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CST 232 : OPERATING SYSTEMS

Technical Report on Differences Between Desktop and Mobile Applications Operating System Architecture

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GROUP 14

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Introduction to Operating System

Basically, a computer is a type of machine encompasses of hardware and software. Hardware is more to the physical of a computer, elements and components that build and equip the computer itself. Software on the other hand, is a set of instructions, data or programs that are used to operate computers and execute specific task. Software is often divided into application software and system software which includes operating system (Rouse, 2019).

Operating system is a part of software and the one that in charge in controlling everything. To be specific, it controls every file, every device, every section of main memory, and every moment of processing time. It controls who can use the system and how (McHoes & Flynn, 2014).

Operating system is not limited to only phones but is also one of the main attributes to run and execute any applications on a desktop. Without an operating system, it would be impossible to run a program as both hardware and software are dependent among each other. Besides, different machines might be using different operating system as well. The technical reason on why we have different operating systems is some applications or processor architectures might work best with operating system optimized for it.

There are a lot of operating systems with different architecture and functions, specifically designed for desktops. The most common used these days are Microsoft Windows, Mac OS and Linux.

Operating system:

1) Windows

Figure 1: Windows

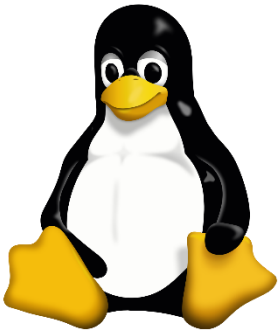
Windows OS, computer operating system developed by Microsoft Corporation to run personal computers. Featuring the first graphical user interface (GUI) for IBM-compatible PCs, the windows soon dominated the PC market. Approximately 90 percent of PCs run some version of Windows. (Gregersen & Rees, 2017)

2) Mac OS

Figure 2: Mac OS

Mac OS is the computer operating system for Apple Computer's Macintosh line of personal computers and workstations. A popular feature of its latest version, Mac OS X, is a desktop interface with some 3D appearance characteristics. OS X has a modular design intended to make it easier to add new features to the operating system in the future. It runs UNIX applications as well as older MAC applications. (Rouse, Mac OS, n.d.)

3) Linux



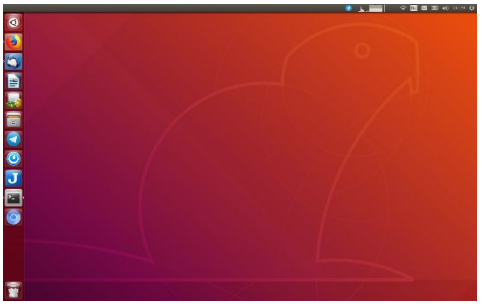


Figure 3: Linux

Linux, computer operating system created in early 1990s by Finnish software engineer Linus Torvalds and the Free Software Foundation (Hosch, 2008). Linux was designed to be similar with UNIX, but has evolved to run on a wide variety of hardware from phones to supercomputers. Every Linux-based OS involves the Linux kernel- which manages hardware resources and a set of software packages that make up the rest of the operating system. (What Is Linux, n.d.).

The three operating systems mentioned above are the most-used operating system globally. But how is it with mobile phones? To date, Android is said to be the one that hugely monopolize humans' mobile devices globally. What is Android exactly? Android is an operating system for mobile phone based on the modified version of Linux kernel and other open source software which means anyone can use it and it is free. Linux is the best-known and most used open source operating system which most commonly found on servers and desktop computers. Android is designed for touchscreen mobile devices such as tablets and smartphones. Android managing the phones basic functions and support any running applications on top of it. It was developed by various developer but mostly Google and Open Handset Alliance. The hardware that support android software is based on ARM architecture (What Everybody Ought to Know About Android : Introduction, Features & Applications, n.d.)

Everything that displayed in the device is part of the operating system. The Android operating system has various version numbers. Android Oreo, Marshmallow, Pie, Nougat and Android 10 are the names of android version. There are many popular device models that running Android such as Samsung Galaxy S4, HTC One, Nexus 4, the Motorola Photon 4G and more. Android is more easy to modify and personalise compare to iPhone's iOS. The

android applications are written using Android software development kit (SDK) and are written in Java (UI), C (core), C++ and other programming languages. Android architecture is divided into five sections and has four main layers which is application frame work, libraries, linux kernel and android runtime. Most android device manufactures have a skin on top of the operating system. A skin is a custom design that adds extra features to the user's phone. Android Custom Distribution is a phone's firmware which is based on Google's Android platform (What is an Android Custom ROM?, n.d.). A custom ROM is a modified android operating system that you can install on your Android device that open-source developers have developed with a bunch of new features. There are many kinds of custom ROM such as Xiaomi's MIUI, OnePlus's OxygenOS, LineageOS, OmniRom and others. A phone with only minor changes are called new-stock and a phone without any major customizations referred as stock android.

Pros and Cons of Windows, Mac OS and Linux

Windows:

Pros	Cons
Cheap pare to other operating system, windows can be considered as cheap. One of the reasons is because it sells it license to most of laptop manufacturers	**Malware and virus attack** are to other operating system, Windows are prone to viruses attack. Windows is a little poor in security
Compatible y software that is highly used in the market right now are compatible with Windows. Most software supported by Windows are free to be	**Lag problems** ndows are really prone to get hijacked, it is sensible that the lagging occurs because of the poor security.

downloaded hence make it many people's choice.	
Choice any computer manufacturers buy windows, most PCs and laptops implement Windows as their operating system. This way, users are able to exercise their own choice and are not constrained to limited amount of options during purchasing.	
Customizable ows are indeed customizable and flexible. Users are free to add their own configurations and cards if they want to.	
Games e huge benefits of Windows is that it supports Gaming. Windows equip with incredible power and provide RGB lighting.	

Mac OS:

Pros	Cons
Simplicity Mac OS offer simpler more straightforward GUI for users. This somehow is really practical to people who just want to get their job done. Compared to windows, Windows has more complicated workflow as app is installed in many roots add folder path.	**High cost** Apple sells expensive gadgets and Mac OS is included. There is a huge wide gap between the price of Windows product and Apple product.
Less virus and malware attacks	**Not customizable**

Apple protect Mac OS from viruses and malwares by introducing app store. Users are bounded to download or install anything via App Store rather than download it from the third party. Apps that are available in App Store have been through countless of security checks and scanning to ensure they are malware-free and virus-free	Mac OS does not provide wide range of options in terms of hardware upgrading. Components like CPU and RAM cannot be upgraded easily. Components upgrading are important as to increase the life span of the machine. Failure of any hardware components might affect the machine and makes it not operable. If any of this cases happen, it would be hard to repair and it needs to be sent to Apple. If we want to repair without warranty, it would be really expensive.
Multitasking feature The OS also has specific multitasking features. It responds to built-in shortcut keys or track-pad and mouse gestures for easily switching between windows or apps that are running in the background. While switching using shortcut keys is also possible in Windows computers, macOS has a richer feature that centres on easy navigability (Bonheur, 2018)	**Not a go-to gaming machine** Mac OS is not invented for gaming. Due to its lack of RAM and dedicated graphic processors, Mac would be the last choice for gamers.
Smooth integration As Apple is a software developer and device manufacturer, most of their products assimilate smoothly with the hardware components. As to this, some users claim that Mac OS has longer longevity and lengthier-lifespan than Windows product.	**Limited number of apps in the app store** Because lots of laptop and PCs manufactures purchase Windows, not many software developers would want to create apps for Mac computers. User will have limited options in choosing applications for their Mac.

Linux:

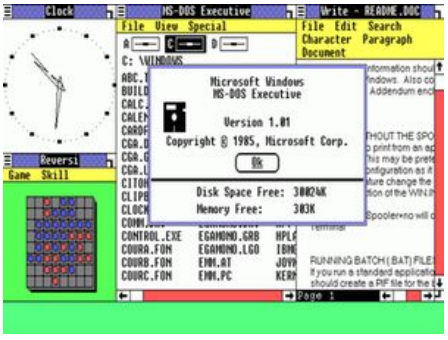
Pros	Cons
Linux is less vulnerable to malwares and viruses Unwanted visitors and malwares are avoidable with 'walls' and flexible file access permission. Additionally, users can download high quality software with high security and for free.	**Hardware drivers problem** Some hardware drivers are not available for Linux. As Mac and Windows have many users compared to Linux, hardware manufacturers tend to manufacture hardware for them and basically those drives are unavailable to be used by Linux.
Free access to software There are many software choices even for a specific task. Software on Linux tend to be more packed with features and greater reusability.	**Not a go-to gaming machine** Same as Mac, most games are made for Windows
Low Cost As it comes with GNU General Public License, there is no need to labour so much money on Linux. In fact, users can download a large repositories for free for any tasks you want to do.	**Linux has no standard** Both windows and Mac has their own updated versions like Windows 10. This is one of the things that Linux is lacking.

Stable Hardly any crashes or blue screen of death likely to happen on Linux because of memory leak or such. In fact, reboot is not needed in Linux to maintain performance.	

Introduction to Microsoft Windows

As we know, Windows is one of the operating system's family that really hits the market off. Windows was under development and introduced to the public back in 1985. Until this moment, Windows is still dominating personal computers globally. It is estimated that almost 90 percent of computers in this world run windows as their operating system. Until the present day, there has been a lot of Windows version that has been introduced to the public and all of them have been well perceived. Despite of providing graphical user interface, virtual memory management and multitasking to personal computers, it does the same to personal devices as well such as mobile phones and servers.

Windows has been through a long journey and first released and operated in 1985. The very first version of Windows is Windows 1, Windows 2, Windows 3 until the latest release which is Windows 10. As to compare the evolution from the early version of windows with the latest, below is a brief go-through information about Windows 1 and Windows 10

Windows version	Description
Windows 1.0  Figure 4	Windows 1.0 was first introduced in 1985 by Windows. Windows 1.0 is said to rely to much on mouse input. It allows the user to point and click to access the windows. It ease the users as they do not have to type MS-DOS commands. Windows 1.0 executes as graphical, 16 bit multitasking shell on MS-DOS.
Windows 10  Figure 5	Windows 10 made it first appearance in 2015. It is sensible to install this version of Windows as it is really complete with useful functions and simple user interface. It overcome shortcomings that came with Windows 8. It is designed to unify with universal apps.

Based on the above comparison, it is really clear that Windows has greatly evolved from time to time with more great features and functions.

Windows architecture and design

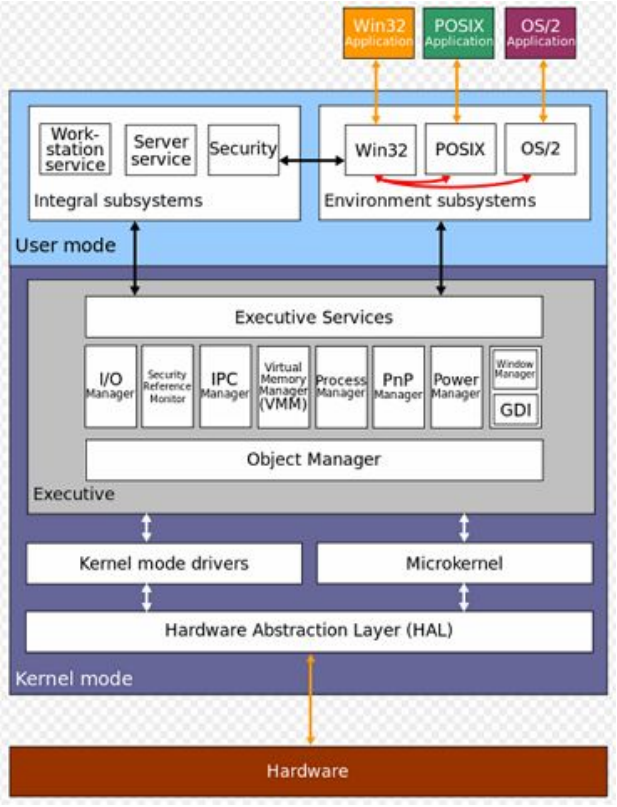


Figure 6: Architecture of Window

Windows architecture encompasses of two modes which are Kernel Mode and User Mode. Processor can choose and free to switch between modes depending on the type of coding running. Kernel mode is unrestricted to access system memory and all CPU instructions. While Kernel Mode has that privilege, user mode is not and it is bounded to access the underlying hardware.

According to Figure 4, user mode consists of integral subsystem and environment subsystems. Environment subsystems, which expose the native OS services to user applications and thus provide an OS environment, or personality. Windows NT ships with three environment subsystems: Win32, POSIX and OS/2 1.2 (Solomon, n.d.).

Another mode is Kernel Mode. Kernel Mode is given privileged to access underlying hardware components and all memory including the memory address space used by User Mode. Compare to user mode, kernel mode processes would not be moved to

virtual memory on the hard disk. The kernel mode in Windows is comprised of the Windows Executive, which includes the Executive Services, the kernel, and the hardware abstraction layer (HAL) (Barakat, 2007). According to Figure 4, The Kernel is between the executive services and HAL Layers. The function is to provide basic operating system services like thread scheduling, first level interrupt handling and deferred calls. HAL or hardware abstraction layer is to enable the same operating system to run on different processors.

Windows File Management

File system is mostly used these days and alternatively recognised as file management. File management is basically a method to organize and storing information at any storage devices especially hard drives. User might encounter difficulties such as storage and retrieval problems without implementing file management. File structures also can vary between operating systems.

Windows utilize file system as its file structure. The easiest analogy is the cabinet scenario. Each cabinet has multiple drawers and each drawer contains folders. Each folder has its own important files that the users might need to access right away. The drawers represent logical drives. Notice that in your computer, for every drive that is created, there will be a letter associates with it. For example, C: and D: Drive C: contains folders like Program Files, Users and Windows. In Windows, it is common to keep things in hierarchical ways. For instance, if we built some spreadsheets and we want to store them, we can simply create one folder for it, and store all the spreadsheets in one folder. That way, it is much more organized and easy to access.

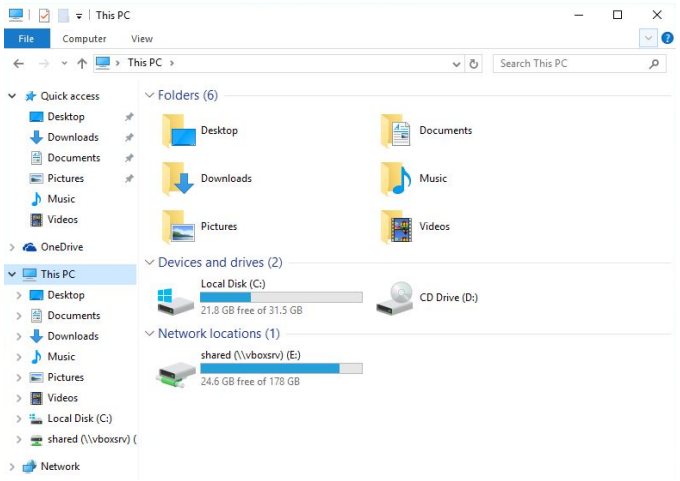


Figure 7: Windows file system

A folder is like a location to put your files or subfolders. If you open your 'This PC' on your Windows 10, there will be an address bar at the top of the windows. The address shown in the address bar is exactly where you are storing your particular folders or files.

When files are deleted from Windows, they are not permanently deleted from the computer. Windows has a folder namely recycle bin and it can be found in The Desktop. Users are able to retrieve back the deleted files and recover the documents.

Windows Memory Management

Windows, Mac OS and Linux use the same approach in their memory management system which is virtual memory. However, the implementations are slightly different with each other. Your computer has limited memory installed by default and as we know, memory is one of the most crucial part in executing a particular application or software. Performance can be enhanced and maximized if a computer has a really fast memory.

Windows, as aforementioned, use virtual memory in their system. Our computer has two different memory which are RAM and virtual memory. Most processes will be loaded into the RAM but when there is no sufficient space for the processes to execute, Windows will temporarily move the processes to hard disk. This process is known as paging file. Windows references memory by using virtual memory addresses. Virtual memory addresses are automatically translated to real (RAM) addresses by the hardware. Only core parts of the operating system kernel bypass this address translation and use real memory addresses directly (RAM, virtual memory, pagefile, and memory management in Windows, n.d.). Each process on 32-bit Microsoft Windows has its own virtual address space that enables addressing up to 4 gigabytes of memory. Each process on 64-bit Windows has a virtual address space of 8 terabytes (About Memory Management, 2018).

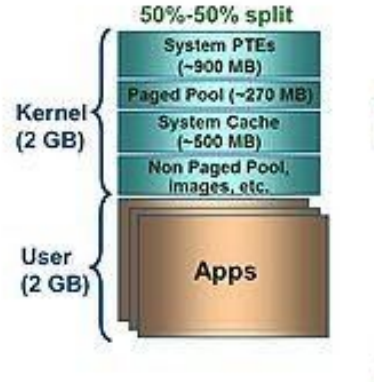


Figure 8: 32-bits windows memory architecture

Based on Figure 8, virtual address space for windows is divided into two partitions which are Kernel and user and each of the partition is assigned with 2GB. One of the partitions are designated for private use of each process while the other one is for the processes and the operating system. When the memory usage exceeds the available RAM, pages of one or more virtual address space (4kb pieces) will be moved to the hard disk and eventually frees up the RAM for other uses.

Windows Device Management

Windows Mobile Device Management as to handle all of the devices in the operating system. Mobile Device Manager (MDM) is implemented on Windows version 8, 8,1 and 10. MDM is a type of software that is used to manage devices. Basically, what MDM will do is that it stores information about mobile devices, decide which app can be present on the device, locating devices or even secure it if it were to be stolen. In short, it roles in device enrolment, profile management, app management and security management.

In terms of device enrolment, it will enrol devices over the air (OTA) with Microsoft's built device management client (Mobile device management (MDM) for Windows Devices, n.d.). Besides, it allows multiple devices to be run for a single user. Next will be profile management. Profile management is tasked so that email settings policy can be created and configured. IT helps to configure our Wi-Fi, VPN and cellular data usage while roaming and provide email access to only MDM enrolled devices with Exchange Activesync (Mobile device management (MDM) for Windows Devices, n.d.).

MDM also helps in security management. It locks your devices when it is stolen so that the thief cannot access to your device. Additionally, missing devices can be identified by activating remote alarm. Another way how security management corporates with your devices is it configure security setting like restricting copy and paste operations.

Windows Security Management

Windows protect its users' data security by security and maintenance. Previously known as Action Centre, it is a part of operating system that monitor the security and status of the computer. Some of the criteria that it monitors are antivirus software, personal firewall, windows update and many more. Users will be notified if the computer encounters one of this problem.

The one that determines the current state of the settings is Security centre. This service will automatically at work when the computer is started and it will continually observe computer behaviours and will immediately notify the users if something go wrong.

In windows 10, Windows Defender Security Centre (WDSC) is introduced. Windows Defender is an anti-malware component. It is in charged in protecting users from spyware. Windows Security continually scans for malware (malicious software), viruses, and security threats. In addition to this real-time protection, updates are downloaded automatically to help keep your device safe and protect it from threats (Stay protected with Windows Security, n.d.).

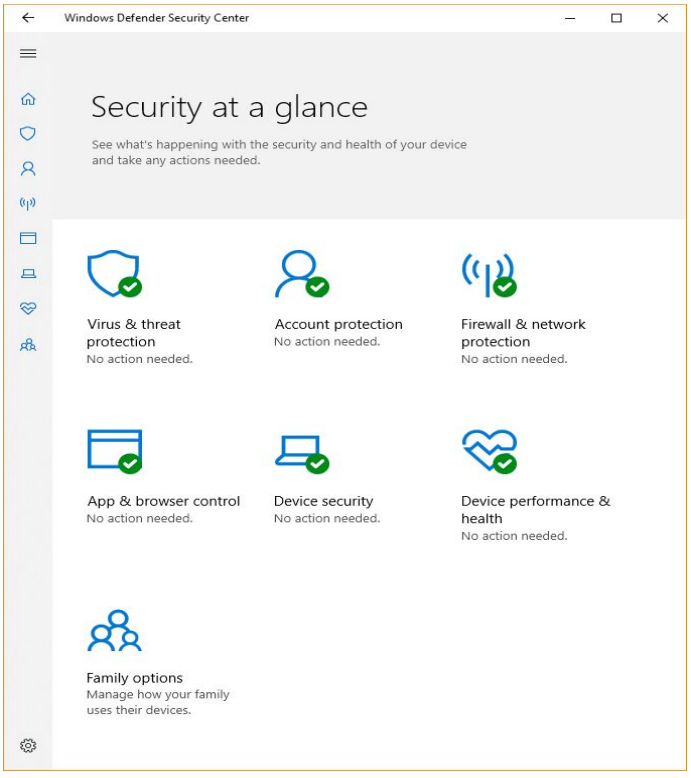


Figure 9

The moment you start your windows 10, windows defender will help protecting and secure you from malware and security threats. **Windows Defender** has now been integrated with **Windows Security** and it includes an **Account Protection** section (What is Account Protection in Windows 10 and how to hide this section, n.d.)

Beside protecting computer from virus and threat, windows security helps in firewall & network protection, app & browser control, device security, device performance and health and family options.

Mac OS Introduction

Mac OS is a series of operating system with multiple versions invented by Apple Inc. Its first initial release was in 2001 and still prolong until this date. It is the primary operating system for Mac's computer and it is the second most-used operating system after Windows. The latest version of Apple's computer which is Mac OS X is popular with its feature which is a desktop with some 3D appearance characteristics. It has modular design as to make it easier for adding new features in the future. Mac OS is made based on UNIX operating system.

Mac OS is previously known as Mac OS X. Mac OS is different with other personal computers as it can only be run on Macs (Apple's PCs) but not in other computers. Hackintosh (computers that run Mac OS but not an authorized Apple hardware) is illegal and not allowed as it violates Mac OS license agreement. Similar to Windows, Mac OS has travelled quite a long journey and Apple has already produced multiple versions of it. The first release was Mac OS X in 2001. The following releases were in 2002 , 2003 , 2005, 2007 and more until now.

Version	Description
Mac OS X 10.0  Figure 10	Mac OS X version 10.0 is the first release of Mac OS X. Its code name is Cheetah. It makes it first debut on 24th March 2001. Mac OS X 10.0 is said to make a radical departure from the classic Mac OS. However, it experienced some performance issues and missing features. There are quite a few lacking in terms of completeness and overall stability but it is still well perceived by the public.

Mac OS 10.15  Figure 11	Mac OS version 10.15 or its code name 'Catalina' is introduced in October 2019. This is the sixteenth major release of Mac OS and is the first version in Apple's line to support 64-bit applications. It does no longer run 32-bits applications and Apple has already removed 32 bits applications from the App Store.

Mac OS Architecture

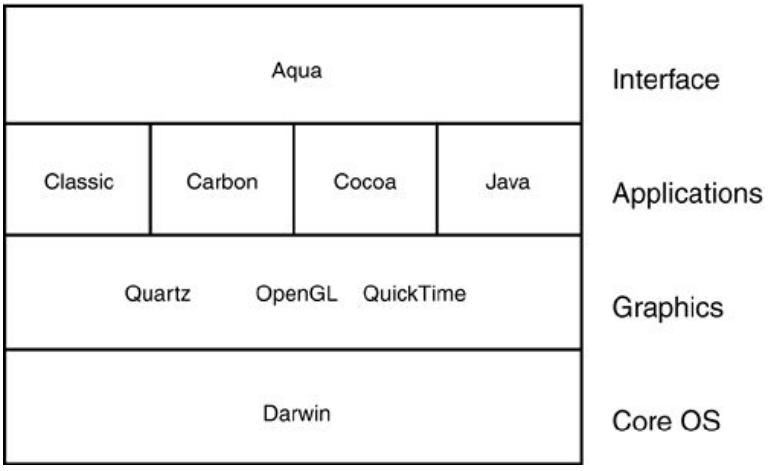


Figure 12: Architecture of Mac OS

The structure of the Mac OS X includes multiple layers. The base layer is Darwin which is the UNIX core of the system. Next layer is the graphics system which contains Quartz, OpenGL and QuickTime. Then is the application layer which has four components, namely Classic, Carbon, Cocoa and Java. The top layer is Aqua, which is the user interface (Mac OS X Structure, n.d.).

The base layer which is Darwin has a few major features include Darwin core are protected memory, multitasking and advanced virtual memory. Darwin is an open source operating system. It also provides I/O services for Mac OS X and supports plug-and-play, hot-swapping and power management (Mac OS X Structure, n.d.). Graphics subsystem consists of three which are Quartz, OpenGL and QuickTime.

Quartz is for displaying 2D text and graphics. The application subsystem in Mac OS X provides the classic environment to run classic applications. Carbon, Cocoa and Java are the three application development environments available (Mac OS X Structure, n.d.). Two environment subsystem like Carbon and Cocoa are two APIs developed software natively for Mac OS.

Mac OS File System.

The default file system that handles storage of data in Mac OS is APFS. It replaces HFS+ and HFS+ replace HFS. HFS was originally used on floppy disks and it was introduced to support Apple's first hard disk drive for the Macintosh. HFS+ came and replaced Hierarchical file System (HFS). It is an improved version of HFS as it supports big files with addresses 32-bit length and it use Unicode instead. After a while, APFS came and took HFS+ position as it is much more sensible and suits needs of today's computers. It is made for solid state and flash drive and it support even bigger files than HFS+ which is up to 64-bits.

That is basically the underlying process of the Mac OS file system. As to the surface, Mac OS file system is designed for Mac Computers to make it accessible not only to users but also to the software. Users can access the file system through The Finder (a user-oriented view of the file system by renaming file and directories).

Next is Mac OS. Mac OS stores files within folders, also known as directories. The top, uppermost folder is known as the root directory. Folders located within (or beneath) the root directory are known as subfolders or subdirectories (Eckel, 2013). Compared to windows, you might find it hard to familiarize with Mac OS directories. The root directory is often referred to as / for example Applications/ or Library/. There will be files resides in every directories. Figure 9 shows the directories in Mac OS.

File system is divided into multiple domains and it separates files based on usage. For example, user home directories are resided on the /Users directory or on a network volume

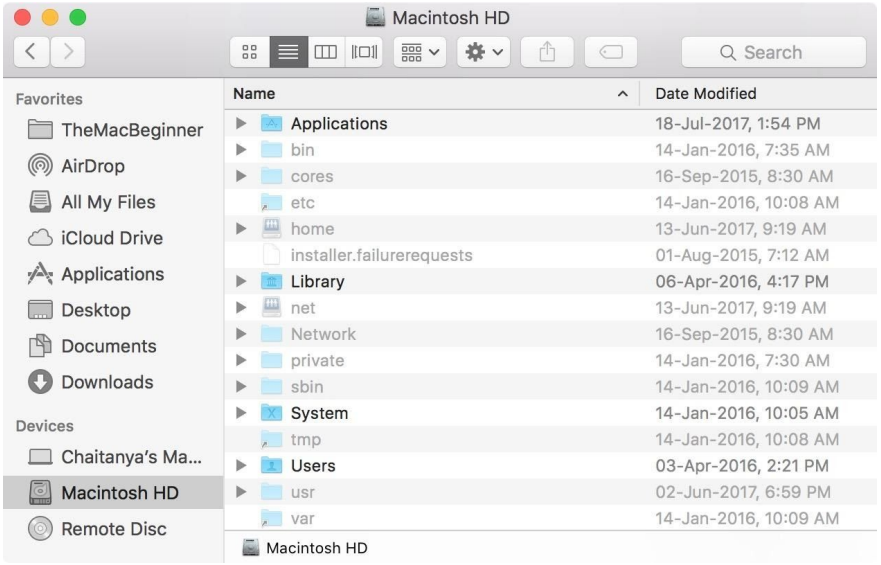


Figure 13: Mac OS file structure

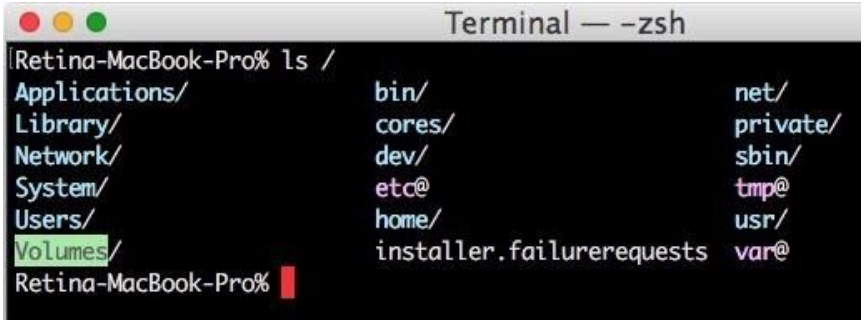


Figure 14: Mac OS directories

Mac OS Memory Management

Next will be Mac OS memory management system. OS X includes a fully integrated virtual memory system and paging is also utilized. If there are no free pages available in physical memory at the moment, virtual memory system in OS X will write pages to the backing store. Backing store is basically part of hard disk for paging and swapping processes that is used to store information that is not currently in main memory. Movement of data to the backing store from physical memory is called paging out and from backing store to physical memory is paging in. In another word, this leads to unlimited memory but as it is limited by the speed of the hard disk, it will be much slower. In addition, reading data from the backing store takes quite amount of time and it is lower than reading directly from RAM. OS provides up to 4 Gigabytes of addressable space per 32-bit processes and approximately 18-exabytes for 64-bit processes.

However, Mac OS is working greatly in reducing the use of virtual memory in their operating system by the implementation of Compression Method. Compression in Mac OS does not occur at all time. Compression method works by looking for inactive memory (memory that is not currently in used but still holds data that will be used by computer) and compress it to reduce the space the memory consume. However, no compression will be performed if there are free memory although there are many inactive memory. When the OS needs the compressed data, the OS will decompress the data and make it available to the one that requested it.

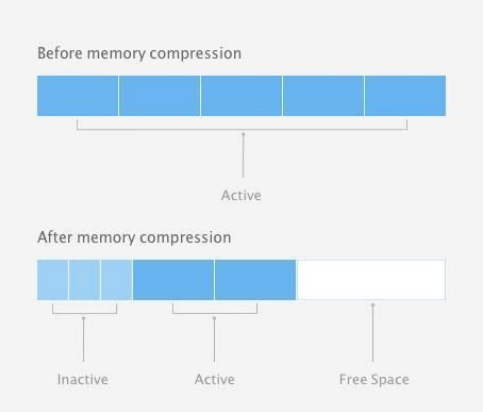


Figure 15: Mac OS memory compression

Mac OS Device Management

Mac MDM is mobile device management for Mac. As aforementioned, MDM is used to secure and manage devices as it contains data and they need to be protected. Mac MDM software not only will let you to monitor your Mac OS, but users are also able to sync it with other Apple devices running on ios, mac OS and many more. Important features like Device enrollment, profile management, security management and application management are vital and will be supported by MDM.

Device enrolment under Mac OS device management can be performed through invites in case of managing machines present in your inventory. For employee-owned personal machines, using self enrolment is ideal. The enrolment URL is accessed to bring machines under management (What is Mac MDM?, n.d.)

In terms of profile, it limits the device from installing unapproved applications. Not only that, it can restrict the user from connecting to unapproved wi-fi networks by configuring restrictions. There will be also file vault encryption where the data stored in the mac machines are encrypted using File Vault encryption.

As in security, MDM will help in terms of remote scan, remote lock, complete wipe and corporate wipe. Remote scan features enable obtain of installed apps, blacklisted apps and any restriction imposed on machine.

Mac OS Security Management

Mac OS is complete with hardware, software and services that provides security so that it will be easier to configure, deploy and manage. Apple has ensured that Mac OS will always be protected by cooperating with standard bodies and is provided with the latest security certifications.

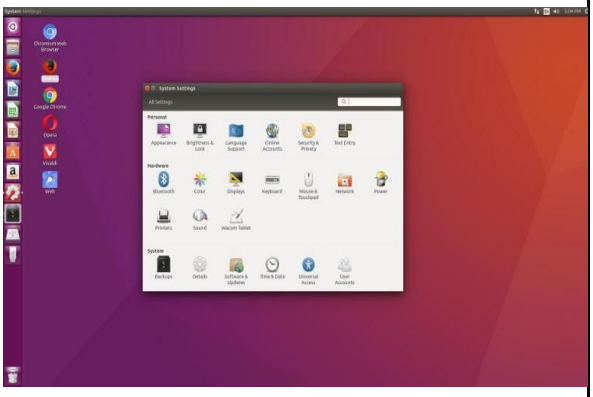
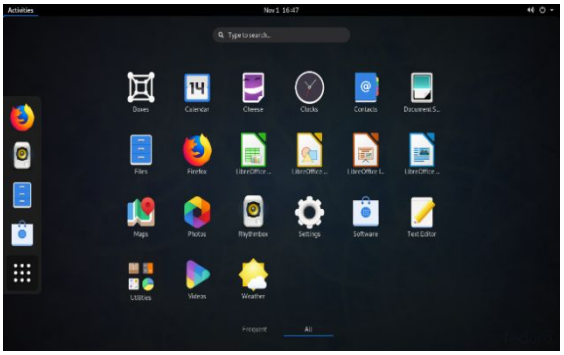
Mac OS is protected in various features and areas including system security, encryption and data protection, app security, authentication and digital signing, network security and device controls. First, in terms of system security, Mac OS is protected by the existence of the macOS kernel which is the heart of operating system. Mac OS Kernel is based on Berkeley Software Distribution (BSD) and the Mach microkernel and these two plays a really big role in securing Mac. BSD security policies and Mach access permissions constitute the essential foundation of security in Mac OS, and they're critical to enforcing local security (macOS Security, n.d.). Password usage is highly recommended and supported by MacOS to prevent unintended modifications of firmware settings on a specific system. Firmware password is used to boot from an unauthorized system volume, unauthorize access to macOS recovery and many more.

In terms of App Security, mac OS is defended against malware as it includes built-in technologies to make sure that only trusted apps are installed. There is a layer approach to app runtime protection and app signing as to avoid any interfere in legitimate apps. Gatekeeper is a feature in mac OS to control the sources and to filter which apps can be installed in Mac. Any organzations and users are allowed to set their own requirements of security level.

In Mac OS, there will be like a scanning and signature-based detection of malware. If there were to be any malware infections, XProtect sigantures will be updated right away. How Xprotect works: It quickly detects and block the installation of malware detected. What happens if the malware succeed in making its way into the computer? Malware removal tool will be activated as to help in remediate infections.

Introduction to Linux

Linux is an operating system or kernel and it is the most open-source operating system. It is invented by a man named Linus in 1991. This operating system is UNIX like just with some amendments and improvements here and there. The advantage of Linux is that it enables the programmers to design their own operating system. With time, Linux has become one of the most popular and highly-used operating system in the world aligned with Mac OS and Windows. Linux is the underlying backbones of operating system distributions like Ubuntu, Knoppix and many more.

Distribution	Description
Ubuntu  Figure 16	Ubuntu has just made it first appearance in 2004 but its achievement is more than its short history. The founder is Mark Shuttleworth and it is run under a company named Canonical. They distribute Ubuntu for free and impacted in their selings.
Fedora  Figure 17	Fedora is Linux distribution developed by the community supported Fedora project. It contains software under free and open source licenses. Fedora is the free version of Red Hat.

Linux Architecture

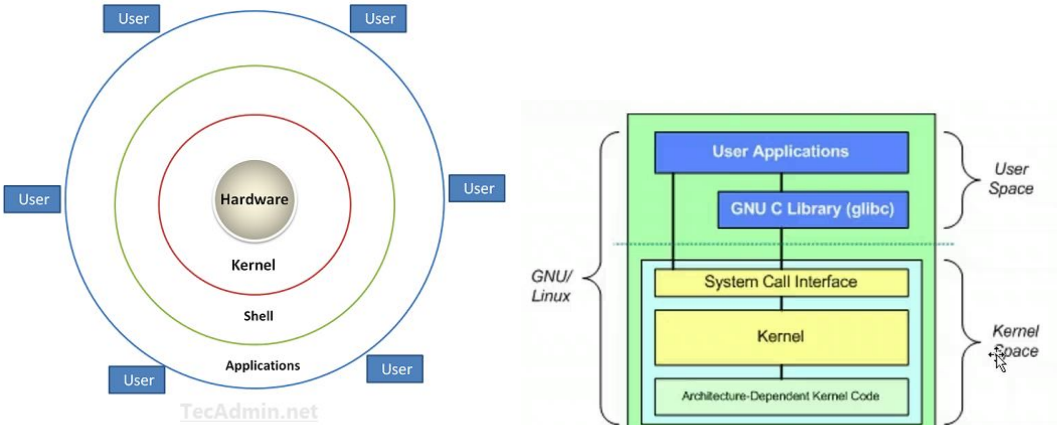


Figure 18: Architecture of Linux

Linux's architecture encompasses of components like the Kernel, Hardware layer, System Library, Shell and System Utility. The Kernel is the main part of the architecture. It is responsible to handle all of Linux's activities. Kernel is used to interact with the underlying hardware. For instance, CPU and memory are the examples of Kernel-managed objects.

There are two types of Kernel which are Monolithic and Micro Kernel. Micro kernel is more to accomplish basic functionalities and provide environment that needs to run in an operating system. Whereas monolithic kernel is the kernel's working space. It is able to load and unload executable modules at run time dynamically.

System utility program is to specify individual tasks. The utility software is system software and it is designed to run applications of a computer system. System software plays as an interface between hardware and user applications. Shells is the interface that receive input from the users and forward it to the Kernel. It also works vice versa. User applications can be anything including our web browser. It runs on shell parts.

Linux File Management System

The Linux directory structure is like a tree. The base of the Linux file system hierarchy begins at the root. Directories branch off the root, but everything starts at root (Linux Directory Structure and File System Hierarchy, n.d.).

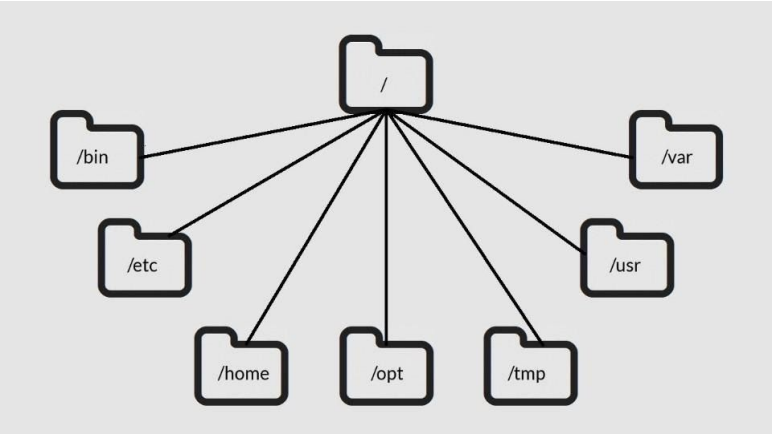


Figure 19: Linux tree structure

One huge difference between windows file structures and Linux file structure is its starting point. For example, in windows, the root begin at the drive letter like C:/ which means it begins at the hard drive while Linux is simply '/'.

The slash in Linux is known as root. Every file path in Linux, they are all begin with '/'. For instance, /bin and /dev. So in /bin, all of the users binary files will be stored and it contains binary executables while in /dev is where your device files are at including your physical devices like hard drive or optical drives.

Linux Memory Management System

Linux corporates Memory Management Unit (MMU) in its operating system. What MMU does is that it translates physical memory address to linear address (Special features of Linux memory management mechanism, n.d.).

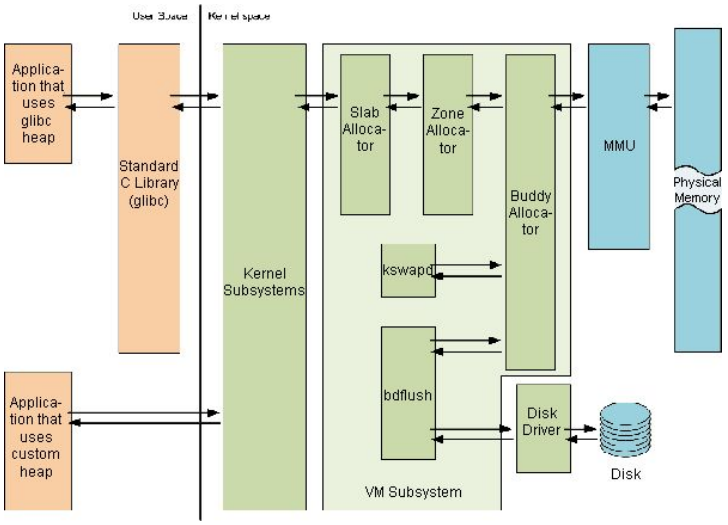


Figure 20: Linux memory management scheme

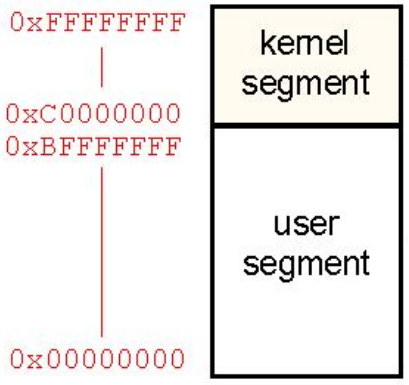


Figure 21: Linux 32-bit address space

Based on Figure 14, processes in Linux will have two segments which are Kernel Segment and User Segment. Kernel segments contains specific data such as kernel instructions, data and some stacks on which kernel code can execute. Physical memory locations can be directly accessed by Kernel as it is directly mapped to physical memory. While user segment

is to process specific data like program code and stack. Each user process is assigned to its own private user segment.

As we can see on the Figure 13, user space allocation always leads to kernel allocation. Kernel allocates memory using the chain of three kernel allocators and maps allocated pages to the address space of the process, which has requested the allocation (Special features of Linux memory management mechanism, n.d.)

Linux Device Management

Linux is able to recognize any hardware component that is plugged into an already running system. This is called Hotplugging and it can be accomplished with the combination of Udev, HAL and Dbus.

Udev supplies a dynamic device directory containing only the nodes for devices which are connected to the system. It creates or removes the device node files in the /dev directory as they are plugged in or taken out. Dbus is like a system bus which is used for inter-process communication. The HAL gets information from the Udev service, when a device is attached to the system and it creates an XML representation of that device. It then notifies the corresponding desktop application like Nautilus through the Dbus and Nautilus will open the mounted device‚Äôs files (Udev: Introduction To Device Management In Modern Linux System, n.d.).

The device manager for Linux 2.6 kernel is called UDev. It is meant to create or remove device nodes in the /dev directory dynamically. Udev is dependent on the sysfs file system as it makes devices visible in user space. Persistent device naming system is provided by Udev through the /dev directory, so that it will be less complicated to identify the device. Additionally, UDev provides user space utilities to organize devices and device nodes in a system.

Udev runs in user space and it creates dynamic /dev with device nodes and provide a user space API as to access device information in the system.

```
/dev/disk/by-label:
lrwxrwxrwx 1 root root 10 Jul 4 06:48 1 -> ../../sda6
lrwxrwxrwx 1 root root 10 Jul 4 06:48 boot1 -> ../../sda2
lrwxrwxrwx 1 root root 10 Jul 4 06:48 project -> ../../sda3
lrwxrwxrwx 1 root root 10 Jul 4 06:48 SWAP-sda7 -> ../../sda7
/dev/disk/by-path:
lrwxrwxrwx 1 root root 9 Jul 4 06:48 pci-0000:00:1f.2-scsi-0:0:0:0 -> ../../sda
lrwxrwxrwx 1 root root 10 Jul 4 06:48 pci-0000:00:1f.2-scsi-0:0:0:0-part1 -> ../../sda1
lrwxrwxrwx 1 root root 10 Jul 4 06:48 pci-0000:00:1f.2-scsi-0:0:0:0-part2 -> ../../sda2
lrwxrwxrwx 1 root root 10 Jul 4 06:48 pci-0000:00:1f.2-scsi-0:0:0:0-part3 -> ../../sda3
lrwxrwxrwx 1 root root 10 Jul 4 06:48 pci-0000:00:1f.2-scsi-0:0:0:0-part4 -> ../../sda4
lrwxrwxrwx 1 root root 10 Jul 4 06:48 pci-0000:00:1f.2-scsi-0:0:0:0-part5 -> ../../sda5
lrwxrwxrwx 1 root root 10 Jul 4 06:48 pci-0000:00:1f.2-scsi-0:0:0:0-part6 -> ../../sda6
lrwxrwxrwx 1 root root 10 Jul 4 06:48 pci-0000:00:1f.2-scsi-0:0:0:0-part7 -> ../../sda7
/dev/disk/by-uuid:
lrwxrwxrwx 1 root root 10 Jul 4 06:48 18283DC6283DA422 -> ../../sda1
lrwxrwxrwx 1 root root 10 Jul 4 06:48 25a4068c-e84a-44ac-85e6-461b064d08cd -> ../../sda6
lrwxrwxrwx 1 root root 10 Jul 4 06:48 3ea7cf15-511b-407a-a56b-c6bfa046fd9f -> ../../sda5
lrwxrwxrwx 1 root root 10 Jul 4 06:48 8878a0a4-604e-4ddf-b62c-637c4fa84d3f -> ../../sda2
lrwxrwxrwx 1 root root 10 Jul 4 06:48 e50bcd6d-61ea-4b05-81a8-3cbe17ad6674 -> ../../sda3
```

Figure 22: Persistent symbolic links created by Udev

Linux Security Management

Linux has several security features and some of them are file permissions, data verification and the system firewall. The way every file and directory is determined to be accessed is based on three sets of file permissions which are the permissions of the owner which is the specific account that is responsible for the file, the permissions of the group that may use the file and the permissions that apply to all other accounts. Program file that only has execute permission is the only one allowed to be accessed by users. While in directories, the users in the relevant set still can see the files but they may not read, write or execute unless it gains permission. Most of the files in UNIX-like systems are owned by the root account and have permissions that block access from all other accounts.

Next, in the context of data verification, Unix-like systems offers GNU Privacy Guard (GnuPG) system for encrypting signing files like emails. Additionally, GnuPG follows the OpenPGP standard. GnuPG allows us to encrypt and sign data and communications. In terms of system firewall, some Linux distributions has configured firewall configure firewall rules by default, and offer utilities for managing simple firewall configurations. You may also manage the firewall rules on any Linux system with the standard iptables and ip6tables command-line utilities, or with third-party utilities such as Firestarter. If you decide to use iptables, remember that it only configures restrictions for IP version 4 connections, and that

you will need to use ip6tables to setup rules for IP version 6 as well (Linux and UNIX Security Features, 2016).

Android Custom ROM: MIUI

Background and History

What is MIUI? MIUI or MI User Interface is basically Xiaomi's user interface. Xiaomi have produced many products includes smartphones that using their own version of android firmware which is MIUI. MIUI is a partial source (List of custom Android distributions, n.d.). The latest release of MIUI is MIUI 11. The initial release of MIUI was 16 August 2010 which is 9 years ago. MIUI is the first product of Xiaomi. MIUI was introduced first before they launch their own phones brand. Based on Wikipedia, MIUI that developed by Chinese electronics manufacturer Xiaomi is a stock and aftermarket firmware which is based on Google's Android operating system for smartphones and tablet computers (MIUI, n.d.). There are many kind of features included by MIUI which are dark mode (MIUI 11), AI preload (MIUI 10), and XiaoAI: Xiaomi's AI-powered Voice Assistant (MIUI 9). Everyone who buy Xiaomi will need to interact with MIUI. MIUI adds a new visual style and more features to pure Android.

We can see many big company like Samsung have the phone management application, battery saving features and storage management included in their own brand phones but did you know which brand with that ideas? The answer is Xiaomi Corporation (Android One vs Xiaomi MIUI, n.d.). Android 2.2.x Froyo is the first version of Android that was based on MIUI ROM. Initially, it was developed by Chinese startup Xiaomi Tech in Chinese language. To enhance the basic framework, Xiaomi added a few number of apps. Actually MIUI does not ship with Google Play Services so MIUI access to Google Service is blocked due to the disagreement between Google and Chinese government but MIUI that releases for android devices outside of China will have the Google Play Services and the Google Apps (List of custom Android distributions, n.d.). Google have certified the MIUI global version. Xiaomi have produced eleven versions of MIUI which we will discuss each version later. Each of Xiaomi's phones have MIUI except Mi A1, Mi A3 and Mi A2 which they are using Android One. Android One is a clean version of android with no skin

and zero bloatware. Android one is a near-stock version of the Android operating system released by the Google (Android One, n.d.)

MIUI Version

1. MIUI V1

MIUI V1 is the first version of MIUI which initially was launched on 16 August 2010 and was based on AOSP build of Froyo. It had only 100 people in the beta tester group. Back then, MIUI V1 was easy to use and simple. If we compare it with Pure AOSP ROM back then, MIUI V1 have more and better functionalities. The android version MIUI V1 using is 2.1 and the initial Beta release is 0.8.16. Figures below show the MIUI V1 icon.

Figure 23

Figure 24

2. MIUI V2

MIUI V2 had a mysterious release. It was released on 29 October 2010. Xiaomi did not release any official statement about it. MIUI V2 occur the changed of user interface. Xiaomi has redesigned the user interface. The android version that MIUI V2 use is 2.1 until 2.3.6. More new functions have been added in MIUI V2. MIUI V2 icons has changed, make it looks more delicate with the re-revised shadow. This current version has been made available for many smartphones so more smartphones can use MIUI V2 back then compared to MIUI V1. Figure below shows the icon of MIUI V2.

Figure 25

From the figure above, if we compare it with MIUI V1 we can see that messages and music icon has completely changed. Overall, we can find that the shape of icon has slightly changed compared to the version before. The shape of MIUI V2 icon looks like a square icon with and ease edge compare to MIUI V1 icon.

3. MIUI V3

MIUI V3 is the third version of MIUI which is it using Android version 2.3.6. The last Beta release was 2.4.20. The third version of MIUI also had user interface notable changed. The user interface has been redesigned which same as MIUI V1 and MIUI V2. User can customise their MIUI ROM based on what the user wants they to look like because themes was first introduced on this version. It is based on Gingerbread, Google's Android Mobile Operating System 2.3 (A Journey Back to the History of MIUI ROM: MIUI V1 to MIUI 8, n.d.). From the figures below we can see a new icon has been added which is theme icon that has become the important thing to

the MIUI development process.

Figure 26 **Figure 27**

4. MIUI V4

Figure 28

MIUI V4 was released on 22 February 2013. A bundle of new features were added in this version. MIUI V4 using 4.0.4 – 4.1.2 Android version and was based on Android's Ice-cream Sandwich or ICS. It introduced a series of Google-related APPs which include Video app, Play Store and Themes. A series of Mi APPS APPs was also developed. The notabled change occur in this version are new user interface and anti-virus was added such as Tencent's Anti Virus. These new function is not found in standard Google's pure AOSP ROM. The last Beta released was 3.2.22 and the last Stable released was ICS24.0

5. MIUI V5

MIUI V5 had a huge changed in its user interface. This version of MIUI had many upgraded, supported new system animation, the gesture to open the notification shade, desktop beautification and other. MIUI V5 hag new user interface and the Google Services were removed from the Chinese Version. The graphic user interface has undergone major redesign but it still maintain the similar users' experience and operations. All Google's App and service were completely removed and the entire new environment of MIUI ROM were assimilated into MIUI V5 ROM since all the access to the Google Service were completely blocked and no smartdevices allowed to install any Google Apps due to the Mainland China government policies. Figures below show that gallery, music, setting and other icon has totally changed. MIUI V5 used 4.1.2 – 4.4.2 Android version. The initial Beta released was 3.3.1 while the last Beta released was 3.3.1. Lastly, the last stable release was 22.0

Figure 29

6. MIUI 6

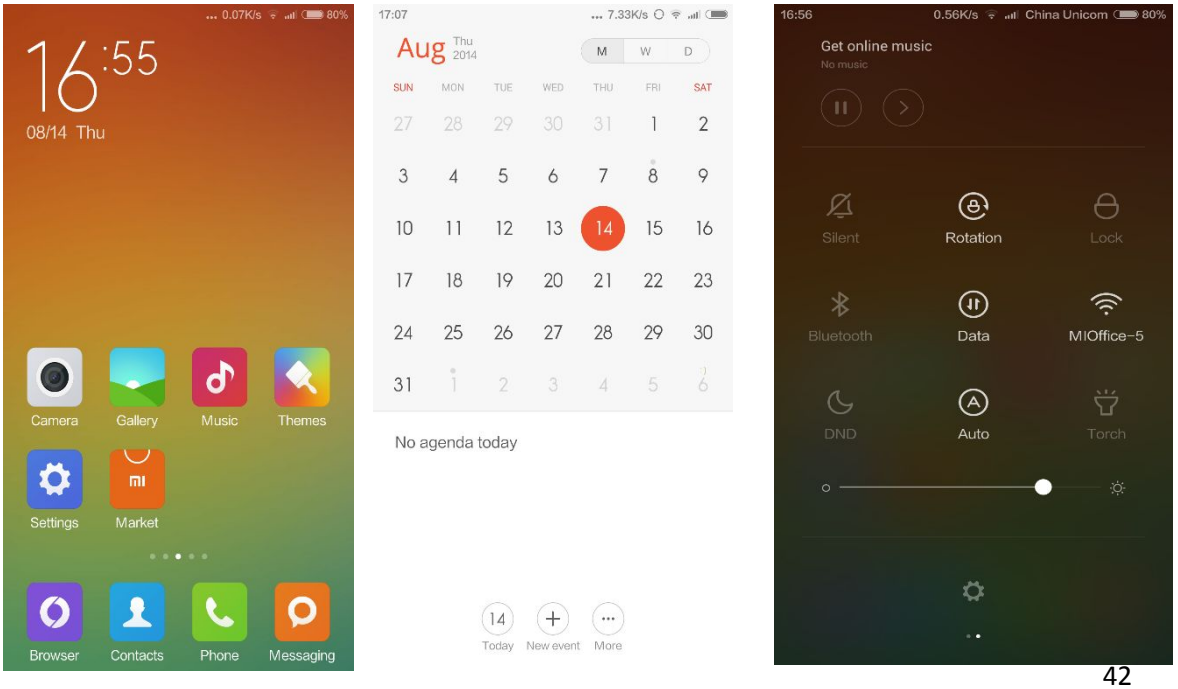


Figure 30 **Figure 31** **Figure 32**

MIUI 6 was released on the fifth birthday of MIUI ROM. MIUI 6 came with a ton of new features and a new look. MIUI 6 was all about the look. MIUI sticks to the orange scheme which it served to distinguish it a little bit from similar themes and design. MIUI 6 has been made available to all Xiaomi's smartphones especially Mi 3 and Mi 4. The MiHome Launcher and the ports for supported devices have not been updated and it still remain at MIUI V5. User now can use quick toggles, notification center and search by using gesture either inside apps or lockscreen. Power Saving mode has been launched and Mi Browser can now syncs to the Mi Cloud. This functions easily switching browsing between Xiaomi devices. This version had the biggest difference MIUI Launcher compared to the older versions. It have all the new look. New messages, calls and downloads are easier to read with this version because it gave a bigger black notifications bar at the top of the screen. It also makes it easier to the user to read number of messages by just look at the lock screen. MIUI V6 new cloud features also able to identified the number phone that's been calling you even though the user does not save that number into the user contact. User can now mark, identify and block all unwanted calls with several details option. There's also a new application called MIUI Life which this application will use the user location then user can explore new restaurant, purchase movie tickets, books or hotels. Clean Master, Xunlei download engine and Data Usage Center also has been added into this version. The last stable release was 6.7.2.0. The first beta release was 4.8.29 while the last beta release was 4.4.2 – 5.0.2. Minimalist design and debuted a new look was the focused things for Xiaomi on MIUI 6 version. The Mail application has been redesigned by putting all mails with the same subject into one folder so it will be easy for user to see what's new at a glance. Users can also view and save attachment easily.

6. MIUI 7

Figure 33

MIUI 7 used 4.4.2 – 6.0.1 Android version. The initial beta released was 5.8.13 and the last beta release was 6.5.26. The stable released was 7.5.10. Xiaomi focus more on optimizing the performance in this version. The UI had not been changed much but it had 4 exclusively designed built-in themes. One of the top features in MIUI 7 is performance optimisation. The speed of MIUI 7 was been increased about 30% by optimising the system response time. It loads both app data and app animation simultaneously. Secondly, is optimised battery life. Before this, background process such as GPS, mobile data and WiFi consumed 48% battery life. To reduce battery life, Xiaomi have optimised background usage and regulating app sync times. They also optimised popular apps to minimise the consumption. Next, MIUI Data Saver ensure an optimal internet experience.by incorporating Opera Max in order to save amount of

data consumed by smartphones. It helps to speed up loading and users can save up to 50% their data usage. Fourthly, is Showtime. Showtime is a Video Caller ID. The feature allows you to record 5 second looping video and set that as a contact card instead of having a static photo. Users can shared their contact card with their friends. Other than that, MIUI 7 also have DND mode for Mi Band or also known as Do Not Disturb mode. Mi Band as an activity tracker helps the phone to detect when users are asleep and then it will automatically turns on the DND mode. It also will disabled the DND mode when it detects the users are awake so the users can start receiving alerts right away. MIUI 7 also came with XXL text. Viewing normal size can be a strain especially for the elderly. Now with XXL text users can adjust the text on their phones to a bigger size. Child mode also one of the features in MIUI 7. This feature allows parents to restrict their child's access to information by letting the parents pick which apps and features are accessible to them.

7. MIUI 8

Figure 34

There are many useful features and customizations in MIUI 8. The stable release for MIUI 8 was 8.5.10.0. MIUI 8 use 4.4.2 – 7.1.1 android version. Devices that are worthy of an MIUI 8 include Xiaomi Redmi 1S, Redmi 2, Redmi 2 Prime, Redmi Note 3 Qualcomm, Redmi Note 3 Special Edition, Redmi Note 3G, Redmi Note 4G, Redmi Note 2, Redmi Note Prime, Redmi 3, Redmi 3S, Redmi 3S Prime, Mi 2, Mi 2s, Mi3, Mi 4, Mi 4i, Mi 6, Mi Note and Mi Max and other. There are a few things users need to know about MIUI 8 which included Second Space, Dual Apps,

new gallery features, Caller ID and messaging, scrolling screenshots, Qucik Ball,

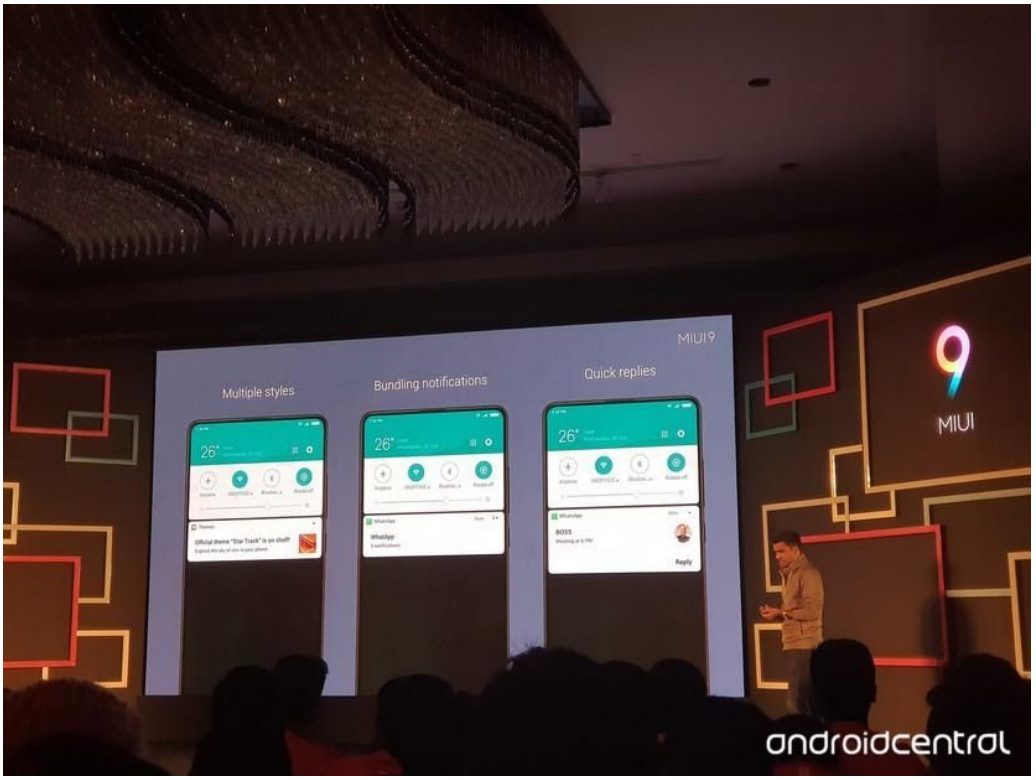
Figure 35

calculator, and note apps. Firstly, Second Space lets users do the work of two smartphones on one. The Second Space features lets users create the secondary profile and then set up a password. Then, users can switch profiles through a Switch app. Switch app will

show up once users enabled the Second Space feature. Next, Dual app is a nifty feature as it brings the ability to run two separate instances of the same app. For example, users can run two separate Whatsapp accounts using one smartphone. The new gallery features have video editing option which users can trim videos, add filters, text and background music. The gallery also has quick sharing option where users can share a picture on different platform with a swipe up gesture. Quick Ball is a hovering button and stays on the display screen all the times. Users will get an overlay with five shortcuts for home, back, recents, lock, and screenshot or users can customise it. Quick Ball will reminds you of iOS' Assistive Touch which both of them have similar functionality.

8. MIUI 9

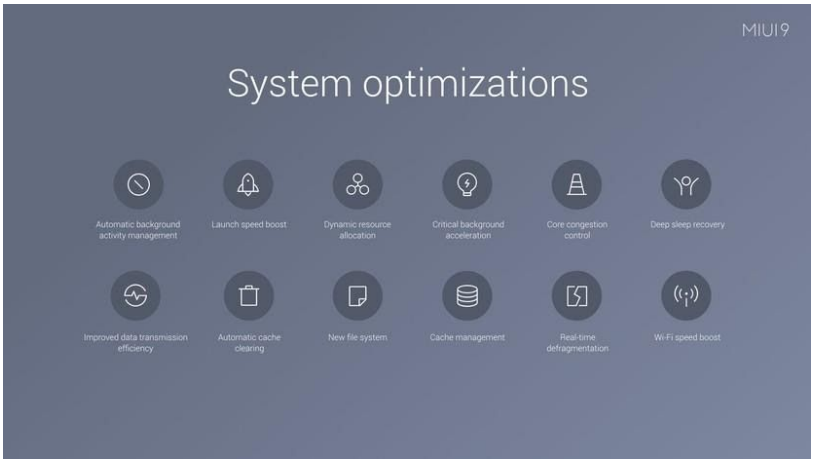
MIUI 9 update has been made available to a lot of Xiaomi's device such as Mi 4, Redmi Note 4G, Mi 3, Mi 2, Mi Note, Mi 4i, Redmi 2, Redmi 2 Prime, Redmi Note 4G



Prime, and Redmi Note 2, Mi Mix, Mi Note 2, Mi 5, Mi 5s, Mi 5s Plus, Mi Max,

Figure 36

Mi Max Prime, Redmi Note 3, Redmi 3, Redmi 3s, Redmi 4, Redmi 4A, Redmi Y1, Redmi Y1s, Mi Mix 2, Mi Note 3, Mi 6, Mi Max 2, Redmi Note 4, Redmi Note 4X, Redmi Note 5A, Redmi 4, Redmi 4X. MIUI 9 was released on 10 August 2017 and the last stable released was 9.6.5.0. MIUI 9 using 4.4.2 – 8.1.0 android version. MIUI 9 came with a lot of new features such as notification shade, image editor, system optimisations and faster app launch, Mi Video app, Mi Drop, split screen. One of the biggest changed in MIUI 9 was the new notification shade. The new notification shade in MIUI 9 behave a lot like it does in stock android. Now, it is easier for user to deal with notifications in MIUI 9 notification shade. The notification panel now supports a bundled of notifications and quick replies by expanding notifications with a single swipe. All the information is now displayed in more succinct manner. Before this, MIUI 7 have Smart SMS Filter but now in MIUI 9 Xiaomi had implemented the their smart filtering mechanisms to the notification panel. Users can allow the important notifications stay at the top of notification panel without getting lost in the clutter. To improve app launch speeds, Xiaomi have optimised the way the systems responds to touch and to deliver an improved overall experience, Xiaomi used the CPU acceleration. In MIUI 9, better background memory management, dynamic resource allocation and more helps to improve app loads. MIUI 9 feels more faster than previous version and the user interface is close to pure android when it comes to loading apps. Other than that, Mi Video app also has been introduced in MIUI 9 which this app will automatically group all the video from the same show in single folder. Users can load multilingual subtitle. It has extensive support for file formats such as AVI, MP4, MOV, MKV, MPG, FLV, RM, TS, ASF and 3GP. Before this, Xiaomi has added a split screen feature in Mi Max 2 but now



split screen is now standard in MIUI 9. Users now can open two apps at the same time and the size of each window can be customized.

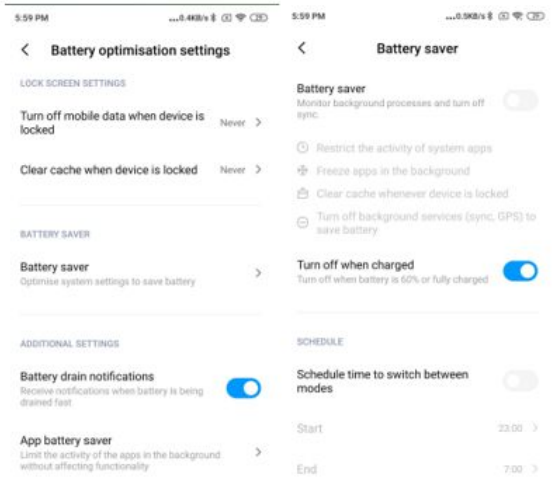
9. MIUI 10

Xiaomi has added a plenty of new features in MIUI 10. MIUI 10 has been made available for device running 6.0 – 10.0 android version. Xiaomi has redesigned 'recents' menu by improving Recent apps pane. The new recents menu has been optimized to include more info on the single screen. This feature offers the app cards that will displayed in a mosaic tile pattern on a vertical scrolling page. Users can kill apps by swipe it away or press and hold on the apps to yield more options such as entering split-screen mode, locking it in the background and checking the application's information. Xiaomi also added Android-P inspired volume controls. Xiaomi has added media volume by default by hitting either of the volume keys. Users also can tap on the silent button at the bottom along with a three-dot menu. Tapping on the three dots below give users access to a lot of more options such as DND buttons, a countdown timer and full volume controls to set the media, ring, and alarm volume levels. Other than that, MIUI 10 also has a very handy feature which is Picture-in-Picture mode. Picture-in-picture mode lets user to do things without switching away from the application that was already on because this mode lets a floating window on top of another application. So, users don't have to close particular app to access a new application momentarily. Autofill support can help users by automatically fill usernames and password without users need to remember the password all the times and type it again and again.

MIUI 10 brings many AI-powered features such as AI preload and AI portrait. AI preload study user's behaviour and anticipating user's actions to predict which application user going to launch and preload it to open instantly. This feature will reduce app load times to zero. AI portrait mode use AI to take pictures with bokeh effect from both front and rear cameras. It works for both single and dual camera phones. MIUI Lab was once an experimental feature that has been test out in MIUI 9. MIUI 9 users might familiar with MIUI lab inside the setting app. Xiaomi has added many new options in MIUI lab in MIUI 10. Firstly, it includes Taplus that can trigger certain actions by pressing and hold on items. There's also a new Car mode that lets users to interact with their phone by using their voice while driving. The feature will help users navigate, play music and read and reply to messages, answer calls and the most important thing is user safety while driving will be more secure. Lastly, Super Resolution feature improve the quality of images by using artificial intelligence.

10. MIUI 11

Xiaomi has announced the MIUI 11Global ROM in New Delhi, India on 16 October 2019. Xiaomi has added a minimalistic design to the interface in MIUI 11. It brings a clean and minimal fork of Android. Xiaomi has designed the new icon shape and redesigned all the native apps to fit into it. Users get new squircle-shaped apps icon that comes with a new classical theme of the MIUI 11. Compared to the previous version of MIUI, this version the apps look uniform, in sync with the overall UI and offers fluid animations. The animation in MIUI 11 feels more smooth and consistent across apps and settings compared to the previous version. MIUI 11 also came with a new font which is Milan Pro that does not look too cartoonish



Ultra-Battery Saver Mode

and has support for Dynamic Font Scaling. Dynamic Font Scaling gives users the freedom to choose the thickness of the character as per their preference and adjusted the text weight based on the content level. One of the headline features of MIUI 11 is Mi Share. Mi Share is a cross-brand file transfer technology from a collaboration of Xiaomi, Oppo and Vivo. Mi Share is an AirDrop for Android that lets users to shares files quickly without any time consuming pairing process. Mi share is said to transfer files locally up to 82 MBps. It can be found under "Connecting and Sharing" menu on the setting page. Xiaomi also enhanced Always-On-Display by taking it a step further. Always-on-display came with a slew of customization options for ambient display. There are animated clocks, colourful backgrounds and the ability to type user own moving quote that users choose as an option. It also has notification light up animation under the ambient display settings that will light up the corners of user's display when receiving notifications. Xiaomi also has a new dynamic sound effect in MIUI 11 that can be played depending on the time and mood of the day which gives a visual theme to notifications, ringtones and alarm sounds. Other than that, MIUI already have a battery saver mode, but in MIUI 11, Xiaomi came out with ultra-battery saver mode. It will disable all the power consuming applications running in the background, resource-intensive cores to bring down the performance, turn on dark theme and decreases screen brightness. Users can enable the ultra-battery saver mode from Security – Battery app and can go on for a full day with just 5% battery left. Lastly, users can force any applications to adopt to dark mode. Dark mode will turn the screen black and text in white colour to make it easy viewing in low light environment. The best part of this feature is it is less power consuming and can extend the phone's battery backup

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MIUI versus Stock Android

Stock Android or also known as “vanilla” android or pure Android is the most basic version of the mobile operating system developed and designed by Google. It’s an unmodified version of Android which means no alteration and changes were made by smartphone manufactures. Stock Android devices run the core kernel of Android (What Exactly Is Stock Android?, n.d.). Companies can modify android to their liking since Android is an open source operating system. Some people might say MIUI is better than Stock Android but some might say otherwise. Be it Stock Android or MIUI, as long as it satisfies user’s need, it’s better because both of them have their

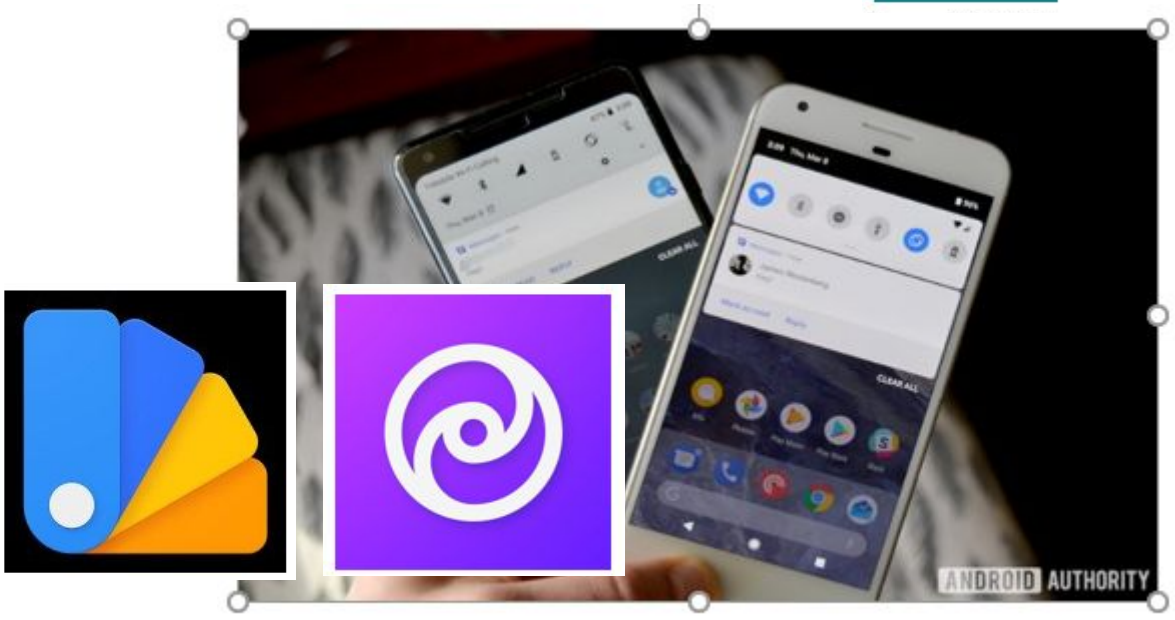
own pros and cons. We will comparing the features on Stock Android and MIUI below.

Figure 37

Figure 38

1. Display and Themes

If we compare the themes of MIUI and Stock Android, we can see that Stock Android still lack of themes. Unlike MIUI, it offers splendid themes support. MIUI has its own theme store where users can multiple free themes from it without having to change the launcher. Users can mix and match from several themes. For example, users



can choose Samsung Note 7 lock style and keep the status bar for pixel. There is no way to change themes in Stock Android without using third-party launchers. If Stock Android user wants to install themes, change the looks of apps, icons, lock screen, navigate bar and change fonts it needs the help from Substratum theme engine and Andromeda. Those users who currently using devices that have Android Oreo 8.0+ do not need to root their device but for those who are having lower than Android Oreo 8.0 needs to root the device. The way to do a screenshot also different in MIUI and Stock Android whereas MIUI has 3 ways which are 3 finger swipe, Volume Down + Power button, and toggle while for Stock Android only has one way which is Volume

Down + Power button. If MIUI has read mode then Stock Android has night light. Other than that, MIUI also has scrolling screenshots features which users can take long screenshot by using 3 finger swipe and tap on scroll option to generate long screenshot. There are so many features that Stock Android don't have in MIUI such as back up themes, change boot animation and boot audio, double tap to wake, full screen mode, one handed mode and set contrast and colours. There is one feature that MIUI doesn't has but Stock Android has it which is change display scaling (DPI).

2. Users & Apps

MIUI also offers Dual apps feature which you can find Dual App option under the Setting. Dual App lets users to run two instances of the same app on their device. For example, nowadays most device can have dual SIM phone, with Dual App users can have two WhatsApp in their phone using both SIM. Users need to download third- party apps to run multiple account such as Parallel Space, App Cloner and 2Accounts. MIUI can restricts applications from running at boot while Stock Android doesn't have this function. To show running apps at the background in Stock Android is by going to the Setting and then tap Developer Options while for MIUI is by going to the Setting and tap Installed Apps.

3. Phone & Contacts App

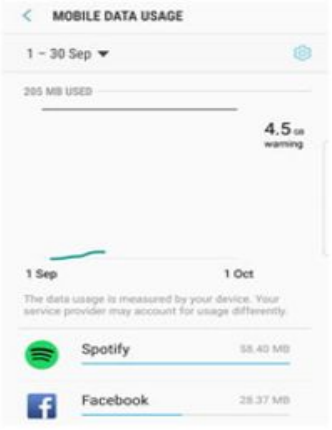
MIUI has a very useful feature for users which is native call recording. There is a small record button right side of the dialer screen when user making a phone call. By pressing that button, it will record both sides of the conversation while on the call and save it in the

recording app on user's phone. There are so many features regarding phone and contact app that Stock Android lacks. Stock Android doesn't provide call blocklist with custom filters, clear all running apps in one click, flash LED on incoming call, flip phone to silence ringtone, incoming call wallpaper, merge duplicate contacts, mute first ring from unknown numbers, sharing contacts via QR Code and turn off screen when call is picked up. All of above were provided in MIUI.

4. Data Usage

Wi-Fi password sharing may be risky based on how your device sharing the password. If your phone running MIUI, it may be not risky as much as Stock Android

because if you want to share your home's Wi-Fi password to your friends and you are MIUI user, you can simply tap on the Wi-Fi name and it will generate a QR code. Your friends can simply scan the QR code and then get access to your home's Wi-Fi without knowing your password. It is different if your phone running Stock Android and a little risky because you either need to tell your home's Wi-Fi password to your friends or you need to type it yourself if you don't want anybody to know your password which is quite boring. Smartphones running MIUI can check or control Wi-Fi or mobile data usage per application while Stock Android still lack of this feature. Smartphones running MIUI can go to Setting and under Wireless & Network, tap on Data usage or Mobile Data, table showing user's data usage for a specific of time will be displayed. If we compare Stock Android and MIUI, Stock Android lack of so many things such as turn off mobile data after plan is



used up, set custom rules for mobile data plan, select Wi-Fi frequency band, set maximum users for mobile hotspot and block users from accessing mobile hotspot.

5. Home Screen & Display Menu

The applications in Stock Android were shown separately in app drawer while in MIUI all applications are shown on home screen. For a quick app switch in stock android, users need to tap recent 2 times and users need to tap it faster compared to Stock Android if users are using smartphones running with MIUI. The applications were arranged based on the install time in MIUI and in Stock Android, the applications arranged sort by alphabet inside the app drawer. MIUI provided many useful features for home screen and display menu which all of these were not offered in Stock Android such as app icon animation after minimizing, change position of applications in split screen mode in one click, clear all running applications in one click, the available RAM were shown, lock running applications in memory, set transition effects, lock or set page layout and uninstall or move multiple applications at once. Other than that, MIUI also provided a very handy features which Stock Android doesn't have which is Inbuilt App Lock. This feature allows users to lock the applications and unlock it using the pattern or fingerprint. If you use a third-party app locker applications, it will show small preview when you first open the application while the native app lock in MIUI doesn't show it. In MIUI users also can hide the application's recent screen. It will quite useful if Stock Android have these kind of features too.

6. Overall Performance

Stock Android offer faster performance compared to MIUI because Stock Android is a clean and uncluttered software. The heavy skin of MIUI will starts to lag. But when it comes to overall performance, it depends on the hardware of the device. If we compare two smartphones on the same hardware, clearly Stock Android will be faster and smoother than any custom ROM. If we compare MIUI device running 4GB RAM and a Stock Android device running 2GB RAM, obviously MIUI will perform better. The RAM management in Stock Android is still better over any skinned ROM.

7. Bloatware

Some people might like bloatware but some might not like it. Stock Android doesn't have bloatware. Users can decide on their own what applications they need. It may sound good but Stock Android lack the basic applications such as music apps, file manager and proper gallery. It still have a few Google apps such as Google Photo, Google Book and Play Music but they are too fancy to do a simple task. There are no third-party applications installed on Stock Android other than Google apps. MIUI is full with Mi Apps which it has built-in gallery, music player, a compass app and screen recorder. Users also get other applications such as Mi Store, Mi Community, Mi Security and Mi Drop. Mostly, all of these applications are a large size which it affects the phone's performance.

CONCLUSION

Operating system is the most crucial part in managing all of the hardware and other software. Operating system is not limited to only phones but is also one of the main attributes to run and execute any applications on a desktop. Without an operating system, it would be impossible to run a program as both hardware and software are dependent among each other.

Based on what we have written above, it is really clear that operating system provides basic functionalities to devices as to make it functional and operate successfully. The features that enable operating system to be the heart of all devices are protected and supervisor mode, enable program execution, handling I/O operation, Error detection and handling, Information and resource protection, virtual memory multitasking, manipulation of the file system, resource allocation and many more. We have tweak some of these features in the above writing like memory management, file systems and so on.

According to what we have discussed, operating system is not only limited to one but we have variety of OS and we are free to choose which one that we want to purchase. For desktops and laptops, the top and the most used operating systems in the market are windows,

Mac OS and Linux. From what we have found, these three operating has its own gains and lose depending to the users' need. These three operating systems have their own specialities over others and really powerful but there are still some lacking that can be improved. If you are a game lovers, Mac OS might be the last choice in your option list as Mac OS is not a pro gamer operating system due to their lack of RAM and dedicated graphic cards. But on the pro side, if you want to buy a desktop with better longevity and life span, Mac OS must be one of your go-to. As Apple is hardware and software manufacturers, they integrated those two components in Mac OS and resulting in a very smooth operating system.

Windows on the other hand has a really huge benefit and it is said that almost 90% of devices are using it for their operating system. Even though Windows is easy to get hijacked or malware attacks, but the functionalities are just incredible. Additionally, most of the apps in the market right now are all designed specifically for windows user. It is quite hard to find a Mac OS application and they are limited. As there are plenty of apps for windows user, users will have their own options and can choose which one they want to use. But as Windows has unlimited number of apps, it makes windows vulnerable to malware and hackers as it is their number one target.

Linux is also categorized as one of the top used operating systems across the world. Linux is an open source operating system where it allows any users to take it code and design it their own. That is why Linux has many distributions and the most popular is Ubuntu and Fedora. However, some hardware drivers are not available for Linux. As Mac and Windows have many users compared to Linux, hardware manufacturers tend to manufacture hardware for them and basically those drives are unavailable to be used by Linux. Even though Linux doesn't have version like Windows and Mac, it is still preferable among users because of its strong wall against malware attack thus, increasing security. In fact, in terms of applications, Linux offers a wide range of apps and they are free. Compare to windows, there might be free and there may be applications that have fees. But still, as it is not a pro-gaming operating system, this might be the last choice for gamers.

Essentially, as operating system are the core component of a device, we know that mobile phones that we are using right now works because of the existence of OS in it. Based

on the previous discussion, we acknowledge the fact that mobile phones OS and desktop OS are different. Mobile phones have many OS but the one that is really famous, easy, reasonable price and complete with top notch performance is Android. As Android is an open source system, the code can be customized and designed depending on the individuals and this is what we call Custom ROM. A custom ROM is a modified android operating system that you can install on your Android device that open-source developers have developed with a bunch of new features.

Xiaomi was gives a good amount of freedom to make certain tweaks to the software by MIUI such as adding some features that useful to the end consumer and offering more smoothly experience. Some people might find this useful but some people might find that MIUI has a lot of layers that remove the charm of Android. MIUI has many kind of versions. Each version of MIUI have the new added features or improvise the existing features or any kinds of things that can improve the performance of device. Xiaomi have produced eleven versions of MIUI so far. People who wants a completely hassle-free experience with some customisability are very recommended to use MIUI. Most of the bloatware can be removed as well. MIUI is a good option for theming and runs well on less powerful hardware (The many flavors of Android: a look at the major Android skins, n.d.). There are a lot to catch up with MIUI when it comes to the consistency and features. Xiaomi still provides MIUI updates even though it might be a little slower in updating android version even the lowest range of Xiaomi devices launched 2 years back are receiving updates to date. MIUI is more polished and offer more customization to users. One of the biggest strengths MIUI is how community-driven it is. Developers value feedback from the users and they have dedicated a forum for users to provide their feedback and recommendations for future software updates which is a very innovative mobile operating system. Some people might say MIUI is better than any other custom ROM but some might say otherwise.

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