CSCI 4061: Input/Output with Files, Pipes

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Logistics

Reading

- Stevens/Rago
  Ch 3, 4, 5, 6
- OR Robbins and Robbins
  Ch 4, 5

Goals

- Assignment 1 Questions
- Standard IO library
- `open()/close()`
- `read()/write()`

Assignment 1

- Questions?

Lab03:

- `wait() + NOHANG`
- `pipe()`
- All things you'll need in first project
- How did it go?

Exercise: C Standard I/O Functions

Recall basic I/O functions from the C Standard Library header `stdio.h`

- Printing things to the screen?
- Opening a file?
- Closing a file?
- Printing to a file?
- Scanning from terminal or file?
- Get whole lines of text?
- Names for standard input, output, error

Give samples of function calls

Answers: C Standard I/O Functions

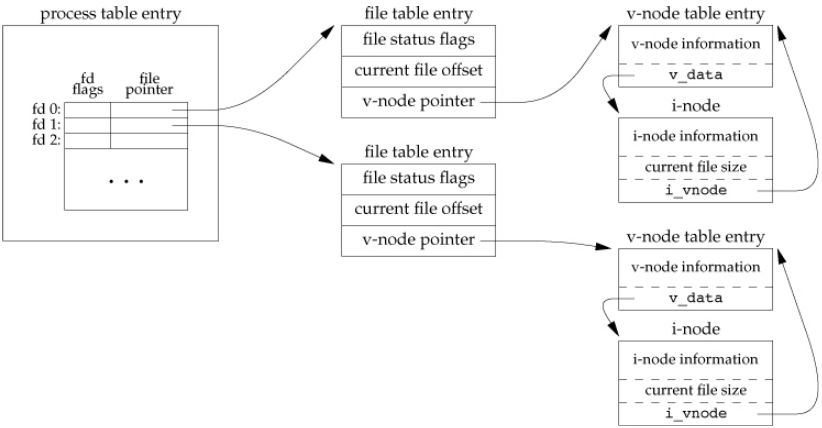
Recall basic I/O functions from the C Standard Library header `stdio.h`

`printf("%d is a number",5);`	Printing things to the screen?
`FILE *file = fopen("myfile.txt","r");`	Opening a file?
`fclose(file);`	Close a file?
`fprintf(file,"%d is a number",5);`	Printing to a file?
`fscanf(file2,"%d %f",&myint,&mydouble);`	Scanning from terminal or file?
`result = fgets(charbuf, 1024, file);`	Get whole lines of text?
`FILE *stdin, *stdout, *stderr;`	Names for standard input, etc

> *The standard I/O library was written by Dennis Ritchie around 1975.*
> *–Stevens and Rago*

- Assuming you are familiar with these and could look up others like `fgetc()` (single char) and `fread()` (read binary)
- Standard C: available wherever there is compiler
- On Unix systems, `fscanf()`, `FILE*`, the like are backed by underlying system calls and concepts

File Descriptors



- OS maintains data on all processes in Process Table
- Data includes file descriptors, refer to other OS tables
- Program deals with `int fd;` : index into table

File Descriptors are Multi-Purpose

- Unix tries to provide most things via files/file descriptor
- Many interactions created via `read()/write()` from/to file descriptors
- Get file descriptors from standard files like `myfile.txt` or `commando.c` to read/change them
- Also get file descriptors for many other things
  - Pipes for interprocess communication
  - Sockets for network communication
  - Special files to manipulate terminal, audio, graphics, terminal
- Even processes themselves have special files in the file system: ProcFS in `/proc/PID#`, provide info on running process

Open and Close: File Descriptors for Files

```
#include <sys/stat.h>
#include <fcntl.h>

int fd1 = open("firstfile", O_RDONLY); // read only
if(fd1 == -1){                         // check for errors on open
  perror("Failed to open 'firstfile'");
}

int fd2 = open("secndfile", O_WRONLY); // write only, better be present
int fd3 = open("thirdfile", O_WRONLY | O_CREAT); // write only, create if needed
int fd4 = open("forthfile", O_WRONLY | O_CREAT | O_APPEND); // append if existing

// 5 options for first arg: open for what ...
// Around 13 options for 2nd argument to open...

...;                            // Do stuff with open files

int result = close(fd1); // close the file associated with fd1
if(result == -1){        // check for an error
  perror("Couldn't close 'firstfile'");
}
```

- Note use of vertical pipe (|) to bitwise-OR several options
- Common for system calls

read() from File Descriptors

```
#define SIZE 128

int in_fd = open(in_name, O_RDONLY);
char buffer[SIZE];
int bytes_read = read(in_fd, buffer, SIZE);
```

- Read up to `SIZE` from an open file descriptor
- Bytes stored in `buffer`, overwrite it
- Return value is number of bytes read, -1 for error
- `SIZE` commonly defined but can be variable, constant, etc
- Examine `read_some.c` : explain what's happening

Warnings

- Bad things happen if `buffer` is actually smaller than `SIZE`
- NOT null terminated: must add a `\0` if this is desired

Exercise: write() to File Descriptors

```
#define SIZE 128

int out_fd = open(out_name, O_WRONLY);
char buffer[SIZE];
int bytes_written = write(out_fd, buffer, SIZE);
```

- Write up to SIZE bytes to open file descriptor
- Bytes taken from buffer, leave it intact
- Return value is number of bytes written, -1 for error

Questions

- Examine write_then_read.c for additional details
- Make sure existing.txt is present, empty
- Compile and run
- Use cat existing.txt: **explain contents**

read()/write() work with bytes

- In C, general correspondence between byte and the char type
- Not so for other types: int is often 4 bytes
- Requires care with non-char types
- All calls read/write actual bytes

```
#define COUNT 16
int out_ints[COUNT];                // array of 16 integers
int bufsize = sizeof(int)*COUNT;    // size in bytes of array
...;
write(out_fd, out_ints, bufsize);   // write whole buffer

int in_ints[COUNT];
...;
read(in_fd, in_ints, bufsize);      // read to capacity of in_ints
```

Questions

- Examine write_read_ints.c, compile/run
- Examine contents of integers.dat
- Explain what you see

Exercise: Explain Use of `read()`

```c
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <errno.h>
#include <sys/stat.h>
#include <fcntl.h>
#include <string.h>

#define BUFSIZE 4

int main(int argc, char *argv[]){
  char *infile = argv[1];
  int in_fd = open(infile,O_RDONLY);
  char buf[BUFSIZE];
  int nread, total=0;
  while(1){
    nread = read(in_fd,buf,BUFSIZE-1);
    if(nread == 0){
      break;
    }
    buf[nread] = '\0';
    total += nread;
    printf("read: '%s'\n",buf);
  }
  printf("%d bytes total\n",total);
  close(in_fd);
  return 0;
}
```

Predict output on the file `data.txt`

```
> cat data.txt
1234567890
> gcc count_bytes.c
> a.out data.txt
???
```

Standard File Descriptors

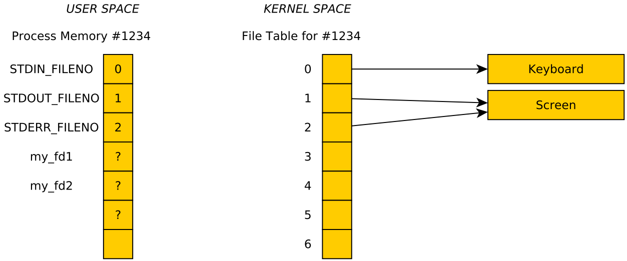
- When a process is born, comes with 3 open file descriptors
- Related to FILE* streams in Standard C I/O library
- Traditionally have FD values given but use the Symbolic name to be safe

Symbol	#	FILE*	FD for...
STDIN_FILENO	0	stdin	standard input (keyboard)
STDOUT_FILENO	1	stdout	standard output (screen)
STDERR_FILENO	2	stderr	standard error (screen)

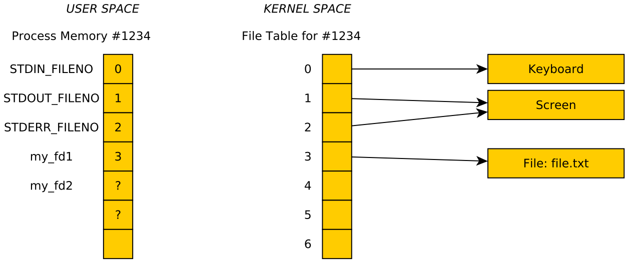
```
// Low level printing to the screen
char message[] = "Wubba lubba dub dub!\n";
int length = strlen(message);
write(STDOUT_FILENO, message, length);
```

See `low_level_interactions.c` to gain an appreciation for what `printf()` and its kin can do for you.

File Descriptors refer to Kernel Structures



```
my_fd1 = open("file.txt",O_RDONLY);
```



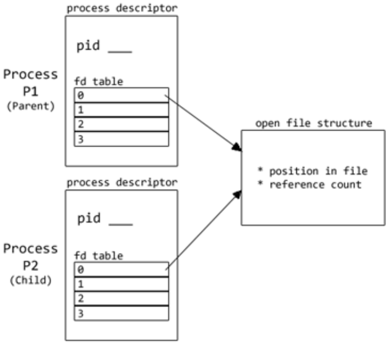
Shell I/O Redirection

- Shells can direct input / output for programs using < and >
- Most common conventions are as follows

```
$> some_program > output.txt
# output redirection to output.txt

$> interactive_prog < input.txt
# read from input.txt rather than typing

$> some_program >& everthing.txt
# both stdout and stderr to file

$> some_program 2> /dev/null
# stderr silenced, stdout normal
```

- Long output can be saved easily
- Can save typing input over and over
- Gets even better with pipes (soon)

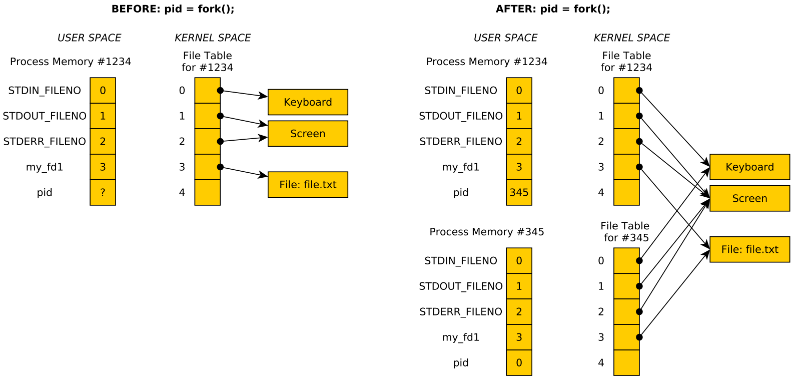
Processes Inherit Open FDs



Source: Eddie Kohler Lecture Notes

- Shells start child processes with `fork()`
- Child processes share all open file descriptors with parents
- Child prints to screen by default, reads from keyboard
- Redirection requires manipulation prior to `fork()`
- See: `fork_write.c`

Processes Inherit Open FDs: Diagram



BEFORE: pid = fork();

USER SPACE

Process Memory #1234

STDIN_FILENO	0
STDOUT_FILENO	1
STDERR_FILENO	2
my_fd1	3
pid	?

KERNEL SPACE

File Table for #1234

0 → Keyboard

1 → Screen

2 → Screen

3 → File: file.txt

4

AFTER: pid = fork();

USER SPACE

Process Memory #1234

STDIN_FILENO	0
STDOUT_FILENO	1
STDERR_FILENO	2
my_fd1	3
pid	345

Process Memory #345

STDIN_FILENO	0
STDOUT_FILENO	1
STDERR_FILENO	2
my_fd1	3
pid	0

KERNEL SPACE

File Table for #1234

0 → Keyboard

1 → Screen

2 → Screen

3 → File: file.txt

4

File Table for #345

0 → Keyboard

1 → Screen

2 → Screen

3 → File: file.txt

4

Typical sequence:

- Parent creates an `output_fd` and/or `input_fd`
- Call `fork()`
- Child changes standard output to `output_fd` and/or `input_fd`
- Changing means calls to `dup2()`

Exercise: Redirecting Output with dup() / dup2()

- System calls dup() and dup2() allow for manipulation of the file descriptor table.
- int backup_fd = dup(fd); creates a copy of the file descriptor
- dup2(from_fd, to_fd); causes to_fd to refer to the same spot as from_fd
- **Diagram** fork-dup.pdf shows how to redirect standard out to a file like a shell ls -l > output.txt

Use dup2() and dup()

1. Open a file
2. Fork a child
3. In child, adjust standard output so printf() goes into file
4. Parent and child use printf()

Variant: restore standard output in child after printing

Answers: Redirecting Output with dup() / dup2()

```c
// dup2_demo.c: demostrate use of dup2() to get a child to print into
// a file using printf; solution to in-class exercise
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <errno.h>
#include <sys/stat.h>
#include <fcntl.h>
#include <string.h>

int main(int argc, char *argv[]){
  system("touch write.txt");           // ensure file exists
  int fd = open("write.txt",O_WRONLY); // open a file
  pid_t child = fork();                // fork a child
  if(child == 0){                      // child section
    int backup = dup(STDOUT_FILENO);   // make backup of stdout
    dup2(fd,STDOUT_FILENO);            // use dup2 so child printf() goes into file, not screen
    printf("I'm the child\n");         // printf() now goes to open file
    fflush(stdout);                    // flush stdout buffers into file
    dup2(backup,STDOUT_FILENO);        // restore stdout
  }
  else{                                // parent section
    printf("I'm the parent\n");
  }
  printf("all done\n");                // both parent and child
  close(fd);
  return 0;
}
```

Pipes

- A vehicle for one process to communicate with another
- Uses internal OS memory rather than temporary files
- A great Unix innovation which allows small programs to be strung together to produce big functionality
- Leads to smaller programs that cooperate
- Preceding OS's lacked communication between programs meaning programs grew to unmanageable size

Pipes on the Command Line

Super slick for those that know what they are doing: string programs with |

```
> ls | grep pdf
00-course-mechanics.pdf
01-introduction.pdf
02-unix-basics.pdf
03-process-basics.pdf
04-making-processes.pdf
05-io-files-pipes.pdf
99-p1-commando.pdf
header.pdf
> ls | grep pdf | sed 's/pdf/PDF/'
00-course-mechanics.PDF
01-introduction.PDF
02-unix-basics.PDF
03-process-basics.PDF
04-making-processes.PDF
05-io-files-pipes.PDF
99-p1-commando.PDF
header.PDF
```

```
cat file.txt |         # Feed input \
tr -sc 'A-Za-z' '\n' | # Translate non-alpha to newline \
tr 'A-Z' 'a-z' |       # Upper to lower case \
sort |                 # Duh \
uniq -c |              # Merge repeated, add counts \
sort -rn |             # Sort in reverse numerical order \
head -n 10             # Print only top 10 lines
```

Pipe C function Calls

- Use the pipe() system call
- Argument is an array of 2 integers
- Filled by OS with file descriptors of opened pipe
- 0th entry is for reading
- 1th entry is for writing

```
int my_pipe[2];                // array of 2 file descriptors
int result = pipe(my_pipe);    // now filled with 2 fds by system

char msg[128] = "hello world";
int nwritten = write(my_pipe[1], msg, strlen(msg)+1);

char buffer[128];
int nread = read(my_pipe[0], buffer, 128);

close(my_pipe[0]);
close(my_pipe[1]);
```

pipe-dup.pdf diagram to shows how to redirect standard output to a pipe so printf() would go into the pipe for later reading