Process Management II

Science

Computer Science

CS 351: Systems Programming

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Recall: all processes turn into *zombies* upon termination

- no longer runnable, but still tracked by OS kernel

§Reaping Processes (& Synchronization)

All processes are responsible for reaping their own (immediate) children

So what happens if we don’t?

```
int main() {
    int i;
    for (i=0; i<3; i++) {
        if (fork() == 0)
            exit(0);
    }
    printf("Parent pid = %d\n", getpid());
    while (1) ; /* non-terminating parent */
}
```

```
$ ./a.out &
Parent pid = 7254

$ ps -g 7254
  PID STAT   TT  STAT      TIME COMMAND
 7254 S    s003  S      0:00.01 ./a.out
 7255 Z    s003  Z      0:00.00 (a.out)
 7256 Z    s003  Z      0:00.00 (a.out)
 7257 Z    s003  Z      0:00.00 (a.out)
```

```
int main() {
    int i;
    for (i=0; i<3; i++) {
        if (fork() == 0)
            exit(0);
    }
    printf("Parent pid = %d\n", getpid());
    return 0; /* (parent exits) */
}
```

```
$ ./a.out
Parent pid = 7409

$ ps -g 7409
  PID STAT   TT  STAT      TIME COMMAND
```

Q: How to kill a zombie?

A: By shooting it in the head!
(i.e., terminating its parent process)

Orphaned processes (i.e., with terminated parents) are *adopted* by the OS kernel

… and the kernel always reaps its children

It is especially important for *long-running* processes to reap their children

(why?)

```c
int main() {
    int i;
    for (i=0; i<3; i++) {
        if (fork() == 0)
            exit(0);
    }
    printf("Parent pid = %d\n", getpid());
    return 0; /* (parent exits) */
}
```

Q: who reaps the parent??

A: The **Shell**!

```
int main() {
    printf("My parent's pid = %d\n", getppid());
    printf("My own pid = %d\n", getpid());
    return 0; /* terminate -> zombie */
}
```

```
$ ./a.out
My parent's pid = 7600
My own pid = 7640

$ ps
  PID STAT    TT   STAT       TIME  COMMAND
 7600 Ss    s005   Ss      0:28.32 -bash
```

The **Shell**! (how does it do it?)

```
pid_t reap(int *stat_loc);
```

(I wish)

```
pid_t wait(int *stat_loc);
pid_t wait(int *stat_loc);
```

when called by a process with ≥ 1 children:

- *waits* (if needed) for a child to terminate
- *reaps* a zombie child (if ≥ 1 zombified children, arbitrarily pick one)
- *returns* reaped child's pid and exit status info via pointer (if non-NULL)

```
pid_t wait(int *stat_loc);
```

when called by a process with **no** children:

- return `-1` *immediately* & populate `errno`

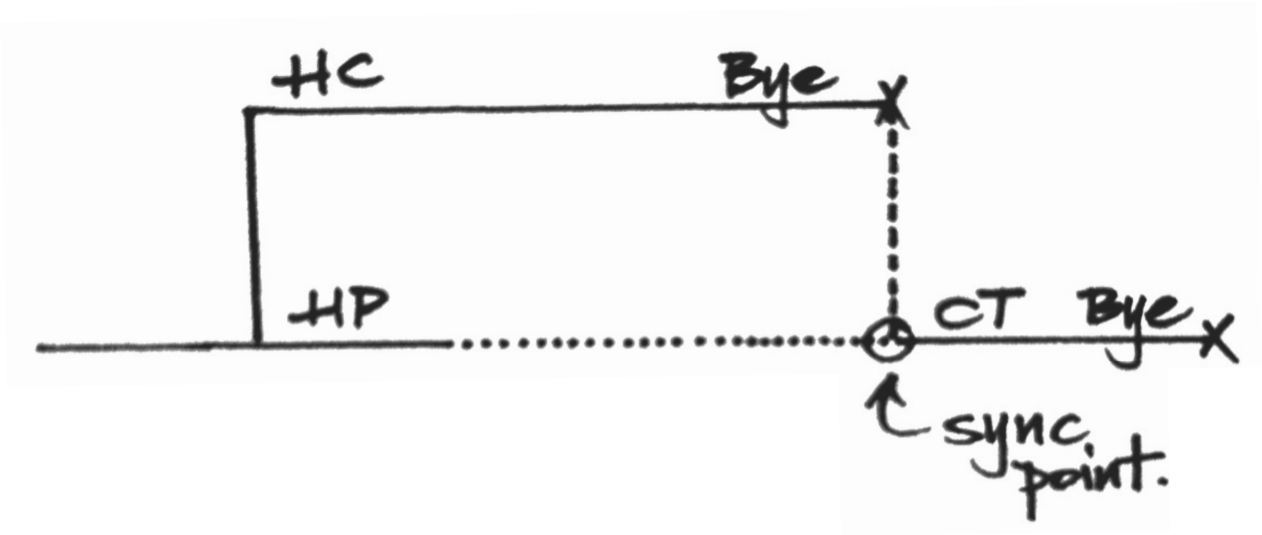
```c
int main() {
    pid_t cpid;
    if (fork() == 0)
        exit(0);            /* child -> zombie */
    else
        cpid = wait(NULL);  /* reaping parent */

    printf("Parent pid = %d\n", getpid());
    printf("Child pid  = %d\n", cpid);
    while (1) ;
}
```

```
$ ./a.out &
Parent pid = 7505
Child pid  = 7506

$ ps -g 7505
  PID STAT   TT  STAT      TIME COMMAND
 7505 R    s003  R      0:00.05 ./a.out
```

```
void fork9() {
    if (fork() == 0) {
        printf("HC: hello from child\n");
    } else {
        printf("HP: hello from parent\n");
        wait(NULL);
        printf("CT: child has terminated\n");
    }
    printf("Bye\n");
}
```



```
void fork9() {
    if (fork() == 0) {
        printf("HC: hello from child\n");
    } else {
        printf("HP: hello from parent\n");
        wait(NULL);
        printf("CT: child has terminated\n");
    }
    printf("Bye\n");
}
```

A	B	C	D	E
HP	HP	HP	HC	HC
CT	HC	HC	Bye	HP
HC	CT	Bye	HP	Bye
Bye	Bye	CT	CT	CT
Bye	Bye	Bye	Bye	Bye

`wait` allows us to *synchronize* one process with events (e.g., termination) in another

```
int main() {
    if (fork() == 0) {
        if (fork() == 0) {
            printf("3");
        } else {
            wait(NULL);
            printf("4");
        }
    } else {
        if (fork() == 0) {
            printf("1");
            exit(0);
        }
        printf("2");
    }
    printf("0");
    return 0;
}
```

A. 2030401

B. 1234000

C. 2300140

D. 2034012

E. 3200410

F. 3401200

```c
int main() {
    int stat;
    if (fork() == 0)
        exit(1);
    else
        wait(&stat);
    printf("%d\n", stat);
    return 0;
}
```

```
$ ./a.out
256
```

"status" reported by wait is more than just the exit status of the child; e.g.,

- normal/abnormal termination
- termination cause
- exit status

```
/* macros */
WIFEXITED(status)    /* exited normally? */
WEXITSTATUS(status)  /*  if so, exit status */
WIFSTOPPED(status)   /* process stopped? */
WIFSIGNALED(status)  /* process signaled? */
WTERMSIG(status)     /*  if so, signal number */

/* prints information about a signal */
void psignal(unsigned sig, const char *s);
```

```
int main() {
    int stat;
    if (fork() == 0)
        exit(1);
    else
        wait(&stat);

    if (WIFEXITED(stat))
        printf("Exit status: %d\n", WEXITSTATUS(stat));
    else if (WIFSIGNALED(stat))
        psignal(WTERMSIG(stat), "Exit signal");
    return 0;
}
```

```
$ ./a.out
Exit status: 1
```

```
int main() {
    int stat;
    if (fork() == 0)
        *(int *)NULL = 0;
    else
        wait(&stat);

    if (WIFEXITED(stat))
        printf("Exit status: %d\n", WEXITSTATUS(stat));
    else if (WIFSIGNALED(stat))
        psignal(WTERMSIG(stat), "Exit signal");
    return 0;
}
```

```
$ ./a.out
Exit signal: Segmentation fault
```

```c
void fork10() {
    int i, stat;
    pid_t pid[5];
    for (i=0; i<5; i++)
        if ((pid[i] = fork()) == 0) {
            sleep(1);
            exit(100+i);
        }
    for (i=0; i<5; i++) {
        pid_t cpid = wait(&stat);
        if (WIFEXITED(stat))
            printf("Child %d terminated with status %d\n",
                   cpid, WEXITSTATUS(stat));
    }
}
```

```
Child 8590 terminated with status 101
Child 8589 terminated with status 100
Child 8593 terminated with status 104
Child 8592 terminated with status 103
Child 8591 terminated with status 102
```

```
/* explicit waiting -- i.e., for a specific child */
pid_t waitpid(pid_t pid, int *stat_loc, int options);
```

```
/** Wait options **/

/* return 0 immediately if no terminated children */
#define WNOHANG    0x00000001

/* also report info about stopped children (and others) */
#define WUNTRACED  0x00000002
```

```c
void fork11() {
    int i, stat;
    pid_t pid[5];
    for (i=0; i<5; i++)
        if ((pid[i] = fork()) == 0) {
            sleep(1);
            exit(100+i);
        }
    for (i=0; i<5; i++) {
        pid_t cpid = waitpid(pid[i], &stat, 0);
        if (WIFEXITED(stat))
            printf("Child %d terminated with status %d\n",
                   cpid, WEXITSTATUS(stat));
    }
}
```

```
Child 8704 terminated with status 100
Child 8705 terminated with status 101
Child 8706 terminated with status 102
Child 8707 terminated with status 103
Child 8708 terminated with status 104
```

```
int main() {
    int stat;
    pid_t cpid;
    if (fork() == 0) {
        printf("Child pid = %d\n", getpid());
        sleep(3);
        exit(1);
    } else {
        /* use with -1 to wait on any child (with options) */
        while ((cpid = waitpid(-1, &stat, WNOHANG)) == 0) {
            sleep(1);
            printf("No terminated children!\n");
        }
        printf("Reaped %d with exit status %d\n",
               cpid, WEXITSTATUS(stat));
    }
}
```

```
Child pid = 8885
No terminated children!
No terminated children!
No terminated children!
Reaped 8885 with exit status 1
```

Recap:

- *fork*: create new (duplicate) process
- *exit*: terminate process
- *wait*: reap terminated (zombie) process

§Running *new programs* (*within* processes)

```
/* the "exec family" of syscalls */

int execl(const char *path, const char *arg, ...);

int execlp(const char *file, const char *arg, ...);

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

int execvp(const char *file, char *const argv[]);
```

Execute a ***new program*** within the ***current process context***

Complements `fork` (1 call → 2 returns):

- when called, `exec` (if successful) never returns!

  - starts execution of new program

```c
int main() {
    execl("/bin/echo", "/bin/echo",
          "hello", "world", (void *)0);
    printf("Done exec-ing...\n");
    return 0;
}
```

```
$ ./a.out
hello world
```

```
int main() {
    printf("About to exec!\n");
    sleep(1);
    execl("./execer", "./execer", (void *)0);
    printf("Done exec-ing...\n");
    return 0;
}
```

```
$ gcc execer.c -o execer
$ ./execer
About to exec!
About to exec!
About to exec!
About to exec!
...
```

```
int main () {
    if (fork() == 0) {
        execl("/bin/ls", "/bin/ls", "-l", (void *) 0);
        exit(0); /* in case exec fails */
    }
    wait(NULL);
    printf("Command completed\n");
    return 0;
}
```

```
$ ./a.out
-rwxr-xr-x  1 lee  staff     8880 Feb 8 01:51 a.out
-rw-r--r--  1 lee  staff      267 Feb 8 01:51 demo.c
Command completed
```

Interesting question:

Why are `fork` & `exec` separate syscalls?

```
/* i.e., why not: */
fork_and_exec("/bin/ls", ...)
```

A1: we might really want to just create *duplicates* of the current process (e.g.?)

A2: we might want to *replace* the current program *without creating* a new process

A3 (more subtle): we might want to “tweak” a process *before* running a program in it