Operating Systems Principles
Processes, Execution and State

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Processes, Execution, and State

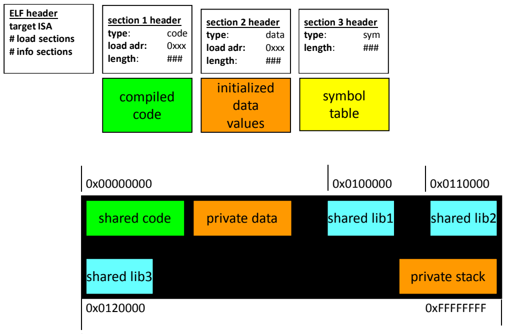
What is a Process?

- an executing instance of a program
  - how is this different from a program?
- a virtual private computer
  - what does a virtual computer look like?
  - how is a process different from a virtual machine?
- a process is an *object*
  - characterized by its properties (state)
  - characterized by its operations

What is “state”?

- the primary dictionary definition of “state” is
  - “a mode or condition of being”
  - an object may have a wide range of possible states
- all persistent objects have “state”
  - distinguishing it from other objects
  - characterizing object's current condition
- contents of state depends on object
  - complex operations often mean complex state
  - we can save/restore the aggregate/total state
  - we can talk of a subset (e.g. scheduling state)

Program vs Process Address Space



Address Space: Code Segments

- load module (output of linkage editor)
  - all external references have been resolved
  - all modules combined into a few segments
  - includes multiple segments (text, data, BSS)
- code must be loaded into memory
  - a virtual code segment must be created
  - code must be read in from the load module
  - map segment into virtual address space
- code segments are read/only and sharable
  - many processes can use the same code segments

Address Space: Data Segments

- data too must be initialized in address space
  - process data segment must be created
  - initial contents must be copied from load module
  - BSS: segments to be initialized to all zeroes
  - map segment into virtual address space
- data segments
  - are read/write, and process private
  - program can grow or shrink it (with sbrk syscall)

Address Space: Stack Segment

- size of stack depends on program activities
  - grows larger as calls nest more deeply
  - amount of local storage allocated by each procedure
  - after calls return, their stack frames can be recycled
- OS manages the process's stack segment
  - stack segment created at same time as data segment
  - some allocate fixed sized stack at program load time
  - some dynamically extend stack as program needs it
- Stack segments are read/write and process private

Address Space: Shared Libraries

- static libraries are added to load module
  - each load module has its own copy of each library
  - program must be re-linked to get new version
- make each library a sharable code segment
  - one in-memory copy, shared by all processes
  - keep the library separate from the load modules
  - operating system loads library along with program
- reduced memory use, faster program loads
- easier and better library upgrades

Other Process State

- registers
  - general registers
  - program counter, processor status
  - stack pointer, frame pointer
- processes own OS resources
  - open files, current working directory, locks
- processes have OS-related state
  - Process ID, User ID, Group ID, scheduling priority
  - registered signal handlers, queued events, …

Process Operations: fork

- parent and child are identical:
  - data and stack segments are copied
  - all the same files are open
- code sample:

```
int rc = fork();
if (rc < 0) {
   fprintf(stderr, “Fork failed\n”);
} else if (rc == 0) {
   fprintf(stderr, “Child\n”);
} else
   fprintf(stderr, “Fork succeeded, child pid = %d\n”, rc);
```

Process Operations: wait

- await termination of a child process
  - collect exit status
- code sample:

```
int rc = waitpid(pid, &status, 0);
if (rc == 0) {
   fprintf(stderr, “process %d exited rc=%d\n”, pid, status);
}
```

Process Operations: exec

- load new program, pass parameters
  - address space is completely recreated
  - all open files remain open
  - available in many polymorphisms
- code sample:

```
char *myargs[3];
myargs[0] = “wc”;
myargs[1] = “myfile”;
myargs[2] = NULL;
int rc = execvp(myargs[0], myargs);
```

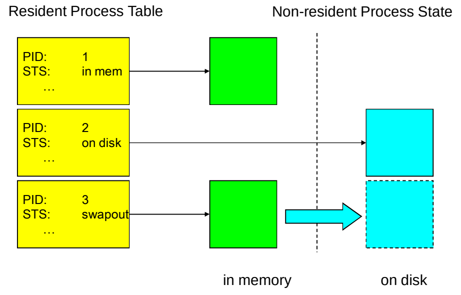
Variations on Process Creation

- tabula rasa – a blank slate
  - a new process with minimal resources
  - it must set up all resources for itself
- run – fork + exec
  - create new process to run a specified command
- a cloning fork is a more expensive operation
  - much data and resources to be copied
  - convenient for setting up pipelines
  - allows inheritance of exclusive use devices

Representing a Process

- all (not just OS) objects have descriptors
  - the identity of the object
  - the current state of the object
  - references to other associated objects
- Process state is in multiple places
  - parameters and object references in a descriptor
  - app execution state is on the stack, in registers
  - each Linux process has a supervisor-mode stack
    - to retain the state of in-progress system calls
    - to save the state of an interrupt preempted process

Resident and non-Resident State



(resident process descriptor)

- state that could be needed at any time
- information needed to schedule process
  - run-state, priority, statistics
  - data needed to signal or awaken process
- identification information
  - process ID, user ID, group ID, parent ID
- communication and synchronization resources
  - semaphores, pending signals, mail-boxes
- pointer to non-resident state

(non-resident process state)

- information needed only when process runs
  - can swap out to free memory for other processes
- execution state
  - supervisor mode stack
  - including: saved register values, PC, PS
- pointers to resources used when running
  - current working directory, open file descriptors
- pointers to text, data and stack segments
  - used to reconstruct the address space

Creating a new process

- allocate/initialize resident process description
- allocate/initialize non-resident description
- duplicate parent resource references (e.g. fds)
- create a virtual address space
  - allocate memory for code, data and stack
  - load/copy program code and data
  - copy/initialize a stack segment
  - set up initial registers (PC, PS, SP)
- return from supervisor mode into new process

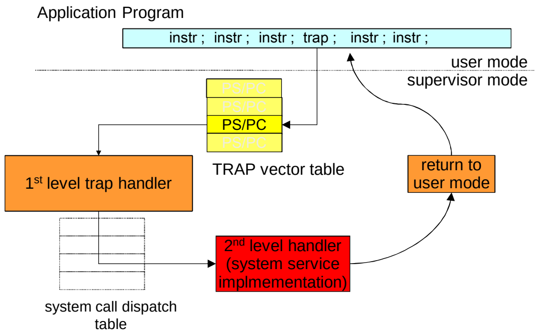
Limited Direct Execution

- CPU directly executes all application code
  - punctuated by occasional traps (for system calls)
  - with occasional timer interrupts (for time sharing)
- Maximizing direct execution is always the goal
  - for Linux user mode processes
  - for OS emulation (e.g. Windows on Linux)
  - for virtual machines
- Enter the OS as seldom as possible
  - get back to the application as quickly as possible

Asynchronous Exceptions

- some errors are routine
  - end of file, arithmetic overflow, conversion error
  - we should check for these after each operation
- some errors occur unpredictably
  - segmentation fault (e.g. dereferencing NULL)
  - user abort (^C), hang-up, power-failure
- these must raise asynchronous exceptions
  - some languages support try/catch operations
  - computers support traps
  - operating systems also use these for system calls

System Call Trap Gates



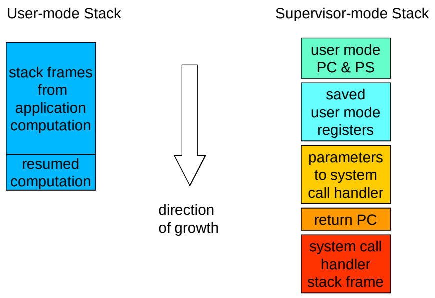
(Trap Handling)

- hardware trap handling
  - trap cause as index into trap vector table for PC/PS
  - load new processor status word, switch to supv mode
  - push PC/PS of program that cuased trap onto stack
  - load PC (w/addr of 1st level handler)
- software trap handling
  - 1st level handler pushes all other registers
  - 1st level handler gathers info, selects 2nd level handler
  - 2nd level handler actually deals with the problem
    - handle the event, kill the process, return …

Using Traps for System Calls

- reserve one illegal instruction for system calls
  - most computers specifically define such instructions
- define system call linkage conventions
  - call: r0 = system call number, r1 points to arguments
  - return: r0 = return code, cc indicates success/failure
- prepare arguments for the desired system call
- execute the designated system call instruction
- OS recognizes & performs requested operation
- returns to instruction after the system call

Stacking and unstacking a System Call



(Returning to User-Mode)

- return is opposite of interrupt/trap entry
  - 2nd level handler returns to 1st level handler
  - 1st level handler restores all registers from stack
  - use privileged return instruction to restore PC/PS
  - resume user-mode execution at next instruction
- saved registers can be changed before return
  - change stacked user r0 to reflect return code
  - change stacked user PS to reflect success/failure

Asynchronous Events

- some things are worth waiting for
  - when I read(), I want to wait for the data
- sometimes waiting doesn't make sense
  - I want to do something else while waiting
  - I have multiple operations outstanding
  - some events demand very prompt attention
- we need event completion call-backs
  - this is a common programming paradigm
  - computers support interrupts (similar to traps)
  - commonly associated with I/O devices and timers

User-Mode Signal Handling

- OS defines numerous types of signals
  - exceptions, operator actions, communication
- processes can control their handling
  - ignore this signal (pretend it never happened)
  - designate a handler for this signal
  - default action (typically kill or coredump process)
- analogous to hardware traps/interrupts
  - but implemented by the operating system
  - delivered to user mode processes

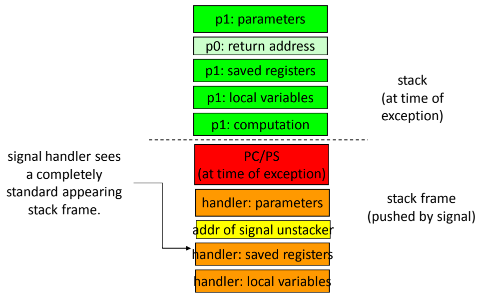
Signals and Signal Handling

- when an asynchronous exception occurs
  - the system invokes a specified exception handler
- invocation looks like a procedure call
  - save state of interrupted computation
  - exception handler can do what ever is necessary
  - handler can return, resume interrupted computation
- more complex than a procedure call and return
  - must also save/restore condition codes & volatile regs
  - may abort rather than return

Signals: sample code

```
int fault_expected, fault_happened;
void handler( int sig) {
        if (!fault_expected) exit(-1); /* if not expected, die */
        else fault_happened = 1;     /* if expected, note it happened */
}
signal(SIGHUP, SIGIGNORE); /* ignore hang-up signals */
signal(SIGSEGV, &handler);  /* handle segmentation faults */
...
fault_happened = 0; fault_expected = 1;
...       /* code that might cause a segmentation fault */
fault_expected = 0;
```

Stacking a signal delivery



assignments

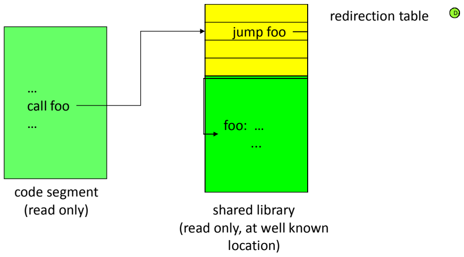
- reading for the next lecture
  - Arpaci ch 7 … CPU Scheduling
  - Arpaci ch 8 … Multi-Level Feedback
  - Arpaci ch 10 … Multi-CPU Scheduling (skim)jjjjkkkk
  - real-time scheduling

Quiz 4 is due <u>before</u> the lecture!

Start project 1 before lab sessionkk

Supplementary Slides

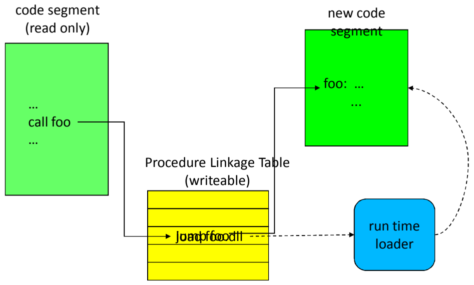
Indirect binding to shared libraries



Limitations of Shared Libraries

- not all modules will work in a shared library
  - they cannot define/include static data storage
- they are read into program memory
  - whether they are actually needed or not
- called routines must be known at compile-time
  - only the fetching of the code is delayed 'til run-time
  - symbols known at compile time, bound at link time
- Dynamically Loadable Libraries are more general
  - they eliminate all of these limitations ... at a price

Loading and Binding w/DLLs



(run-time binding to DLLs)

- load module includes a Procedure Linkage Table
  - addresses for routines in DLL resolve to entries in PLT
  - each PLT entry contains a system call to run-time loader (asking it to load the corresponding routine)
- first time a routine is called, we call run-time loader
  - which finds, loads, and initializes the desired routine
  - changes the PLT entry to be a jump to loaded routine
  - then jumps to the newly loaded routine
- subsequent calls through that PLT entry go directly

Shared Libraries vs. DLLs

- both allow code sharing and run-time binding
- shared libraries
  - do not require a special linkage editor
  - shared objects obtained at program load time
- Dynamically Loadable Libraries
  - require smarter linkage editor, run-time loader
  - modules are not loaded until they are needed
    - automatically when needed, or manually by program
  - complex, per-routine, initialization can be performed
    - e.g. allocation of private data area for persistent local variables

Dynamic Loading

- DLLs are not merely “better” shared libraries
  - libraries are loaded to satisfy static external references
  - DLLs are designed for <u>dynamic binding</u>
- Typical DLL usage scenario
  - identify a needed module (e.g. device driver)
  - call RTL to load the module, get back a descriptor
  - use descriptor to call initialization entry-point
  - initialization function <u>registers</u> all other entry points
  - module is used as needed
  - later we can unregister, free resources, and unload