Windows Kernel Internals
Process Architecture

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Process

- Container for an address space and threads
- Primary Token
- Quota, Debug port, Handle Table etc
- Unique process ID
- Queued to the Job, global process list and Session list
- MM structures like the VAD tree, AWE etc

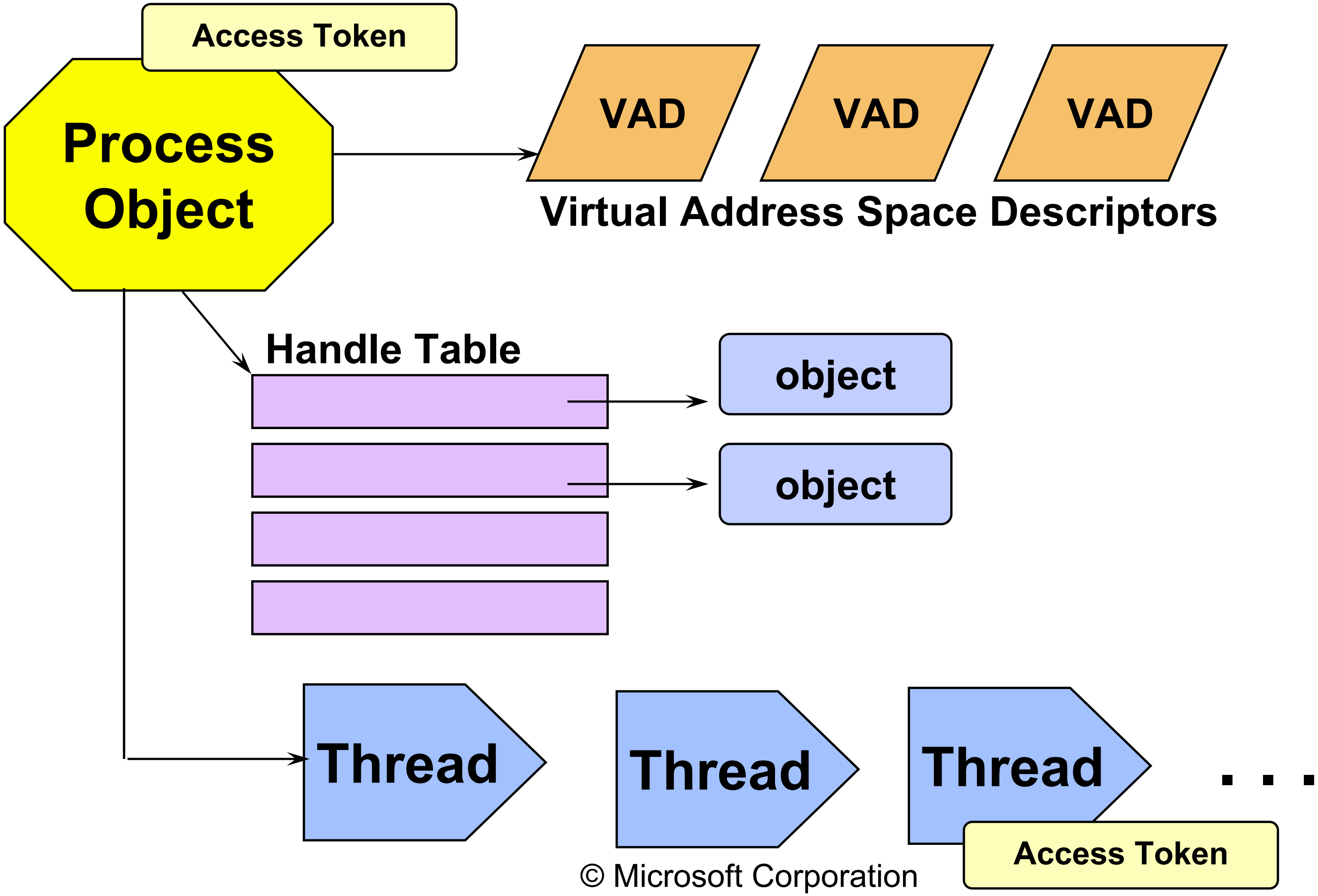
Thread

- Fundamental schedulable entity in the system
- Structure is the ETHREAD that holds a KTHREAD
- Queued to the process (both E and K thread)
- IRP list
- Impersonation information
- Unique thread ID
- Flags or various sorts and TEB pointer

Job

- Container for multiple processes
- Queued to global job list, processes and jobs in the job set
- Security token filters and job token
- Completion ports
- Counters, limits etc

Processes & Threads



Each process has its own…

- Virtual address space (including program global storage, heap storage, threads’ stacks)
    - processes cannot corrupt each other’s address space by mistake
- Working set (physical memory “owned” by the process)
- Access token (includes security identifiers)
- Handle table for Win32 kernel objects
- These are common to all threads in the process, but separate and protected between processes

Each thread has its own…

- Stack (automatic storage, call frames, etc.)
- Instance of a top-level function
- Scheduling state (Wait, Ready, Running, etc.) and priority
- Current access mode (user mode or kernel mode)
- Saved CPU state if it isn’t Running
- Access token (optional -- overrides process’s if present)

KPROCESS fields

```
DISPATCHER_HEADER Header
ULPTR DirectoryTableBase[2]
KGDTENTRY LdtDescriptor
KIDTENTRY Int21Descriptor
USHORT IopmOffset
UCHAR Iopl
volatile KAFFINITY ActiveProcessors
ULONG KernelTime
ULONG UserTime
LIST_ENTRY ReadyListHead
SINGLE_LIST_ENTRY SwapListEntry
LIST_ENTRY ThreadListHead
KSPIN_LOCK ProcessLock
KAFFINITY Affinity
USHORT StackCount
SCHAR BasePriority
SCHAR ThreadQuantum
BOOLEAN AutoAlignment
UCHAR State
BOOLEAN DisableBoost
UCHAR PowerState
BOOLEAN DisableQuantum
UCHAR IdealNode
```

EPROCESS fields

KPROCESS Pcb
EX_PUSH_LOCK ProcessLock
LARGE_INTEGER CreateTime
LARGE_INTEGER ExitTime
EX_RUNDOWN_REF
    RundownProtect
HANDLE UniqueProcessId
LIST_ENTRY ActiveProcessLinks
Quota Felds
SIZE_T PeakVirtualSize
SIZE_T VirtualSize
LIST_ENTRY SessionProcessLinks
PVOID DebugPort
PVOID ExceptionPort
PHANDLE_TABLE ObjectTable
EX_FAST_REF Token
PFN_NUMBER WorkingSetPage

KGUARDED_MUTEX
    AddressCreationLock
KSPIN_LOCK HyperSpaceLock
struct _ETHREAD *ForkInProgress
ULONG_PTR HardwareTrigger;
PMM_AVL_TABLE
    PhysicalVadRoot
PVOID CloneRoot
PFN_NUMBER
    NumberOfPrivatePages
PFN_NUMBER
    NumberOfLockedPages
PVOID Win32Process
struct _EJOB *Job
PVOID SectionObject
PVOID SectionBaseAddress
PEPROCESS_QUOTA_BLOCK
    QuotaBlock

EPROCESS fields

PPAGEFAULT_HISTORY
WorkingSetWatch

HANDLE Win32WindowStation

HANDLE InheritedFromUniqueProcessId

PVOID LdtInformation

PVOID VadFreeHint

PVOID VdmObjects

PVOID DeviceMap

PVOID Session

UCHAR ImageFileName[16]

LIST_ENTRY JobLinks

PVOID LockedPagesList

LIST_ENTRY ThreadListHead

ULONG ActiveThreads

PPEB Peb

IO Counters

PVOID AweInfo

MMSUPPORT Vm

Process Flags

NTSTATUS ExitStatus

UCHAR PriorityClass

MM_AVL_TABLE VadRoot

KTHREAD fields

```
DISPATCHER_HEADER Header
LIST_ENTRY MutantListHead
PVOID InitialStack, StackLimit
PVOID KernelStack
KSPIN_LOCK ThreadLock
ULONG ContextSwitches
volatile UCHAR State
KIRQL WaitIrql
KPROC_MODE WaitMode
PVOID Teb
KAPC_STATE ApcState
KSPIN_LOCK ApcQueueLock
LONG_PTR WaitStatus
PRKWAIT_BLOCK WaitBlockList
BOOLEAN Alertable, WaitNext
UCHAR WaitReason
SCHAR Priority
UCHAR EnableStackSwap
volatile UCHAR SwapBusy
LIST_ENTRY WaitListEntry
NEXT SwapListEntry
PRKQUEUE Queue
ULONG WaitTime
SHORT KernelApcDisable
SHORT SpecialApcDisable
KTIMER Timer
KWAIT_BLOCK WaitBlock[N+1]
LIST_ENTRY QueueListEntry
UCHAR ApcStateIndex
BOOLEAN ApcQueueable
BOOLEAN Preempted
BOOLEAN ProcessReadyQueue
BOOLEAN KernelStackResident
```

KTHREAD fields cont.

```
UCHAR IdealProcessor
volatile UCHAR NextProcessor
SCHAR BasePriority
SCHAR PriorityDecrement
SCHAR Quantum
BOOLEAN SystemAffinityActive
CCHAR PreviousMode
UCHAR ResourceIndex
UCHAR DisableBoost
KAFFINITY UserAffinity
PKPROCESS Process
KAFFINITY Affinity
PVOID ServiceTable
PKAPC_STATE ApcStatePtr[2]
KAPC_STATE SavedApcState
PVOID CallbackStack
PVOID Win32Thread
```

```
PKTRAP_FRAME TrapFrame
ULONG KernelTime, UserTime
PVOID StackBase
KAPC SuspendApc
KSEMAPHORE SuspendSema
PVOID TlsArray
LIST_ENTRY ThreadListEntry
UCHAR LargeStack
UCHAR PowerState
UCHAR Iopl
CCHAR FreezeCnt, SuspendCnt
UCHAR UserIdealProc
volatile UCHAR DeferredProc
UCHAR AdjustReason
SCHAR AdjustIncrement
```

ETHREAD fields

KTHREAD tcb

Timestamps

LPC locks and links

CLIENT_ID Cid

ImpersonationInfo

IrpList

pProcess

StartAddress

Win32StartAddress

ThreadListEntry

RundownProtect

ThreadPushLock

Thread and Process Enumeration

- Threads and processes all enumerable until their last reference is released
- No need to hold locks while processing each process/thread
- Code uses safe references to prevent the double return to zero problem

Thread Enumeration Example

```
for (Thread = PsGetNextProcessThread (Process, NULL);
    Thread != NULL;
    Thread = PsGetNextProcessThread (Process, Thread)) {

    st = STATUS_SUCCESS;
    if (Thread != Self) {
       PspTerminateThreadByPointer (Thread, ExitStatus);
    }
}
```

Process Enumeration Internals

```
PEPROCESS PsGetNextProcess (IN PEPROCESS Process)
{
    for (ListEntry = Process->ActiveProcessLinks.Flink;
         ListEntry != &PsActiveProcessHead;
         ListEntry = ListEntry->Flink) {

         NewProcess = CONTAINING_RECORD (ListEntry,
                                         EPROCESS,
                                         ActiveProcessLinks);

        if (ObReferenceObjectSafe (NewProcess)) {
            break;
        }
        NewProcess = NULL;
    }
```

Process Creation

```
BOOL
WINAPI
CreateProcessW(
    LPCWSTR lpApplicationName,
    LPWSTR lpCommandLine,
    LPSECURITY_ATTRIBUTES lpProcessAttributes,
    LPSECURITY_ATTRIBUTES lpThreadAttributes,
    BOOL bInheritHandles,
    DWORD dwCreationFlags,
    LPVOID lpEnvironment,
    LPCWSTR lpCurrentDirectory,
    LPSTARTUPINFOW lpStartupInfo,
    LPPROCESS_INFORMATION lpProcessInformation
    )
```

Process Creation – CreateProcess

CreateProcess()

Locate imagefile (path search)

Convert DOS name to NT name

Call **NtOpenFile()**

Call **NtCreateSection(SEC_IMAGE)**

Check for special handling: VDM, WoW64, restrictions, CMD files

Call **NtQuerySection()** to get ImageInformation

Use **LdrQueryImageFileExecutionOptions()** to see if debugging

Special handling for POSIX executable

Create the new process in the kernel via **NtCreateProcessEx()**

If requested, call **NtSetInformationProcess(ProcessPriorityClass)**

If (dwCreationFlags & CREATE_DEFAULT_ERROR_MODE)
  call NtSetInformationProcess(ProcessDefaultHardErrorMode)

CreateProcess() – cont.

Call **BasePushProcessParameters()** to push params into new process

Stuff in the standard handles if needed

Call **BaseCreateStack()** to create a user-mode stack in process

Call **BaseInitializeContext()** to create an initial thread context

Call **NtCreateThread()** to create the first thread

// thread may run, so no more modification to new process virtual space

Use **CsrClientCallServer(BasepCreateProcess)** to register new process and thread with CSRSS

If app is restricted

Set a restricted token on the process

assign it to a job object so that it can't escape the token.

Unless the initial thread was created suspended, start it with **NtResumeThread()**

NtResumeThread()

Acquire the thread's ApcQueueLock and raise to Synch Level

Decrement the SuspendCount

If SuspendCount and FreezeCount both 0

- Lock the dispatcher database
- Increment the thread's SuspendSemaphore and call KiWaitTest() to resume the thread
- Unlock the dispatcher database

Release the thread's ApcQueueLock

Call KiExitDispatcher(), which may schedule a new thread

BaseCreateStack(Process, [StackSize], [MaxStackSize], pInitialTeb)

If not specified, fill StackSize and MaxStackSize out of image header, check PEB for minimum StackSize

Use **NtAllocateVirtualMemory (&Stack, MaxStackSize, MEM_RESERVE)** to reserve the usermode stack

Remember Base/Limit of stack in the TEB

StackTop = Stack + MaxStackSize - StackSize

Commit stack: **NtAllocateVirtualMemory(StackTop, StackSize, MEM_COMMIT)**

If there is room (StackTop > Stack), create a guard page: **NtProtectVirtualMemory(StackTop - PAGE_SIZE, PAGE_GUARD)**

BasePushProcessParameters()

```
BasePushProcessParameters(
    dwBasePushProcessParametersFlags,
    ProcessHandle,
    Peb,
    lpApplicationName,
    CurdirBuffer,
    QuoteInsert || QuoteCmdLine ? QuotedBuffer : lpCommandLine,
    lpEnvironment,
    &StartupInfo,
    dwCreationFlags | dwNoWindow,
    bInheritHandles,
    IsWowBinary ? IMAGE_SUBSYSTEM_WINDOWS_GUI : 0,
    pAppCompatData,
    cbAppCompatData
)
```

BasePushProcessParameters

BasePushProcessParameters(newproc)

Build up the DLL and EXE search paths, the CommandLineString, CurrentDirString, DesktopInfo, and WindowTitle

Call RtlCreateProcessParameters() to put them into a RTL_USER_PROCESS_PARAMETERS buffer

Call **NtAllocateVirtualMemory(newproc**) for the environment block

Call **NtWriteVirtualMemory(newproc)** to copy the environment block

Finish filling in the ProcessParameterBlock

- Copy in more of the main window settings
- Set the console handles for stdin/stdout/stderr
- Set PROFILE flags

Call **NtAllocateVirtualMemory(newproc)** for ProcessParameterBlock

Copy in with **NtWriteVirtualMemory(newproc)**

Modify the PEB in newproc so that it points to the parameter block

Allocate and write AppCompat data to the new process

Set pointer in new process' PEB

RtlCreateProcessParameters()

Formats NT style RTL_USER_PROCESS_PARAMETERS record

Record self-contained in block of memory allocated by this function

Allocation method is opaque so free with **RtlDestroyProcessParameters**

The process parameters record is created in a de-normalized form

Caller will fill in additional fields before calling **RtlCreateUserProcess**()

Kernel: NtCreateProcessEx()

Take reference on parent process, if specified

Create an object of PsProcessType for KPROCESS/EPROCESS object

Initialize rundown protection in the thread

Call **PspInheritQuota()** to set the quota block

Call **ObInheritDeviceMap()** to setup DosDevices to right device map

If passed section handle, take reference -- otherwise clone parent VA

If cloning parent, acquire rundown protection to avoid parent exit

If passed debug and/or exception ports, point newproc at them

Call **MmCreateProcessAddressSpace()**

If **not cloning** a parent

Process->ObjectTable = CurrentProcess->ObjectTable

Call **KeInitializeProcess()** to init newproc with default scheduling information and mark newproc as InMemory

Call **PspInitializeProcessSecurity()** to duplicate the parents token as the primary token for the process

Initialize the fast references for newproc's token

Set newproc's scheduling parameters

If **cloning** a parent Call **ObInitProcess()**

NtCreateProcessEx() – cont.

```
// Initialize newproc’s address space.  Four possibilities
    Boot Process: Address space already initialized by MmInit()
    System Process:  Address space only maps system space
        (process is same as PspInitialSystemProcess)
    Cloned User Process: Address space cloned from specified parent
    New User Process:  Address is initialized to map specified section
If cloning parent
    Call MmInitializeProcessAddressSpace(Process, Parent)
else
    Call MmInitializeProcessAddressSpace(Process, SectionObject)
Call ExCreateHandle(PspCidTable) to allocate a CID for the process
Set the process CID in the handle table (for checks and debugging)
If parent in a job add in this process to the job
If cloning parent
    Call MmCreatePeb()
else
    Copy the parents PEB via MmCopyVirtualMemory()
```

NtCreateProcessEx() – cont. 2

Insert new process into the global process list (PsActiveProcessHead)

Call **SeCreateAccessStateEx()** to create an AccessState structure

Call **ObInsertObject(Process, AccessState, DesiredAccess, &handle)** into the handle table

Write the handle back into the user-mode handle buffer

Call **ObGetObjectSecurity (Process, &SecurityDescriptor)** and pass to **SeAccessCheck()**

If the access check fails, take away all process access rights

Call **KeQuerySystemTime (&Process->CreateTime)**

Give back the extra reference we used to keep the process from being prematurely deleted

NtCreateSection(SEC_IMAGE)

Validate/capture parameters and call MmCreateSection()

Call **CcWaitForUninitializeCacheMap()** to synch with teardown of residual data section refs in cache manager

Allocate a temporary ControlArea

Acquire the ERESOURCE lock to synchronize with the file system

Call **MiFindImageSectionObject()** to find an existing image ControlArea for this file

Call **MiLockPfnDatabase()** to take PFN lock

Deal with race conditions, like existing ControlArea being deleted

Call **MiUnlockPfnDatabase()** to release PFN lock

NtCreateSection (SEC_IMAGE) – 2

If existing ControlArea

- New SectionObject will share the segment in the existing ControlArea, so NumberOfSectionReferences++
- Call **MiFlushDataSection()** to flush any data section for the file
- Discard the temporary ControlArea
- Release the ERESOURCE file system lock

else

- Use the temporary ControlArea we allocated
- Call **MiInsertImageSectionObject(File, ControlArea)** to insert the new ControlArea into the FileObject
- Call **MiCreateImageFileMap(File, &Segment)** to do the actual mapping and create real ControlArea
- Call **KeAcquireQueuedSpinLock(LockQueuePfnLock)**
- Call **MiRemoveImageSectionObject (File, NewControlArea)**
- Call **MiInsertImageSectionObject (File, real ControlArea)**
- Delete the temporary ControlArea
- Deal with race conditions, like another thread creating the same section
- Call **KeReleaseQueuedSpinLock(LockQueuePfnLock)**

NtCreateSection (SEC_IMAGE) – 3

Call **ObCreateObject (MmSectionObjectType, &NewSectionObject)** to create the real section object

Fill in NewSectionObject with the values we have accumulated on our stack

Pass out the NewSectionObject

ObInsertObject(Section, ..., &handle)

MiFindImageSectionObject()

Searches the control area chains (if any) for an existing cache of the specified image file

For non-global control areas, there is no chain and control area is shared for all callers and sessions

Likewise for systemwide global control areas

For global PER-SESSION control areas, we must walk the list

MiInsertImageSectionObject()

Inserts the control area into the file's section object pointers

For non-global control areas and systemwide, there is no chain …

For global PER-SESSION control areas, we must do a list insertion

MiCreateImageFileMap()

- Call **FsRtlGetFileSize(File,&EndOfFile)**
- Read in the image header and validate it:
  - Initialize an Event and an Mdl on the stack
  - Call **MiGetPageForHeader()** to allocate pageframe for image header
  - Call MiFlushDataSection()
  - Call **IoPageRead(File, Mdl, 0, Event)** to do the read
  - Wait on the Event
  - Call **MiMapImageHeaderInHyperSpace()** to map the image header into per-process KVA
  - Validate image header
  - If header more than one page, read another 8KB
- Compute the number of PTEs needed to map the image
- Allocate a control area and a subsection for each section header plus one for the image header which has no section
- Establish the prototype PTEs for each subsection, and point them all at their subsection
- Return the Segment

MmCreateProcessAddressSpace (x86)

Take the WorkingSet lock

Take the PFN lock so we can get physical pages

Allocate the page directory and set into DirectoryTableBase[0]

Allocate the page directory for hyperspace and set into DirectoryTableBase[1]

Allocate pages for the VAD allocation bitmap and the working set list

Release the PFN lock

Initialize the hyperspace map

Under the expansion lock insert the new process onto MM's internal ProcessList

Map the page directory page into hyperspace

Setup the self-map

Fill in the system page directories

Release the WorkingSet lock

Increment the session reference count

MmCreatePeb()

Attach to the target process

Map in the NLS tables

Call **MiCreatePebOrTeb()** to allocate a PEB in the user address space

Initialize the PEB, including values from the InitialPeb, the NLS tables, the system defaults, and the image header

Detach from the process

Return the allocated PEB address

MiCreatePebOrTeb()

Allocate VAD and mark non-deletable and with unchangeable protection

Lock the address space

Find a VA for the block

Finish initializing the VAD

Unlock the address space

NtCreateThread()

Take a reference on the process that will contain the thread

Create an object of PsThreadType (this will contain the KTHREAD/ETHREAD data structure)

Initialize the rundown protection in the thread

Point the thread at its process

Initialize the various fields used by MM, LPC, IO, Registry, thread lock, timers, queues, etc.

Call **ExAcquireRundownProtection()** to keep the process from terminating (bail if it is already doing so)

Call **MmCreateTeb()** to create the user-mode TEB

Set the StartAddress and Win32StartAddress in the kernel thread object

Call **KeInitThread()** to finish setting up the thread object

N.B. kernel-mode execution will begin at PspUserThreadStartup

NtCreateThread() – cont.

Take the process lock: **PspLockProcessExclusive()**

Process->ActiveThreads++

Insert thead at tail of Process->ThreadList

Call **KeStartThread()** to set up thread

Call **PspUnlockProcessExclusive()**

Call **ExReleaseRundownProtection()**

If this is the first thread in the process invoke callbacks registered for notification of process creation

If process is in a job and this is our first chance to report in, send the notification to the job's CompletionPort

Invoke callbacks for notification of thread creation

If thread was to be created suspended, call **KeSuspendThread()** on it

Call **SeCreateAccessStateEx()** to create an AccessState structure

Call **ObInsertObject(Thread, AccessState, DesiredAccess, &handle)** into the handle table

Write the handle back into the user-mode handle buffer

NtCreateThread() – cont. 2

Set the thread CreateTime

Call **ObGetObjectSecurity (Thread, &SecurityDescriptor)** and pass to **SeAccessCheck()**

If the access check fails, take away all access to the thread except terminate, set/query information

Call **KeReadyThread()**

Give back the extra reference we used to keep the thread from being prematurely deleted

CsrClientCallServer (BasepCreateProcess)

AcquireProcessStructureLock()

Duplicate handles to the process and thread into CSRSS

Allocate a process structure within CSRSS

Copy any per-process data from parent structure to child structure

Set CSRSS' CsrApiPort to be the child's exception port

If the process being debugged, setup debug port and the process group, if we are the leader.

Capture thread creation time as a sequence number for the tid

Allocate a thread structure within CSRSS

Increment process ThreadCount, insert thread into process ThreadList

Insert thread into CsrThreadHashTable[]

Bump reference count on current session

Write the pid/tid into process and thread structures

Save the duplicated process/thread handles in their respective structures

Add the process to the tail of the global list

For each DLL loaded in CSRSS notify it about the new process

Tell the kernel that the new process is a background process

ReleaseProcessStructureLock()

KeInitThread()

The priority, affinity, and initial quantum are taken from the parent process object

Initialize most the other fields including the thread context

Thread->State = Initialized

Set intial code to run: **PspUserThreadStartup()**

PspUserThreadStartup()

Call **KiInitializeUserApc()** to set an initial user-mode APC to the thread

Initial APC will execute **LdrInitializeThunk()**

KeStartThread()

Initialize some more fields (DisableBoost, Iopl, Quantum, ...)

Raise to SYNC_LEVEL and acquire ProcessLock

Copy the BasePriority and Affinity from the process

Set the IdealProcessor

Lock the dispatcher database

Insert thread into process list and increment process StackCount

Unlock the dispatcher database

Lower the IRQL and release ProcessLock

LdrInitialize()/LdrpInitialize()

```
// LdrpProcessInitialized
//   0 means no thread has been tasked to initialize the process
//   1 means a thread has been tasked but has not yet finished
//   2 means a thread has been tasked and initialization is complete

while (1 == InterlockCompExch (&LdrpProcessInitialized, 1, 0))
    while (LdrpProcessInitialized == 1) NtDelayExecution(30mS)
If LdrpProcessInitialized == 0
    Initialize the LoaderLock
    Call LdrpInitializeProcess()
    LdrpTouchThreadStack (Peb->MinimumStackCommit)
    InterlockedIncrement (&LdrpProcessInitialized)          // 1 -> 2
else
    if (Peb->InheritedAddressSpace)
        Initialize critical section list  // otherwise don't clobber the clone
    else
        Call LdrpInitializeThread()
```

LdrpInitializeProcess()

Figure out the image name from the ProcessParameters
NtHeader = RtlImageNtHeader(Peb->ImageBaseAddress)
Check ImageFileExecutionOptions for this image in the registry
ProcessParameters = **RtlNormalizeProcessParams (Peb->ProcessParameters)**
RtlInitNlsTables (Peb->AnsiCodePageData, Peb->OemCodePageData, Peb->UnicodeCaseTableData, &xInitTableInfo)
Setup process parameters based on the image file
Initialize process data structures for allocation TLS and FLS
Initialize the LoaderLock
Initialize various critical sections
Call **RtlInitializeHeapManager()**
ProcessHeap = **RtlCreateHeap()**
LdrpHeap = **RtlCreateHeap()**
Call **RtlInitializeAtomPackage()**
Setup DLL search path and current directory from ProcessParameters

LdrpInitializeProcess() – cont.

Initialize the loaded module list and insert the image into the list

If this is a Windows GUI app, load Call **LdrLoadDll(kernel32.dll)**

Call **LdrpWalkImportDescriptor()** to recursively walk the Import Descriptor Table (IDT) and load each referenced DLL

If the image was not loaded at the base address in the binary, toggle page protections and call **LdrRelocateImage()**

Call **LdrpInitializeTls()**

Now that all DLLs are loaded, if (Peb->BeingDebugged)

Call **DbgBreakPoint()** to notify the debugger

Load AppCompat shim engine and shims

Call **LdrpRunInitializeRoutines()** to run all the DLL initialization routines

LdrpInitializeThread()

Take the LoaderLock
Walk the loaded module list calling the DLL init routines:
    LdrpCallInitRoutine(DLL_THREAD_ATTACH)
If the image has TLS, call its initializaers:
    LdrpCallTlsInitializers(DLL_THREAD_ATTACH)
Release the LoaderLock

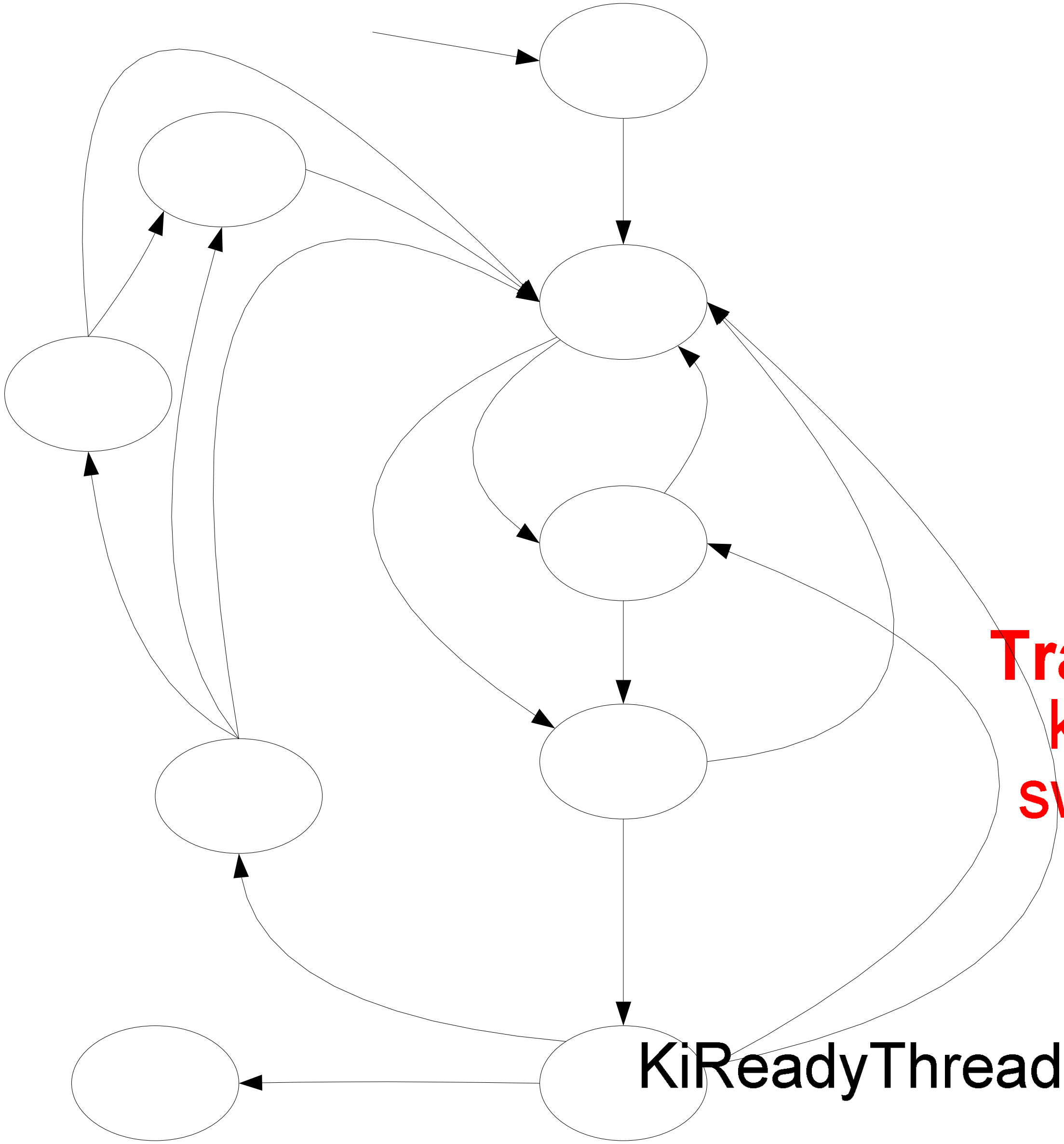
Synchronization Classes

- Write once fields like process job and thread impersonation info
- Torn down (rundown) structures like handle table, thread TEB etc
- Infrequently changing fields like the process token
- Frequently changing stuff like thread list of a process or impersonation token

Process Synchronization

- ProcessLock – Protects thread list, token
- RundownProtect – Cross process address space, image section and handle table references
- Token, Prefetch – Uses fast referencing
- AWE – Uses cache aware pushlocks
- Token, Job – Torn down at last process dereference without synchronization

Thread scheduling states



KeInitThre

Transition
k stack
swapped

KiInsertDeferred

KiReadyThread

Ready

Thread scheduling states

- Main quasi-states:
  - Ready – able to run
  - Running – current thread on a processor
  - Waiting – waiting an event
- For scalability Ready is three real states:
  - DeferredReady – queued on any processor
  - Standby – will be imminently start Running
  - Ready – queue on target processor by priority
- Goal is granular locking of thread priority queues
- Red states related to swapped stacks and processes

Process Lifetime

- Created as an empty shell
- Address space created with only ntdll and the main image unless forked
- Handle table created empty or populated via duplication from parent
- Process is partially destroyed on last thread exit
- Process totally destroyed on last dereference

Thread Lifetime

- Created within a process with a CONTEXT record
- Starts running in the kernel but has a trap frame to return to use mode
- Kernel queues user APC to do ntdll initialization
- Terminated by a thread calling NtTerminateThread/Process

NtTerminateThread(thandle,status)

```
PspTerminateThreadByPointer(pThread, status, bSelf)
if (bSelf)
    PspExitThread(status)  // never returns
if Thread->CrossThreadFlags & _TERMINATED
    return
exitApc = ExAllocatePool(sizeof(KAPC))
KeInitializeApc (ExitApc,
    Thread,
    OriginalApcEnvironment,     // thread has to detach before exiting
    PsExitSpecialApc,
    PspExitApcRundown,          // runs at end to free exitApc
    PspExitNormalApc,
    KernelMode,
    status)
KeInsertQueueApc (ExitApc, ExitApc, NULL, 2)
KeForceResumeThread (&Thread->Tcb)
```

PspExitThread(status)

```
ExWaitForRundownProtectionRelease (&Thread->RundownProtect)
<Notify registered callout routines of thread exit>
PspLockProcessExclusive (Process, Thread)
Process->ActiveThreads--
if (Process->ActiveThreads == 0)
    LastThread = TRUE
    Process->Flags |= PROCESS_DELETE
    Wait until all other threads have exited
PspUnlockProcessExclusive (Process, Thread)
if (Process->DebugPort)
    LastThread? DbgkExitProcess (status) :  DbgkExitThread (status)
// rundown Win32
(PspW32ThreadCallout) (Thread, PsW32ThreadCalloutExit)
if (LastThread)
    (PspW32ProcessCallout) (Process)
```

PspExitThread(status) cont. 1

```
IoCancelThreadIo (Thread)
ExTimerRundown ()
CmNotifyRunDown (Thread)
KeRundownThread ()
<Delete the thread's TEB>
LpcExitThread (Thread)
Thread->ExitStatus = ExitStatus;
KeQuerySystemTime (&Thread->ExitTime)
if (! LastThread)
    <Rundown pending APCs>
    KeTerminateThread ()
```

PspExitThread(status) cont. 2

```
Process->ExitTime = Thread->ExitTime
PspExitProcess (TRUE, Process)
ProcessToken = PsReferencePrimaryToken (Process)
SeAuditProcessExit (Process);
PsDereferencePrimaryTokenEx (Process, ProcessToken)
ObKillProcess (Process)                   // Rundown the handle table
ObDereferenceObject (Process->SectionObject)
PspExitProcessFromJob (Process->Job, Process)
<Rundown pending APCs>
MmCleanProcessAddressSpace (Process)
KeSetProcess (&Process->Pcb, 0)           // signal the process
KeTerminateThread ()
```

PspExitProcess(LastThread, Process)

```
ObDereferenceObject (Process->SecurityPort)
if (LastThread)
    <Notify registered callout routines of process exit>
    <Finish cleaning up Job Object>
    return
// we were called from PspDeleteProcess()
MmCleanProcessAddressSpace (Process)
```

KeTerminateThread()

```
<Raise to SYNCH_LEVEL, acquire process lock, set swap busy>
<Insert the thread in the reaper list>
<Acquire dispatcher lock>
<Queue reaper work item if needed>
if (Thread->Queue)
    RemoveEntryList(&Thread->QueueListEntry)
    KiActivateWaiterQueue (Queue)
RemoveEntryList(&Thread->ThreadListEntry)        // from parent's list
<Release process lock without dropping IRQL>
Thread->State = Terminated
Process->StackCount -= 1
<Initiate an outswap of the process if StackCount now 0>
KiRundownThread (Thread)                  // rundown arch-specific data
<Acquire dispatcher lock>
KiSwapThread (Thread, CurrentPrcb)       // yield processor final time
```

PspProcessDelete ()

```
<Remove the process from the global list>
PspRemoveProcessFromJob (Process->Job, Process)
ObDereferenceObjectDeferDelete (Process->Job)
ObDereferenceObject (Process->DebugPort)
ObDereferenceObject (Process->ExceptionPort)
ObDereferenceObject (Process->SectionObject)
PspDeleteLdt (Process)
KeStackAttachProcess (&Process->Pcb, &ApcState)
    ObKillProcess (Process)
    PspExitProcess (FALSE, Process)
KeUnstackDetachProcess (&ApcState)
MmDeleteProcessAddressSpace (Process)
ExDestroyHandle (PspCidTable, Process->UniqueProcessId)
PspDeleteProcessSecurity (Process)
ObDereferenceDeviceMap (Process)
PspDereferenceQuota (Process)
```

PspThreadDelete()

```
MmDeleteKernelStack()
ExDestroyHandle (PspCidTable, Thread->Cid.UniqueThread)
PspDeleteThreadSecurity (Thread)
if (! Thread->Process) return      // never inserted in process

PspLockProcessExclusive (Process, CurrentThread)
RemoveEntryList (&Thread->ThreadListEntry)
PspUnlockProcessExclusive (Process, CurrentThread)
ObDereferenceObject (Process)
```

Summary: Native NT Process APIs

NtCreateProcess()
NtTerminateProcess()
NtQueryInformationProcess()
NtSetInformationProcess()
NtGetNextProcess()
NtGetNextThread()
NtSuspendProcess()
NtResumeProcess()

NtCreateThread()
NtTerminateThread()
NtSuspendThread()
NtResumeThread()
NtGetContextThread()
NtSetContextThread()
NtQueryInformationThread()
NtSetInformationThread()
NtAlertThread()
NtQueueApcThread()

Discussion