Pipes and FIFOs

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Announcement

- **Assignment0 is graded**
  - Uploaded on i-campus
  - If any questions, please contact hsewan2495@gmail.com or ask me directly.

Contents

- **IPC (Inter-Process Communication)**

  Mechanisms that OS provides to allow processes to manage shared data

  - Shared Address Space
    - Shared Memory
    - Memory mapped files
  - Message transported by OS
    - Representation of open files in kernel
    - I/O redirection
    - Anonymous Pipe
    - Named Pipe (FIFO)

Everything is a file

- **Actually, "Everything is a file descriptor"**

- **Pros**
  - Can reuse tools, APIs on a wide range of resources
- **Cons**
  - Not a fast or portable approach

- **Communication using file interface?**

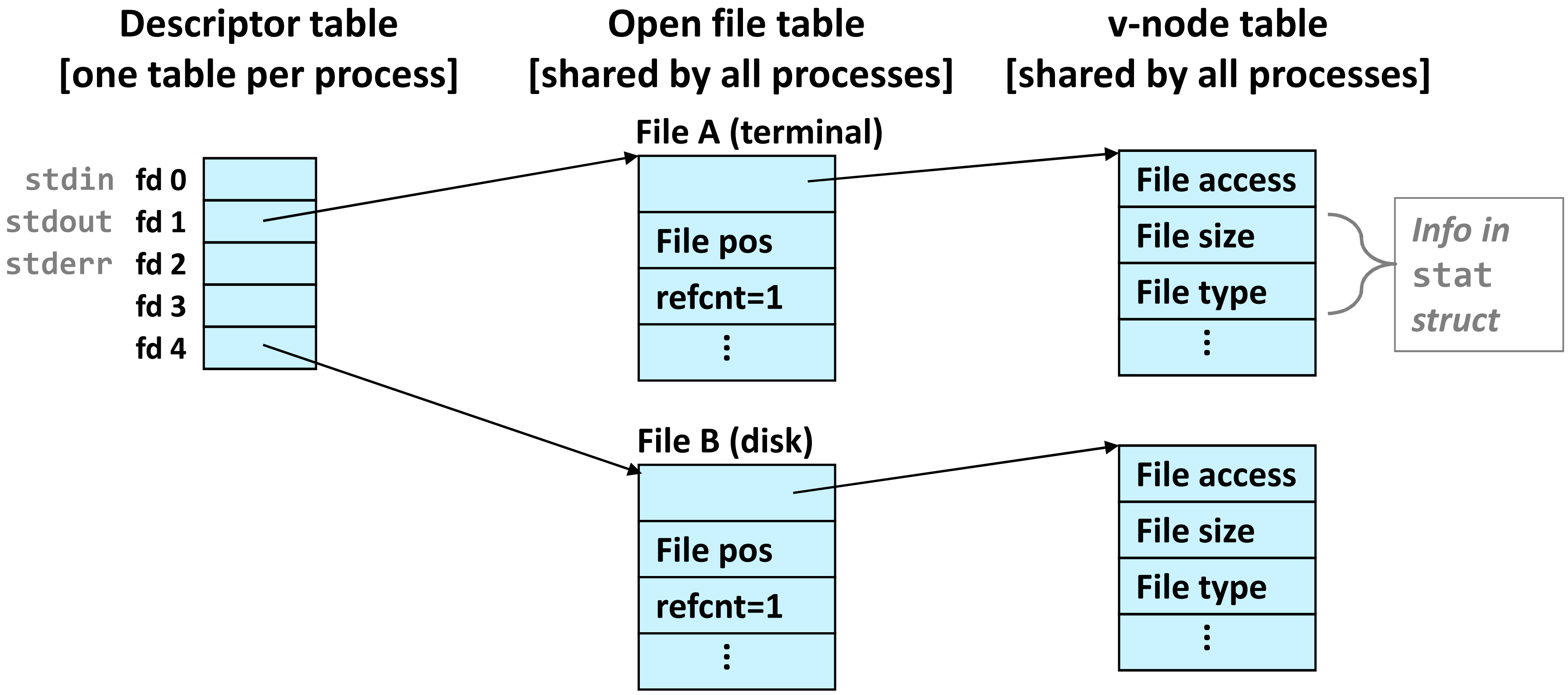
Open Files in Kernel

- **How the Unix kernel represents open files?**

- **3-levels**
  - Descriptor table
    - 1 table per process
    - Pointer to entry in the "file table"
  - File table
    - Shared by all processes
    - Current file position, mode, reference count, pointer to entry in the "v-node table"
  - v-node table
    - Shared by all processes
    - Information about file itself (size, permission, …)

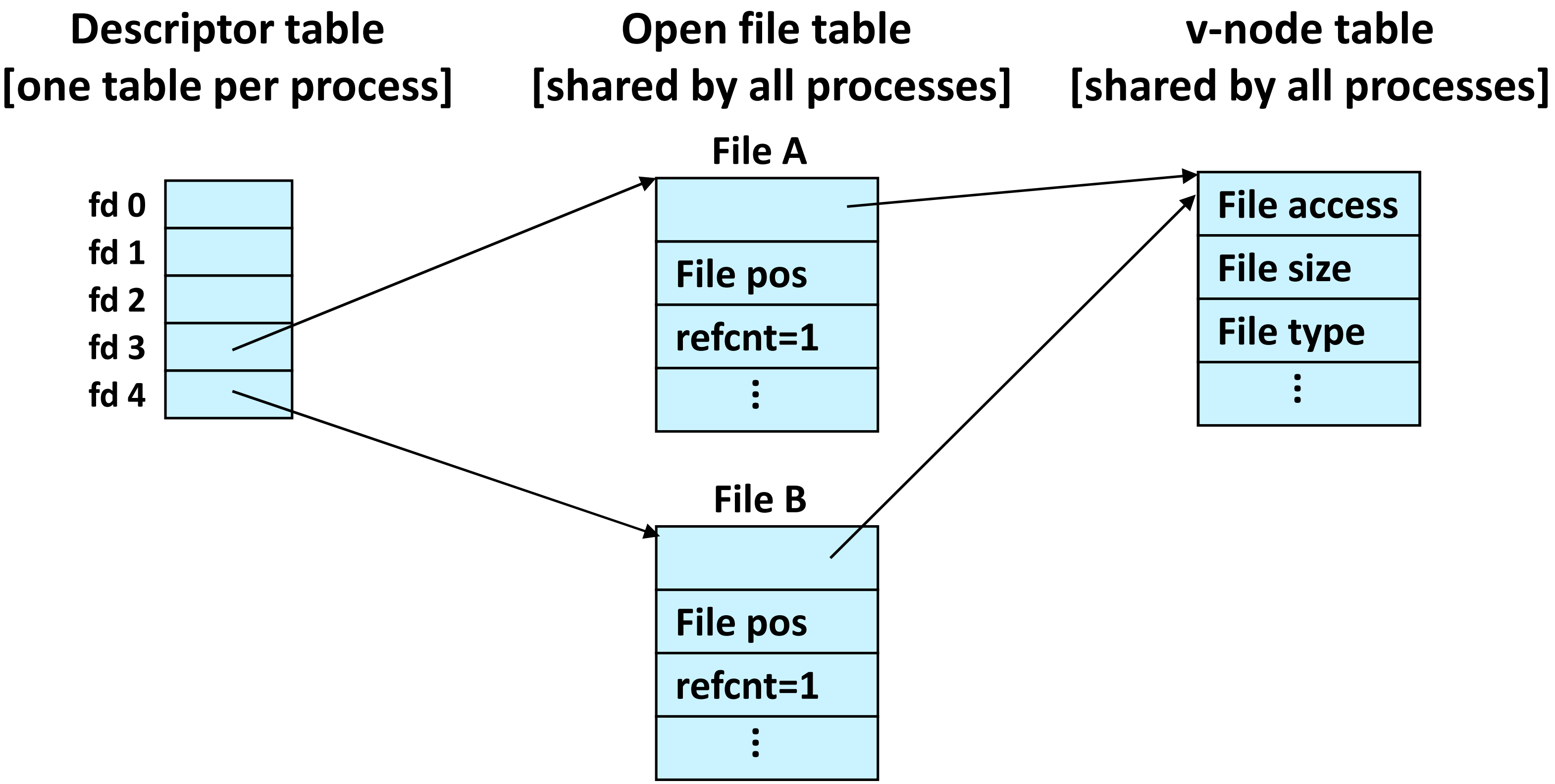
Open Files in Kernel (2)

- How the Unix kernel represents open files?



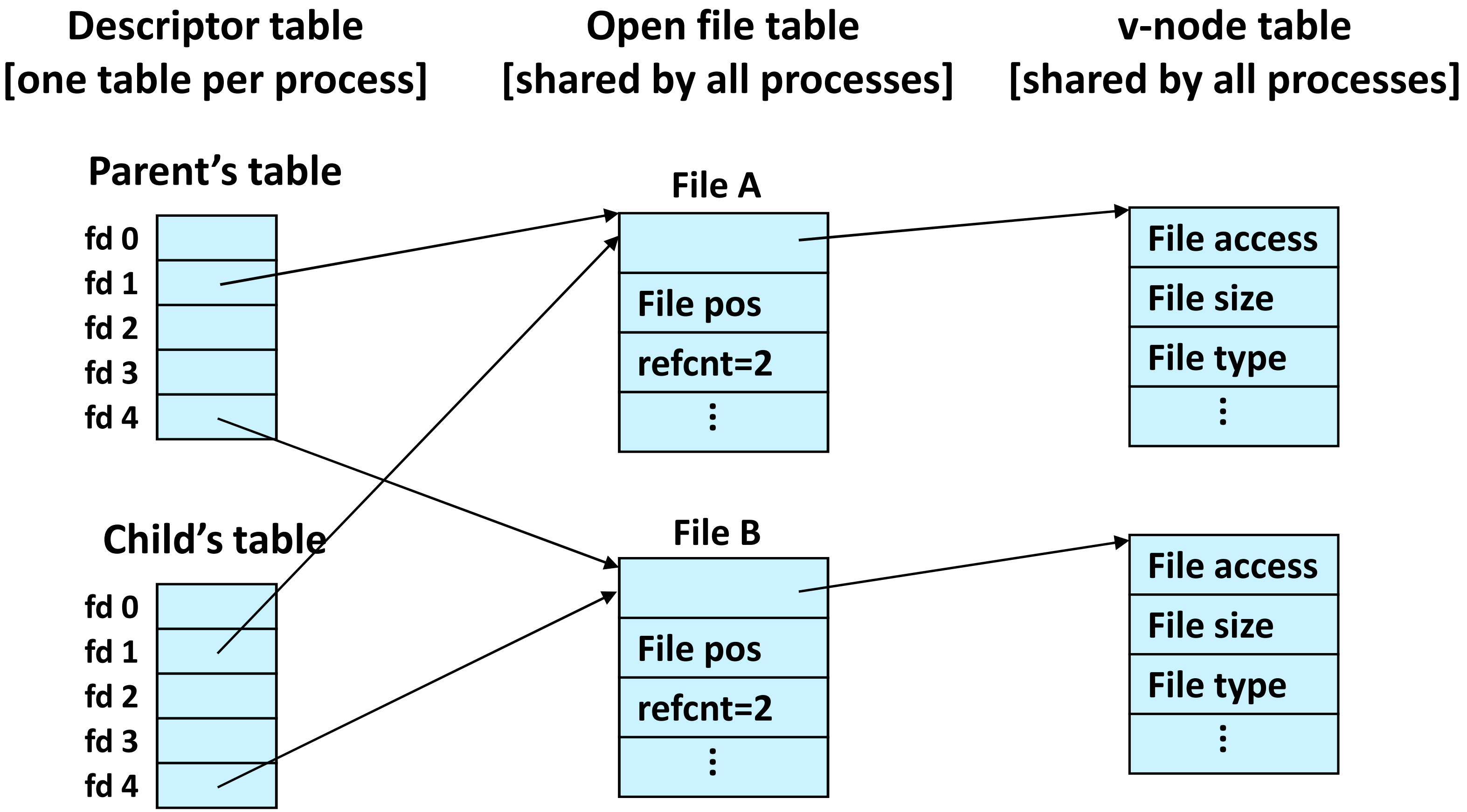
Open Files in Kernel (3)

- Calling open() twice with the same filename



Open Files in Kernel (4)

- Calling fork()



Open Files in Kernel (5)

- **What will be the result?**

```
int main(void)
{
    char buf[512];
    int fd = open("./tmp.txt", O_RDONLY);

    if (fork() == 0) {
        assert(read(fd, buf, 5) >= 0);
        exit(0);
    } else {
        wait(NULL);
        assert(read(fd, buf, 5) >= 0);
        assert(write(1, buf, 5) >= 0);
        assert(write(1, "₩n", 1) >= 0);
    }

    return 0;
}
```

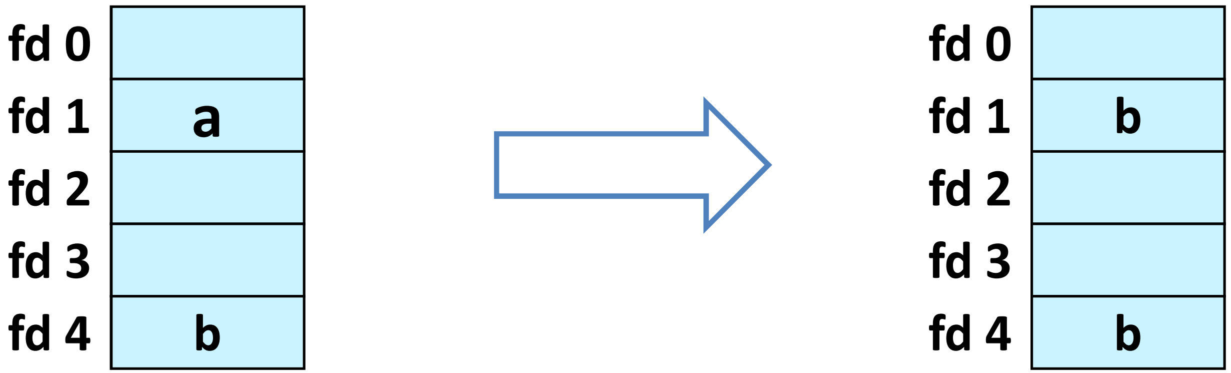
```
#include <unistd.h>
#include <fcntl.h>
#include <stdlib.h>
#include <sys/wait.h>
#include <assert.h>
```

I/O Redirection

- Q: How does a shell implement I/O redirection?

```
$ ls > foo.txt
```

- A: By calling the dup2(oldfd, newfd) function.
  - Copies (per-process) descriptor table entry **oldfd** to entry **newfd**



Descriptor table before dup2(4,1)

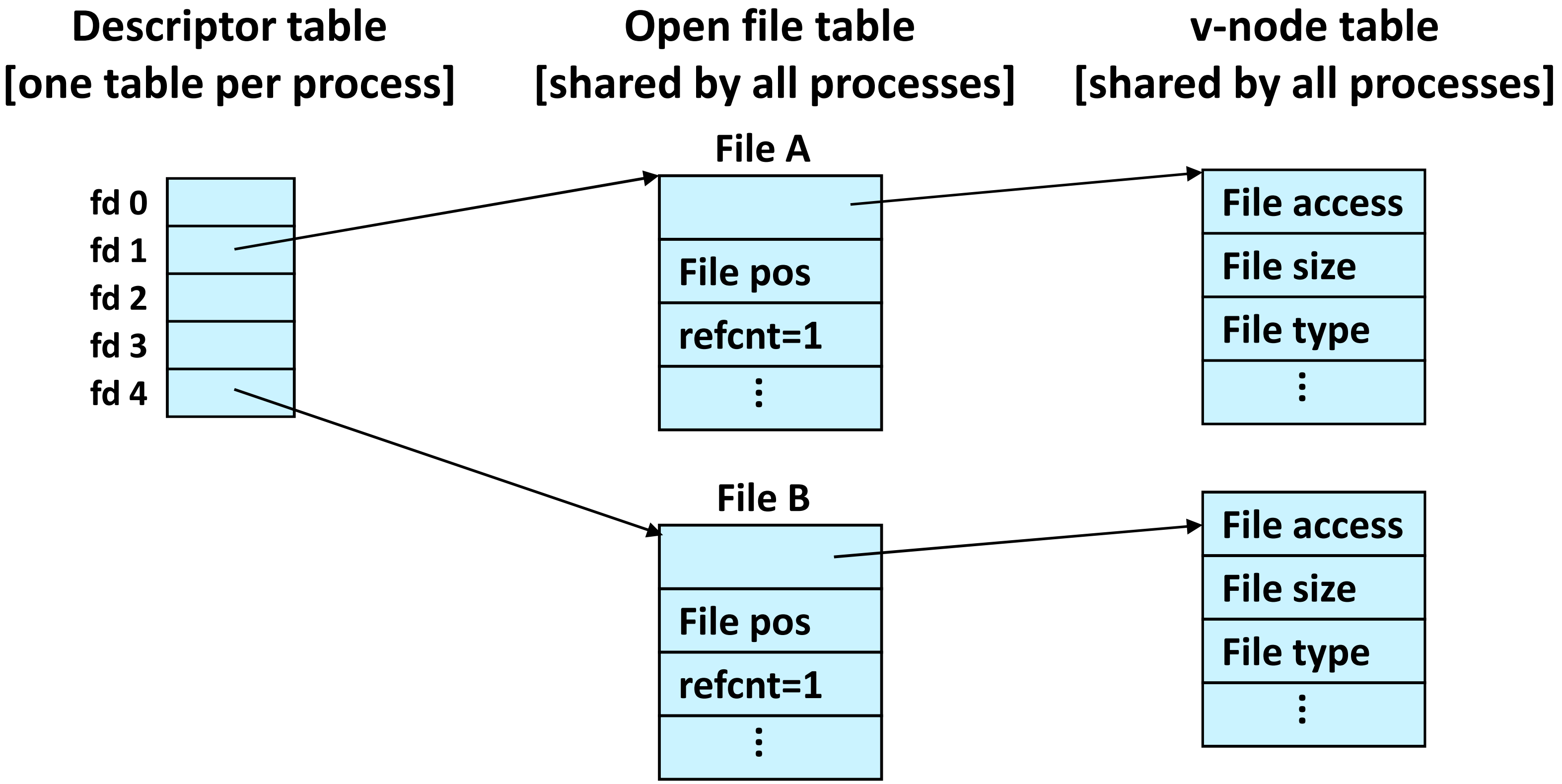
fd 0	
fd 1	a
fd 2	
fd 3	
fd 4	b

Descriptor table after dup2(4,1)

fd 0	
fd 1	b
fd 2	
fd 3	
fd 4	b

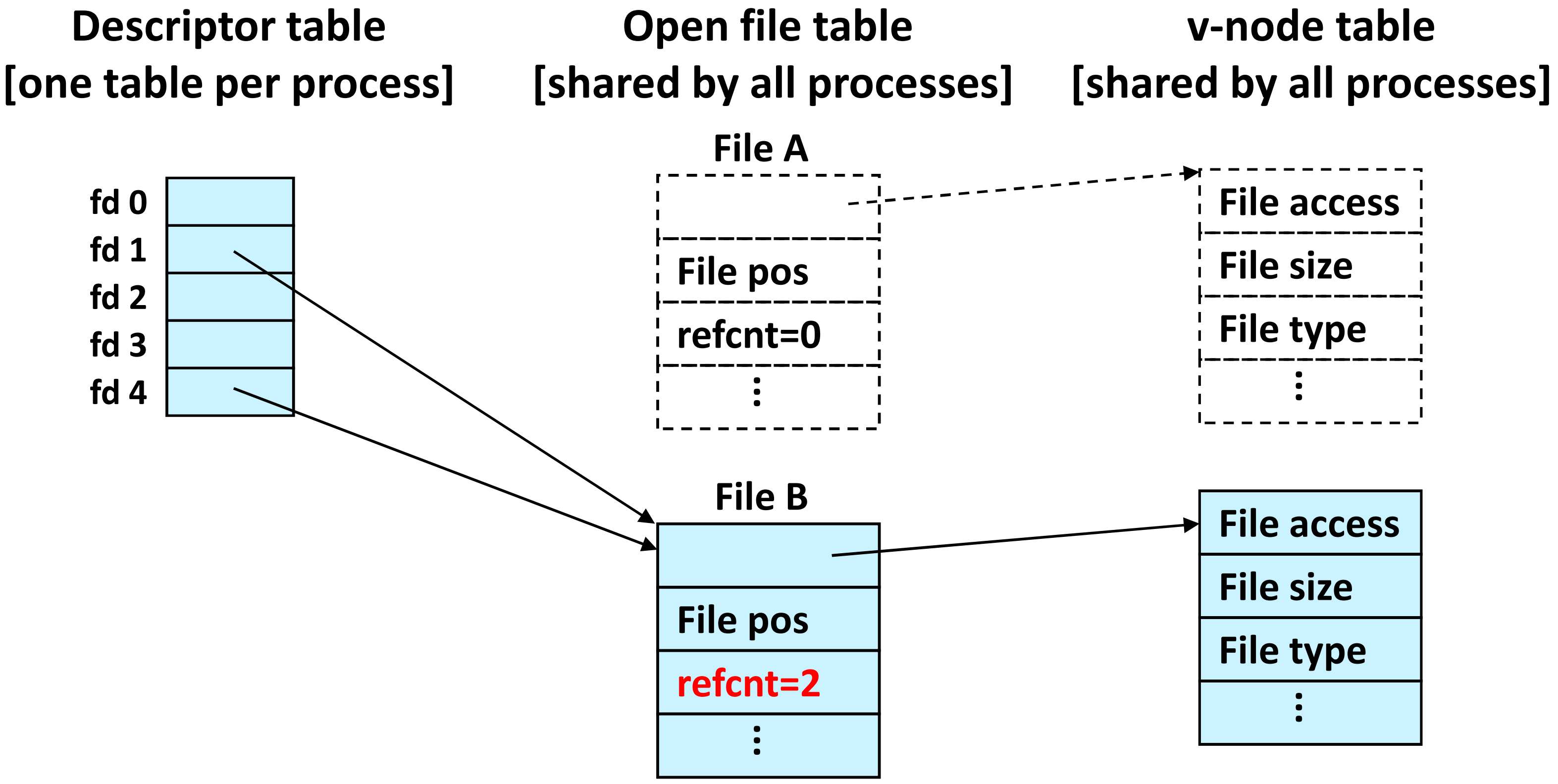
I/O Redirection Example (1)

- Before calling dup2(4,1), stdout (descriptor 1) points to a terminal and descriptor 4 points to an open disk file.



I/O Redirection Example (2)

- After calling dup2(4,1), stdout is not redirected to the disk file pointed at by descriptor 4.



Pipes

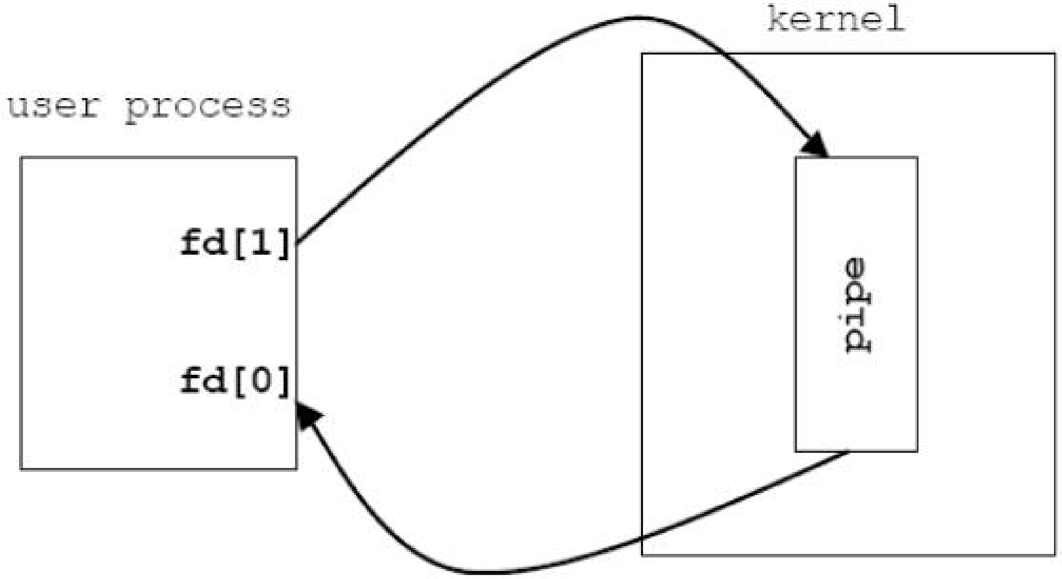
- **Pipes**
  - The oldest form of UNIX IPC (Inter-process Communication) and provide by all Unix systems.
  - IPC using ‘file interface’

- **Limitations**
  - Half-duplex: data flows only in one direction.
  - Data only can be read once. : **processes cannot seek() on pipe**

- **Two pipes**
  - Anonymous pipe
    - No name
  - Named pipe(FIFOs)
    - We can see it with a file-system

Anonymous Pipe (1)

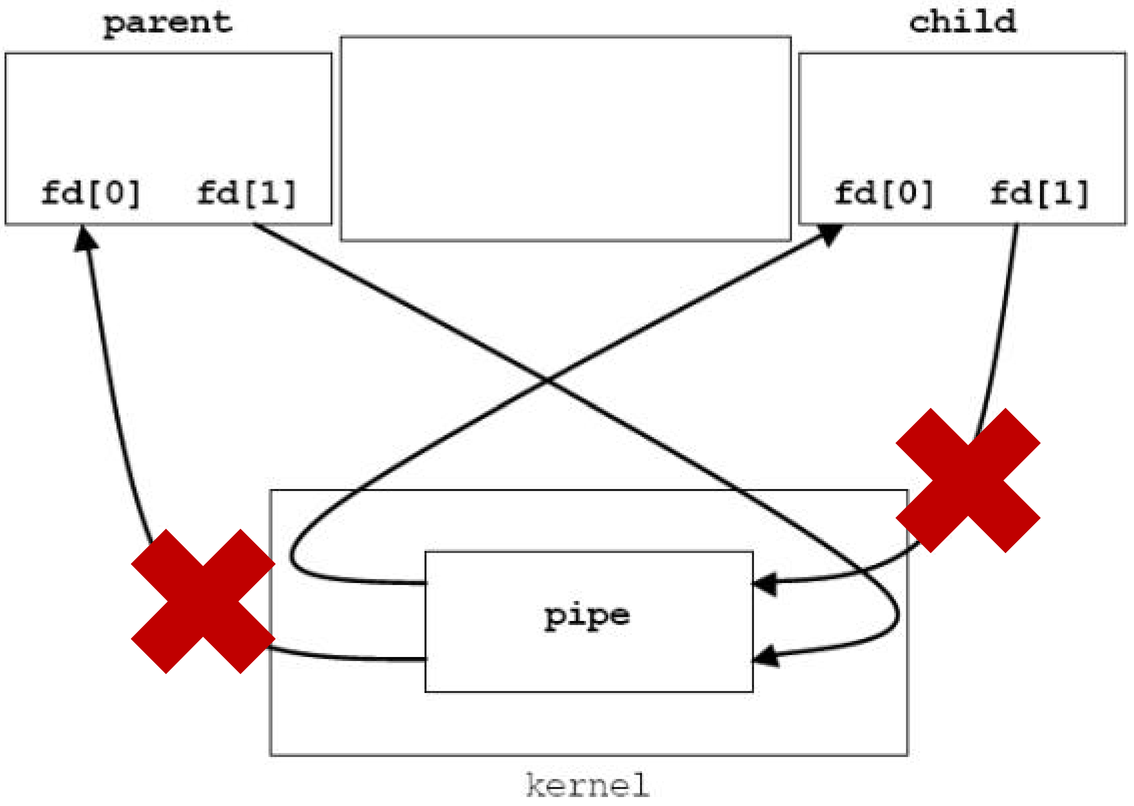
- int pipe (int fd[2]);
  - #include <unistd.h>
  - Two file descriptors are returned through the **fd** argument
    - **fd[0]**: open for reading / **fd[1]**: open for writing
  - The output of **fd[1]** is the input for **fd[0]**.
  - Return:
    - 0 (if successful)
    - -1 (otherwise)



Anonymous Pipe (2)

parent => child:
parent closes fd[0];
child closes fd[1];

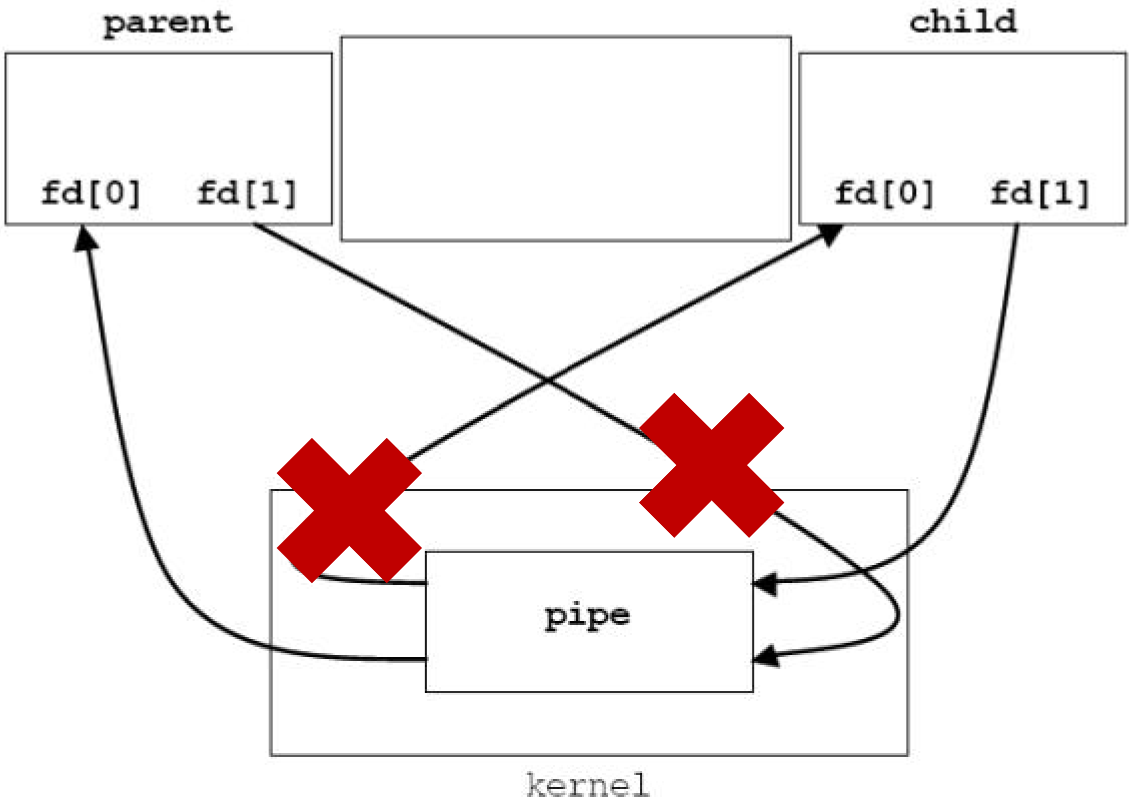
parent <= child:
parent closes fd[1];
child closes fd[0];



Anonymous Pipe (3)

parent => child:
parent closes fd[0];
child closes fd[1];

parent <= child:
parent closes fd[1];
child closes fd[0];



Reading/Writing Pipe

- **When one end of a pipe is closed,**
  - reading from a pipe returns an end of file.
  - writing to a pipe causes **SIGPIPE** is generated and the write returns an error (**EPIPE**).

  - **fstat** function returns a file type of FIFO for the pipe file descriptors (can be tested by **S_ISFIFO** macro)
- **You should close unused file descriptors!**

Using Anonymous Pipe

```
#include <unistd.h>
#define MAXLINE       80

int main(void)
{
        int n, fd[2];
        pid_t pid;
        char line[MAXLINE];

        if(pipe(fd) < 0) exit(1);
        if((pid = fork()) < 0) exit(2);

        if (pid > 0) {        /* parent */
            close(fd[0]);
            write(fd[1], "hello world\n", 12);
        } else {                    /* child */
            close(fd[1]);
            n = read(fd[0], line, MAXLINE);
            write(1, line, n);
        }
        exit(0);
}
```

Duplicating File Descriptor

- **int dup(int fd);**
  - #include <unistd.h>
  - Create a copy of a file descriptor(fd), and put new copy in **first unused file descriptor**
  - Returns :
    - New file descriptor (if succeed) / -1 (otherwise)
- **int dup2(int oldfd, int newfd);**
  - #include <unistd.h>
  - **Copy** old file descriptor(oldfd) to new file descriptor(newfd)
    - After closing newfd, if it was open
  - Returns:
    - newfd (if succeed) / -1 (otherwise)

Named Pipe (FIFO)

- An Anonymous Pipe disappears when no process has it open
- FIFOs = named pipes
  - Special pipes that persist even after all the process have closed them
- int mknod (const char *path, mode_t mode,
  dev_t dev)
  - mknod (“path”, S_IFIFO, 0);
- /usr/bin/mkfifo program can also be used to make FIFOs on the command line.

Making FIFOs

- **mknod PIPE_NAME p**
  - mknod : creating device special files
  - Example
    - mknod pipe p (check pipe using ls -l)
    - cat < pipe &
    - ls –l > pipe
- **mkfifo PIPE_NAME**
- **int mkfifo(const char *pathname, mode_t mode);**
  - #include <sys/type.h> + #include <sys/stat.h>
  - Example
    - mkfifo(“PIPE”, 0666);

Using FIFOs

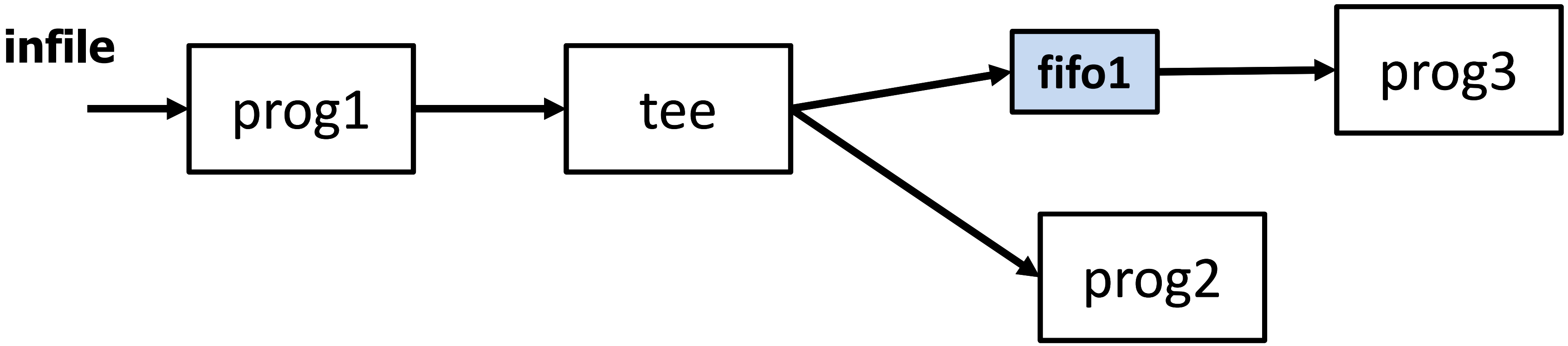
- **Opening a FIFO**
  - An open for read(write)-only blocks until some other process opens the FIFO for writing(reading).
- **Reading/Writing a FIFO**
  - Writing to a FIFO that no process has open for reading causes **SIGPIPE** to generate.
  - When the last writer for a FIFO closes the FIFO, an end of file is generated for the reader of the FIFO.
  - **PIPE_BUF**: the maximum amount of data that can be written atomically to a FIFO (without being interleaved among multiple writers).

Use of FIFOs (1)

Duplicating a Stream

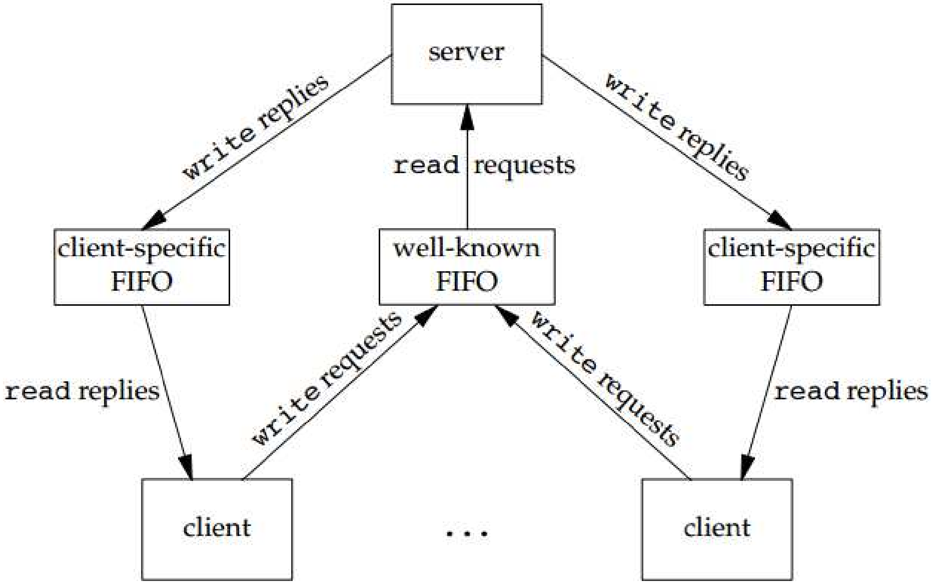
- Shell commands to pass data from one shell pipeline to another without creating intermediate temporary files

```
$ mkfifo fifo1
$ prog3 < fifo1 &
$ prog1 < infile | tee fifo1 | prog2
```



Use of FIFOs (2)

- **Client-server Communication**
  - A client-server application to pass data between the client and server on the same machine.
    - Clients write to a "well-known" FIFO to send a request to the server.



Summary

- IPC (Inter-Process Communication)
  - Signal
  - Pipe
  - Named pipe (FIFO)

  - Shared memory
  - Semaphore
  - Sockets
  - …

Exercise(1)

- Make C programs run the following tasks:

```
$ echo "124 * (42 + 3) % 17" | bc
```

- main -> pipe -> fork
  - dup2 -> exec family ➔ echo
  - dup2 -> exec family ➔ bc

Exercise(1)

```c
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>

int main(void)
{
        int pd[2];

        pipe(pd);

        if(fork()==0)
        {
        //child process code : echo
        //hint execlp(const char *file, const char *arg, …)
        }
        else
        {
        //parent process code : bc
        }
        exit(0);
}
```

Exercise(2)

- Using exercise(1), make C programs run the following tasks:

```
$ ./exercise2 command (+option) “|” command (+option)
```

Example)

```
$./exercise2 echo "124 * (42 + 3) % 17" “|” bc
```

- main -> pipe -> fork
  - dup2 -> execvp ➔ command
  - dup2 -> execvp ➔ command
  - hint) execvp(const char *file, char *const argv[]);
  - e.g. execvp(“echo”, {“echo”, “124 * (42 + 3) % 17”, NULL});
  - *const argv[] must terminate with NULL