System 101

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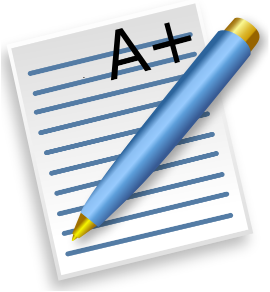
Figure: sys-101.auzias.net

Course details

Objectives

- How do *computers* work?
- What are they made of?
- What is an OS?

Course details



Evaluation

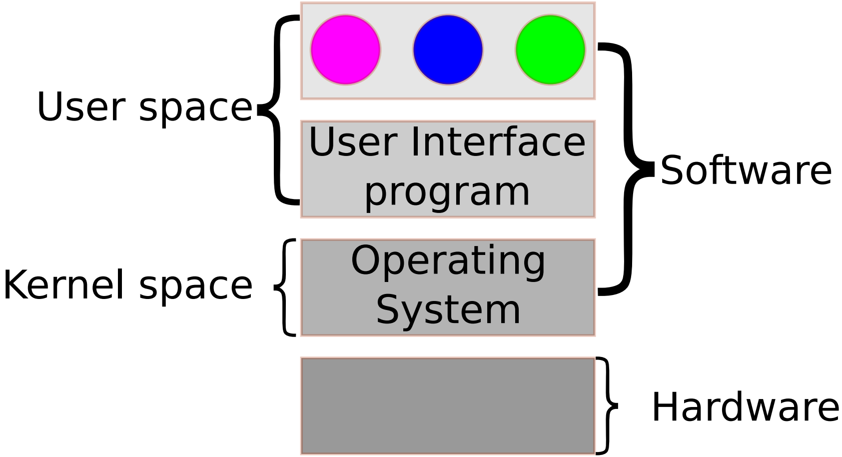
- Short test at the end of each practice
- Final exam (1 hour)
- All equal weighting

Material

- Slides available at sys-101.auzias.net (github too)
- **To read**: Modern Operating System - Andrew Tanenbaum. ISBN-13: 978-0133591620

Presentation Outline

Operating System



Operating System

Two basic unrelated functions

- provide application programmers a clean abstract set of resources,
- manage hardware resources.

Customers

OS real customers are **programs developpers**, not end users of theses developed programs.

The OS as an API provider

Abstraction challenge

- Hardware design, as well made as it can be, only offer awkward and ugly interface to communicate.
- Instruction set, memory organization, I/O, bus structure are not user friendly.
- Programmers need not to worry about all of that thanks to the **abstraction level** provided by OS.

The OS as the resource manager

Resource challenge

- Orderly allocation of the processors, memory, I/O devices for all the programs competing for them.
- Software resources (files, DB, network access) are also managed by the OS.
- Multiplexing:
  - Time multiplexing (CPU, printer),
  - Space multiplexing (RAM, disk).

The OS history

1945-55	First generation: vacuum tubes
1955-65	Second generation: Transistors and Batch Systems
1965-80	Third generation: ICs[1] and Multiprogramming[2]
1980-now	Fourth generation: Personal Computers
future	Fifth generation: any suggestion?

[1] Integrated Circuit
[2] several programs running at once

The OS Zoo

Mainframe Thousands of disks and millions gigabytes of data (high end web servers, servers for business-to-business transactions). Theses OS are focused on executing many jobs at once.

Server Multiple users served at once through a network, they provide print/file/web services.

Multiprocessor Multiples CPUs are hosted into one system (also called, according to what and how they share it: parallel computers, multicomputers, or multiprocessors).

Personal Computers Usually used for game, spreadsheet, word processing and web browsing (laptop, desktop).

The OS Zoo

Handheld	Small computers offering telephony, address book, web apps. They are becoming more and more sophisticated and blurring the difference between personal computers and handheld computers.
Embedded	Microwave ovens, (non-smart) TV and swatches, (not connected) cars, Bluray readers... They usual do not allow user-installed softwares.
Sensor Node	Usually small and simple to run on constraint devices with little RAM/ROM and battery life (TinyOS).
RTS[3]	Industrial process control, avionics, military...
Smart Card	Credit card.

[3] Real-Time System

Presentation Outline

OS Concepts

Overview

- Processes,
- Address spaces,
- Files,
- Input/Output,
- Permissions.

Processes

A process is a program being executed.

Each process:

- has an address space (**core image**),
- has a register (program counter and stack pointer),
- has a list of open files,
- has a list of related processes,
- and all the details needed to run a program.

Process

OS management of Processes

- Execute,
- Save execution state (file pointers list, number of bytes to be read next) in a **process table**[4],
- Stop.

A process corresponds to its **core image** and its **process table entry**.

[4] Array or linked list

Child Process

Process life

- A **system call** starts a process.
- Binary code is executed.
  - The process can create other processes, called **child processes** (and so on – tree).
  - Processes can communicate together using **IPC** means[5].
- The OS may send **alarm** signal (interruption) to the process.
- The process executes a **system call** to terminates itself.

[5] Inter Process Communication

Users Process

Process life

- **UID**[6] is a unique number assigned to each system user.
- Every process started has the UID of the user who started it.
- Every child process has the UID of its parent.
- One UID is called the super-user. The super-user has all permission.
- Users may also be members of groups. Each group has a **GID**.

[6] User Identification

Address Space

An address space is a memory location (from 0 to some maximum) and contains:

- executable program,
- program's data,
- program's stack.

Address Space

- Physical memory,
- Virtual memory (swap).

File

OS hide all peculiar disk operations to offer abstracted model of device-independent file management.

- System calls are required to:
    - Create, remove, read and write files; create and remove directories.
- File system also match a tree structure.

File

- Path
- Several files may have the same name.
- Each file has a unique absolute path (and an infinity of relative ones).
- Mounted file system, merging trees.

Special Files

I/O devices are abstracted to be used through same system calls as files do.

- Devices:
  - Block files,
  - Character files.
  - Special files are kept in /dev.
- Pipe:
  - IPC mean,
  - a special system call needs to be performed to known it's not a real file.

Tree

- Both process and file are structured as tree.
- Process tree are usually not very deep, unlike file trees.
- Process hierarchy are usually short-lived (minutes or less) while directories may exist for years.
- Ownership and protection differs too.

Permissions

u g o : user group other

- Three 3-bit fields
  - read
  - write
  - execute
- rwx rwx rwx do-what-ever-you-want-file
- rwx rwx r-x web-file
- rw- rwx rwx virus
- r-x — — personal-backup.tgz

Right	File	Directory
r	can read	can list files
w	can write	can add/delete files
x	can execute	can go through

Figure: Permissions meaning

Boot procedure

The BIOS[7] contains the procedures to read the keyboard, write to the screen, perform I/O on disk. Held in RAM, OS can modify it when bugs are found.

1. The BIOS is started,
2. The BIOS checks how much RAM is available,
3. The BIOS verifies if keyboard, mouse (and other basic devices) are correctly installed and responding,
4. The BIOS scans PCI[8] and ISA[9] buses to detect attached devices,
    4.1 If new devices are found since last boot, these new devices are configured.

[7] Basic Input Output System: low level I/O software system program present on the parentboard

[8] Peripheral Component Interconnect

[9] Industry Standard Architecture

Boot procedure

5. The BIOS determines the boot device (floppy? CD-ROM? DVD? USB? ...?) by using a list of devices stored in CMOS memory,
6. The program contained at the first sector of the boot device is executed,
   6.1 It usually examines the partition table at the end of the boot sector to determine which partition is active.
   6.2 A secondary boot loader is read from that partition.
   6.3 This loader reads the operation system from the active partition and starts it.
7. The OS queries the BIOS to get configuration details,
8. The OS checks the driver of each device,
9. The OS loads all these modules into the kernel,
10. The OS initializes its table, creates background processes and starts up a login program.

Presentation Outline

Processes and Thread

Overview

- Why processes are so important?
- What differences between processes and threads?

Processes

- Most important abstraction,
- Turn single-CPU into multiple virtual CPU
- Enable pseudo concurrent operations (pseudoparallelism),
- Without, modern computing could not exit.

Processes

Processes

- are instance of executing program
- include currents values of
  - program counter,
  - registers,
  - variables.
- have their own virtual CPU (multiprogramming) – considerations about time management, RTS.

The student partying (a fictional analogy)

- The student, at a home party, makes a cocktail.
  - Student: CPU, recipe: program, drinks: data, glasses: resource, action: process.
- While pouring the last ingredient her/his phone rang and s/he answers.
  - Student: CPU, phone-skill: program, phone: resource, phone call details: data, action: process.

A process is an activity having a program, input, output and a state. OS uses scheduling algorithm to determines when to stop/start which process.

Processes

Creation

- System initialization,
- Process creation done by a running process,
- User request,
- Initiation of a batch jobs.

Termination

- Voluntary
  - Normal exit,
  - Error exit.
- Involuntary
  - Fatal error,
  - Killed by another process.

Process states

State

a. Running,
b. Ready,
c. Blocked.

Transition

1. Scheduler pick another process.
2. Scheduler pick this process.
3. Input available.
4. Input required.

Threads

Threads

1. Processes within a process.
2. Enable to decompose big task into multiple sequential smaller tasks ..
3. .. while **sharing** a memory space.
4. Easier, faster, to create and destroy than processes as they are lighter.

Web browser example with multiple threads.

Threads

Concurrent programming: race condition (example)

- Thread S, and N, respectively correspond to the South, and North, gate in a Park.
- They count the current number of visitors:
  - When a visitor enters, the counter is incremented by one.
  - When a vistor leaves, the counter is decremented by one.
- Both threads share a common variable, the counter.
- They run on the same computer and, thus, share a sole CPU.
- To increment a variable at least three operations are required:
  1. Read the variable.
  2. Compute the incrementation.
  3. Write the new value of the variable.

What could go wrong?

Presentation Outline

System calls

System operations

- Read file, create directory or a process, modify permissions ..
- .. results in a system call.

System calls

System calls procedure

1. Switch from the program, within the user space, into the kernel space by executing a TRAP instruction.
2. The program starts the execution at a **fixed** address in the kernel space.
3. The kernel code then examine the system call number and execute the matching system call handler.
4. The system call handler execute its code and then returnes the control to the program at the instruction following the TRAP instruction.
   - unless the system call blocks (i.e., waiting for an input on the keyboard).
5. The program is put back into user space and continues.

Main system calls: Process management

Call	Description
pid = fork()	Create a child process (identical to the parent)
pid = waitpid(pid, &stat, opt)	Waif for a child to terminate
s = execve(name, argv, envp)	Execute a program
exit(status)	Terminate a process and return status

Figure: Process management

Main system calls: File management

Call	Description
fd = open(file, flags)	Open (or create) a file
close(fd)	Close a file
n = read(fd, buff, nbytes)	Read data from a file into a buffer
n = write(fd, buff, nbytes)	Write data from a buffer into a file
p = lseek(fd, offset, whence)	Reposition the pointer within the file
s = stat(name, buff)	Get file status

Figure: File management

Main system calls: Directory and file system management

Call	Description
s = mkdir(name, mode)	Create a directory
s = rmdir(name)	Delete a directory
s = link(oldpath, newpath)	Make a new name for a file
s = unlink(path)	Delete a name and possibly the file it refers to
s = mount(s, t, fst, f, d)	Mount a filesystem
s = umount(target)	Unmount a filesystem

Figure: Directory and file system management

Main system calls: Miscellaneous management

Call	Description
s = chdir(dirname)	Change the working directory
s = chmod(name, mode)	Change a file's protection bits
s = kill(pid, signal)	Send a signal to a process
seconds = time(&seconds)	Get the elapsed time since 01/01/70

Figure: Miscellaneous

Presentation Outline

Memory Management

System operations

- ..
- ..

Presentation Outline

File System

Challenges

- How to store very large amount of data?
- How to store it after *t*he process has been killed?
- How to allow multiple processes to access it concurrently?

File System

Two operations

- read_block(block_number)
- write_block(block_number)

File System

Two operations

- read_block(block_number)
- write_block(block_number)

How to, with these two, ..

- Find information?
- Keep a user from reading another user's data?
- Know which blocks are free?

File Abstraction

OSes abstract processor into process, physical memory into virtual address space and file system into files.
Processes (Threads), address space and files are the three most important abstractions that an Operation System offers.

File Naming

Naming rules

- Different rules for different OS.
- Names length varies from 1 to 255 characters.
- Case-sensitive (UNIX), or not (MS-DOS).
- Extension consideration.

Files Structure

File Structure

1. Unstructured sequence of byte (any meaning is imposed by the user procces). Offers the maximum flexibility.[10]
2. Fixed length-records each with internal structure (80 characters records, 132 char for line printer).[11]
3. Tree records, each files has a key value, tree sorted according to these values.[12]

[10] UNIX, MS-DOS, Windows
[11] Not used anymore
[12] Still used in some commercial data processing

Files Types

File Types

- Regular files (ASCII or binary files).
- Names length varies from 1 to 255 characters.
- Case-sensitive (UNIX), or not (MS-DOS).
- Extension consideration.

Binary File Example

Executable binary example:

- header,
  - Magic-number (identifying the file as executable),
  - Size of the various pieces of the file,
  - Address at which execution starts
  - Various flags.
- text,
- data,
- relocation bits,
- symbol table (for debugging purposes).

Binary File Example

Archive example (collection of library procedures compiled but not linked):

- header (telling its name),
- Creation date,
- Owner,
- Protection code,
- Size.

Files Extension and OS

- An OS must at least recognize its own executable file type (they usually recognized more than this one type),
- TOPS-20 checked the creation date of executable file, sought for its source file, and recompile it if the source file was updated.
- *make* program reproduce this behavior, file extensions are mandatory.
- Strong mandatory file extensions make an OS unusable (e.g., all extension file output produced are ".dat" – impossible to copy a file!)

File Access

- Sequential access: files were read from the beginning to the end (magnetic tape).
- Random access files: files can be read in any order. To choose the position in the file and read you can:
  - Give the position as a parameter at teach read operation,
  - Seek at a specific position and then sequentially read (UNIX and Windows).

File Attributes (Metadata)

- Right: who and how can the file be accessed.
- Password: required to access the file.
- Creator: ID of the user who created the file.
- Owner: ID of the user who owns the file.
- Read-only flag.
- Hidden flag.
- System flag.
- Archive flag (set by the system when changed, cleared by the back-up program).

File Attributes (Metadata)

- ASCII/binary flag: 0 for ASCII file, 1 for binary file.
- Random access flag: 0 for sequential access only, 1 for random access.
- Temporary flag: 0 for normal, 1 for delete file on process exit
- Lock flag: 0 for unlocked, nonzero for locked.
- Creation time.
- Time of last access.
- Time of last change.
- Current size.

File Operations

- Create: while no data are put into, the file is announced and some of its attributes are set.
- Delete: frees up some disk space (sys-call).
- Open: the system fetchs attributes and list of disk addresses into main memory for rapid access later on.
- Close: frees up internal table space. Some OS impose a maximum number of open files.
- Read: the user must specify how many data are expected and a buffer to put them in.
- Write: data are written. If position is the end of the file, the file size increases, if it is in the middle, existing data are overwritten.
- Append: write-like but only at the end of the file.

File Operations

- Seek: for random access files, set the file pointer at the requested position.
- Get attributes: many programs need it, i.e.*make*.
- Set attributes: allows the user to modify some of the file attributes.
- Rename: simple as that.

GH.com/p-e-w/maybe

Directories

- Single-level directory system: only **one** folder (digital cameras, music players, first PCs).
- Hierarchical directory system.

Path Names

- Absolute (from **root** directory): */etc/apt/source.list*, */var/log/messages*.
- Relative (from **current** directory):
  - Implicit: *Download/Gramatik.zip*, *../Movies/*.
  - Explicit: *./Download/Gramatik.zip*, *./../Movies/*.

What are dot and dotdot?

Directory Operation

- Create: creates a directory with dot and dotdot.
- Delete: deletes a directory (only empty directories can be deleted).
- Opendir: opens a directory so it can read.
- Readdir: reading a directory allows to list all files within it.
- Closedir: frees up internal table space.
- Rename: simple as that.
- Link: (hard link) increments the file's i-node counter and allows to make the file appear in different directories.
- Unlink: decrements the file's i-node counter. If it is zero the file is delete from the system, otherwise only the path name specified is removed (UNIX system call to delete a file is unlink).

File System Layout

- Sector 0 contains the MBR[13], used to boot the computer, at the end of the MBR is the partition table.
- Partition table contains starting and ending disk addresses of the different partitions. One is marked as active.
- At boot time, the BIOS reads and executes the MBR, the MBR program locates the active partition, reads its first block (boot block) and execute it.
- The boot block loads the OS contained in that partition.
  - All partition contains a boot block, even if it does not contain a bootable OS.

[13] Master Boot Record

Partition System Layout

- Boot block: cf previous slide.
- Superblock: details include a magic number to identify the file system type and the number of blocks in the file system.
- Free space management: can be in a form of a list of pointers.
- I-nodes: array of data structure, one per file.
- Root directory: contains the top of the system tree.
- Files and directories: remainder of the disk.

Implementing Files

How to keep track of which disk blocks match with which file?

- Contiguous allocation,
- Linked list allocation,
- Linked list allocation using a table in memory,
- I-nodes[14].

[14] Index-nodes

Implementing Files: contiguous allocation

Each file occupies consecutive disk blocks.

Advantages

- Simple to implement:
  - Keeping track of a file's block requires only two numbers: starting disk address, number of blocks.
- Read performance is excellent (the entire file can be read from the disk in a single operation).

Drawbacks

- Fragmentation.
- Disk space.
- What about a file becoming bigger?

Implementing Files: linked list allocation

Each file is matched with a linked list of disk blocks.

Advantages

- Every block of the disk can be used (no waste, no fragmentation).
- Directories entry only need to store the disk address of the first block (no matter how big are the files).

Drawbacks

- Performance
  - Many head rotation may be required.
  - Amount of data storage in a block is not a power of two.
- Each block starts with the address of the next block

Implementing Files: linked list allocation using a table in memory

Let's put the pointers and put them in a table in memory (FAT).

Advantages

- Every block of the disk can be used (no waste, no fragmentation).
- Random access is much easier as no disk references are needed (as these references are in the memory).

Drawbacks

- Memory usage. The whole table must be in memory all the time.
  - 200-GB disk, 1-kB block size, entries of 3 bytes: 600 MB.

Implementing Files: i-nodes

The index lists the attributes and disk addresses of the file's blocks.

Advantages

- The memory is occupied only when file is open.
- The footprint is smaller, the RAM usage does not depends on the disk size (but the number of opened files).

Indexes have the same size, thus, for big files, the last disk address point for an address of a block containing more disk block addresses.

Implementing Directories

Main function of directories: map the ASCII name of the file onto the information needed to locate the data.

- Directories entry provide the needed details to find file's disk blocks
  - Disk address of the entire file,
  - Number of the first block,
  - Number of the i-node.

Implementing Directories: File Names' Length

How to deal with file names' length?

- Fixed-length
  - MS-DOS: 1-8 character base name and optional extension of 1-3 characters.
  - UNIX v7: 1-16 characters, including any extensions.
- Variable-length
  - Set a maximum limit and use it for the design.
  - In-line.
  - In a heap.

Shared Files

- Disk blocks are listed in a data structure[15] associated with the shared file, not in directories.
- Symbolic linking.

[15] the i-node in Linux

Other File Systems

- Log-Structured File System (LFS).
  - Computer speed bottleneck is the hard drive speed. reads are OK, writes are buffered and done by burst.
- Journaling File System (NTFS, ext3).
  - The OS keep a log of what the FS is going to do before it does it, so if a crash occurs, on the reboot it can repair it.

Virtual File Systems

A VFS integrates multiple file systems into an orderly structure.

- /: ext4 on an SSD.
- /media/cd-rom: ISO 9660.
- /home: NFS.
- /usr: NTFS on a HDD.

While there are 4 different FS, users access any file with the standard POSIX calls.

Defragmentation

Free blocks become scattered all over the disk among the used blocks. Big files are then stored in many places that slows read-calls.

Questions

1. Why a magic number is giver for executable files whereas random ones are given to other files (UNIX - old versions)?
2. Is *open* required? Is there a way to avoid this and used *read* or *write* without calling *open*?

I hope you liked it and learnt something new !

Figure: sys-101.auzias.net