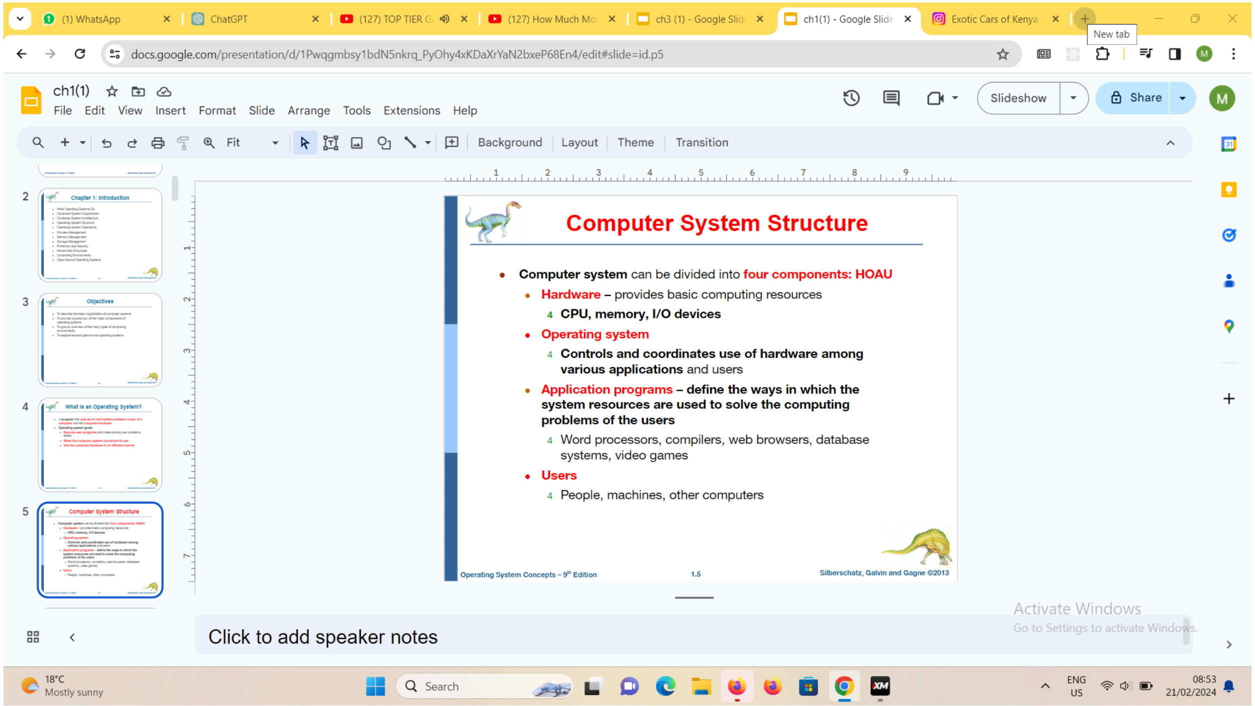
Chapter 1


Computer System Structure
Computer system can be divided into four components: HOAU
Hardware – provides basic computing resources
CPU, memory, I/O devices
Operating system
Controls and coordinates use of hardware among various applications and users
Application programs – define the ways in which the system resources are used to solve the computing problems of the users
Word processors, compilers, web browsers, database systems, video games
Users
People, machines, other computers
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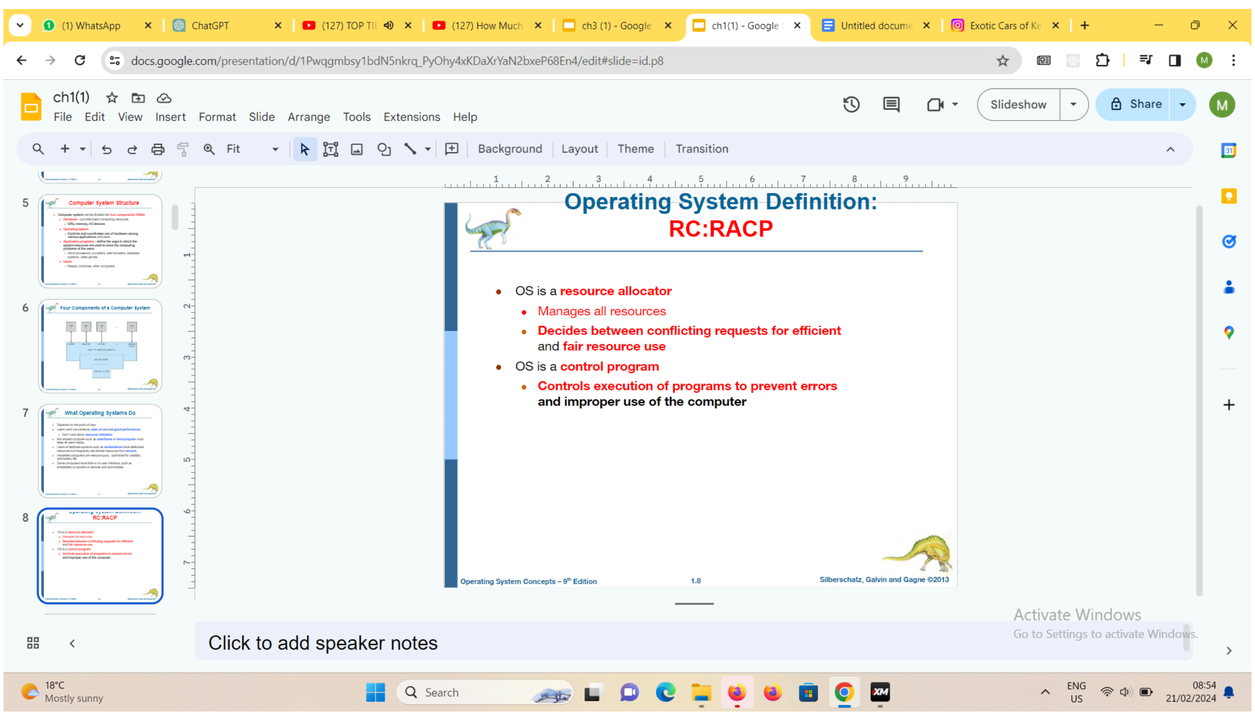
Operating System Definition:
RC:RACP
OS is a resource allocator
Manages all resources
Decides between conflicting requests for efficient and fair resource use
OS is a control program
Controls execution of programs to prevent errors and improper use of the computer
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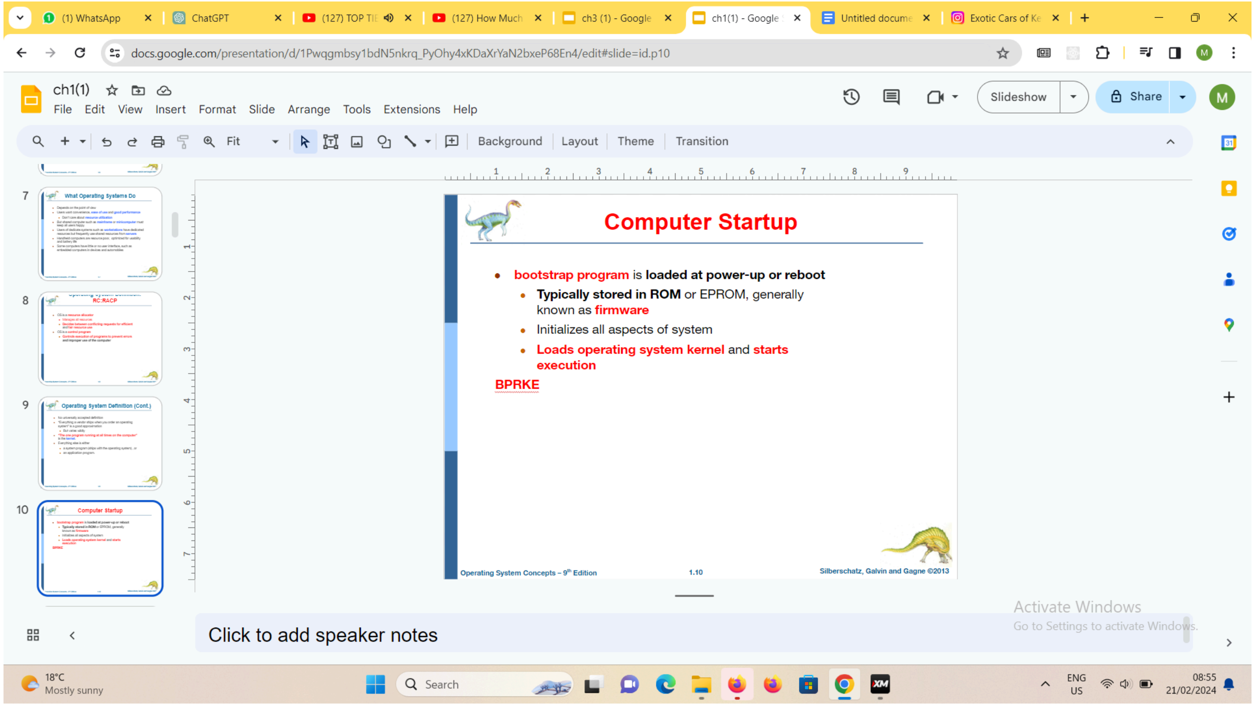
Computer Startup
bootstrap program is loaded at power-up or reboot
Typically stored in ROM or EPROM, generally known as firmware
Initializes all aspects of system
Loads operating system kernel and starts execution
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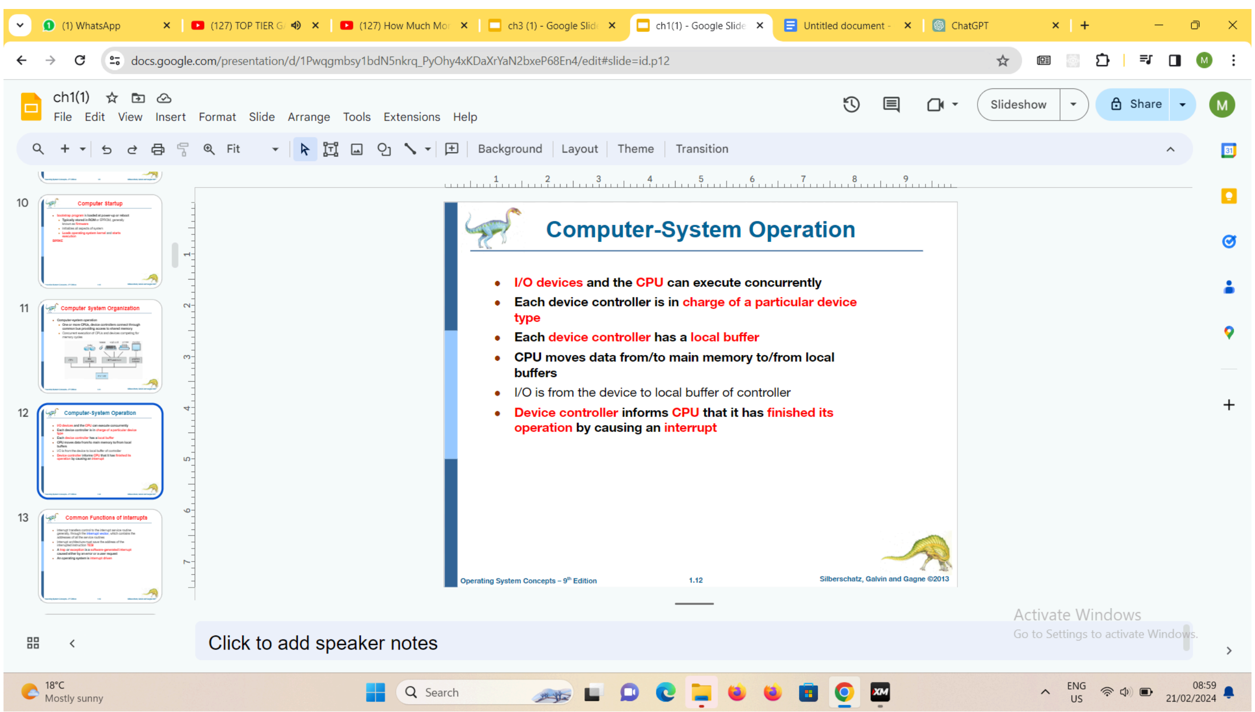
Computer-System Operation
I/O devices and the CPU can execute concurrently
Each device controller is in charge of a particular device type
Each device controller has a local buffer
CPU moves data from/to main memory to/from local buffers
I/O is from the device to local buffer of controller
Device controller informs CPU that it has finished its operation by causing an interrupt
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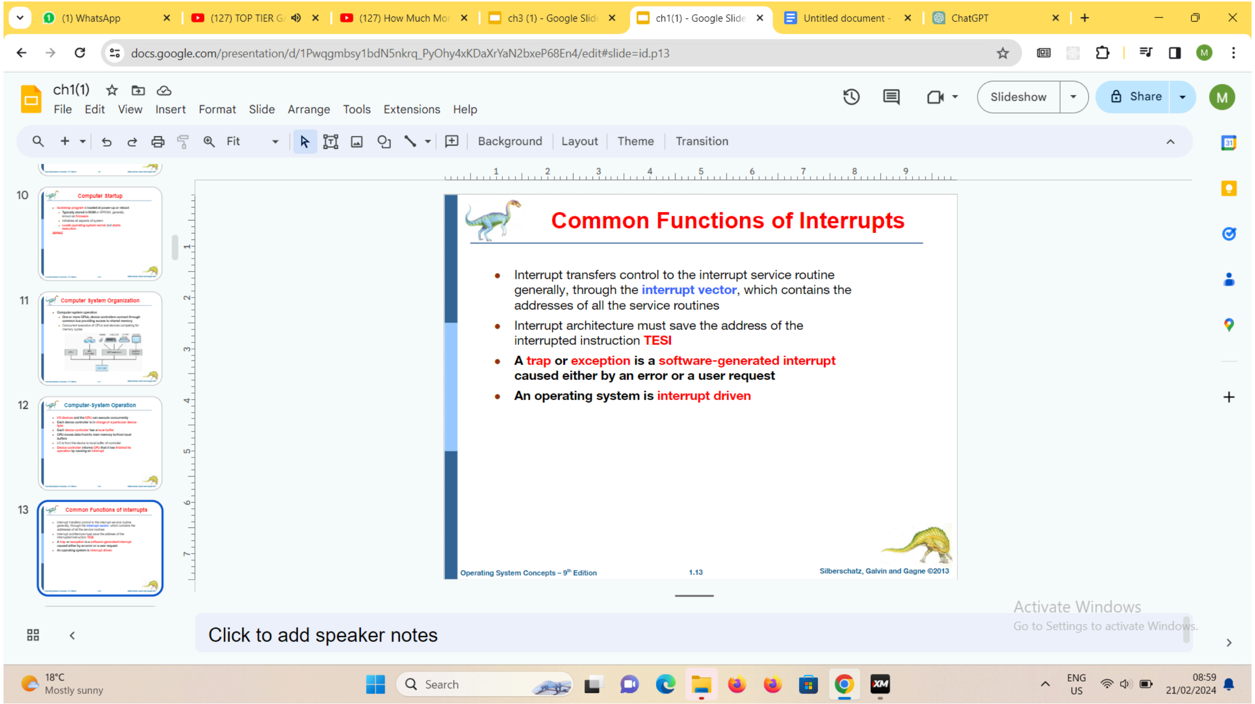
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Common Functions of Interrupts
Interrupt transfers control to the interrupt service routine generally, through the interrupt vector, which contains the addresses of all the service routines
Interrupt architecture must save the address of the interrupted instruction TESI
A trap or exception is a software-generated interrupt caused either by an error or a user request
An operating system is interrupt driven
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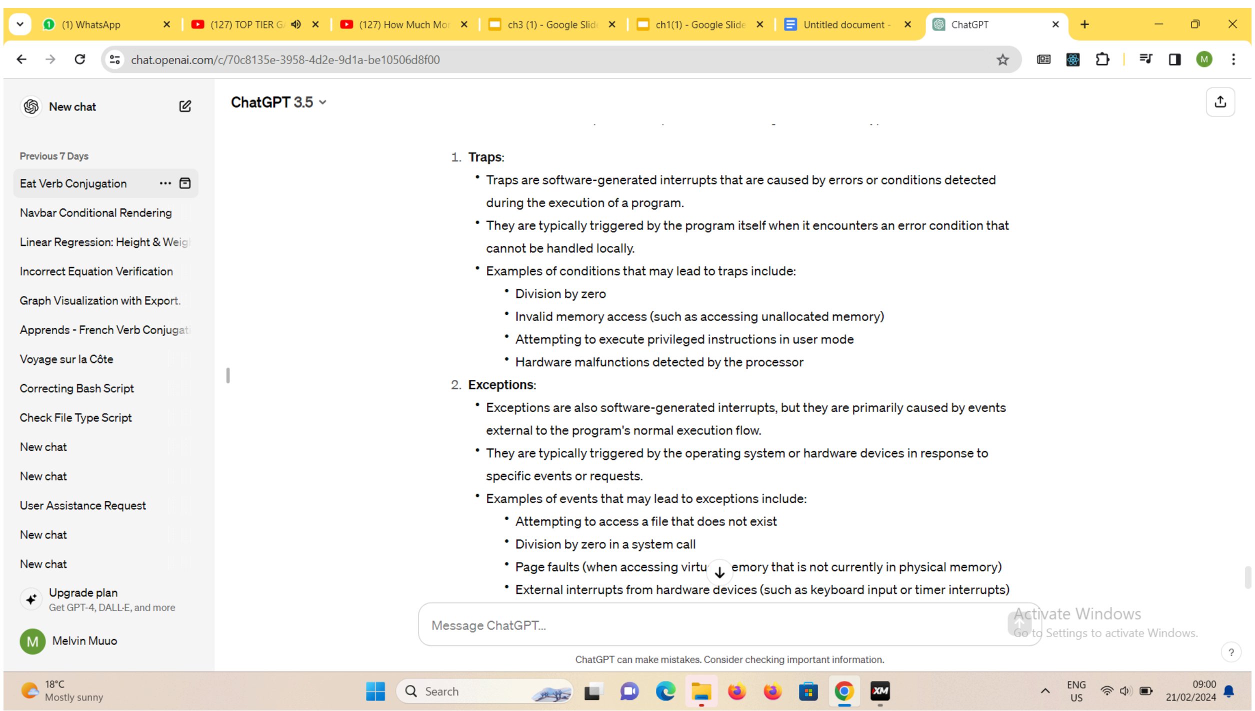
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1. Traps:
Traps are software-generated interrupts that are caused by errors or conditions detected during the execution of a program.
They are typically triggered by the program itself when it encounters an error condition that cannot be handled locally.
Examples of conditions that may lead to traps include:
Division by zero
Invalid memory access (such as accessing unallocated memory)
Attempting to execute privileged instructions in user mode
Hardware malfunctions detected by the processor
2. Exceptions:
Exceptions are also software-generated interrupts, but they are primarily caused by events external to the program's normal execution flow.
They are typically triggered by the operating system or hardware devices in response to specific events or requests.
Examples of events that may lead to exceptions include:
Attempting to access a file that does not exist
Division by zero in a system call
Page faults (when accessing virtu emory that is not currently in physical memory)
External interrupts from hardware devices (such as keyboard input or timer interrupts)
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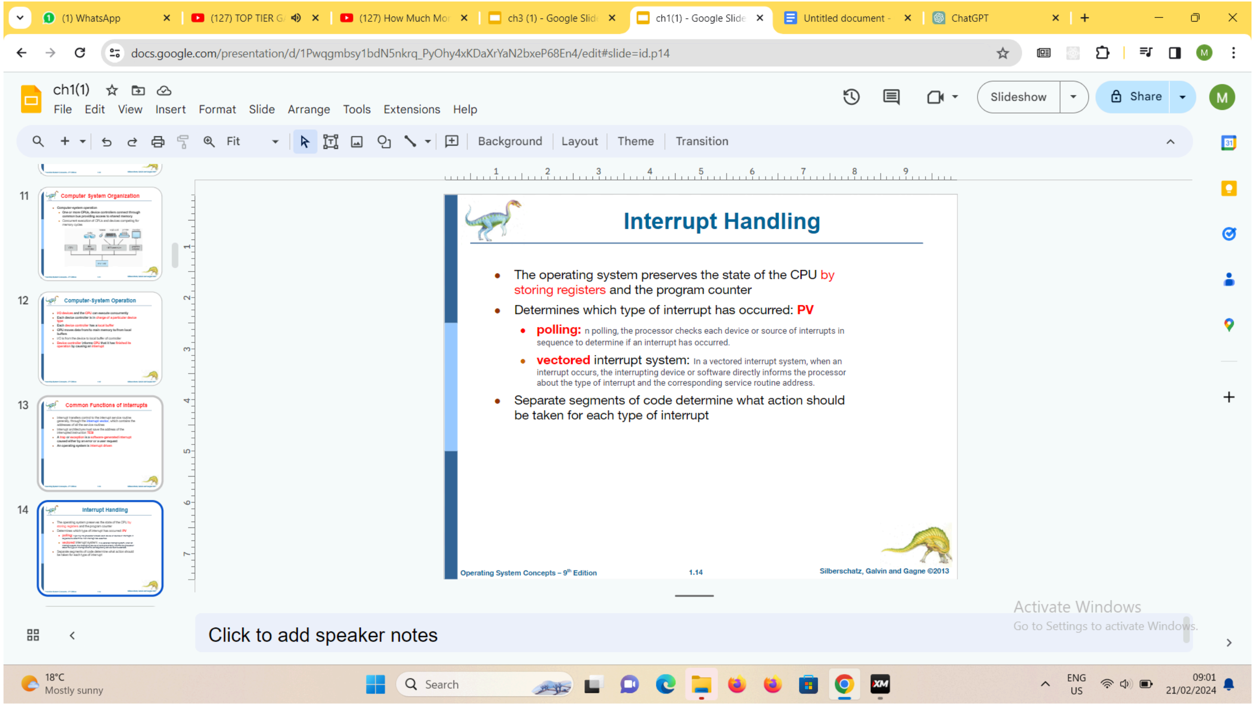
Interrupt Handling
The operating system preserves the state of the CPU by storing registers and the program counter
Determines which type of interrupt has occurred: PV
polling: n polling, the processor checks each device or source of interrupts in sequence to determine if an interrupt has occurred.
vectored interrupt system: In a vectored interrupt system, when an interrupt occurs, the interrupting device or software directly informs the processor about the type of interrupt and the corresponding service routine address.
Separate segments of code determine what action should be taken for each type of interrupt
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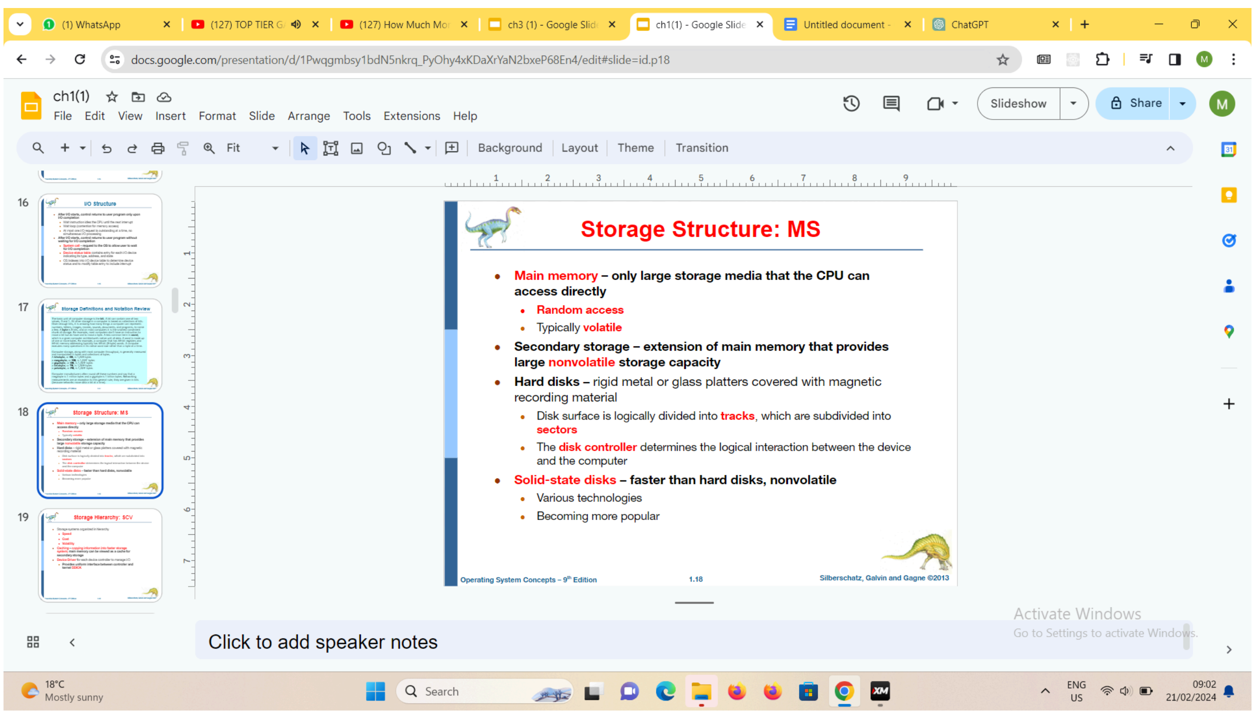
Storage Structure: MS
Main memory – only large storage media that the CPU can access directly
Random access
Typically volatile
Secondary storage – extension of main memory that provides large nonvolatile storage capacity
Hard disks – rigid metal or glass platters covered with magnetic recording material
Disk surface is logically divided into tracks, which are subdivided into sectors
The disk controller determines the logical interaction between the device and the computer
Solid-state disks – faster than hard disks, nonvolatile
Various technologies
Becoming more popular
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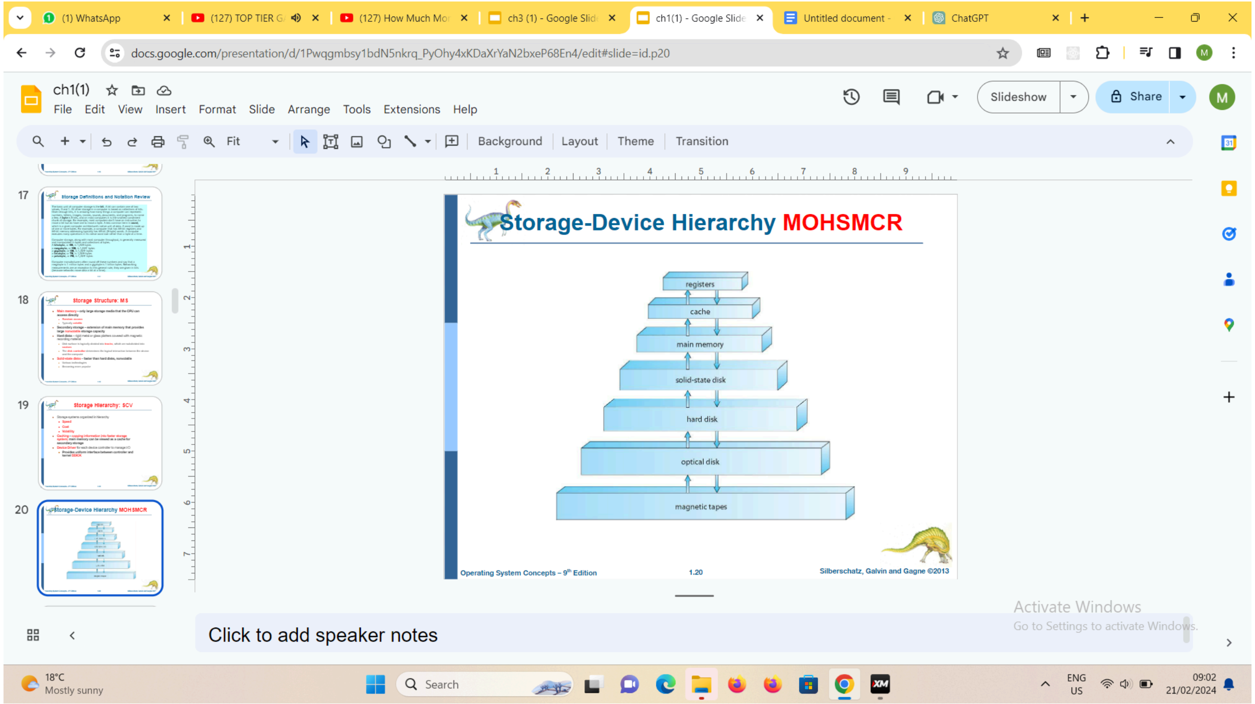
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Storage-Device Hierarchy MOHSMCR
registers
cache
main memory
solid-state disk
hard disk
optical disk
magnetic tapes
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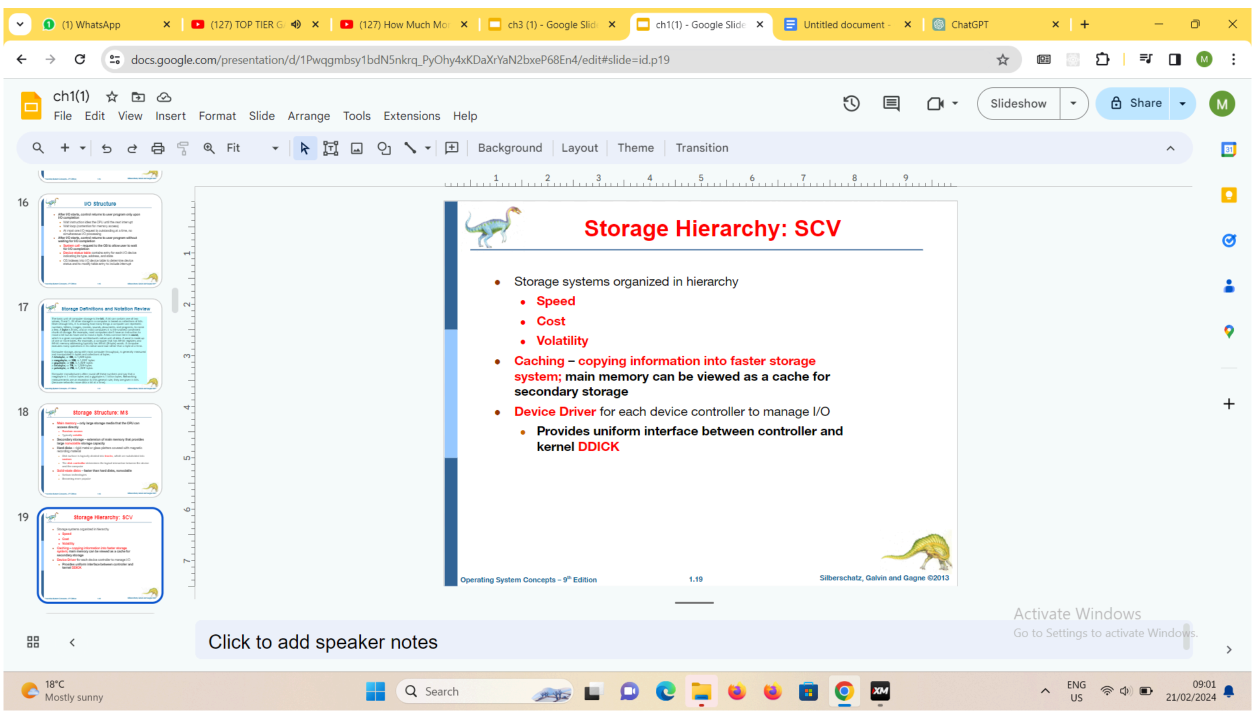
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Storage Hierarchy: SCV
Storage systems organized in hierarchy
Speed
Cost
Volatility
Caching – copying information into faster storage system; main memory can be viewed as a cache for secondary storage
Device Driver for each device controller to manage I/O
Provides uniform interface between controller and kernel DDICK
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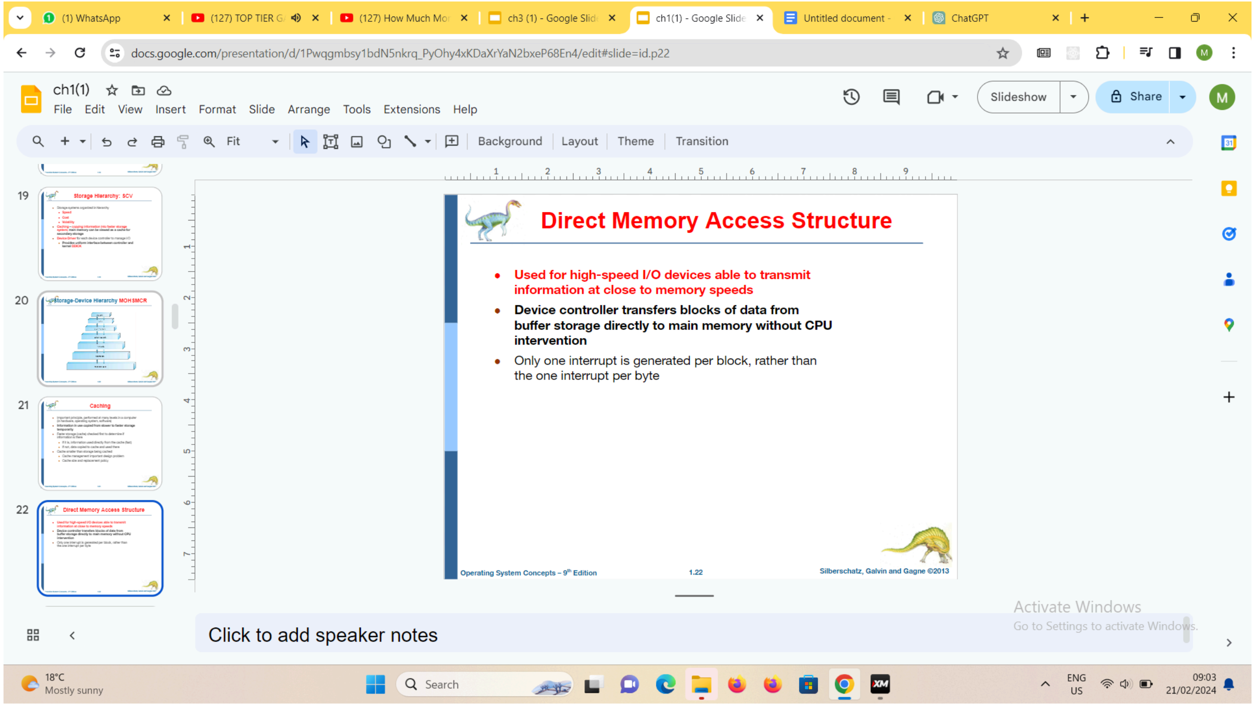
Direct Memory Access Structure
Used for high-speed I/O devices able to transmit information at close to memory speeds
Device controller transfers blocks of data from buffer storage directly to main memory without CPU intervention
Only one interrupt is generated per block, rather than the one interrupt per byte
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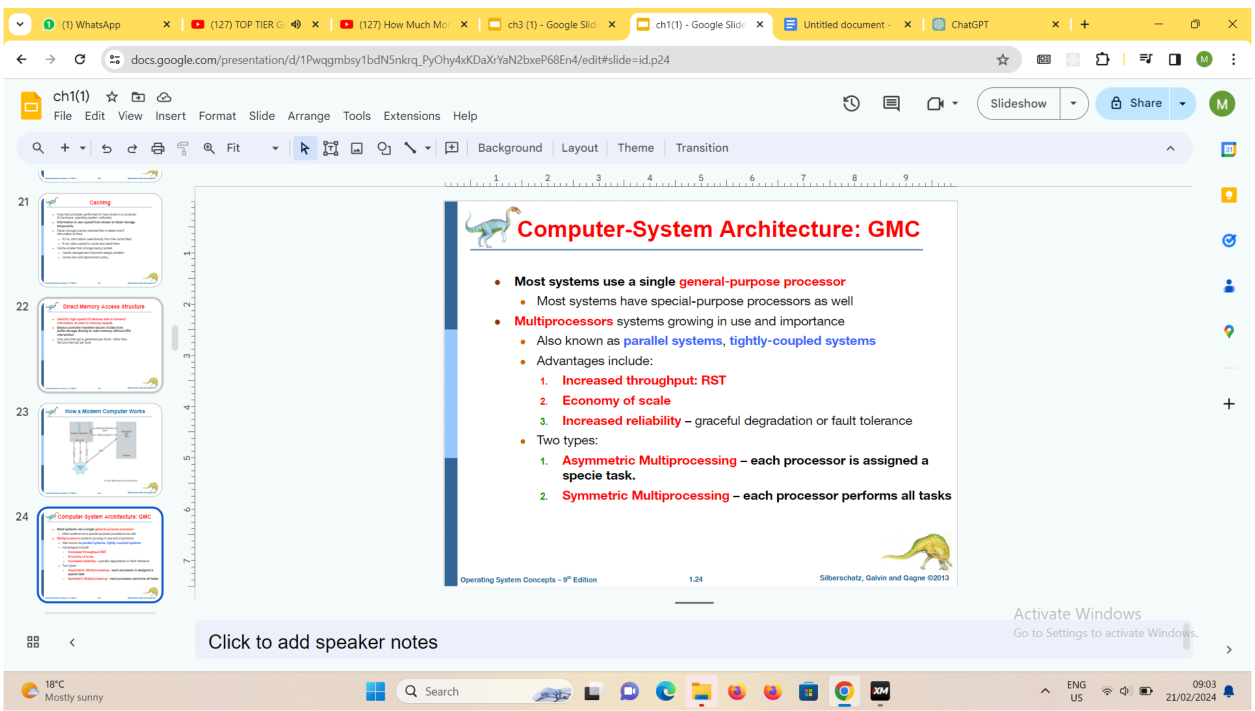
Computer-System Architecture: GMC
Most systems use a single general-purpose processor
Most systems have special-purpose processors as well
Multiprocessors systems growing in use and importance
Also known as parallel systems, tightly-coupled systems
Advantages include:
1. Increased throughput: RST
2. Economy of scale
3. Increased reliability – graceful degradation or fault tolerance
Two types:
1. Asymmetric Multiprocessing – each processor is assigned a specie task.
2. Symmetric Multiprocessing – each processor performs all tasks
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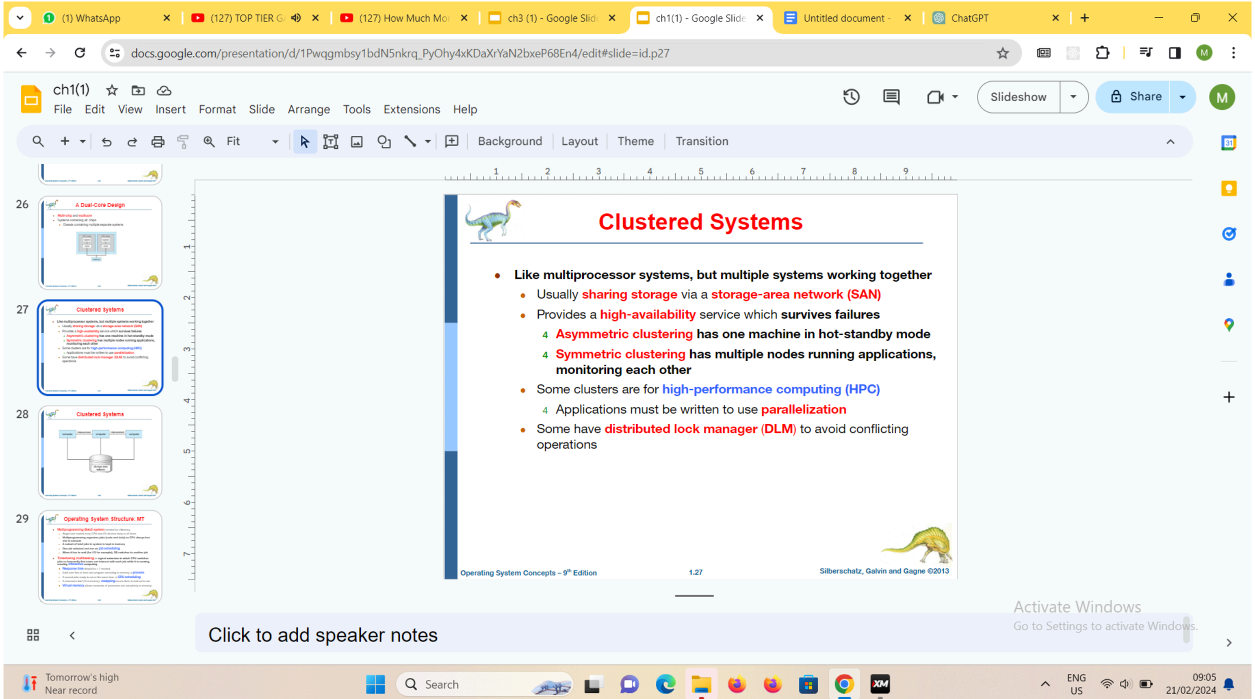
Clustered Systems
Like multiprocessor systems, but multiple systems working together
Usually sharing storage via a storage-area network (SAN)
Provides a high-availability service which survives failures
Asymmetric clustering has one machine in hot-standby mode
Symmetric clustering has multiple nodes running applications, monitoring each other
Some clusters are for high-performance computing (HPC)
Applications must be written to use parallelization
Some have distributed lock manager (DLM) to avoid conflicting operations
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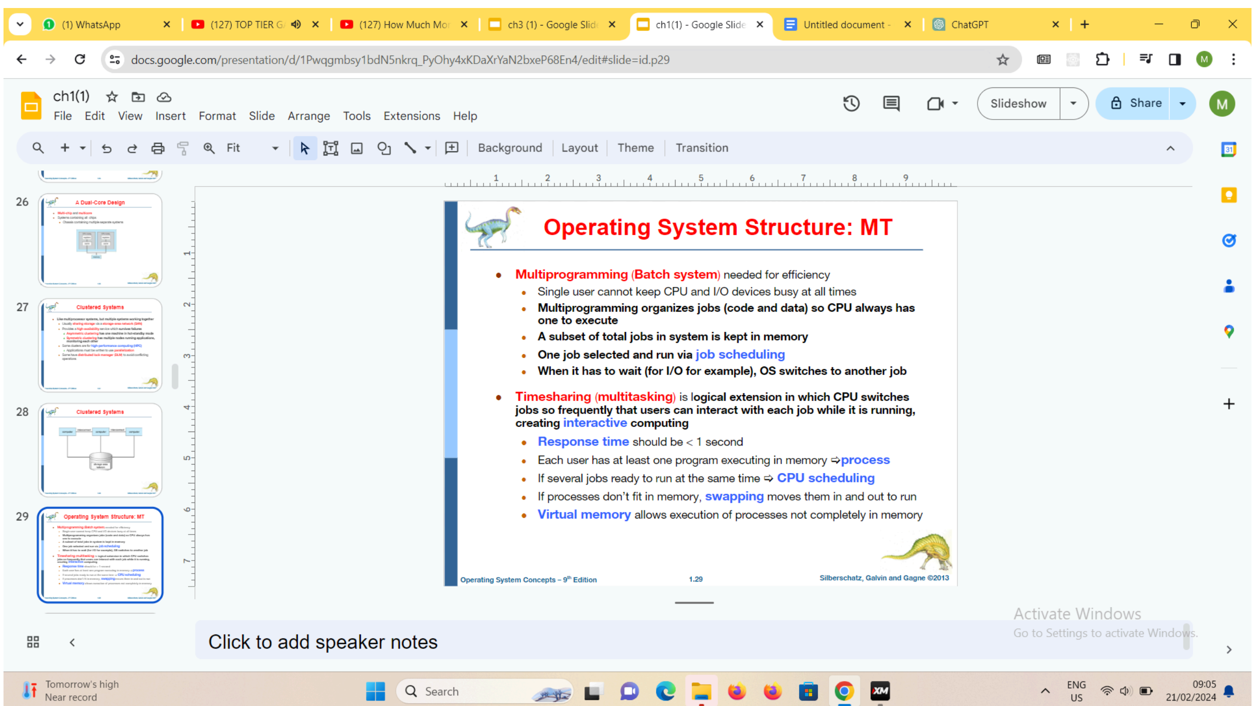
Operating System Structure: MT
Multiprogramming (Batch system) needed for efficiency
Single user cannot keep CPU and I/O devices busy at all times
Multiprogramming organizes jobs (code and data) so CPU always has one to execute
A subset of total jobs in system is kept in memory
One job selected and run via job scheduling
When it has to wait (for I/O for example), OS switches to another job
Timesharing (multitasking) is logical extension in which CPU switches jobs so frequently that users can interact with each job while it is running, creating interactive computing
Response time should be < 1 second
Each user has at least one program executing in memory ⇒process
If several jobs ready to run at the same time ⇒ CPU scheduling
If processes don't fit in memory, swapping moves them in and out to run
Virtual memory allows execution of processes not completely in memory
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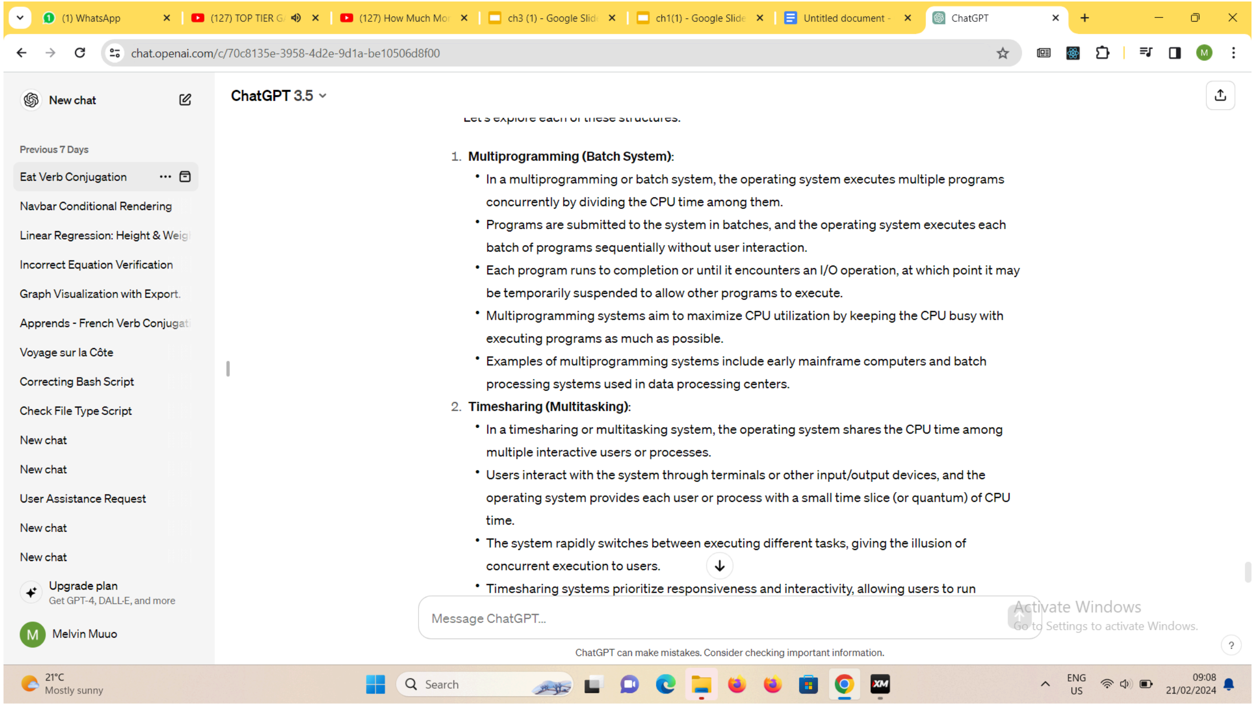

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1. Multiprogramming (Batch System):
In a multiprogramming or batch system, the operating system executes multiple programs concurrently by dividing the CPU time among them.
Programs are submitted to the system in batches, and the operating system executes each batch of programs sequentially without user interaction.
Each program runs to completion or until it encounters an I/O operation, at which point it may be temporarily suspended to allow other programs to execute.
Multiprogramming systems aim to maximize CPU utilization by keeping the CPU busy with executing programs as much as possible.
Examples of multiprogramming systems include early mainframe computers and batch processing systems used in data processing centers.
2. Timesharing (Multitasking):
In a timesharing or multitasking system, the operating system shares the CPU time among multiple interactive users or processes.
Users interact with the system through terminals or other input/output devices, and the operating system provides each user or process with a small time slice (or quantum) of CPU time.
The system rapidly switches between executing different tasks, giving the illusion of concurrent execution to users.
Timesharing systems prioritize responsiveness and interactivity, allowing users to run
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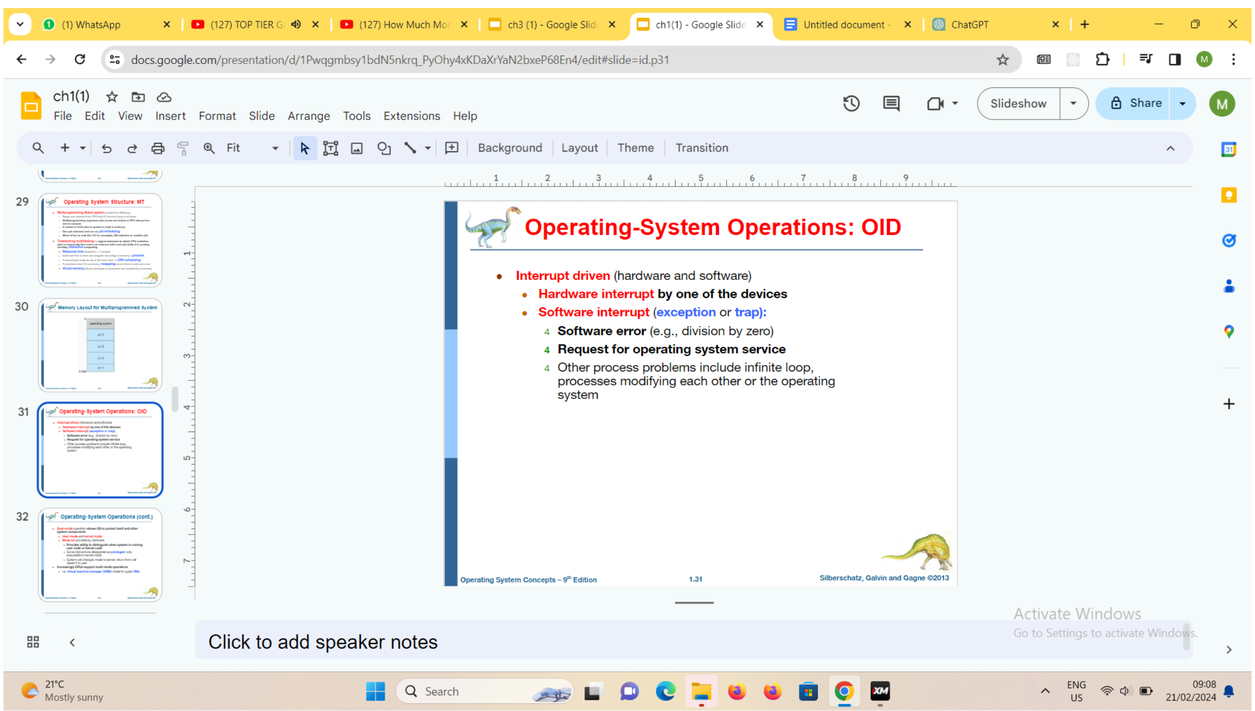

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Operating-System Operations: OID
Interrupt driven (hardware and software)
Hardware interrupt by one of the devices
Software interrupt (exception or trap):
Software error (e.g., division by zero)
Request for operating system service
Other process problems include infinite loop, processes modifying each other or the operating system
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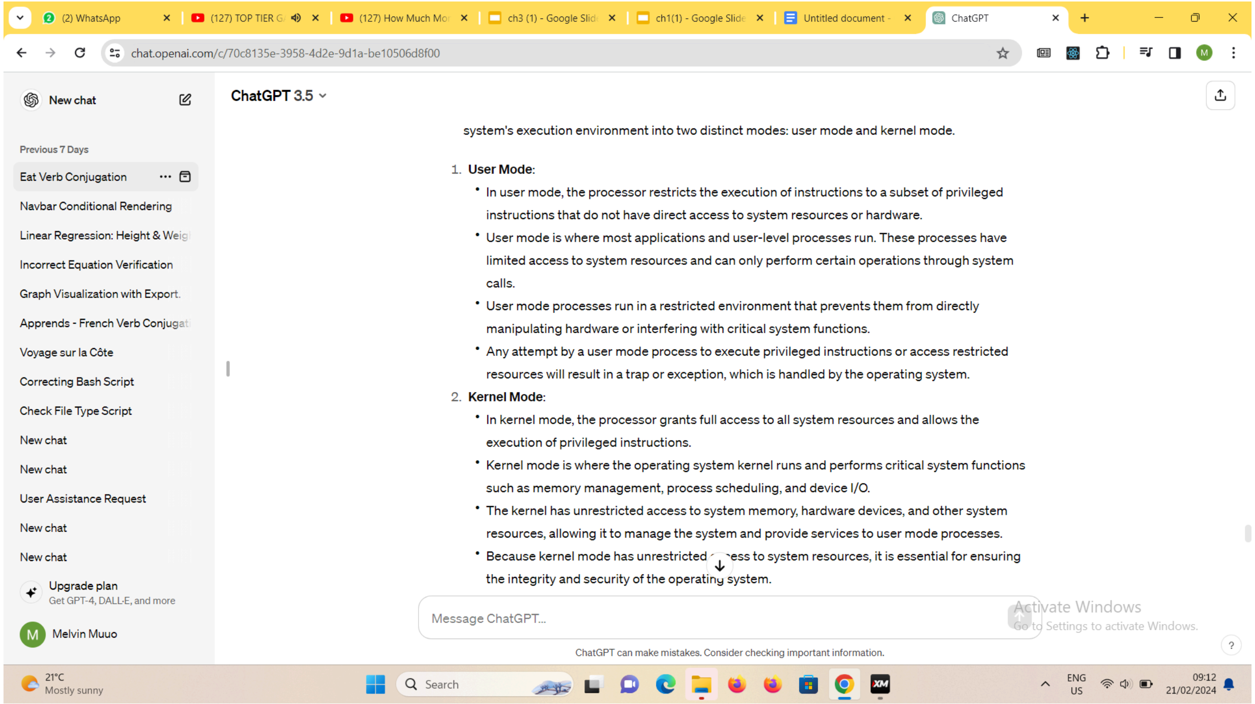
Operating-System Operations (cont.)

- **Dual-mode** operation **allows OS to protect itself and other system components**
  - **User mode** and **kernel mode**
  - **Mode bit** provided by hardware
    - **Provides ability to distinguish when system is running user code or kernel code**
    - Some instructions designated as **privileged**, only executable in kernel mode
    - System call changes mode to kernel, return from call resets it to user
- **Increasingly CPUs support multi-mode operations**
  - i.e. **virtual machine manager** (**VMM**) mode for guest **VMs**

Process Management: SM

- **A process is a program in execution.** It is a unit of work within the system. Program is a ***passive entity***, process is an ***active entity***.
- Process needs resources to accomplish its task
  - CPU, memory, I/O, files
  - Initialization data
- Process termination requires reclaim of any reusable resources
- **Single-threaded process has one program counter specifying location of next instruction to execute**
  - Process executes instructions sequentially, one at a time, until completion
- **Multi-threaded process has one program counter per thread**
- Typically system has many processes, some user, some operating system running concurrently on one or more CPUs
  - Concurrency by multiplexing the CPUs among the processes / threads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system's execution environment into two distinct modes: user mode and kernel mode.
1. User Mode:
• In user mode, the processor restricts the execution of instructions to a subset of privileged instructions that do not have direct access to system resources or hardware.
• User mode is where most applications and user-level processes run. These processes have limited access to system resources and can only perform certain operations through system calls.
• User mode processes run in a restricted environment that prevents them from directly manipulating hardware or interfering with critical system functions.
• Any attempt by a user mode process to execute privileged instructions or access restricted resources will result in a trap or exception, which is handled by the operating system.
2. Kernel Mode:
• In kernel mode, the processor grants full access to all system resources and allows the execution of privileged instructions.
• Kernel mode is where the operating system kernel runs and performs critical system functions such as memory management, process scheduling, and device I/O.
• The kernel has unrestricted access to system memory, hardware devices, and other system resources, allowing it to manage the system and provide services to user mode processes.
• Because kernel mode has unrestricted access to system resources, it is essential for ensuring the integrity and security of the operating system.
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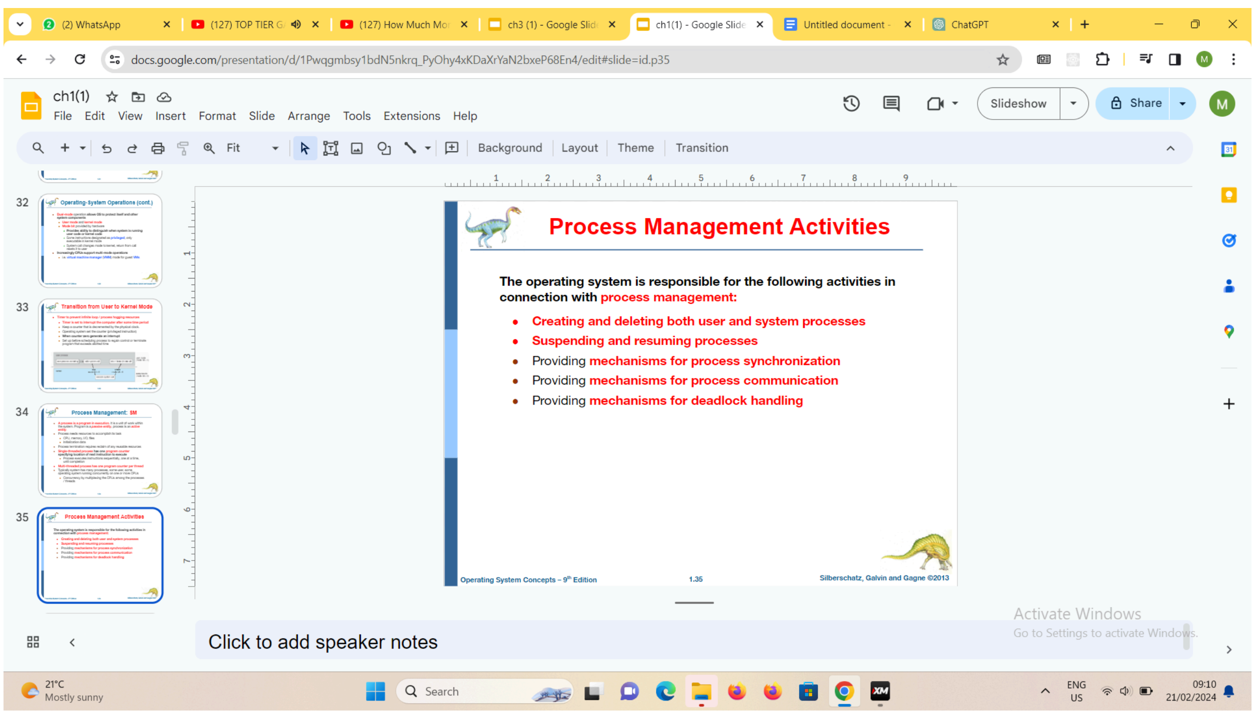
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Process Management Activities
The operating system is responsible for the following activities in connection with process management:
• Creating and deleting both user and system processes
• Suspending and resuming processes
• Providing mechanisms for process synchronization
• Providing mechanisms for process communication
• Providing mechanisms for deadlock handling
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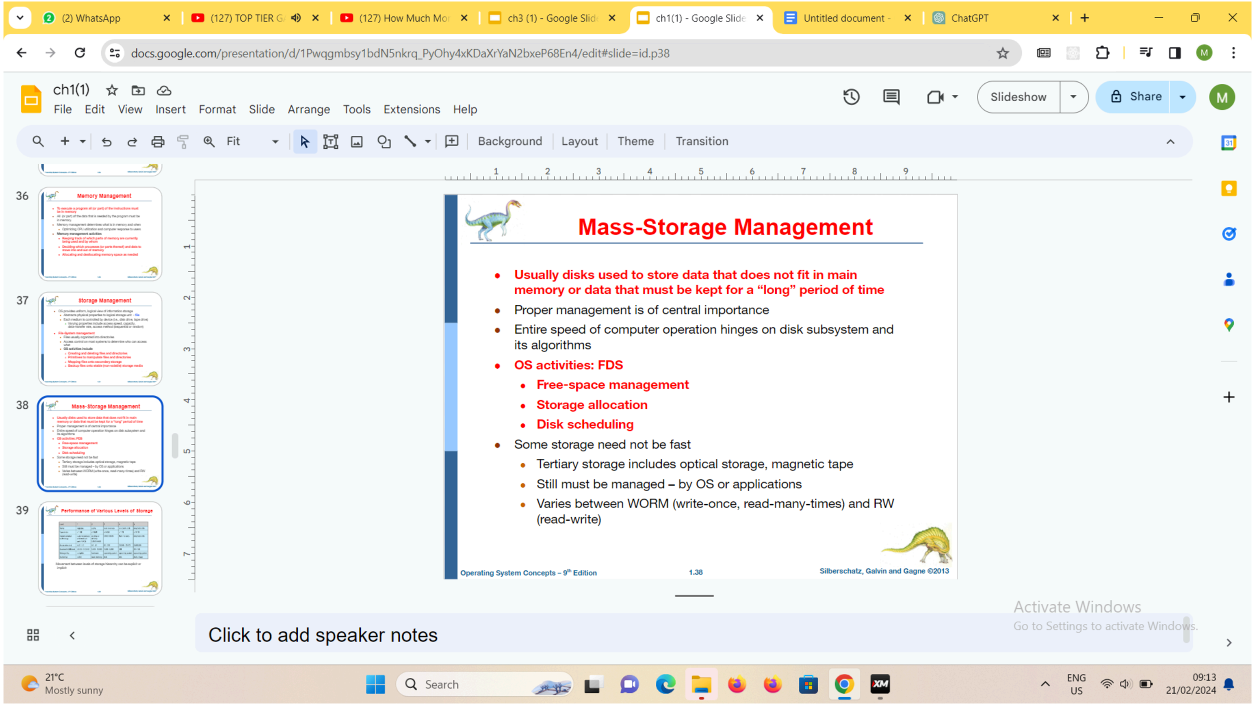
Mass-Storage Management
Usually disks used to store data that does not fit in main memory or data that must be kept for a "long" period of time
Proper management is of central importance
Entire speed of computer operation hinges on disk subsystem and its algorithms
OS activities: FDS
Free-space management
Storage allocation
Disk scheduling
Some storage need not be fast
Tertiary storage includes optical storage, magnetic tape
Still must be managed – by OS or applications
Varies between WORM (write-once, read-many-times) and RW (read-write)
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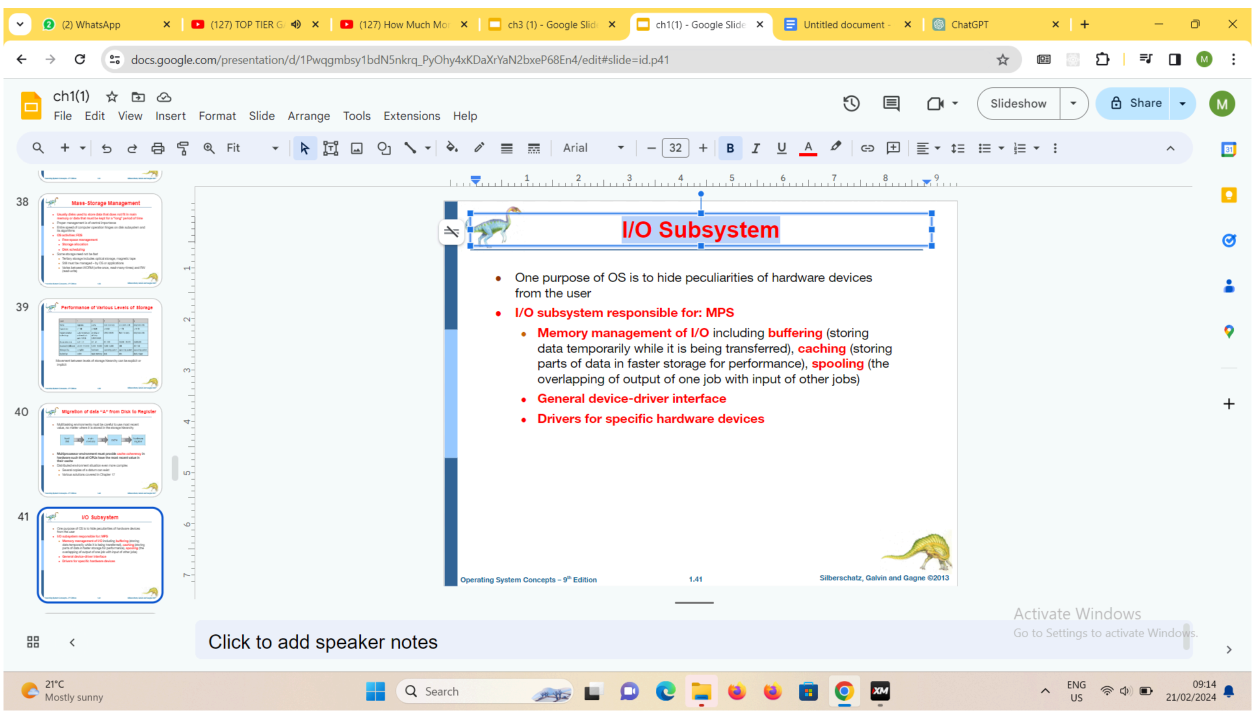
I/O Subsystem
One purpose of OS is to hide peculiarities of hardware devices from the user
I/O subsystem responsible for: MPS
Memory management of I/O including buffering (storing data temporarily while it is being transferred), caching (storing parts of data in faster storage for performance), spooling (the overlapping of output of one job with input of other jobs)
General device-driver interface
Drivers for specific hardware devices
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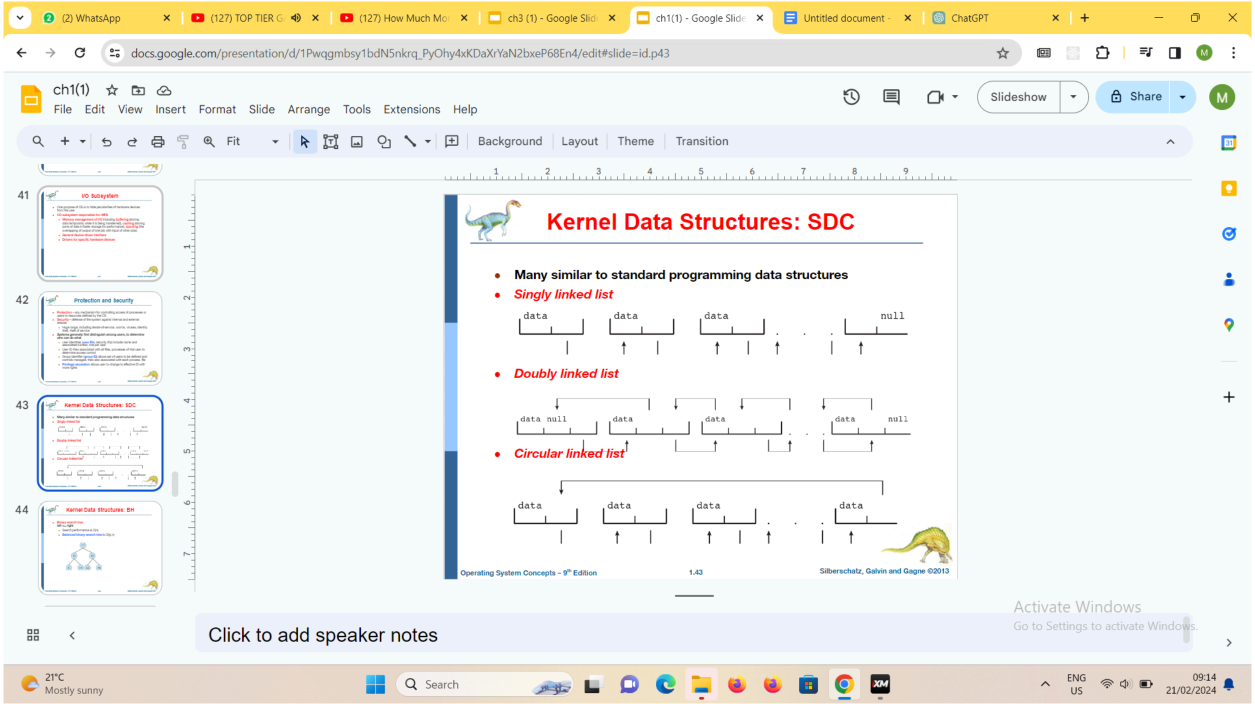
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Kernel Data Structures: SDC
Many similar to standard programming data structures
Singly linked list
data
data
data
null
Doubly linked list
data null
data
data
data
null
Circular linked list
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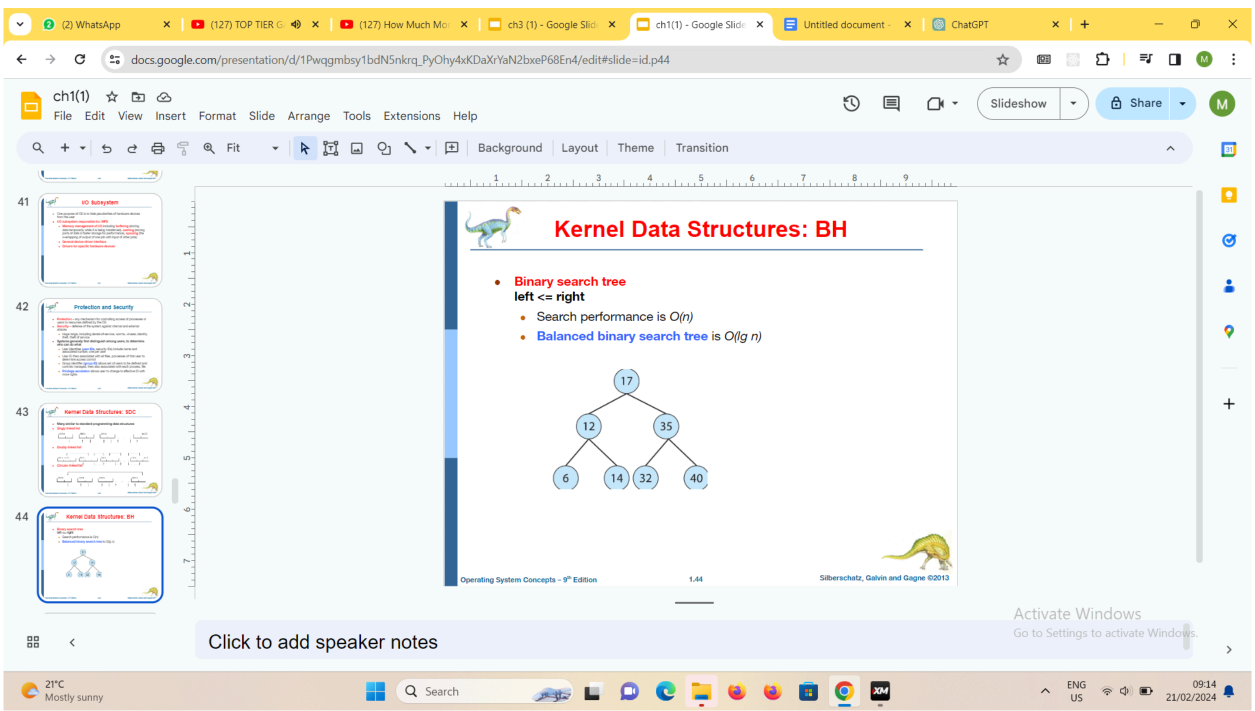
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Kernel Data Structures: BH
Binary search tree
left <= right
Search performance is O(n)
Balanced binary search tree is O(lg n)
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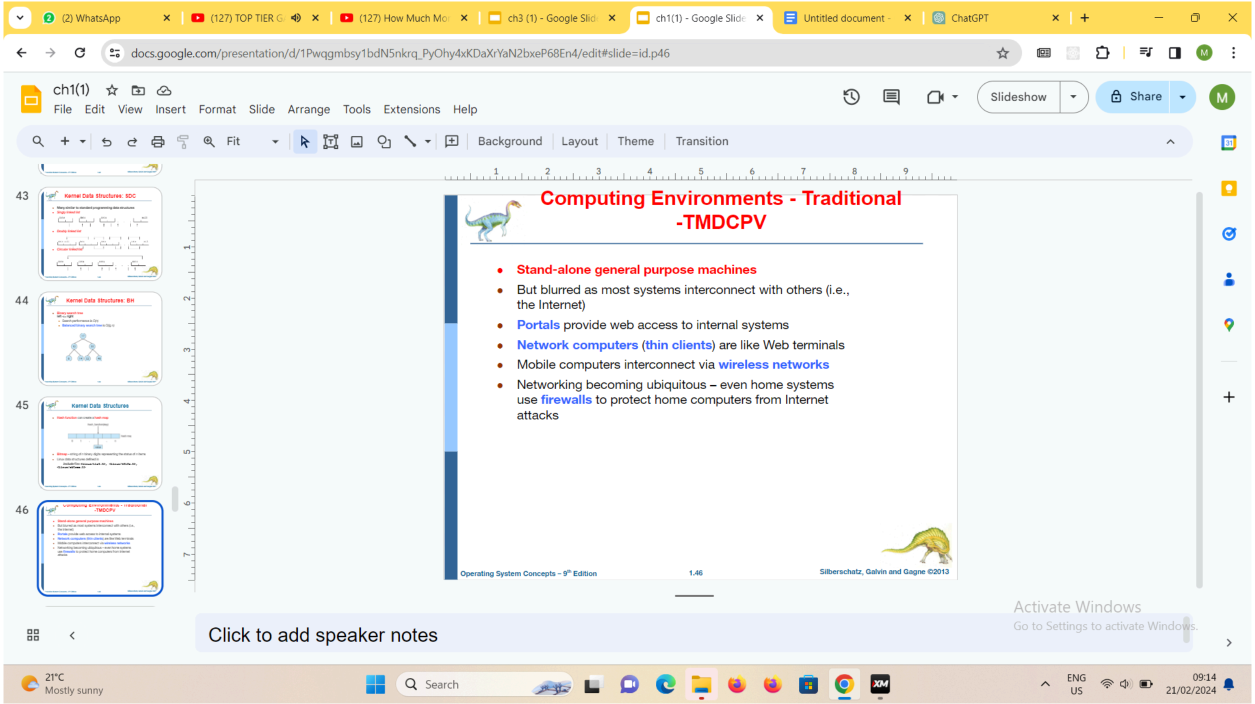
Computing Environments - Traditional -TMDCPV
Stand-alone general purpose machines
But blurred as most systems interconnect with others (i.e., the Internet)
Portals provide web access to internal systems
Network computers (thin clients) are like Web terminals
Mobile computers interconnect via wireless networks
Networking becoming ubiquitous – even home systems use firewalls to protect home computers from Internet attacks
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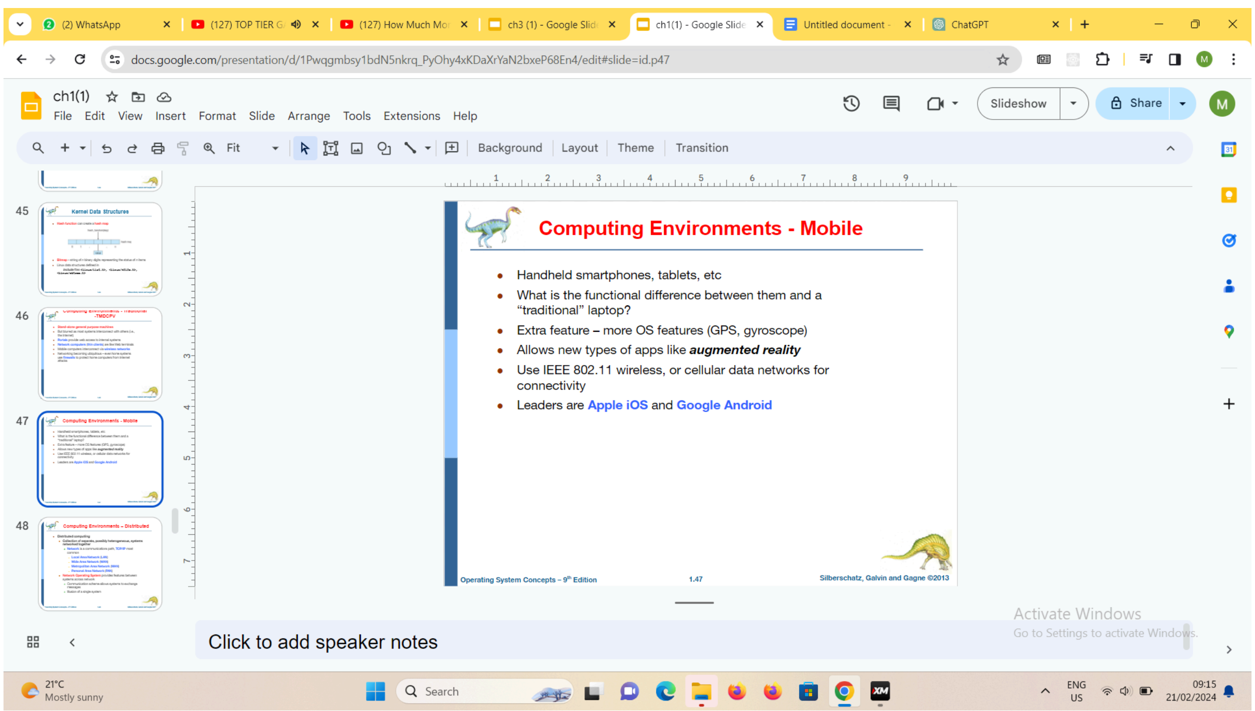
Computing Environments - Mobile
Handheld smartphones, tablets, etc
What is the functional difference between them and a "traditional" laptop?
Extra feature – more OS features (GPS, gyroscope)
Allows new types of apps like augmented reality
Use IEEE 802.11 wireless, or cellular data networks for connectivity
Leaders are Apple iOS and Google Android
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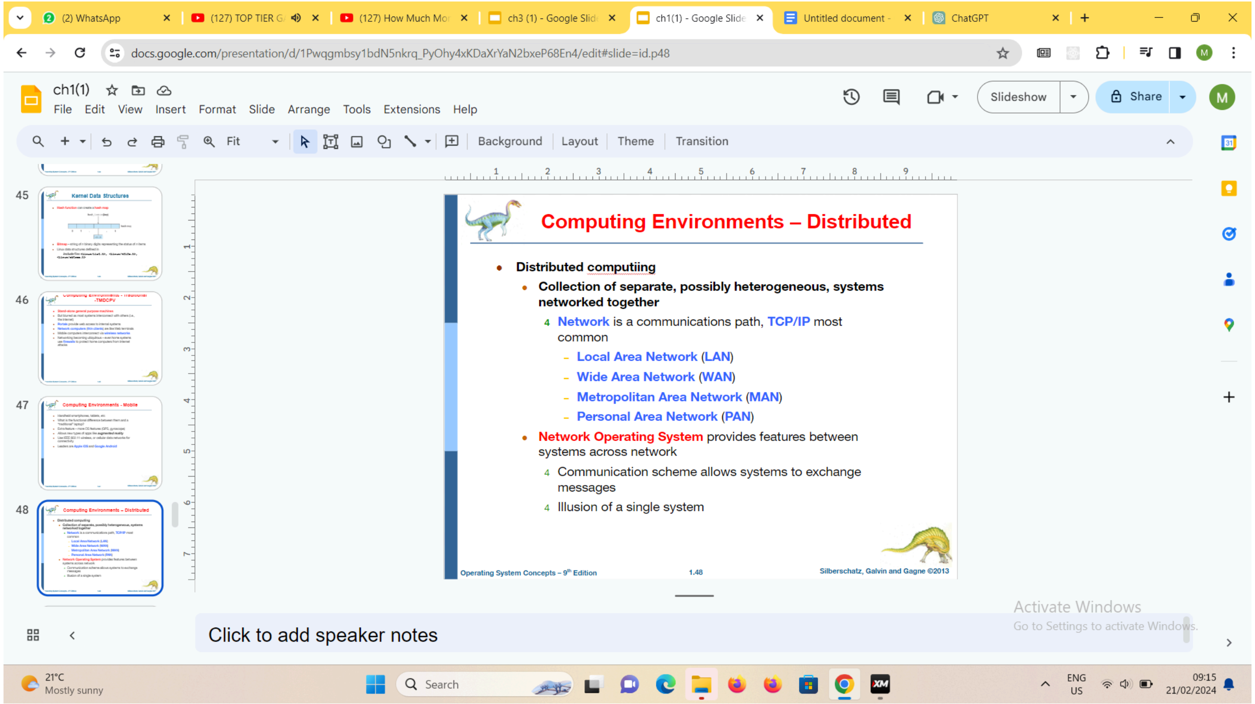

Computing Environments – Distributed
Distributed computiing
Collection of separate, possibly heterogeneous, systems networked together
Network is a communications path, TCP/IP most common
Local Area Network (LAN)
Wide Area Network (WAN)
Metropolitan Area Network (MAN)
Personal Area Network (PAN)
Network Operating System provides features between systems across network
Communication scheme allows systems to exchange messages
Illusion of a single system
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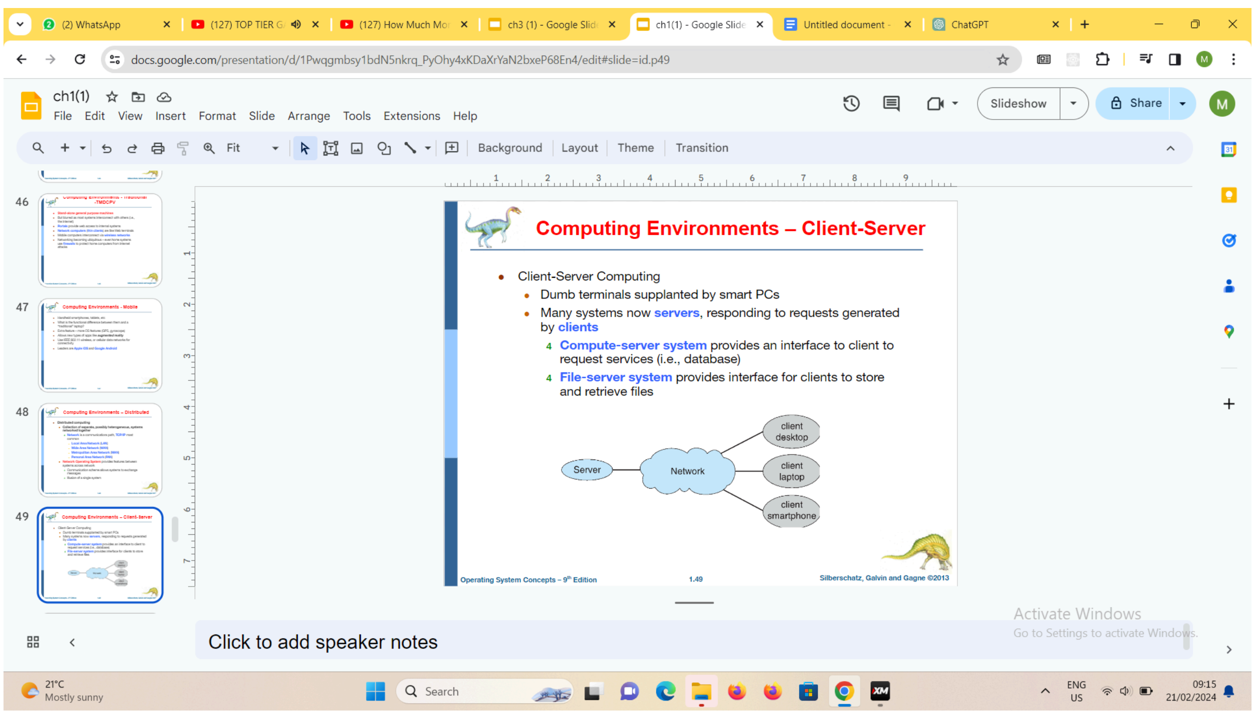

Computing Environments – Client-Server
Client-Server Computing
Dumb terminals supplanted by smart PCs
Many systems now servers, responding to requests generated by clients
Compute-server system provides an interface to client to request services (i.e., database)
File-server system provides interface for clients to store and retrieve files
Server
Network
client desktop
client laptop
client smartphone
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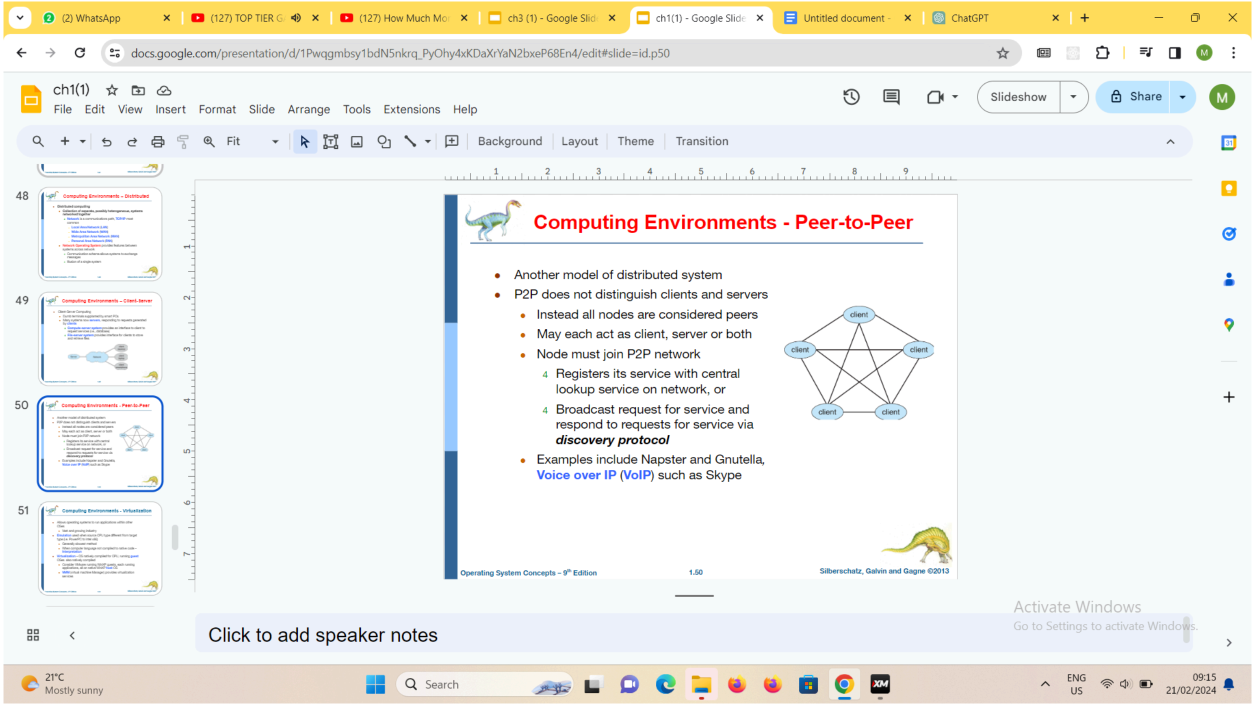
Computing Environments - Peer-to-Peer
Another model of distributed system
P2P does not distinguish clients and servers
Instead all nodes are considered peers
May each act as client, server or both
Node must join P2P network
Registers its service with central lookup service on network, or
Broadcast request for service and respond to requests for service via discovery protocol
Examples include Napster and Gnutella, Voice over IP (VoIP) such as Skype
client
client
client
client
client
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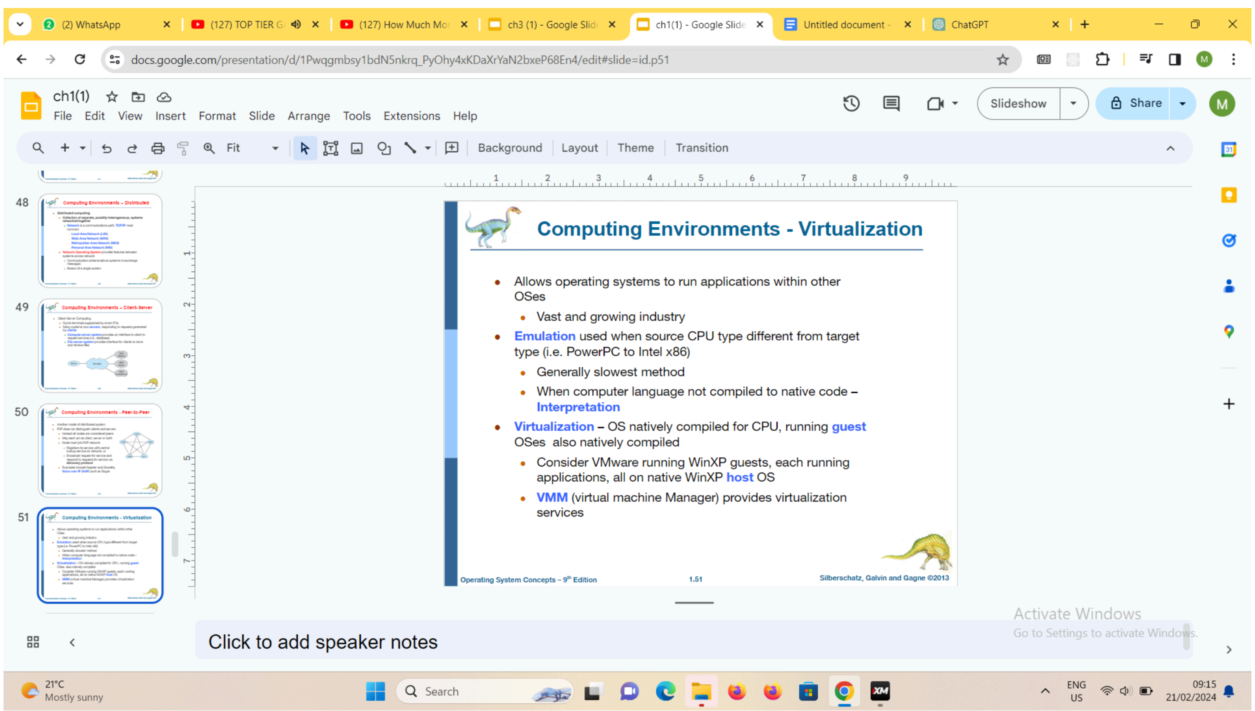
Computing Environments - Virtualization
Allows operating systems to run applications within other OSes
Vast and growing industry
Emulation used when source CPU type different from target type (i.e. PowerPC to Intel x86)
Generally slowest method
When computer language not compiled to native code – Interpretation
Virtualization – OS natively compiled for CPU, running guest OSes also natively compiled
Consider VMware running WinXP guests, each running applications, all on native WinXP host OS
VMM (virtual machine Manager) provides virtualization services
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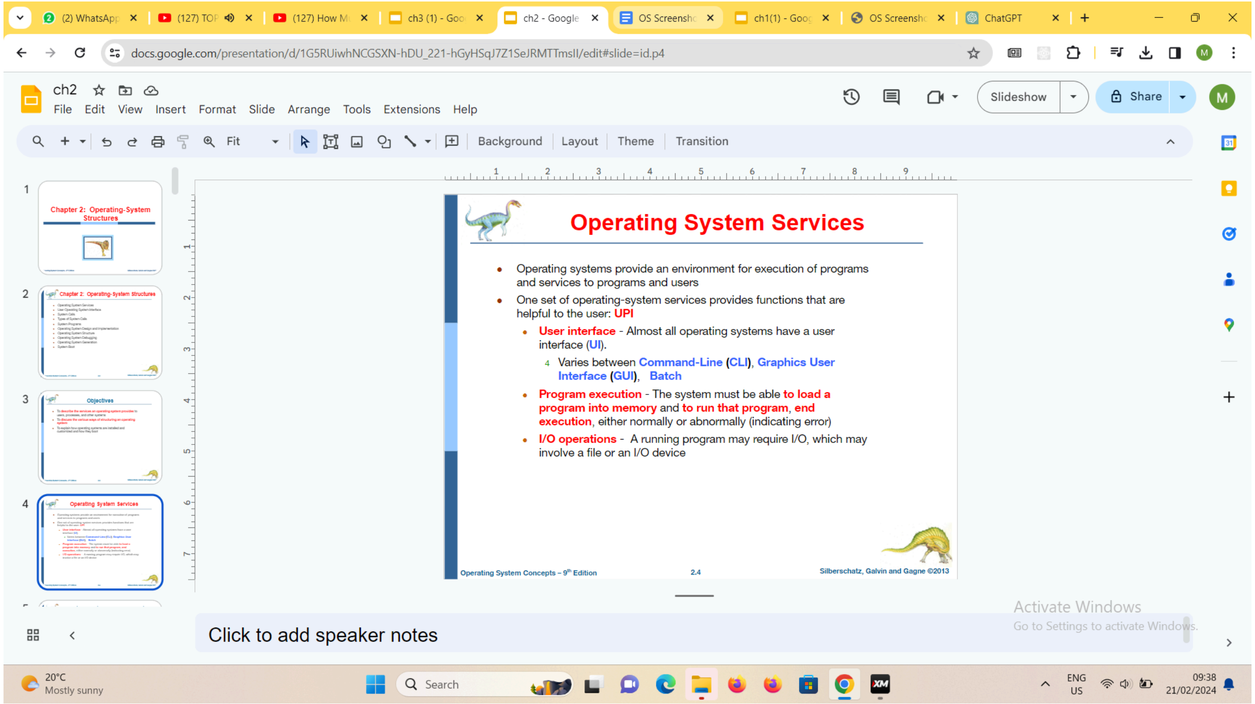
Chapter 2


Operating System Services
Operating systems provide an environment for execution of programs and services to programs and users
One set of operating-system services provides functions that are helpful to the user: UPI
User interface - Almost all operating systems have a user interface (UI).
Varies between Command-Line (CLI), Graphics User Interface (GUI), Batch
Program execution - The system must be able to load a program into memory and to run that program, end execution, either normally or abnormally (indicating error)
I/O operations - A running program may require I/O, which may involve a file or an I/O device
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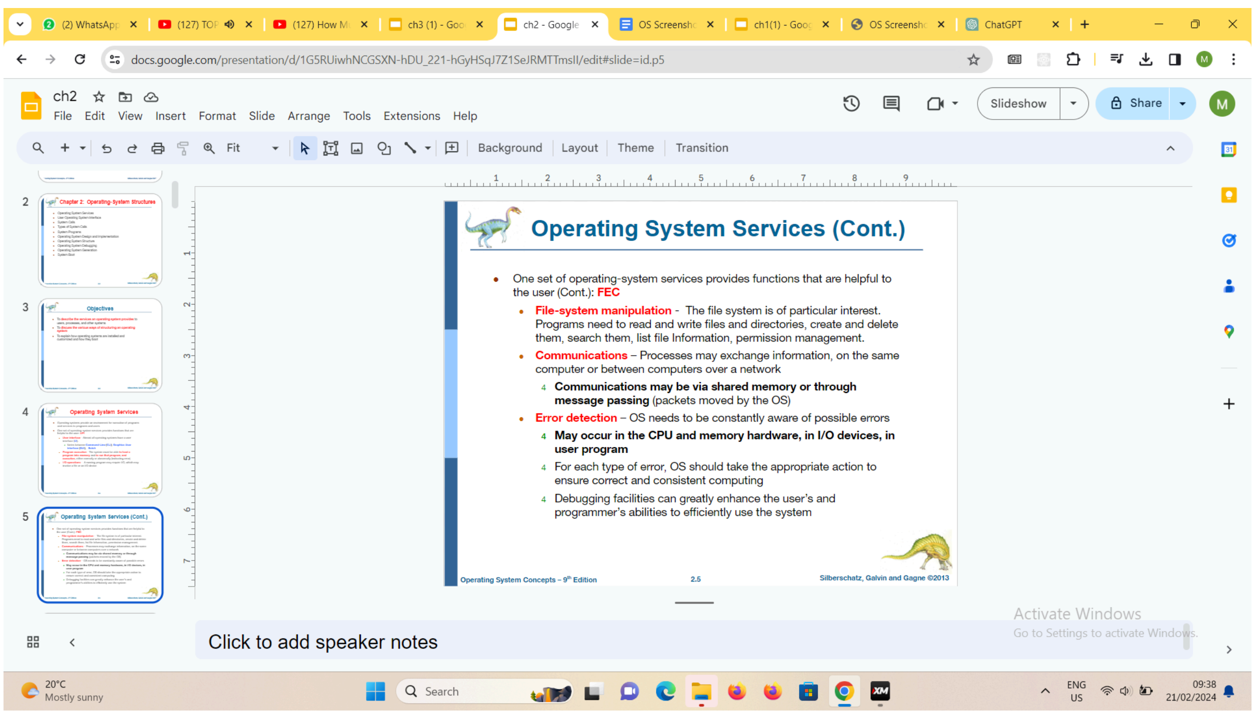
Operating System Services (Cont.)
One set of operating-system services provides functions that are helpful to the user (Cont.): FEC
File-system manipulation - The file system is of particular interest. Programs need to read and write files and directories, create and delete them, search them, list file Information, permission management.
Communications – Processes may exchange information, on the same computer or between computers over a network
Communications may be via shared memory or through message passing (packets moved by the OS)
Error detection – OS needs to be constantly aware of possible errors
May occur in the CPU and memory hardware, in I/O devices, in user program
For each type of error, OS should take the appropriate action to ensure correct and consistent computing
Debugging facilities can greatly enhance the user's and programmer's abilities to efficiently use the system
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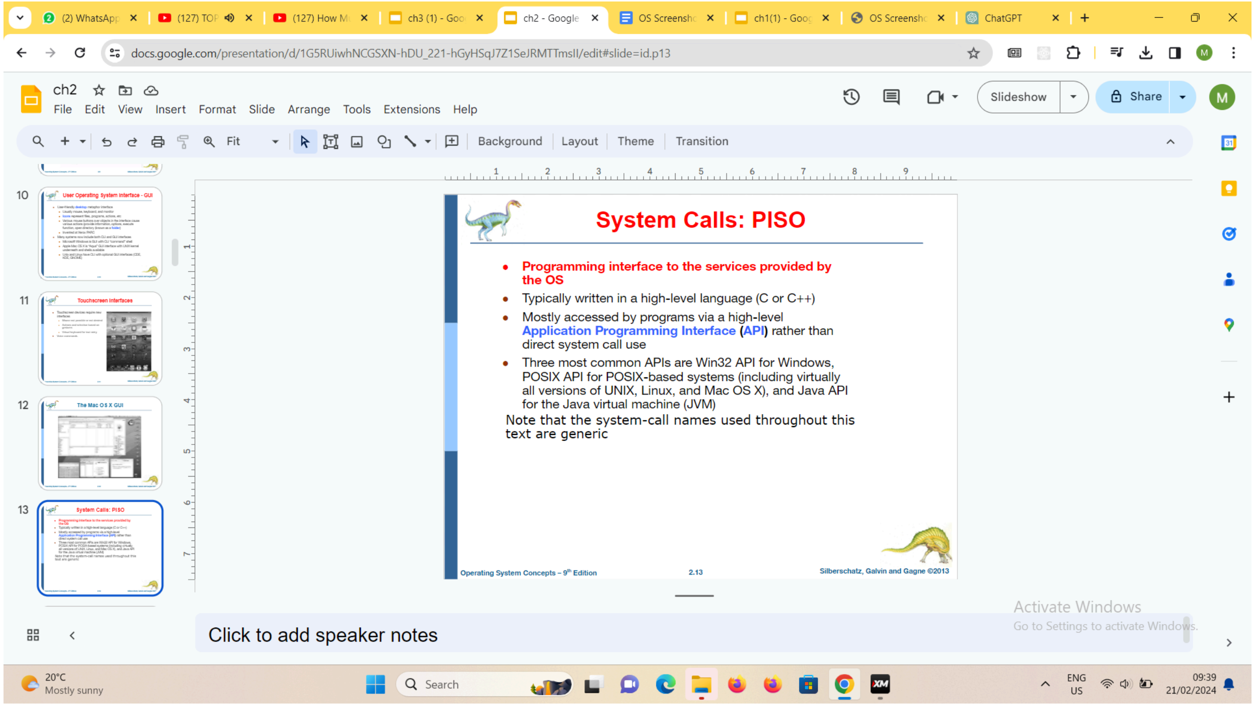
System Calls: PISO
Programming interface to the services provided by the OS
Typically written in a high-level language (C or C++)
Mostly accessed by programs via a high-level Application Programming Interface (API) rather than direct system call use
Three most common APIs are Win32 API for Windows, POSIX API for POSIX-based systems (including virtually all versions of UNIX, Linux, and Mac OS X), and Java API for the Java virtual machine (JVM)
Note that the system-call names used throughout this text are generic
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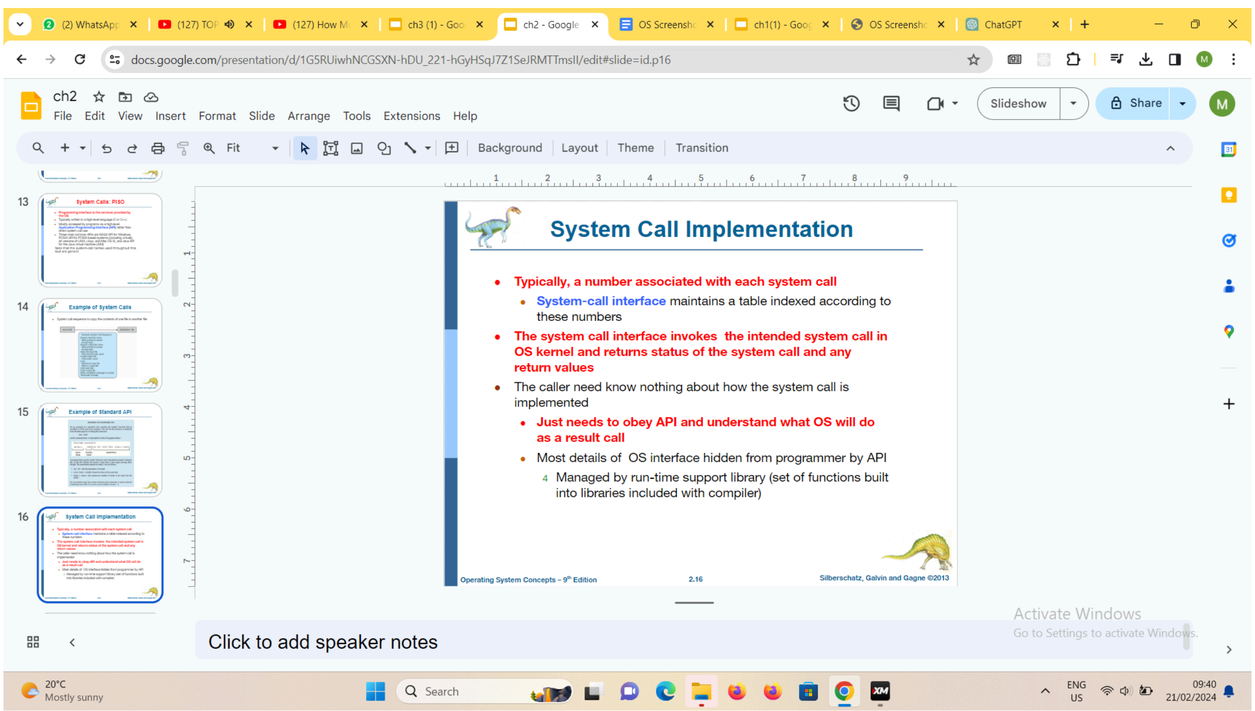
System Call Implementation
Typically, a number associated with each system call
System-call interface maintains a table indexed according to these numbers
The system call interface invokes the intended system call in OS kernel and returns status of the system call and any return values
The caller need know nothing about how the system call is implemented
Just needs to obey API and understand what OS will do as a result call
Most details of OS interface hidden from programmer by API
Managed by run-time support library (set of functions built into libraries included with compiler)
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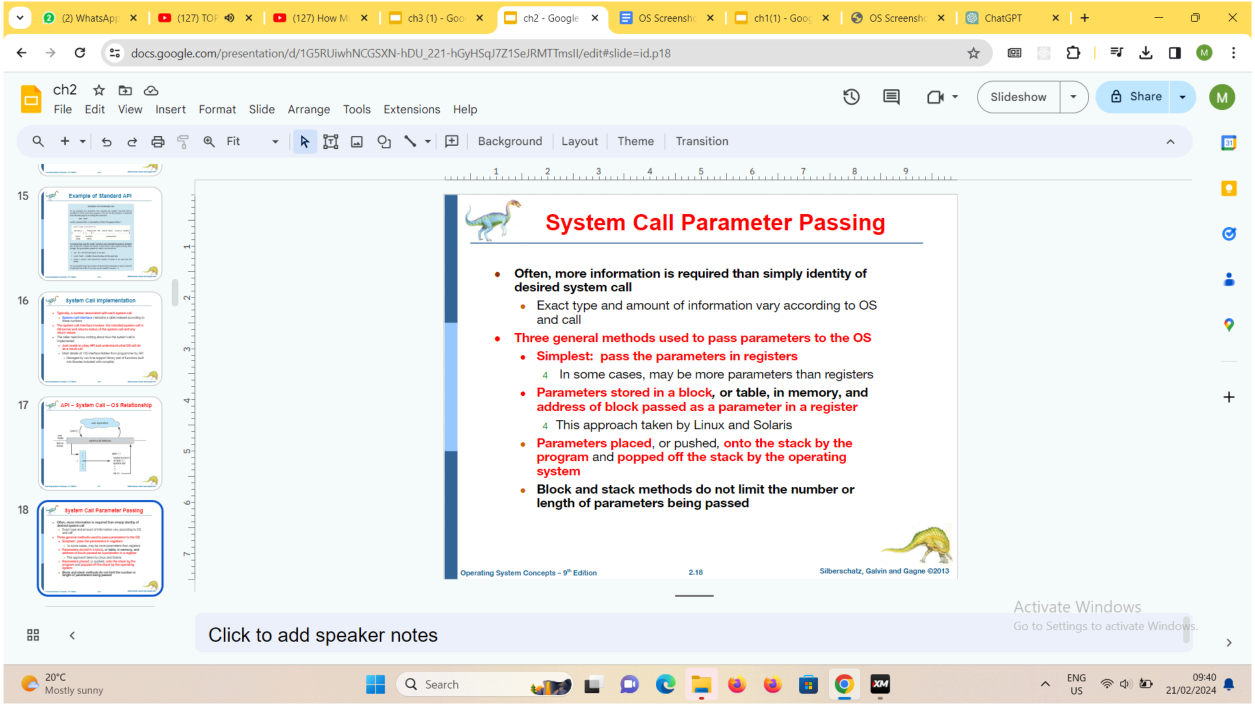
System Call Parameter Passing
Often, more information is required than simply identity of desired system call
Exact type and amount of information vary according to OS and call
Three general methods used to pass parameters to the OS
Simplest: pass the parameters in registers
In some cases, may be more parameters than registers
Parameters stored in a block, or table, in memory, and address of block passed as a parameter in a register
This approach taken by Linux and Solaris
Parameters placed, or pushed, onto the stack by the program and popped off the stack by the operating system
Block and stack methods do not limit the number or length of parameters being passed
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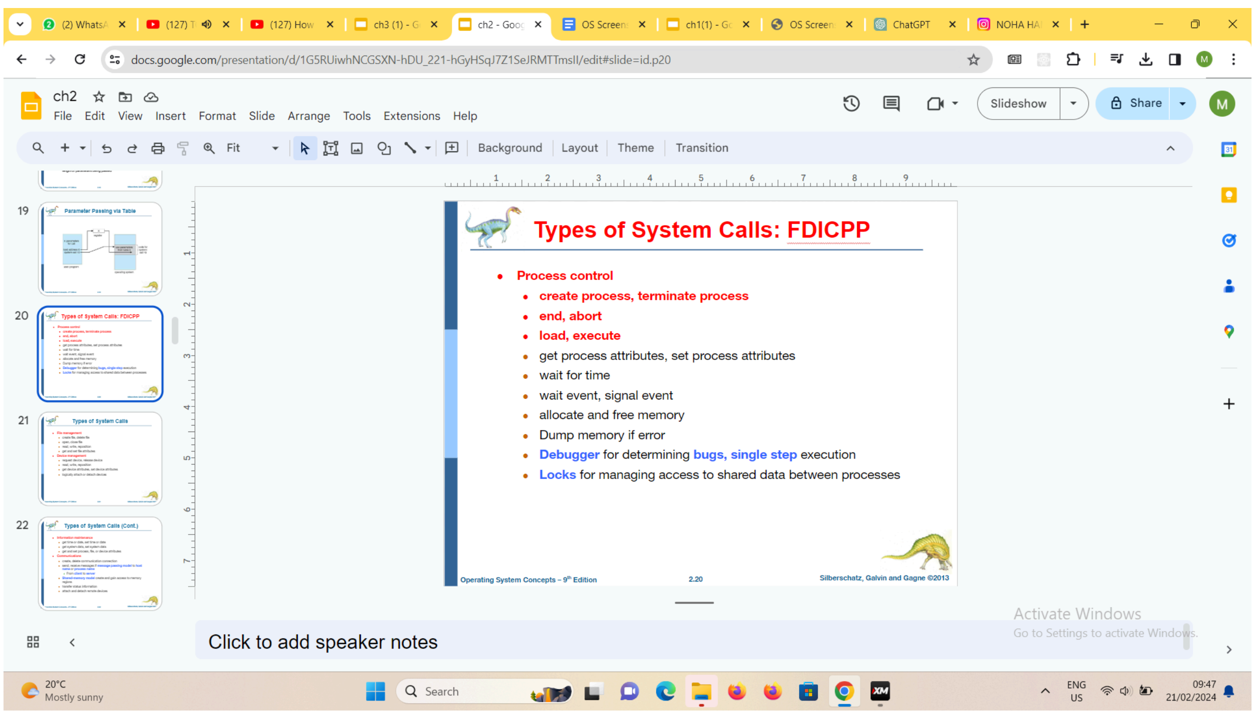
Types of System Calls: FDICPP
Process control
create process, terminate process
end, abort
load, execute
get process attributes, set process attributes
wait for time
wait event, signal event
allocate and free memory
Dump memory if error
Debugger for determining bugs, single step execution
Locks for managing access to shared data between processes
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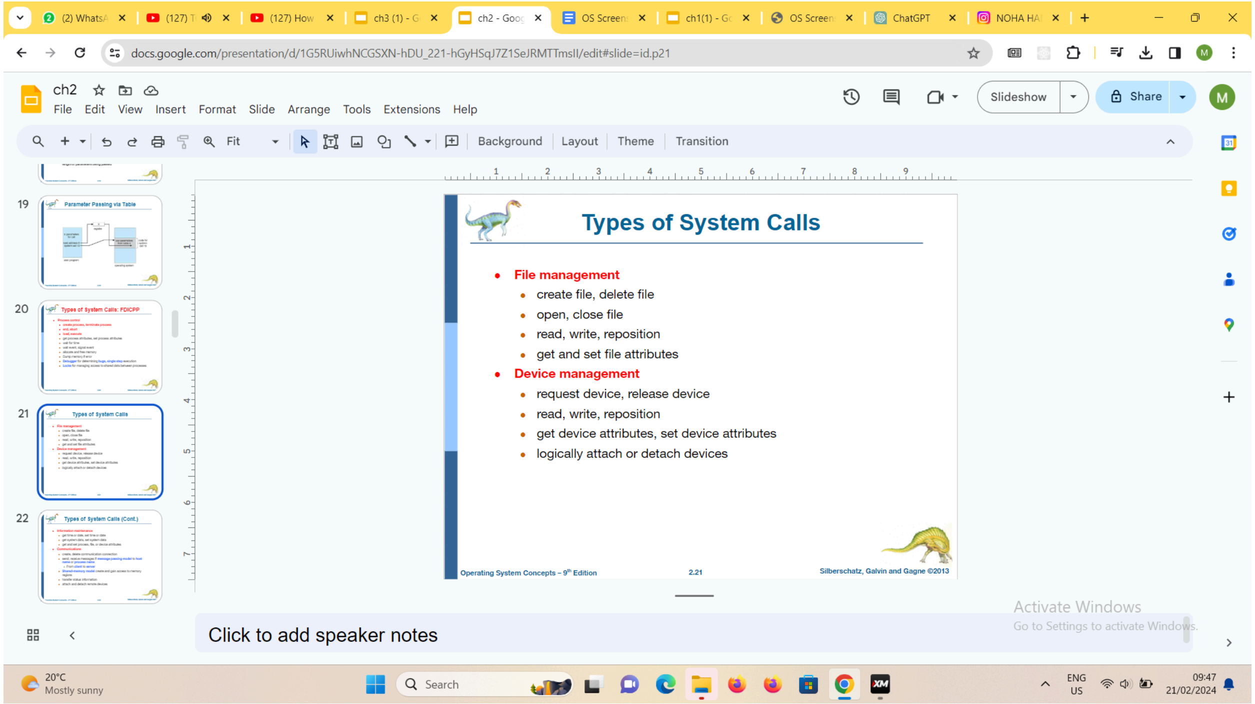
Types of System Calls
File management
create file, delete file
open, close file
read, write, reposition
get and set file attributes
Device management
request device, release device
read, write, reposition
get device attributes, set device attributes
logically attach or detach devices
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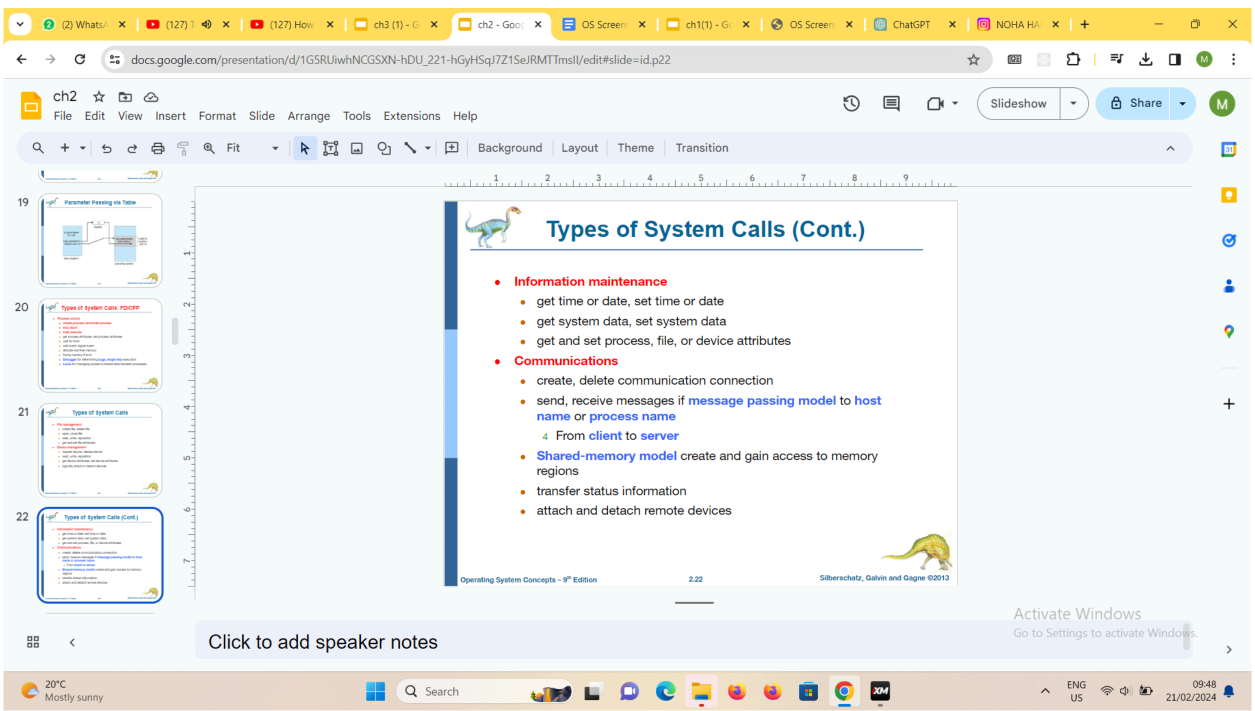
Types of System Calls (Cont.)
Information maintenance
get time or date, set time or date
get system data, set system data
get and set process, file, or device attributes
Communications
create, delete communication connection
send, receive messages if message passing model to host name or process name
From client to server
Shared-memory model create and gain access to memory regions
transfer status information
attach and detach remote devices
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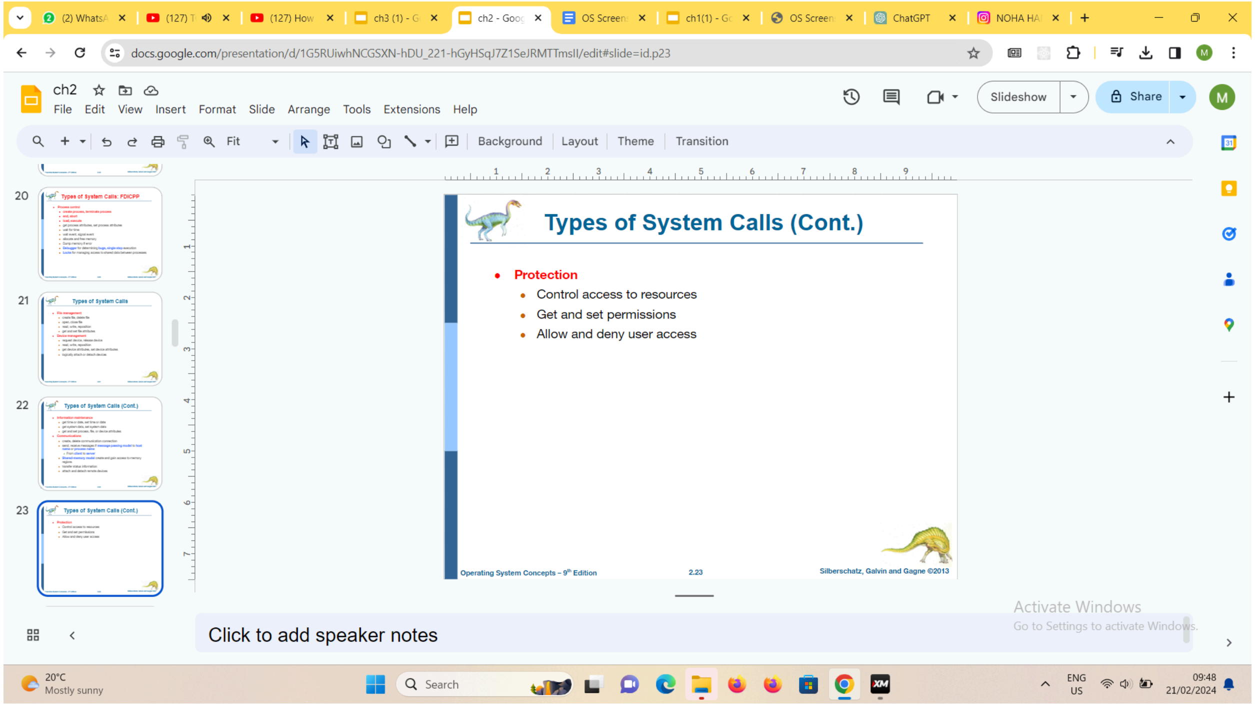
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Types of System Calls (Cont.)
Protection
Control access to resources
Get and set permissions
Allow and deny user access
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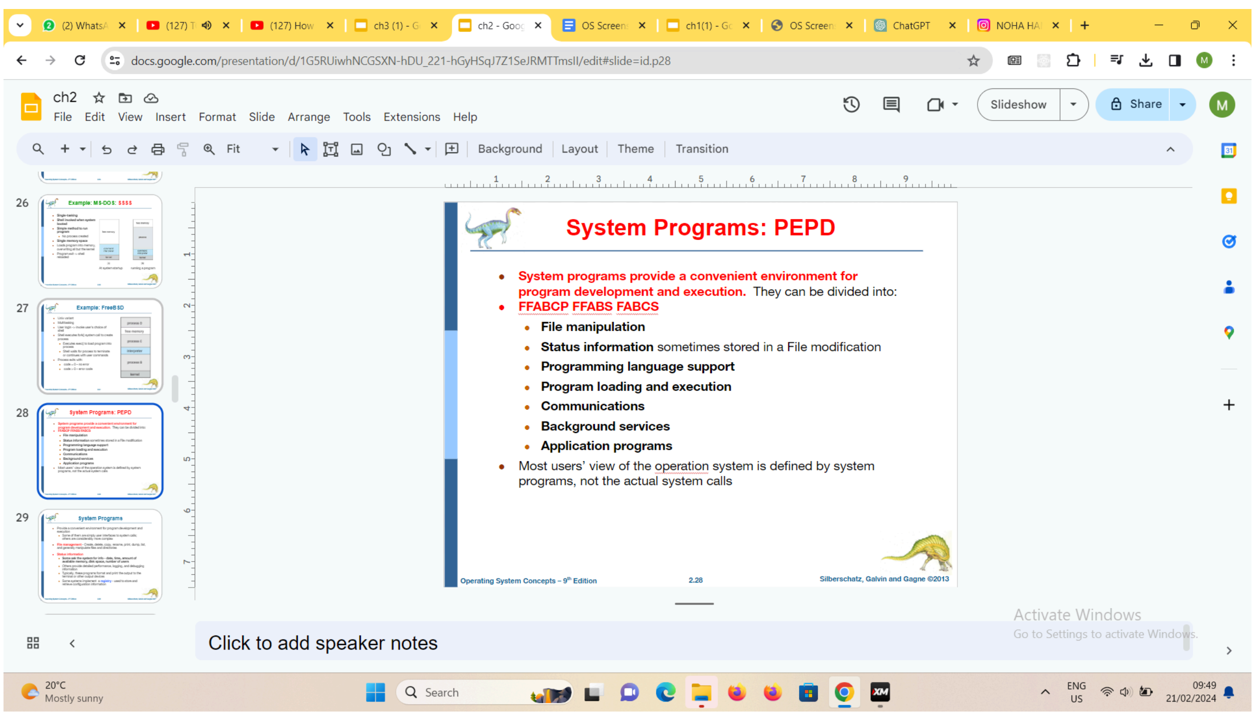
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System Programs: PEPD
System programs provide a convenient environment for program development and execution. They can be divided into:
FFABCP FFABS FABCS
File manipulation
Status information sometimes stored in a File modification
Programming language support
Program loading and execution
Communications
Background services
Application programs
Most users' view of the operation system is defined by system programs, not the actual system calls
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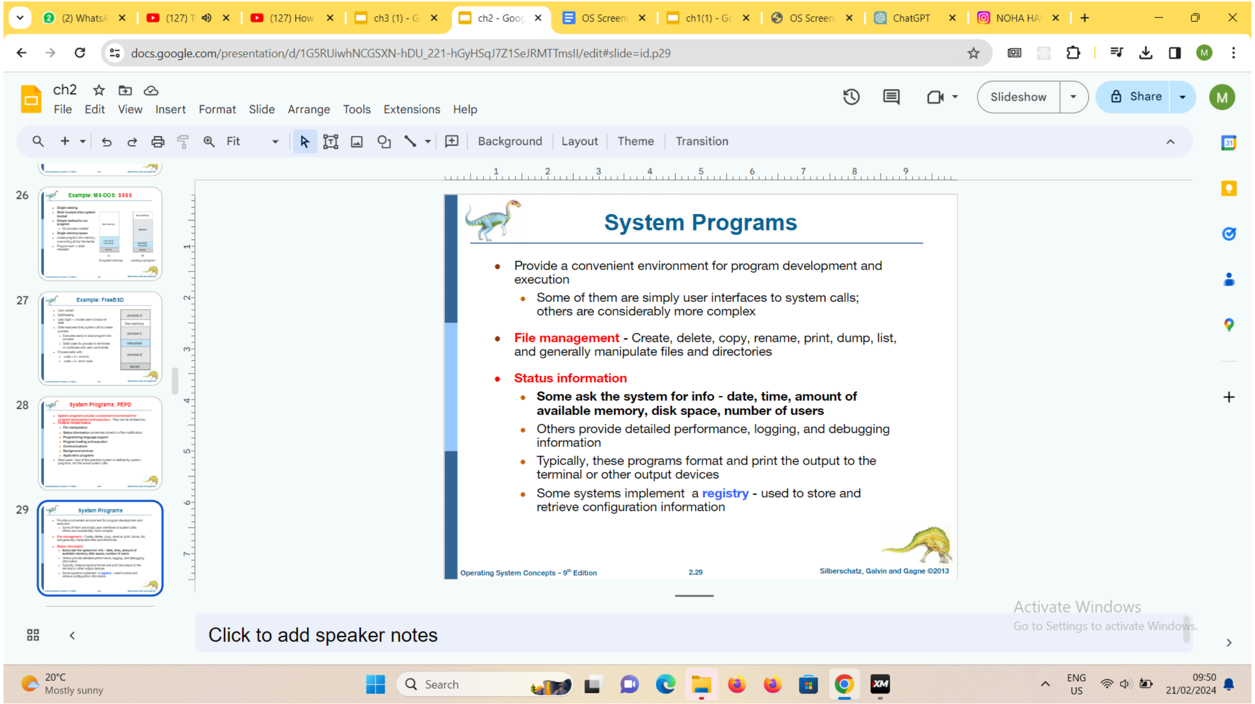
System Programs
Provide a convenient environment for program development and execution
Some of them are simply user interfaces to system calls; others are considerably more complex
File management - Create, delete, copy, rename, print, dump, list, and generally manipulate files and directories
Status information
Some ask the system for info - date, time, amount of available memory, disk space, number of users
Others provide detailed performance, logging, and debugging information
Typically, these programs format and print the output to the terminal or other output devices
Some systems implement a registry - used to store and retrieve configuration information
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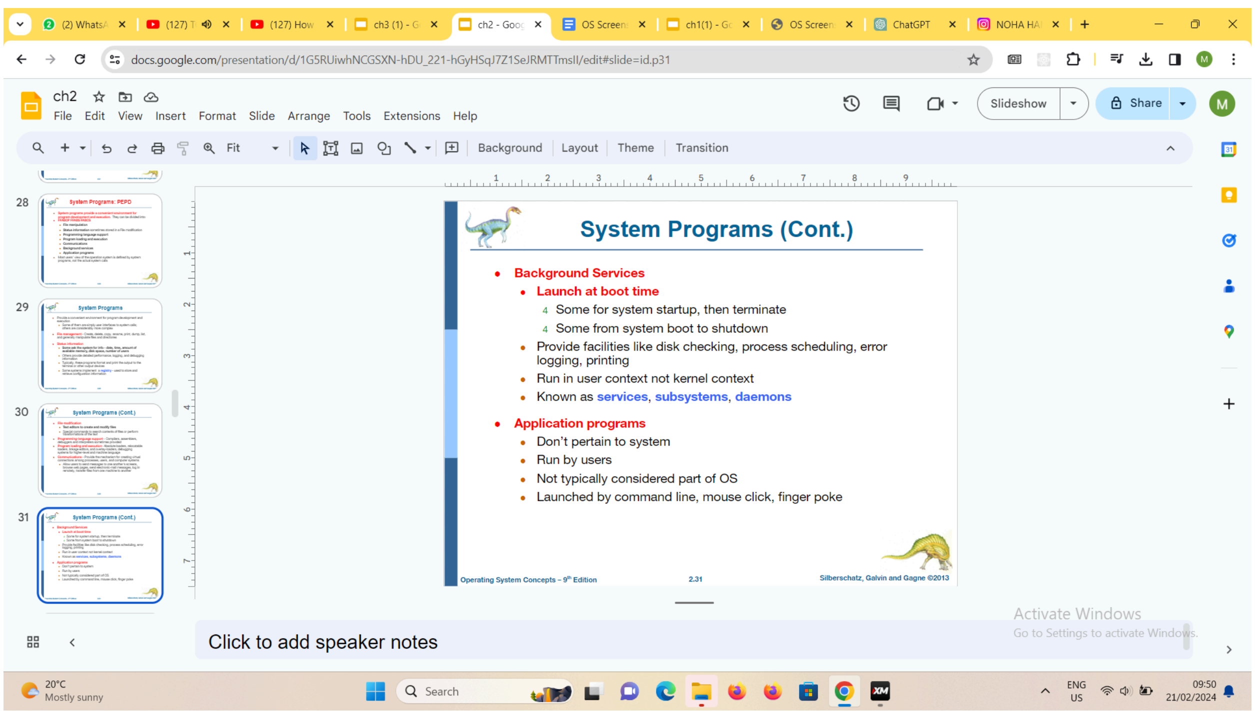
System Programs (Cont.)
Background Services
Launch at boot time
Some for system startup, then terminate
Some from system boot to shutdown
Provide facilities like disk checking, process scheduling, error logging, printing
Run in user context not kernel context
Known as services, subsystems, daemons
Application programs
Don't pertain to system
Run by users
Not typically considered part of OS
Launched by command line, mouse click, finger poke
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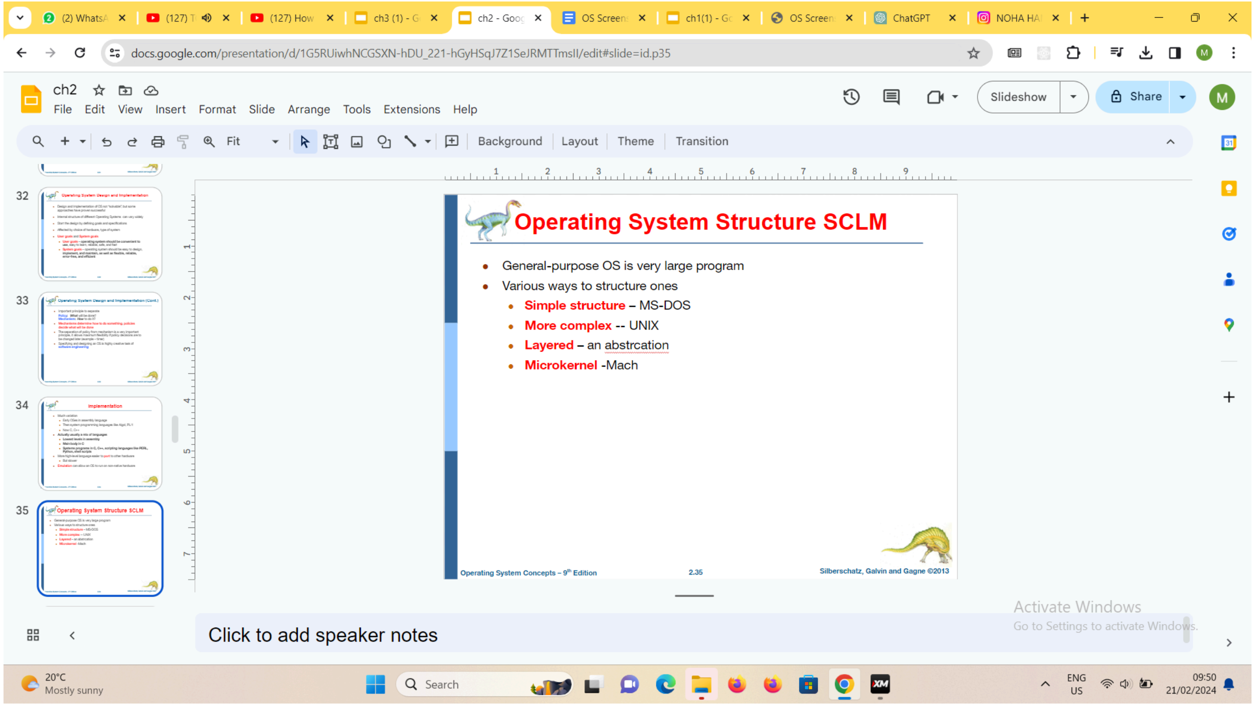

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Operating System Structure SCLM
General-purpose OS is very large program
Various ways to structure ones
Simple structure – MS-DOS
More complex -- UNIX
Layered – an abstrcation
Microkernel -Mach
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ENG
US
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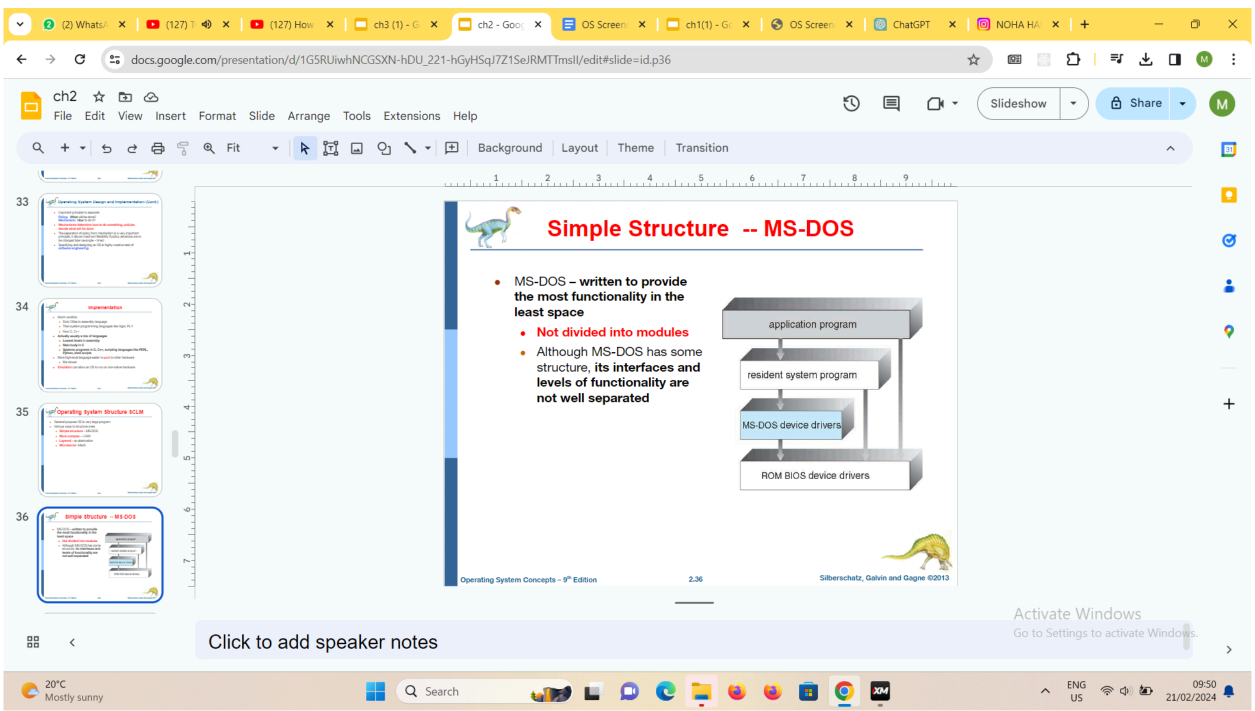

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Simple Structure -- MS-DOS
MS-DOS – written to provide the most functionality in the least space
Not divided into modules
Although MS-DOS has some structure, its interfaces and levels of functionality are not well separated
application program
resident system program
MS-DOS device drivers
ROM BIOS device drivers
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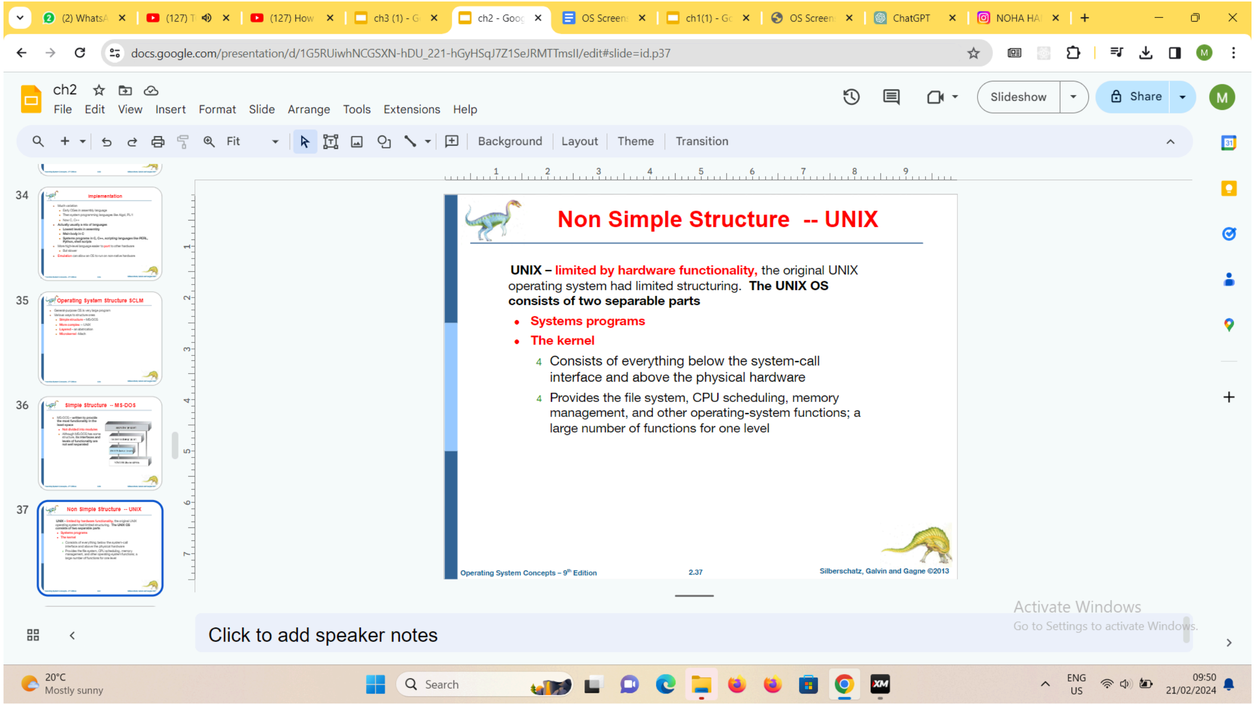
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Non Simple Structure -- UNIX
UNIX – limited by hardware functionality, the original UNIX operating system had limited structuring. The UNIX OS consists of two separable parts
Systems programs
The kernel
Consists of everything below the system-call interface and above the physical hardware
Provides the file system, CPU scheduling, memory management, and other operating-system functions; a large number of functions for one level
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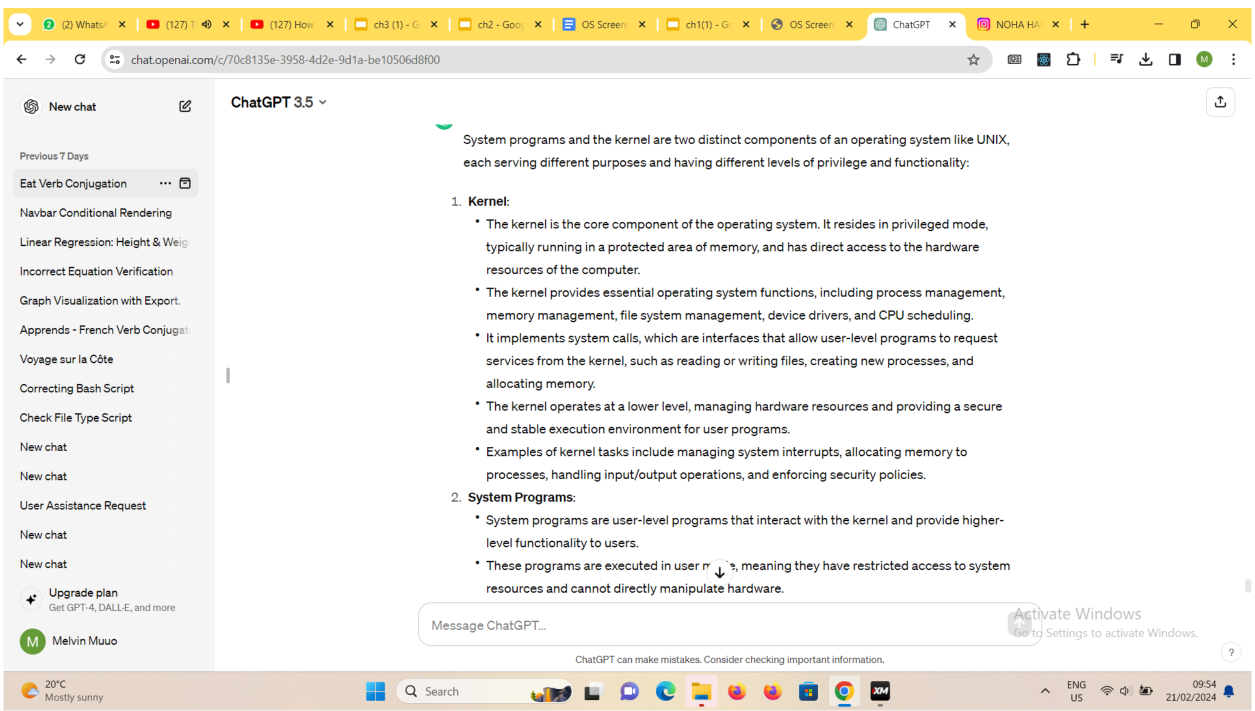
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New chat
ChatGPT 3.5
Previous 7 Days
Eat Verb Conjugation
Navbar Conditional Rendering
Incorrect Equation Verification
Graph Visualization with Export.
Voyage sur la Côte
Correcting Bash Script
Check File Type Script
New chat
New chat
User Assistance Request
New chat
New chat
Upgrade plan
Get GPT-4, DALL·E, and more
Melvin Muuo
System programs and the kernel are two distinct components of an operating system like UNIX, each serving different purposes and having different levels of privilege and functionality:
1. Kernel:
The kernel is the core component of the operating system. It resides in privileged mode, typically running in a protected area of memory, and has direct access to the hardware resources of the computer.
The kernel provides essential operating system functions, including process management, memory management, file system management, device drivers, and CPU scheduling.
It implements system calls, which are interfaces that allow user-level programs to request services from the kernel, such as reading or writing files, creating new processes, and allocating memory.
The kernel operates at a lower level, managing hardware resources and providing a secure and stable execution environment for user programs.
Examples of kernel tasks include managing system interrupts, allocating memory to processes, handling input/output operations, and enforcing security policies.
2. System Programs:
System programs are user-level programs that interact with the kernel and provide higher-level functionality to users.
resources and cannot directly manipulate hardware.
Message ChatGPT...
ChatGPT can make mistakes. Consider checking important information.
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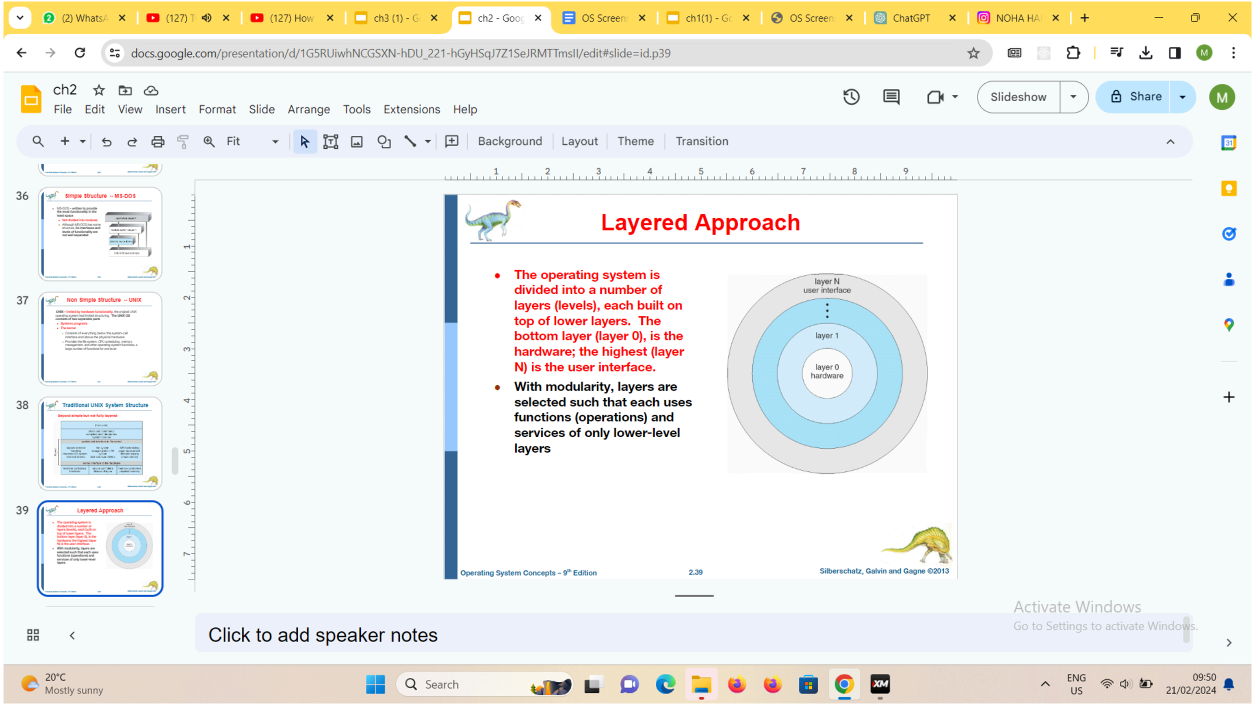

Layered Approach
The operating system is divided into a number of layers (levels), each built on top of lower layers. The bottom layer (layer 0), is the hardware; the highest (layer N) is the user interface.
With modularity, layers are selected such that each uses functions (operations) and services of only lower-level layers
layer N
user interface
layer 1
layer 0
hardware
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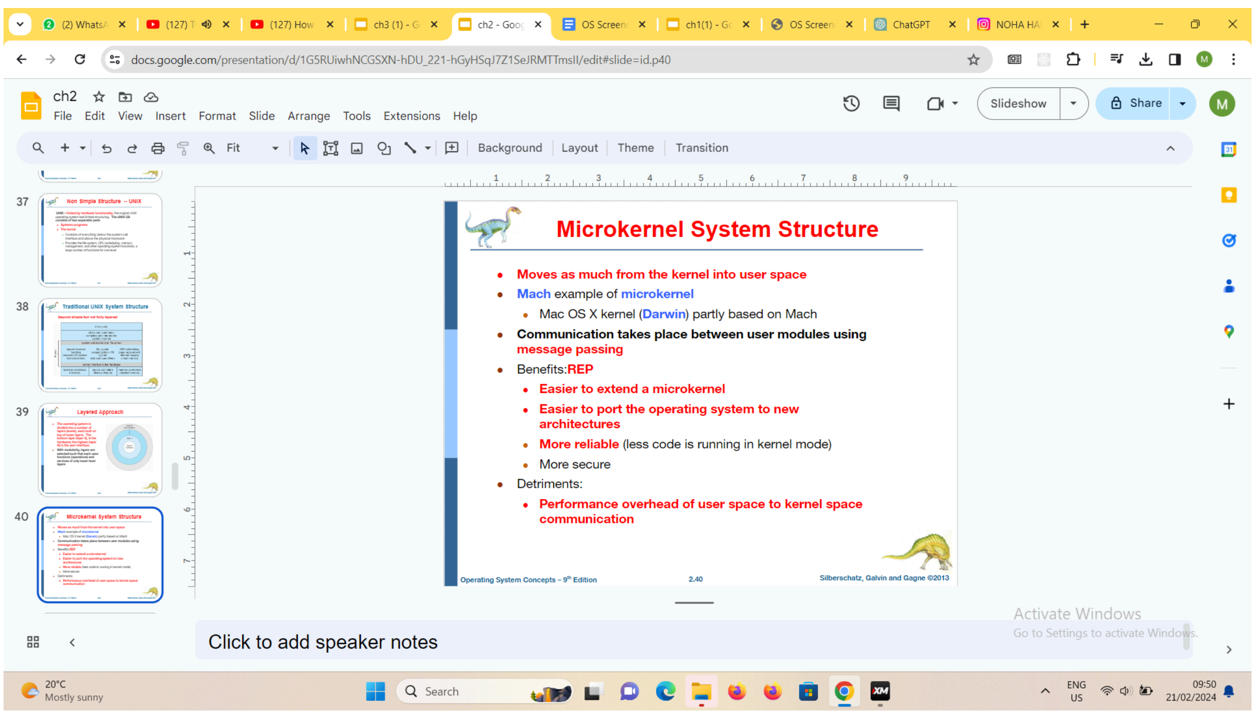

Microkernel System Structure
Moves as much from the kernel into user space
Mach example of microkernel
Mac OS X kernel (Darwin) partly based on Mach
Communication takes place between user modules using message passing
Benefits:REP
Easier to extend a microkernel
Easier to port the operating system to new architectures
More reliable (less code is running in kernel mode)
More secure
Detriments:
Performance overhead of user space to kernel space communication
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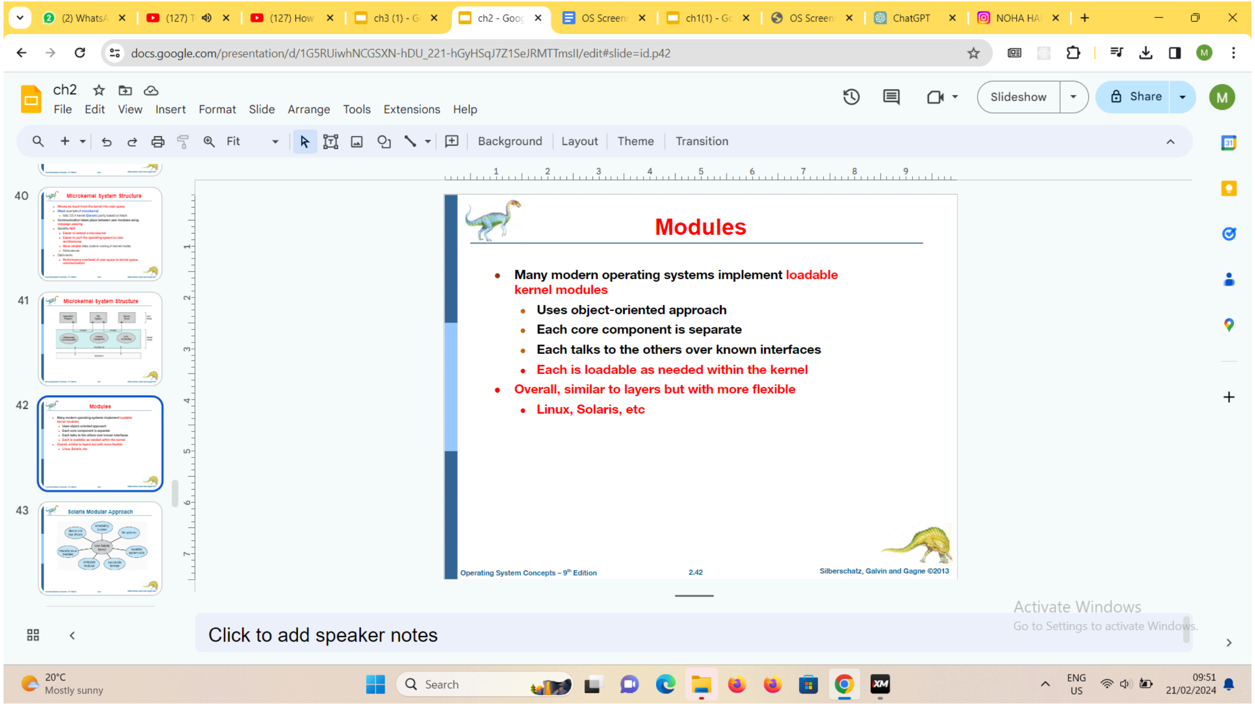
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Modules
Many modern operating systems implement loadable kernel modules
Uses object-oriented approach
Each core component is separate
Each talks to the others over known interfaces
Each is loadable as needed within the kernel
Overall, similar to layers but with more flexible
Linux, Solaris, etc
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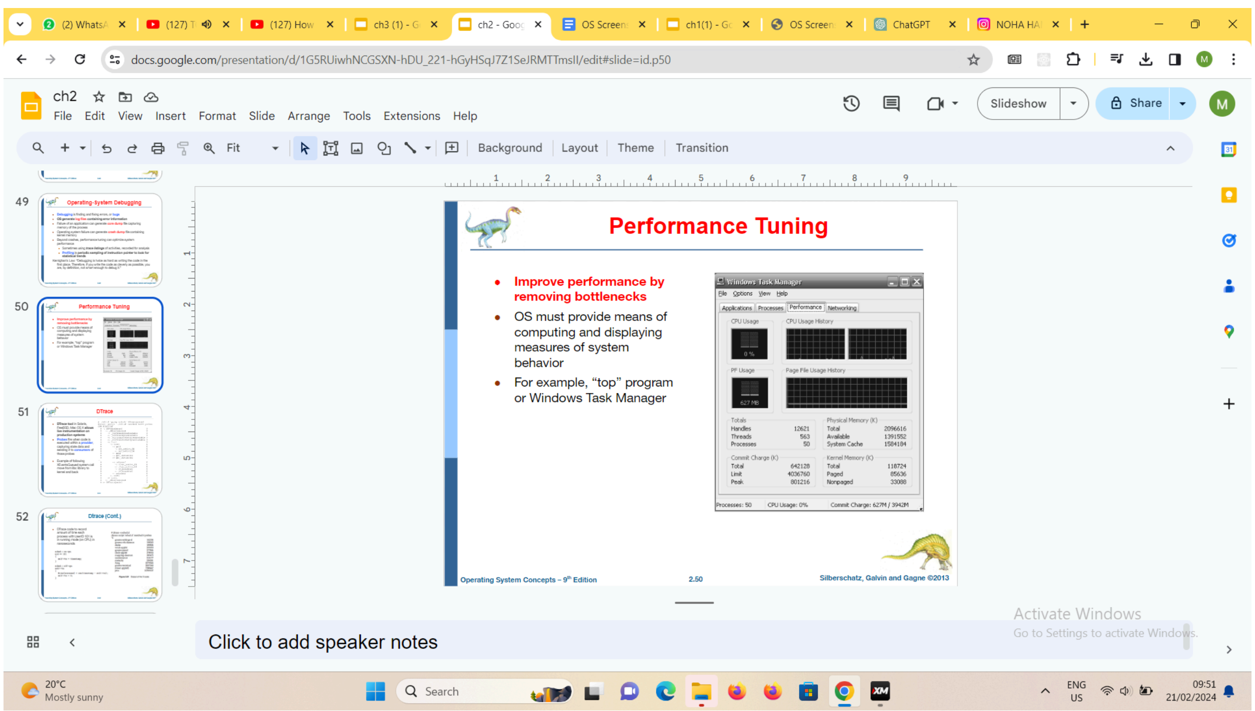
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Performance Tuning
Improve performance by removing bottlenecks
OS must provide means of computing and displaying measures of system behavior
For example, "top" program or Windows Task Manager
Windows Task Manager
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