Operating Systems: Processes and Threads

keleher, shankar

February 6, 2024

Outline

1. Process State
2. Process Creation
3. Process Termination
4. User-Threads Management
5. Booting the OS
6. Inter-Process Communication: Pipes
7. Inter-Process Communication: Signals
8. Inter-Process Communication: Internet Sockets
9. Schedulers

User Perspective

- Process: executing instance of a program
  - Threads: active agents of a process
  - Address space
    - text segment: code
    - data segment: global and static
    - stack segment, one per thread
  - Resources: open files, sockets, *pipes*
- Code: non-privileged instructions
  - including syscalls to access OS services
- All threads execute concurrently (scheduling undefined)

Single-Threaded Process

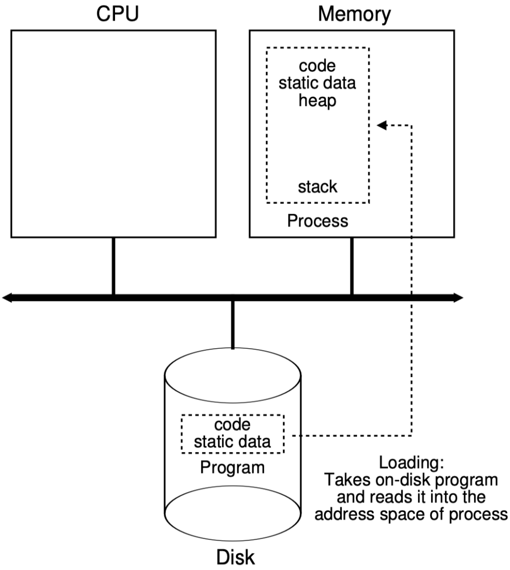


Figure 4.1: **Loading: From Program To Process**

In the OS Kernel

- Data structures: state of processes
- Process: address space, resources, threads ("kernel threads")
  - kernel thread: user-stack, kernel-stack, processor state
  - user thread: user-stack, only per-process kernel-stack, not visible to kernel
  - mapping of content to hardware location (eg, memory, disk)
    - memory vs disk (swapped out)
  - thread status: running, ready, waiting, mode
  - kernel *process*: kernel-stack, processor state, no user-level visibility
- Schedulers, queues:
  - short-term: ready $\rightarrow$ running
  - io device: waiting $\rightarrow$ io service $\rightarrow$ ready
  - medium-term: ready/waiting $\leftrightarrow$ swapped-out
  - long-term: start $\rightarrow$ ready
  - efficiency and responsiveness

Single-Threaded Process

- PCB (process control block): one per process
  - holds enough state to resume the process
  - process id (pid)
  - processor state: gpr, ip, ps, sp, ...
  - address-space: text, data, user-stack, kernel-stack
    - mapping to memory/disk
  - io state: open files/sockets, current positions, access, ...
  - accounting info: processor time, memory limits, ...
  - ...
- Status
  - running: executing on a processor
  - ready (aka runnable): waiting for a processor
  - waiting: for a non-processor resource (eg, memory, io, ...)
  - swapped-out: holds no memory

Multi-Threaded Process

- PCB (process control block): one per process
  - address-space: text, data
  - io state
  - accounting info
  - TCBs (thread control block): one per thread
    - processor state
    - user-stack, kernel-stack
    - status: running, ready, waiting, ...
  - ...
- Process swapped-out → all threads swapped out
- Kernel threads operate in two contexts:
  - user-mode: executing user code, using user-stack
  - kernel-mode: executing kernel code, using kernel-stack

Kernel process

- Process that runs only in the kernel
  - asynchronous services: io, reaper, ...
  - always in kernel-mode
  - TCB (thread control block): one per kernel thread
    - holds enough state to resume the thread
    - processor state: gpr, ip, ps, sp, ...
    - kernel-stack // no user-stack
    - status: running, ready, waiting

User threads

- Threads implemented entirely in user process
- not visible or schedulable by kernel
  - process might have multiple user threads
  - but kernel only sees one
- User code maintains
  - TCBs
  - signal handlers (for timer/io/etc interrupts)
  - dispatcher, scheduler
- OS provides low-level functions via which user process can
  - get processor state
  - dispatch processor state
  - to/from environment variables
- User-level vs kernel-level
  - Pro: application-specific scheduling
  - Con: cannot exploit additional processors

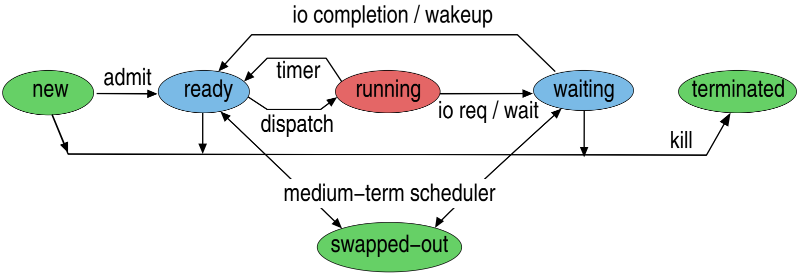
Disambiguation...

- Different types of threads:
  - *kernel threads* - can be seen and scheduled by the kernel, have both user and kernel stacks
  - *user threads* - not visible to kernel, only user stacks
- Also *kernel processes* - threads that execute only in the OS kernel
  - term not used as much as the above
  - not user visible
  - only kernel stack

Process queues

- Kernel keeps PCBs/TCBs in queues
  - new queue: processes to be started
  - run queue
  - ready (aka runnable) queue
  - io queue(s)
  - swapped-out queue
  - terminated queue: processes to be cleaned up

- Transitions between queues



Outline

1. Process State
2. Process Creation
3. Process Termination
4. User-Threads Management
5. Booting the OS
6. Inter-Process Communication: Pipes
7. Inter-Process Communication: Signals
8. Inter-Process Communication: Internet Sockets
9. Schedulers

Approach 1: Create Process from Scratch

- CreateProcess(*path*, *context*): // GeekOS **Spawn()**
  - read file from file system's *path* // executable file
  - acquire memory segments // code, data, stack(s), ...
  - unpack file into its segments
  - create PCB // pid, ...
  - update PCB with *context* // user, directory, ...
  - add PCB to ready queue
- Drawback: *context* has a lot of parameters to set
- Your version of GeekOS only has this type of process creation

Approach 2: Fork-Exec

- Fork(): creates a copy of the caller process
  // returns 0 to child, and child's pid to parent
  - create a duplicate PCB
    - except for pid, accounting, pending signals, timers, outstanding io operations, memory locks, ...
    - only one thread in new process (the one that called fork)
  - allocate memory and copy parent's segments
    - minimize overhead: copy-on-write; memory-map hardware
  - add PCB to the ready queue

- Exec(path, ...): replaces all segments of executing process
  - exec[elpv] variants: different ways to pass args, ...
  - open files are inherited
  - not inherited: pending signals, signal handlers, timers, memory locks, ...
  - environment variables are inherited except with exec[lv]e
- *Project 1*

Outline

1. Process State
2. Process Creation
3. Process Termination
4. User-Threads Management
5. Booting the OS
6. Inter-Process Communication: Pipes
7. Inter-Process Communication: Signals
8. Inter-Process Communication: Internet Sockets
9. Schedulers

Zombie

- Process *A* becomes a zombie when
  - *A* executes relevant OS code (intentionally or o/w)
    - exit syscall
    - illegal op
    - exceeds resource limits
    - ...
  - *A* gets kill signal from a (ancestor) process
- *A* is moved to terminated queue
- What happens to *A*'s child process?
  - becomes a root process's child (orphan) // Unix
  - is terminated // VMS

Reap

- Zombie process *A* is eventually *reaped*
  - its memory is freed
  - its parent is signalled (SIGCHILD)
  - it waits for parent to do `wait()` syscall
    - parent gets exit status, accounting info, ...

Outline

1. Process State
2. Process Creation
3. Process Termination
4. User-Threads Management
5. Booting the OS
6. Inter-Process Communication: Pipes
7. Inter-Process Communication: Signals
8. Inter-Process Communication: Internet Sockets
9. Schedulers

POSIX threads

- thread_create(thrd, func, arg)
  - create a new user thread executing func(arg)
  - return pointer to thread info in thrd
- thread_yield():
  - calling thread goes from running to ready
  - scheduler will resume it later
- thread_join(thrd):
  - wait for thread thrd to finish
  - return its exit code
- thread_exit(rval):
  - terminate caller thread, set caller's exit code to rval
  - if a thread is waiting to join, resume that thread
- POSIX threads is an API (not implementation) definition
  - can be implemented either as user threads, or kernel threads

Outline

1. Process State
2. Process Creation
3. Process Termination
4. User-Threads Management
5. Booting the OS
6. Inter-Process Communication: Pipes
7. Inter-Process Communication: Signals
8. Inter-Process Communication: Internet Sockets
9. Schedulers

OS initialization

- Power-up:
  - BIOS: disk boot sector $\rightarrow$ RAM reset address
  - processor starts executing contents
- Boot-sector code:
  - load kernel code from disk sectors to RAM, start executing
- Kernel initialization:
  - identify hardware: memory size, io adaptors, ...
  - partition memory: kernel, free, ...
  - initialize structures: vm/mmap/io tables, pcb queues, ...
  - start daemons: OS processes that run in the background
    - idle
    - io-servers
    - login/shell process bound to console
  - mount filesystem(s) in io device(s)

Outline

1. Process State
2. Process Creation
3. Process Termination
4. User-Threads Management
5. Booting the OS
6. Inter-Process Communication: Pipes
7. Inter-Process Communication: Signals
8. Inter-Process Communication: Internet Sockets
9. Schedulers

Kernel file data structures

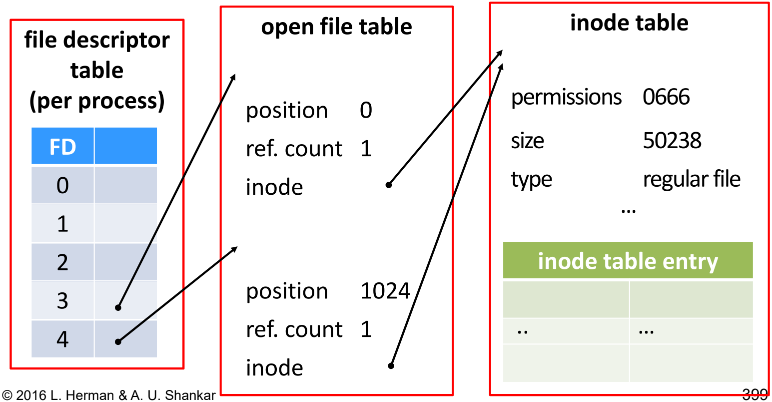
- Inode table: has a copy of the inode of every open vertex (file or directory)
  - may differ from the inode in the disk
- Open-file table: has an entry for every open call not yet succeeded by a close call (across all processes)

  Each entry holds:
  - current file position, reference count (how many file descriptors point to the entry), inode pointer, etc.
  - Entry is removed when the reference count is 0
- For each process: a file descriptor table, mapping integers to open-file table entries

The open-files-table is system wide, and only has refs>1 after fork() or dup().

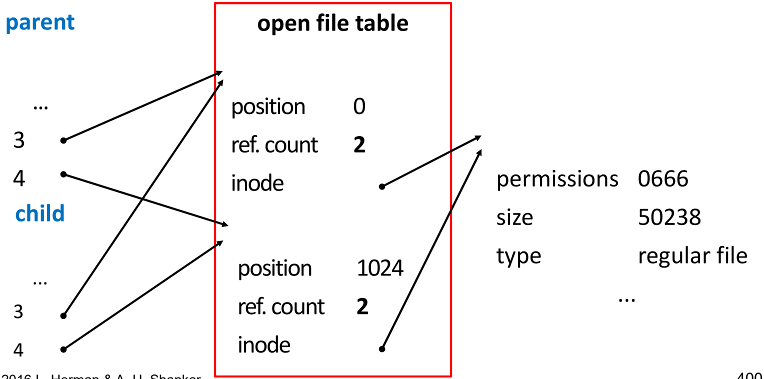
Opening the same file twice

```
fd1= open("file.txt", O_RDONLY);
fd2= open("file.txt", O_RDONLY);
read(fd2, buffer, 1024);
```



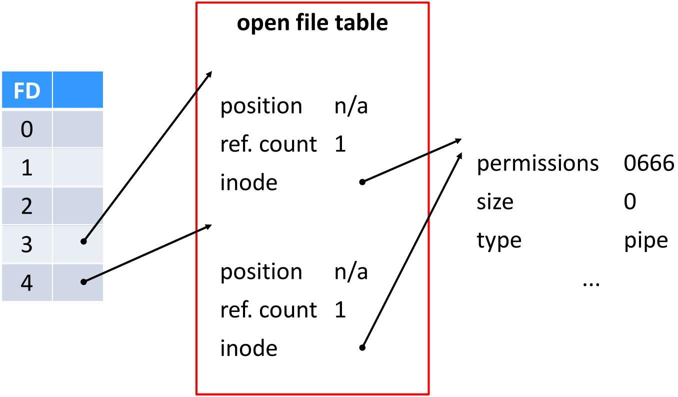
After a fork()

```
fd1= open("file.txt", O_RDONLY);
fd2= open("file.txt", O_RDONLY);
read(fd2, buffer, 1024);
fork();
```



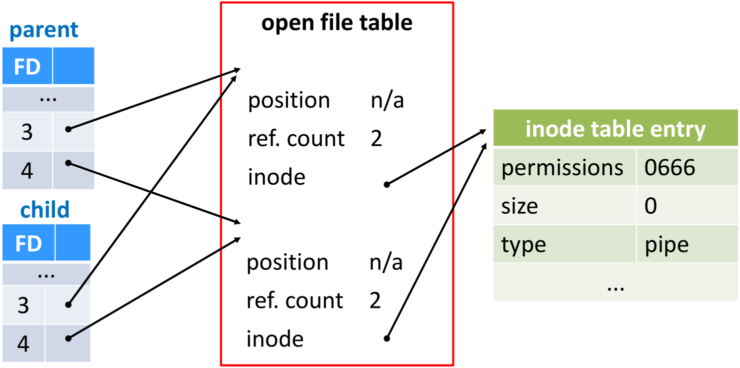
Opening a pipe

```
int pfd[2];
pipe(pfd);
```



After a `fork()`

```
int pfd[2];
pipe(pfd);
fork();
```



Example `pipe-example.c`

Example: data transfer on pipe from parent to child

- Process, say *A*, creates pipe
- *A* forks, creating child process, say *B*
- *A* closes its read-end of pipe, writes to pipe
- *B* closes its write-end of pipe, reads from pipe
- byte stream: in-chunks need not equal out-chunks
- *A* blocks if buffer is full and *B* has not closed read-end
- *B* blocks if buffer is empty and *A* has not closed write-end

- read when no data and no writers (write-end has zero ref count):
  - read returns 0
- write when no readers (read-end has zero ref count):
  - writer process receives SIGPIPE signal
  - write returns EPIPE