CSGE602055 Operating Systems
CSF2600505 Sistem Operasi
Week 03: File System & FUSE

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https://docOS.vlsm.org/Slides/os03.pdf
Always check for the latest revision!

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OS241[3]): Operating Systems Schedule 2023 - 2

Week	Topic[1])	OSC10[2])
Week 00	Overview (1), Assignment of Week 00	Ch. 1, 2
Week 01	Overview (2), Virtualization & Scripting	Ch. 1, 2, 18.
Week 02	Security, Protection, Privacy, & C-language.	Ch. 16, 17.
Week 03	File System & FUSE	Ch. 13, 14, 15.
Week 04	Addressing, Shared Lib, & Pointer	Ch. 9.
Week 05	Virtual Memory	Ch. 10.
Week 06	Concurrency: Processes & Threads	Ch. 3, 4.
Week 07	Synchronization & Deadlock	Ch. 6, 7, 8.
Week 08	Scheduling + W06/W07	Ch. 5.
Week 09	Storage, Firmware, Bootloader, & Systemd	Ch. 11.
Week 10	I/O & Programming	Ch. 12.

[1]) For schedule, see https://os.vlsm.org/#idx02

[2]) Silberschatz et. al.: **Operating System Concepts**, 10^{th} Edition, 2018.

[3]) This information will be on **EVERY** page two (2) of this course material.

STARTING POINT — https://os.vlsm.org/

- **Text Book** — Any recent/decent OS book. Eg. (**OSC10**) Silberschatz et. al.: **Operating System Concepts**, 10^{th} Edition, 2018. (See https://codex.cs.yale.edu/avi/os-book/OS10/).
- **Resources** (https://os.vlsm.org/#idx03)
  - **SCELE** — https://scele.cs.ui.ac.id/course/view.php?id=3743. The enrollment key is **XXX**.
  - **Download Slides and Demos from GitHub.com** — (https://github.com/os2xx/docOS/)
    os00.pdf (W00), os01.pdf (W01), os02.pdf (W02), os03.pdf (W03), os04.pdf (W04), os05.pdf (W05), os06.pdf (W06), os07.pdf (W07), os08.pdf (W08), os09.pdf (W09), os10.pdf (W10).
  - **Problems**
    195.pdf (W00), 196.pdf (W01), 197.pdf (W02), 198.pdf (W03), 199.pdf (W04), 200.pdf (W05), 201.pdf (W06), 202.pdf (W07), 203.pdf (W08), 204.pdf (W09), 205.pdf (W10).
  - **LFS** — http://www.linuxfromscratch.org/lfs/view/stable/
  - **OSP4DISS** — https://osp4diss.vlsm.org/
  - **This is How Me Do It!** — https://doit.vlsm.org/
    - PS: "Me" rhymes better than "I", duh!

Agenda

1. Start
2. OS241 Schedule
3. Agenda
4. Week 03
5. OSC10 (Silberschatz) Chapter 13, 14, and 15
6. File System Interface
7. File System Organization
8. FHS: Filesystem Hierarchy Standard
9. Devices
10. File System Implementation
11. File System Internals

Week 03 File System & FUSE: Topics[1]

- Files: data, metadata, operations, organization, buffering, sequential, nonsequential
- Directories: contents and structure
- File systems: partitioning, mount/unmount, virtual file systems
- Standard implementation techniques
- Memory-mapped files
- Special-purpose file systems
- Naming, searching, access, backups
- Journaling and log-structured file systems

[1]Source: ACM IEEE CS Curricula

Week 03 File System & FUSE: Learning Outcomes[1]

- Describe the choices to be made in designing file systems. [Familiarity]
- Compare and contrast different approaches to file organization, recognizing the strengths and weaknesses of each. [Usage]
- Summarize how hardware developments have led to changes in the priorities for the design and the management of file systems. [Familiarity]
- Summarize the use of journaling and how log-structured file systems enhance fault tolerance. [Familiarity]

[1]Source: ACM IEEE CS Curricula

OSC10 (Silberschatz) Chapter 13: File-System Interface, Chapter 14: File System Implementation, and Chapter 15: File System Internals

- OSC10 Chapter 13
  - File Concept
  - Access Methods
  - Disk and Directory Structure
  - Protection
  - Memory-Mapped Files
- OSC10 Chapter 14
  - File-System Structure
  - File-System Operations
  - Directory Implementation
  - Allocation Methods
  - Free-Space Management
  - Efficiency and Performance
  - Recovery
  - Example: WAFL File System
- OSC10 Chapter 15
  - File Systems
  - File-System Mounting
  - Partitions and Mounting
  - File Sharing
  - Virtual File Systems
  - Remote File Systems
  - Consistency Semantics
  - NFS

File System Interface

- File Concept
  - File Attributes: Name, Id, Type, Location, Size, Protection, Time Stamp: create, last modified, last accessed.
  - File Operation
    - Create/Delete/Truncate
    - Open/Close
    - Read/Write
  - File Types: Executable, Object, Source Code, Library, Markup, Markdown, Archive, Compressed.
  - File Structure: No Structure (just a string).
  - Access Methods: Sequential vs Direct Access
- Directory and Disk Structure
  - Three-Structured Directories
  - Directory Operation: create/delete, search/list, rename, traverse
  - Path Name: Absolute vs. Relative
  - FS Mounting vs. Volume Based System
- File Sharing
- Protection: Access Control (eg. -rwx–x–x)

File System Organization

- Disk Partition
  - One Disk — Many Partitions
  - Many Disks — One Partitions
  - Many Disks — Many Partitions
  - One Partition — One File System (Volume)
- Mounting vs. Volumes

```
demo@badak:~$ df
Filesystem     1K-blocks     Used Available Use% Mounted on
/dev/sda2        9515660  1435776   7573468  16% /
/dev/sdb1       32895760 12156672  19045036  39% /usr
/dev/sdc1      412322216 79695252 311639116  21% /home
udev               10240        0     10240   0% /dev
tmpfs           16508828        0  16508828   0% /dev/shm
tmpfs            6603532     8880   6594652   1% /run
tmpfs               5120        0      5120   0% /run/lock
tmpfs           16508828        0  16508828   0% /sys/fs/cgroup
tmpfs            3301768        0   3301768   0% /run/user/1002
demo@badak:~$
```

FHS: Filesystem Hierarchy Standard

- Source (URL) http://refspecs.linuxfoundation.org/FHS_3.0/fhs-3.0.pdf
- A file placement guidelines/requirements for GNU/Linux-like OS.

FILES	shareable (multiple hosts)	unshareable (single hosts)
static (read only, except for update)	/usr, /opt	/etc, /boot
variable (r/w)	/var/mail, /var/spool/news	/var/run, /var/lock

- The Root File System (Required)

Directory	Description
/bin	Essential command binaries
/boot	Static files of the boot loader
/dev	Device files
/etc	Host-specific system configuration
/lib	Essential shared libraries and kernel modules
/media	Mount point for removable media
/mnt	Mount point for mounting a filesystem temporarily
/opt	Add-on application software packages
/run	Data relevant to running processes
/sbin	Essential system binaries
/srv	Data for services provided by this system
/tmp	Temporary files
/usr	Secondary hierarchy
/var	Variable data

More FHS 1

- Specific Options

Directory	Description
/home	User home directories (optional)
/lib<qual>	Alternate format essential shared libraries(optional)
/root	Home directory for the root user (optional)

- The /usr Hierarchy

Directory	Description
/usr/bin	Most user commands (required)
/usr/lib	Libraries (required)
/usr/local	Local hierarchy (empty after main installation) (required)
	/usr/local/{bin|etc|games|include|lib|man|sbin|share|src} (required)
/usr/sbin	Non-vital system binaries (required)
/usr/share	Architecture-independent data (required)
	/usr/share/{man|misc} (required)
	/usr/share/{color|dict|doc|games|info|locale} (optional)
	/usr/share/{nls|ppd|sgml|terminfo|tmac|xml|zoneinfo} (optional)
/usr/games	Games and educational binaries (optional)
/usr/include	Header files included by C programs (optional)
/usr/libexec	Binaries run by other programs (optional)
/usr/lib<qual>	Alternate Format Libraries (optional)
/usr/src	Source code (optional)

More FHS 2

- The /var Hierarchy

Directory	Description
/var/cache	Application cache data (required)
/var/lib	Variable state information (required)
	/var/lib/misc (required)
/var/local	Variable data for /usr/local (required)
/var/lock	Lock fileslogLog files and directories (required)
/var/opt	Variable data for /opt (required)
/var/run	Data relevant to running processes (required)
/var/spool	Application spool data (required)
/var/tmp	Temporary files preserved between system reboots (required)
/var/backups	(reserved names, do not use)
/var/cron	(reserved names, do not use)
/var/msgs	(reserved names, do not use)
/var/preserve	(reserved names, do not use)
/var/account	Process accounting logs (optional)
/var/crash	System crash dumps (optional)
/var/games	Variable game data (optional)
/var/mail	User mailbox files (optional)
/var/yp	Network Information Service (NIS) database files(optional)

More FHS 3

- (Mostly) Linux

Directory	Description
/proc	Kernel and process information virtual filesystem
/sys	Kernel and system information virtual filesystem
/usr/include	Header files included by C programs
/usr/src	Source code
/var/spool/cron	cron and at jobs

Devices

- the `/dev/` directory
  - `/etc/fstab`: configuration of filesystems
  - `/etc/mtab` → `/proc/mounts`: mounted filesystems
  - `/proc/swaps`: swap filesystems
  - `df`: checking diskspace and filesystems
  - Device Major and Minor Numbers
  - UUID - Universally Unique IDentifier (128 bits)
  - GUID - Globally Unique IDentifiers: `ls -al /dev/disk/by-uuid`
  - practically is NOT guaranteed unique
  - FUSE: Filesystem in Userspace
  - More Storage Structure
    - `tmpfs` — a temporary file storage, stored in RAM that grows and shrinks.
    - `objfs` — dynamic kernel object filesystem.
    - `ctfs` — (creating, controlling, and observing) contract file system .
    - `loopfs` — loop filesystem allows to dynamically allocate loop devices.
    - `procfs` — proc filesystem presents information about processes.
    - `ufs` — the original Unix Filesystem (before Linux ext2).
    - `zfs` — the Zettabyte Filesystem is both a volume manager and a file system.

A Typical Ubuntu 20.04 Work Station

```
cbkadal@ubuntu2004:~$ df
Filesystem      1K-blocks       Used Available Use% Mounted on
udev              8138664          0   8138664   0% /dev
tmpfs             1634140       1948   1632192   1% /run
tmpfs             8170684     210348   7960336   3% /dev/shm
tmpfs                5120          4      5116   1% /run/lock
tmpfs             8170684          0   8170684   0% /sys/fs/cgroup
tmpfs             1634136         76   1634060   1% /run/user/1000
/dev/sda1           98304      33523     64781  35% /boot/efi
/dev/sda3       286082372   78565916 207516456  28% /altfs/ntfs
/dev/sda5        32999120    9181772  22111364  30% /altfs/linux1
/dev/sda6        38186548   12054612  24162428  34% /altfs/linux2
/dev/sda7       126265680   13342928 106465768  12% /
/dev/sdb2        62216964   13238156  45788588  23% /var
/dev/sdb3      3532259904 2605226568 747535200  78% /home
/dev/loop0         101632      101632         0 100% /snap/core/10859
/dev/loop1          65920       65920         0 100% /snap/gtk-common-themes/1513
/dev/loop2          66432       66432         0 100% /snap/gtk-common-themes/1514
/dev/loop3         678016      678016         0 100% /snap/intellij-idea-community/273
/dev/loop4         679040      679040         0 100% /snap/intellij-idea-community/270
/dev/loop5          52352       52352         0 100% /snap/snap-store/498
/dev/loop6         223232      223232         0 100% /snap/gnome-3-34-1804/60
/dev/loop7         267008      267008         0 100% /snap/kde-frameworks-5-core18/32
/dev/loop8         166784      166784         0 100% /snap/gnome-3-28-1804/145
/dev/loop9         102784      102784         0 100% /snap/kotlin/57
/dev/loop10         52352       52352         0 100% /snap/snap-store/518
/dev/loop11         56832       56832         0 100% /snap/core18/1988
############       ##### TL;DR #####         # #### ##################
/dev/loop18         56832       56832         0 100% /snap/core18/1944
/dev/loop19        142080      142080         0 100% /snap/chromium/1506
```

File Systems Implementation

- File System Layers / Structure
  - Application Programs
  - Logical File Systems
  - File-Organization Module
  - Basic File Systems
  - I/O Control
  - Hardware Device
- File System Implementation
- File Control Block
- FS In Memory Structure
- VFS: Virtual File Systems
  - How to support multiple File Systems
  - I.e. How to support multiple `open()/close()` `read()/write()` operations

Implementation and Allocation Method

- Directory Implementation
  - Linear List
  - Hash Table
- Allocation Method
  - Contiguous
  - Linked
  - Indexed
  - Combined Scheme
- Free Space Management
- Performance & Efficiency
- Unified Buffer Cache
- Recovery
- Log Structured File System

File Systems Internals

- File Systems
- File-System Mounting
- Partitions and Mounting
- File Sharing
- Virtual File Systems
- Remote File Systems
- Consistency Semantics
- NFS