System Call Programming

Low Level Process Safety

Questions:

- How do we protect processes from breaking each other? What about breaking the OS?
- Should every process be allowed to execute any command?
- How do we decide what processes deserve which permissions?

Processor Modes

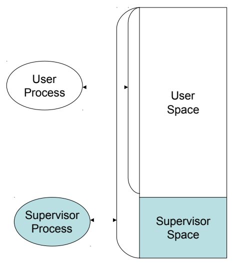
- Mode bit used to distinguish between execution on behalf of OS & behalf of user
- **Supervisor mode**: processor executes every instruction in it's hardware repertoire
- **User mode**: can only use a subset of instructions

Processor Modes

- Instructions can be executed in supervisor mode are supervisor privileges, or protection instruction
  - **I/O instructions** are protected. If an application needs to do I/O, it needs to get the OS to do it on it's behalf
  - Instructions that can change the **protection state** of the system are privileges (e.g. process' authorization status, pointers to resources, etc)

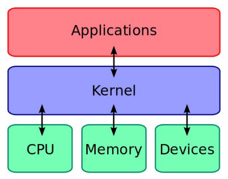
Processor Modes

- Mode bit may define areas of memory to be used when the processor is in supervisor mode vs user mode



What About User Processes?

- The **kernel** executes privileged operations on behalf of untrusted user processes



The Kernel

- Code of the OS **executing** in **supervisor** state
- Trusted software:
  - manages hardware resources (CPU, memory, and I/O)
  - Implements protection mechanisms that could not be changed through actions of untrusted software in user space

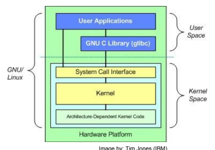
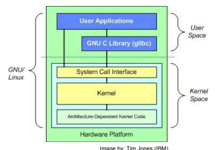


Image by: Tim Jones (IBM)

The Kernel

System call interface is a **safe way** to expose privileged functionality and services of the processor



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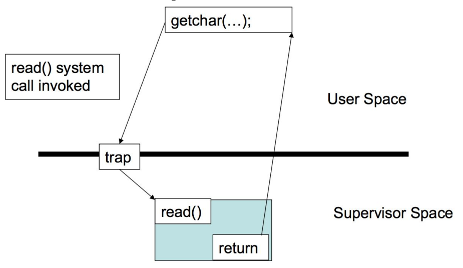
System Calls



Trap: System call causes a switch from user mode to kernel mode

System calls

- A system call involves the following
  - The system call causes a 'trap' that interrupts the execution of the user process (user mode)
  - The kernel takes control of the processor (kernel mode\privilege switch)
  - The kernel executes the system call on behalf of the user process
  - The user process gets back control of the processor (user mode\privilege switch)
- System calls have to be used **with care**.
- Expensive due to **privilege switching**

System calls

- `ssize_t` **`read`**`(int fildes, void *buf, size_t nbyte)`
  - fildes: file descriptor
  - buf: buffer to write to
  - nbyte: number of bytes to read
- `ssize_t` **`write`**`(int fildes,const void *buf,size_t nbyte)`
  - fildes: file descriptor
  - buf: buffer to write to
  - nbyte: number of bytes to write
- `int` **`open`**`(const char *pathname,int flags,mode_t mode)`
- `int` **`close`**`(int fd)`
- File descriptors:
  - 0 stdin
  - 1 stdout
  - 2 stderr
- *Why are these system calls and not just regular library functions?*

More examples: System calls

- `pid_t` **`getpid`**`(void)`
  - returns the process id of the calling process
- `int` **`dup`**`(int fd)`
  - Duplicates a file descriptor fd. Returns a second file descriptor that points to the same file table entry as fd does.
- `int` **`fstat`**`(int filedes, struct stat *buf)`
  - Returns information about the file with the descriptor filedes to buf

More examples: System calls

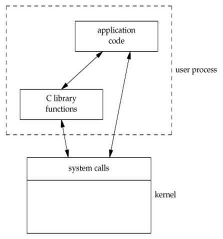
```
struct stat {
dev_t     st_dev;       /* ID of device containing file */
ino_t     st_ino;       /* inode number */
mode_t    st_mode;      /* protection */
nlink_t   st_nlink;     /* number of hard links */
uid_t     st_uid;       /* user ID of owner */
gid_t     st_gid;       /* group ID of owner */
dev_t     st_rdev;      /* device ID (if special file) */
off_t     st_size;      /* total size, in bytes */
blksize_t st_blksize;   /* blocksize for filesystem I/O */
blkcnt_t  st_blocks;    /* number of 512B blocks allocated */

time_t st_atime;  /* time of last access */
time_t st_mtime;  /* time of last modification */
time_t st_ctime;  /* time of last status change */
};
```

Library Functions

- Functions that are a part of standard C library
- To avoid system call overhead use equivalent library functions
  - getchar, putchar vs. read, write (for standard I/O)
  - fopen, fclose vs. open, close (for file I/O), etc.
- How do these functions perform privileged operations?
  - They make system calls

So What's the Point?



- Many library functions invoke system calls indirectly
- So why use library calls?
- Usually equivalent library functions make fewer system calls
- non-frequent switches from user mode to kernel mode => less overhead

Buffering issues

- What is buffering?
- Why do we buffer?
- Can we make our buffer really big?
- What happens if our program exits with a non-empty buffer?

Unbuffered vs. Buffered I/O

- **Unbuffered**
  - Every byte is read/written by the kernel through a system call
- **Buffered**
  - collect as many bytes as possible (in a buffer) and read more than a single byte (into buffer) at a time and use one system call for a block of bytes

Takeaway: Buffered I/O decreases the number of read/write system calls and the corresponding overhead

Unbuffered vs. Buffered I/O examples

- **Buffered** output improves I/O performance and can reduce system calls.
- **Unbuffered** output when you want to ensure that the output has been written before continuing.
  - **stderr** under a C runtime library is *unbuffered* by default. Errors are infrequent, but we want to know about them immediately.
  - **stdout** is *buffered* because it's assumed there will be far more data going through it, and more urgent input can use stderr.
  - **logging**: log messages of a process?

Laboratory

- Write `tr2b` and `tr2u` C programs that transliterate bytes. They take two arguments 'from' and 'to'. The programs will transliterate every byte in 'from' to corresponding byte in 'to'.
  - `./tr2b 'abcd' 'wxyz' < bigfile.txt`
    - Replace 'a' with 'w', 'b' with 'x', etc
  - `./tr2b 'mno' 'pqr' < bigfile.txt`
- `tr2b` uses **getchar** and **putchar** to read from STDIN and write to STDOUT.
- `tr2u` uses **read** and **write** to read and write each byte, instead of using getchar and putchar. The nbyte argument should be 1 so it reads/writes a single byte at a time.
- Test it on a big file with 5000000 bytes

```
$ head --bytes=# /dev/urandom > output.txt
```

`time` and `strace`

- **time [***options***]** *command* **[***arguments...***]**
- Output:
  - real 0m4.866s: elapsed time as read from a wall clock
  - user 0m0.001s: the CPU time used by your process
  - sys 0m0.021s: the CPU time used by the system on behalf of your process
- **strace**: intercepts and prints out system calls to stderr or to an output file
  - $ strace –o strace_output ./tr2b 'AB' 'XY' < input.txt
  - $ strace –o strace_output2 ./tr2u 'AB' 'XY' < input.txt

`Pointers on System Calls`

www.cs.uregina.ca/Links/class-info/330/SystemCall_IO/SystemCall_IO.html

courses.engr.illinois.edu/cs241/sp2009/Lectures/04-syscalls.pdf

www.bottomupcs.com/system_calls.xhtml

Homework 5

- Rewrite `sfrob` using system calls (`sfrobu`)
- `sfrobu` should behave like `sfrob` except:
  - If stdin is a regular file, it should initially allocate enough memory to hold all data in the file all at once
  - Consider outputting the number of comparisons performed
- Necessary system calls: `read`, `write`, and `fstat` (read the man pages)
- Measure differences in performance between `sfrob` and `sfrobu` using the **`time`** command
- Estimate the number of comparisons as a function of the number of input lines provided to `sfrobu`

Homework 5

- Write a shell script "`sfrobs`" that uses `tr` and the `sort` utility to perform the same overall operation as `sfrob`
- Encrypted input
  -> tr (decrypt)
  -> sort (sort decrypted text)
  -> tr (encrypt)
  -> encrypted output