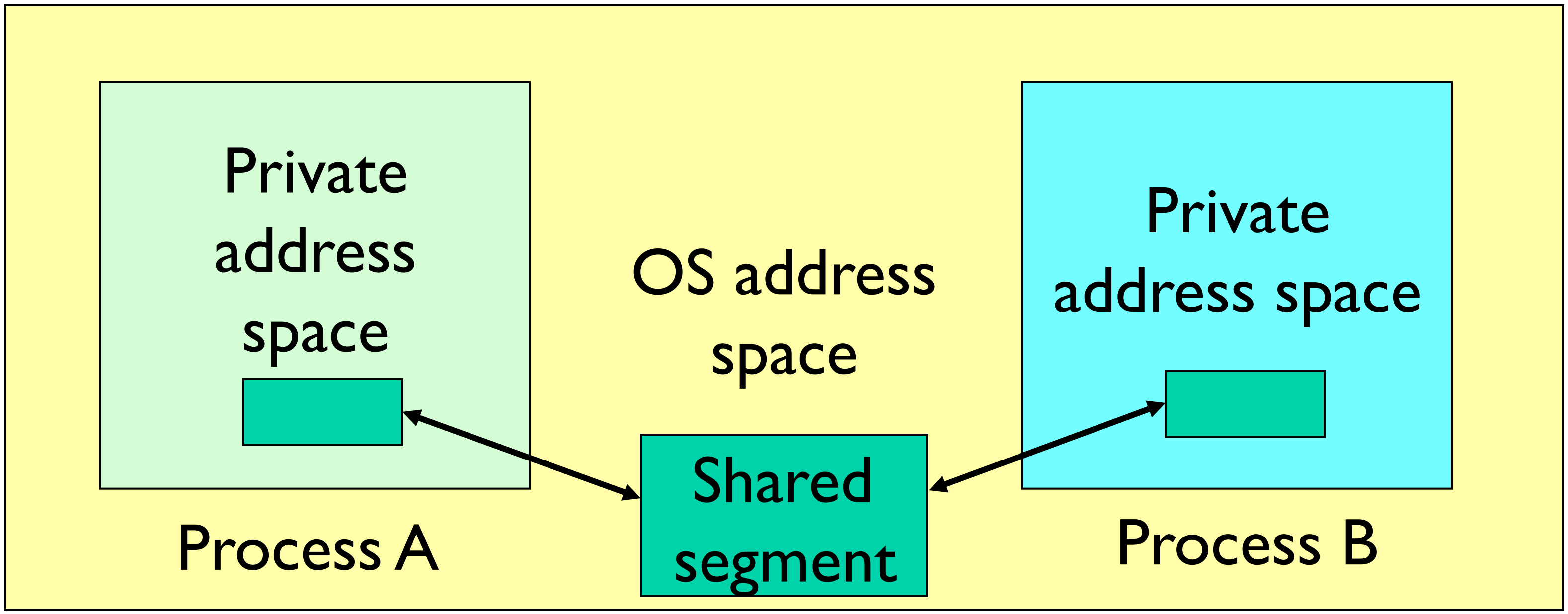
Interprocess Communication: Memory mapped files and pipes

CS 241

April 4, 2014

University of Illinois

Shared Memory

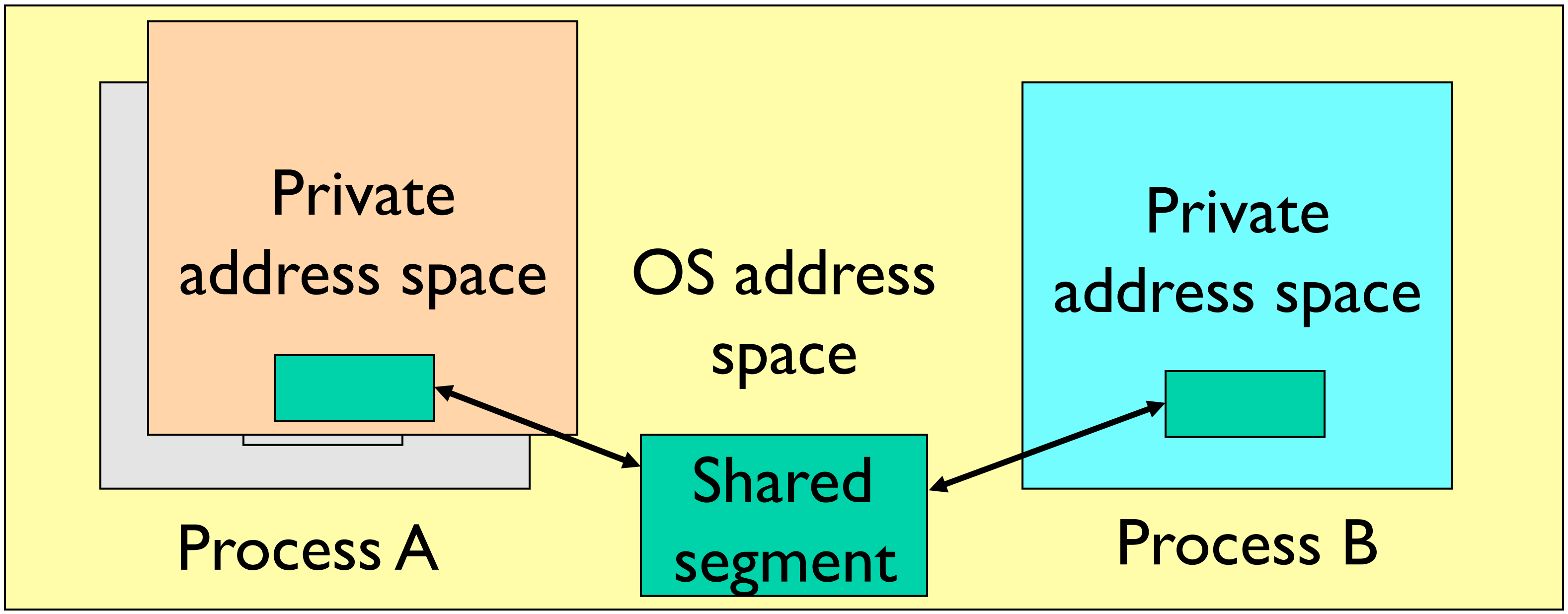


Processes request the segment

OS maintains the segment

Processes can attach/detach the segment

Shared Memory



Can mark segment for deletion on last detach

Shared Memory example

```
/* make the key: */
if ((key = ftok("shmdemo.c", 'R')) == -1) {
    perror("ftok");
    exit(1);
}
/* connect to (and possibly create) the segment: */
if ((shmid = shmget(key, SHM_SIZE, 0644 | IPC_CREAT)) == -1) {
    perror("shmget");
    exit(1);
}
/* attach to the segment to get a pointer to it: */
data = shmat(shmid, (void *)0, 0);
if (data == (char *)(-1)) {
    perror("shmat");
    exit(1);
}
```

Shared Memory example

```
/* read or modify the segment, based on the command line: */
if (argc == 2) {
    printf("writing to segment: \"%s\"\n", argv[1]);
    strncpy(data, argv[1], SHM_SIZE);
} else
    printf("segment contains: \"%s\"\n", data);

/* detach from the segment: */
if (shmdt(data) == -1) {
    perror("shmdt");
    exit(1);
}

return 0;
}
```

Run demo

Memory Mapped Files

Memory-mapped file I/O

- Map a disk block to a page in memory
- Allows file I/O to be treated as routine memory access

Use

- File is initially read using demand paging
  - i.e., loaded from disk to memory only at the moment it's needed
- When needed, a page-sized portion of the file is read from the file system into a physical page of memory
- Subsequent reads/writes to/from that page are treated as ordinary memory accesses

Memory Mapped Files

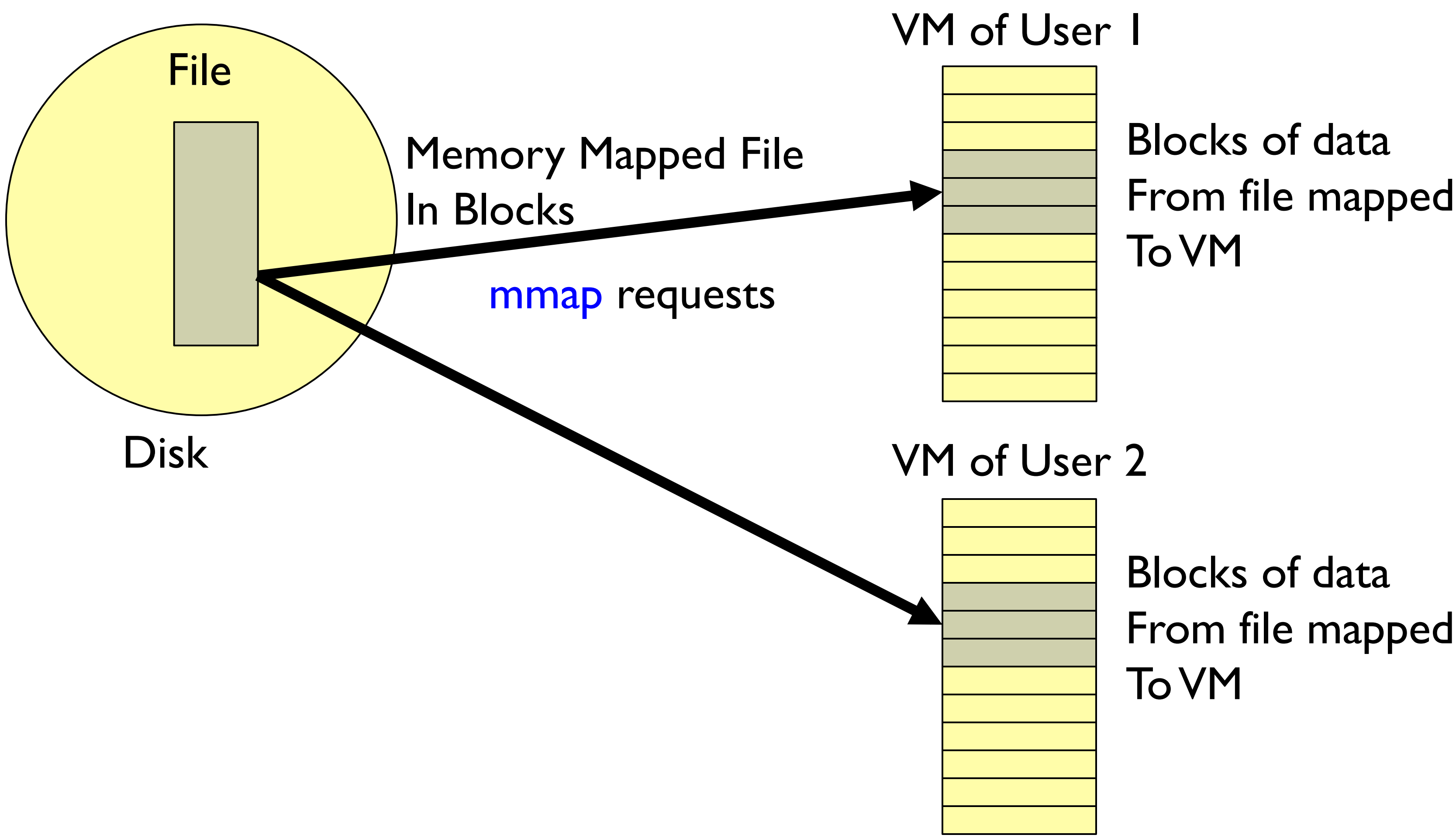
Traditional File I/O

- Calls to file I/O functions (e.g., read() and write())
  - First copy data to a kernel's intermediary buffer
  - Then transfer data to the physical file or the process
- Intermediary buffering is slow and expensive

Memory Mapping

- Eliminate intermediary buffering
- Significantly improve performance
- Random-access interface

Memory Mapped Files



Memory Mapped Files: Benefits

Treats file I/O like memory access rather than `read()`, `write()` system calls

- Simplifies file access; e.g., no need to `fseek()`

Streamlining file access

- Access a file mapped into a memory region via pointers
- Same as accessing ordinary variables and objects

Dynamic loading

- Map executable files and shared libraries into address space
- Programs can load and unload executable code sections dynamically

Memory Mapped Files: Benefits

Several processes can map the same file

- Allows pages in memory to be shared -- saves memory space

Memory persistence

- Enables processes to share memory sections that persist independently of the lifetime of a certain process

Enables IPC!

POSIX Memory Mapping

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

void *mmap(void *addr, size_t len, int prot,
                   int flags, int fd, off_t off);
```

Memory map a file

- Establish mapping from the address space of the process to the object represented by the file descriptor

Parameters:

- `addr`: the starting memory address into which to map the file (not previously allocated with malloc; argument can just be NULL)
- `len`: the length of the data to map into memory
- `prot`: the kind of access to the memory mapped region
- `flags`: flags that can be set for the system call
- `fd`: file descriptor
- `off`: the offset in the file to start mapping from

POSIX Memory Mapping

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Memory map a file

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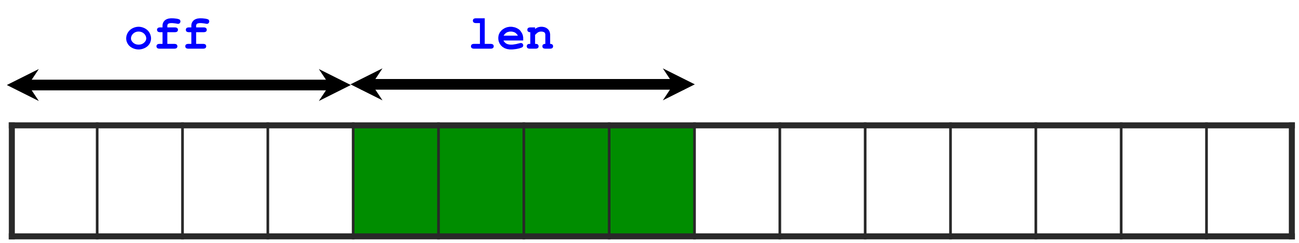
File `fd`



POSIX Memory Mapping

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

void *mmap(void *addr, size_t len, int prot,

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```

Memory map a file

- Establish a mapping between the address space of the process to the memory object represented by the file descriptor

Return value: pointer to mapped region

- On success, implementation-defined function of addr and flags.
- On failure, sets errno and returns MAP_FAILED

POSIX Memory Mapping

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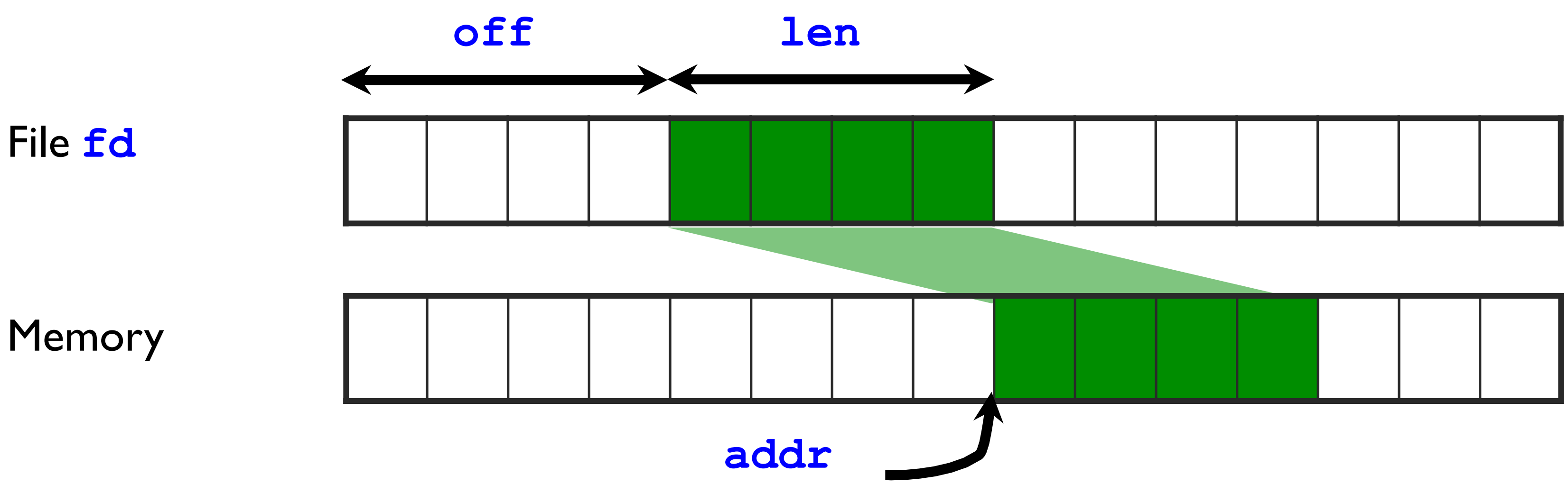
Memory map a file

- Establish a mapping between the address space of the process to the memory object represented by the file descriptor



mmap options

Protection Flags

• PROT_READ	Data can be read
• PROT_WRITE	Data can be written
• PROT_EXEC	Data can be executed
• PROT_NONE	Data cannot be accessed

Flags

• MAP_SHARED	Changes are shared.
• MAP_PRIVATE	Changes are private.
• MAP_FIXED	Interpret addr exactly

mmap example

```
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <errno.h>
#include <fcntl.h>
#include <string.h>
#include <sys/mman.h>
#include <sys/types.h>
#include <sys/stat.h>

static const int MAX_INPUT_LENGTH = 20;

int main(int argc, char** argv) {
    ....
```

mmap example

```
int main(int argc, char** argv) {
    int    fd;
    char * shared_mem;
    fd = open(argv[1], O_RDWR | O_CREAT);
    shared_mem = mmap(NULL, MAX_INPUT_LENGTH, PROT_READ | PROT_WRITE,
                      MAP_SHARED, fd, 0);
    close(fd);

    if (!strcmp(argv[2], "read")) {
        while (1) {
            shared_mem[MAX_INPUT_LENGTH-1] = '\0';
            printf("%s", shared_mem);
            sleep(1);
        }
    }
    else if (!strcmp(argv[2], "write"))
        while (1)
            fgets(shared_mem, MAX_INPUT_LENGTH, stdin);
    else
        printf("Unrecognized command\n");
}
```

Run demo!

munmap

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

int munmap(void *addr, size_t len);
```

Remove a mapping

Return value

- 0 on success
- -1 on error, sets errno

Parameters:

- addr: returned from mmap()
- len: same as the len passed to mmap()

msync

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

int msync(void *addr, size_t len, int flags);
```

Write all modified data to permanent storage locations

Return value

- 0 on success
- -1 on error, sets `errno`

Parameters:

- `addr`: returned from `mmap()`
- `len`: same as the `len` passed to `mmap()`
- `flags`:
  - `MS_ASYNC` = Perform asynchronous writes
  - `MS_SYNC` = Perform synchronous writes
  - `MS_INVALIDATE` = Invalidate cached data

Recall POSIX Shared Memory…

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

#include <sys/shm.h>
```

Create identifier ("key") for a shared memory segment

```
key_t ftok(const char *pathname, int proj_id);
k = ftok("/my/file", 0xaa);
```

Create shared memory segment

```
int shmget(key_t key, size_t size, int shmflg);
id = shmget(key, size, 0644 | IPC_CREAT);
```

Access to shared memory requires an attach

```
void *shmat(int shmid, const void *shmaddr, int shmflg);

shared_memory = (char *) shmat(id, (void *) 0, 0);
```

How do mmap and POSIX shared memory compare?

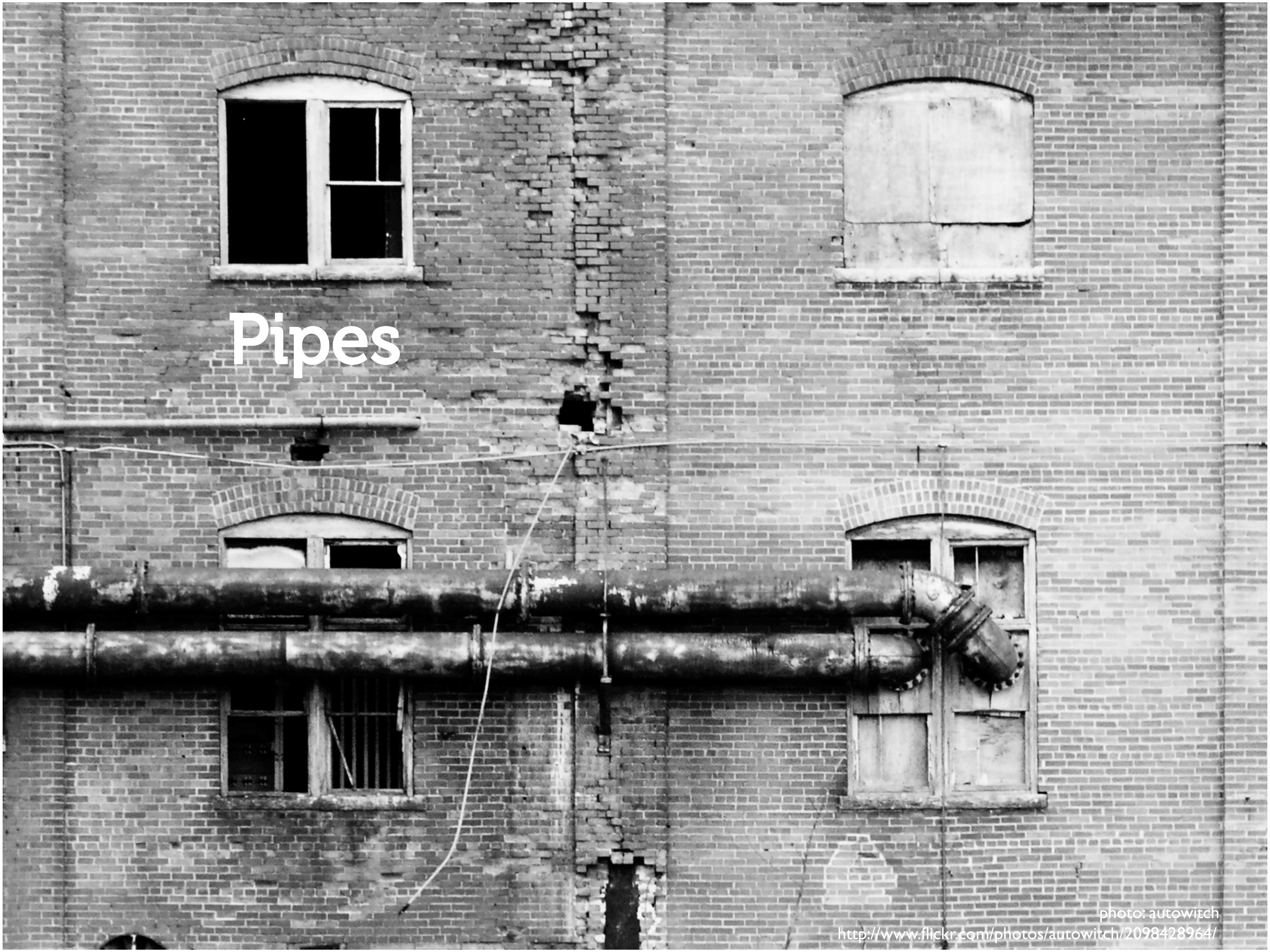
Persistence!

shared memory

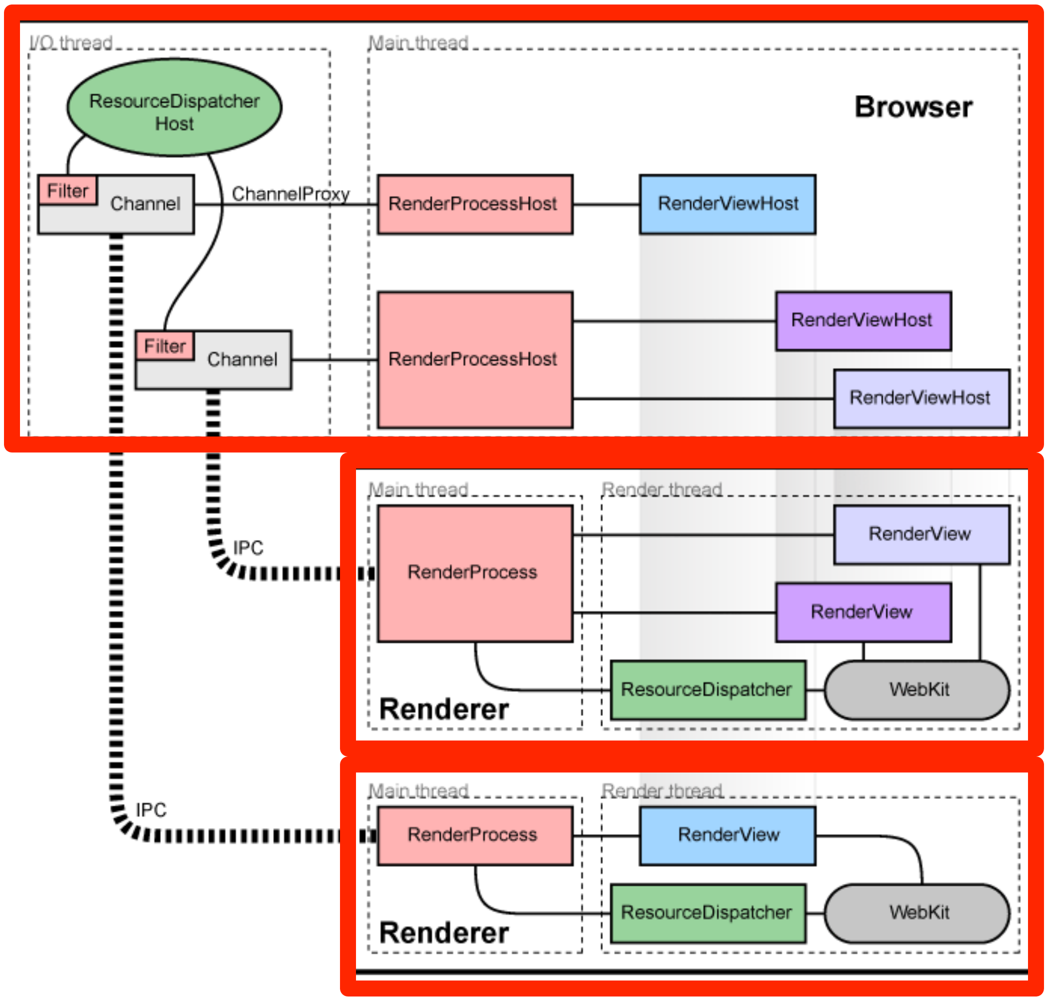
- Kept in memory
- Remains available until system is shut down

mmap

- Backed by a file
- Persists even after programs quit or machine reboots


Pipes
photo: autowitch
http://www.flickr.com/photos/autowitch/2098428964/

Google Chrome architecture (figure borrowed from Google)

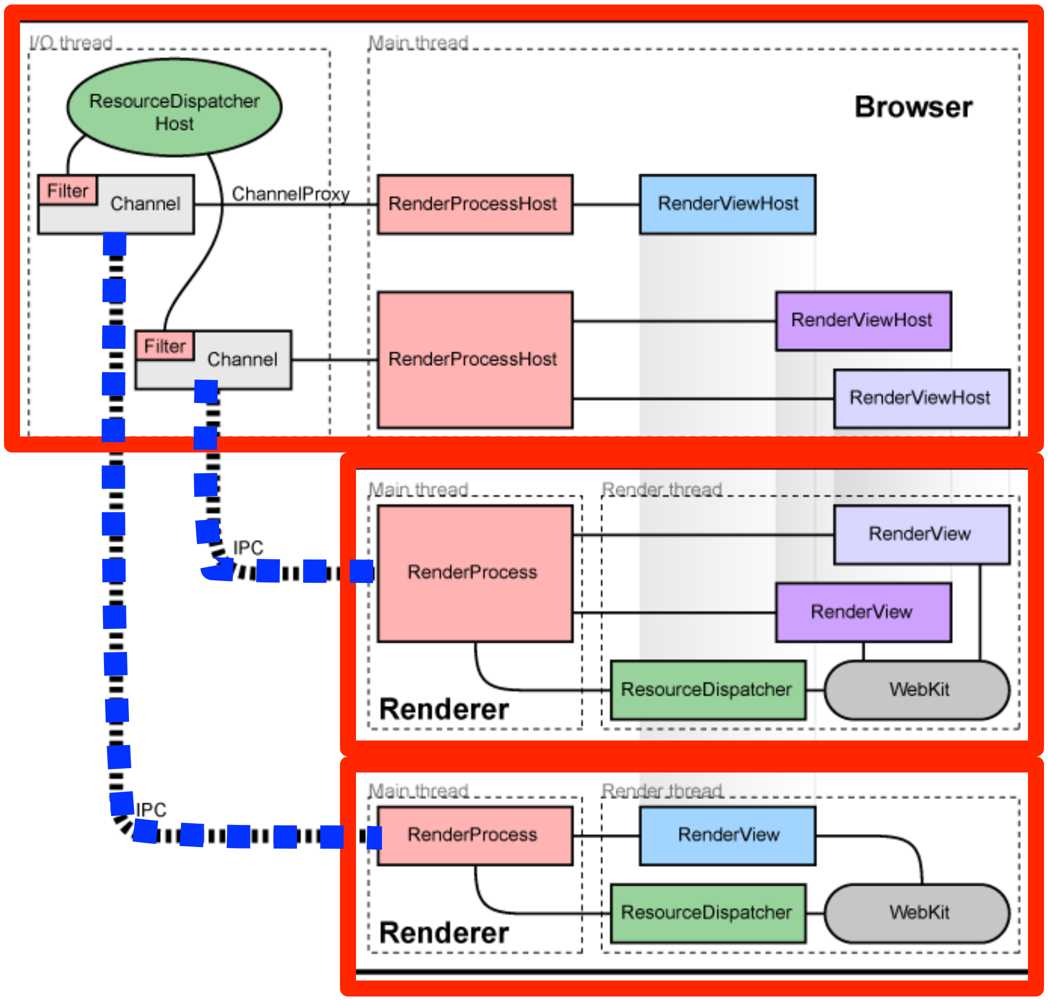


Separate processes for browser tabs to protect the overall application from bugs and glitches in the rendering engine

Restricted access from each rendering engine process to others and to the rest of the system

https://sites.google.com/a/chromium.org/dev/developers/design-documents/multi-process-architecture

Google Chrome architecture (figure borrowed from Google)



A named pipe is allocated for each renderer process for communication with the browser process

Pipes are used in asynchronous mode to ensure that neither end is blocked waiting for the other

https://sites.google.com/a/chromium.org/dev/developers/design-documents/multi-process-architecture

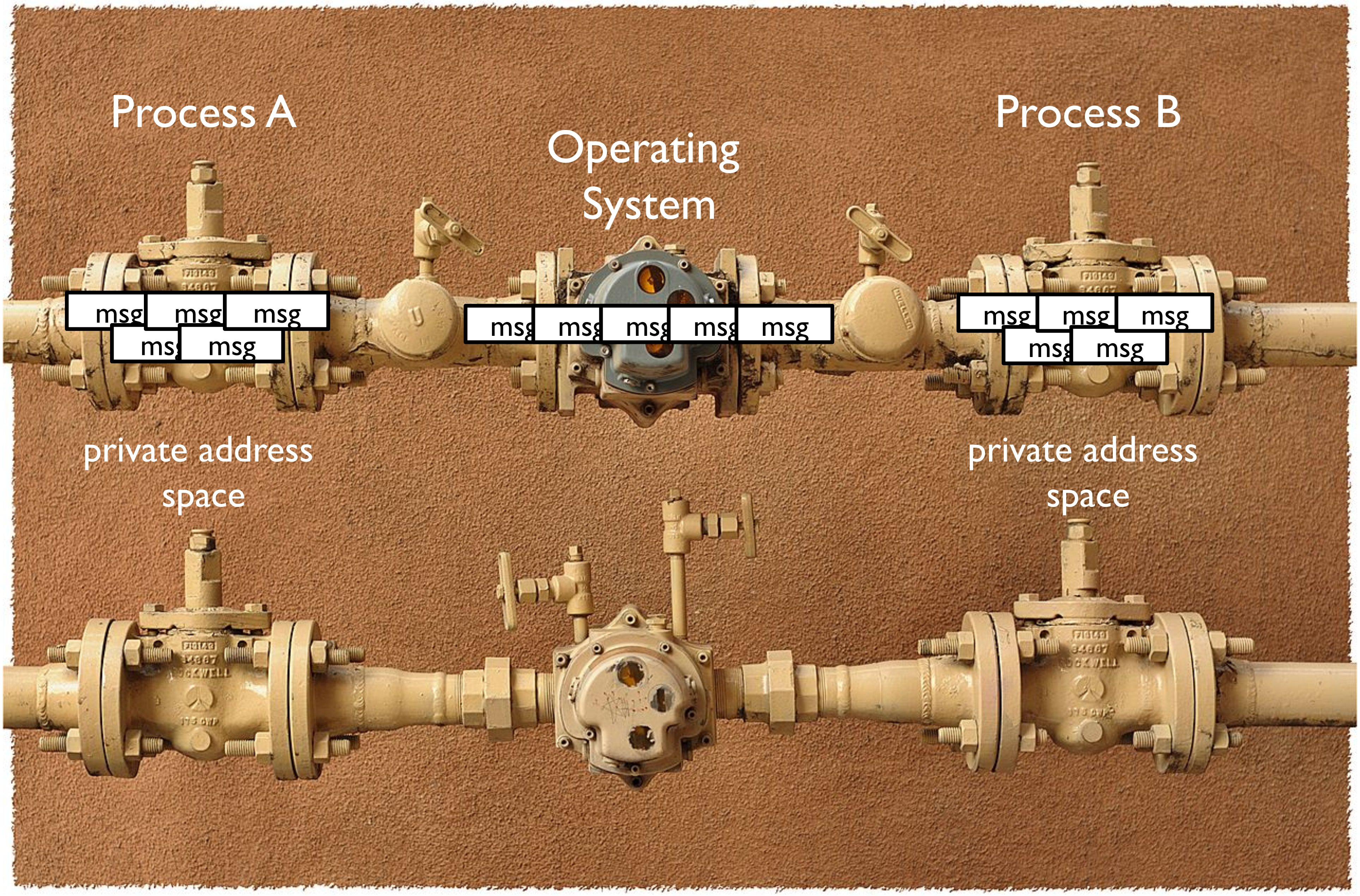


photo: theilr
http://www.flickr.com/photos/theilr/4283377543/

UNIX Pipes

```
#include <unistd.h>

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

Create a message pipe

- Anything can be written to the pipe, and read from the other end
- Data is received in the order it was sent
- OS enforces mutual exclusion: only one process at a time
- Accessed by a file descriptor, like an ordinary file
- Processes sharing the pipe must have same parent process

Returns a pair of file descriptors

- `fildes[0]` is the read end of the pipe
- `fildes[1]` is the write end of the pipe

Pipe example

```
#include <stdio.h>
#include <stdlib.h>
#include <errno.h>
#include <sys/types.h>
#include <unistd.h>

int main(void) {
    ...
}
```

Pipe example

```c
int main(void) {
    int pfds[2];
    char buf[30];

    pipe(pfds);

    if (!fork()) {
        printf(" CHILD: writing to pipe\n");
        write(pfds[1], "test", 5);
        printf(" CHILD: exiting\n");

    } else {
        printf("PARENT: reading from pipe\n");
        read(pfds[0], buf, 5);
        printf("PARENT: read \"%s\"\n", buf);
        wait(NULL);
    }

    return 0;
}
```

`pfds[0]`: read end of pipe
`pfds[1]`: write end of pipe

A pipe dream

```
ls | wc -l
```

Can we implement a command-line pipe with `pipe()`?

How do we attach the stdout of `ls` to the stdin of `wc`?

Duplicating a file descriptor

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

```
int dup(int oldfd);
```

Create a copy of an open file descriptor

Put new copy in first unused file descriptor

Returns:

- Return value ≥ 0 : Success. Returns new file descriptor
- Return value = -1: Error. Check value of `errno`

Parameters:

- `oldfd`: the open file descriptor to be duplicated

Duplicating a file descriptor

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

```
int dup2(int oldfd, int newfd);
```

Create a copy of an open file descriptor

Put new copy in specified location

- ...after closing **`newfd`**, if it was open

Returns:

- Return value ≥ 0 : Success. Returns new file descriptor
- Return value = -1: Error. Check value of **`errno`**

Parameters:

- **`oldfd`**: the open file descriptor to be duplicated

Pipe dream come true: ls | wc –l

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

int main(void) {
    int pfds[2];

    pipe(pfds);

    if (!fork()) {

        ???

    } else {

        ???

    }
    return 0;
}
```

Run demo