Inter-process Communication

Pipes (Haviland – Ch. 7)

Exchanging data between processes

- After fork() is called we end up with two independent processes.
- We cannot use variables to communicate between processes since they each have separate address spaces, and separate memory.
- One easy way to communicate is to use files.
  - process A writes to a file and process B reads from it.
- See usefiles.c example. We need to be pretty careful.

Buffering

- un-buffered – output appears immediately
  - `stderr` is not buffered
- line buffered – output appears when a full line has been written.
  - `stdout` is line buffered when going to the screen
- block buffered – output appears when a buffer is filled or a buffer is flushed (on close or explicit flush).
  - normally output to a file is block buffered
  - `stdout` is block buffered when redirected to a file.

File Objects and File Descriptors

- The stdio library provides FILE objects which handle buffering.
- Why buffering? Efficiency.

- FILE objects are built on top of file descriptors. A file descriptor is an index into a per-process table of open file descriptors.
- We will also use file descriptors for other communication such as pipes and sockets.

File Descriptors

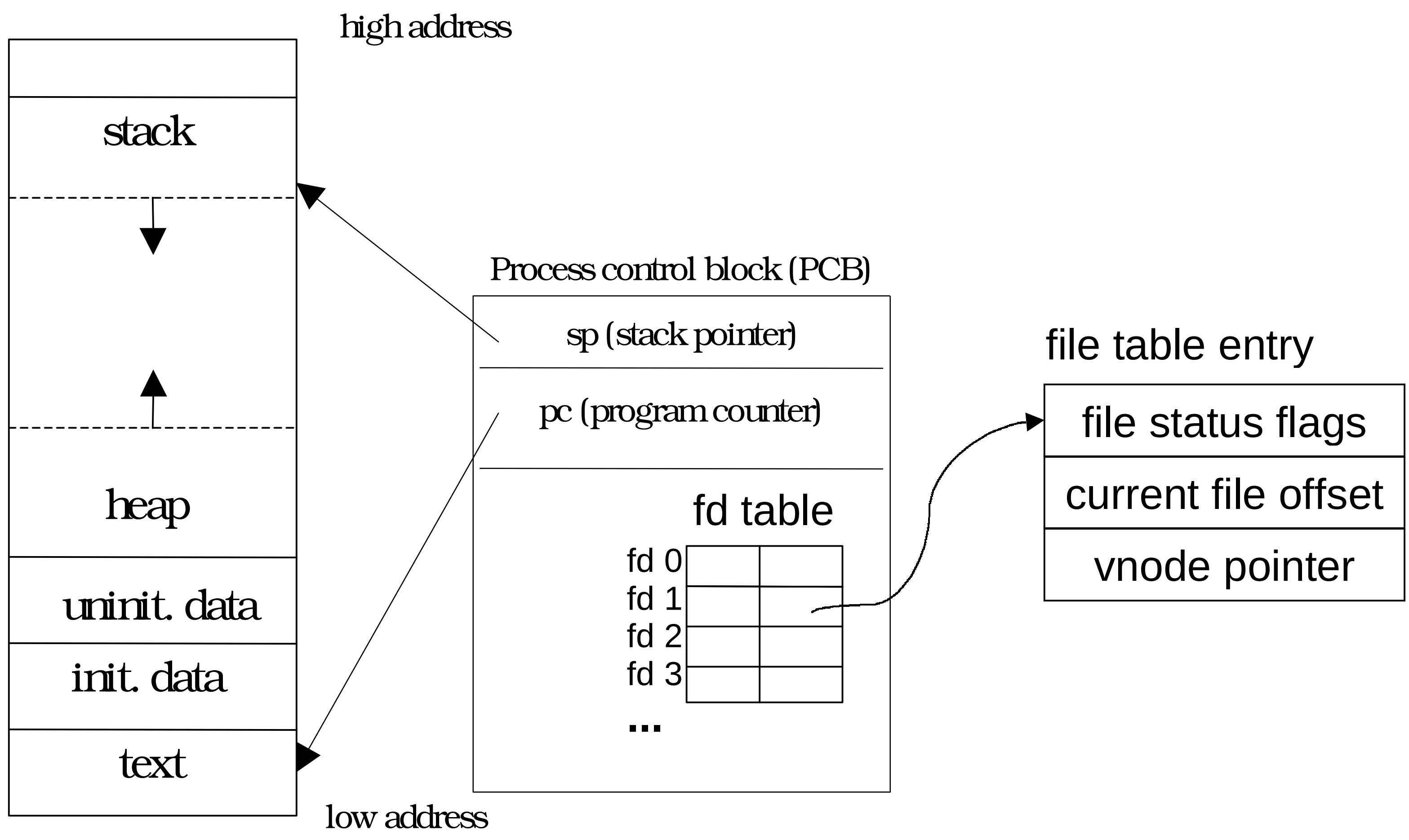
- Used by low-level I/O
  - `open(), close(), read(), write()`
- declared as an integer
  - `int fd;`
- A useful system call to convert a FILE object to a fd

```
int fileno( FILE *fp);
```

- Of course it is possible to assign a stream interface to a file descriptor

```
FILE *fdopen(int fd, const char *mode);
```

Process state



Producer/Consumer Problem

- Simple example: `who | wc –l`
- Both the writing process (`who`) and the reading process (`wc`) of a pipeline execute concurrently.
- A pipe is usually implemented as an internal OS buffer.
- It is a resource that is concurrently accessed by the reader and the writer, so it must be managed carefully.

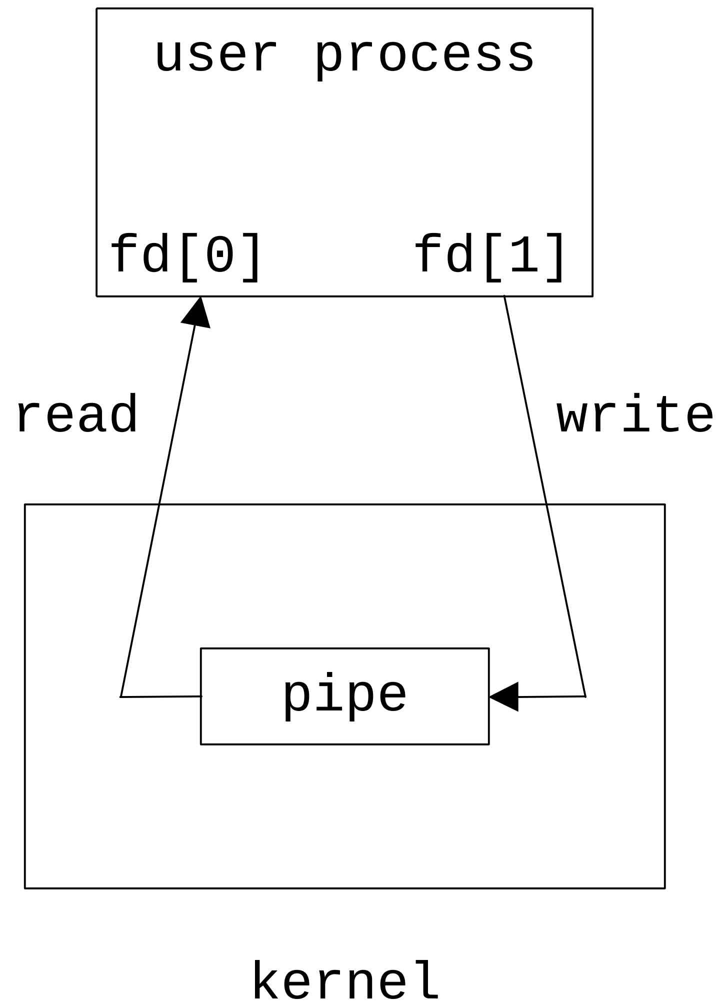
Producer/Consumer

- Consumer blocks when buffer is empty
- Producer blocks when buffer is full
- They should run independently as far as buffer capacity and contents permit
- They should never be updating the buffer at the same instant (otherwise data integrity cannot be guaranteed)

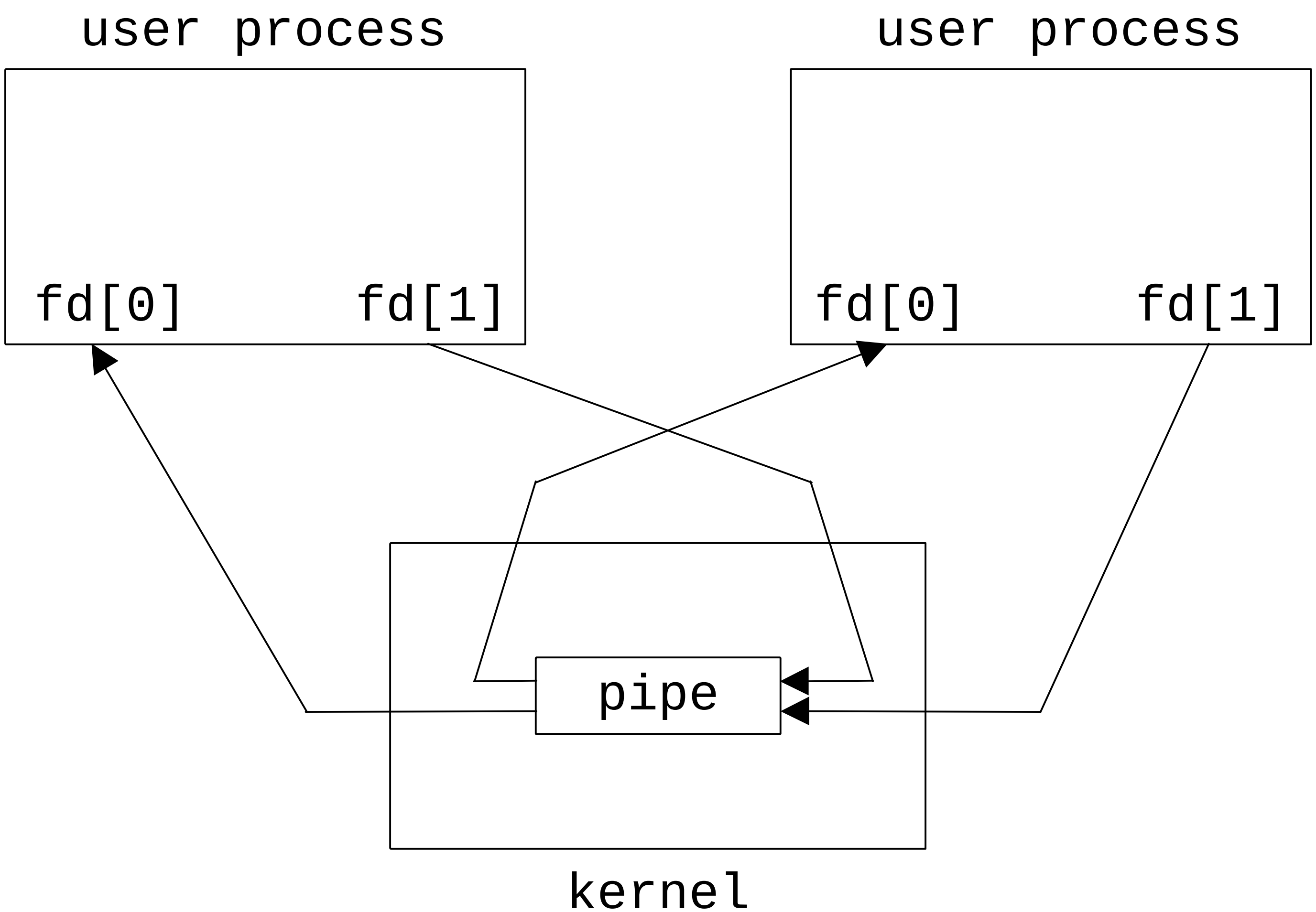
→ Harder problem if there is more than one consumer and/or more than one producer.

int pipe(int filedes[2])

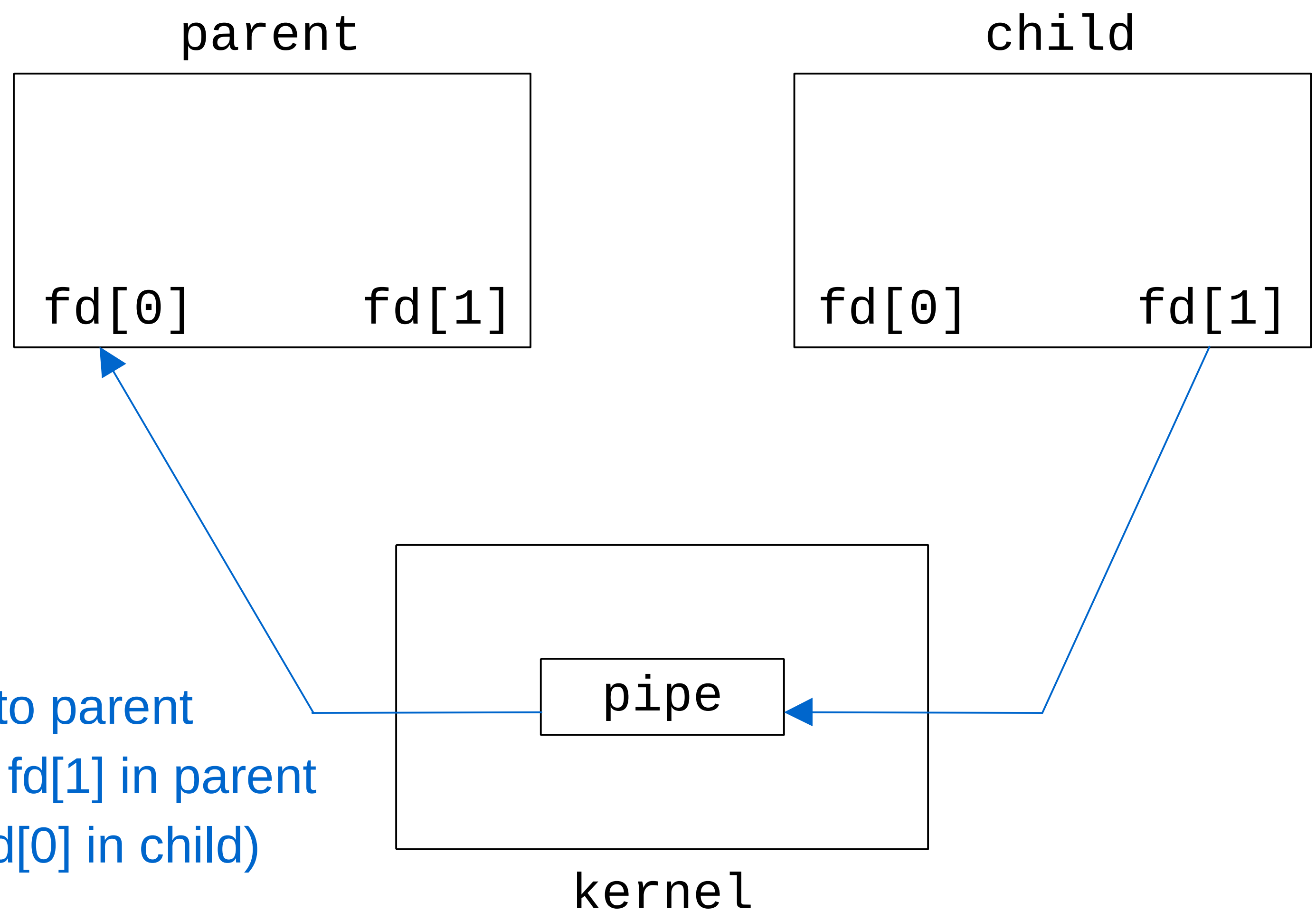
- half-duplex (one-way) communication



What happens after fork?

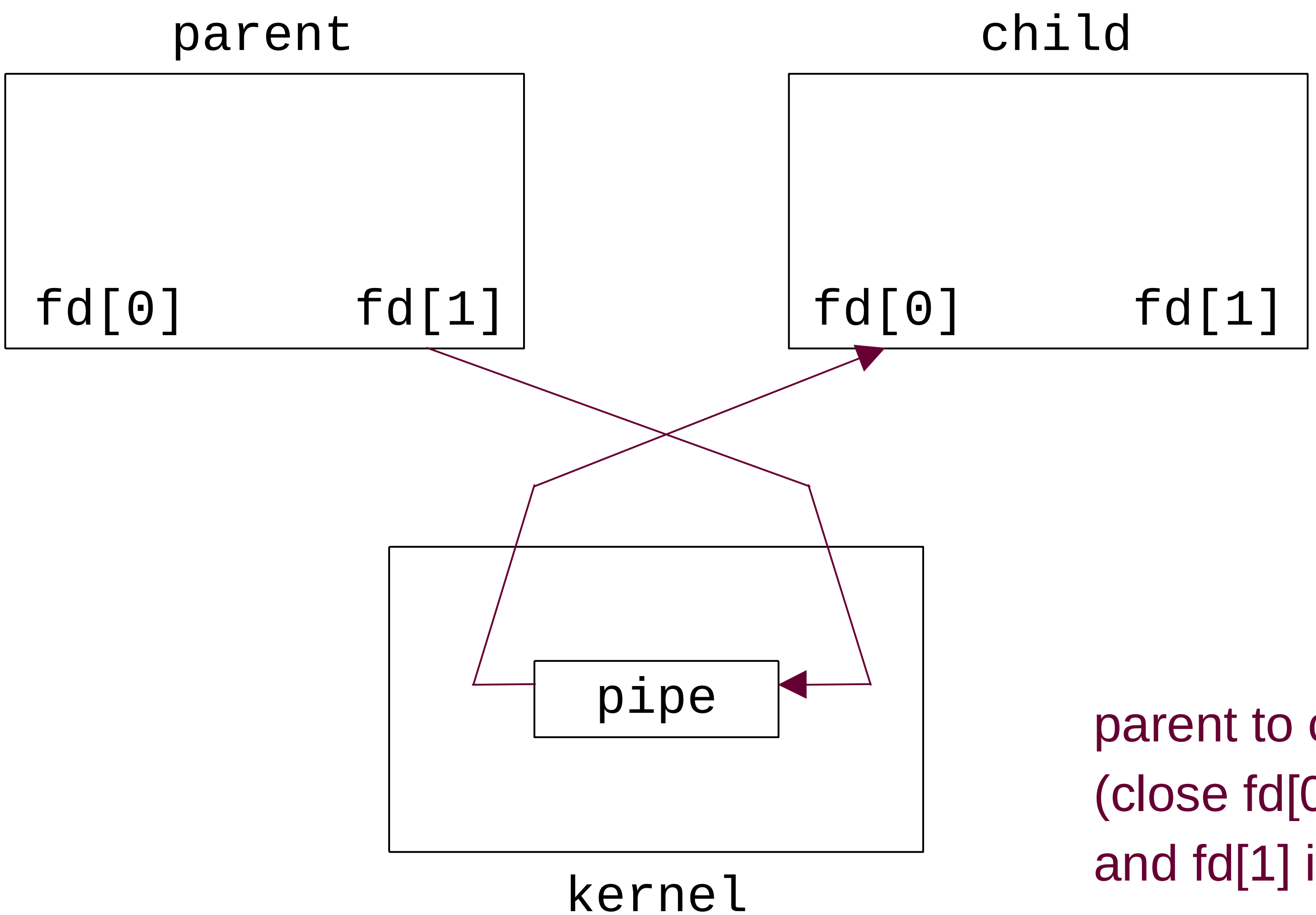


Direction of data flow?



child to parent
close fd[1] in parent
and fd[0] in child)

Direction of data flow?



parent to child
(close fd[0] in parent
and fd[1] in child)

Pipes and File Descriptors

- A forked child inherits file descriptors from its parent
- pipe() creates an internal system buffer and two file descriptors, one for reading and one for writing.
- After the pipe call, the parent and child should close the file descriptors for the opposite direction. Leaving them open does not permit full-duplex communication.

dup2()

- Often we want the stdout of one process to be connected to the stdin of another process.
- Set one FD to the value of another.

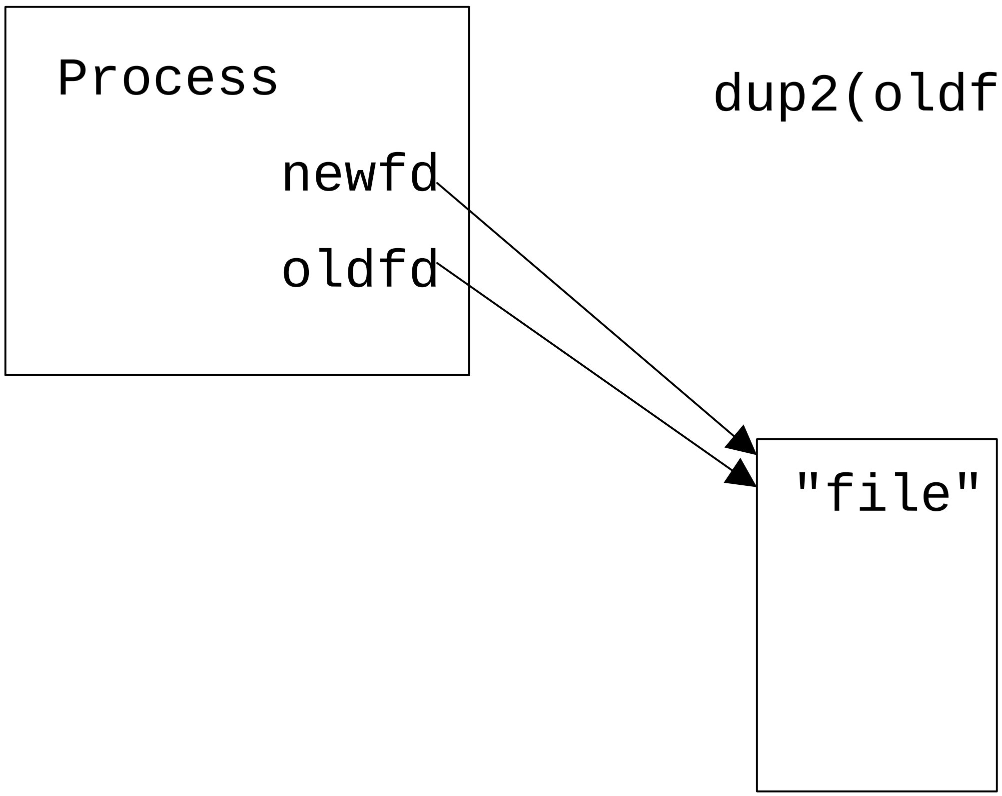
```
returnCode = dup2(oldFD, newFD);
```

  - newFD and oldFD now refer to the same file
  - if newFD is open, it is first automatically closed
  - Note that `dup2()` refer to fds not streams

dup2()

```
oldfd = open("file");

dup2(oldfd, newfd);
```



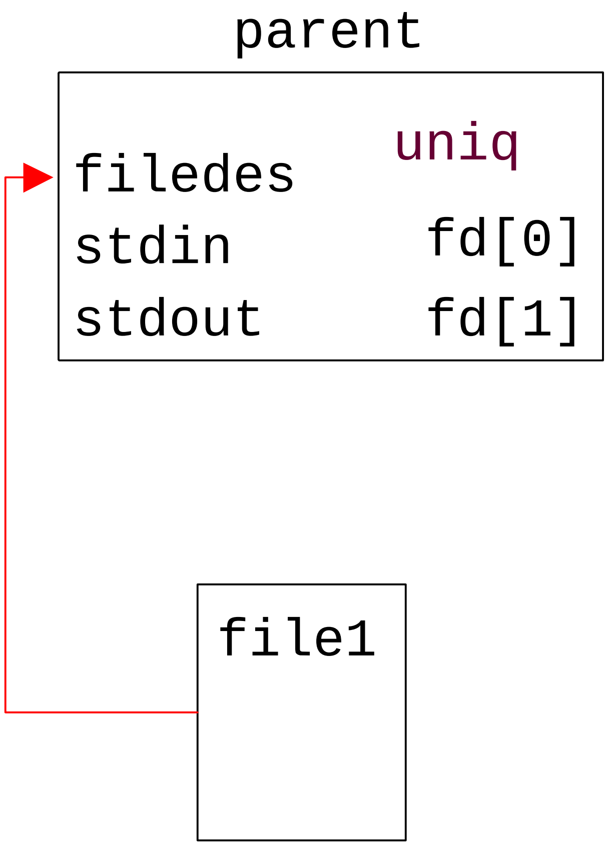
pipe()/dup2() example

```
/* equivalent to “sort < file1 | uniq” */
int fd[2], pid;
int filedes = open("file1", O_RDONLY);
dup2(filedes, fileno(stdin));
close(filedes);
pipe(fd);
```

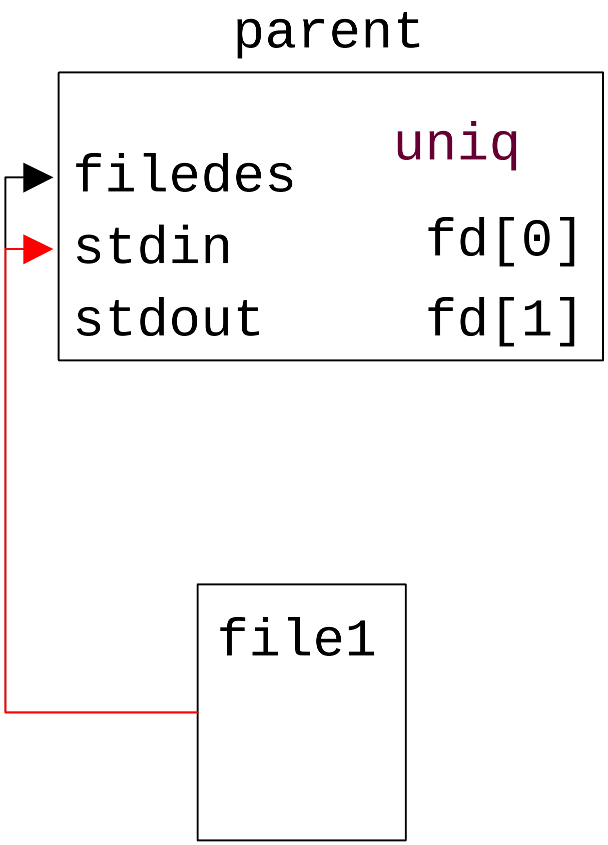
pipe()/dup2() example

```
if((pid = fork()) == 0) {/* child */
  dup2(fd[1], fileno(stdout));
  close(fd[0]); close(fd[1]);
  execl("/usr/bin/sort", "sort", (char *) 0);
} else if(pid > 0){       /* parent */
  dup2(fd[0], fileno(stdin));
  close(fd[1]); close(fd[0]);
  execl("/usr/bin/uniq", "uniq", (char *) 0);
} else {
  perror("fork"); exit(1);
}
```

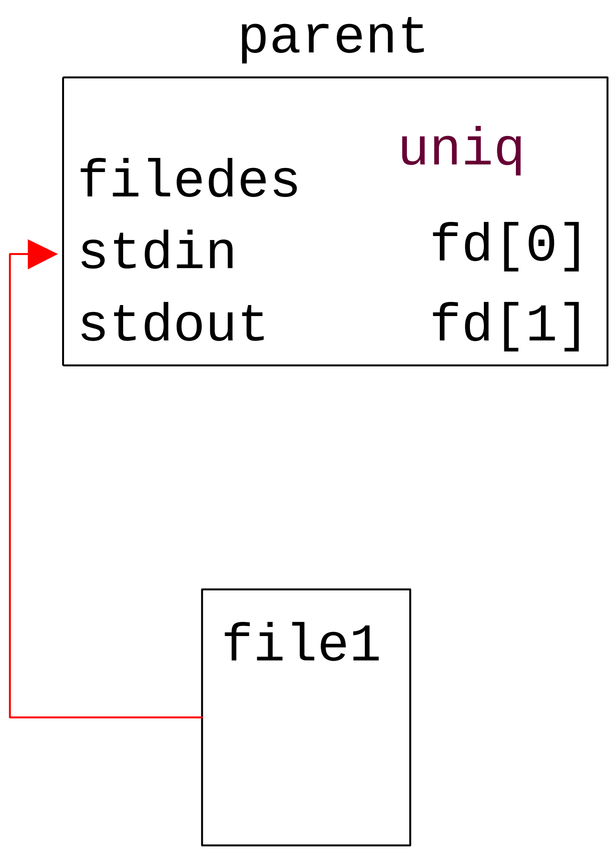
```
int filedes = open("file1", O_RDONLY);
```

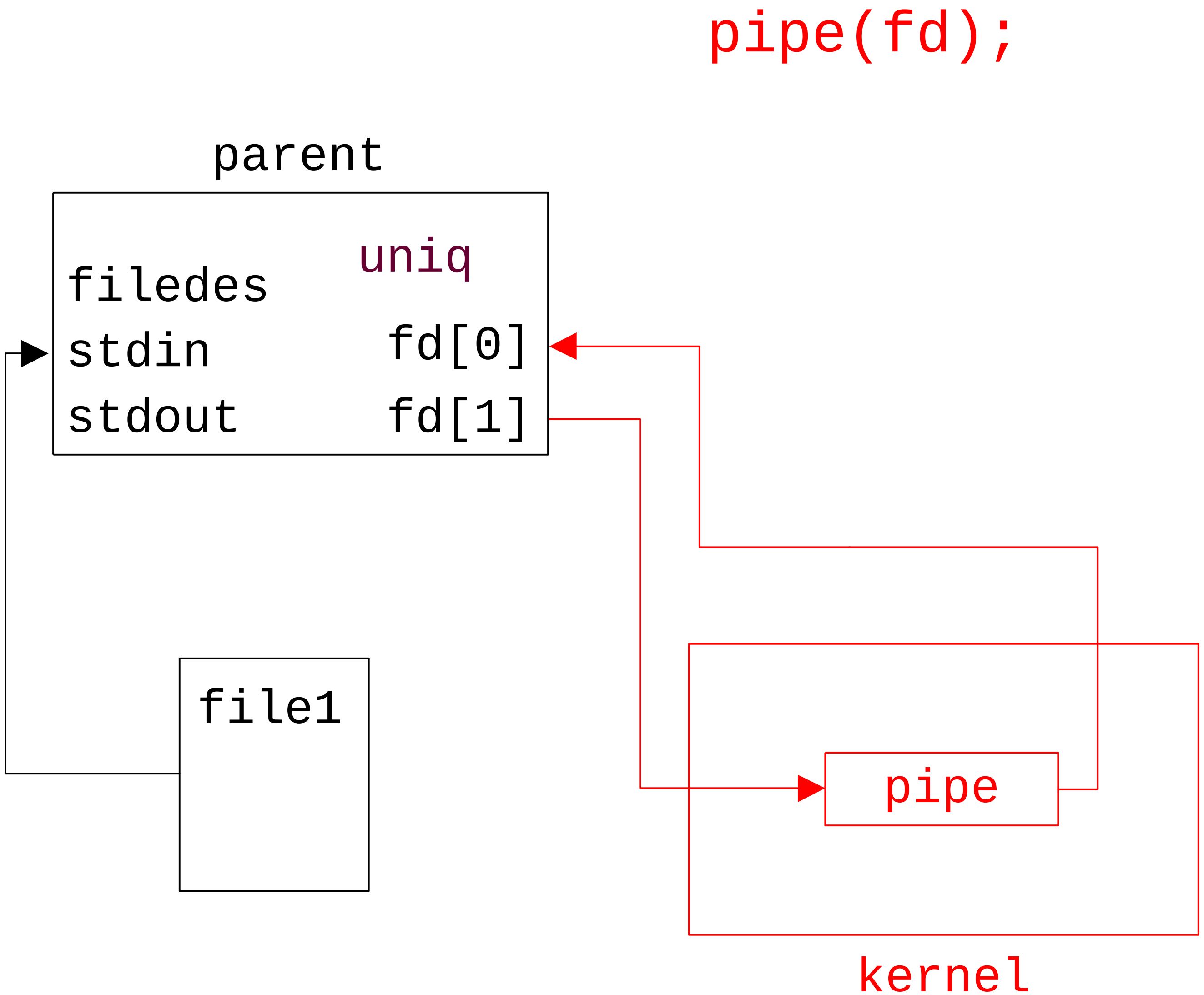


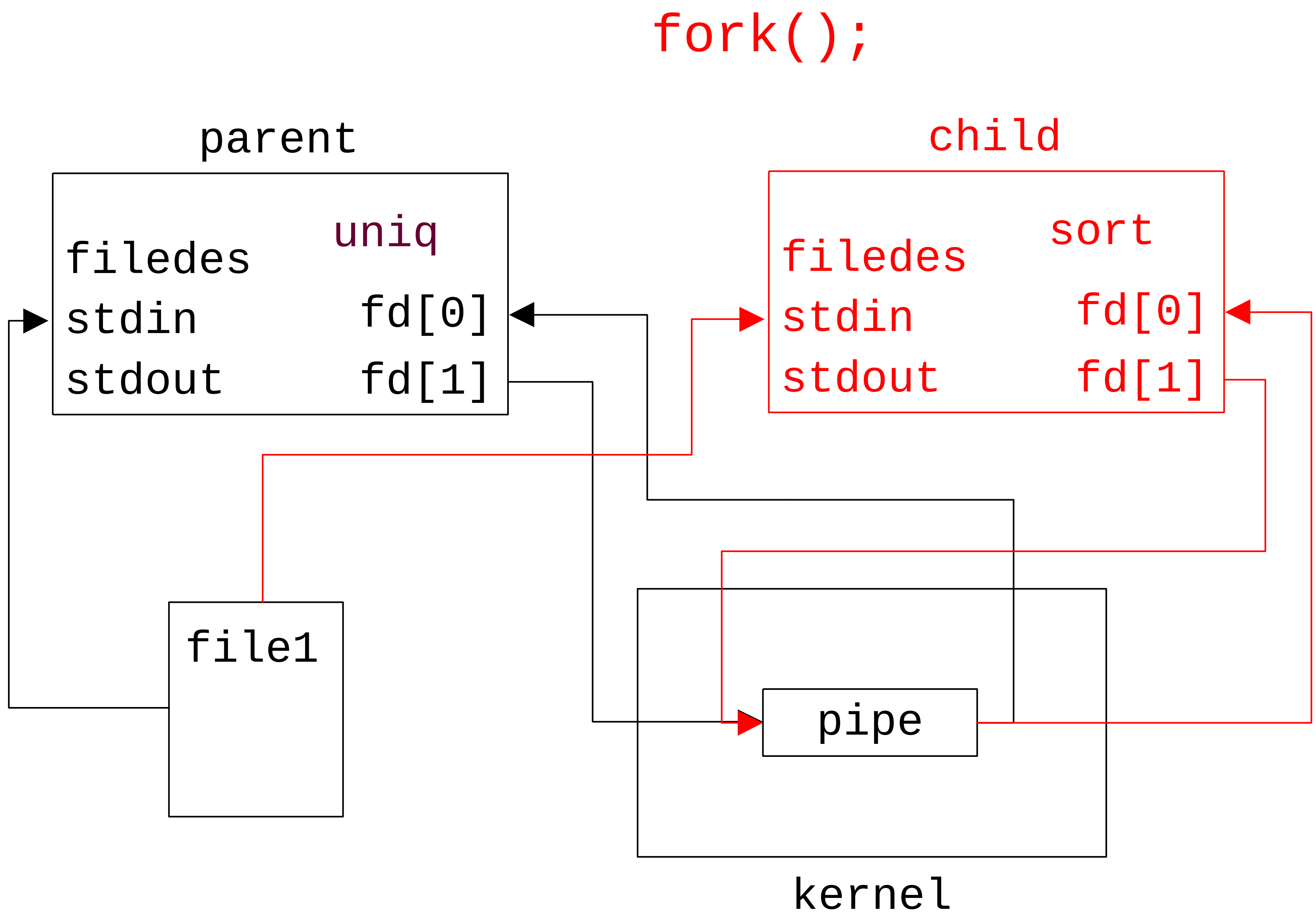
`dup2(filedes, fileno(stdin));`



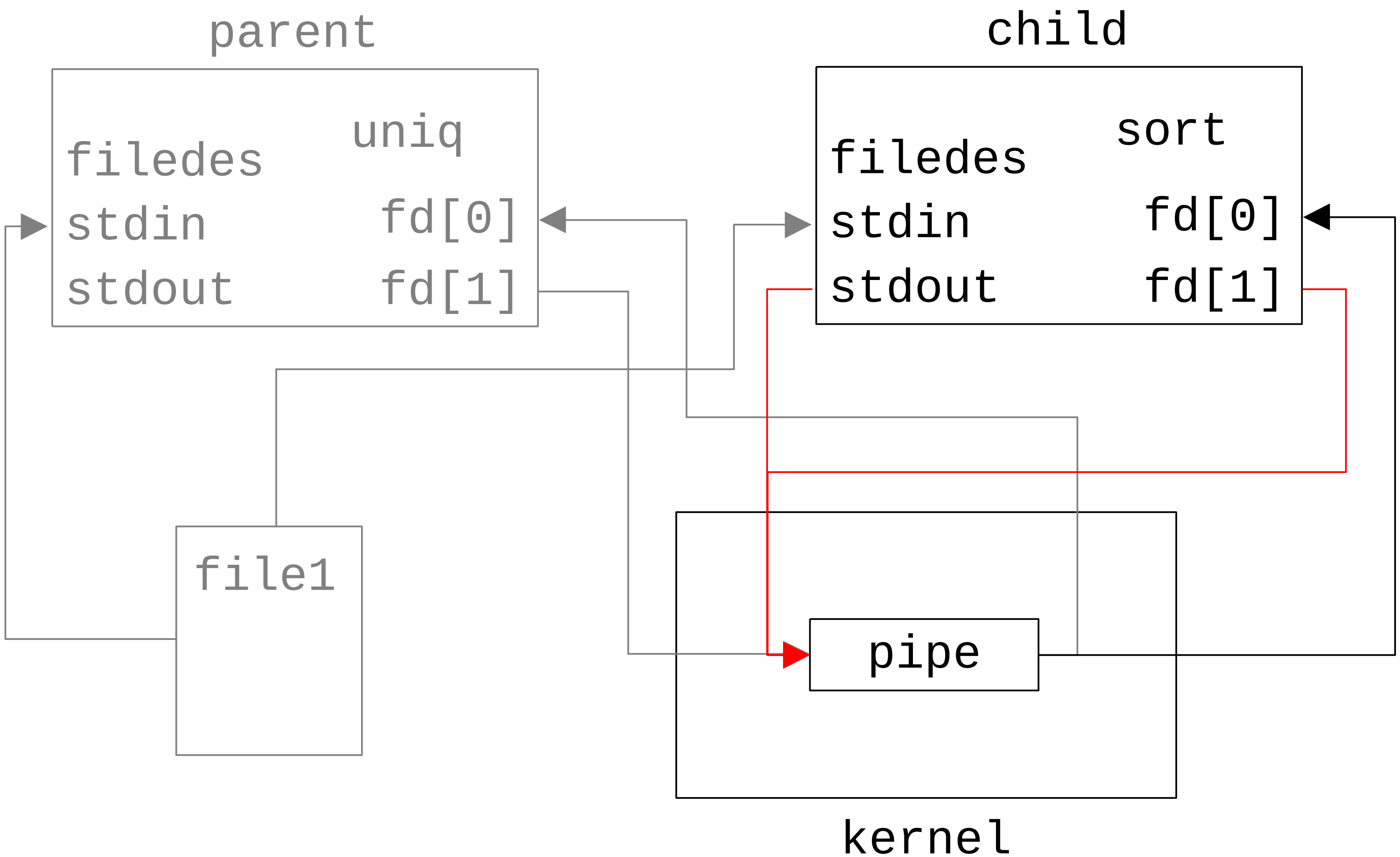
```
close(filedes);
```



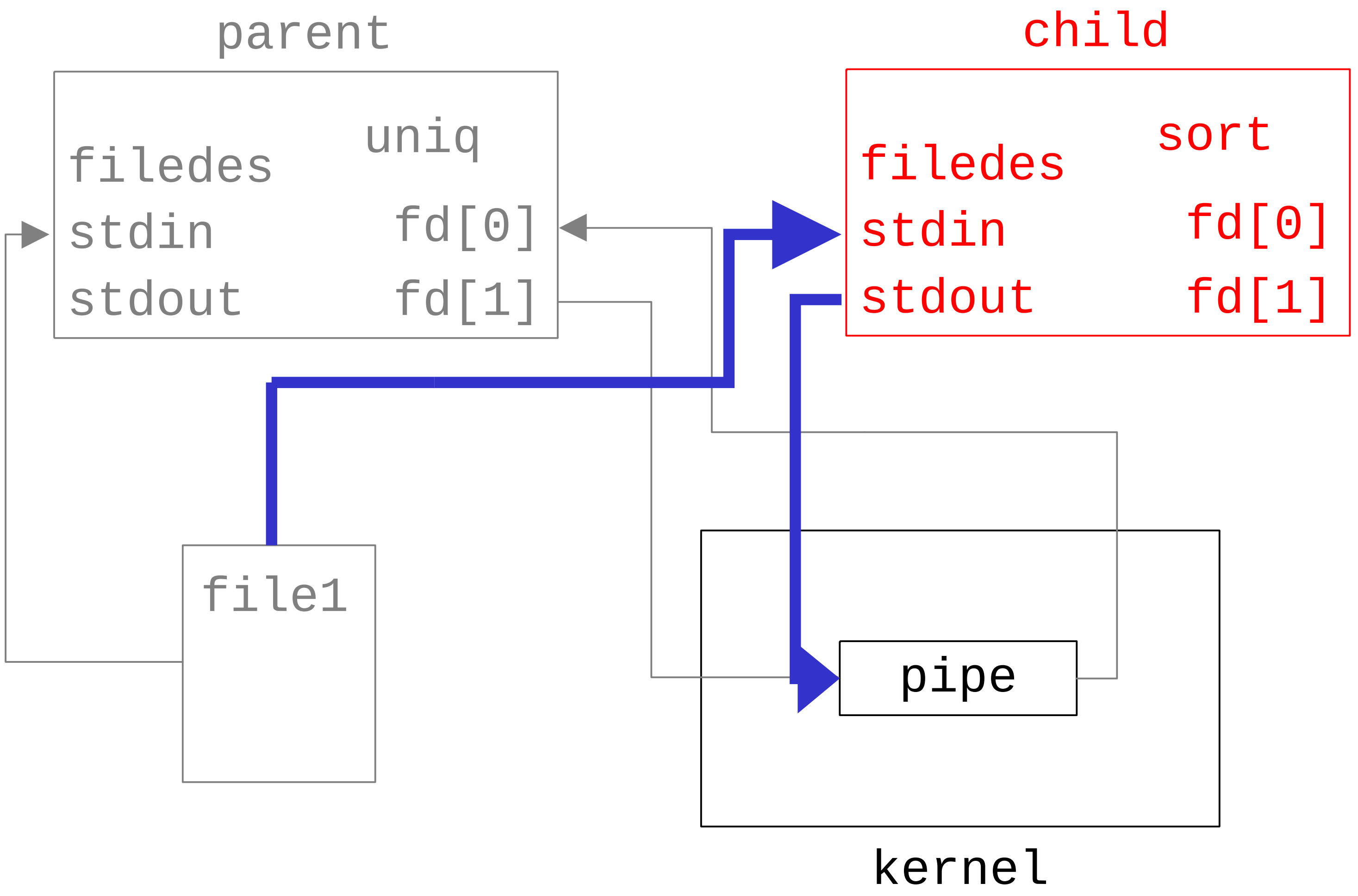

pipe(fd);
parent
uniq
filedes
stdin
stdout
fd[0]
fd[1]
file1
pipe
kernel


fork();
parent
filedes
uniq
stdin
fd[0]
stdout
fd[1]
child
filedes
sort
stdin
fd[0]
stdout
fd[1]
file1
pipe
kernel

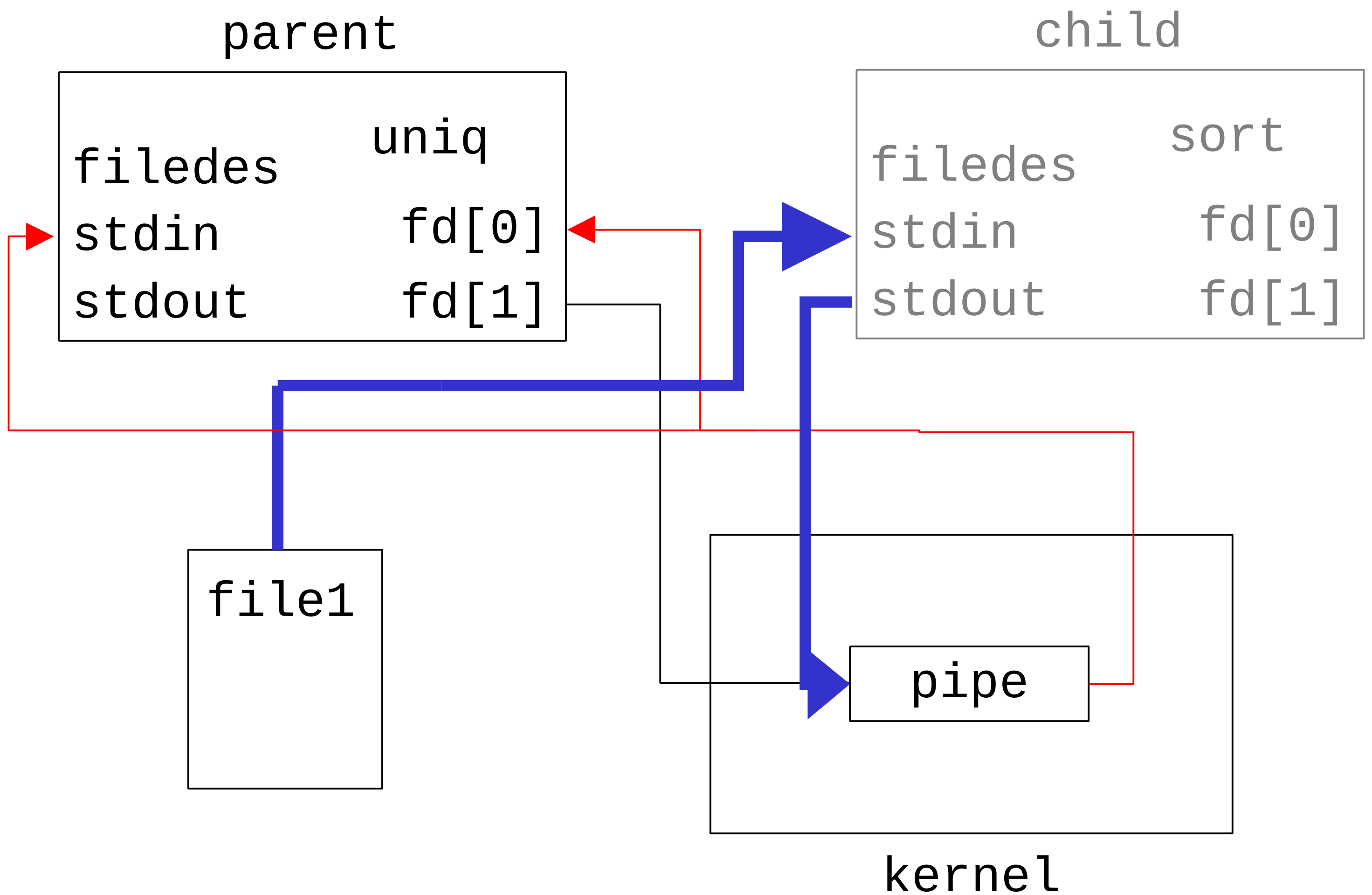
dup2(fd[1], fileno(stdout));



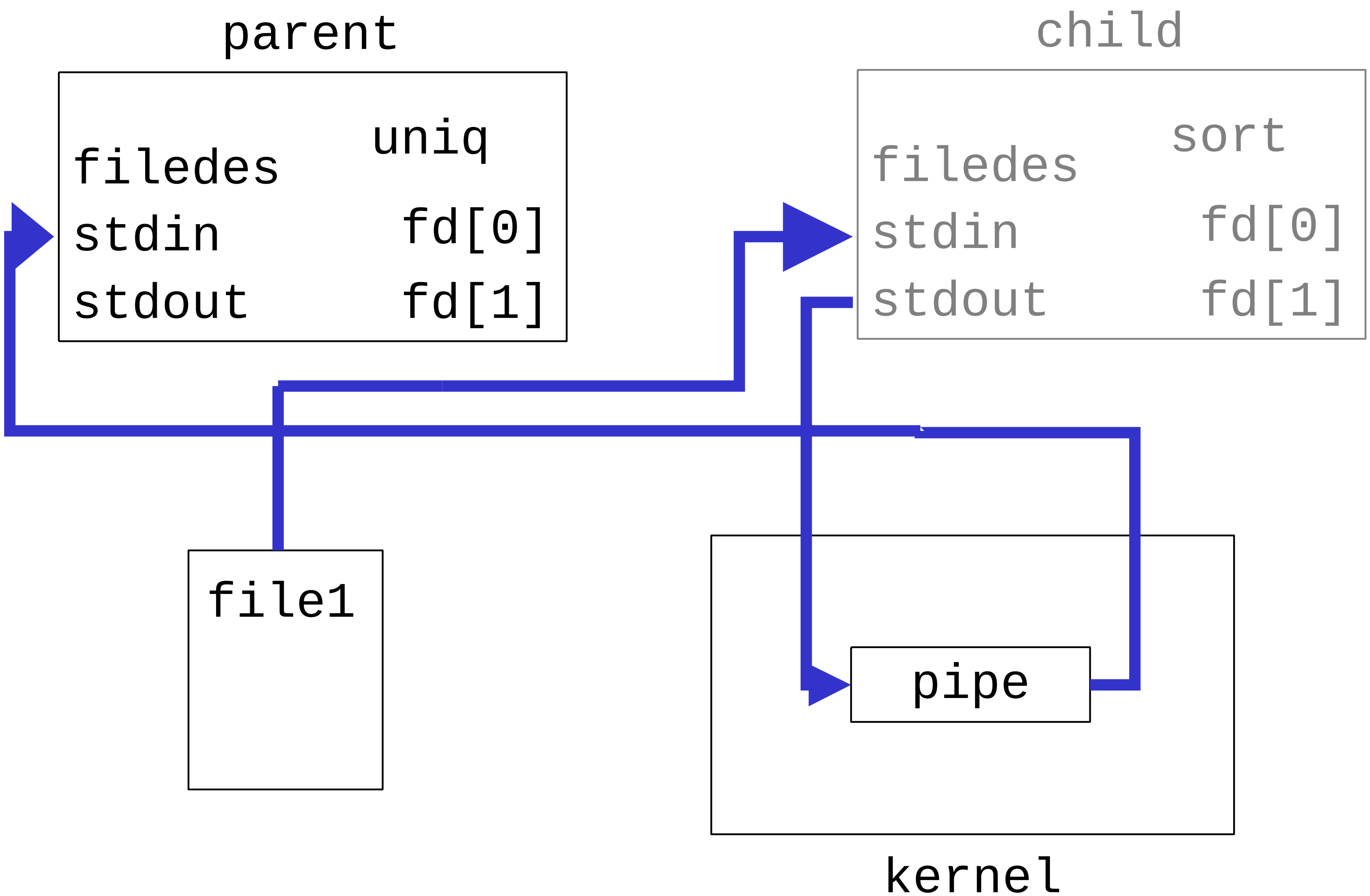
```
close(fd[0]); close(fd[1]);
```



dup2(fd[0], fileno(stdin));



close(fd[1]); close(fd[0]);



Reading and writing to a pipe

- A read on an empty pipe will block until there is something to read.
- A write on a full pipe will block until there is more space. (Pipes have a finite size.)

- Writing to a pipe that has been closed by the other end will result in a SIGPIPE or “Broken Pipe” message.
- Read will return 0 if the write end of the pipe is closed.

`popen()` and `pclose()`

- `popen()` simplifies the sequence of:
  - generating a pipe
  - forking a child process
  - duplicating file descriptors
  - passing command execution via an `exec()`
- Usage:

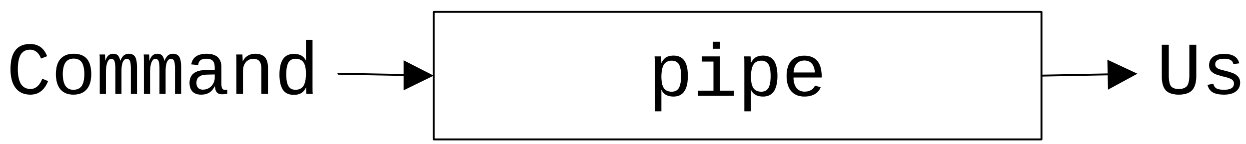
```
FILE *popen( const char *command,
             const char *type );
```

- Example:

```
FILE *pipeFP;
pipeFP = popen("/usr/bin/ls *.c", "r");
```

popen()

"r"



"w"