Windows Internals III

Services

Introduction to Services

- A Service Application is a program that provides some functionality without being tied to the logged on user (Services may run without any user logging in).
- Examples: IIS service and SQL server.
- A service needs to register with Service Control Manager, SCM.
- A service can be controlled by a Service Control Program, SCP.

Service Characteristics

- A service is built just like any Win32 application.
- It must be registered with SCM using CreateService API.
- It communicates with the SCM using a named pipe.
- It may run automatically when Windows boots, loaded by the SCM (services.exe)
- It usually run under a special user account (Local system, network service or local service).
- Service Control programs can manipulate a service (StartService, ControlService APIs).

Service Configuration

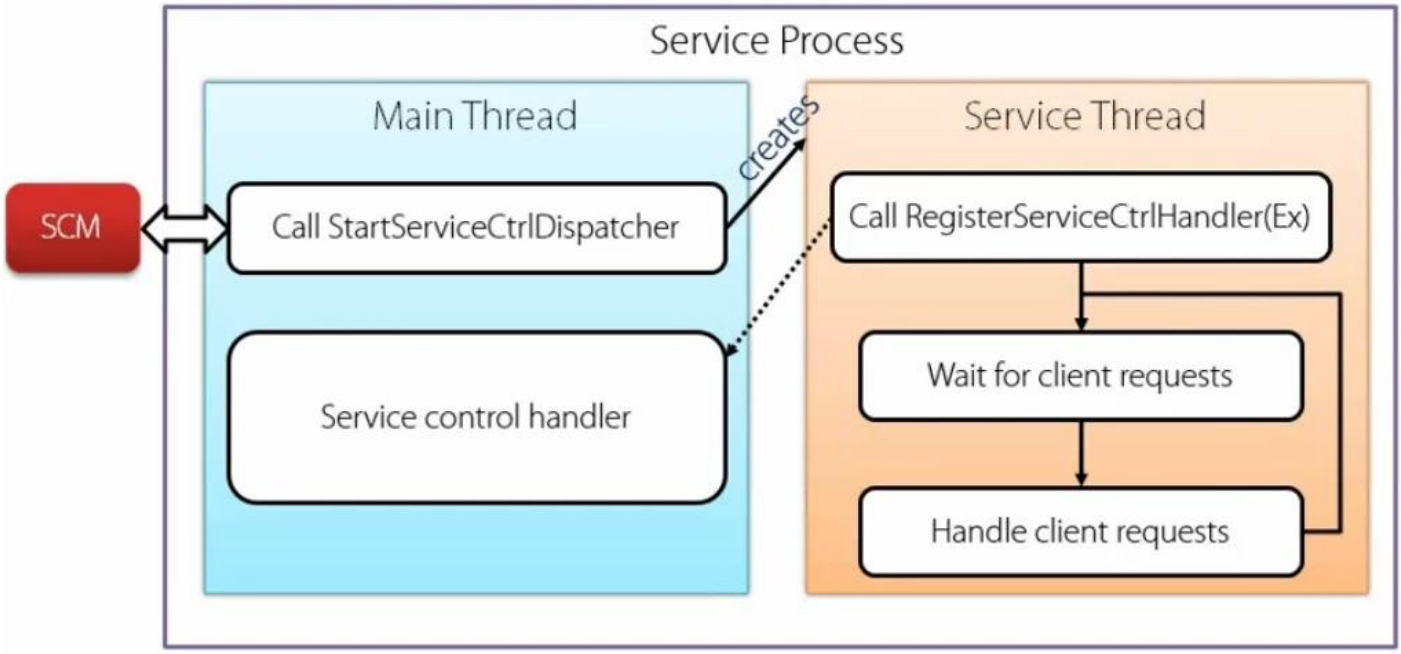
- A service application is installed by calling the CreateService API or any equivalent tool.
- It inserts a new key into the registry under HKLM\System\CCS\Services
  - The entries in the Services key correspond to services and device drivers.
- The services MMC snap-in can be used to view services only.
- To start a service, a SCP calls the StartService API or any equivalent tool.

Important Service Key Parameters

- Start
  - SERVICE_BOOT_START (0) – Drivers only.
  - SERVICE_SYSTEM_START (1) – Drivers only.
  - SERVICE_AUTO_START (2) – Start service when the system starts.
  - SERVICE_DEMAND_START (3) – Start service on demand (StartService API).
  - SERVICE_DISABLED (4) – Do not start the service.
- DelayedAutoStart
  - Relevant to auto start services only.
  - If true (1), a service is started some time after the SCM is started.
- Type
  - SERVICE_WIN32_OWN_PROCESS (16) – Runs in a process that hosts only one service.
  - SERVICE_WIN32_SHARE_PROCESS (32) – Runs in a process that hosts multiple services.
- ImagePath: The path to the service executable.

- DisplayName
  - The service name visible in the Services applet.
  - If it's not specified, the service key becomes the name.
- Description: Textual description of the service.
- ObjectName: The account under which the service process should execute.

Service Architecture



Controlling Services

- Service Control Program, such as the Services MMC use the Windows API to control services.
  - OpenSCManager: Opens a connection to the SCM.
  - OpenService, CreateService: Opens a connection to an existing service or installs a new one.
  - StartService: Starts a service.
  - ControlService: Sends other commands to the service (stop, pause, etc).
  - QueryServiceStatus: Returns current service status.
  - DeleteService: Uninstalls a service.

Service Accounts

- LocalSystem: Most powerful account on local computer and it should be used with cautions.
- NetworkService
  - It allows a service to authenticate outside the local computer.
  - It has less privilege locally.
- LocalService: It's similar to NetworkService but can only be access network elements accepting anonymous access.

Shared Service processes

- Some services run in their own process.
- Some services are sharing a single process
  - Less system overhead of extra processes.
  - If one service crashes, it brings down all other services in that process.
  - All services running in a shared process run with the same account.
- Microsoft uses the SvcHost.exe generic host to host multiple services within the same process.

Trigger Start Services

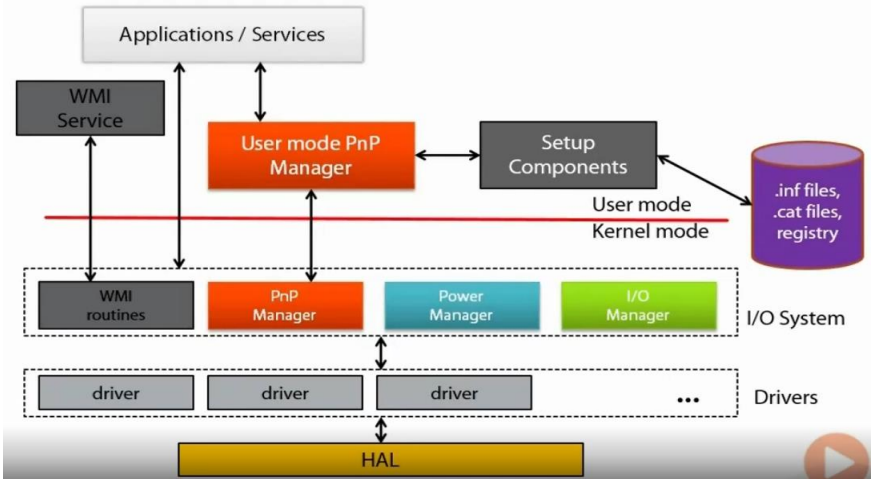
- It was introduced in Windows 7.
- Services can start with a certain trigger.
- It cannot be configured using the Services MMC (must call ChangeServiceConfig2 API to do so).
- Possible Triggers: Computer joins a domain, Device arrival, Firewall port open, Group or User policy change, IP address availability, Network protocol, ETW based.

The I/O System

Introduction to the I/O System

- It abstracts logical and physical devices.
- Most I/O system parts are within the executive and kernel.
- It provides:
  - Uniform naming mechanisms across devices and files.
  - Uniform security model.
  - Asynchronous packet I/O based.
  - Support for Plug & Play.
  - Dynamic loading and unloading of device drivers.
  - Support for power management.
  - Support for multiple file systems.

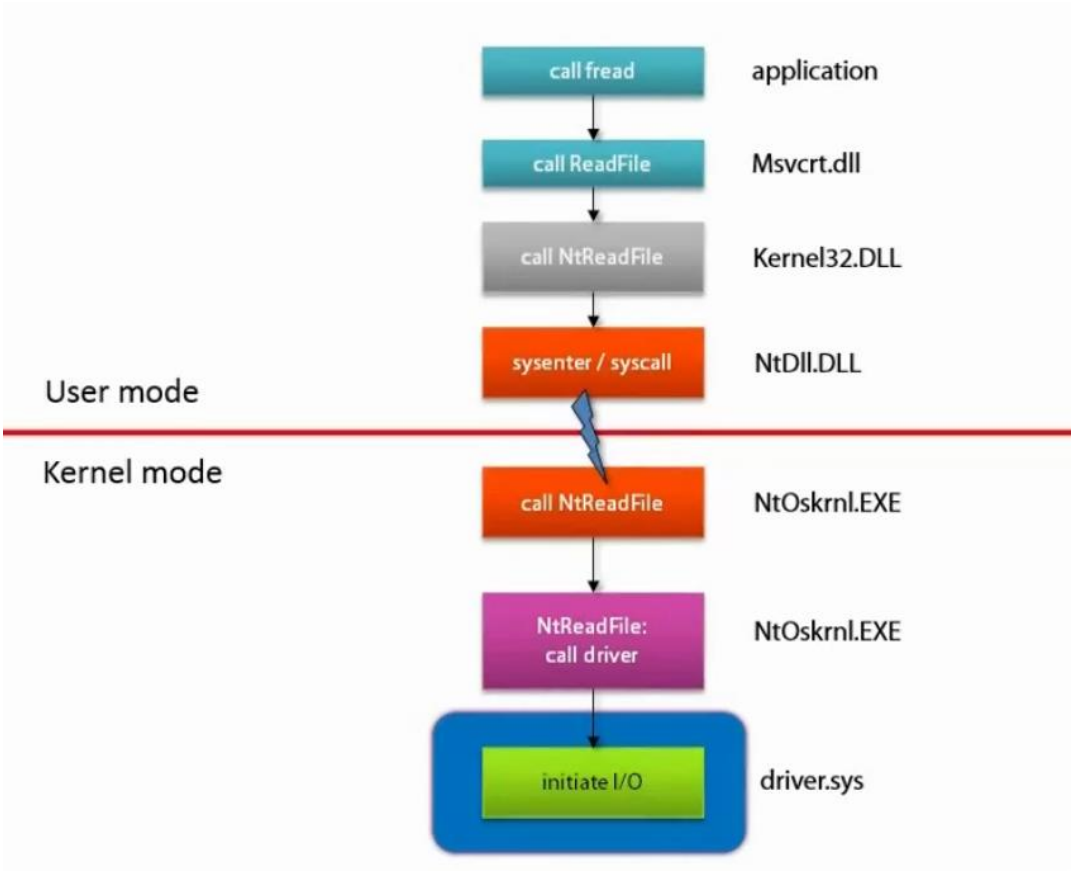
I/O System components



Device Drivers

- Device drivers are loadable kernel modules (The only official supported way to get 3rd party code into the kernel).
- Classic device drivers provide the “glue” between hardware devices and the operating system.
- Several ways to segregate device driver into categories
  - User mode device drivers: Printer drivers and Drivers based on UDMF.
  - Kernel mode drivers: File system drivers, Plug & Play drivers and Software drivers.

Invoking a Driver

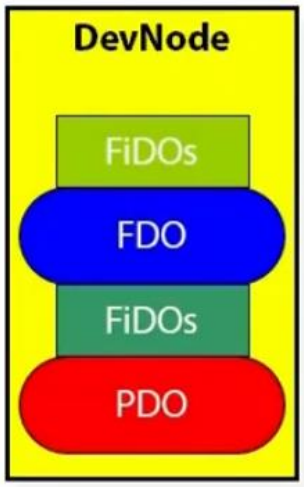


Plug & Play

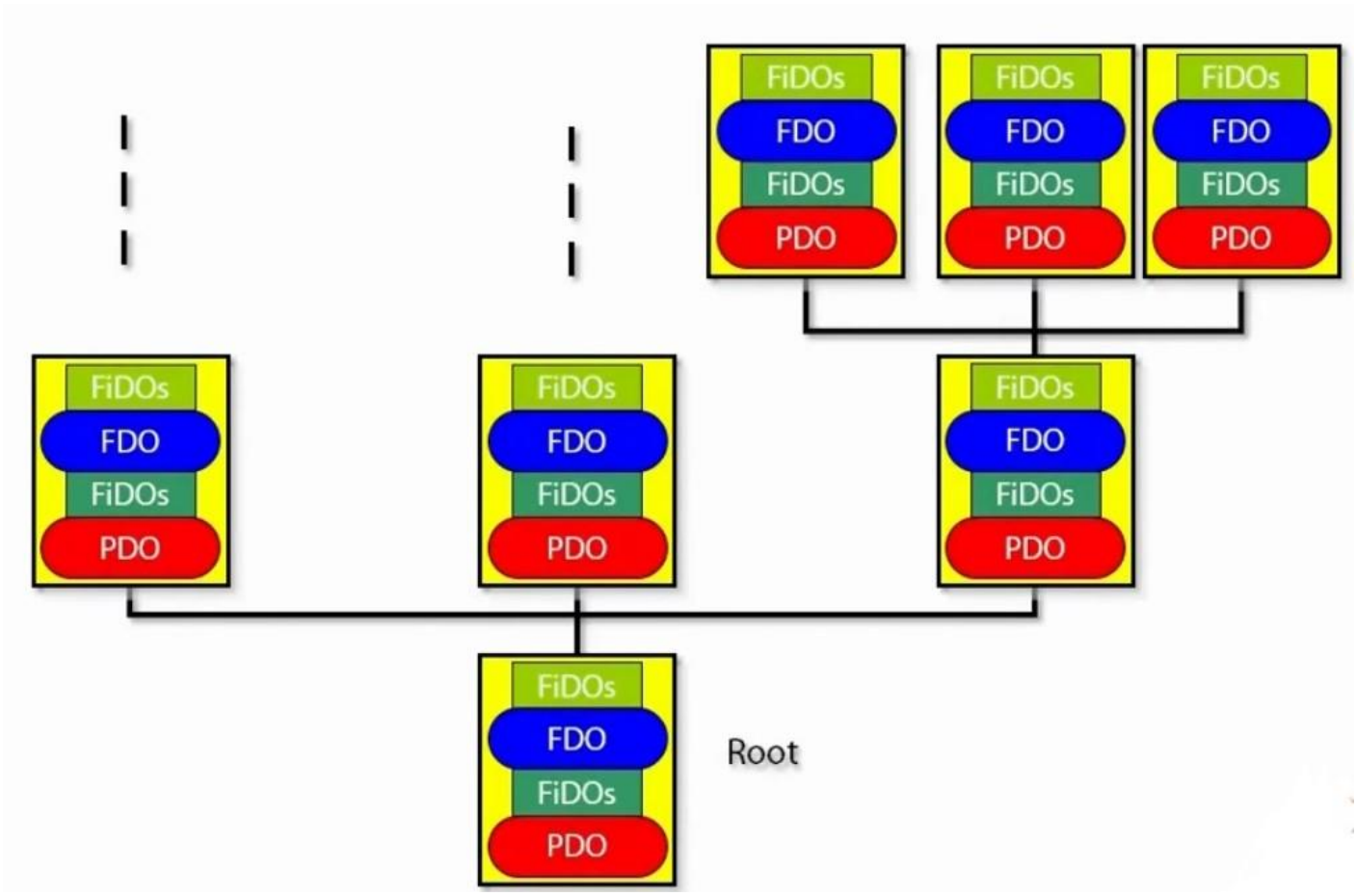
- Automatic and dynamic recognition of installed hardware.
  - Hardware detected at initial system installation.
  - Recognition of PnP hardware changes between boots.
  - Run-time response to PnP hardware changes.
- Dynamic loading and unloading of drivers in response to hardware insertion or removal.
- Hardware resource allocation and reallocation.
  - PnP manager may reconfigure resources at run-time in response to new hardware requesting resources that are already in use.

Device Enumeration

- Upon boot, the PnP Manager performs enumeration of buses and devices.
  - It starts from an imaginary root device.
  - It scans the system recursively to the walk the device tree.
- Bus driver creates a PDO for each physical device.
- PnP Manager loads drivers
  - It loads lower filter drivers (If exist).
  - They create their FiDOs.
  - It loads the function driver.
  - It should create the FDO.
  - It loads upper filter drivers (If exist).
  - They create their FiDOs.



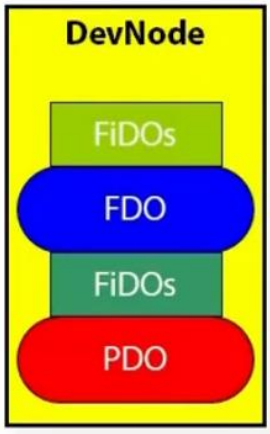
Device Enumeration Tree



Important Registry Key

- Hardware instance keys: Information about a single device.
  - HKLM\System\CCS\Enum (CCS = CurrentControlSet).
- Class keys: Information about all devices of the same type.
  - HKLM\System\CCS\Control\Class
- Software or Service keys: Information about a specific driver.
  - HKLM\System\CCS\Services*drivername*

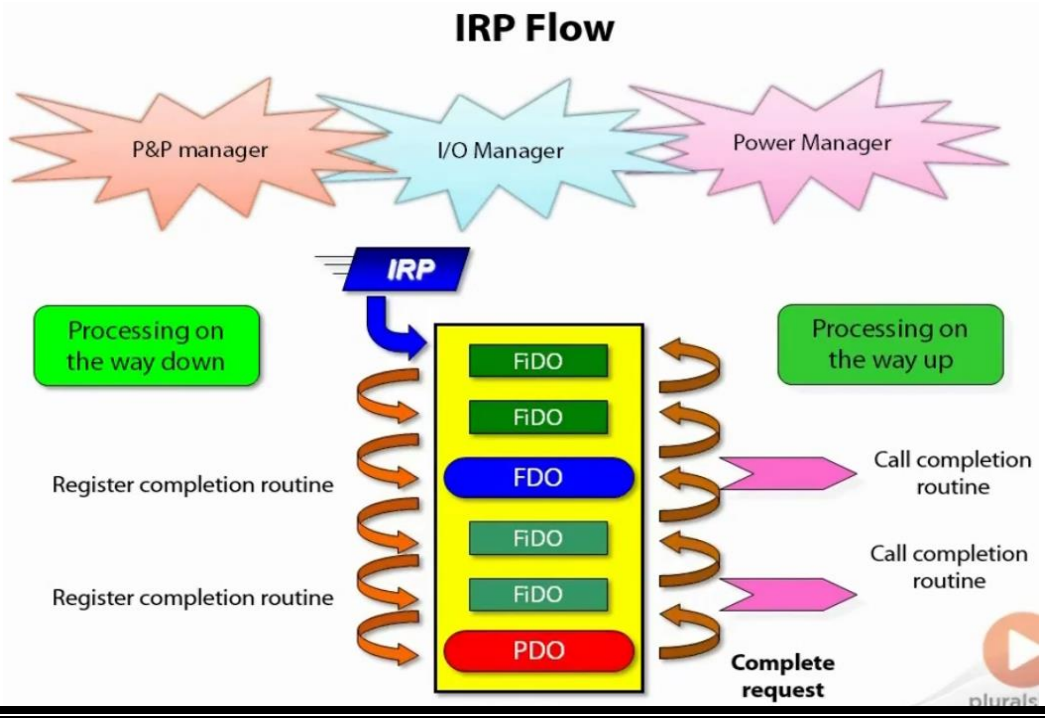
Device Node, DevNode



- It represents a stack of devices.
- Physical Device Object, PDO: It's created by the bus driver.
- Filter Device Object, FiDO: Optional lower/upper device objects.
- Functional Device Object, FDO: The actual driver created device object.
- Stack of device, not drivers.

I/O Request Packet, IRP

- A structure representing some request.
  - Represented by the IRP structure.
  - Contains all details needed to handle the request (codes, buffers, sizes, etc).
- Always allocated from non-paged pool.
- Accompanied by a set of structures of type IO_STACK_LOCATION
  - Number of structures in the number of the devices in this DevNode.
  - Complements the data in the IRP.
- IRPs are typically created by the I/O Manager, PnP Manager or the Power Manager.
  - Can be explicitly created by drivers as well.



Accessing Devices

- A client that wants to communicate with a device must open a handle to the device.
  - CreateFile or CreateFile2 from user mode (System.IO.FileStream class in .NET).
  - ZwCreateFile from kernel mode.
- CreateFile accepts a filename which is actually a device symbolic link.
  - file being just one specific case.
  - The name should have the format \\.\name for devices.
    - Cannot access non-local device.
    - Must use double backslashes "\\\\.\\name" in C/C++.

Asynchronous I/O

- The I/O Manager supports an asynchronous model.
  - Client initiates request, may not block, and get a notification later.
- Device drivers must be written with asynchrony in mind.
  - Should start an operation, mark the IRP as pending and return immediately.
- The I/O Manager supports several ways of receiving a notification when the operation completes.
- To use I/O asynchronously, CreateFile must be called with the FILE_FLAG_OVERLAPPED flag.
- Other I/O functions must provide a non-null OVERLAPPED structure pointer.

Device Drivers

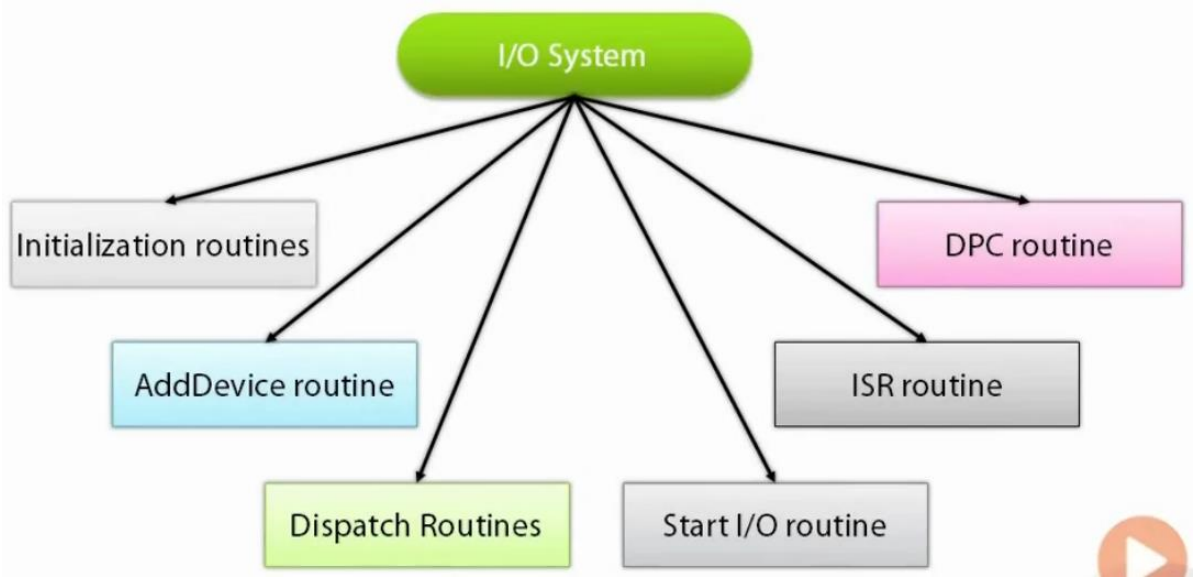
Kernel Device Drivers

- Always execute in kernel mode.
  - Use the kernel mode stack of a thread.
  - Image part of system space.
  - Unhandled exceptions will crash the system.
- Typically has a SYS file extension.
- Usually invoked by clients code (ReadFile, WriteFile, DeviceControl, etc).
- Exports entry points for various functions (called by system code when it's appropriate).
- System handles all device independent aspects of I/O and there's no need for hardware specific code or assembly.

Plug & Play Drivers

- Communicate with the PnP Manager and the Power Manager via IRPs.
- Driver types:
  - Function driver: Manages the hardware device. The driver that knows the device intimately.
  - Bus driver: Manages a bus (PCI, USB, IEEE1394, etc). Written by Microsoft.
  - Filter drivers: Sit on top of a function driver (upper filter) or on top of a bus driver (below the function driver, lower filter). Allow intercepting requests.

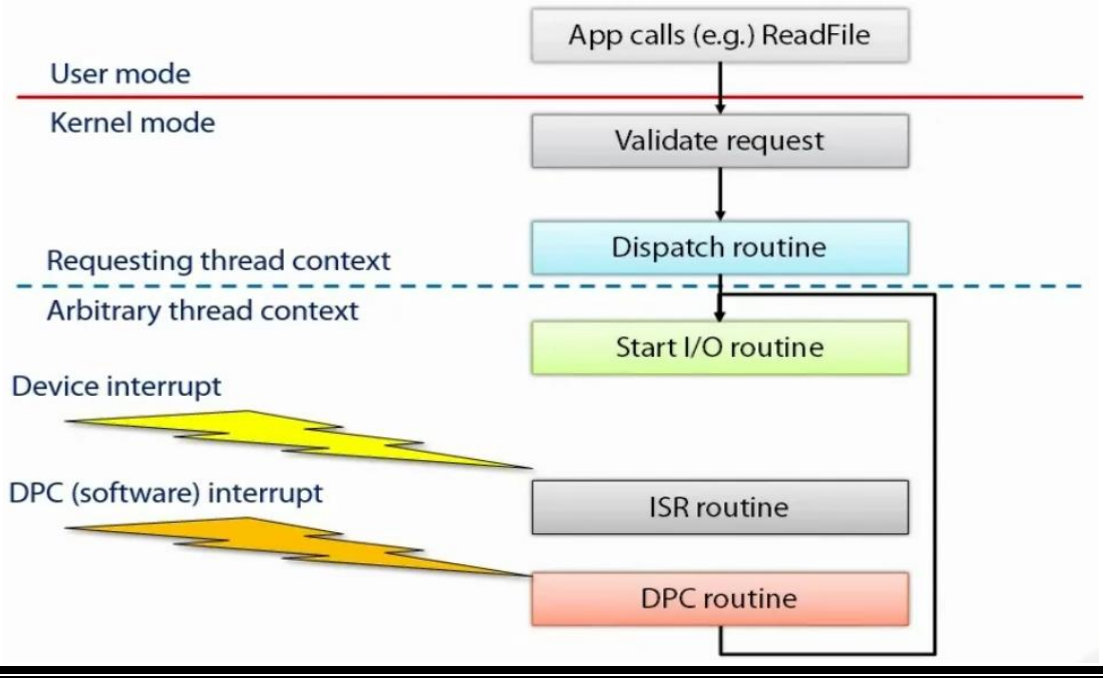
Anatomy of a Driver



Driver and Device Objects

- Drivers are represented in memory using a DRIVER_OBJECT structure.
  - Created by the I/O system.
  - Provided to the driver in the DriverEntry function.
  - Holds all exported functions.
- Device objects are created by the driver on a per-device basis.
  - Represented by the DEVICE_OBJECT structure.
  - Typically created in the Driver's AddDevice routine.
  - Severalty can be associated with a single driver object.

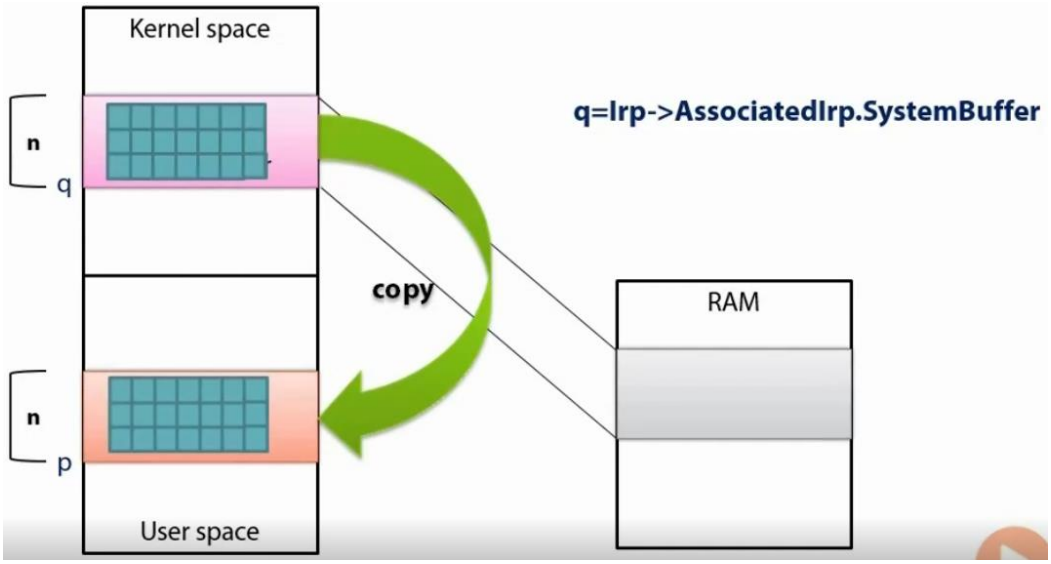
Typical IRP Processing



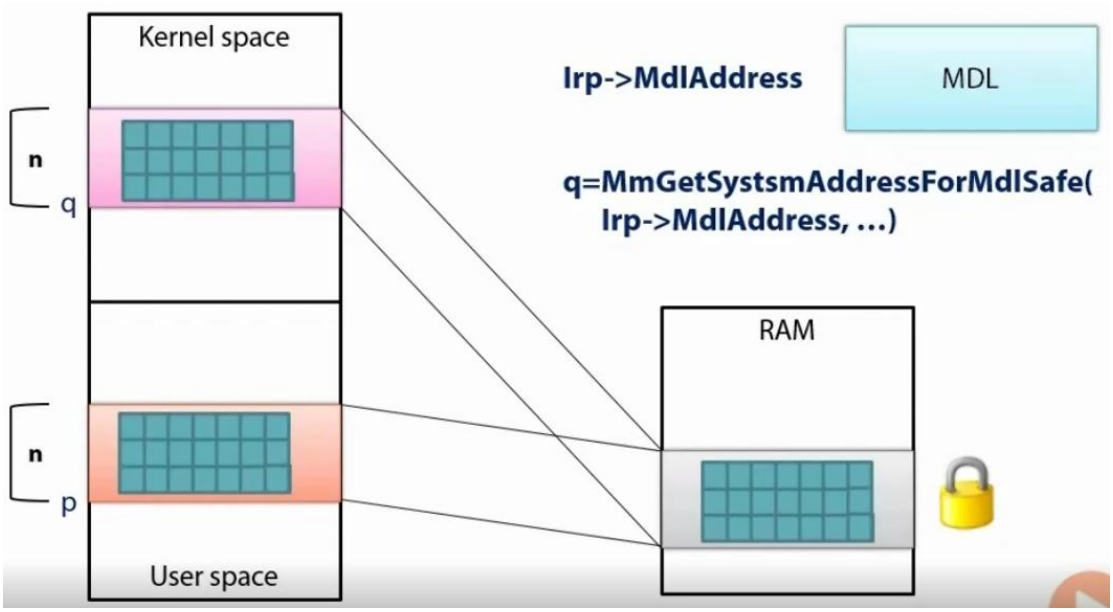
Referencing User Buffers

- Buffers provided in user space are not generally accessible from an arbitrary thread context and/or high IRQL>=2.
- The I/O system provides ways to mitigate that.
- Buffered I/O
  - Transfer is to-and-from an intermediate buffer in system address space.
  - I/O Manager does all of the setup work.
- Direct I/O
  - Transfer is to-and-from user's physical pages.
  - I/O Manager does not most of the setup work.

Buffered I/O



Direct I/O



The Windows Driver Model, WDM

- Drivers for Windows 95 and NT4 were completely separate.
- WDM is a model for writing device drivers.
  - Mostly source compatible between Windows 98/ME and Windows 2000/XP.
  - Supports a wide range of buses such as PCI, USB, IEEE1394 and more.
  - Extensible to support future buses.
  - Supports a wide range of device classes such as HID, Scanners, Cameras and more.
  - Can still be used today.
- File system drivers and Video drivers are not included in WDM.
- WDM shows its age.

The Windows Driver Foundation, WDF

- A new driver model which was introduced in Windows Vista.
- WDF has two distinct parts:
  - KMDF: Kernel Mode Driver Framework.
  - UDMF: User Mode Driver Framework.
- KMDF is a replacement for WDM
  - Consistent object based model (properties, methods and events).
  - Boilerplate PnP and Power code implemented by the framework.
  - Object lifetime management.
  - Versioning with side by side support.
- UMDF
  - Allows building drivers in user mode (easier development and debugging).
  - Works for certain device categories.
  - UMDF 1.x is based around the Component Object Model, COM.
  - UMDF drivers hosted in a system supplied host (WDFHost.exe).
  - Object model similar in concept to KMDF.
  - UMDF 2.0 was introduced in Windows 8.1
    - Near identical object model compared to KMDF.
    - Some form of translation is possible both ways.

Driver Installation

- Drivers for hardware devices must be installed with an INF file.
- INF file:
  - Text file, format similar to the classic INI file.
  - Sections in square brackets and instructions as key=value pairs.
  - INF looked up by hardware ID and compatibles IDs.
    - Precise matches are proffered.
    - Digitally signed files and Newer files are preferred.

- Installed INF files are stored in %SystemRoot%\INF.
- User mode PnP service requests INF file if no match found in the system.

Driver Verifier Options Examples

- I/O verification
  - IRPs are allocated from a special pool and monitored in various ways.
- Special pool
  - The driver's allocations will be made from a special pool and monitored for overruns, underruns and illegal usage.
- Forcing IRQL checking
  - Forces paging of all paged driver code/data, forcing checks of correct behavior in IRQL and Spin Lock usage.
- Low resources simulation
  - Causes random failure in memory allocations.

Writing Software Device Drivers

Introduction

- A software driver does not manage any hardware.
- Typically used as a method to get code to run in kernel mode.
- Examples: Process Explorer and Process Monitor.
- This means
  - No AddDevice routine needed.
  - Driver exports a well-known name for the only device.
  - Installation does not have to use an INF file.

The DriverEntry Function

- The main function called when the driver first loads.
- Should fill exported functions supported by the driver
  - Unload routine
    - Setup in DriverEntry.
    - Responsibility: Undo everything that was done in DriverEntry and any required cleanup.
  - AddDevice (for hardware based drivers).
  - Dispatch routines.
- For a software driver
  - Creates the one and the only device object.
  - Creates a symbolic link so the device can be accessed from user mode.

Installing the Driver

- A software driver can be installed just like a service (using SC.exe command line tool).
- You need to specify a kernel driver type and you start right after that.

Dispatch Routines

- Dispatch routines are a set of functions for particular operations (Read, Write, PnP, Power,….).
- Set up in DriverEntry in the MajorFunction array of function pointers.
- A driver must set the IRP_MJ_CREATE and IRP_MJ_CLOSE entries.
  - which makes CreateFiles and CloseHandle possible.
- Unset entries will return an unsupported operation to the caller.

Testing the Driver

- Once Create and Close exist, we can open a handle to the device.
  - Using CreateFile with the following semantics:
    - FileName should be \\.\SymbolicLinkName.
    - GENERIC_READ and GENERIC_WRITE flags to allow read/write access.
    - OPEN_EXISTING flag is the only one that makes sense.
- If anything goes wrong, the returned handle is INVALID_HANDLE_VALUE (-1).
  - which can call GetLastError() to get specific error information.

Implementing Device Control

- For Device Control, we need to define a control code.
  - Using the CTI_CODE macro.
  - In a header file that's also accessible by client code.
- CTL_CODE also sets up the buffering method.
  - METHOD_BUFFERED is a common choice since buffers are typically small.
- Important request parameters are in the current I/O stack location.

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