Linux Internals & Networking

System programming using Kernel interfaces

Team Emertxe

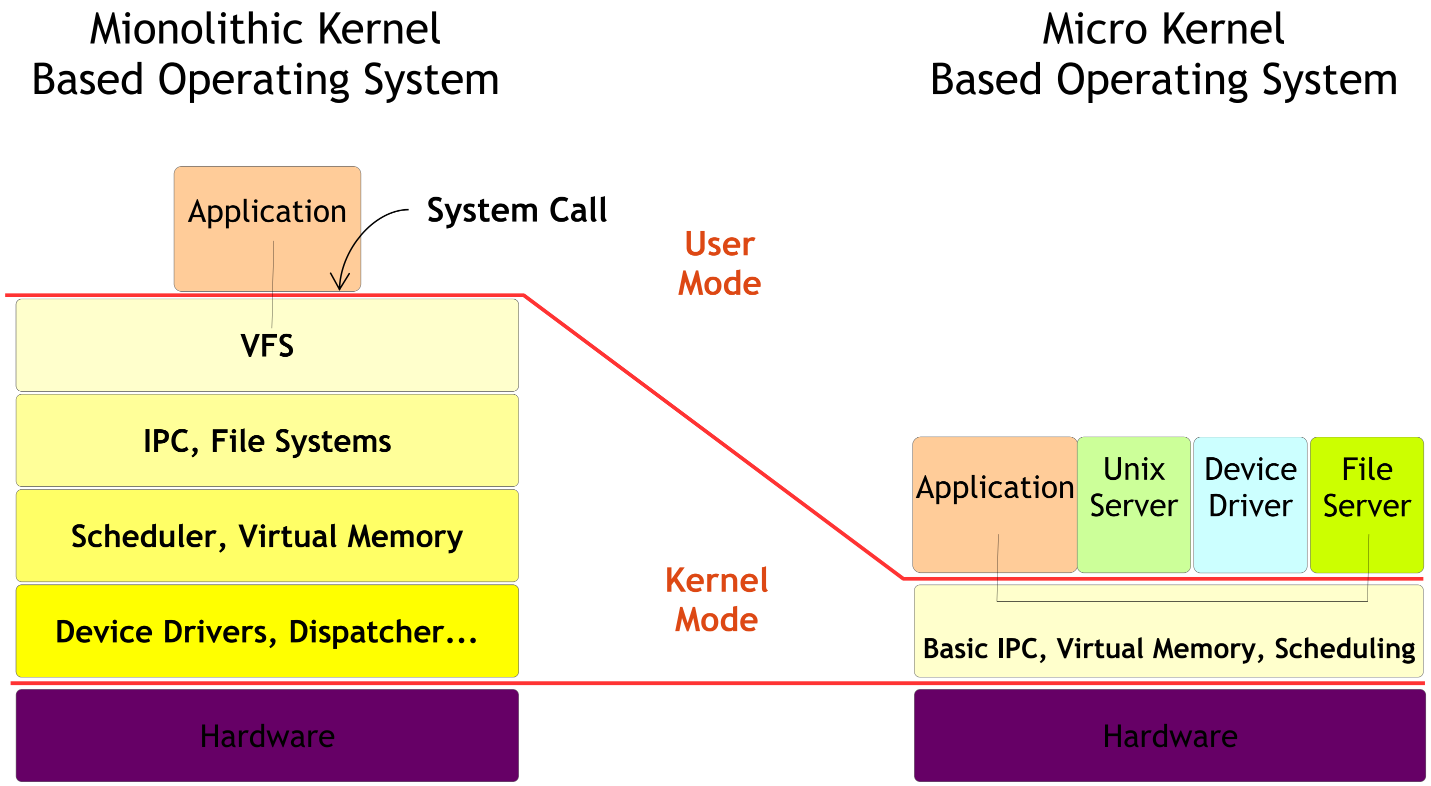
Contents

Contents

Introduction

Introduction

Kernel Architecture



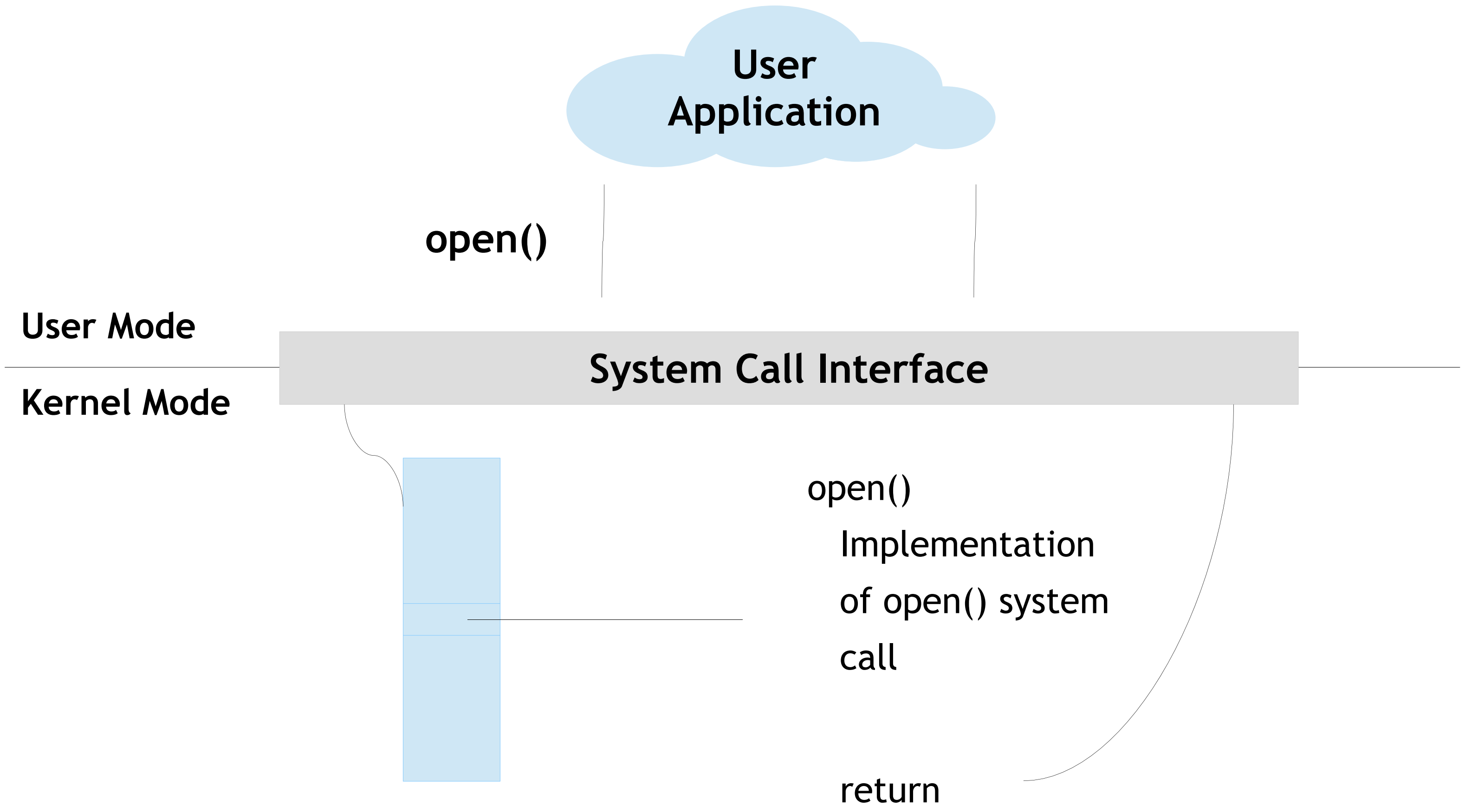
Introduction

Mono vs Micro

Monolithic kernel	Microlithic kernel
•Kernel size increases because kernel + kernel subsystems compiled as single binary •Difficult to extension or bug fixing, •Need to compile entire source code. •Bad maintainability •Faster, run as single binary •Communication between services is faster. •No crash recovery. •More secure •Eg: Windows, Linux etc	•Kernel size is small because kernel subsystems run as separate binaries. •Easily extensible and bug fixing. •Easily recover from crash •Slower due to complex message passing between services •Process management is complex •Communication is slow •Easily recoverable from crashing •Eg: MacOS, WinNT

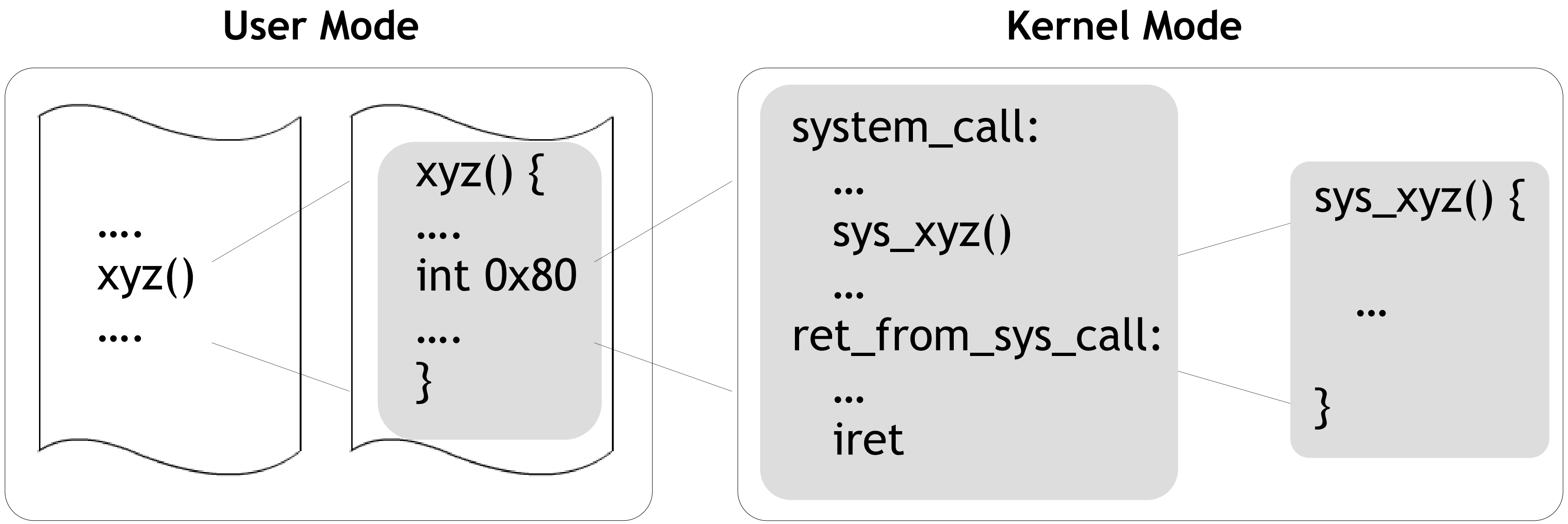
System Calls

System calls



System Call

Implementation



System Call Invocation in application program

Wrapper routine in libc standard library

System call handler

System call service routine

System Call
Example: Others

- open
- read
- write
- exit
- close
- wait
- waitpid
- getpid
- sync
- nice
- kill etc..

Process

Process

- Running instance of a program is called a PROCESS
- If you have two terminal windows showing on your screen, then you are probably running the same terminal program twice-you have two terminal processes
- Each terminal window is probably running a shell; each running shell is another process
- When you invoke a command from a shell, the corresponding program is executed in a new process
- The shell process resumes when that process complete

Process

vs Program

- A program is a passive entity, such as file containing a list of instructions stored on a disk
- Process is a active entity, with a program counter specifying the next instruction to execute and a set of associated resources.
- A program becomes a process when an executable file is loaded into main memory

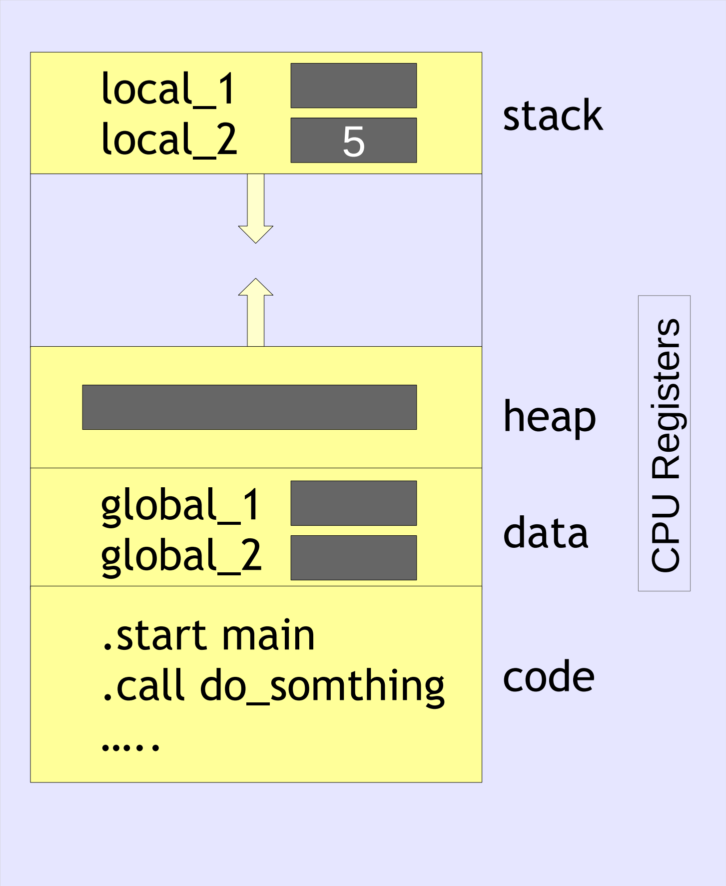
Factor	Process	Program
Storage	Dynamic Memory	Secondary Memory
State	Active	Passive

Process
vs Program

Program

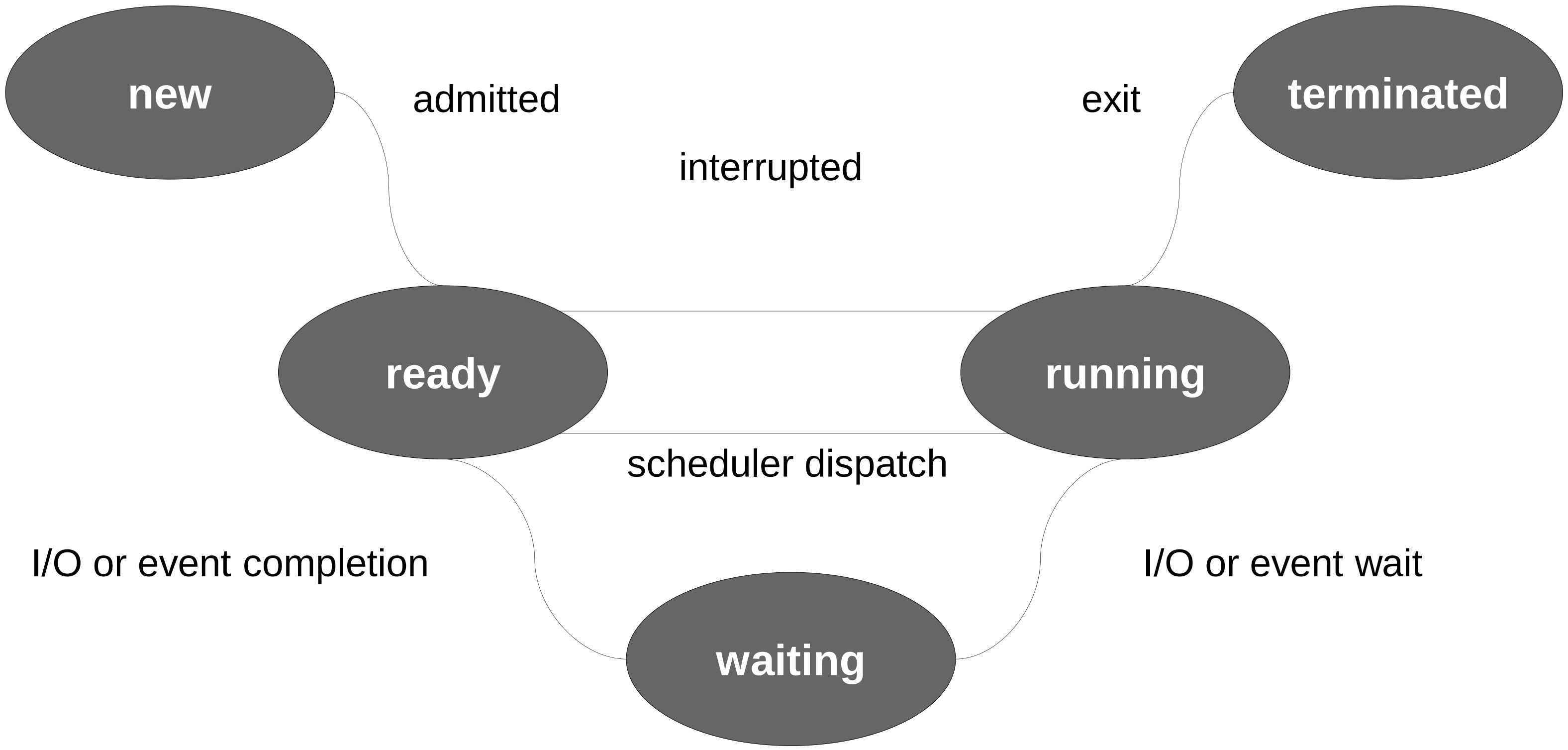
```
int global_1 = 0;
int global_2 = 0;

void do_somthing()
{
        int local_2 = 5;
        local_2 = local_2 + 1;
}

int main()
{
        char *local_1 = malloc(100);

        do_somthing();
        …..
}
```

Task



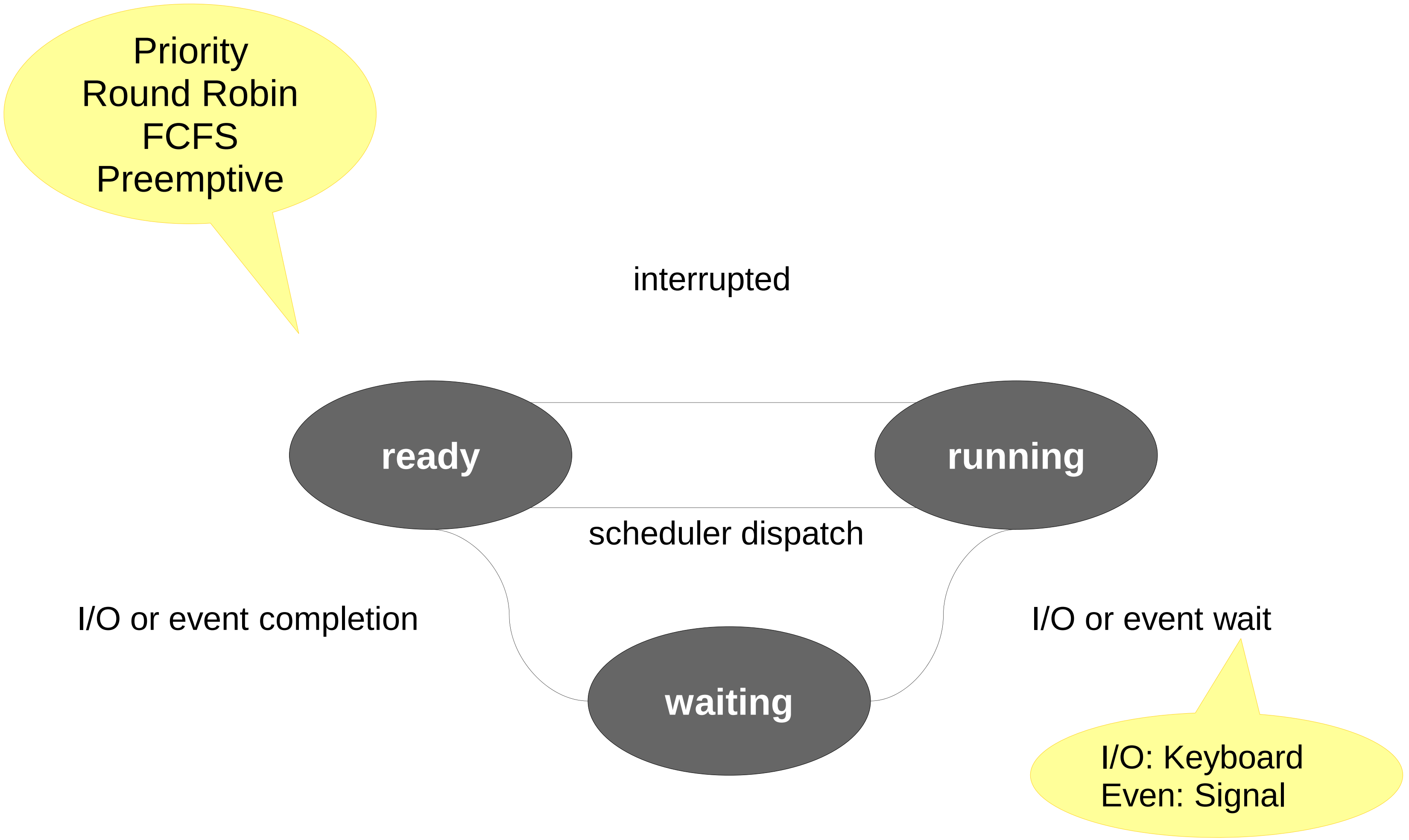
Process

State Transition Diagram



Process

State Transition Diagram



Process
States

A process goes through multiple states ever since it is created by the OS

State	Description
New	The process is being created
Running	Instructions are being executed
Waiting	The process is waiting for some event to occur
Ready	The process is waiting to be assigned to processor
Terminated	The process has finished execution

Process
Descriptor

- To manage tasks:
  - OS kernel must have a clear picture of what each task is doing.
  - Task's priority
  - Whether it is running on the CPU or blocked on some event
  - What address space has been assigned to it
  - Which files it is allowed to address, and so on.
- Usually the OS maintains a structure whose fields contain all the information related to a single task

Process
Descriptor

Pointer	Process State
Process ID	
Program Counter	
Registers	
Memory Limits	
List of Open Files	
. . . . . .	

- Information associated with each process.
- Process state
- Program counter
- CPU registers
- CPU scheduling information
- Memory-management information
- I/O status information

Process

Descriptor – State Field

- State field of the process descriptor describes the state of process.
- The possible states are:

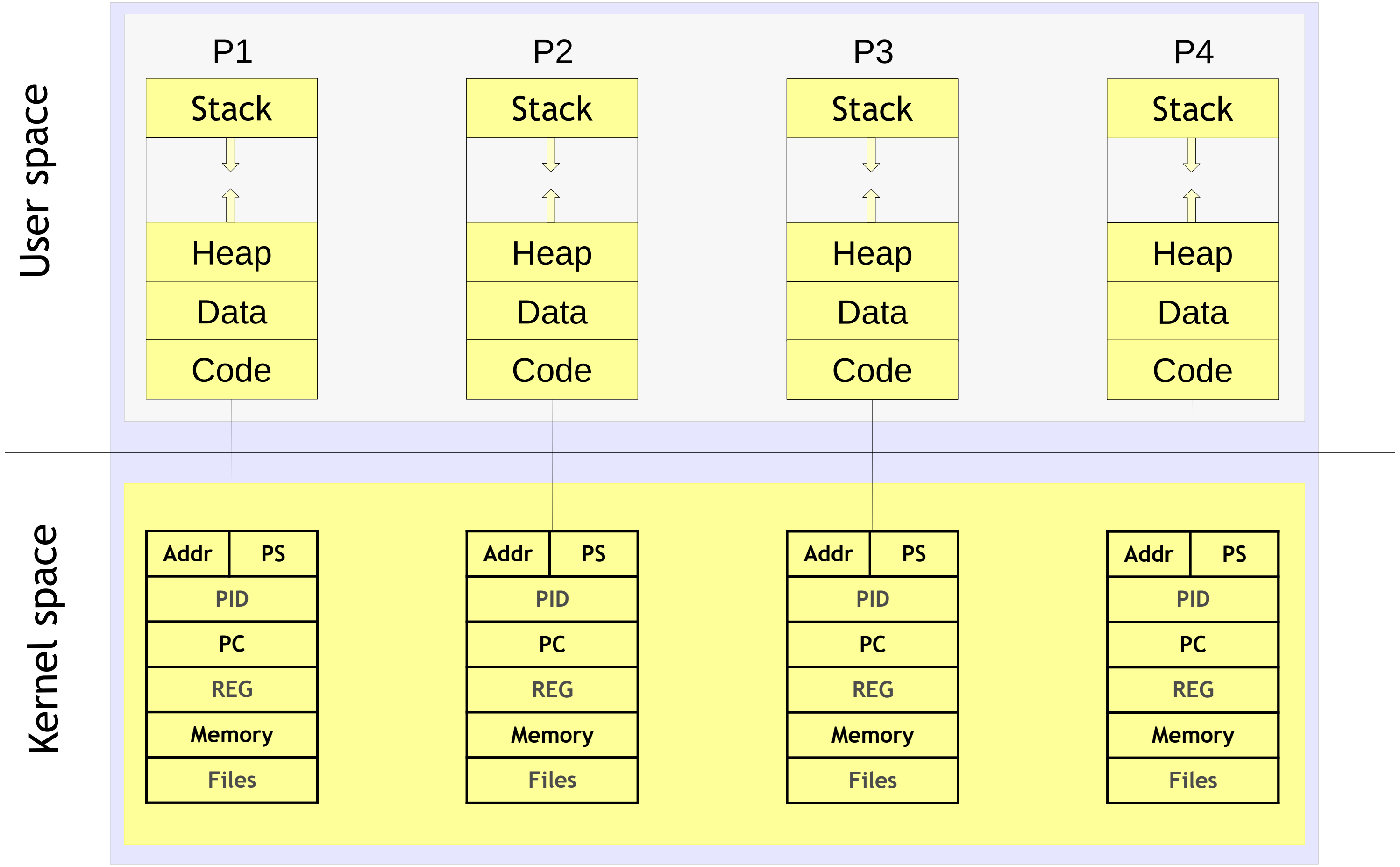
State	Description
TASK_RUNNING	Task running or runnable
TASK_INTERRUPTIBLE	process can be interrupted while sleeping
TASK_UNINTERRUPTIBLE	process can't be interrupted while sleeping
TASK_STOPPED	process execution stopped
TASK_ZOMBIE	parent is not issuing wait()

Process
Descriptor - ID

- Each process in a Linux system is identified by its unique process ID, sometimes referred to as PID
- Process IDs are numbers that are assigned sequentially by Linux as new processes are created
- Every process also has a parent process except the special init process
- Processes in a Linux system can be thought of as arranged in a tree, with the init process at its root
- The parent process ID or PPID, is simply the process ID of the process's parent

Process

Schedule



Process
Active Processes

- The *ps* command displays the processes that are running on your system
- By default, invoking ps displays the processes controlled by the terminal or terminal window in which ps is invoked
- For example (Executed as “ps –aef”):

Process ID

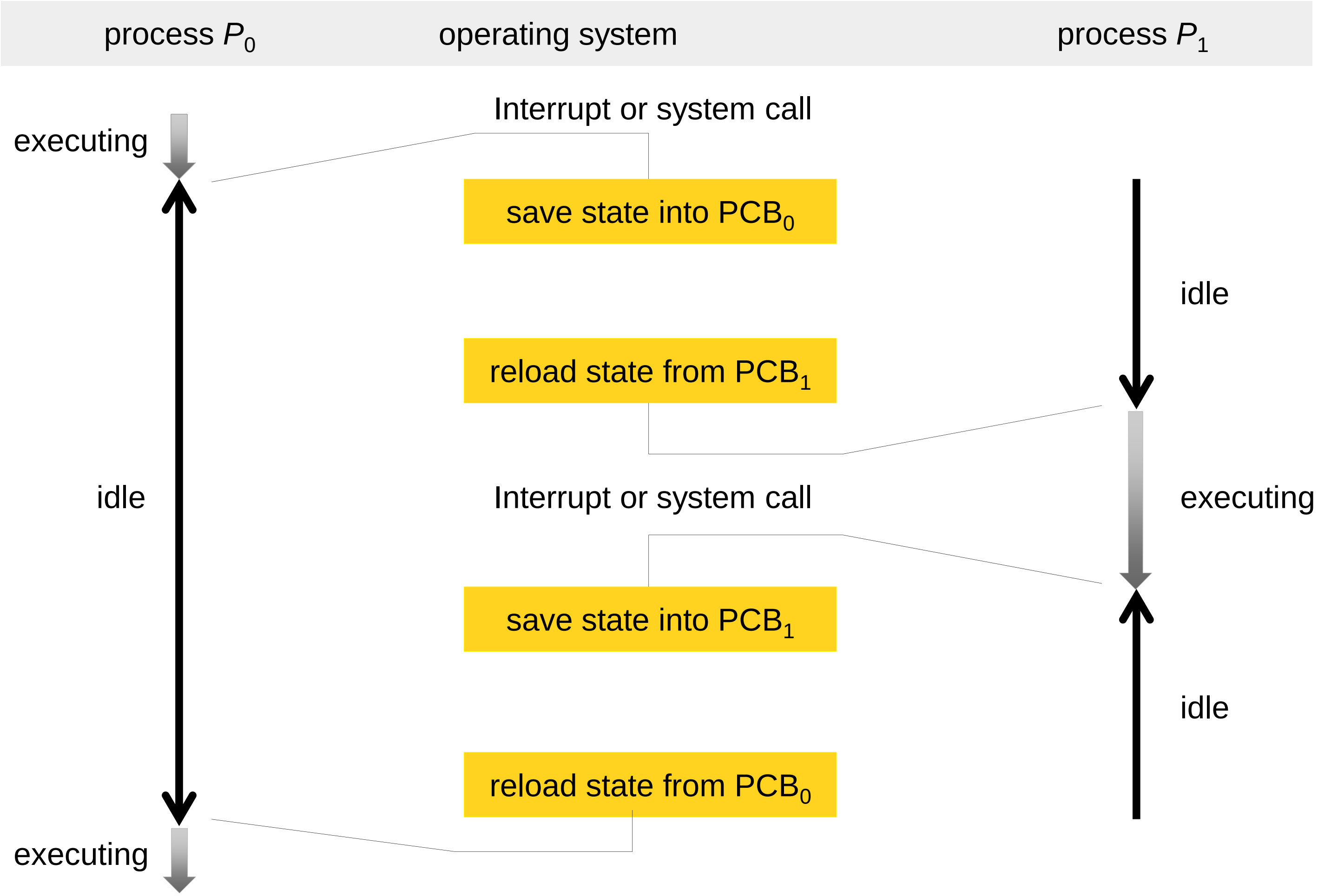
Parent Process ID

```
user@user:~] ps -aef
UID        PID   PPID  C STIME TTY          TIME CMD
root         1      0  0 12:17  ?       00:00:01 /sbin/init
root         2      0  0 12:17  ?       00:00:00 [kthreadd]
root         3      2  0 12:17  ?       00:00:02 [ksoftirqd/0]
root         4      2  0 12:17  ?       00:00:00 [kworker/0:0]
root         5      2  0 12:17  ?       00:00:00 [kworker/0:0H]
root         7      2  0 12:17  ?       00:00:00 [rcu_sched]
```

Process
Context Switching

- Switching the CPU to another task requires saving the state of the old task and loading the saved state for the new task
- The time wasted to switch from one task to another without any disturbance is called context switch or scheduling jitter
- After scheduling the new process gets hold of the processor for its execution

Context Switching



Process
Creation

- Two common methods are used for creating new process
- Using system(): Relatively simple but should be used sparingly because it is inefficient and has considerably security risks
- Using fork() and exec(): More complex but provides greater flexibility, speed, and security

Process

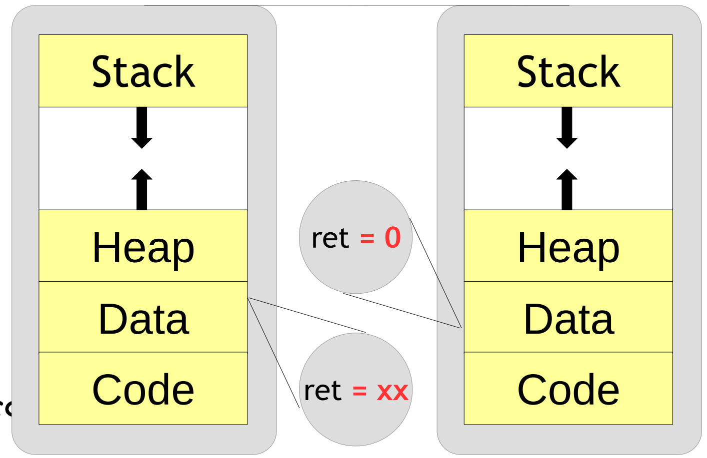
Creation - fork()

- fork makes a child process that is an exact copy of its parent process
- When a program calls fork, a duplicate process, called the child process, is created
- The parent process continues executing the program from the point that fork was called
- The child process, too, executes the same program from the same place
- All the statements after the call to fork will be executed twice, once, by the parent process and once by the child process

Process
Creation - fork()

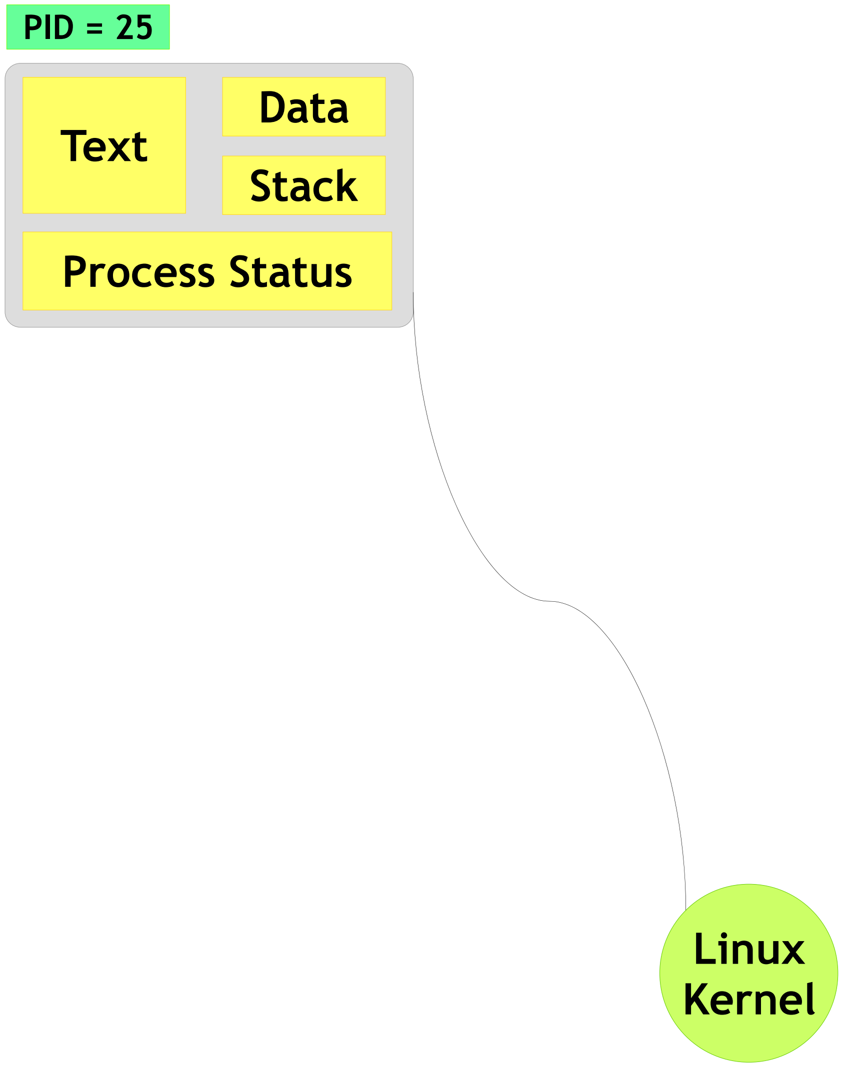
- The execution context for the child process is a copy of parent's context at the time of the call

```
int child_pid;
int child_status;

int main()
{
        int ret;

        ret = fork();
        switch (ret)
        {
                case -1:
                        perror("fork");
                        exit(1);
                case 0:
                        <code for child pro
                        exit(0);
                default:
                        <code for parent process>
                        wait(&child_status);
        }
}
```



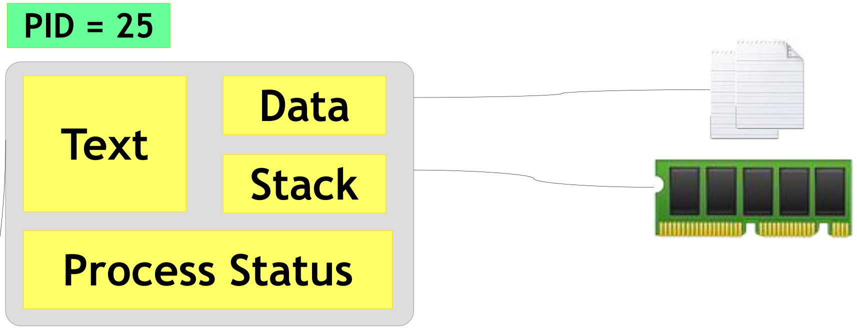
Process

fork() - The Flow



Process

fork() - The Flow

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switch (ret)
{
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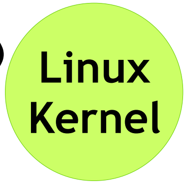
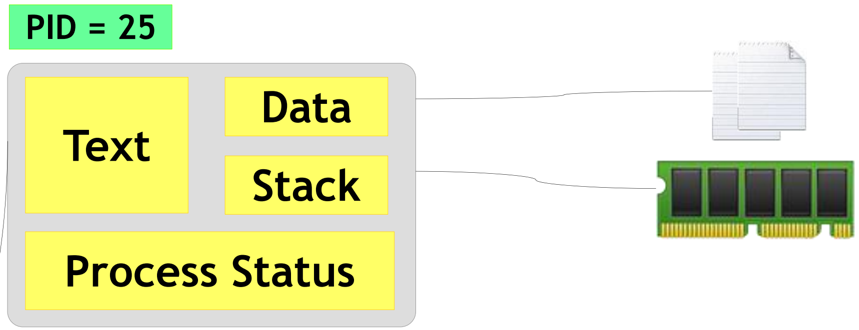
}
```



Process

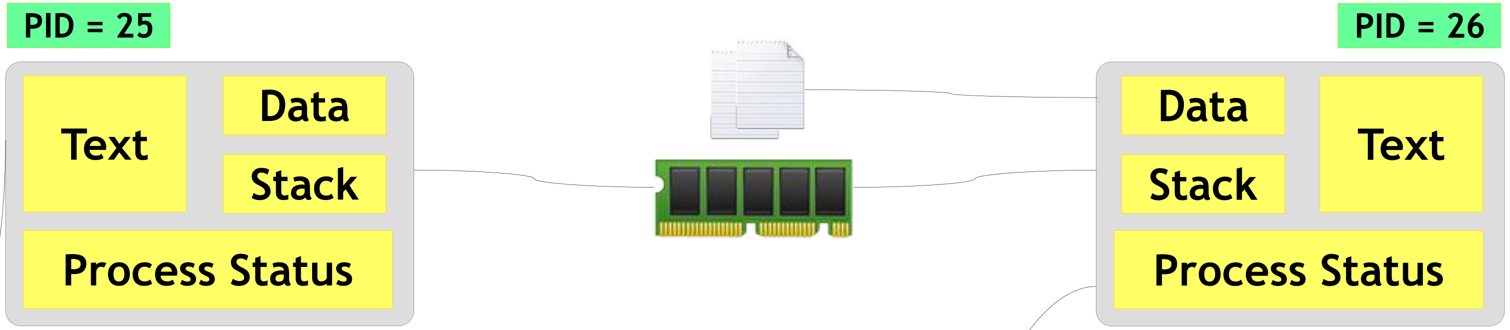
fork() - The Flow




```
ret = fork();
switch (ret)
{
        case -1:
                perror(“fork”);
                exit(1);
        case 0:
                <code for child>
                exit(0);
        default:
                <code for parent>
                wait(&child_status)
}
```

Linux Kernel

Process
fork() - The Flow

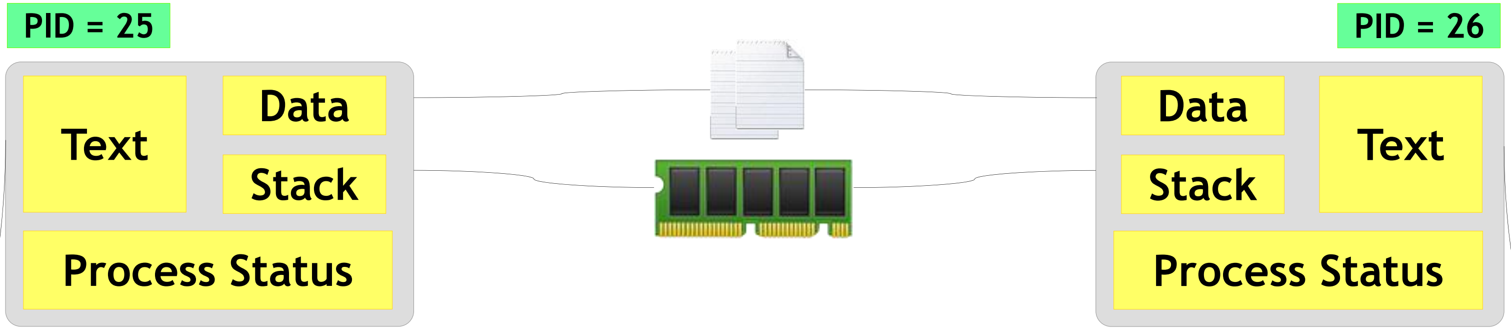



```
ret = fork();          ret = 26
switch (ret)
{
        case -1:
                perror("fork");
                exit(1);
        case 0:
                <code for child>
                exit(0);
        default:
                <code for parent>
                wait(&child_status)
}
```

Linux
Kernel

Process

fork() - The Flow

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switch (ret)
{
        case -1:
                perror("fork");
                exit(1);
        case 0:
                <code for child>
                exit(0);
        default:
                <code for parent>
                wait(&child_status);
}
```
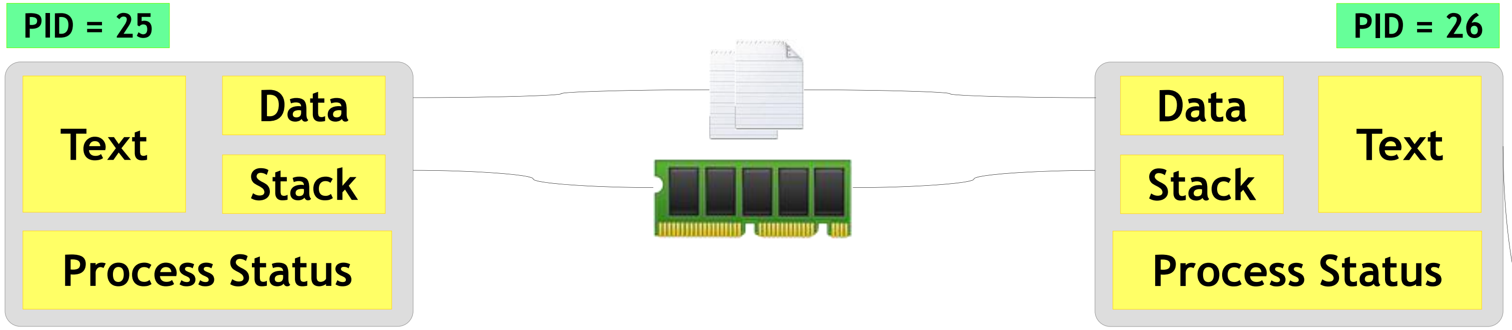

```
ret = fork();
switch (ret)
{
        case -1:
                perror("fork");
                exit(1);
        case 0:
                <code for child>
                exit(0);
        default:
                <code for parent>
                wait(&child_status);
}
```

Process

fork() - The Flow




```
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switch (ret)
{
        case -1:
                perror("fork");
                exit(1);
        case 0:
                <code for child>
                exit(0);
        default:
                <code for parent>
                wait(&child_status)
}
```

Linux Kernel

```
ret = fork();                 ret = 0
switch (ret)
{
        case -1:
                perror("fork");
                exit(1);
        case 0:
                <code for child>
                exit(0);
        default:
                <code for parent>
                wait(&child_status);
}
```

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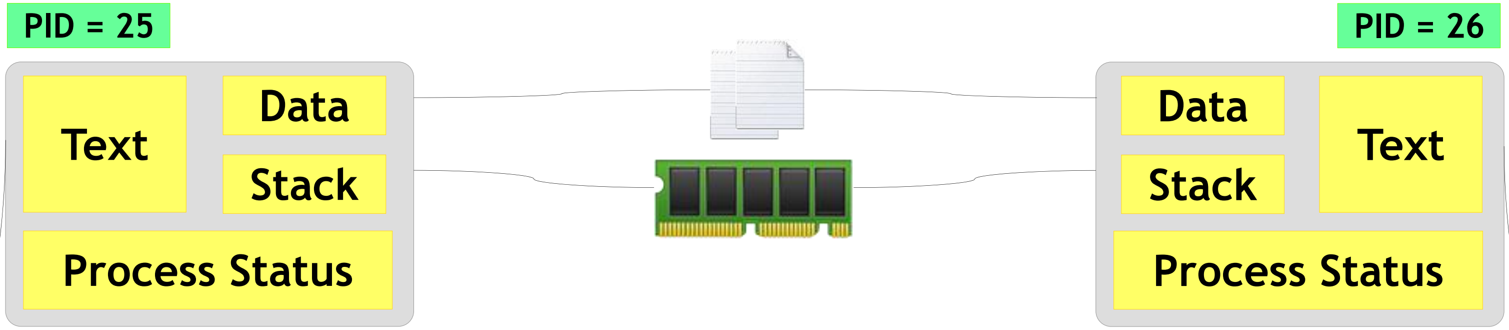
Process

fork() - The Flow

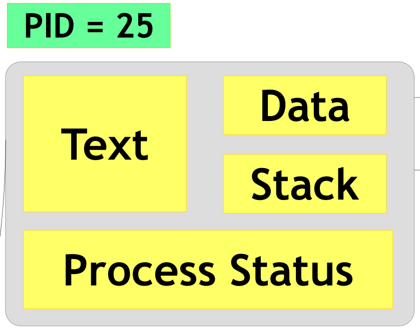



```
ret = fork();          ret = 26
switch (ret)
{
        case -1:
                perror("fork");
                exit(1);
        case 0:
                <code for child>
                exit(0);
        default:
                <code for parent>
                wait(&child_status)
}
```

Linux Kernel

```
ret = fork();                ret = 0
switch (ret)
{
        case -1:
                perror("fork");
                exit(1);
        case 0:
                <code for child>
                exit(0);
        default:
                <code for parent>
                wait(&child_status);
}
```

Process
fork() - The Flow



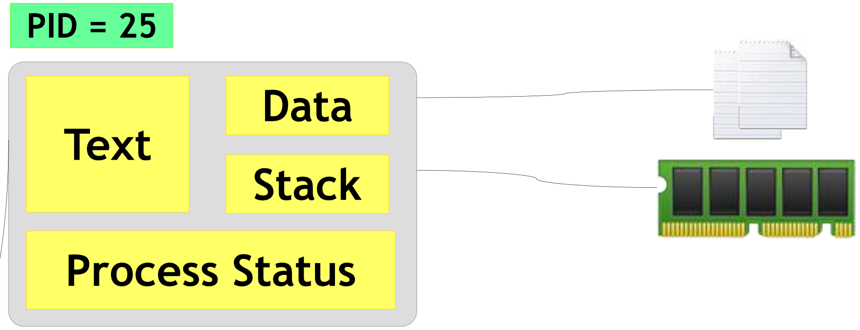

```
ret = fork();          ret = 26
switch (ret)
{
        case -1:
                perror("fork");
                exit(1);
        case 0:
                <code for child>
                exit(0);
        default:
                <code for parent>
                wait(&child_status);
}
```

[redacted]

Kernel

Process

fork() - The Flow




```
ret = fork();          ret = 26
switch (ret)
{
        case -1:
                perror("fork");
                exit(1);
        case 0:
                <code for child>
                exit(0);
        default:
                <code for parent>
                wait(&child_status)
}
```

Linux Kernel

Process

fork() - How to Distinguish?

- First, the child process is a new process and therefore has a new process ID, distinct from its parent’s process ID
- One way for a program to distinguish whether it’s in the parent process or the child process is to call getpid
- The fork function provides different return values to the parent and child processes
- One process “goes in” to the fork call, and two processes “come out,” with different return values
- The return value in the parent process is the process ID of the child
- The return value in the child process is zero

Process
Zombie

- Zombie process is a process that has terminated but has not been cleaned up yet
- It is the responsibility of the parent process to clean up its zombie children
- If the parent does not clean up its children, they stay around in the system, as zombie
- When a program exits, its children are inherited by a special process, the init program, which always runs with process ID of 1 (it's the first process started when Linux boots)
- The init process automatically cleans up any zombie child processes that it inherits.

Process
Orphan

- An orphan process is a computer process whose parent process has finished or terminated, though it remains running itself.
- Orphaned children are immediately "adopted" by init .
- An orphan is just a process. It will use whatever resources it uses. It is reasonable to say that it is not an "orphan" at all since it has a parent but "adopted".
- Init automatically reaps its children (adopted or otherwise).
- So if you exit without cleaning up your children, then they will not become zombies.

Process
Overlay - exec()

- The exec functions replace the program running in a process with another program
- When a program calls an exec function, that process immediately ceases executing and begins executing a new program from the beginning
- Because exec replaces the calling program with another one, it never returns unless an error occurs
- This new process has the same PID as the original process, not only the PID but also the parent process ID, current directory, and file descriptor tables (if any are open) also remain the same
- Unlike fork, exec results in still having a single process

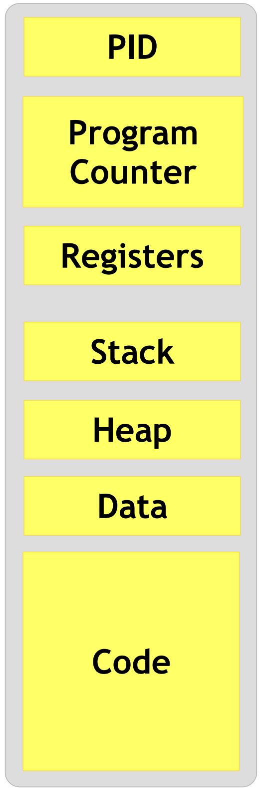
Process

Overlay - exec()

- Let us consider an example of execlp (variant of exec() function) shown below

```
/* Program: my_ls.c */

int main()
{
        print("Executing my ls :)\n");
        execlp("/bin/ls", "ls", NULL);
}
```



Process

Overlay - exec()

- After executing the exec function, you will note the following changes

```
/* Program: my_ls.c */

int main()
{
        print("Executing my ls :)\n");
        execlp("/bin/ls", "ls", NULL);
}
```

PID	Preserved
Program Counter	
Registers	Reset
Stack	Overwritten by New Code
Heap	Overwritten by New Code
Data	Overwritten by New Code
Code	Overwritten with New Code

Process

exec() - Variants

- The exec has a family of system calls with variations among them
- They are differentiated by small changes in their names
- The exec family looks as follows:

System call	Meaning
execl(const char *path, const char *arg, ...);	Full path of executable, variable number of arguments
execlp(const char *file, const char *arg, ...);	Relative path of executable, variable number of arguments
execv(const char *path, char *const argv[]);	Full path of executable, arguments as pointer of strings
execvp(const char *file, char *const argv[]);	Relative path of executable, arguments as pointer of strings

Process

Blending fork() and exec()

- Practically calling program never returns after exec()
- If we want a calling program to continue execution after exec, then we should first fork() a program and then exec the subprogram in the child process
- This allows the calling program to continue execution as a parent, while child program uses exec() and proceeds to completion
- This way both fork() and exec() can be used together

Process

COW – Copy on Write

- Copy-on-write (called COW) is an optimization strategy
- When multiple separate process use same copy of the same information it is not necessary to re-create it
- Instead they can all be given pointers to the same resource, thereby effectively using the resources
- However, when a local copy has been modified (i.e. write) , the COW has to replicate the copy, has no other option
- For example if exec() is called immediately after fork() they never need to be copied the parent memory can be shared with the child, only when a write is performed it can be re-created

Process
Termination

- When a parent forks a child, the two process can take any turn to finish themselves and in some cases the parent may die before the child
- In some situations, though, it is desirable for the parent process to wait until one or more child processes have completed
- This can be done with the wait() family of system calls.
- These functions allow you to wait for a process to finish executing, enable parent process to retrieve information about its child's termination

Process
Wait

fork() in combination with wait() can be used for child monitoring

Appropriate clean-up (if any) can be done by the parent for ensuring better resource utilization

Otherwise it will result in a ZOMBIE process

There are four different system calls in the wait family

System call	Meaning
wait(int *status)	Blocks & waits the calling process until one of its child processes exits. Return status via simple integer argument
waitpid (pid_t pid, int* status, int options)	Similar to wait, but only blocks on a child with specific PID
wait3(int *status, int options, struct rusage *rusage)	Returns resource usage information about the exiting child process.
wait4 (pid_t pid, int *status, int options, struct rusage *rusage)	Similar to wait3, but on a specific child

Thank You