Processes

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Processes (1)

- What’s difference among
  - Program
  - Process
  - Processor

- Process
  - An instance of a program in execution
  - ‘Context’ + ‘Resource’
Processes (2)

- Process provides each program with two key abstractions:
  - Logical control flow
    - Each program seems to have exclusive use of the CPU
  - Private address space
    - Each program seems to have exclusive use of main memory

- How are these illusions maintained?
  - Process executions interleaved (multitasking).
  - Address space managed by virtual memory system.
Logical Control Flows

- Each process has its own logical control flow

![Diagram showing time quantum and time slice with processes A, B, and C]
Concurrent Processes (1)

- **Definition**
  - Two processes run concurrently (are concurrent) if their flows overlap in time.
  - Otherwise, they are sequential.
  - Examples (running on single core):
    - Concurrent: A & B, A & C
    - Sequential: B & C

![Diagram showing concurrent processes A, B, and C over time]

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SWE2007: Software Experiment 2 | Fall 2016 | Jin-Soo Kim (jinsookim@skku.edu)
### User View of Concurrent Processes

- Control flows for concurrent processes are physically disjoint in time
- However, we can think of concurrent processes are running in parallel with each other
Context Switching

- Control flow passes from one process to another via a context switch

![Diagram showing context switching between processes A and B]

- Time

- Process A
  - User code
  - Kernel code
  - User code
  - Kernel code
  - User code

- Process B
  - User code
  - Kernel code
  - User code
  - Kernel code
  - User code

\{ context switch \}
Creating a New Process

- `pid_t fork(void)`
  - Creates a new process (child process) that is identical to the calling process (parent process)
  - Returns 0 to the child process
  - Returns child’s `pid` to the parent process

```c
if (fork() == 0) {
    printf("hello from child\n");
} else {
    printf("hello from parent\n");
}
```

Fork is interesting (and often confusing) because it is called once but returns twice.
Fork Example (1)

- **Key points**
  - Parent and child both run **same code**
    - Distinguish parent from child by **return value** from `fork()`
  - Start with same state, but each has private copy.
    - Share file descriptors, since child inherits all open files.

```c
void fork1() {
    int x = 1;
    pid_t pid = fork();
    if (pid == 0) {
        printf("Child has x = %d\n", ++x);
    } else {
        printf("Parent has x = %d\n", --x);
    }
    printf("Bye from process %d with x = %d\n", getpid(), x);
}
```
### Key points

- Both parent and child can continue forking.

```c
void fork2()
{
    printf("L0\n");
    fork();
    printf("L1\n");
    fork();
    printf("Bye\n");
}
```
Destroying a Process

- **void exit (int status)**
  - Exits a process.
    - Normally returns with status 0
  - **atexit()** registers functions to be executed upon exit.

```c
void cleanup(void) {
    printf("cleaning up\n");
}

void fork6() {
    atexit(cleanup);
    fork();
    exit(0);
}
```
Synchronizing with Children

- **pid_t wait (int *status)**
  - suspends current process until one of its children terminates.
  - return value is the **pid** of the child process that terminated.
  - if **status != NULL**, then the object it points to will be set to a status indicating why the child process terminated.

- **pid_t waitpid (pid_t pid, int *status, int options)**
  - Can wait for specific process
  - Various options
void fork9() {
    int child_status;

    if (fork() == 0) {
        printf("HC: hello from child\n");
    }
    else {
        printf("HP: hello from parent\n");
        wait(&child_status);
        printf("CT: child has terminated\n");
    }
    printf("Bye\n");
    exit();
}
Wait Example (2)

- If multiple children completed,
  - will take in arbitrary order.
  - Can use macros `WIFEXITED` and `WEXITSTATUS` to get information about exit status.

```c
void fork10() {
    pid_t pid[N];
    int i, child_status;
    for (i = 0; i < N; i++)
        if ((pid[i] = fork()) == 0)
            exit(100+i); /* Child */
    for (i = 0; i < N; i++) {
        pid_t wpid = wait(&child_status);
        if (WIFEXITED(child_status))
            printf("Child %d terminated with exit status %d\n", wpid, WEXITSTATUS(child_status));
        else
            printf("Child %d terminate abnormally\n", wpid);
    }
}
```
void fork11()
{
    pid_t pid[N];
    int i;
    int child_status;
    for (i = 0; i < N; i++)
        if ((pid[i] = fork()) == 0)
            exit(100+i); /* Child */
    for (i = 0; i < N; i++) {
        pid_t wpid = waitpid(pid[i], &child_status, 0);
        if (WIFEXITED(child_status))
            printf("Child %d terminated with exit status %d\n", wpid, WEXITSTATUS(child_status));
        else
            printf("Child %d terminated abnormally\n", wpid);
    }
}
Zombies (1)

- **Idea**
  - When a process terminates, still consumes system resources.
    - Various tables maintained by OS
  - Called a “zombie”
    - Living corpse, half alive and half dead

- **Reaping**
  - Performed by parent on terminated child.
  - Parent is given exit status information.
  - Kernel discards the terminated process.

- **What if parent doesn’t reap?**
  - If any parent terminates without reaping a child, then child will be reaped by *init* process.
  - Only need explicit reaping for long-running processes.
    - e.g. shells and servers
Zombies (2)

void fork7()
{
    if (fork() == 0) {
        /* Child */
        printf("Terminating Child, PID = %d\n", getpid());
        exit(0);
    } else {
        printf("Running Parent, PID = %d\n", getpid());
        while (1); /* Infinite loop */
    }
}

- ps shows child processes as “defunct”
- Killing parent allows child to be reaped
Running New Programs (1)

- **int execl (char *path, char *arg0, ..., NULL)**
  - loads and runs executable at **path** with arguments arg0, arg1, ...
    - **path** is the complete path of an executable
    - **arg0** becomes the name of the process
      » Typically **arg0** is either identical to **path**, or else it contains only the executable filename from path.
      – “real” arguments to the executable start with **arg1**, etc.
      – list of args is terminated by a (char *) 0 argument.
  - returns −1 if error, otherwise doesn’t return!

- **int execv (char *path, char *argv[])**
  - argv : null terminated pointer arrays
Running New Programs (2)

- Example: running /bin/ls

```c
main() {
    if (fork() == 0) {
        execl("/bin/ls", "ls", ", ", 0);
    }
    wait(NULL);
    printf("completed
");
    exit();
}
```

```c
main() {
    char *args[] = {"ls", ", ", NULL};
    if (fork() == 0) {
        execv("/bin/ls", args);
    }
    wait(NULL);
}
```
Summary

- **Process abstraction**
  - Logical control flow
  - Private address space

- **Process-related system calls**
  - `fork()`
  - `exit()`, `atexit()`
  - `wait()`, `waitpid()`
  - `execl()`, `execle()`, `execv()`, `execve()`, ...
Lab 3. Exercise 1 (1)

- Make the following program:

  - main
    - fork()
    - if child
      » exec()
      » [ls -al /sys/kernel/debug]
    - if parent
      » wait()
      » get the child’s return value
      » print the child’s pid and the value