



CS3281 / CS5281

Inter-Process Communications

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Overview

- Interprocess communication is about ways to make processes “talk” to one another or “synchronize” with one another
 - Recall that processes have separate virtual address spaces, so they can’t just share variables
- Three big categories of IPC
 - Communication: how do processes exchange data
 - Example: send a list of files from one process to another
 - Synchronization: synchronize the actions of processes or threads
 - Think of synchronization as how to coordinate actions
 - Example: allow processes to avoid updating the same part of a file simultaneously
 - Signals: can be used for synchronization (but are primarily for other purposes)

Taxonomy

- The figure on the right shows a taxonomy of IPC mechanisms
 - We've looked at signals, mutexes, condition variables, and semaphores
 - We'll look at pipes next

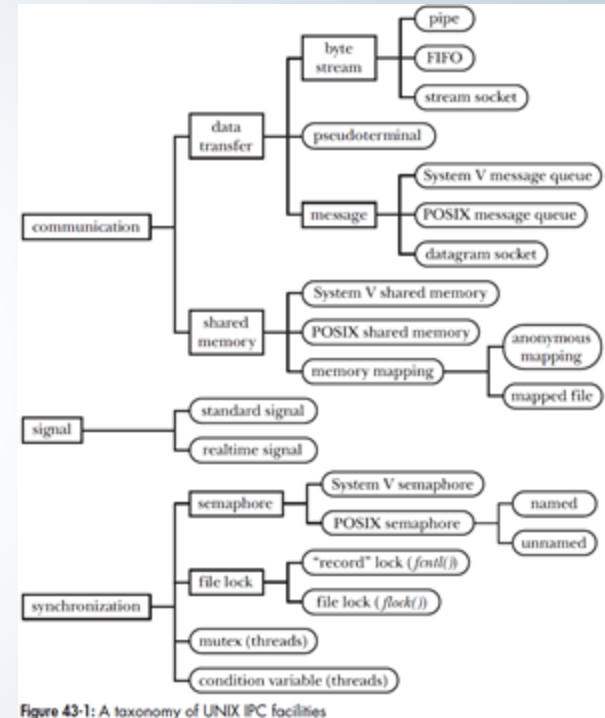


Figure 43-1: A taxonomy of UNIX IPC facilities

*Figure from *The Linux Programming Interface* by Michael Kerrisk

Fundamental Concept: File Descriptors

- File descriptor: normally small, non-negative integers that the kernel uses to identify the files accessed by a process
 - Example: when a process opens an existing file or creates a new file, the kernel returns a file descriptor that can be used to read or write the file
- All shells open three descriptors when a new program is run:
 - 0: standard input
 - 1: standard output
 - 2: standard error
- If nothing special is done: all of them are connected to the terminal
 - In other words, input comes from the terminal, and output (including errors) are written to the terminal
- How does the kernel view and use file descriptors?

Kernel Data Structures for I/O

- (a) Per-process file descriptor table contains a pointer to a file table entry
- (b) Kernel maintains file table for all open files
 - Flags are read, write, append, sync, etc
 - V-node pointer is a pointer to v-node table entry
- (c) Kernel maintains V-node table
 - Each entry contains information about the type of file and pointers to functions that operate on the file
 - Usually also contains the file's *i-node*, which is its metadata
 - Note: Linux uses two i-nodes instead of a v-node: one generic and one specific

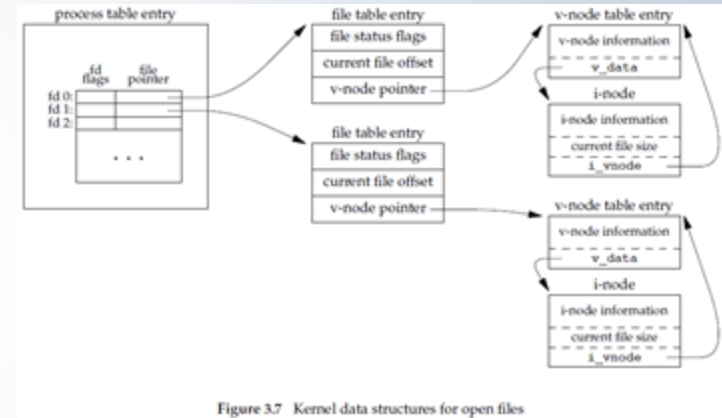
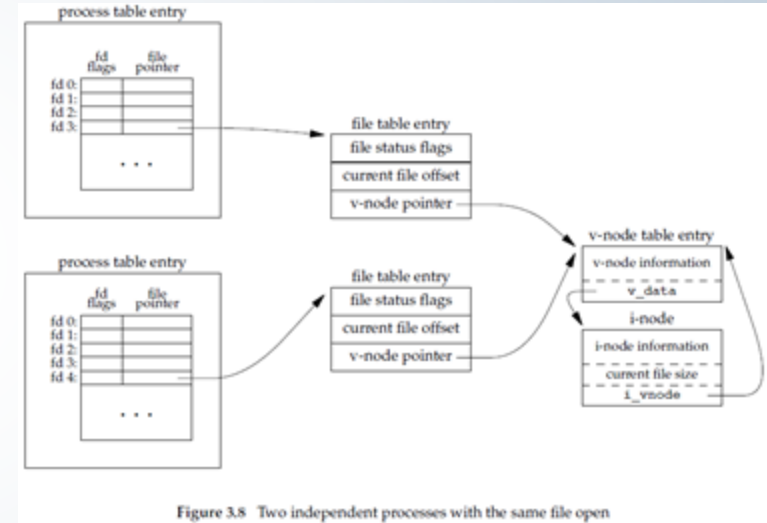


Figure 3.7 Kernel data structures for open files

*Figure from *Advanced Programming in the Unix Environment 3rd Edition*
by Richard Stevens and Stephen Rago

Kernel Data Structures for I/O

- Figure on the right shows two processes with the same open file
- Two fds from the same process can also point to the same file table entry
 - The dup() system call
- Two fds from different processes can also point to the same file table entry
 - For instance, after a fork()
- Let's use this knowledge to do something interesting



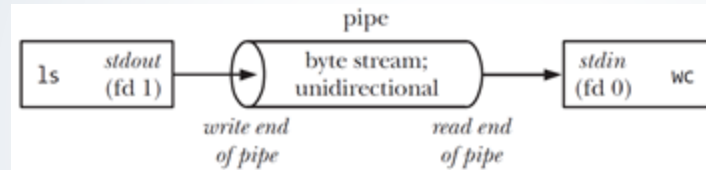
*Figure from *Advanced Programming in the Unix Environment 3rd Edition*
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Pipes: Motivation

- Big “real-world” use: connecting programs
 - How can the shell send the output of one program to the input of another program?
- Example
 - The ls program will show the contents of a directory
 - The wc program will count the number of lines in its input
 - How can we use these together to count the number of files in a directory?
- One (poor) solution:
 - Run ls and send its output to a temporary file (temp.txt)
 - Run wc using temp.txt as the input
 - Delete temp.txt

Pipes

- Better solution: use a pipe!
 - Think of it as a piece of “plumbing” that lets data flow from one process to another



- More formally: a pipe is a byte-stream IPC mechanism that provides a one-way flow of data between processes
 - All data written to the pipe is routed by the kernel to another process, which can then read it
 - Think of them as open files that have no corresponding image on your filesystem

Using Pipes

- A process can create a pipe using the pipe system call:
 - `int pipe(int fildes[2]);`
 - That is, the pipe system call takes an integer array of size 2 (returns 0 on success)
 - `fildes[0]` can be used to read from the pipe
 - `fildes[1]` can be used to write to the pipe

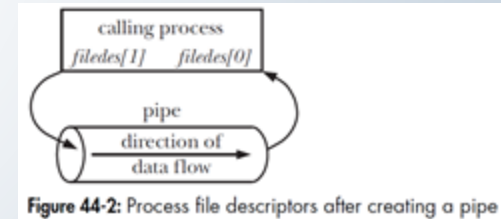


Figure 44-2: Process file descriptors after creating a pipe

*Figure from *The Linux Programming Interface* by Michael Kerrisk

The Shell and Pipes

- Back to our motivation: how can pipes help the shell connect the output of one program to the input of another program?
 - Recall how the shell works:
 - Read a command
 - Do a `fork()` to create a new process
 - Do an `exec()` in the new process to run the program
 - Repeat
- We need the “standard output” of one process to go to the “standard input” of another process
 - Solution: have the shell “fix-up” the two processes’ file descriptors!

The Shell and Pipes (cont.)

- **Step 0:** the shell has the three “standard” file descriptors open

Shell

| | |
|-------|--------|
| fd[0] | stdin |
| fd[1] | stdout |
| fd[2] | stderr |

The Shell and Pipes (cont.)

- **Step 0:** the shell has the three “standard” file descriptors open
- **Step 1:** the shell process calls `pipe()` to create the pipe

Shell

| | |
|-------|-------------------|
| fd[0] | stdin |
| fd[1] | stdout |
| fd[2] | stderr |
| fd[3] | Read end of pipe |
| fd[4] | Write end of pipe |

The Shell and Pipes (cont.)

- **Step 0:** the shell has the three “standard” file descriptors open
- **Step 1:** the shell process calls `pipe()` to create the pipe
- **Step 2:** the shell process calls `fork()` twice to create the two child processes

Shell

| | |
|-------|-------------------|
| fd[0] | stdin |
| fd[1] | stdout |
| fd[2] | stderr |
| fd[3] | Read end of pipe |
| fd[4] | Write end of pipe |

Child 1

| | |
|-------|-------------------|
| fd[0] | stdin |
| fd[1] | stdout |
| fd[2] | stderr |
| fd[3] | Read end of pipe |
| fd[4] | Write end of pipe |

Child 2

| | |
|-------|-------------------|
| fd[0] | stdin |
| fd[1] | stdout |
| fd[2] | stderr |
| fd[3] | Read end of pipe |
| fd[4] | Write end of pipe |

The Shell and Pipes (cont.)

- **Step 0:** the shell has the three “standard” file descriptors open
- **Step 1:** the shell process calls `pipe()` to create the pipe
- **Step 2:** the shell process calls `fork()` twice to create the two child processes
- **Step 3:** in the first child process, the write end of the pipe is dup’ed onto the file descriptor for standard output

- The `dup` system call:

- `int dup2(int oldfd, int newfd);`
- Duplicates the descriptor in `oldfd` to the descriptor in `newfd`

in xv6 is it just `dup(oldfd)`

Shell

| | |
|-------|-------------------|
| fd[0] | stdin |
| fd[1] | stdout |
| fd[2] | stderr |
| fd[3] | Read end of pipe |
| fd[4] | Write end of pipe |

Child 1

| | |
|-------|-------------------|
| fd[0] | stdin |
| fd[1] | Write end of pipe |
| fd[2] | stderr |
| fd[3] | Read end of pipe |
| fd[4] | Write end of pipe |

Child 2

| | |
|-------|-------------------|
| fd[0] | stdin |
| fd[1] | stdout |
| fd[2] | stderr |
| fd[3] | Read end of pipe |
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The Shell and Pipes (cont.)

- **Step 0:** the shell has the three “standard” file descriptors open
- **Step 1:** the shell process calls `pipe()` to create the pipe
- **Step 2:** the shell process calls `fork()` twice to create the two child processes
- **Step 3:** in the first child process, the write end of the pipe is dup’ed onto the file descriptor for standard output
 - Child process closes both pipe fds and calls `exec`

Shell

| | |
|-------|-------------------|
| fd[0] | stdin |
| fd[1] | stdout |
| fd[2] | stderr |
| fd[3] | Read end of pipe |
| fd[4] | Write end of pipe |

Child 1

| | |
|-------|-------------------|
| fd[0] | stdin |
| fd[1] | Write end of pipe |
| fd[2] | stderr |
| fd[3] | |
| fd[4] | |

Child 2

| | |
|-------|-------------------|
| fd[0] | stdin |
| fd[1] | stdout |
| fd[2] | stderr |
| fd[3] | Read end of pipe |
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The Shell and Pipes (cont.)

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- **Step 1:** the shell process calls `pipe()` to create the pipe
- **Step 2:** the shell process calls `fork()` twice to create the two child processes
- **Step 3:** in the first child process, the write end of the pipe is dup’ed onto the file descriptor for standard output
- Child process closes both pipe fds and calls `exec`
- **Step 4:** in the second child process, the read end of the pipe is dup’ed onto the file descriptor for standard input

Shell

| | |
|-------|-------------------|
| fd[0] | stdin |
| fd[1] | stdout |
| fd[2] | stderr |
| fd[3] | Read end of pipe |
| fd[4] | Write end of pipe |

Child 1

| | |
|-------|-------------------|
| fd[0] | stdin |
| fd[1] | Write end of pipe |
| fd[2] | stderr |
| fd[3] | |
| fd[4] | |

Child 2

| | |
|-------|-------------------|
| fd[0] | Read end of pipe |
| fd[1] | stdout |
| fd[2] | stderr |
| fd[3] | Read end of pipe |
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The Shell and Pipes (cont.)

- **Step 0:** the shell has the three “standard” file descriptors open
- **Step 1:** the shell process calls `pipe()` to create the pipe
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- **Step 3:** in the first child process, the write end of the pipe is dup’ed onto the file descriptor for standard output
- Child process closes both pipe fds and calls `exec`
- **Step 4:** in the second child process, the read end of the pipe is dup’ed onto the file descriptor for standard input
- Child process closes both pipe fds and calls `exec`

Shell

| | |
|-------|-------------------|
| fd[0] | stdin |
| fd[1] | stdout |
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| fd[3] | Read end of pipe |
| fd[4] | Write end of pipe |

Child 1

| | |
|-------|-------------------|
| fd[0] | stdin |
| fd[1] | Write end of pipe |
| fd[2] | stderr |
| fd[3] | |
| fd[4] | |

Child 2

| | |
|-------|------------------|
| fd[0] | Read end of pipe |
| fd[1] | stdout |
| fd[2] | stderr |
| fd[3] | |
| fd[4] | |

The Shell and Pipes (cont.)

- **Step 0:** the shell has the three “standard” file descriptors open
- **Step 1:** the shell process calls `pipe()` to create the pipe
- **Step 2:** the shell process calls `fork()` twice to create the two child processes
- **Step 3:** in the first child process, the write end of the pipe is dup’ed onto the file descriptor for standard output
- **Step 4:** in the second child process, the read end of the pipe is dup’ed onto the file descriptor for standard input
- **Step 5:** shell process closes both pipe fds

Shell

| | |
|-------|--------|
| fd[0] | stdin |
| fd[1] | stdout |
| fd[2] | stderr |
| fd[3] | |
| fd[4] | |

Child 1

| | |
|-------|-------------------|
| fd[0] | stdin |
| fd[1] | Write end of pipe |
| fd[2] | stderr |
| fd[3] | |
| fd[4] | |

Child 2

| | |
|-------|------------------|
| fd[0] | Read end of pipe |
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