Fundamentos de los Sistemas Operativos (FSO)

Departamento de Informática de Sistemas y Computadoras (DISCA)
Universitat Politècnica de València

Part 3: File systems and I/O

Seminar 7

Unix file system calls

fSO

Goals and bibliography

- **Goals**
  - To know the **file descriptor** concept
  - To know the **file descriptor table** and its utility
  - To use **Unix file system calls** in C programs
  - To use **Unix process input/output redirection**
  - To do **pipe based process communication** in Unix
- **Bibliography**
  - "UNIX Systems Programming ", Kay A. Robbins, Steven Robbins. Prentice Hall. ISBN 0-13-042411-0, chapters 4, 5 and 6

- **Unix files**
- Unix file system calls
- Redirections and pipes
- Redirection and pipe system calls
- C examples

Unix files

- Secondary storage abstraction
- File types:
  - **Regular:** common files that contain data or binary code (text files, image files, executable files, etc.)
  - **Directory:** file containers which content is directory entries
  - **Pipe:** unnamed sequential access files for interprocess communication
  - **FIFO:** named sequential access files for interprocess communication
  - **Special:** hardware or virtual device system abstraction, for instance:
    - Console devices are /dev/ttyX (X=0,1,..)
    - Sound card is /dev/dsp
    - Virtual sink is /dev/null

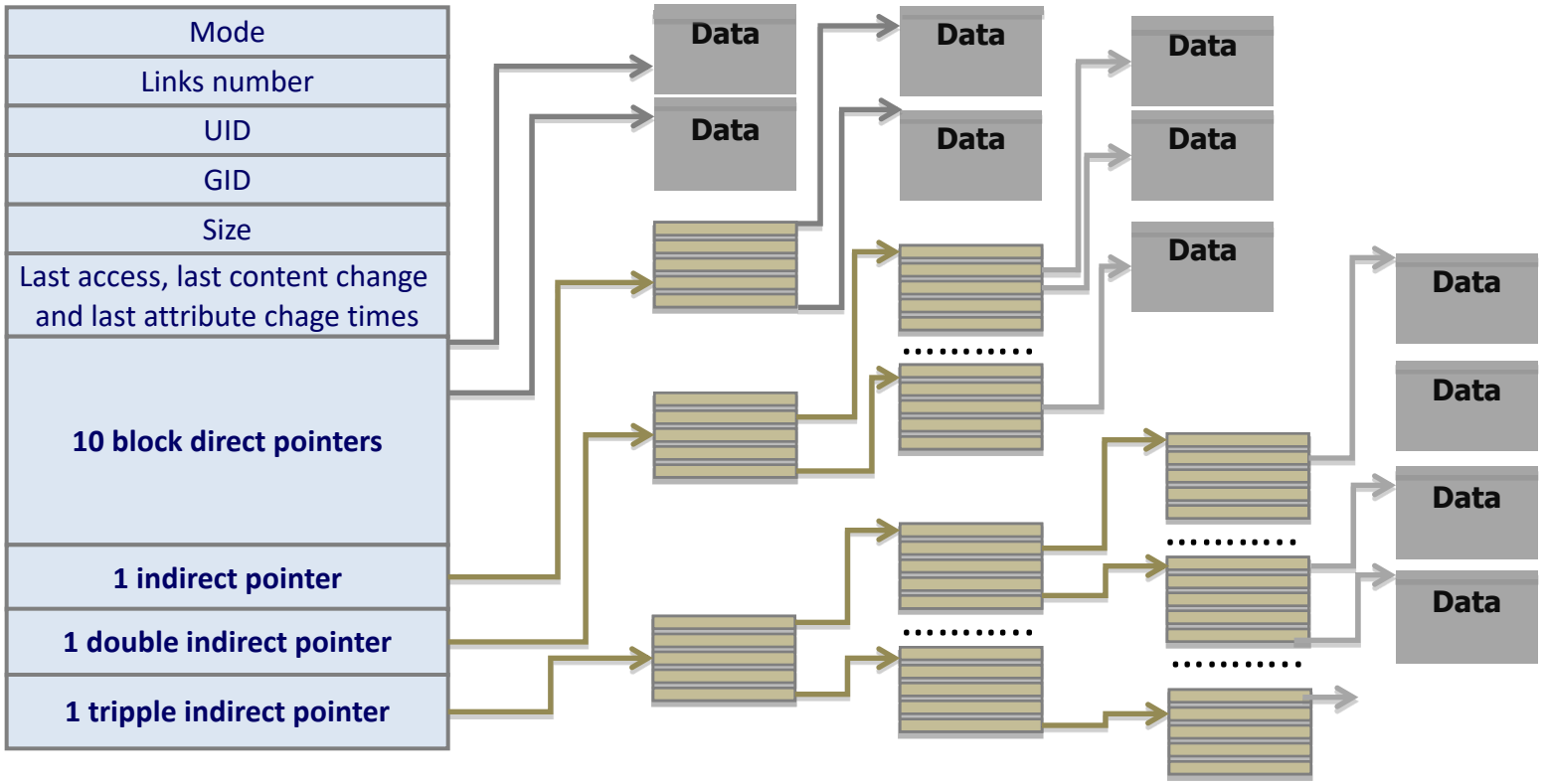
Note: In the UNIX shell the file type is shown by `ls -la` command as:

- Regular file: '–'
- Directory: 'd'
- Special: 'c' (character device) o 'b' (block device)
- FIFO: 'p'

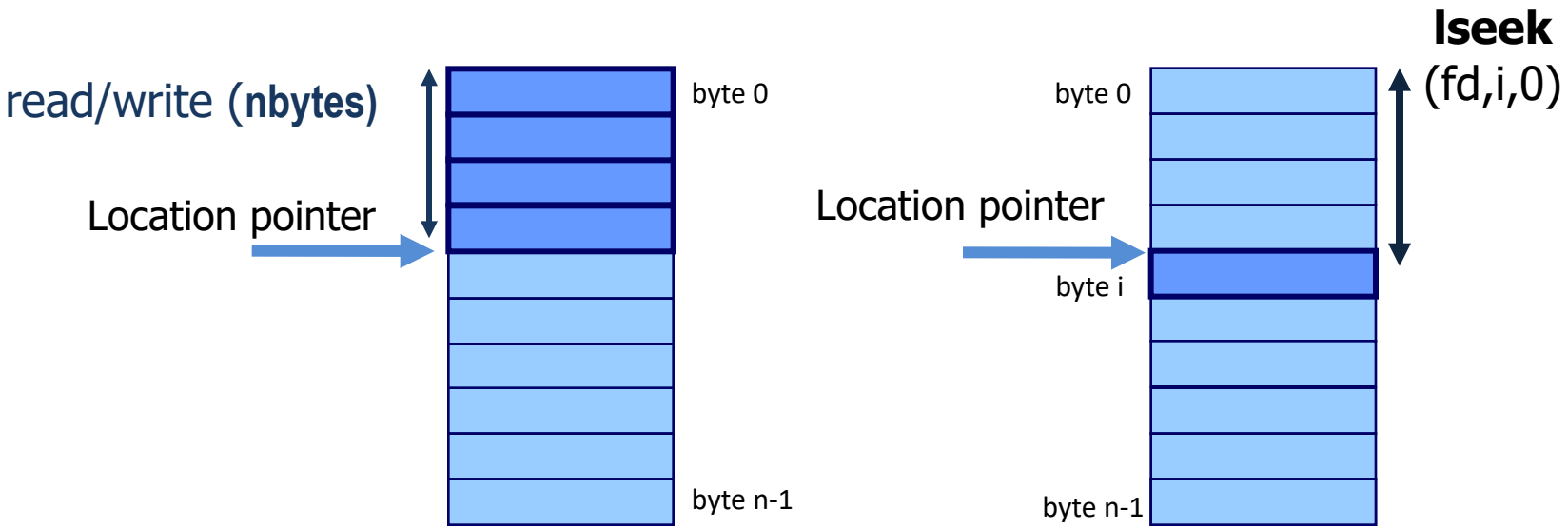
Unix files

- **File attributes in Unix**
  - File type
  - Owner user (UID)
  - Owner group (GID)
  - Access permissions (permission bits)
  - Number of links
  - Creation, last access and last change time stamps
  - Size

- **Unix directory entry: i-node**
  - OS data structure to store file attributes except its name (a file can have several names or links)
    - Every Unix file has one i-node
    - It points to file content using indexed block allocation that can be direct, indirect, double indirect and triple indirect



- **File structure**
  - Vector of bytes
- **File access mode**
  - **Sequential access** with ***read/write*** calls:
    - **read/write (fd, buffer, nbytes)**
  - ***lseek*** allows direct access specifying an offset from the file start, end or actual location
    - **lseek (fd, offset, from_where)**



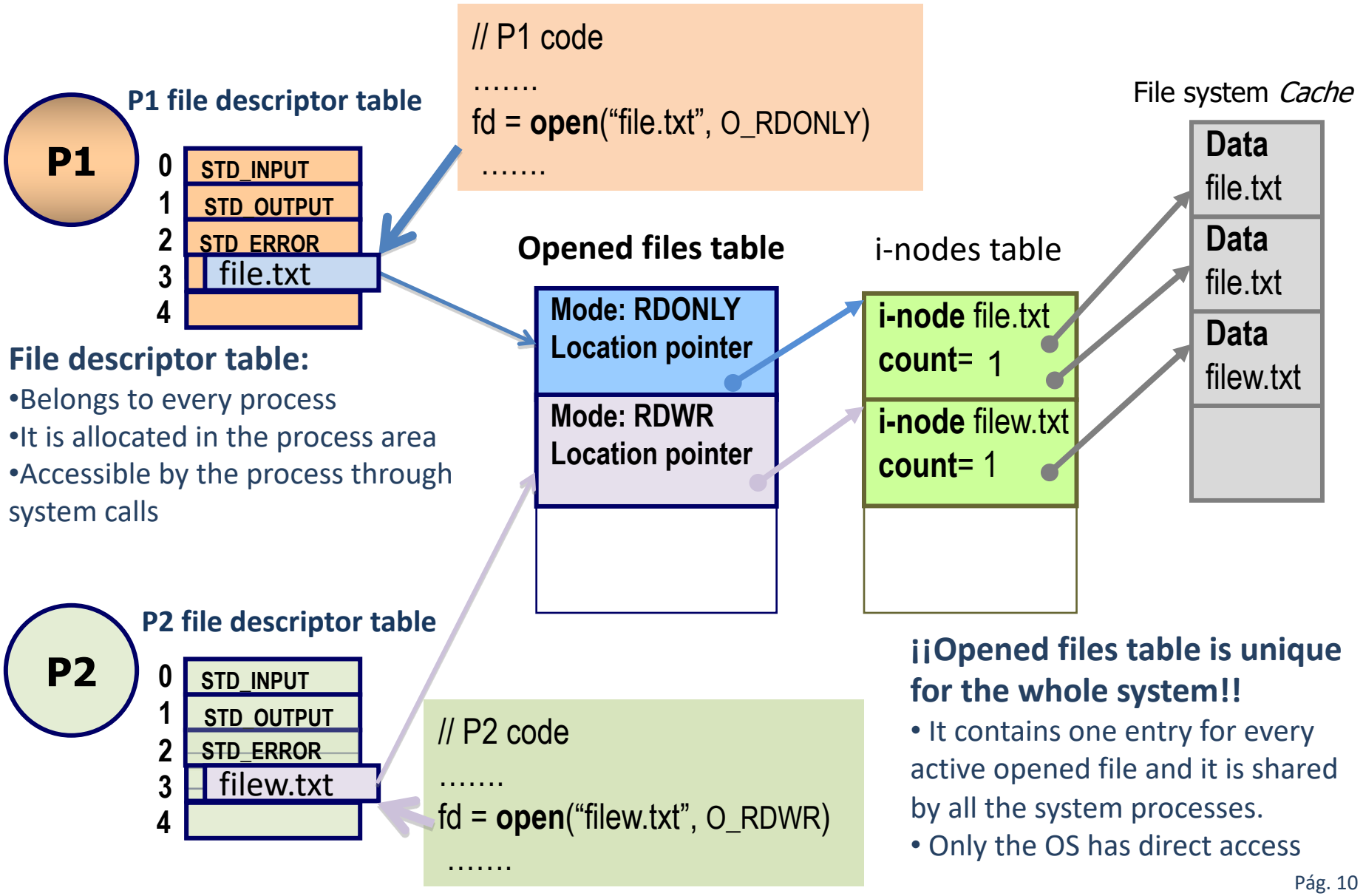
- **File descriptor**
  - To read or write a file it must be first opened and last closed

```
Open:    fd = open(filename, mode)
Access:  read(fd,…), write(fd,…),
         lseek(fd,…), …
Close:   close (fd)
```

  - A file descriptor (fd) is an abstract file identifier local to every process
    - File access inside a process is done through the file descriptor (table index) given by ***open***
    - Working with file descriptors does file access more efficient, avoids looking for them in disk for every access

- **Open file operation**
  - It looks for the file in the directory structure and brings its attributes to an entry in the opened files table located in main memory
  - It registers some additional attributes like:
    - Location pointer
    - Number of active open calls
    - Disk location of data
  - The file content is brought partially into memory buffers
- **Close file operation**
  - It frees the corresponding entry in the opened files table

- **Opened files table vs file descriptor table**



File descriptor table:

- Belongs to every process
- It is allocated in the process area
- Accessible by the process through system calls

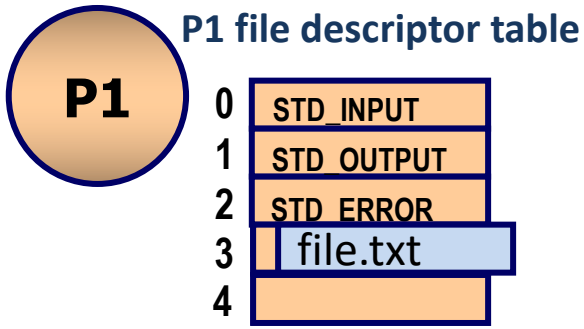
¡¡Opened files table is unique for the whole system!!

- It contains one entry for every active opened file and it is shared by all the system processes.
- Only the OS has direct access

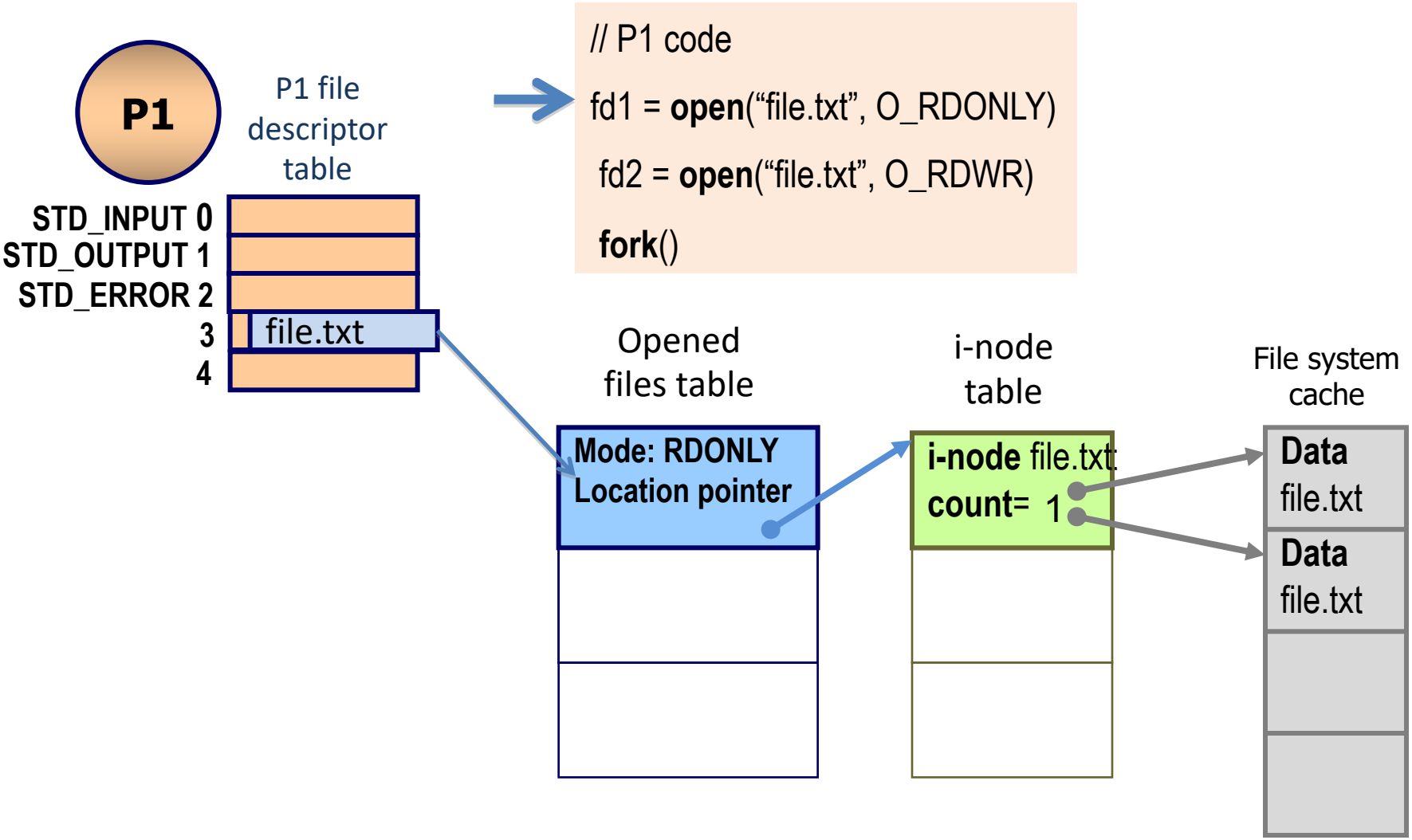
- File descriptors and standard I/O
  - The first three file descriptors in a process have a proper name:

Descriptor	Constants	FILE *
0	STDIN_FILENO	*stdin*, standard input
1	STDOUT_FILENO	*stdout,* standard output
2	STDERR_FILENO	*stderr,* standard error

  - By default these file descriptors are associated to the console
    - Console devices are /dev/ttyn or /dev/ptn/n
    - This associations can be modified using pipes or redirections
- Use examples:
  - **From the C library** *scanf* reads from standard input and *printf* writes on the standard output
  - **From the Shell**: its commands read and write on the standard I/O, for instance, command "ls" writes the file listing on the standard outputand writes the error message "No such file or directory" in the standard error

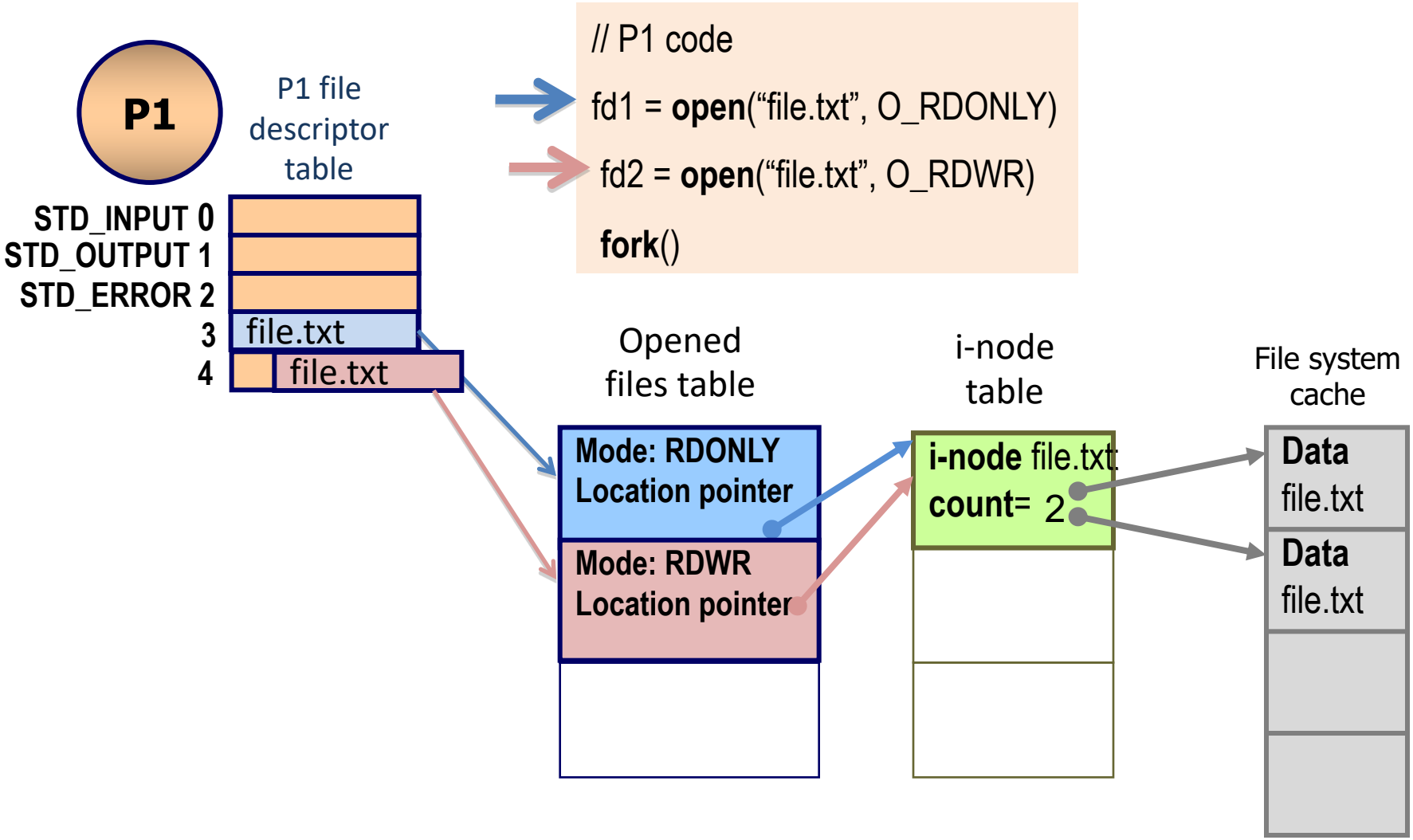


- **Inheriting the file descriptor table**

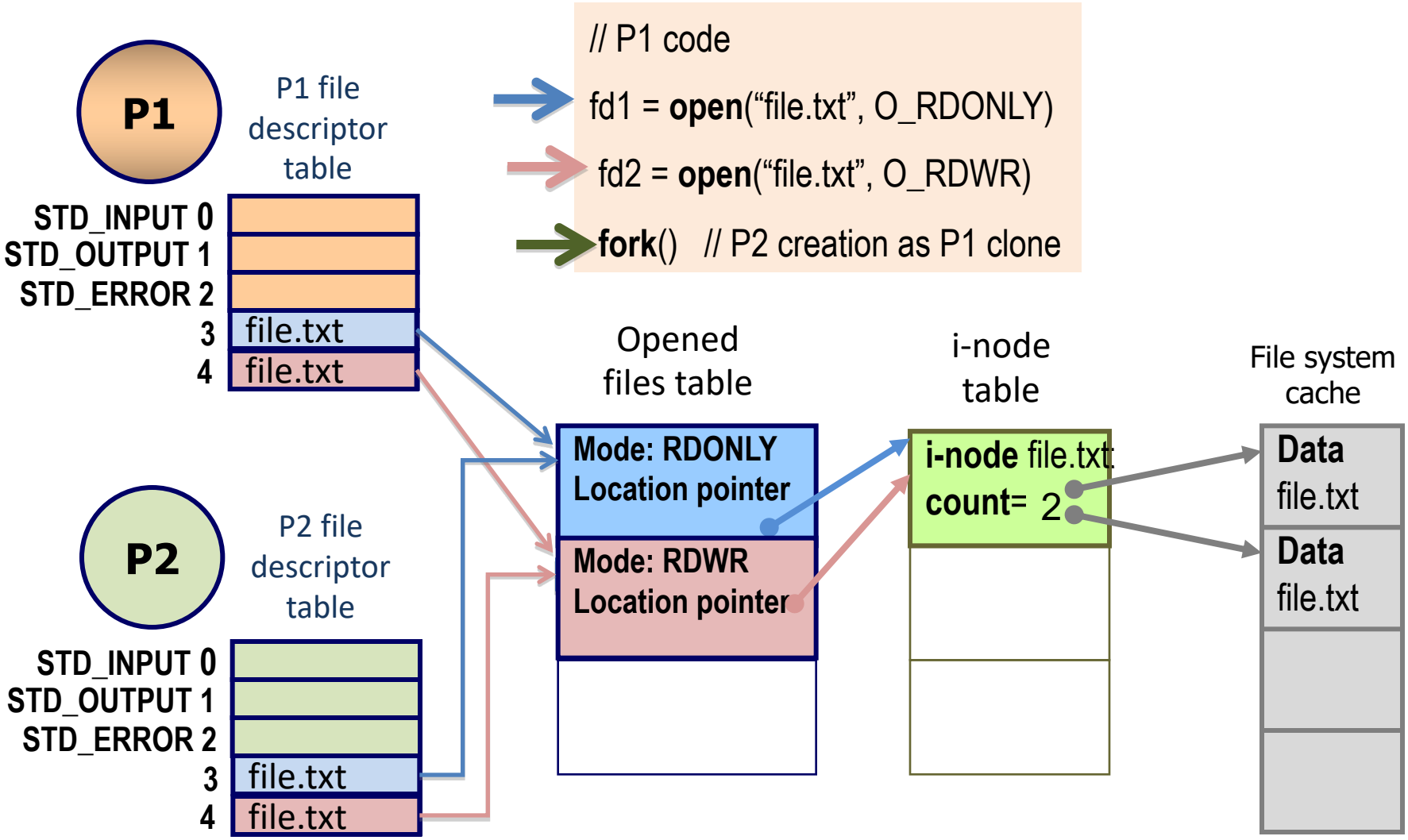


¡¡There is only one opened files table in the system!!

- **Inheriting the file descriptor table**



- **Inheriting the file descriptor table**



!!!Opened file descriptor are inheritable attributes

- Unix files
- **Unix file system calls**
- Redirections and pipes
- Redirection and pipe system calls
- C examples

Unix file system calls

- System call to work with files and devices
  - Unix implements a unified interface to access files and I/O devices

	Description
open	It opens/creates files
read	It reads files
write	It writes files
close	It closes a file
lseek	It sets file pointer location
stat	It gets information from file i-node

Note. Sytem calls “read” and “write” don’t perform any format conversion, so formated I/O functions in C like *scanf* and *printf* include format conversion code

open: opening/creating files

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

int open(const char *path, int flags)
int open(const char *path, int flags, mode_t mode)
```

Description

- It associates a file descriptor with a file or hardware device
  - The lower free descriptor in the file descriptor table is chosen
  - Opened file descriptors are inheritable attributes
- `Flags`

  `O_RDONLY, O_WRONLY, O_RDWR`
  `O_CREAT, O_EXCL, O_TRUNC, O_APPEND`
- `Mode` `Examples: 0755, 04755`

  `S_IRUSR, S_IWUSR, S_IXUSR, S_IRWXU`
  `S_IRGRP, S_IWGRP, S_IXGRP, S_IRWXG`
  `S_IROTH, S_IWOTH, S_IXOTH, S_IRWXO`
  `S_ISUID, S_ISGID`

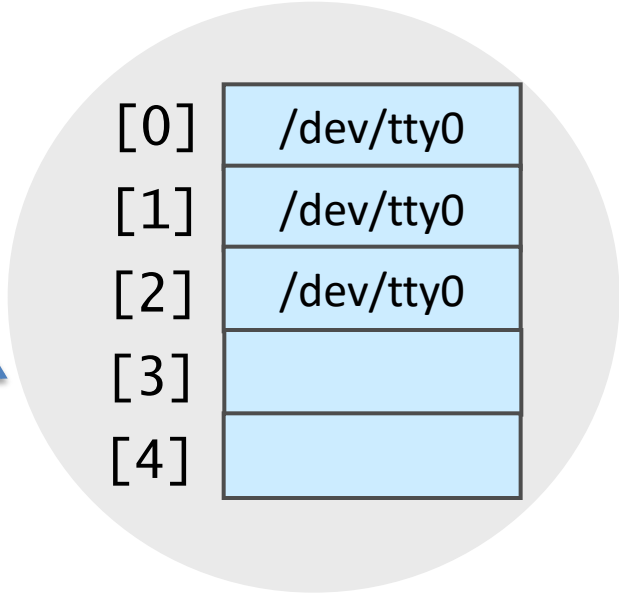
Unix file system calls

- open(): opening/creating a file
  - Example

```
#include <fcntl.h>
#include <stdlib.h>

main ( int argc, char* argv[] )
{
    int fd = open ("my_file", O_RDONLY);

    if (fd == -1)
    {
         perror("Open file error:");
         exit(1);
    }
}
```



File named "my_file" is associated to entry 3 on the file descriptor table → fd = 3

read/write: reading/writing files

```
#include <unistd.h>

ssize_t read(int fd, void *buf, size_t nbyte)
ssize_t write(int fd, const void *buf, size_t nbyte)
```

Description

- **read:** it asks for reading "nbyte" bytes from the file with **fd** file descriptor
  - Read bytes are stored in **buf**
  - It can read less bytes than the ones asked for if the end of file is reached
- **write:** It asks for writing "nbyte" bytes taken from **buf** in the file with **fd** file descriptor.
- By default **read** and **write** are blocking and can be interrupted by a signal
- **Returning value**

  integer > 0: it corresponds to the number of read/written bytes

  -1: error or interrupted by a signal (errors: fd is not a valid descriptor, `buf` is not a valid address, disk full, not allowed operation, etc.)

  0: a read attempt after end of file

Unix file system calls

close: closing a file

```
#include <unistd.h>

int  close(int fd)
```

Description

- It closes the fd file descriptor freeing that file descriptor table location
- Returning value

  0: success

  -1: error and sets appropriate *errno* printable with “perror” (errno.h)

  i.e. EBADF: fd is not a valid file descriptor

Content

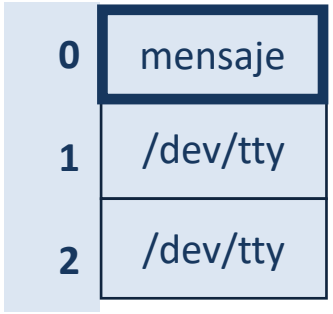
- Unix files
- Unix file system calls
- **Redirections and pipes**
- Redirection and pipe system calls
- C examples

Redirections and pipes

- Standard I/O redirection from the shell

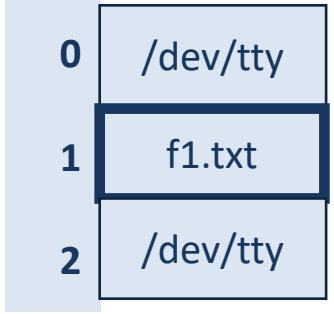
—Standard input redirection

```
$ mail gandreu < mensaje
```



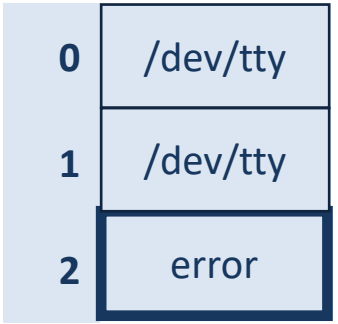
—Standard output redirection

```
$ echo hola > f1.txt
```



—Standard error redirection

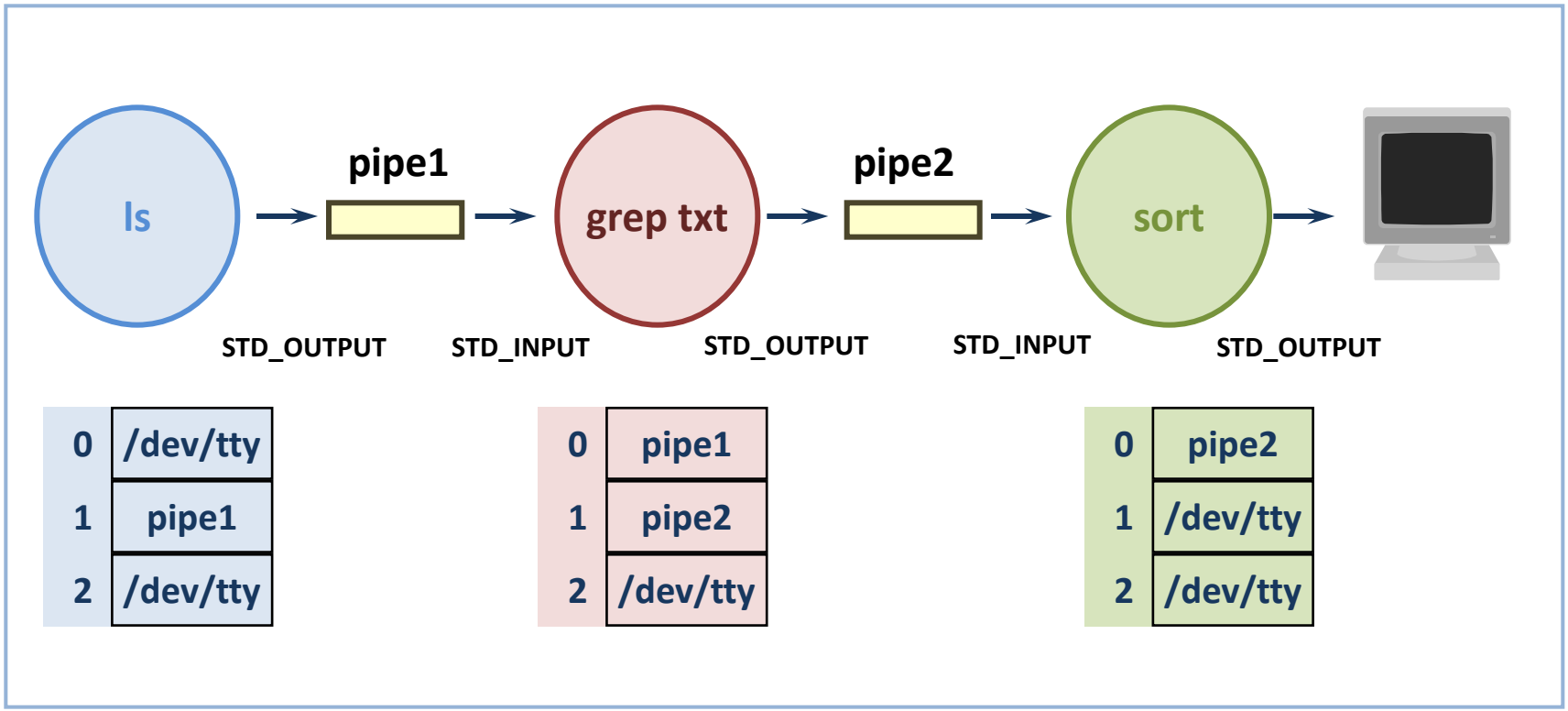
```
$ gcc prg.c -o prg 2> error
```



Redirections and pipes

- **Unix interprocess communication**
  - Unix provides the **pipe** mechanism to support interprocess communication
    - They are a special type of sequential access files with limited capacity
    - They can be shared due to inheritance mechanism

$ ls | grep txt | sort



- Unix files
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- **Redirection and pipe system calls**
- C examples

Redirection and pipe system calls

- They allow performing communication between parent and children processes relying on inheritance

	Description
dup2	It duplicates a file descriptor
pipe	It creates an unnamed pipe
mkfifo	It creates a named pipe

dup, dup2: duplicating a file descriptor

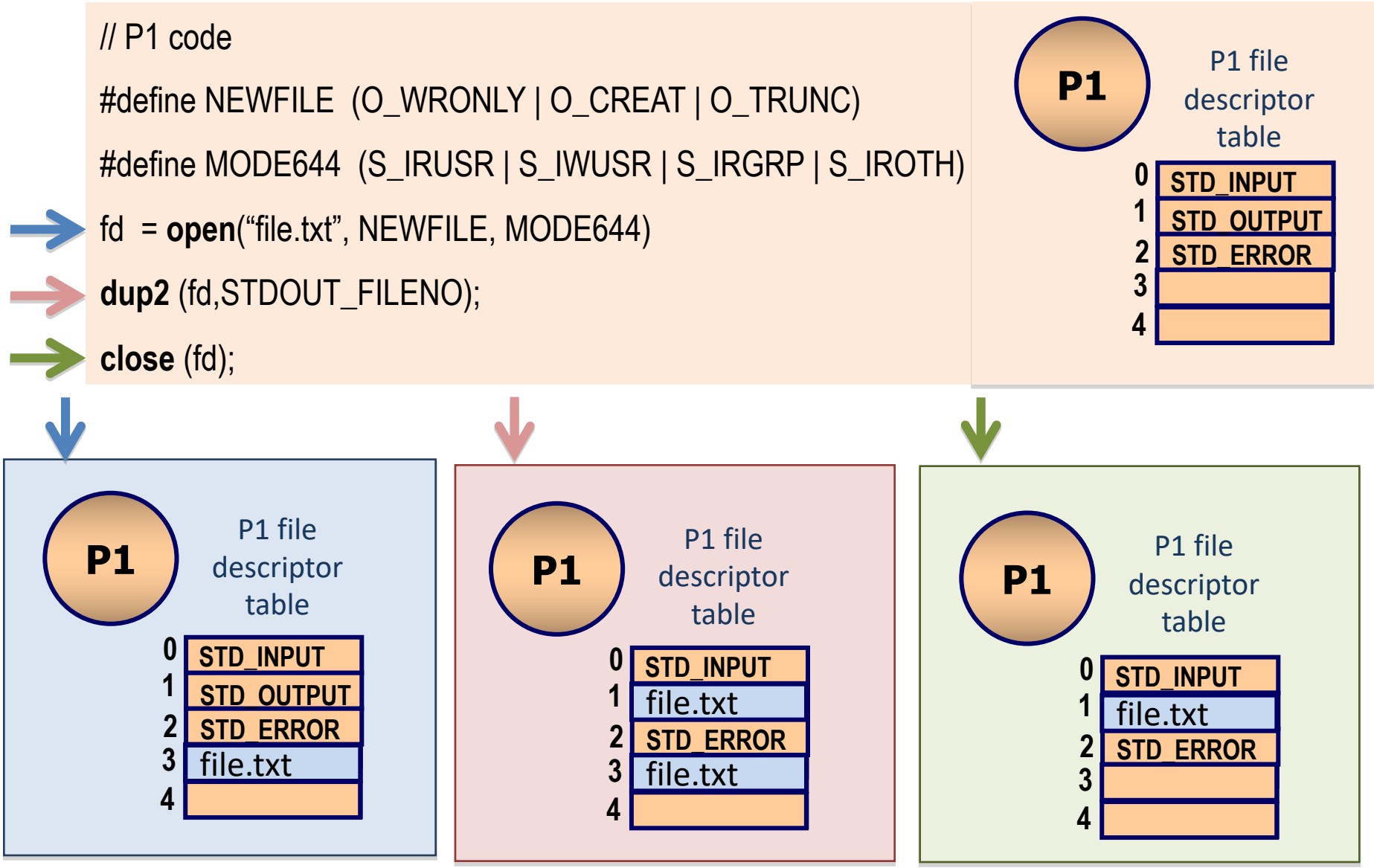
```
#include <unistd.h>
int dup(int fd)
int dup2(int oldfd, int newfd)
```

Description

- **dup:** it returns a file descriptor value of a file which content is a copy of the one that corresponds to parameter **fd**
  - The returning descriptor is the lowest available in the process file descriptor table
- **dup2:** it closes **newfd** descriptor and then it copies **oldfd** into **newfd**
- Returning value
  - New descriptor file
  - -1 **error**: fd is not a valid descriptor. It surpasses the maximum number allowed of opened files (OPEN_MAX)

Example: dup2

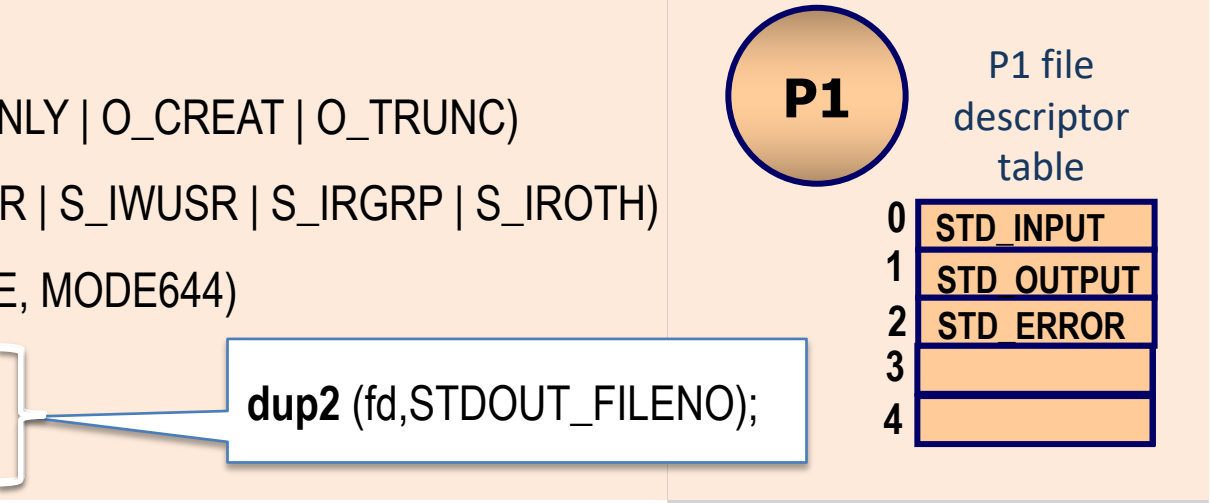
```
// P1 code
#define NEWFILE  (O_WRONLY | O_CREAT | O_TRUNC)
#define MODE644  (S_IRUSR | S_IWUSR | S_IRGRP | S_IROTH)
fd  = open("file.txt", NEWFILE, MODE644)
dup2 (fd,STDOUT_FILENO);
close (fd);
```

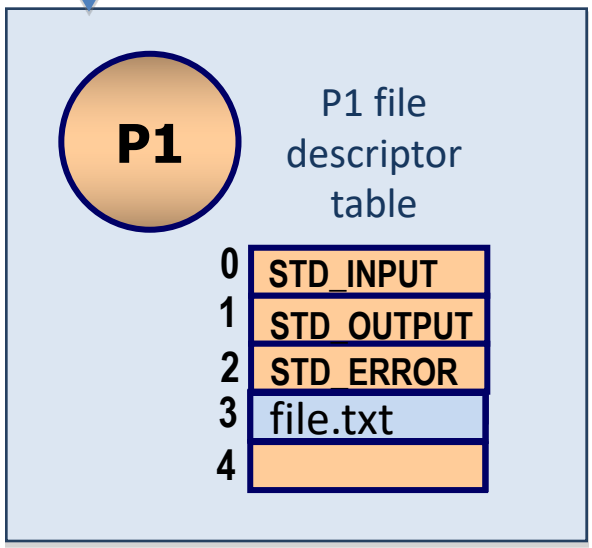


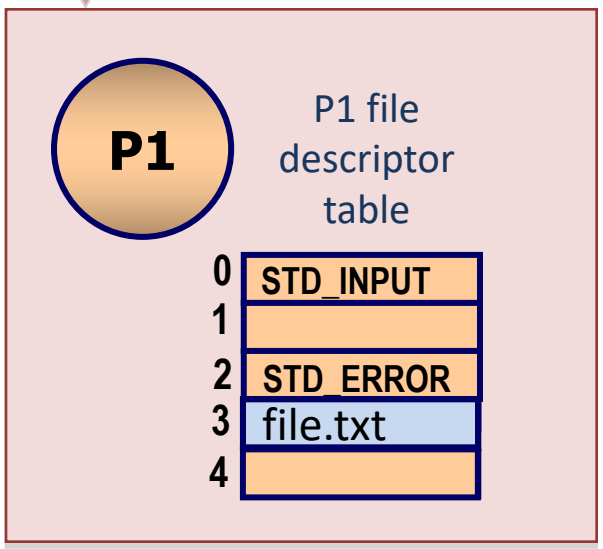
Example: dup

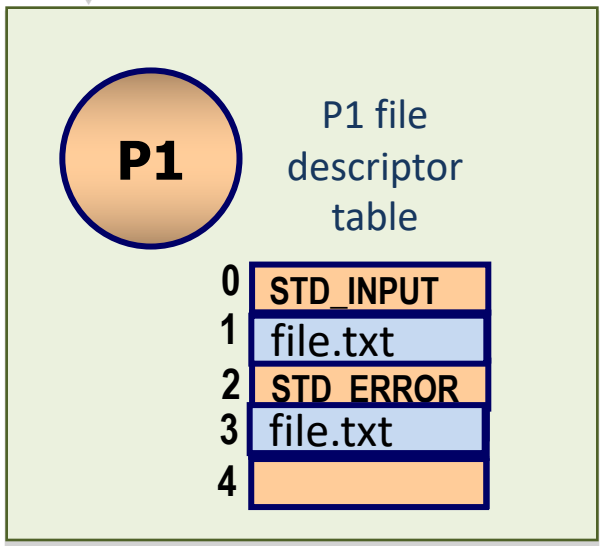
```
// P1 code
#define NEWFILE  (O_WRONLY | O_CREAT | O_TRUNC)
#define MODE644  (S_IRUSR | S_IWUSR | S_IRGRP | S_IROTH)
fd  = open("file.txt", NEWFILE, MODE644)
close (STDOUT_FILENO);
dup (fd);
```

dup2 (fd,STDOUT_FILENO);









pipe: creating a pipe

```
#include <unistd.h>
int pipe(int fildes[2])
```

Description

- It creates a *pseudofile* (pipe) structured as a FIFO queue of bytes that is initially empty
  - Pipes are a interprocess communication provided by UNIX
  - The maximum pipe capacity is limited by the OS
- After **pipe** call, **fildes[0]** is a file descriptor to read the pipe and **fildes[1]** is a file descriptor to write the pipe
- Pipes together with the access descriptors are inherited by children processes and preserved after **exec** call
- Returning value
  - 0 success
  - -1 error: **fildes** is not valid, it surpasses the maximum number allowed of opened files (OPEN_MAX)

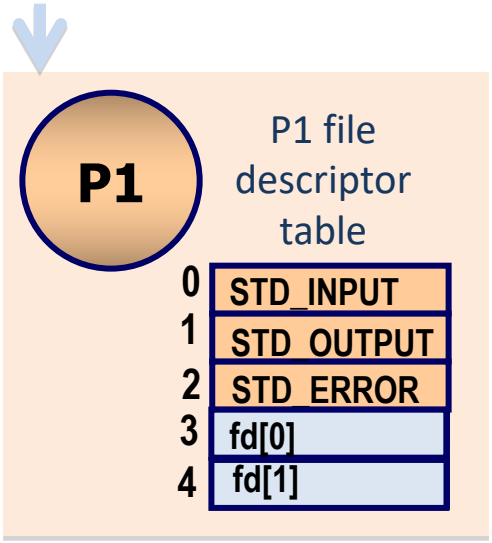
Pipe operation

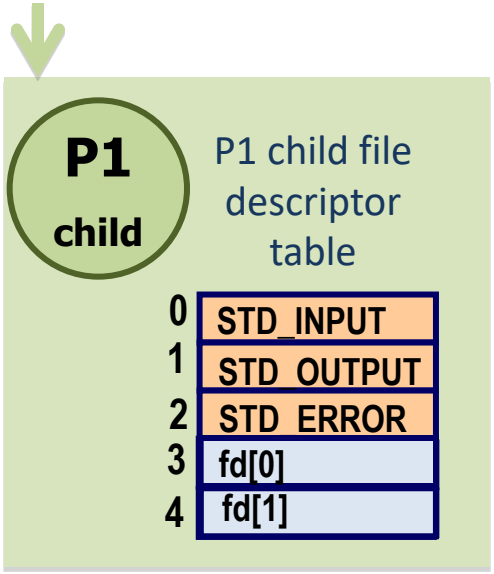
- **read**
  - If there are bytes available, at most the requested **nbytes** are read
  - It pipe is empty, **read** suspends the calling process until bytes are available in the pipe
  - When there is no pipe writing descriptor (bellowing to the reading process or any other one) **read** doesn't suspend the process and returns 0, noticing in this way the ending data condition (end of file)
- **write**
  - If there is enough pipe capacity to allocate the nbytes to write they are stored into the pipe in FIFO order
  - If there is not enough capacity (pipe full) the writing process is suspended until space is available
  - If writing is done into a pipe that doesn't own a reading descriptor (bellowing to the reading process or any other one) the process that intends to write receives a SIGPIPE signal
    - This mechanism eases automatic removing of a pipe communicating process chain when one of its components aborts unexpectedly

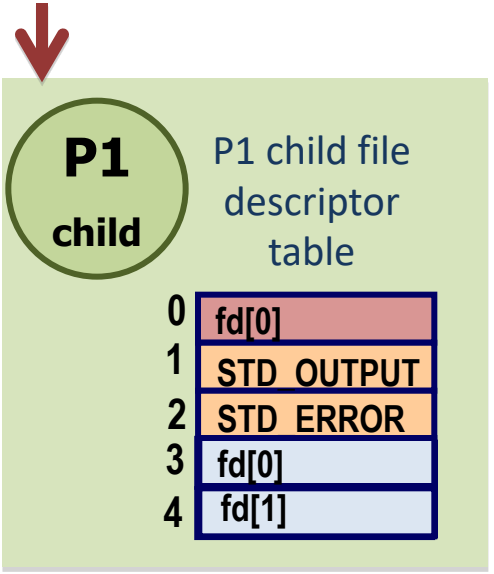
Redirection and pipe system calls


```
// P1 process code
pipe(fd);
if (fork() == 0)  {

// Child process code
    dup2 (fd[0], STDIN_FILENO);
    close (fd[0]);
    close (fd[1]);
    ...
} else {
// Parent process code
  dup2 (fd[1], STDOUT_FILENO);
  close (fd[0]);
  close (fd[1]);
  ...
}
```







Redirection and pipe system calls

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    ...
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  close (fd[0]);
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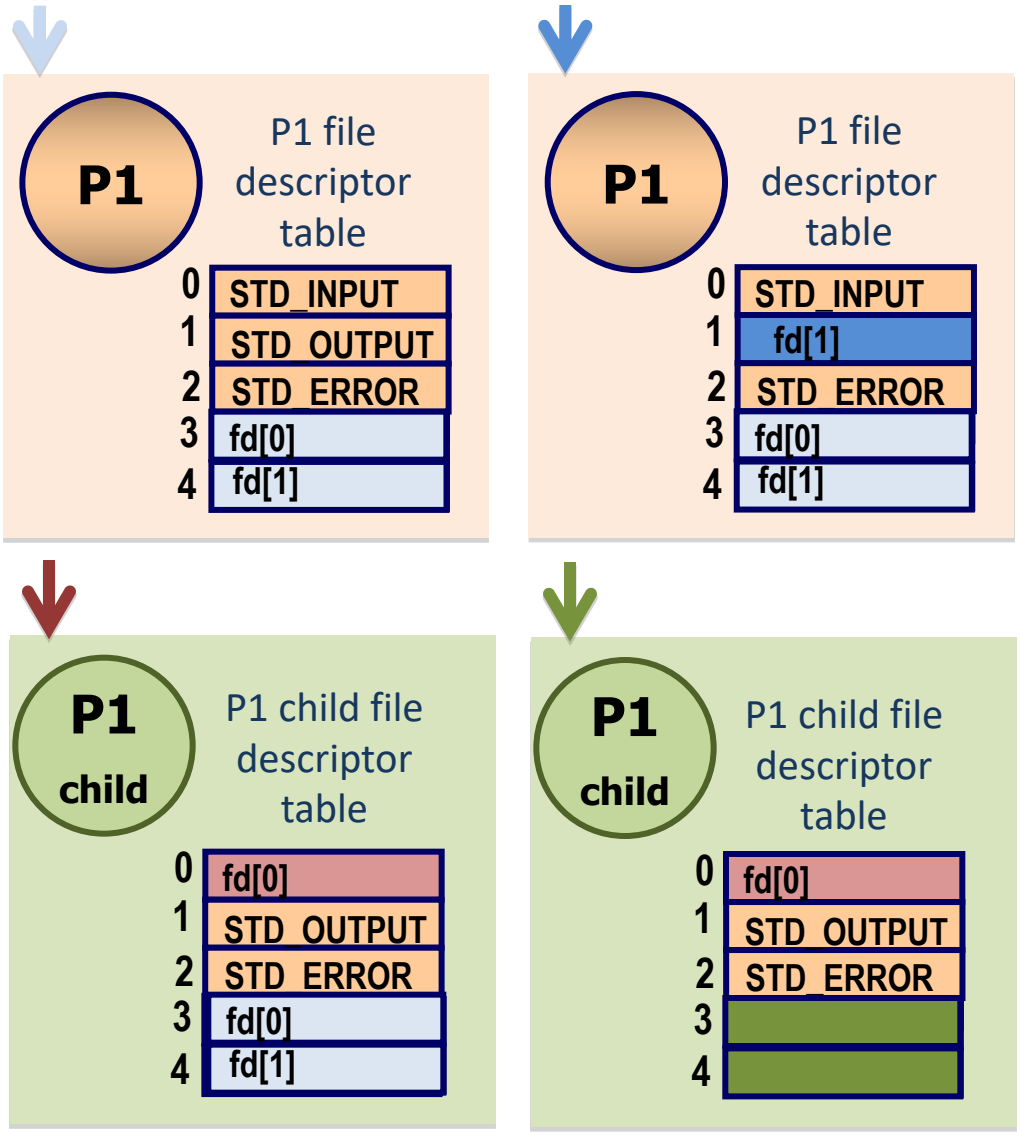
}
```



Redirection and pipe system calls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// Child process code
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// Parent process code
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  close (fd[0]);
  close (fd[1]);
  ...
}
```

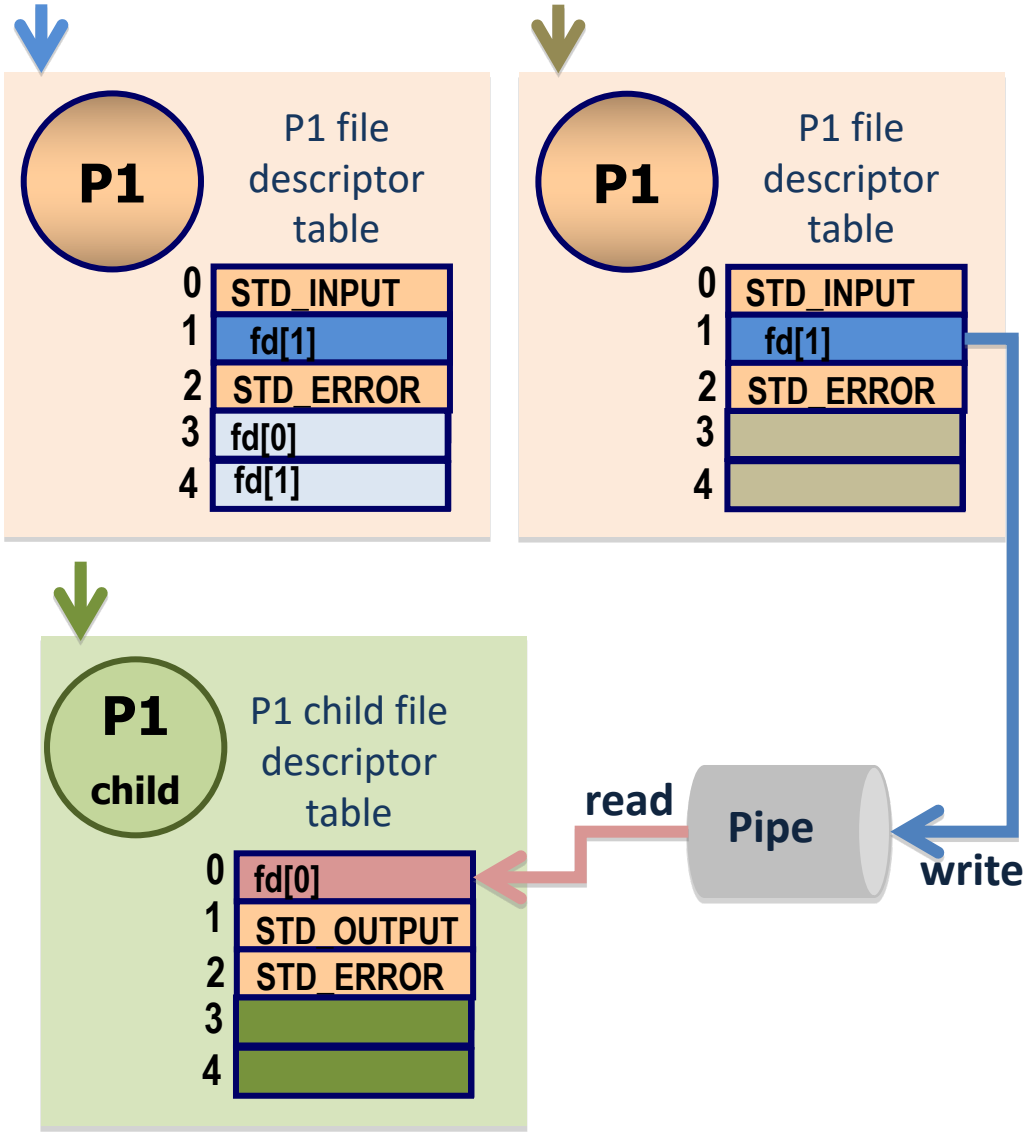

Content

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- **C examples**

C examples

- **Example:** open, write and read

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

#define BLKSIZE 1
#define NEWFILE (O_WRONLY| O_CREAT | O_EXCL)
#define MODE600 (S_IRUSR | S_IWUSR)
```

```
int main(int argc, char *argv[]) {
  int from_fd, to_fd;
  int count;
  char buf[BLKSIZE];

  if (argc != 3) {
    fprintf(stderr, "Usage: %s from_file to_file\n", argv[0]);
    exit(1);}
  if ( (from_fd = open(argv[1], O_RDONLY)) == -1) {
    fprintf(stderr,"Could not open %s: %s\n", argv[1],strerror(errno));
    exit(1);
  }
  if ( (to_fd = open(argv[2], NEWFILE,MODE600)) == -1) {
    fprintf(stderr, "Could not create %s: %s\n", argv[2],strerror(errno));
    exit(1);
  }
  while ( (count= read(from_fd, buf, sizeof(buf))) >0 ) {
    if (write(to_fd, buf, count) != count){
      fprintf(stderr,"Could not write %s: %s\n", argv[2],strerror(errno));
      exit(1); }
    }
  if (count==-1){
    fprintf(stderr, "Could not read %s: %s\n", argv[1],strerror(errno));
    exit(1);
  }
  close(from_fd);
  close(to_fd);
  exit(0);
}
```

To compile and execute do:

```
$ gcc my_copy.c -o my_copy
$ echo 'Hello read write' > hi.txt
$ ./my_copy hi.txt hi_copy.txt
$ cat hi_copy.txt
```

- **Example:** dup2

```
#include <sys/types.h>
#include <sys/stat.h>
#include <stdio.h>
#include <unistd.h>
#include <fcntl.h>

#define NEWFILE (O_WRONLY | O_CREAT | O_EXCL)
#define MODE644 (S_IRUSR | S_IWUSR | S_IRGRP | S_IROTH)
```

```
int redirect_output(const char *file) {
  int fd;
  if ((fd = open(file, NEWFILE, MODE644)) == -1) return -1;
  if ( dup2(fd, STDOUT_FILENO) == -1) return -1;
  close (fd);
  return 0;
}
int main(int argc, char *argv[]) {
  int from_fd, to_fd;
  if (argc < 3) {
    fprintf(stderr,"Usage: %s to_file command args\n",argv[0]);
    exit(1);
  }
  if ( redirect_output(argv[1]) == -1){
    fprintf(stderr,"Could not redirect output to: %s\n",argv[1]);
    exit(1);
  }
  if ( execvp(argv[2], &argv[2]) < 0){
    fprintf(stderr, "Could not execute: %s\n", argv[2]);
    exit(1);
  }
  return 0;
}
```

To compile and execute do:

```
$ gcc dup2.c -o dup2
$ ./dup2 prueba ls
$ cat prueba
```

- **Example:** pipe

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

```
int main(int argc, char *argv[]) {
  int i, fd[2];
  if (argc < 2) {
    fprintf(stderr, "Usage: %s filter\n", argv[0]);
    exit(1);
  }
  pipe(fd);
  for(i=0; i<2; i++) {
    if (fork() == 0) { // children
      dup2 (fd[1], STDOUT_FILENO);
      close (fd[0]);
      close (fd[1]);
      execlp("/bin/ls", "ls", NULL);
      perror("The exec of ls failed");
    }
  }
  // parent
  dup2 (fd[0], STDIN_FILENO);
  close (fd[0]);
  close (fd[1]);
  execvp(argv[1],&argv[1]);
  fprintf(stderr,"The exec of %s failed", argv[1]);
  exit(1);
}
```

To compile and execute do:

```
$ gcc pipe.c –o pipe
$ ./pipe wc
```