Process Control

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Overview

- Process Identifiers
  - init program (`/sbin/init`)
    - `/etc/inittab`
    - `/etc/rc*`
    - `/etc/events.d`
    - never dies
    - parent of all orphaned process
- List of Running Processes
  - `ps`
    - `a`: all with tty, including other users
    - `u`: user-oriented format
    - `x`: processes without controlling ttys
  - `top`
  - `htop`
- Process Relationship: `pstree`
- Retrieve Process Identifiers
  - `pid_t getpid(void);`
  - `pid_t getppid(void);`
  - `uid_t getuid(void);`
  - `uid_t geteuid(void);`
  - `gid_t getgid(void);`
  - `gid_t getegid(void);`
  - no error return

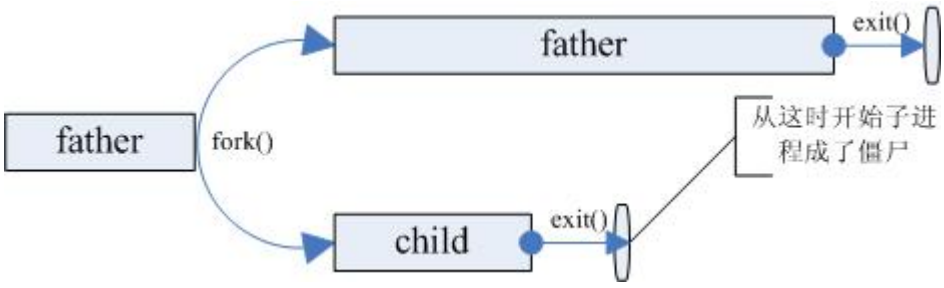
Process Creation

- The Fork Function
  - `pid_t fork(void);`
    - return: 0 in child, PID of child in parent, -1 error
  - the child is a copy of the parent
    - copy of data space, heap, and stack
    - share the text segment
    - fork, then exec -> copy-on-write (COW)

- Handling File Descriptors After Fork
  - The parent waits for the child to complete
    - The parent does not need to do anything with its descriptors
    - Any of the shared descriptors that the child reads from or writes to have their file offsets updated accordingly
  - Both the parent and the child go their own ways
    - After the fork, the parent closes the descriptors that it doesn't need
    - The child does the same thing
    - This scenario is often the case with network servers
- Other Properties Inherited by the Child
  - real UID, real GIP, EUID, EGID, SUID, SGID
  - supplementary GIDs
  - controlling terminal
  - current working directory
  - file mode creation mask
  - signal mask and dispositions
  - **close-on-exec flag for and open file descriptors**
  - environment variables
- Uses of Fork
  - network servers
  - shells
- Variants of Fork
  - `vfork`
    - without copy the address space of the parent into the child
    - usually used when child calls `exec` or `exit`
    - runs in the address space of the parent until `exec` or `exit`
    - more efficient than use `fork`
  - `clone`
    - allow the caller to control what is shared between parent and child

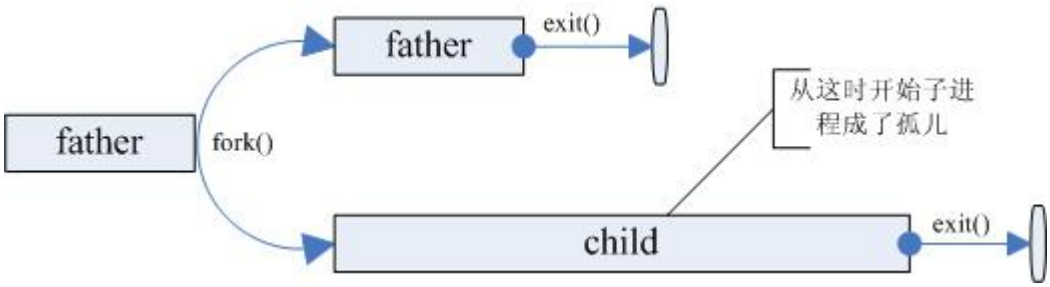
Process Termination

- Child Process Termination
  - zombie process
    - parent doesn't read exit status of child
    - resources are freed
    - but PID and termination state are kept in kernel



  - orphan process
    - parent is terminated before its child

        - reparenting by init, therefore PPID is 1



    - parent receives `SIGCHLD` when its child terminates
        - termination is an asynchronous event
        - signal is asynchronous from kernel to parent
        - parent can use signal handler function

- `wait` and `waitpid` function
    - behavior
        - block, if all children are running
        - return termination status, if child terminates and waits for its status to be fetched
        - return an error, if it doesn't have any child processes
    - `pid_t wait(int *status);`
    - `pid_t waitpid(pid_t pid, int *status, int options);`
    - difference between them
        - `wait` always block the caller until a child process terminates
        - `waitpid` has an option that control which process it waits for
        - `waitpid` has an option that prevents it from being blocked

- Macros to Interpret Exit Status

Marco	Description
`WIFEXITED(status)`	True if child terminates normally, i.e. `exit(3)`, `_exit(2)`, `_Exit(2)` or return from `main()`
`WEXITSTATUS(status)`	Fetch LS 8 bits of return value, used only if `WIFEXITED(status)` returns true
`WIFSIGNALED(status)`	True if child terminates abnormally by receiving a signal
`WTERMSIG(status)`	Fetch the signal number, used only if `WIFSIGNALED (status)` returns true
`WCOREDUMP(status)`	True if a core file was generated, not a specified in POSIX.1-2001 (some UNIX OS may not implement)
`WIFSTOPPED(status)`	True if the child was stopped by delivery of a signal
`WSTOPSIG(status)`	Fetch the signal number, used only if `WIFSTOPPED (status)` returns true
`WIFCONTINUED (status)`	True if child was resumed by delivery of `SIGCONT`

- example

```
void pr_exit(int status) {
  if (WIFEXITED(status)) {
    printf("normal termination, exit status = %d\n",
WEXITSTATUS(status));
  } else if (WIFSIGNALED(status)) {
    printf("abnormal termination, signal number = %d\n",
WTERMSIG(status));
  } else if (WIFSTOPPED(status)) {
    printf("child stopped, signal number = %d\n",
WSTOPSIG(status));
  }
}
int main(void) {
  pid_t pid;
  int status;
  if ((pid = fork()) < 0) {
    exit(1);
  } else if (pid == 0) {
    // do something and return
  }
  if (wait(&status) == pid) {
    pr_exit(status);
  }
}
```

- `pid_t waitpid(pid_t pid, int *status, int options);`
  - wait for a specific child process
  - argument `pid`

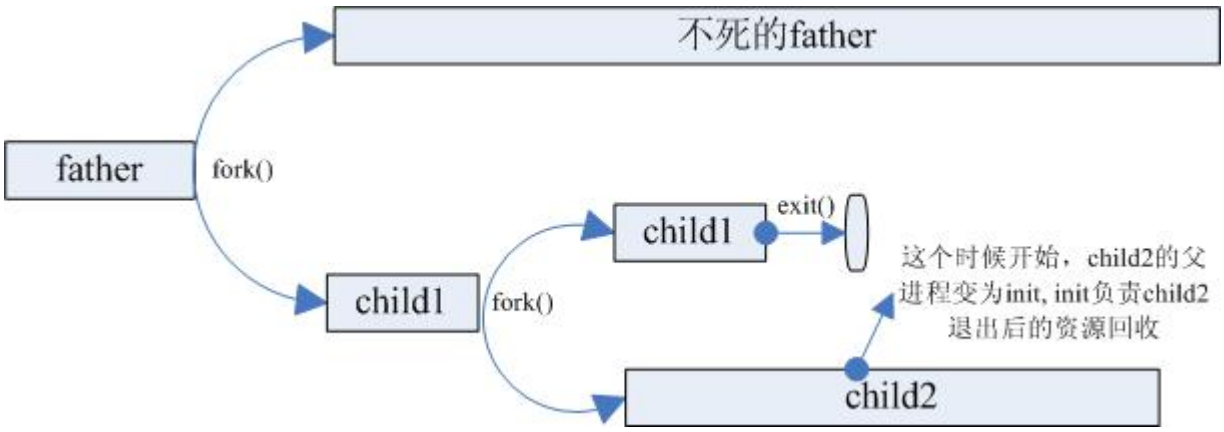
`pid`	**Interpretation**
`< -1`	child's GID equals |`pid`|
`== -1`	any child (same as `wait` in this respect)
`== 0`	child's GID equals the that of the calling process
`> 0`	child's PID equals `pid`

  - options

Constant	**Description**
`WNOHANG`	return 0, not block if the specified child pid is not immediately available
`WUNTRACED`	return specified child pid, when it stop, and its status hasn't reported
`WCONTINUED`	return specified child pid, when it is resumed from stop (`SIGCONT`), and its status hasn't reported

- Avoid Zombies by Calling fork twice

```c
int main() {
  pid_t pid;
  if ((pid = fork()) < 0) {
    printf("error");
  } else if (pid == 0) {
    if ((pid = fork()) < 0) {
      printf("error");
    } else if (pid > 0) {
      /* child */
      exit(0);
    }
    /* grandchild */
  }
  /* self */
  return 0;
}
```



- Race Conditions
  - parent waits for child to terminate
    - call `wait`: make sure child runs before calling
  - child waits for parent to terminate
    - polling by `getppid` to know if parent terminates
    - not efficient
  - communication via IPC
    - these functions are defined in apue example code
    - `TELL_WAIT()`: Initialize
    - `WAIT_PARENT()`: blocks execution and waits for its parent
    - `TELL_CHILD(pid)`: tell a child that it has finished
    - `WAIT_CHILD()`: blocks execution and waits for its child
    - `TELL_PARENT(ppid)`: tell its parent that it has finished

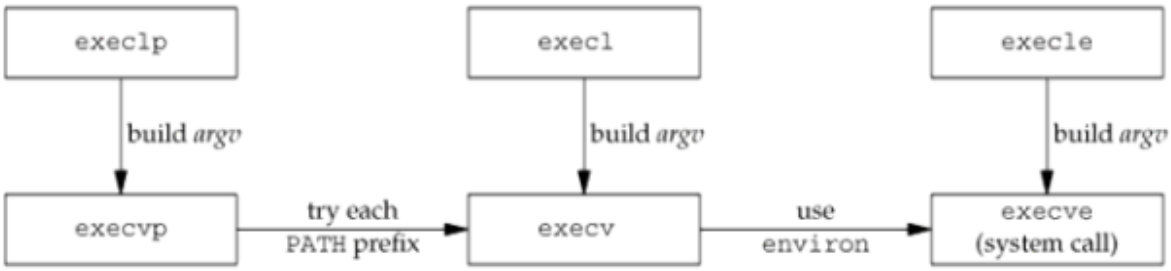
```c
int main(void) {
  pid_t pid;
  TELL_WAIT();
  if ((pid = fork()) < 0) {
    printf("error\n");
  } else if (pid == 0) {
    WAIT_PARENT();
    /* parent goes first */
    printf("output from child\n");
  } else {
    printf("output from parent\n");
    TELL_CHILD(pid);
  }
  exit(0);
}
```

Process Execution

- The `exec` Functions
  - replace the calling process with a new program
  - `extern char **environ;`
  - `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 *path, char *const argv[], char *const envp[]);`
  - `path`: relative path or absolute path
  - `file`: not contain slash, search `file` from directories in `PATH`

Function	`path`	`file`	`arg list`	`argv[]`	`environ`	`envp[]`
`execl`	•		•		•	
`execlp`		•	•		•	
`execle`	•		•			•
`execv`	•			•	•	
`execvp`		•		•	•	
`execve`	•			•		•
letter		p	l	v		e

- relationships



- How UNIX Recognizes Binaries
  - ELF binary: `7f 45 4c 46` -> `.ELF`
  - Interpreter files: `23 21` -> `#!`
  - exe file: `4d 5a` -> `MZ`
  - `hexdump -C a.out | head`
- Support More Binaries
  - binfmt_misc file system
  - add new binary format
    - format: `:name:type:offset:magic:mask:interpreter:flags`
      - name: generate file in `/proc/sys/fs/binfmt_misc`
      - type: M for header, E for extension
      - offset: offset position when type is M
      - magic: the value to compare (either M or E type)

```
# echo ":DOSWin:M::MZ::/usr/bin/wine:" >
/proc/sys/fs/binfmt_misc/register
# cat /proc/sys/fs/binfmt_misc/DOSWin
enabled
interpreter /usr/bin/wine
flags:
offset: 0
magic: 4d5a
```

- `exec` Example
  - `char *env_init[] = { "V0=0", "V1=1", NULL };`
  - `execle(“./pg", "arg0", "arg1", (char *)0, env_init);`
    - result
      - `argv[0]`: `arg0`
      - `argv[1]`: `arg1`
  - `execlp("pg", "arg0", "arg1", (char *)0);`
    - use environment of the parent program
  - use on interpreter files

        - `execl("/path/to/interp", "interp", "arg1", "arg2", (char *)0) < 0);`
        - file interp: `#!/path/to/echo foo`
        - result
            - `argv[0]`: `/path/to/echo`
            - `argv[1]`: `foo`
            - `argv[2]`: `/path/to/interp`
            - `argv[3]`: `arg1`
            - `argv[4]`: `arg2`
    - if `script.sh` uses `#!/bin/bash`
        - then `./script.sh 1 2` equals `/bin/bash ./script.sh 1 2`

- `system` function
    - `int system(const char *cmdstring);`
    - implemented by calling `fork`, `exec`, and `waitpid`
        - `fork` fail or `waitpid` fail with `errno` is not `EINTR`
            - return -1 with `errno` set
        - `exec` fail
            - back to program and return -127 to system parent
            - system parent return -127 to caller
    - a simple implementation

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

    - suid/sgid program
        - if the program uses the system function to execute a command
            - the command has the same euid/egid as the calling process
            - security problem
        - solution

        - use exec functions instead
        - change euid/egid before calling exec
        - `seteuid` and `setegid`
    - user identification
        - any process can find out its RUID, RGID, EUID, EGID
        - `struct passwd *getpwuid(uid_t uid);`
        - `getpwuid(getuid())`
    - may not work for a single user that has multiple login names, but the same UID
    - an alternative
        - `char *getlogin(void);`
        - `int getlogin_r(char *buf, size_t bufsize);`
        - use `getpwnam` to get passwd with the login name

- Process Times: `time(2)`
    - `clock_t times(struct tms *buf);`

      ```
      struct tms {
        clock_t tms_utime;  /* user time */
        clock_t tms_stime;  /* system time */
        clock_t tms_cutime; /* user time of children */
        clock_t tms_cstime; /* system time of children */
      };
      ```

    - all waited processes
    - child's CPU times are counted after `wait` read termination status