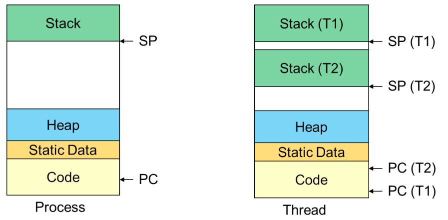
Inter-process Communication (IPC)

ECE 650
Systems Programming & Engineering
Duke University, Spring 2016

Recall Process vs. Thread



- A process is –
  - Execution context
    - PC, SP, Regs
  - Code
  - Data
  - Stack
- A thread is –
  - Execution context
    - Program counter (PC)
    - Stack pointer (SP)
    - Registers

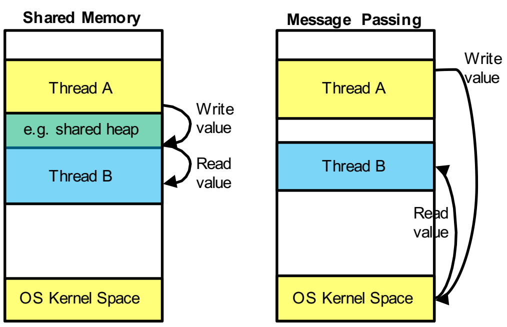
Cooperation

- Two or more threads or processes execute concurrently
- Sometimes cooperate to perform a task
  - Sometimes independent; not relevant for IPC discussion
- How do they communicate?
  - Threads of the same process: Shared Memory
    - Recall they share a process context
      - Code, static data, *heap*
    - Can read and write the same memory
      - variables, arrays, structures, etc.
  - What about threads of different processes?
    - They do not have access to each other's memory

Models for IPC

- Shared Memory
  - E.g. what we've discussed for threads of same process
  - Also possible across processes
    - E.g. memory mapped files (mmap)
- Message Passing
  - Use the OS as an intermediary
  - E.g. Files, Pipes, FIFOs, Messages, Signals

Models for IPC



Shared Memory vs. Message Passing

- Shared Memory
  - Advantages
    - Fast
    - Easy to share data (nothing special to set up)
  - Disadvantages
    - Need synchronization! Can be tricky to eliminate race conditions
- Message Passing
  - Advantages
    - Trust not required between sender / receiver (receiver can verify)
    - Set of shared data is explicit
    - Is synchronization needed?
  - Disadvantages
    - Explicit programming support needed to share data
    - Performance overhead (e.g. to copy messages through OS space)

Shared Memory Across Processes

- Different OSes have different APIs for this
- UNIX
  - System V shared memory (shmget)
    - Allows sharing between arbitrary processes
    - http://www.tldp.org/LDP/lpg/node21.html
  - Shared mappings (mmap on a file)
    - Different forms for only related processors or unrelated processes (via filesystem interaction)
  - POSIX shared memory (shm_open + mmap)
    - Sharing between arbitrary processes; no overhead of filesystem I/O
- Still requires synchronization!

mmap

#include <sys/mman.h>

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

- Creates new mapping in virtual address space of caller
  - addr: starting address for mapping (or NULL to let kernel decide)
  - length: # bytes to map starting at "offset" of the file
  - prot: desired memory protection of the mampping
    - PROT_EXEC, PROT_READ, PROT_WRITE, PROT_NONE
  - flags: are updates to mapping are visible to other processes?
    - MAP_SHARED, MAP_PRIVATE
    - Other flags can be added, e.g. MAP_ANON (more later)
  - fd: file descriptor for open file
    - Can close the "fd" file after calling mmap()
  - Return value is the address where the mapping was made

mmap operation

- Kernel takes an open file (given by FD)
- Maps that into process address space
  - In unallocated space between stack & heap regions
  - Thus also maps file into physical memory
  - Creates one-to-one correspondence between a memory address and a word in the file
- Useful even apart from the context of IPC
  - Allows programmer to read/write file contents without read(), write() system calls
- Multiple (even non-related) processes can share mem
  - They open & mmap the same file

munmap

#include <sys/mman.h>

int munmap(void *addr, size_t length);

- Removes mapping from process address space
  - addr: address of the mapping
  - length: # bytes in mapped region

#include <sys/mman.h>

int msync(void *addr, size_t length, int flags);

- Removes mapping from process address space
  - addr: address of the mapping
  - length: # bytes in mapped region

Synchronization

- Semaphores

```
#include <fcntl.h>          /* For O_* constants */
#include <sys/stat.h>       /* For mode constants */
#include <semaphore.h>
sem_t *sem_open(const char *name, int oflag, mode_t mode, int value);
or
int sem_init(sem_t *sem, int pshared, unsigned int value);
```

```
sem_t *mutex;
mutex = sem_open("my_sem_name", O_CREAT | O_EXCL,
MAP_SHARED, 1);

sem_wait(mutex);
//Critical section
sem_post(mutex);
```


Example

- Show code & run in class

Taking it Further

- This required some work
  - Create file in file system
  - Open the file & initialize it (e.g. with 0's)
- There is a better way if just sharing mem across a fork()
  - Anonymous memory mapping
- Use mmap flags of MAP_SHARED | MAP_ANON
  - File descriptor will be ignored (also offset)
  - Memory initialized to 0
  - Alternative approach: open /dev/zero & mmap it
- Can anonymous approach work across non-related processes?

Message Passing

- Messages between processes, facilitated by OS
- Several approaches:
  - Files
    - Can open the same file between processes
    - Communicate by reading and writing info from the file
    - Can be difficult to coordinate
  - Pipes
  - FIFOs
  - Messages (message passing)
  - Signals

Pipes

```
#include <unistd.h>
int pipe(int pipefd[2]);
```

- Creates a unidirectional channel (pipe)
- Can be used for IPC between processes / threads
- Returns 2 file descriptors
  - pipefd[0] is the read end
  - pipefd[1] is the write end
- Kernel support
  - Data written to write end is buffered by kernel until read
  - Data is read in same order as it was written
  - No synchronization needed (kernel provides this)
  - Must be related processes (e.g. children of same parent)

Example

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

#define N 1024

int main(int argc, char *argv[]) {
    int pipefd[2];
    char data_buffer[N];

    pipe(pipefd);
    int id = fork();
    if (id == 0) { //child
        write(pipefd[1], "hello", 6);
    } else {
        read(pipefd[0], data_buffer, 6);
        printf("Received data: %s\n", data_buffer);
    }

    return 0;
}
```


More Complex Uses of Pipes

- Can use pipes to coordinate processes
- For example, chain output of one process to input of next
  - E.g. command pipes in UNIX shell!
- Requires 1 additional (very useful) piece

```
#include <unistd.h>
int dup2(int oldfd, int newfd);
```

- Creates a copy of an open file descriptor into a new one
  - After closing the new file descriptor if it was open

UNIX Pipes Example

- Show code & run in class

UNIX FIFOs

- Similar to a pipe
  - Also called a "named pipe"
- Persist beyond lifetime of the processes that create them
- Exist as a file in the file system

```
#include <sys/types.h>
#include <sys/stat.h>
int mkfifo(const char *pathname, mode_t mode);
```

- pathname points to the file
- Mode specifies the FIFO's permissions (similar to a file)

UNIX FIFOs (2)

- After FIFO is created, processes must open it
  - By default, first open blocks until a second process also opens
- Since FIFOs persist, they can be re-used
- No synchronization needed (like pipes, OS handles it)

Multiple Producers

- Multiple producers problem:
  - What if >1 producers and 1 consumer
  - Producers are performing write(…)
  - Consumer is performing (blocking) read(…)
  - What if consumer is blocked, but other IPC channels have data?
- Would like to be notified if one channel is ready

Select

```
#include <sys/select.h>
int select(int nfds, fd_set *readfds, fd_set *writefds,
           fd_set *exceptfds, struct timeval *timeout);
```

- nfds = number of file descriptors to monitor
- readfds, writefds, exceptfds are bit vectors of file descriptors to check
- timeout is a maximum time to wait
- Macros are available to work with bit sets:
  - FD_ZERO(&fds), FD_SET(n, &fds), FD_CLEAR(n, &fds)
  - int FD_ISSET(n, &fds); //useful after select() returns

Poll

```
#include <poll.h>
int poll(struct pollfd *fds, nfds_t nfds, int timeout);
```

- nfds = number of file descriptors to monitor
- fds is an array of descriptor structures
  - File descriptors, desired events, returned events
- timeout is a maximum time to wait
- Returns number of descriptors with events