Mechanisms for entering the system

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- Introduction
- Mechanisms for entering the system
  - Initialization
  - Management
  - Example
- Procedure for entering the system
- Procedure to exit from system
- Exceptions
- Interrupts
- System calls
- Summary

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Introduction

- OS implements access to machine resources
  - Isolates users from low-level machine-dependent code
  - Groups common code for all users: save disk space
  - Implements resource allocation policies
    - Arbitrates the usage of the machine resources in multi-user and multiprogrammed environments
  - Prevents machine and other users from user damage
    - Some instructions can not be executed by user codes: I/O instructions, halt,…

Privilege levels (I)

- Requirement:
  - Prevent users from direct access to resources
    - Ask the OS for services
- Privilege instructions
  - Instructions that only can execute the OS
  - HW support is needed
  - When a privilege instruction is executed, the hw checks if it is executing system code
    - If not → exception
- How to distinguish user code from system code?
  - Privilege levels
    - At least 2 different levels
    - System execution mode vs User execution mode
  - Intel defines 4 different privilege levels.

Privilege levels (II)

- How to scale privileges?
  - Intel offers interrupts
    - Interrupt Driven Operating System
  - When an interrupt/exception happens
    - Hw changes the current privilege level and enables the execution of privilege instructions
  - When the interrupt/exception management ends
    - Hw changes the current privilege level to unable the execution of privilege instructions

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Mechanisms for entering the system

- Exceptions
  - Synchronous, produced by the CPU control unit after terminating the execution of an instruction
- Interrupts
  - Asynchronous, produced by other hardware devices at arbitrary times
- System calls
  - Synchronous: assembly instruction to cause it
    - Trap (in Pentium: INT, sysenter…)
  - Mechanism to request OS services
- All of them are managed through the interrupts vector
  - New arquitectures implement a fast system call mechanism that skip the interrupts vector: sysenter instruction

Interrupts Vector

- Pentium
  - IDT: Interrupt Descriptor Table: 256 entries
- Three groups of entries, one for each kind of event:
  - 0 - 31: Exceptions
  - 32 - 47: Masked interrupts
  - 48 - 255: Software interrupts (Traps)

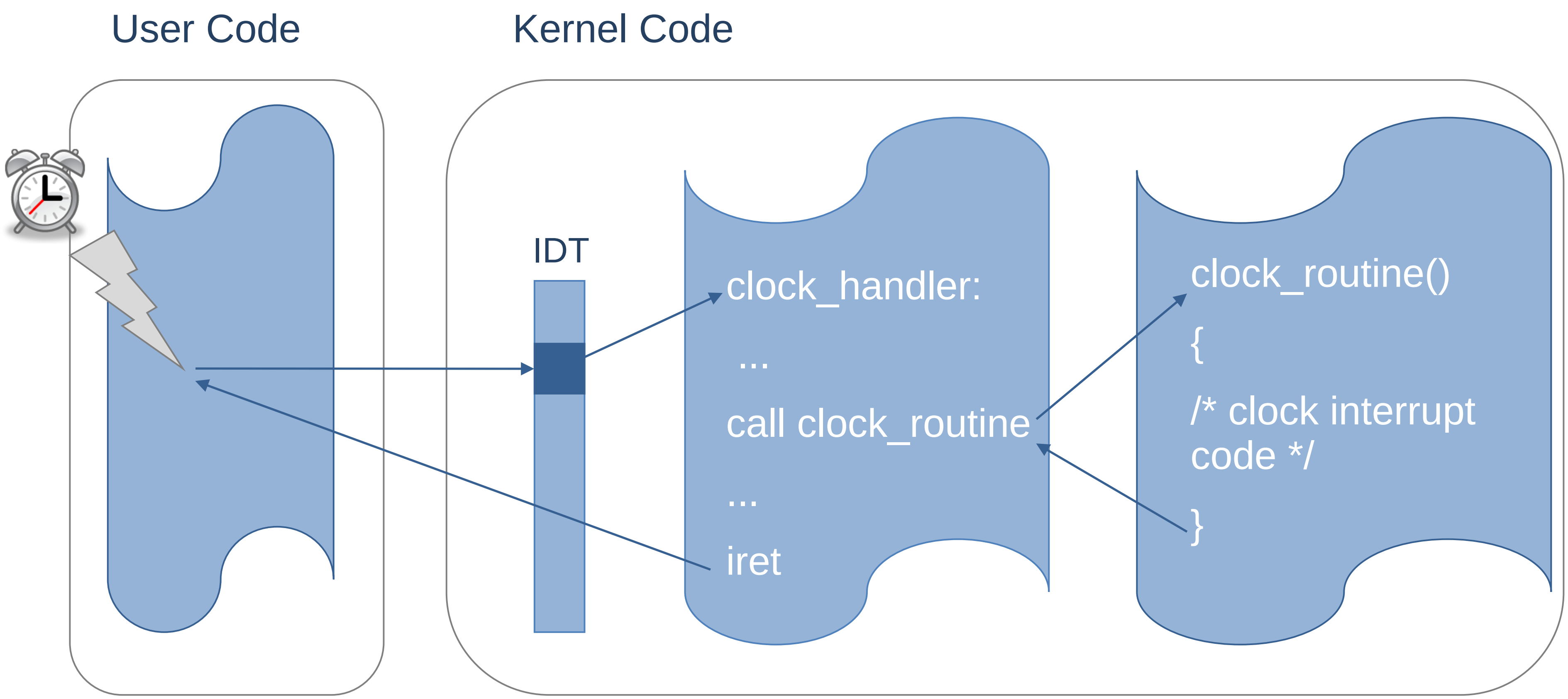
Initialization

- Each entry in the IDT, identifying an interrupt number, has:
  - A code address
    - Entry point to the routine's code to be executed
  - A privilege level
    - The minimum needed to execute the previous code

Management Code

- It could be done in a single routine
  - Divided in two parts: hw context mgmt + solve int.
- Hw context mgmt
  - Entry point handler
  - Basic hardware context management
  - Assembly code
  - Call to a Interrupt Service Routine
- Solve interrupt
  - Interrupt Service Routine
  - High level code (C for example)
  - Specific algorithm for each interrupt

Example: clock interrupt behavior



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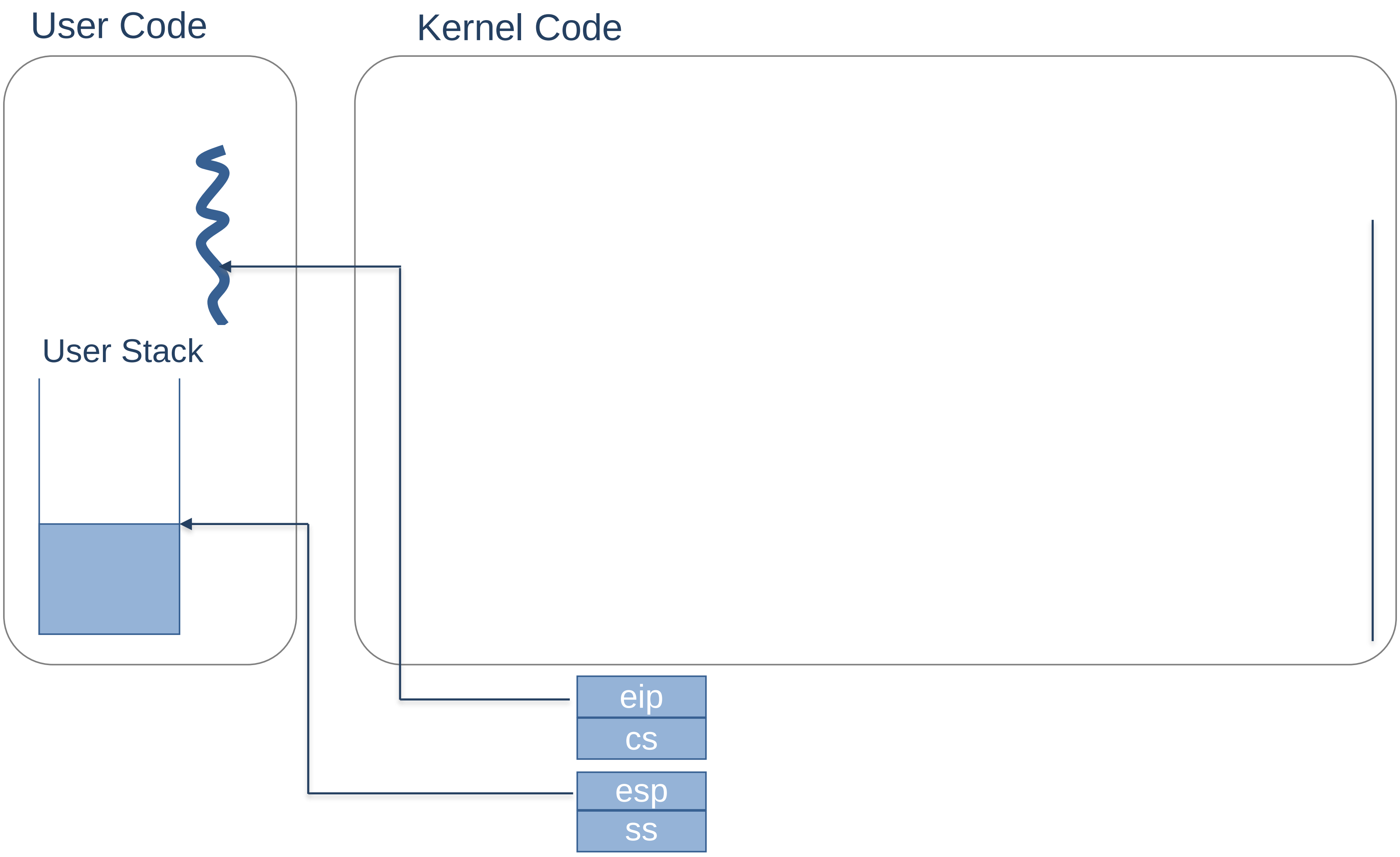
Procedure for entering the system

- Switch to protected execution mode
  - User Mode → Kernel Mode
- Save hardware context: CPU registers
  - ss, esp, psw, cs i eip
  - General purpose registers
- Execute service routine

HW

handler

Procedure for entering the system



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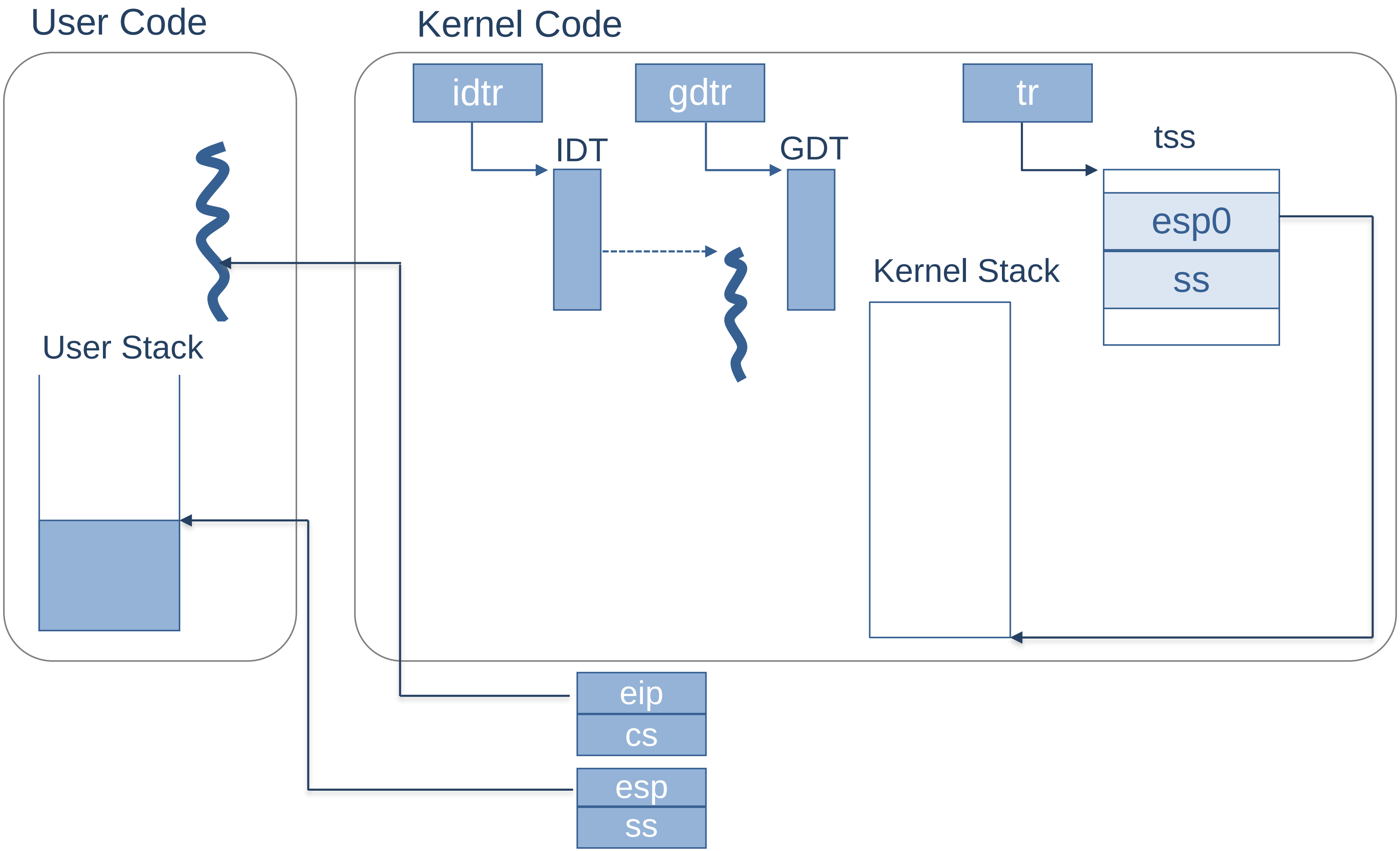

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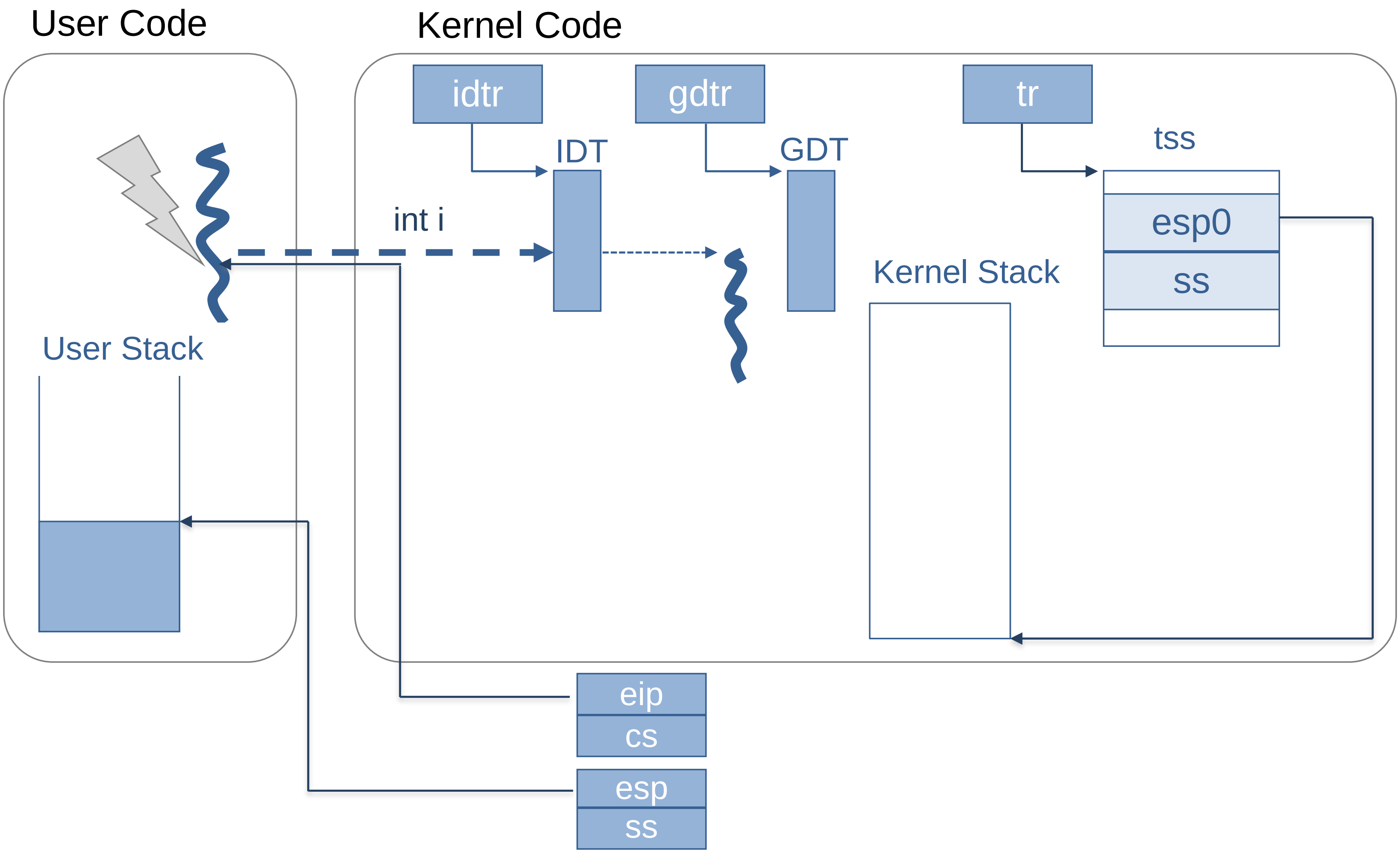

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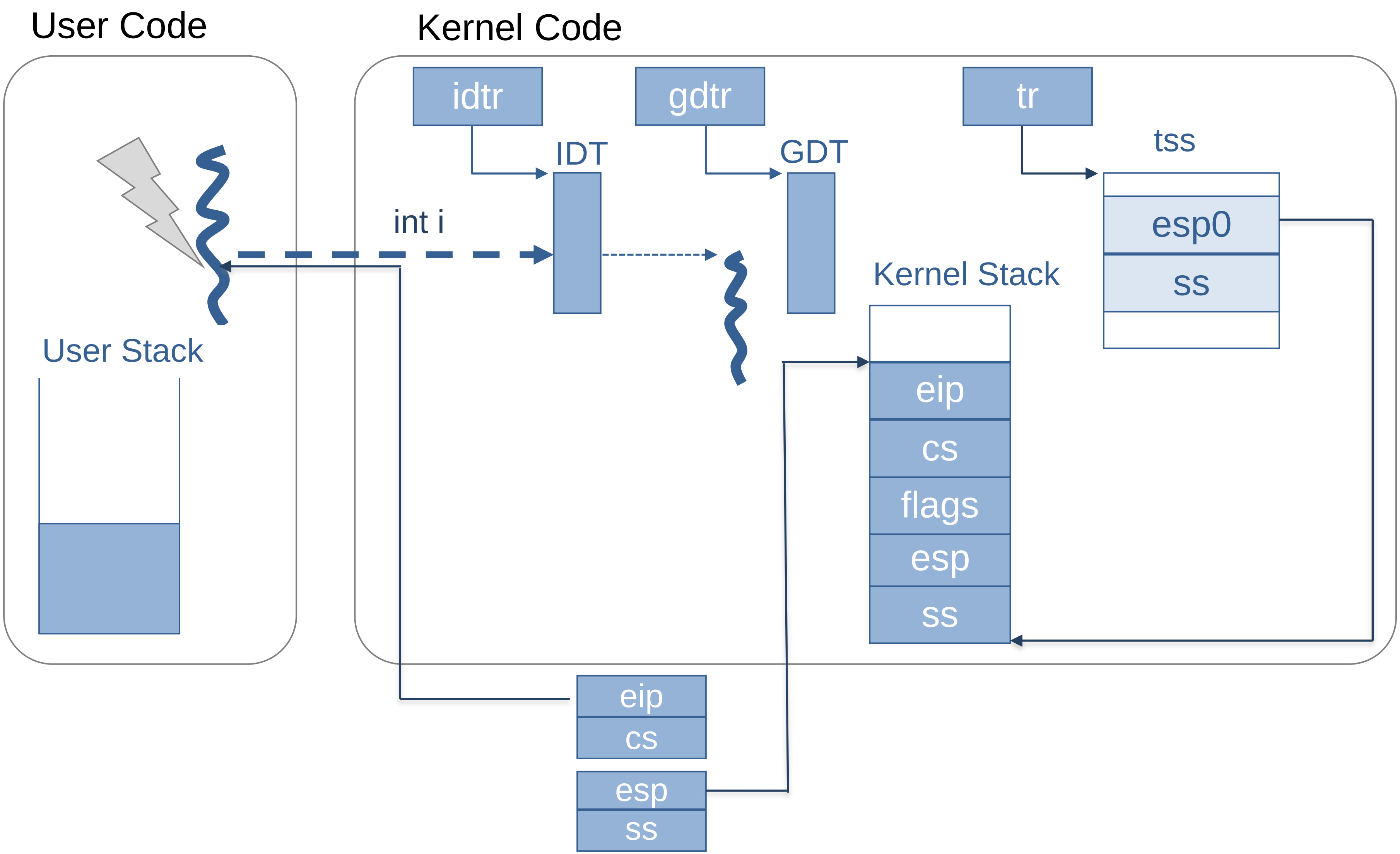

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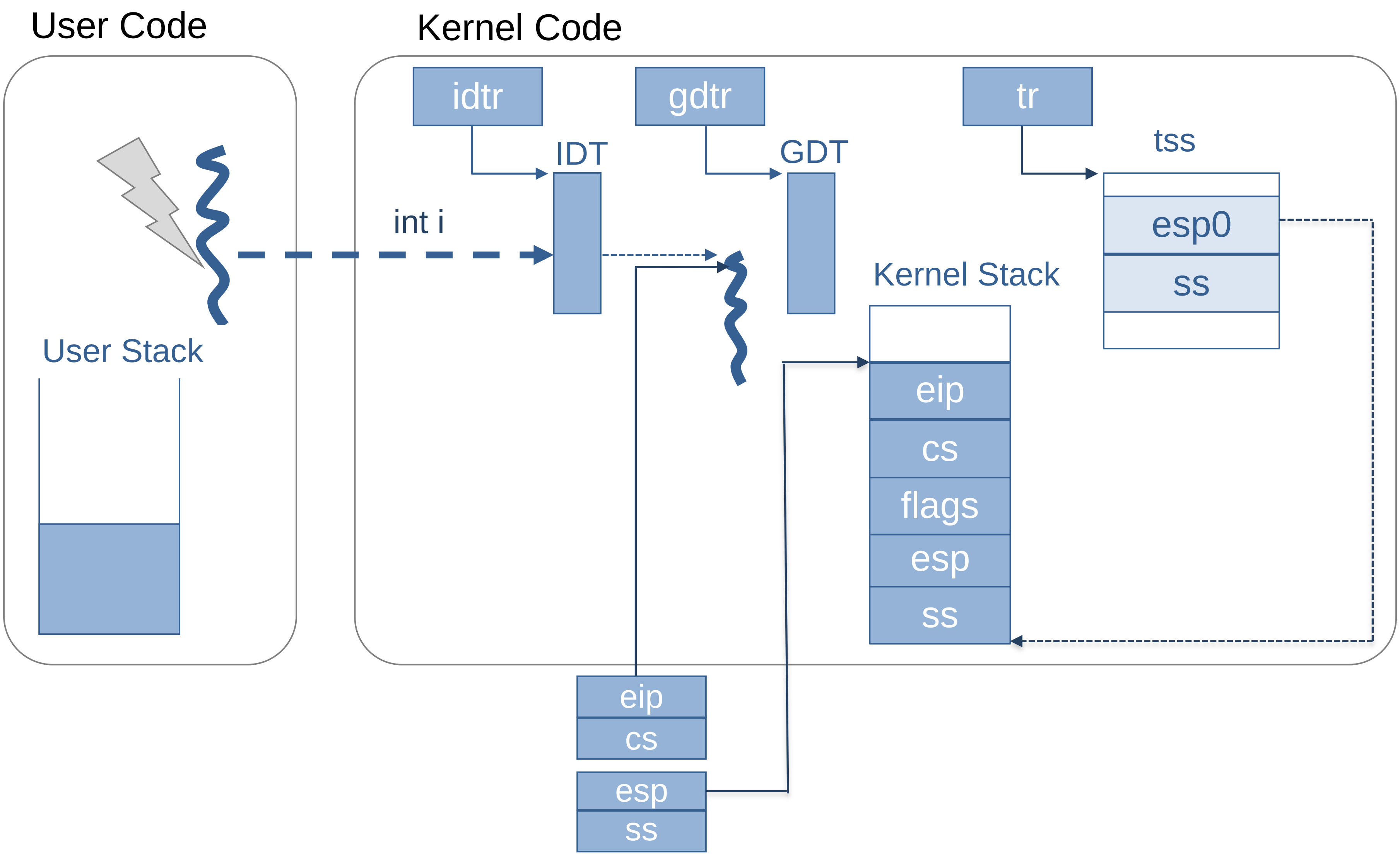

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Procedure to exit the system

- Restore HW context
  - General purpose registers
  - ss, esp, flags, cs, eip
- Switch execution mode
  - Kernel mode → User mode

handler

HW (iret instruction)

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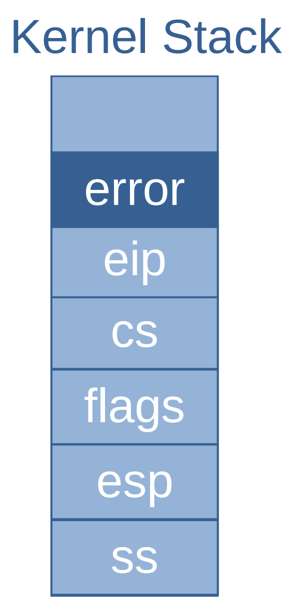
Exceptions: Stack layout

- There are some exceptions that push a parameter of 4 bytes (a hardware error code) to the kernel stack after entering the system:



Exception´s handler

- Save hardware context
- Call exception service routine
- Restore hardware context
- Remove error code (if present) from kernel stack
- Return to user (iret)

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Interrupt´s handler

- Similar to exception, but:
  - No hardware error code in kernel stack
  - It is necessary to notify the interrupt controller when the interrupt management finishes
    - Meaning that a new interrupt can be processed
    - End Of Interrupt (EOI)

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Handling system calls

- Why cannot be invoked like a regular user function?
- Which is the mechanism to identify the system call?
- How to pass parameters to the kernel?
- How to get results from the kernel

System calls: invocation and identification

- Assembly instruction that causes a software generated interrupt
  - int assembly instruction (int idt_entry)
  - sysenter assembly instruction: fast system call mechanism
- An entry point per syscalls?
  - Limitation for the potential number of syscalls
- A single entry point is used for all system calls
  - int
    - 0x80 for Linux
    - 0x2e for Windows
  - sysenter
    - system call handler @ is kept on a control register: SYSENTER_EIP_MSR
- And an extra parameter (EAX) to identify the requested service
- A table is used to translate the user service request to a kernel function to execute

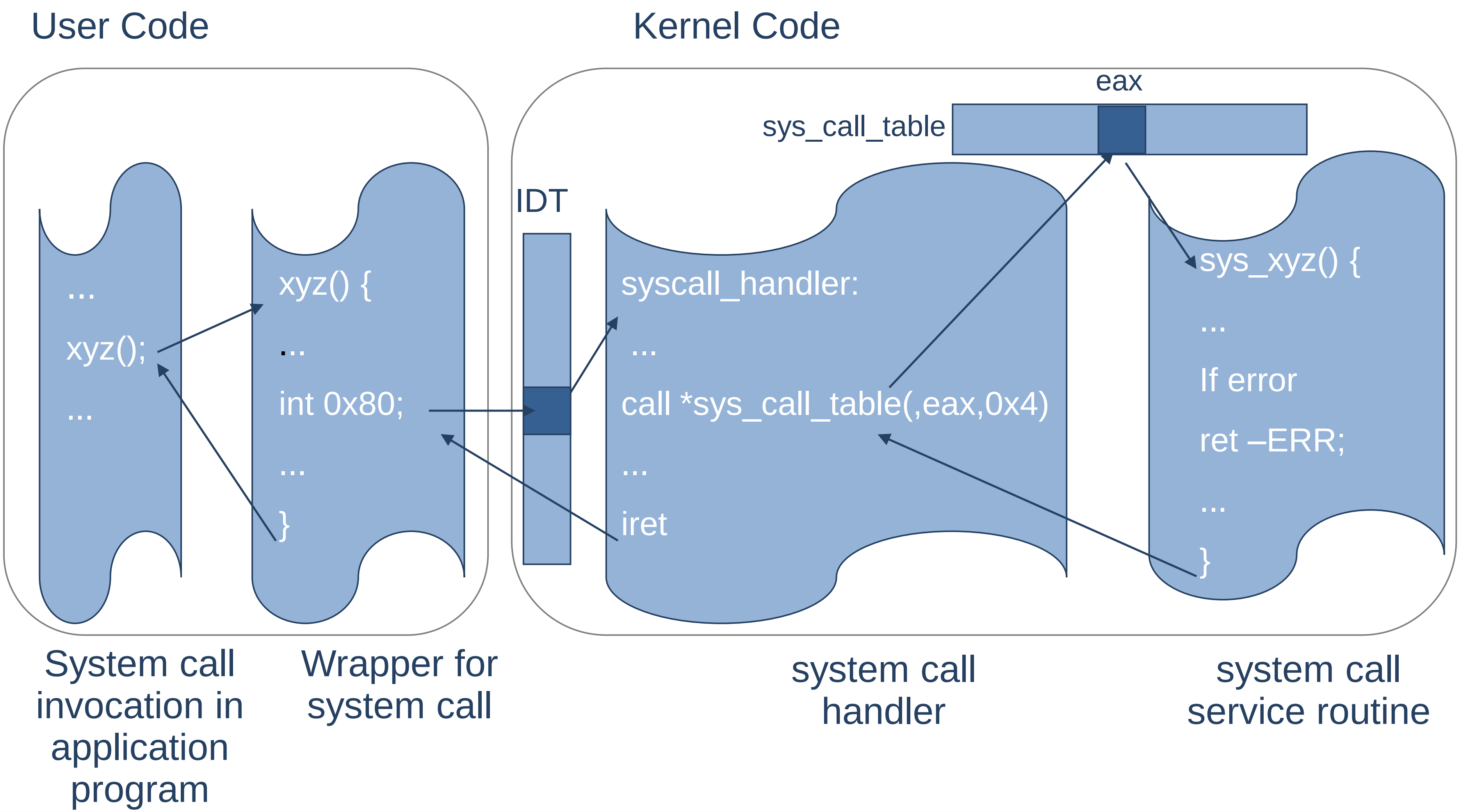
System calls: parameters and results

- Parameter passing: Stack is NOT shared
  - Linux: syscall handler expects parameters in the registers
    - (first parameter) ebx, ecx, edx, esi, edi, ebp
    - Copy parameters from user stack
  - Windows: Use a register to pass a pointer to parameters
    - EBX
- Returning results:
  - EAX register: contains error code

System call wrappers

- System must provide the users with an easy and portable way to use them
  - New layer: wrappers
    - wrap all the gory details in a simple function call
- Wrapper responsibilities
  - Invoke the system call handler
    - Responsible for parameter passing
    - Identify the system call requested
    - Generate the trap
  - Return the result to the user code
    - Use errno variable to codify type of error and returns -1 to users

System call mechanism overview



System call handler

- Save hardware context and prepare parameters for the service routine
  – Linux: stores registers with system call parameters at the top of the kernel stack
  – Windows: copy parameters from the address stored in ebx to the top of the kernel stack
- Execute system call service routine
  – Error checking: system calls identifiers
  – Using system_call_table
- Update kernel context with the system call result
- Restore hardware context
- Return to user

System calls service routines

- Check parameters
  - User code is NOT reliable
    - System MUST validate ALL data provided by users
- Access the process address space (if needed)
- Specific system call code algorithm

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Interrupt Handling Summary

- Save user context
- Restore system context
- Retrieve user parameters [if needed]
- Identify service [if needed]
- Execute service
- Return result [if needed]
- Restore user context