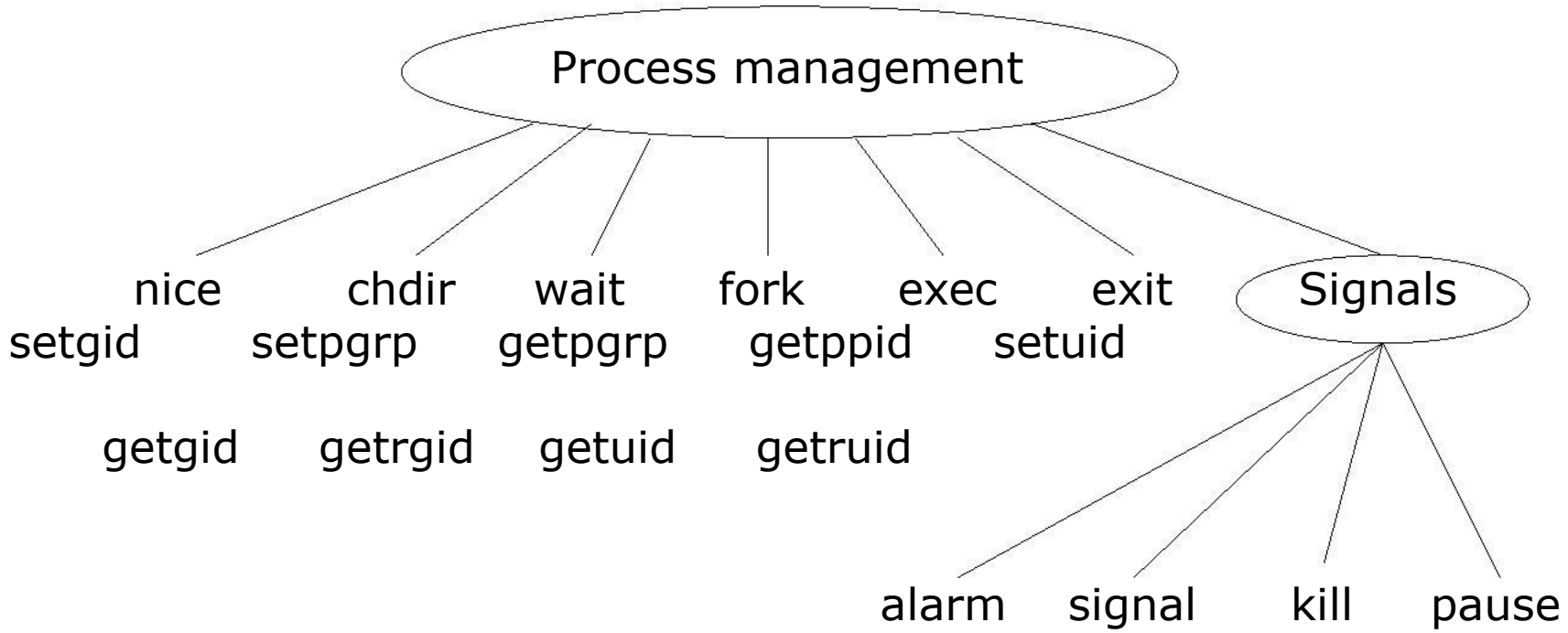
Systems Software/Programming

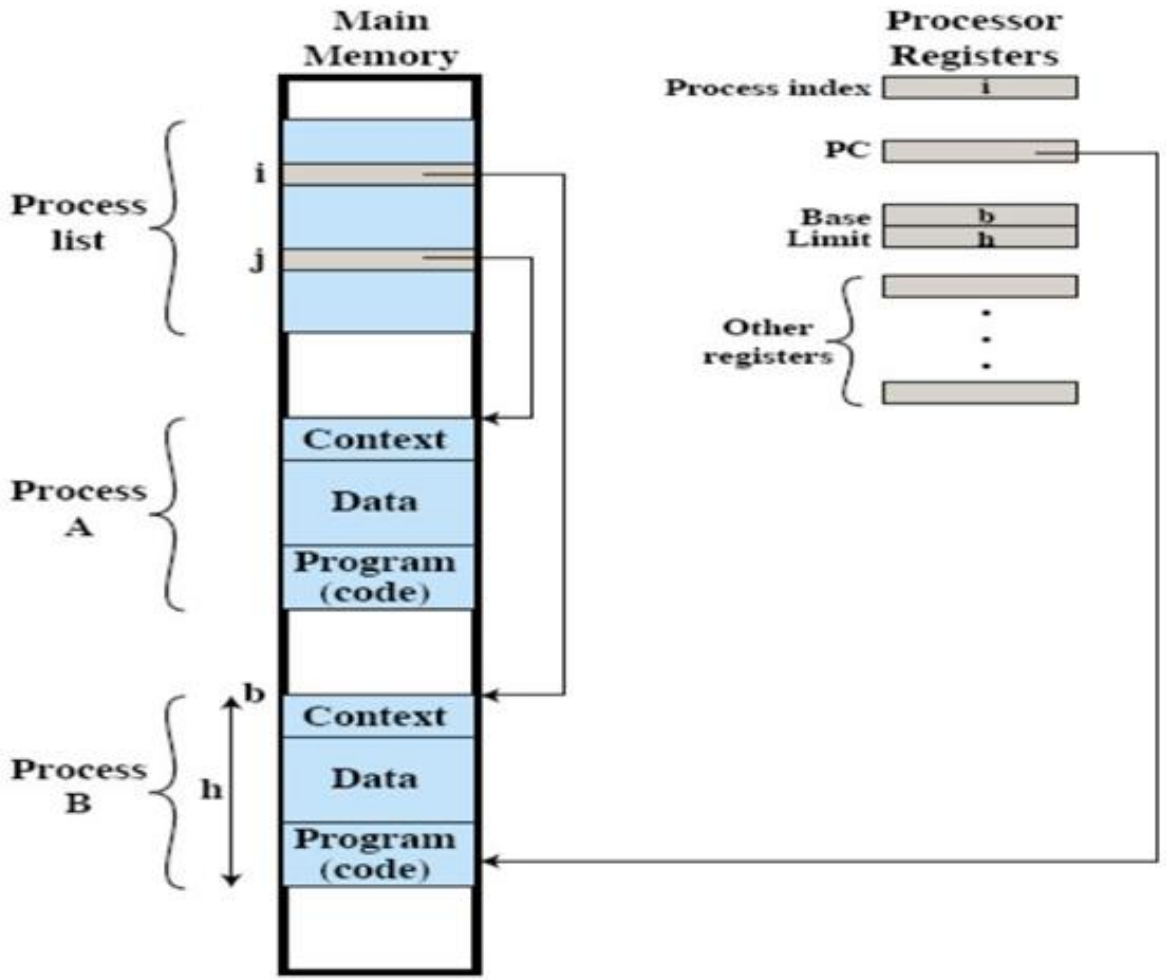
Process Management

Process Management System Call Hierarchy



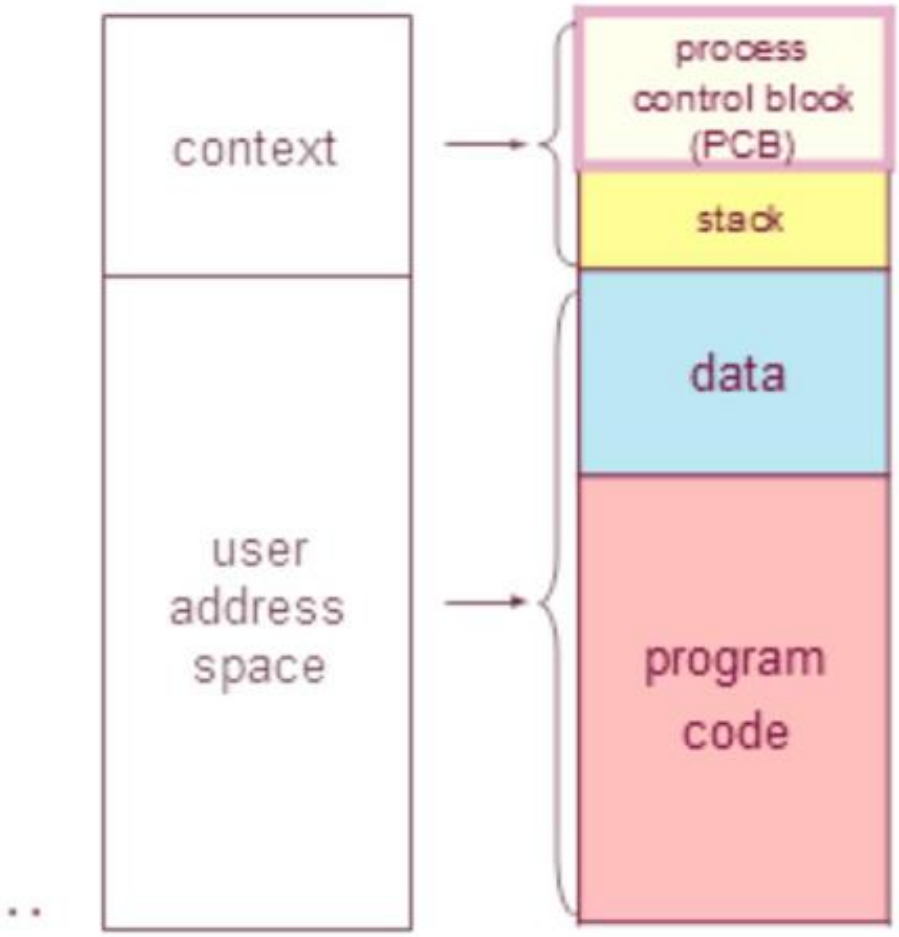
Process Concept

- A process is program in execution. **Multiple instances of the same program are different processes**
- Process memory image contains 3 components in 2 address spaces:
  - User Address Space
    - An executable program code
    - Associated data needed by program
  - Kernel Address Space
    - Execution context needed by OS to manage the process (Process ID, CPU registers, CPU time, stack, open files, memory space for code data and stack, signals etc)

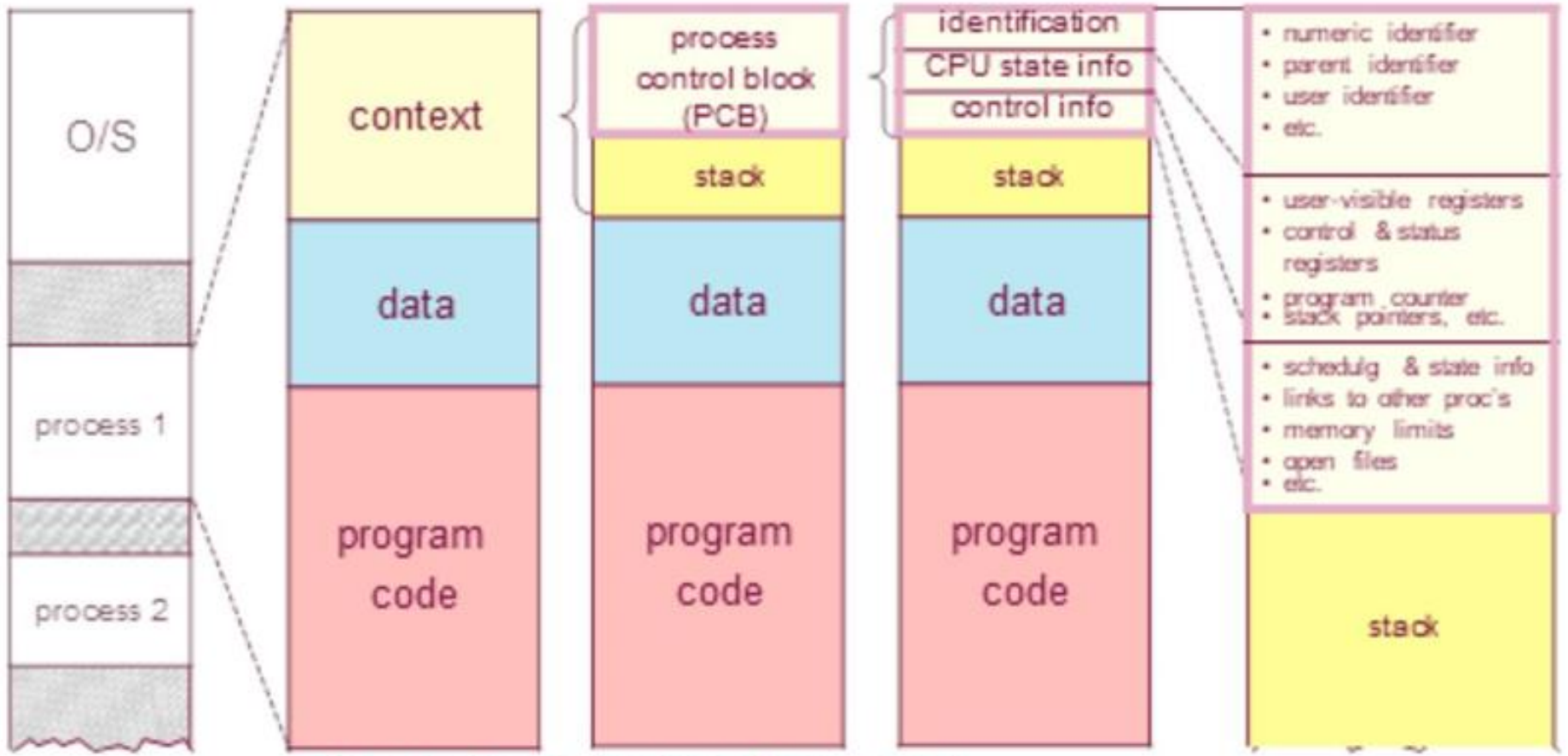


Process Control Block (PCB)

- For each process PCB is maintained in system's process table array or linked list
- PCB is included in context along with stack
- Typical PCB contains:
  - Process ID, Parent Process ID
  - Process State
  - CPU State: CPU register contents, PSW (Process Status Word)
  - Priority and other Scheduling Info
  - Pointers to different memory areas
  - Open file information
  - Signals and signal handler info
  - Various accounting info like CPU time etc
  - Many other OS specific fields can be there e.g. Linux PCB has 100+ fields



Example of process and PCB in memory



Illustrative contents of a process image in (virtual) memory

Operations on Process

- Process Creation
  - Data structures like PCB set up and initialized
  - Initial resources allocated and initialized if needed
  - Process added to ready queue (queue of processes ready to run)
- Process Scheduling
  - CPU is allotted to process and process start running
- Process Termination
  - Process is removed
  - Resources are reclaimed
  - Some data may be passed to parent process such as exit status
  - Parent process may be informed (e.g. SIGCHLD signal in Unix)

Events Leading to Process Creation

- System boot – During system booting several background processes or daemons are started
- User Request – When command is executed on CLI shell or double-click on application
- A process can spawn another i.e. child process using fork() e.g. server can create new process for each client request or init daemon waits for login and spawns new shell
- Batch system takes next job to process

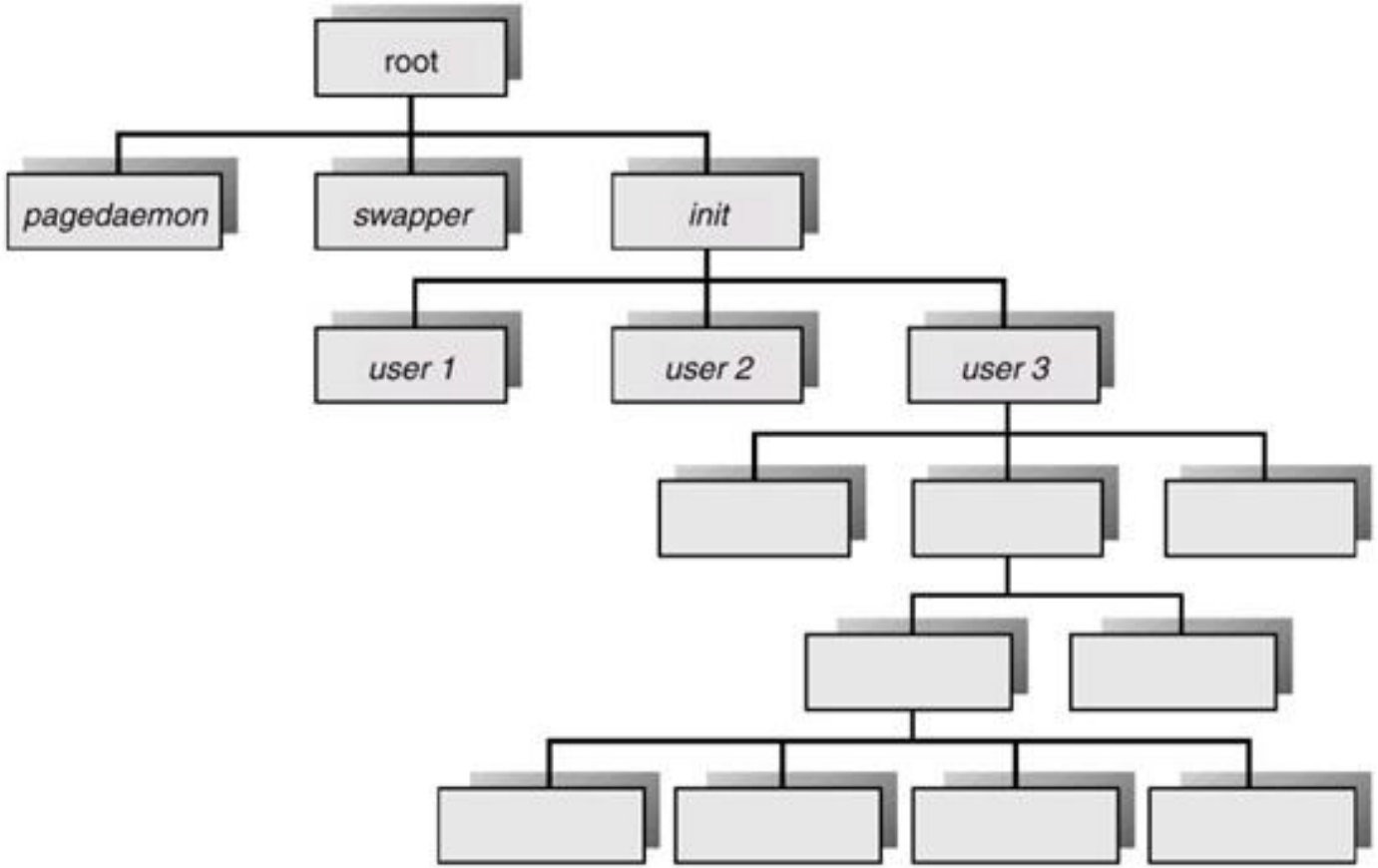
Stages of Linux Boot Process

- BIOS: Basic Input/output System →performs system integrity checks, search boot loader on cd-rom or disk, and executes MBR boot loader
- MBR: Master Boot Record → available in 1st sector of bootable disk, executes GRUB boot loader
- GRUB: GRand Unified Bootloader → if multiple kernel images are installed you can select using GRUB , executes selected Kernel
- Kernel: Kernel → Mounts the root file system, executes Init (init is the first program to run)
- Init: Init → executes run level programs depending on runlevel (runlevels: halt, single user, multiuser without NFS, Full multiuser etc)
- Runlevel → Runlevel programs are executed from etc/rc.d/rc*.d

Runlevel Definition

0 - System halt; no activity, the system can be safely powered down.
1 - Single user; rarely used.
2 - Multiple users, no NFS (network filesystem); also used rarely.
3 - Multiple users, *command line* (i.e., all-text mode) interface; the standard runlevel for most Linux-based server hardware.
4 - User-definable
5 - Multiple users, GUI (graphical user interface); the standard runlevel for most Linux-based desktop systems.
6 - Reboot; used when restarting the system.

Process Tree on Unix System



- Swapper is scheduler
- Init is the root of all user processes
- Pagedaemon is responsible for virtual page management

Events Leading to Process Termination

- Process executes last statement and asks operating system to terminate it using exit() function
- Process encounter fatal error like divide by zero, I/O error, memory allocation errors etc
- Parent may terminate execution of child process by executing kill (SIGKILL signal) function for some specific reason
  - Task assigned to child is no longer needed
  - Child has exceeded the allocated resources
- Parent is exiting
  - Some OS may not allow child to continue if parent terminates

Process Relation Between Parent and Child Processes

- Resource sharing possibilities
  - Parent and children share all resources
  - Children share subset of parent ’s resources
  - Parent and child share no resources
- Execution possibilities
  - Parent and children execute concurrently
  - Parent waits until children terminate
- Memory address space possibilities
  - Address space of child duplicate of parent
  - Child has a new program loaded into it

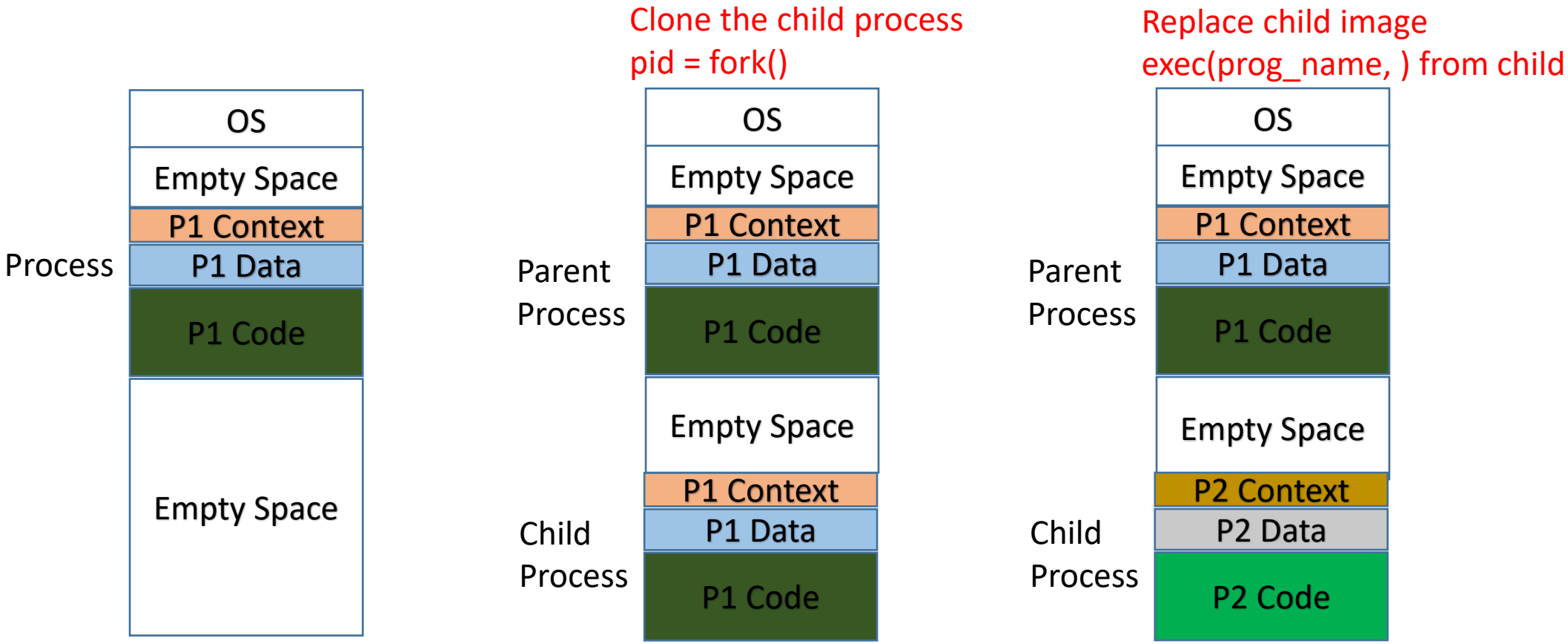
Process Management System Call

System Call Signature	Purpose of System Call	Return Values
pid_t getpid(void)	Get process ID	Returns process ID of calling process
pid_t getppid(void)	Get parent's process ID	Returns parent process ID of calling process
pid_t fork(void)	Create child process by duplicating memory of parent process. Child gets copy of data space etc. Now uses Copy-On-Write (COW)	Returns 0 in child, process ID of child in parent, -1 on error
pid_t vfork(void)	Now Absolete: Earlier fork() used to copy a complete memory of parent to child so vfork was used as optimized method	Returns 0 in child, process ID of child in parent, -1 on error
void exit(int)	Terminated the process	Parent of process will receive the success value passed as int

Process Management System Call

System Call Signature	Purpose of System Call	Return Values
pid-t wait(int *statloc) pid_t wait(pid_t pid, int *statloc..)	Wait for a child process to Terminate Wait for child with given pid	Returns process ID of child that terminated and statloc indicates returned status
int exec???(const chat pathname, const chat *arg0, …)	Replaces the current process memory with new process to be executed in pathname	Return -1 on error and no return on success

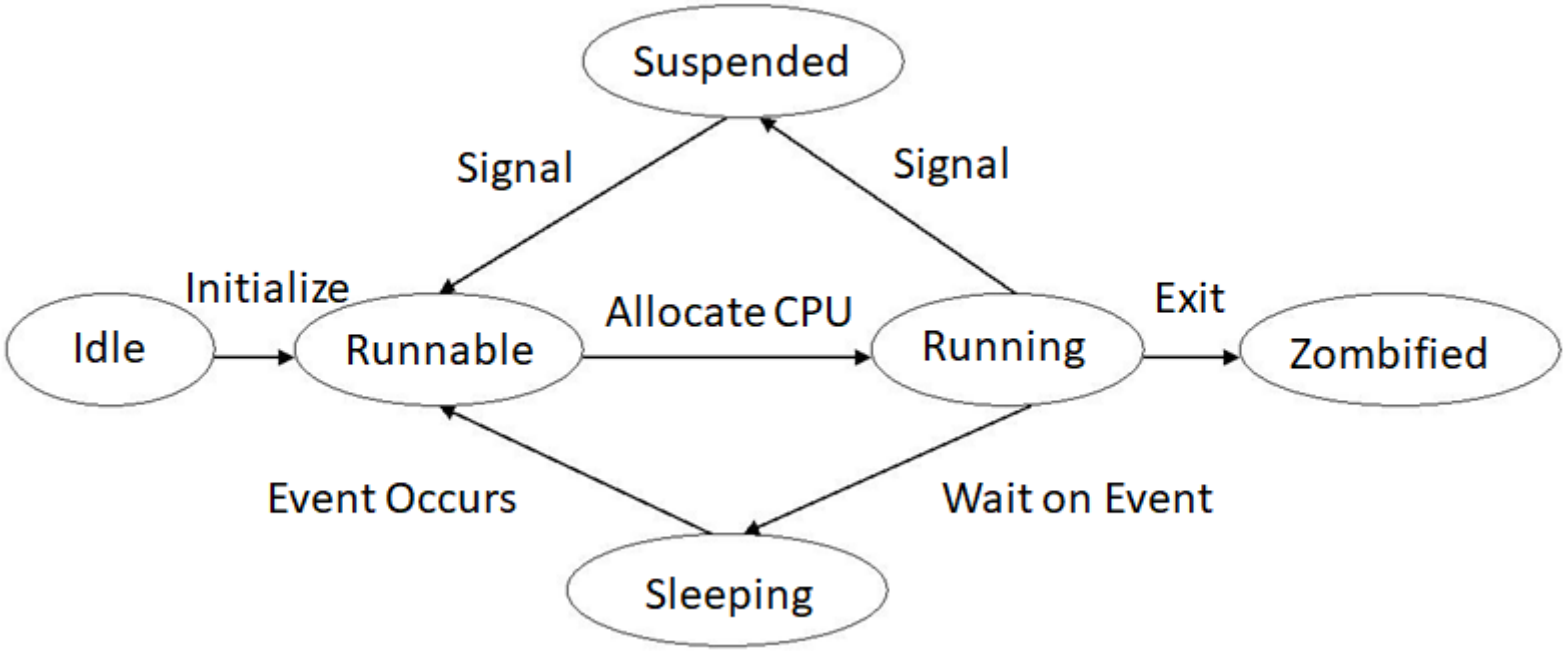
fork() and exec() memory changes



Process States (6 State Model)

- Process changes state as it executes:
  - Idle → process is being create by fork() system call and is not yet runnable
  - Runnable → process is waiting for CPU to start running
  - Running → process is current running executing instructions
  - Sleeping → process is waiting for an event to occur e.g. if process has executed read() system calls, it will go in sleep until I/O request is complete
  - Suspended → process has been “frozen” by signal such as SIGSTOP, it will resume when SIGCONT signal is received e.g. Ctrl-Z suspend all the processes of foreground job
  - Zombified → process has terminated but has not yet returned its exit code to its parent. The process remains in zambie state until parent accepts return code using wait() system call

Process State Transition



System Calls fork(), getpid() and getppid() example ProcessManagement\fork_example.c

```
#include <stdio.h>
main()
{  int pid;
   printf("I'm the original process with PID %d and PPID %d. \n", getpid(), getppid() );
   pid = fork(); /* Duplicate. Child and parent continue from here */
   if ( pid!= 0 ) /* pid is non-zero, so I must be the parent */ ← Parent and Child execute from this point
   {
      printf("I'm the parent process with PID %d and PPID %d. \n", getpid(), getppid() );
      printf("My child's PID is %d \n", pid );
   }
```

System Calls fork(), getpid() and getppid() example

```
 else /* pid is zero, so I must be the child */
    {
        printf("I'm the child process with PID %d and PPID %d. \n", getpid(), getppid() );
    }
    printf("PID %d terminates. \n", getpid() ); /* Both processes execute this */
}
```

System Calls fork(), getpid() and getppid() example

$ fork_example

I’m the original process with PID 13292 and PPID 13273.

I’m the parent process with PID 13292 and PPID 13273.

My child’s PID is 13293.

I’m the child process with PID 13293 and PPID 13292.

PID 13293 terminates. ---> child terminates.

PID 13292 terminates. ---> parent terminates.

WARNING:

it is dangerous for a parent process to terminate without waiting for the death of its child.

The only reason our program doesn’t wait for its child to terminate is because we haven’t yet used the “wait()” system call!.

Parent and Child Process Variable scope ProcessManagement\fork_var_scope_example.c

- Before fork there is only one process so only one copy of variable
- Immediately after fork, two copies of the variables are created (one for parent and the other for child).
  - After fork any changes to the variable is done in the local copy of the respective process, hence the other process variable value will be different

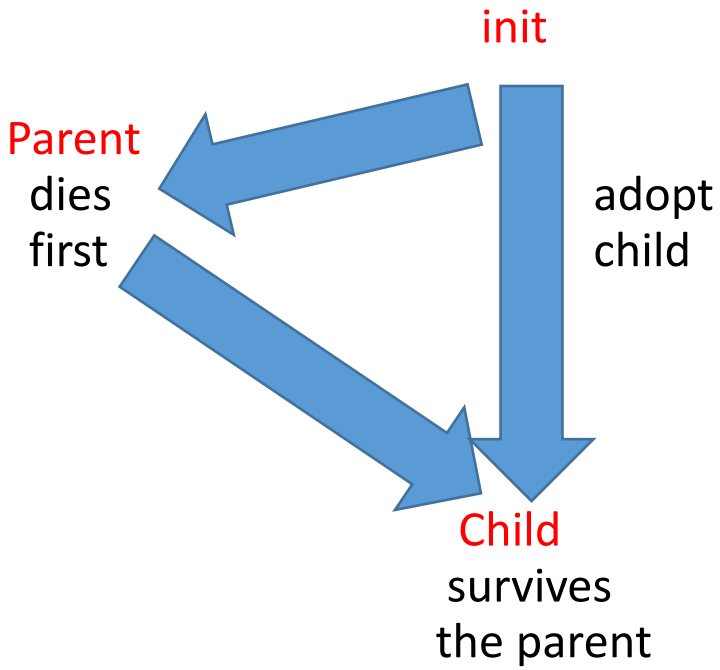
What happens with this code?

```
int main(void)
{
fork();
fork();
fork();
}
```

How many total processes will be created?

Orphan Process

- If parent process does not wait for child and it first terminates leaving child process orphan
  - Orphan processes are adopted by init process which started the parent (i.e. parent of parent)



Orphan Process Example

ProcessManagement\orphan_child.c

```
   else /* pid is zero, so I must be the child */
   {
      sleep(10); // add sleep so child process will terminate later then parent
      printf("I'm the child process with • PID 13364 terminates. PID %d and PPID %d. \n", getpid(), getppid() );
   }
   printf("PID %d terminates. \n", getpid() ); /* Both processes execute this */
}
```

$ orphan ---> run the program.

I'm the original process with PID 13364 and PPID 13346.

I'm the parent process with PID 13364 and PPID 13346.

PID 13364 terminates.

I'm the child process with PID 13365 and PPID 1. ---> orphaned!

PID 13365 terminates.

$

Note the change in PPID for child processes

System Call wait() to avoid orphans

ProcessManagement\wait_example.c

```
#include <stdio.h>
main()
{   int pid, status;
    printf("I'm the original process with PID %d and PPID %d. \n", getpid(), getppid() );
    pid = fork(); /* Duplicate. Child and parent continue from here */
    if ( pid!= 0 ) /* pid is non-zero, so I must be the parent */
    {
        printf("I'm the parent process with PID %d and PPID %d. \n", getpid(), getppid() );
        printf("My child's PID is %d \n", pid );
        childPid = wait( &status ); // add wait in parent process to wait for child process, child will not become orphan
    }
    else.....
```

Zombie Process

ProcessManagement\zambi_example.c

```
#include <stdio.h>
main()
{
   int pid;
   pid = fork(); /* Duplicate */
   if ( pid!= 0 ) /* Branch based on return value from fork() */
   {
      while (1) /* Never terminate, and never execute a wait() */
      sleep(1000);
   }
   else
   {
      exit(42); /* Exit with a silly number */
   }
}
```

```
$ zombie & ---> execute the program in the background using &
[1] 13545
$ ps ---> obtain process status.
PID   TT STAT TIME COMMAND
13535 p2 S    0:00 -ksh (ksh) ---> the shell.
13545 p2 S    0:00 zombie ---> the parent process.
13546 p2 Z    0:00 <defunct> ---> the zombile child.
13547 p2 R    0:00 ps

$ kill 13545 ---> kill the parent process.
[1] Terminated zombie

$ ps ---> notice that the zombie is gone now.
PID   TT STAT TIME COMMAND
13535 p2 S    0:00 -ksh (ksh)
13547 p2 R    0:00 ps
```

Race Condition

ProcessManagement\racecondition_example.c

```
You can call this as critical section
static void charatatime(char *str)
{
char *ptr;
int c;
setbuf(stdout, NULL);
for (ptr=str;c=*ptr++;) putc(c,stdout);
}
main()
{
pid_t pid;
if ((pid = fork())<0) printf("fork error!\n");
else if (pid ==0) charatatime("12345678901234567890\n");
else charatatime("abcdefghijklmnopqrstuvwxyz\n");
}
```

```
$ test_fork
12345678901234567890
abcdefghijklmnopqrstuvwxyz
$ test_fork
12a3bc4d5e6f78901g23hi4567jk890
Lmnopqrstuvwxyz
```

Need to have parent wait for child or child wait for parent to complete the critical section code. This can be done using signals which will study in next chapter

Additional Status Info from wait() System Call

ProcessManagement\child_exit_reason_example.c

childpid = wait(&wstatus); → returns the exit status from child which can further be inspected using these macros

WIFEXITED(wstatus) → returns true if child terminated normally

WEXITSTATUS(wstatus) → returns exit status (least significant 8 bits)

WIFSIGNALED(wstatus) → returns true if child process was terminated by a signal

WTERMSIG(wstatus) → returns the number of signal

WCOREDUMP(wstatus) → returns true if child produced a core dump

WIFSTOPPED(wstatus) → returns true if child was stopped by a signal

WSTOPSIG(wstatus) → returns the signal number which caused child to stop

WIFCONTINUED(wstatus) → returns true if child was resumed with SIGCONT signal

exec() family of System Calls

When fork() creates a child process with a copy of same code, data etc as parent process but if you need to run another process as child process then →

A process may replace its current code, data, and stack with those of another executable by using one of the “exec()” family of system calls

When a process executes an “exec()” system call, its PID and PPID numbers stay the same - only the code that the process is executing changes.

System Call:

int execl(const char* path, const char* arg0, const char* arg1,…, const char* argn, NULL)

int execv(const char* path, const char* argv[])

int execlp(const char* path, const char* arg0, const char* arg1, …, const char* argn, NULL)

int execvp(const char* path, const char* argv[])

The “exec()” family of system calls replaces the calling process’ code, data, and stack with those of the executable whose pathname is stored in path.

Difference in exec() System Calls

- “execlp()” and “execvp()” use the $ PATH environment variable to find path.
  - If the executable is not found, the system call returns a value of -1; otherwise, the calling process replaces its code, data, and stack with those of the executable and starts to execute the new code.
- “execl()” and “execlp()” invoke the executable with the string arguments pointed to by arg1 through argn.
  - arg0 must be the name of the executable file itself, and the list of arguments must be null terminated.
- “execv()” and “execvp()” invoke the executable with the string arguments pointed to by argv[1] to argv[n], where argv[n+1] is NULL.
  - argv[0] must be the name of the executable file itself.

System Call exec() example ProcessManagement\exec_example.c

the program displays a small message and then replaces its code with that of the “ls”.

```
#include <stdio.h>
main()
{
   printf(“I’m process %d and I’m about to exec an ls -l \n”, getpid() );
   execl( “/bin/ls”, “ls”, “-l”, NULL ); /* Execute ls */
   printf(“This line should never be executed \n”);
}
```

$ myexec ---> run the program.

I’m process 13623 and I’m about to exec an ls -l

total 125

-rw-r--r-- 1 glass 277 Feb 15 00:47 myexec.c

-rwxr-xr-x 1 glass 24576 Feb 15 00:48 myexec

Background Process using fork() and exec() System Calls ProcessManagement\run_exec_in_child.c

```
#include <stdio.h>
int main( int argc, char* argv[] )
{
if ( fork() == 0 ) /* Child */
{
execvp( argv[1], &argv[1] ); /* Execute other program */
fprintf( stderr, "Could not execute %s \n", argv[1] );
}
}
```

$ ./background ls -R -ltr /usr/ ---> run the program.

Confirm that "ls" command is showing up in ps listing

faculty@faculty-OptiPlex-3040:~$ ps 2579

PID TTY STAT TIME COMMAND

2579 pts/22 D 0:24 ls -R -ltr /usr/

Master-Slave implementation

- Master accepts n values from command line
- Set of 2 values to be passed to each child process i.e. argv[1] and argv[2] pass to child 1, argv[2] and argv[3] pass tp child 2 and so on
- forks as many child processes as required i.e. n/2
- Reads the value returned using exit() call using WEXISTSTATUS macro
- ProcessManagement\process_parent.c

- Child process accepts the 2 command line arguments as argv[1] and argv[2]
- Perform the required processing
- Return the result back as exit status using exit() system call
- ProcessManagement\process_child.c

System Call : system()

int system(const char *command);

- Implemented using fork(), exec() and waitpid()
- Used to execute the command passed as parameter

e.g. system(“ls -ltr”); → runs “ls –ltr” command

system(“date > tempfile”); → create tempfile with output redirected from date

How to get additional information about process which is running

- When a process starts it create a directory with process ID under /proc for per process information

First check the pid using ps command

faculty@faculty-OptiPlex-3040:/proc$ ps –aux

USER PID %CPU %MEM VSZ RSS TTY STAT START TIME COMMAND

…

faculty 29593 0.7 3.9 2194648 156540 ? Sl Jan17 20:48 /usr/lib/firefox/firefox -contentproc -chil

….

Process ID for this process is 29593

How to get additional information about process which is running – Collect System Information

Now change directory to /proc/29593 which is the directory for this process. List the content of the that directory

faculty@faculty-OptiPlex-3040:/proc/29593$ ls –l

total 0

dr-xr-xr-x 2 faculty faculty 0 Jan 19 11:17 attr

-rw-r--r-- 1 faculty faculty 0 Jan 19 11:17 autogroup

-r-------- 1 faculty faculty 0 Jan 19 11:17 auxv

-r--r--r-- 1 faculty faculty 0 Jan 19 11:17 cgroup

--w------- 1 faculty faculty 0 Jan 19 11:17 clear_refs

-r--r--r-- 1 faculty faculty 0 Jan 18 17:48 cmdline

-rw-r--r-- 1 faculty faculty 0 Jan 19 11:17 comm

-rw-r--r-- 1 faculty faculty 0 Jan 19 11:17 coredump_filter

-r--r--r-- 1 faculty faculty 0 Jan 19 11:17 cpuset

lrwxrwxrwx 1 faculty faculty 0 Jan 19 02:46 cwd -> /home/faculty

-r-------- 1 faculty faculty 0 Jan 19 11:08 environ

lrwxrwxrwx 1 faculty faculty 0 Jan 19 02:44 exe -> /usr/lib/firefox/firefox

dr-x------ 2 faculty faculty 0 Jan 19 02:46 fd

dr-x------ 2 faculty faculty 0 Jan 19 11:17 fdinfo

-rw-r--r-- 1 faculty faculty 0 Jan 19 11:17 gid_map

-r-------- 1 faculty faculty 0 Jan 19 11:17 io

-r--r--r-- 1 faculty faculty 0 Jan 19 11:17 limits

-rw-r--r-- 1 faculty faculty 0 Jan 19 11:17 loginuid

dr-x------ 2 faculty faculty 0 Jan 19 11:17 map_files

-r--r--r-- 1 faculty faculty 0 Jan 19 02:46 maps

-rw------- 1 faculty faculty 0 Jan 19 11:17 mem

How to get additional information about process which is running – Collect System Information

```
-r--r--r--  1 faculty faculty 0 Jan 19 11:17 mountinfo
-r--r--r--  1 faculty faculty 0 Jan 19 11:17 mounts
-r--------  1 faculty faculty 0 Jan 19 11:17 mountstats
dr-xr-xr-x  6 faculty faculty 0 Jan 19 11:17 net
dr-x--x--x  2 faculty faculty 0 Jan 19 11:17 ns
-r--r--r--  1 faculty faculty 0 Jan 19 11:17 numa_maps
-rw-r--r--  1 faculty faculty 0 Jan 19 11:17 oom_adj
-r--r--r--  1 faculty faculty 0 Jan 19 11:17 oom_score
-rw-r--r--  1 faculty faculty 0 Jan 19 11:17 oom_score_adj
-r--------  1 faculty faculty 0 Jan 19 11:17 pagemap
-r--------  1 faculty faculty 0 Jan 19 11:17 personality
-rw-r--r--  1 faculty faculty 0 Jan 19 11:17 projid_map
lrwxrwxrwx  1 faculty faculty 0 Jan 19 02:46 root -> /
-rw-r--r--  1 faculty faculty 0 Jan 19 11:17 sched
-r--r--r--  1 faculty faculty 0 Jan 19 11:17 schedstat
-r--r--r--  1 faculty faculty 0 Jan 19 11:17 sessionid
-rw-r--r--  1 faculty faculty 0 Jan 19 11:17 setgroups
-r--r--r--  1 faculty faculty 0 Jan 19 11:17 smaps
-r--------  1 faculty faculty 0 Jan 19 11:17 stack
-r--r--r--  1 faculty faculty 0 Jan 18 17:48 stat
-r--r--r--  1 faculty faculty 0 Jan 19 11:17 statm
-r--r--r--  1 faculty faculty 0 Jan 18 17:48 status
-r--------  1 faculty faculty 0 Jan 19 11:17 syscall
dr-xr-xr-x 33 faculty faculty 0 Jan 19 11:17 task
-r--r--r--  1 faculty faculty 0 Jan 19 11:17 timers
-rw-r--r--  1 faculty faculty 0 Jan 19 11:17 uid_map
-r--r--r--  1 faculty faculty 0 Jan 19 11:17 wchan
faculty@faculty-OptiPlex-3040:/proc/29593$
```

How to get additional information about process which is running – Collect System Information

- Most files with its content is described here

File	Content
clear_refs	Clears page referenced bits shown in smaps output
cmdline	Command line arguments
cpu	Current and last cpu in which it was executed
cwd	Link to the current working directory
environ	Values of environment variables
exe	Link to the executable of this process
fd	Directory, which contains all file descriptors
maps	Memory maps to executables and library files
mem	Memory held by this process

How to get additional information about process which is running – Collect System Information

File	Content
root	Link to the root directory of this process
stat	Process status
statm	Process memory status information
status	Process status in human readable form
wchan	Present with CONFIG_KALLSYMS=y: it shows the kernel function symbol the task is blocked in - or "0" if not blocked
Pagemap	Page table
stack	Report full stack trace, enable via CONFIG_STACKTRACE
Smaps	an extension based on maps, showing the memory consumption of each mapping and flags associated with it
numa_maps	an extension based on maps, showing the memory locality and binding policy as well as mem usage (in pages) of each mapping

How to get additional information about process which is running – Collect System Information

File	Content
oom_adj & oom_score_adj	Adjust the oom-killer (Out-Of_Memory) score
oom_score	Display current oom-killer score
io	Display the IO accounting fields
coredump_filter	Core dump filtering settings
mountinfo	Information about mounts
comm & /task/<tid>/comm	common content info about the parent task and each of the child task e.g. on web browser there may be multiple windows each of which is child task
/task/<tid>/children	Information about task children. For each process there may be multiple child task, hence for each of the child task a subdirectory with process ID of child i.e. <tid> is created user /proc/<pid>/task/<tid>

How to get additional information about process which is running – Collect System Information

File	Content
/fdinfo/<fd>	Information about opened file (fd is file descriptor)
map_files	Information about memory mapped files
timerslack_ns	Task timerslack value
patch_state	Livepatch patch operation state

- How each file is structure with field names and use can be found at: https://www.kernel.org/doc/Documentation/filesystems/proc.txt

Environment Variables in C

```
$ env
SESSION=ubuntu
TERM=xterm-256color
SHELL=/bin/bash
USER=faculty
LD_LIBRARY_PATH=/home/faculty/torch/install/lib:
PATH=/home/faculty/ApacheSpark/spark/bin:/home/faculty/torch/install/bin:/usr/local/sbin:/usr/local/bin:/usr/sbin:/usr/bin:/sbin:/bin:/usr/games:/usr/local/games:/snap/bin
PWD=/home/faculty/SystemProgramming
HOME=/home/faculty
LANGUAGE=en_IN:en
LOGNAME=faculty
OLDPWD=/home/faculty
_=/usr/bin/env
$
```

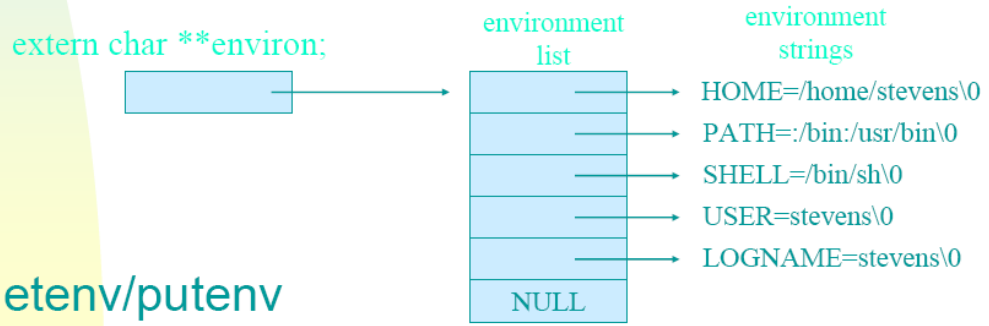
Set User Defined Environment Variable:

```
$ course=it628
$ export course
$ env | grep course
course=it628
$
```

Environment Variables in C

ProcessManagement\disp_env_vars.c

- Environment Variables
  - int main(int agrc, char **argv, char **envp);



- getenv/putenv

```
#include <stdio.h>
int main(int argc, char*argv[],
char*env[])
{

        char **ptr;

        for(ptr=env; *ptr != 0; ptr++)
                printf("%s\n",*ptr);

}
```

Environment Variables in C

ProcessManagement\getenv_setenv_example.c

char *getenv(const char *name);

name – search for this name in environment of current process

Returns pointer to value

```
#include <stdio.h>
#include <stdlib.h>
main()
{
printf("SHELL = %s\n", getenv("SHELL"));
printf("HOST = %s\n", getenv("HOST"));
}
```

int setenv(const char *name, const char *value, int overwrite);

Adds or change name parameter and its value

```
#include <stdio.h>
#include <stdlib.h>
main()
{
setenv(“COURSE", “Systems Programming", 1);
printf(" COURSE = %s\n", getenv(" COURSE "));
}
```