Processes

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Announcement (1)

- “sys.skku.edu” is now available
Announcement (2)
Announcement (3)

- **You must use “tar.gz”**
  - **To extract**
    
    `tar xzf <file_name>.tar.gz`
  
  - **To create**
    
    `tar czf <file_name>.tar.gz <target_dir>`
Processes (1)

- It is not same as “program” or “processor”

- What’s the difference?
  - Program
  - Process
  - Processor

- Process
  - An instance of a program in execution
  - One of the most profound ideas in computer science
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

```
<table>
<thead>
<tr>
<th>Process A</th>
<th>Process B</th>
<th>Process C</th>
</tr>
</thead>
</table>
```

Time quantum of time slice
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
Concurrent Processes (2)

- 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 Process A and Process B.]
Private Address Space

- Process in memory

![Diagram of address space]

- Unused
- Read-only segment (.init, .text, .rodata)
- Read/write segment (.data, .bss)
- Run-time heap (managed by malloc)
- User stack (created at runtime)
- Kernel virtual memory (code, data, heap, stack)

Virtual Address

Program

Code

Data

Memory invisible to user code
Process State Transition

- **new**
- **admitted** → **ready**
- **interrupt** → **running**
- **exit** → **terminated**
- **ready**
  - “Ready to use CPU”
  - **scheduler dispatch** → **running**
  - **I/O or event completion** → **waiting**
- **waiting**
  - **I/O or event wait** → **ready**

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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
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\n");
    exit();
}

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()`, ...
Exercise

- Make “xcp” using “cat”
  - Call “cat <src>” after change fd 1 to <dest>
  - $ xcp <src> <dest>
    - fork()
    - if child
      » close() / open()
      » exec(cat, <src>)
      » return <your student id>
    - if parent
      » wait(&status)
      » printf(“pid: <pid>”);
      » printf(“status: <status>”);

You should include <fcntl.h>, <unistd.h>, <sys/wait.h>, <sys/types.h>
You can also use <stdio.h>