Napredni operativni sistemi

Windows

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Windows

Chapter 11

History of Windows through Windows 8.1

Year	MS-DOS	MS-DOS based Windows	NT-based Windows	Modern Windows	Notes
1981	1.0				Initial release for IBM PC
1983	2.0				Support for PC/XT
1984	3.0				Support for PC/AT
1990		3.0			Ten million copies in 2 years
1991	5.0				Added memory management
1992		3.1			Ran only on 286 and later
1993			NT 3.1		
1995	7.0	95			MS-DOS embedded in Win 95
1996			NT 4.0		
1998		98			
2000	8.0	Me	2000		Win Me was inferior to Win 98
2001			XP		Replaced Win 98
2006			Vista		Vista could not supplant XP
2009			7		Significantly improved upon Vista
2012				8	First Modern version
2013				8.1	Microsoft moved to rapid releases

Figure 11-1. Major releases in the history of Microsoft operating systems for desktop PCs.

2000s: NT-based Windows (1)

Year	DEC operating system	Characteristics
1973	RSX-11M	16-bit, multiuser, real-time, swapping
1978	VAX/VMS	32-bit, virtual memory
1987	VAXELAN	Real-time
1988	PRISM/Mica	Canceled in favor of MIPS/Ultrix

Figure 11-2. DEC Operating Systems developed by Dave Cutler.

2000s: NT-based Windows (2)

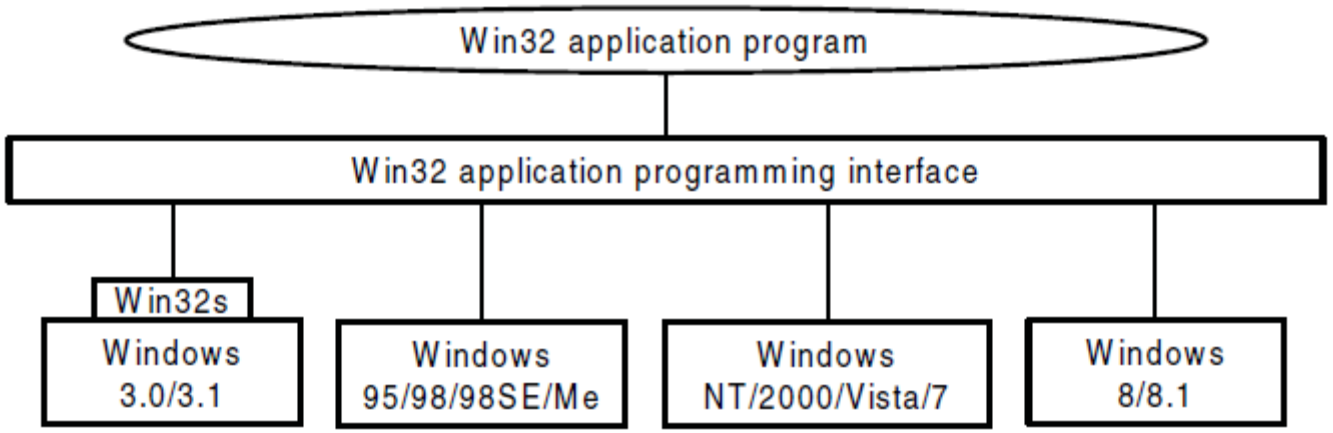


Figure 11-3. The Win32 API allows programs to run on almost all versions of Windows.

Programming Windows (1)

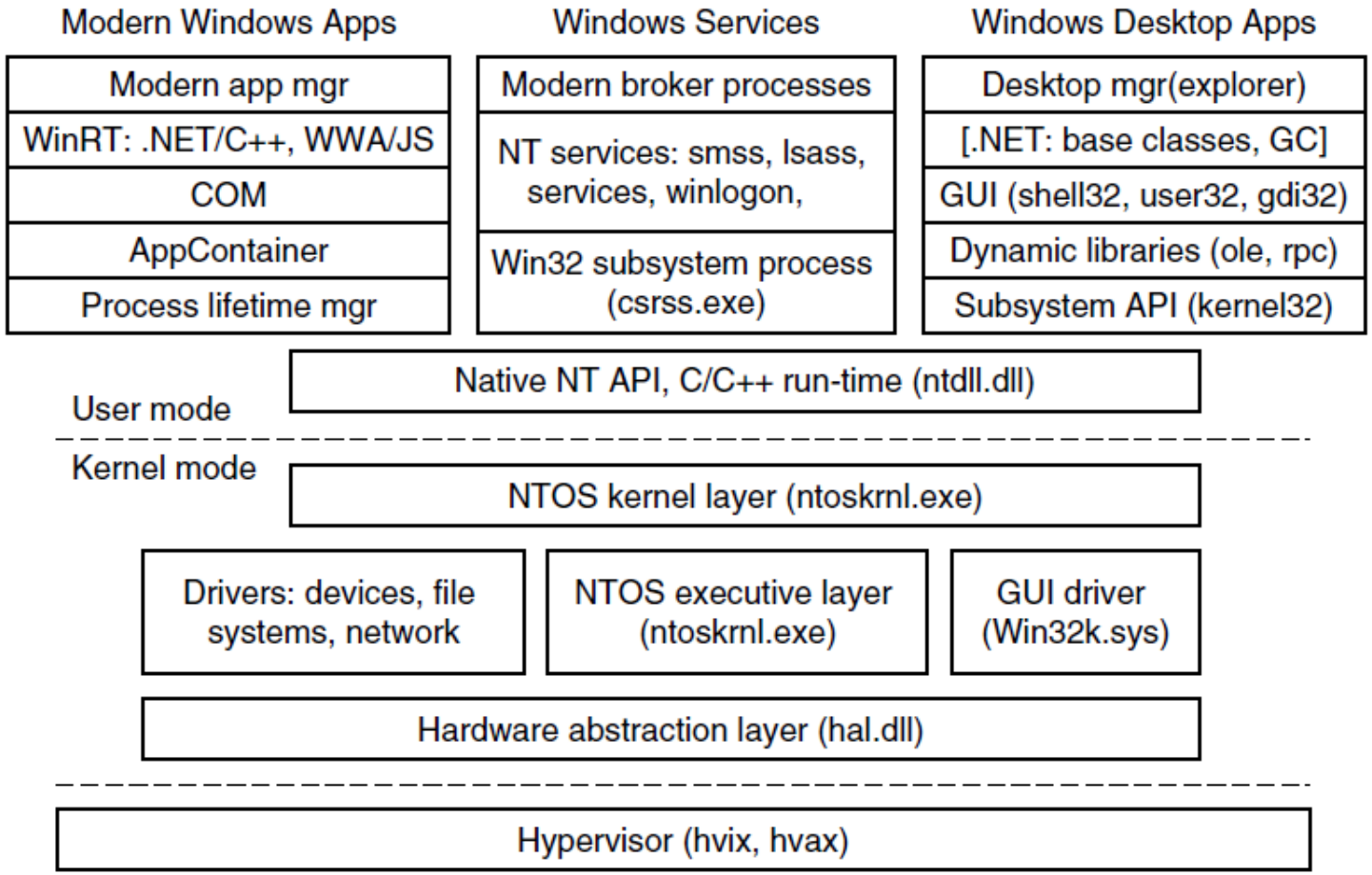


Figure 11-4. The programming layers in Modern Windows

Programming Windows (2)

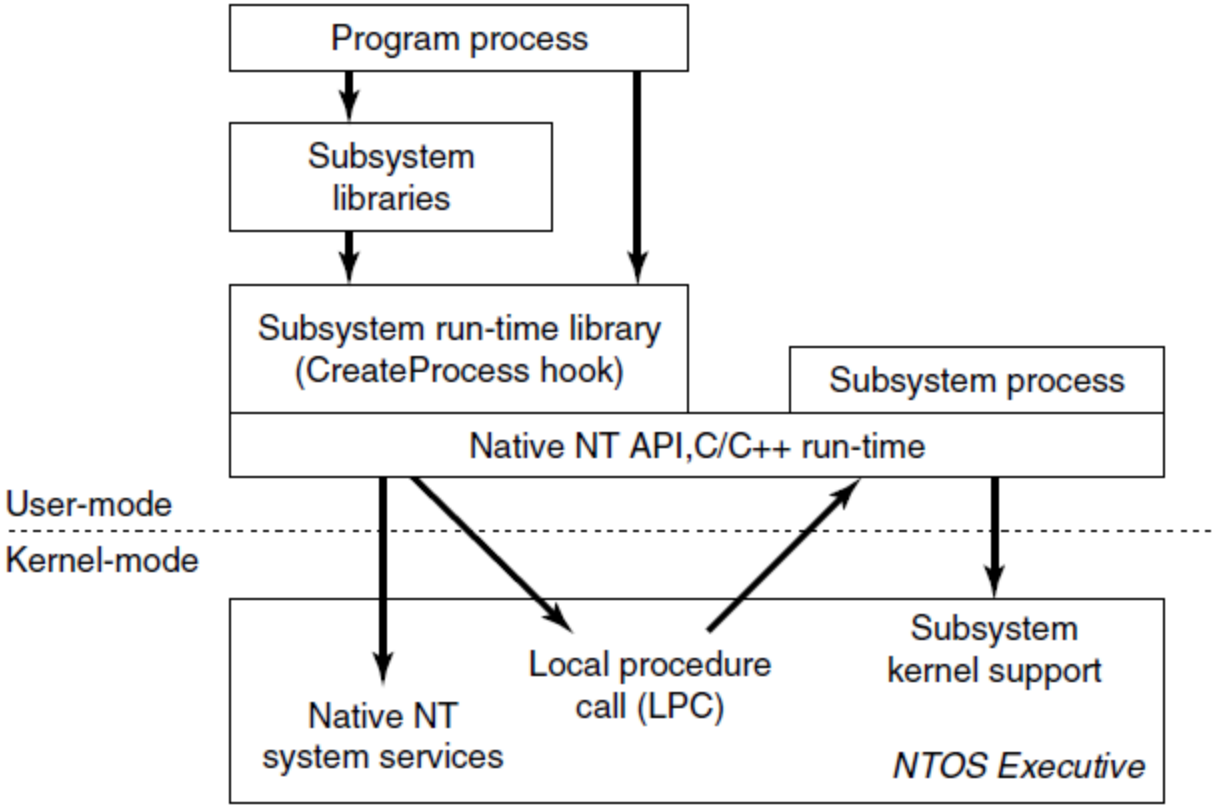


Figure 11-5. The components used to build NT subsystems.

The Native NT Application Programming Interface (1)

Object category	Examples
Synchronization	Semaphores, mutexes, events, IPC ports, I/O completion queues
I/O	Files, devices, drivers, timers
Program	Jobs, processes, threads, sections, tokens
Win32 GUI	Desktops, application callbacks

Figure 11-6. Common categories of kernel-mode object types.

The Native NT Application Programming Interface (2)

NtCreateProcess(&ProcHandle, Access, SectionHandle, DebugPortHandle, ExceptPortHandle, ...)
NtCreateThread(&ThreadHandle, ProcHandle, Access, ThreadContext, CreateSuspended, ...)
NtAllocateVirtualMemory(ProcHandle, Addr, Size, Type, Protection, ...)
NtMapViewOfSection(SectHandle, ProcHandle, Addr, Size, Protection, ...)
NtReadVirtualMemory(ProcHandle, Addr, Size, ...)
NtWriteVirtualMemory(ProcHandle, Addr, Size, ...)
NtCreateFile(&FileHandle, FileNameDescriptor, Access, ...)
NtDuplicateObject(srcProcHandle, srcObjHandle, dstProcHandle, dstObjHandle, ...)

Figure 11-7. Examples of native NT API calls that use handles to manipulate objects across process boundaries.

The Win32 Application Programming Interface

Win32 call	Native NT API call
CreateProcess	NtCreateProcess
CreateThread	NtCreateThread
SuspendThread	NtSuspendThread
CreateSemaphore	NtCreateSemaphore
ReadFile	NtReadFile
DeleteFile	NtSetInformationFile
CreateFileMapping	NtCreateSection
VirtualAlloc	NtAllocateVirtualMemory
MapViewOfFile	NtMapViewOfSection
DuplicateHandle	NtDuplicateObject
CloseHandle	NtClose

Figure 11-8. Examples of Win32 API calls and the native NT API calls that they wrap.

The Windows Registry (1)

Hive file	Mounted name	Use
SYSTEM	HKLM\SYSTEM	OS configuration information, used by kernel
HARDWARE	HKLM\HARDWARE	In-memory hive recording hardware detected
BCD	HKLM\BCD*	Boot Configuration Database
SAM	HKLM\SAM	Local user account information
SECURITY	HKLM\SECURITY	lsass' account and other security information
DEFAULT	HKEY_USERS\.DEFAULT	Default hive for new users
NTUSER.DAT	HKEY_USERS\<user id>	User-specific hive, kept in home directory
SOFTWARE	HKLM\SOFTWARE	Application classes registered by COM
COMPONENTS	HKLM\COMPONENTS	Manifests and dependencies for sys. components

Figure 11-9. The registry hives in Windows. HKLM is a short-hand for *HKEY LOCAL MACHINE.*

The Windows Registry (2)

Win32 API function	Description
RegCreateKeyEx	Create a new registry key
RegDeleteKey	Delete a registry key
RegOpenKeyEx	Open a key to get a handle to it
RegEnumKeyEx	Enumerate the subkeys subordinate to the key of the handle
RegQueryValueEx	Look up the data for a value within a key

Figure 11-10. Some of the Win32 API calls for using the registry

Operating System Structure

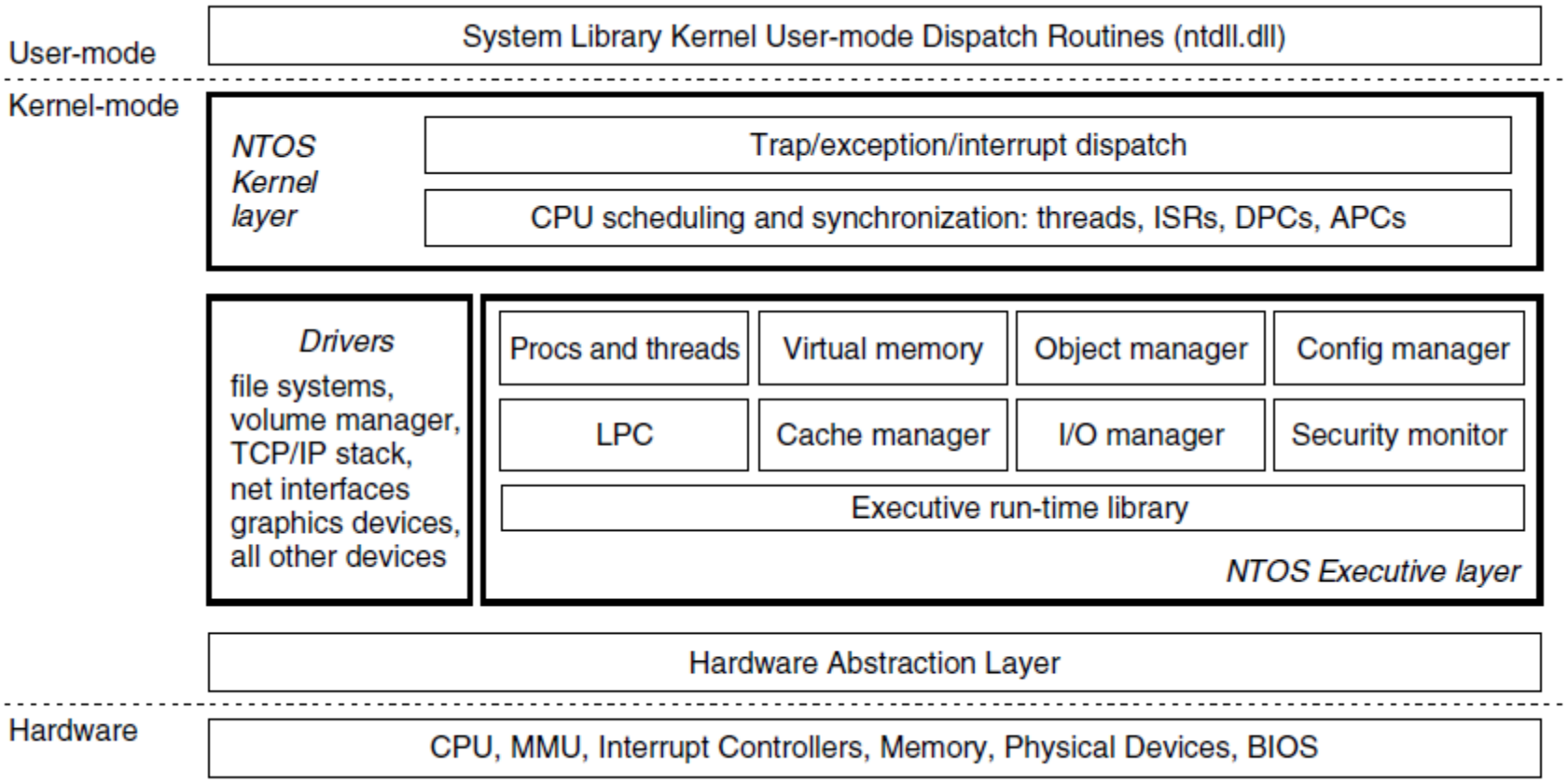


Figure 11-11. Windows kernel-mode organization.

The Hardware Abstraction Layer

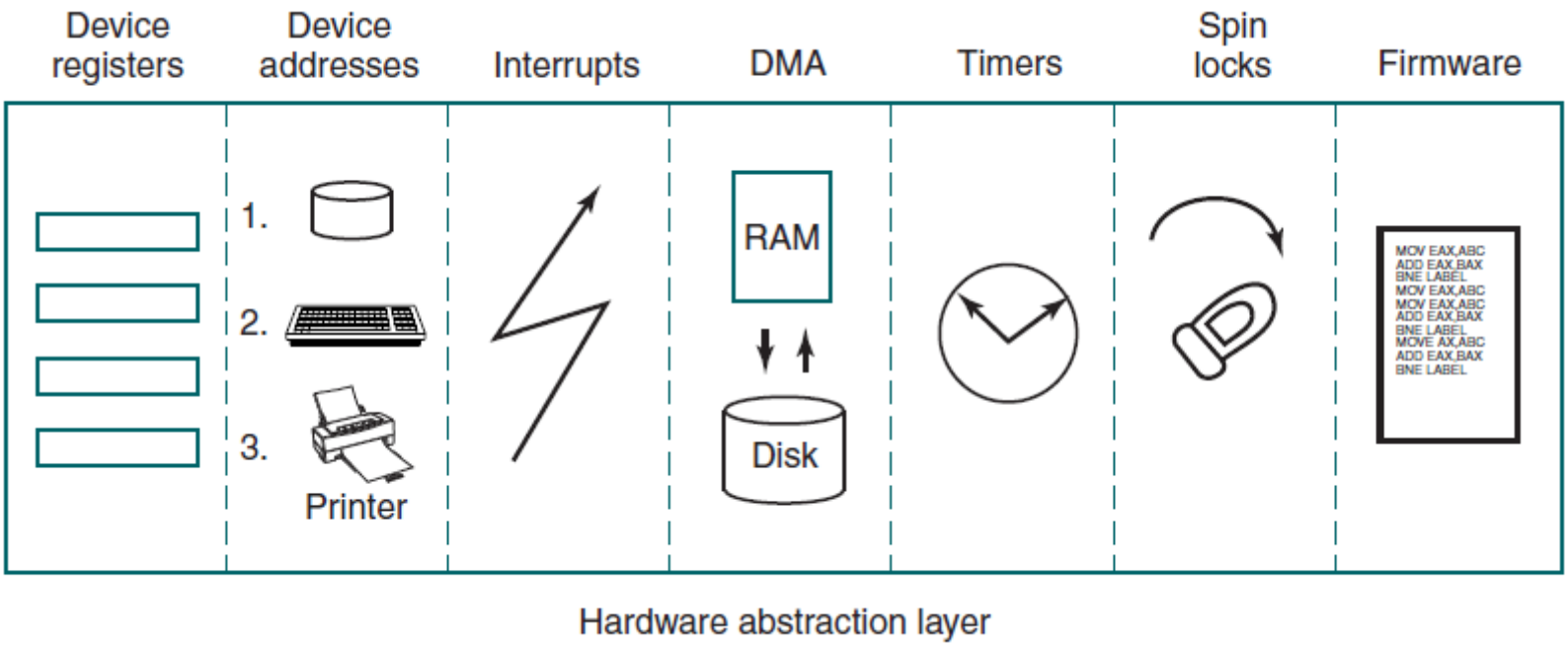


Figure 11-12. Some of the hardware functions the HAL manages

Dispatcher Objects

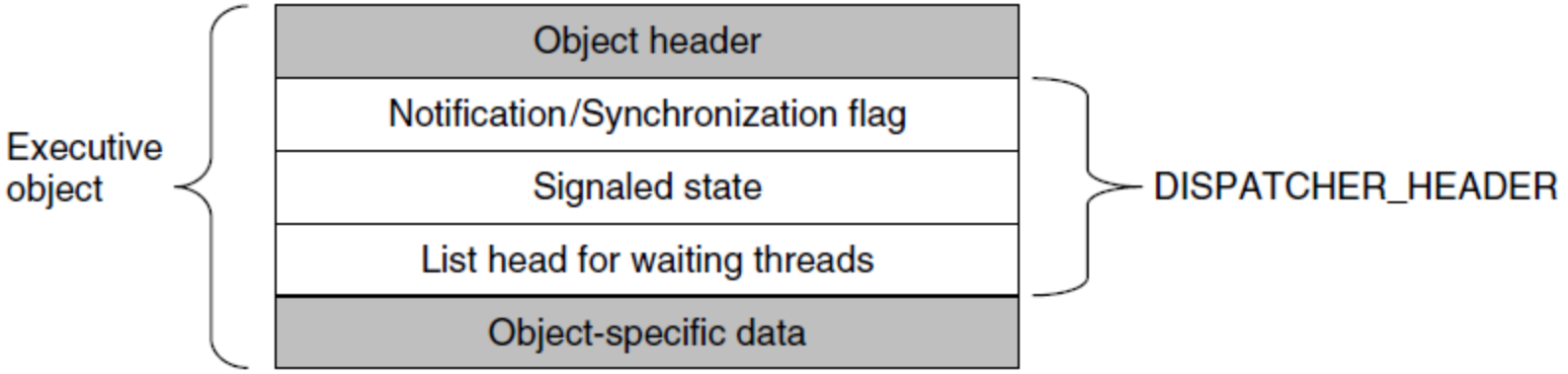


Figure 11-13. *dispatcher_header* data structure embedded in many executive objects (*dispatcher objects*).

The Device Drivers (1)

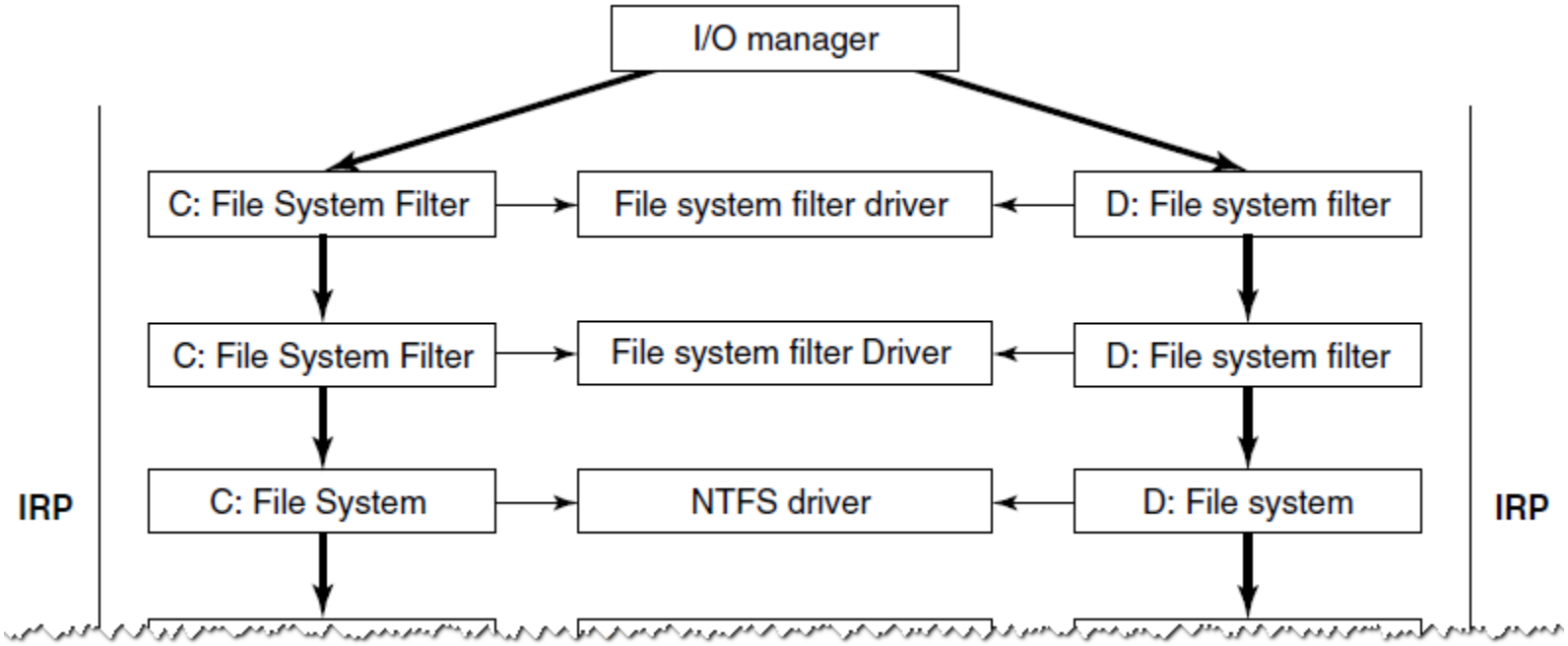


Figure 11-14. Simplified depiction of device stacks for two NTFS file volumes. The I/O request packet is passed from down the stack. The appropriate routines from the associated drivers are called at each level in the stack. The device stacks themselves consist of device objects allocated specifically to each stack.

The Device Drivers (2)

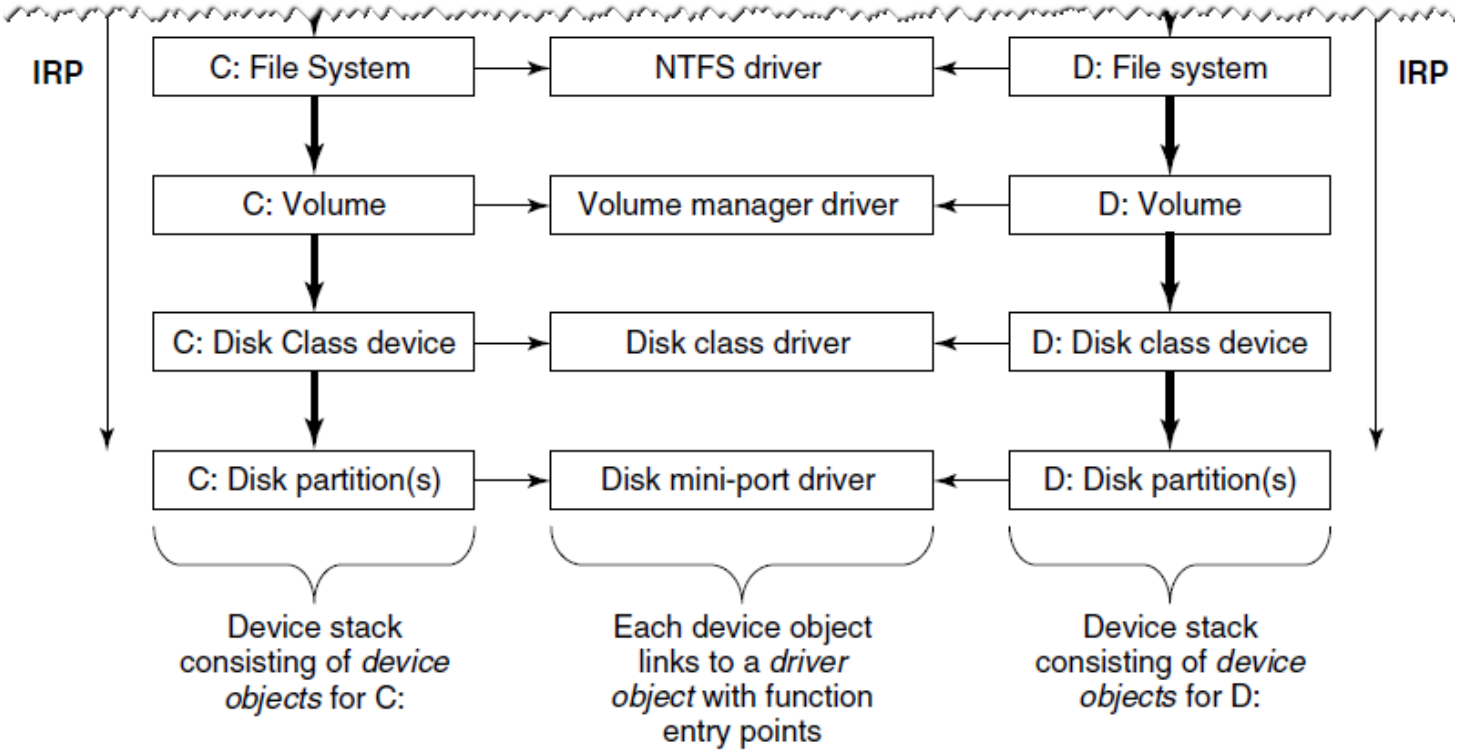


Figure 11-14. Simplified depiction of device stacks for two NTFS file volumes. The I/O request packet is passed from down the stack. The appropriate routines from the associated drivers are called at each level in the stack. The device stacks themselves consist of device objects allocated specifically to each stack.

Implementation of the Object Manager

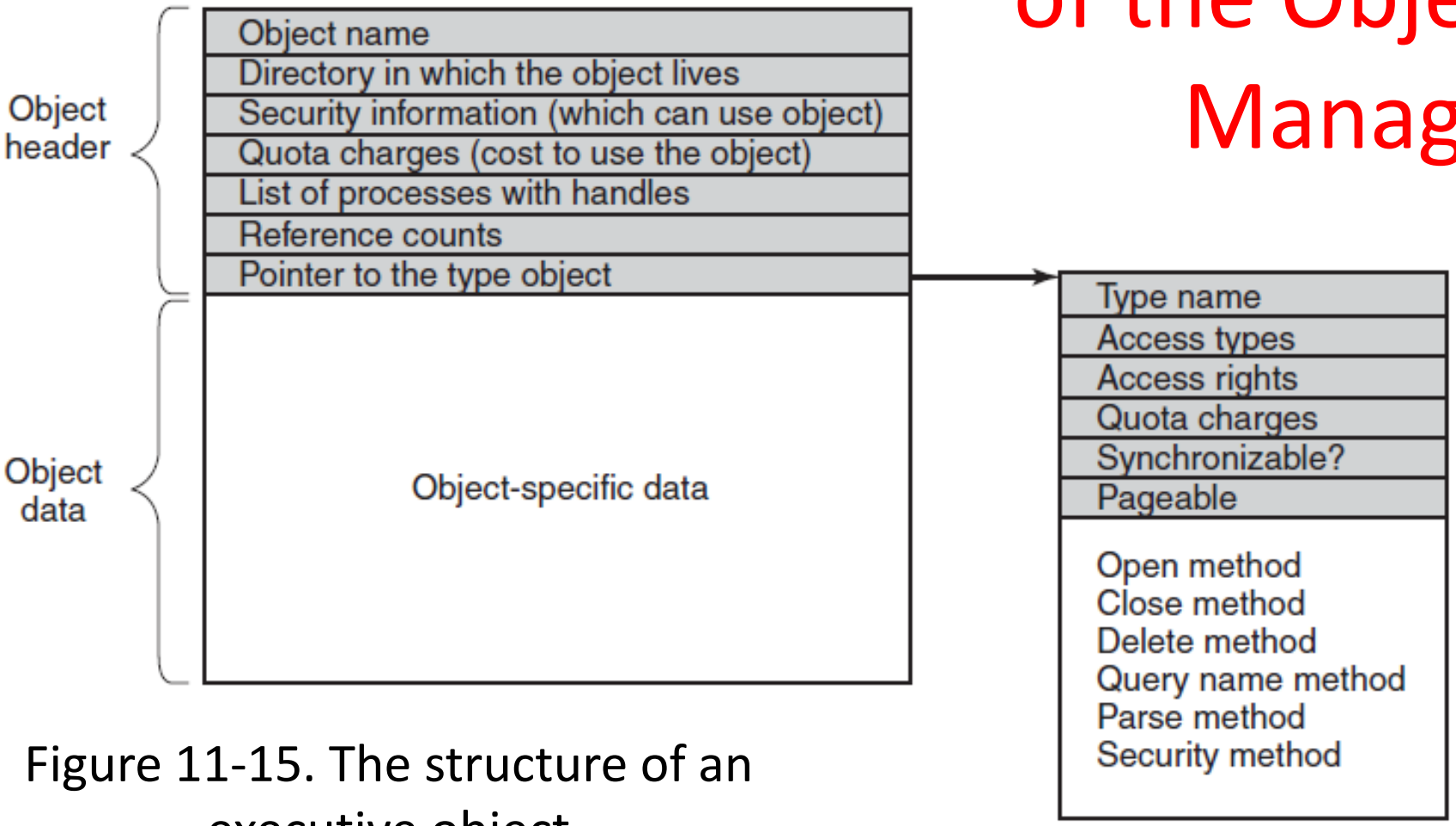


Figure 11-15. The structure of an executive object managed by the object manager

Handles (1)

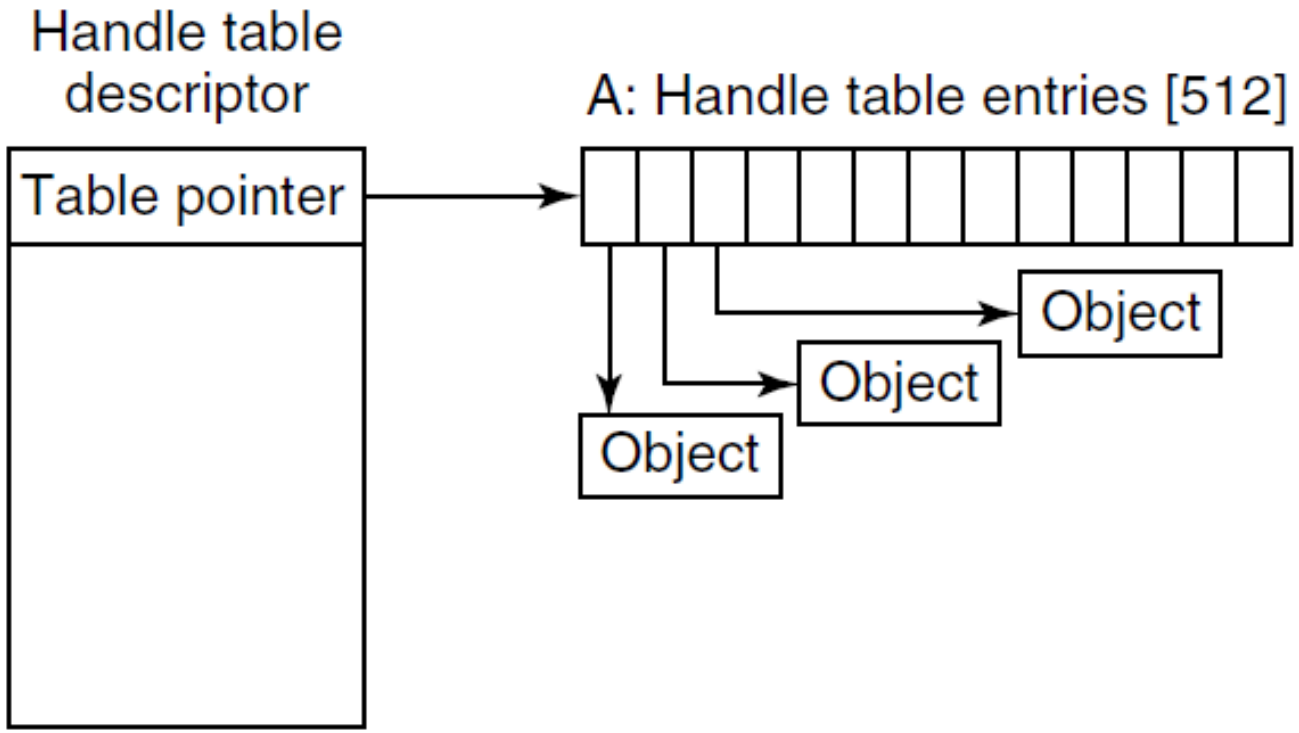


Figure 11-16. Handle table data structures for a minimal table using a single page for up to 512 handles.

Handles (2)

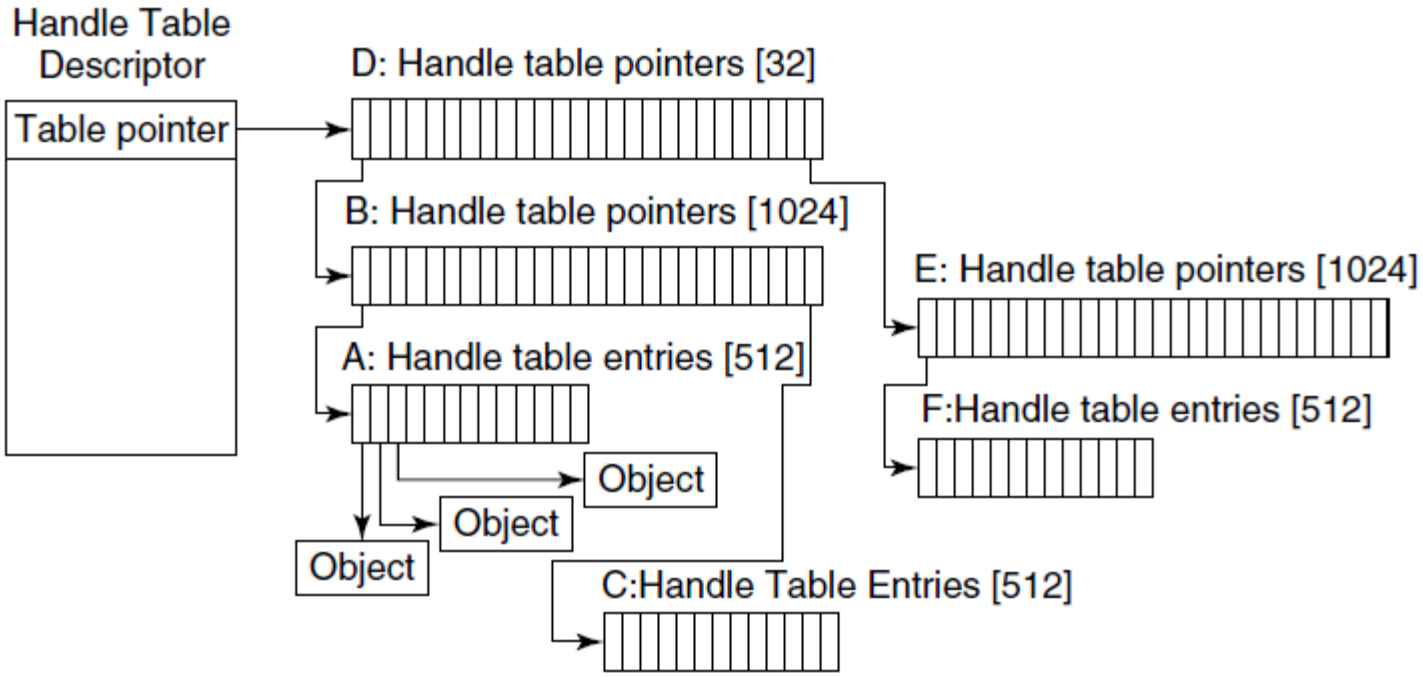


Figure 11-17. Handle table data structures for a maximal table of up to 16 million handles.

The Object Name Space (1)

Procedure	When called	Notes
Open	For every new handle	Rarely used
Parse	For object types that extend the namespace	Used for files and registry keys
Close	At last handle close	Clean up visible side effects
Delete	At last pointer dereference	Object is about to be deleted
Security	Get or set object's security descriptor	Protection
QueryName	Get object's name	Rarely used outside kernel

Figure 11-18. The object procedures supplied when specifying a new object type.

The Object Name Space (2)

Directory	Contents
\??	Starting place for looking up MS-DOS devices like C:
\DosDevices	Official name of \??, but really just a symbolic link to \??
\Device	All discovered I/O devices
\Driver	Objects corresponding to each loaded device driver
\ObjectTypes	The type objects such as those listed in Fig. 11-22
\Windows	Objects for sending messages to all the Win32 GUI windows
\BaseNamedObjects	User-created Win32 objects such as semaphores, mutexes, etc.
\Arcname	Partition names discovered by the boot loader
\NLS	National Language Support objects
\FileSystem	File system driver objects and file system recognizer objects
\Security	Objects belonging to the security system
\KnownDLLs	Key shared libraries that are opened early and held open

Figure 11-19. Some typical directories in the object name space.

The Object Name Space (3)

Use of *parse* procedure:

1. Executive component passes Unicode pathname for namespace
2. Object manager searches through directories and symbolic links
3. Object manager calls the *Parse* procedure for object type
4. I/O manager creates IRP, allocate file object, send request to stack of I/O devices

The Object Name Space (4)

Use of *parse* procedure:

5. IRP passed down the I/O stack until it reaches device object representing the file system instance
6. Device objects encountered as the IRP heads toward the file system represent file system filter drivers
7. File system device object has a link to file system driver object

The Object Name Space (5)

Use of *parse* procedure:

8. NTFS fills in file object and returns it to I/O manager, which returns back up through all devices on the stack
9. Object manager is finished with its namespace lookup
10. Final step is to return back to the user-mode caller

The Object Name Space (6)

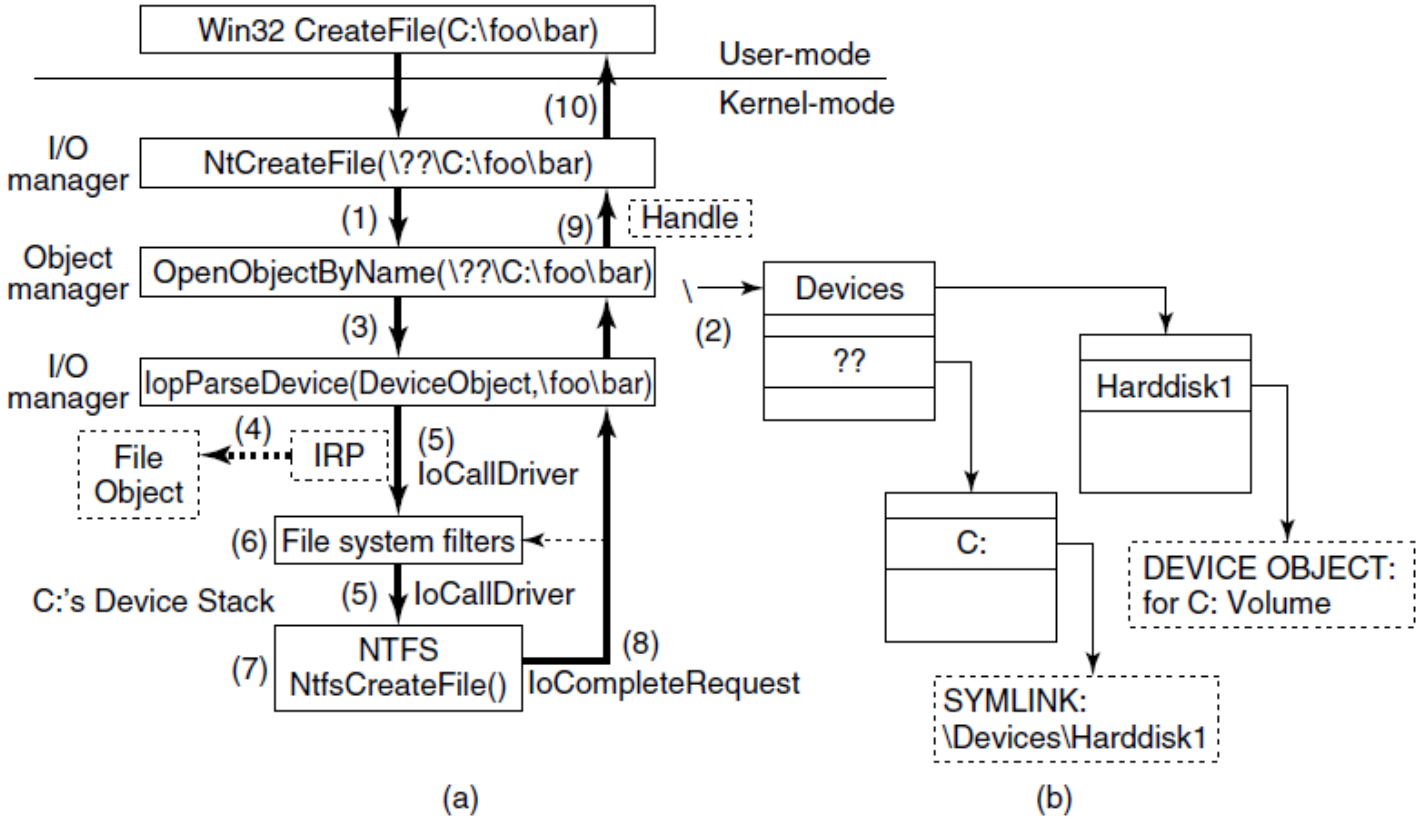


Figure 11-20. I/O and object manager steps for creating/opening a file and getting back a file handle.

The Object Name Space (7)

Type	Description
Process	User process
Thread	Thread within a process
Semaphore	Counting semaphore used for interprocess synchronization
Mutex	Binary semaphore used to enter a critical region
Event	Synchronization object with persistent state (signaled/not)
ALPC Port	Mechanism for interprocess message passing
Timer	Object allowing a thread to sleep for a fixed time interval
Queue	Object used for completion notification on asynchronous I/O
Open file	Object associated with an open file
Access token	Security descriptor for some object

Figure 11-21. Some common executive object types managed by the object manager.

The Object Name Space (8)

Queue	Object used for completion notification on asynchronous I/O
Open file	Object associated with an open file
Access token	Security descriptor for some object
Profile	Data structure used for profiling CPU usage
Section	Object used for representing mappable files
Key	Registry key, used to attach registry to object manager namespace
Object directory	Directory for grouping objects within the object manager
Symbolic link	Refers to another object manager object by pathname
Device	I/O device object for a physical device, bus, driver, or volume instance
Device driver	Each loaded device driver has its own object

Figure 11-21. Some common executive object types managed by the object manager.

Jobs, Processes, Threads, Fibers

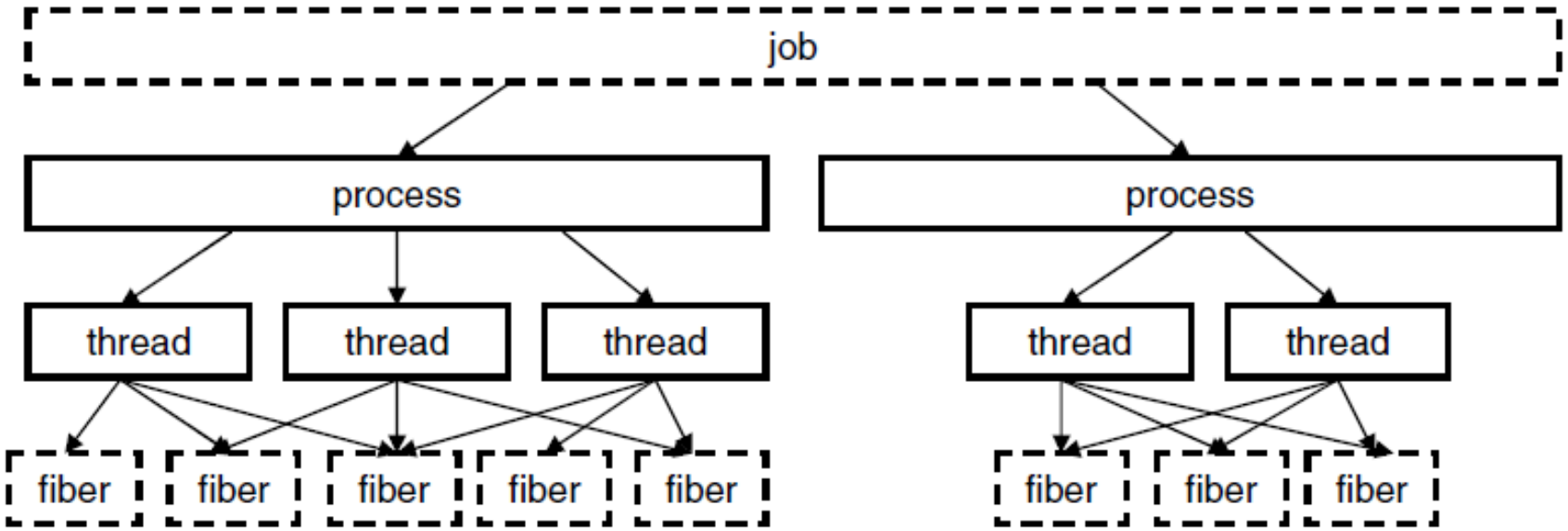


Figure 11-22. The relationship between jobs, processes, threads and fibers. Jobs and fibers are optional; not all processes are in jobs or contain fibers.

Thread Pools and User-Mode Scheduling (1)

Key elements of UMS implementation:

1. User-mode switching
2. Re-entering the user-mode scheduler
3. System call completion

Thread Pools and User-Mode Scheduling (2)

Name	Description	Notes
Job	Collection of processes that share quotas and limits	Used in AppContainers
Process	Container for holding resources	
Thread	Entity scheduled by the kernel	
Fiber	Lightweight thread managed entirely in user space	Rarely used
Thread Pool	Task-oriented programming model	Built on top of threads
User-mode Thread	Abstraction allowing user-mode thread switching	An extension of threads

Figure 11-23. Basic concepts used for CPU and resource management.

Job, Process, Thread, and Fiber Management API Calls (1)

Differences from UNIX:

1. Actual search path for finding program to execute buried in library code for Win32, but managed more explicitly in UNIX.
2. Current working directory is a kernel-mode concept in UNIX but a user-mode string in Windows.
3. UNIX parses command line and passes array of parameters, while Win32 leaves argument parsing up to individual program.

Job, Process, Thread, and Fiber Management API Calls (2)

Differences from UNIX:

4. Inheritance of file descriptors in UNIX a property the handle. In Windows is also property of handle to process creation.
5. New processes directly passed information about primary window in Win32. Passed as parameters to GUI applications in UNIX.
6. Windows does not have SETUID bit as property of the executable, but one process can create a process that runs as a different user (with proper token)

Job, Process, Thread, and Fiber Management API Calls (3)

Differences from UNIX:

7. Process and thread handle returned from Windows can be used at any time to modify new process/thread in many ways.
   UNIX only makes modifications to new process between fork and exec calls, and only in limited ways

Implementation of Processes and Threads (1)

Win32 API Function	Description
CreateProcess	Create a new process
CreateThread	Create a new thread in an existing process
CreateFiber	Create a new fiber
ExitProcess	Terminate current process and all its threads
ExitThread	Terminate this thread
ExitFiber	Terminate this fiber
SwitchToFiber	Run a different fiber on the current thread
SetPriorityClass	Set the priority class for a process
SetThreadPriority	Set the priority for one thread
CreateSemaphore	Create a new semaphore
CreateMutex	Create a new mutex
OpenSemaphore	Open an existing semaphore
OpenMutex	Open an existing mutex

Figure 11-24. Some of the Win32 calls for managing processes, threads, and fibers.

Implementation of Processes and Threads (2)

CreateSemaphore	Create a new semaphore
CreateMutex	Create a new mutex
OpenSemaphore	Open an existing semaphore
OpenMutex	Open an existing mutex
WaitForSingleObject	Block on a single semaphore, mutex, etc.
WaitForMultipleObjects	Block on a set of objects whose handles are given
PulseEvent	Set an event to signaled then to nonsignaled
ReleaseMutex	Release a mutex to allow another thread to acquire it
ReleaseSemaphore	Increase the semaphore count by 1
EnterCriticalSection	Acquire the lock on a critical section
LeaveCriticalSection	Release the lock on a critical section
WaitOnAddress	Block until the memory is changed at the specified address
WakeByAddressSingle	Wake the first thread that is waiting on this address
WakeByAddressAll	Wake all threads that are waiting on this address
InitOnceExecuteOnce	Ensure that an initialize routine executes only once

Figure 11-24. Some of the Win32 calls for managing processes, threads, and fibers.

Scheduling (1)

Conditions that invoke scheduling

1. A running thread blocks on a semaphore, mutex, event, I/O, etc.
2. Thread signals an object (e.g., does an up on a semaphore).
3. The quantum expires.
4. An I/O operation completes.
5. A timed wait expires.

Scheduling (2)

		Win32 process class priorities					
		Real-time	High	Above Normal	Normal	Below Normal	Idle
Win32 thread priorities	Time critical	31	15	15	15	15	15
	Highest	26	15	12	10	8	6
	Above normal	25	14	11	9	7	5
	Normal	24	13	10	8	6	4
	Below normal	23	12	9	7	5	3
	Lowest	22	11	8	6	4	2
	Idle	16	1	1	1	1	1

Figure 11-25. Mapping of Win32 priorities to Windows priorities.

Scheduling (3)

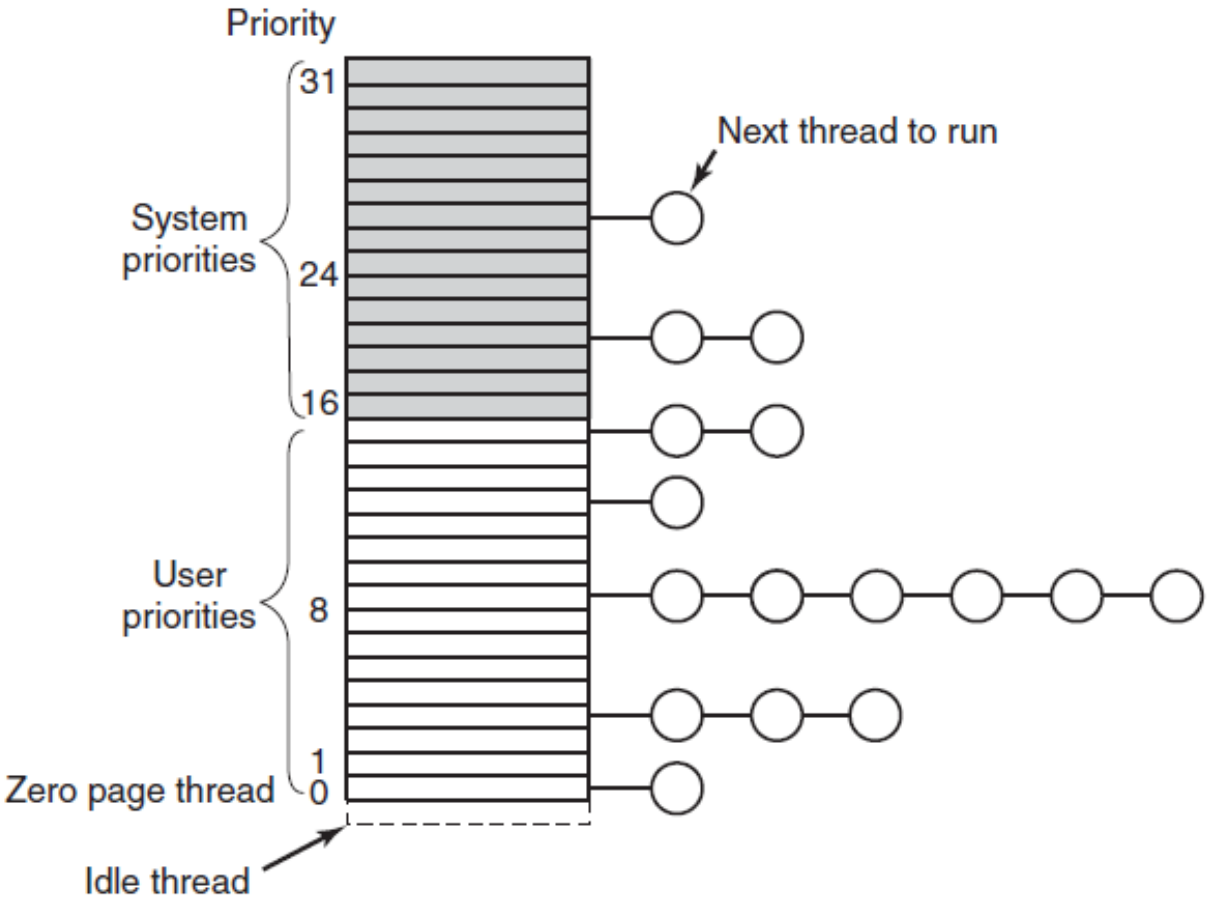


Figure 11-26. Windows supports 32 priorities for threads.

Scheduling (4)

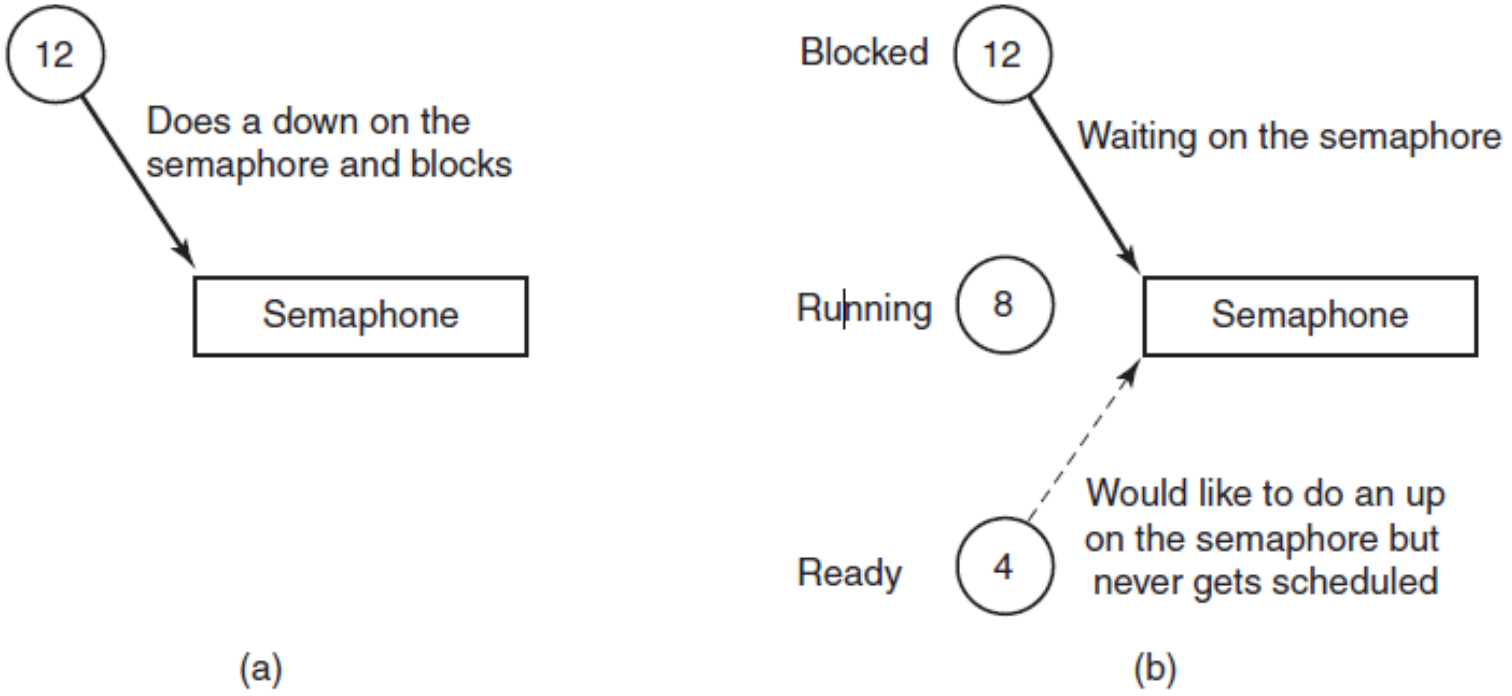


Figure 11-27. An example of priority inversion.

Memory Management Fundamental Concepts

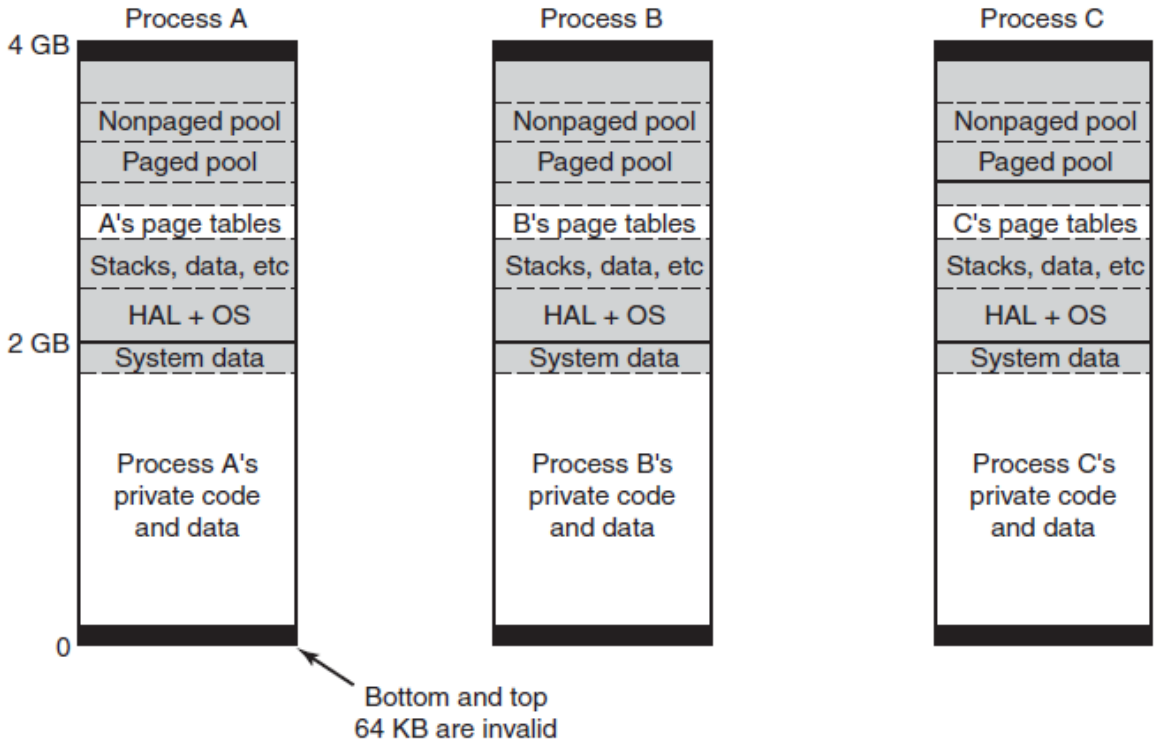


Figure 11-28. Virtual address space layout for three user processes on the x86. The white areas are private per process. The shaded areas are shared among all processes.

Memory-Management System Calls

Win32 API function	Description
VirtualAlloc	Reserve or commit a region
VirtualFree	Release or decommit a region
VirtualProtect	Change the read/write/execute protection on a region
VirtualQuery	Inquire about the status of a region
VirtualLock	Make a region memory resident (i.e., disable paging for it)
VirtualUnlock	Make a region pageable in the usual way
CreateFileMapping	Create a file mapping object and (optionally) assign it a name
MapViewOfFile	Map (part of) a file into the address space
UnmapViewOfFile	Remove a mapped file from the address space
OpenFileMapping	Open a previously created file mapping object

Figure 11-29. The principal Win32 API functions for managing virtual memory in Windows.

Implementation of Memory Management

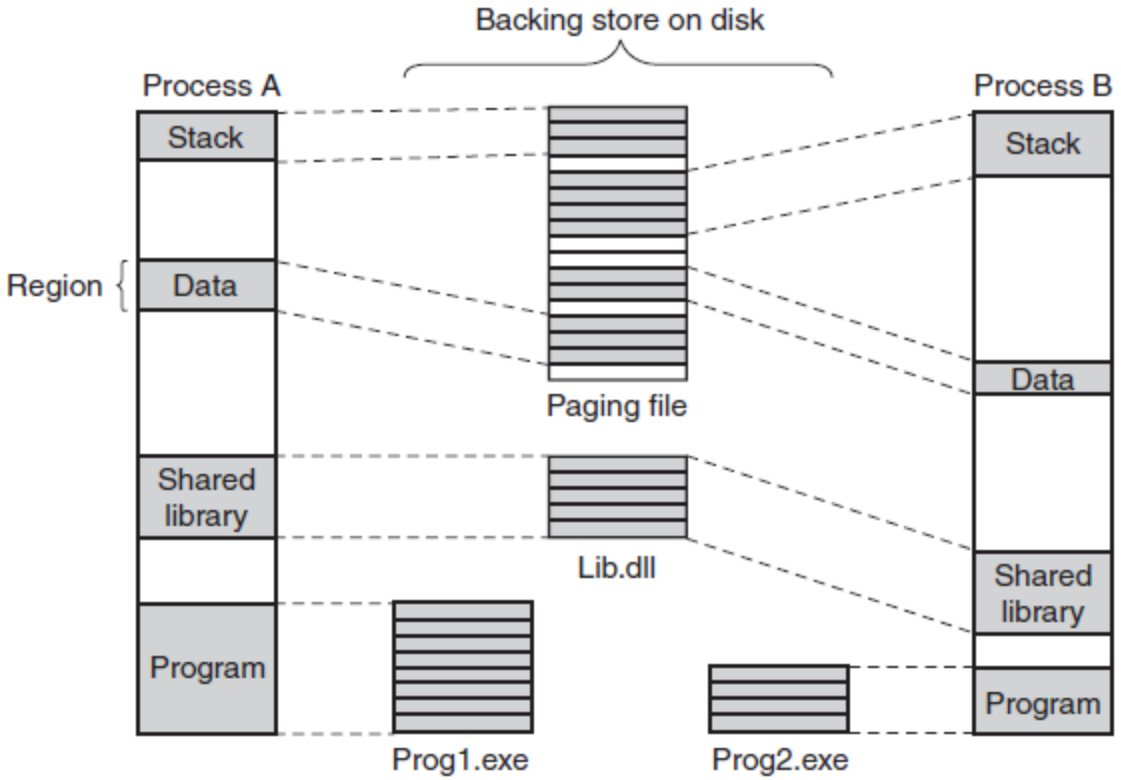
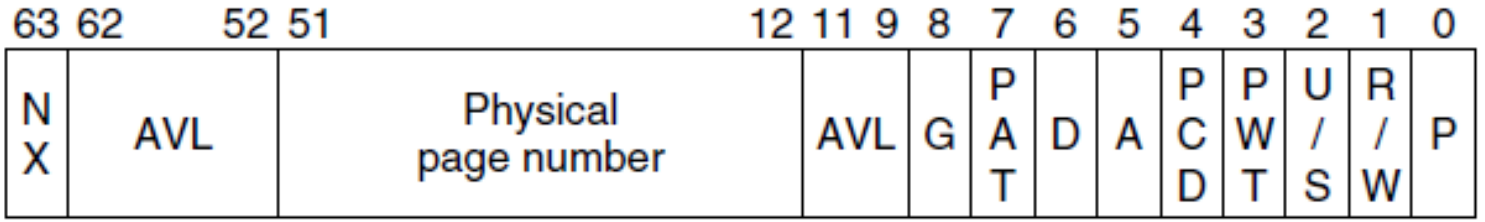


Figure 11-30. Mapped regions with their shadow pages on disk. The *lib.dll* file is mapped into two address spaces at the same time.

Page Fault Handling (1)



NX No eXecute
AVL AVaiLable to the OS
G Global page
PAT Page Attribute Table
D Dirty (modified)
A Accessed (referenced)

PCD Page Cache Disable
PWT Page Write-Through
U/S User/Supervisor
R/W Read/Write access
P Present (valid)

Figure 11-31. A page table entry (PTE) for a mapped page on the Intel x86 and AMD x64 architectures.

Page Fault Handling (2)

Categories of page faults:

1. The page referenced is not committed.
2. Attempted access to a page in violation of the permissions.
3. A shared copy-on-write page was about to be modified.
4. The stack needs to grow.
5. The page referenced is committed but not currently mapped in.

The Page Replacement Algorithm (1)

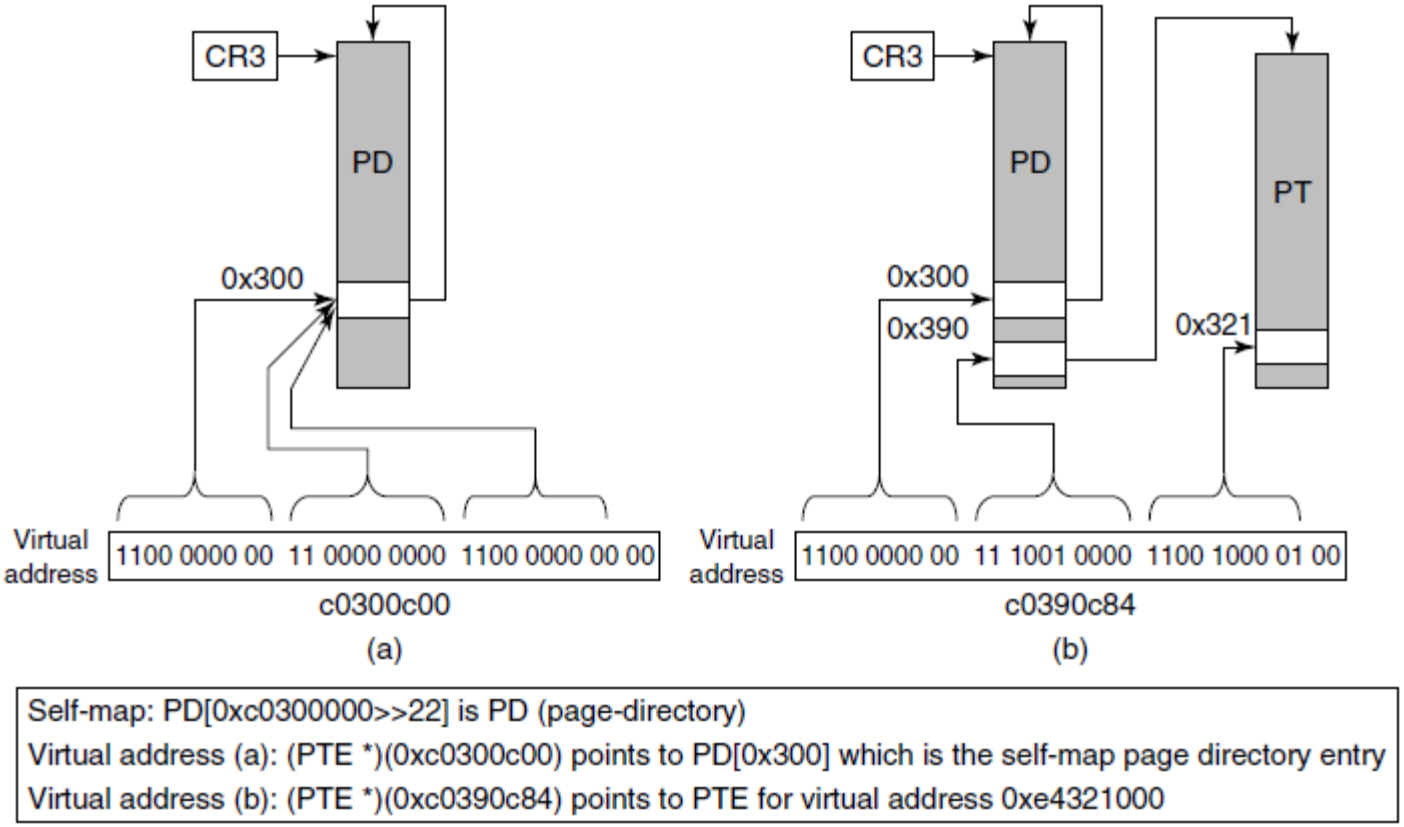


Figure 11-32. The Windows self-map entries are used to map the physical pages of the page tables and page directory into kernel virtual addresses (shown for 32-bit PTEs).

The Page Replacement Algorithm (2)

Three levels of activity by the working-set manager:

1. Lots of memory available
2. Memory getting tight
3. Memory is tight

Physical Memory Management (1)

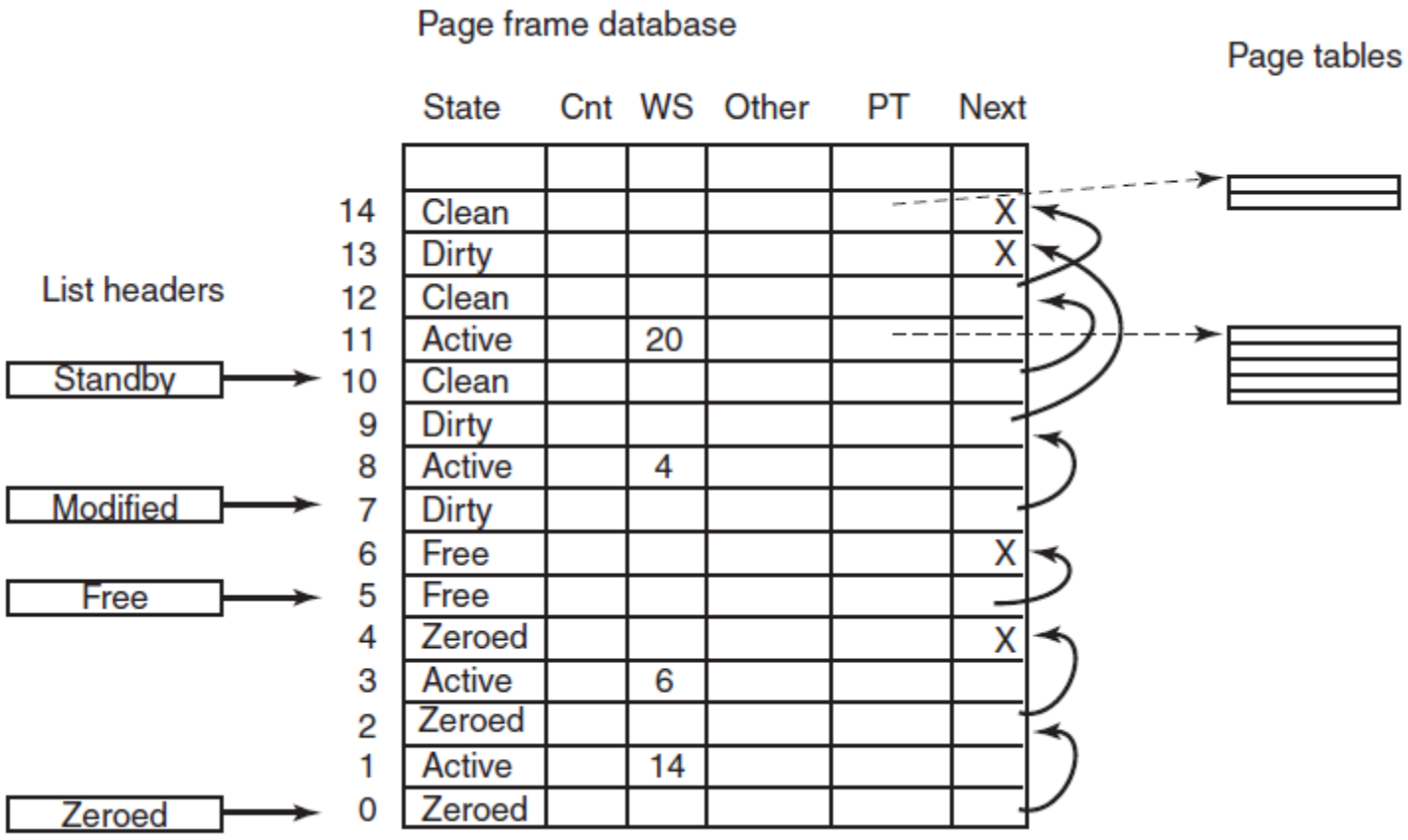


Figure 11-33. Some of the major fields in the page frame database for a valid page.

Physical Memory Management (2)

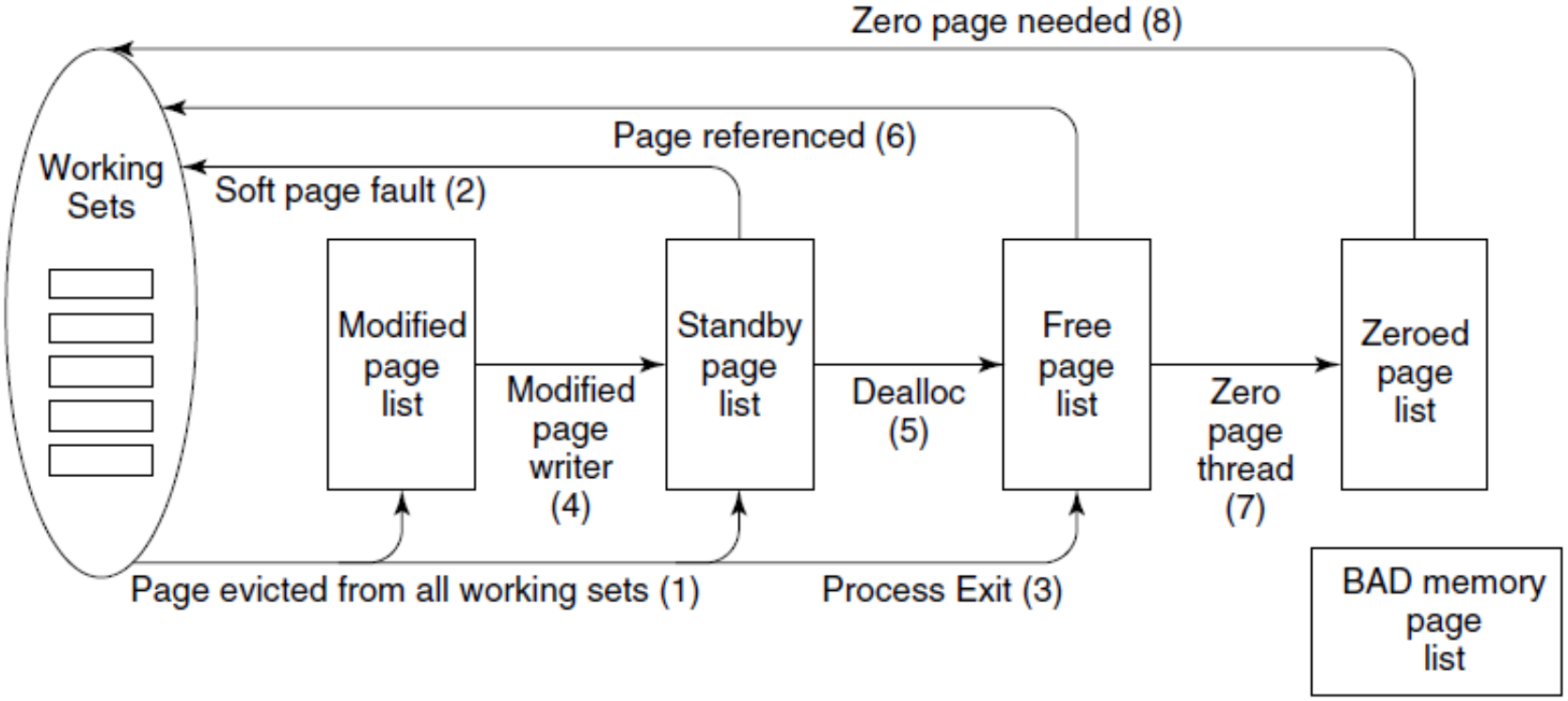


Figure 11-34. The various page lists and the transitions between them.

Input/Output API Calls

I/O system call	Description
NtCreateFile	Open new or existing files or devices
NtReadFile	Read from a file or device
NtWriteFile	Write to a file or device
NtQueryDirectoryFile	Request information about a directory, including files
NtQueryVolumeInformationFile	Request information about a volume
NtSetVolumeInformationFile	Modify volume information
NtNotifyChangeDirectoryFile	Complete when any file in the directory or sub-tree is modified
NtQueryInformationFile	Request information about a file
NtSetInformationFile	Modify file information
NtLockFile	Lock a range of bytes in a file
NtUnlockFile	Remove a range lock
NtFsControlFile	Miscellaneous operations on a file
NtFlushBuffersFile	Flush in-memory file buffers to disk
NtCancelIoFile	Cancel outstanding I/O operations on a file
NtDeviceIoControlFile	Special operations on a device

Figure 11-35. Native NT API calls for performing I/O.

Device Drivers

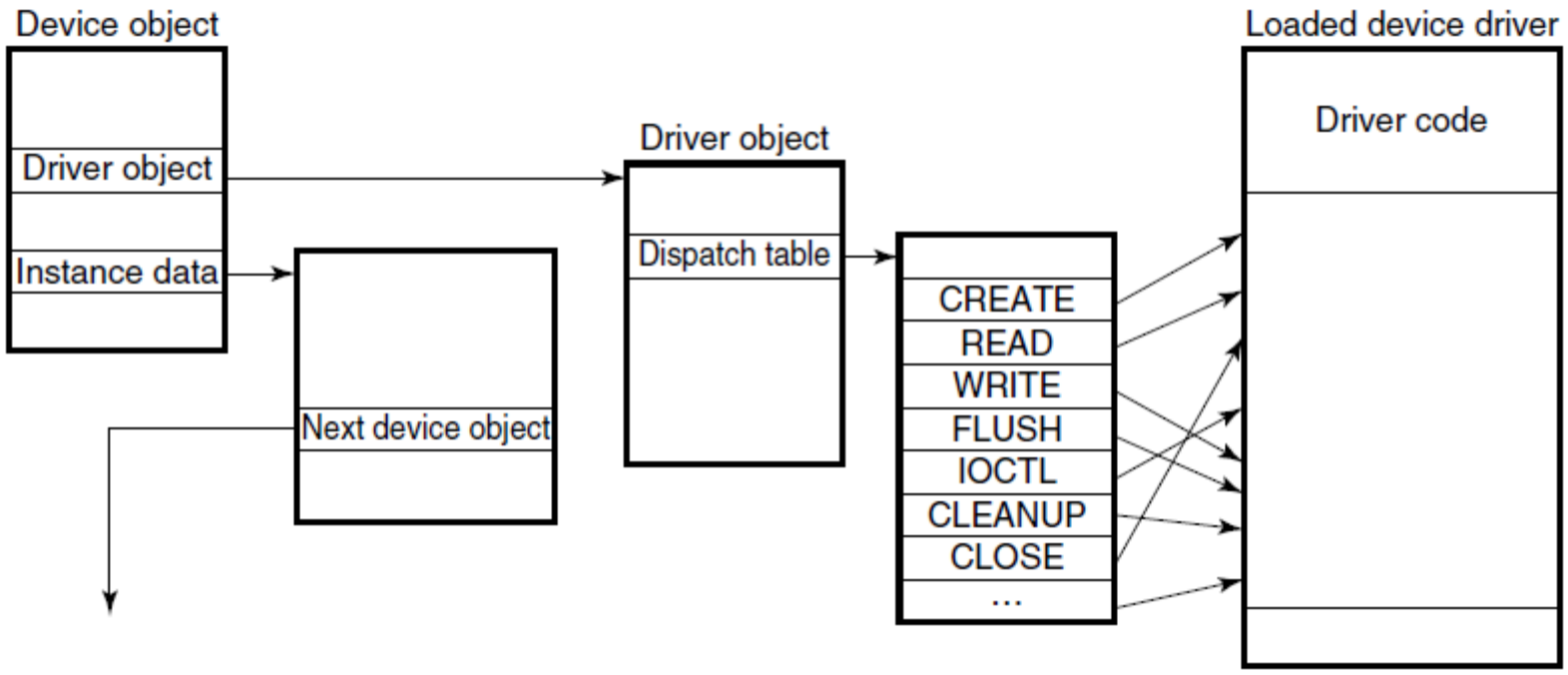


Figure 11-36. A single level in a device stack.

I/O Request Packets

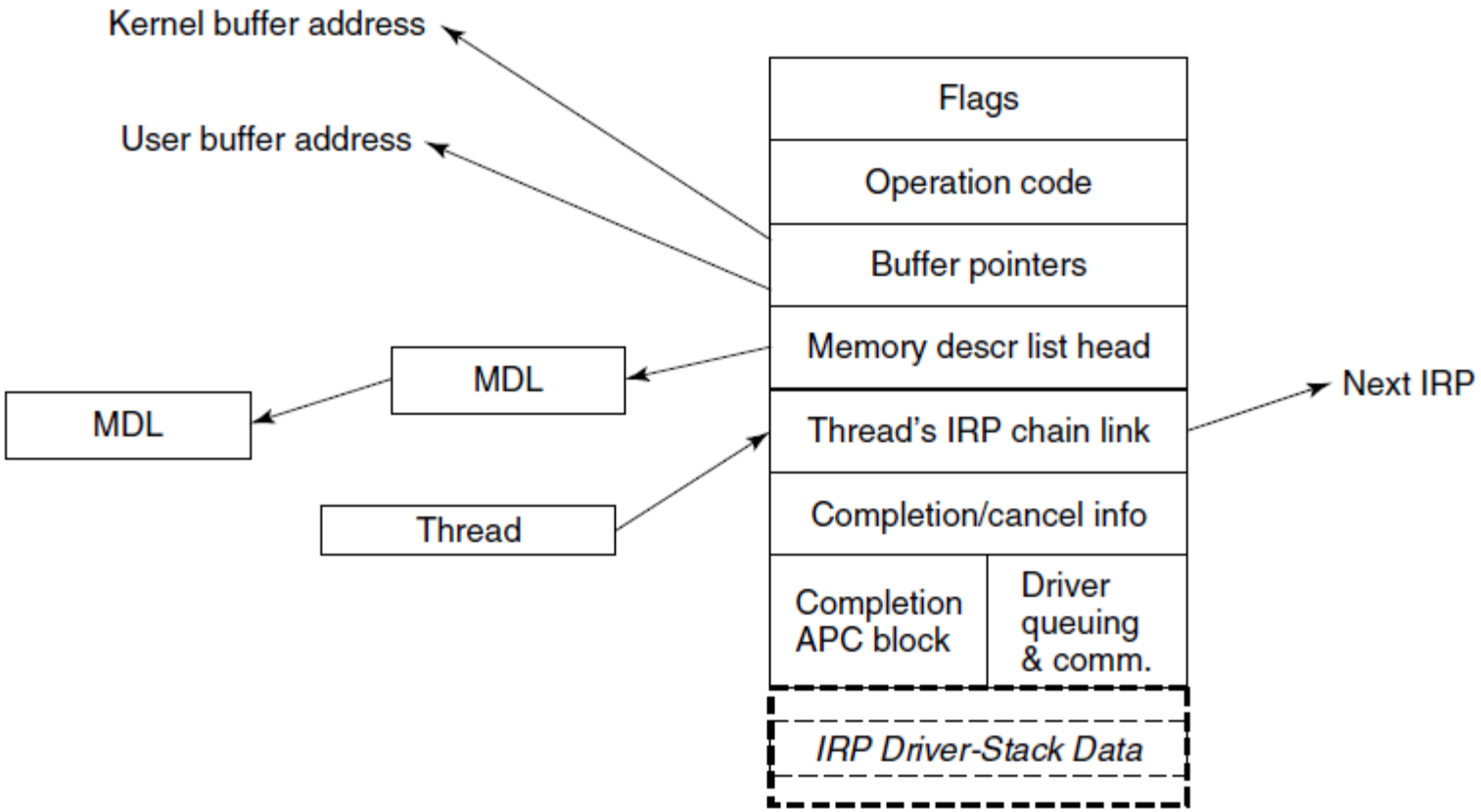


Figure 11-37. The major fields of an I/O Request Packet.

Device Stacks

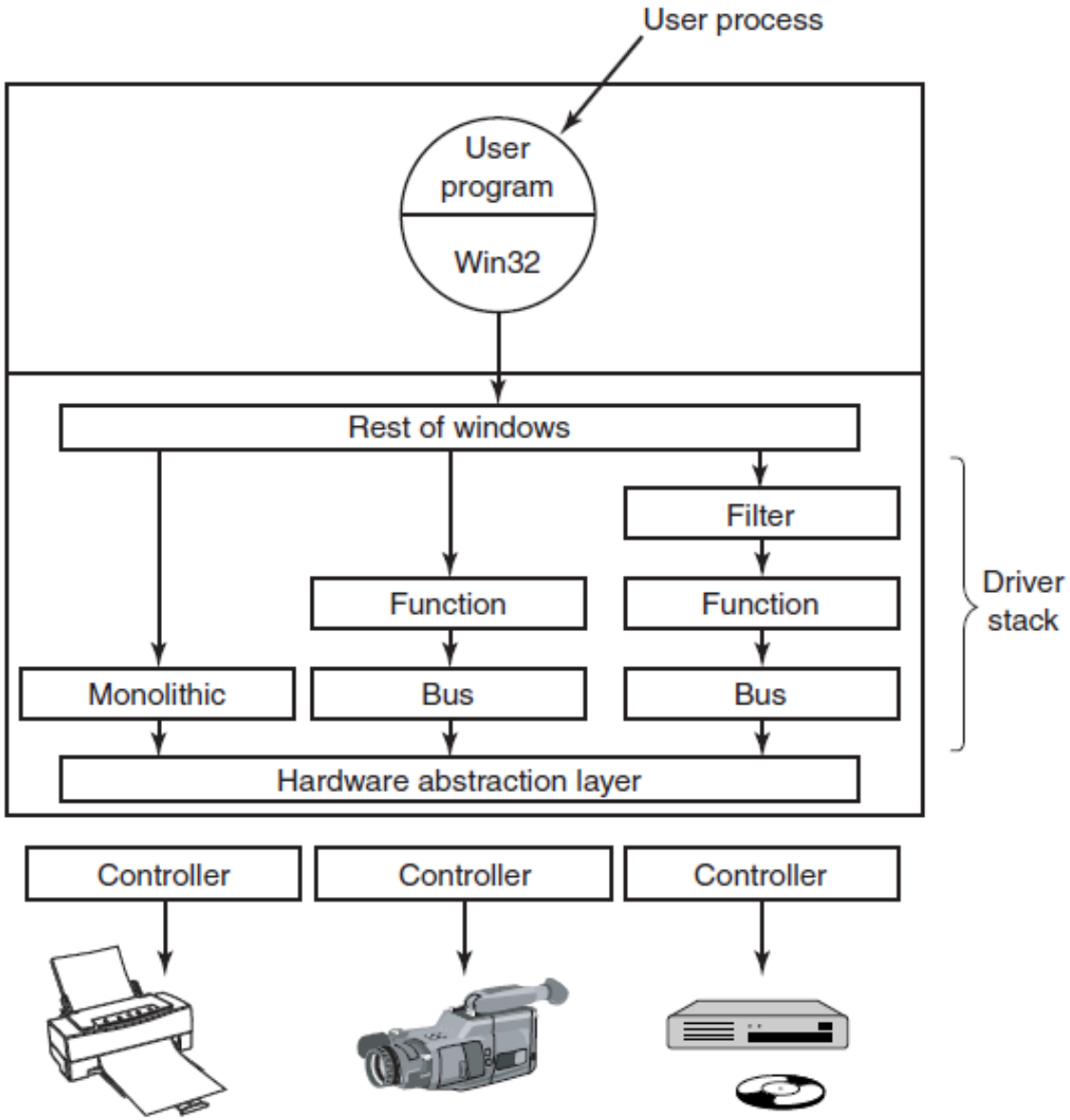


Figure 11-38. Windows allows drivers to be stacked to work with a specific instance of a device. The stacking is represented by device objects.

Implementation of the NT File System (1)

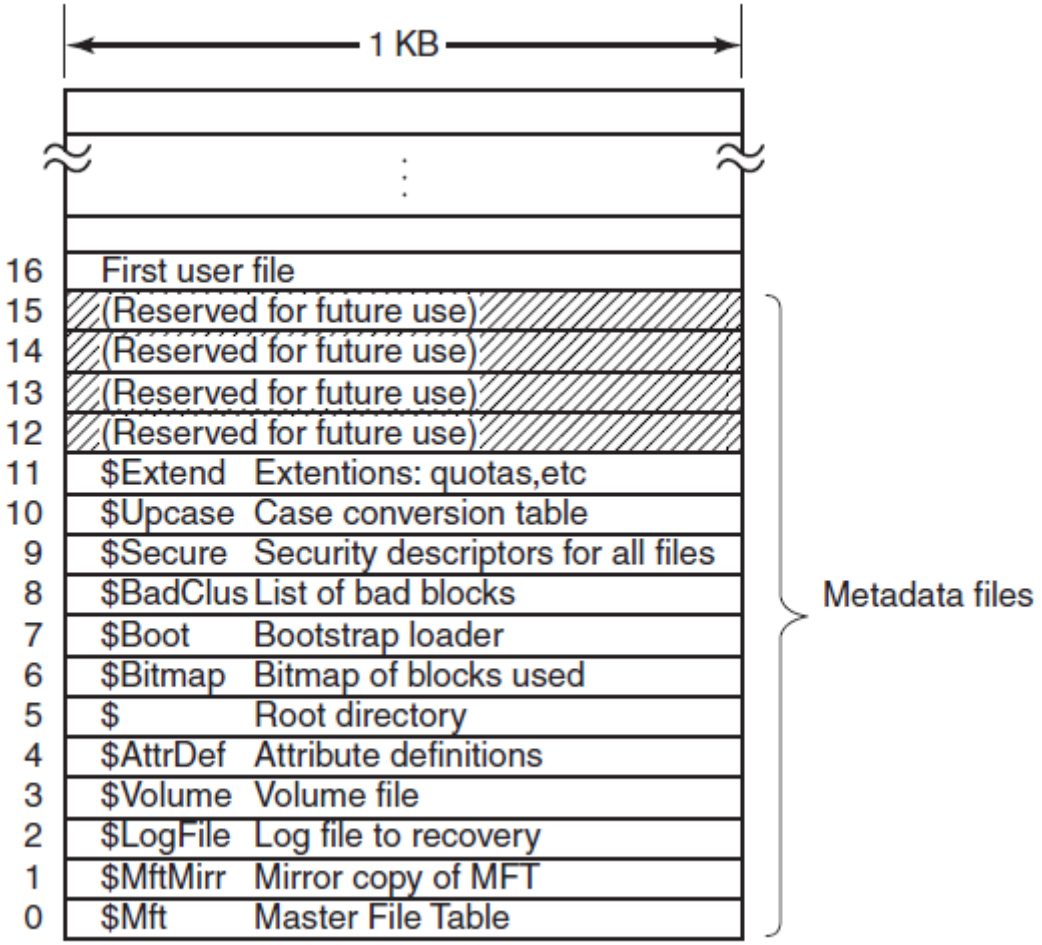


Figure 11-39. The NTFS master file table.

Implementation of the NT File System (2)

Attribute	Description
Standard information	Flag bits, timestamps, etc.
File name	File name in Unicode; may be repeated for MS-DOS name
Security descriptor	Obsolete. Security information is now in $Extend$Secure
Attribute list	Location of additional MFT records, if needed
Object ID	64-bit file identifier unique to this volume
Reparse point	Used for mounting and symbolic links
Volume name	Name of this volume (used only in $Volume)
Volume information	Volume version (used only in $Volume)
Index root	Used for directories
Index allocation	Used for very large directories
Bitmap	Used for very large directories
Logged utility stream	Controls logging to $LogFile
Data	Stream data; may be repeated

Figure 11-40. The attributes used in MFT records.

Storage Allocation (1)

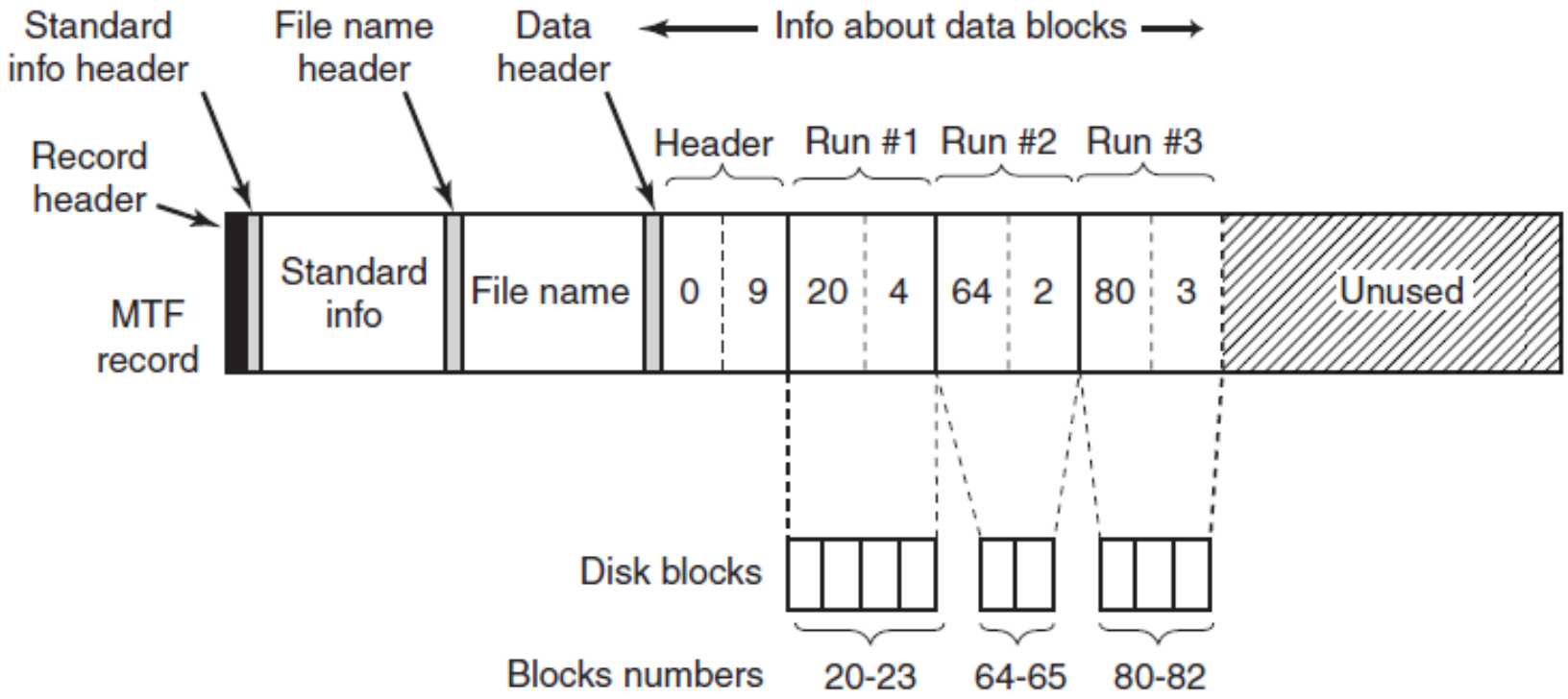


Figure 11-41. An MFT record for a three-run, nine-block stream.

Storage Allocation (2)

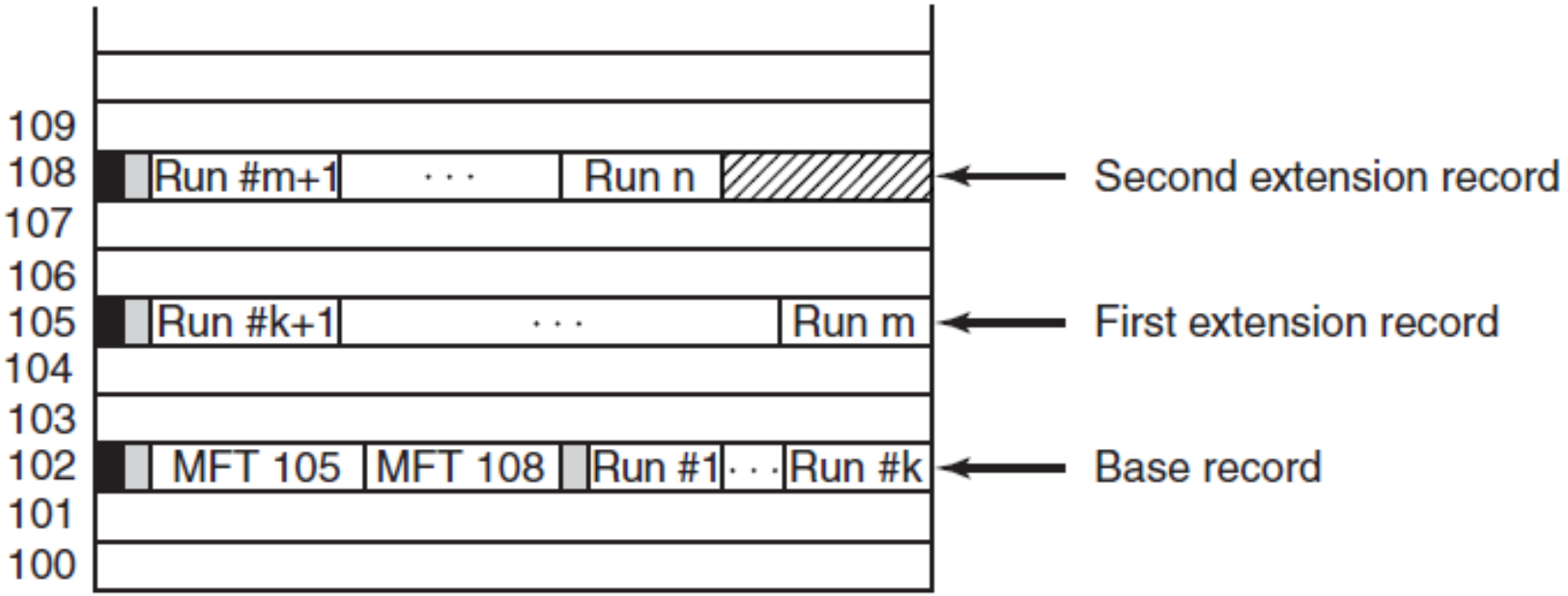


Figure 11-42. A file that requires three MFT records to store all its runs.

Storage Allocation (3)

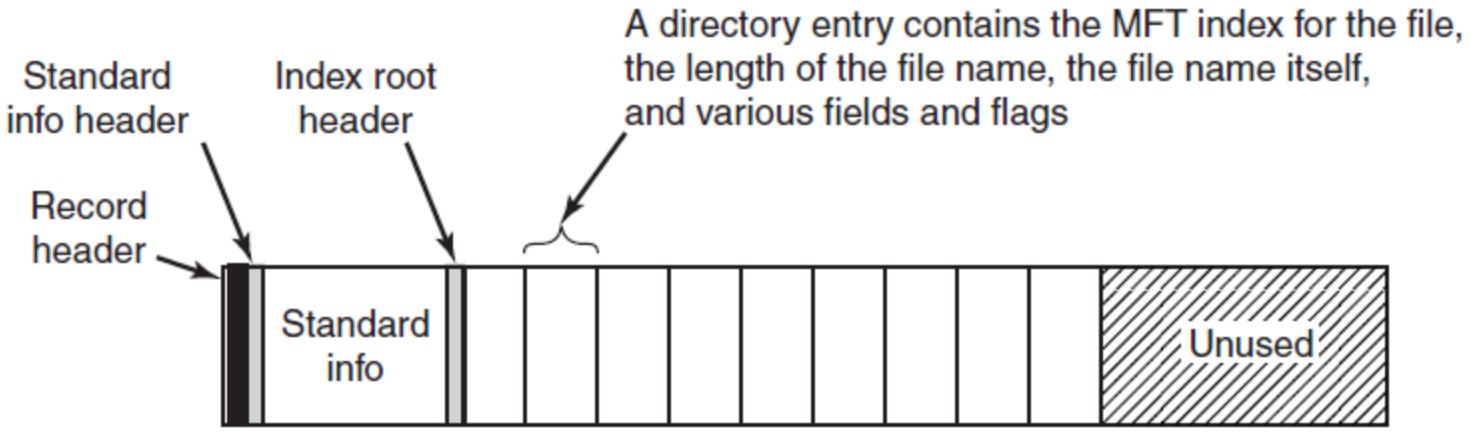


Figure 11-43. The MFT record for a small directory.

File Compression

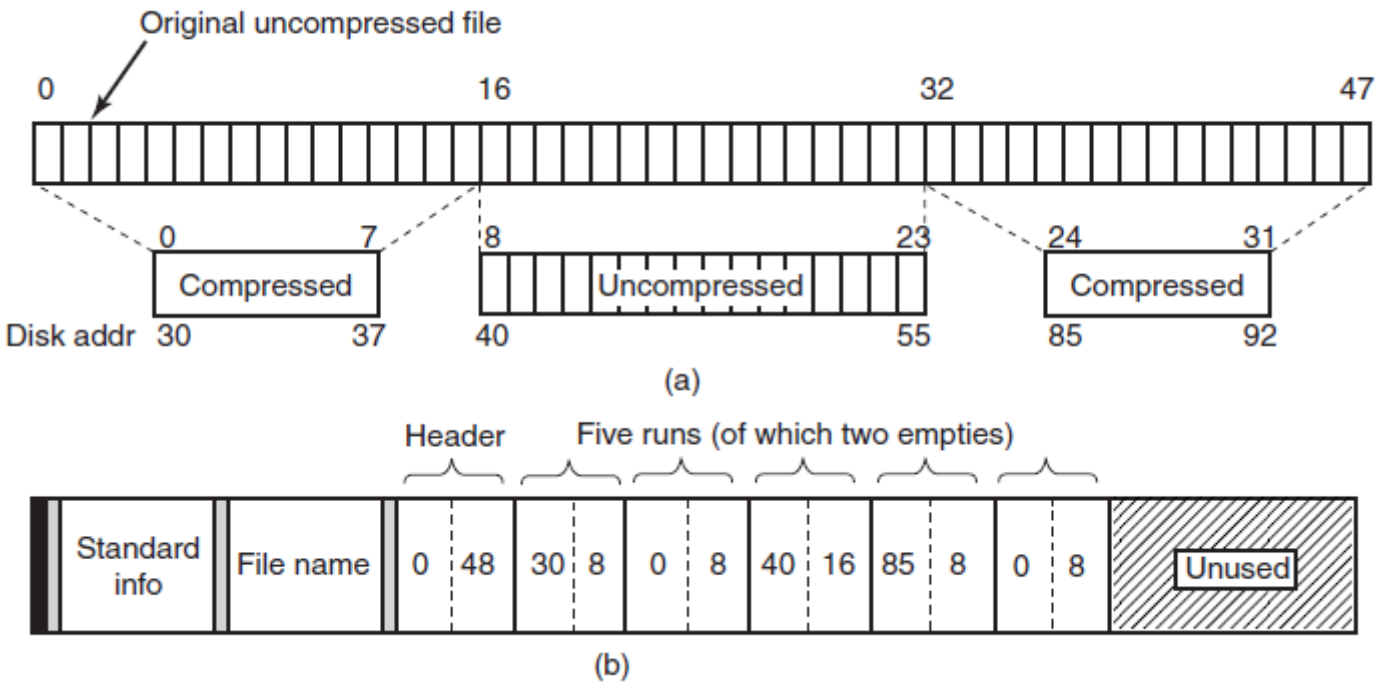


Figure 11-44. (a) An example of a 48-block file being compressed to 32 blocks. (b) The MFT record for the file after compression.

Security in Windows 8

Security properties inherited from NT:

1. Secure login with antispoofing measures.
2. Discretionary access controls.
3. Privileged access controls.
4. Address space protection per process.
5. New pages must be zeroed before being mapped in.
6. Security auditing.

Fundamental Security Concepts

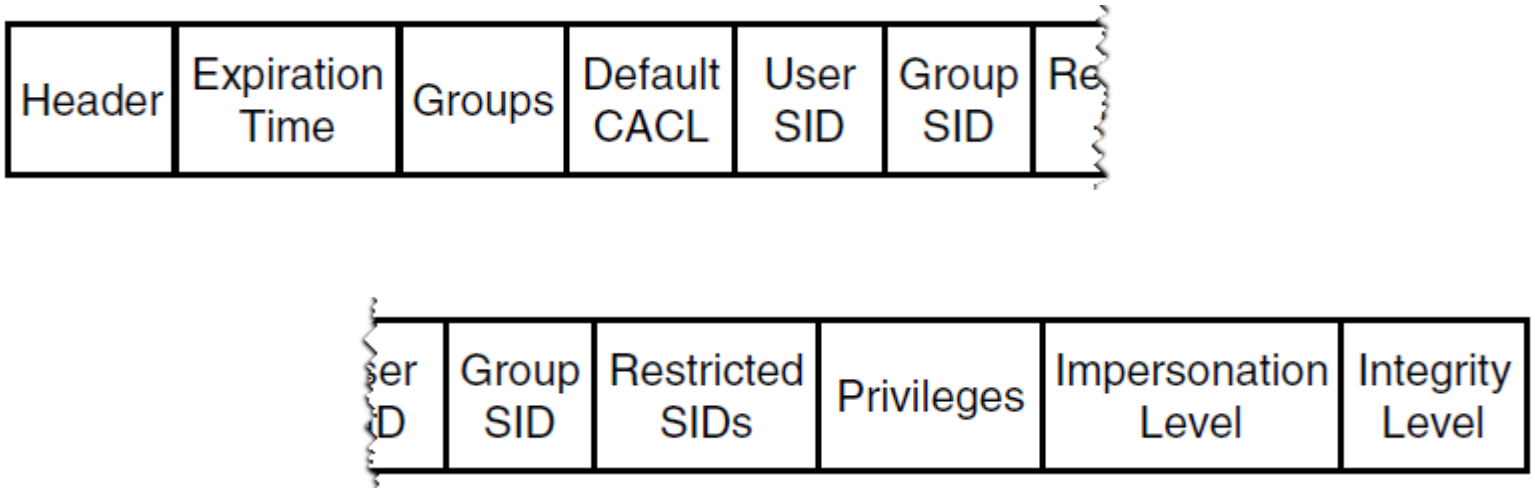


Figure 11-45. Structure of an access token.

Security API Calls (1)

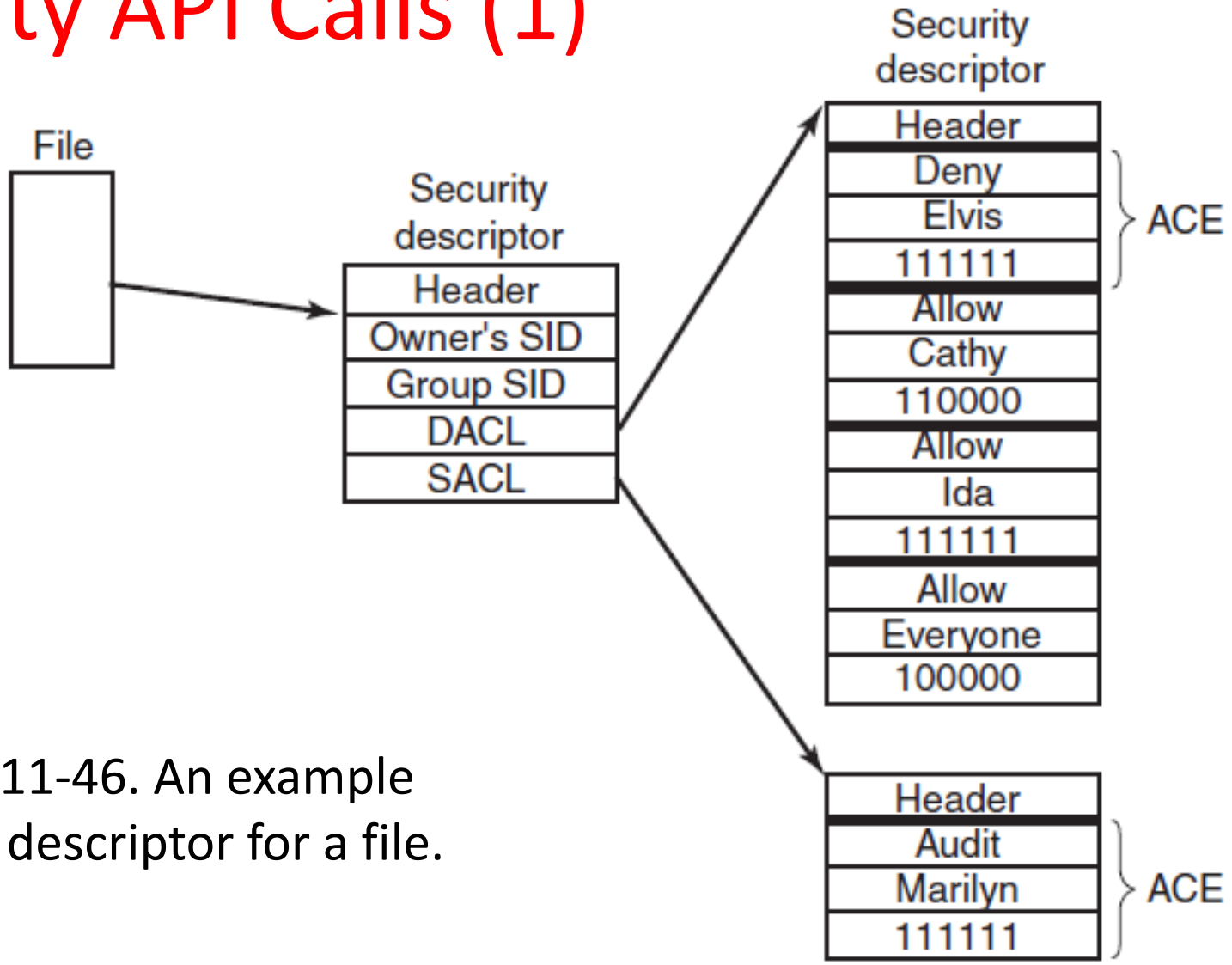


Figure 11-46. An example security descriptor for a file.

Security API Calls (2)

Win32 API function	Description
InitializeSecurityDescriptor	Prepare a new security descriptor for use
LookupAccountSid	Look up the SID for a given user name
SetSecurityDescriptorOwner	Enter the owner SID in the security descriptor
SetSecurityDescriptorGroup	Enter a group SID in the security descriptor
InitializeAcl	Initialize a DACL or SACL
AddAccessAllowedAce	Add a new ACE to a DACL or SACL allowing access
AddAccessDeniedAce	Add a new ACE to a DACL or SACL denying access
DeleteAce	Remove an ACE from a DACL or SACL
SetSecurityDescriptorDacl	Attach a DACL to a security descriptor

Figure 11-47. The principal Win32 API functions for security.

Security Mitigations

Mitigation	Description
/GS compiler flag	Add canary to stack frames to protect branch targets
Exception hardening	Restrict what code can be invoked as exception handlers
NX MMU protection	Mark code as non-executable to hinder attack payloads
ASLR	Randomize address space to make ROP attacks difficult
Heap hardening	Check for common heap usage errors
VTGuard	Add checks to validate virtual function tables
Code Integrity	Verify that libraries and drivers are properly cryptographically signed
Patchguard	Detect attempts to modify kernel data, e.g. by root kits
Windows Update	Provide regular security patches to remove vulnerabilities
Windows Defender	Built-in basic antivirus capability

Figure 11-48. Some of the principal security mitigations in Windows.

End

Chapter 11