Processes

Inter-process communication (and pipe)

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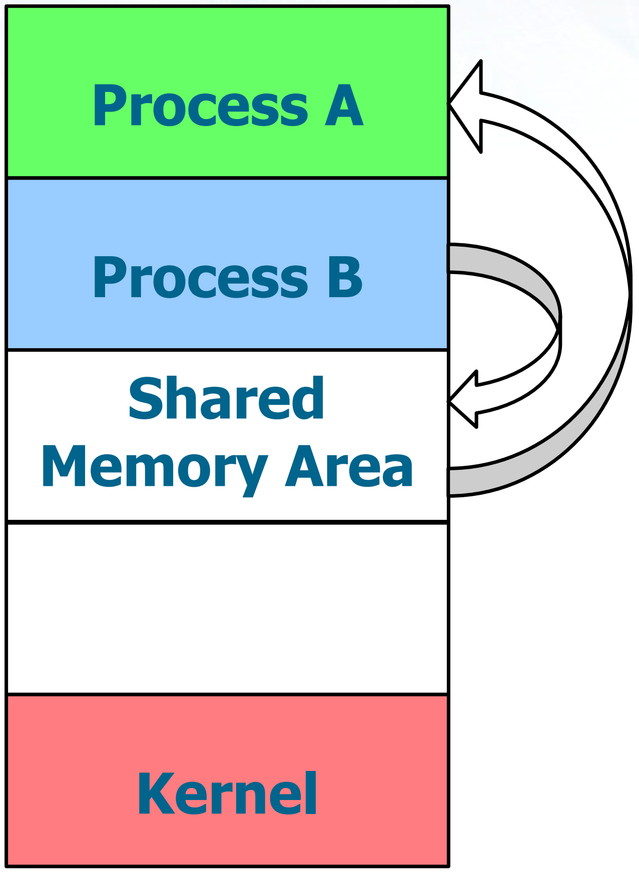
Independent and cooperating processes

- Concurrent processes can be
  - Independent
  - Cooperating
- An **independent** process
  - **Cannot** be influenced by other processes
  - **Cannot** influence other processes
- A set of **cooperating** processes
  - can cooperate only by **sharing data** or by **exchanging messages**
  - Both require appropriate synchronization mechanisms

Inter-Process Communication

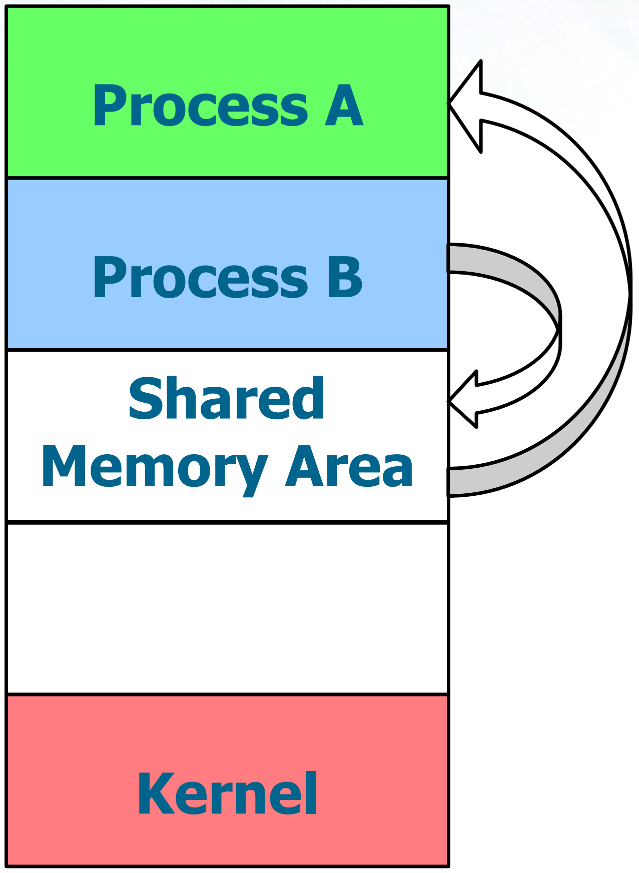
- Information sharing among processes is referred to as **IPC** or **I**nter**P**rocess **C**ommunication
- The main communication models are based on
  - Shared memory
  - Message exchange

Communication models



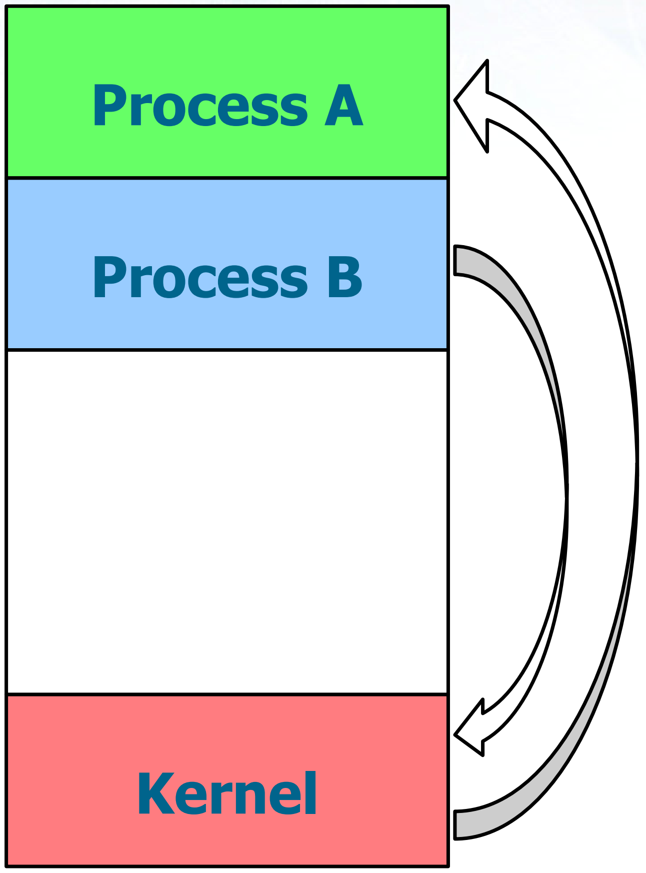
- Shared memory
  - Sharing of a memory area and writing of data in this area
    - Normally the kernel **does not allow** a process to access the memory of another process
    - Processes must agree on the:
      - Access rights
      - Access strategies
        - e.g., Producer-consumer with bounded or unbounded buffer

Communication models



- The most common methods for shared buffer use a
  - **File**
    - Sharing the name or the file pointer or descriptor before `fork/exec`
  - **Mapped file** in memory
    - A file mapped in memory associates a shared memory region to a file
- These techniques allow sharing a large amount of data

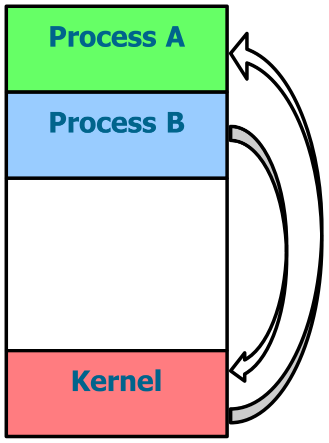
Communication models



- Message exchange
  - Communication takes place through the exchange of messages
  - Need to setup a communication channel
  - Useful for exchanging limited amounts of data
  - Uses system calls
    - which request kernel intervention
    - and introduce overhead

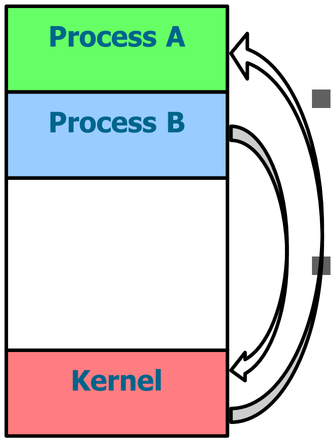
Communication channels

- A communication channel can offer direct or indirect communication
  - Direct
    - Is performed naming the sender or the receiver
      - `send    (to_process,    message)`
      - `receive (from_process, &message)`
  - Indirect
    - Performed through a **mailbox**
      - `send    (mailboxAddress, message)`
      - `receive (mailBoxAddress, &message)`



Communication channels

- A communication channel can be characterized by
  - Synchronization
    - Both sending or receiving messages can be
      - Synchronous, i.e., blocking
      - Asynchronous, i.e., non-blocking
  - Capacity
    - If the capacity is **zero**, the channel cannot allow waiting messages (no buffering); the sender blocks waiting for the receiver
    - If the capacity is **limited** the sender blocks when the queue is full
    - If the capacity is **unlimited** the sender does not block



Communication channels

- UNIX makes available
  - **Half-duplex pipes**
  - FIFOs
  - Full-duplex pipes
  - Named full-duplex pipes
  - Message queues
  - **Semaphores**
  - Sockets
  - STREAMS

Extensions of the pipes not covered in this course

For process synchronization

Network process communication. Each process is identified by a socket to which it is associated a network address

Used starting from UNIX System V

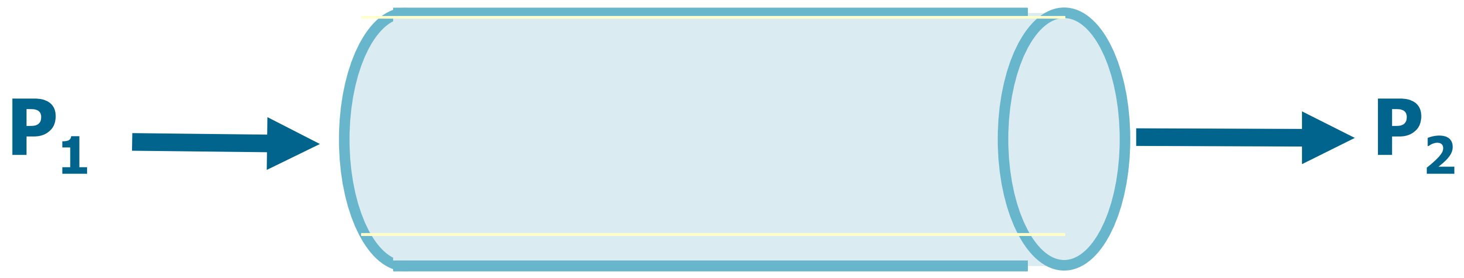
Not all the types of communication are supported by all the UNIX versions

Pipes

- Pipes are the oldest form of communication in UNIX SO
- Provide a communication channel, which is
  - Direct
  - Asynchronous
  - With limited capacity
- Pipes "live" in memory and they are more efficient than using of files

Pipes

- Allow creating a **data stream among** processes
  - The user interface to a pipe is similar to file access
  - A pipe is accessed by means of two descriptors (integers), one for each end of the pipe
  - A process (P_1) writes to an end of the pipe, another process (P_2) reads from the other end



Pipes

- Historically, they have been
  - **half-duplex**
    - Data can flow in both directions (from P_1 to P_2 or from P_2 to P_1), but **not** at the same time
    - Full-duplex models have been proposed more recently, but they have limited portability
  - A pipe can be used for communication among a parent and its childs, or among processes with a **common ancestor**
    - The file descriptor must be common to the two communicating processes and therefore these processes must have a common ancestor

Simplex, for synchronization problems

Terminology:
Simplex: Mono-directional
Half-Duplex: One-way, or bidirectional, but alternate (walkie-talkie)
Full-Duplex: Bidirectional (telephone)

pipe() system call

```
#include <unistd.h>

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

- System call **`pipe`** creates a pipe
- It returns **two** file descriptors in vector **fileDescr**
  - fileDescr[0]: Typically used for reading
    fileDesrc[1]: Typically used for writing
  - The input stream written on fileDescr[1] corresponds to the output stream read on fileDescr[0]

pipe() system call

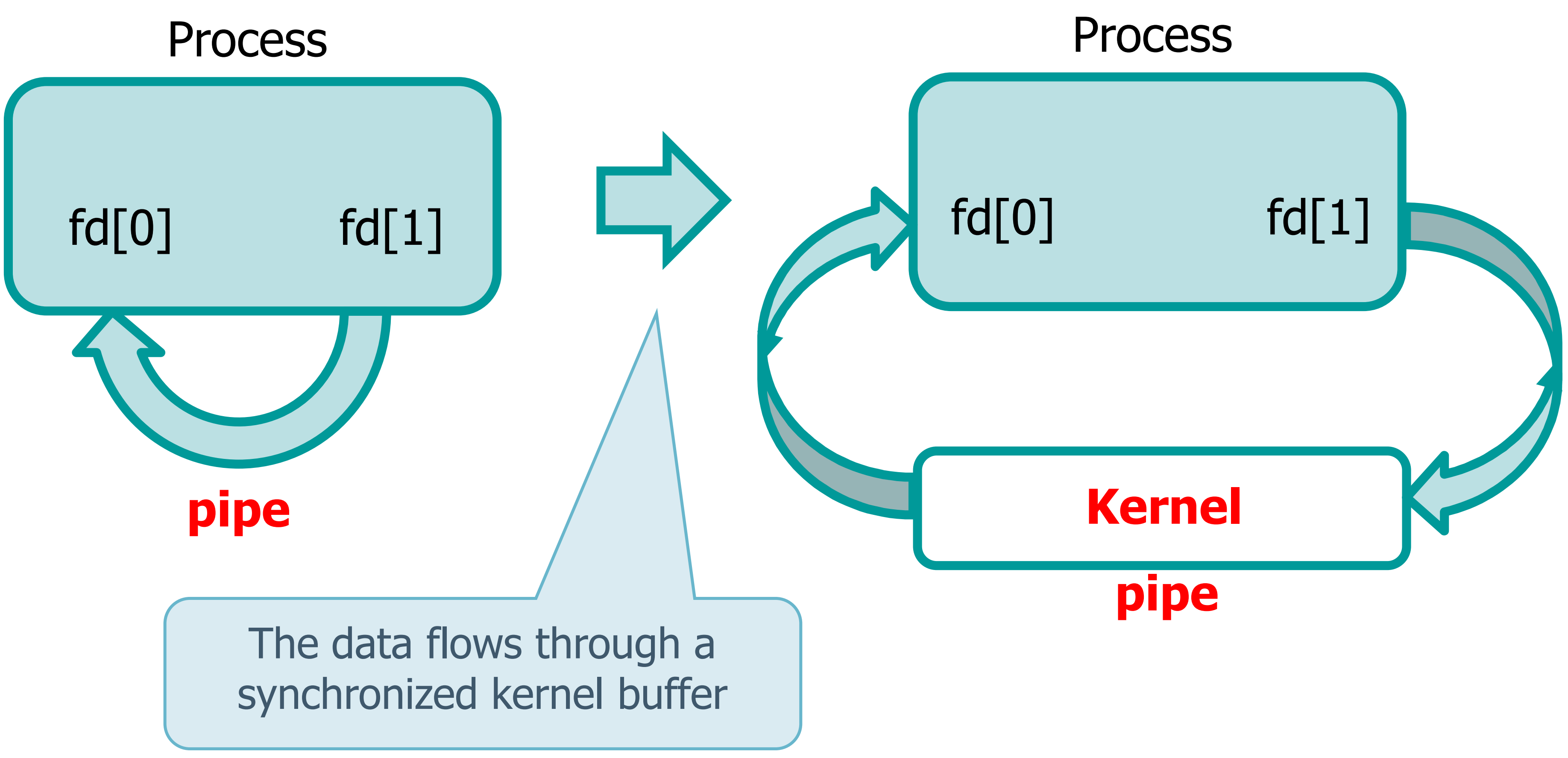
```
#include <unistd.h>

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

- Returned values
  - 0 on success
  - -1 on error
- Resources associated to a pipe are released when all involved processes
  - Closed their terminals, or
  - They are terminated

pipe() system call

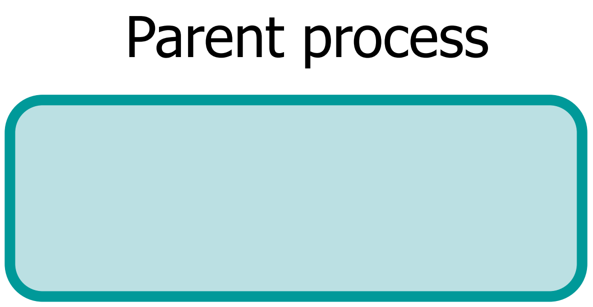
- Using a pipe inside a process is possible but not much useful



The data flows through a synchronized kernel buffer

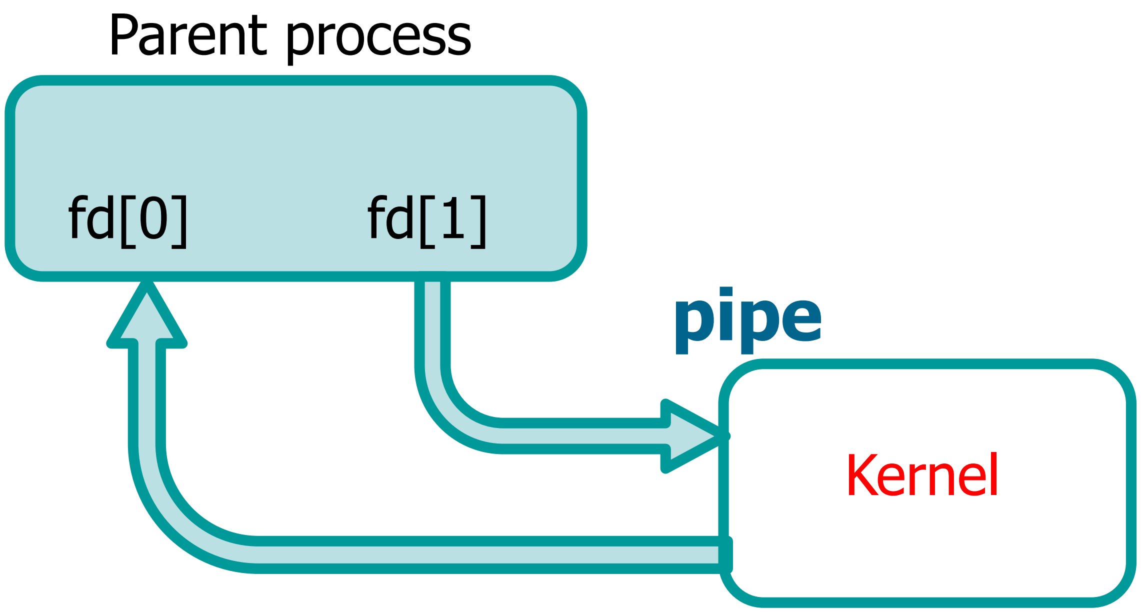
pipe() system call

- A pipe typically allows a parent and a child to communicate
- Parent must fork (e.g., by means of the fork() system call) **after** creating the pipe



pipe() system call

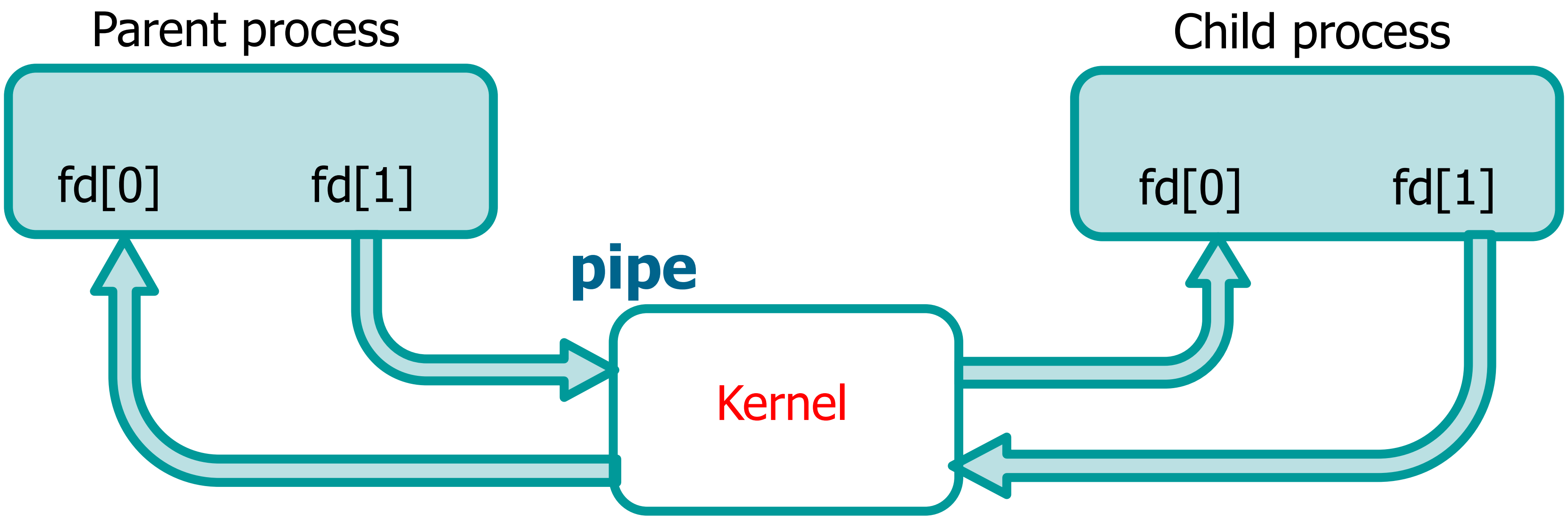
- The "parent" process creates a pipe



pipe() system call

- The "parent" process creates a pipe
- Performs a fork
- The child process **inherits** the file descriptors

If the pipe were made **after** the fork(), the descriptors would **not** be inherited

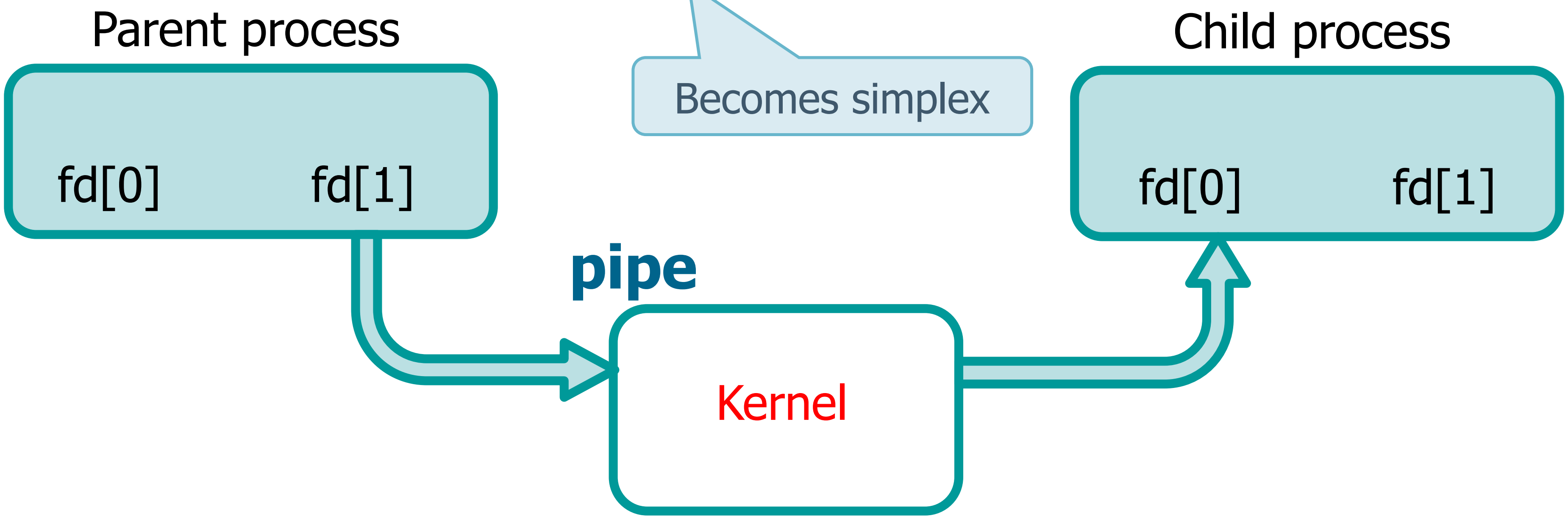


pipe() system call

- The "parent" process creates a pipe
- Performs a fork
- The child process **inherits** the file descriptors
- One of the two processes (e.g., the parent) writes in the pipe, while the other (e.g., the child) reads from the pipe
- The unused descriptor can be closed

Half-duplex mode

Becomes simplex



Pipe I/O

- The descriptor of the pipe is an integer number
- R/W on pipes do not differ to R/W on files
  - Use **`read`** and **`write`** system calls
  - It is possible to have more than one reader and writer on a pipe, but
    - The standard case is to have a single writer and a single reader
    - Data can be interlaced using more than one writer
    - Using more readers, it is undetermined which reader will read the next data from the pipe

Pipe I/O

- System call **read**
  - Blocks the process if the pipe is empty (**it is blocking**)
  - If the pipe contains less bytes than the ones specified as argument of the read, it **returns only the bytes available on the pipe**
  - If all file descriptors referring to the write-end of a pipe have been closed, then an attempt to read from the pipe will see end-of-file (read returns 0)

Pipe I/O

- System call **write**
  - Blocks the process if the pipe is full (**it is blocking**)
  - The dimension of the pipe depends on the architecture and implementation
    - Constant **`PIPE_BUF`** defines the number of bytes that can be written atomically on a pipe
    - Standard value of **`PIPE_BUF`** is **`4096`** on Linux
  - If all file descriptors referring to the read-end of a pipe have been closed, then a write to the pipe will cause a SIGPIPE signal to be generated for the calling process
  - If the end of the write operations are not to be verified based on the return value of the read, it is always possible to transfer a "sentinel" (end-of-message marker)

Example

- Create a pipe shared between parent and child, that is
  - Create a pipe that is common between a parent process and a child process
  - Transfer a single character from the parent process to the child process
- Logical flow
  - Pipe creation
  - Process fork
  - Close the unused-ends of the pipe
  - **`read`** and **`write`** operations at the two pipe ends

Example

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

int main () {
  int n;
  int file[2];
  char cW = 'x';
  char cR;
  pid_t pid;
  if (pipe(file) == 0) {
    pid = fork ();
    if (pid == -1) {
      fprintf(stderr, "Fork failure");
      exit(EXIT_FAILURE);
    }
```

Firstly create the pipe

Then fork the process

Example

```
  if (pid == 0) {
      // Child reads
      close (file[1]);
      n = read (file[0], &cR, 1);
      printf("Read %d bytes: %c\n", n, cR);
      exit(EXIT_SUCCESS);
    } else {
      // Parent writes
      close (file[0]);
      n = write (file[1], &cW, 1);
      printf ("Wrote %d bytes: %c\n", n, cW);
    }
  }
  exit(EXIT_SUCCESS);
}
```

Close unused end (good practice)

Child reads

Parent writes

The two process synchronize because read and write are possibly blocking.

More complex data communication requires a communication protocol

Example

- Do pipes have infinite dimensions?
  - Which is the dimension of a pipe?
- Since `write` is a blocking system call, we can continue to write a byte to the pipe until the process is blocked because the pipe is full

Example

```
...
#define SIZE  512*1024

int fd[2];


int main () {
...
int i, n, nR, nW;
char c = '1';
setbuf (stdout, 0);

...

pipe(fd);
n = 0;
```

Firstly create the pipe

Example

Then fork the process

```
if (fork()) {
  fprintf (stdout, "\nParent PID=%d\n", getpid());
  sleep (1);
  for (i=0; i<SIZE; i++) {
    nW = write (fd[1], &c, 1);
    n = n + nW;
    fprintf (stdout, "W %d\r", n);
  }
} else {
  fprintf (stdout, "Child  PID=%d\n", getpid());
  sleep (10);
  for (i=0; i<SIZE; i++) {
    nR = read (fd[0], &c, 1);
    n = n + nR;
    fprintf (stdout, "\t\t\t\tR %d\r", n);
  }
}
```

Parent writes a byte at a time

The child reads **after 10 seconds**

\r = CR = Carriage Return (not Line Feed)

Example

```
> ./pgrm
Parent PID=2272
Child  PID=2273
W 0

...

W 65536

...

W 65536 R 0

...

W 524288 R 524288
```

The number of written bytes increases up to the dimension of the pipe

When the pipe is full, write blocks the parent

After 10 seconds the child begins to read the pipe, consuming its data

R & W are concurrent, the processes terminate after SIZE writes and reads

Exercise

- In previous examples the program wirtes and reads **exactly** SIZE characters
- How do you proceed to write a variable number of characters?
  - Managing the returned value of **read**
  - Writing a "sentinel" data (end-of-message marker)
    - Try …
    - The transmission of complex information requires the management of some kind of communication protocol

Solution

```c
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <sys/wait.h>

int main() {
  char c;
  int n, fd[2];
  pid_t p;

  setbuf (stdout, 0);

  pipe(fd);
  fprintf (stdout, "Reading from %d; ", fd[0]);
  fprintf (stdout, "Writing to %d\n", fd[1]);

  p = fork();
```

Before create the pipe

Then fork the process

Solution

Buggy ...

```
  if (p > 0) {
    write (fd[1], "Hi Child!", 9);
    wait (NULL);
    fprintf (stdout, " - Parent ends\n");
  } else {
    while ((n = read (fd[0], &c, sizeof (char))) > 0) {
      fprintf (stdout, "%c", c);
    }
    fprintf (stdout, " - Child ends\n");
  }

  return 0;
}
```

Parent

Child

Example of execution

```
➢ ./pgrm
Reading from 3; Writing to 4
Hi Child!
```

The program does not terminate !
read is **blocking**

Solution

Correct …

```
  if (p > 0) {
    close (fd[0]);
    write (fd[1], "Hi Child!", 9);
    close (fd[1]);
    wait (NULL);
    fprintf (stdout, " – Parent ends\n");
  } else {
    close (fd[1]);
    while ((n = read (fd[0], &c, sizeof (char))) > 0) {
      fprintf (stdout, "%c", c);
    }
    fprintf (stdout, " – Child ends\n");
  }

  return 0;
}
```

Not used terminals have to be closed

Example of execution

```
➢ ./pgrm
Reading from 3; Writing to 4
Hi Child!
 – Parent ends
```

The program terminates !

Example

- What happens if a pipe is not used according to the half-duplex protocol?
  - It is possible to interleave read and write operations?
  - It is possible to have multiple readers and/or writers?
- The result is undefined, but it is possible to obtain corrected results for the first case

Example

Program receives a string in argv[1]

```
int fd[2];
setbuf (stdout, 0);
pipe (fd);
if (fork()!=0) {
  while (1) {
    if (strcmp(argv[1],"P")==0||strcmp(argv[1],"PC")==0) {
      c = 'P';
      fprintf (stdout, "Parent writes %c\n", c);
      write (fd[1], &c, 1);
    }
    sleep (2);
    if (strcmp(argv[1],"C")==0||strcmp(argv[1],"PC")==0) {
      read (fd[0], &c, 1);
      fprintf (stdout, "Parent reads %c\n", c);
    }
    sleep (2);
  }
  wait ((int *) 0);
}
```

If argv[1] is "P"
the parent writes only
and the child reads only

If argv[1] is "C"
the parent reads only
and the child writes only

Example

```
} else {
  while (1) {
    if (strcmp(argv[1],"P")==0||strcmp(argv[1],"PC")==0) {
      read (fd[0], &c, 1);
      fprintf (stdout, "Child reads %c\n", c);
    }
    sleep (2);
    if (strcmp(argv[1],"C")==0||strcmp(argv[1],"PC")==0) {
      c = 'C';
      fprintf (stdout, "Child writes %c\n", c);
      write (fd[1], &c, 1);
    }
    sleep (2);
  }
  exit (0);
}
```

If argv[1] is "PC"
parent and child
alternate write operations

Example

```
> ./pgrm P
Parent writes P
Child reads P
...
^C
> ./pgrm C
Child Write C
Parent Read C
...
^C
> ./pgrm PC
Parent writes P
Child reads P
Child writes C
Parent reads C
...
^C
```

Only parent writes

Only child writes

Parent and child alternate writing Every 2 secs

How they would alternate without sleep?