CSC 4320/6320: Operating Systems

Chapter 02: Operating System Structures

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Announcement

HW1 will be posted TODAY

Deadline: Jan 31, 2025, 11:59 PM

Outline

- Operating System Services
- User and Operating System-Interface
- System Calls
- System Services
- Linkers and Loaders
- Why Applications are Operating System Specific
- Operating System Structure

Operating System Services

- Operating systems provide an environment for execution of programs and services to programs and users
- One set of operating-system services provides functions that are helpful to the user:
  - **User interface** - Almost all operating systems have a user interface (**UI**).
    - Varies between **Command-Line** (**CLI**), **Graphics User Interface** (**GUI**), **touch-screen**, **Batch**
  - **Program execution** - The system must be able to load a program into memory and to run that program, end execution, either normally or abnormally (indicating error)
  - **I/O operations** - A running program may require I/O, which may involve a file or an I/O device
  - **File-system manipulation** - The file system is of particular interest. Programs need to read and write files and directories, create and delete them, search them, list file Information, permission management.

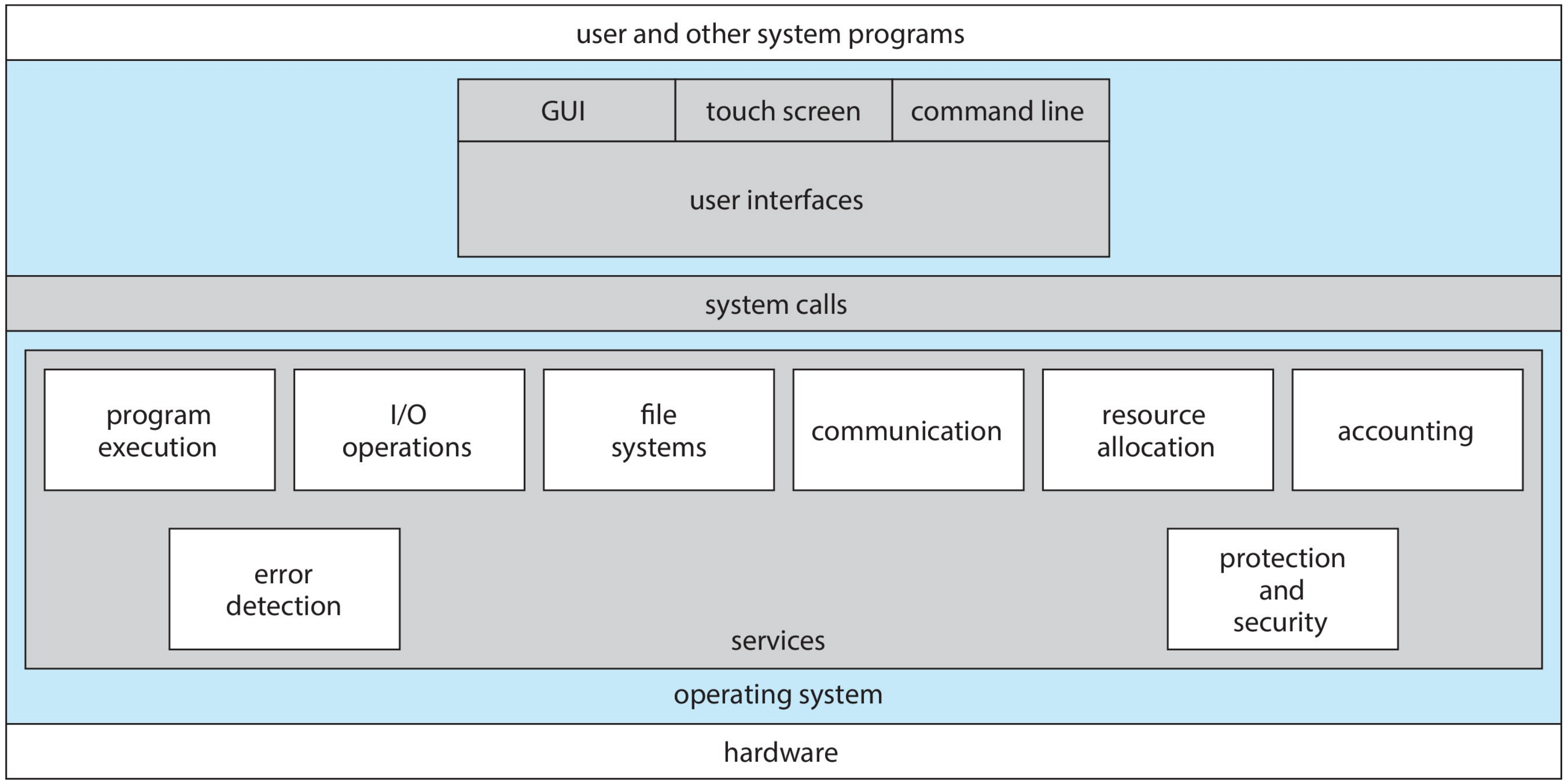
Operating System Services (Cont.)

- One set of operating-system services provides functions that are helpful to the user (Cont.):
  - **Communications** – Processes may exchange information, on the same computer or between computers over a network
    - Communications may be via shared memory or through message passing (packets moved by the OS)
  - **Error detection** – OS needs to be constantly aware of possible errors
    - May occur in the CPU and memory hardware, in I/O devices, in user program
    - For each type of error, OS should take the appropriate action to ensure correct and consistent computing
    - Debugging facilities can greatly enhance the user's and programmer's abilities to efficiently use the system

Operating System Services (Cont.)

- Another set of OS functions exists for ensuring the efficient operation of the system itself via resource sharing
  - **Resource allocation -** When multiple users or multiple jobs running concurrently, resources must be allocated to each of them
    - Many types of resources -   CPU cycles, main memory, file storage, I/O devices.
  - **Logging -** To keep track of which users use how much and what kinds of computer resources
  - **Protection and security -** The owners of information stored in a multiuser or networked computer system may want to control use of that information, concurrent processes should not interfere with each other
    - **Protection** involves ensuring that all access to system resources is controlled
    - **Security** of the system from outsiders requires user authentication, extends to defending external I/O devices from invalid access attempts

A View of Operating System Services



Questions to ponder

1. System call interface is the boundary between user programs and operating system services.

   Yes. ✓

   No

2. Graphical User Interface (GUI) is the most common user interface.

   Yes ✓

   No

3. Touch screen is a user interface on mobile systems.

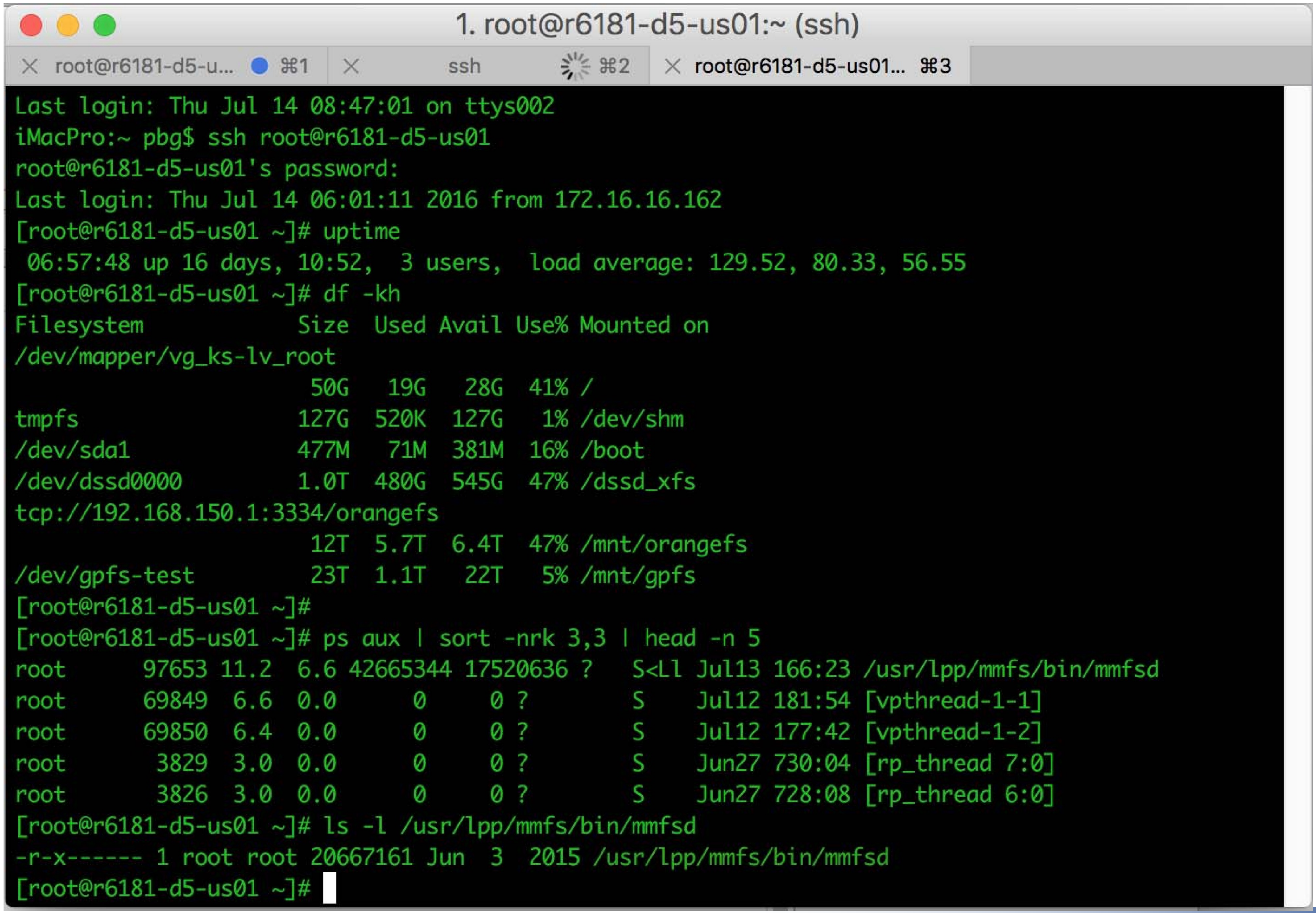
   Yes ✓

   No

Command Line interpreter

- CLI allows direct command entry
- Sometimes implemented in kernel, sometimes by systems program (as a separate utility)
  - i.e., CLI can be closely tight with OS kernel or can be a separate utility
- Sometimes multiple flavors implemented
  - Multiple **shells** exist **(C shell, Bourne-Again shell, Korn shell, and others)** and user can choose from.
- Primarily fetches a command from user and executes it
- Sometimes commands built-in (part of shell), sometimes just names of programs
  - If the latter, adding new features doesn't require shell modification
  - Commands are maintained as system programs

Bourne-Again Shell CLI



```
Last login: Thu Jul 14 08:47:01 on ttys002
iMacPro:~ pbg$ ssh root@r6181-d5-us01
root@r6181-d5-us01's password:
Last login: Thu Jul 14 06:01:11 2016 from 172.16.16.162
[root@r6181-d5-us01 ~]# uptime
 06:57:48 up 16 days, 10:52,  3 users,  load average: 129.52, 80.33, 56.55
[root@r6181-d5-us01 ~]# df -kh
Filesystem            Size  Used Avail Use% Mounted on
/dev/mapper/vg_ks-lv_root
                       50G   19G   28G  41% /
tmpfs                 127G  520K  127G   1% /dev/shm
/dev/sda1             477M   71M  381M  16% /boot
/dev/dssd0000         1.0T  480G  545G  47% /dssd_xfs
tcp://192.168.150.1:3334/orangefs
                       12T  5.7T  6.4T  47% /mnt/orangefs
/dev/gpfs-test         23T  1.1T   22T   5% /mnt/gpfs
[root@r6181-d5-us01 ~]#
[root@r6181-d5-us01 ~]# ps aux | sort -nrk 3,3 | head -n 5
root      97653 11.2  6.6 42665344 17520636 ?   S<Ll Jul13 166:23 /usr/lpp/mmfs/bin/mmfsd
root      69849  6.6  0.0      0     0 ?        S    Jul12 181:54 [vpthread-1-1]
root      69850  6.4  0.0      0     0 ?        S    Jul12 177:42 [vpthread-1-2]
root       3829  3.0  0.0      0     0 ?        S    Jun27 730:04 [rp_thread 7:0]
root       3826  3.0  0.0      0     0 ?        S    Jun27 728:08 [rp_thread 6:0]
[root@r6181-d5-us01 ~]# ls -l /usr/lpp/mmfs/bin/mmfsd
-r-x------ 1 root root 20667161 Jun  3  2015 /usr/lpp/mmfs/bin/mmfsd
[root@r6181-d5-us01 ~]#
```

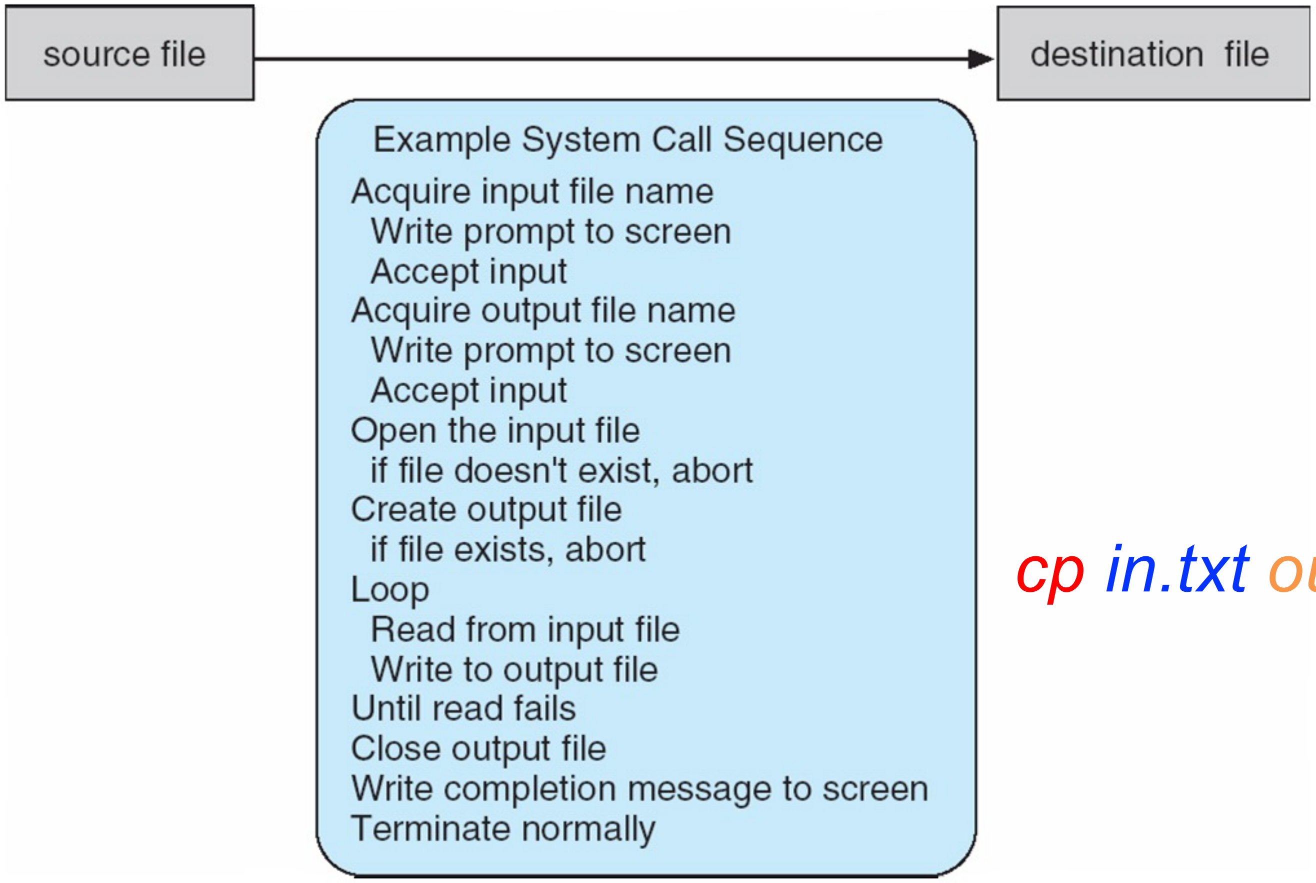
System Calls

- Provide programming interface to the services provided by the OS
- Typically functions written in a high-level language (C/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. Each operating system has its own name for each system call.

Example of System Calls

- System call sequence to copy the contents of one file to another file



```
Acquire input file name
  Write prompt to screen
  Accept input
Acquire output file name
  Write prompt to screen
  Accept input
Open the input file
  if file doesn't exist, abort
Create output file
  if file exists, abort
Loop
  Read from input file
  Write to output file
Until read fails
Close output file
Write completion message to screen
Terminate normally
```

cp in.txt out.txt

How to access system calls?

- A programmer accesses an API via a library of code provided by the operating system.
  – In the case of UNIX and Linux for programs written in the C language, the library is called libc.
- functions that make up an API typically invoke the actual system calls on behalf of the application programmer.
  – For example, the Windows function CreateProcess() actually invokes the NTCreateProcess() system call in the Windows kernel.

Question

There is only a single flavor of shells for users to choose.

True

[✓ False]

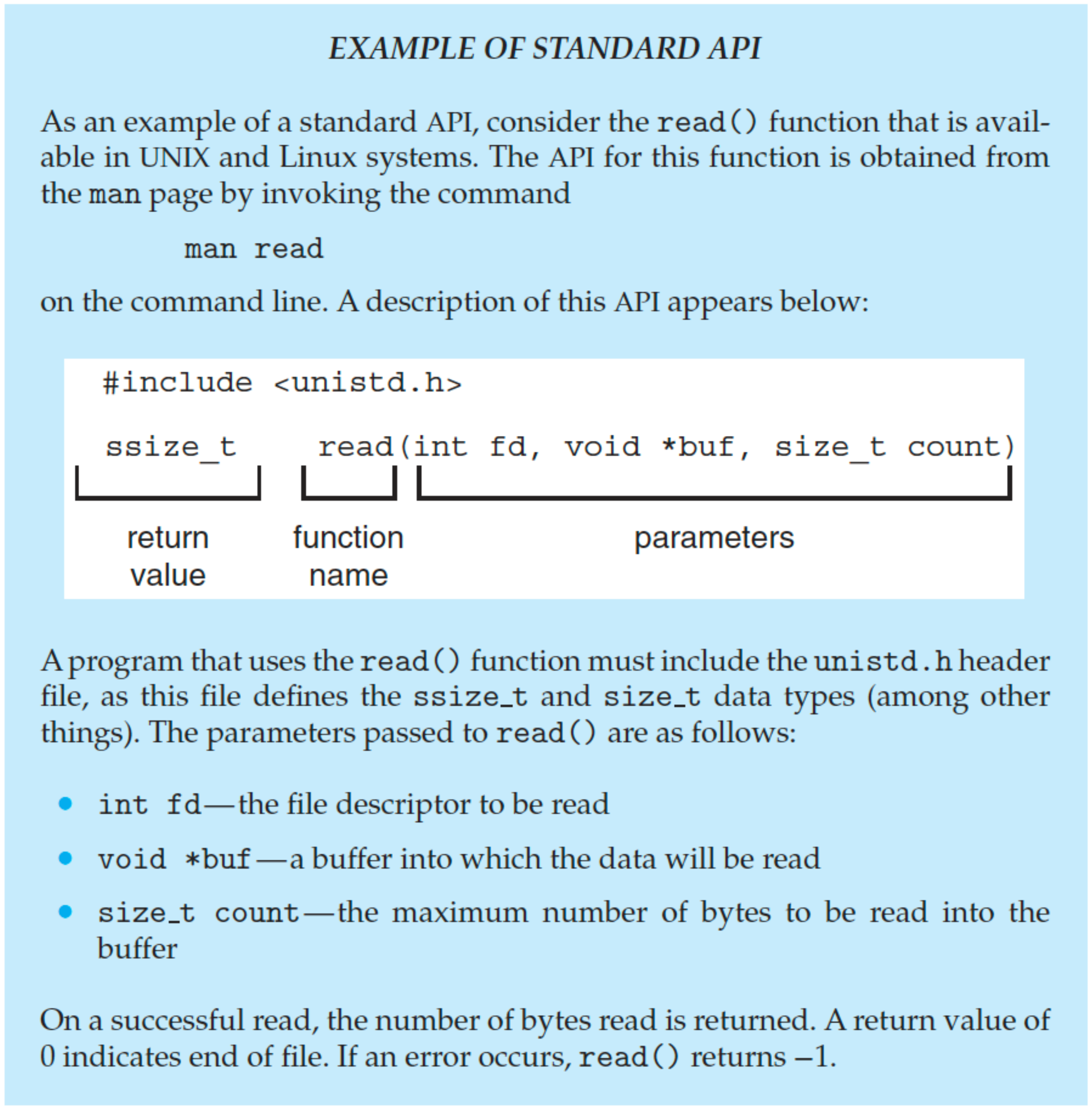
System calls can be run in either user mode or kernel mode.

True

[✓ False]

Example of Standard API

ssize_t is the signed counterpart of size_t, used when a function needs to return both the size and an error code. (positive implies success, negative return value indicates error)



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>
```

$$\underbrace{\texttt{ssize\_t}}_{\text{return value}}\quad \underbrace{\texttt{read}}_{\text{function name}}\underbrace{\texttt{(int fd, void *buf, size\_t count)}}_{\text{parameters}}$$

A program that uses the `read()` function must include the `unistd.h` header file, as this file defines the `ssize_t` and `size_t` data types (among other things). The parameters passed to `read()` are as follows:

- `int fd`—the file descriptor to be read
- `void *buf`—a buffer into which the data will be read
- `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.

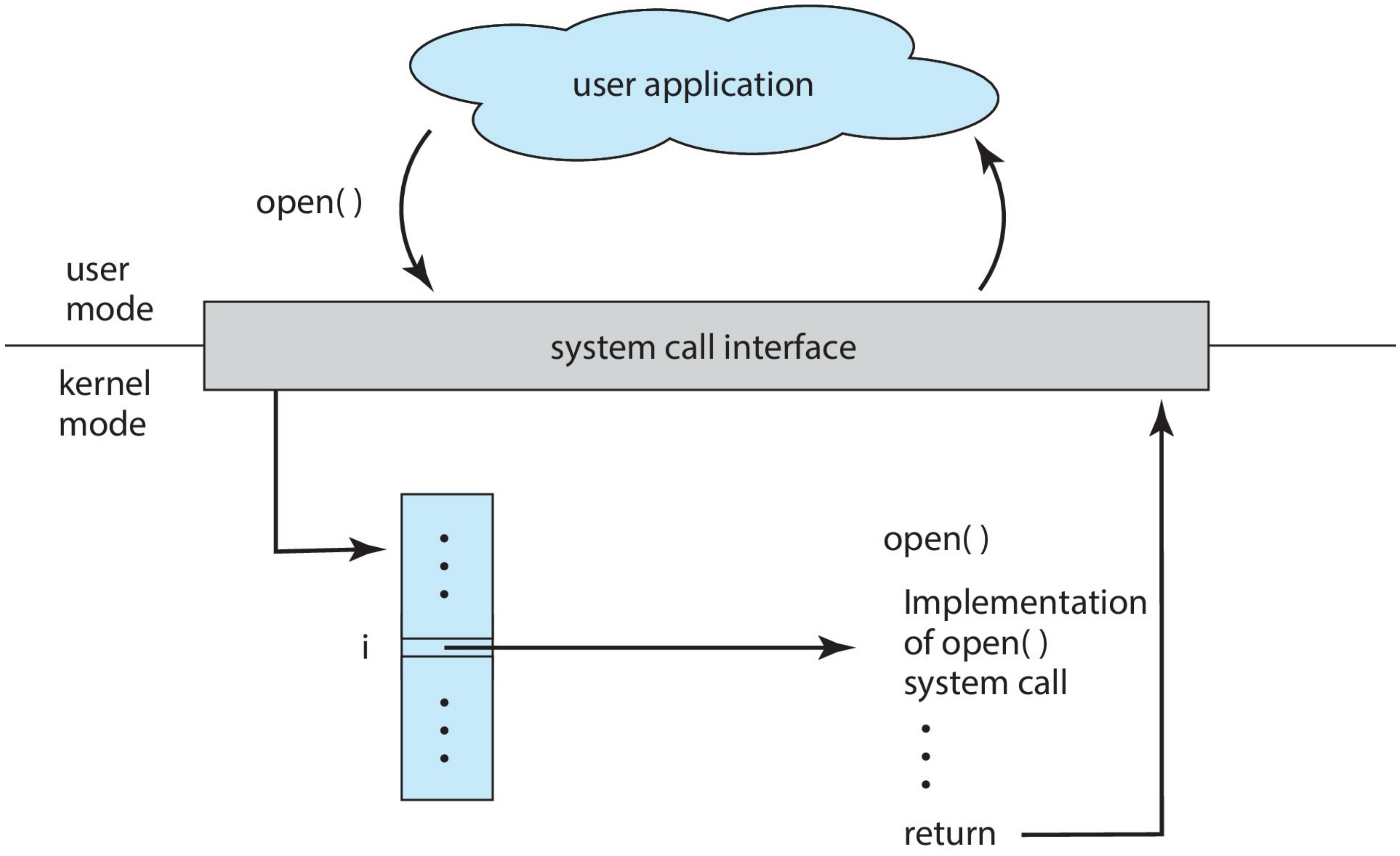
System Call Interface

- The RTE (Runtime environment) provides a system-call interface that serves as the link to system calls.
- RTE: the full suite of software needed to execute applications written in a language. (e.g. compilers, interpreters, libraries, loaders, etc.)
- System-call interface intercepts function calls in the API and invokes the necessary system calls within the operating system.

System Call Implementation

- Typically, a number is 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

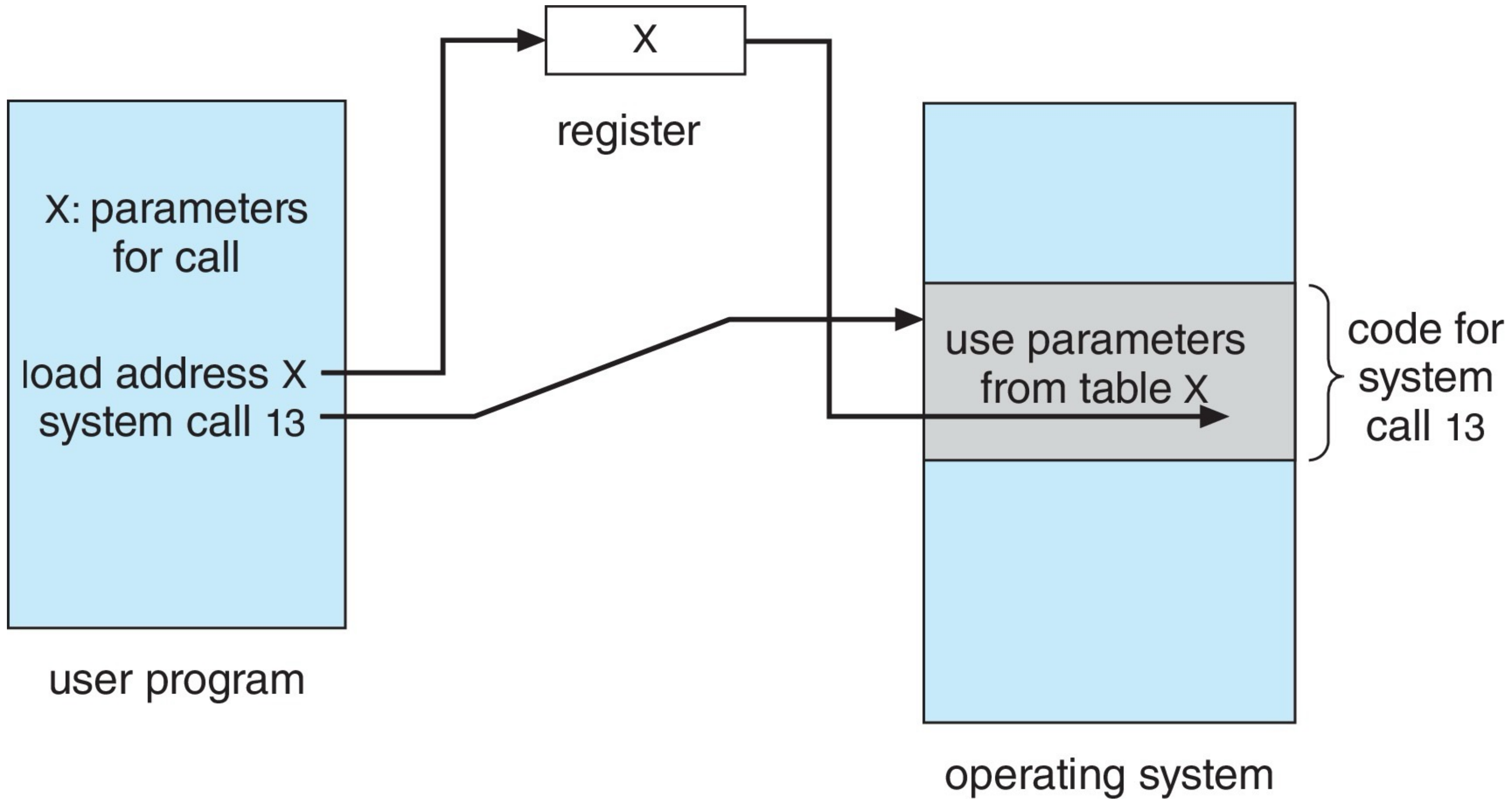


The handling of a user application invoking the open() system call.

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



Assume X is a table or a block of memory containing parameters

Which parameter passing technique to choose?

- The parameter-passing method (registers, stack, or memory) is fixed by the **OS and architecture**.
    - For example, there may have a rule: send first m parameters to registers and then the rest to stack or block, etc.
- Operating systems (e.g., Linux and Unix) usually have their own conventions
- The compiler adheres to this convention for all programs
- Application programs (users) do not control these methods

Types of System Calls

- Process control
  - create process, terminate process
  - end, abort (normal or abnormal termination)
  - load, execute
  - get process attributes, set process attributes
  - wait for time (e.g., multiple child processes running)
  - wait event, signal event
  - allocate and free memory
  - Dump memory if error (memory dump copies all information from RAM to a storage disk)
  - **Debugger** for determining **bugs**
  - **Locks** for managing access to shared data between processes

Types of System Calls (Cont.)

- File management
  - create file, delete file
  - open, close file
  - read, write, reposition
  - get and set file attributes
- Device management
  - request device, release device
  - read, write, reposition
  - get device attributes, set device attributes
  - logically attach or detach devices

Types of System Calls (Cont.)

- Information maintenance
  - get time or date, set time or date
  - get system data, set system data
  - get and set process, file, or device attributes
- Communications
  - create, delete communication connection
  - send, receive messages if **message passing model** to **host name** or **process name (communicator/other party name)**
  - **Shared-memory model** create and gain access to memory regions
  - transfer status information
  - attach and detach remote devices

Types of System Calls (Cont.)

- Protection
  - Control access to resources
  - Get and set permissions (set_permission() and get_permission())
  - Allow and deny user access (allow_user() and deny_user())

Questions

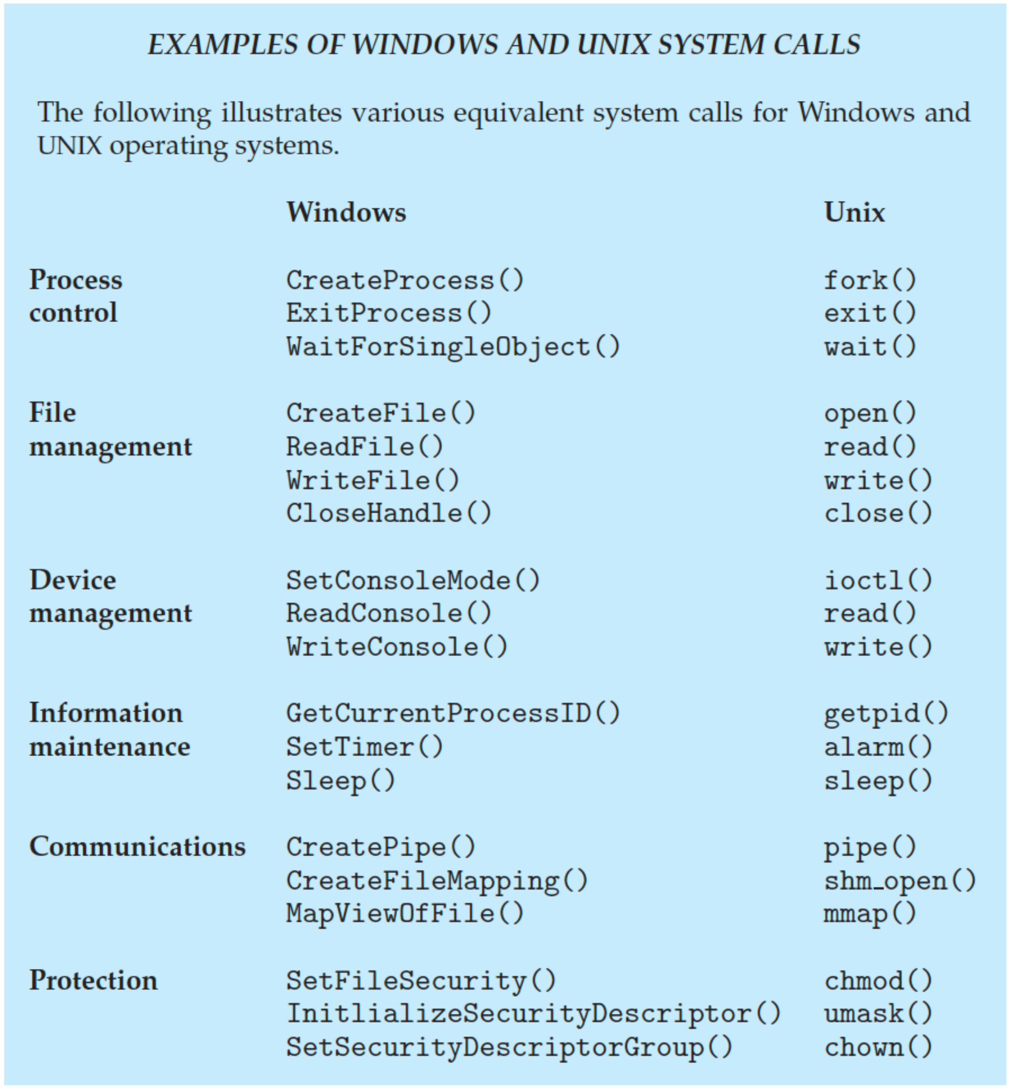
1. ______ is not one of the major categories of system calls.

A) Process control
B) Communications
C) Protection
D) Security ✓

2. ______ is/are not a technique for passing parameters from an application to a system call.

A) Cache memory ✓
B) Registers
C) Stack
D) Special block in memory

Examples of Windows and Unix System Calls



EXAMPLES OF WINDOWS AND UNIX SYSTEM CALLS

The following illustrates various equivalent system calls for Windows and UNIX operating systems.

	Windows	**Unix**
Process control	`CreateProcess()`	`fork()`
	`ExitProcess()`	`exit()`
	`WaitForSingleObject()`	`wait()`
File management	`CreateFile()`	`open()`
	`ReadFile()`	`read()`
	`WriteFile()`	`write()`
	`CloseHandle()`	`close()`
Device management	`SetConsoleMode()`	`ioctl()`
	`ReadConsole()`	`read()`
	`WriteConsole()`	`write()`
Information maintenance	`GetCurrentProcessID()`	`getpid()`
	`SetTimer()`	`alarm()`
	`Sleep()`	`sleep()`
Communications	`CreatePipe()`	`pipe()`
	`CreateFileMapping()`	`shm_open()`
	`MapViewOfFile()`	`mmap()`
Protection	`SetFileSecurity()`	`chmod()`
	`InitlializeSecurityDescriptor()`	`umask()`
	`SetSecurityDescriptorGroup()`	`chown()`

What system calls needed?

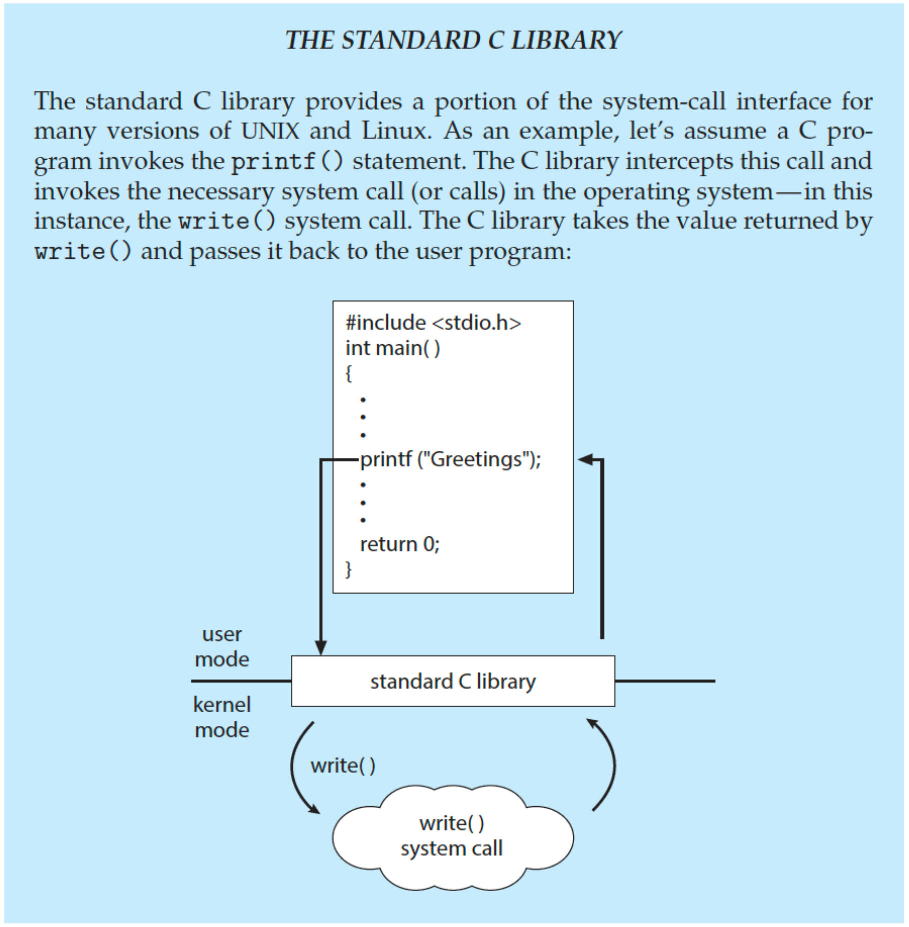
A fork() system call, and an exec() system call need to be performed to start a new process.

- The fork() call clones the currently executing process,
- The exec() call overlays a new process based on a different executable over the calling process.

```c
#include<unistd.h>
#include<stdio.h>
int main()
{
  printf ("I'm process %d and I'm about to exec a ls -l\n", getpid());
  execl ("/bin/ls", "ls", "-l", NULL);  /* Execute ls */
  printf ("This line should never be executed\n");
  return 0;
}
```

Standard C Library Example

- C program invoking printf() library call, which calls write() system call



THE STANDARD C LIBRARY

The standard C library provides a portion of the system-call interface for many versions of UNIX and Linux. As an example, let's assume a C program invokes the `printf()` statement. The C library intercepts this call and invokes the necessary system call (or calls) in the operating system—in this instance, the `write()` system call. The C library takes the value returned by `write()` and passes it back to the user program:

```
#include <stdio.h>
int main( )
{
  .
  .
  .
  printf ("Greetings");
  .
  .
  .
  return 0;
}
```

System Services

- System programs (also called system utilities) provide a convenient environment for program development and execution. They can be divided into:
  - File manipulation
  - Status information sometimes stored in a file
  - Programming language support
  - Program loading and execution
  - Communications
  - Background services
  - Application programs
- Most users' view of the operating system is defined by system programs, not the actual system calls

System Services (Cont.)

- Provide a convenient environment for program development and execution
  - Some of them are simply user interfaces to system calls; others are considerably more complex
- **File management** - Create, delete, copy, rename, print, dump, list, and generally manipulate files and directories
- **Status information**
  - Some ask the system for info - date, time, amount of available memory, disk space, number of users
  - Others provide detailed performance, logging, and debugging information
  - Typically, these programs format and print the output to the terminal or other output devices
  - Some systems implement a **registry** - used to store and retrieve configuration information

System Services (Cont.)

- **File modification**
  - Text editors to create and modify files
  - Special commands to search contents of files or perform transformations of the text
- **Programming-language support -** Compilers, assemblers, debuggers and interpreters sometimes provided
- **Program loading and execution**- Absolute loaders, relocatable loaders, linkage editors, and overlay-loaders, debugging systems for higher-level and machine language
- **Communications** - Provide the mechanism for creating virtual connections among processes, users, and computer systems
  - Allow users to send messages to one another's screens, browse web pages, send electronic-mail messages, log in remotely, transfer files from one machine to another

System Services (Cont.)

- **Background Services**
  - Launch at boot time
    - Some for system startup, then terminate
    - Some from system boot to shutdown
  - Provide facilities like disk checking, process scheduling, error logging, printing
  - Run in user context not kernel context
  - Known as **services**, **subsystems**, **daemons**
- **Application programs**
  - Don’t pertain to system
  - Run by users
  - Not typically considered part of OS
  - Launched by command line, mouse click, finger poke (i.e., by multiple user interfaces)

Questions

1. A _____ is an example of a systems program.

A) [✓ command interpreter]
B) Web browser
C) text formatter
D) database system

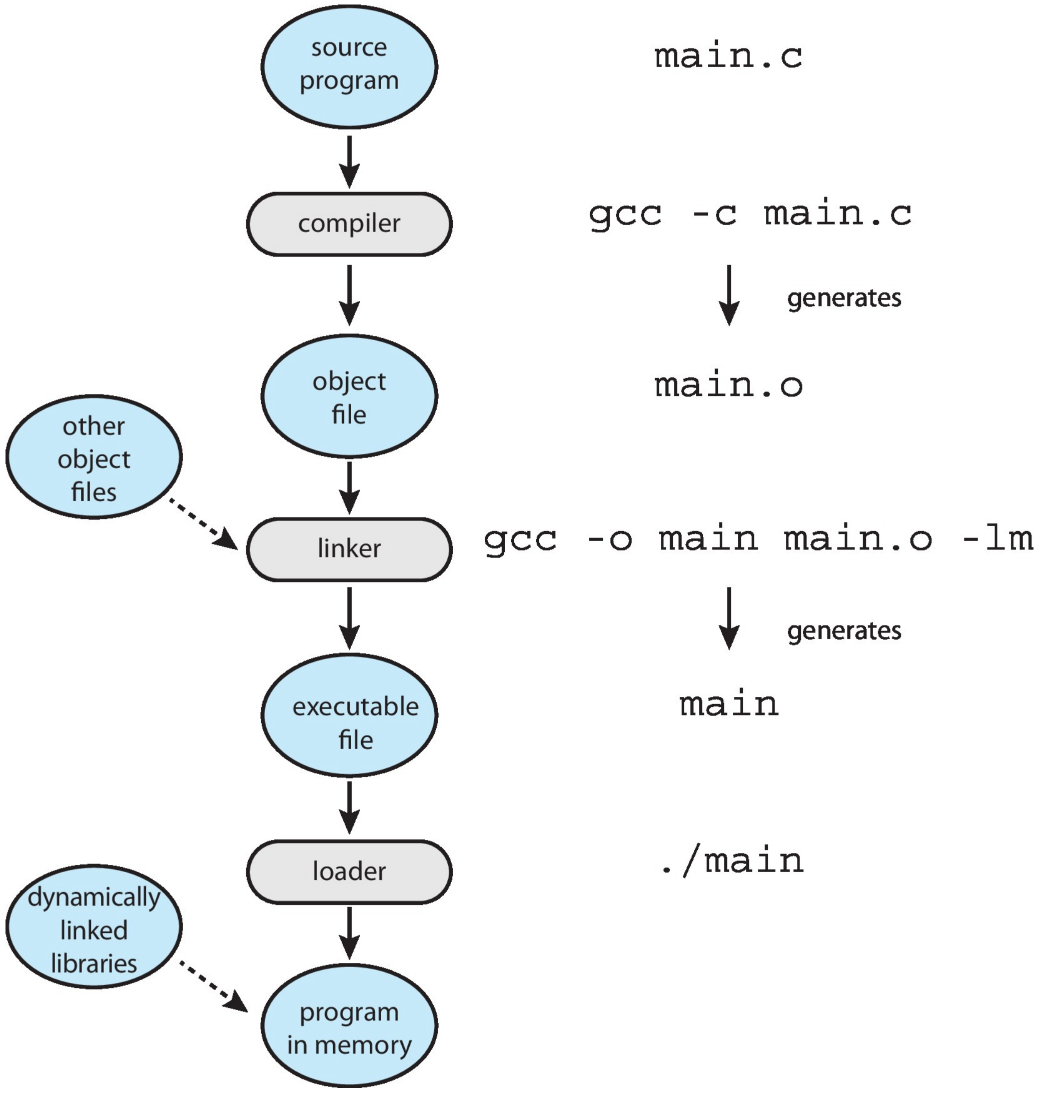
2. System programs all run in kernel mode.
   True
   [✓ False]

3. Web browser is a system program
   True
   [✓ False]

Linkers and Loaders

- Source code compiled into object files designed to be loaded into any physical memory location – **relocatable object file**
- **Linker** combines these into single binary **executable** file
  - Also brings in other libraries
- Program resides on secondary storage as binary executable
- Must be brought into memory by **loader** to be executed
  - **Relocation** assigns final addresses to program parts and adjusts code and data in program to match those addresses
- Modern general-purpose systems don't link libraries into executables
  - Rather, **dynamically linked libraries** (in Windows, **DLLs**) are loaded as needed, shared by all that use the same version of that same library (loaded once)
- Object, executable files have standard formats, so operating system knows how to load and start them

The Role of the Linker and Loader



- The math library is not linked into the executable file main. Rather, the linker inserts relocation information
- Allows it to be dynamically linked and loaded as the program is loaded and needed during run time.