Introduction to Linux processes

Process identifier

Every process has a unique identifier PID or Process Identifier. The PID is a non negative integer.
Although a PID is unique, UNIX reuses the numbers of terminated processes.
PID can be used by concurernt processes for creationg unique objects, or temporary filnames.
For example :

```
sprintf(filename, "file-%d" getpid());
```

creates a different process-dependent filename

Some identifiers are reserved

- PID=0.
  - The `swapper`, which is responsible for memory management and process scheduling
- PID=1.
  - `init` which is a daemon
    - invoked at the end of the bootstrap
    - Becomes the parent of each orphan process, i.e., child processes whos parent process already terminated

```
#include <unistd.h>
pid_t getpid(); // Process ID
pid_t getppid(); // Parent Process ID

uid_t getuid(); // User ID
gid_t getgid(); // Group ID
```

`getpid` returns the identifier of the calling process.
`getppid` returns the identifier of the parent process.
There is no system call to obtain the PID of a child.

Associated effective

To the UID and to the GID there exist associated Effective-UID and Effective-GID. A process with a UID/GID can change it identity assumng a different EUID/EGID

Example:
The command `passwd` allows to hcange the password of a user; this requires root permissions; as a consequence, the process `passwd` with l'UID of the user assumes the EUID of the root to perform the operation

Process creation

WIndows and UNIX use diiferent procedures.
With Windows API a processis created by means of the system call `CreateProcess`:

- In practice it executes a new process specifying the executable
- The new process is distinct from the caller

In UNIX a new process is generated by means of the system call `fork`:

- It clones the current process

fork()

System call `fork()` creates a new child process, the child is a copy of the parent excluding the PID returend by `fork`.

- The parent process receives the child PID
  - A process may have more than one child that can identify on the basis of its PID

- The child process receives the value 0
    - It can identify its parent by means of the system call getppid

`fork` is issued one in the parent process, but returns in two different processes, and returns different values to the parent, and to the child.

```
#include <unistd.h>
pid_t fork (void);
```

`returns`:

- with out error:
    - Child PID in the parent process
    - Zero in the child process
- With error:
    - -1 (usually occurs because a limit on the number of allowed process has been reached)

Code is equal
Value of the data at the time of the fork is equal.
PCB is different, Process COntrol Block (a data structure which holds all information about a process).

```
#include <sys/types.h>
#include <unisted.h>
#include <stdio.h>

int main(){
     printf("P PID: %d PPID: %d\n". getpid(), getppid());
     fork();
     printf("F PID: %d PPID: %d\n", getpid(), getppid());
     return 0;
}
```

```
➜  OPERATING SYSTEMS ./a.out
P PID: 3010085 PPID: 3004901
F PID: 3010085 PPID: 3004901
F PID: 3010086 PPID: 3010085
```

Before the fork i have P, after the fork i have two processes the og process is the first F, and the child process is teh second F.
Fork returns two different values, and prints two times, since it makes copy of the C code and runs it with the child values.
If you place a sleep:

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

int main(){
     printf("P PID: %d PPID: %d\n", getpid(), getppid());
     int p=fork();
     if(p==0)sleep(10); //this sleep is only for child
     printf("F PID: %d PPID: %d\n", getpid(), getppid());
     return 0;
}
```

```
➜  OPERATING SYSTEMS ./a.out
P PID: 1961395 PPID: 3004901
```

```
F PID: 1961395 PPID: 3004901
➜  OPERATING SYSTEMS F PID: 1961396 PPID: 1870
```

The termianl takes you out of the c program, since aprent doesnt have sleep active, but when the fork goes into the child, it sees sleep for 10 sec and then prints.
So we se the terminal exit, and then we get a print from the "hidden" child C program.
So since the parent terminated before the child, its child got addopted by daemon (systemd) which is father of all orphans.

Resources

The child process is anew entry in the Process table, but the resource can be:

- completerly shared among parent and children (same address space)
- Partially shared (address spaces partially overlapped)
- Non shared (separate address spaces)

In UNIX/Linux parent and child share

- The source code (C)
- The open file descriptors (File Description Table)
  - In particular, stdin, stdout, and stderr
    - Concurrent I/O operation implies producing interlaced I/O
- User ID (UID), Group ID (GID), etc.
- The root and the working directory
- System resources and their utilization limits
- Signal Table
- Etc.

In UNIX/Linux parent and child have different

- Return fork value
- PID
  - The parent keeps its PID
  - The child gets a new PID
- Data, heap and stack space
  - The initial value of the variables is inherited, but the spaces are completely separated
  - copy-on-write technique is used by modern OSs
    - New memory is allocated only when one of the processes changes the content of a variable

Proces termination

Five standard methods for process termination

- `return` from main()
- `exit` system call
- `_exit` or `_Exit`
  - Synonyms defined in ISO C or POSIX
  - Similar effects of exit, but different management of stdio flushing etc.
- `return` from main() of the last process thread
- `pthread_exit` from the last process thread

Three not-normal method for process termination

- Call of the function abort
  - Generates the signal SIGABORT, this is a sub-case of the next because a signal is generated
- If a termination signal, or a signal not caught is received
- If the last thread of a process is cancelled

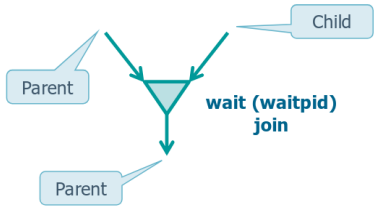
System call wait () and waitpid ()

When a process terminates (normally or not)
The kernel sends a signal (`SIGCHLD`) to its parent

- For the parent this is an asynchronous event
- The parent process may
  - Manage the child termination (and/or the signal)
    - Asynchronously
    - Synchronously
  - Ignore the event (default)

A parent process can manage child termination

- Asynchronously: using a signal handler for signal `SIGCHLD`
  - This approach will be introduced in the section devoted to signals
- Synchronously: by means of system calls
  - `wait`
  - `waitpid`



wait()

```
#include <sys/wait.h>

pid_t wait (int *statLoc);
```

`statLoc` : is an integer pointer, if not `NULL` collects the exit value of the child. The status information are implementation dependent.
`return` :

- The PID of a terminated child on success
- -1 on error

A call of the system call wait by means of a process:

- Returns an error if the callin process doesnt have children, this is because a process wihtout children is not supposed to do a wait.
- Blocks the calling process if all its children are running (none are already terminated)
  - wait will return as soon as one of its children terminates
- Returns to the process (immediately) the termination status of a child, if at least one of the children has ended (and it is waiting for his termination status to be recovered)
  - When a process ends and the parent does not do a wait, its termination status remains pending
  - Some resources assoicated with the process remain blocked

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

int main(){
     printf("P PID: %d PPID: %d\n", getpid(), getppid());
     int p=fork();
     if(p==0)sleep(10); //this sleep is only for child
     printf("F PID: %d PPID: %d\n", getpid(), getppid());
     wait(&p);
```

```
    return 0;
}
```

```
➜  OPERATING SYSTEMS ./a.out
P PID: 2856215 PPID: 2855711
F PID: 2856215 PPID: 2855711
//here it waited for 10 seconds
F PID: 2856216 PPID: 2856215
```

With out hte wait the sleep is done after exiting parent:

```
➜  OPERATING SYSTEMS ./a.out
P PID: 1961395 PPID: 3004901
F PID: 1961395 PPID: 3004901
➜  OPERATING SYSTEMS F PID: 1961396 PPID: 1870
```

`WIFEXITED(statLoc)` is true if wait terminates correctly. In this case `WEXITSTATUS(statLoc)` catches the 8 LSBs of the parameter passed to a exit (`_exit` or `_Exit`).

Zombie processes

A child process termianted, whose parent is running, but has not executed `wait` is in the zombie state:

- The data segment of the process remains in the process table because the parent could need the child exit status
- The child entry is removed only when the parent executes wait
- It the parent process terminates (without executing wait, and the child is still running, the latter is inherited by init the process (PID=1). The child does not become zombie because the system knows that no one is waiting for its exit status.

Orphan processes

If the parent terminates before executing `wait` , the child process:

- Becomes an orphan
- The orphan processes, in order not to remain in this state, are inherited by the init process (the one with PID=1) or by a user custom init process
- Orphan processes and processes inherithed by init will no longer become zombie processes

waitpid ( )

If a parent needs to `wait` a specific child it is better to use `waitpid` , which

- suspends execution of the calling process until a child, specified by pid argument, has changed state
- `waitpid()` has a not blocking form (not default)

```
#include <sys/wait.h>
pid_t waitpid ( pid_t pid, int *statLoc, int options);
```

`pid` allows waitin for:

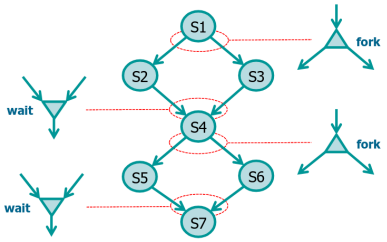
- Any child (waitpid==wait) (pid = -1)
- The child whose PID=pid (pid > 0)
- Any child whose GID is equal to that of the calling process (pid = 0)
- Any child whose GID=abs(pid) (pid < -1)

`options` :

Option	Description
`0`	Default behavior — block until a child terminates
`WNOHANG`	Don’t block if no child has exited yet — return `0` immediately

Option	Description
`WUNTRACED`	Report if a child has stopped (but not terminated) due to a signal (e.g. `SIGSTOP`)
`WCONTINUED`	Report if a previously stopped child has continued due to `SIGCONT`
`WNOWAIT` *(POSIX.1-2001)*	Keep the child's state info — don't remove it from the process table (can wait for it again)

❖ Implement this Precedence Graph (PG) by means of the system calls **fork** and **wait**



Theoretical Aspects

Definitions algorithm and program

Algorithm: a logical procedure that in a finite number of steps solves a problem
Program: formal expression of an algorithm by means of a programming language

Process

A sequence of operatons performed by a program in execution on a given set of input data.

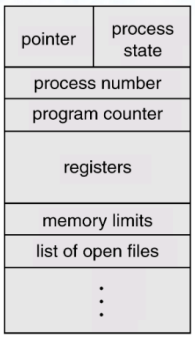
- Dynamic entity
- Program in execution (running)
  - Text area (executable code)
  - Data area (glob. var)
  - Stack (func params and local var)
  - Heap (dynamic variable allocated during execution)
  - Registers (Program counter, stack pointer, etc.)

PCB

Process Control Block
The kernal stores for each process a set of data

- the process state
- copy of the CPU registers
  - Their number and type is hardware-dependent
- The program counter (Address of the next instruction to be exectuted)
- Data useful for CPU scheduling
  - Priority, pointers to queues
- Data useful for memory management
  - Base register, limit register, segment and paging registers
- Various administration data
  - CPU usage, limits, etc.
- I/O status information

- I/O device list, open files, etc.

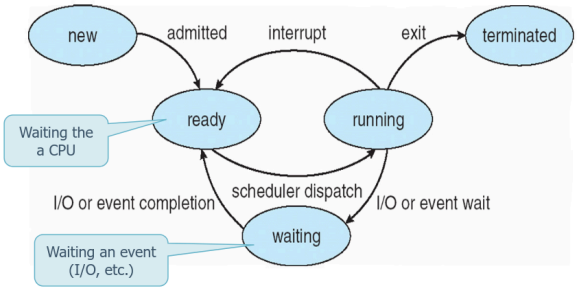


Process state

- New: process is created and submitted to the OS
- Running: a CPU is allocated to the process (in execution)
- Ready: logically ready to run, waiting that a CPU is available
- Waiting: for an event or for resources
- Terminated: releases the resource it is usin

State diagram

The possible state evolution of a process is described by a state diagram.

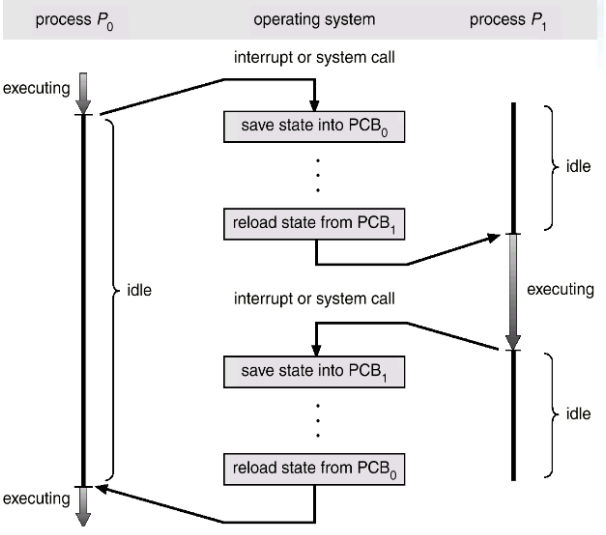


Context switching

When a CPU is assigned to another process, the kernel:

- saves the state of the running process
- Loads the state previously saved for the new process

The time devoted to the context switching is overhead, i.e., time not direclty useful for any process, this amount of time is hardware-dependent



Process scheduling

Multiprogramming aims at maximizing the CPU usage by processes
Processes can be classified as:

- I/O-bound
  - Spend more time for I/0 than for computation
  - Require short CPU service times
- CPU-bound
  - Spend more time for computation than for I/0
  - Require long CPU service times

CPU scheduler

The context Switching operations are controlled by the scheduler of the CPU.
The goal of the scheduler is to:

- Maximize the CPU usage (by means of the processes)
- Attempting to satisfy various system-level requests timely (hardware and software interrupts

Ultimately, the scheduler is in charge of:

- Determine when the current process should finish its execution
- Select the next process to run from the available processes

Advanced Control exec

Use of `fork`

System call `fork` created a new process duplicating the calling process.
THere are two main applications of this mechanism:

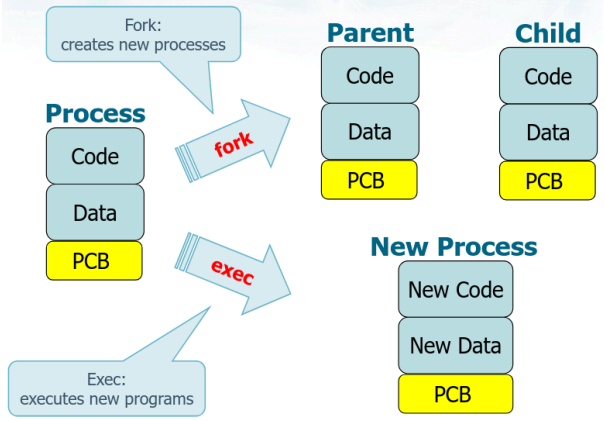
- Parent and child execute different code sections
  - example: a network server duplicates itself at each client request, and the child serves the request while the parent waits for a new client request
- Parent and child execute different code:
  - Uses the family of `exec` system calls.

exec

System call `exec` substitutes the process code with the executable code of another program. The new program begins its execution as usual (from main)
In particular it:

- Does not create a new process
- Substitutes the calling process image (i.e., its code, its data, the stack and the heap) with the image of another program.
- The process PID does not change
  - fork -> duplicates an existent process
  - exec -> executes a new program

Address space



exec versions

6 versions of exec system call

- `execl` , `execlp` , `execle`
- `execv` , `execvp` , `execve`

Type	Action	
l (list)	Arguments are a list of strings	The first variable is the name, then n arguments folow, each with its own declaration, so a list is not passed.
v (vector)	Arguments is a vector of strings arguments (`char **`)	arg[0] name, arg[1...n-1] argument, arg[n]=NULL
p (path)	The executable filename is looked for in the directories listed in the environment variable PATH	
e (environment)	The last argument is an environment vector `envp[]` which defines a set of new associations strings name=value	Only here enviroment variables are not enherited from the parent process. They are explicitly specified, in a vectore of pointers to strign characters. The strings specify the vales of the desired environment variable. (variable=value).

```c
#include <unistd.h>
int execl (char *path, char *arg0, ..., (char *)0);
int execlp (char *name, char *arg0, ..., (char *)0);
int execle(char *path, char *arg0,..., (char *)0,
char *envp[]);
int execv (char *path, char *arg[]);
int execvp (char *name, char *arg[]);
int execve (char *path, char *arg[], char *envp[]);
```

`return` :

- none on success
- -1 on error

`path` :
Pathname of the execturable file. It can be the name, or the path.

- In the exec has 'p', its better to use only name (its inheritad from the environment variable PATH)
- In the non -'p', the path in unknown if not specified

l version

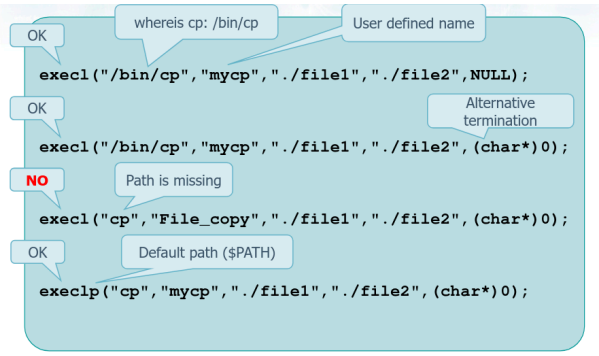
```c
execl("/bin/ls", "ls", "-l", "-a", NULL); // here -l and -a are arguments
```

v version

```
char *args[] = {"ls", "-l", "-a", NULL};
execv("/bin/ls", args);
```

e version

```
char *env[] = {
"USER=unknown",
"PATH=/tmp",
NULL
};
execle (path, arg0, ..., argn, 0, env);
execve (path, argv, env);
```



Considerations

Note that during the exec

- all open file descriptors are mantained (including stdin, stdout, stderr)
- This allow the process to inherit possible redirections previously set (e.g., by shell)

Many kernels

- Implement only system call execve
- The other versions are macros that use this system call

UNIX shell skeleton

Command run in foreground
`<command>` :

```
while (TRUE) {
     write_prompt();
     read_command (command, parameters);
     if (fork() == 0){}
          /* Child: Execute command */
          execve (command, parameters);
     }
     else{
          /* Parent: Wait child */
          wait (&status);
     }
}
```

`<command> &` :

```
while (TRUE) {
     write_prompt();
     read_command (command, parameters);
     if (fork() == 0){
```

```
          /* Child: Execute command */
          execve (command, parameters);
     }
     /* else */
     /* Parent: DOES NOT wait */
     /* wait (&status); */
}
```

system()

It can be useful to execute a shell command from a process, this is the purpose of `system()`

```
#include <stdlib.h>
int system (const char *string);
```

System call `system()`:
forks a shell, which executre the string command, while the parent process waits the termination of the shell command
`returns:`

- -1 if fork or waitpid fail
- 127 if the exec fails
- The exit value of the shell that executed the command

```
int system (const char *cmd) {
     pid_t pid;
     int status;
     if (cmd == NULL){
          return(1);
     }
     if ( (pid = fork()) < 0) { //Error in fork
          status = -1;
     }
     else if (pid == 0) {
          execl("/bin/sh", "sh", "-c", cmd, (char *) 0);
          _exit(127);
     }
     else {
          while (waitpid (pid, &status, 0) < 0)
          if (errno != EINTR) {
          status = -1;
          break;
          }
     }
     return(status);
}
```

Signals

A signal is a software interrupt, which is an asynchronous notifiaction sent by the kernel or by another process to a process to notify it of an event that occured.
They permit asynchronous events to comunicate.

Interrupts

Interruption of the current execuion due to the occurrence of an extraoridnary event:

- A hardware device that sends a service request to the CPU
- A software process that requires the execution of a particular operation

Common signals

Examples of common signals

- Termination of a child
  - `SIGCHLD` sent to the parent; default action = ignore the signal
- Press on the terminal `Ctrl-C`
  - `SIGINT` sent to the running process (in foreground); default action = terminate the process
- Invalid memory access
  - `SIGTSTP` sent by the kernel to the process;
  - default action = suspend the execution
- The system call alarm(t)
  - `SIGALRM` sent after t seconds; default action = terminate the process
- Press on the terminal `Ctrl-Z`
  - `SIGTSTP` sent to the running process (in foreground); default action = suspend the execution
- Press on the terminal `Ctrl-\`
  - `SIGQUIT` sent to the running process (in foreground); default action = terminate the process and dump core

Eccezione	Exception Handler	Segnale
Divide error	`divide_erro()`	`SIGFPE`
Debug	`debug()`	`SIGTRAP`
Breakpoint	`int3()`	`SIGTRAP`
Overflow	`overflow()`	`SIGSEGV`
Bounds check	`bounds()`	`SIGSEGV`
Invalid opcode	`invalid_op()`	`SIGILL`
Segment not present	`segment_not_present()`	`SIGBUS`
Stack segment fault	`stack_segment()`	`SIGBUS`
General protection	`general_protection()`	`SIGSEGV`
Page fault	`page_fault()`	`SIGSEGV`
Interval reserved	none	None
Floating point error	`coprocessor_erro()`	`SIGFPE`

Characteristics

Standardized by the POSIX standard, they are
now stable and relatively reliable

- Each signal has a name
- Names start with SIG...
- The file `signal.h` defines signal names
- Unix FreeBSD, Mac OS X and Linux support 31 signals
- Solaris (oracle) supports 38 signals

Main signals

You can display the complete list of signals using the shell command

```
kill -l
```

Name	Description
SIGABRT	Process abort, generated by system call `abort`
SIGALRM	Alarm clock, generated by system call `alarm`
SIGFPE	Floating-point exception
SIGILL	Illegal instruction
SIGKILL	Kill (non-maskable)

Name	Description
SIGPIPE	Write on a pipe with no reader
SIGSEGV	Invalid memory segment access
SIGCHLD	Child process stopped or exited
SIGUSR1	User-defined signal 1
SIGUSR2	User-defined signal 2

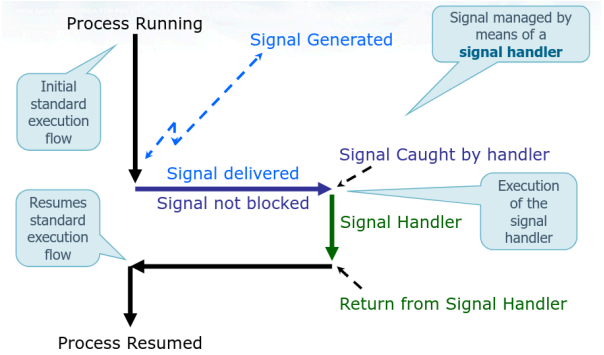
Notes:

- Default action = terminate the process
- `SIGUSR1` and `SIGUSR2` are available for use in user applications

Signal management

Singnal management goes through three phases:

1. Signal generation
   - When the kernel or a source process causes an event that generate a signal
2. Signal delivery
   - A not yet delivered signal remains pending
   - At signal delivery a process executes the actions related to that signal
   - The lifetime of a signal is from its generation to its delivery
   - There is no signal queue; the kernel sets a flag in the process table
3. Reaction to a signal
   - To properly react to the asynchronous arrival of a given type of signal, a process must inform the kernel about the action that it will perform when it will receive a signal of that type
   - A process may
     - Accept the default behavior (be terminated)
     - Declare to the kernel that it wants to ignore the signals of that type
     - Declare to the kernel that it wants to catch and manage the signals of that type by means of a signal handler function (similarly to the interrupt management



Signal management can be carried out with the following system calls:

- `signal`
  - Instantiates a signal handler
- `kill` (and `raise`)
  - Sends a signal
- `pause`
  - Suspends a process, waiting the arrive of a signal
- `alarm`
  - Sends a `SIGALARM` signal, after a preset time
- `sleep`
  - Suspends the process for a specified amount of time (waits for signal `SIGALRM`)

Notice:

- The terms `signal` and `kill` are relatively inappropriate, `signal` does not send a signal

signal()

Allow to instatiate a signal handler

```
include <`signal.h`>
void (*signal (int sig, void (*func)(int)))(int);
```

`sig` : specifies the signal to be managed (`SIGALRM` , `SIGUSR1` , etc.)
`func` : the function use to manage it, i.e. the signal handler (you give a pointer to that function, it takes int and returns int)
return:

- on success, the previous value of the signal handler (pointer to the previous signal handler pointer)
- on error: `SIG_ERR` , `errno` is set to indicate the cause

Reaction to a signal

`signal` system call allows setting three different reactions to the delivery of a signal:

1. Accept the default behavior
   - `signal (SIGname, SIG_DFL)`
   - Where `SIG_DFL` is defined in `signal.h`
     - `#define SIG_DFL ((void (*)()) 0`
   - Every signal has its own default behavior, defined by the system
   - Most of the default reactions is `process termination`
2. Ignore signal delivery:
   - `signal (SIGname, SIG_IGN)`
   - Where `SIG_IGN` is defined in `signal.h`
     - `#define SIG_IGN ((void (*)()) 1`
   - Applicable to the majority of signals
     - Ignoring a signal often leads to an indefinite behavior
   - Some signals cannot be ignored
     - `SIGKILL` and `SIGSTOP` cannot be ignored because the kernel and the superuser would maintain the possibility to control all processes
     - Ignoring an illegal memory access, signaled by `SIGSEGV` , would produce an undefined process behavior
3. Catch the signal
   - `signal (SIGname, signalHandlerFunction)`
   - where
     - `SIGname` indicates the signal type
     - `signalHandlerFunction` is the user defined signal handler function
   - The signal handler
     - Can take action considered correct for the management of the signal
     - Is executed asynchronously when the signal is received
     - When it returns, the process continues with the next instruction, as it happens for interrupts

example:

```
void manager (int sig) {
if (sig==SIGUSR1)
printf ("Received SIGUSR1\n");
else if (sig==SIGUSR2)
printf ("Received SIGUSR2\n");
else printf ("Received %d\n", sig);
return;
}
...
int main () {
...
```

```
signal (SIGUSR1, manager);
signal (SIGUSR2, manager);
...
}
```

kill()

```
#include <signal.h>
int kill (pid_t pid, int sig);
```

send signal `sig` to a process or to a group of processes `pid`
return:

- `0` on success
- `-1` on error

Notice:

- If sig=0 a NULL signal is sent (i.e., no signal is sent). This is often used to check if a process exists: if the kill returns -1 the process does not exist.

To send a signal to a process you must have the rights. A user process can send signals only to processes having the same `UID`. The superuser can send signal to any process

`pid` Value	Signal Sent To
`> 0`	The process with PID equal to `pid`
`== 0`	All processes with GID equal to the sender's GID (if it has the rights)
`< 0`	All processes with GID equal to the absolute value of `pid` (if it has the rights)
`== -1`	All processes (if it has the rights)

Notice:

- All processes excludes a set of system processes.

raise()

The raise system call allows a process to send a signal to itself

```
#include <signal.h>
int raise (int sig);
```

`raise (sig)` is equivalent to `kill (getpid(), sig)`

pause()

Suspends the calling process until a signal is received

```
#include <unistd.h>
int pause (void);
```

Returns after the completion of the signal handler

- In this case the function returns -1

alarm()

```
#include <unistd.h>
unsigned int alarm (unsigned int seconds);
```

`return`:

- The number of seconds remaining until the delivery of a previously scheduled alarm
- `0` if there was no previously scheduled alarm

warning:

- The signal is generated by the kernel
  - It is possible that the process get the CPU control after some time, depending on the scheduler decisions
- There is only one time counter for each process, and system calls sleep and alarm uses the same kernel timer

example of implementation of sleep using alarm and pause:

```
#include <signal.h>
#include <unistd.h>
static void sig_alrm(int signo) {return;}
unsigned int sleep1(unsigned int nsecs)
{
     if (signal(SIGALRM, sig_alrm) == SIG_ERR){
          return (nsecs);
     }
     alarm (nsecs);
     pause ();
     return (alarm(0)); //Returns 0, or the remaining time before the delivery if pause returns because
another signal has been received
}
```

Notice:

- The signal handler must be instanced before setting the alarm

example of implementation of alarm using fork, signal, kill, and pause:

```
#include <stdio.h>
#include <unistd.h>
#include <signal.h>
void myAlarm (int sig) {
     if (sig==SIGALRM)
     printf ("Alarm on ...\n");
     return;
}

int main (void) {
     pid_t pid;
     (void) signal (SIGALRM, myAlarm);
     pid = fork();
     switch (pid) {
          case -1: /* error */
               printf ("fork failed");
               exit (1);
          case 0: /* child */
               sleep(5);
               kill (getppid(), SIGALRM); //The child waits and sends SIGALRM
               exit(0);
     }
     /* parent */
     pause (); //The parent pauses, and continues only when it receives the SIGALRM sent by the child
     exit (0);
}
```

Signal limitations

- Signals do not convey any information
- The memory of the pending signals is limited

    - Max one signal pending (sent but not delivered) per type. Forthcoming signals of the ame type are lost
    - Signals can be ignored
- Signals require funcitons that must be `reentrant`
- Produce race conditions

Some limitations are avoided in POISX.4

Memory limit

The memory related to "pending" signals is limited

- There is at most one "pending" signal (sent, delivered, but not managed) for each type of signal
    - Subsequent signals (of the same type) are lost
- Signals can be blocked, i.e., you can avoid receiving them

```
...
static void sigUsr1 (int);
static void sigUsr2 (int);
static void sigUsr1 (int signo) {
     if (signo == SIGUSR1){
          printf("Received SIGUSR1\n");
     }
     else{
          printf("Received wrong SIGNAL\n");
     }
     fprintf (stdout, "sigUsr1 sleeping ...\n");
     sleep (5);
     fprintf (stdout, "... sigUsr1 end sleeping.\n");
     return;
}

static void sigUsr2 (int signo) {
     if (signo == SIGUSR2){
     printf("Received SIGUSR2\n");
     }
     else{
     printf("Received wrong SIGNAL\n");
     }
     fprintf (stdout, "sigUsr2 sleeping ...\n");
     sleep (5);
     fprintf (stdout, "... sigUsr2 end sleeping.\n");
     return;
}

int main (void) {
     if (signal(SIGUSR1, sigUsr1) == SIG_ERR) {
          fprintf (stderr, "Signal Handler Error.\n");
          return (1);
     }
     if (signal(SIGUSR2, sigUsr2) == SIG_ERR) {
          fprintf (stderr, "Signal Handler Error.\n");
          return (1);
     }
     while (1) {
          fprintf (stdout, "Before pause.\n");
          pause ();
          fprintf (stdout, "After pause.\n");
     }
     return (0);
}
```

```
> ./pgrm &
[3] 2636
> Before pause.
```

```
> kill -USR1 2636
> Received SIGUSR1
sigUsr1 sleeping ...
... sigUsr1 end sleeping.
After pause.
Before pause.
> kill -USR2 2636
> Received SIGUSR2
sigUsr2 sleeping ...
... sigUsr2 end sleeping.
After pause.
Before pause.
```

```
> kill -USR1 2636 ; kill -USR2 2636
> Received SIGUSR2
sigUsr2 sleeping ...
... sigUsr2 end sleeping.
Received SIGUSR1
sigUsr1 sleeping ...
... sigUsr1 end sleeping.
After pause.
Before pause.
```

Reentrant functions

A signal has the following behavior:

1. The interruption of the current execution flow
2. The execution of the signal handler
3. The return to the standard execution flow at the end of the signal handler

Consequently

- The kernel knows where a signal handler returns, but
- The signal handler does not know where it was called, i.e., the control flow was interrupted by the signal

Suppose a `malloc` is interrupted, and the signal handler calls another `malloc`

- Function `malloc` manages the list of the free memory regions, which could be corrupted

Suppose that the execution of a function that uses a static variable is interrupted, but is then called by the signal handler

- The static variable could be used to store a new value, i.e., it does not remain the same it was before the signal was delivered

The "Single UNIX Specification" defines the reentrant functions, which can be interrupted without problems

- read, write, sleep, wait, etc.

Most of the I/O standard C functions are not reentrant

- printf, scanf, etc.
- They use static variables or global variables
- They must be used carefully and being aware of possible problems

Race conditions

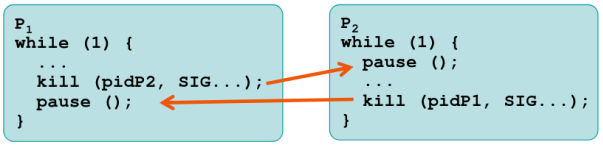
- The result of more concurrent processes working on common data depends on the execution order of the processes instructions.
- Concurrent programming is subject to race conditions and using signals increases the probability of race conditions.
- Using signals increases the probability of race conditions.

example a:
suppose a process decides to suspend itself for a given number of seconds,.

The signal could be delivered before the execution of pause due to a contest switching and scheduling decisions (especially in high loaded systems.

examle b:
Suppose two processes P_1 and P_2 decide to synchronize by means of signals.
Unfortunately:

- If P1 (P2) signal is delivered before P_2 (P_1) executes pause
- Process P_2 (P_1) blocks forever waiting a signal



Despite their defects, signals can provide a rough synchronization mechanism.

Shell commands for process management

Foreground execution

The "standard" shell commands

- Allow executing processes sequentially
- Each process is executed in foreground, i.e., using the control terminal

```
> command1
Output of command1
> command2
Output of command2
```

Background execution

The shell interpret character `&` as an indication to run the command in the background

- The process is executed in concurrency with the shell. It loses the control terminal input
- The shell outputs immediately a new prompt
- It is possible to run several processes in parallel

```
> command1 &
> command2 &
>
Output of command1
Output of command2
```

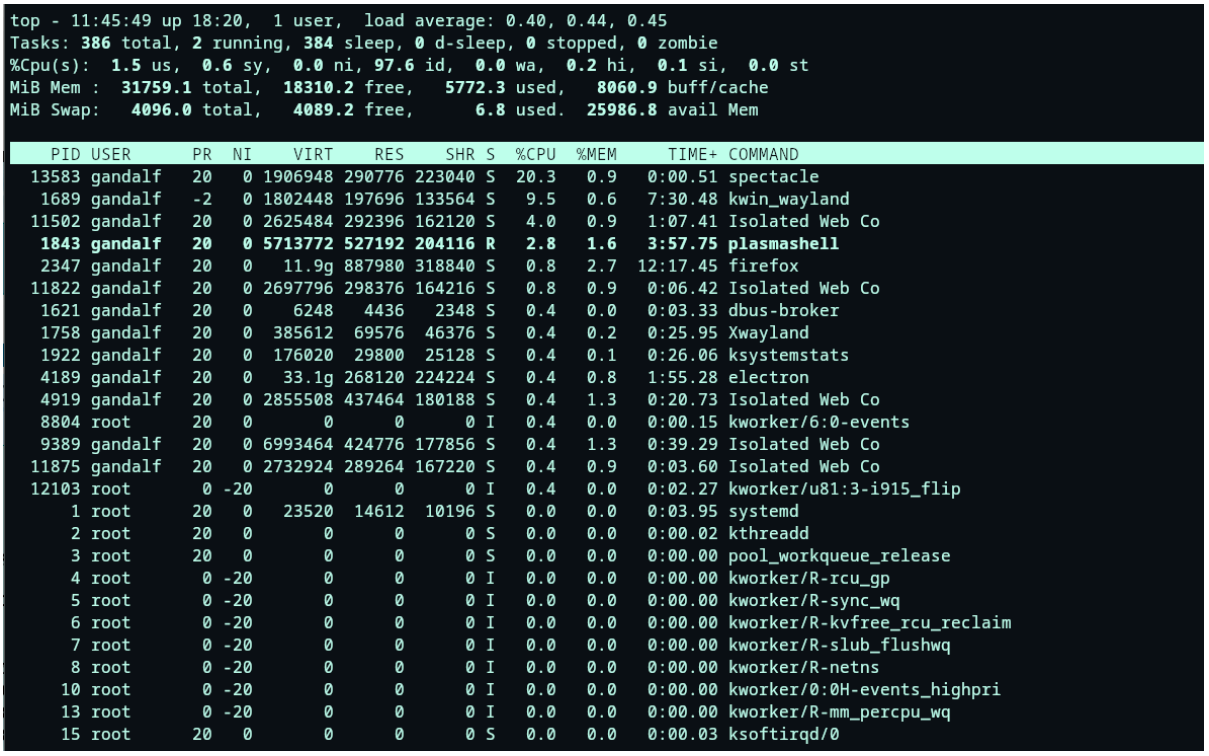
ps

The command ps (process status of active process):
 Lists active processes and related details
 Without options (default) prints (in a compact format) the status of the processes with the same user ID of the user from which the command is executed

options:
 `-a` Lists the processes of all system users
 `-u` Prints more detailed information (resident size, virtual size, etc.)
 `-u <user>` Shows only the `<user>` processes
 `-x` Adds to the list the processes that do not have a control terminal
(e.g., daemon)
 `-e` (or `–A`) Lists all processes running in the system
 `-f` Extended format
 `r` (not –r) Shows only the "running" processes

top

Display and updates information about the system used resources, and the active processes



```
top - 11:45:49 up 18:20,  1 user,  load average: 0.40, 0.44, 0.45
Tasks: 386 total, 2 running, 384 sleep, 0 d-sleep, 0 stopped, 0 zombie
%Cpu(s):  1.5 us,  0.6 sy,  0.0 ni, 97.6 id,  0.0 wa,  0.2 hi,  0.1 si,  0.0 st
MiB Mem :  31759.1 total,  18310.2 free,   5772.3 used,   8060.9 buff/cache
MiB Swap:   4096.0 total,   4089.2 free,      6.8 used.  25986.8 avail Mem

    PID USER      PR  NI    VIRT    RES    SHR S  %CPU  %MEM     TIME+ COMMAND
  13583 gandalf   20   0 1906948 290776 223040 S  20.3   0.9   0:00.51 spectacle
   1689 gandalf   -2   0 1802448 197696 133564 S   9.5   0.6   7:30.48 kwin_wayland
  11502 gandalf   20   0 2625484 292396 162120 S   4.0   0.9   1:07.41 Isolated Web Co
   1843 gandalf   20   0 5713772 527192 204116 R   2.8   1.6   3:57.75 plasmashell
   2347 gandalf   20   0   11.9g 887980 318840 S   0.8   2.7  12:17.45 firefox
  11822 gandalf   20   0 2697796 298376 164216 S   0.8   0.9   0:06.42 Isolated Web Co
   1621 gandalf   20   0    6248   4436   2348 S   0.4   0.0   0:03.33 dbus-broker
   1758 gandalf   20   0  385612  69576  46376 S   0.4   0.2   0:25.95 Xwayland
   1922 gandalf   20   0  176020  29800  25128 S   0.4   0.1   0:26.06 ksystemstats
   4189 gandalf   20   0   33.1g 268120 224224 S   0.4   0.8   1:55.28 electron
   4919 gandalf   20   0 2855508 437464 180188 S   0.4   1.3   0:20.73 Isolated Web Co
   8804 root      20   0       0      0      0 I   0.4   0.0   0:00.15 kworker/6:0-events
   9389 gandalf   20   0 6993464 424776 177856 S   0.4   1.3   0:39.29 Isolated Web Co
  11875 gandalf   20   0 2732924 289264 167220 S   0.4   0.9   0:03.60 Isolated Web Co
  12103 root       0 -20       0      0      0 I   0.4   0.0   0:02.27 kworker/u81:3-i915_flip
      1 root      20   0   23520  14612  10196 S   0.0   0.0   0:03.95 systemd
      2 root      20   0       0      0      0 S   0.0   0.0   0:00.02 kthreadd
      3 root      20   0       0      0      0 S   0.0   0.0   0:00.00 pool_workqueue_release
      4 root       0 -20       0      0      0 I   0.0   0.0   0:00.00 kworker/R-rcu_gp
      5 root       0 -20       0      0      0 I   0.0   0.0   0:00.00 kworker/R-sync_wq
      6 root       0 -20       0      0      0 I   0.0   0.0   0:00.00 kworker/R-kvfree_rcu_reclaim
      7 root       0 -20       0      0      0 I   0.0   0.0   0:00.00 kworker/R-slub_flushwq
      8 root       0 -20       0      0      0 I   0.0   0.0   0:00.00 kworker/R-netns
     10 root       0 -20       0      0      0 I   0.0   0.0   0:00.00 kworker/0:0H-events_highpri
     13 root       0 -20       0      0      0 I   0.0   0.0   0:00.00 kworker/R-mm_percpu_wq
     15 root      20   0       0      0      0 S   0.0   0.0   0:00.03 ksoftirqd/0
```

kill

kill allows sending signal from the shell
Format:

- `kill [-sig] pid`
- Sends signal sig to process with `PID=pid`
- Option `sig` indicates the signal code
- `pid` is the process identifier (PID) of the target process

A signal sig can be indicated by mean of its name or its number:

- `SIGKILL` = KILL = 9
- `SIGUSR1` = USR1 = 10
- `SIGUSR2` = USR2 = 12
- `SIGALRM` = ALRM = 14

If you type `kill -l`, you get all options
The default is `SIGTERM`

example of killing 10234:\

```
kill -9 10234
kill –SIGKILL 10234
kill –KILL 10234
```

killall

Shell command killall terminates all process with a specified name

```
killall -9 name
```

Useful to terminate all processes generated by the same program avoiding to specify their PIDs

Inter-process communication

Indipendent and cooperating process

Concurrent processes can be:

- indiprendent
- cooperating

And indipendent process

- Cannot be influenced by other processes
- Cannot influence other processes

A set of cooperating processes

- can cooperate only by sharing data or by exchanging messages
- Both require appropriate synchronization mechanisms

IPC

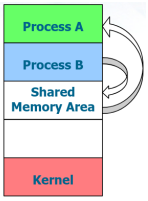
Information sharing among processes is refered to as InterProcess Comunication
The main communication models are based on:

- Shared memeory
- Message exchange

Shared memory

Sharing of a memory area and writing of data in this area

- Normally the kernel does not allow a process to access the memory of another process.
- Processes must agree on the:
  - Access rights
  - Access strategies



The most common methods for shared buffer use a:

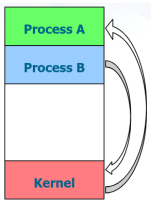
- File
  - Sharing the name or the file pointer or descriptor before `fork` / `exec`
- Mapped file in memory
  - A file mapped in memory associates a shard memory region to the file

These tecniques allow sharing a large amount of data

Message exchange

Communication takes place through the exchange of messages:

- Need to setup a communication channel
- Useful for exchanging limited amounts of data
- Uses system calls
  - which request kernel intervention
  - and introduce overhead



A communication channel can offer direct or indirect communication

- direct
  - Is performed naming the sender or the receiver
    - send (to_process, message)
    - receive (from_process, &message)
- Indirect
  - Performed through a mailbox
    - send (mailboxAddress, message)
    - receive (mailBoxAddress, &message)

A communication channel can be characterized by

- Synchronization
  - Both sending or receiving messages can be
    - Synchronous, i.e., blocking
    - Asynchronous, i.e., non-blocking
- Capacity
  - If the capacity is zero, the channel cannot allow waiting messages (no buffering); the sender blocks waiting for the receiver
  - If the capacity is limited the sender blocks when the queue is full
  - If the capacity is unlimited the sender does not block

UNIX makes available:

- Half-duplex pipes
- FIFOs //not covered
- Full-duplex pipes //not covered
- Named full-duplex pipes //not covered
- Message queues
- Semaphores //for process synchronization
- Sockets //network process communication. Each process is identified by a socket to which it is assocaited a network address
- STREAMS

Pipes

Pipesa re the oldest form of communication in UNIX SO.
They provide a communication channel, which is:

- Direct
- asynchronous
- with limited capacity

They live in memory and they are more efficient than using of files

They exist to create a data stream among processes

- The user interface to a pipe is similar to file access
- A pipe is accessed by means of two descriptors (integers), one for each end of the pipe
- A process (P1) writes to an end of the pipe, another process (P2) reads from the other end

Historically they have been half-dupelx

- Data can flow in both directions (from P1 to P2 or from P2 to P1), but not at the same time
- Full-duplex models have been proposed more recently, but they have limited portability

Simplex: Mono-directional
Half-Duplex: One-way, or bidirectional, but alternate (walkie-talkie)
Full-Duplex: Bidirectional (telephone)

A pipe can e used for communcation among a parent and its children, or among processes with a common ancestor

- The file descriptor must be common to the two communicating processe and therfore these processes must have a common ancestor

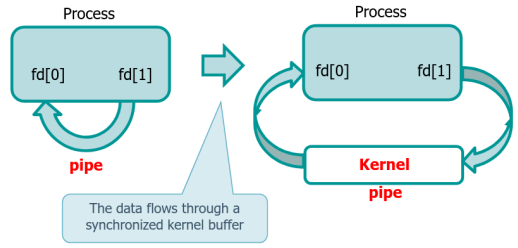
pipe()

```
# include <unistd.h>
int pipe (int fileDescr[2]);
```

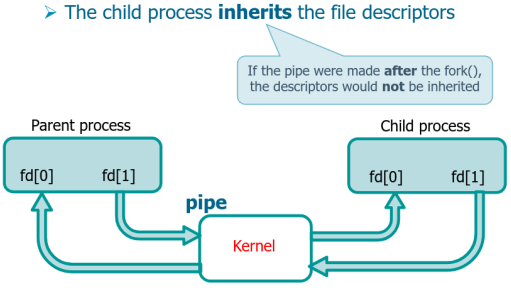
This system call creates a pipe
It return two file descriptors in vectore `fileDescr` fileDescr[0] `: Typically used for reading` fileDescr[1] `: Typically used for writing The input stream written on` fileDescr[1] `corresponds to the output stream read on` fileDescr[0]`
return:

- 0 on success
- -1 or error
  Resources associated to a pipe released when all involved processes close their terinals or they are terminated.

Using a pipe inside a process is possible but not that usefull:



A pipe typically allows a parent and a child to communicate. Parent must fork after creating the pipe.
➢ The child process **inherits** the file descriptors



Pipe I/O

The descriptor of the pipe is an integer number
R/W on pipies do not differ to R/W on files

- Use read and write system calls
- It is possible to have more than one reader and writer on a pipe, but
  - The standard case is to have a single writer and a single reader
  - Data can be interlaced using more than one writer
  - Using more readers, it is undetermined which reader will read the next data from the pipe

System call read

- Blocks the process if the pipe is empty (it is blocking)

- If the pipe contains less bytes than the ones specified as argument of the read, it returns only the bytes available on the pipe
- If all file descriptors referring to the write-end of a pipe have been closed, then an attempt to read from the pipe will see end-of-file (read returns 0)

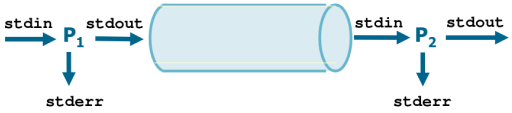
System call write

- Blocks the process if the pipe is full (it is blocking)
- The dimension of the pipe depends on the architecture and implementation
  - Constant `PIPE_BUF` defines the number of bytes that can be written atomically on a pipe
  - Standard value of `PIPE_BUF` is 4096 on Linux
- If all file descriptors referring to the read-end of a pipe have been closed, then a write to the pipe will cause a `SIGPIPE` signal to be generated for the calling process
- If the end of the write operations are not to be verified based on the return value of the read, it is always possible to transfer a "sentinel" (end-of-message marker)

Shell commands for Pipes and redirections

Pipe

Inter-process communication can be performed also by processes executed by shell commands. A shell pipe connects the standard output of a sender process, and the standard input of a receiving process




```
command1 | command2 | command3 ...
```

Examples:

```
ls -la | more
ps | grep main
cat file1.txt file2.txt file3.txt | sort
```

I/O redirection

The term redirection indicates the deviation of the standard channels (`stdin` 0, `stdout` 1, `stderr` 2). So a process (command) read/writes to a non standard source/destination.

null file

`/dev/null` is a special file, wrting on it doesnt produce any output, but reading it returns a sequence of zeros
It actas a a sink in the write.

Redirection types

Channel	Action	Operator	Description	Example
Standard Input	Read from file	`< file`	stdin (descriptor 0) reads input **from the file** instead of the keyboard.	`pgrm < file`
Standard Output	Overwrite file	`> file` or `1> file`	stdout (descriptor 1) is redirected to the file, **overwriting** any existing content.	`wc pgrm.c > file_pout.txt`
Standard Output	Append to file	`>> file` or `1>> file`	stdout (descriptor 1) is redirected to the file, **appending** to the existing content.	`wc pgrm.c >> file_pout.txt`
Standard Error	Overwrite file	`2> file`	stderr (descriptor 2) is redirected to the file, **overwriting** any existing content.	`pgrm 2> fileErr`

Channel	Action	Operator	Description	Example
Standard Error	Append to file	`2>> file`	stderr (descriptor 2) is redirected to the file, **appending** to the existing content.	
Both (Output/Error)	Overwrite file	`&> file` or `>& file`	stdout and stderr are both redirected to the file, **overwriting** it. (Shorthand for `> file 2>&1`)	
Both (Output/Error)	Append to file	`&>> file`	stdout and stderr are both redirected to the file, **appending** to it. (Shorthand for `>> file 2>&1`)	

Multiple redirections

You can redirect standard output and standard error to different files:

- bash shell:

```
`command 1> fileOut 2> fileErr`
```

ONLY u10 is missing, not part of course