Operating systems and concurrency - B03

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Introduction

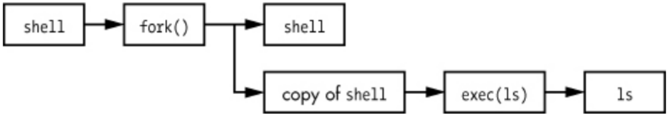
- Processes and multitasking
- `fork()` and `exec()`
- Process identifiers
- `fork()` example
- `exit()`
- `exec()` example
- `wait()`, `waitpid()`
- Summary

Processes and multitasking

- A key function of the OS is to share the CPU, or a set of CPUs, between many different tasks, also called *processes*
- A process is an instance of a program in execution
- It has its own data: static variables, stack, heap, open files etc
- There can be several processes running based on the same program, e.g.

```
for i in {1..4}
do
  xterm&
done
```

Fork and exec



Ward, B., How Linux Works, 2nd edition, No Starch Press, 2014, § 1.3.4

- In Unix, all user processes, except `init`, are created by `fork()`
- `fork()` is a system call
- When a process calls `fork()` the kernel creates an almost identical copy of the process
- When a process calls `exec(`*`program`*`)`, the kernel starts the execution of *program*, replacing the current process
- Assume we type `ls` into our terminal; the command is passed to the shell, which forks itself, creating a copy of itself, which then runs `exec(ls)` to start the `ls` program, which replaces the copy of the shell

Process identifiers

- Every process has a unique *process identifier*, a non-negative integer
- Every process also has other identifiers associated with it:

```
#include <unistd.h>

pid_t getpid(void)     // process id
pid_t getppid(void)    // parent process id
uid_t getuid(void)     // real user id
uid_t geteuid(void)    // effective user id
gid_t getgid(void)     // real group id
gid_t getegid(void)    // effective group id
```

- There are some special processes:
  - process 0 - usually a system process called the *swapper*
  - process 1 - *init*, called by the kernel at the end of the boot process

Process identifiers example

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

int main(void) {
  printf("My process id is %d\n", getpid());
  printf("The id of my parent process is %d\n",
          getppid());
  printf("My real user id is %d\n", getuid());
  printf("and my group id is %d\n", getgid());
  return(0);
}
```

```
$ gcc -o hellopid hellopid.c
$ ./hellopid
My process id is 25419
The id of my parent process is 2924
My real user id is 1000
and my group id is 1000
$ ls -n hellopid
-rwxrwxr-x 1 1000 1000 8733 Feb  5 17:13 hellopid
```

Fork example

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

int globvar = 6;

int main(void) {
  int var = 88;
  pid_t pid;

  printf("before fork\n");
  if ((pid = fork()) < 0) {
      fprintf(stderr, "fork failed\n");
      exit(-1);
  } else if (pid == 0) {
      globvar++; //child
      var++;
  } else {
      sleep(2); // parent
  }
  printf("pid = %d, globvar = %d, var = %d\n",
           getpid(), globvar, var);
  exit(0);
}
```

Fork example compilation and output

```
$ gcc -o forkexample forkexample.c
$ ./forkexample
before fork
pid = 26087, globvar = 7, var = 89
pid = 26086, globvar = 6, var = 88
```

- A *copy* has been made of the `forkexample` process
    - The global and local variables in the child process are different from the parent
    - Notice that only the child process increments these values; both processes print them; the parent process retains the original values

Fork example compilation and output

```
$ ./forkexample > forkexample.out
$ less forkexample.out
before fork
pid = 25838, globvar = 7, var = 89
before fork
pid = 25837, globvar = 6, var = 88
```

- The file descriptors of the parent have also been copied to the child
- So if the parent process has redirected `stdout`, the child process also redirects `stdout`
- Notice the slight difference in behaviour when `stdout` has been redirected; the output `before fork` appears twice this time.
- This because the `\n` causes the output buffer to be flushed in interactive mode, but not when output is sent to a file – and even the output buffer of the parent is copied to the child!

`exec`

- A process can choose to replace itself - text and data - using the `exec()` system call
- Actually there is a family of system calls - `execl`, `execlp`, `execle`, `execv`, `execvp`, `execve`, `fexecve`, which differ in
  - How the command arguments are presented
  - Which environment is used to run the new program
- Usually, the new process runs using the same *environment* as its parent
  - Discover the environment of the shell using the `env` command, e.g. `HOME=/home/cgdk2`, `SHELL=/bin/bash`, `USER=cgdk2`, `PATH=/home/cgdk2/bin:/usr/local/sbin:/usr/local/bin:/usr/sbin:/usr/bin:/sbin:/bin`
- `PATH` is particularly important; used to determine where the shell looks for its commands; can be set per user using `~/.bashrc`, e.g. add a line like this to your `~/.bashrc`

```
export PATH=/home/cgdk2/special/bin:$PATH
```

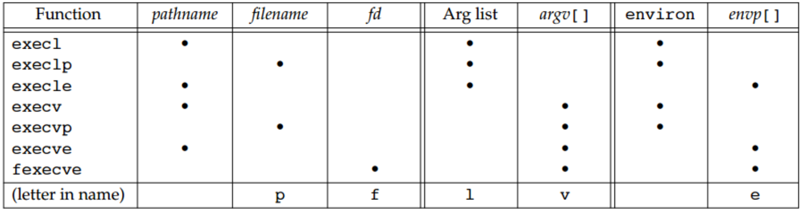
`exec()` example

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

int main(void) {
  pid_t pid;
  char *argv[] = {"ls", "-l"};

  if ((pid = fork()) < 0) {
      fprintf(stderr, "fork failed\n");
      exit(-1);
  } else if (pid == 0) { // child
      execl("/bin/ls", "ls", "-l", NULL);
  } else {               // parent
      waitpid(pid, NULL, 0);
  }
  exit(0);
}
```

The `exec` functions



Function	*pathname*	*filename*	*fd*	Arg list	*argv*[ ]	environ	*envp*[ ]
`execl`	•			•		•	
`execlp`		•		•		•	
`execle`	•			•			•
`execv`	•				•	•	
`execvp`		•			•	•	
`execve`	•				•		•
`fexecve`			•		•		•
(letter in name)		p	f	l	v		e

- Alternative forms of `exec()`

```
execl("/bin/ls", "ls", "-l", NULL);
execlp("ls", "ls", "-l", NULL);
execv("/bin/ls", argv);
execvp("ls", argv);
```

Summary of process management in C

- Process creation
  `fork()`
  More information - `man fork`
- Process replacement
  `execl()`
  More information - `man execl`
- Process wait
  `wait(), waitpid()`
  More information - `man wait`
- Process termination
  `exit()`
  More information - `man exit`