Lecture 4

Introduction to Unix Processes

Introduction to Systems Programming: Processes and Signals

Introduction to Systems Programming

Processes

Signals

Introduction to Processes

- Multiuser OS
  - Ability of an OS to have multiple users using the system *at the same time*
- Multitasking OS
  - Ability of an OS to run multiple programs *at the same time*
  - "Pay No Attention To The Man Behind the Screen"
    - Concurrency versus Parallelism
  - timesharing quantums done by the system scheduler (called swapper), which is a kernel thread and has process ID of 0

An Analogy

- Assume a computer scientist is sitting in his office reading a book. His eyes are busily reading each word, his brain is focused on processing all this when there's a knock on the door, and the computer scientist is interrupted by someone who looks like this:

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What is a Process?

- A process is an executable “cradle” in which a program may run
- This “cradle” provides an environment in which the program can run, offering memory resources, terminal IO, via access to kernel services.
- When a new process is created, a copy of the parent process’ environment variables is provided as a default to the new process
- A process is an address space married to a single default thread of control that executes on code within that address space
- ps -yal

Introduction to Processes

- Other kernel threads are created to run the following services (various Unix kernels vary, YMMV):
  - initd (1): parent initializer of all processes
  - keventd (2): kernel event handler
  - kswapd (3): kernel memory manager
  - kreclaimd (4): reclaims pages in vm when unused
  - bdflush (5): cleans memory by flushing dirty buffers from disk cache
  - kupdated (6): maintains sanity of filesystem buffers

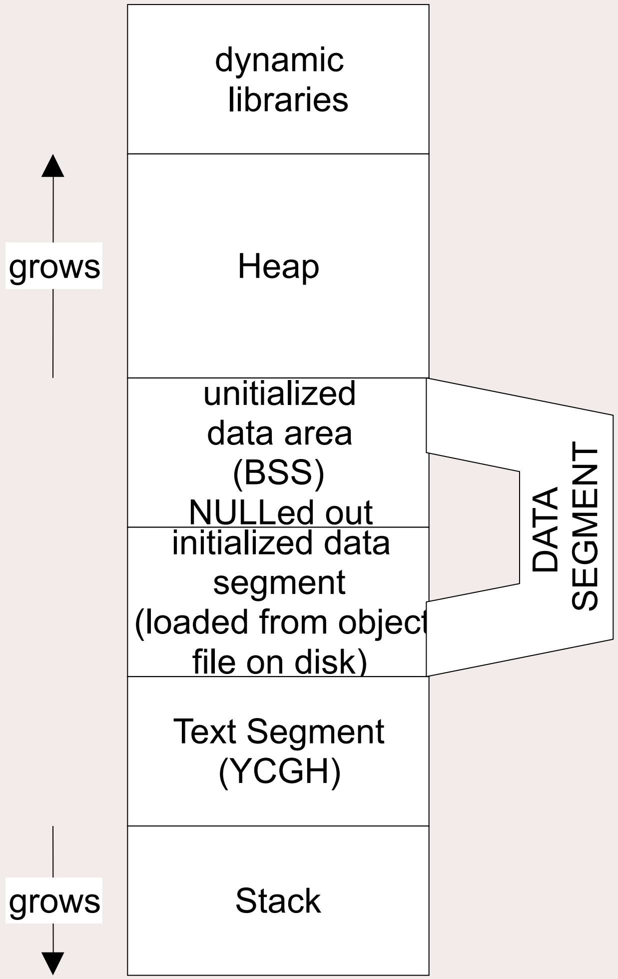
User and Kernel Space

- System memory is divided into two parts:
  - user space
    - a process executing in user space is executing in user mode
    - each user process is protected (isolated) from another (except for shared memory segments and mmapings in IPC)
  - kernel space
    - a process executing in kernel space is executing in kernel mode
- Kernel space is the area wherein the kernel executes
- User space is the area where a user program normally executes, *except when it performs a system call.*

Anatomy of a System Call

- A System Call is an explicit request to the kernel made via a software interrupt
- The standard C Library (libc) provides *wrapper routines*, which basically provide a user space API for all system calls, thus facilitating the context switch from user to kernel mode
- The wrapper routine (in Linux) makes an interrupt call 0x80 (vector 128 in the Interrupt Descriptor Table)
- The wrapper routine makes a call to a system call handler (sometimes called the “call gate), which executes in kernel mode
- The system call handler in turns calls the system call interrupt service routine (ISR), which also executes in kernel mode.

ELF (Executable and Linking Format)



- Heap is for dynamic memory demand (malloc())
- Stack is for function call storage and automatic variables
- BSS (Block Started by Symbol) stores ***uninitialized*** static data

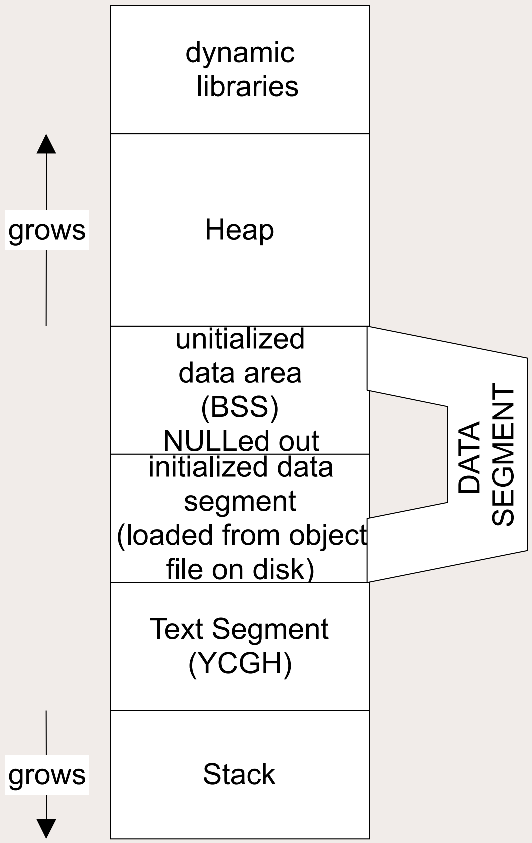
  int array[100];

- Data Segment stores ***initialized*** static data

  char name[] = “bob”;

- Multiple processes can share the same code segment

C Language Allocation




```
char * p = malloc(1024);

int iarray[20];

int iarray2[] = { 1,2,3 };

int main() { ... }

int myfunc(int x, float y) { int z; }
```

The Linux Process Descriptor

- Each Linux process is described by a task_struct structure defined in include/linux/sched.h
- This structure holds information on most aspects of a process in memory, including, among other items:
  - process state
  - next and previous task pointers
  - next and previous *runnable* task pointers
  - Parent, Child, and Sibling pointers
  - tty information
  - current directory information
  - open file descriptors table
  - memory pointers
  - signals received

Task State

- TASK_RUNNING: running or waiting to be executed
- TASK_INTERRUPTIBLE: a sleeping or suspended process, can be awakened by signal
- TASK_STOPPED: process is stopped (as by a debugger or SIGTSTP, Ctrl-Z)
- TASK_ZOMBIE: process is in “walking dead” state waiting for parent process to issue wait() call
- TASK_UNINTERRUPTIBLE: task is performing critical operation and should not be interrupted by a signal (usually used with device drivers)

Signal Processing

"Introduction to Interprocess Communication"

What is a Signal?

- A signal is a software interrupt delivered to a process by the OS because:
  - it did something (oops)
  - the user did something (pressed ^C)
  - another process wants to tell it something (SIGUSR?)
- A signal is asynchronous, it may be raised at any time (almost)
- Some signals are directly related to hardware (illegal instruction, arithmetic exception, such as attempt to divide by 0)
- Others are purely software signals (interrupt, bad system call, segmentation fault)

Common Signals

- SIGHUP (1): sent to a process when its controlling terminal has disconnected
- SIGINT (2): Ctrl-C (or DELETE key)
- SIGQUIT (3): Ctrl-\ (default produces core)
- SIGSEGV (11): Segmentation fault
- SIGILL (4): Illegal instruction (default core)
- SIGUSR[1,2]: User-defined signals (10,12)
- kill –l will list all signals
- SIGFPE (8): Floating Point Exception (divide by 0; integer overflow; floating-point underflow)

Chris Brown’s Top 6 List of Things to Do with a Signal Once You Trap It

1. Ignore a signal
2. Clean up and terminate
3. Handle Dynamic Configuration (SIGHUP)
4. Report status, dump internal tables
5. Toggle debugging on/off
6. Implement a timeout condition

   (cf. Chris Brown, *Unix Distributed Programming*, Prentice Hall, 1994)

Reliable and Unreliable Signal APIs

- Signal model provided by AT&T Version 7 was "not reliable", meaning that signals could get "lost" on the one hand, and programs could not turn signal delivery "off" during critical sections, on the other hand.
- BSD 4.3 and System V Release 3 delivered reliable signals, which solved many of the problems with signals present in Version 7.
- And if that weren't enough, SVR4 introduced POSIX signals.

Signal Disposition

- Ignore the signal (most signals can simply be ignored, except SIGKILL and SIGSTOP)
- Handle the signal disposition via a *signal handler* routine. This allows us to gracefully shutdown a program when the user presses Ctrl-C (SIGINT).
- Block the signal. In this case, the OS queues signals for possible later delivery
- Let the default apply (usually process termination)

Original Signal Handling (Version 7)

- Two includes: <sys/types.h> and <signal.h>
- void (*signal(int sig, void (*handler)(int)))(int)
  - Translation?
- handler can either be:
  - a function (that takes a single int which is the signal)
  - the constant SIG_IGN
  - the constant SIG_DFL
- signal will return SIG_ERR in case of error
- *Examples*: (in ~mark/pub/51081/signals): nosignal.c and ouch.c

Original Signal Handling (Version 7)

- Stopping processing until a signal is received:
  - int pause(void);   // must include <unistd.h>
- Sending signals (2 forms)
  - int kill (pid_t, int sig);
  - int raise(int sig); // notice can't specify which process
- Printing out signal information (#include <siginfo.h>)
  - void psignal(int sig, const char *s);
- *Examples:* ouch.c, sigusr.c, fpe.c

Alarming Signals

- SIGALRM can be used as a kind of “alarm clock” for a process
- By setting a disposition for SIGALRM, a process can set an alarm to go off in x seconds with the call:
  - unsigned int alarm(unsigned int numseconds)
- Alarms can be interrupted by other signals
- *Examples:* mysleep.c, impatient.c

BSD and SysV Handle Unreliability Issue—In Incompatible Ways

- Berkeley Unix 4.2BSD responded with inventing a new signal API, but it also rewrote the original signal() function to be reliable
- Thus, old code that used signal() could now work unchanged with reliable signals, optionally calling the new API (sigvec(), etc.)
- Luckily, few programmers used the new (incompatible) API, most stuck with signal() usage

BSD and SysV Handle Unreliability Issue—In Incompatible Ways

- AT&T SVR3 provided reliable signals through a new API, and kept the older signal() code unreliable (for backward compatibility reasons)
- Introduced a new primary function:
  - void (*sigset(int sig, void (*handler)(int)))(int)
  - Since sigset accepted the same parameters as before:
    - #define signal sigset /* would port older or BSD4.2 code */
- Introduced a new default for disposition: SIG_HOLD (in addition to SIG_DFL, SIG_IGN)

BSD and SysV Handle Unreliability Issue—In Incompatible Ways

- SVR3 added its own set of new functions for reliable signals:
  - int sighold(int sig); /*adds sig to the signal mask disposition */
  - int sigrelse(int sig); /* removes sig from the signal mask disposition, and waits for signal to arrive (suspends)*/
  - int sigignore(int sig); /* sets disposition of sig to SIG_IGN */
  - int sigpause(int sig); /* combination of sigrelse and pause(), but safe */
- *examples (sigset.c)*

Enter POSIX Signals

- Uses the concept of signal sets from 4.2BSD
- A signal set is a bitmask of signals that you want to *block*, i.e., signals that you specifically *don't* want to handle
- Each bit in the bitmask (an array of 2 unsigned longs) corresponds to a given signal (i.e., bit 10 == SIGUSR1)
- All signals not masked (not blocked) will be delivered to your process
- In POSIX signals, a blocked signal is not thrown away, but buffered as *pending*, should it become unmasked by the process at some later time

Central POSIX Functions

- int sigaddset(sigset_t * set, int signo);
  - adds a particular signal to the set
- int sigemptyset(sigset_t * set);
  - Zeros out the bitmask (program wants *all* signals)
- int sigfillset(sigset_t * set);
  - Masks all signals (blocks all signals)
- int sigdelset(sigset_t * set, int signo);
  - unmasks signo from the set (program wants the signal)
- int sigsend(idtype_t idtype, id_t id, int sig);
- int sigsuspend(const sigset_t * set);

POSIX sigaction

int sigaction (int sig, const struct sigaction *iact, struct sigaction *oact);

```
struct sigaction {
        __sighandler_t sa_handler;
        void (*sa_sigaction)(int, siginfo_t *, void *);
        unsigned long sa_flags
        …
        sigset_t sa_mask;  //set of signals to be BLOCKED
};
```

- sa_flags
  - * SA_RESTART flag to automatically restart interrupted system calls
  - * SA_NOCLDSTOP flag to turn off SIGCHLD signaling when children die.
  - * SA_RESETHAND clears the handler (ie. resets the default) when the signal is delivered (recidivist).
  - * SA_NOCLDWAIT flag on SIGCHLD to inhibit zombies.
  - * SA_SIGINFO flag indicates use value in sa_sigaction over sa_handler

POSIX Reentrant Functions

- Reentrant functions are those functions which are safe for reentrance:
  - Scenario: a signal SIGUSR1 is received in the middle of myfunc().
  - The handler for SIGUSR1 is called, which makes a call to myfunc()
  - myfunc() has just been "reentered"
- A function "safe" for reentrance is one that:
  - defines no static data
  - calls only reentrant functions or functions that do not raise signals

POSIX Reentrant-Safe Functions

- alarm, sleep, pause
- fork, execle, execve
- stat, fstat
- open, close, creat, lseek, read, write, fcntl, fstat
- sigaction, sigaddset, sigdelset, sig* etc.
- chdir, shmod, chown, umask, uname