Processes - Part I

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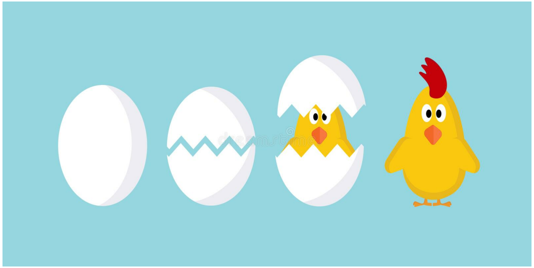
2022

What Is A Process?

Process

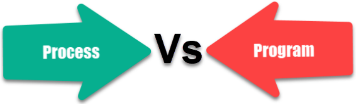
An instance of a program running.



https://tinyurl.com/53pecc99

Program vs. Process

- Program is a passive entity stored on disk (executable file).



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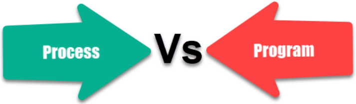

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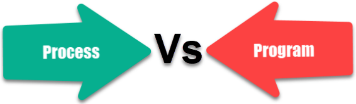
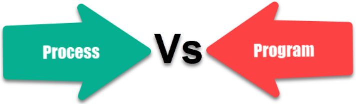


Program vs. Process

- Program is a passive entity stored on disk (executable file).
- Process is an active entity.
- Program becomes process when executable file loaded into memory.
- One program can be several processes.



Parts of a Process (1/2)

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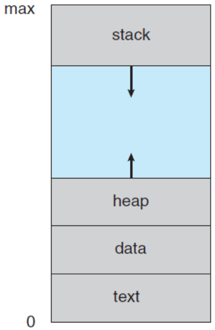

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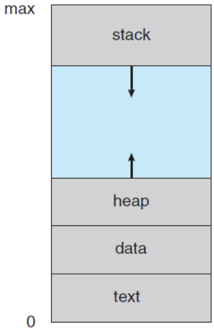

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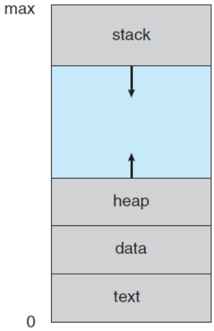

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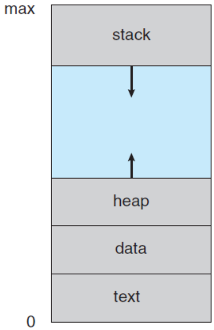

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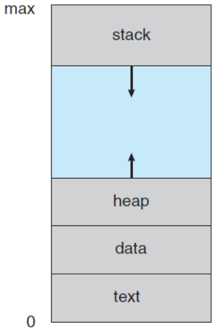
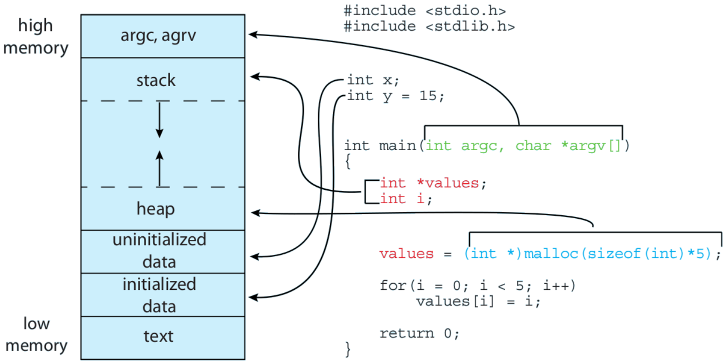
- A process is more than the program code.
- Multiple parts of a process:
  - Text section: the executable code
  - Data section: global variables
  - Heap section: memory that is dynamically allocated during program run time
  - Stack section: temporary data storage when invoking functions (e.g., function parameters, return addresses, and local variables)

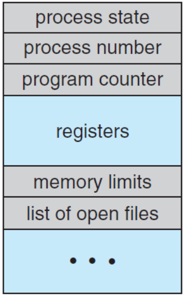


Parts of a Process (2/2)



Process Control Block (PCB)

- The information of each process.



Process Data Structure in Linux Kernel

- Represented by `task_struct` in the Linux kernel.
  - At `<include/linux/sched.h>`

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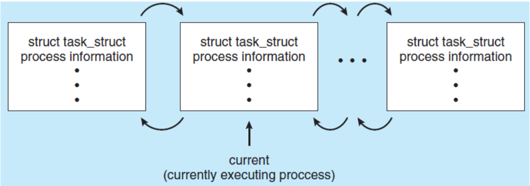
  - At `<include/linux/sched.h>`
- All active processes are represented using a doubly linked list of `task_struct`.



Process ID

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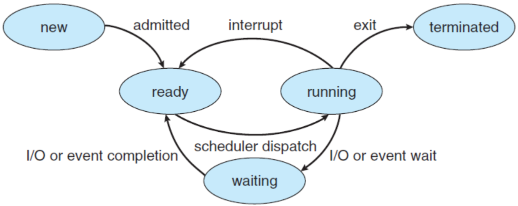
- The kernel allocates PIDs to processes in a strictly linear fashion.
- The `getpid()` system call returns the PID of the invoking process.

```
#include <sys/types.h>
#include <unistd.h>

pid_t getpid(void);
```

Process States

- As a process executes, it changes state.



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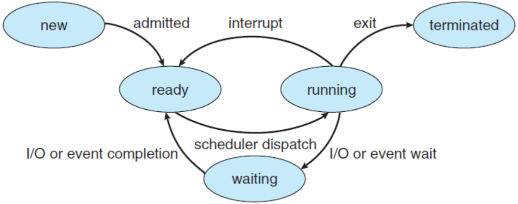

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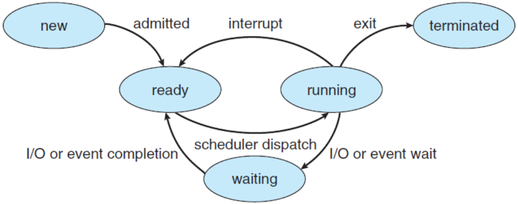

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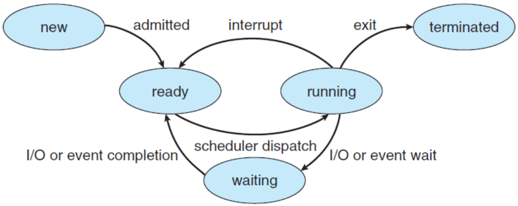

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- running: Instructions are being executed.

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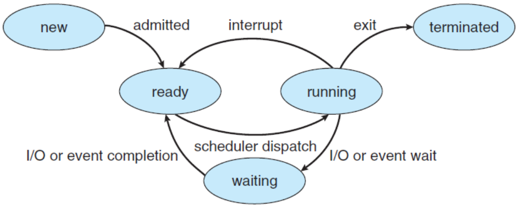

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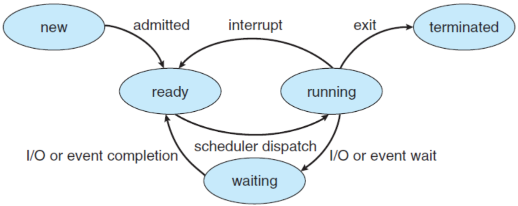

- new: The process is being created.
- ready: The process is waiting to be assigned to a processor.
- running: Instructions are being executed.
- waiting: The process is waiting for some event to occur.
- terminated: The process has finished execution.

Process Scheduling

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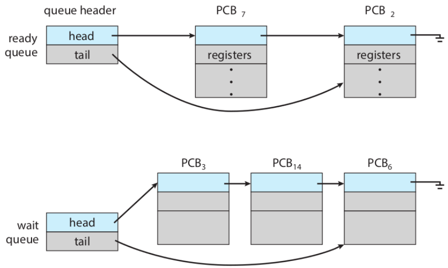
- Goal: Maximize CPU use, quickly switch processes onto CPU core

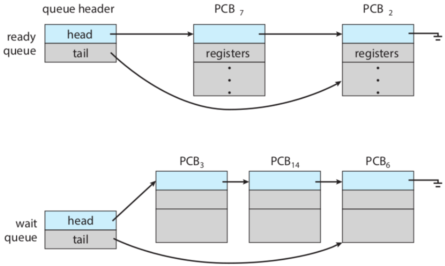
Scheduling Queues

- Ready queue: set of all processes residing in main memory, ready and waiting to execute.

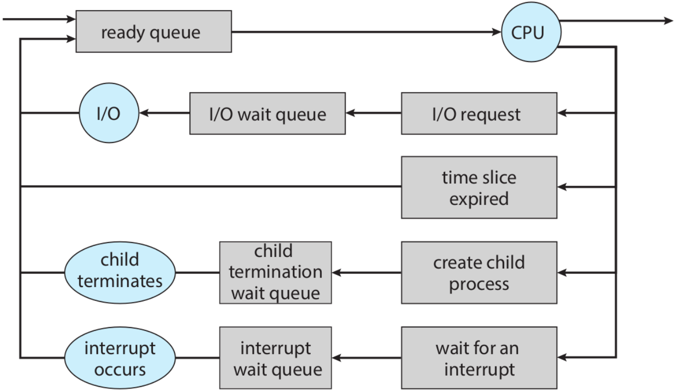


Scheduling Queues

- Ready queue: set of all processes residing in main memory, ready and waiting to execute.
- Wait queues: set of processes waiting for an event (e.g., I/O device).

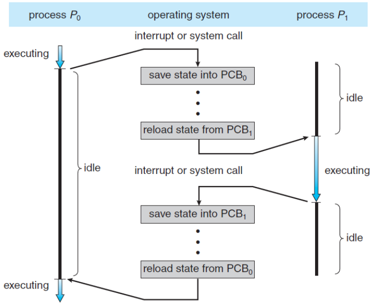


Queuing Diagram



Context Switching

- When CPU switches to another process:



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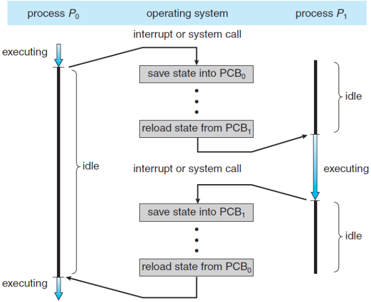

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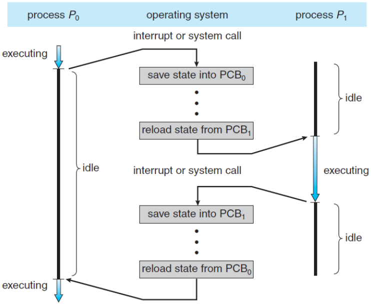

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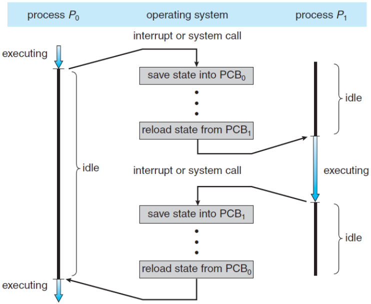

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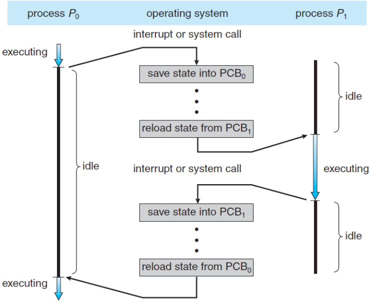

- Context of a process represented in the PCB.

Operations on Processes

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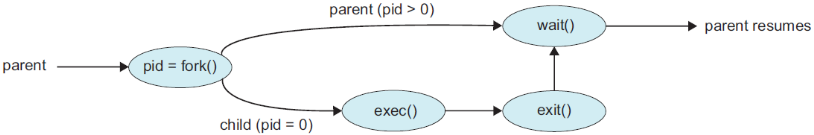
- OS must provide mechanisms for:
  - Process creation
  - Process termination



Process Creation (1/5)

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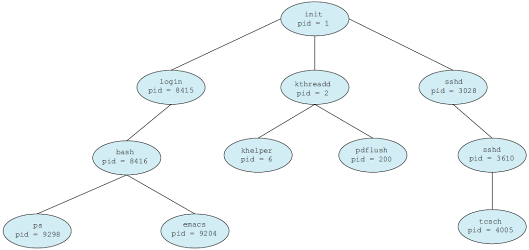
- These processes are forming a tree of processes.



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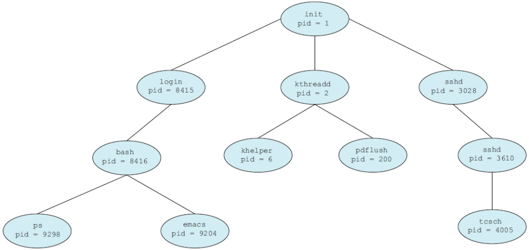


```
# it lists complete information for all active processes in the system
ps -el
```

Process Creation (2/5)

- fork() creates a new process.

```
#include <sys/types.h>
#include <unistd.h>

pid_t fork(void);
```

Process Creation (2/5)

- fork() creates a new process.
- The new process (child) running the same image as the current one (parent).

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- fork() is called once, but it returns twice.

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Process Creation (2/5)

- `fork()` creates a new process.
- The new process (child) running the same image as the current one (parent).
- `fork()` is called once, but it returns twice.
  - The PID of the new child → to the parent.
  - 0 → to the child.

```
#include <sys/types.h>
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pid_t fork(void);
```

Process Creation (3/5)

```c
pid_t pid = fork();

if (pid == -1) {
  perror("fork");
  exit(1);
}

if (pid > 0)
  printf("I am the parent of pid = %d!\n", pid);
else
  printf("I am the child!\n");
```

Process Creation (4/5)

- exec() executs a new program.

```
#include <unistd.h>
int execl(const char *path, const char *arg, ...);
```

Process Creation (4/5)

- `exec()` executs a new program.
- Used after `fork()` to replace the process' memory space with a new program.

```c
#include <unistd.h>
int execl(const char *path, const char *arg, ...);
```

Process Creation (5/5)

```c
pid_t pid = fork();

if (pid == -1) {
  perror("fork");
  exit(1);
}

if (pid == 0) { // the child
  const char *args[] = {"windlass", NULL};
  int ret;
  ret = execv("/bin/windlass", args);
  if (ret == -1) {
    perror("execv");
    exit(1);
  }
}
```

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- Returns status data from the child to the parent.
- Process resources are deallocated by the OS.

Process Termination (2/4)

- The `exit()` then instructs the kernel to terminate the process.

```
#include <stdlib.h>

void exit(int status);
```

Process Termination (2/4)

- The `exit()` then instructs the kernel to terminate the process.
- The `status` is used to denote the process's exit status.

```c
#include <stdlib.h>

void exit(int status);
```

Process Termination (3/4)

- The parent process may wait for termination of a child via `wait()`.

```
#include <sys/types.h>
#include <sys/wait.h>

pid_t wait(int *status);
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- The `wait()` returns the status information and the PID of the terminated process.
- If a process has terminated, but whose parent has not yet called `wait()`, the process is a zombie.
- If the parent terminated without invoking `wait()`, the process is an orphan.
    - In Linux, the `init` process becomes the parent of all orphans.

```
#include <sys/types.h>
#include <sys/wait.h>

pid_t wait(int *status);
```

Process Termination (4/4)

```c
int main (void) {
  int status;
  pid_t pid;

  if (fork() == 0) return 1; // the child

  pid = wait(&status);

  if (pid == -1) perror("wait");

  printf("pid = %d\n", pid);

  return 0;
}
```

Inter-Process Communication (IPC)

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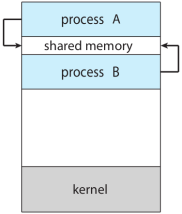
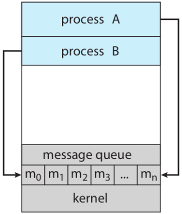


Shared-memory

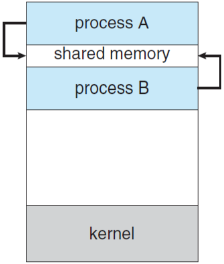


Message-passing

Shared Memory

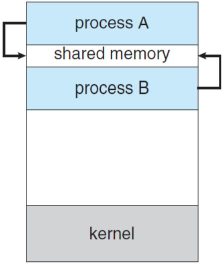
Shared Memory (1/4)

- An area of memory shared among the processes that wish to communicate.



Shared Memory (1/4)

- An area of memory shared among the processes that wish to communicate.
- It is resides in the address space of the process creating the shared-memory segment.



Shared Memory (2/4)

- shm_open() creates and opens a new shared memory object or opens an existing object.

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

int shm_open(const char *name, int oflag, mode_t mode);

void *mmap(void *addr, size_t length, int prot, int flags, int fd, off_t offset);

int shm_unlink(const char *name);
```

Shared Memory (2/4)

- `shm_open()` creates and opens a new shared memory object or opens an existing object.
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Shared Memory (2/4)

- `shm_open()` creates and opens a new shared memory object or opens an existing object.
- `mmap()` creates a new mapping in the virtual address space of the calling process.
- `shm_unlink()` removes a shared memory object.

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#include <sys/stat.h>
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int shm_open(const char *name, int oflag, mode_t mode);

void *mmap(void *addr, size_t length, int prot, int flags, int fd, off_t offset);

int shm_unlink(const char *name);
```

Shared Memory (3/4)

- Producer

```
int SIZE = 4096;
char *my_shm = "/tmp/myshm";
char *write_msg = "hello";
char *addr;
int fd;

// create the shared memory object
fd = shm_open(my_shm, O_CREATE | O_RDWR, 0666);

// configuare the size of the shared memory object
ftruncate(fd, SIZE);

// memory map to the shared memory object
addr = mmap(NULL, SIZE, PROT_WRITE, MAP_SHARED, fd, 0);

// write to the shared object
sprintf(addr, "%s", write_msg);
```

Shared Memory (4/4)

- Consumer

```
int SIZE = 4096;
char *my_shm = "/tmp/myshm";
char *addr;
int fd;

// open the shared memory object
fd = shm_open(my_shm, O_RDONLY, 0666);

// memory map to the shared memory object
addr = mmap(NULL, SIZE, PROT_READ, MAP_SHARED, fd, 0);

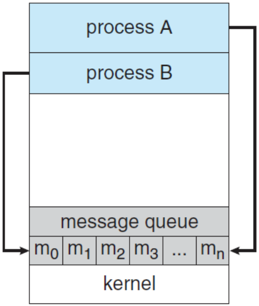
// read from to the shared object
printf("%s", (char *)addr);

// remove the shared memory object
shm_unlink("my_shm");
```

Message Passing

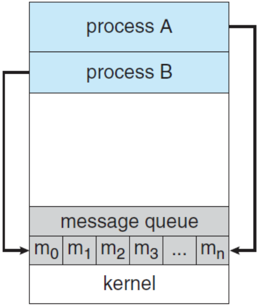
Message Passing

- Communicating with each other without resorting to shared variables.



Message Passing

- Communicating with each other without resorting to shared variables.
- Useful in a distributed environment: processes on different computers.



Message Passing: Data Message vs. Data Stream

- Stream protocols send a continuous flow of data.
  - E.g., phone calls

Message Passing: Data Message vs. Data Stream

- Stream protocols send a continuous flow of data.
  - E.g., phone calls
- Message oriented protocols send data in distinct chunks or groups.
  - E.g., SMS

Message Passing IPC Facilities

- Data stream:
  - Pipe
  - FIFO (named pipe)
- Data message:
  - Message queue

Pipe

Pipe (1/4)

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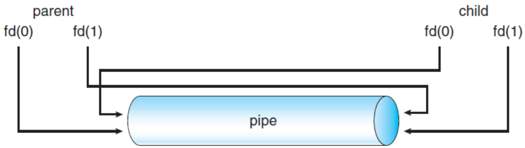
```
ls | wc -l
```

Pipe (2/4)

- pipe() creates a new pipe.

```
#include <unistd.h>

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



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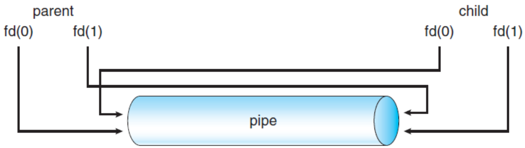

Pipe (2/4)

- `pipe()` creates a new pipe.
- It returns two open file descriptors in `fd`:
  - `fd[0]` to read from the pipe

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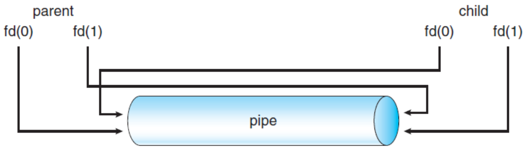
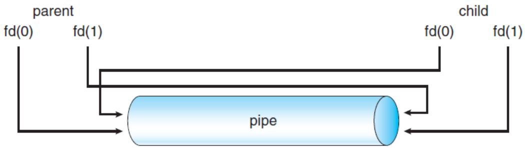


Pipe (2/4)

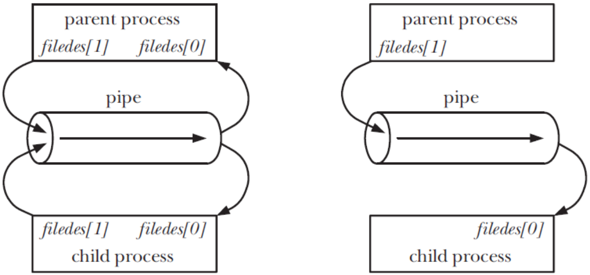
- pipe() creates a new pipe.
- It returns two open file descriptors in fd:
  - fd[0] to read from the pipe
  - fd[1] to write to the pipe

```
#include <unistd.h>

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



Pipe (3/4)



[Michael Kerrisk, The Linux Programming Interface, No Starch Press, 2010]

Pipe (4/4)

```c
int BUFFER_SIZE = 25;
char write_msg[BUFFER_SIZE] = "hello";
char read_msg[BUFFER_SIZE];
int fd[2];

pipe(fd); // Create the pipe

switch (fork()) {
  case -1: // fork error
    break;
  case 0: // Child
    close(fd[1]); // Close unused write end
    read(fd[0], read_msg, BUFFER_SIZE);
    printf("read %s", read_msg);
    break;
  default: // Parent
    close(fd[0]) // Close unused read end
    write(fd[1], write_msg, strlen(write_msg) + 1);
    break;
}
```

FIFO

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- FIFO is similar to a pipe, but it has a name within the file system and is opened in the same way as a regular file.
- Communication is bidirectional.
- No parent-child relationship is necessary.
- Several processes can use a FIFO for communication.

FIFO (2/4)

- The `mkfifo()` function creates a new FIFO.

```c
#include <sys/stat.h>

int mkfifo(const char *pathname, mode_t mode);
```

FIFO (3/4)

- Producer

```
char *my_fifo = "/tmp/myfifo";
char *write_msg = "hello";
int fd;

// Create the FIFO (named pipe)
mkfifo(my_fifo, 0666);

// Write "hello" to the FIFO
fd = open(my_fifo, O_WRONLY);
write(fd, write_msg, strlen(write_msg));
close(fd);

// Remove the FIFO
unlink(my_fifo);
```

FIFO (4/4)

- Consumer

```c
int MAX_SIZE = 100;
char *my_fifo = "/tmp/myfifo";
char buf[MAX_SIZE];
int fd;

// Open the FIFO
fd = open(my_fifo, O_RDONLY);

// Read the message from the FIFO
read(fd, buf, MAX_SIZE);
printf("Received: %s\n", buf);

// Close the FIFO
close(fd);
```

Message Queue

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- Message queues allows processes to exchange data in the form of messages.
- In message queue the consumer receives whole messages, as written by the producer.
  - It is not possible to read part of a message.

Message Queue (2/6)

- `mq_open()` creates a new message queue or opens an existing queue.

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

mqd_t mq_open(const char *name, int oflag, ...);

int mq_close(mqd_t mqdes);

int mq_unlink(const char *name);
```

Message Queue (2/6)

- mq_open() creates a new message queue or opens an existing queue.
- mq_close() closes the message queue descriptor mqdes.

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

mqd_t mq_open(const char *name, int oflag, ...);

int mq_close(mqd_t mqdes);

int mq_unlink(const char *name);
```

Message Queue (2/6)

- `mq_open()` creates a new message queue or opens an existing queue.
- `mq_close()` closes the message queue descriptor `mqdes`.
- `mq_unlink()` removes the message queue identified by `name`.

```c
#include <fcntl.h>
#include <sys/stat.h>
#include <mqueue.h>

mqd_t mq_open(const char *name, int oflag, ...);

int mq_close(mqd_t mqdes);

int mq_unlink(const char *name);
```

Message Queue (3/6)

- `mq_send()` adds the message `msg_ptr` to the message queue.

```c
#include <mqueue.h>

int mq_send(mqd_t mqdes, const char *msg_ptr, size_t msg_len, unsigned int msg_prio);

ssize_t mq_receive(mqd_t mqdes, char *msg_ptr, size_t msg_len, unsigned int *msg_prio);
```

Message Queue (3/6)

- `mq_send()` adds the message `msg_ptr` to the message queue.
- `mq_receive()` removes the oldest message from the message queue.

```c
#include <mqueue.h>

int mq_send(mqd_t mqdes, const char *msg_ptr, size_t msg_len, unsigned int msg_prio);

ssize_t mq_receive(mqd_t mqdes, char *msg_ptr, size_t msg_len, unsigned int *msg_prio);
```

Message Queue (4/6)

- Specifies attributes of a message queue.

```
struct mq_attr {
  long mq_flags; // Message queue description flags
  long mq_maxmsg; // Maximum number of messages on queue
  long mq_msgsize; // Maximum message size (in bytes)
  long mq_curmsgs; // Number of messages currently in queue
};
```

Message Queue (5/6)

- Producer

```c
char *my_mq = "/mymq";
char *write_msg = "hello";
mqd_t mqd;

// Open an existing message queue
mqd = mq_open(my_mq, O_WRONLY);

// Write "hello" to the message queue
mq_send(mqd, write_msg, strlen(write_msg), 0);

// Close the message queue
mq_close(mqd);
```

Message Queue (6/6)

- Consumer

```
int MAX_SIZE = 100;
int MAX_NUM_MSG = 10;
char *my_mq = "/mymq";
char buf[MAX_SIZE];
mqd_t mqd;
struct mq_attr attr;

// Form the queue attributes
attr.mq_maxmsg = MAX_NUM_MSG;
attr.mq_msgsize = MAX_SIZE;

// Create message queue
mqd = mq_open(my_mq, O_RDONLY | O_CREAT, MQ_MODE, &attr);

// Read the message from the message queue
mq_receive(mqd, buf, MAX_NUM_MSG, NULL);
printf("Message: %s\n", buf);

// Close the message queue
mq_close(mqd);
```

Summary

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- Process vs. Program

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- Process operations: creation (parent-child), termination

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- Inter-Process Communication: shared memory vs. message passing

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- Data stream: pipe, FIFO
- Data message: message queue

Questions?