ARCOS Group
Universidad Carlos III de Madrid

Lesson 3B
Signals, exceptions and pipes

Operating Systems
Computer Science and Engineering

To remember…

Before classes	Class	After class

Prepare the prerequisites.

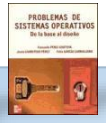
Study the material associated with the **bibliography**: slides alone are not enough.
Please ask questions (especially after study).

Exercising skills:

- Perform all **exercises**.
- Carrying out the **practice notebooks** and **the practical exercises** progressively.

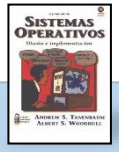
Recommended reading

Base



1. Carretero 2020:
   1. Cap. 5
2. Carretero 2007:
   1. Cap. 3.6 and 3.7
      Cap. 3.9 and 3.13

Suggested



1. Tanenbaum 2006:
   1. (es) Cap. 2.2
   2. (en) Cap.2.1.7
2. Stallings 2005:
   1. 4.1, 4.4, 4.5 and 4.6
3. Silberschatz 2006:
   1. 4

WARNING!

- This material is a script for the class but it is not the notes of the full course.
- The books given in the bibliography together with what is explained in class represent the study material for the course syllabus.

Contents

1. Signals and exceptions.
2. Timers.
3. Process environment.
4. Process communication with pipes, local message passing

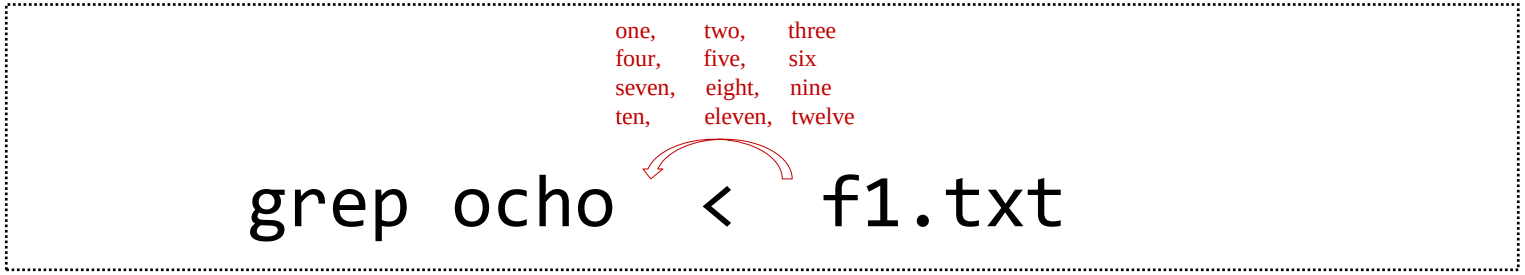
Contents

1. Signals and exceptions.
2. Timers.
3. Process environment.
4. Process communication with pipes, local message passing
   1. **Command interpreter: redirection and piping**
   2. File descriptors:
      - Model: abstraction provided
      - Redirection, duplication and *fork*()
   3. Pipes

Example of input redirection

```
one,    two,    three
four,   five,   six
seven,  eight,  nine
ten,    eleven, twelve
```

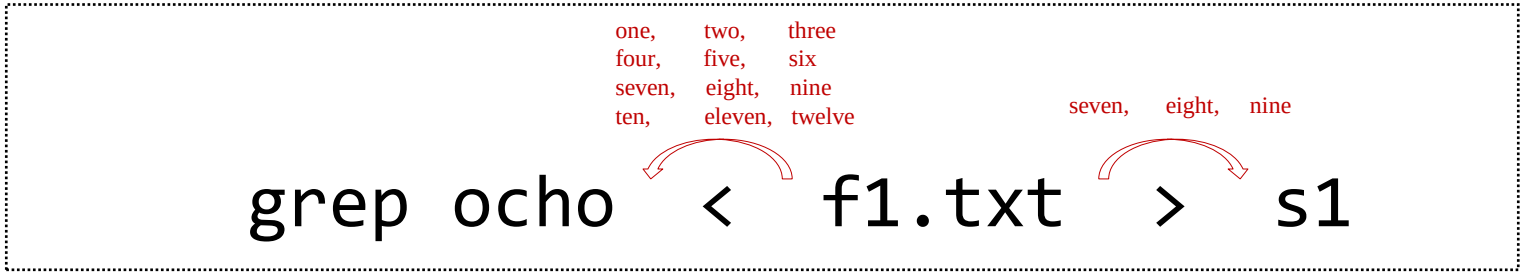
f1.txt



Example of output redirection

```
one,    two,    three
four,   five,   six
seven,  eight,  nine
ten,    eleven, twelve
```

f1.txt



Example of output redirection

f1.txt

```
one,        two,        three
four,       five,       six
seven,      eight,      nine
ten,        eleven,     twelve
```

Dependent on the command interpreter used

seven, eight, nine

```
grep ocho f1.txt 1> s1
```

Example of error redirection

```
one,        two,        three
four,       five,       six
seven,      eight,      nine
ten,        eleven,     twelve
```

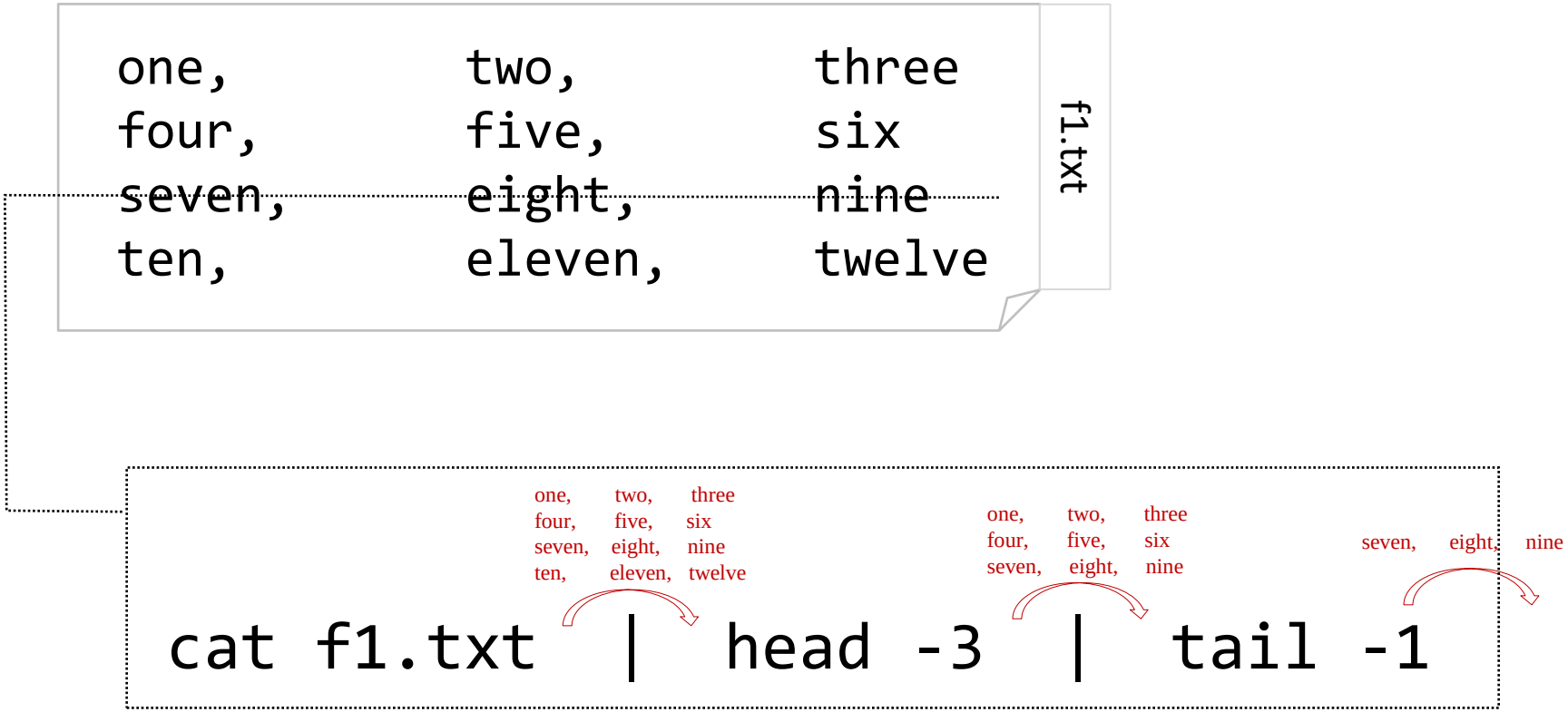
f1.txt

Dependent on the command interpreter used

grep: xx: No such file or directory

```
grep ocho xx  2>  s1
```

Example of the use of pipes



Contents

1. Signals and exceptions.
2. Timers.
3. Process environment.
4. Process communication with pipes, local message passing
   1. Command interpreter: redirection and piping
   2. **File descriptors:**
      - **Model: abstraction provided**
      - **Redirection, duplication and *fork*()**
   3. Pipes

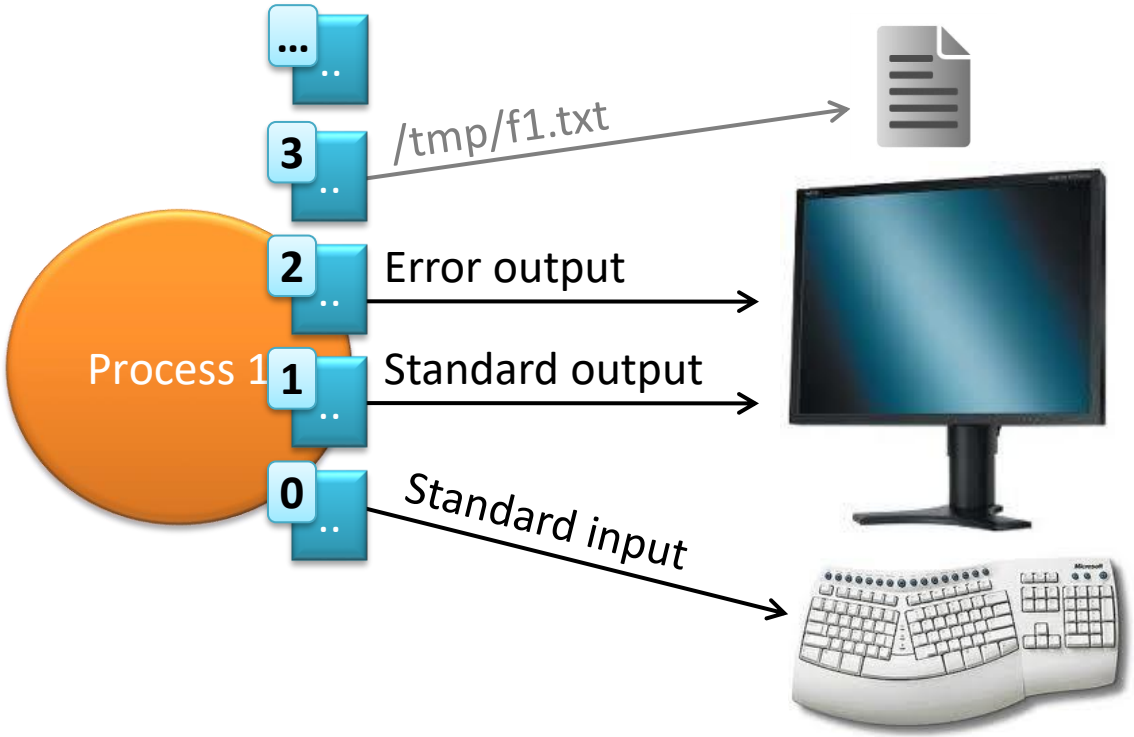
File descriptors

model | redirection | duplication | *fork*()

File descriptors are the index of a table per process (in the BCP)
that allows you to identify the possible files (or devices) with which to communicate.

File descriptors

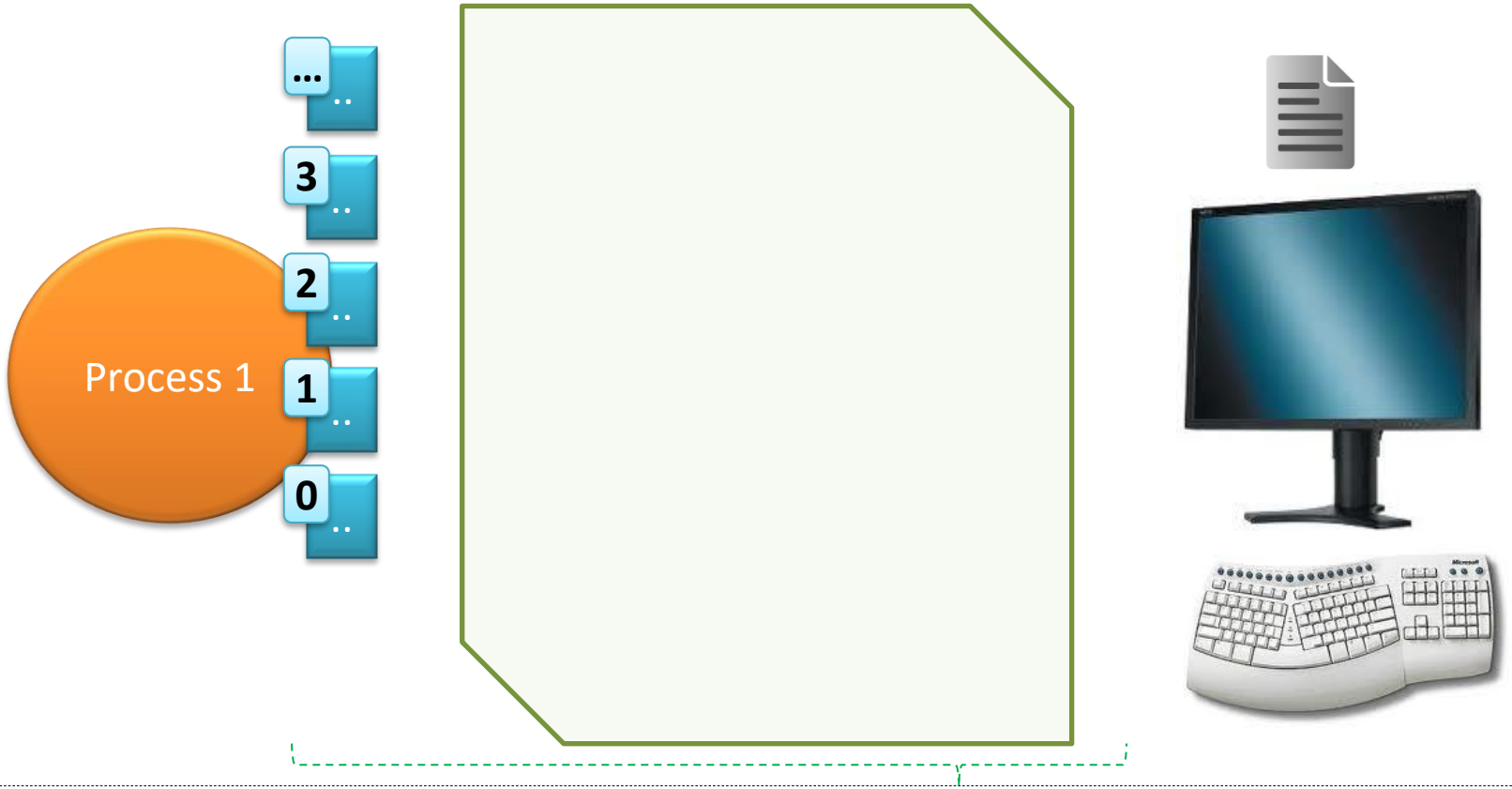
model | redirection | duplication | *fork*()



By default, the first three indexes (file descriptors) are used for standard input, standard output and error output respectively.

File descriptors

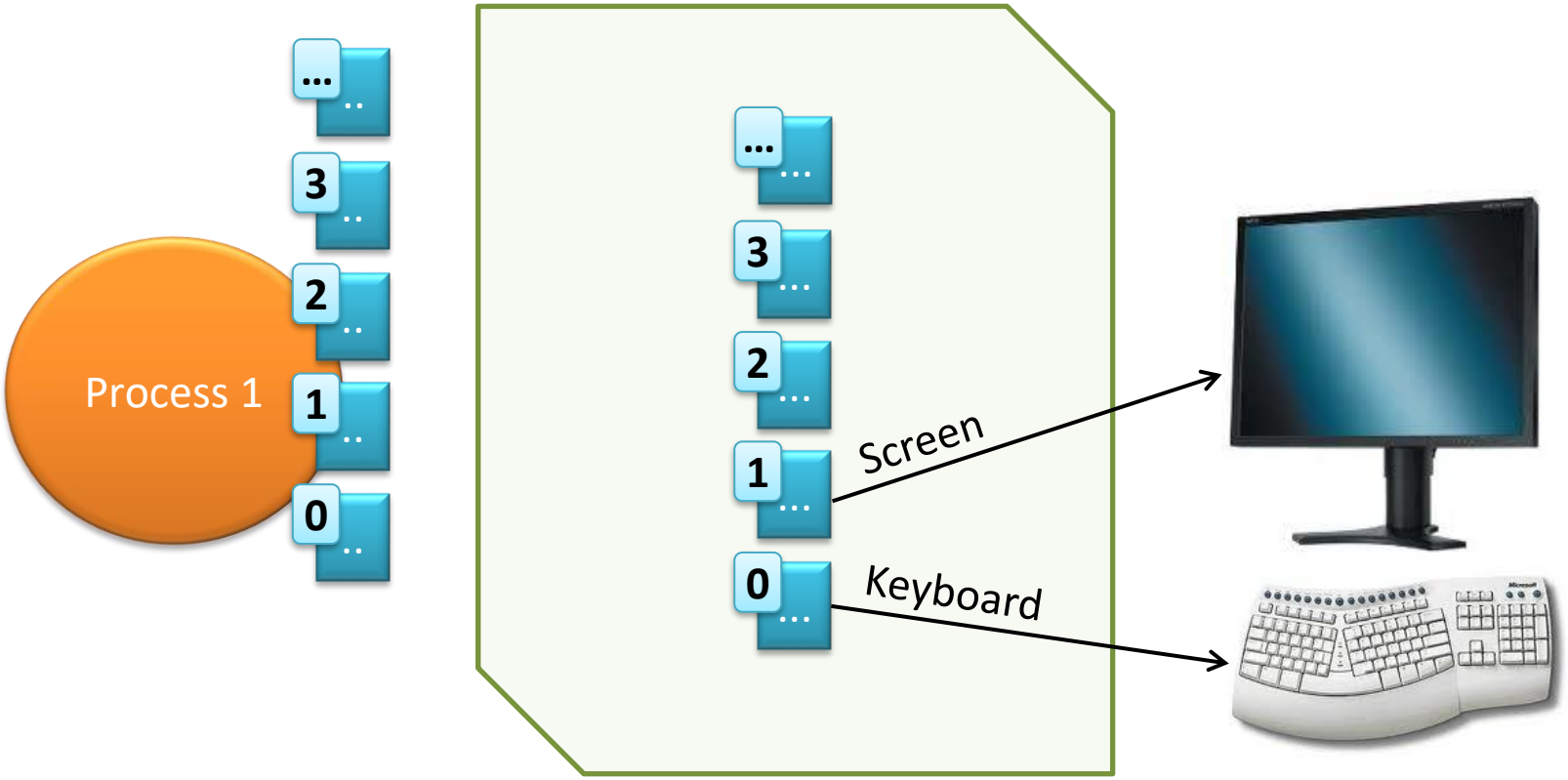
model | redirection | duplication | *fork*()



File descriptors: abstraction provided by the operating system to reference the actual devices and files. Same as a numbered key for a locker.

File descriptors

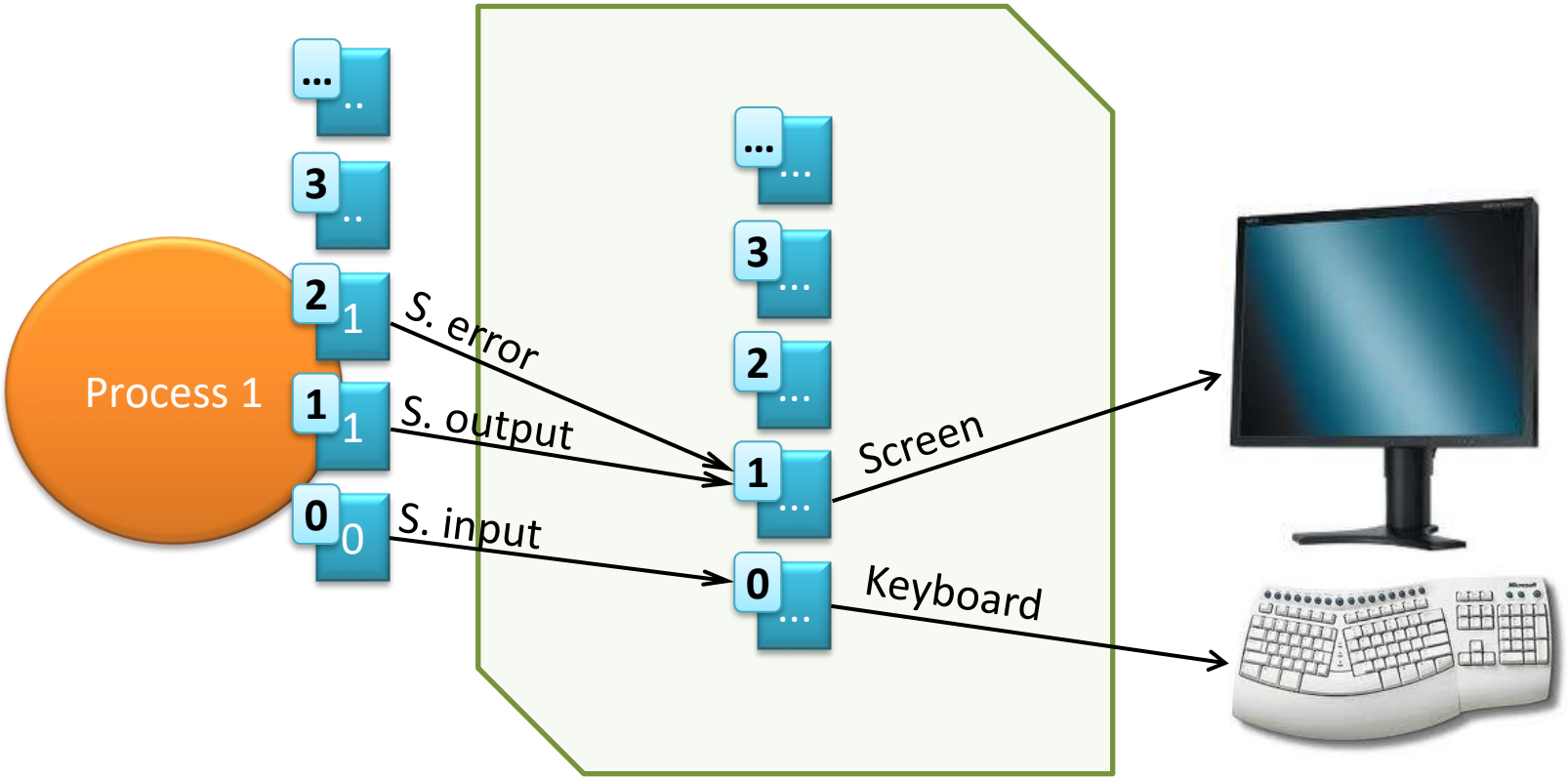
model | redirection | duplication | *fork*()



The operating system maintains an internal table with the actual contact information with the devices and files with which the processes request to communicate…

File descriptors

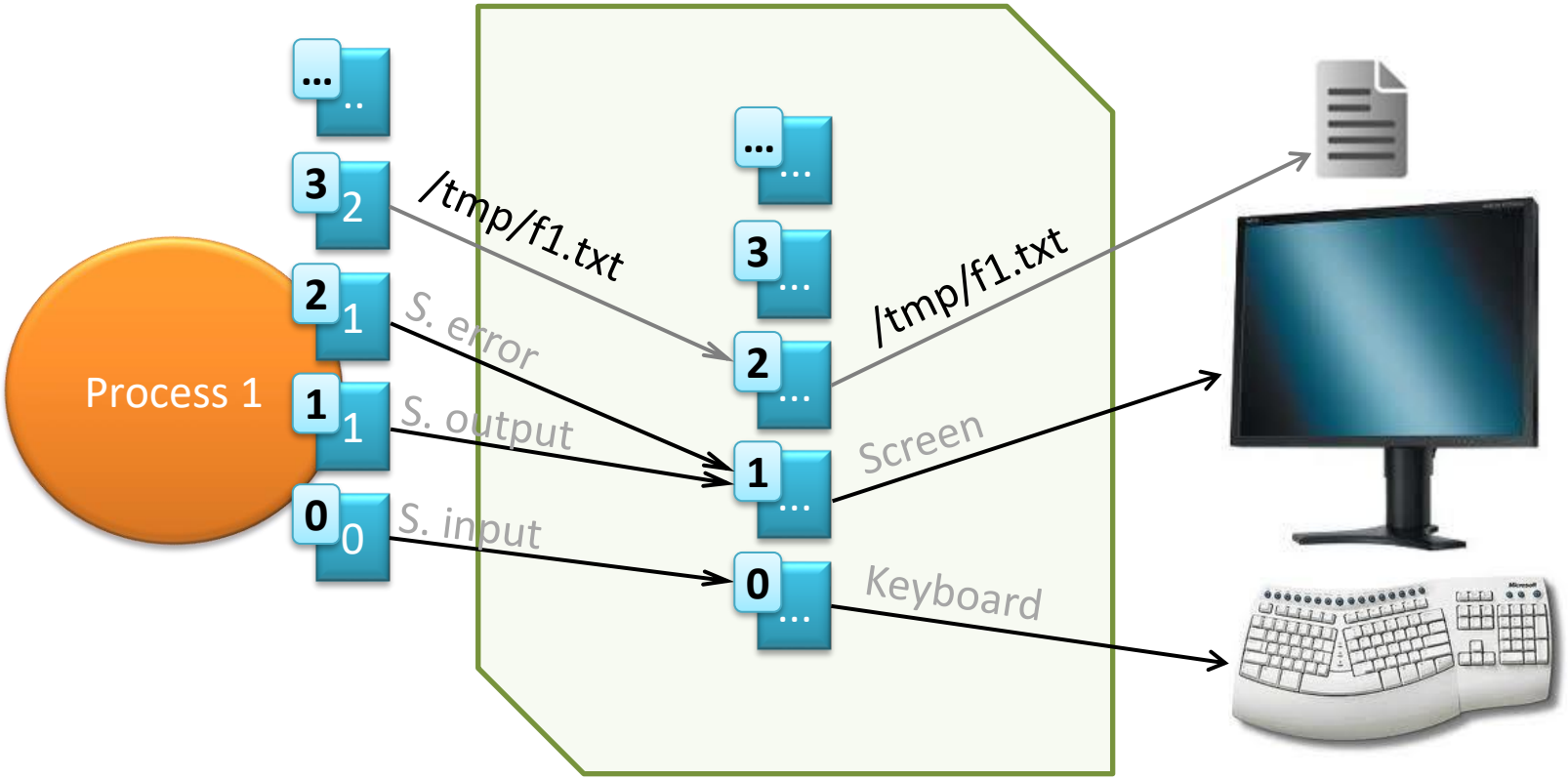
model | redirection | duplication | *fork*()



…And File descriptors are the index of the per-process table, whose content is in turn the index of the internal operating system table.

File descriptors

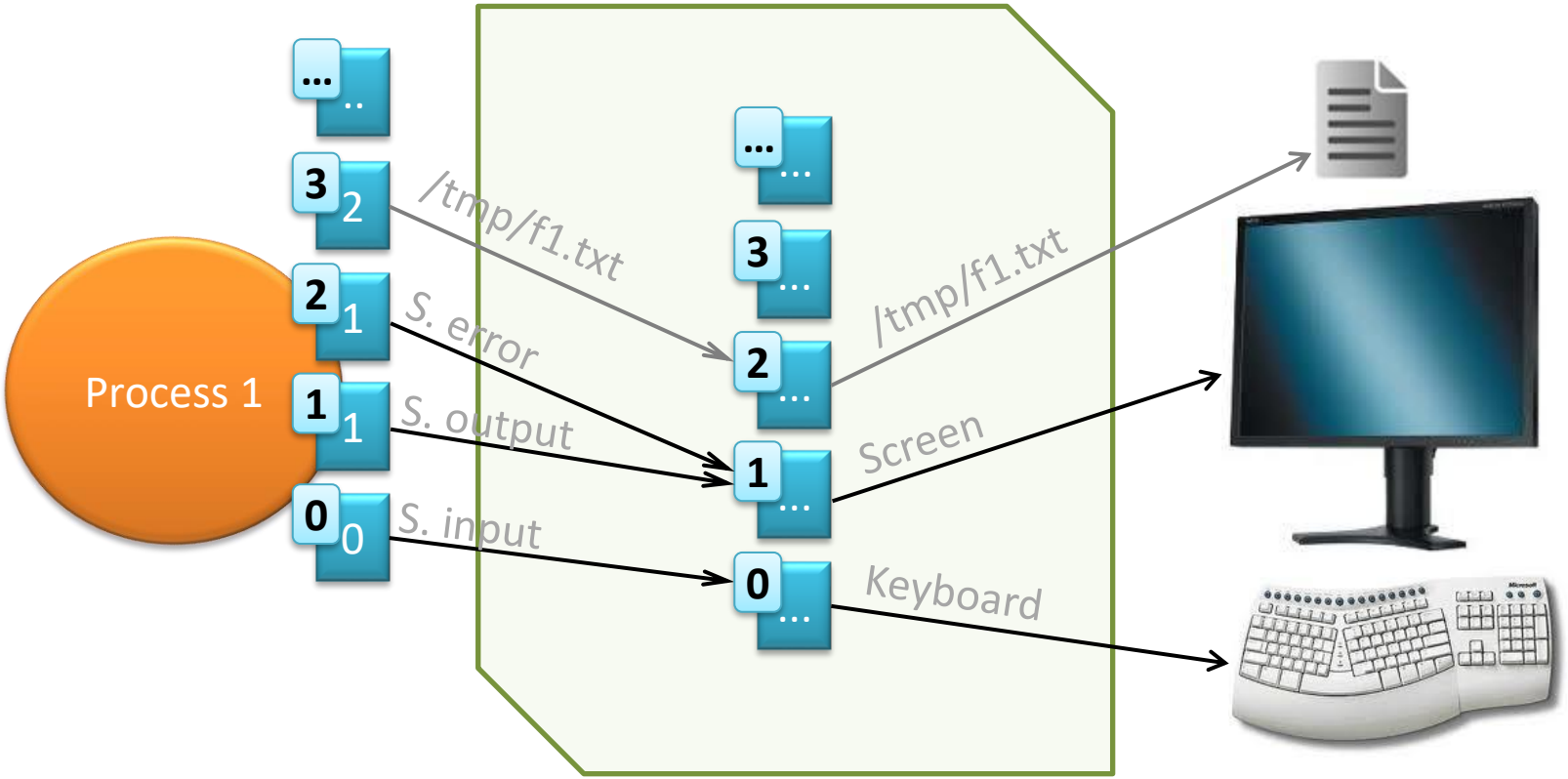
model | redirection | duplication | *fork*()



When a new file descriptor is requested (when opening a file) the first free slot in the table is searched and the index of that position is the assigned descriptor.

File descriptors

model | redirection | duplication | *fork*()



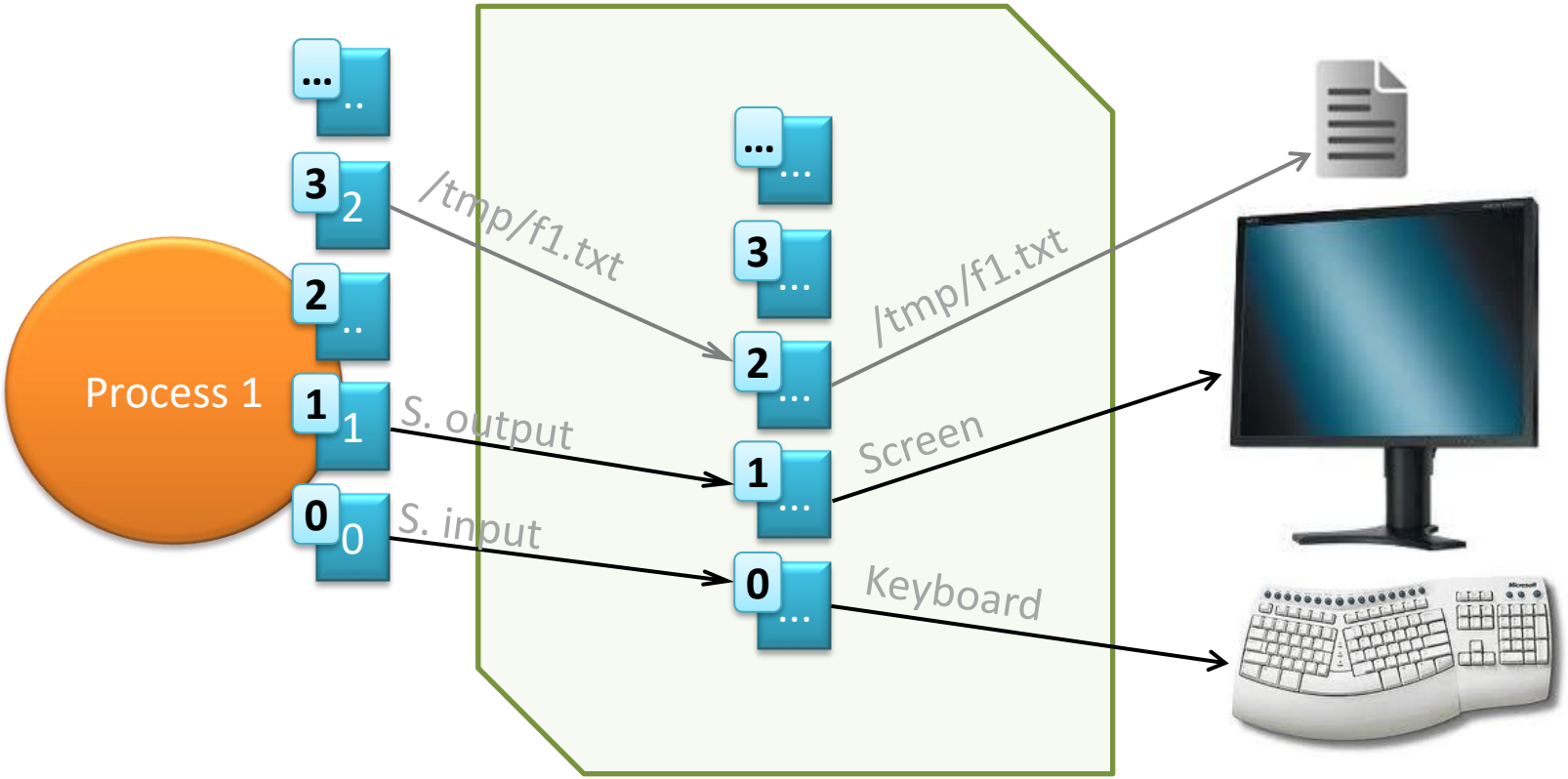
¿

1. close(2) ;
2. open("/tmp/errors.txt") ;

?

File descriptors

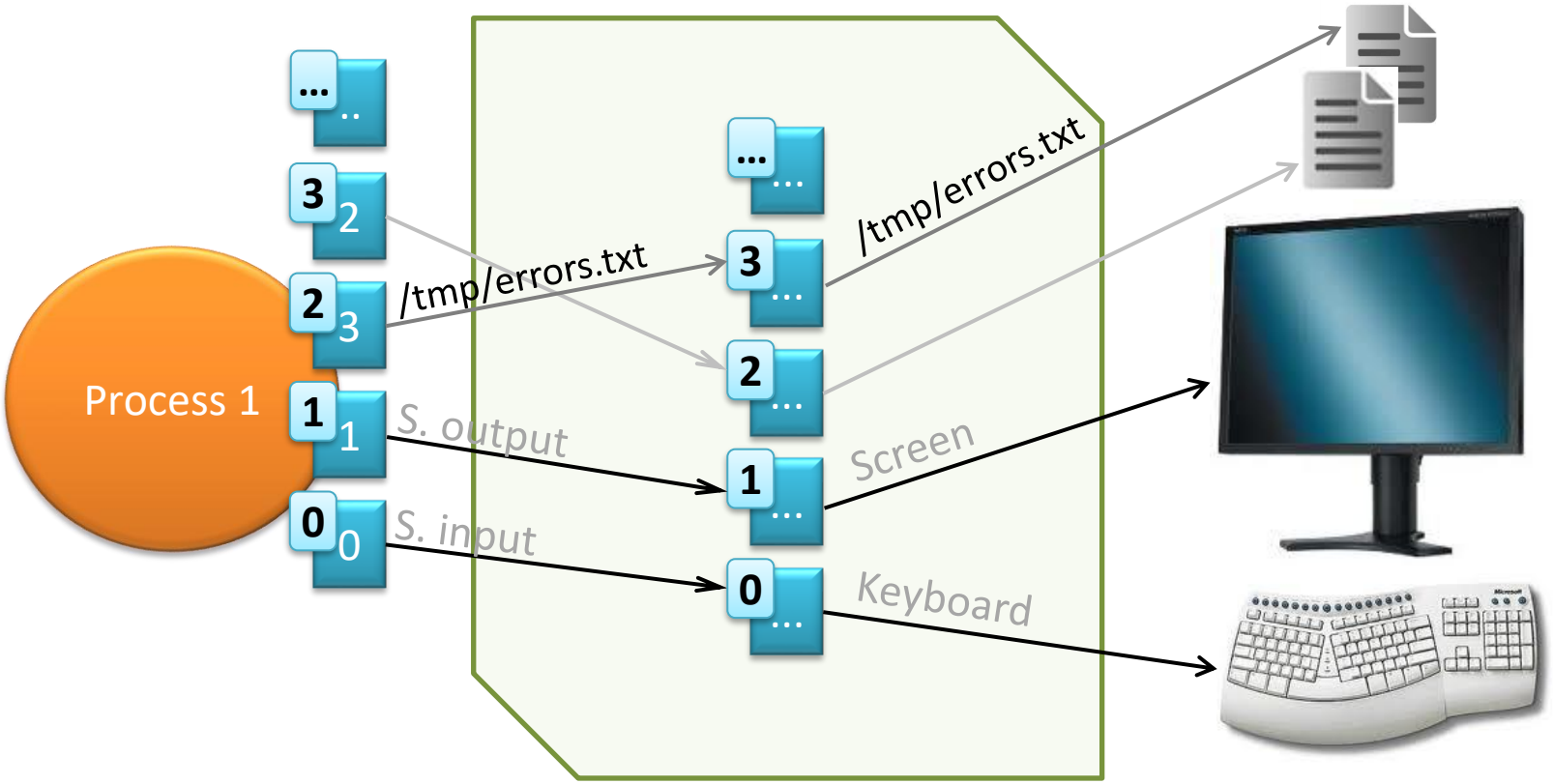
model | redirection | duplication | *fork*()



1. **close(2) ;**
2. open("/tmp/errors.txt") ;

File descriptors

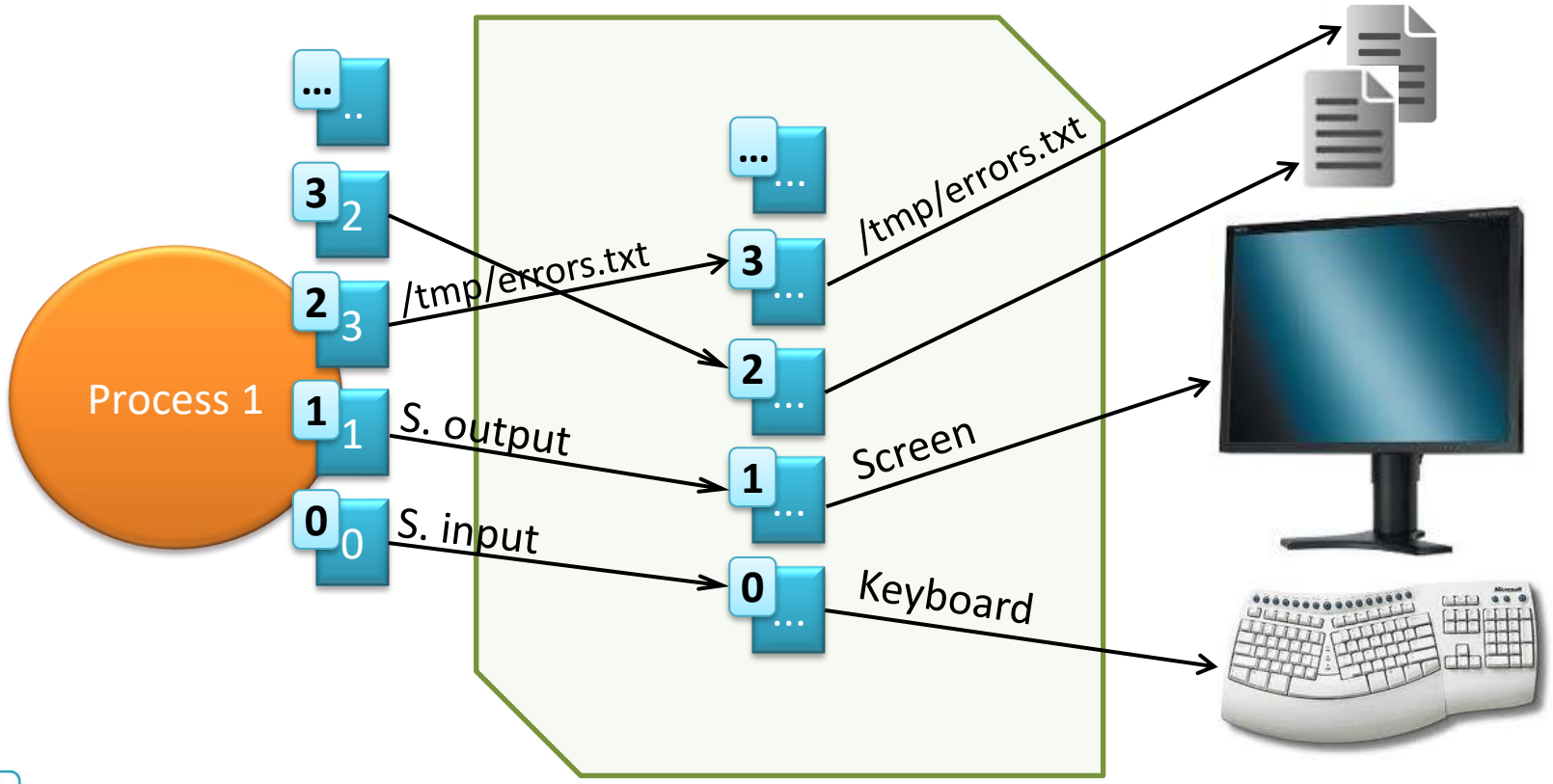
model | redirection | duplication | *fork*()



1. close(2) ;
2. **open("/tmp/errors.txt") ;**

File descriptors

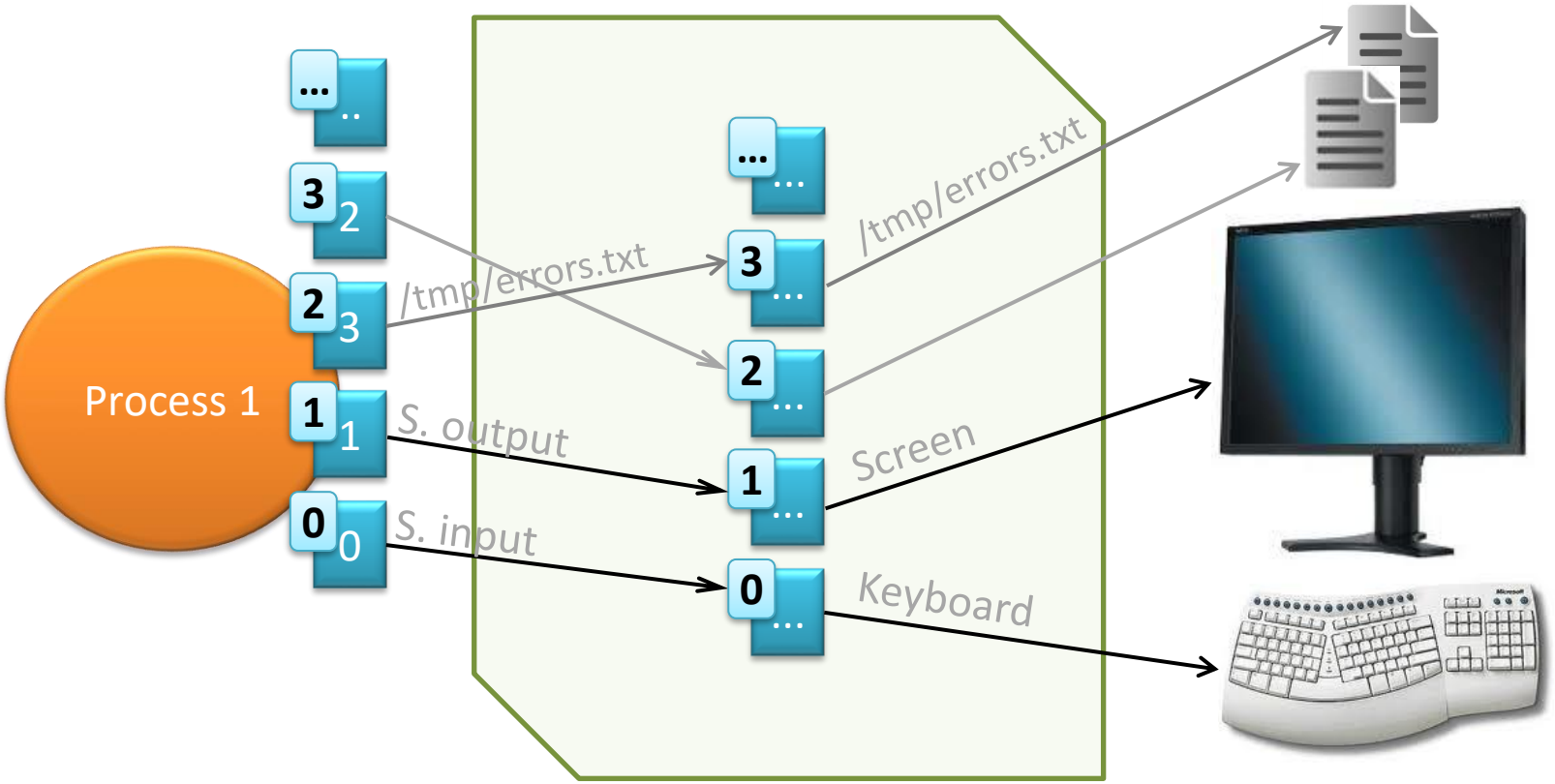
model | redirection | duplication | *fork*()



close(2) + open("/tmp/errors.txt")
It is possible to change the file associated with a descriptor (redirection).

File descriptors

model | redirection | duplication | *fork*()



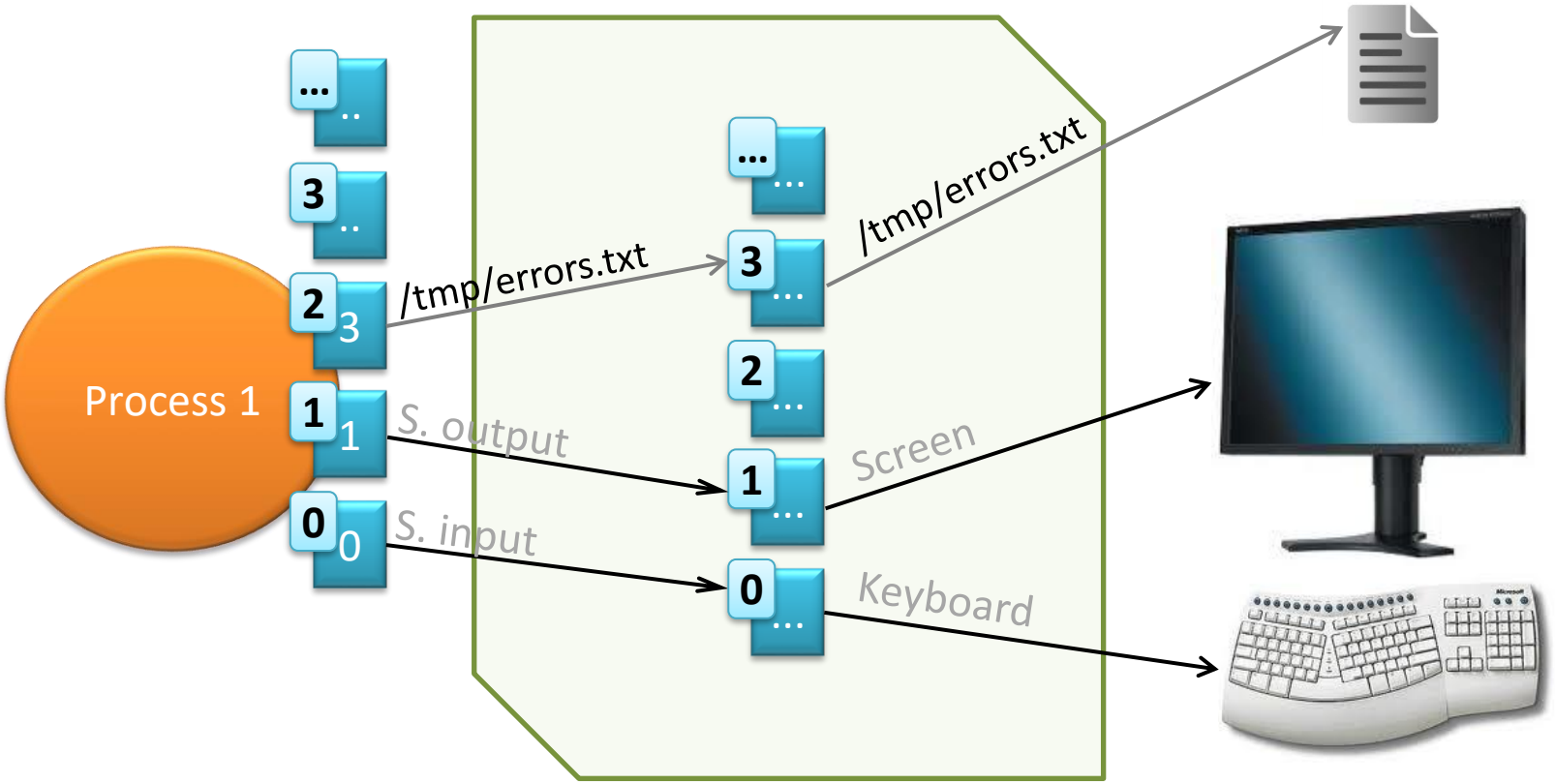
¿

1. close(3) ;
2. dup(2) ;

?

File descriptors

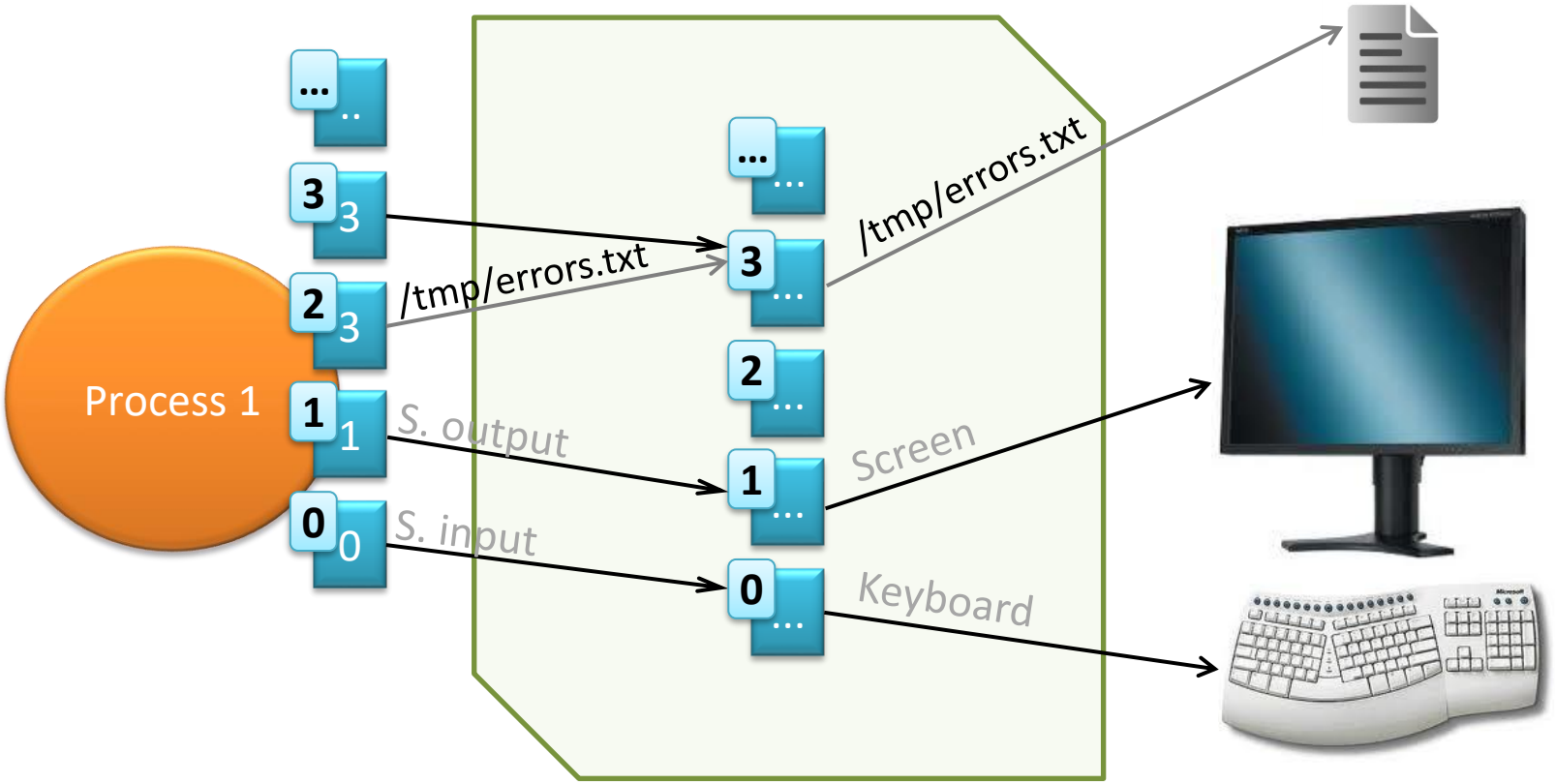
model | redirection | duplication | *fork*()



1. **close(3)** ;
2. dup(2) ;

File descriptors

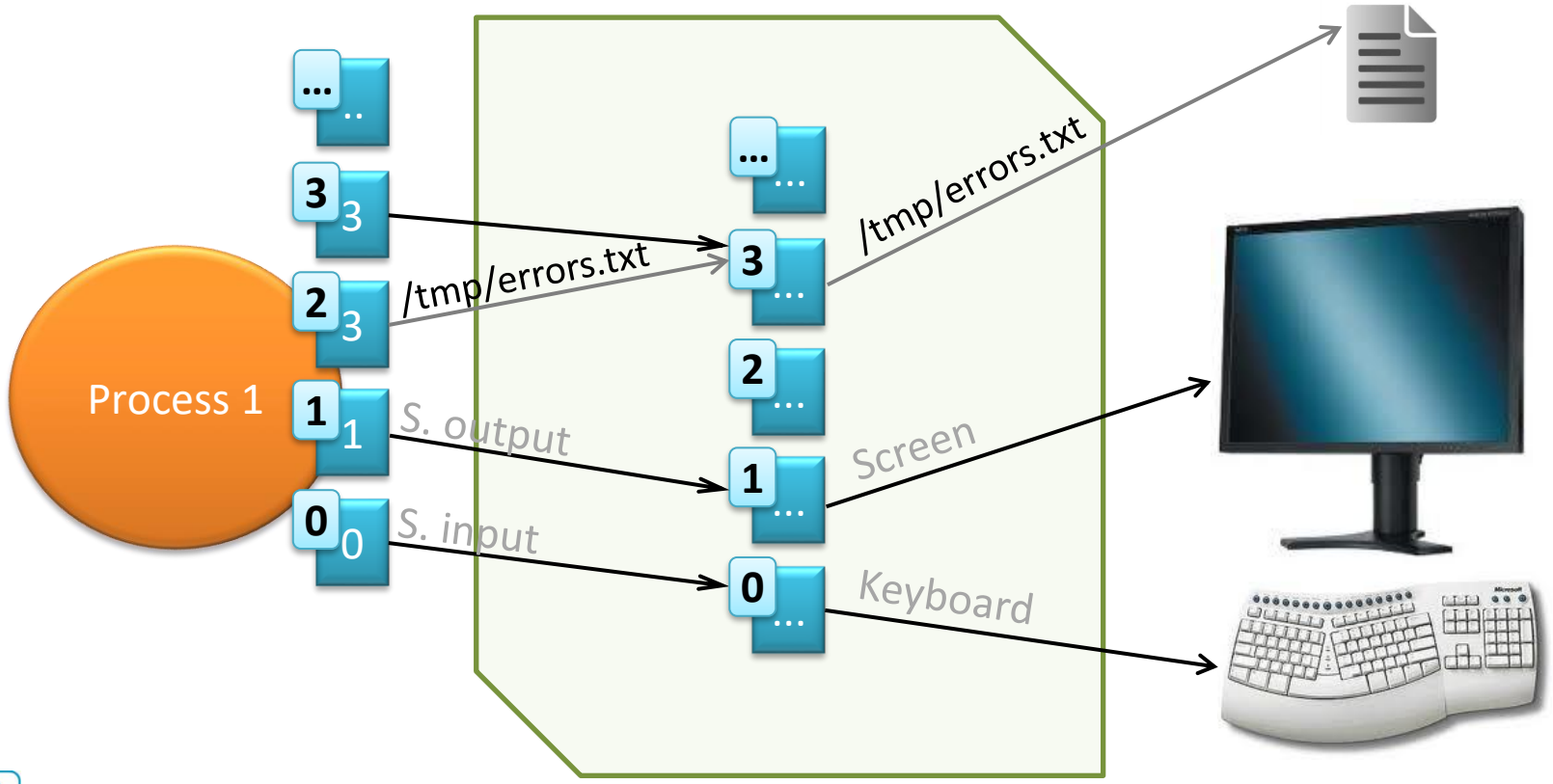
model | redirection | duplication | *fork*()



1. close(3) ;
2. **dup(2) ;**

File descriptors

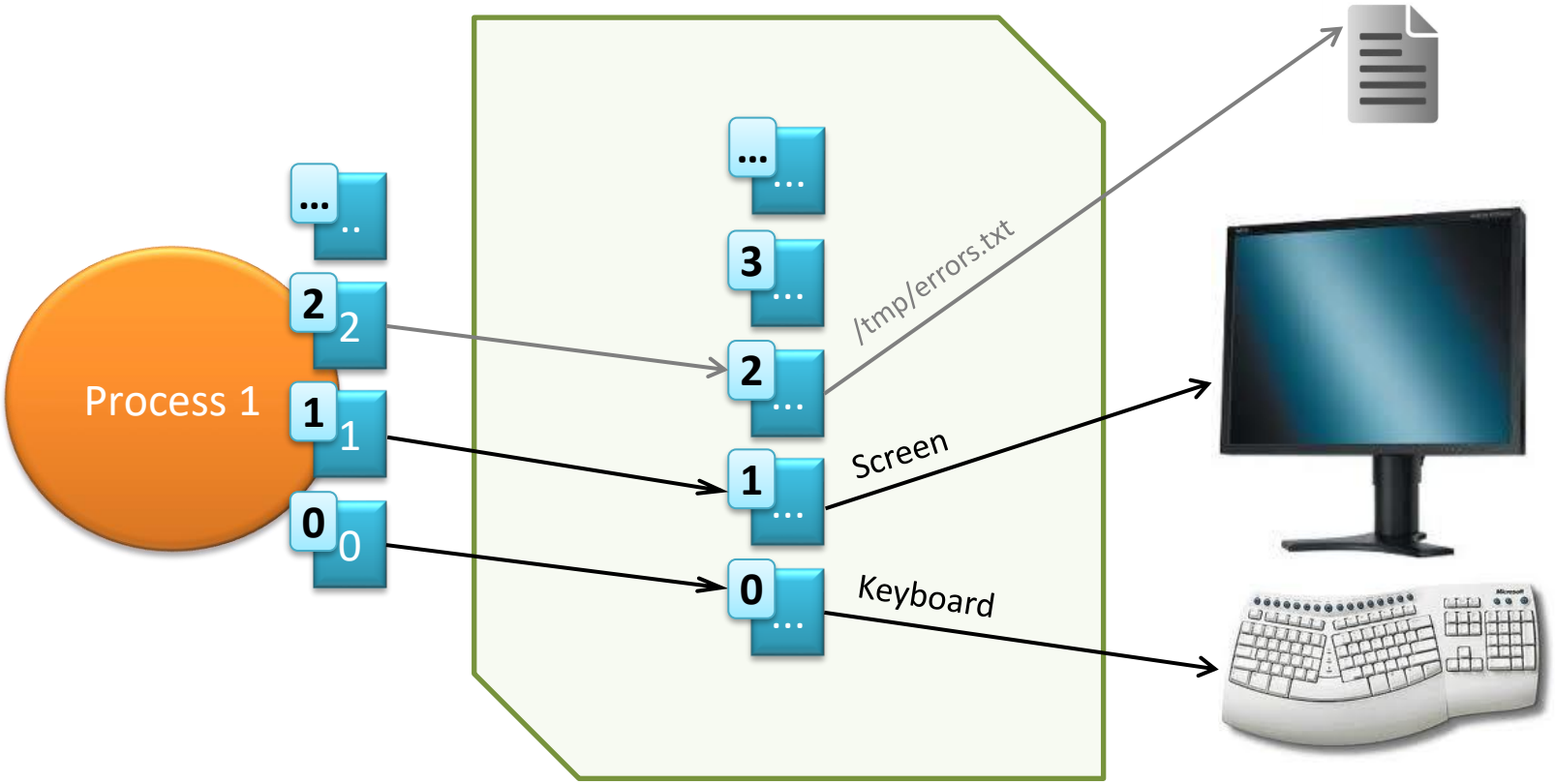
model | redirection | duplication | *fork*()



close(3) + dup(2)
Allows access to the same file from two different descriptors (duplication).

File descriptors

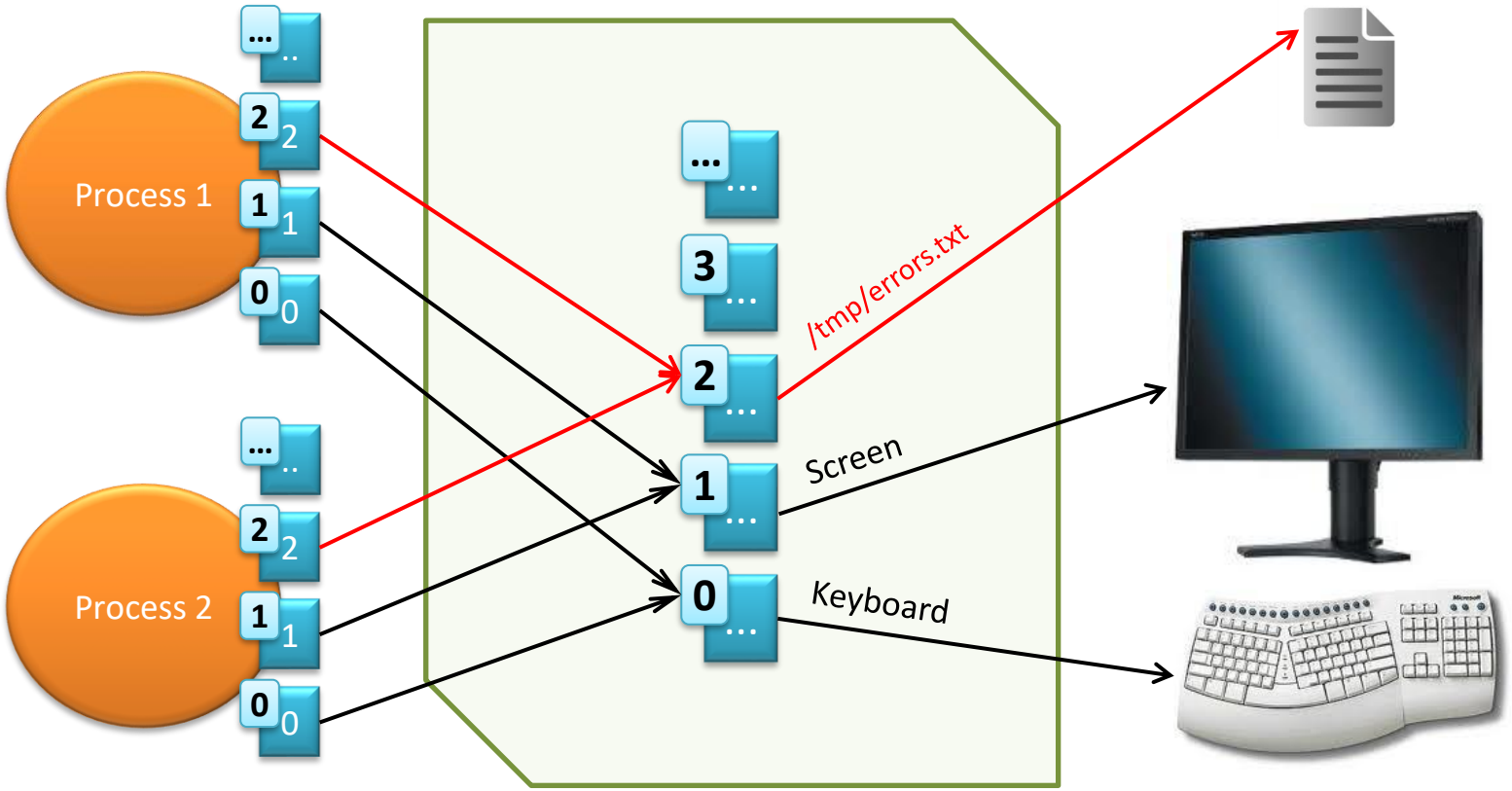
model | redirection | duplication | *fork()*



fork() creates a duplicate of the process (child process) that calls the function (parent process)

File descriptors

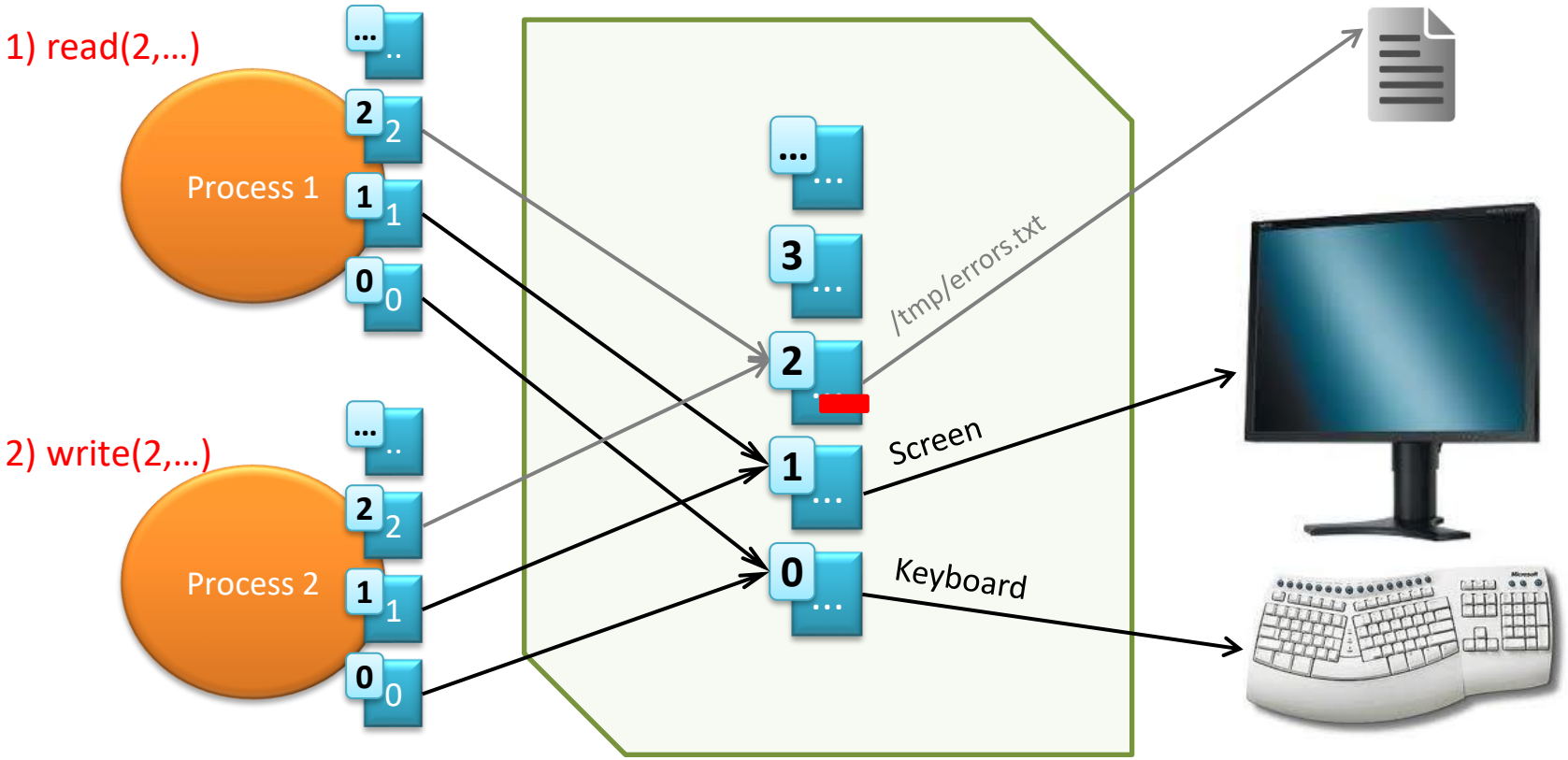
model | redirection | duplication | *fork()*



- **Both have the same descriptors (redirects before fork() are inherited).**
- Both reference the same elements (common R/W position after *fork()*)

File descriptors

model | redirection | duplication | *fork()*



- Both have the same descriptors (redirects before fork() are inherited).
- **Both reference the same elements (common R/W position after fork())**

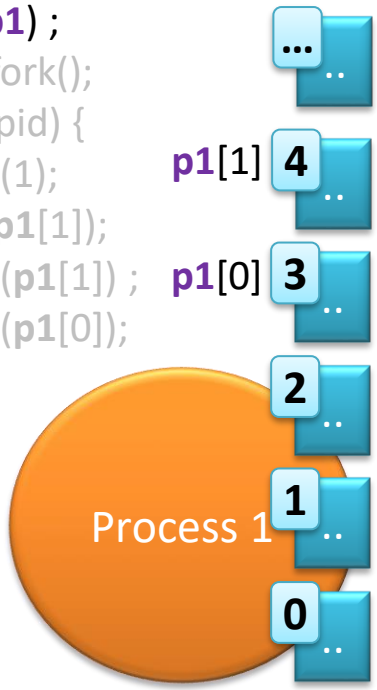
Contents

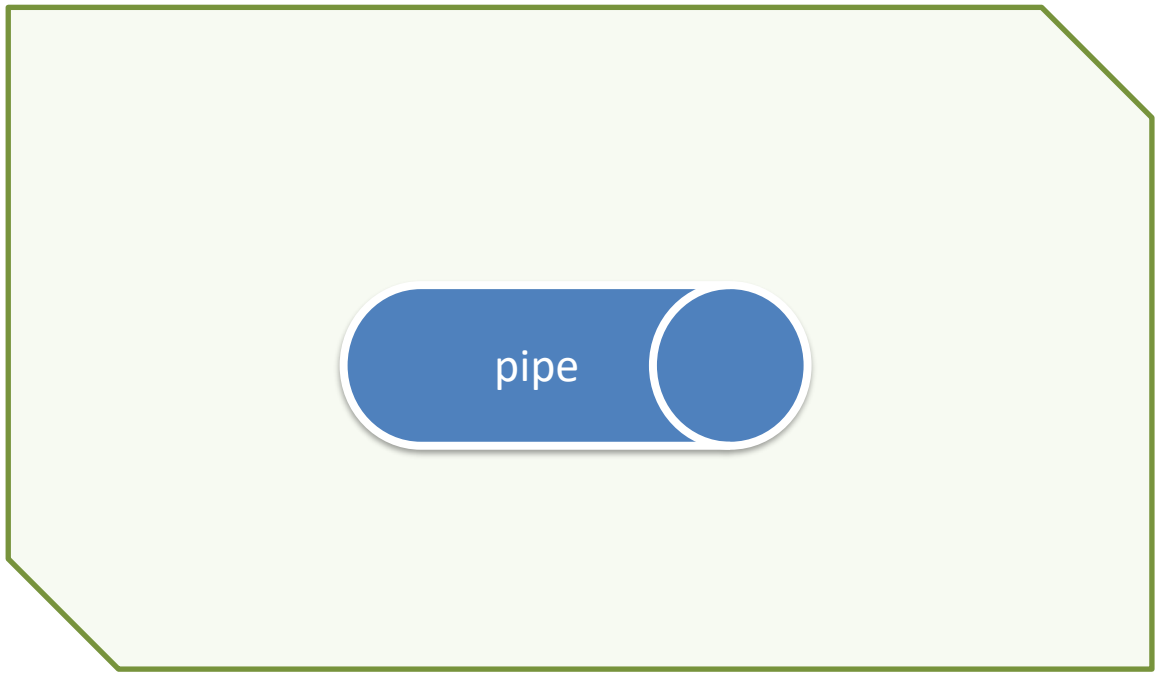
1. Signals and exceptions.
2. Timers.
3. Process environment.
4. Process communication with pipes, local message passing
   1. Command interpreter: redirection and piping
   2. File descriptors:
      - Model: abstraction provided
      - Redirection, duplication and *fork*()
   3. **Pipes**

Pipes

(1) creation + (2) fork() + (3) redirection + (4) cleanup

```
int p1[2] ;
...
pipe(p1) ;
pid = fork();
if (0!=pid) {
  close(1);
  dup(p1[1]);
  close(p1[1]) ;
  close(p1[0]);
  ...
}
```



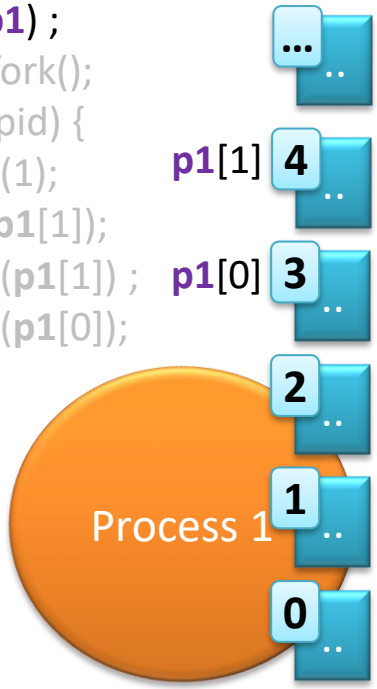


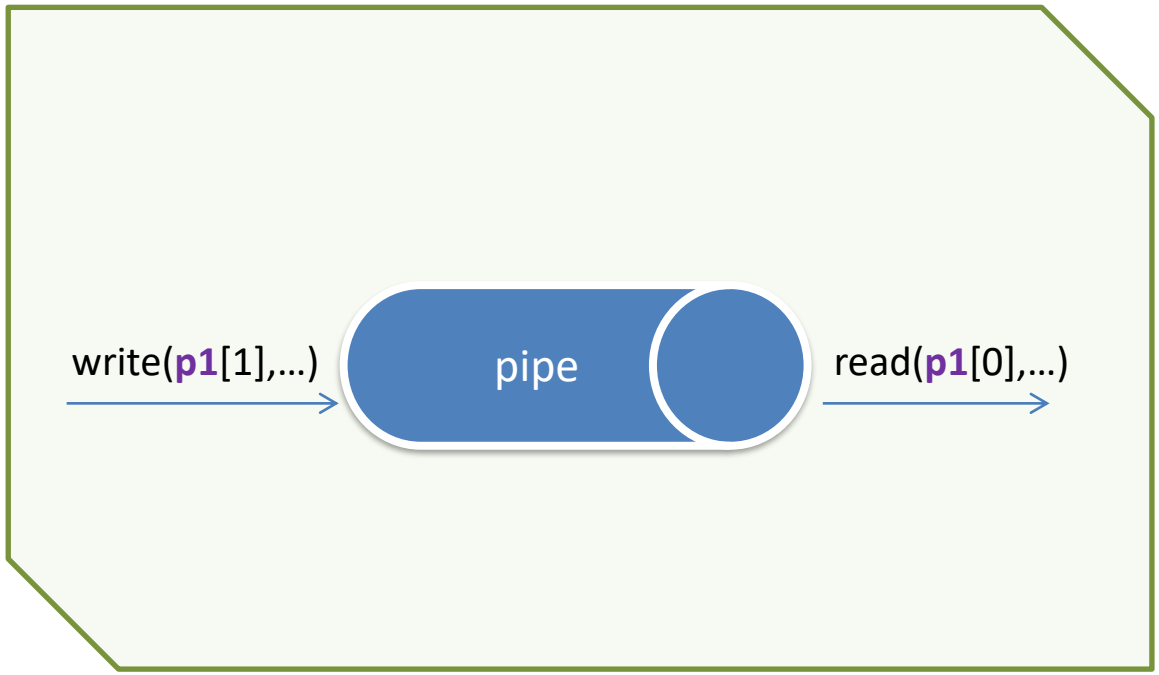
A pipe is a special file that is created with the *pipe()* system call.

Pipes

(1) creation + (2) fork() + (3) redirection + (4) cleanup

```
int p1[2] ;
...
pipe(p1) ;
pid = fork();
if (0!=pid) {
  close(1);
  dup(p1[1]);
  close(p1[1]) ;
  close(p1[0]);
  ...
}
```



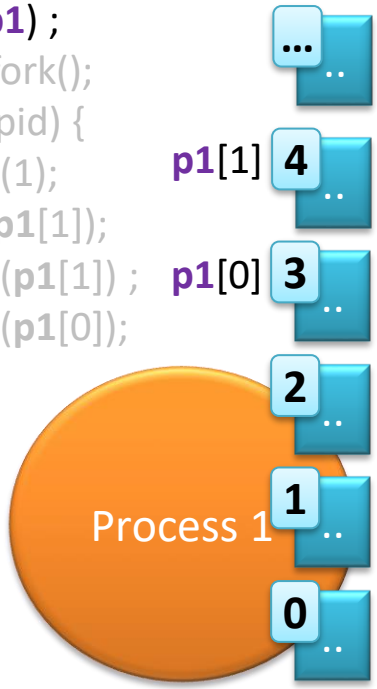


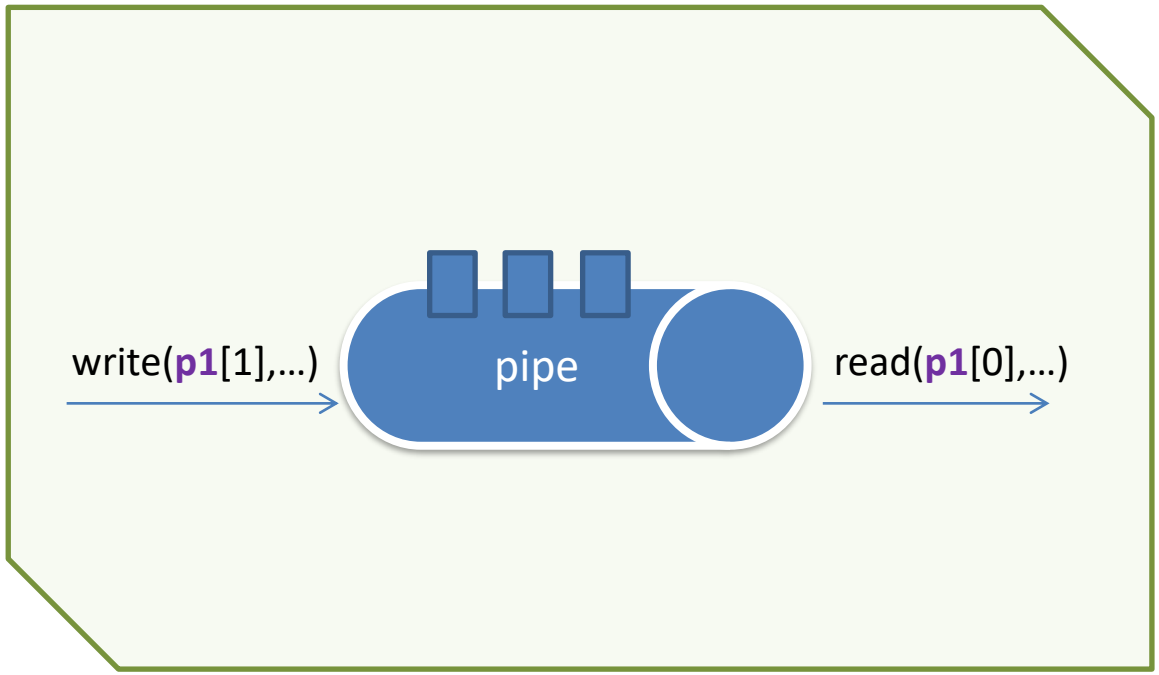
A pipe is a special file that is created with the *pipe()* system call.
This call creates the pipe and reserves two file descriptors: read and write.

Pipes

(1) creation + (2) fork() + (3) redirection + (4) cleanup

```
int p1[2] ;
...
pipe(p1) ;
pid = fork();
if (0!=pid) {
  close(1);
  dup(p1[1]);
  close(p1[1]) ;
  close(p1[0]);
  ...
}
```





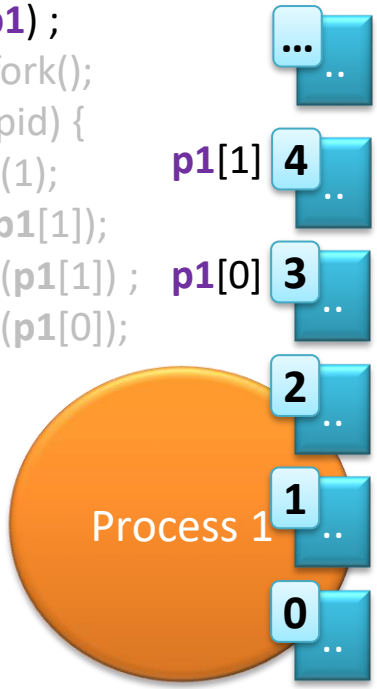
Tip

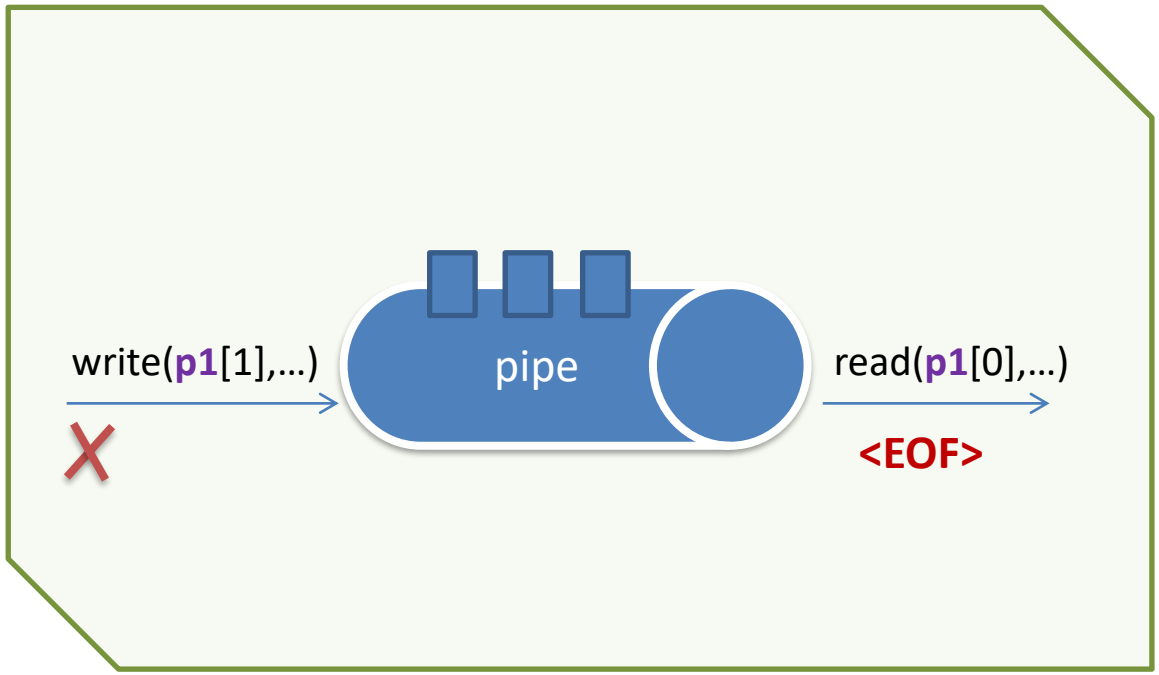
- If you write to a full pipe, the execution of the process is blocked until you can write.
- If you read from an empty pipe, process execution is blocked until you can read something.

Pipes

(1) creation + (2) fork() + (3) redirection + (4) cleanup

```
int p1[2] ;
...
pipe(p1) ;
pid = fork();
if (0!=pid) {
  close(1);
  dup(p1[1]);
  close(p1[1]) ;
  close(p1[0]);
  ...
}
```





Tip

- When all possible writing processes in the pipe close the writing part, then an end-of-file (EOF) is sent to the readers.

Pipes

(1) creation + **(2) fork()** + (3) redirection + (4) cleanup

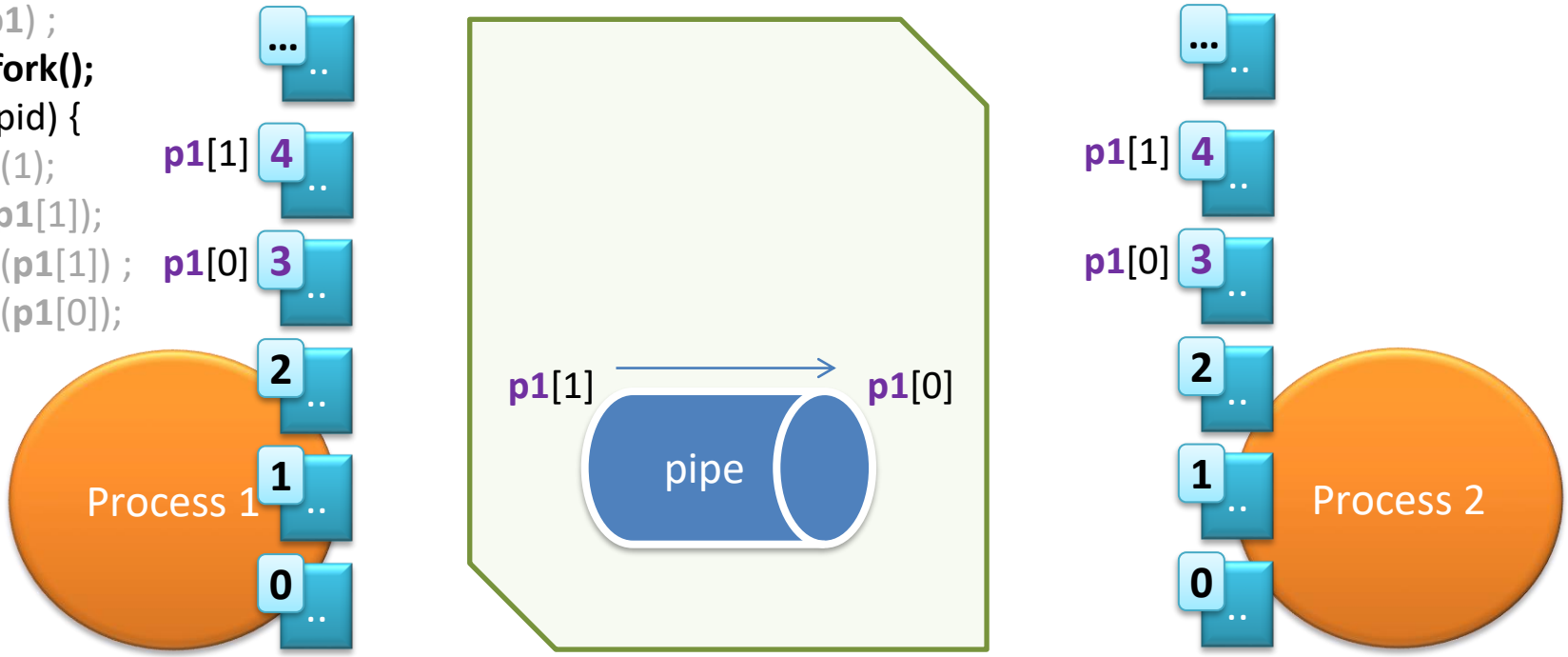
```
int p1[2] ;
...
pipe(p1) ;
pid = fork();
if (0!=pid) {
  close(1);
  dup(p1[1]);
  close(p1[1]) ;
  close(p1[0]);
  ...
}
```

pipe() + fork() -> father and son view the same pipe

Pipes

(1) creation + **(2) fork()** + (3) redirection + (4) cleanup

```
int p1[2] ;
...
pipe(p1) ;
pid = fork();
if (0!=pid) {
  close(1);
  dup(p1[1]);
  close(p1[1]) ;
  close(p1[0]);
  ...
}
```

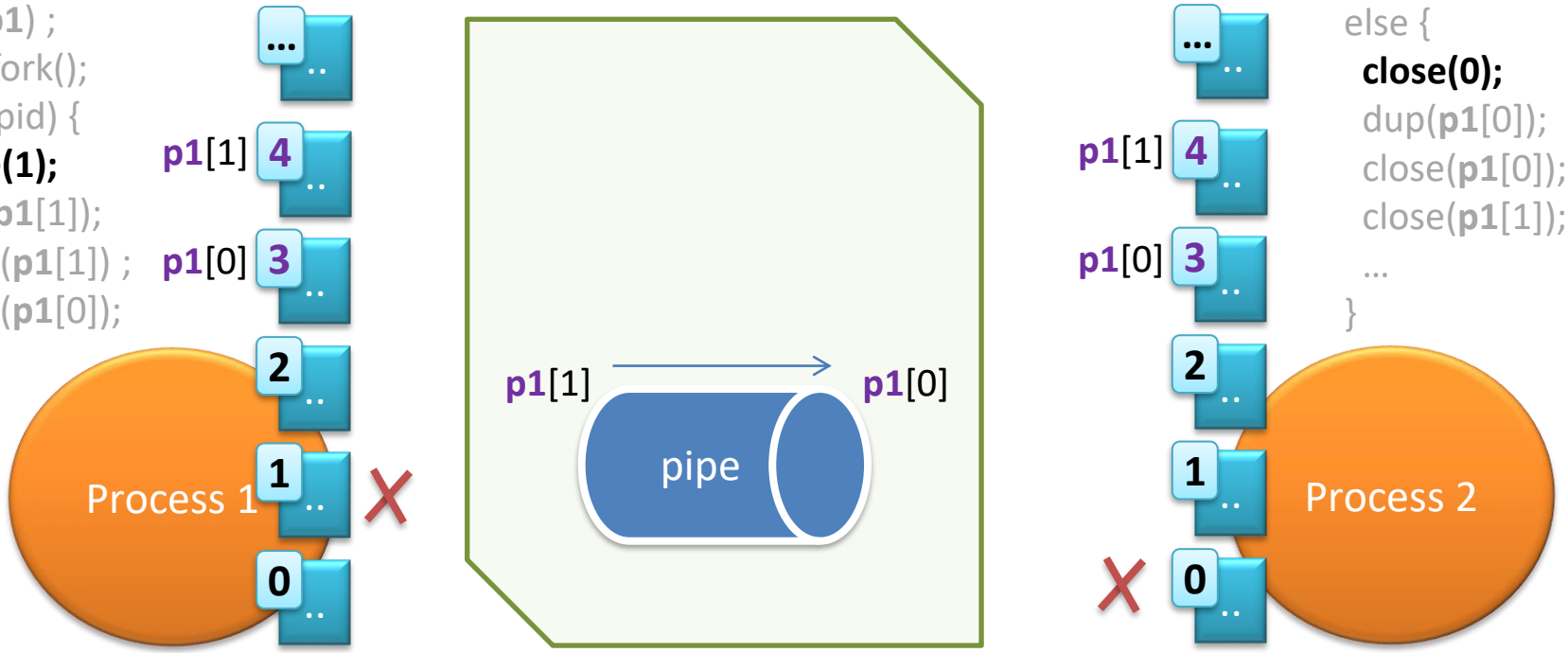


pipe() + fork() -> father and son view the same pipe
-> both could read and write on it

Pipes

(1) creation + (2) fork() + **(3) redirection** + (4) cleanup

```
int p1[2] ;
...
pipe(p1) ;
pid = fork();
if (0!=pid) {
  close(1);
  dup(p1[1]);
  close(p1[1]) ;
  close(p1[0]);
  ...
}
```



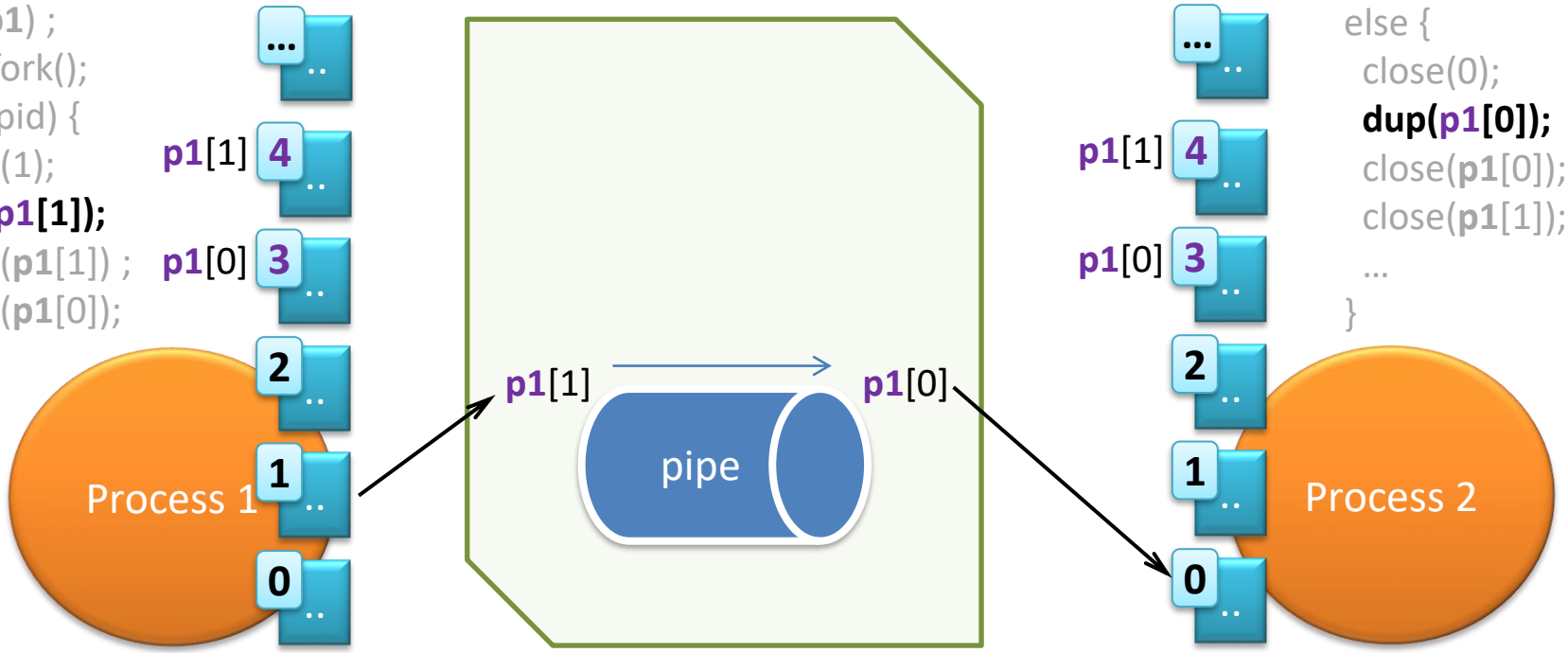

```
else {
  close(0);
  dup(p1[0]);
  close(p1[0]);
  close(p1[1]);
  ...
}
```

Redirection of the standard output on the parent...
Redirection of the standard input on the child...

Pipes

(1) creation + (2) fork() + **(3) redirection** + (4) cleanup

```
int p1[2] ;
...
pipe(p1) ;
pid = fork();
if (0!=pid) {
  close(1);
  dup(p1[1]);
  close(p1[1]) ;
  close(p1[0]);
  ...
}
```



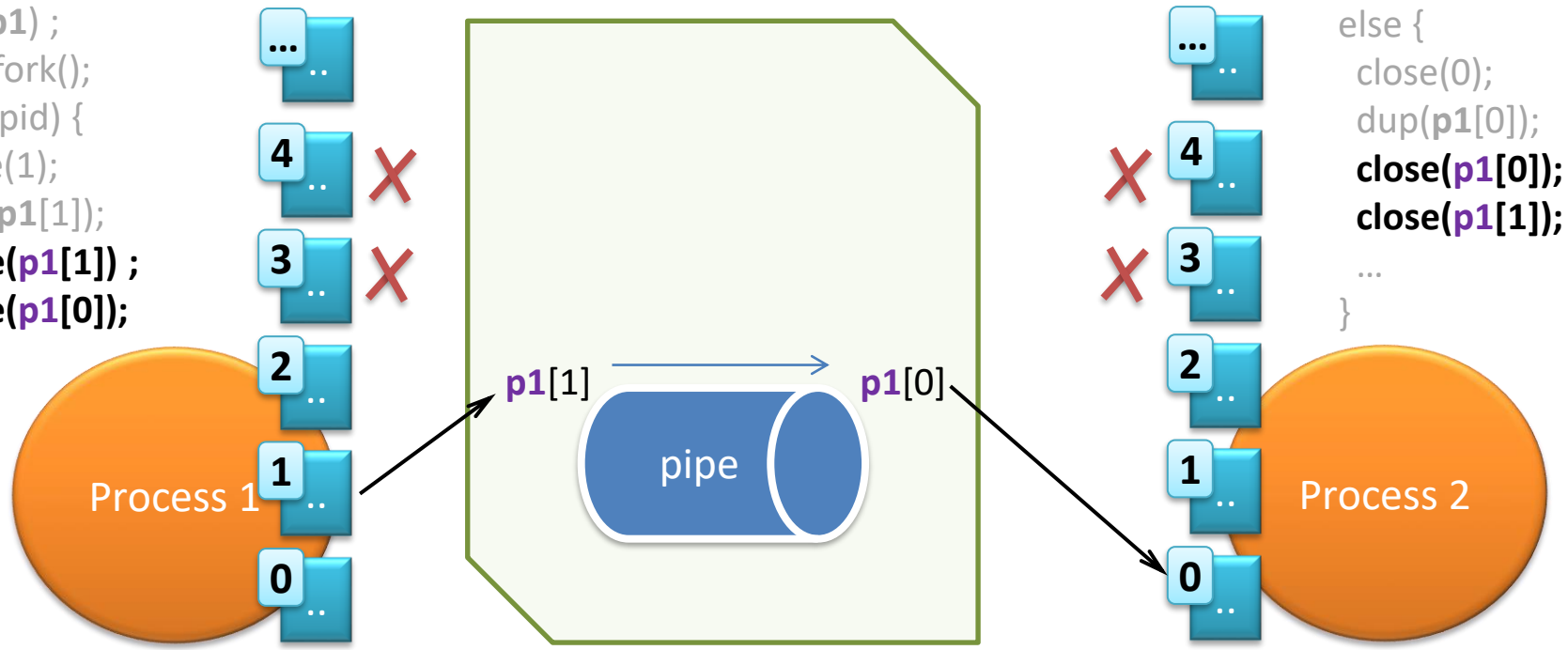

```
else {
  close(0);
  dup(p1[0]);
  close(p1[0]);
  close(p1[1]);
  ...
}
```

Redirection of the standard output on the parent...
Redirection of the standard input on the child...

Pipes

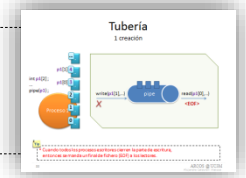
(1) creation + (2) fork() + (3) redirection + **(4) cleanup**

```
int p1[2] ;
...
pipe(p1) ;
pid = fork();
if (0!=pid) {
  close(1);
  dup(p1[1]);
  close(p1[1]) ;
  close(p1[0]);
  ...
}
```




```
else {
  close(0);
  dup(p1[0]);
  close(p1[0]);
  close(p1[1]);
  ...
}
```

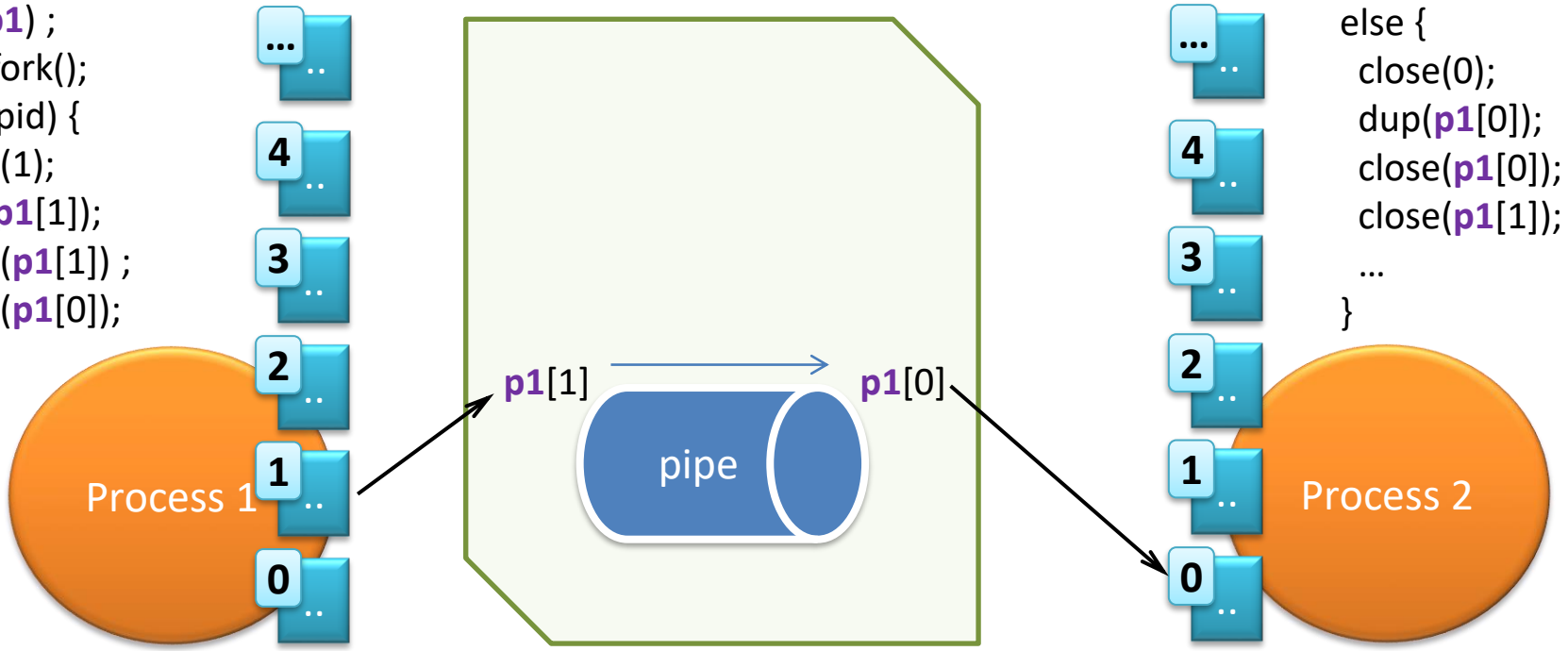
Closing of descriptors that are not used in the parent...
Closure of descriptors that are not used in the child...



File descriptors

summary

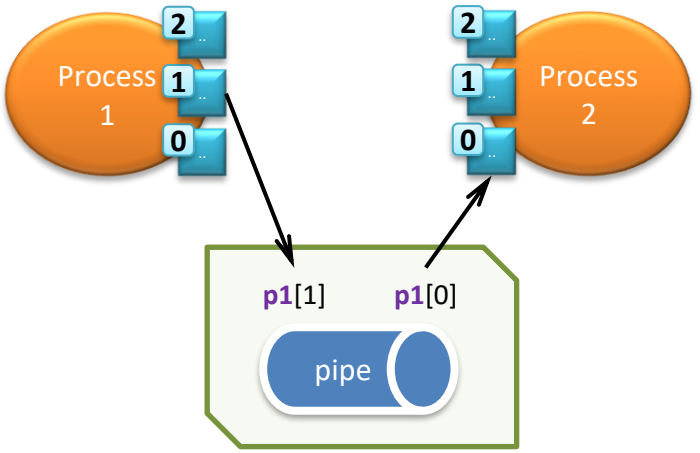
```
int p1[2] ;
…
pipe(p1) ;
pid = fork();
if (0!=pid) {
  close(1);
  dup(p1[1]);
  close(p1[1]) ;
  close(p1[0]);
  …
}
```



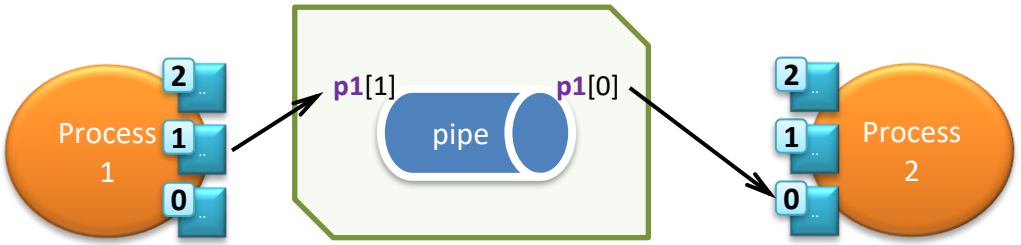
File descriptors

summary

```
int p1[2] ;                          } 1) Creation
...
pipe(p1) ;
pid = fork();                        } 2) fork()
if (0!=pid) {
   close(1);                         } 3) Redirection (father)
   dup(p1[1]);
   close(p1[1]) ;                    } 4) Cleanup (father)
   close(p1[0]);
   ...
} else {
   close(0);                         } 3) Redirection (son)
   dup(p1[0]);
   close(p1[0]);                     } 4) Cleanup (son)
   close(p1[1]);
   ...
}
```

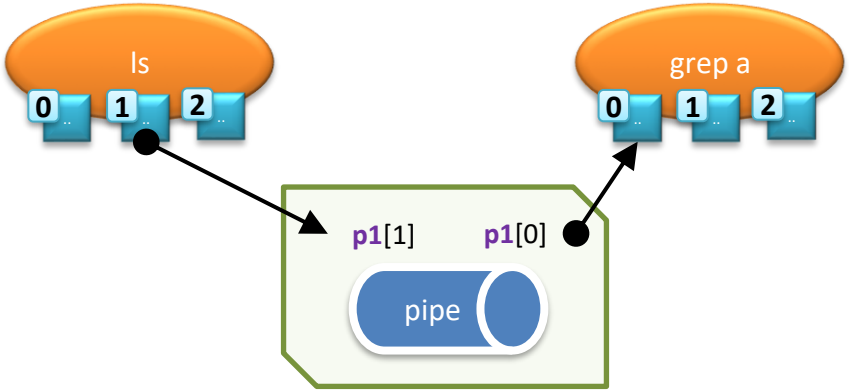


Pipes
limitations



- **Semi-duplex**:
  - One way: data is written by one process at one end of the pipe and read by another process from the other end of the pipe.
- They can only be used between **related processes** that have a common ancestor.
- **Reading** is **destructive**.

Example 1: "ls | grep a"

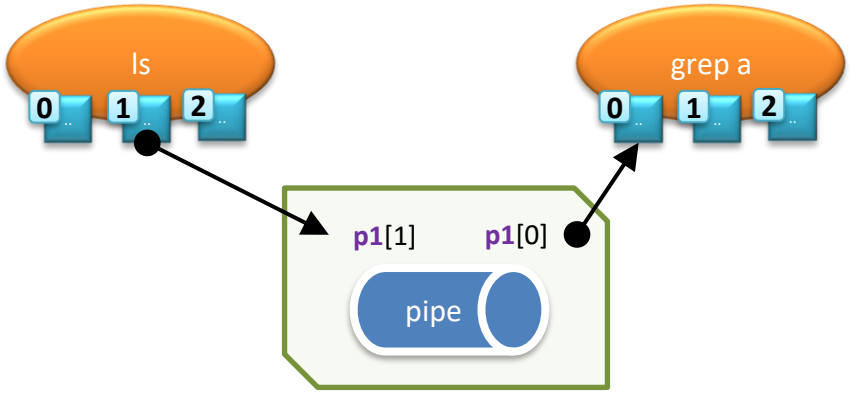


Example 1: "ls | grep a"

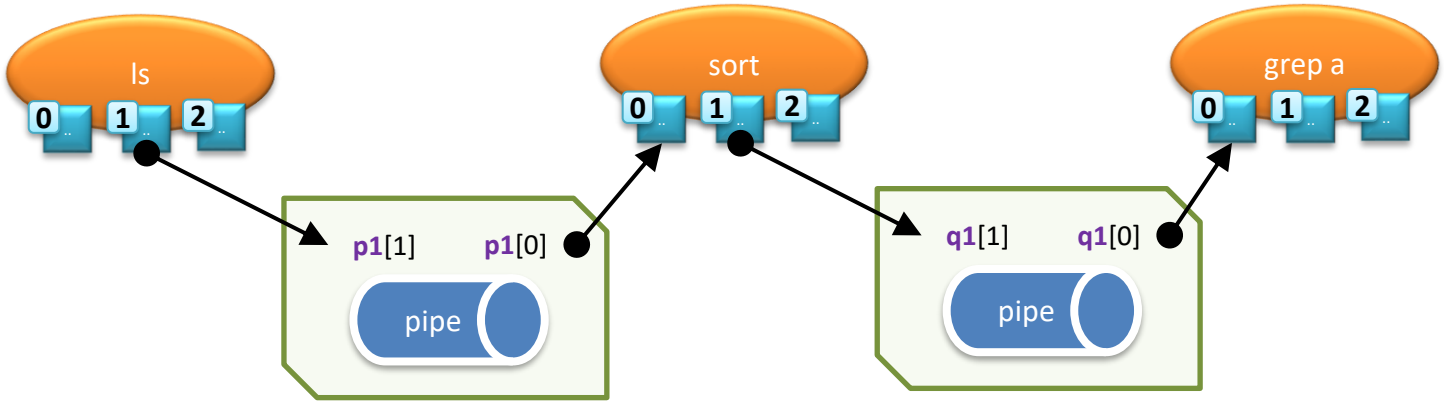
```
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>

int main (int argc, char *argv[])
{
  int fd[2];

  pipe(fd);
  if (fork()!=0) { /* code for father */
     close(STDIN_FILENO);
     dup(fd[STDIN_FILENO]);
     close(fd[STDIN_FILENO]);
     close(fd[STDOUT_FILENO]);
     execlp("grep", "grep", "a", NULL);
  } else { /* code for son */
     close(STDOUT_FILENO);
     dup(fd[STDOUT_FILENO]);
     close(fd[STDOUT_FILENO]);
     close(fd[STDIN_FILENO]);
     execlp("ls", "ls", NULL);
  }
  return 0;
}
```

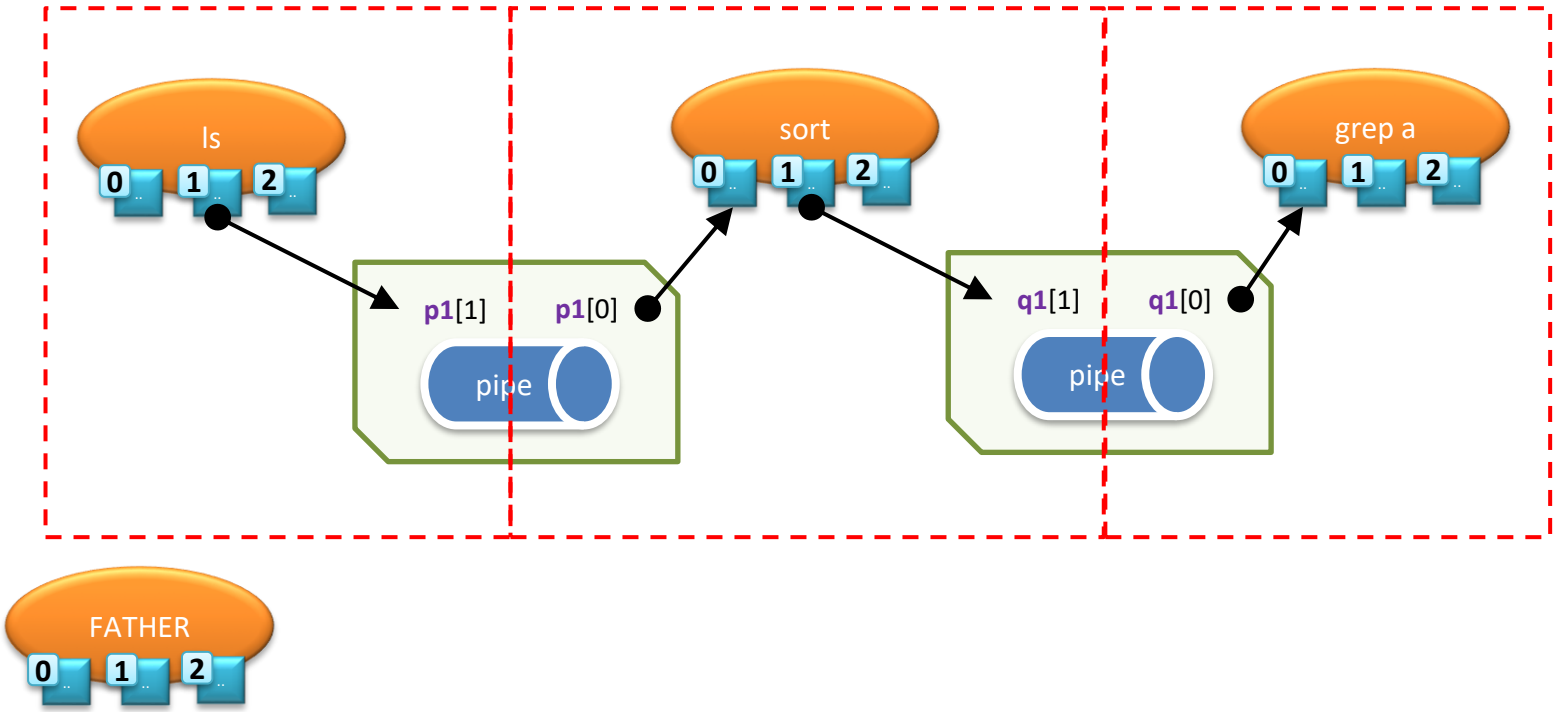


Example 2: "ls | sort | grep a"



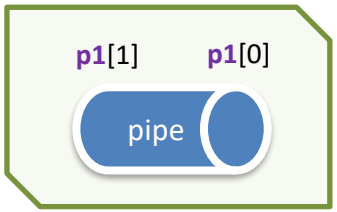
It is possible to work with several pipes in a similar way.
A "FATHER" process is used to create the structure.

Example 2: "ls | sort | grep a"



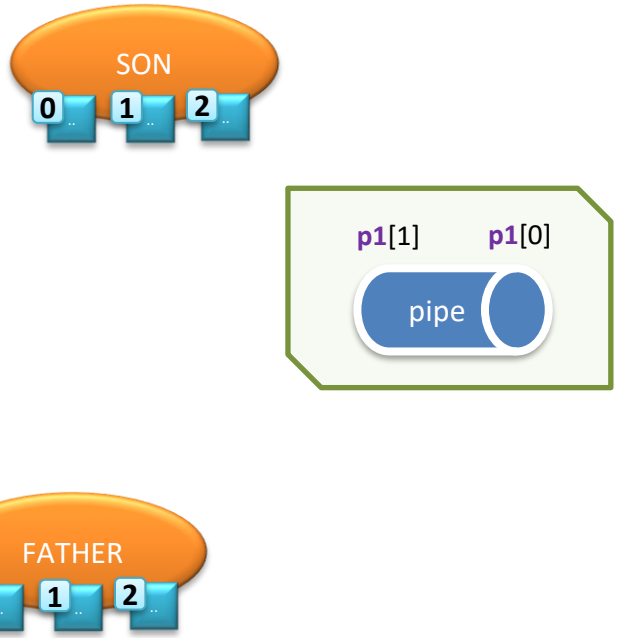
The idea is to apply a "divide and conquer" approach on each pipe and its associated processes. Three types of cases: first process, intermediate processes and last process.

Example 2: "ls | sort | grep a"
(1/4) creation



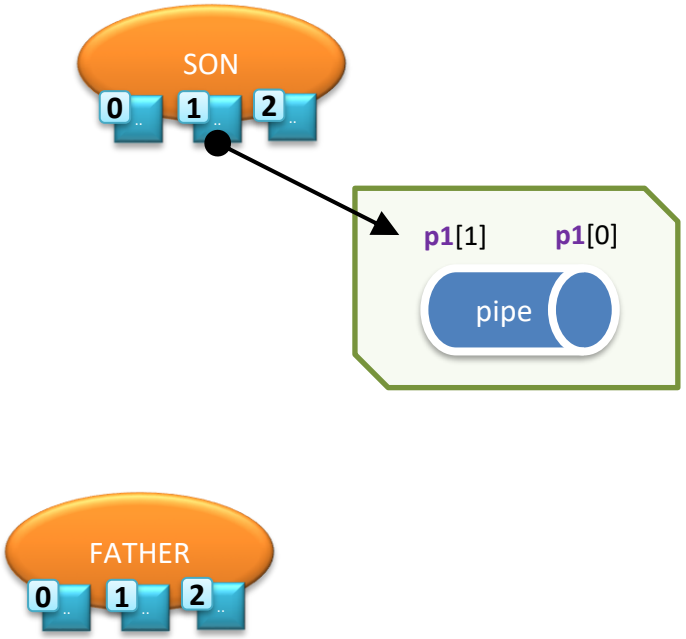
The 4 steps should be done for each pipe (**pipe**, fork, redirection and cleanup)

Example 2: "ls | sort | grep a"
(2/4) fork()



The 4 steps should be done for each pipe (pipe, **fork**, redirection and cleanup)

Example 2: "ls | sort | grep a"
(3/4) redirection

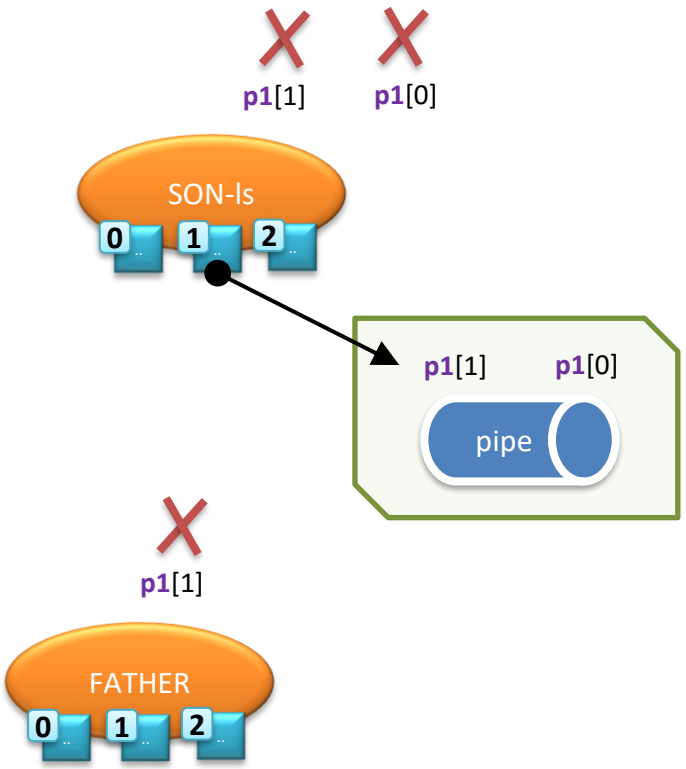


The 4 steps should be done for each pipe (pipe, fork, **redirection** and cleanup)

The first process only uses the pipe in the output redirection.

Example 2: "ls | sort | grep a"

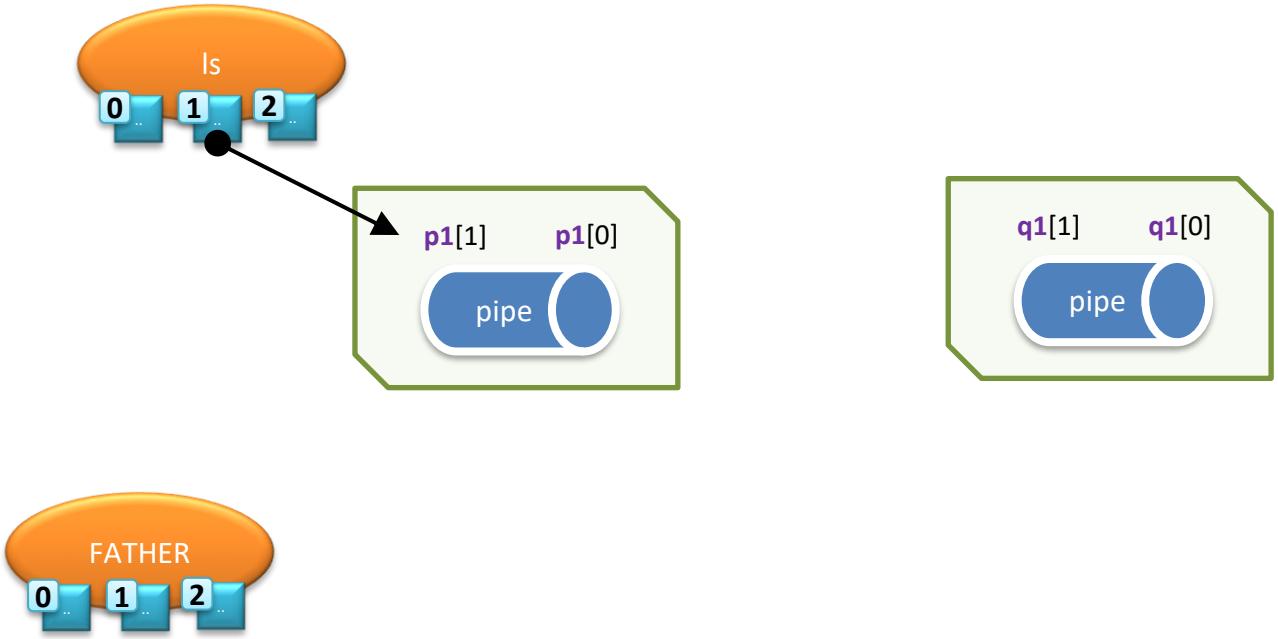
(4/4) cleanup (+exec in son)



The 4 steps should be done for each pipe (pipe, fork, redirection and **cleanup**)

The father would still not do a total cleanup for the next child to have access to "p1[0]".

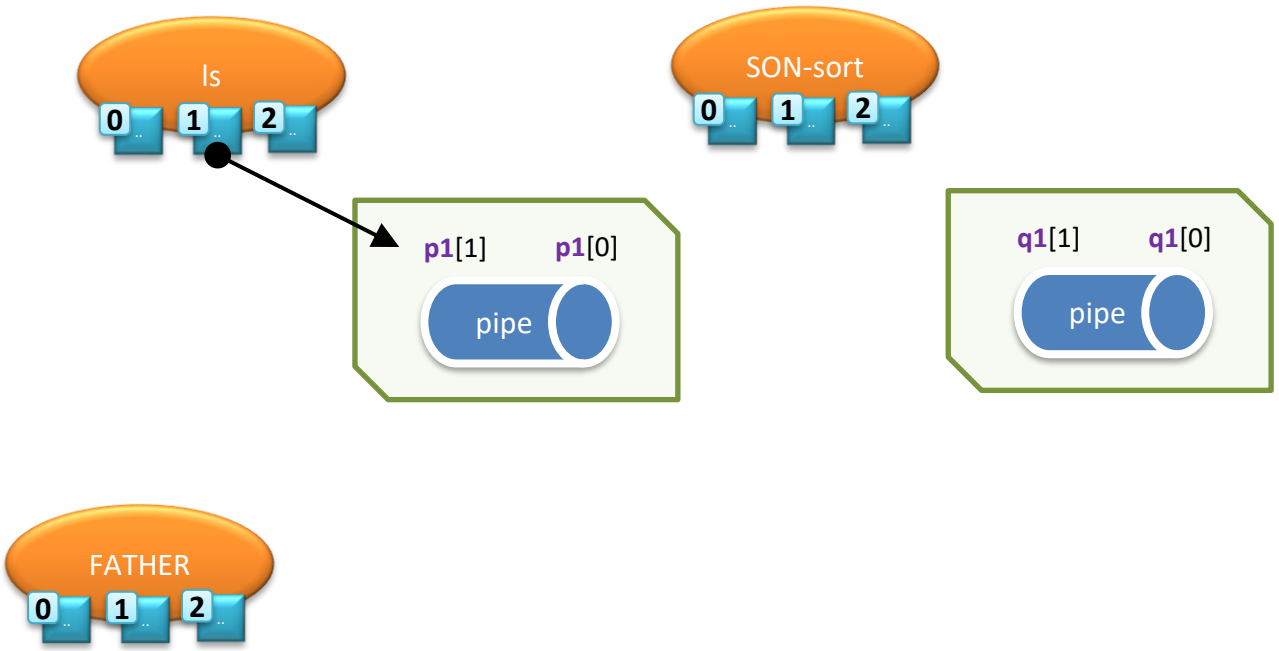
Example 2: "ls | sort | grep a"
(1/4) creation



The 4 steps should be done for each pipe (**creation**, fork, redirection and cleanup)

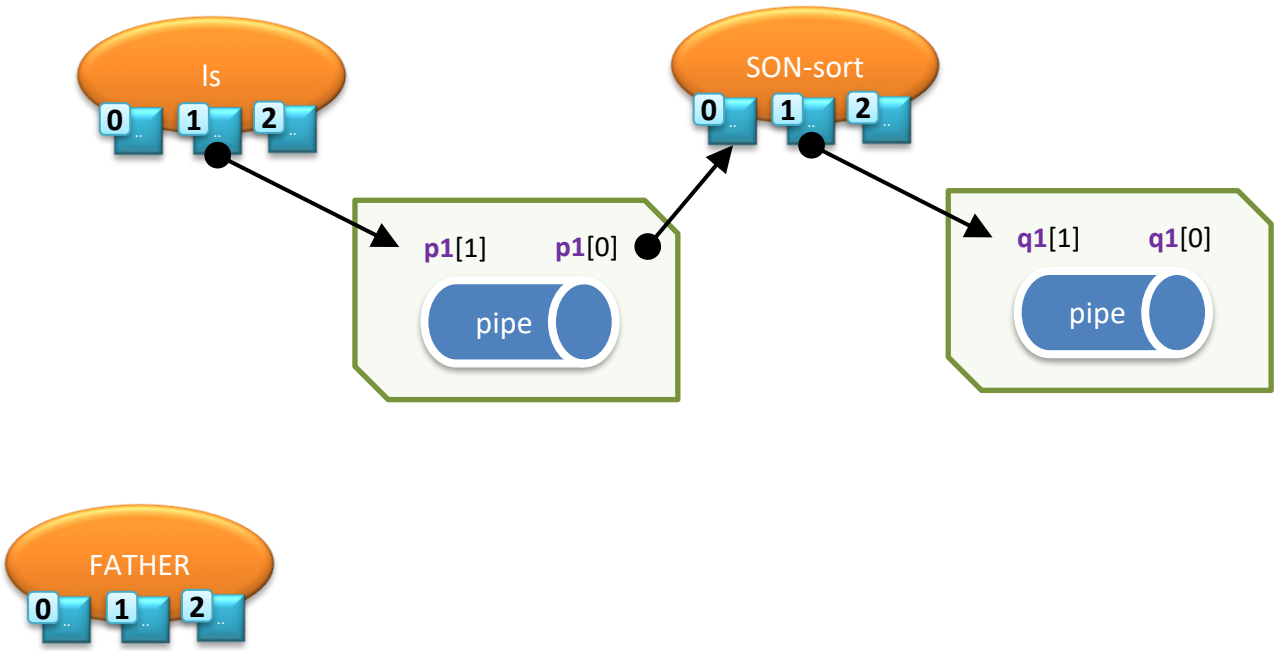
Example 2: "ls | sort | grep a"

(2/4) fork()



The 4 steps should be done for each pipe (creation, **fork**, redirection and cleanup)

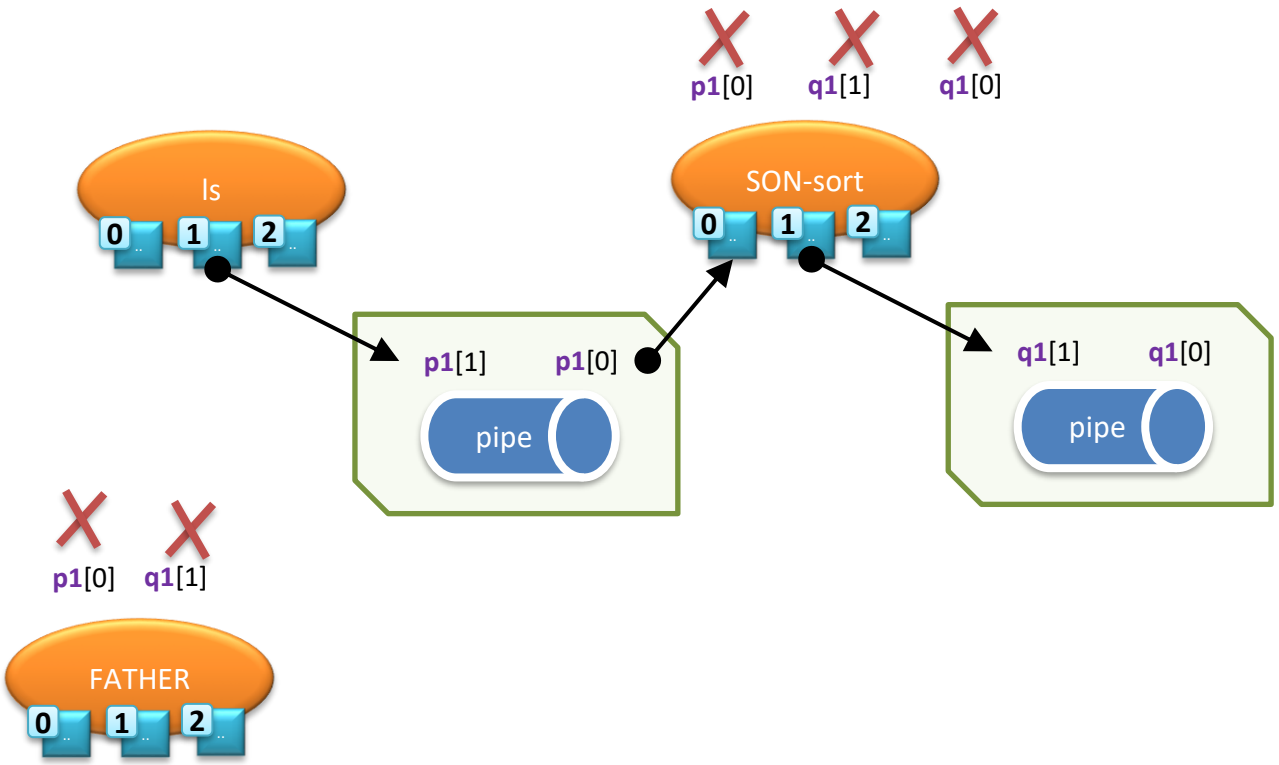
Example 2: "ls | sort | grep a"
(3/4) redirection



The 4 steps should be done for each pipe (creation, fork, **redirection** and cleanup)
Intermediate processes redirect their standard input and output to pipe.

Example 2: "ls | sort | grep a"

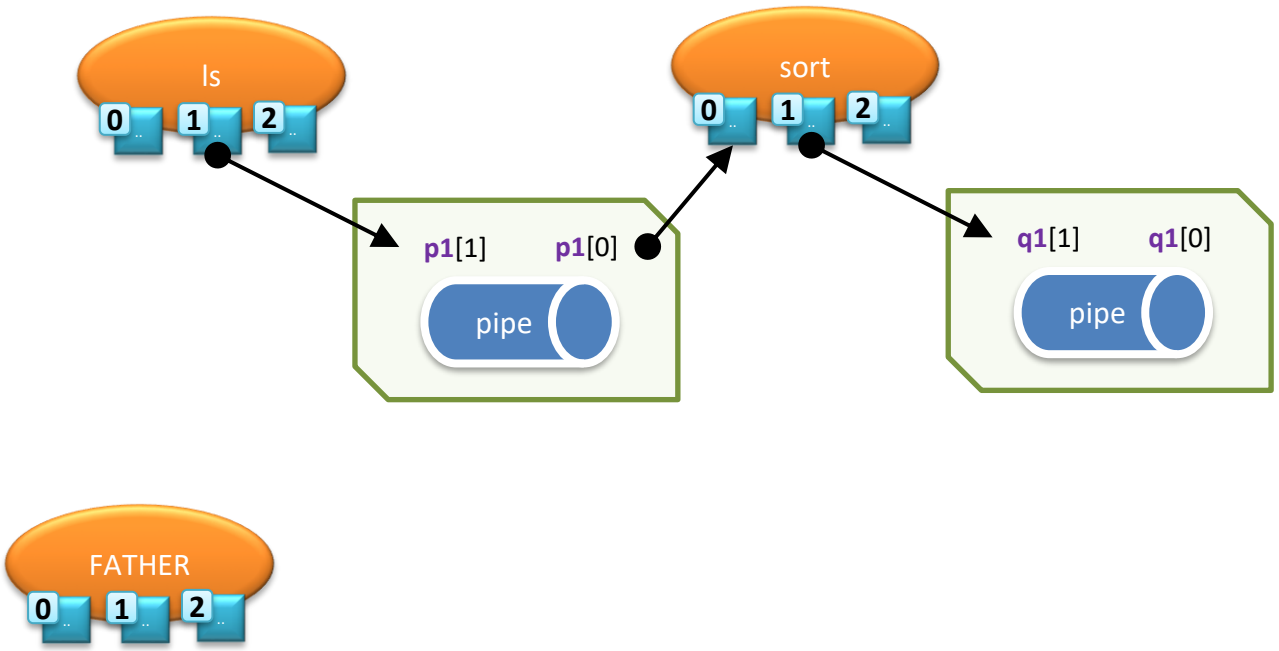
(4/4) cleanup (+exec in son)



The 4 steps should be done for each pipe (creation, fork, redirection and **cleanup**)

The father would still not do total a cleanup so next child would have access to "q1[0]"

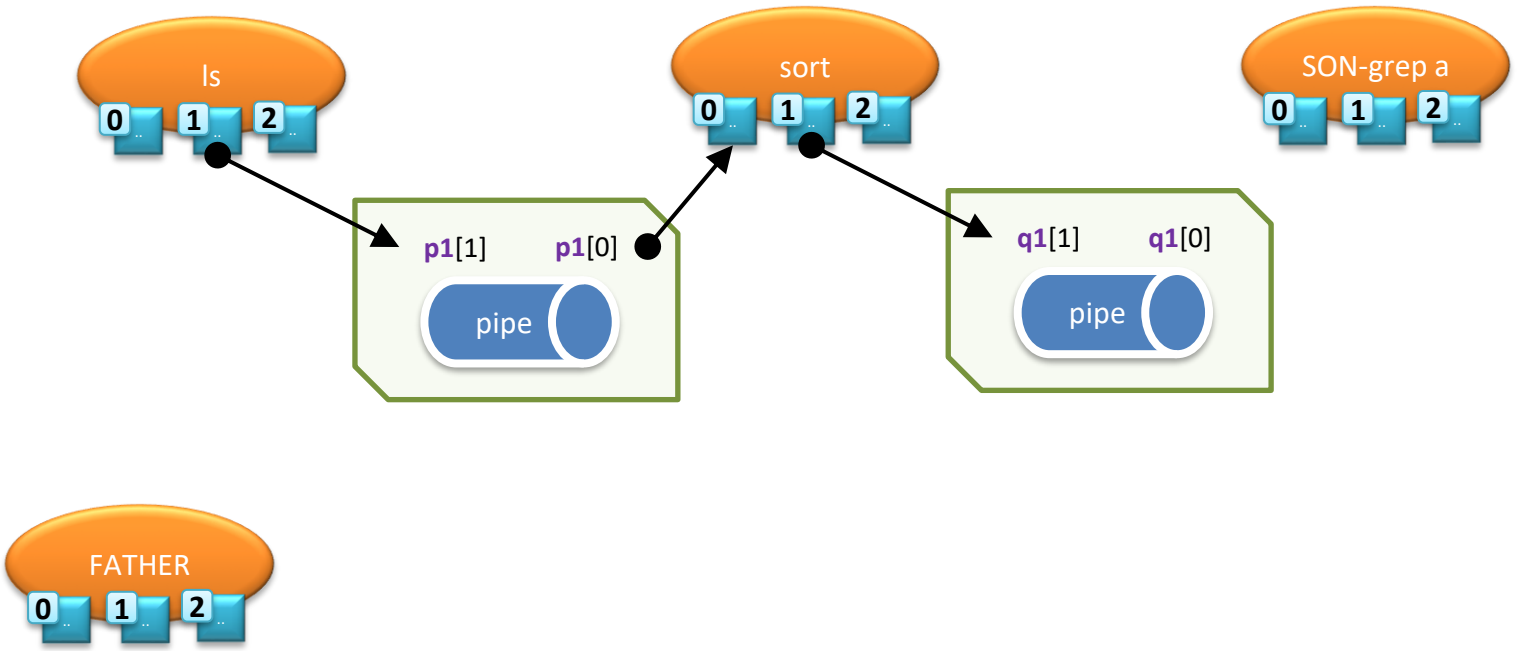
Example 2: "ls | sort | grep a"
(1/4) creation



The 4 steps should be done for each pipe (~~**creation**~~, fork, redirection and cleanup)
The last process uses the pipe already created (there are n processes and n-1 pipes)

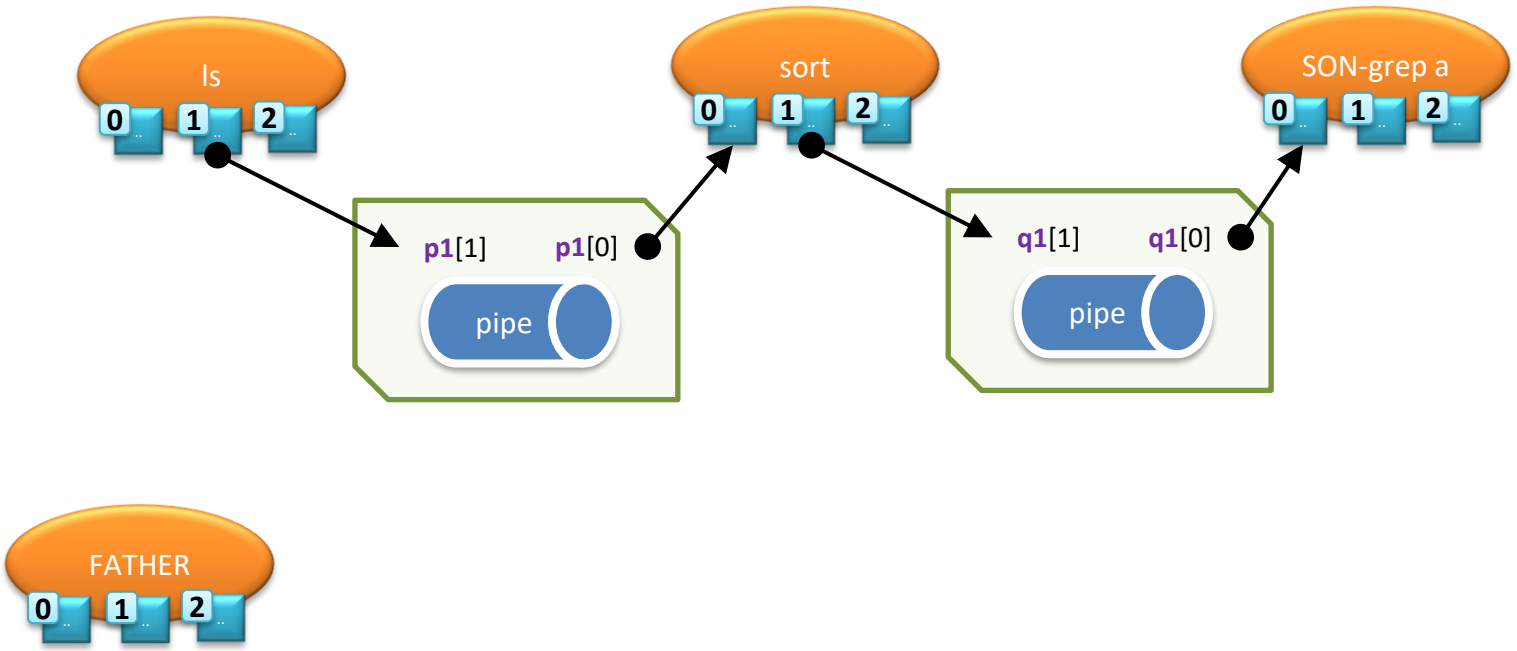
Example 2: "ls | sort | grep a"

(2/4) fork()



The 4 steps should be done for each pipe (creation, **fork**, redirection and cleanup)

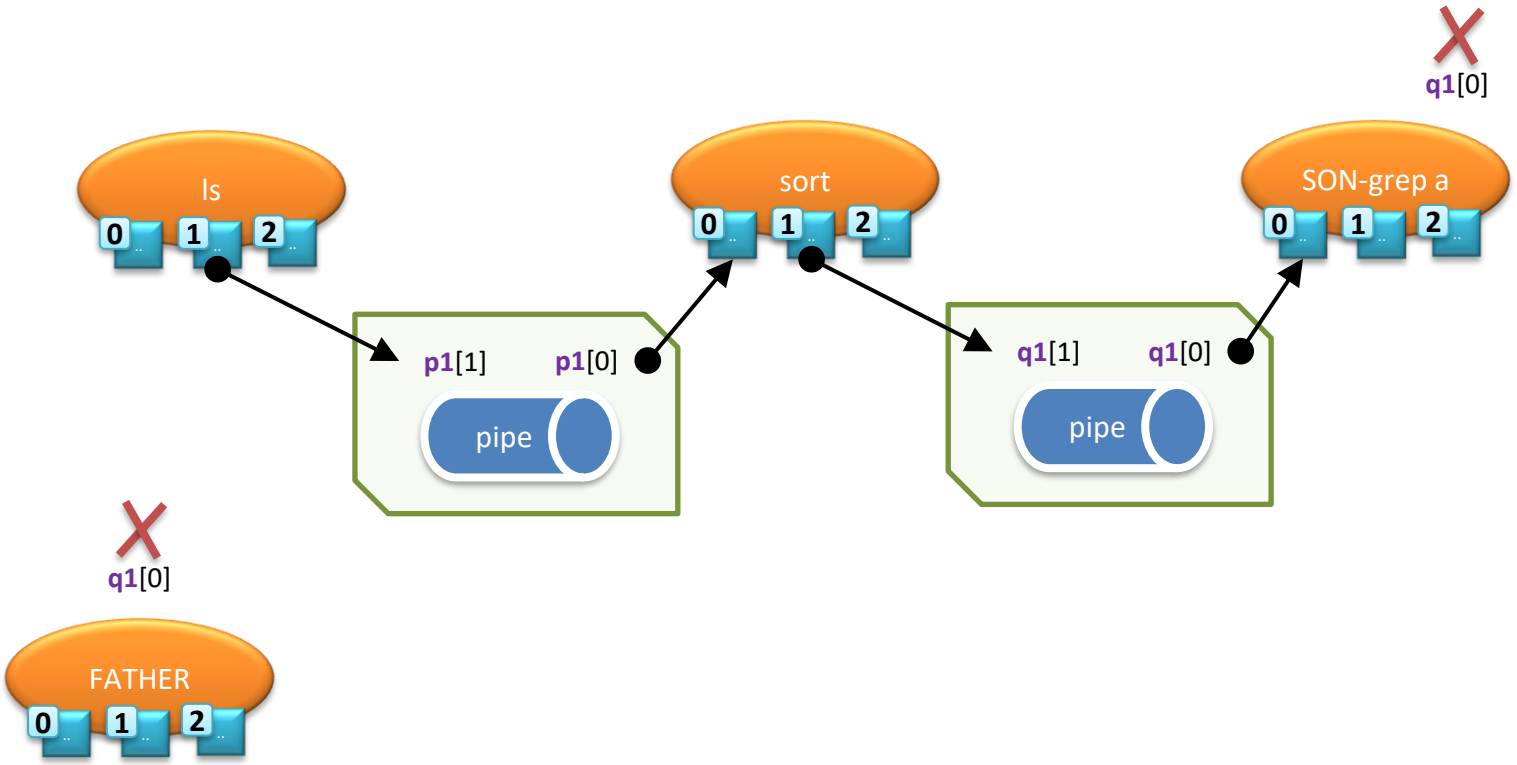
Example 2: "ls | sort | grep a"
(3/4) redirection



The 4 steps should be done for each pipe (creation, fork, **redirection** and cleanup)
The last process uses the pipe for redirection on its standard input.

Example 2: "ls | sort | grep a"

(4/4) cleanup (+exec in son)

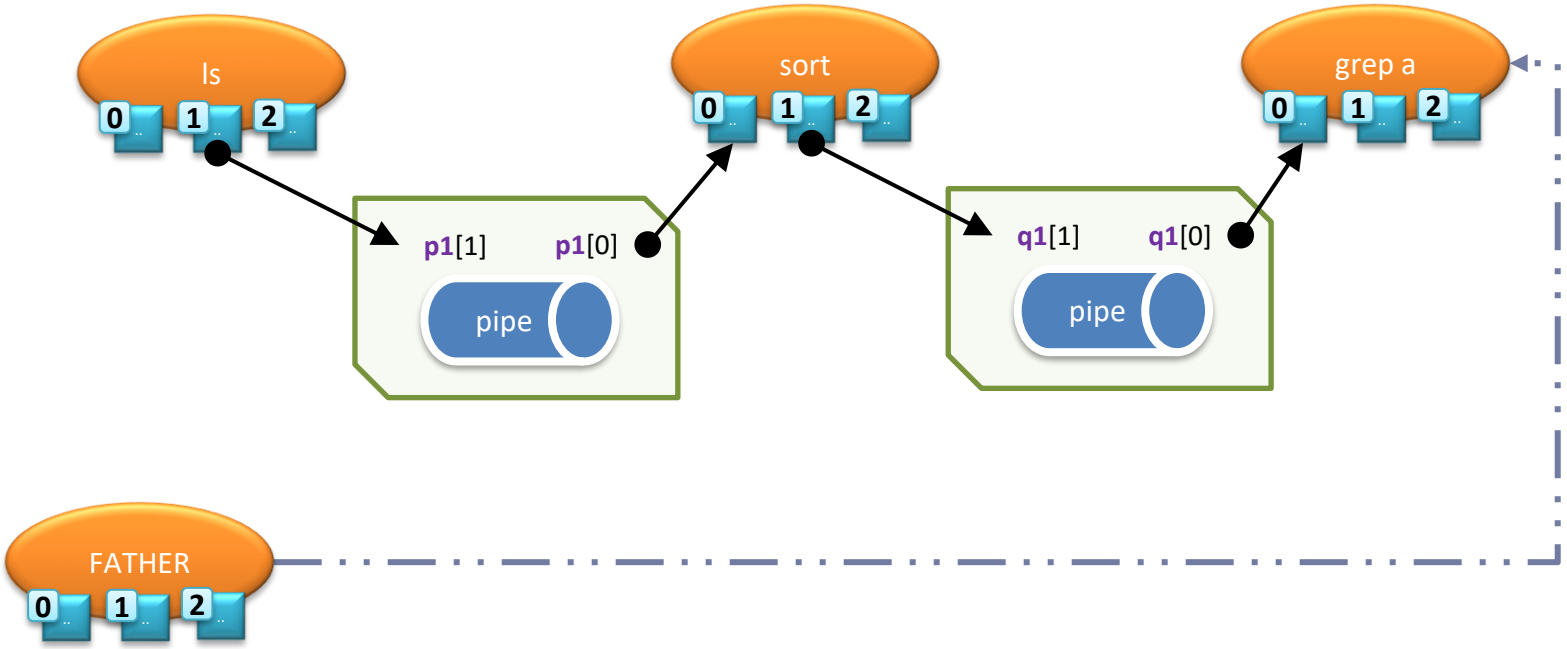


The 4 steps should be done for each pipe (creation, fork, redirection and **cleanup**)

The parent process closes all remaining descriptors.

Example 2: "ls | sort | grep a"

if (! bg) then wait(...) for the last son created



If it is not a *background* task, then the parent process does a *wait*(...) waiting for the last process (which becomes "grep a")

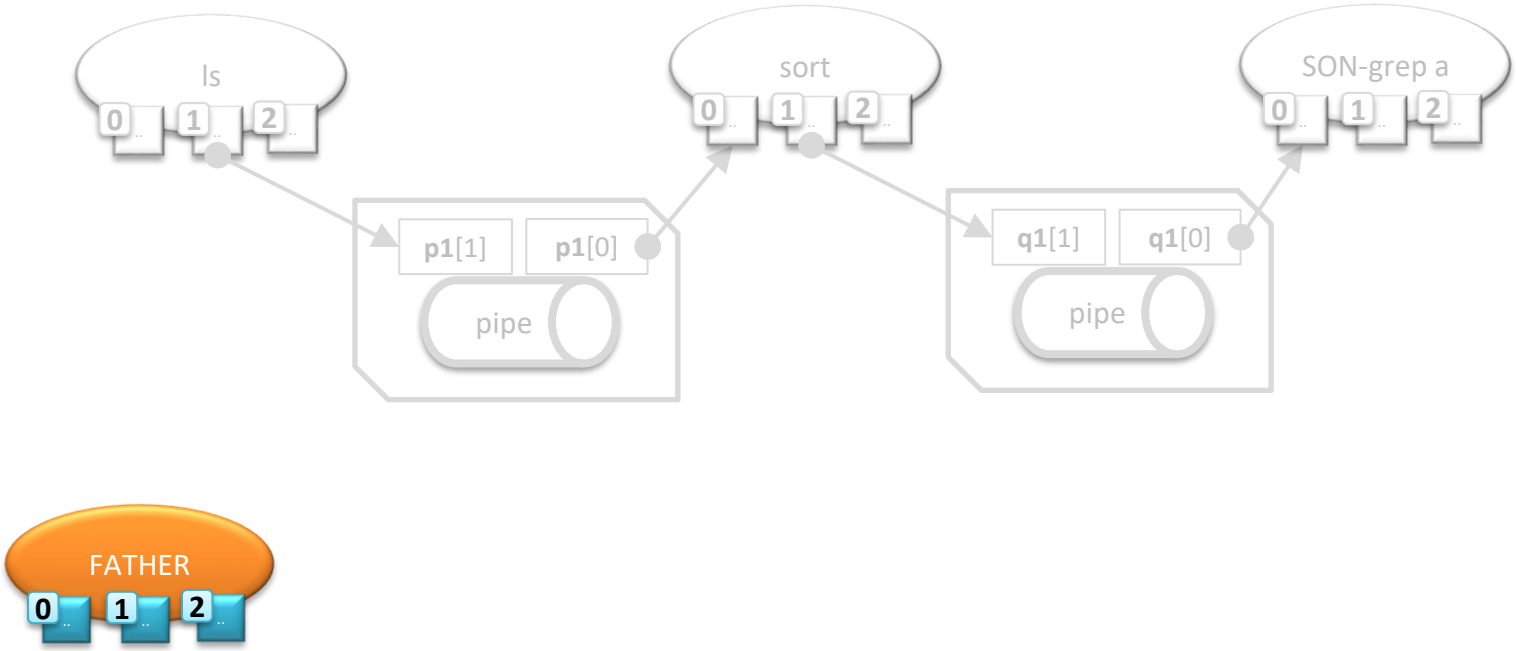
Example 2: "ls | sort | grep a"

The 4 steps should be done for each pipe (pipe, fork, redirection and cleanup)

Take 2: generalization for a number of processes >= 3.

Example 2: "ls | sort | grep a"

Take 2

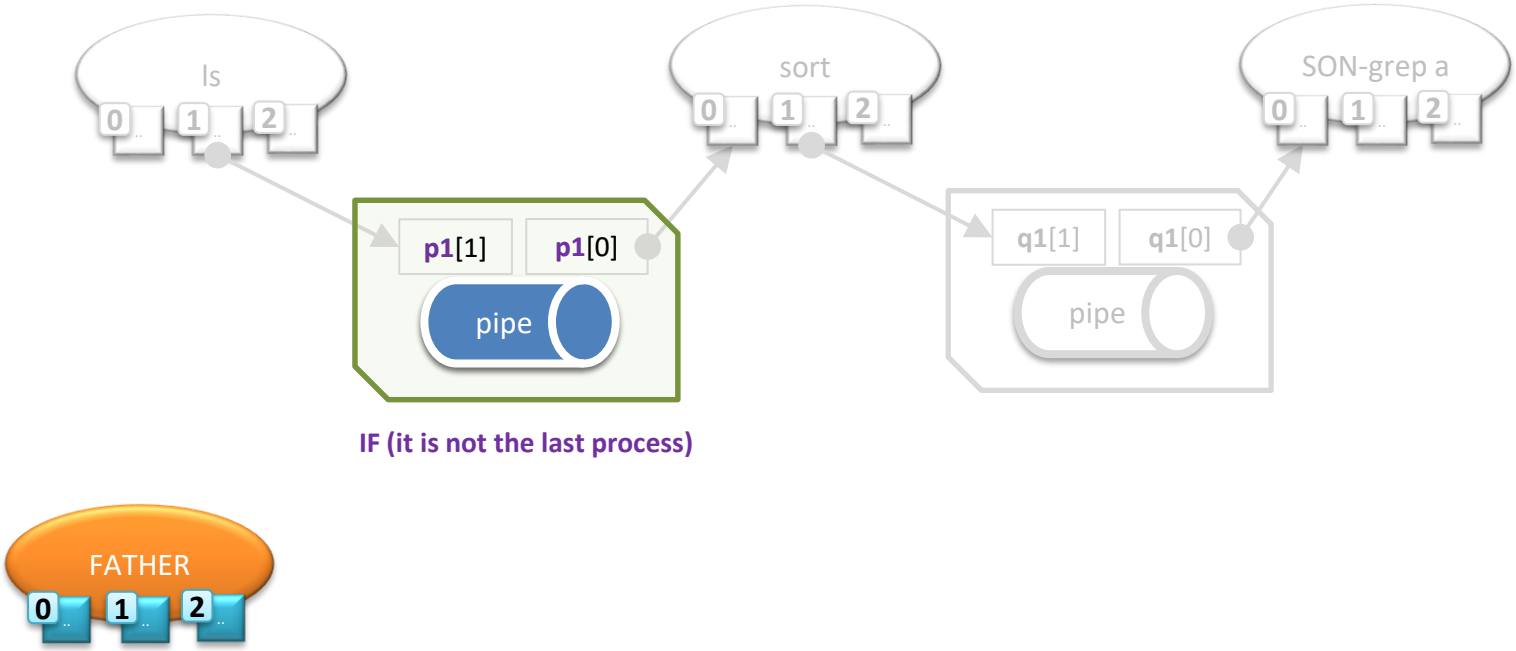


The 4 steps should be done for each pipe (pipe, fork, redirection and cleanup)

Example 2: "ls | sort | grep a"

(1/4) creation

Take 2

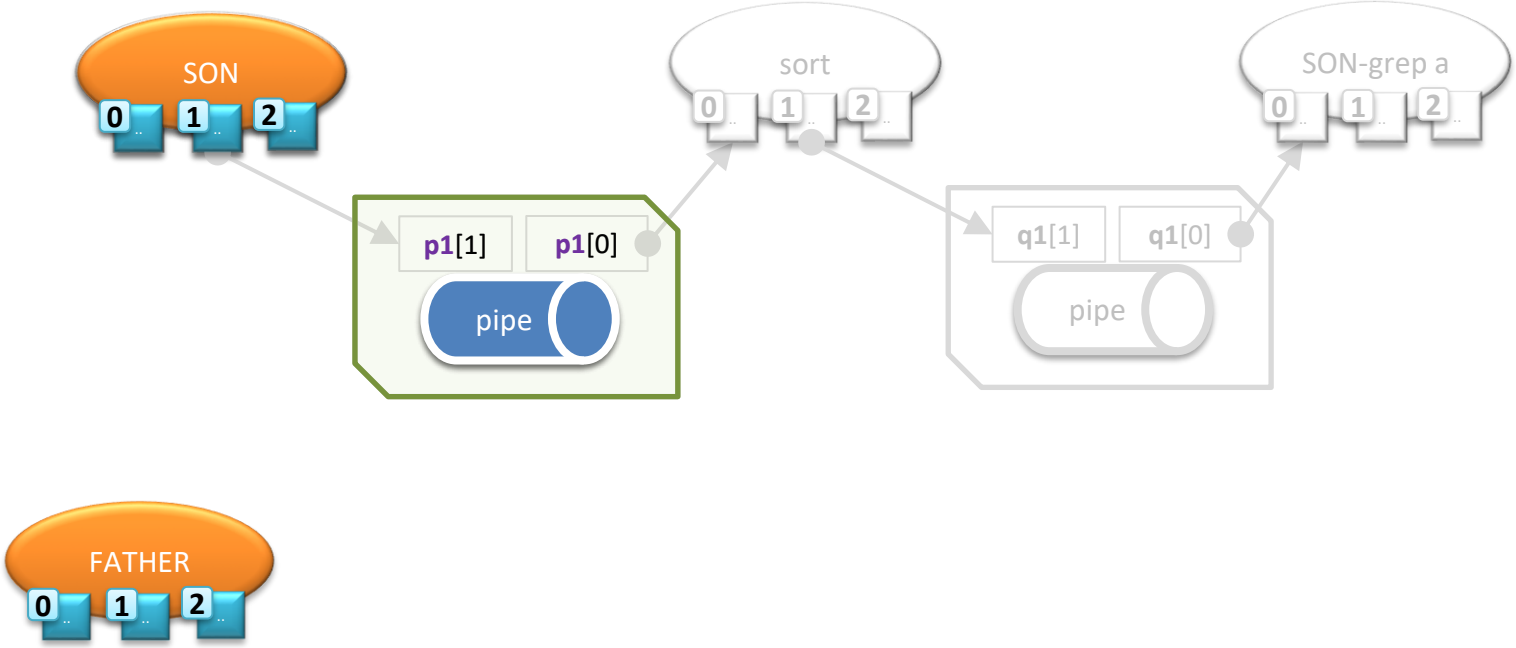


The 4 steps should be done for each pipe (**pipe**, fork, redirection and cleanup)

Example 2: "ls | sort | grep a"

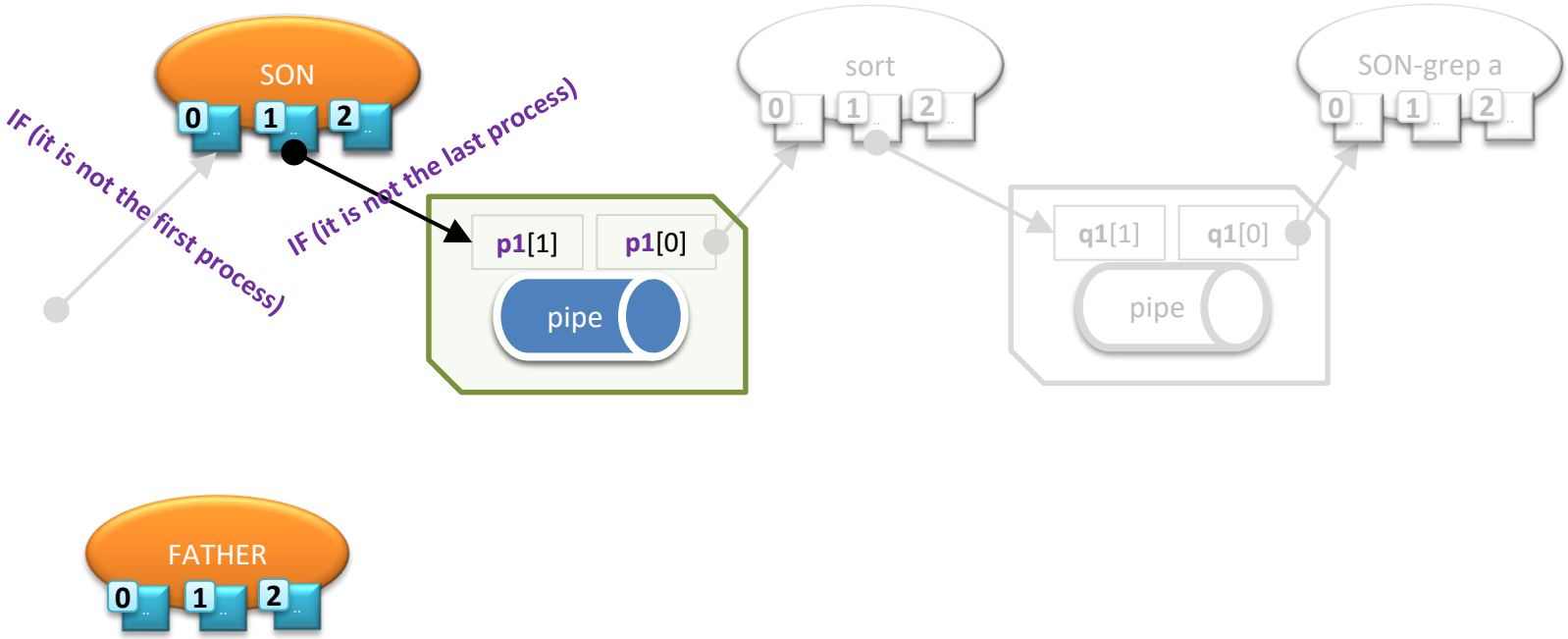
(2/4) fork()

Take 2



The 4 steps should be done for each pipe (pipe, **fork**, redirection and cleanup)

Example 2: "ls | sort | grep a"
(3/4) redirection



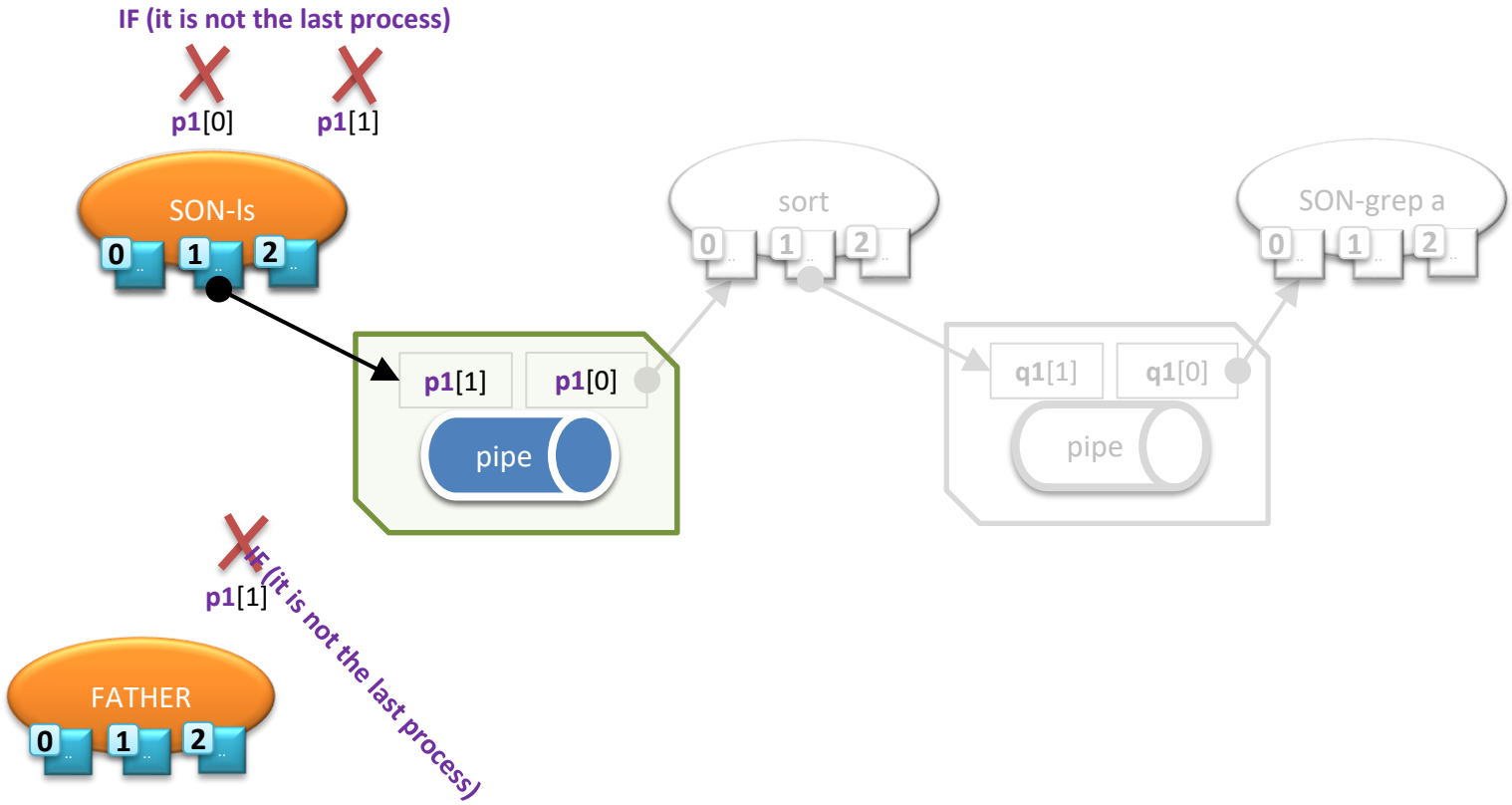
The 4 steps should be done for each pipe (pipe, fork, **redirection** and cleanup)

The first process only uses the pipe in the output redirection.

Example 2: "ls | sort | grep a"

(4/4) cleanup (+exec in son)

Take 2



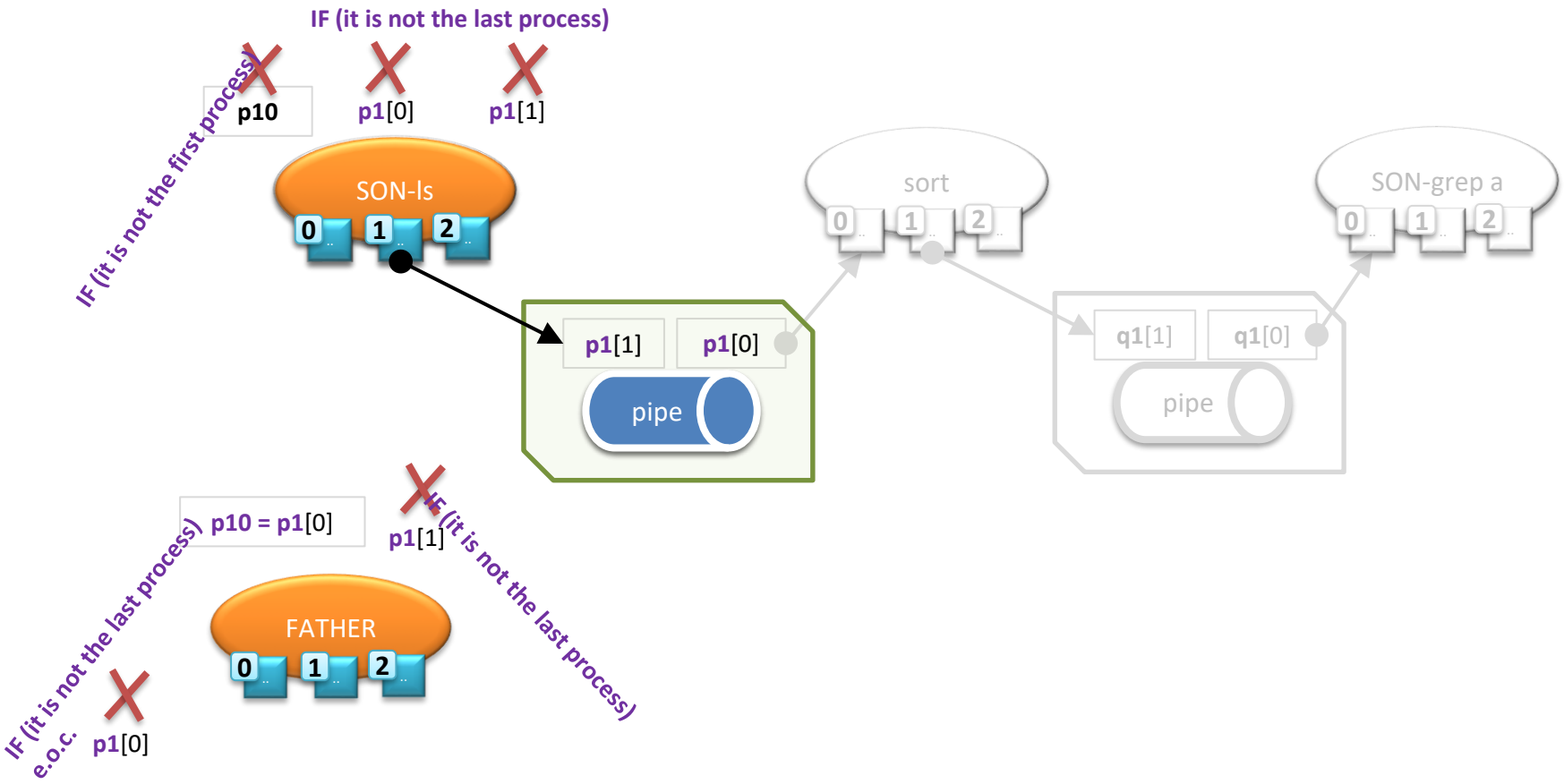
The 4 steps should be done for each pipe (pipe, fork, redirection and **cleanup**)

The father would still not do a total cleanup for the next child to have access to "p1[0]"

Example 2: "ls | sort | grep a"

(4/4) cleanup (+exec in son)

Take 2



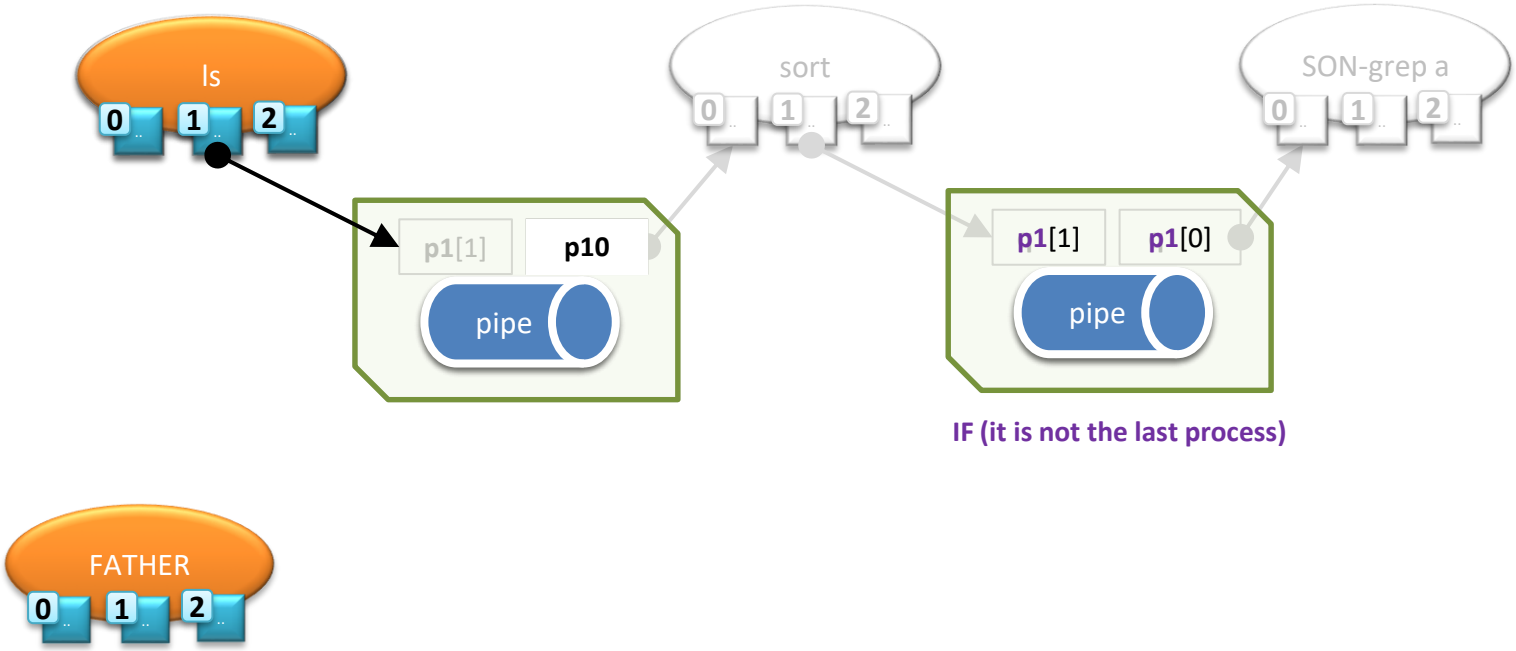
The 4 steps should be done for each pipe (pipe, fork, redirection and **cleanup**)

The parent stores in p10 the value of "p1[0]" for reusing the same pipe (if not the last)

Example 2: "ls | sort | grep a"

(1/4) creation

Take 2

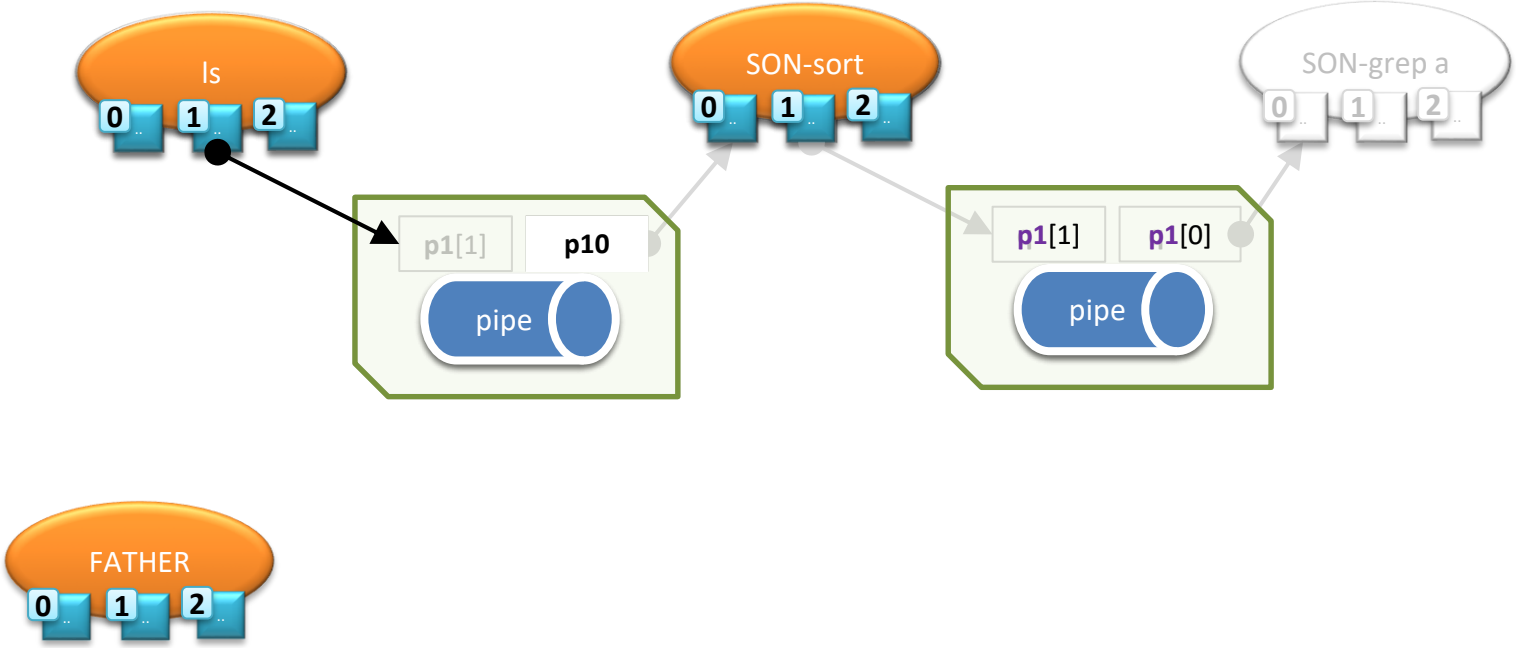


The 4 steps should be done for each pipe (**creation**, fork, redirection and cleanup)

Example 2: "ls | sort | grep a"

(2/4) fork()

Take 2

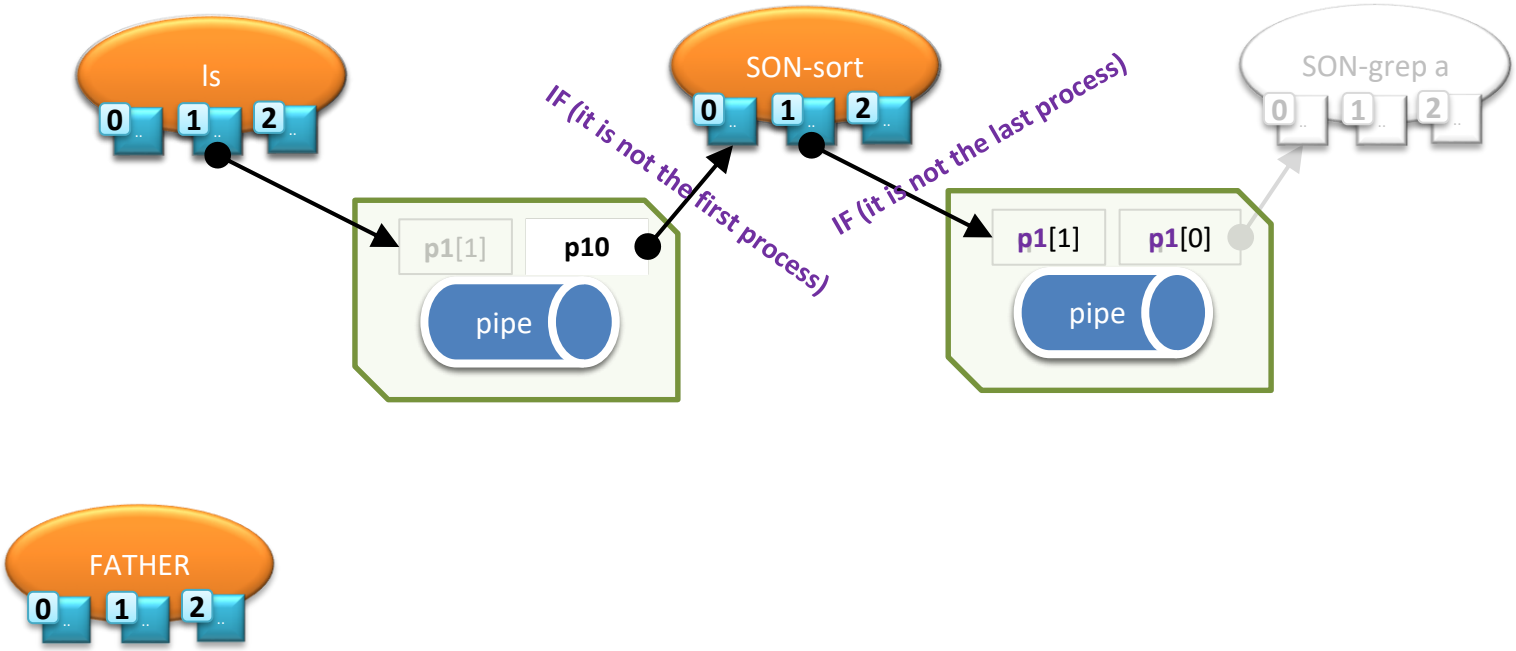


The 4 steps should be done for each pipe (creation, **fork**, redirection and cleanup)

Example 2: "ls | sort | grep a"

(3/4) redirection

Take 2



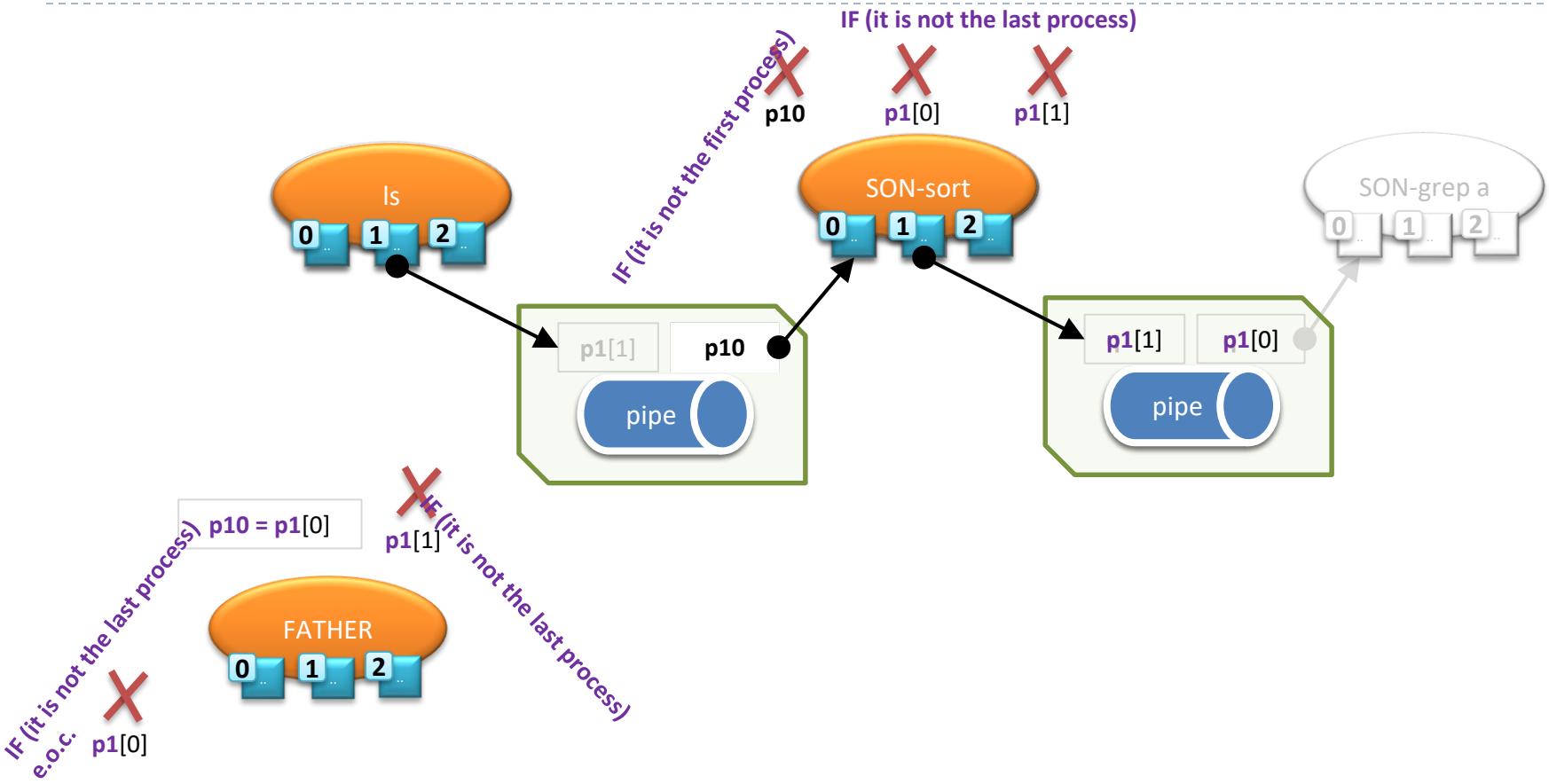
The 4 steps should be done for each pipe (creation, fork, **redirection** and cleanup)

Intermediate processes redirect their standard input and output to the pipe.

Example 2: "ls | sort | grep a"

(4/4) cleanup (+exec in son)

Take 2



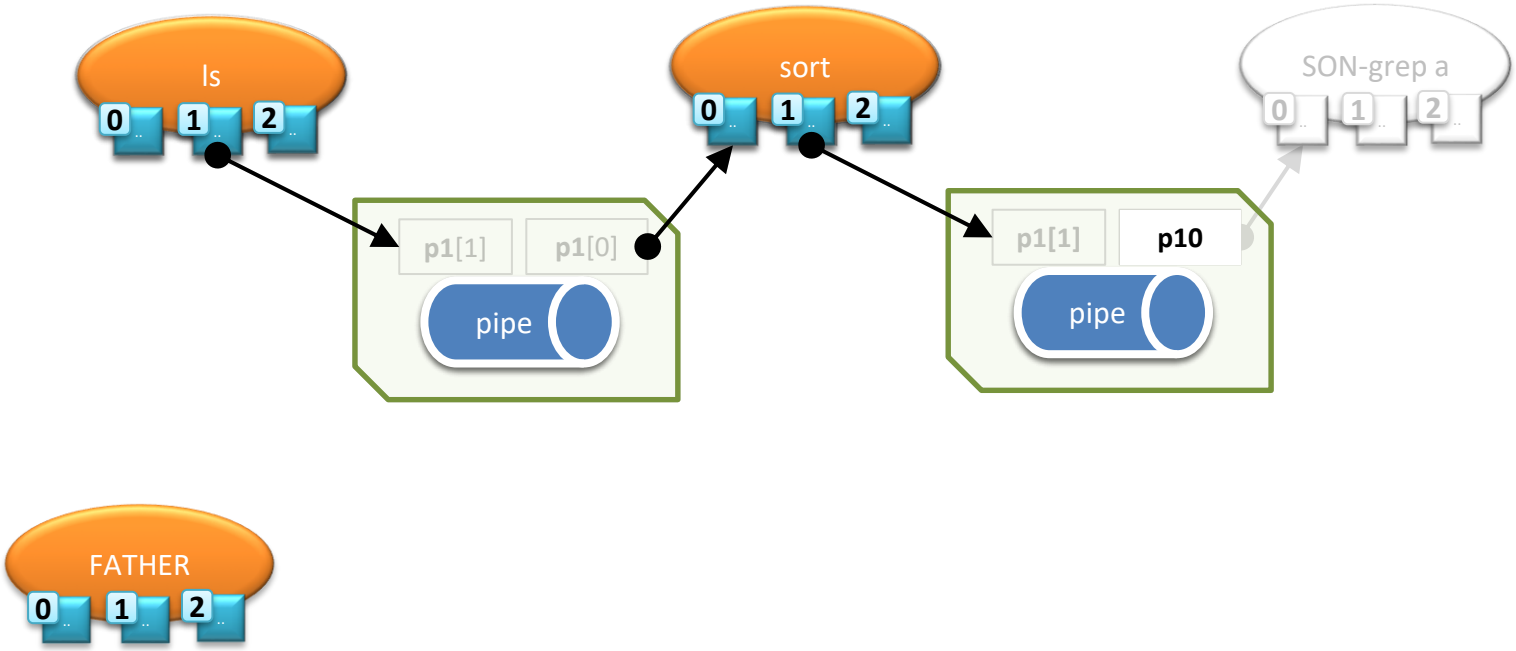
The 4 steps should be done for each pipe (pipe, fork, redirection and **cleanup**)

The father stores in p10 the value of "p1[0]" for reusing the same pipe (if not last one)

Example 2: "ls | sort | grep a"

(1/4) creation

Take 2

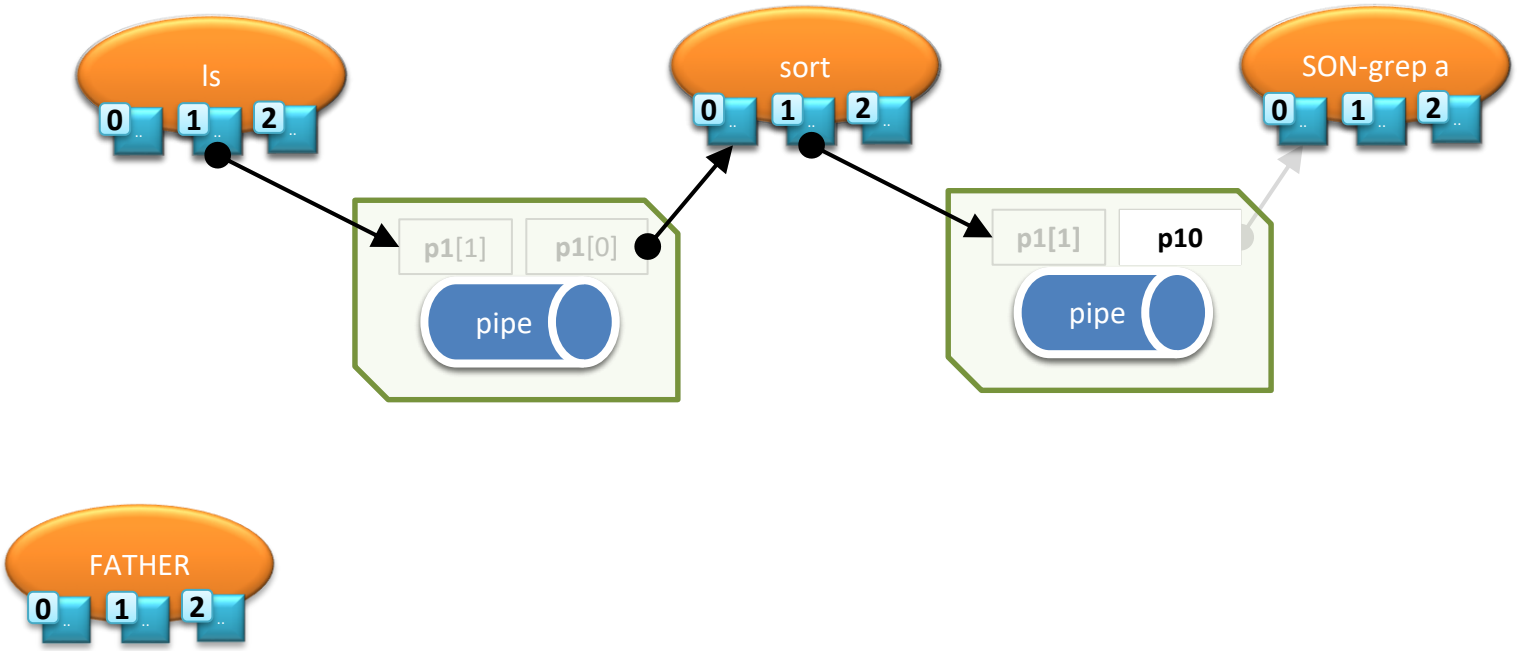


The 4 steps should be done for each pipe (~~**creation**~~, fork, redirection and cleanup)
The last process uses the pipe already created (there are n processes and n-1 pipes)

Example 2: "ls | sort | grep a"

(2/4) fork()

Take 2

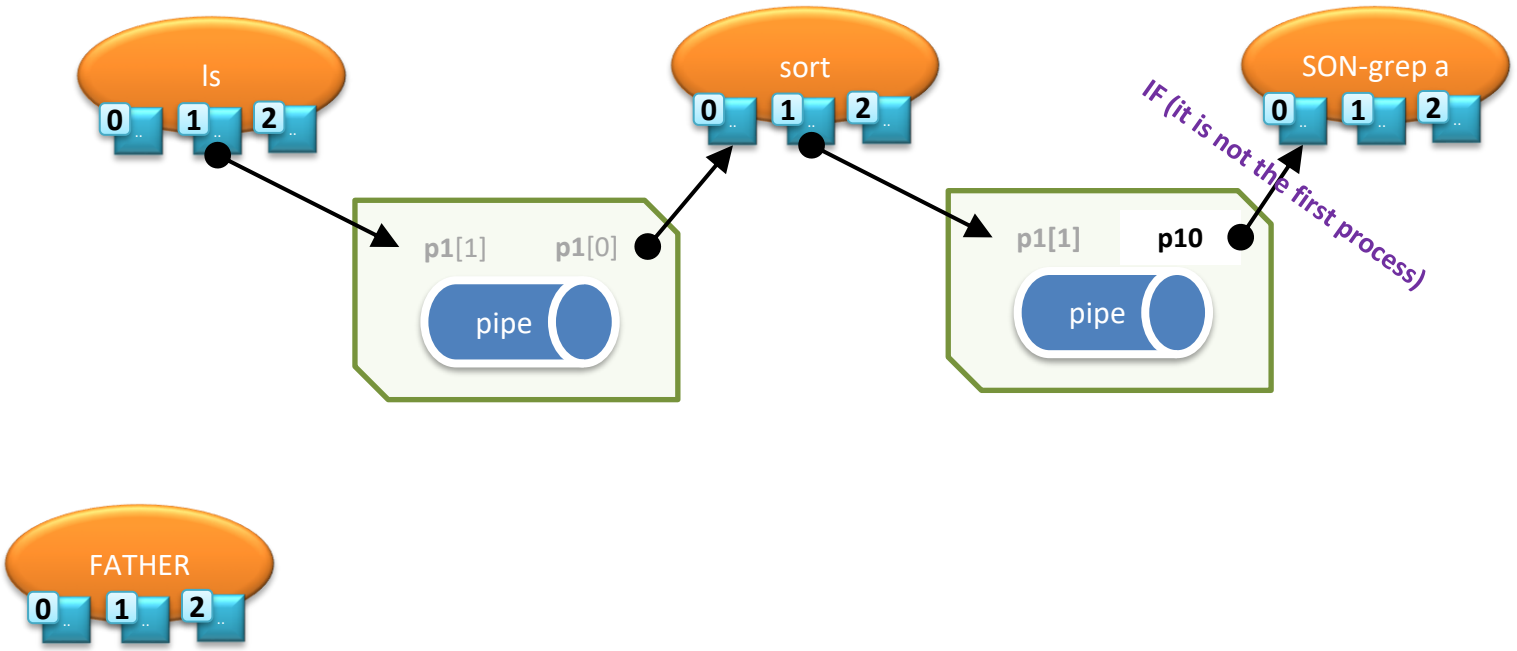


The 4 steps should be done for each pipe (creation, **fork**, redirection and cleanup)

Example 2: "ls | sort | grep a"

(3/4) redirection

Take 2



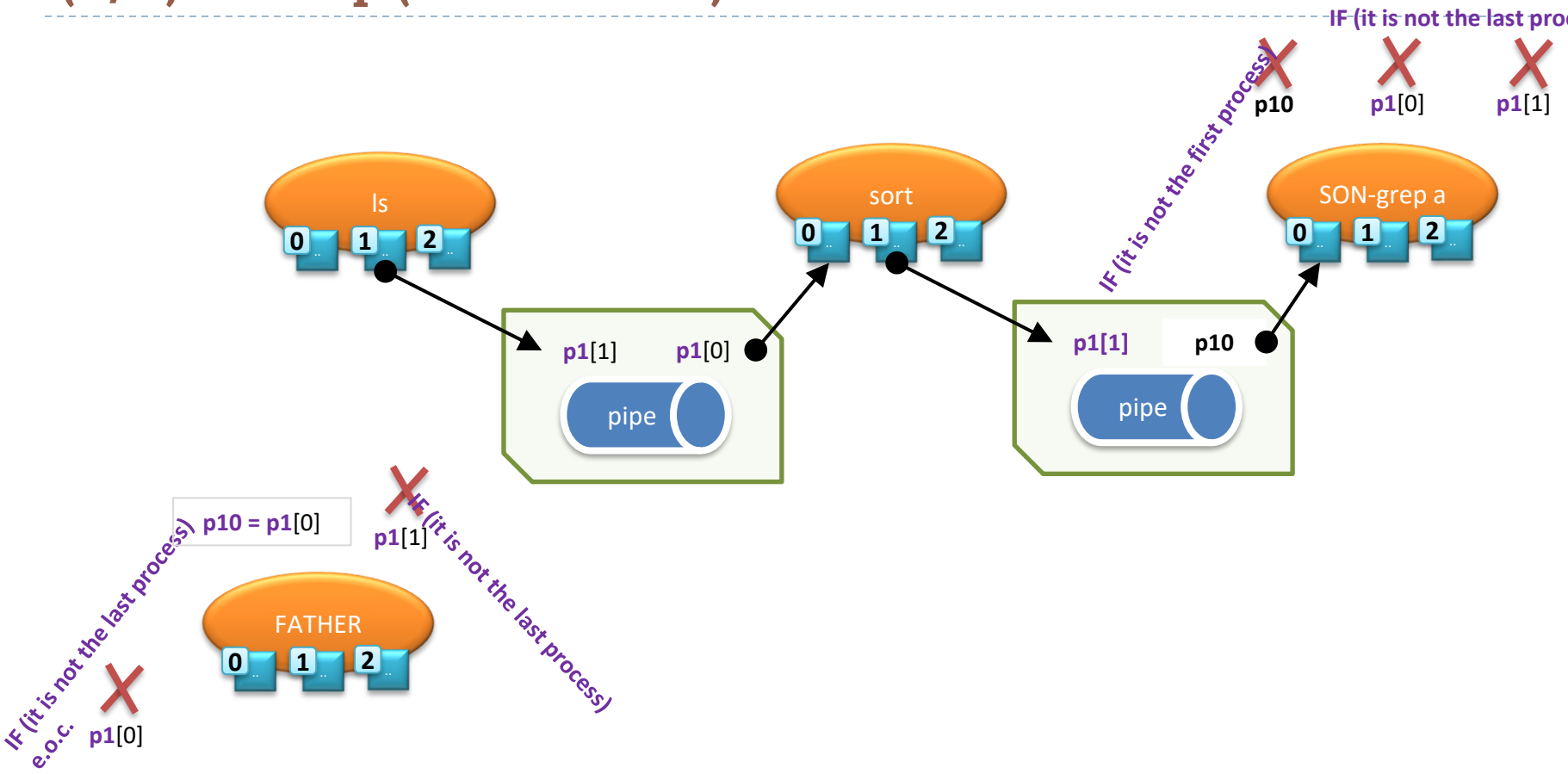
The 4 steps should be done for each pipe (creation, fork, **redirection** and cleanup)

The last process uses the pipe for redirection on its standard input.

Example 2: "ls | sort | grep a"

(4/4) cleanup (+exec in son)

Take 2



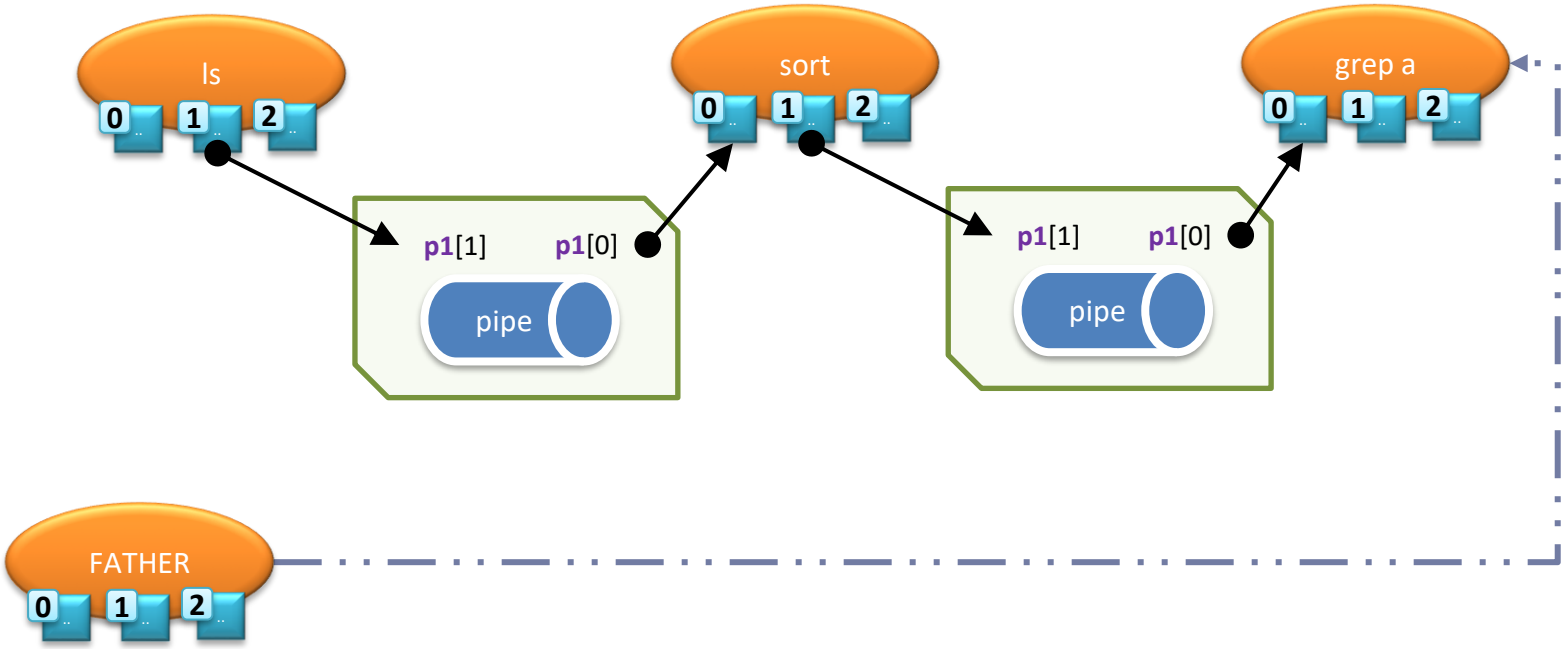
The 4 steps should be done for each pipe (creation, fork, redirection and **cleanup**)

The parent process closes all remaining descriptors.

Example 2: "ls | sort | grep a"

if (! bg) then wait(...) for the last son created

Take 2



If it is not a *background* task, then the parent process does a *wait*(...) waiting for the last process (which becomes "grep a")

ARCOS Group
Universidad Carlos III de Madrid

Lesson 3B
Signals, exceptions and pipes

Operating Systems
Computer Science and Engineering