System Calls

- Programming interface to the services provided by the OS
- Typically written in a high-level language (C or C++)
- Mostly accessed by programs via a high-level **Application Programming Interface (API)** rather than direct system call use
- Three most common APIs are Win32 API for Windows, POSIX API for POSIX-based systems (including virtually all versions of UNIX, Linux, and Mac OS X), and Java API for the Java virtual machine (JVM)

Note that the system-call names used throughout this text are generic
Example of Standard API

As an example of a standard API, consider the read() function that is available in UNIX and Linux systems. The API for this function is obtained from the man page by invoking the command

```
man read
```
on the command line. A description of this API appears below:

```
#include <unistd.h>

ssize_t read(int fd, void *buf, size_t count)
```

The parameters passed to read() are as follows:

- **int fd** — the file descriptor to be read
- **void *buf** — a buffer where the data will be read into
- **size_t count** — the maximum number of bytes to be read into the buffer

On a successful read, the number of bytes read is returned. A return value of 0 indicates end of file. If an error occurs, read() returns −1.
System Call Implementation

- Typically, a number associated with each system call
  - **System-call interface** maintains a table indexed according to these numbers
- The system call interface invokes the intended system call in OS kernel and returns status of the system call and any return values
- The caller need know nothing about how the system call is implemented
  - Just needs to obey API and understand what OS will do as a result call
  - Most details of OS interface hidden from programmer by API
    - Managed by run-time support library (set of functions built into libraries included with compiler)
API – System Call – OS Relationship

user application

open()

user mode

system call interface

kernel mode

Implementation of open() system call

return
System Call Parameter Passing

- Often, more information is required than simply identity of desired system call
  - Exact type and amount of information vary according to OS and call
- Three general methods used to pass parameters to the OS
  - Simplest: pass the parameters in registers
    - In some cases, may be more parameters than registers
  - Parameters stored in a block, or table, in memory, and address of block passed as a parameter in a register
    - This approach taken by Linux and Solaris
  - Parameters placed, or **pushed**, onto the **stack** by the program and **popped** off the stack by the operating system
  - Block and stack methods do not limit the number or length of parameters being passed
Parameter Passing via Table

- User program loads address x
- Uses system call 13
- Parameters x are loaded into the register
- Parameters are used from table x
- Code for system call 13
# Examples of Windows and Unix System Calls

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</tbody>
</table>
Example: MS-DOS

- Single-tasking
- Shell invoked when system booted
- Simple method to run program
  - No process created
- Single memory space
- Loads program into memory, overwriting all but the kernel
- Program exit -> shell reloaded

At system startup          running a program
Example: FreeBSD

- Unix variant
- Multitasking
- User login -> invoke user’s choice of shell
- Shell executes fork() system call to create process
  - Executes exec() to load program into process
  - Shell waits for process to terminate or continues with user commands
- Process exits with:
  - code = 0 – no error
  - code > 0 – error code
Operating System Structure

- General-purpose OS is very large program
- Various ways to structure ones
  - Simple structure – MS-DOS
  - More complex -- UNIX
  - Layered – an abstraction
  - Microkernel -Mach
Simple Structure  -- MS-DOS

- MS-DOS – written to provide the most functionality in the least space
  - Not divided into modules
  - Although MS-DOS has some structure, its interfaces and levels of functionality are not well separated
Non Simple Structure -- UNIX

UNIX – limited by hardware functionality, the original UNIX operating system had limited structuring. The UNIX OS consists of two separable parts:

- Systems programs
- The kernel
  - Consists of everything below the system-call interface and above the physical hardware
  - Provides the file system, CPU scheduling, memory management, and other operating-system functions; a large number of functions for one level
### Traditional UNIX System Structure

Beyond simple but not fully layered

<table>
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<th>(the users)</th>
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#### System-call interface to the kernel

- signals terminal handling
- character I/O system
- terminal drivers
- file system
- swapping block I/O system
- disk and tape drivers
- CPU scheduling
- page replacement
- demand paging
- virtual memory

#### Kernel interface to the hardware

- terminal controllers
- terminals
- device controllers
- disks and tapes
- memory controllers
- physical memory
Layered Approach

- The operating system is divided into a number of layers (levels), each built on top of lower layers. The bottom layer (layer 0), is the hardware; the highest (layer N) is the user interface.

- With modularity, layers are selected such that each uses functions (operations) and services of only lower-level layers.
Microkernel System Structure

- Moves as much from the kernel into user space
- **Mach** example of microkernel
  - Mac OS X kernel (**Darwin**) partly based on Mach
- Communication takes place between user modules using **message passing**

**Benefits:**
- Easier to extend a microkernel
- Easier to port the operating system to new architectures
- More reliable (less code is running in kernel mode)
- More secure

**Detriments:**
- Performance overhead of user space to kernel space communication
Microkernel System Structure

- Application Program
- File System
- Device Driver

- Interprocess Communication
- memory management
- CPU scheduling

- microkernel

- hardware

- User mode
- Kernel mode
Modules

- Many modern operating systems implement **loadable kernel modules**
  - Uses object-oriented approach
  - Each core component is separate
  - Each talks to the others over known interfaces
  - Each is loadable as needed within the kernel
- Overall, similar to layers but with more flexible
  - Linux, Solaris, etc
Solaris Modular Approach

- core Solaris kernel
- device and bus drivers
- scheduling classes
- file systems
- loadable system calls
- executable formats
- STREMS modules
- miscellaneous modules
Hybrid Systems

- Most modern operating systems are actually not one pure model
  - Hybrid combines multiple approaches to address performance, security, usability needs
  - Linux and Solaris kernels in kernel address space, so monolithic, plus modular for dynamic loading of functionality
  - Windows mostly monolithic, plus microkernel for different subsystem *personalities*
- Apple Mac OS X hybrid, layered, *Aqua* UI plus *Cocoa* programming environment
  - Below is kernel consisting of Mach microkernel and BSD Unix parts, plus I/O kit and dynamically loadable modules (called *kernel extensions*)
Mac OS X Structure

- Graphical user interface: Aqua
- Application environments and services:
  - Java
  - Cocoa
  - Quicktime
  - BSD
- Kernel environment:
  - Mach
  - BSD
- I/O kit
- Kernel extensions
iOS

- Apple mobile OS for *iPhone, iPad*
  - Structured on Mac OS X, added functionality
  - Does not run OS X applications natively
    - Also runs on different CPU architecture (ARM vs. Intel)
  - **Cocoa Touch** Objective-C API for developing apps
  - **Media services** layer for graphics, audio, video
  - **Core services** provides cloud computing, databases
  - Core operating system, based on Mac OS X kernel

Cocoa Touch
Media Services
Core Services
Core OS
Android

- Developed by Open Handset Alliance (mostly Google)
  - Open Source
- Similar stack to IOS
- Based on Linux kernel but modified
  - Provides process, memory, device-driver management
  - Adds power management
- Runtime environment includes core set of libraries and Dalvik virtual machine
  - Apps developed in Java plus Android API
    - Java class files compiled to Java bytecode then translated to executable than runs in Dalvik VM
- Libraries include frameworks for web browser (webkit), database (SQLite), multimedia, smaller libc
Android Architecture

Application Framework

Libraries
- SQLite
- openGL
- surface manager
- media framework
- webkit
- libc

Android runtime
- Core Libraries
- Dalvik virtual machine
System Boot

- When power initialized on system, execution starts at a fixed memory location
  - Firmware ROM used to hold initial boot code
- Operating system must be made available to hardware so hardware can start it
  - Small piece of code – **bootstrap loader**, stored in ROM or EEPROM locates the kernel, loads it into memory, and starts it
  - Sometimes two-step process where **boot block** at fixed location loaded by ROM code, which loads bootstrap loader from disk
- Common bootstrap loader, **GRUB**, allows selection of kernel from multiple disks, versions, kernel options
- Kernel loads and system is then **running**