Part II
Processes and Threads
Process Basics

Program testing can be used to show the presence of bugs, but never to show their absence.

Edsger W. Dijkstra
From Compilation to Execution

- A compiler compiles source files to \texttt{.o} files.
- A linker links \texttt{.o} files and other libraries together, producing a binary executable (e.g., \texttt{a.out}).
- A loader loads a binary executable into memory for execution.
What Is a Process?

- When the OS runs a program (i.e., a binary executable), this program is loaded into memory and the control is transferred to this program’s first instruction. Then, the program runs.

- **A process is a program in execution.**

- A process is more than a program, because a process has a program counter, stack, data section, code section, etc. (i.e., the runtime stuffs)

- Moreover, multiple processes may be associated with one program (e.g., running the same program, say `a.out`, multiple times at the same time).
Process Space

- **Text/Code**
  - Program code
  - Program counter points to an instruction

- **Data**
  - Global data

- **Heap**
  - Dynamic allocations with `malloc()` obtain space here

- **Stack**
  - Local data
  - Stack top

- **Notes**
  - Out of memory if these two pointers cross each other

Process States

At any moment, a process can be in one of the five states: new, running, waiting, ready and terminated.

- **New**: The process is being created
- **Running**: The process is executing on a CPU
- **Waiting**: The process is waiting for some event to occur (e.g., waiting for I/O completion)
- **Ready**: The process has everything but the CPU. It is waiting to be assigned to a processor.
- **Terminated**: The process has finished execution.
Process State Diagram

- **new**
  - converting to process
  - admitted

- **ready**
  - scheduler dispatch
  - interrupt

- **running**
  - I/O or event completion

- **waiting**
  - I/O or event wait
  - waiting for I/O or event

- **terminated**
  - reclaim resource
  - destroy process
  - exit

Waiting for CPU
**Process Representation in OS**

- Each process is assigned a unique number, the **process ID**.
- Process info are stored in a table, the **process control block (PCB)**.
- These PCBs are chained into a number of lists. For example, all processes in the ready state are in the **ready queue**.

<table>
<thead>
<tr>
<th>pointer</th>
<th>process state</th>
</tr>
</thead>
<tbody>
<tr>
<td>process ID</td>
<td></td>
</tr>
<tr>
<td>program counter</td>
<td></td>
</tr>
<tr>
<td>registers</td>
<td></td>
</tr>
<tr>
<td>scheduling info</td>
<td></td>
</tr>
<tr>
<td>memory limits</td>
<td></td>
</tr>
<tr>
<td>list of open files</td>
<td></td>
</tr>
</tbody>
</table>
Process Scheduling: 1/2

- Since the number of processes may be larger than the number of available CPUs, the OS must maintain **maximum CPU utilization** (i.e., all CPU’s being as busy as possible).
- To determine which process can do what, processes are chained into a number of **scheduling queues**.
- For example, in addition to the ready queue, each event may have its own scheduling queue (i.e., waiting queue).
The ready queue, which may be organized into several sub-queues, has all processes ready to run. The OS has a **CPU scheduler**. When a CPU is free, the CPU scheduler looks at the ready queue, picks a process, and resumes it. The way of picking a process from the ready queue is referred to as **scheduling policy**. Scheduling policy is unimportant to this course because we **cannot make any assumption about it**.
**Context Switch: 1/2**

- **What is a process context?** The context of a process includes process ID, process state, the values of CPU registers, the program counter, and other memory/file management information (i.e., execution environment).

- **What is a context switch?** After the CPU scheduler selects a process and before allocates CPU to it, the CPU scheduler must:
  - save the context of the currently running process,
  - put it back to the ready queue or waiting state,
  - load the context of the selected process, and
  - go to the saved program counter.

  mode switching may be needed
Context Switch: 2/2

Always remember mode switch
Operations on Processes

- There are three commonly seen operations:
  - **Process Creation**: Create a new process. The newly created is the child of the original. Unix uses `fork()` to create new processes.
  - **Process Termination**: Terminate the execution of a process. Unix uses `exit()`.
  - **Process Join**: Wait for the completion of a child process. Unix uses `wait()`.

- `fork()`, `exit()` and `wait()` are system calls.
Some Required Header Files

- Before you use processes, include header files `sys/types.h` and `unistd.h`.
- `sys/types.h` has all system data types, and `unistd.h` declares standard symbolic constants and types.

```c
#include <sys/types.h>
#include <unistd.h>
```
The `fork()` System Call

- The purpose of `fork()` is to create a child process. The creating and created processes are the parent and child, respectively.
- `fork()` does not require any argument!
- If the call to `fork()` is successful, Unix creates an identical but separate address space for the child process to run.
- Both processes start running with the instruction following the `fork()` system call.
**fork() Return Values**

- A negative value means the creation of a child process was unsuccessful.
- A zero means the process is a child.
- Otherwise, `fork()` returns the process ID of the child process. The ID is of type `pid_t`.
- Function `getpid()` returns the process ID of the caller.
- Function `getppid()` returns the parent’s process ID. If the calling process has no parent, `getppid()` returns 1.
Before the Execution of `fork()`

```c
main()
{
    int a, b;
    pid_t pid
    fork();
    pid = ...;
    ......
}
```
After the Execution of `fork()` in different address spaces

**parent**

```c
main()
{
    int a, b;
    pid_t pid;
    fork();
    pid = ...;
    ..... 
}
```

**child**

```c
main()
{
    int a, b;
    pid_t pid;
    fork();
    pid = ...;
    ..... 
}
```
Example 1: 1/2

```c
#include <stdio.h>
#include <string.h>
#include <sys/types.h>
#include <unistd.h>

void main(void)
{
    pid_t  MyID, ParentID;
    int    i;
    char   buf[100];

    fork();          // create a child process
    MyID     = getpid();   // get my process ID
    ParentID = getppid(); // get my parent’s process ID
    for (i = 1; i <= 200; i++) {
        sprintf(buf, "From MyID=%ld, ParentID=%ld, i=%3d\n",
                MyID, ParentID, i);
        write(1, buf, strlen(buf)); // why don’t we
    } // why don’t we
    // use printf?
}
```

this is stdout
Example 1: 2/2

Processes 19087 and 19088 run concurrently.

Parent: 19087
Child: 19088

Parent 19087’s parent is 19004, the shell that executes `fork-1`.

19004
↓
19087
↓
19088
```c
void child(void)
{
    int i;
    for (i=1; i<=10; i++)
        printf(" Child:%d\n", i);
    printf("Child done\n");
}

void parent(void)
{
    int i;
    for (i=1; i<=10; i++)
        printf("Parent:%d\n", i);
    printf("Parent done\n");
}
```

we use `printf`s here to save space.
Before the Execution of `fork()`

```c
int main(void)
{
    int pid = fork();
    if (pid == 0)
        child();
    else
        parent();
}

void child(void)
{
    // ……
}

void parent(void)
{
    // ……
}
```
After the Execution of `fork()` 1/2

**parent**

```c
main(void)
{
    pid = fork();
    if (pid == 0)
        child();
    else
        parent();
}

void child(void)
{ ...... }

void parent(void)
{ ...... }
```

**child**

```c
main(void)
{
    pid = fork();
    if (pid == 0)
        child();
    else
        parent();
}

void child(void)
{ ...... }

void parent(void)
{ ...... }
```

In two different address spaces
After the Execution of `fork()` 2/2

```
parent

main(void) { pid = 123
    pid = fork();
    if (pid == 0)
        child();
    else
        parent();
}

void child(void) {
    ...... }

void parent(void) {
    ...... }

child

main(void) { pid = 0
    pid = fork();
    if (pid == 0)
        child();
    else
        parent();
}

void child(void) {
    ...... }

void parent(void) {
    ...... }
```
Example 2: 1/2

```
#include ............ // child exits first

void main(void)
{
    pid_t pid;

    pid = fork();
    if (pid == 0) {
        // child here
        printf("From child %ld: my parent is %ld\n",
                getpid(), getppid());
        sleep(5);
        printf("From child %ld 5 sec later: parent %ld\n",
                getpid(), getppid());
    }
    else {
        // parent here
        sleep(2);
        printf("From parent %ld: child %ld, parent %ld\n",
                getpid(), pid, getppid());
        printf("From parent: done!\n");
    }
}
```

force the child to print after the parent terminates
Example 2: 2/2

while parent is still running

19004

parent 19291

19292

parent terminated

1 is the ID of init, the Unix process that spawns all processes

child 19292

Orphan children have a new parent init, the Unix process that spawns all processes

child 19292

19004 is the shell process that executes 19291

19004

parent 19291

19292

child
Example 3: 1/2

```c
#include ...... // separate address spaces

void main(void)
{
    pid_t pid;
    char out[100];
    int i = 10, j = 20;

    if ((pid = fork()) == 0) { // child here
        i = 1000; j = 2000; // child changes values
        sprintf(out, "From child: i=%d, j=%d\n", i, j);
        write(1, out, strlen(out));
    }
    else { // parent here
        sleep(3);
        sprintf(out, "From parent: i=%d, j=%d\n", i, j);
        write(1, out, strlen(out));
    }
}
```

This is equivalent to

```c
pid = fork();
if (pid == 0) {
    i = 1000; j = 2000;
    sprintf(out, "From child: i=%d, j=%d\n", i, j);
    write(1, out, strlen(out));
}
```

force the parent to print after the child terminated
Example 3: 2/2

child changes $i$ and $j$ to 1000 and 2000 from 10 and 20, respectively

parent’s $i$ and $j$ are not affected because parent and child have independent and separate address space
**The `wait()` System Call**

- The `wait()` system call blocks the caller until **one of its child processes** exits or a signal is received.
- `wait()` takes a pointer to an integer variable and returns the process ID of the completed process. If no child process is running, `wait()` returns `-1`.
- Some flags that indicate the completion status of the child process are passed back with the integer pointer.
How to Use `wait()`?

- Wait for an unspecified child process:
  
  ```c
  wait(&status);
  ```

- Wait for a number, say `n`, of unspecified child processes:
  
  ```c
  for (i = 0; i < n; i++)
      wait(&status);
  ```

- Wait for a specific child process whose ID is known:
  
  ```c
  while (pid != wait(&status))
  ```
wait() System Call Example

```c
void main(void)
{
    pid_t pid, pid_child;
    int    status;

    if ((pid = fork()) == 0)    // child here
        child();
    else {                        // parent here
        parent();
        pid_child = wait(&status);
    }
}
```
A **zombie** or **defunct** process is a process that terminates its execution before its parent executes the `wait()` system call.

A zombie process only has an entry in the system process table and does not consume much system resource.

A zombie process will be removed completely when its parent terminates or when its parent executes the `wait()` system call waiting for this child.
Zombie Processes: 2/4

- Between the termination of the child and the termination of its parent (or the parent executes the `wait()` system call), the child is a **zombie** or **defunct** process.
- A zombie process is in the terminated state.
- The `kill` command **cannot** kill zombie processes because they had died (terminated)!
- To find out whether you have zombie processes, use `ps -af`. 
Suppose we have the following code:

```c
if (fork() > 0)
    if (fork() > 0)
        for (fork() > 0)
            while (1 == 1) ;
```

The parent creates three child processes and loops forever (i.e., never dies). Each child process does nothing and terminates immediately.

Therefore, we have three zombie processes!
Zombie Processes: 4/4

- We have three zombie processes, marked as defunct.

![Process List]

- You need to kill the parent to kill its child zombies.

![Process List]

- process 1313 created 1314, 1315 and 1316, the three zombie processes

- kill the parent 1313

- no more zombie processes
 Daemon Processes: 1/2

- A **daemon** (*DEE-mun* or *DAY-mun*) process is a background process that is detached from a terminal.
- They are used to answer requests and/or to provide services. Commonly seen ones are `inetd`, `httpd`, `nfsd`, `sshd`, `lpd`, `syslogd` ...
- Daemon processes are usually created when the system started by the `init` process, the mother of all processes with PID 1.
- It could also be created by a process that immediately exits after creation, making the created process adapted by `init`. 
Daemon Processes: 2/2

- Daemon processes usually have PPID 1 (the `init` process) and have names like `*d`.
- Not all process names end with `d` are daemons.
- You may use `ps -ef | awk '$3 == 1'` to list all processes whose parent is `init`:

<table>
<thead>
<tr>
<th>PID</th>
<th>PPID</th>
<th>User</th>
<th>State</th>
<th>Time</th>
<th>Command</th>
</tr>
</thead>
<tbody>
<tr>
<td>2124</td>
<td>1</td>
<td>root</td>
<td>S</td>
<td>00:00:00</td>
<td>/usr/sbin/lvmetad -f</td>
</tr>
<tr>
<td>2159</td>
<td>1</td>
<td>root</td>
<td>S</td>
<td>00:00:03</td>
<td>/usr/lib/systemd/systemd-udevd</td>
</tr>
<tr>
<td>4158</td>
<td>1</td>
<td>root</td>
<td>S</td>
<td>00:00:26</td>
<td>/sbin/auditd</td>
</tr>
<tr>
<td>4185</td>
<td>1</td>
<td>root</td>
<td>S</td>
<td>00:03:18</td>
<td>/usr/sbin/irqbalance --foreground</td>
</tr>
<tr>
<td>4187</td>
<td>1</td>
<td>rpc</td>
<td>S</td>
<td>00:00:04</td>
<td>/sbin/rpcbind -w</td>
</tr>
<tr>
<td>4188</td>
<td>1</td>
<td>rtkit</td>
<td>S</td>
<td>00:00:24</td>
<td>/usr/libexec/rtkit-daemon</td>
</tr>
<tr>
<td>4221</td>
<td>1</td>
<td>root</td>
<td>S</td>
<td>00:00:00</td>
<td>/usr/sbin/smartd -n -q never</td>
</tr>
<tr>
<td>4951</td>
<td>1</td>
<td>root</td>
<td>S</td>
<td>00:00:01</td>
<td>rhnsd</td>
</tr>
<tr>
<td>4961</td>
<td>1</td>
<td>root</td>
<td>S</td>
<td>00:00:22</td>
<td>/usr/sbin/ypbind -n</td>
</tr>
</tbody>
</table>
The exec() System Calls

- A newly created process may run a different program rather than that of the parent.
- This is done using the `exec` system calls. We will only discuss `execvp()`:

```c
int execvp(char *file, char *argv[]);
```

- **file** is a `char` array that contains the name of an executable file. Depending on your system settings, you may need the `. /` prefix for files in the current directory.
- **argv[]** is the argument passed to your main program.
- **argv[0]** is a pointer to a string that contains the program name.
- **argv[1], argv[2], ...** are pointers to strings that contain the arguments.
```c
#include <stdio.h>
#include <unistd.h>

void main(void)
{
    char   prog[] = { "cp" };
    char   in[]   = { "this.c" };
    char   out[]  = { "that.c" };
    char   *argv[4];
    int    status;
    pid_t  pid;

    argv[0] = prog;  argv[1] = in;

    // see next slide
```
execvp() : An Example 2/2

```c
if ((pid = fork()) < 0) {
    printf("fork() failed\n");
    exit(1);
}
else if (pid == 0)
    if (execvp(prog, argv) < 0) {
        printf("execvp() failed\n");
        exit(1);
    }
else
    wait(&status);
}```
A Mini-Shell: 1/3

void parse(char *line, char **argv)
{
    while (*line != '\0') { // not EOLN
        while (*line == ' ' || *line == '\t' || *line == '\n')
            *line++ = '\0'; // replace white spaces with 0
        *argv++ = line; // save the argument position
        while (*line != '\0' && *line != ' ' && *line != '\t' && *line != '\n')
            line++; // skip the argument until ...
    }
    *argv = '\0'; // mark the end of argument list
}

line[]
A Mini-Shell: 2/3

```c
void execute(char **argv)
{
    pid_t pid;
    int status;
    if ((pid = fork()) < 0) { // fork a child process
        printf("*** ERROR: forking child process failed\n");
        exit(1);
    }
    else if (pid == 0) { // for the child process:
        if (execvp(*argv, argv) < 0) { // execute the command
            printf("*** ERROR: exec failed\n");
            exit(1);
        }
    }
    else { // for the parent:
        while (wait(&status) != pid) // wait for completion
            ;
    }
}
```
void main(void)
{
    char line[1024]; // the input line
    char *argv[64];  // the command line argument

    while (1) {  // repeat until done ....
        printf("Shell -> "); // display a prompt
        gets(line); // read in the command line
        printf("\n");
        parse(line, argv); // parse the line
        if (strcmp(argv[0], "exit") == 0) // is it an "exit"?
            exit(0); // exit if it is
        execute(argv); // otherwise, execute the command
    }
}

Don’t forget that gets() is risky! Use fgets() instead.
What is Shared Memory?

- The parent and child processes are run in independent and separate address spaces. All processes, parent and children included, do not share anything.

- A shared memory segment is a piece of memory that can be allocated and attached to an address space. Processes that have this memory segment attached will have access to it.

- But, race conditions can occur!
Procedure for Using Shared Memory

- Find a **key**. Unix uses this key for identifying shared memory segments.
- Use `shmget()` to allocate a shared memory.
- Use `shmat()` to attach a shared memory to an address space.
- Use `shmdt()` to detach a shared memory from an address space.
- Use `shmctl()` to deallocate a shared memory.
To use shared memory, include the following:

```c
#include <sys/types.h>
#include <sys/ipc.h>
#include <sys/shm.h>
```

A key is a value of type `key_t`. There are three ways to generate a key:

- Do it yourself
- Use function `ftok()`
- Ask the system to provide a private key.
Do it yourself:

```c
key_t SomeKey;
SomeKey = 1234;
```

Use `ftok()` to generate one for you:

```c
key_t = ftok(char *path, int ID);
```
- `path` is a path name (e.g., ``./``)
- `ID` is an integer (e.g., ‘a’)
- Function `ftok()` returns a key of type `key_t`:
  ```c
  SomeKey = ftok("./", 'x');
  ```

Keys are global entities. If other processes know your key, they can access your shared memory.

Ask the system to provide a private key with `IPC_PRIVATE`. 
Ask for a Shared Memory: 1/4

- Include the following:
  ```
  #include <sys/types.h>
  #include <sys/ipc.h>
  #include <sys/shm.h>
  ```

- Use `shmget()` to request a shared memory:
  ```
  shm_id = shmget(
      key_t  key,    /* identity key    */
      int    size,   /* memory size     */
      int    flag);  /* creation or use */
  ```
  `shmget()` returns a shared memory ID.

- The flag means permission, which is either `0666` (you and your group can read and write) or `IPC_CREAT | 0666`. 
The following creates a shared memory of size

```c
struct Data { int a; double b; char x; }; 
int ShmID; 

ShmID = shmget(
    IPC_PRIVATE,  /* private key */
    sizeof(struct Data), /* size */
    IPC_CREAT | 0666);  /* cr & rw */
```
The following creates a shared memory with a key based on the current directory:

```c
struct Data { int a; double b; char x;};
int    ShmID;
key_t   Key;

Key = ftok("./", 'h');
ShmID = shmget(
    Key, /* a key */
    sizeof(struct Data),
    IPC_CREAT | 0666);
```
Ask for a Shared Memory: 4/4

- When asking for a shared memory, the process that creates it uses `IPC_CREAT | 0666` and processes that access a created one use `0666`.

- If the return value is negative (Unix convention), the request was unsuccessful, and no shared memory is allocated.

- **Create a shared memory before its use!**
**After the Execution of `shmget()`**

Process 1:

```
shmget(..., IPC_CREAT | 0666);
```

Process 2:

Shared memory is allocated; but, is not part of the address space.
**Attaching a Shared Memory: 1/3**

- Use `shmat()` to attach an existing shared memory to an address space:

  ```c
  shm_ptr = shmat(
      int  shm_id, /* ID from shmget() */
      char *ptr,   /* use NULL here    */
      int  flag);  /* use 0 here       */
  ```

- `shm_id` is the shared memory ID returned by `shmget()`.

- Use `NULL` and 0 for the second and third arguments, respectively.

- `shmat()` returns a `void` pointer to the memory. If unsuccessful, it returns a negative integer.
struct Data { int a; double b; char x;};
int    ShmID;
key_t  Key;
struct Data *p;

Key = ftok("./", ‘h’);
**ShmID = shmget**(Key, sizeof(struct Data),
  IPC_CREAT | 0666);
**p = (struct Data *) shmat**(ShmID, NULL, 0);
if ((int) p < 0) {
    printf("shmat() failed\n"); exit(1);
}
p->a = 1; p->b = 5.0; p->x = ‘.’;
Now processes can access the shared memory
Detaching/Removing Shared Memory

- To detach a shared memory, use
  ```c
  shmdt(shm_ptr);
  ```
  `shm_ptr` is the pointer returned by `shmat()`.

- After a shared memory is detached, it is still there. You can attach and use it again.

- To remove a shared memory, use
  ```c
  shmctl(shm_ID, IPC_RMID, NULL);
  ```
  `shm_ID` is the shared memory ID returned by `shmget()`. After a shared memory is removed, it no longer exists.
void main(int argc, char *argv[]) {
    int ShmID, *ShmPTR, status;
    pid_t pid;

    ShmID = shmget(IPC_PRIVATE,4*sizeof(int),IPC_CREAT|0666);
    ShmPTR = (int *) shmat(ShmID, NULL, 0);
    ShmPTR[0] = getpid();
    ShmPTR[1] = atoi(argv[1]);
    ShmPTR[2] = atoi(argv[2]);
    ShmPTR[3] = atoi(argv[3]);
    if ((pid = fork()) == 0) {
        Child(ShmPTR);
        exit(0);
    }
    wait(&status);
    shmdt((void *) ShmPTR);
    shmctl(ShmID, IPC_RMID, NULL);
    exit(0);
}
Communicating with a Child: 2/2

```c
void Child(int SharedMem[])
{
    printf("%d %d %d %d\n", SharedMem[0],
            SharedMem[1], SharedMem[2], SharedMem[3]);
}
```

- **Why are `shmget()` and `shmat()` not needed in the child process?**
Define the structure of a shared memory segment as follows:

```c
#define NOT_READY (-1)
#define FILLED (0)
#define TAKEN (1)

struct Memory {
    int status;
    int data[4];
};
```
Communicating Among Separate Processes: 2/5

The “Server”

```c
int main(int argc, char *argv[]) {
    key_t          ShmKEY;
    int            ShmID, i;
    struct Memory  *ShmPTR;

    ShmKEY = ftok("./", 'x');
    ShmID = shmget(ShmKEY, sizeof(struct Memory),
                   IPC_CREAT | 0666);
    ShmPTR = (struct Memory *) shmat(ShmID, NULL, 0);
}```
Communicating Among Separate Processes: 3/5

shared memory not ready

filling in data

\[\text{ShmPTR->status = NOT\_READY;}\]

\[\text{ShmPTR->data[0] = getpid();}\]
\[\text{for (i = 1; i < 4; i++)}\]
\[\text{\quad ShmPTR->data[i] = atoi(argv[i]);}\]

wait until the data is taken

\[\text{ShmPTR->status = FILLED;}\]
\[\text{while (ShmPTR->status != TAKEN)}\]
\[\quad \text{sleep(1); /* sleep for 1 second */}\]
\[\quad \text{printf("My buddy is %ld\n", ShmPTR->data[0]);}\]
\[\quad \text{shmdt((void *) ShmPTR);}\]
\[\quad \text{shmctl(ShmID, IPC\_RMID, NULL);}\]
\[\quad \text{exit(0);}\]

detach and remove shared memory

\[\text{ exit(0); }\]
int main(void)
{
    key_t        ShmKEY;
    int          ShmID;
    struct Memory  *ShmPTR;

    ShmKEY=ftok(“./”, ‘x’);
    ShmID = shmget(ShmKEY, sizeof(struct Memory), 0666);
    ShmPTR = (struct Memory *) shmat(ShmID, NULL, 0);
    while (ShmPTR->status != FILLED)
    {
        printf(“%d %d %d %d\n”, ShmPTR->data[0],
                ShmPTR->data[1], ShmPTR->data[2], ShmPTR->data[3]);
        ShmPTR->data[0] = getpid();
        ShmPTR->status = TAKEN;
        shmdt((void *) ShmPTR);
    }
    exit(0);
}

The “Client”

prepare for shared memory
Communicating Among Separate Processes: 5/5

- The “server” must run first to prepare a shared memory.
- Run the server in one window, and run the client in another a little later.
- Or, run the server as a background process. Then, run the client in the foreground later:
  
  ```
  server 1 3 5 &
  client
  ```
- This version uses busy waiting.
- One may use Unix semaphores for mutual exclusion.
Important Notes: 1/3

- If you do not remove your shared memory segments (e.g., program crashes before the execution of `shmctl()`), they will be in the system forever until the system is shut down. This will degrade the system performance.
- Use the `ipcs` command to check if you have shared memory segments left in the system.
- Use the `ipcrm` command to remove your shared memory segments.
Important Notes: 2/3

- To see existing shared memory segments in the system, use `ipcs -m`, where `m` means shared memory.
- The following is a snapshot on `wopr`:
Important Notes: 3/3

- To remove a shared memory, use the `ipcrm` command as follows:
  - `ipcrm -M shm-key`
  - `ipcrm -m shm-ID`

- You have to be the owner (or super user) to remove a shared memory.
The End