Operating System Interfaces

ICS332

Operating Systems

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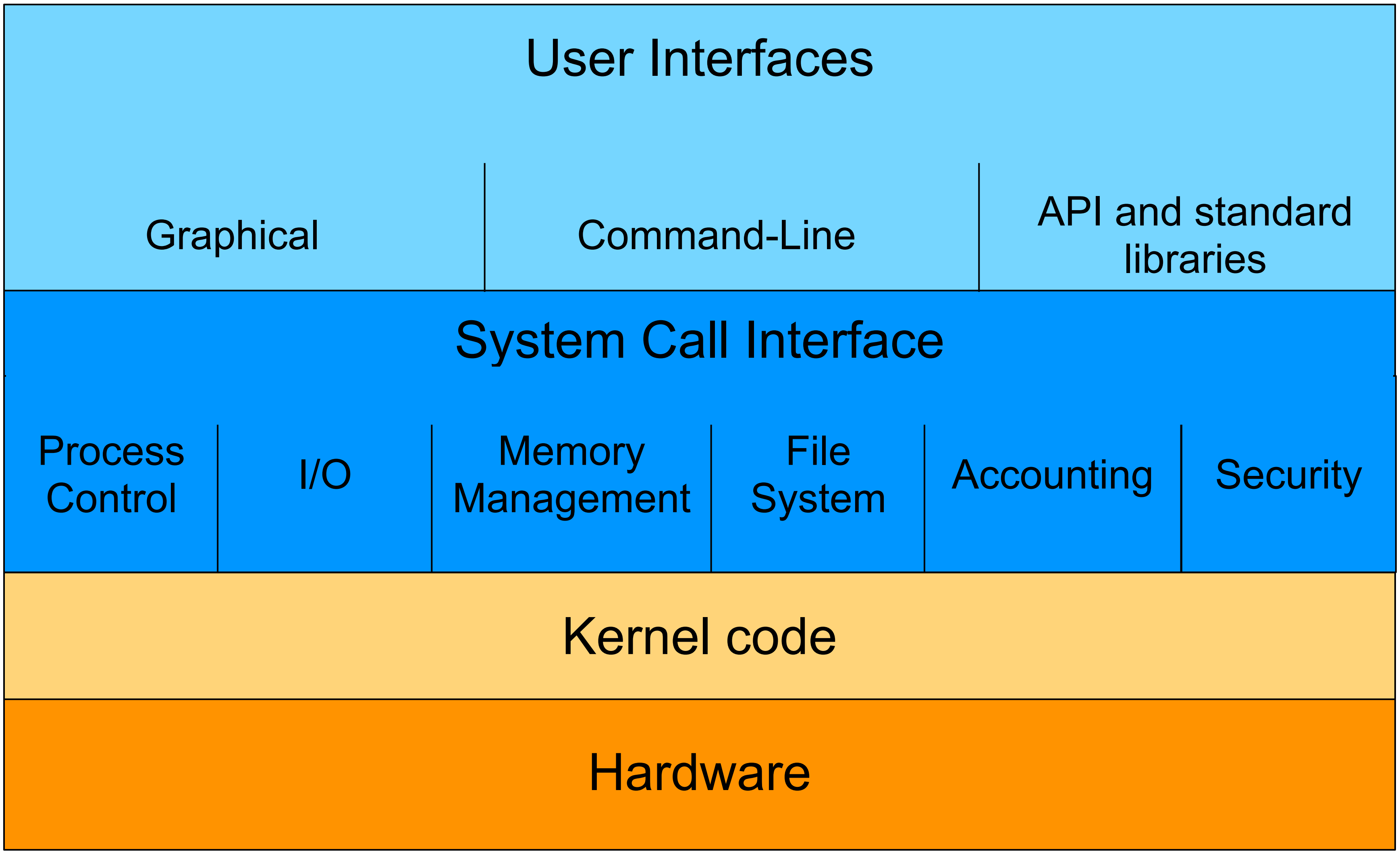
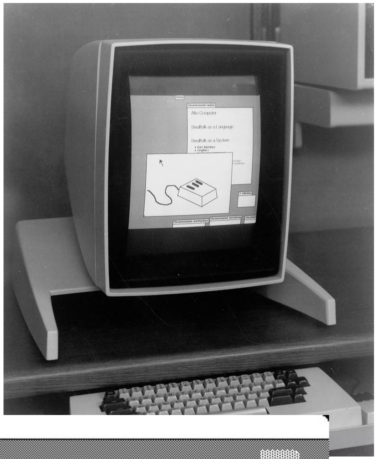
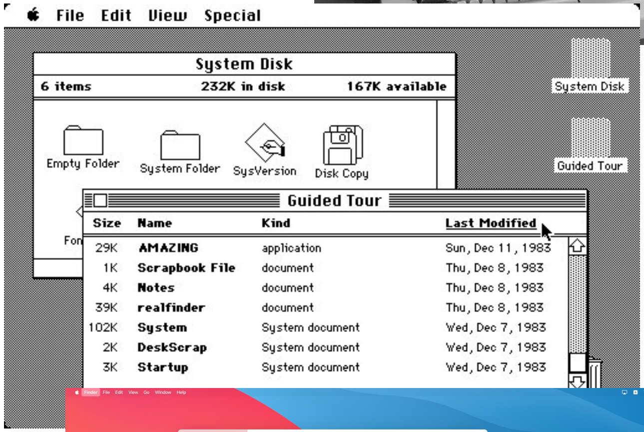
OS Interfaces

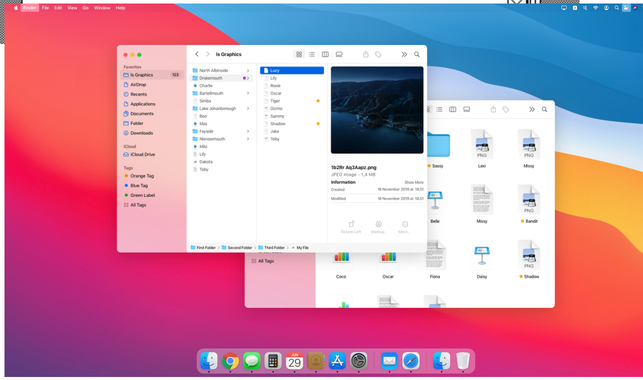


Graphical User Interfaces

- Early 1970s (Xerox PARC research)
- Popularized by Apple's Macintosh (1980s)
- Many UNIX users still use the command-line heavily, while Windows users usually prefer the GUI
- Mac OS < 10: no CLI, but Mac OS ≥ 10 does: Terminal
- Question: Is the GUI part of the OS or not?
  - Windows: YES
  - MacOS: YES
  - Linux: NO







Command-Line Interfaces (CLI)

- Also known as the Shell
- Provides many built-in commands
  - On my Mac: **`man builtin`** (**`cd, echo, pwd, which`**, …)
- It is often used to invoke low-level system programs
  - On UNIX-like systems, often brief one-word executables (**`ls, ps, sed, grep,`** …)
  - Not part of the OS, but often installed with it
- It is often used to invoke user programs
- The distinction between system and user programs is vague at best and really not useful because it's a matter of perspective
  - What about ls? If you're a kernel developer, then it's a high-level application. If you're a novice Linux user, then you probably think of it as some "OS thing"…

The System Call (Syscall) API

- System calls, or syscalls, provide the lowest-level interface to the OS
- GUIs and CLIs (and in fact all programs!) are built on top of the System Call API
- Often programs will use some library, that uses some library, that uses some “standard” library, and then uses the system call API
  - It all boils down to system calls (unless your program does nothing but compute)
- You can think of your running program as doing one of two things:
  - Either fetch-decode-execute instructions that you wrote or that are in the libraries that you use
  - Or fetch-decode-execute instructions that are in the kernel because your program placed a system call
- We will use the system call API (or low-level standard libraries that use it) in programming assignments
- But turns out you can spy on system call usage…

Spying on System Calls

- There are tools to "spy on processes" and see the system calls they place as they happen!
  - strace in Linux
  - dtruss in macOS
  - ProcMon in Windows
- Why is this useful?
  - Find bugs, find performance bugs, detect malware, reverse-engineer code, and learning :)
- Let's look at strace in Linux…

strace Example Uses

-i option: shows the value of the Program Counter

```
strace -i sleep 1
```

-x option: shows non-ASCII characters in hex

```
strace -x touch /tmp/foo
```

-c option: obtain cumulative statistics

```
mkdir tmp; cd tmp
for a in `seq 0 9`; do
  for b in `seq 0 9`; do
    touch $a$b;
  done
done
strace -c rm *
```

-p option: attach to a running process (may require sudo)

```
strace -p <pid of process>  # let's spy on sshd!
```

System calls

- There are many system calls in a typical OS (~300-400 in Linux)
- Each system call is identified by a unique number, stored in an internal table called the syscall table
- Let's look at the ChromiumOS syscall table
  - Linux kernel, open-source version of ChromeOS, developed by Google (support stopped in 2022…ChromeBooks weren't a commercial success)
  - The system call numbers are in some standard header file (.h)
- There are system calls for everything that you'd expect (to manage processes, memory, files, devices, communication, permissions, etc.)
- System calls make it possible to access hardware resources virtualized by the OS

Timing Programs and System Calls

- The UNIX `time` command can be used to see what time a program spends running user code and what time it spends running kernel code (i.e., system calls)
  - Does not have a great resolution, so results can be weird when timing lightning quick programs
- It reports:
  - Real time: The time you experience (also called wall-clock time, elapsed time, execution time, run time…)
  - User time: The time spent executing user code
  - System time: The time spent executing kernel code

Measuring System Time

- Lets use the time command for
  - Archiving/Compressing some directory
  - Running du on a large and deep directory
  - Running jekyll

Measuring System Time

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  - Archiving/Compressing some directory
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- We observe: real time ≠ user time + system time
- What’s the missing time?

Measuring System Time

- Lets use the time commend for
  - Archiving/Compressing some directory
  - Running du on a large and deep directory
  - Running jekyll
- We observe: real time ≠ user time + system time
- What's the missing time? **I/O!**

- I/O time could be waiting for the disk, network, keyboard, etc.
- real time = user time + system time + i/o time

System Calls are Expensive

- The OS tries to be fast
  - Kernel developers are good at writing lean/mean code
- But system calls can be expensive
  - Especially when they involve some hardware overhead (i.e., waiting for the disk)
- As a programmer you should use system calls wisely (if you care about speed at all)
- This can fly in the face of what you learn in the CS curriculum
- Well-known example
  - ICS111/211: Data structures are great, so use them
  - BUT, your code may end up calling malloc/free all the time!
  - So then you want to use arrays
  - But then everything's ugly/cumbersome because an array is such a restrictive data structure
- The life of the developer is about making difficult compromises

The System Call API

- System calls can be complicated to place
- Therefore, there is a system call interface, i.e., a set of useful functions ,often provided in standard libraries, that are “easier-to-use wrappers” around the raw system calls e.g., the fork() “system call” is a simple interface to the clone() system call
  - e.g., When in C you open a file with `fopen()`, and `fopen()` calls the more complicated `open()` system call on your behalf
- Often one says “I am placing a system call” even when calling a higher-level library function
- If the API is standard then the code can be portable!
  - Windows: Windows 16, Windows 32, Windows 64 API
  - UNIX: POSIX (Portable Operating Systems Interface IEEE-IX)
  - Java API: The JVM has OS-like functionalities on top of the OS

Standard APIs: Writing a file

- System Call in C (`man 2 write`)
  - Really a low-level library that directly invokes the system call for you, since one doesn't simply call a system call from user code, as we'll see
  - `ssize_t write(int fildes, const void *ptr, size_t nbyte);`
- Higher level library in C (`man fwrite`)
  - `size_t fwrite(const void *ptr, size_t size, size_t nitems, FILE *stream);`
- Java: OutputStream::write (see JavaDoc)
  - `public void write(byte[] b) throws IOException;`
  - Most details are hidden thanks to OO approach

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Returns a possibly negative number (-1 means "failure")

Returns a >=0 number (< size means failure)

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Takes in a number of bytes

Takes in a number of elements and an element size

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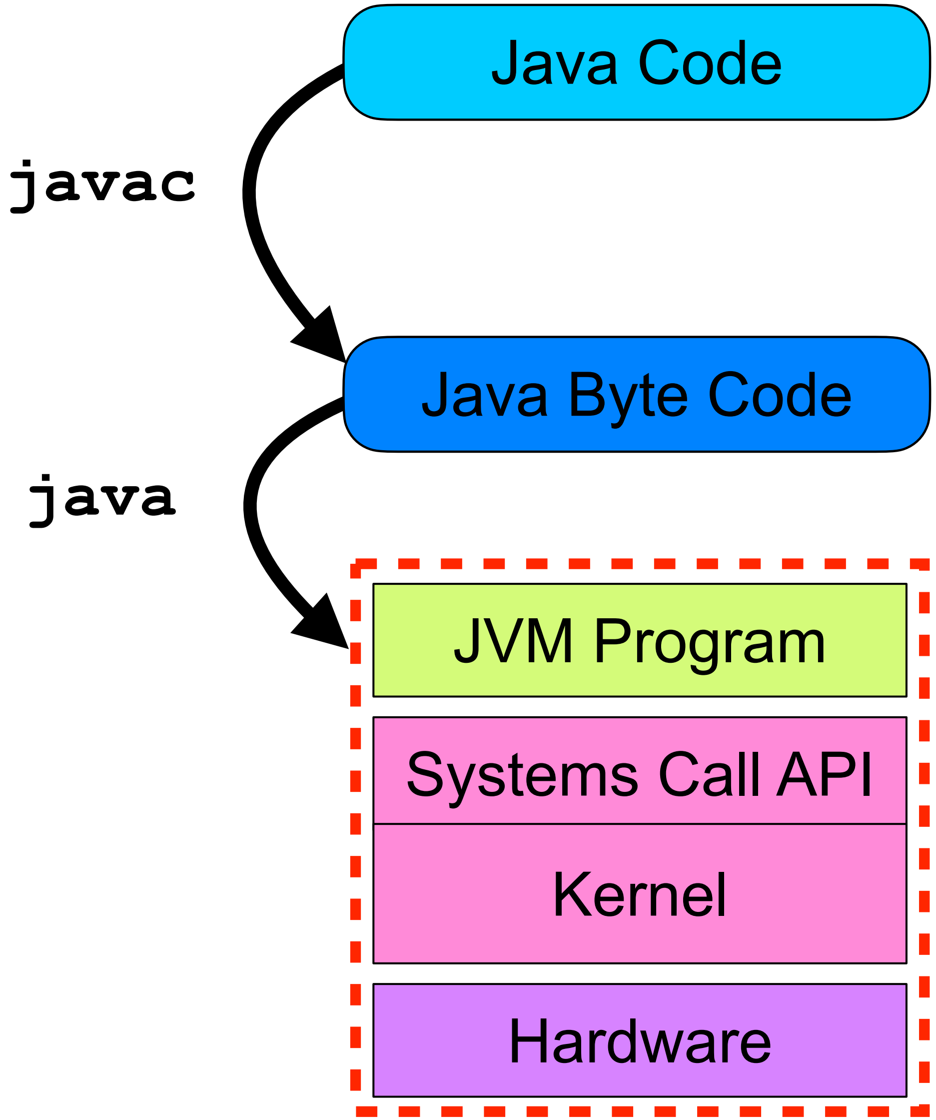
Takes in a file descriptor number

Takes in a higher-level FILE "object"

A Word on the JVM



- The JVM is just a program
- It interacts with the OS using the System Call API, like any other program
- It knows how to interpret byte code that places calls to the Java API
- To implement some of these Java API calls, the JVM places System Calls

Conclusion

- OSes come with interactive interfaces
  - Shells, GUIs
- All are based on the System Call API
  - All (useful) programs use this API
  - Directly or indirectly via standard library calls
- On Linux, the strace tool makes it possible to spy on how a program uses the System Call API
- On UNIX-ish systems, the time tool makes it possible to measure time spent in system calls