CS3.301 Operating Systems and Networks

Process Virtualisation - Mechanisms

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Acknowledgement

The materials used in this presentation have been gathered/adapted/generate from various sources as well as based on my own experiences and knowledge -- Karthik Vaidhyanathan

Sources:

- OSTEP Educator Materials, Remzi et al.
- OSTEP Book by Renzi et al.
- Modern Operating Systems, Tanenbaum et al.
- Other online sources which are duly cited

How does the Shell work? - Ever thought?

- Init process is started upon hardware initialisation
- The init process spawns a shell like bash
- Shell does the following
  - Read user command
  - Forks a child and exec the command
  - Wait for it to finish -> next command

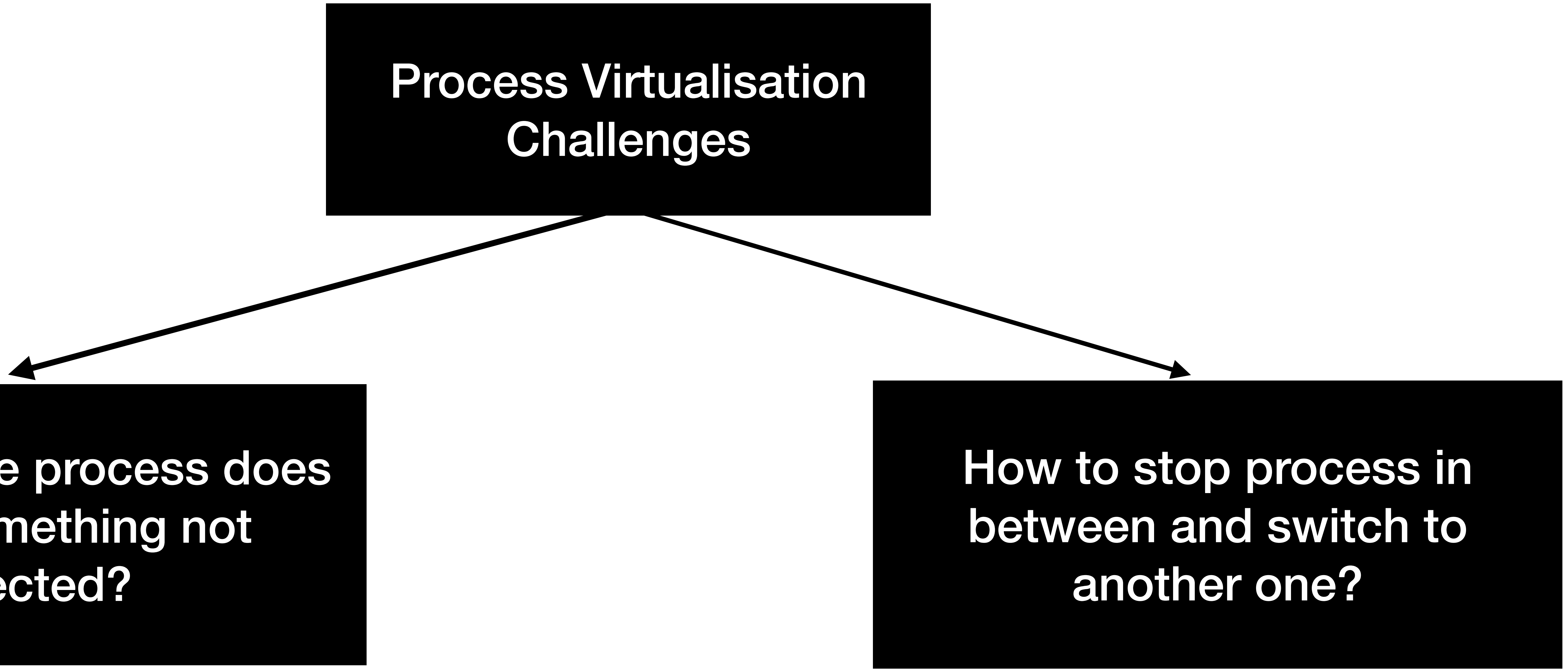
Can you think how this works?

- **> wc process_sample3.c > output.txt**
- Shell will fork a child
  - Rewires its standard output to text file (output.txt)
  - Calls exec on the child (wc process_sample.c)
  - The output will be redirected to output.txt
- Have you seen Unix pipes “|”
  - Output of one goes as input to the other

Note: fork() and exec(), both are required

The Big Question - How to run multiple Processes?

Two Major Problems to be Solved



Process Virtualisation Challenges

How to ensure process does not do something not expected?

How to stop process in between and switch to another one?

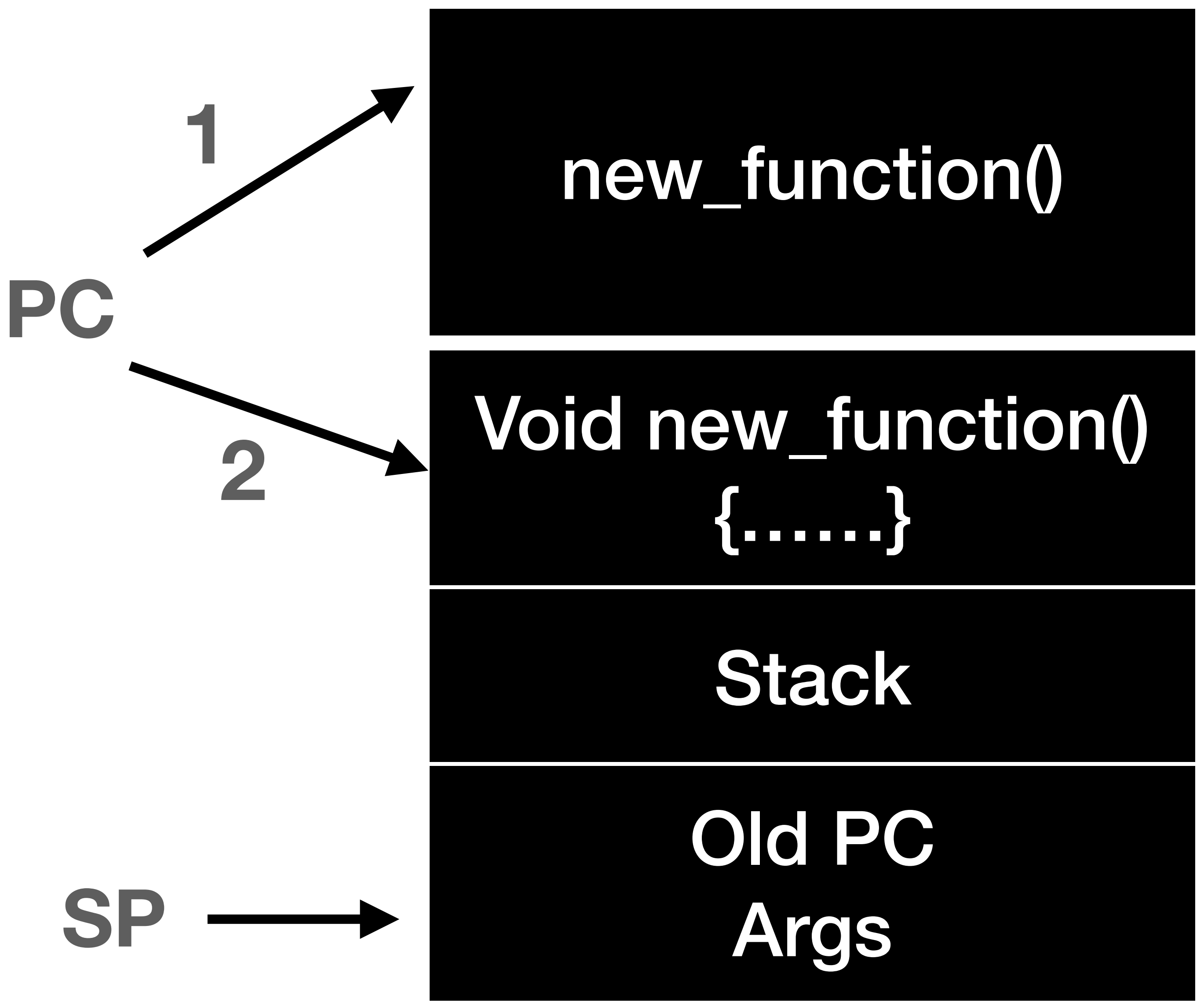
What if we allow process to do whatever it wants?

How can multiple processes run?

- Hardware Support
  - Have some low level mechanisms to switch process
  - What are the challenges?
    - Performance Overhead?
- Software support
  - Have some policies which decides what needs to be executed
  - What are some of the challenges?
    - Control overhead?

Normal Function call

- Function call translates to a jump instruction
  - One instruction to another instruction
- A new stack frame is pushed to the stack, Stack pointer is updated
- Old value of program counter (return value) pushed to stack and PC is updated
- Stack frame contains return value, function arguments, etc,



Is this enough?

OS	Program
1. Create an entry in process list 2. Allocate memory for the program 3. Load program into memory 4. Setup stack with argc/argv 5. Clear registers 6. Execute call main()	
	7. Run main () 8. Execute return from main()
9. Free memory of process 10. Remove process from process list	

What if?

- The process wants to perform operations such as:
    - Issuing I/O request to disk
    - Access to memory or other system resources
- Can we let the process do whatever it wants?

Idea: Can we think of limiting the access of a process?

Challenge 1: Prevent Unintentional behaviour

Limit Direct Execution

Only Kernel has access

https://tribuneindia.com

User program can go until this point

Lets draw some Parallels

Library

Library Users

Reference Books

- As a visitor/user in the library - check sections, read books, magazines,..
- What about accessing the reference section and get access to some treasured books?

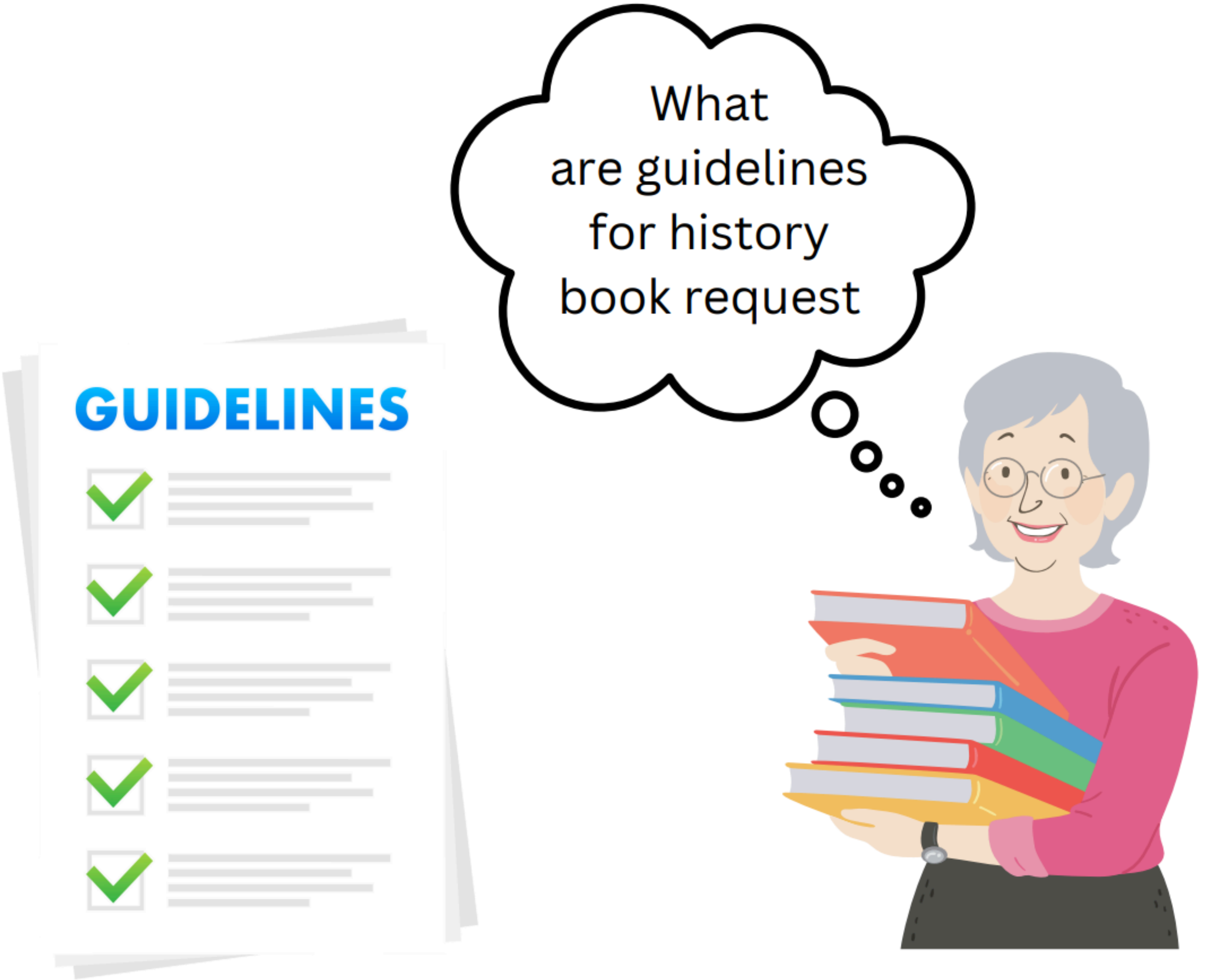
Lets draw some Parallels

Visitor/User

Librarian

Reference Books Section

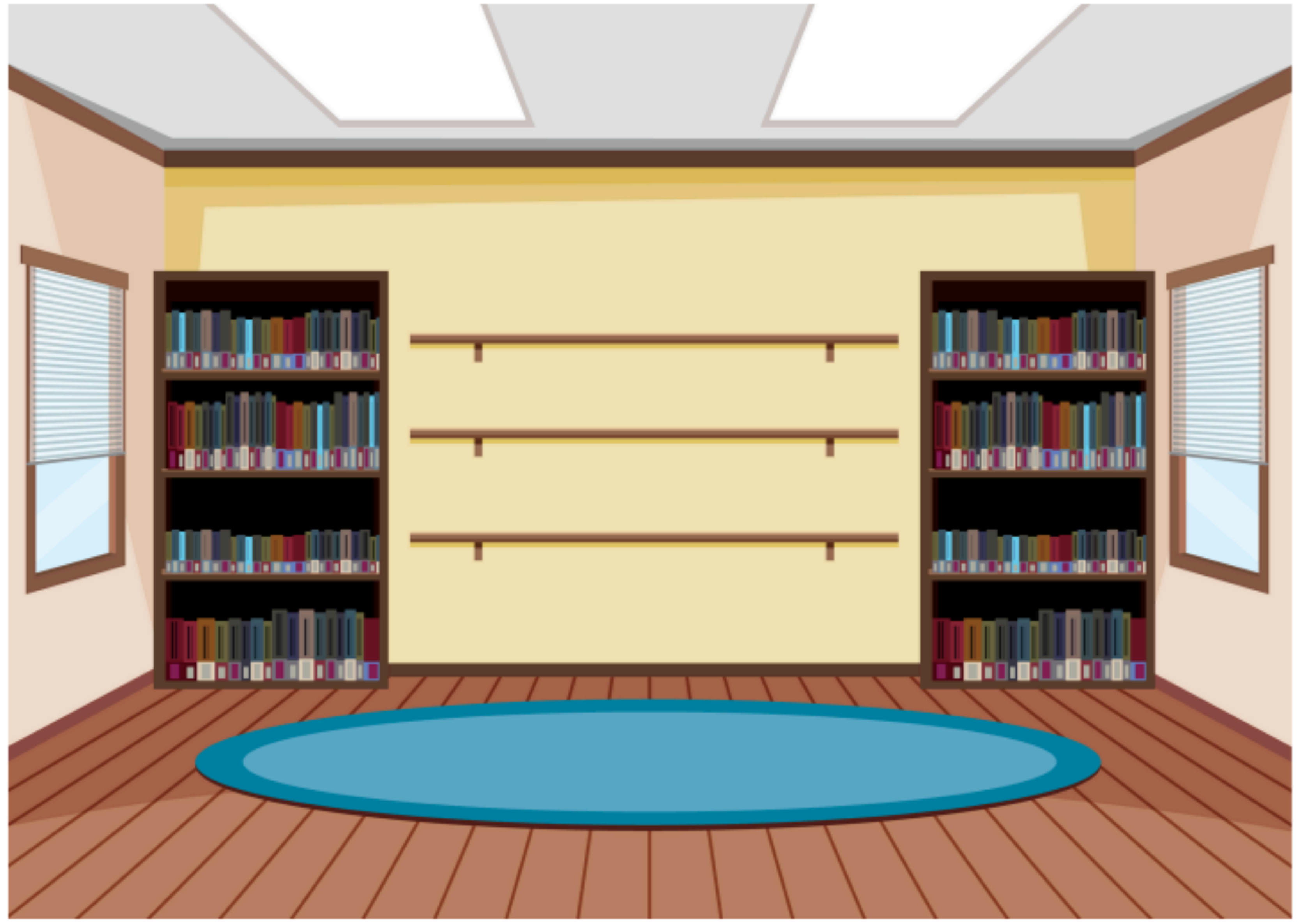
Lets draw some Parallels



Librarian

Provides access to the visitor/User as per guidelines

Lets draw some Parallels



Access completed

User is out of the reference section and continues normal access

Librarian waits for next request

Restricted Operations

- Bring hardware into the picture
  - Introduce a new processor mode
- **User mode**
  - Code is restricted in what it can do
  - Eg: no I/O request, Processor will raise an exception
- **Kernel mode**
  - Code can do whatever it likes to do
  - All privileged operations can be executed

Any challenges that you can think of?

Limited Direct Execution (LDE)

- Low level mechanism that separates the user space from kernel space
- Let the program directly run on the CPU
- Limits what process can do
- Offer privileged operations through well defined channels with the help of OS

At the end we need OS to be more than just a library!

How to move from User to Kernel?

- System calls - Kernel performs on behalf of user process
  - Key pieces of functionality exposed by the kernel
    - File system, process management, process communication, memory allocation, etc
  - Most OS provides few 100s of calls
  - Early unix - 20 calls
- Some privileged hardware instruction support is needed - Cannot use normal function call mechanism

System call works little differently

- Kernel does not trust the user stack - You don't want to jump to random addresses
  - Maintains a separate kernel stack (kernel mode)
- Kernel cannot rely on user provided address
  - Uses a table - Interrupt Descriptor table (boot time) - **Guidelines in our example**
  - IDT consists of addresses of different kernel functions to run on system calls or other events

TRAP Instruction

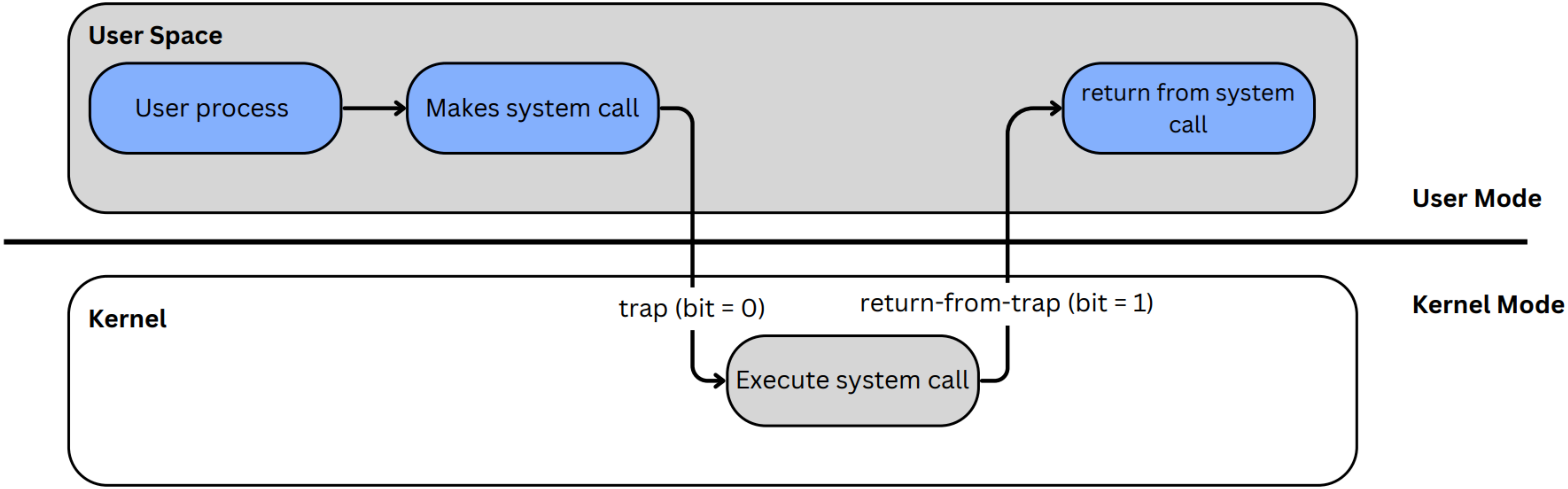
- Special kind of instruction to switch mode from user to kernel
- Allows system to perform what it wants
- When a system call is made, the trap instruction allows to jump into kernel
    - Raise the privilege mode to kernel mode
    - **Return-from-trap** instruction allows switch back to user mode
    - Return into the calling user program
- Normal routine is interrupted

More about TRAP instruction

- During TRAP instruction execution
  - CPU to higher privilege level
  - Switch to Kernel Stack
  - Save context (old PC, registers) on Kernel Stack
  - Look up in IDT (Trap Table) and jump to trap handler function in OS code
  - Once in Kernel, privileged instructions can be performed
- Once done, OS calls a special **return-from-trap** instruction
- Returns into calling program, with back to **User mode**

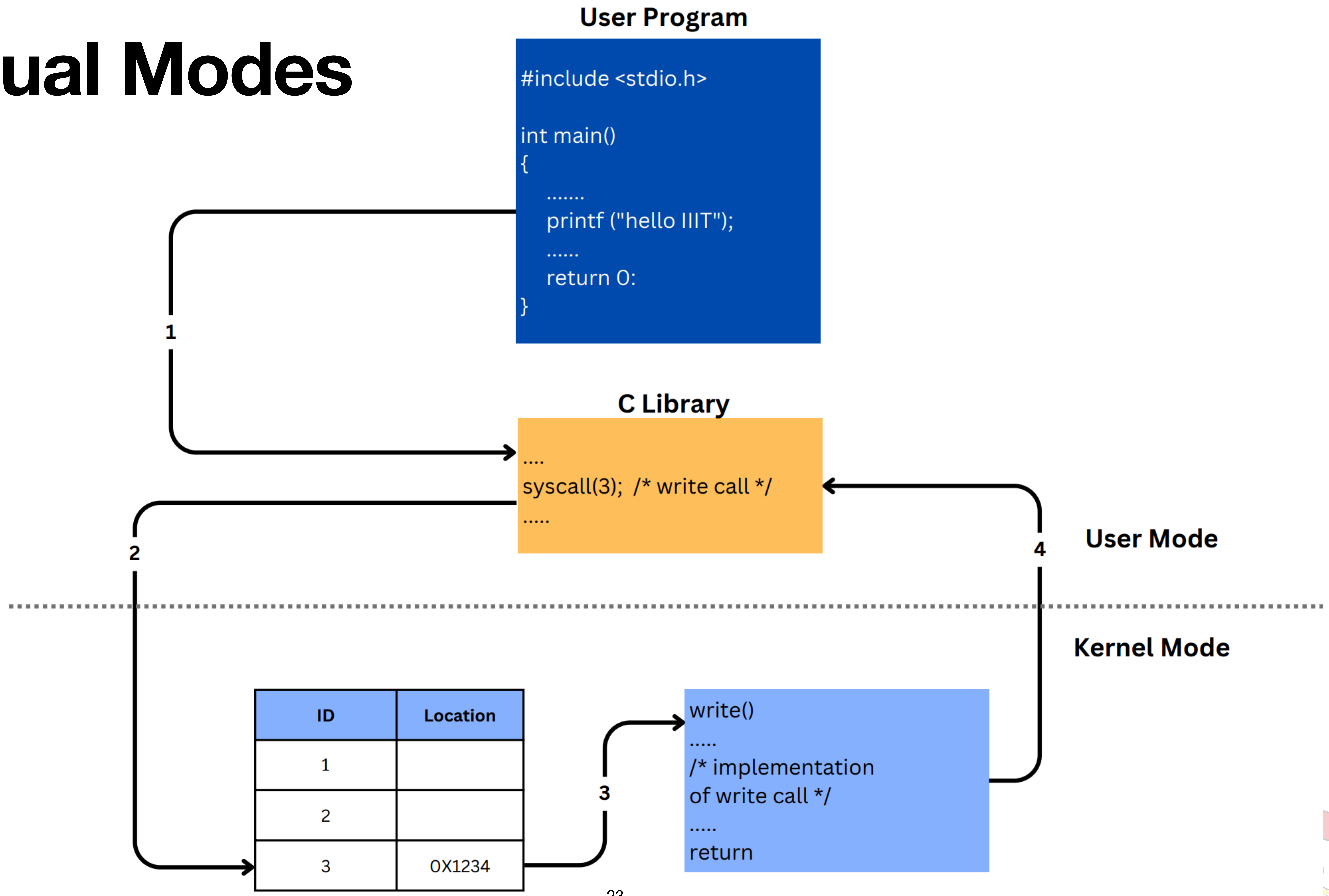
The dual modes

User Mode and Kernel Mode



Adapted from: OS02-Limited Direct Execution, Dongkun Shin, SKKU

The Dual Modes



User Program

```
#include <stdio.h>

int main()
{
    .......
    printf ("hello IIIT");
    ......
    return 0:
}
```

C Library

```
....
syscall(3);  /* write call */
.....
```

1

2

3

4

User Mode

Kernel Mode

ID	Location
1	
2	
3	0X1234

```
write()
.....
/* implementation
of write call */
.....
return
```

Adapted from: OS02-Limited Direct Execution, Dongkun Shin, SKKU

Interrupt and Trap

- **Interrupt**
  - Signal sent to the CPU due to unexpected event
  - I/O Interrupt, clock Interrupt, Console Interrupt
  - From either Software or Hardware interrupt
    - Hardware may trigger an interrupt by signalling to the CPU
- **Trap**
  - Software generated interrupt caused by
    - Exception: Error from running program (divide by Zero)
    - System call: Invoked by user program

LDE Protocol

OS @ boot (Kernel mode)	**Hardware**	
Initialize trap table	Remember address of.. Syscall handler..	
OS @ run (Kernel mode)	**Hardware**	**Program (User mode)**
Create entry for process list Allocate memory for program Load program into memory Setup user stack with arg Fill kernel stack with reg/PC		
	Restore regs from kernel stack Move to user mode Jump to main	
		Run main() .. System call **trap** into OS

LDE Protocol

OS @ boot (Kernel mode)	Hardware	Program (User mode)
	…. Save regs to kernel stack Move to kernel mode Jump to trap handler	
Handle trap Execute the system call Return-from-trap		
	Restore regs from kernel stack Move to user mode Jump to PC after trap	
		… Return from main() trap (via exit())
Free memory of process Remove process from process list		

Problem 2: How to Switch between Process?

Lets draw some parallels

Librarian does not have a control
when the person is inside the reference section
(only one reference section and a person is already inside)

More users/visitors have requested
to access the reference section

How can this situation be handled? - What can be the possibilities?

Cooperative Approach

Non-Preemptive

- Wait for system calls
- OS trusts the processes to behave reasonably (Give control back - **Yield()** call)
- Process transfer the control to the CPU by making a system call
- There can be misbehaving process (They may try to do something they shouldn’t)
  - Divide by zero or attempting to access memory it shouldn’t
  - Trap to OS -> OS will terminate the process
- Used in initial versions of Mac OS, Old Xerox alto system
- What if there is an infinite loop & process never terminates? - **Reboot**

Non-Cooperative Approach

Preemptive

- OS takes control
  - The only way in cooperative approach to take control is reboot
  - Without Hardware support, OS can’t do much!
  - How can OS gain control?
- Simple solution - Use interrupts
  - Timer interrupt was invented many years ago
  - Every X milliseconds, raise an interrupt -> halt the process -> invoke interrupt handler -> OS regains control

Non-Cooperative Approach

Preemptive - Timer Interrupt

- During boot sequence, OS starts the timer
- The time raises an interrupt every “X” milliseconds
- The timer interrupt gives OS the ability to run again on CPU
- Two decisions are possible - Component called Scheduler comes into picture
  - Continue with current process after handling interrupt
  - Switch to a different process => OS executes **Context Switch**

Context Switch

- A low-level piece of assembly code
- **Save a few register values** from executing process registers to kernel stack
  - General purpose registers
  - Program counter
  - Kernel stack pointer
- Restore values for the next process
  - essentially retrun-from-trap will go to new process
- Switch to Kernel stack for the next process

LDE Protocol (Timer Interrupt)

OS @ boot (Kernel mode)	**Hardware**	
Initialise trap table	Remember address of.. Syscall handler.. Timer handler	
Start interrupt timer	Start timer Interrupt CPU every “X” milliseconds	
OS @ run (Kernel mode)	**Hardware**	**Program (User mode)**
		Process A ….
	Timer interrupt Save regs(A) to k-stack(A) Move to kernel mode Jump to trap handler	

LDE Protocol (Timer Interrupt)

OS @ boot (Kernel mode)	Hardware	Program (User mode)
Handle the trap Call switch() routine Save regs(A) to proc-struct(A) Restore regs(B) from proc-struct(B) Switch to k-stack(B) **Return-from-trap (into B)**		
	….. Restore regs(B) from k-stack(B) Move to user mode Jump to B's PC	
		Process B …

What if?

- During handling of one interrupt another interrupt occurs?
  - Disable interrupt during interrupt processing
  - Sophisticated locking mechanism to protect concurrent access to internal data structures

How to decide which process to run next?

SCAN ME

Thank you

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