# Issues involved with Programming a Shell

Program Execution
Unix I/O
File Redirection
Pipes

# Basic Code Outline

```
while (1) {
   get a line from the user
   if line is a builtin command
      process builtin
   else
      process external command
}
```

# Shell Built-in (internal) commands

Bash:

- set, echo, cd, true, false, type, ...
- if – then,  while -do, for, test, ...
- history, fg, bg, kill, ...
- lots more: try “help”

Homework #3:

- whatever you want from hw1/2
- `cd` (change directory)

# External Commands (executable files)

- Shell needs to know where to look for executable files:
  - it would take too long to look in all directories
  - it is possible for there to be multiple executable files with the same name.
- Real shells use PATH environment variable:

```
PATH = /usr/bin:/usr/local/bin:/opt/foo:.
```

- HW3: use XPATH environment variable.

# Exec functions

- There are a bunch of them.
  - different ways to specify the command line.
  - different ways the executable is specified.
  - some support new environments
- For HW3 – you need to use execl or execv, not execlp or execvp.
  - the 'p' versions use PATH, you need to search yourself and use X.

# I/O Redirection

- Your shell must support I/O redirection for standard input and standard output:

```
ls > savedls
sort < savedls
cat < savedls
cat savedls > anothercopy
```

etc.

# Implementing I/O Redirection

- The general idea is to set up standard input (or output) before calling `exec()`.
  - open a file and assign it as standard input, or standard output.
  - the new program inherits stdin and stdout
    - The program was written to read from stdin and write to stdout, it doesn't have to know what these are actually connected to.

# Unix File I/O

- C and C++ include standard libraries
  - `cin, cout, iostream, fstream, ...`
  - `fopen, fclose, fread, fwrite, ...`
- We will deal with Unix directly via system calls (not via libraries).
  - `open, close, read, write, ...`
  - system calls use “file descriptors” to refer to open files.

# open()

**`int open(const char *path, int flags, ...);`**

- path is C string containing a pathname.
- flags indicate what kind of access:

```
O_RDONLY        open for reading only
O_WRONLY        open for writing only
O_RDWR          open for reading and writing
O_NONBLOCK      do not block on open
O_APPEND        append on each write
O_CREAT         create file if it does not exist
O_TRUNC         truncate size to 0
```

... (there are more)

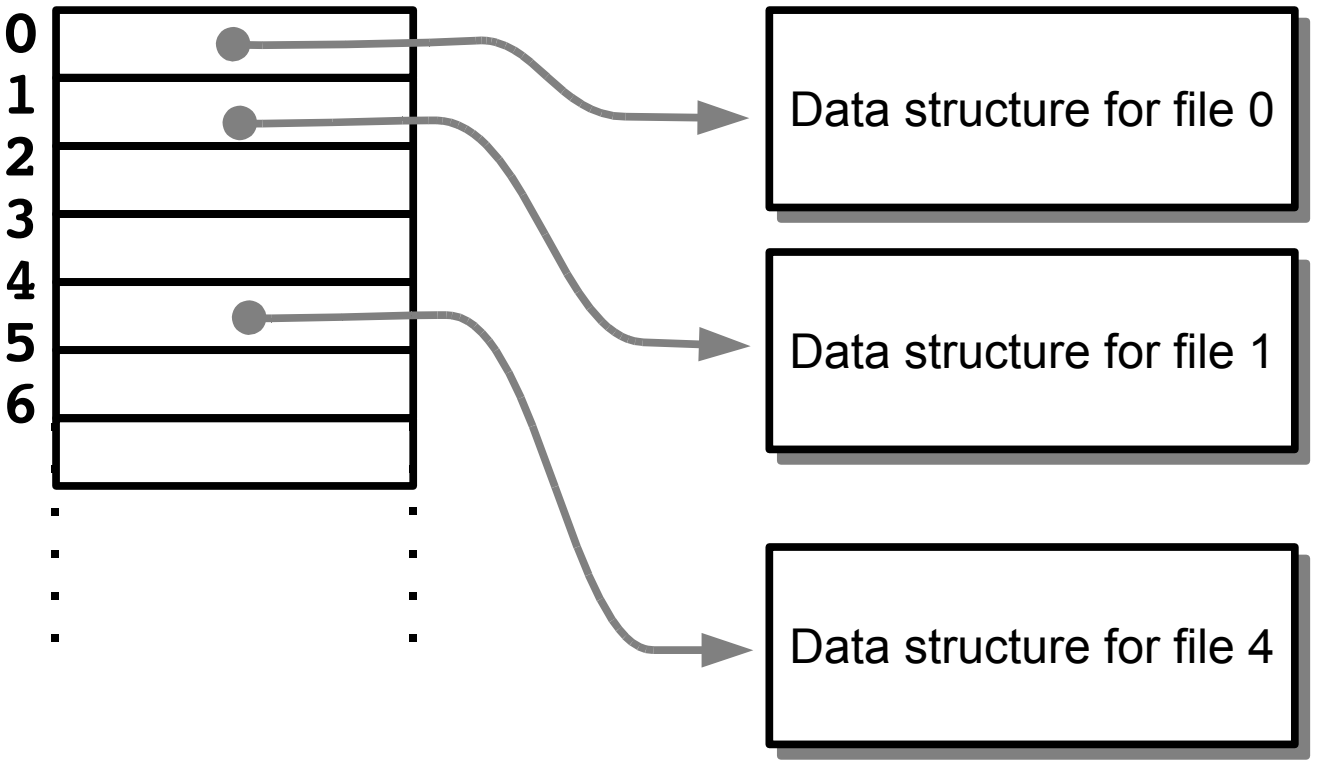
# `open()` return value

- Anything less than 0 means ERROR
  - check `errno` for specific error.

- `open()` returns a *file descriptor* (a small integer).

- The O.S. manages a *file descriptor table* for each process, a *file descriptor* is an index into this table.

# File Descriptor Table



# Using File Descriptors

- When calling Unix I/O system calls, you give them an open file descriptor:

```
write(fd,"hello",5);
read(fd,buff,22);
close(fd);
```

- File descriptors can refer to open files, pipes, fifos, sockets, etc.

# `read()`

```
ssize_t read(int fd, void *buf, size_t nbytes);
```

- `fd` is an open file descriptor.
- `buff` is the address where you want `read` to store what it reads.
- `nbytes` is the maximum number of bytes
  - often the size of the buffer.

# `read()` continued.

- The return value is the number of bytes read, 0 means EOF. Anything less than 0 means ERROR (check errno).
- By default, `read` will block until there is some data available (it could return less than `nbytes`).
- For files, `read` will always read `nbytes` unless it hits the end of the file first.
  - reading from pipes and sockets is a little different.

# write()

```
ssize_t write(int fd,void *buf, size_t nbytes);
```

- `fd` is an open file descriptor.
- `buff` is the address of the bytes you want to write.
- `nbytes` is the number of bytes to be written.
- Write does not know anything about strings!
  - doesn't know about null termination, etc.

# `write()` continued.

- Return value is the number of bytes written. Negative number means an error occurred.
- Write can block!
  - max capacity of a pipe has been reached.
  - network buffer full.
- Typically doesn't block when writing to a file...

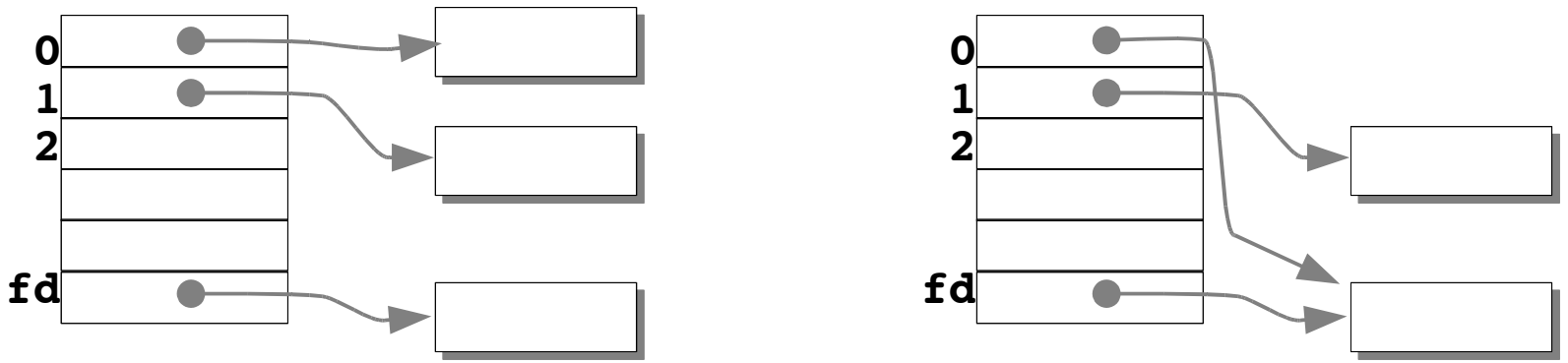
# `dup()` and `dup2()`

- `open()` creates a new file descriptor
  - typically the lowest file descriptor that is not currently used.
- `dup(fd)` will duplicate a file descriptor, creates a new file descriptor that refers to the same file as `fd`.
- `dup2(fd,newfd)` will duplicate a file descriptor, the new descriptor will be `newfd`.

# Using dup2

- `dup2` can be used to assign an open file to stdin:

```
dup2(fd,0);
/* or dup2(fd,STDIN_FILENO); */
```



# Example: `sortfile`

- We want to make a command that will sort a file for us (never mind that sort will do this without any help...).

```
sortfile somefile
```

- sortfile will
  - `open` somefile
  - `dup2` the new file descriptor to `STDIN_FILENO`
  - `exec` the `sort` command.

# sortfile.c

- Complete source is on the web.
- Abbreviated source here is missing lots of stuff
  - includes
  - error checking
  - comments...

# sortfile.c (abbreviated)

```
int main(int argc, char **argv) {
  int fd;
  fd = open(argv[1],O_RDONLY);  /* errors! */
  dup2(fd,0);                   /* errors! */
  execlp("sort","sort",NULL);   /* errors! */
  /* should never get here */
  return(1);
}
```

# Re-directing STDOUT

- Same idea, but now replace file descriptor 1
  - `STDOUT_FILENO` is a better name than 1
- Sample code: `logusers.c`
  - uses the who command to write list of logged-in users to a log file
    - appends to the log file each time run.
  - also writes timestamp to the file

# logusers.c (abbreviated)

```
int main(int argc, char **argv) {
  int fd;
  char *curtime;
  time_t t;
  fd = open(argv[1],O_WRONLY | O_APPEND | O_CREAT,0755);
  time(&t); curtime = ctime(&t);
  write(fd,curtime,strlen(curtime));
  dup2(fd,STDOUT_FILENO);
  execlp("who","who",NULL);
}
```

# Pipes

- Your shell must support command lines that include pipes:

```
ls | grep fred | sort
```

- The `ls` command should run, it's output is sent to the `grep` command, which acts as a filter (printing only those lines that contain the string “fred”). The `grep` command's output is feed to the `sort` command, the result is a sorted list of all files whose names contain “fred”.

# Unix Pipes

- A *pipe* is basically a buffer held by the kernel, and two file descriptors
  - one for reading, one for writing.
  - The pipe maintains the order of the bytes, so that the first byte written to the pipe is the first byte read from the pipe.
- The `pipe()` system call creates a pipe and generates two file descriptors.

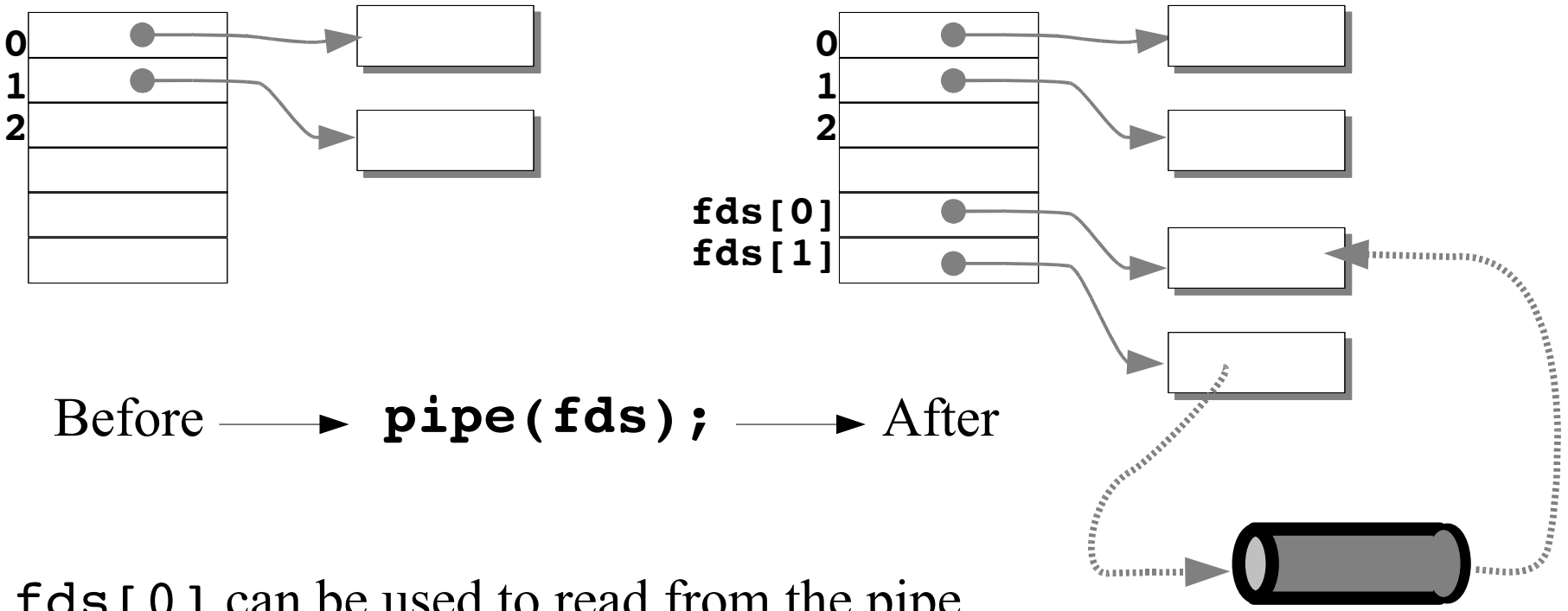
# `pipe()`

```
int pipe(int *fildes)
```

- `fildes` is an array of (at least) two `int`s. This array must exist before calling `pipe`!
- `pipe` returns 0 if successful, -1 on errror.
- If successful, `filedes[0]` is a file descriptor for reading from the pipe, and `filedes[1]` is for writing to the pipe.

# Calling `pipe()`

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




`fds[0]` can be used to read from the pipe.
`fds[0]` can be used to write to the pipe.

# Example: `peterpiper.c` (abbreviated)

```
int main(int argc, char **argv) {
  int n,fds[2];
  char buff[10];

  pipe(fds);
  write(fds[1],data,sizeof(data));
  close(fds[1]);
  while ( (n=read(fds[0],buff,10))>0)
        write(STDOUT_FILENO,buff,n);
}
```

# Pipe Capacity

- The O.S. has some buffer space that is used by the pipe – there is a limit.
  - if you hit the limit, `write` will block!

```
while (write(fds[1],data,BUFSIZE)>0) {
   tot += BUFSIZE;
   printf("pipe can hold %u\n",tot);
}
```

Run this an see what the largest number printed is. At this point the process is blocked (it won't quit – just waits!). Hit ^C to kill it...

# `sortedls.c`

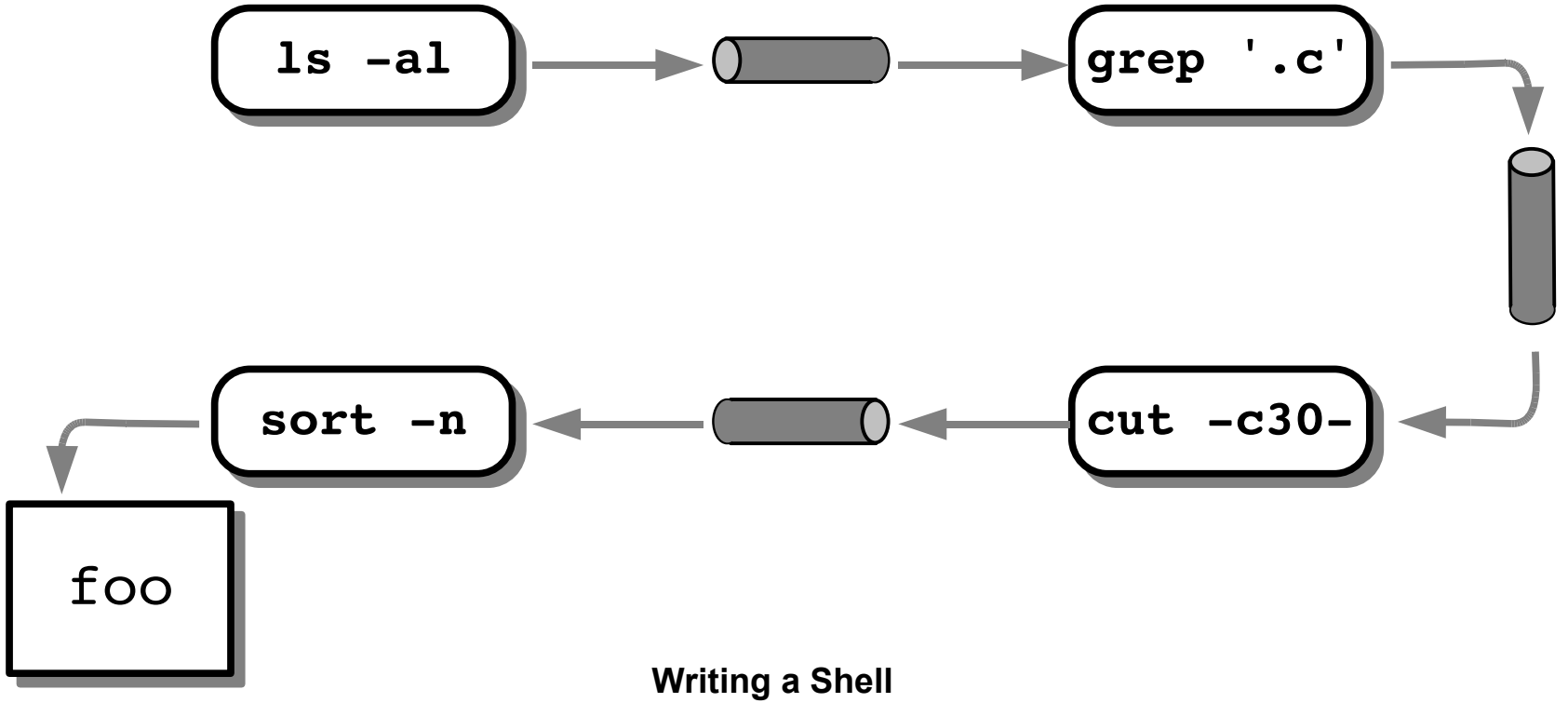
- Sample program:
  - creates a pipe.
  - forks
    - parent process attaches the writing end of the pipe to stdout.
    - child process attaches the reading end of the pipe to stdin.
    - parent exec's `ls`
    - child exec's `sort`.
- Result is basically this: `ls | sort`

# `sortedls.c` (abbreviated)

```
int main() {
  int fds[2];
  pipe(fds);
  if (fork()) {
    dup2(fds[1],STDOUT_FILENO);
    execlp("ls","ls",NULL);
  } else {
    dup2(fds[0],STDIN_FILENO);
    execlp("sort","sort",NULL);
  }
}
```

# Putting is all together

```
ls -al | grep '.c' |  cut -c30- | sort -n > foo
```



# Pipe Issues

- If you want two processes to share a pipe, you create the pipe first, then `fork()`.
  - The parent and child will have copies of the pipe file descriptors.
- Close any unused descriptors before calling `exec`
  - If any process has an open file descriptor that is the writing end of a pipe, EOF will never be seen!

# Parsing Idea

**`ls -al | grep '.c' |  cut -c30- | sort -n > foo`**

is

**`ls -al |`** ***`something`***

- Parse the first command (everything before the first '|').
  - fork – child will become ls.
  - Have child create pipe, and fork.
    - child execs ls.
    - grandchild processes *something* (in the same way).