Interprocess Communication

CS 241

April 2, 2012

University of Illinois

Interprocess Communciation

What is IPC?

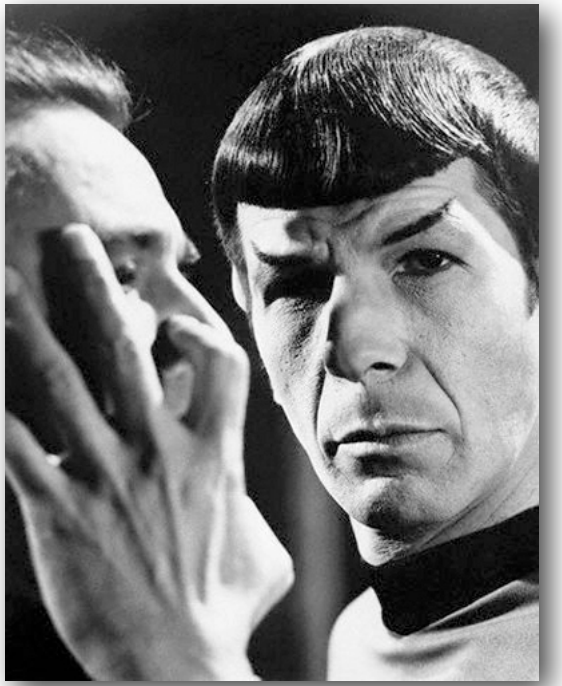
- Mechanisms to transfer data between processes

Why is it needed?

- Not all important procedures can be easily built in a single process

Two kinds of IPC

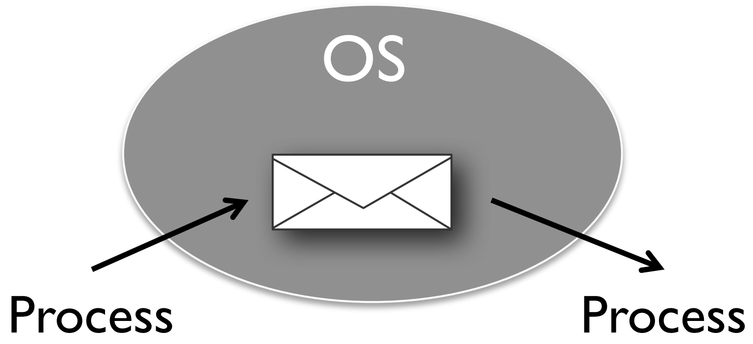
"Mind meld"



Shared address space

- Shared memory
- Memory mapped files

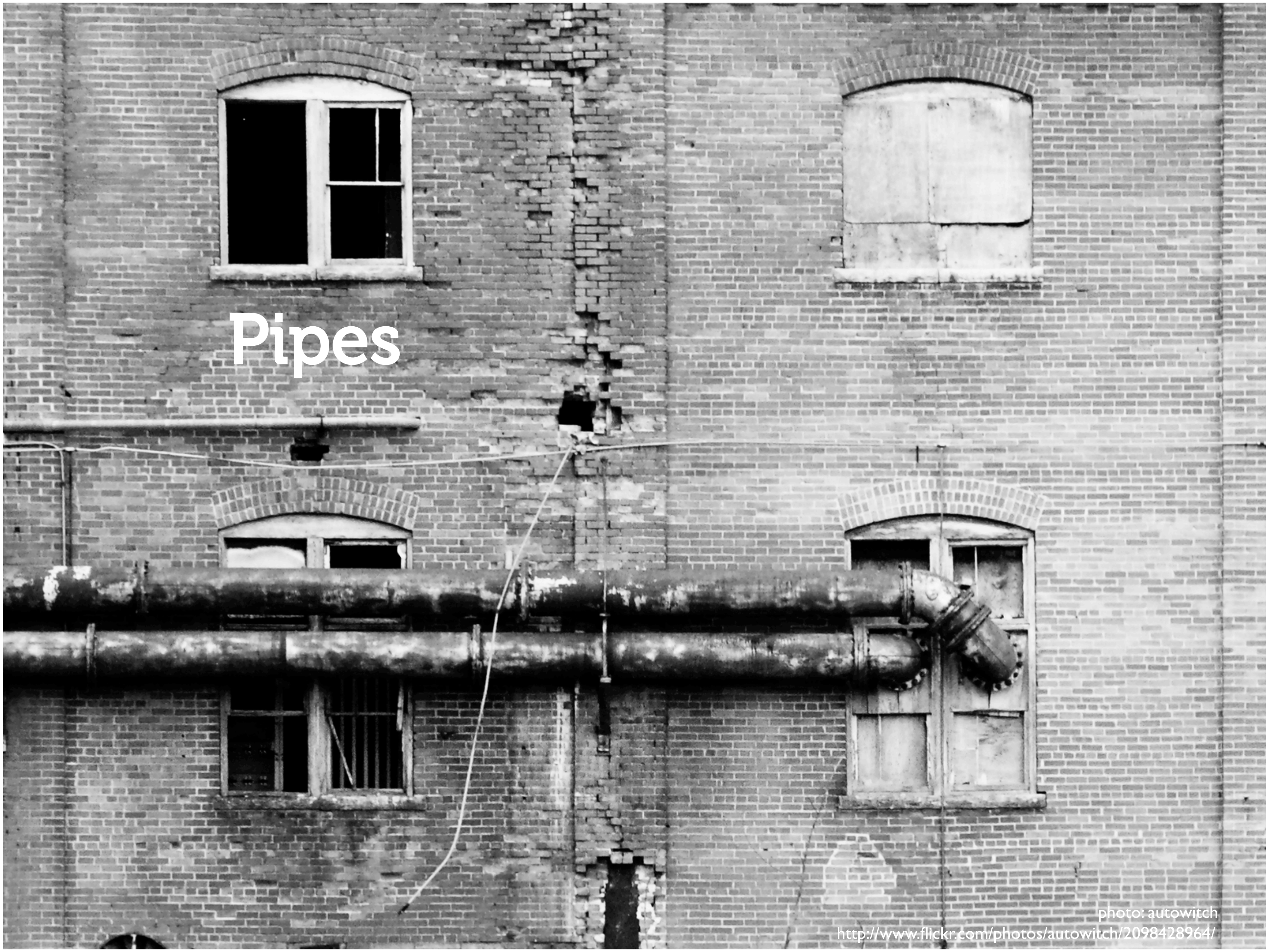
"Intermediary"



Message transported by OS from one address space to another

- Files
- Pipes
- FIFOs

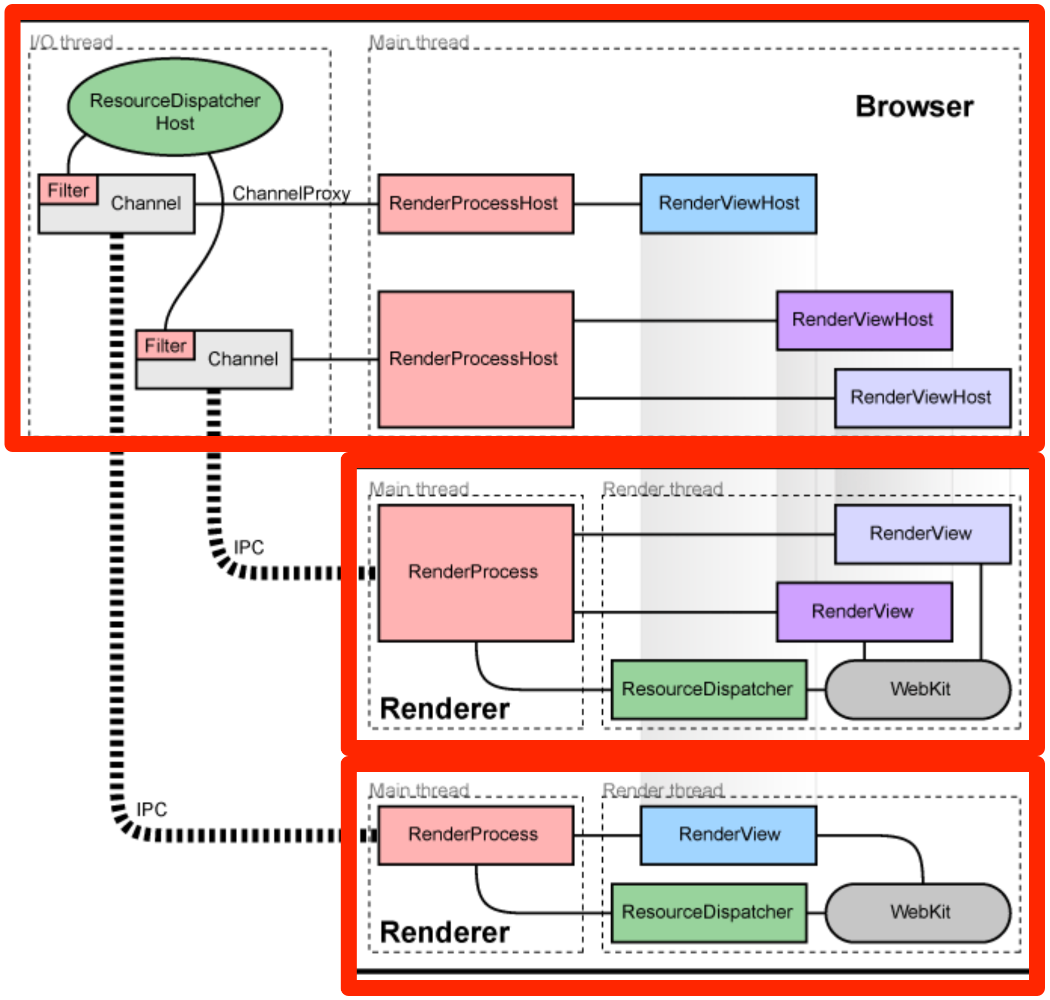
Today



Pipes

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

Google Chrome architecture (figure borrowed from Google)

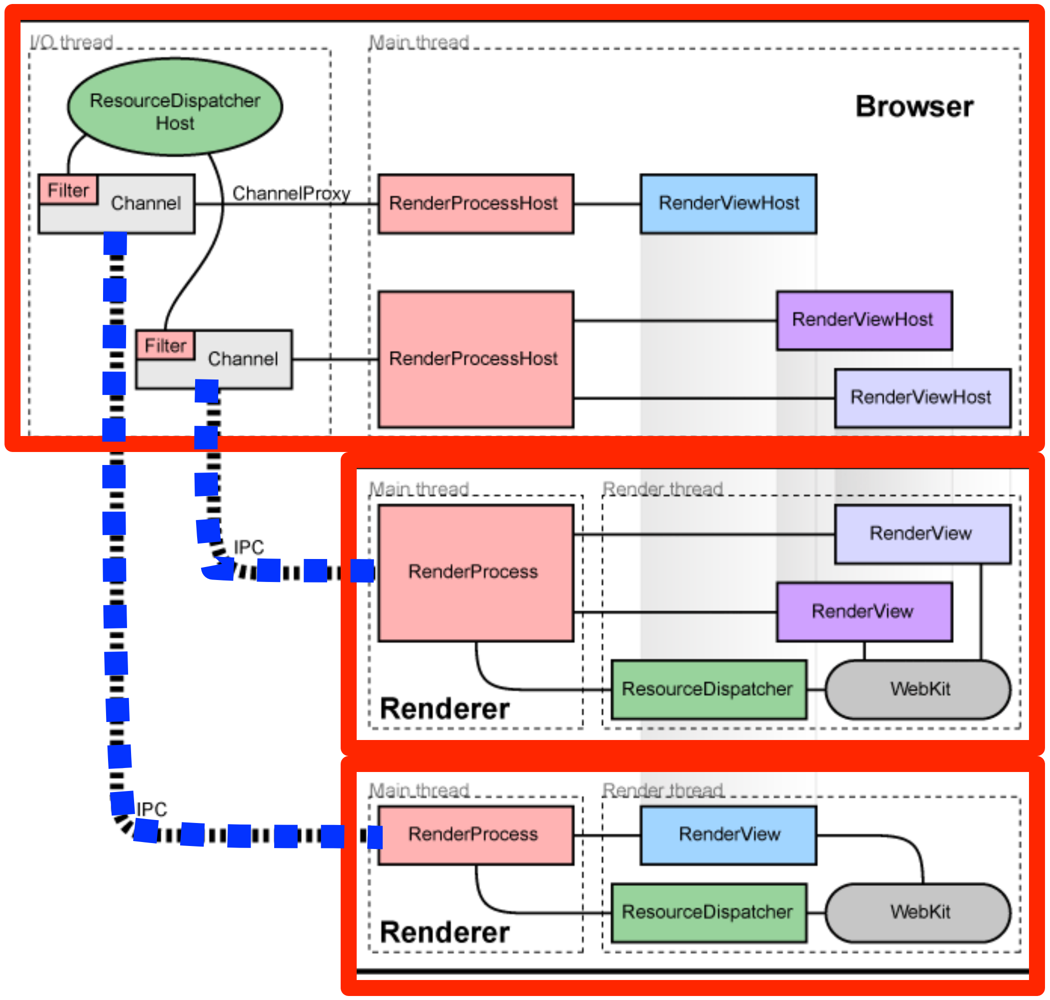


Separate processes for browser tabs to protect the overall application from bugs and glitches in the rendering engine

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

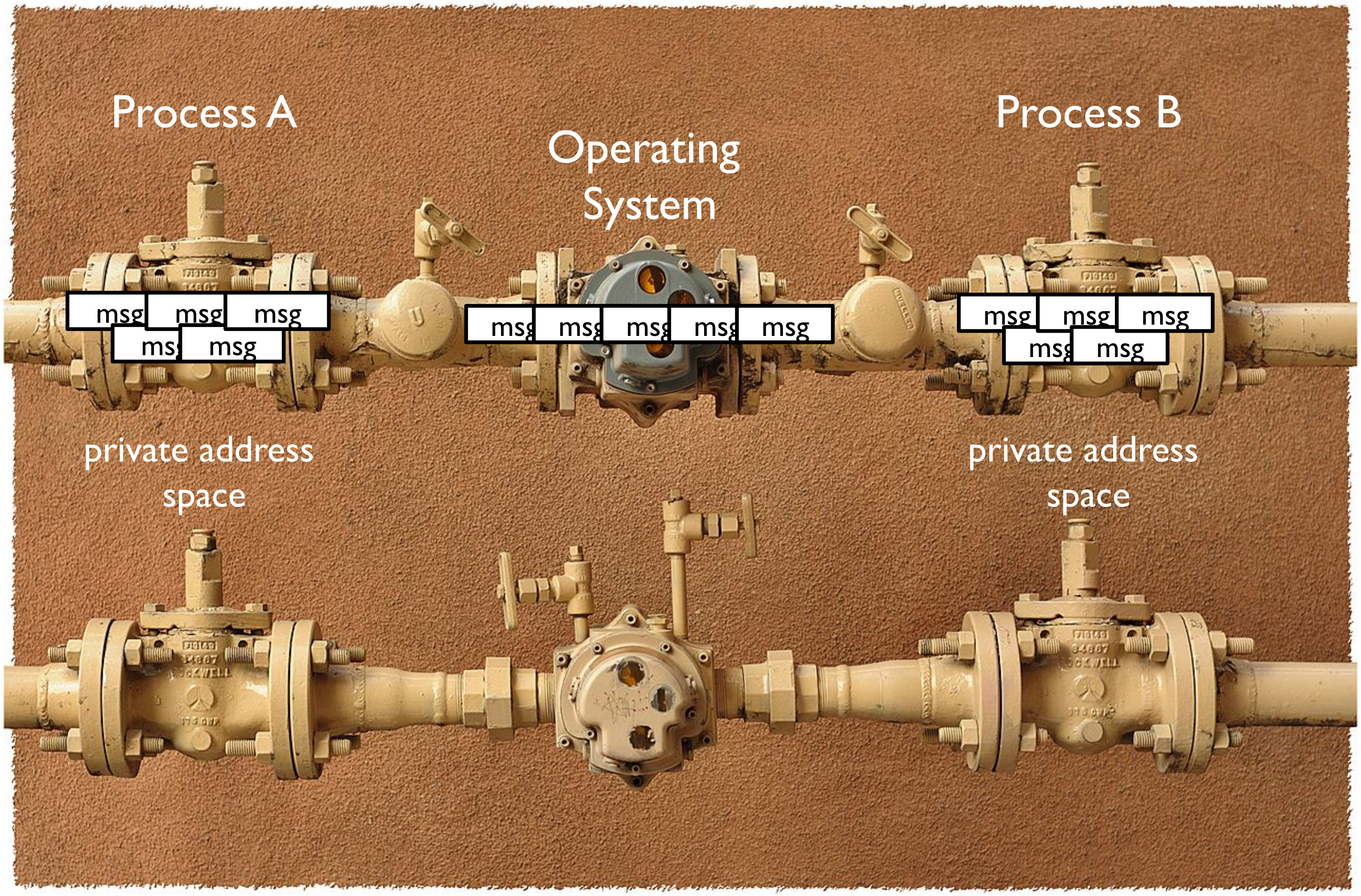


photo: theilr
http://www.flickr.com/photos/theilr/4283377543/

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

```c
#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:

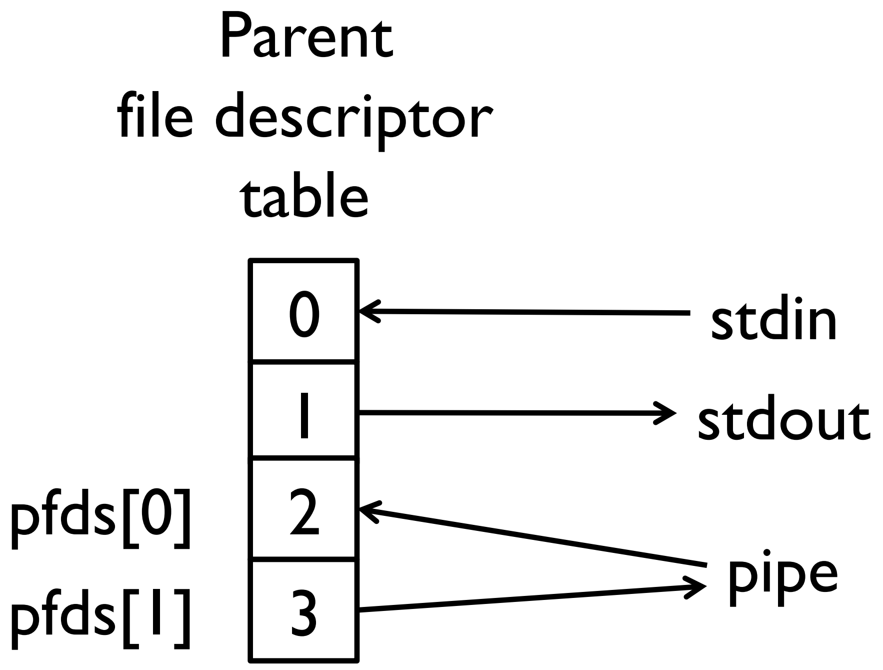
- **`oldfd`**: the open file descriptor to be duplicated

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()) {
        close(1);       /* close stdout */
        dup(pfds[1]);   /* make stdout pfds[1] */
        close(pfds[0]); /* don't need this */
        execlp("ls", "ls", NULL);
    } else {
        close(0);       /* close stdin */
        dup(pfds[0]);   /* make stdin pfds[0] */
        close(pfds[1]); /* don't need this */
        execlp("wc", "wc", "-l", NULL);
    }
    return 0;
}
```

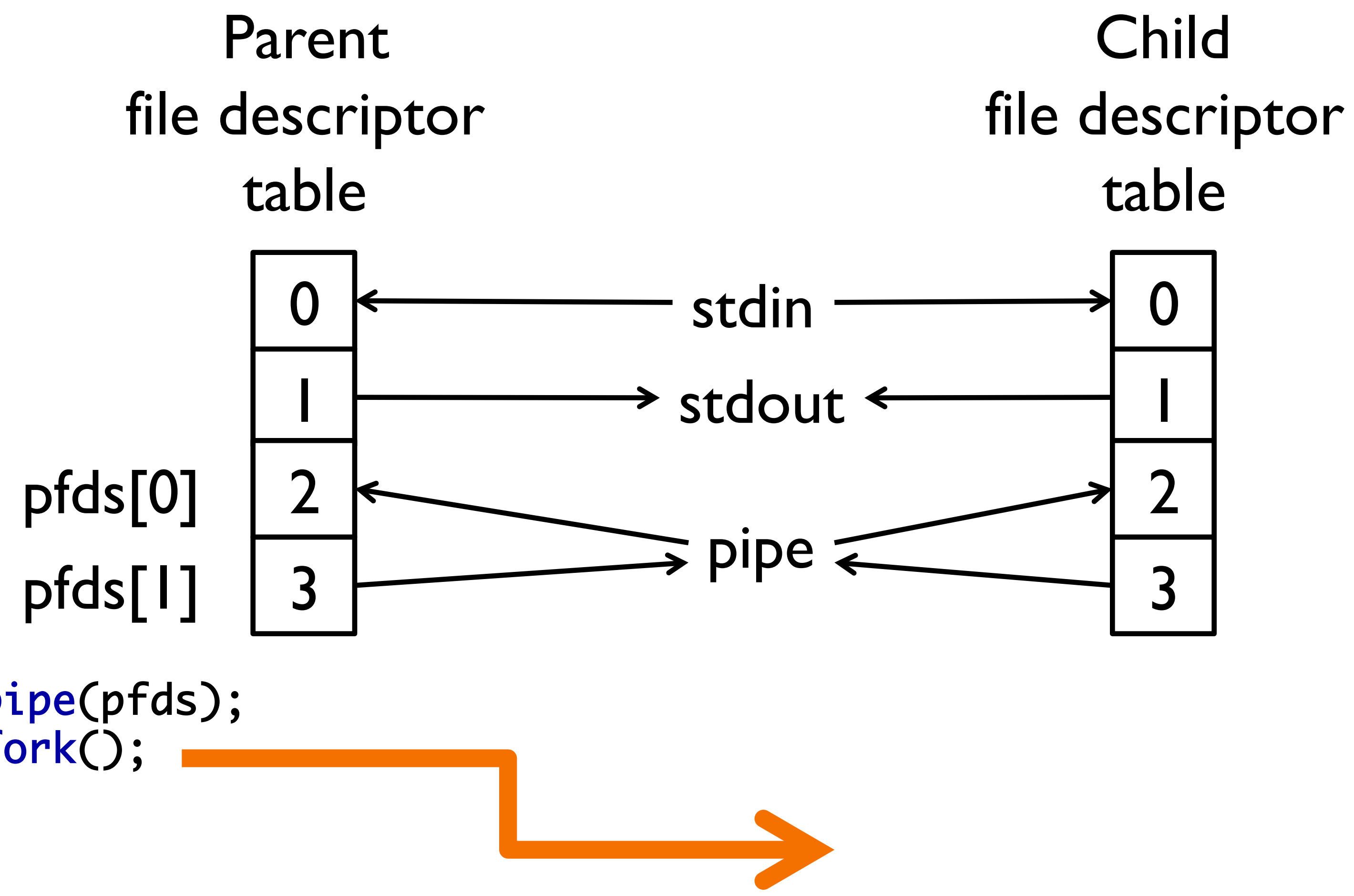
Run demo

Pipe dream come true: ls | wc –l



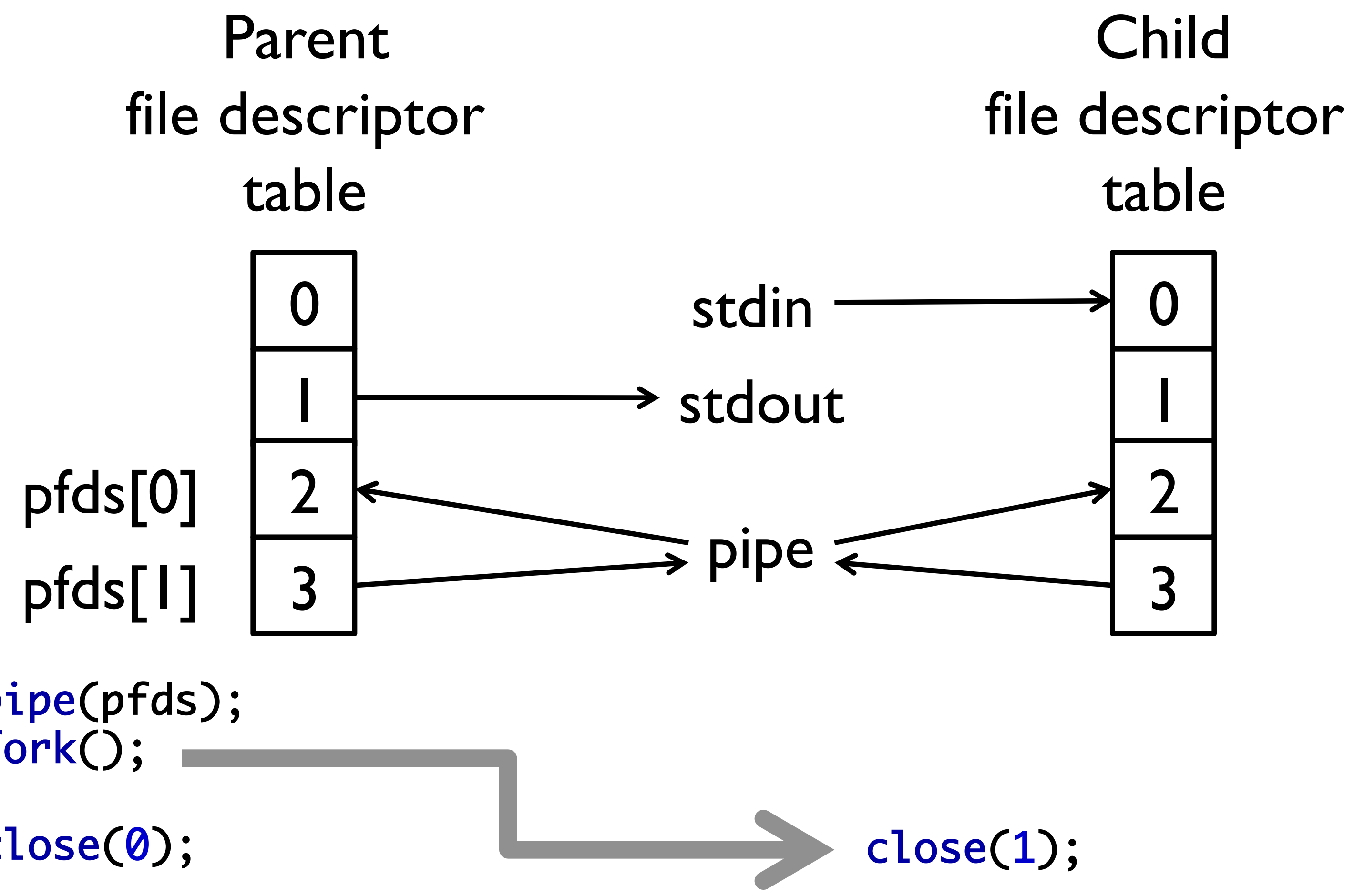
```
pipe(pfds);
```

Pipe dream come true: ls | wc –l



```
pipe(pfds);
fork();
```

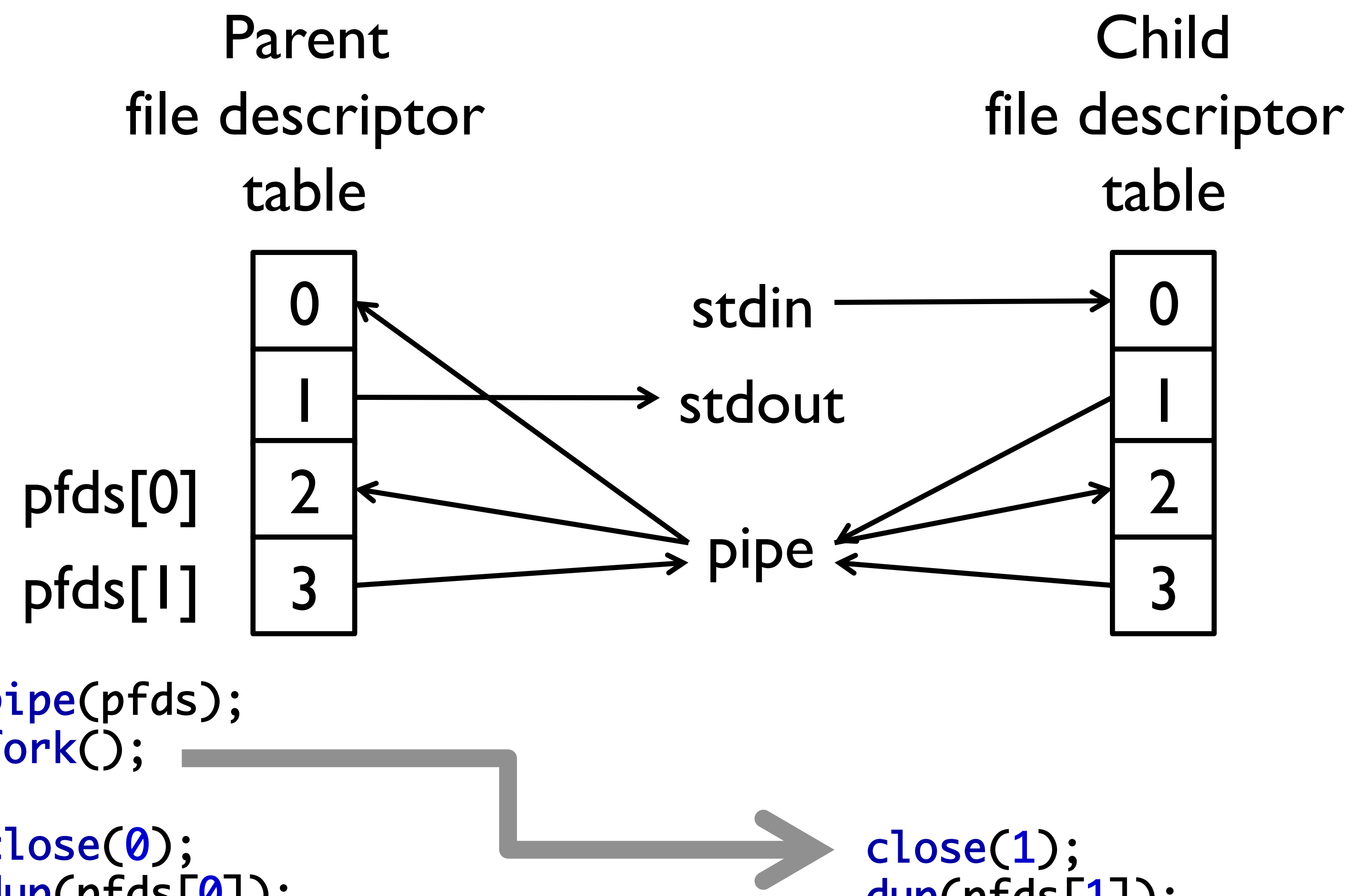
Pipe dream come true: ls | wc –l



```
pipe(pfds);
fork();

close(0);
```

```
close(1);
```

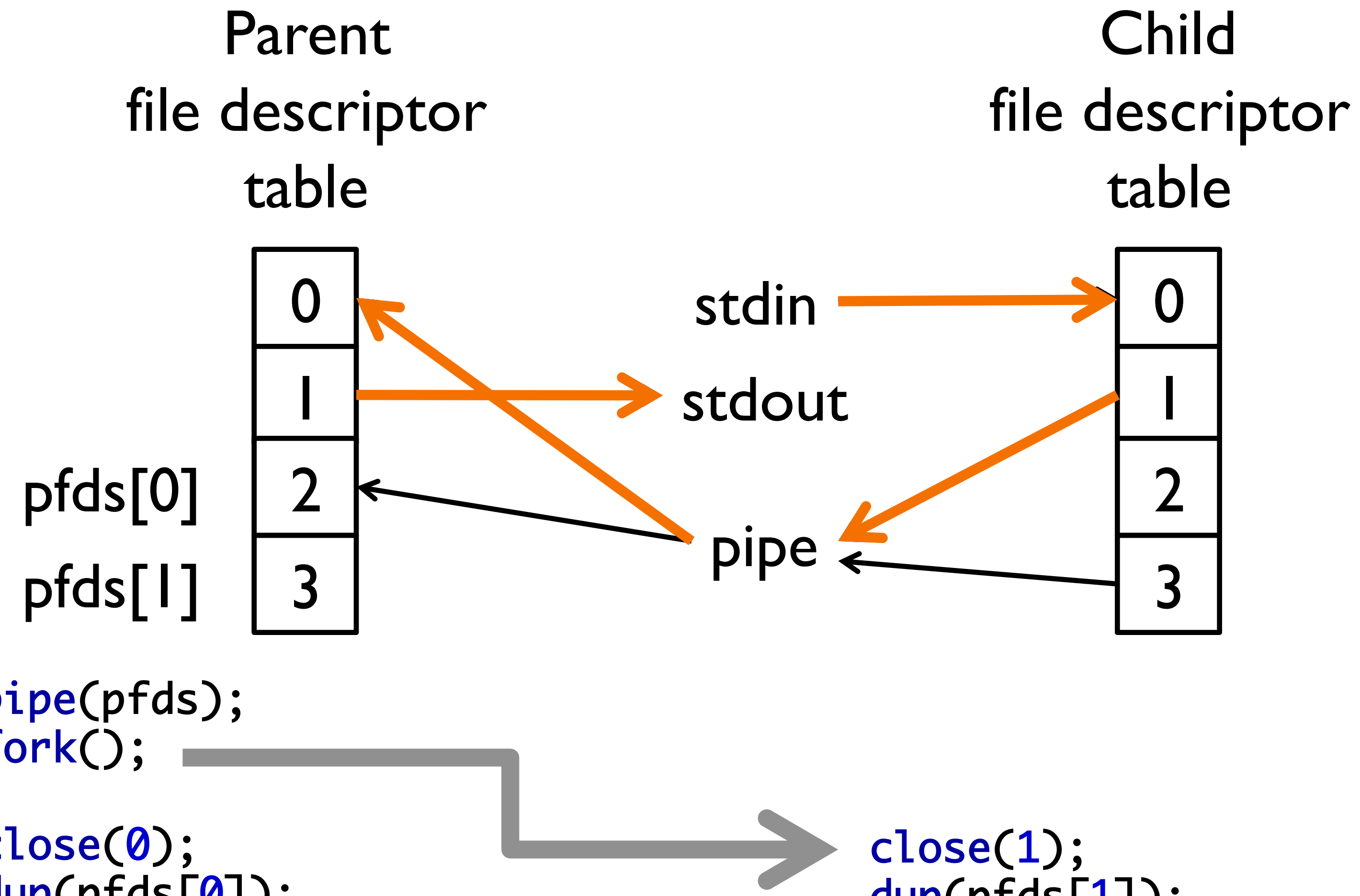
Pipe dream come true: ls | wc –l



```
pipe(pfds);
fork();

close(0);
dup(pfds[0]);
```

```
close(1);
dup(pfds[1]);
```

Pipe dream come true: ls | wc –l



```
pipe(pfds);
fork();

close(0);
dup(pfds[0]);
close(pfds[1]);
execlp("wc", "wc", "-l", NULL);
```

```
close(1);
dup(pfds[1]);
close(pfds[0]);
execlp("ls", "ls", NULL);
```

FIFOs

FIFOs

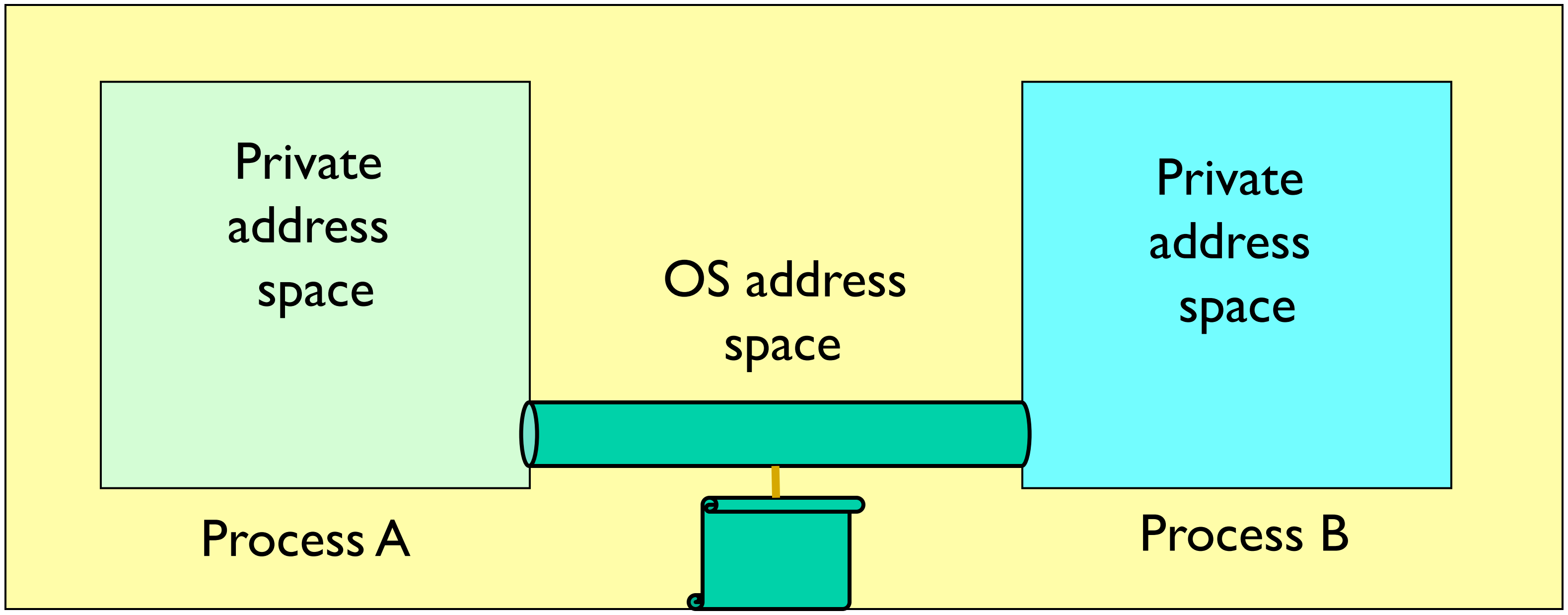
A pipe disappears when no process has it open

FIFOs = named pipes

- Special pipes that persist even after all the processes have closed them
- Actually implemented as a file

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

int status;
...
status = mkfifo("/home/cnd/mod_done", /* mode=0644 */
              S_IWUSR | S_IRUSR | S_IRGRP | S_IROTH);
```

Communication Over a FIFO



First **open** blocks until second process opens the FIFO

Can use **O_NONBLOCK** flag to make operations non-blocking

FIFO is persistent : can be used multiple times

Like pipes, OS ensures atomicity of writes and reads

FIFO Example: Producer-Consumer

Producer

- Writes to FIFO

Consumer

- Reads from FIFO
- Outputs data to file

FIFO ensures atomicity of write

FIFO Example

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

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

  if (argc != 2) { /* name of consumer fifo on the command line */
    fprintf(stderr, "Usage: %s fifoname > logfile\n", argv[0]);
    return 1;
  }
```

FIFO Example

```
/* create a named pipe to handle incoming requests */
 if ((mkfifo(argv[1], S_IRWXU | S_IWGRP| S_IWOTH) == -1)
     && (errno != EEXIST))
 {
   perror("Server failed to create a FIFO");
   return 1;
 }
```

```
  /* open a read/write communication endpoint to the pipe */
 if ((requestfd = open(argv[1], O_RDWR)) == -1) {
   perror("Server failed to open its FIFO");
   return 1;
 }
  /* Write to pipe like you would to a file */
  ...
}
```

What if there are multiple producers?

Examples

- Multiple children to compute in parallel; wait for output from any
- Network server connected to many clients; take action as soon as any one of them sends data

Problem

- Can use read / write scanf, but ..... problem?
- Blocks waiting for that one file, even if another has data ready & waiting!

Solution

- Need a way to wait for any one of a set of events to happen
- Something similar to wait() to wait for any child to finish, but for events on file descriptors

Select & Poll

Select and Poll: Waiting for input

Similar parameters

- Set of file descriptors
- Set of events for each descriptor
- Timeout length

Similar return value

- Set of file descriptors
- Events for each descriptor

Notes

- Select is slightly simpler
- Poll supports waiting for more event types
- Newer variant available on some systems: epoll

Select

```
int select (int num_fds, fd_set* read_set,
            fd_set* write_set, fd_set* except_set,
            struct timeval* timeout);
```

Wait for readable/writable file descriptors.

Return:

- Number of descriptors ready
- -1 on error, sets **`errno`**

Parameters:

- **`num_fds`**:
  - number of file descriptors to check, numbered from 0
- **`read_set`**, **`write_set`**, **`except_set`**:
  - Sets (bit vectors) of file descriptors to check for the specific condition
- **`timeout`**:
  - Time to wait for a descriptor to become ready

File Descriptor Sets

Bit vectors

- Often 1024 bits, only first `num_fds` checked
- Macros to create and check sets

```
fds_set myset;
void FD_ZERO (&myset);      /* clear all bits */
void FD_SET (n, &myset);    /* set bits n to 1 */
void FD_CLEAR (n, &myset); /* clear bit n */
int FD_ISSET (n, &myset);  /* is bit n set? */
```

File Descriptor Sets

Three conditions to check for

- Readable
  - Data available for reading
- Writable
  - Buffer space available for writing
- Exception
  - Out-of-band data available (TCP)

Select: Example

```
fd_set my_read;
FD_ZERO(&my_read);
FD_SET(0, &my_read);

if (select(1, &my_read, NULL, NULL) == 1) {
      ASSERT(FD_ISSET(0, &my_read);
      /* data ready on stdin */
```

Poll

```
#include <poll.h>
```

```
int poll (struct pollfd* pfds, nfds_t nfds, int timeout);
```

Poll file descriptors for events.

Return:

- Number of descriptors with events
- -1 on error, sets **`errno`**

Parameters:

- **`pfds`**:
  - An array of descriptor structures. File descriptors, desired events and returned events
- **`nfds`**:
  - Length of the **`pfds`** array
- **`timeout`**:
  - Timeout value in milliseconds

Descriptors

Structure

```
struct pollfd {
  int fd;                   /* file descriptor */
  short events;             /* queried event bit mask */
  short revents;            /* returned event mask */
```

Note:

- Any structure with `fd` < 0 is skipped

Event Flags

`POLLIN`:

- data available for reading

`POLLOUT`:

- Buffer space available for writing

`POLLERR`:

- Descriptor has error to report

`POLLHUP`:

- Descriptor hung up (connection closed)

`POLLVAL`:

- Descriptor invalid

Poll: Example

```
struct pollfd my_pfds[1];

my_pfds[0].fd = 0;
my_pfds[0].events = POLLIN;

if (poll(&my_pfds, 1, INFTIM) == 1) {
      ASSERT (my_pfds[0].revents & POLLIN);
      /* data ready on stdin */
```

Bonus Slides!

IPC Solutions

Two options

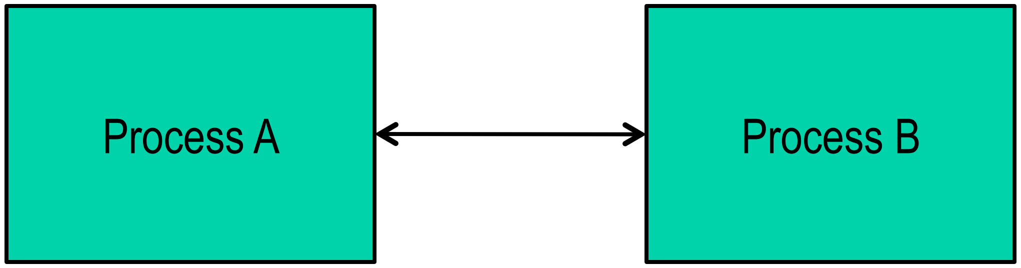
- Support some form of shared address space
  - Shared memory, memory mapped files
- Use OS mechanisms to transport data from one address space to another
  - Pipes, FIFOs
  - Messages, signals

Message-based IPC

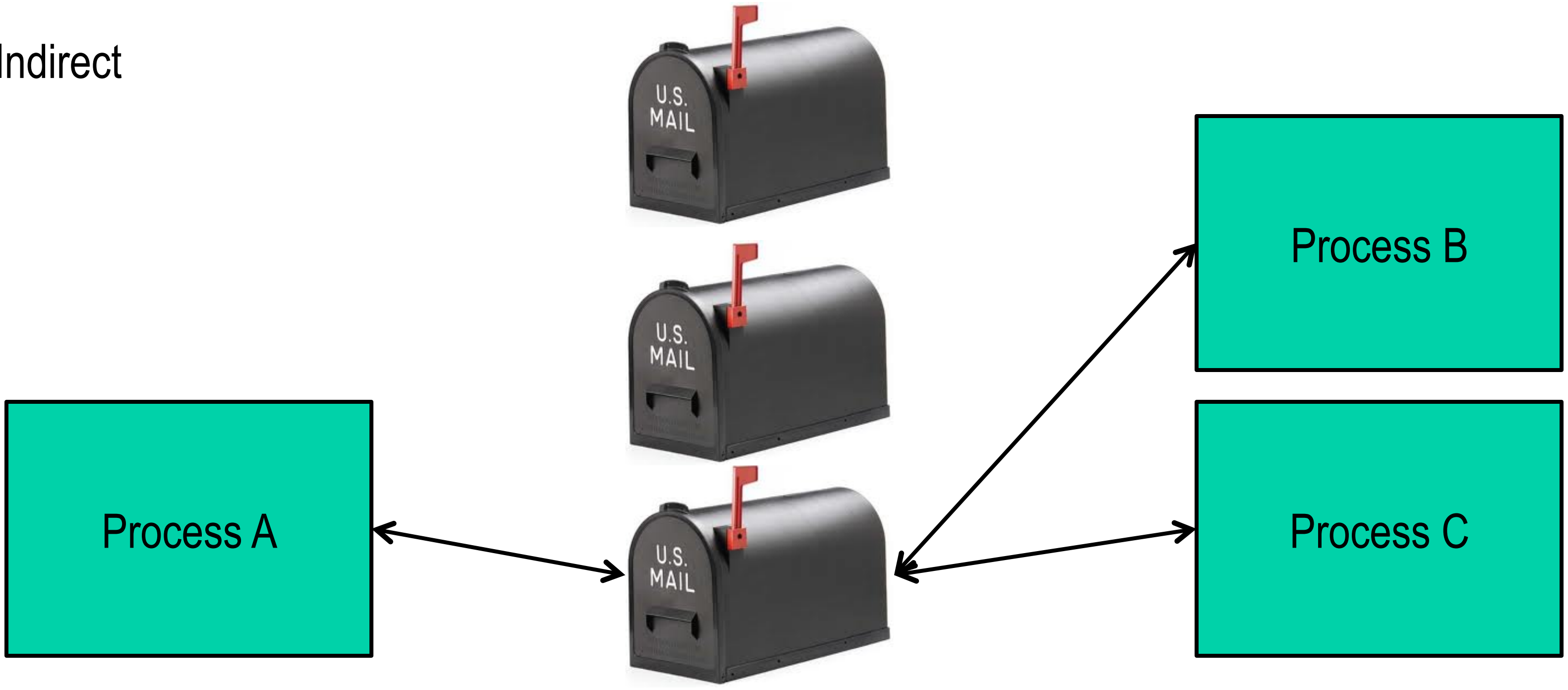
- Message system
  - Enables communication without resorting to shared variables
- To communicate, processes P and Q must
  - Establish a communication link between them
  - Exchange messages
- Two operations
  - send(message)
  - receive(message)

Message Passing

Direct



Indirect



Direct Message Passing

Processes must name each other explicitly

- `send (P, message)`
  - Send a message to process `P`
- `receive(Q, message)`
  - Receive a message from process `Q`
- `receive(&id, message)`
  - Receive a message from any process

Link properties

- Established automatically
- Associated with **exactly** one pair of processes
- There exists **exactly** one link between each pair

Limitation

- Must know the name or ID of the process(es)

Indirect Message Passing

Process names a mailbox (or port)

- Each mailbox has a unique id
- Processes can communicate only if they share a mailbox

Link properties

- Established only if processes share a common mailbox
- May be associated with **many** processes
- Each pair of processes may share **multiple** links
- Link may be unidirectional or bi-directional

Mailbox Ownership

Process

- Only the owner receives messages through mailbox
- Other processes only send.
- When process terminates, any “owned” mailboxes are destroyed

System

- Process that creates mailbox owns it (and so may receive through it) but may transfer ownership to another process.

Indirect Message Passing

Mailboxes are a resource

- Create and Destroy

Primitives

- **`send(A, message)`**
  - Send a message to mailbox **`A`**
- **`receive(A, message)`**
  - Receive a message from mailbox **`A`**

Indirect Message Passing

Mailbox sharing

- `P1`, `P2`, and `P3` share mailbox `A`
- `P1`, sends; `P2` and `P3` receive
- Who gets the message?

Options

- Allow a link to be associated with at most two processes
- Allow only one process at a time to execute a receive operation
- Allow the system to arbitrarily select the receiver and notify the sender

IPC and Synchronization

- Blocking == synchronous
  - Blocking send
    - Sender blocks until the message is received
  - Blocking receive
    - Receiver blocks until a message is available
- Non-blocking == asynchronous
  - Non-blocking send
    - Sender sends the message and continues
  - Non-blocking receive
    - Receiver receives a valid message or null

Buffering

IPC message queues

1. Zero capacity
    - No messages may be queued
    - Sender must wait for receiver
2. Bounded capacity
    - Finite buffer of n messages
    - Sender blocks if link is full
3. Unbounded capacity
    - Infinite buffer space
    - Sender never blocks

Buffering

Is a buffer needed?

```
P1:   send(P2, x)          P2: receive(P1, x)
      receive(P2, y)           send(P1, y)
```

Is a buffer needed?

```
P1:   send(P2, x)          P2: send(P1, x)
      receive(P2, y)           receive(P1, y)
```

Example: Message Passing

```
void Producer() {
    while (TRUE) {
        /* produce item */
        build_message(&m, item);
        send(consumer, &m);
        receive(consumer, &m); /* wait for ack */
    }
}

void Consumer {
    while(TRUE) {
        receive(producer, &m);
        extract_item(&m, &item);
        send(producer, &m); /* ack */
        /* consume item */
    }
}
```

Signals == Messages

Signals are a simple form of message passing

- Non-blocking
- No buffering