Windows Kernel Internals
NT Registry Implementation

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Outline

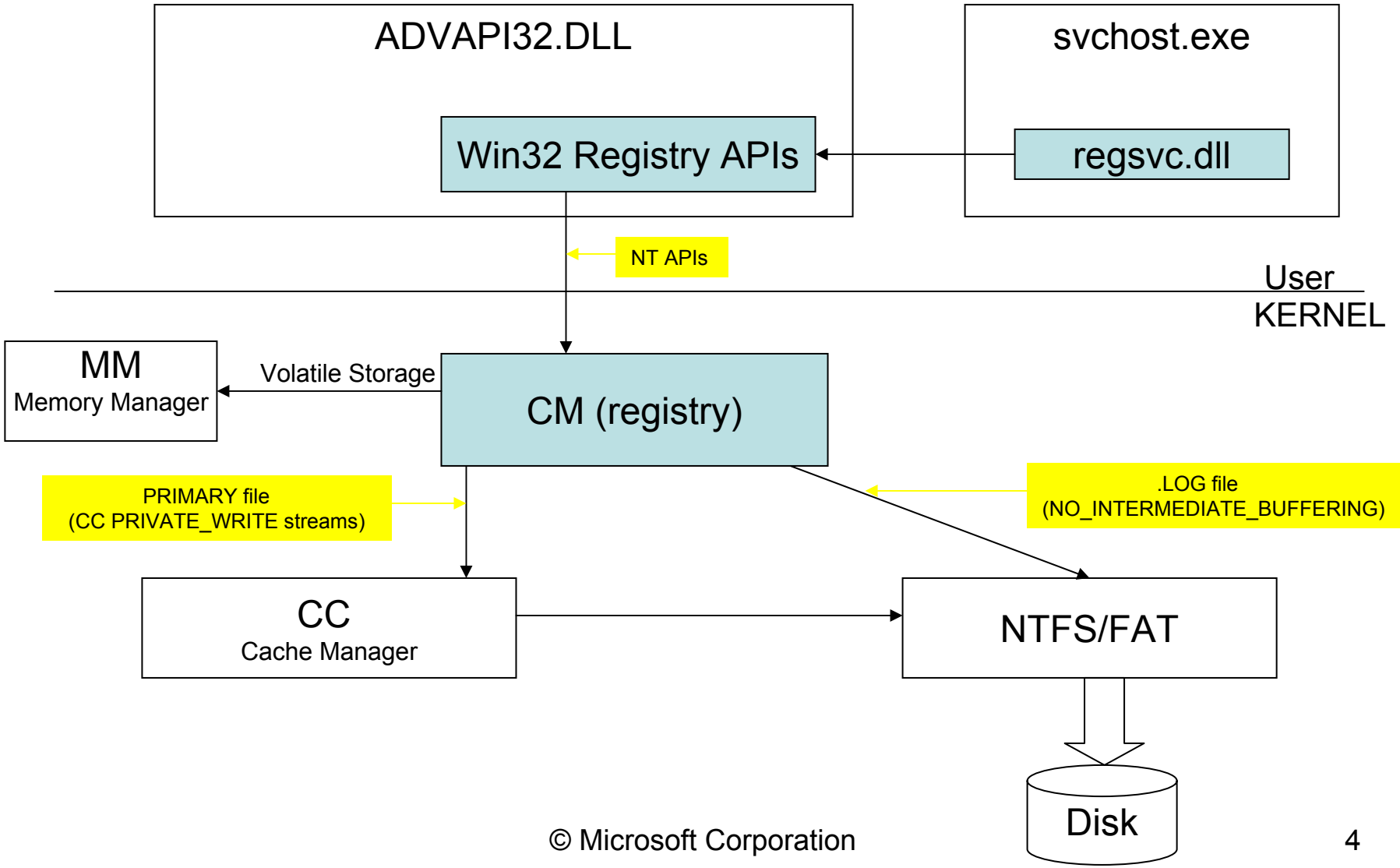
- High level overview
- System whereabouts
- Native registry APIs
- Implementation Details
- I/O
- Mounting a Hive
- Life Span
- Backup/Restore
- Limits

High Level Overview

- Logical:
  - Registry = “a FS within a file”
  - Keys ←→ directories
  - Values ←→ files

- Physical:
  - Registry = collection of Hives
  - Hive = collection of Bins
  - Bin = collection of Cells
  - Cell = unit of allocation (contains raw data)

Whereabouts



NT Registry APIs: **Key Ops**

NtCreateKey (kname)	open a new or existing key
NtDeleteKey (khandle)	mark key to delete at last handle close
NtEnumerateKey (khandle, i)	return the name/info of subkey[i] of key
NtQueryKey (khandle)	get info about a key
NtSetInformationKey (khandle, info)	set info on key
NtRenameKey (khandle, string)	change the name of key
NtFlushKey (khandle)	flush changes associated with key to disk
NtNotifyChangeKey (khandle, bsubtree)	notify caller of changes to a key/subtree
NtNotifyChangeMultipleKeys (knames[], bsubtree)	Multi-key version of NtNotifyChangeKey

NT Registry APIs: **Value Ops**

NtEnumerateValueKey (khandle, i)	return the name/info of value[i] of key
NtQueryValueKey (khandle, vname)	get value (data & type)
NtQueryMultipleValueKey (khandle, vnames[])	get multiple values
NtSetValueKey (khandle, vname, value)	set a value
NtDeleteValueKey (khandle, vname)	delete a value belonging to a key

Misc Ops

NtQueryOpenSubKeys (kpath)	get count of open khandles under kpath
NtCompactKeys (count, khandles[])	optimize access to khandles[]

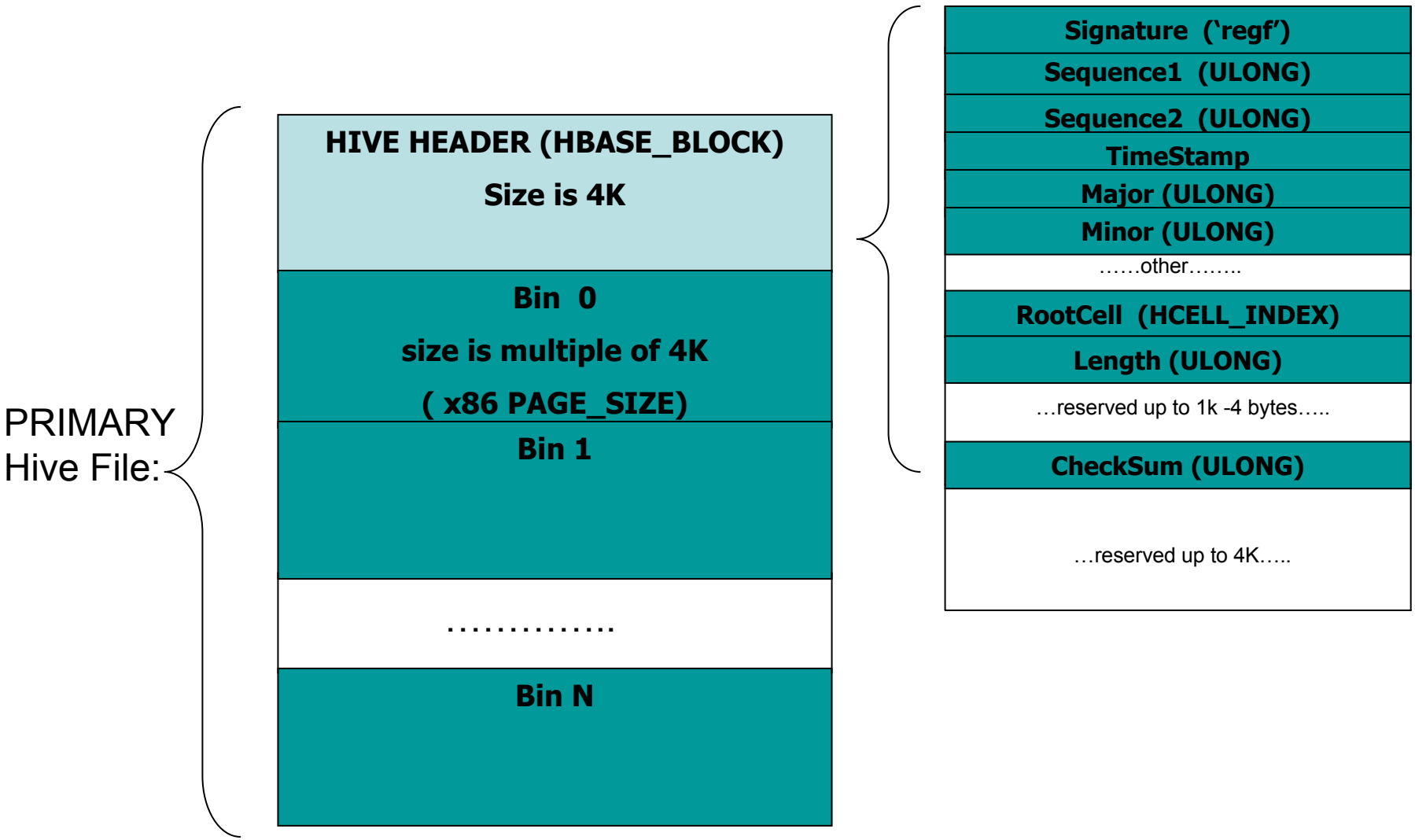
NT Registry APIs: **Hive Ops**

NtSaveKey (khandle, fhandle)	write the subtree at key khandle to file via fhandle
NtRestoreKey (khandle, hivefilename)	copy a subtree or complete hive at key
NtLoadKey (khandle, hivefilename)	mount a subtree or complete hive at key
NtUnloadKey (kname)	remove a subtree or hive loaded or restored at key kname
NtReplaceKey (newfile, roothandle, oldfile)	prepare to replace hive at next reboot
NtCompressKey (roothandle)	compress hive (inplace SaveKey)

Implementation Details

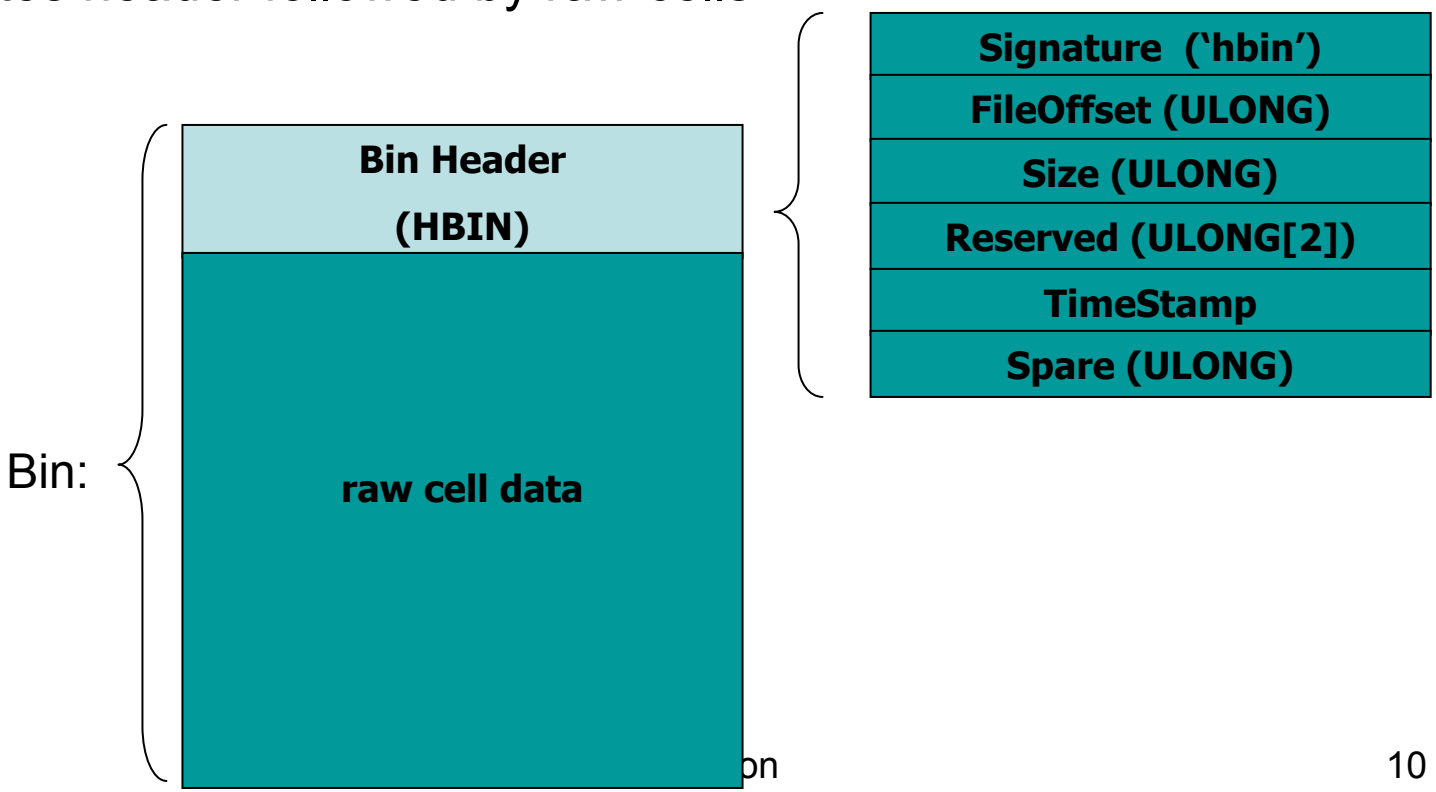
- A Hive is a file (two if you also count the .LOG)
  - PRIMARY – holds the actual hive data
  - .LOG – used only when flushing (crash recovery)
- Two storage mappings:
  - Stable – maps to the backing file
  - Volatile – in paged pool, lost after reboot
- PRIMARY grows in 256K increments – to avoid fragmentation
- First page (4k) is the header
- Followed by chained Bins
- I/O to primary is cached, PRIVATE_WRITE stream (no CC Lazy Flush, no MPW)

Hive Layout



Bin

- Collection of cells
- Size is increment of 4K
- Unit of hive growth
- 0x20 bytes header followed by raw cells

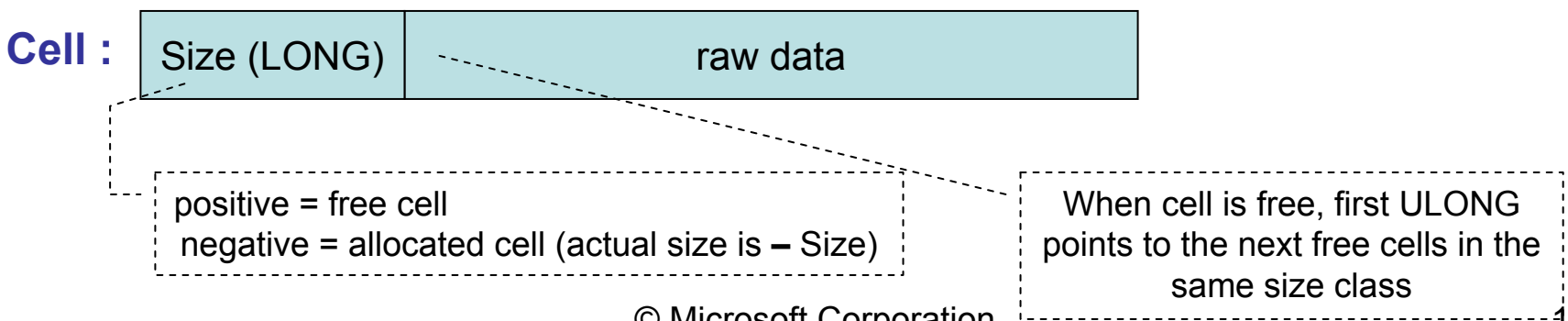


Reading Stable Storage

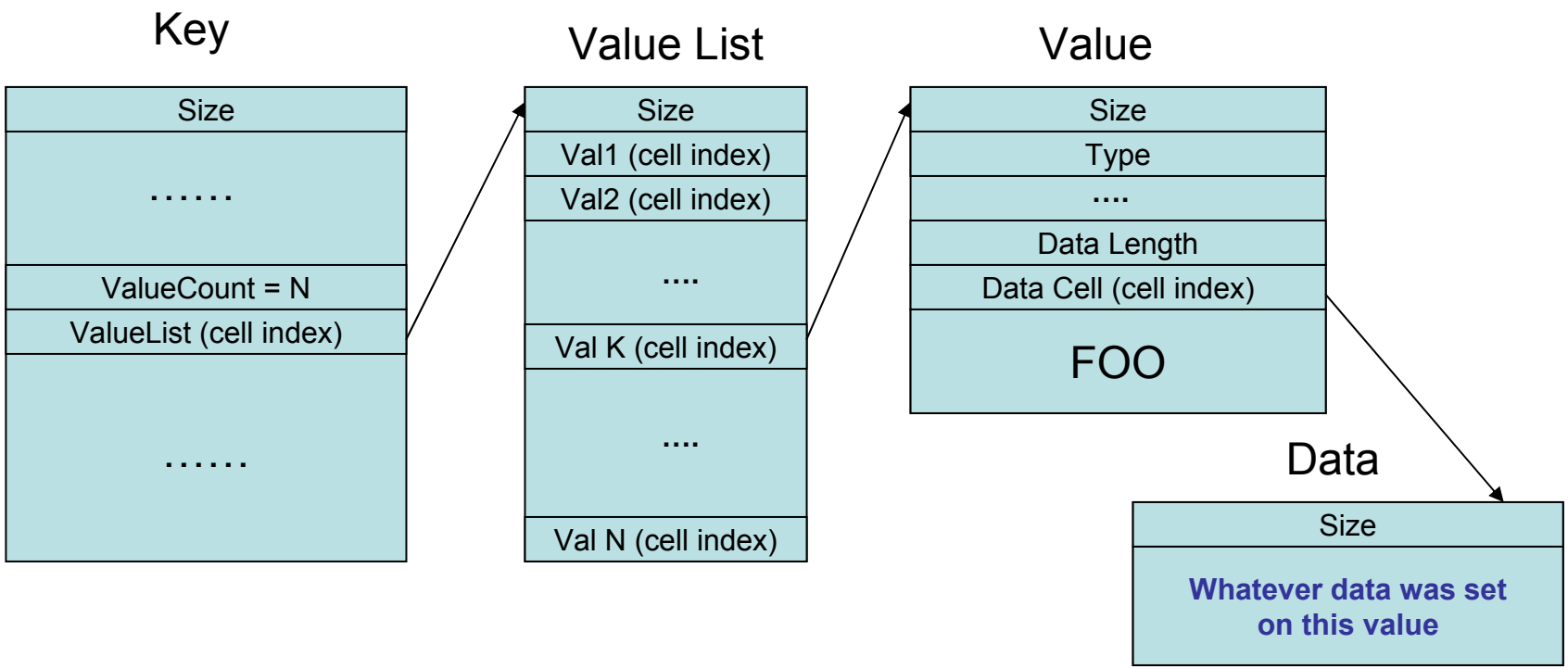
- PRIMARY file is CC PRIVATE_WRITE stream
  - no CC Lazy Flush, no MM MPW, no read ahead
  - complete control over when data hits the disk
- Map/fault in 16K views of the hive in the system cache address space (CcMapData)
  - Views cannot cross 256K boundary
- Max 256 views per hive, then reuse the oldest unused view (LRU)
  - Regardless of hive size, we only commit 4 megs of address space / hive (XP/.NET) → no RSL
- PRIMARY is loaded as Stable storage, Volatile storage is allocated from paged pool
- Dirtied data is pinned (CcPinMappedData) in physical memory up to the first hive flush

Cell

- Unit of storage allocation within the hive
- Size rounded at 8 bytes boundary
- Referenced as a ‘cell index’ (HCELL_INDEX)
  - Cell index is offset within the file (minus 0x1000 – the header) – ULONG
  - Volatile cell indexes have first MSB set (i.e. 0x8xxxxxxx)
- Free Display bitmap keeps track of free cells with the same size
  - Up to 128 bytes exact match
  - 128 bytes up to 2048 bytes, rounded at power of 2
  - 2048 OR higher in the same list
  - Free cells in the same ‘size class’ linked together
- Always reuse free cells if one with the same size (or bigger) exists
  - If size is bigger than what we need, split & reenlist remaining
- Every time a cell is dirtied the whole page is marked dirty (in the Dirty Vector)



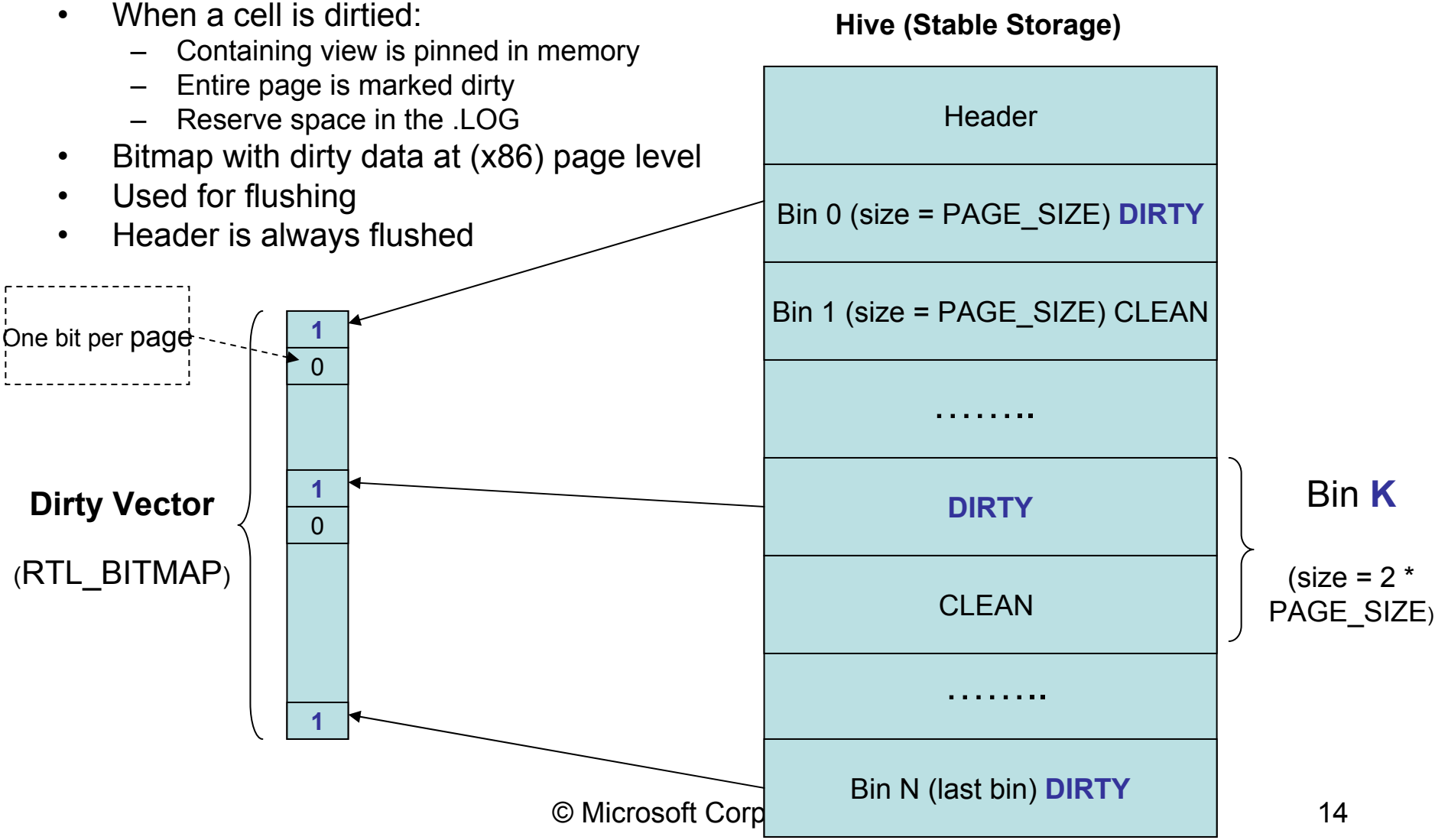
Example – value lookup “foo”



- Raw cells are used to build up logical data
  - Keys, values, security descriptors, indexes etc all are made up of cells
  - Fetching in a key, might involve several faults spread across the hive file
    → Caching (Win2K) + locality enforcement (XP/.NET) to help with performance

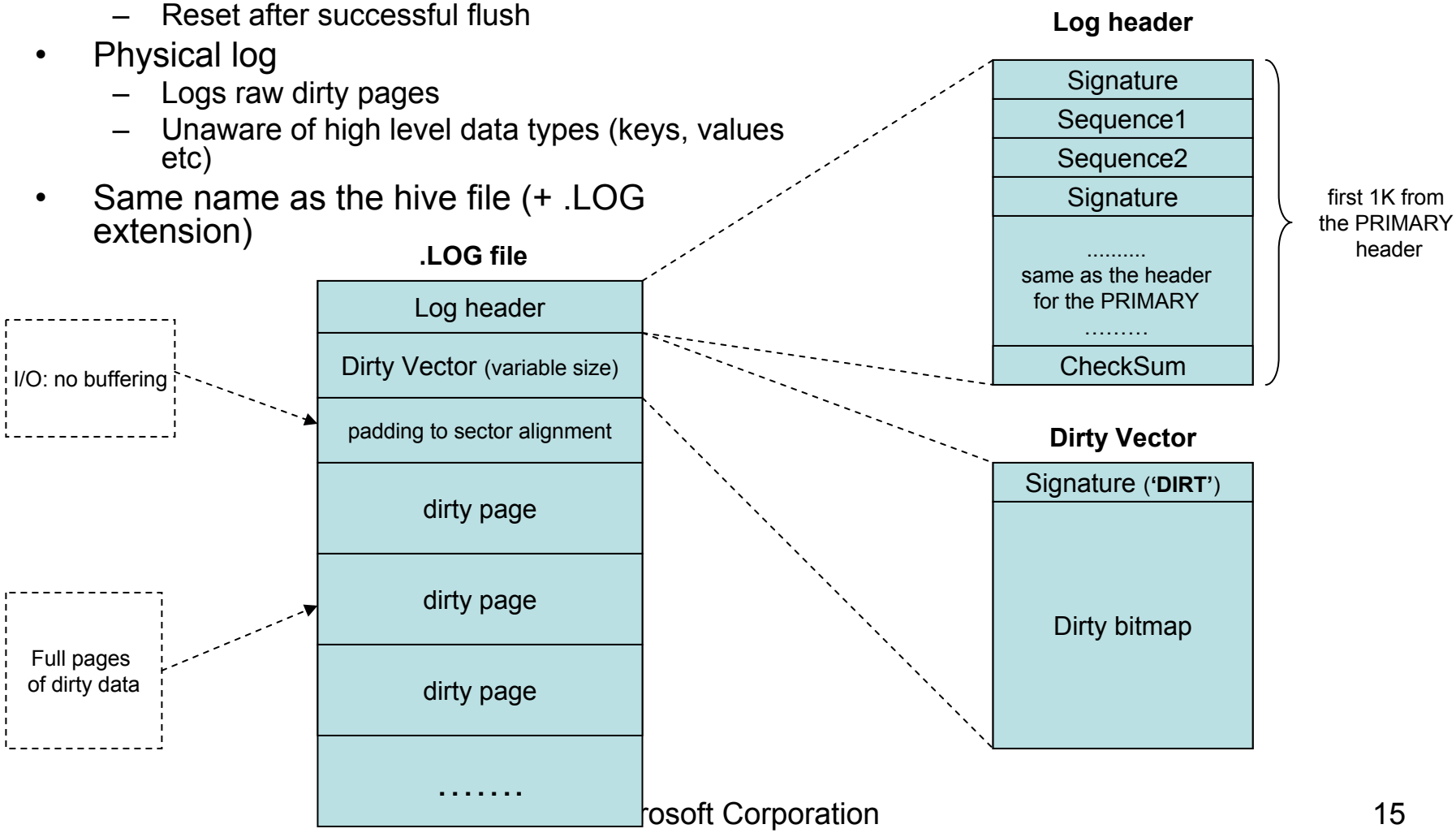
Dirty Data

- When a cell is dirtied:
  - Containing view is pinned in memory
  - Entire page is marked dirty
  - Reserve space in the .LOG
- Bitmap with dirty data at (x86) page level
- Used for flushing
- Header is always flushed



.LOG

- .LOG file used only while flushing
  - In the event of a crash during flushing
  - Reset after successful flush
- Physical log
  - Logs raw dirty pages
  - Unaware of high level data types (keys, values etc)
- Same name as the hive file (+ .LOG extension)



Hive Flush

- The most expensive operation (by far)
- Triggered from outside – NtFlushKey/RegFlushKey
- … or from inside - Lazy Flush
  - Fires off 5 seconds after the write occurs (SetValue/DeleteValue/CreateKey/DeleteKey etc).
  - Walks the list of the hives loaded in the system and flushes every one that has dirty data
  - Ignores hives marked as NO_LAZY_FLUSH
- Others may read during flush, no write allowed
- All dirty data in the hive is written out
- All or none makes it to the backing file
- It is only after the flush that data is persisted to disk
  - i.e. If you:
    - CreateKey + SetValue
    - machine crashes (before lazy flush has a chance to flush the hive)
    - → the key/value is lost
- Automatic flush at hive unload

Hive Flush – algorithm

1.Write the LOG
2.Flush the LOG

Past this point all dirty data
is in the log (on disk)

3.Header.Sequence1++; compute checksum
4.Write the Header to PRIMARY
5.Flush the PRIMARY

Crash past this point → Sequence1 != Sequence2
so we know the PRIMARY image has partial data

6.Write all dirty pages
7.Flush the PRIMARY

CcSetDirtyPinnedData
CcUnpinData
CcFlushCache

8.Header.Sequence2++; compute checksum
9.Write the Header to PRIMARY
10.Flush the PRIMARY

PRIMARY image is valid (on disk).

11.Reset LOG

Loading (Mounting) a Hive

- **When:**
  - At boot: boot loader (NTLDR) & kernel (ntoskrnl.exe)
  - Explicitly, by calling NtLoadKey/RegLoadKey
    - Requires Restore privilege
  - File are opened in exclusive mode; and kept open by the kernel

Loading (Mounting) a Hive

- **How:**
  - Read PRIMARY header; check it's validity (checksum, signature etc)
  - If sequence numbers don't match:
    - Hive has partial data, apply .LOG on top of PRIMARY
  - Build internal mappings as needed (Bins to Views)
  - Physical integrity check:
    - Walk the whole hive, check every single cell
  - Logical integrity check:
    - Walk the tree, check every key/value etc.

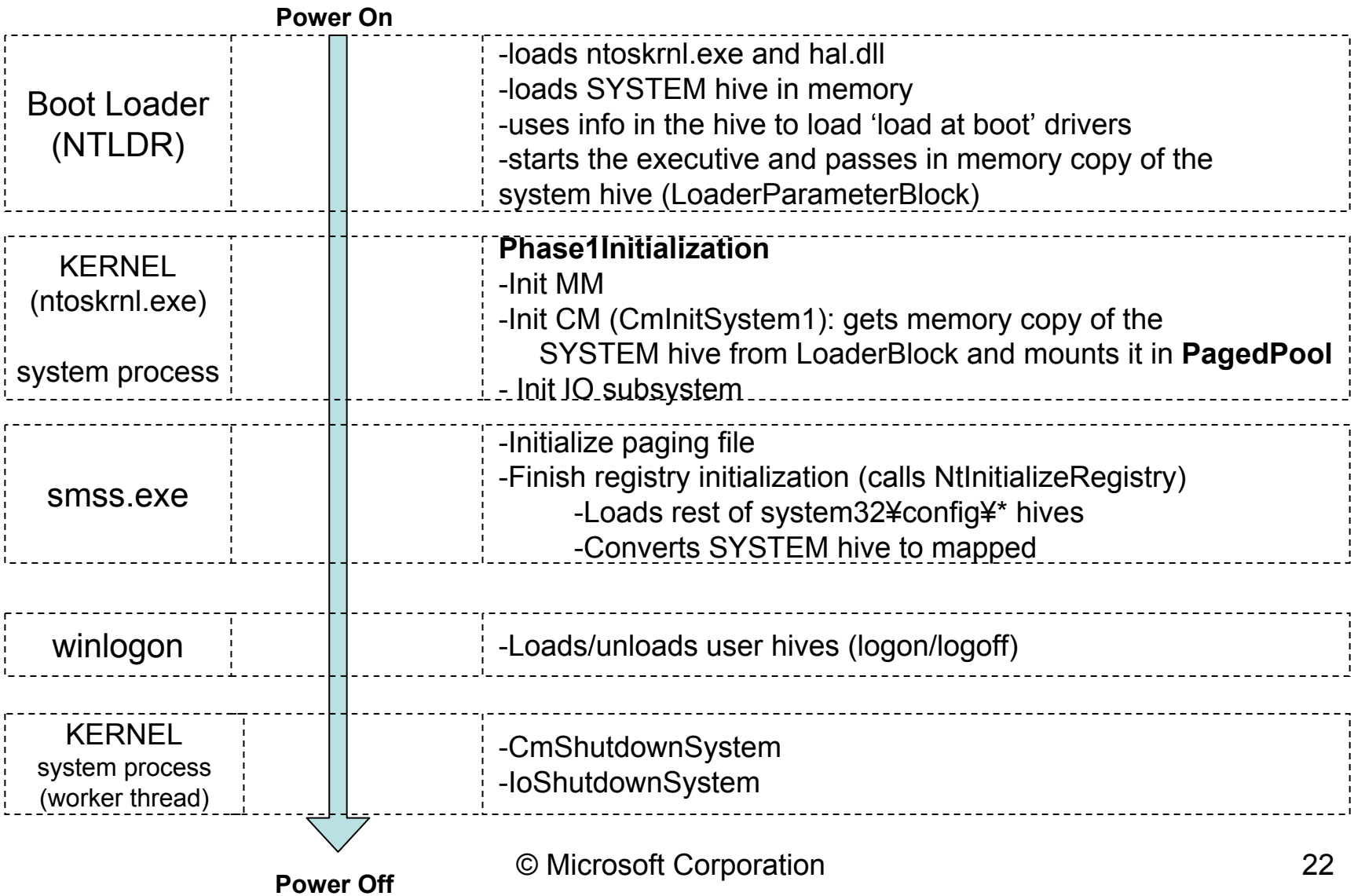
Hives On a Typical (Clean) System

- Machine hives → %windir%¥system32¥config¥*
  - SYSTEM – mounted at HKLM¥System
  - SOFTWARE – mounted at HKLM¥Software
  - SAM – mounted at HKLM¥SAM
  - SECURITY – mounted at HKLM¥Security
  - .DEFAULT – used when a new account is created
    - Failure to load any of these → OS will not boot

Hives On a Typical (Clean) System

- User hives → two per each user account
  - NTUSER.DAT – roams (if roaming profile enabled)
    - Mounted under HKEY_USERS¥<SID>
    - Mounted under HKEY_USERS¥<SID>_Classes
  - UsrClass.DAT – local (does not roam) – per user registration data
  - Stored in %USERPROFILE% folder.
  - Loaded at logon, or whenever the user is impersonated
- 'Special' user hives
  - Two per account as above; always loaded
    - S-1-5-18 → SYSTEM account
    - S-1-5-19 → Local Service
    - S-1-5-20 → Network Service
- Clusters – one additional hive: CLUSTER (cluster db)
  - → %windir%¥Cluster¥Cluster
- Any user/app with Restore privilege can mount own hive

Life Span



Backup/Restore …of the registry

- **Backup:**
  - NtSaveKey(Ex) – saves an entire hive to a file
  - Also does compression
    - Tree copy to a in memory temporary & volatile hive
    - Save temporary to destination file
      - Slow on big hives
  - Ex called with REG_NO_COMPRESSION much faster
    - Just dumps what's there to the file
    - No compression.
  - Requires SeBackupPrivilege
- **Restore:**
  - NtReplaceKey(ExistingFile,NewFile,OldFileName) – followed by a reboot
    - NewFile hive is mounted/checked/unmounted
    - ExistingFile → OldFileName ; NewFile → ExistingFile
    - Both files are kept open until reboot
      - Any changes made to the hive past this are lost at reboot
        - » Because the hive still maps to the old (existing) file
  - Requires SeRestorePrivilege

Limits

- Win2K
  - RSL (Registry Size Limit) up to 80% sizeof(PagedPool)
    - Entire hive file loaded in paged pool
  - SYSTEM hive ~ 12 MB
    - sizeof(SYSTEM hive) + sizeof(ntoskrnl.exe) + sizeof(hal.dll) + sizeof(all drivers loaded at boot) <= 16 MB
      - Win2k loader only sees the first 16 MB of physical memory
- XP/WS03
  - No RSL – up to available space on system drive
    - only 4MB commit per hive
  - Sizeof(SYSTEM hive) <= min(200 MB, ¼ physical memory)
    - XP/.NET loader sees ¼ physical memory

Summary

Registry intended to maintain config info

Win32 registry interfaces in Advapi32

Registry implementation in kernel

Native APIs are NT APIs

Used by kernel, drivers, system, apps, security, policy, etc.

Discussion