Processes
Threads
Interprocess Communication

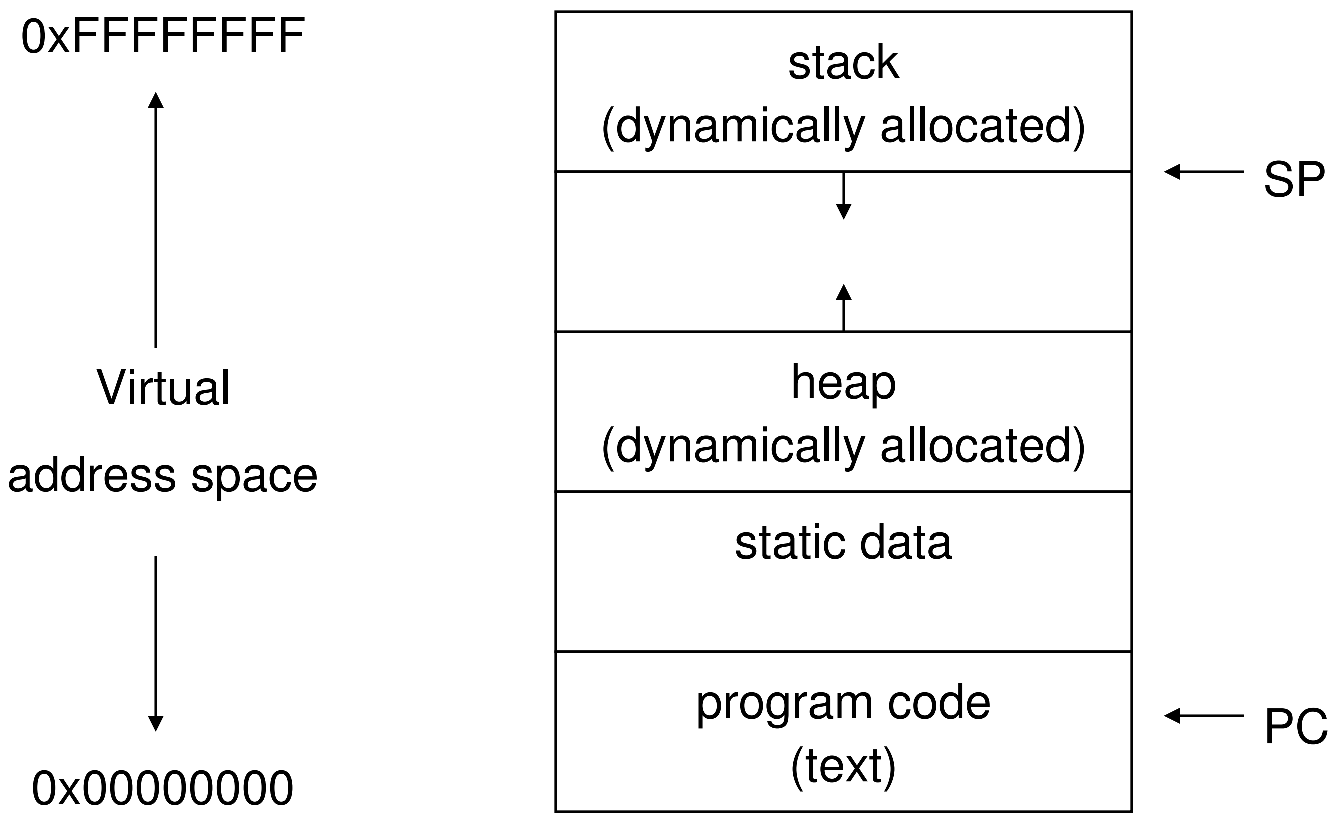
Processes – Defined

- The process is the OS's abstraction for execution
  - the unit of execution
  - a unit of scheduling
  - the dynamic execution context
- Process is often called a job, task, or sequential process

Processes – Contents

- A process in Unix or Windows comprises (at least):
  - an *address space* – usually protected and virtual – mapped into memory
  - the *code* for the running program
  - the *data* for the running program
  - an *execution stack* and *stack pointer* (SP)
  - the *program counter* (PC)
  - a set of processor *registers* – general purpose and status
  - a set of system *resources*
    - files, network connections, privileges, …

Processes – Address Space



Processes in the OS – Representation

- A process is identified by its *Process ID* (PID)
- In the OS, processes are represented by entries in a *Process Table* (PT)
  - PID “points to” a PT entry
  - PT entry = *Process Control Block* (PCB)
- PCB is a large data structure that contains or points to all info about the process

PCB

- Typical PCB contains:
  - execution state
  - PC, SP & processor registers – stored when process is made inactive
  - memory management info
  - Privileges and owner info
  - scheduling priority
  - resource info
  - accounting info

Process – starting and ending

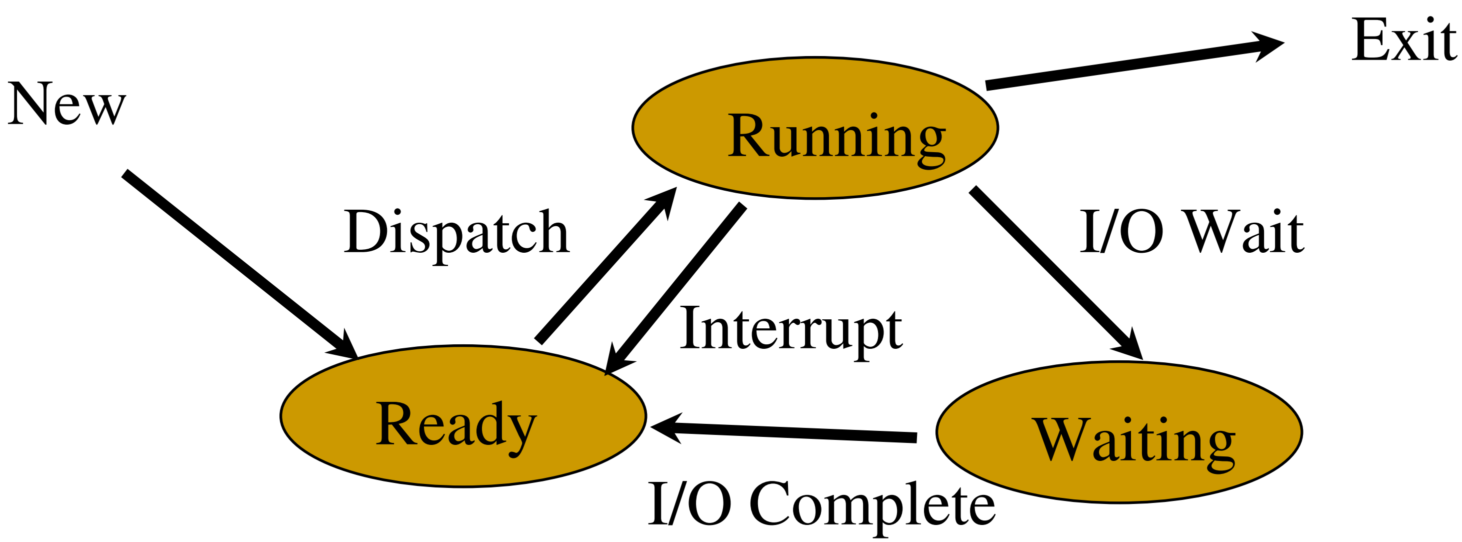
- Processes are created …
  - When the system boots
  - By another process
  - By user
  - By batch manager
- Processes terminate when …
  - Normally – exit
  - Voluntarily on an error
  - Involuntarily on an error
  - Terminated (killed) by the actions a user or a process

Processes – Switching

- When a process is running, its *hardware state* is in the CPU – PC, SP, processor registers
- When the OS suspends running a process, it saves the hardware state in the PCB
- *Context switch* is the act of switching the CPU from one process to another
  - timesharing systems may do 100s or 1000s of switches/sec
  - takes 1-100 microseconds on today's hardware

States

- Process has an execution **state**
  - *ready*: waiting to be assigned to CPU
  - *running*: executing on the CPU
  - *waiting*: waiting for an event, e.g. I/O



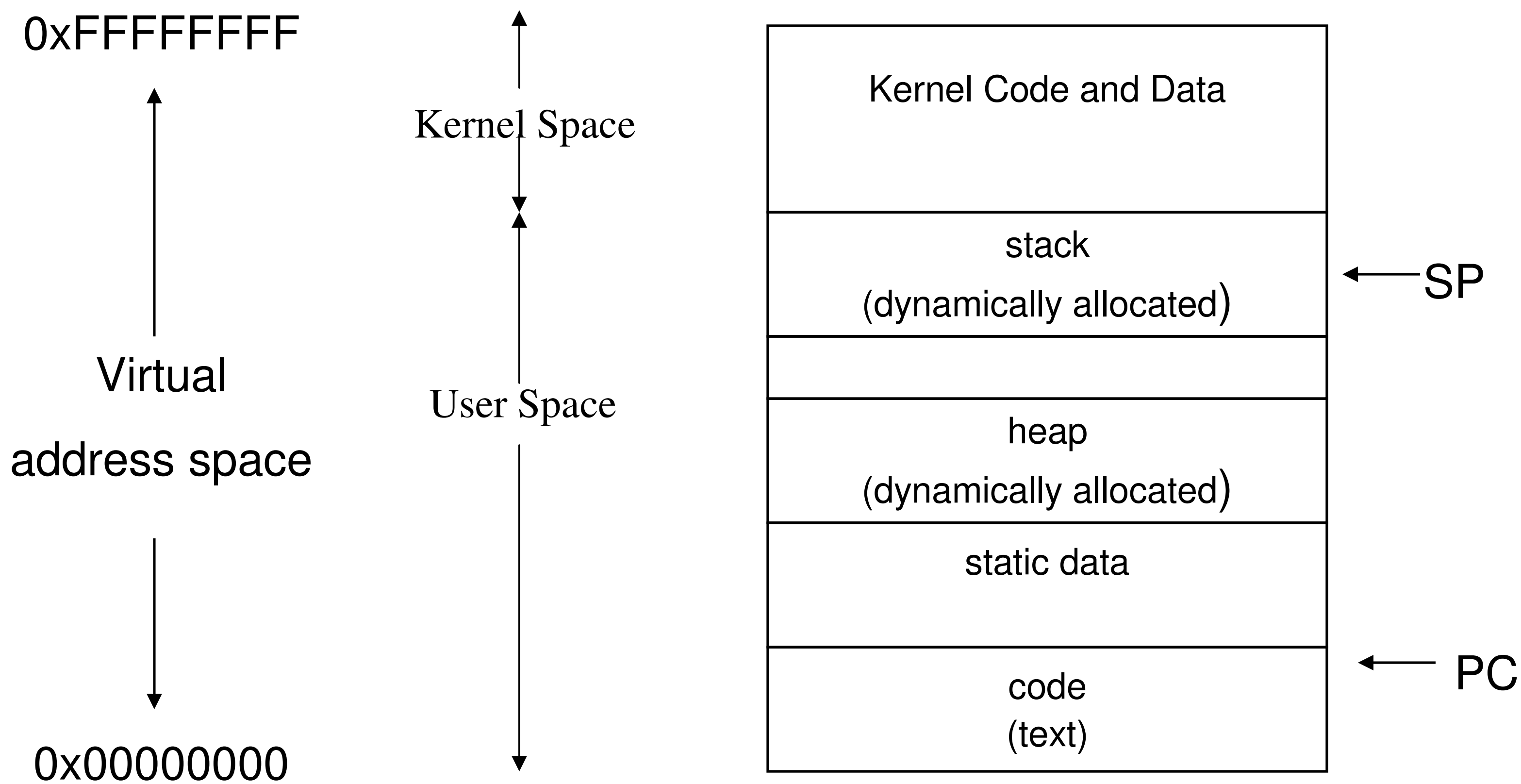
State Queues

- The OS maintains a collection of *process state* queues
  - typically one queue for each state – e.g., ready, waiting, …
  - each PCB is put onto a state queue according to its current state
  - as a process changes state, its PCB is unlinked from one queue, and linked to another
- Process state and the queues change in response to events – interrupts, traps

Process Creation

- Unix/Linux
  - Create a new (child) process – ***fork***();
    - Allocates new PCB
    - Clones the calling process (almost)
      - Copy of parent process address space
      - Copies resources in kernel (e.g. files)
    - Places PCB on <u>Ready</u> queue
    - Return from *fork*() call
      - 0 for child
      - child PID for parent

Processes – Address Space



Example of fork( )

```
int main(int argc, char **argv)
{
  char *name = argv[0];
  int child_pid = fork();
  if (child_pid == 0) {
    printf(“Child of %s is %d\n”,
           name, child_pid);
    return 0;
  } else {
    printf(“My child is %d\n”, child_pid);
    return 0;
  }
}
```

Child

Parent

% ./forktest
Child of forktest is 0
My child is 486

Another example

```
#include <stdio.h>

main(int argc, char *argv[])
   /* argc -- number of arguments */
   /* argv -- an array of strings */
{
   int pid;
   int i;

   /* print out the arguments */
   printf("There are %d
    arguments:\n", argc);
   for (i = 0; i < argc; i++)
      printf("%s\n", argv[i]);

 if ((pid = fork()) < 0) {
      fprintf(stderr, "Fork error\n");
      exit(1);
   }
   else if (pid == 0) { /* child process */
      for (i = 0; i < 5; i++)
         printf("child (%d) : %s\n",
             getpid(), argv[2]);
      exit(0);
   }
   else {
      /* parent */
      for (i = 0; i < 5; i++)
         printf("parent (%d): %s\n",
             getpid(), argv[1]);
      exit(0);
   }
}
```

Result?

- > gcc -o ptest ptest.c
- > ./ptest x y
- output:

There are 3 arguments:
ptest
x
y
parent (690): x
parent (690): x
child (7686) : y
parent (690): x
child (7686) : y
parent (690): x
child (7686) : y
parent (690): x
child (7686) : y
child (7686) : y

New Programs

- Starting another program
  - Unix – **int *exec* (char *prog, char **argv)**
    - Check privileges and file type
    - Loads program “prog” into address space
    - Initializes context – e.g. passes arguments (*argv)
    - Place PCB on <u>ready</u> queue
  - Windows/NT – combines *fork* & *exec*
    - ***CreateProcess*** (`10 arguments`)
    - Not a parent child relationship
    - Note – privileges required to create a new process

execve

- *execve(name, argv, envp)*:
- **name**
  - -- name of the file to execute.
- **argv**
  - NULL-terminated array of pointers to NULL-terminated character strings.
- **envp**
  - NULL-terminated array of pointers to NULL-terminated strings. Used to pass *environment* information to the new process.

process execution

- a process first starts up
  - started via ***exec***
- After startup the C library:
  - makes the arguments passed to *exec* available as arguments to the main procedure in the new process.
  - places a copy of *envp* in the global variable ***environ***.

Process Creation

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

```
pid_t fork(void);

int execve (const char *filename,
                  char *const argv[],
                  char *const envp[]);
```

Execve

```
int main(int argc, char **argv)
{ char *argvNew[5];
  int pid;
  if ((pid = fork()) < 0) {
        printf( "Fork error\n“);
        exit(1);
  } else if (pid == 0) { /* child process */
        argvNew[0] = "/bin/ls";
        argvNew[1] = "-l";
        argvNew[2] = NULL;
        if (execve(argvNew[0], argvNew, environ) < 0) {
            printf( "Execve error\n“);
            exit(1);
        }
   } else { /* parent */
        wait(pid); /* wait for the child to finish */
   }
}
```

Returns only in error condition

utility functions

- execl(name, arg0, arg1, arg2, ..., 0)
  - used when the arguments are known in advance.
  - 0 terminates the argument list.
- execv(name, argv)
  - argv is the same for *execve*.
- execvp(name, argv)
  - argv is the same as for *execve*.
  - executable file is searched for in the path
- eventually *execve* will be called
  - global variable *environ* in place of the *envp* argument
- child processes *inherits* the parent's environment.

basic shell like application

```
while (1) {
    type_prompt();          /* show prompt */
    read_command(command,parameters); /* get input */
    if (fork != 0) {
            /* Parent code */
            waitpid(-1,&status,0);
    } else {
            /* child code */
            execve(command,parameters,0);
    }
}
```

source: Operating Systems Design and Implementation – Tannenbaum & Woodhull

Synchronization
Interprocess Communication (IPC)

Interprocess Communication

- Mechanism for processes to communicate and to synchronize their actions.

Interprocess Communication

- Types
  - Pipes & streams
  - Sockets & Messages
  - Remote Procedure Call
  - Shared memory
- OS dependent
- Depends on whether the communicating processes share all or part of an address space

Interprocess Communication

- Common IPC mechanisms
  - *shared memory* – read/write to shared region
    - E.g., `shmget()`, `shmctl()` in Unix
    - Memory mapped files in WinNT/2000
    - Need critical section management
  - *semaphores*
    - *post_s*() notifies *wait* ing process
    - Shared memory or not
  - *software interrupts* - process notified asynchronously
    - *signal* ()
  - *pipes* - unidirectional stream communication
  - *message passing* - processes send and receive messages
    - Across address spaces

Software Interrupts

- Similar to hardware interrupt.
  - Processes interrupt each other
  - Non-process activities interrupt processes
- Asynchronous
- Stops execution then restarts
  - Keyboard driven – e.g. cntl-C
  - An alarm scheduled by the process expires
    - Unix: SIGALRM from `alarm()` or `settimer()`
  - resource limit exceeded (disk quota, CPU time...)
  - programming errors: invalid data, divide by zero

Software Interrupts (continued)

- `SendInterrupt(pid, num)`
  - Send signal type `num` to process `pid`,
  - `kill()` in Unix
  - (NT doesn't allow signals to processes)
- `HandleInterrupt(num, handler)`
  - type `num`, use function `handler`
  - `signal()` in Unix
  - Use exception handler in WinNT/2000
- Typical handlers:
  - ignore
  - terminate (maybe w/core dump)
  - user-defined

Pipes

- A *pipe* is a unidirectional stream connection between 2 processes
  - Unix/Linux
    - 2 file descriptors
    - Byte stream
  - Win/NT
    - 1 handle
    - Byte stream and structured (messages)

(Named) Pipes

- Classic IPC method under UNIX:

  `> ls -l | more`

  - shell runs two processes `ls` and `more` which are linked via a pipe
  - the first process (`ls`) writes data (e.g., using `write`) to the pipe and the second (`more`) reads data (e.g., using `read`) from the pipe

- the system call `pipe( fd[2] )`
  creates one file descriptor for reading
  (`fd[0]`) and one for writing (`fd[1]`)
  - allocates memory page to hold data

Pipe Example

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

char *msg = "Hello Pipe!";

main()
{
   char inbuf[MSGSIZE];
   int p[2];
   pid_t pid;

   /* open pipe */
   if (pipe(p) == -1) { perror("pipe
    call error"); exit(1); }

   switch( pid = fork() ) {

   case -1: perror("error: fork
    call");
         exit(2);

case 0:  close(p[0]);  /* close the
   read end of the pipe */
         write(p[1], msg,
   MSGSIZE);
         printf("Child: %s\n",
   msg);
         break;

   default: close(p[1]);  /* close
   the write end of the pipe */
         read(p[0], inbuf,
   MSGSIZE);
         printf("Parent: %s\n",
   inbuf);
         wait(0);
   }
   exit(0);
}
```

creating file descriptors

- $ exec 3< file1
  - creates a file descriptor called 3
  - 3 is descriptor for file called file1
- Standard descriptors
  - 0 – read
  - 1 – write
  - 2 – error
- $ read <&3 var1
  - reads from file with descriptor 3
  - result is places in var1
  - echo $var1

example: file_descriptor_read_write

```
#/bin/sh
#process a file line by line


if [ $# != 1 ] ; then
    echo "Usage: $0 input-file"
    exit 1
else
    processfile=$1
fi

# assign file descriptor 3 to file

exec 3< $processfile

#read from file through
    descriptor

until [ $done ]
do
    read <&3 out
    if [ $? != 0 ] ; then
        done=1
        continue
    fi

# process file
echo $out
done
echo " That is al folks!"
```

Processing

file1:

date

users

pwd

ls

```
uskudarli@uskudarli:~/code/shell$ ./file_descriptor_read_write file1
date
users
pwd
ls
 That is all folks!!!
```

IPC – Message Passing

- Communicate information from one process to another via primitives:

```
send(dest, &message)
receive(source, &message)
```

- Receiver can specify *ANY*
- Receiver can choose to **block** or not

Message Passing

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

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

send

- send ( ) operation
  - Synchronous
    - Returns after data is sent
    - Blocks if buffer is full
  - Asynchronous
    - Returns as soon as I/O started
    - Done?
      - Explicit check
      - Signal
    - Blocks if buffer is full

receive

- receive () operation
  - Syncronous
    - Returns if there is a message
    - Blocks if not
  - Asyncronous
    - Returns if there is a message
    - Returns indication if no message

Mailbox

- Indirect Communication – mailboxes
  - Messages are sent to a named area – *mailbox*
  - Processes read messages from the mailbox
  - Mailbox must be created and managed
  - Sender blocks if mailbox is full
  - Enables many-to-many communication

Message Passing issues

- Scrambled messages (checksum)
- Lost messages (acknowledgements)
- Lost acknowledgements (sequence no.)
- Process unreachable (down, terminates)
- Naming
- Authentication
- Performance (copying, message building)

Buffering/Queuing

- Queue of messages attached to the link
  1. Zero capacity – 0 messages
     Sender must wait for receiver (rendezvous).
  2. Bounded capacity – finite length of *n* messages
     Sender must wait if link full.
  3. Unbounded capacity – infinite length
     Sender never waits.

Message Passing (2)

- Message passing may be:
  - **Blocking**
    - **synchronous.**
  - **Non-blocking**
    - **asynchronous.**
- **send** and **receive** primitives may be either blocking or non-blocking.

Synchronization in message passing (1)

- For the sender
  - convenient to not to be blocked after send
    - send several messages to multiple destinations.
    - usually expects acknowledgment of message receipt
- For the receiver
  - it is more natural to be blocked after issuing receive:
    - the receiver usually needs the info before proceeding.
    - but could be blocked indefinitely if sender process fails before send.

Synchronization in message passing (2)

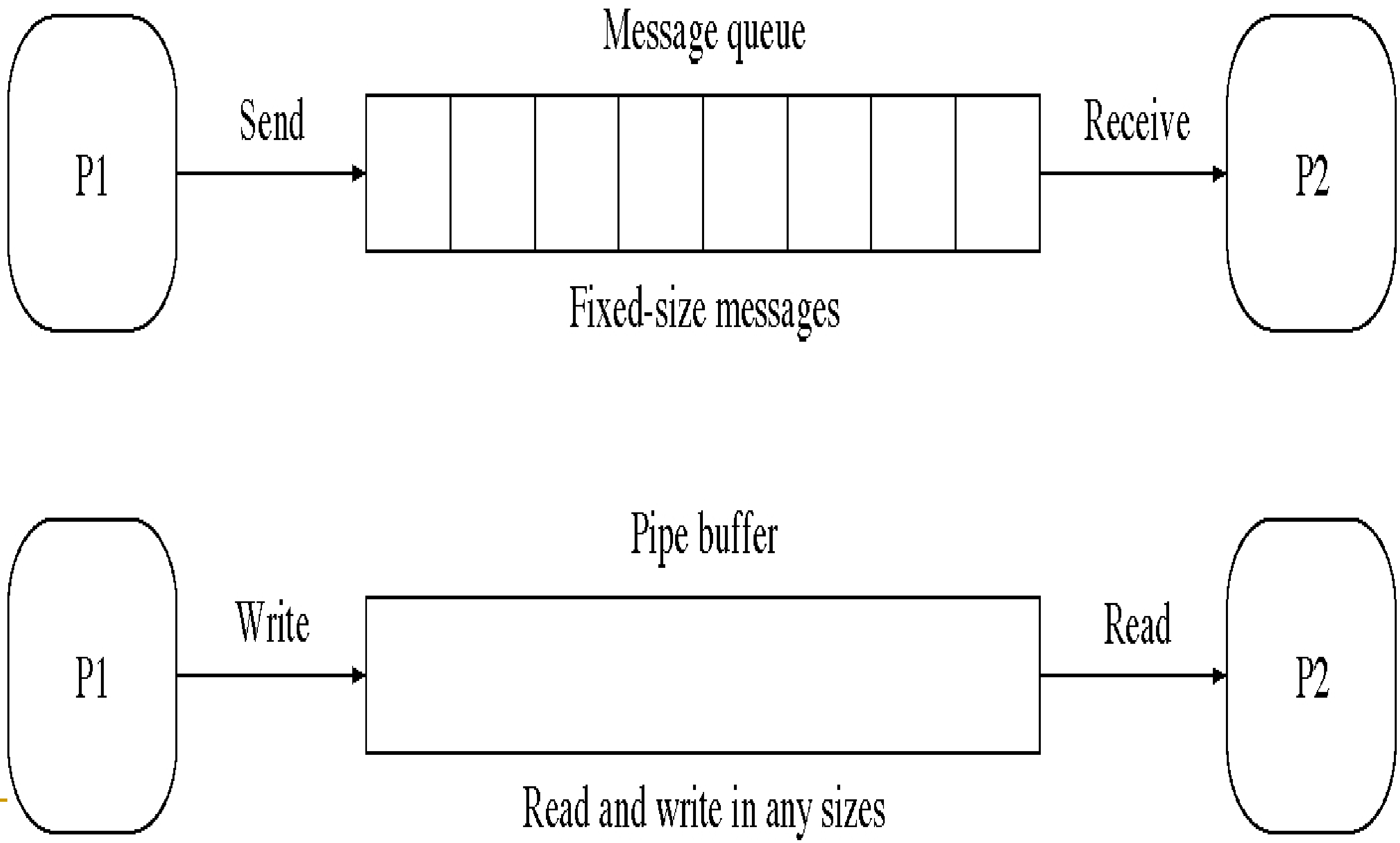
- Other aternatives
  - blocking send and blocking receive:
    - both are blocked until the message is received.
    - when the communication link is unbuffered (no message queue).
  - tight synchronization (*rendezvous*).

Synchronization in message passing (3)

- 3 meaningful combinations:
  1. Blocking send, Blocking receive
  2. Nonblocking send, Nonblocking receive
  3. Nonblocking send, Blocking receive

3rd is most popular

Messages and Pipes Compared



Some Signals

SIGHUP	1	Exit	Hangup
SIGINT 2	**Exit**	**Interrupt**	
SIGQUIT	**3**	**Core**	**Quit**
SIGILL 4	Core	Illegal Instruction	
SIGTRAP	5	Core	Trace/Breakpoint Trap
SIGABRT	**6**	**Core**	**Abort**
SIGEMT	7	Core	Emulation Trap
SIGFPE	8	Core	Arithmetic Exception
SIGKILL	**9**	**Exit**	**Killed**
SIGBUS	**10**	**Core**	**Bus Error**
SIGSEGV	**11**	**Core**	**Segmentation Fault**
SIGSYS	12	Core	Bad System Call
SIGPIPE	13	Exit	Broken Pipe
SIGALRM	14	Exit	Alarm Clock
SIGTERM	15	Exit	Terminated

Signal Example

```
#include <stdio.h>
#include <signal.h>

void sigproc()
{
    signal(SIGINT, sigproc);

    printf("you have pressed ctrl-c -
    disabled \n");
}

void quitproc()
{
    printf("ctrl-\\ pressed to quit\n");
    exit(0); /* normal exit status */
}
```

```
main()
{
    signal(SIGINT, sigproc);
 /* DEFAULT ACTION: term */
    signal(SIGQUIT, quitproc);
/* DEFAULT ACTION: term */
    printf("ctrl-c disabled use ctrl-\\
    to quit\n");

    for(;;);
}
```

signal example

```
#include <stdio.h>
#include <signal.h>

void sighup();
void sigint();
void sigquit();

main()
{
   int pid;

   /* get child process */
   if ((pid=fork()) < 0)
   { perror("fork"); exit(1); }

   if (pid == 0) {        /* child
   */
        signal(SIGHUP, sighup);
        signal(SIGINT, sigint);
        signal(SIGQUIT, sigquit);
        for(;;);
```

```
} else {     /* parent */
      printf("\nPARENT:
   sending SIGHUP\n\n");

      kill(pid,SIGHUP);
       sleep(3);
      printf("\nPARENT:
   sending SIGINT\n\n");

      kill(pid,SIGINT);
       sleep(3);

      printf("\nPARENT:
   sending SIGQUIT\n\n");

      kill(pid,SIGQUIT);
             sleep(3);
    }
}
```

Signal Example

```
void sighup()
{
   signal(SIGHUP,sighup);
   /* reset signal */
       printf("CHILD:
   received SIGHUP\n");
}

void sigint()
{
   signal(SIGINT,sigint);
   /* reset signal */
    printf("CHILD:received
   SIGINT\n");
}
```

```
void sigquit()
{
  printf("Parent
  Killed me!!!\n");
   exit(0);
}
```

Summary

- Many ways to perform send messages or perform IPC on a machine
  - mailboxes - FIFO, messages has types
  - pipes – FIFO, no type
  - shared memory – shared memory mapped into virtual space
  - signals – send a signal which can invoke a special handler

Critical Sections

- Critical section of code involve shared access in a concurrent situation
- More than one process/thread must not enter
- Synchronization mechanisms must be used

Blocking

- Blocking is synchronous
- Non-blocking is asynchronous

Threads

Processes are very heavyweight

- Lots of data in process context
- Processor caches a lot of information
  - Memory Management information
- Costly context switches and traps
  - 100’s of microseconds

Processes are Heavyweight

- Separate processes have separate address spaces
  - Shared memory is limited or nonexistent
  - Applications with internal concurrency are difficult
- Isolation between independent processes *vs.* cooperating activities
  - Fundamentally different goals

Example

- Web Server – How to support multiple concurrent requests
- One solution:
  - create several processes that execute in parallel
  - Use shared memory (`shmget()`) to map to the *same* address space in the processes
  - have the OS schedule them in parallel
- Not efficient
  - space: PCB, page tables, etc.
  - time: creating OS structures (`fork()`) and context switch

Example 2

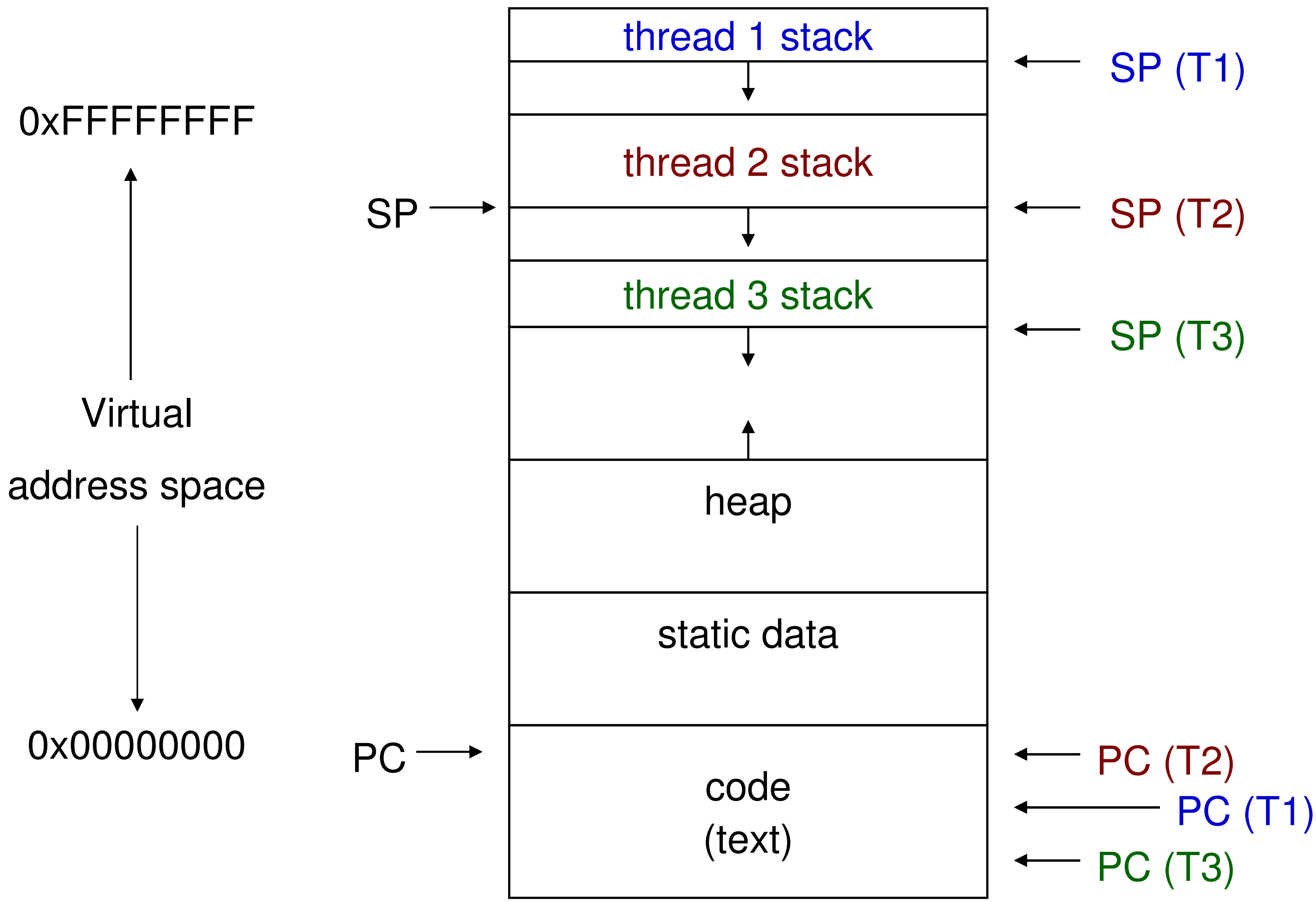
- Transaction processing systems
  - E.g, airline reservations or bank ATM transactions
- 1000’s of transactions *per second*
  - Very small computation per transaction
- Separate processes per transaction are too costly

Solution:– *Threads*

- A *thread* is the execution of a program or procedure within the context of a Unix or Windows process
    - I.e., a specialization of the concept of *process*
- A thread has its own
    - Program counter, registers
    - Stack
- A thread shares
    - Address space, heap, static data
    - All other resources

with other threads in the same process

Threads



0xFFFFFFFF
Virtual
address space
0x00000000
SP
PC
thread 1 stack
thread 2 stack
thread 3 stack
heap
static data
code
(text)
SP (T1)
SP (T2)
SP (T3)
PC (T2)
PC (T1)
PC (T3)

Thread Interface

- From POSIX pthreads API:
  - int **pthread_create**(*pthread_t *thread, const pthread_attr_t *attr, void**(**start_routine*) (*void*), *void *arg*) *;*
    - creates a new thread of control
    - new thread begins executing at start_routine
  - **pthread_exit**(*void *value_ptr*)
    - terminates the calling thread
  - **pthread_join**(*pthread_t thread, void **value_ptr*)*;*
    - blocks the calling thread until the thread specified terminates
  - pthread_t **pthread_self()**
    - Returns the calling thread's identifier

Threads

- Linux, Windows, and various versions of Unix have their own thread interfaces
  - Similar, not standardized

- Some issues
  - E.g., `ERRNO` in Unix — a static variable set by system calls

Threads – Management

- Who/what creates and manages threads?
  - *Kernel* level – new system calls and new entity to manage
    - Linux: *lightweight process*
    - Win/NT & XP: *threads*
  - *User* level
    - done with function library (POSIX)
    - Runtime system – similar to process management except in user space
    - Win/NT – *fibers: x* user-level thread mechanism

Threads – User Space

- Thread Scheduler
  - Queues to keep track of threads' state
  - Scheduler – non-preemptive
    - Assume threads are **well-behaved**
    - Thread gives up CPU by calling yield() – does context switch to another thread
  - Scheduler – preemptive
    - Assumes threads may not be well-behaved
    - Scheduler sets timer to create a *signal* that invokes scheduler
    - Scheduler can force thread context switch
    - Increased overhead
- Application must handle *all* concurrency itself!

Threads inside the OS kernel

- Kernels have evolved into large, multi-threaded programs.
- Lots of concurrent activity
  - Multiple devices operating at one time
  - Multiple application activities at one time

Threads – Summary

- Processes are very heavyweight in Unix, Linux, Windows, etc.
    - Need for isolation between processes conflicts the need for concurrency within processes
- Threads provide an efficient alternative Thread implementation and management strategies depend upon expected usage
    - Kernel support or not
    - Processor support or not

Processes

- Processes are created in a hierarchical structure
- depth is limited by the virtual memory available to the virtual machine
- A process may control the execution of any of its descendants
  - suspend
  - resume
  - change relative priority
  - terminate
- Termination of a process causes termination of all its descendants
- Termination of the root process terminates the session
- Linux assigns a *process ID* (PID) to the process

Processes

- Foreground
  - a process runs in terminal
  - invoked from prompt
  - when process terminates it returns to prompt
- Background
  - process runs in the background
  - invoked with “`&`” at the end of the command line,
  - the prompt immediately returns
  - terminal is free to execute other commands

Processes

- Daemons
  - Background processes for system administration are referred to as "daemons"
  - These processes are usually started during the boot process
  - The processes are not assigned any terminals

```
UID          PID  PPID  C STIME TTY          TIME CMD
root           5     1  0  1999 ?        00:00:14 [kswapd]
bin          254     1  0  1999 ?        00:00:00 [portmap]
root         307     1  0  1999 ?        00:00:23 syslogd -m 0
root         350     1  0  1999 ?        00:00:34 httpd
```

Processes

& causes process to be run in "background"

```
[root@penguinvm log]# sleep 10h &
[1] 6718
[root@penguinvm log]# ps -ef
UID        PID  PPID  C STIME TTY          TIME CMD
root      6718  6692  0 14:49 ttyp0    00:00:00 sleep 10h
```

Job Number

Process ID (ID)

Parent Process ID

Processes - UID & GID

- Real UID
  - At process creation, the real UID identifies the user who has created the process
- Real GID
  - At process creation, the real GID identifies the current connect group of the user for which the process was created

Processes - UID & GID

- Effective UID
  - The effective UID is used to determine owner access privileges of a process.
  - Normally the same as the real UID. It is possible for a program to have a special flag set that, when this program is executed, changes the effective UID of the process to the UID of the owner of the program.
  - A program with this special flag set is said to be a set-user-ID program (SUID). This feature provides additional permissions to users while the SUID program is being executed.

Processes - UID & GID

- Effective GID
  - Each process also has an effective group
  - The effective GID is used to determine group access privileges of a process
  - Normally the same as the real GID. A program can have a special flag set that, when this program is executed, changes the effective GID of the process to the GID of the owner of this program
  - A program with this special flag set is said to be a set-group-ID program (SGID). Like the SUID feature, this provides additional permission to users while the set-group-ID program is being executed

Processes - Process Groups

- Each process belongs to a process group
- A *process group* is a collection of one or more processes
- Each process group has a unique process group ID
- It is possible to send a signal to every process in the group just by sending the signal to the process group leader
- Each time the shell creates a process to run an application, the process is placed into a new process group
- When an application spawns new processes, these are members of the same process group as the parent

Processes - PID

- PID
  - A process ID is a unique identifier assigned to a process while it runs
  - Each time you run a process, it has a different PID (it takes a long time for a PID to be reused by the system)
  - You can use the PID to track the status of a process with the `ps` command or the `jobs` command, or to end a process with the `kill` command

Processes - PGID

- PGID
  - Each process in a process group shares a process group ID (PGID), which is the same as the PID of the first process in the process group
  - This ID is used for signaling-related processes
  - If a command starts just one process, its PID and PGID are the same

Processes - PPID

- PPID
  - A process that creates a new process is called a *parent process*; the new process is called a *child process*
  - The parent process (PPID) becomes associated with the new child process when it is created
  - The PPID is not used for job control