Linux System Programming Part 4 - Processes

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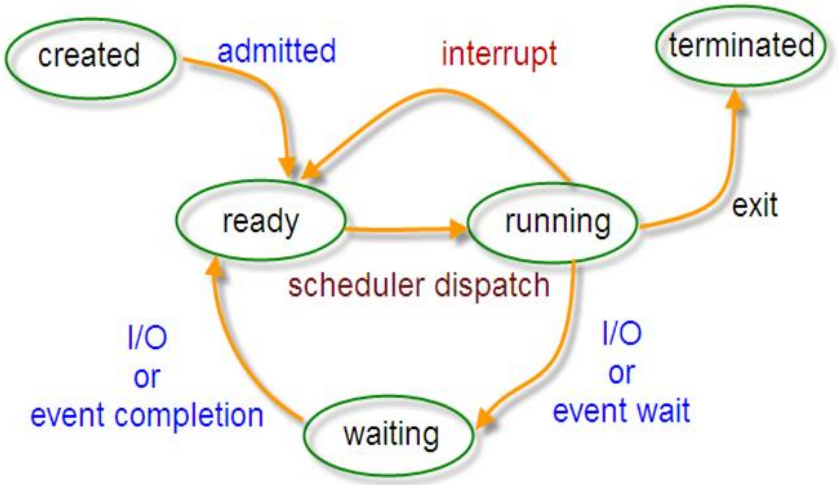
Processes in Linux

- **Processes** are object code in execution: active, alive, running programs.
- Processes consist of **data**, **resources**, **state**, and a **virtualized computer**.
- Each process is represented by a **unique identifier**, the process ID (**pid**).
- The process that the kernel "runs" when there are no other runnable processes is the **idle process** (pid=0).
- The process that spawns a new process is known as the **parent**; the new process is known as the **child**.
- Each process is owned by a **user** and a **group**.

The process state:



Managing the processes

- **ps** - report a snapshot of the current processes.
- **top** - display Linux processes.
- **kill** - send a signal to a process.
- **pgrep**, **pkill** - look up or signal processes based on name and other attributes.
- **killall** - kill processes by name.
- **Ctrl-C** - kill the foreground process.
- **Ctrl-Z** - suspend the foreground process.
- **jobs** - display status of jobs.
- **fg** - returns the suspended process to the foreground.

Process programming in C

- **getpid**() - get the pid of the calling process.
- **getppid**() - get the pid of the parent process.
- **execl**(), **execlp**(), **execle**(), **execv**(), **execvp**(), **execvpe**() - execute a file.
- **fork**() - create a child process.
- **exit**() - cause normal process termination.
- **wait**(), **waitpid**(), **waitid**() - wait for process to change state.

Execute a command

```c
#include <unistd.h>

int execl (const char *path, const char *arg, ...);
int execlp (const char *file, const char *arg, ...);
int execle (const char *path, const char *arg, ..., char * const envp[]);
int execv (const char *path, char *const argv[]);
int execvp (const char *file, char *const argv[]);
int execve (const char *filename, char *const argv[], char *const envp[]);
```

The mnemonics are simple:

- **l** and **v** delineate whether the arguments are provided via a list or an array (vector).
- **p** denotes that the user's full path is searched for the given file. Commands using the p variants can specify just a filename, so long as it is located in the user's path.
- **e** notes that a new environment is also supplied for the new process.

showsrc.c

Show own source file

- Initialize the variables
- Execute ‘**nano showsrc.c**’
- If execution failed, write a message and exit
- Print unreachable message for demo purposes

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

int main(int argc, char * argv[])
{
    int ret;
    ret = execl ("/bin/nano", "nano", "showsrc.c", NULL);
/* Or we could use this:
    const char *args[] = { "nano", "showsrc.c", NULL };
    ret = execvp ("nano", args); */
    if (ret == -1){
        printf("Failed to run nano!\n");
        return EXIT_FAILURE;
    }

    printf("I shouldn't be here!\n");
    return EXIT_SUCCESS;
}
```

Running a child process

```c
#include <sys/types.h>
#include <unistd.h>
pid_t fork (void);
pid_t getpid (void);
pid_t getppid (void);
```

Parent process
pid = 15

```c
pid = fork ( );
if (pid > 0){
    printPIDs("PARENT");
    wait(&child_status);
}
else if (!pid){
    printPIDs("CHILD");
    exit(0);
}
else if (pid == -1) {
    printf("ERROR!");
    return EXIT_FAILURE;
}
```

Child process
pid = 16

```c
pid = fork ( );
if (pid > 0){
    printPIDs("PARENT");
    wait(&child_status);
}
else if (!pid){
    printPIDs("CHILD");
    exit(0);
}
else if (pid == -1) {
    printf("ERROR!");
    return EXIT_FAILURE;
}
```

- A successful call to **fork**( ) creates a new process, identical in almost all aspects to the invoking process.
- The parent process gets the **pid** of the child process and the child process gets **0**.
- On error, a child process is not created, **fork**( ) returns -1, and **errno** is on of:
  - **EAGAIN** - The kernel failed to allocate certain resources, such as a new pid.
  - **ENOMEM** - Insufficient kernel memory was available to complete the request.

printpids.c

Write sentences into file

Initialize the functions and variables

Fork the process and store the **pid**(s)

If **pid** is positive (parent):

Print parent **pid** and **ppid**

If **pid** is zero (child):

Print child **pid** and **ppid**

If **pid** is -1 print error and exit

```c
void printPIDs(char* process_name)
...
int main(int argc, char* argv[])
{
    pid_t pid;

    pid = fork ( );
    if (pid > 0) printPIDs("PARENT");
    else if (!pid){
        printPIDs("CHILD");
        exit(0);
    }
    else if (pid == -1) {
        printf("ERROR while forking!");
        return EXIT_FAILURE;
    }
    return EXIT_SUCCESS;
}
```

Waiting and Terminating child processes

```c
#include <stdlib.h>

void exit (int status);
```

- A call to **exit()** performs some basic shutdown steps, and then instructs the kernel to terminate the process.
- The **status** parameter is used to denote the process' exit status.
- When a process terminates, the kernel sends the signal **SIGCHLD** to the parent.

Parent process
pid = 15

```c
pid = fork ( );
if (pid > 0){
    printPIDs("PARENT");
    wait(&child_status);
}
else if (!pid){
    printPIDs("CHILD");
    exit(0);
}
else if (pid == -1) {
    printf("ERROR!");
    return EXIT_FAILURE;
}
```

Child process
pid = 16

```c
pid = fork ( );
if (pid > 0){
    printPIDs("PARENT");
    wait(&child_status);
}
else if (!pid){
    printPIDs("CHILD");
    exit(0);
}
else if (pid == -1) {
    printf("ERROR!");
    return EXIT_FAILURE;
}
```

Waiting and Terminating child processes

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

pid_t wait (int *status);
int WIFEXITED (status);
int WIFSIGNALED (status);
int WIFSTOPPED (status);
int WIFCONTINUED (status);
int WEXITSTATUS (status);
int WTERMSIG (status);
int WSTOPSIG (status);
int WCOREDUMP (status);
```

- A call to **wait()** returns the ***pid*** of a terminated child, or ***-1*** on error.
- If no child has terminated, the call blocks until a child terminates.
- **WIFEXITED** returns true if the process terminated normally.
- In terminated normally, **WEXITSTATUS** provides the loworder eight bits that were passed to _exit.
- **WIFSIGNALED** returns true if a signal caused the process' termination.
- In case of signal termination, **WTERMSIG** returns the number of that signal.
- In case of signal termination, **WCOREDUMP** returns true if the process dumped core in response to receipt of the signal.
- **WIFSTOPPED** and **WIFCONTINUED** return true if the process was stopped or continued, respectively.
- If **WIFSTOPPED** is true, **WSTOPSIG** provides the number of the signal that stopped the process.

Execute and print status

- Verify we have enough arguments
- Fork the process and store the **pid**(s)
- The parent waits for the child and exits on error
- On success, prints the status of the termination
- The child executes the command in the arguments
- Exit with success

```c
if (argc < 2) {
  printf("Usage: %s command, [arg1 [arg2]...]\n", argv[0]);
  return EXIT_FAILURE;
}
```

```c
if (pid == 0) {
  execvp(argv[1], &argv[1]);
  perror("execvp");
  return EXIT_FAILURE; // Never get there normally
}
else {
  if (wait(&status) == -1) {
    perror("wait");
    return EXIT_FAILURE;
  }
  if (WIFEXITED(status))
    printf("Child terminated normally with exit code %i\n",
    WEXITSTATUS(status));
  if (WIFSIGNALED(status))
    printf("Child was terminated by a signal #%i\n",
    WTERMSIG(status));
  if (WCOREDUMP(status))
    printf("Child dumped core\n");
  if (WIFSTOPPED(status))
    printf("Child was stopped by a signal #%i\n", WSTOPSIG
    (status));
}
```

Zombies and simple signals handling

- When a child dies before its parent, the kernel puts the child into a special process state - the process is then called a **zombie**.
- A process in this state waits for its parent to inquire about its status and only after this the child process cease to exist even as a zombie.
- If the parent never inquires about a child's status then the zombie becomes a **ghost** - very bad practice.
- If the parent process terminates before its children, then they a **reparented** to the **init** process.
- The init process, in turn, periodically waits on all of its children, ensuring that none remain zombies for too long.

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

pid_t waitpid(pid_t pid, int *wstatus, int options);
```

```c
#include <signal.h>

int sigaction(int signum, const struct sigaction *act,
              struct sigaction *oldact);

struct sigaction {
    void     (*sa_handler)(int);
    void     (*sa_sigaction)(int, siginfo_t *, void *);
    sigset_t   sa_mask;
    int        sa_flags;
    void     (*sa_restorer)(void);
};
```

zombietest.c

Play with zombies

- Define the termination signal handler
- Initialize variables to use the signal handler
- Set action for SIGCHLD,exit on error
- Do 10 times:
  - Fork the process and store the **pid**(s)
  - The parent prints the pid of the new child
  - The child prints a message and exits
- Enter endless loop

```c
static void sigchld_hdl (int sig)
{
        while (waitpid(-1, NULL, WNOHANG) > 0) {}
}
...
act.sa_handler = sigchld_hdl;
if (sigaction(SIGCHLD, &act, 0)) {
    perror ("sigaction");
    return 1;
}
for (i = 0; i < 10; i++) {
    int pid = fork();
    if (pid == 0) {
        printf("I will leave no zombie\n");
        exit(0);
    } else {
        printf("Created a process with the PID %i\n", pid);
    }
}
while (1) {
        sleep(1);
}
```

Exercise

Program *TempFileGenerator*:

Write a program (‘**tempgen.c**’), which takes 1 argument: **files_count**. The program should generate **files_count** files called ‘**temp<nr>.tmp**’ (where **nr** is between **1** and **files_count**). Each file is created by a separate process and contains **1000** times the **pid** of the corresponding process as text (pid=1001 should take 4 bytes per ID).

The parent process should notify after each file is created.

Modify the program or write a new one, in which the processes write only in one file, where the **pid** sequences do not overlap (we have 1000 times **pid*_file_1***, then 1000 times **pid*_file_2***… then 1000 times **pid*_files_cound***).