

Windows 2000 - The I/O Structure

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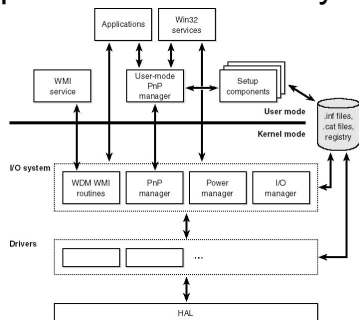
Outline

- Components of I/O System
- Plug'n'Play Management
- Power Management
- I/O Data Structures
 - File Object
 - Driver Object
 - Device Object
 - IRPs / DPCs

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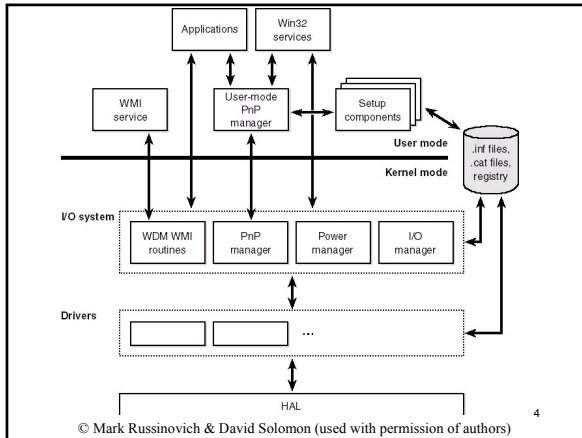
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Components of the I/O System



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Overview

- **I/O Manager:**
 - Connects applications and system components to devices
 - Defines infrastructure
- **Device Driver:**
 - Provides I/O interface for particular device
- **PnP Manager:**
 - Guide allocation of HW resources
 - Detect and respond to arrival and removal of devices
- **Power Manager:**
 - Guides system and device drivers through power-state transitions

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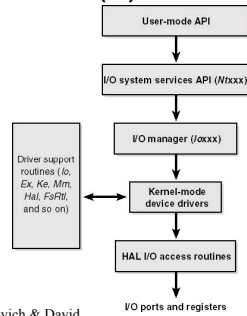
Overview (2)

- **Windows Management Instrumentation (WMI):**
 - Support routines, which allow drivers to act as Windows Driver Model (WDM) WMI providers
- **Registry:**
 - Stores description of basic hardware devices
- **INF files:**
 - Driver installation files
 - Link hardware device and driver
- **HAL:**
 - Provides API to hide platform differences
 - Is bus driver for driver-less devices on motherboard

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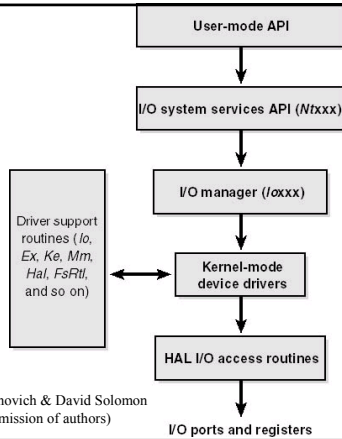
Overview (3)

- I/O is performed on virtual files
- All data is regarded as stream of bytes
- Typical flow of I/O request (see picture)



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I/O Manager

- I/O system is packet-driven (I/O request packet – IRP)
- Creates IRP and passes reference to driver and disposes it after completion
- Driver receives IRP, performs specified action and passes IRP back
- Supplies common code (e.g. Call another driver, time-out support, ...)
- Uniform, modular interface of drivers allows I/O manager to call driver without special knowledge about driver

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Device Drivers

- Must conform to implementation guidelines
- Kernel mode device drivers
 - File system drivers (direct file I/O requests to mass storage)
 - Windows 2000 drivers (mass storage, protocol stacks, ...)
 - Legacy drivers (NT driver w/o power mgmt., PnP)
 - Win32 subsystem display drivers (translate device independent graphic into device dependant)
 - WDM drivers (adhere to WDM = W2K drivers + WMI)
- User mode device drivers
 - Virtual device drivers: emulate 16-bit MS-DOS applications
 - Win32 subsystem printer drivers

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WDM drivers

- Source code compatible between Windows 2000, Windows 98, Windows Me, Windows XP
- Bus drivers:
 - Manage logical or physical bus
 - Responsible for detecting devices and reporting to PnP manager
 - Manages power settings of bus
- Function drivers:
 - Exports operational interface of device to OS
- Filter driver:
 - Layer above or below function drivers

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Functional separation

- Class driver:
 - implement I/O processing for specific class of devices (disk, tape, ...)
- Port driver:
 - implement I/O processing for specific port type (SCSI, ...)
 - Mostly implemented as kernel-mode library
- Miniport driver:
 - Map generic I/O request to type of port into adapter type

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Layered Device Drivers

- “normal” layered drivers connect to lower and higher driver
- transparent drivers slip in between lower-layer driver and its clients: has to mimic behavior of lower driver
- virtual or logical device layers: expose virtual or logical device objects (e.g. named pipe)

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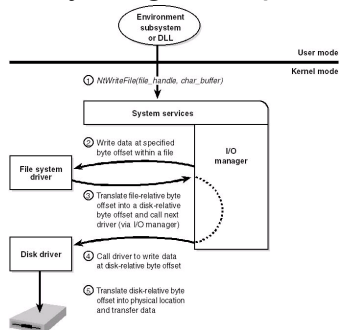
Layered Device Drivers (2)

- Call lower layer driver:
 - retrieve stack location for next lower driver
 - set up stack location (function code, parameters)
 - associate completion routine with IRP to be informed when lower driver completes
 - send IRP to lower driver (is asynchronous call)
 - mark IRP pending
- Complete request
- Create new IRPs to pass to lower drivers

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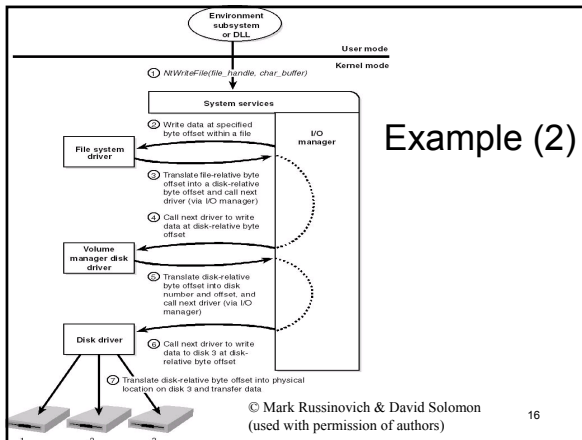
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Layering example



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Example (2)

Driver Object

- Unique object for each loaded driver
- Consist of set of routines
- Routines process various stages of an I/O request e.g. load, unload, start I/O, etc.
- Linked list of device object, serviced by driver
- I/O Manager uses "back pointer" to find driver for object
- Driver removes device objects during unload

Key Device Driver Routines

- Initialization routine (when loading a driver)
- Add-device routine (PnP)
- Dispatch routines (process IRPs)
- Start I/O routine (initiate data transfer via I/O manager)
- Interrupt service routine (ISR – executed when interrupt occurs, queues DPC)
- Interrupt-servicing DPC routine (DPC: deferred procedure call = interrupt handling at lower IRQL)

Key Device Driver Routines (2)

- I/O completion routines (used to notify stacked drivers of I/O completion)
- Cancel I/O routine (cancel IRP processing)
- Unload routine (release system resources)
- System shutdown notification routine (called before system shuts down)
- Error-logging routine (write errors to error-log)

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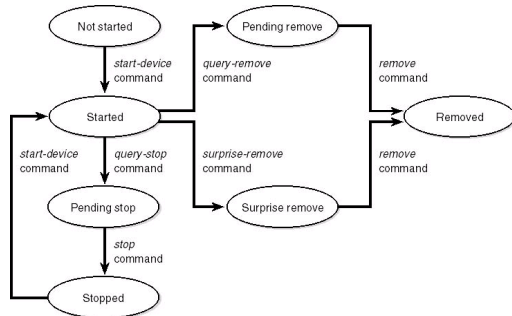
Plug and Play Manager

- Automatically recognizes installed devices (enumerates devices during boot process, detect addition or removal)
- Hardware resource allocation and reallocation for devices (interrupts, DMA addresses, etc.)
- Load appropriate drivers:
 - Determine driver and instruct I/O Manager to load
 - If none found install driver via user-mode PnP manager → "Found new Hardware"

P'n'P Manager (2)

- Implements mechanisms for applications and drivers to detect configuration changes (notification)
- Support level depends on attached devices and installed drivers

Device PnP state transitions



P'n'P state transitions

- Pending remove:
 - Finish pending I/O requests
 - Do not accept further I/O requests
 - Power down device
- Surprise remove:
 - Immediately stop running I/O requests
 - Remove pending I/O requests

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Power Management

- Requires hardware that complies with Advanced Configuration and Power Interface (ACPI) specification
- 6 system power states
- Power manager request driver to move to other power state
- If driver is busy it rejects request → system stays at current power level

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Power Management (2)

- Multiple driver objects associated with one device:
 - Only one driver designated as device power-policy owner
 - Decides device's power state based on system power state
 - Asks power manager to inform other drivers
 - Thus power manager can control number of power commands in system (e.g. number of devices powering up)

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ACPI standard and Win2K

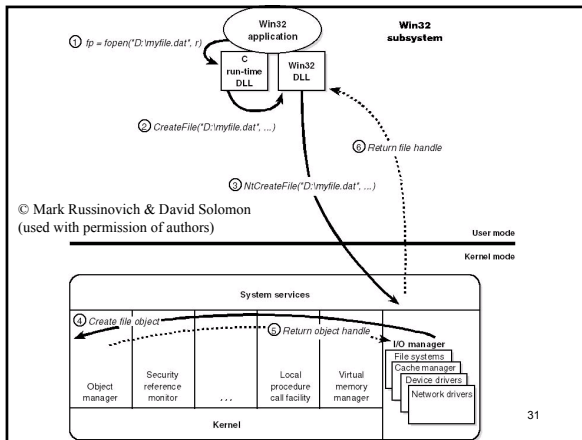
- Defines various power levels for:
 - System: S0 (fully on) – S5 (fully off)
 - Devices: D0 (fully on) – D3 (fully off)
- D1 and D2 are free to be defined by device
- Driver reports supported power level to PnP manager at load time
- Bus driver provides mapping from system power states to device power states

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File objects

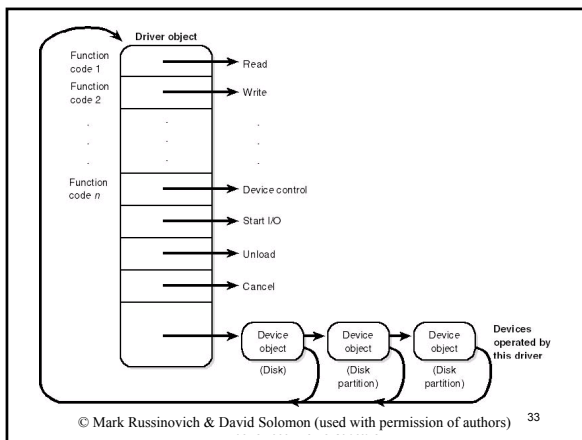
- Kernel-mode construct for handles to files or devices
- Provide memory-based representation of resources which can be read or written
- Protected by security descriptor (including ACL)
- Contains data unique to object handle (byte offset, ...)
- Every time a new file handle is opened a new file object is created
- File object is unique to process, except:
 - Child inherits from parent
 - Duplicate handle to another process



Device and Driver Objects

- Driver object:
 - Represents an individual driver
 - I/P manager obtains address of dispatch routines from it
- Device object:
 - Represents physical or logical device and its characteristics (e.g. buffer alignment and location of device queue for IRPs)
- Driver creates device object when PnP manager informs it
- Driver may export a name for device to allow applications to open it
- One driver can have multiple device objects
- Device objects have back-link to driver

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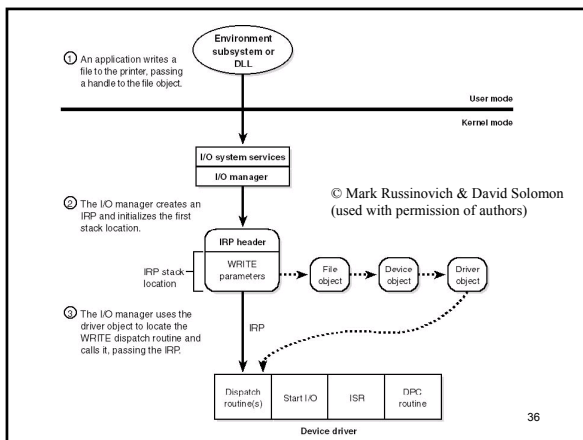


IRP

- Header contains (fixed part):
 - Type and size of request
 - Synchronous or asynchronous request
 - Pointer to buffer for buffered I/O
 - State information

IRP (2)

- Stack location contains (one or more):
 - Function code and parameters (identifies driver's dispatch routine)
 - Pointer to caller's file object
 - Used to find "answer point" for layered drivers (I/O completion routine)
 - Number of stack locations determined by number of driver layers



IRP Buffer Management

- I/O Manager perform three types of I/O buffer management:
 - Buffered I/O: I/O manager allocates memory from non-paged pool and copies data from/to user's buffer
 - Direct I/O: user's buffer is locked by I/O manager (DMA)
 - Neither I/O: I/O manager does not do any buffer management (driver might do it)
- Driver registers type of buffer management in device object

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IRP Buffer Management (2)

- Drivers usually use buffered I/O if smaller than one page (4KB)
copy operation = overhead of memory lock
- File systems driver usually use Neither I/O, because no buffer management needed for copy from/to file system cache

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I/O Completion Ports

- Introduced for servers with multiple parallel threads
- Threads wait for I/O packets to arrive at port
- System controls number of currently running threads (should be the same as number of processors)
- Can be regarded as thread pool

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Driver Loading/Initialization

- Enumeration-based loading: PnP manager dynamically loads drivers for devices that bus driver reports
- Explicit loading: is guided by HKLM\SYSTEM\CurrentControlSet\Services
- Registry key „Start“ value:
 - 0 – at boot time (loaded by System)
 - 1 – after initialization (loaded by I/O manager)
 - 2 – auto-start (after System started)
 - 3 – demand-start (started when first called)

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Types of I/O

- Synchronous I/O:
 - Application waits for I/O to complete
 - I/O manager mimics synchronous behavior to application
- Asynchronous I/O:
 - Allows application to continue
 - APC is queued after completion
 - Has to synchronize with completion of I/O using a synchronization object

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Types of I/O (2)

- Fast I/O:
 - Special mechanism, that bypasses IRP generation
 - Entry points have to be registered in driver object
 - Used to signal completed I/O request
 - E.g. used by File System to check if file is in file cache

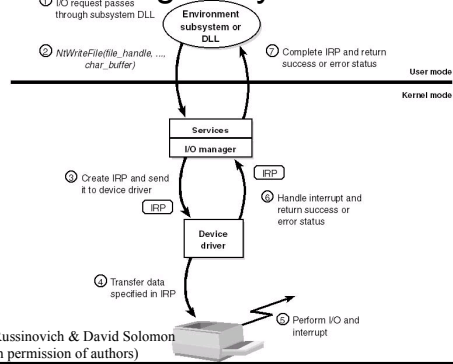
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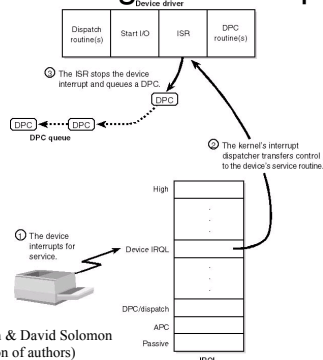
Types of I/O (3)

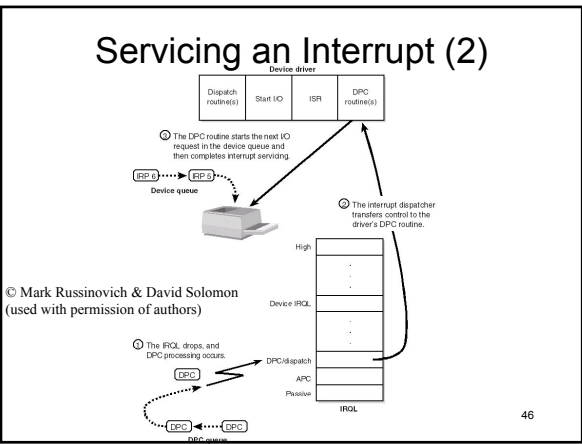
- Mapped File I/O and File Caching
 - File (or parts of it) loaded into memory, and paging mechanism does I/O
 - Mapped Files used by Cache Manager
- Scatter/Gather I/O
 - Allow single read or write from multiple buffers in memory to a contiguous area on disk
 - Buffers have to be page aligned
 - I/O must be aligned on device sector boundary

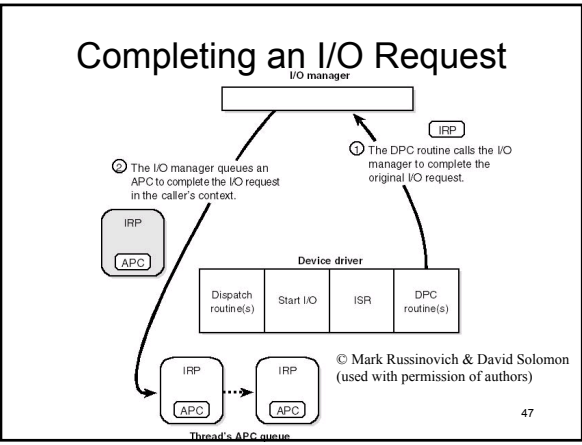
I/O to Single-Layered Driver

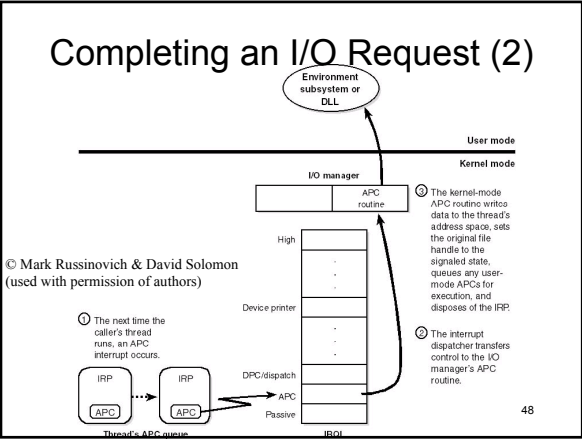


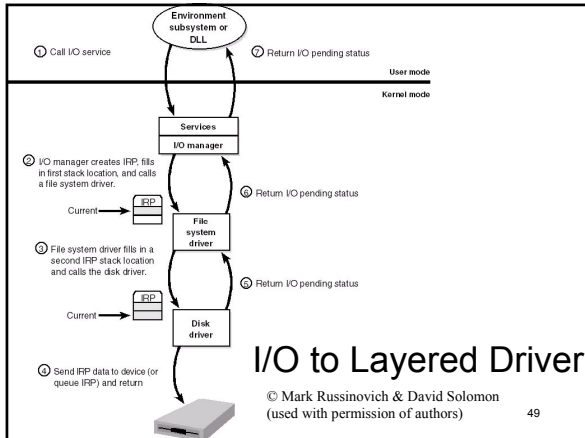
Servicing an Interrupt

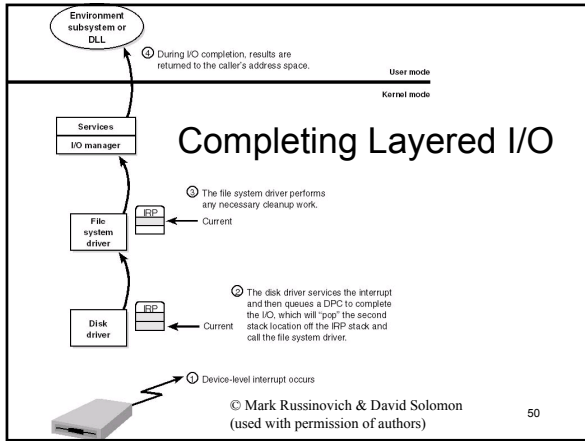












Synchronization

- Drivers have to synchronize using kernel-synchronization routines
- On single processor by raising IRQL
- On multiple processors also using spin locks

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