

# EMBEDDED OPERATING SYSTEMS

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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-defined 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

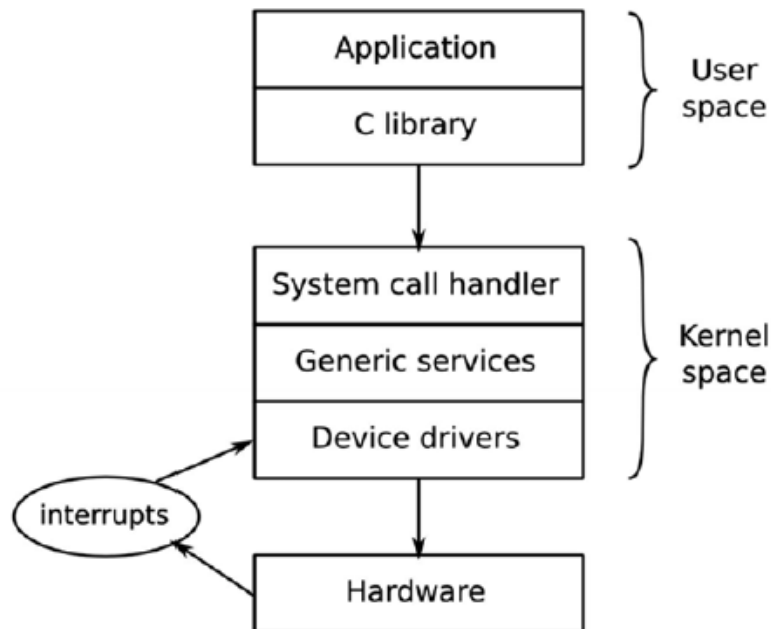


# Linux syscalls: System info

- 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!

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