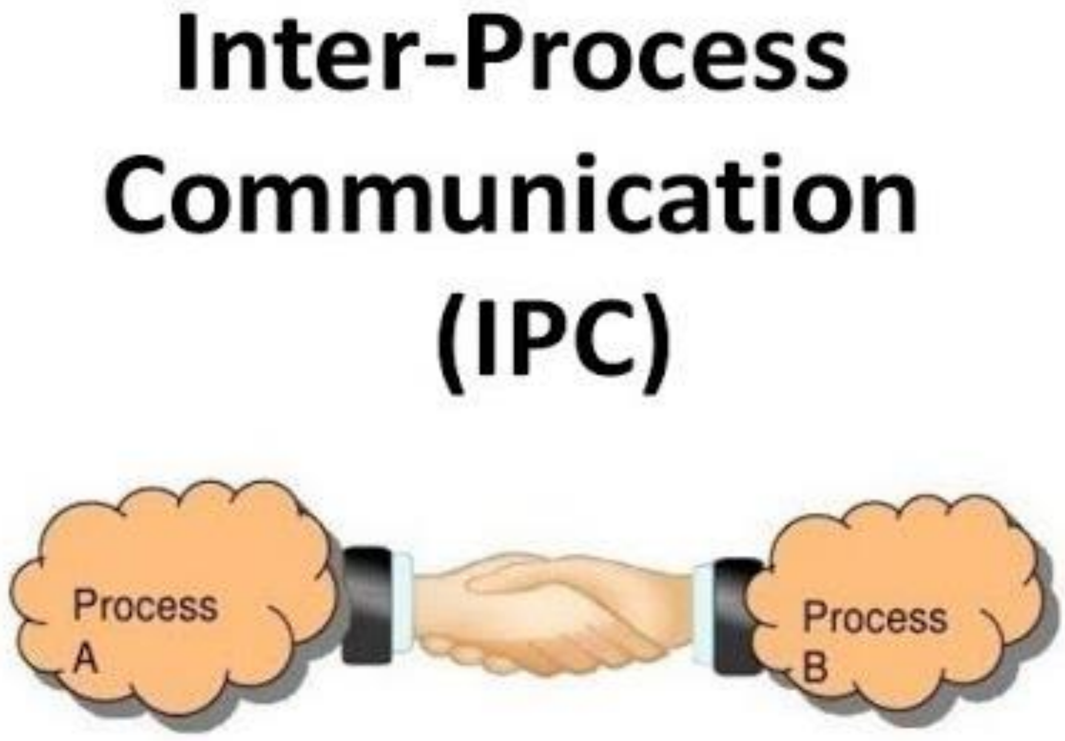


Cooperating Processes

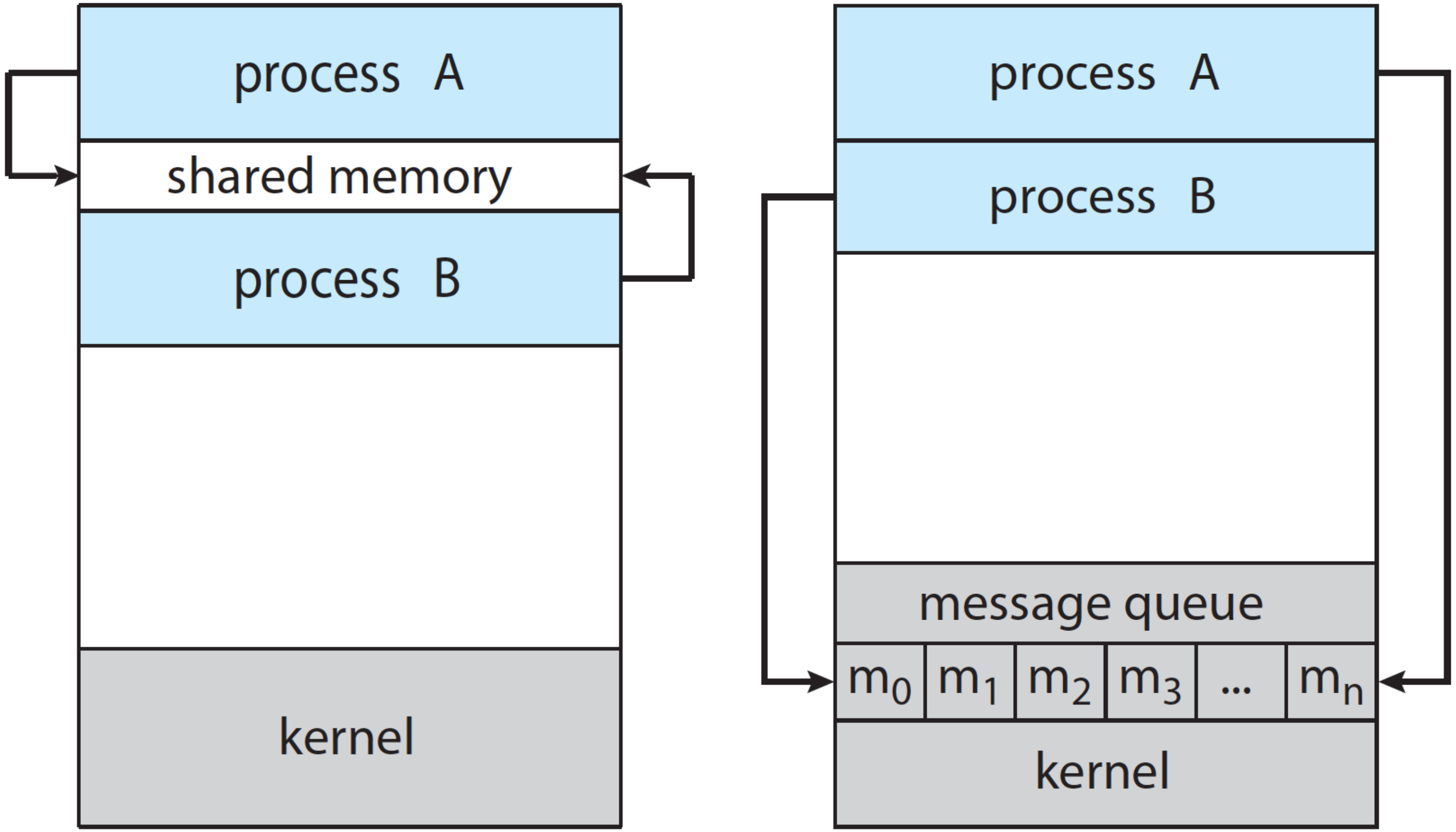
- **Independent** process cannot affect or be affected by the execution of another process
- **Cooperating** process can affect or be affected by the execution of another process
- Advantages of process cooperation
  - Information sharing
  - Computation speed-up
  - Modularity
  - Convenience, e.g., A user can performs several tasks at the same time (editing, printing, compiling)

Interprocess Communication (IPC)

- Mechanism for processes to **communicate** and to **synchronize** their actions



IPC Communication Models



(a)
Shared memory

(b)
Message passing

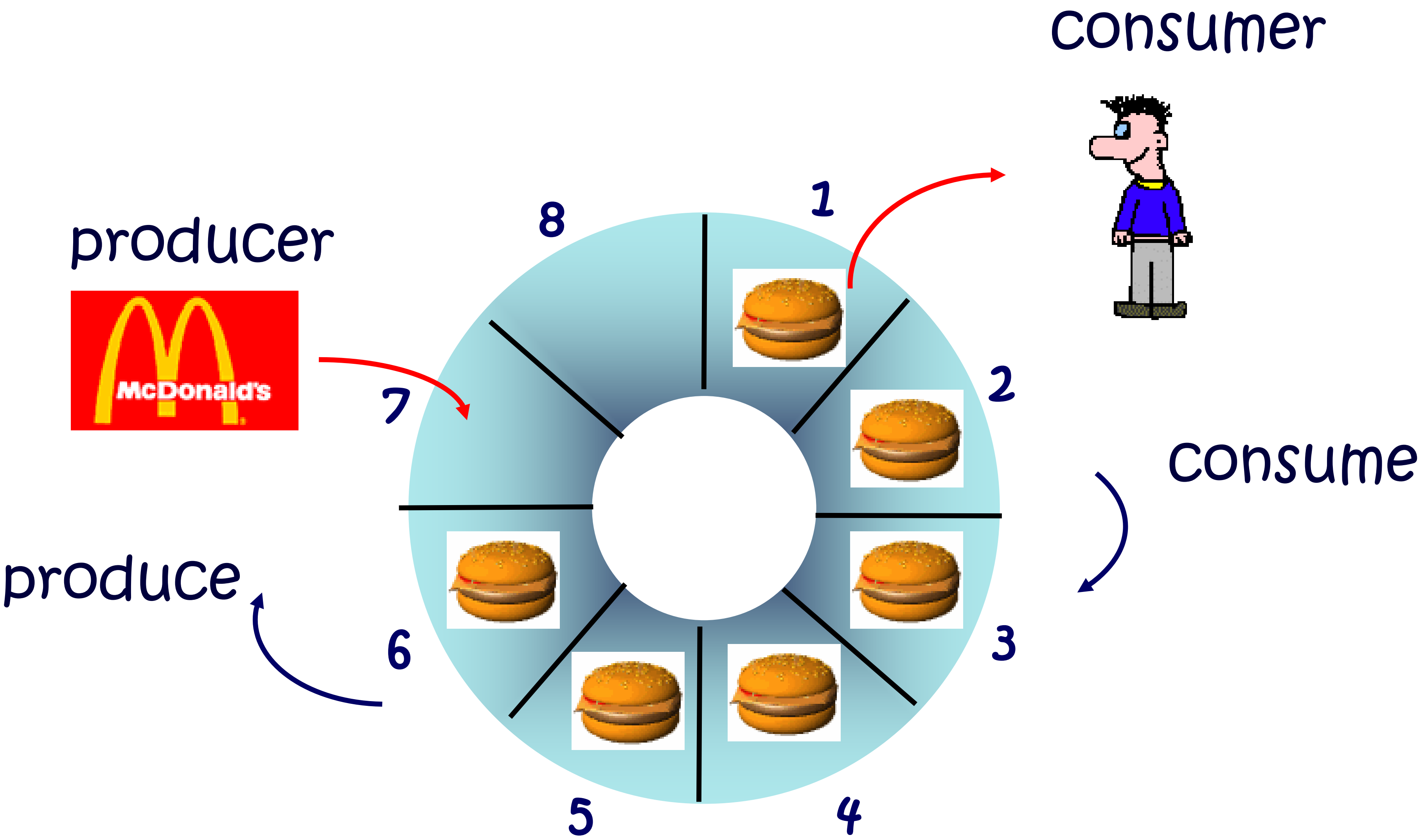
IPC Communication Models

- Most OSs implement both models
- **Shared memory**
  - low-overhead: a few system calls initially, and then none
  - more convenient for the user since we're used to simply reading/writing from/to RAM
  - more difficult to implement in the OS
- **Message-passing**
  - useful for exchanging small amounts of data
  - simple to implement in the OS
  - sometimes cumbersome for the user as code is sprinkled with send/receive operations
  - high-overhead: one system call per communication operation

Producer-Consumer Problem

- Paradigm for cooperating processes, producer process produces information that is consumed by a consumer process
  - unbounded-buffer places no practical limit on the size of the buffer
    - producer: no wait
    - consumer: wait when buffer is empty
  - bounded-buffer assumes that there is a fixed buffer size
    - producer: wait when buffer is full
    - consumer: wait when buffer is empty

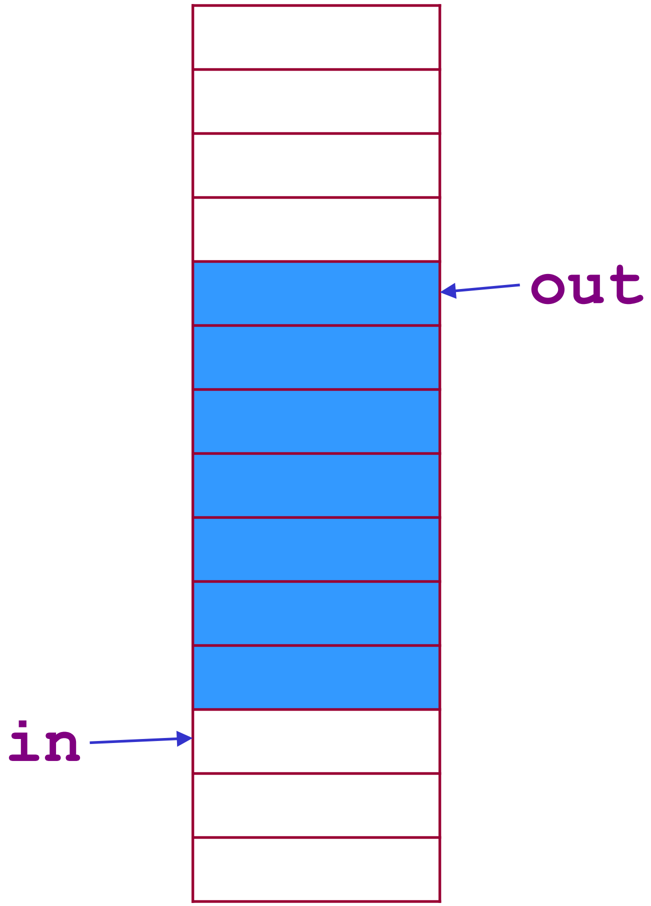
Example of Producer-Consumer Problem



Bounded-Buffer: Shared-Memory Solution

- Shared data: Buffer as a circular array

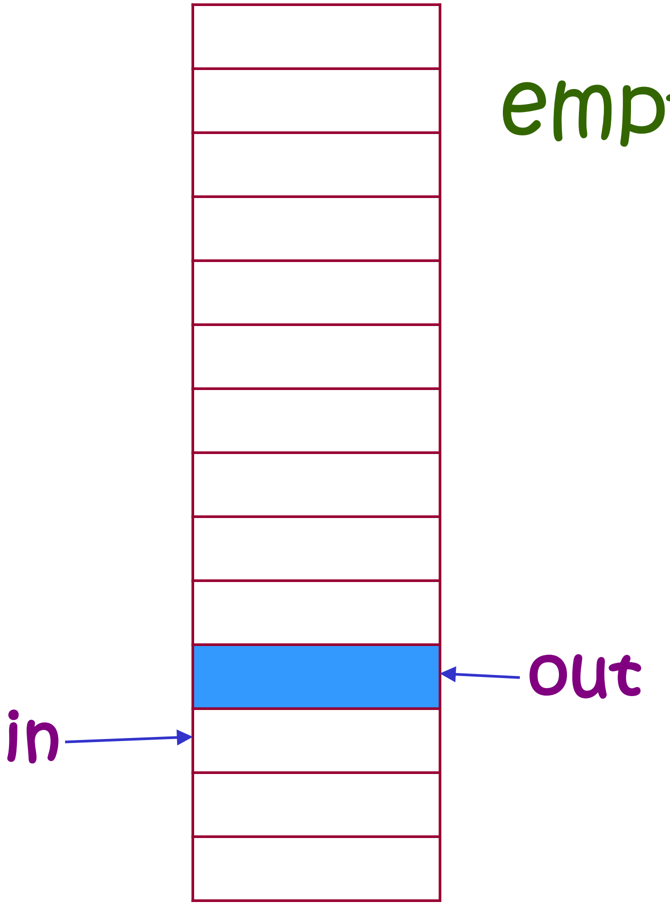
```
#define BUFFER_SIZE 10
typedef struct {
  . . .
} item;

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

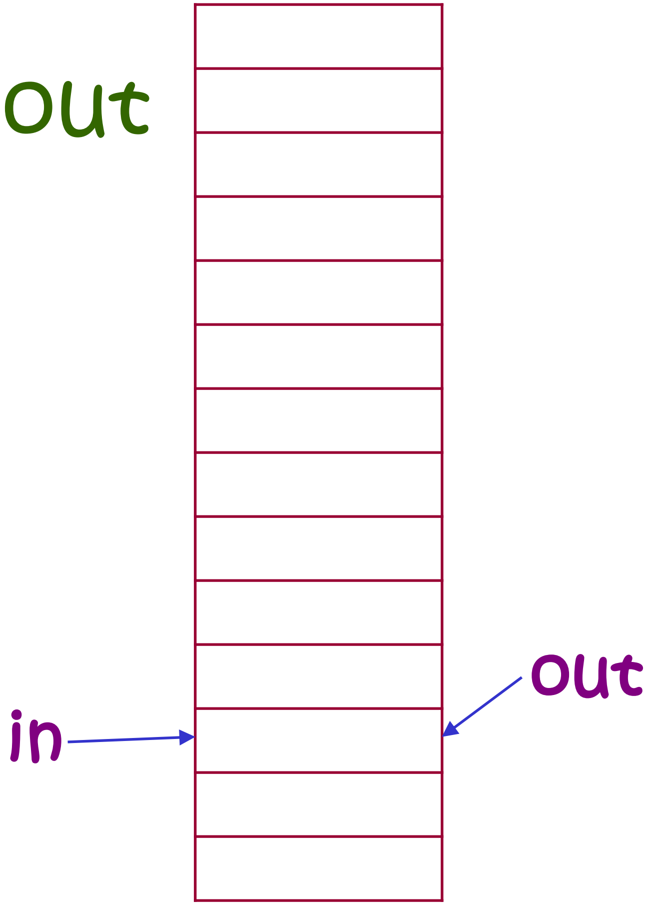


- Shared data: Buffer as a circular array
  - next free: **in**
  - first available: **out**
  - empty: **in** = **out**
  - full: (**in+1**) % B = **out**

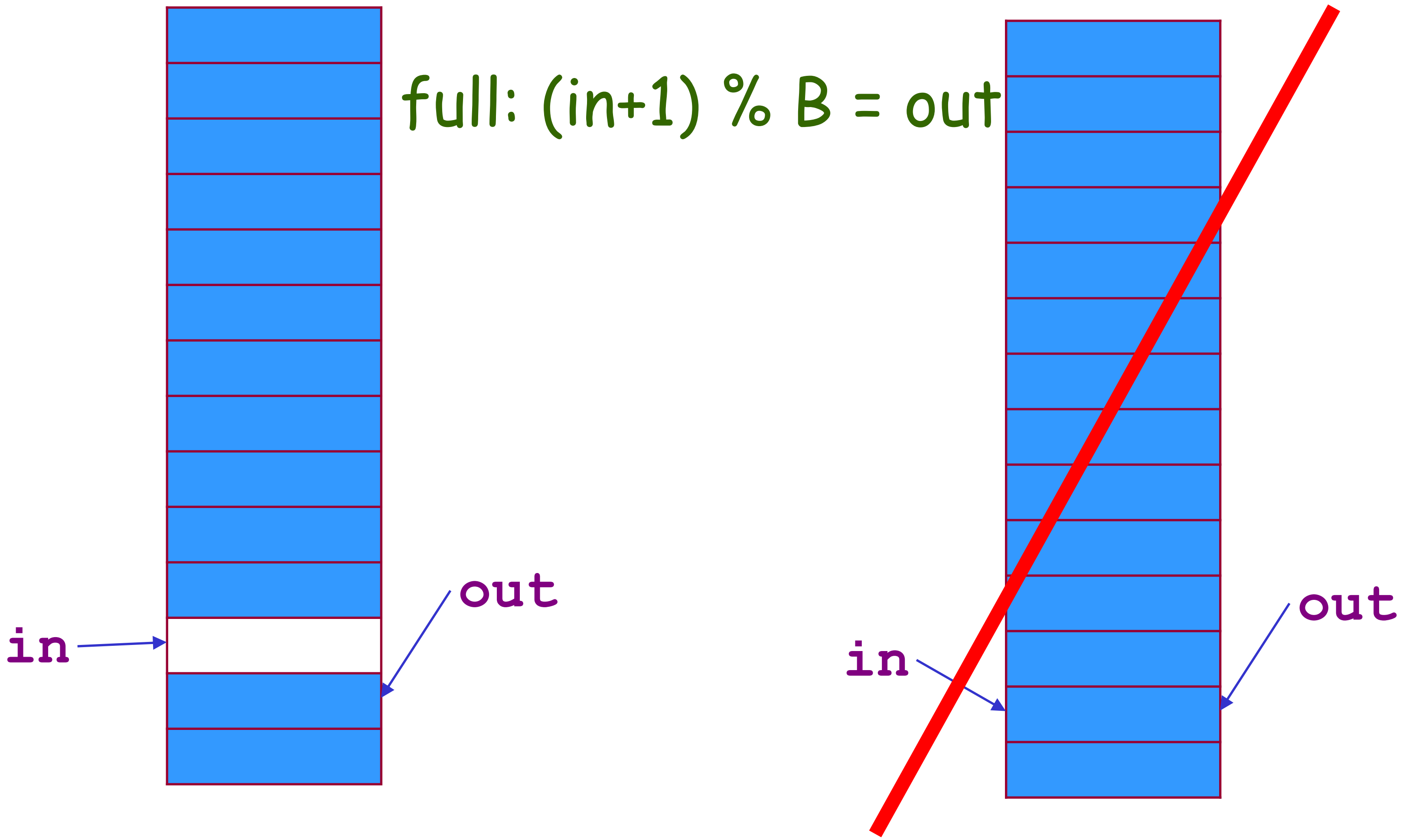
Bounded-Buffer: Shared-Memory Solution

empty: in = out





Bounded-Buffer: Shared-Memory Solution



Bounded-Buffer: Producer Process—Insert()

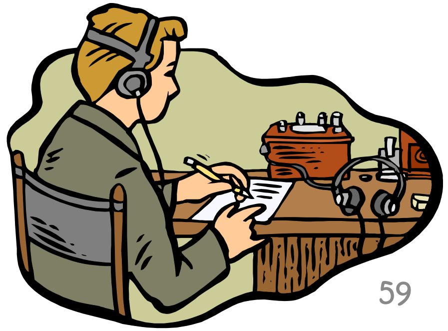
```
while (true) {
 /* Produce an item */
   while (((in+1) % BUFFER SIZE)== out)
     ;/*do nothing--no free buffers */
 buffer[in] = item;
 in = (in + 1) % BUFFER SIZE;
}
```

Bounded Buffer: Consumer Process – Remove()

```
while (true) {
   while (in == out)
      ; // do nothing -- nothing to consume

  // remove an item from the buffer
  item = buffer[out];
  out = (out + 1) % BUFFER SIZE;
  return item;
 }
```

Message system

- **Message system** – processes communicate with each other without resorting to shared variables
- IPC facility provides two operations:
  - **send**(message) – message size fixed or variable
  - **receive**(message)
- If P and Q wish to communicate, they need to:
  - establish a communication link between them
  - exchange messages via send/receive

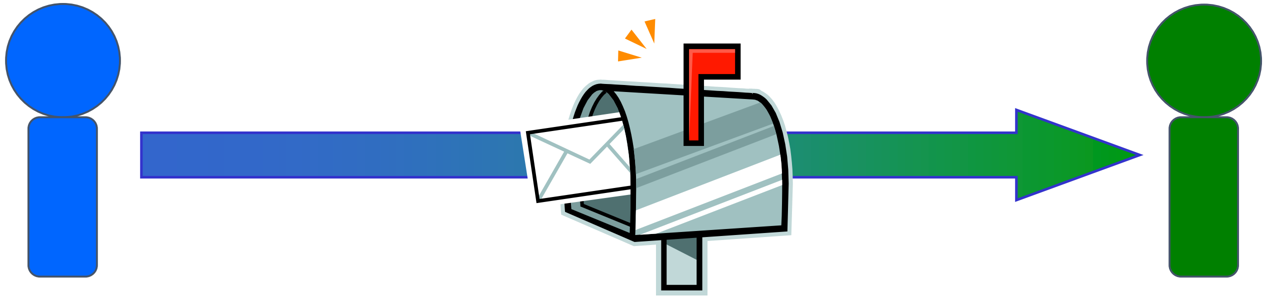


Direct Communication

- Processes must name each other explicitly:
  - **send** (P, message) – send a message to process P
  - **receive**(Q, message) – receive a message from process Q
- limited modularity: if the name of a process is changed, all old names should be found. It is not easy for separate compilation

Indirect Communication

- Messages are sent and received from **mailboxes** (also referred to as ports)
  - Each mailbox has a unique id
  - Processes can communicate only if they share a mailbox



Indirect Communication

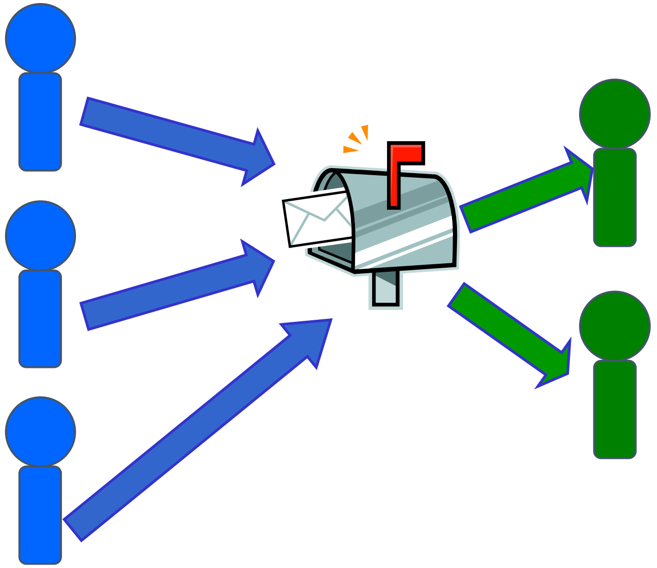
- Operations
  - create a new **mailbox**
  - send and receive messages through mailbox
  - destroy a mailbox
- Primitives are defined as:

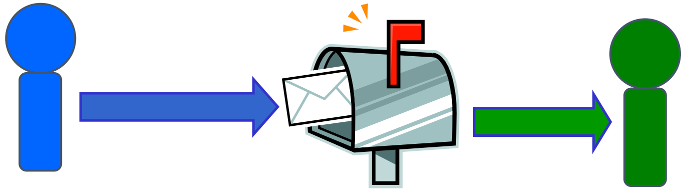
send(A, message) – send a message to mailbox A

receive(A, message) – receive a message from mailbox A

Indirect Communication

- 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





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

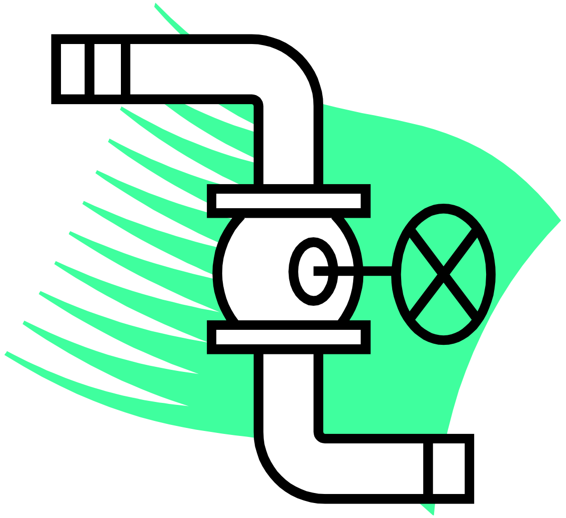
Mailslots

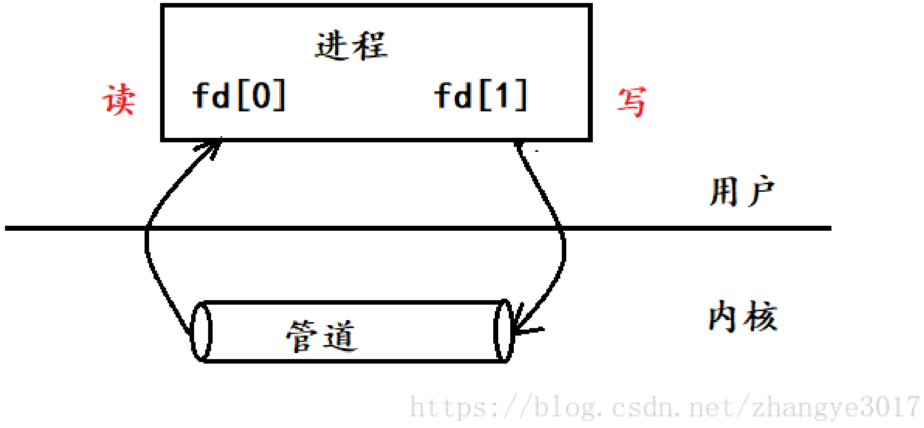
- Mailslots are supported by three specialized functions: **CreateMailslot**, **GetMailslotInfo**, and **SetMailslotInfo**.

Pipe

- CreatePipe
- CreateNamedPipe

- ReadFile
- WriteFile





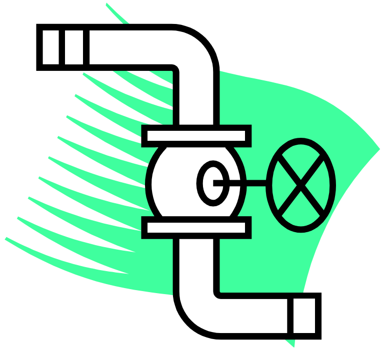
Pipe

- CreatePipe
  - BOOL CreatePipe(

```
PHANDLE hReadPipe,              // pointer to read handle
PHANDLE hWritePipe,             // pointer to write handle
LPSECURITY_ATTRIBUTES lpPipeAttributes,
                                // pointer to security attributes
DWORD nSize                     // pipe size
);
```

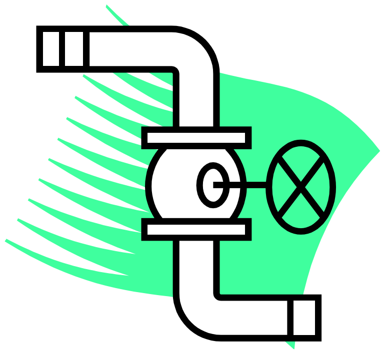
- CreateNamedPipe
  - HANDLE Createnamedpipe(

```
LPCTSTR lpName,             // pointer to pipe name
DWORD dwOpenMode,           // pipe open mode
DWORD dwPipeMode,           // pipe-specific modes
DWORD nMaxInstances,        // maximum number of instances
DWORD nOutBufferSize,       // output buffer size, in bytes
DWORD nInBufferSize,        // input buffer size, in bytes
DWORD nDefaultTimeOut,      // time-out time, in milliseconds
LPSECURITY_ATTRIBUTES lpSecurityAttributes
                            // pointer to security attributes structure
);
```



Pipe

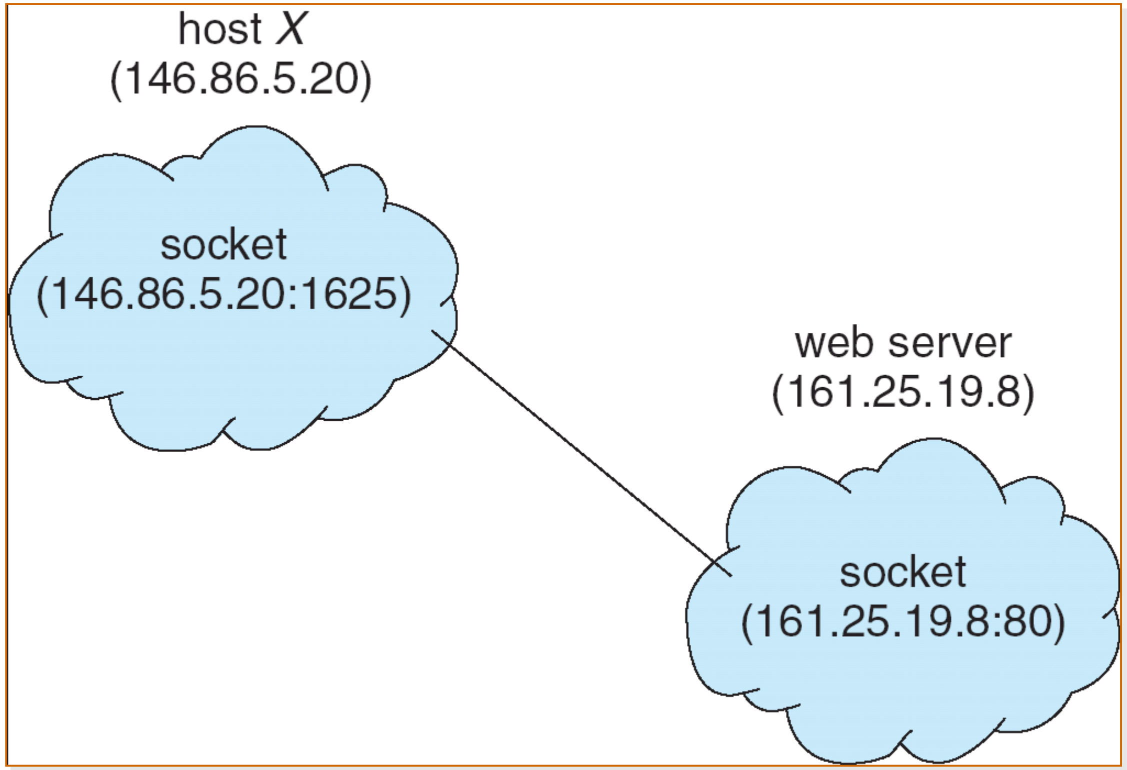
- WriteFile
  - BOOL WriteFile(
    HANDLE hFile,
    LPCVOID lpBuffer,
    DWORD nNumberOfBytesToWrite,
    LPDWORD lpNumberOfBytesWritten,
    LPOVERLAPPED lpOverlapped
    );
- ReadFile
  - BOOL ReadFile(
    HANDLE hFile,
    LPVOID lpBuffer,
    DWORD nNumberOfBytesToRead,
    LPDWORD lpNumberOfBytesRead,
    LPOVERLAPPED lpOverlapped
    );

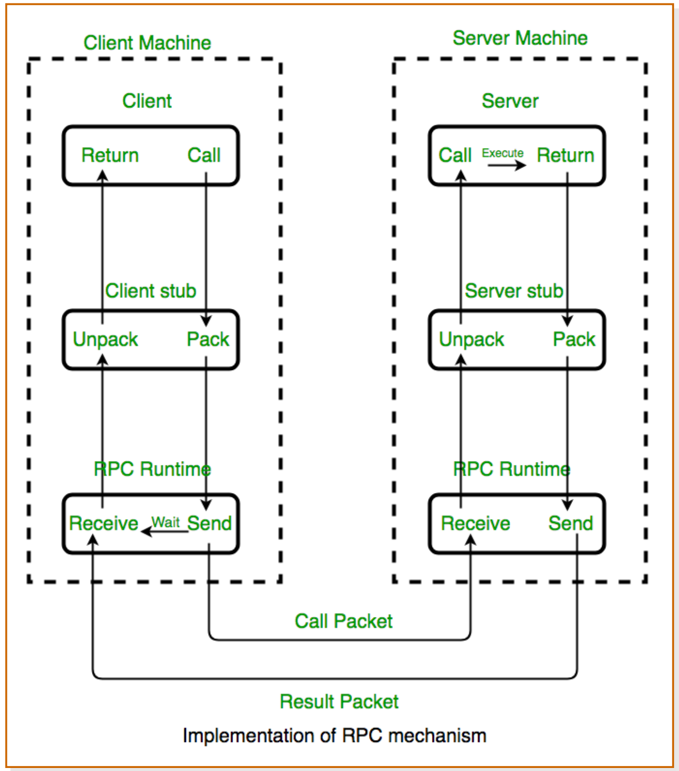


Communication in Client-Server Systems

Client-Server Communication

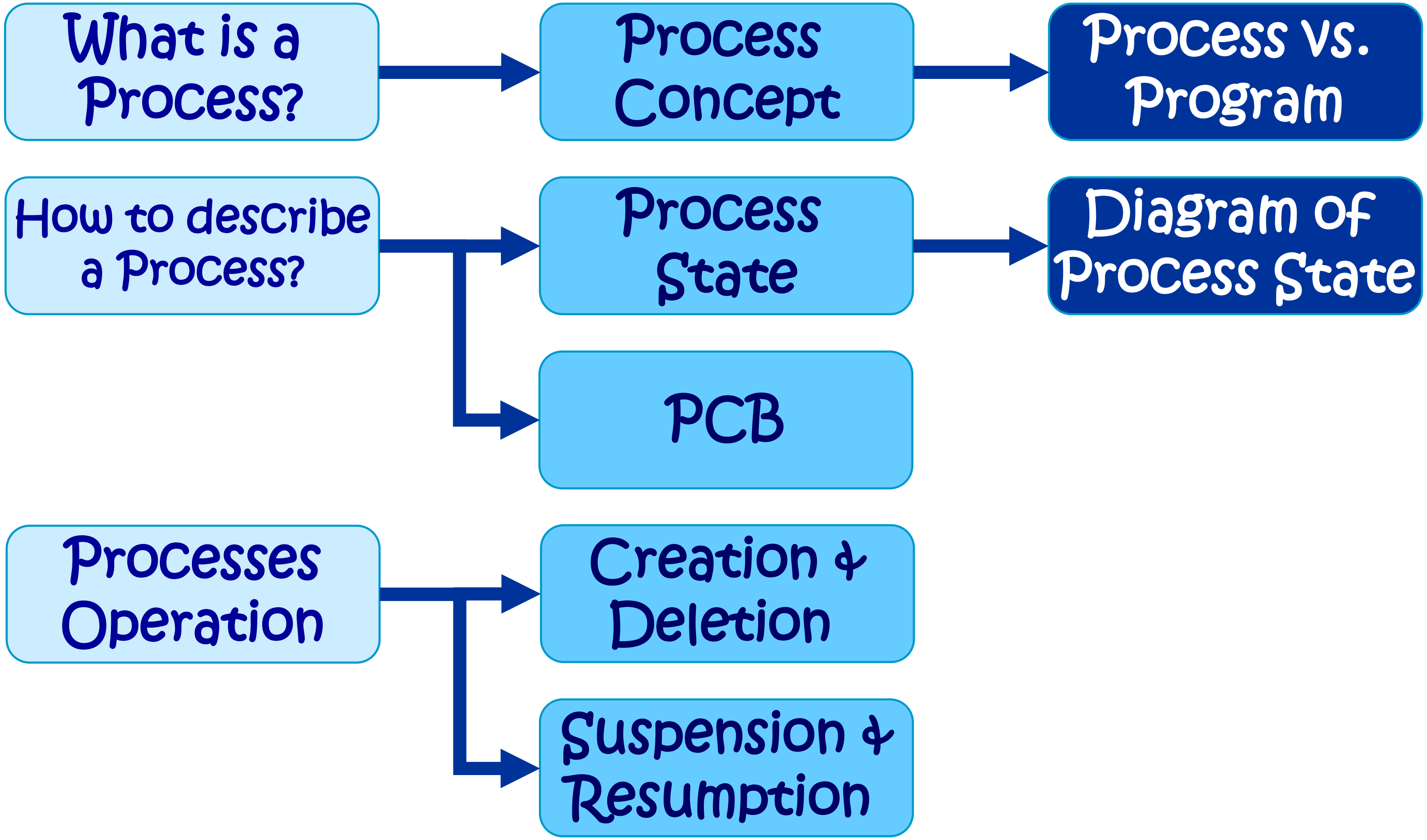
- Sockets
- Remote Procedure Calls https://www.cnblogs.com/swordfall/p/8683905.html



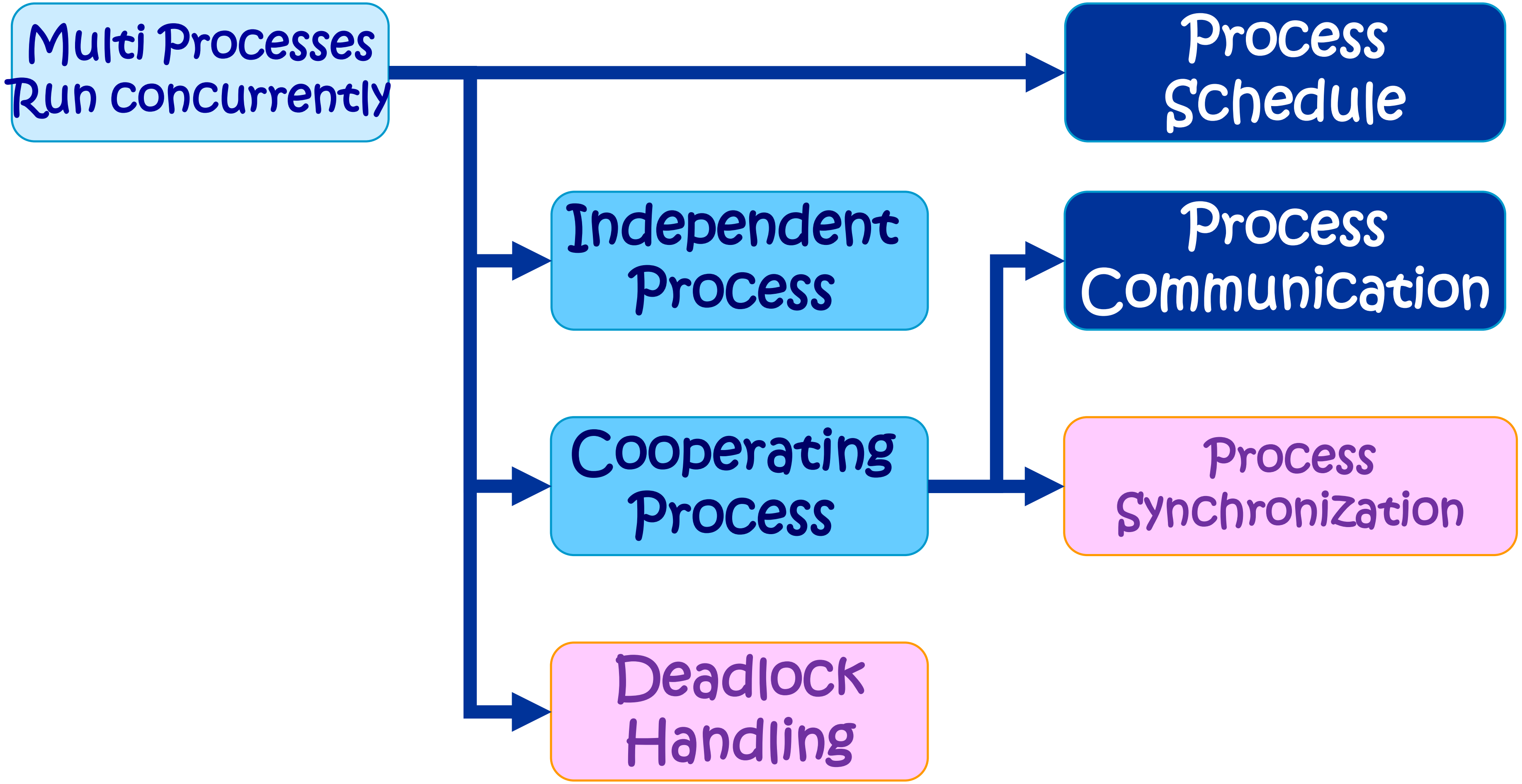


Summary

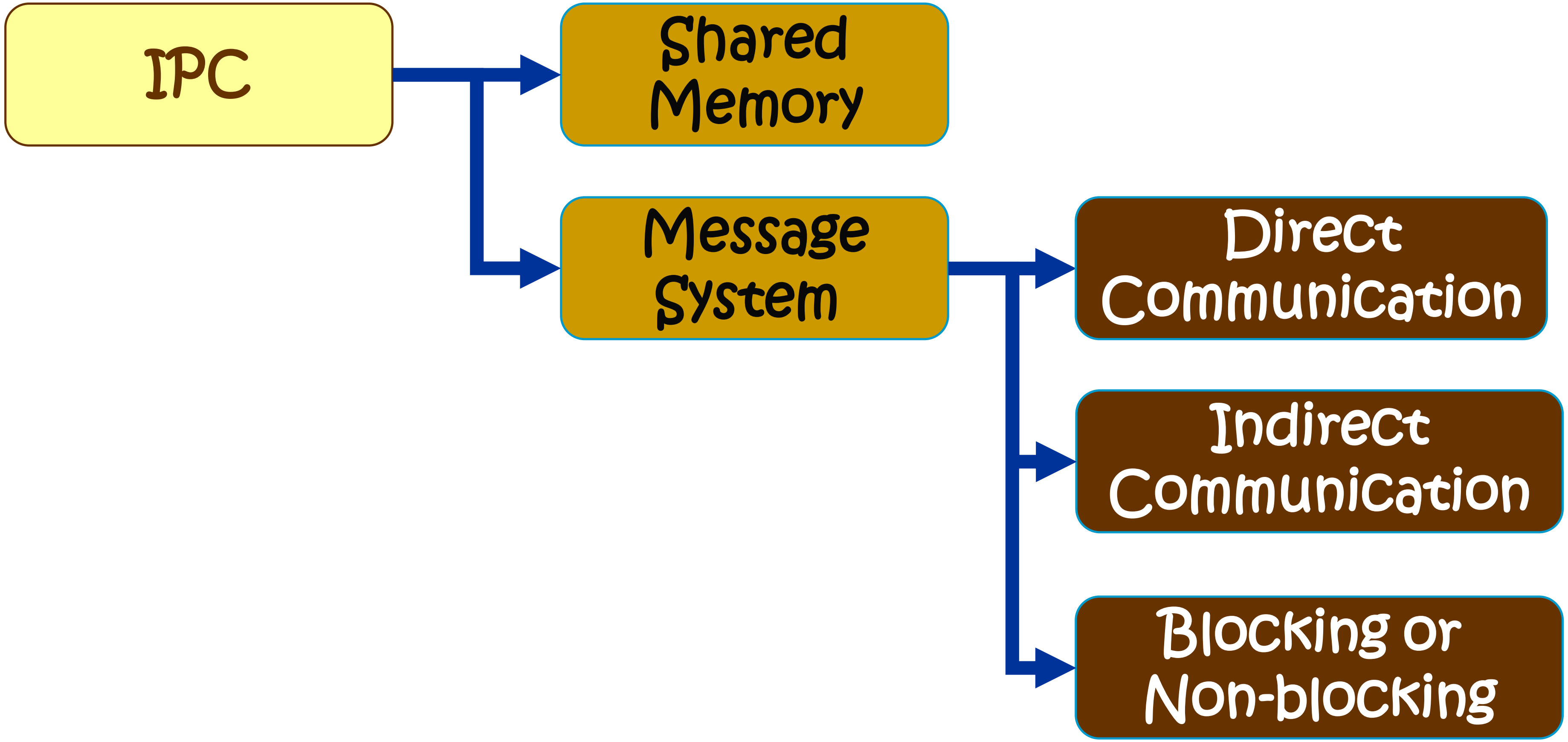
Process


What is a Process?
Process Concept
Process vs. Program
How to describe a Process?
Process State
Diagram of Process State
PCB
Processes Operation
Creation & Deletion
Suspension & Resumption

Process/Thread



Interprocess Communication



Thank you !

Q & A