Windows Kernel Internals
Object Manager

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Windows Kernel Development

Microsoft Corporation

Kernel Object Manager (OB)

- Provides underlying NT namespace
- Unifies kernel data structure referencing
- Unifies user-mode referencing via handles
- Simplifies resource charging
- Central facility for security protection

NT Name Space

```
¥
    arcname¥
    BaseNamedObjects¥
    callback¥
    device
        HardDisk0¥
                dr0
    driver¥
    FileSystem¥
        ntfs
    KernelObjects¥
    KnownDlls¥
    ObjectTypes¥
    RPC Control¥
    Windows¥
        apiport
        SbApiPort
        WindowsStations¥
          winsta0
```

¥ObjectTypes

Adapter
Callback
Controller
DebugObject
Desktop
Device
Directory
Driver
Event
EventPair
File
IoCompletion
Job
Key
KeyedEvent
Mutant
Port
Process
Profile
Section
Semaphore
SymbolicLink
Thread
Timer
Token
Type
WaitablePort
WindowsStation
WMIGuid

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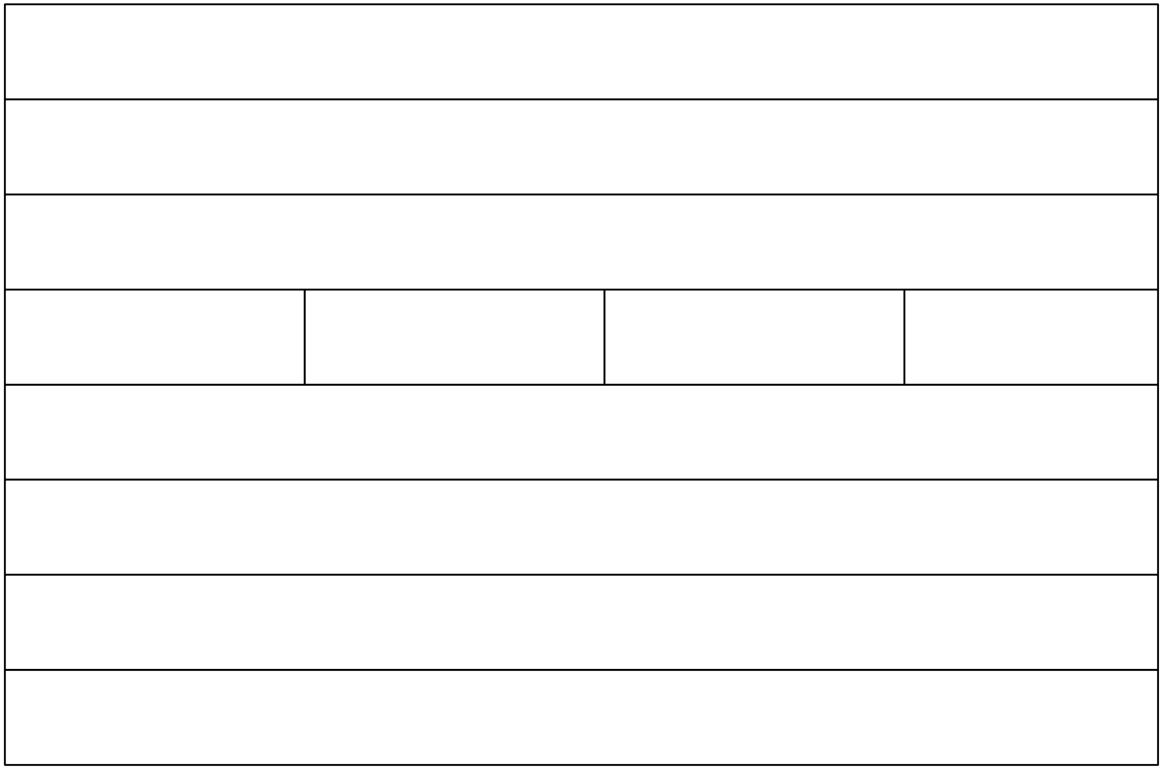
OBJECT_HEADER



Generic object services

- namespace ops: directories, symlinks
- NtQueryObject
- NtQuery/SetSecurityObject
- NtWaitForSingle/MultipleObjects
- ObOpenObjectByName/Pointer
- ObReferenceObjectByName/Handle
- NtDuplicateObject
- NtClose
- ObDereferenceObject

OBJECT_DIRECTORY

OBJECT_DIRECTORY

OBJECT_DIRECTORY_ENTRY *pHashBuckets[ ]
Lock
pDeviceMap
SessionId

OBJECT_DIRECTORY_ENTRY

OBJECT_DIRECTORY_ENTRY *pChainLink
pObject

ObpLookupDirectoryEntry(pD, s)

```
object = NULL
idx = HASH(s)
pE = pD->HashBuckets[idx]
LockDirectoryShared(pD)
while (pE && !eqs(s, pE->Object->Name))
    pE = pE->pChainLink
if (pE)
    ObpReferenceObject(object = pE->Object)
UnlockDirectory(pD)
return object
```

Object Methods

OPEN:	Create/Open/Dup/Inherit handle
CLOSE:	Called when each handle closed
DELETE:	Called on last dereference
PARSE:	Called looking up objects by name
SECURITY:	Usually *SeDefaultObjectMethod*
QUERYNAME:	Return object-specific name
OKAYTOCLOSE:	Give veto on handle close

Object Manager Types

Directory - namespace object

- **Implementation hardwired**

SymbolicLink - namespace object

- **DeleteProcedure = ObpDeleteSymbolicLink**
- **ParseProcedure = ObpParseSymbolicLink**

Type **- represent object types**

- **DeleteProcedure = ObpDeleteObjectType**

Object Manager lookups

ObpLookupObjectName(Name,Context)

- Search a directory for specified object name
- Use ObpLookupDirectoryEntry() on Directories
- Otherwise call object-specific ParseProcedure
  - Implements symbolic links (SymbolicLink type)
  - Implements file systems (DeviceObject type)

I/O Manager Types

Adapter - ADAPTER_OBJECT

Controller - CONTROLLER_OBJECT

Device - DEVICE_OBJECT

- **ParseProcedure = IopParseDevice**
- **DeleteProcedure = IopDeleteDevice**
- **SecurityProcedure = IopGetSetSecurityObject**

Driver - DRIVER_OBJECT

- **DeleteProcedure = IopDeleteDriver**

IoCompletion - KQUEUE

- **DeleteProcedure = IopDeleteIoCompletion**

I/O Manager File Type

File - FILE_OBJECT

CloseProcedure = IopCloseFile
DeleteProcedure = IopDeleteFile
ParseProcedure = IopParseFile
SecurityProcedure = IopGetSetSecurityObject
QueryNameProcedure = IopQueryName

IopParseDevice

(DeviceObject, Context, RemainingName)

- Call SeAccessCheck()
- If (!*RemainingName) directDeviceOpen = TRUE
- For file opens, get Volume from DeviceObject
- Update references on Volume and DeviceObject
- Construct an I/O Request Packet (IRP)
- FileObject = ObCreateObject(IoFileObjectType)
- Initialize FileObject
- Initiate I/O via IoCallDriver(VolumeDevice, IRP)
- Wait for I/O to signal FileObject->Event
- Return the FileObject to caller

FILE_OBJECT

pDeviceObject
pVolumeParameterBlock
pFsContext/pFsContext2
pSectionObjectPointers
pPrivateCacheMap
pRelatedFileObject

Flags
CurrentByteOffset
FinalNTStatus
nWaiters
nBusy
Lock
Event
pIOCompletionContext

File Object (FO) flags

FO_FILE_OPEN

FO_SYNCHRONOUS_IO

FO_ALERTABLE_IO

FO_REMOTE_ORIGIN

FO_WRITE_THROUGH

FO_SEQUENTIAL_ONLY

FO_CACHE_SUPPORTED

FO_NAMED_PIPE

FO_STREAM_FILE

FO_MAILSLOT

FO_FILE_MODIFIED

FO_FILE_SIZE_CHANGED

FO_CLEANUP_COMPLETE

FO_TEMPORARY_FILE

FO_DELETE_ON_CLOSE

FO_OPENED_CASE_SENSITIVE

FO_HANDLE_CREATED

FO_FILE_FAST_IO_READ

FO_RANDOM_ACCESS

FO_FILE_OPEN_CANCELLED

FO_VOLUME_OPEN

FO_FILE_OBJECT_HAS_EXTENSION

FO_NO_INTERMEDIATE_BUFFERING

FO_GENERATE_AUDIT_ON_CLOSE

FO_DIRECT_DEVICE_OPEN

Process/Thread Types

Job - JOB

DeleteProcedure = PspJobDelete

CloseProcedure = PspJobClose

Process - EPROCESS

DeleteProcedure = PspProcessDelete

Profile - EPROFILE

DeleteProcedure = ExpProfileDelete

Section - SECTION

DeleteProcedure = MiSectionDelete

Thread - ETHREAD

DeleteProcedure = PspThreadDelete

Token - TOKEN

DeleteProcedure = SepTokenDeleteMethod

Job methods - Close

PspJobClose - called by OB when a handle is closed

```
Return unless final close
Mark Job as closed
Acquire the job's lock
If job marked PS_JOB_FLAGS_CLOSE_DONE
    Release the JobLock
    Call PspTerminateAllProcessesInJob()
    Reacquire the JobLock
Acquire the job's MemoryLimitsLock
Remove any completion port from the job
Release the MemoryLimitsLock
Release the JobLock
Dereference the completion port
```

Job methods - Delete

PspJobDelete - called by OB at final dereference

- Holding the Joblock callout to ntuser
- Acquire the PspJobListLock
- If part of a jobset then we are the job pinning the jobset
    - tJob = next job in set and remove current job
- Release the PspJobListLock
- If (tJob) ObDereferenceObjectDeferDelete (tJob)
- If (Job->Token) ObDereferenceObject (Job->Token)
- Free pool allocated for job filters
- Unlink our JobLock from the global list

Synchronization Types

Event - KEVENT

EventPair - EEVENT_PAIR

KeyedEvent - KEYED_EVENT_OBJECT

Mutant - KMUTANT

DeleteProcedure = ExpDeleteMutant

Port - LPCP_PORT_OBJECT

DeleteProcedure = LpcpDeletePort

CloseProcedure = LpcpClosePort

Semaphore - KSEMAPHORE

Timer - ETIMER

DeleteProcedure = ExpDeleteTimer

Win32k.sys

Callback - CALLBACK_OBJECT

DeleteProcedure = ExpDeleteCallback

WindowsStation, Desktop

CloseProcedure = ExpWin32CloseProcedure

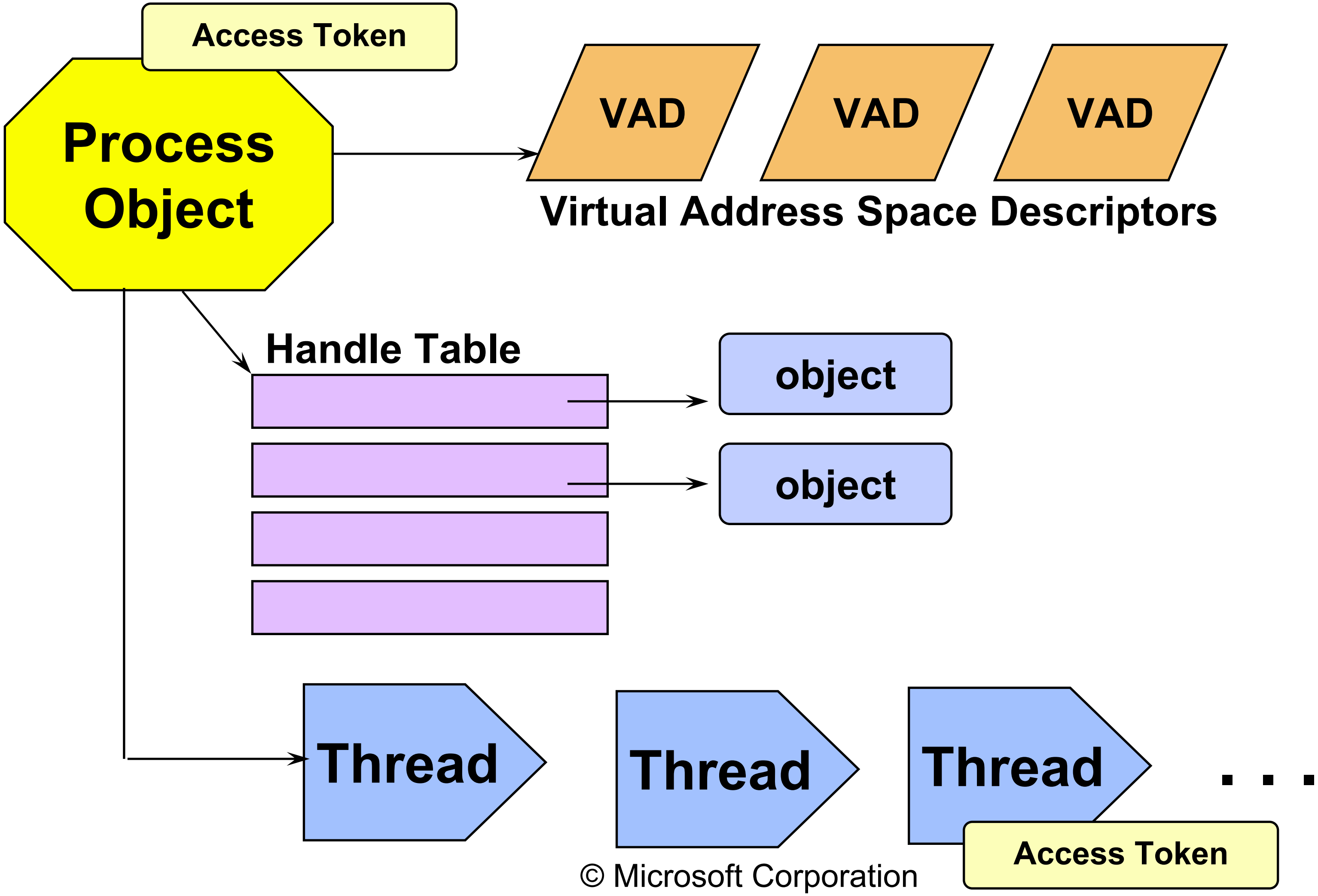
DeleteProcedure = ExpWin32DeleteProcedure

OkayToCloseProcedure = ExpWin32OkayToCloseProcedure

ParseProcedure = ExpWin32ParseProcedure

OpenProcedure = ExpWin32OpenProcedure

Processes & Threads



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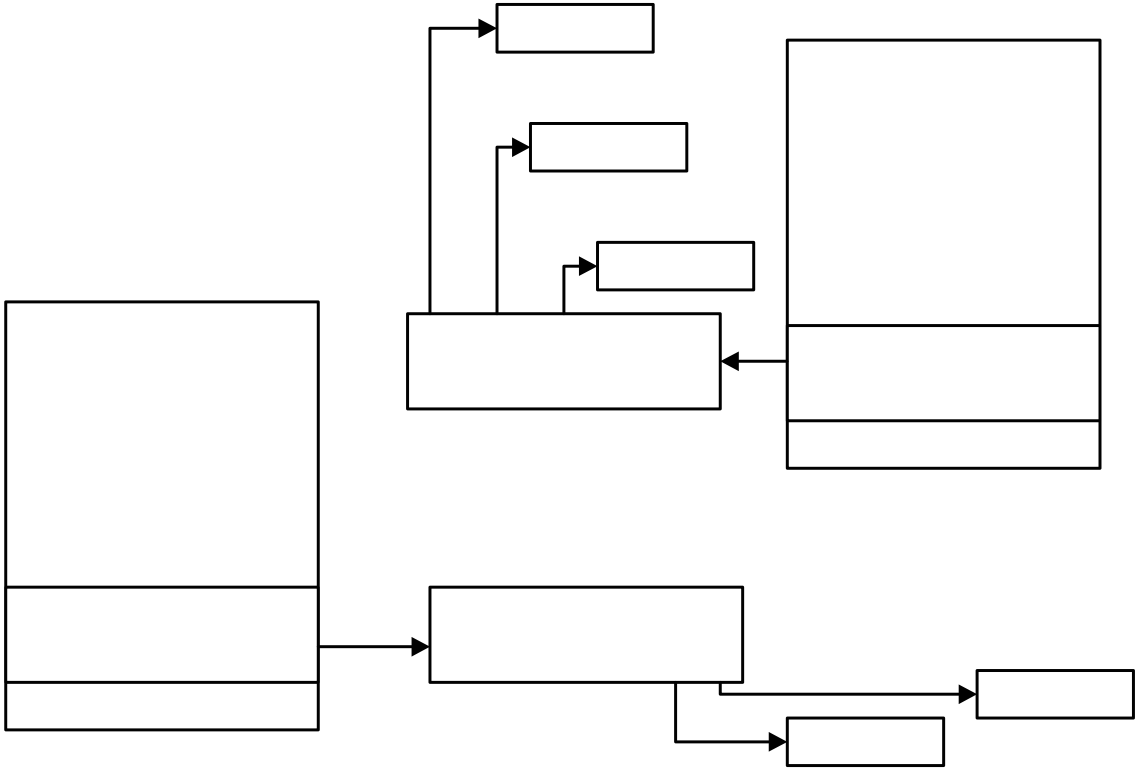
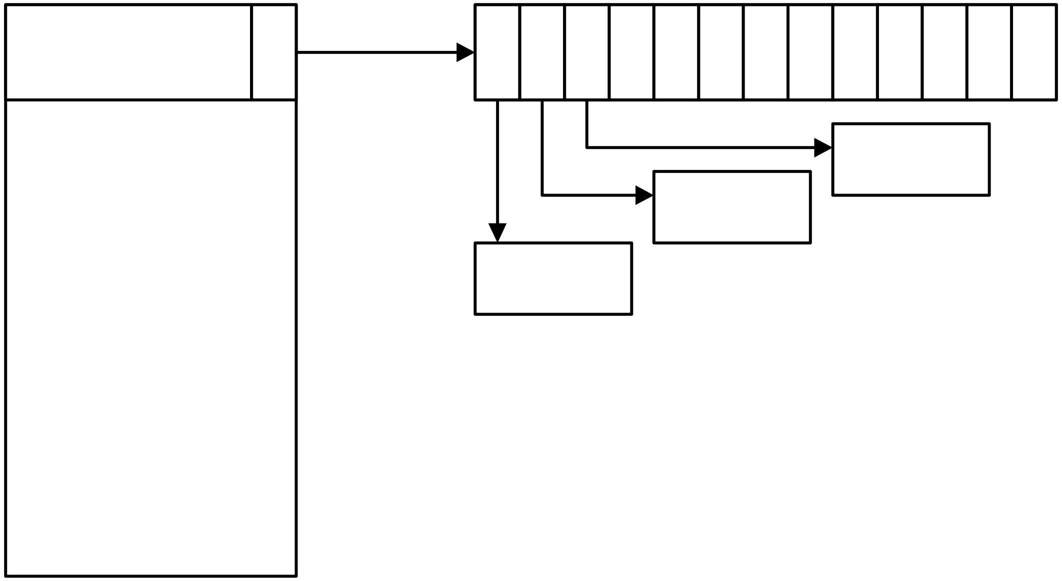
Handle Table (Executive)

- Efficient, scalable object index structure
- One per process containing ‘open’ objects
- Kernel handle table (system process)
- Also used to allocate process/thread IDs

Process Handle Tables



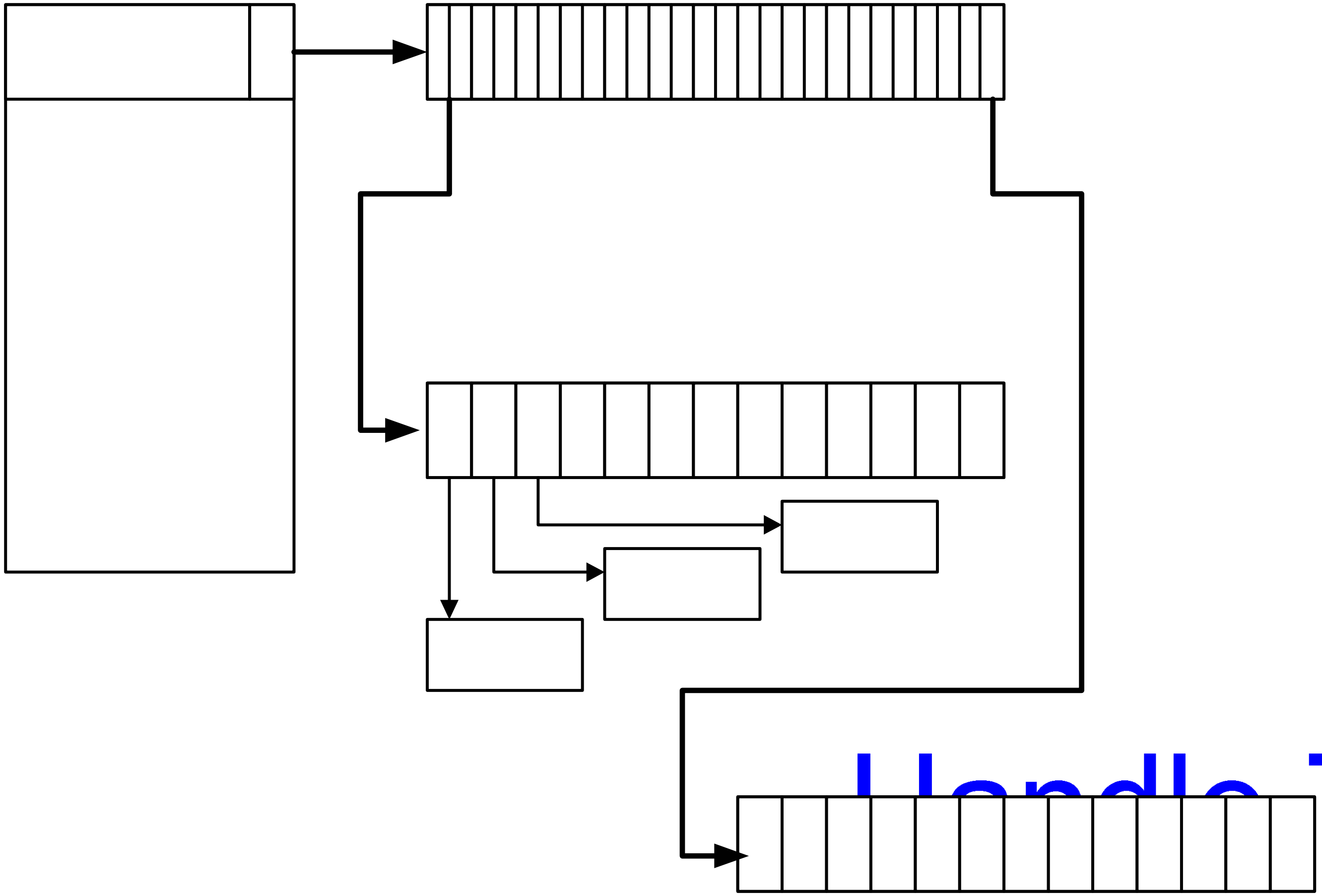
One level: (to 512 handles)



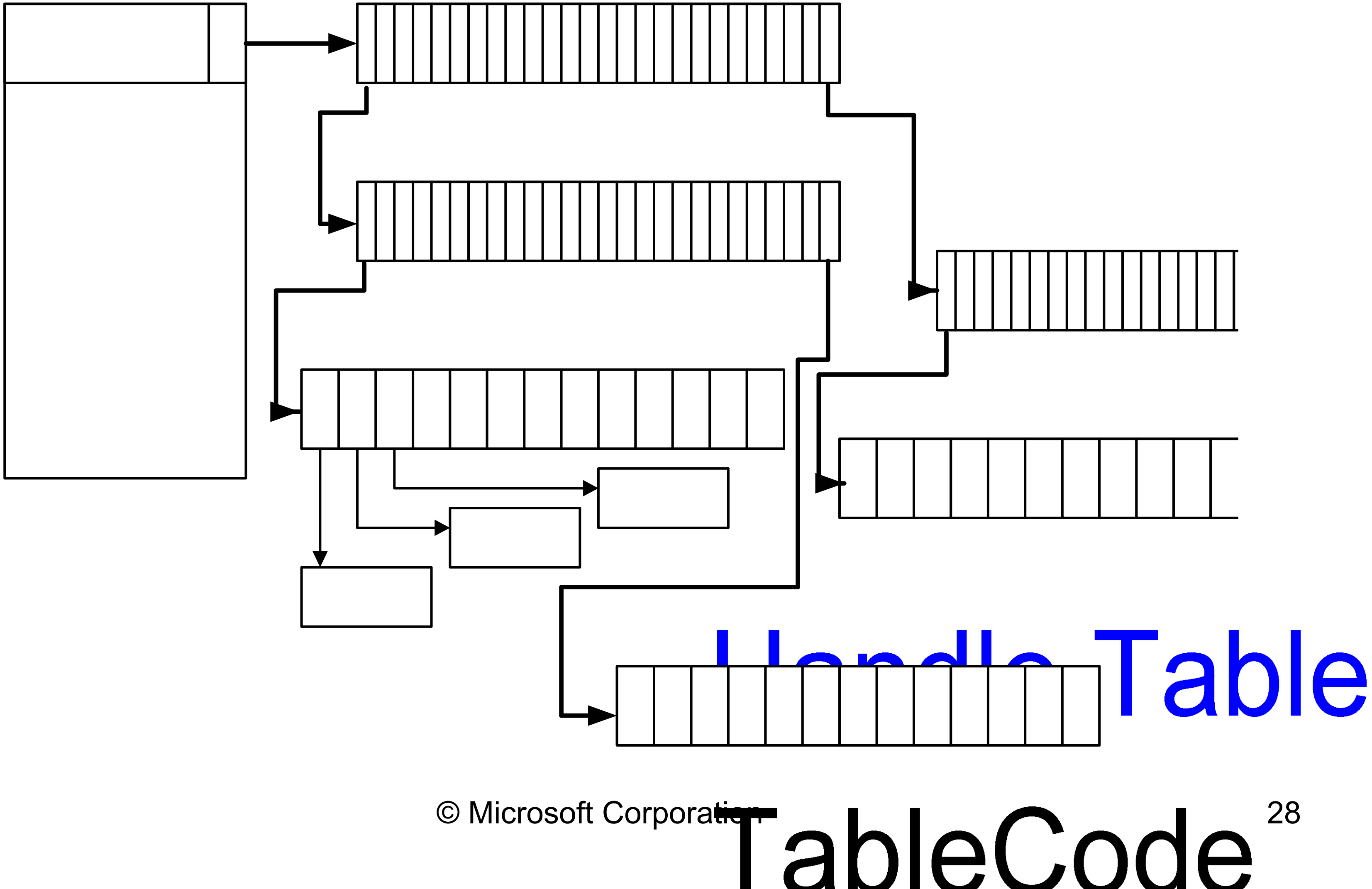
Handle Table

TableCode

Two levels: (to 512K handles)



Three levels: (to 16M handles)



Handle Table Data Structure

TablePointer/Level	Points at handles
QuotaProcess	Who to charge
UniqueProcessId	Passed to callbacks
HandleTableLocks[N]	Locks for handles
HandleTableList	Global list of tables
HandleContentionEvent	Event to block on
DebugInfo	Stacktraces
ExtraInfoPages	Parallel table for audits
FirstFree/LastFree	The two handle free lists
NextHandleNeedingPool	Handles w/ memory
HandleCount	Handles in use

Handle Table Functions

ExCreateHandleTable – create non-process tables
ExDupHandleTable – called creating processes

ExSweepHandleTable – for process rundown
ExDestroyHandleTable – called destroying processes

ExCreateHandle – setup new handle table entry
ExChangeHandle – used to set inherit and/or protect
ExDestroyHandle – implements CloseHandle
ExMapHandleToPointer – reference underlying object

ExReferenceHandleDebugInfo – tracing handles
ExSnapShotHandleTables – handle searchers (oh.exe)

ExCreateHandle(table, entry)

```
NewHandleTableEntry = ExpAllocateHandleTableEntry()
KeEnterCriticalRegionThread()
*NewHandleTableEntry = *HandleTableEntry
ExUnlockHandleTableEntry()
KeLeaveCriticalRegionThread()
```

ExpAllocateHandleTableEntry()

```
while (1) {
    while (! (OldValue = Table->FirstFree)) {
        ExAcquirePushLockExclusive(TableLock[0]);
        If (OldValue = Table->FirstFree)  break;
        If (OldValue = ExpMoveFreeHandles())  break;
        ExpAllocateHandleTableEntrySlow();
        ExReleasePushLockExclusive(TableLock[0]);
    }
    ExpUnlockHandleTableExclusive();
    Handle.Value = (OldValue & FREE_HANDLE_MASK);
    Entry = ExpLookupHandleTableEntry();
    Idx = ((Handle.Value)>>2) % HANDLE_LOCKS;
    ExAcquirePushLockExclusive(TableLock[idx]);
    if (OldValue != *(volatile)&Table->FirstFree) {
        ExReleasePushLockExclusive(TableLock[idx]);
        continue;
    }
    KeMemoryBarrier ();
    NewValue = *(volatile)&Entry->NextFreeTableEntry;
    Expected = InterlockedCompareExchange (&Table->FirstFree, NewValue, OldValue);
        ExReleasePushLockExclusive(Lock[idx]);
    if (Expected == OldValue) break;
}

InterlockedIncrement (HandleCount);
*pHandle = Handle;
```

ExpLookupHandleTableEntry

```
If Handle.Value >= NextHandleNeedingPool
    return NULL;
CapturedTable = *(volatile)&Table->TableCode;
CapturedTable = CapturedTable - TableLevel;
switch (CapturedTable & LEVEL_CODE_MASK) {
   … index into tables according to level …
}

return Entry;
```

ExpMoveFreeHandles

```
// Move all free entries from the delayed free list
Old = InterlockedExchange (&Table->LastFree, 0);
Acquire and immediately release all the TableLocks to synch
if (! StrictFIFO) {
    // If FirstFree list is empty just stash the delayed list
    if (InterlockedCompareExchange (&Table->FirstFree,
                    Old + GetNextSeq(), 0) == 0) return Old;
}
Reverse the chain to get:  FirstEntry -> … -> LastEntry
New = FirstEntry + GetNextSeq();
while (1) {
    tmp = Table->LastFree;
    Entry->NextFreeTableEntry = tmp;
    if (tmp == InterlockedCompareExchange (Index, New, tmp))
        break;
}
return Old;
```

Object Manager Summary

- Manages the NT namespace
- Common scheme for managing resources
- Extensible method-based model for building system objects
- Memory management based on reference counting
- Uniform/centralized security model
- Support handle-based access of system objects
- Common, uniform mechanisms for using system resources

Discussion