EMBEDDED OPERATING SYSTEMS

Embedded Linux on Beaglebone Black

System calls: What?

- Programmatic way in which
  - A user space program
  - Requests a service/resource
  - From the OS kernel
- Method for program interaction with kernel
  - The only entry points into the kernel
- Services provided by system calls:
  - Process creation and management
  - Main memory management
  - File access, directory and file system management
  - Device handling (I/O)
  - Protection / security
  - Networking

System calls: Features

- Interface
  - Well-define API for programs to access kernel
- Protection
  - Used to access privileged operations
- Kernel mode
  - User mode program temporarily switched to kernel mode
- Context switching
  - Needs context switch (user«»kernel); impacts performance
- Error handling
  - Return defined error codes to indicate problems
- Synchronization
  - Sync access to shared resources like memory, files, resources

System calls: Advantages

- Access to hardware
  - Streamlined access to hardware through kernel
- Memory management
  - Controlled usage of memory and mem-mapped devices
- Process management
  - Allows programs to create/terminate processes, IPC
- Security
  - Allows secure access to privileged operations
- Standardization
  - Documented interface with specific APIs

Linux syscalls: Process

- Process management
  - fork()
    - Create new processes
    - Parent creates child / children
  - exec()
    - To run different program from the current one
    - Image changed in place
  - wait()
    - Parent waits for child(ren) to terminate
    - For monitoring child(ren)
  - exit()
    - Terminate the current process with error code
    - Returns error code to caller

Linux syscalls: File

- File access and operations
  - open()
    - Open / create a file on the file system
  - read()
    - Read data from an existing file on file system
    - Can be used on pipes, sockets and /dev devices
  - write()
    - Send data to a file on file system
  - close()
    - Finalizes the file and saves it on file system

Linux syscalls: Network

- Network access and operations
  - socket()
    - Create a ‘socket’ for networked communication
  - bind()
    - Bind the socket to a port and address on local network
  - listen()
    - Act as a listening server on the socket
  - accept()
    - Accept an incoming request on the socket
  - connect()
    - Connect to the external endpoint
  - send()
    - Send data over the socket
  - recv()
    - Receive data over the socket

Linux syscalls: Device

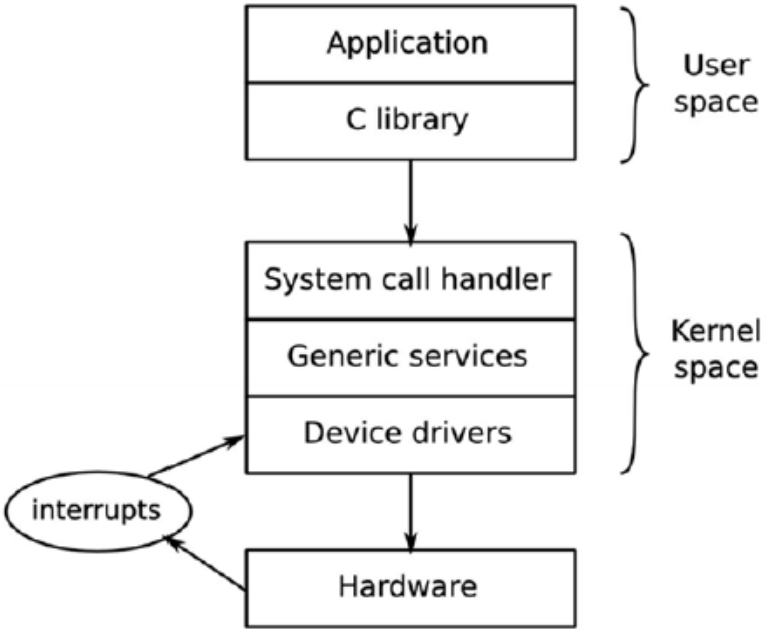
- Device access and operations
  - ioctl()
    - Send control commands to underlying device
  - mmap()
    - Map a partition of a file into the memory of the process
    - Used for operating on small portions of large files

Linux syscalls: System info

- Get information on system resources
  - getpid()
    - Get process ID (PID) of current process
  - getppid()
    - Get PID of process's parent
  - getuid()
    - Get User ID (UID) of current process
  - getgid()
    - Get Group ID (GID) of current process
  - uname()
    - Get system name, version, release info, etc.
  - sysinfo()
    - Get resource info like free memory, total memory, current processes
  - time()
    - Gets current system time (since 01 Jan 1970)

System calls and C library

- C library and system calls
  - Form the bridge between
  - User space and kernel space



Error handling

- Most library functions and system calls
  - Return codes on success / failure
  - Called error codes

- System calls
  - Return -1 to indicate error
  - Place an integer in a global variable ***errno***

- User space programs should
  - Test return status
  - If error occurred, inspect ***errno*** variable

Using errno for error handling

- Global, positive integer (>0) - each value has a specific meaning
  $ sudo apt-get install moreutils
  $ errno –l (gives all errors)

- Header file: ***errno.h*** (also, *man errno*)

- 2 ways to print errno details
  - perror() *[stdio.h, errno.h]*
    - void perror(const char *s);
    - Eg. **perror(str);** ➔ str: No such file or directory
  - strerror() *[string.h]*
    - char *strerror(int errnum);
    - Eg. **strerror(2);** ➔ No such file or directory

File IO: Using C library

- Header
  - #include <stdio.h>
- Default streams
  - **stdout, stdin, stderr**
- Functions
  - File open
    - FILE ***fopen**(const char *pathname, const char *mode);
  - File read
    - char ***fgets**(char *s, int size, FILE *stream);
    - size_t **fread**(void *ptr, size_t size, size_t nmemb, FILE *stream);
  - File write
    - int **fprintf**(FILE *stream, const char *format, ...);
    - size_t **fwrite**(const void *ptr, size_t size, size_t nmemb, FILE *stream);
  - File close
    - int **fclose**(FILE *stream);

File IO: Using system calls

- Headers
  - #include <sys/types.h> // system types
  - #include <sys/stat.h> // open
  - #include <unistd.h> // read, write
  - #include <fcntl.h> // fd manipulation

- Functions
  - File open
    - int **open**(const char *pathname, int flags, mode_t mode);
  - File read
    - ssize_t **read**(int fd, void *buf, size_t count);
  - File write
    - ssize_t **write**(int fd, const void *buf, size_t count);
  - File close
    - int **close**(int fd);

Syscall: open()

- int **open**(const char *pathname, int flags, mode_t mode);
  - Flags
    - Access modes:
      - O_RDONLY / O_WRONLY / O_RDWR
    - Creation flags:
      - O_CREAT, O_EXCL, O_TRUNC
    - Status flags:
      - O_APPEND, O_SYNC, O_NONBLOCK
  - Modes *(denote permissions)*
    - User: S_IRUSR, S_IWUSR, S_IXUSR, S_IRWXU
    - Group: S_IRGRP, S_IWGRP, S_IXGRP, S_IRWXG
    - Others: S_IROTH, S_IWOTH, S_IXOTH, S_IRWXO
  - Returns
    - Non-negative number as the fd
    - -1 on failure
- Example:
  - int **fd** = **read**("a.bin", O_RDWR | O_CREAT | O_EXCL | O_TRUNC | O_NONBLOCK | S_IRWXU); // *rwx------*

Syscall: read()

- ssize_t **read**(int fd, void *buf, size_t count);
  - Arguments:
    - fd: file descriptor from *open()*
    - buf: buffer to read into (no null termination!)
    - count: number of bytes to read
  - Returns:
    - >0: number of bytes read (could be < count!)
    - 0: end of file
    - -1: error; check ***errno***

Syscall: write()

- ssize_t write(int fd, const void *buf, size_t count);
  - Arguments:
    - fd: file descriptor from *open()*
    - buf: buffer to write from
    - count: number of bytes to write
  - Returns:
    - Number of bytes written (could be < count!)
    - -1: error, check ***errno***

Syscall: close()

- int **close**(int fd);
  - Argument:
    - fd: file descriptor from *open()*
  - Returns:
    - 0: success
    - -1: error, check ***errno***

Syscalls vs C library

- Run the Makefile in bb-codes/syscalls
- Run ./perror-strerror.out
  - Illustrates all defined error codes in Linux
- Run ./io-clib.out
  - Illustrates use of C library functions for file I/O
- Run ./compare.sh
  - Timings for a large file copy
    - Using syscalls as well as C library functions
    - Are compared

THANK YOU!