Windows Processes and Threads

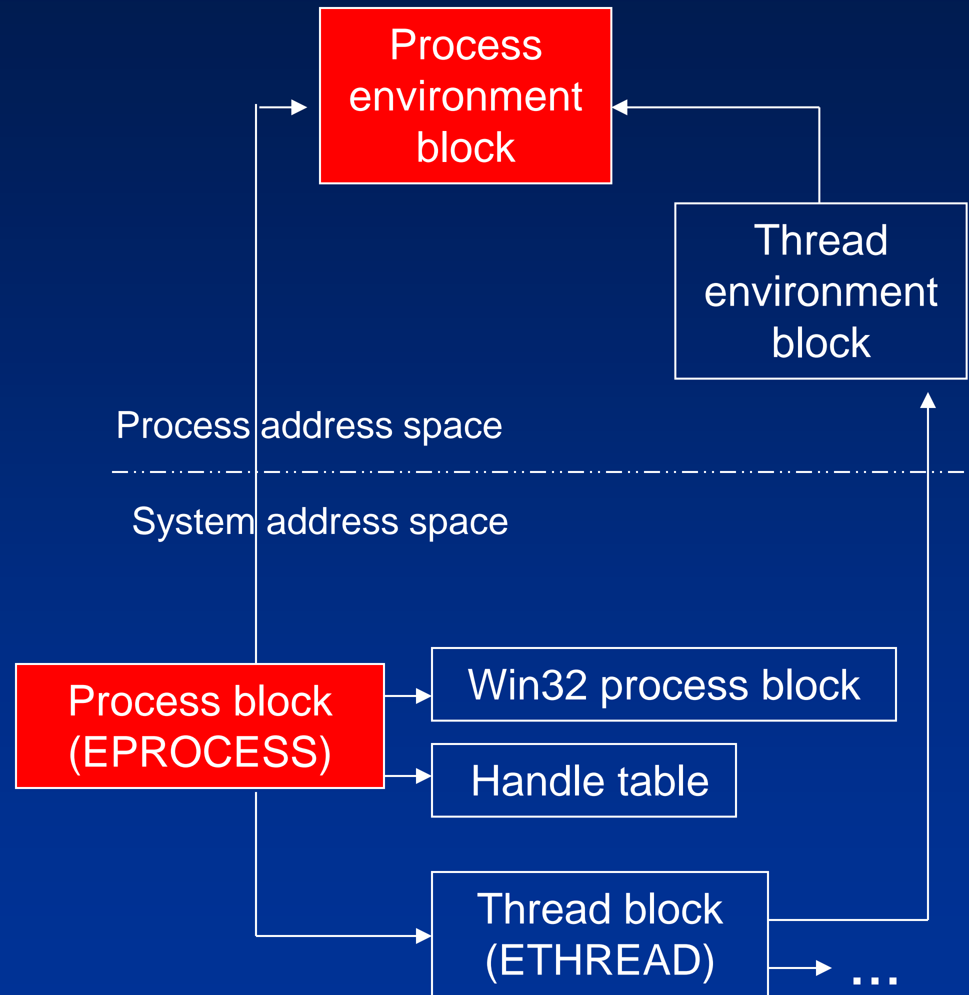
Roadmap for This Lecture

- Windows Process Internals
  - Process data structures
  - Performance counters
  - Process APIs
  - Protected Processes
  - Process creation
- Windows Thread Internals
  - Thread data structures
  - Performance counters
  - Thread APIs
  - Thread creations
- Windows tools for Processes and Threads
- Windows Jobs
- Labs Demo

Windows Process Internals

Data Structures for each process/thread:

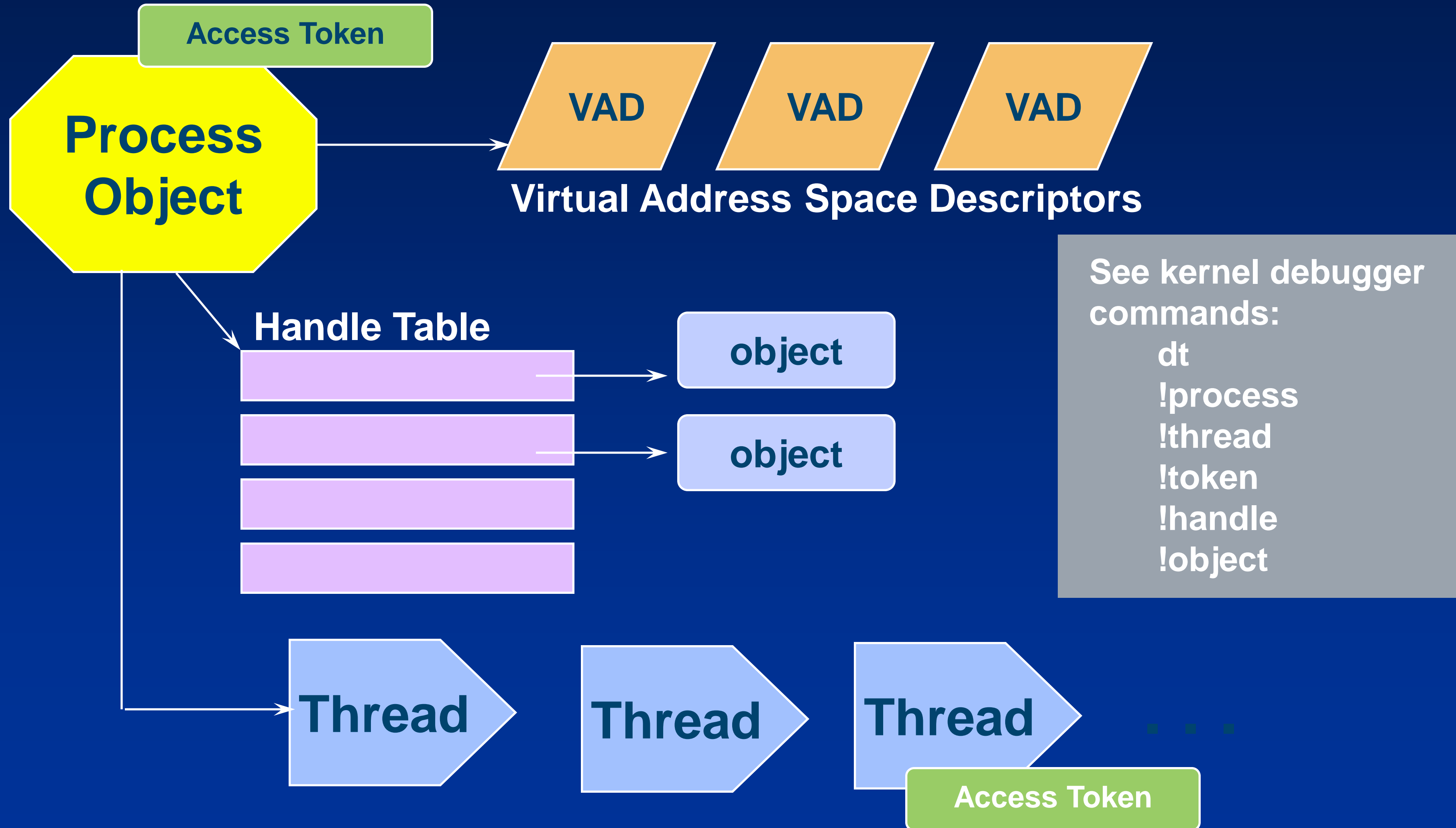
- Executive process block (EPROCESS)
- Executive thread block (ETHREAD)
- Win32 process block
- Process environment block
- Thread environment block



Process

- Container for an address space and threads
- Associated User-mode Process Environment Block (PEB)
- Primary Access Token
- Quota, Debug port, Handle Table etc
- Unique process ID
- Queued to the Job, global process list and Session list
- Memory management structures like the Working Set, VAD tree, AWE etc

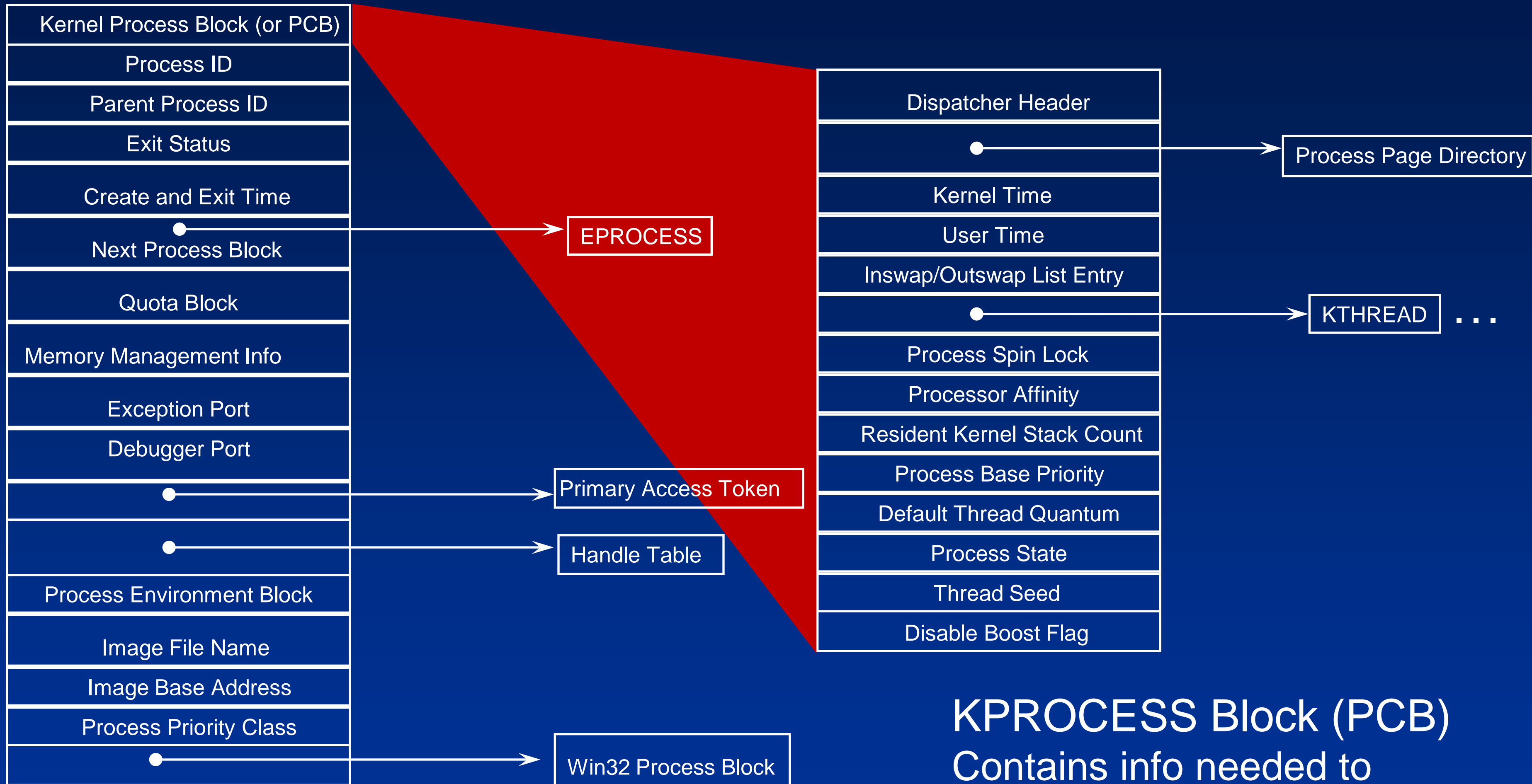
Processes & Threads Internal Data Structures



Per-Process Data

- Each process has its own…
  - Virtual address space (including program code, 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 Windows kernel objects
  - Environment strings
  - Command line
  - These are common to all threads in the process, but separate and protected between processes

Executive Process Block Layout

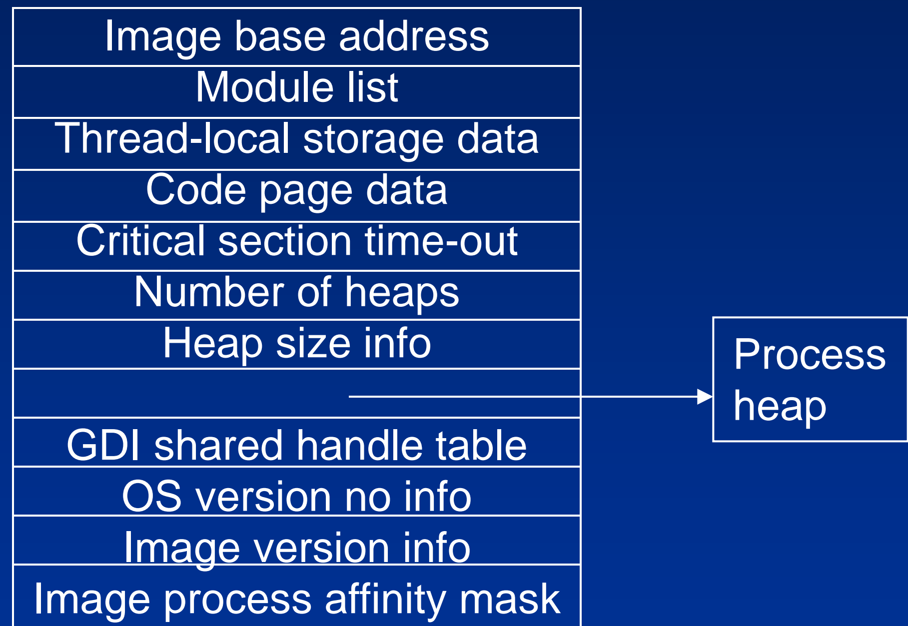


EPROCESS Block

KPROCESS Block (PCB)
Contains info needed to schedule threads in the process

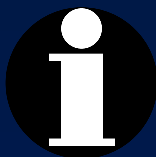
Process Environment Block (PEB)

- Mapped in user space
- Image loader, heap manager, Windows system DLLs use this info
- View with !peb or dt nt!_peb



Process-Related Performance Counters

Object: Counter	Function
Process:%PrivilegedTime	Percentage of time that the threads in the process have run in kernel mode
Process:%ProcessorTime	Percentage of CPU time that threads have used during specified interval %PrivilegedTime + %UserTime
Process:%UserTime	Percentage of time that the threads in the process have run in user mode
Process: ElapsedTime	Total lifetime of process in seconds
Process: ID Process	PID – process IDs are re-used
Process: ThreadCount	Number of threads in a process



Process Windows APIs

- CreateProcess
- OpenProcess
- GetCurrentProcessId - returns a global ID
- GetCurrentProcess - returns a pseudo-handle
- ExitProcess – notifies attached DLL
- TerminateProcess - no DLL notification
- Get/SetProcessShutdownParameters
- GetExitCodeProcess
- GetProcessTimes
- GetStartupInfo

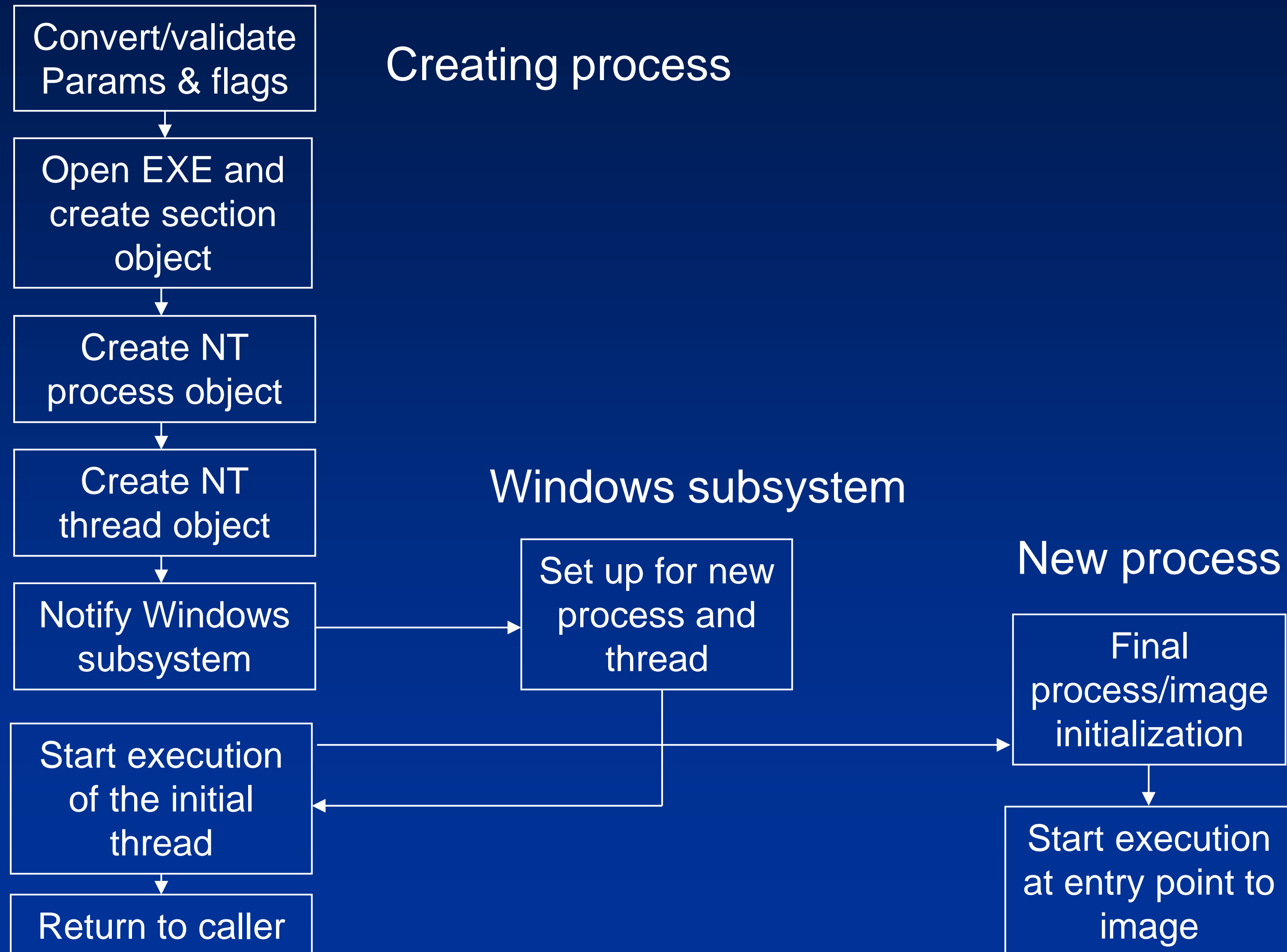
Protected Processes

- Process with debug privilege:
  - Read/write any process memory
  - Inject code
  - Suspend and resume thread, etc
  - E.g. Process explorer and task manager
- Media industry requires protection when playing back advanced, high quality digital content
  - Blueray, HD-DVD
- Images file with Windows Media Certificate
  - Audiodg.exe and Windows Error Reporting (WER)
- Indicated by a flag in EPROCESS block
- Accessible to Windbg (kernel mode)

Flow of CreateProcess()

1. Validate parameters; convert subsystems flags and options to their native counterparts; parse, validate and convert attribute list to native counterparts
2. Open the image file (.EXE) to be executed inside the process
3. Create Windows NT executive process object
4. Create initial thread (stack, context, Win NT executive thread object)
5. Notify Windows subsystem of new process so that it can set up for new proc.& thread
6. Start execution of initial thread (unless CREATE_SUSPENDED was specified)
7. In context of new process/thread: complete initialization of address space (load DLLs) and begin execution of the program

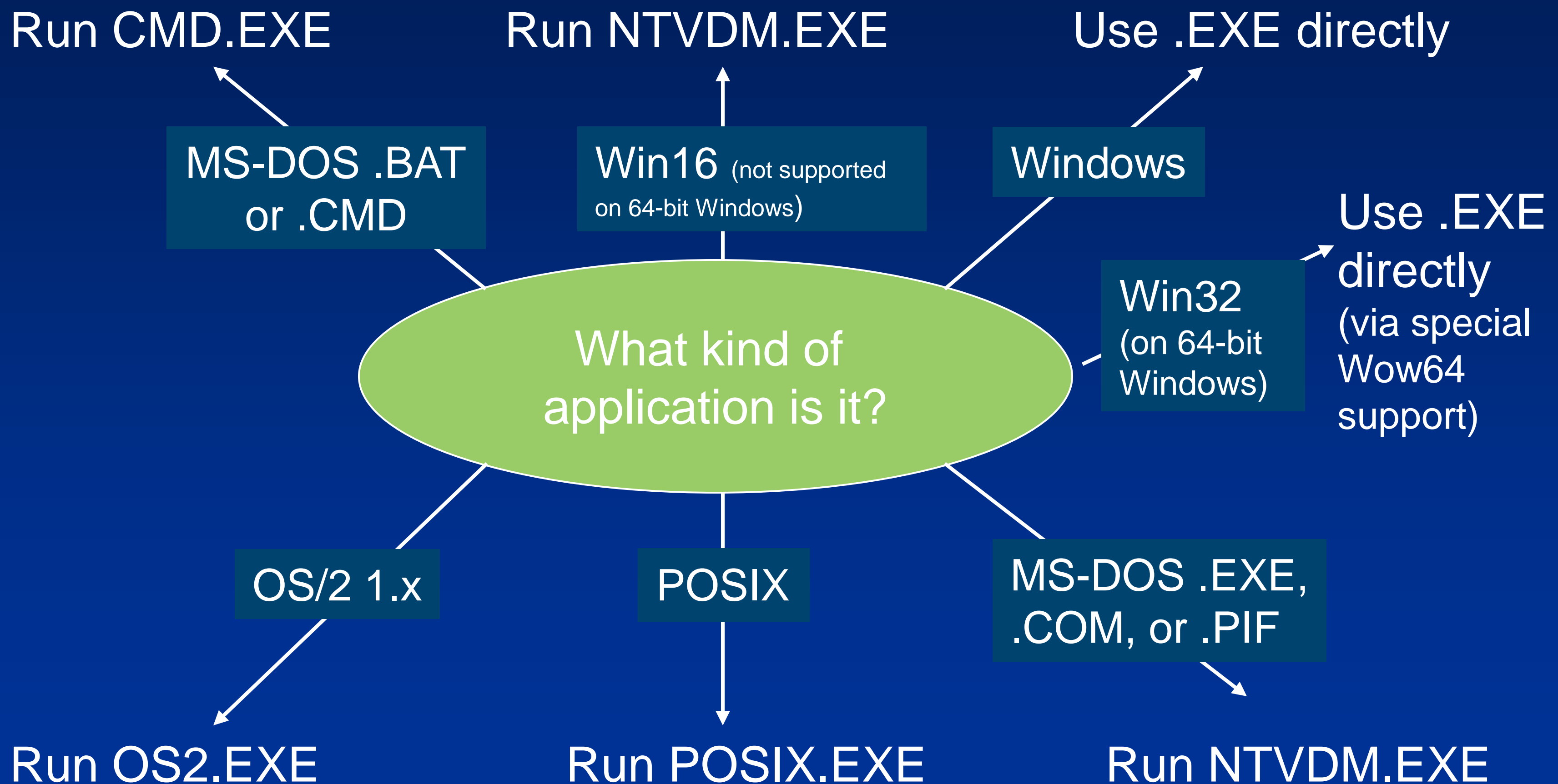
Create a Windows Process



Converting and validating params

- CreationFlags: independent bits for priority class → NT assigns *lowest-priority* class set
- Default priority class is normal unless creator has priority class idle
- If real-time priority class is specified and creator has insufficient privileges:
  - The high priority class is used
- Caller's current desktop is used if no desktop is specified

Opening the image to be executed



If executable has no Windows format...

- CreateProcess uses Windows “support image”
- No way to create non-Windows processes directly
  - OS2.EXE runs only on Intel systems
  - Multiple MS-DOS apps may share virtual dos machine
  - .BAT of .CMD files are interpreted by CMD.EXE
  - Win16 apps may share virtual dos machine (VDM)
    Flags: CREATE_SEPARATE_WOW_VDM
    CREATE_SHARED_WOW_VDM
    Default: HKLM\System...\Control\WOW\DefaultSeparateVDM
  - Sharing of VDM only if apps run on same desktop under same security
- Debugger may be specified under (run instead of app !!)

  \Software\Microsoft\WindowsNT\CurrentVersion\ImageFileExecutionOptions

Process Creation - next Steps...

- CreateProcess has opened Windows executable and created a section object to map in process' address space
- Now: create executive process object via NtCreateProcess
  - Set up EPROCESS block
  - Create initial process address space (page directory, hyperspace page, working set list)
  - Create kernel process block (set initial priority and quantum)
  - Conclude setup of process address space (VM, map NTDLL.DLL, map language support tables, register process: PsActiveProcessHead)
  - Set up Process Environment Block
  - Complete setup of executive process object

Further Steps...(contd.)

- Create Initial Thread and Its Stack and Context
  - NtCreateThread; new thread is suspended until CreateProcess returns
- Notify Windows Subsystem about new process

  KERNEL32.DLL sends message to Windows subsystem including:
  - Process and thread handles
  - Entries in creation flags
  - ID of process's creator
  - Flag describing Windows app (CSRSS may show startup cursor)
- Windows subsystem:
  - duplicate handles (inc usage count), set priority class, bookkeeping
  - allocate CSRSS proc/thread block, init exception port, init debug port
  - Show cursor (arrow & hourglass), wait 2 sec for GUI call, then wait 5 sec for app to show window

CreateProcess: final steps

Process Initialization in context of new process:

- *KiThreadStartup* Lowers IRQL level (DPC/Dispatch → APC level)
- Enable working set expansion
- Queue APC to exec *LdrInitializeThunk* in NTDLL.DLL
- Lower IRQL level to 0 – APC fires,
  - Init loader, heap manager, NLS tables, TLS array, crit. sect. Structures
  - Load DLLs, call DLL_PROCESS_ATTACH function
- Debuggee: all threads are suspended
  - Send msg to proc's debug port
    (Windows creates CREATE_PROCESS_DEBUG_INFO event)
- Image begins execution in user-mode (return from trap)

Process Shutdown Sequence

1. DLL notification
   - unless TerminateProcess used
2. All handles to executive and kernel objects are closed
3. Terminate any active threads
4. Process's exit code changes from STILL_ACTIVE to the specified exit code

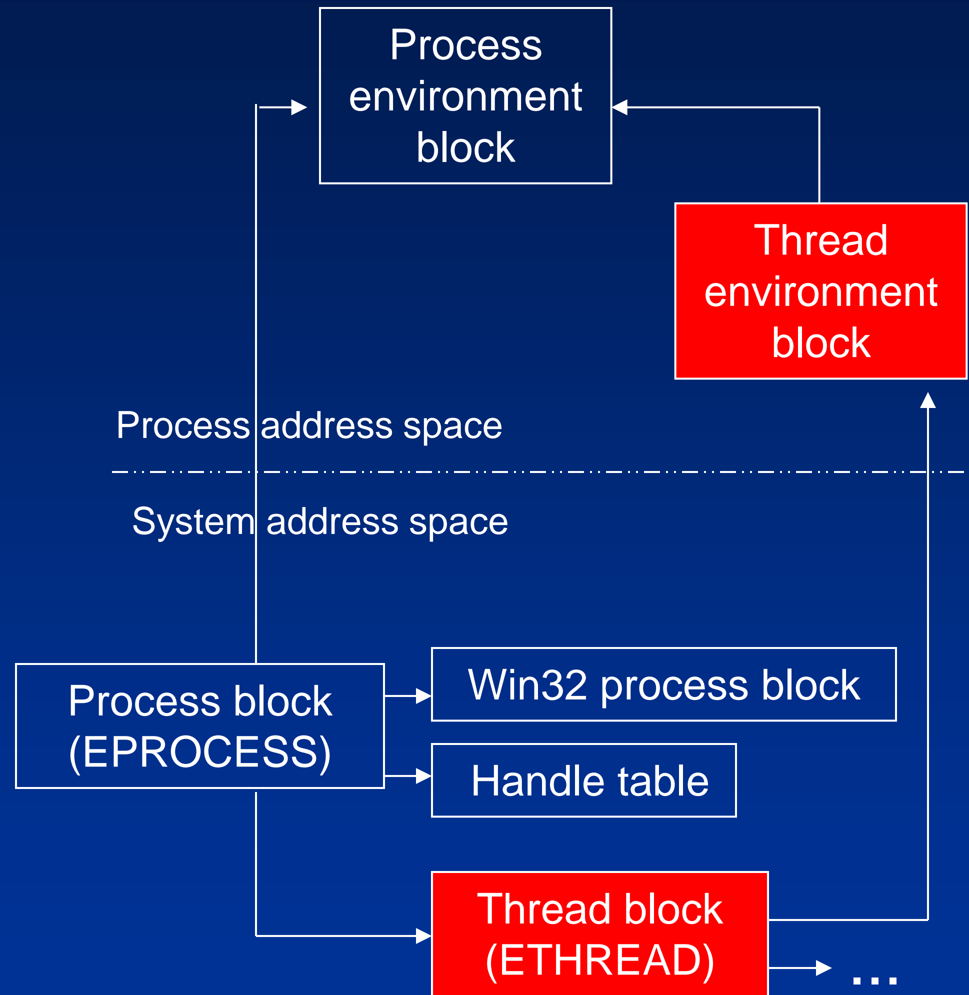
```
BOOL GetExitCodeProcess(
        HANDLE hProcess,
        LPDWORD lpdwExitCode);
```

5. Process object & thread objects become signaled
6. When handle and reference counts to process object == 0, process object is deleted

Windows Thread Internals

Data Structures for each process/thread:

- Executive process block (EPROCESS)
- Executive thread block (ETHREAD)
- Win32 process block
- Process environment block
- Thread environment block



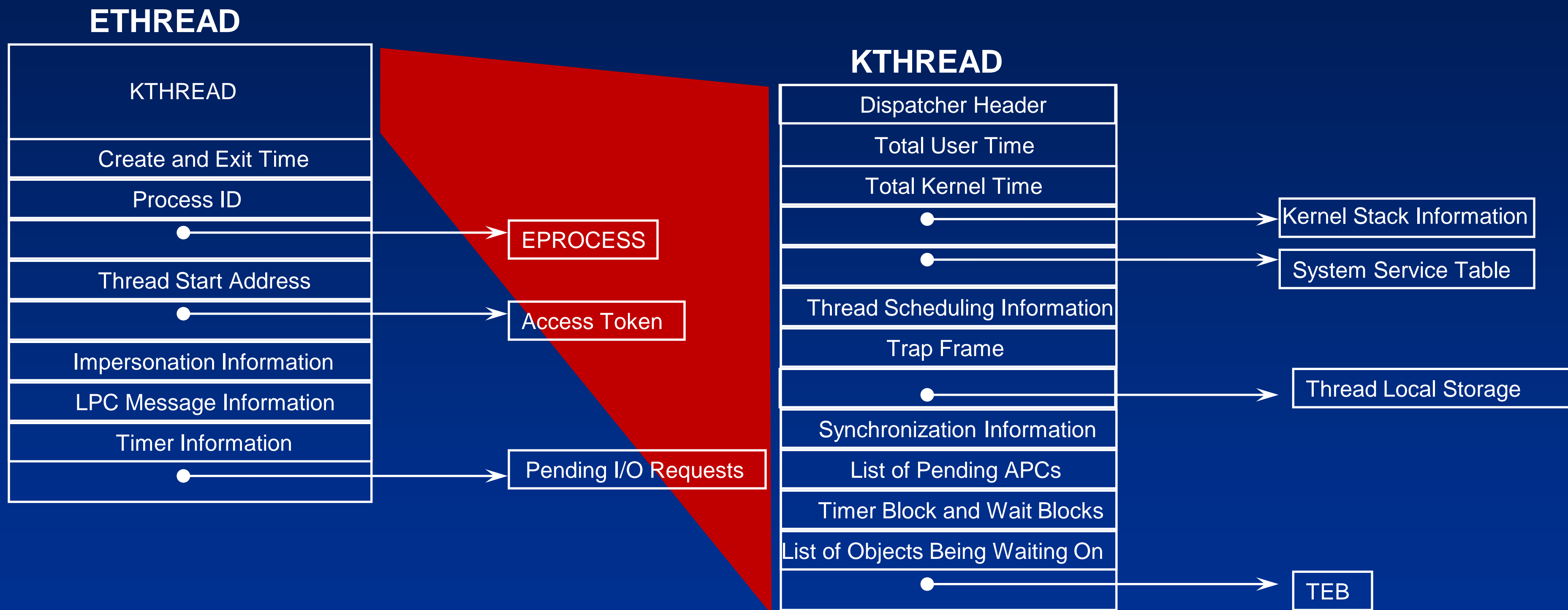
Thread

- Fundamental schedulable entity in the system
- Represented by ETHREAD that includes a KTHREAD
- Queued to the process (both E and K thread)
- I/O Request Packet list
- Impersonation Access Token
- Unique thread ID
- Associated User-mode Thread Environment Block (TEB)
- User-mode stack
- Kernel-mode stack

Per-Thread Data

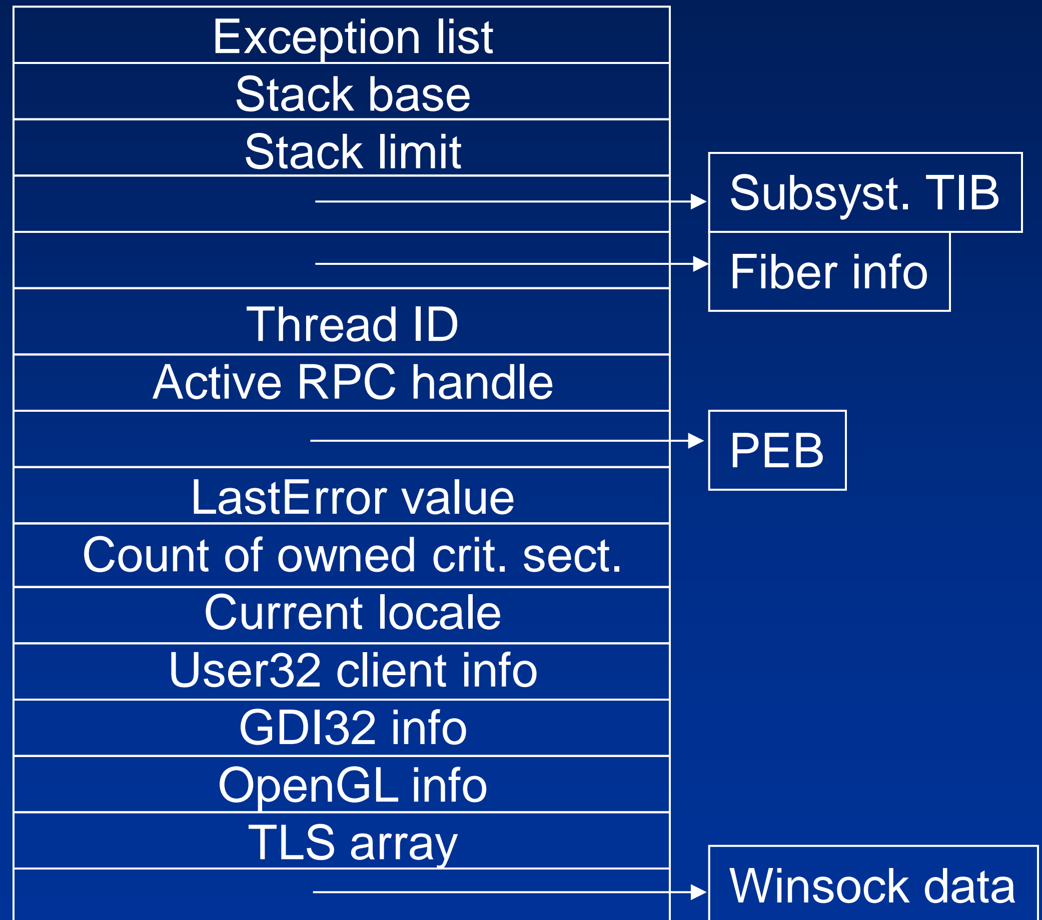
- Each thread has its own…
  - User-mode stack (arguments passed to thread, automatic storage, call frames, etc.)
  - Kernel-mode stack (for system calls)
  - Thread Local Storage (TLS) – array of pointers to allocate unique data
  - Scheduling state (Wait, Ready, Running, etc.) and priority
  - Hardware context (saved in CONTEXT structure if not running)
    - Program counter, stack pointer, register values
    - Current access mode (user mode or kernel mode)
  - Access token (optional -- overrides process’s if present)

Thread Block



Thread Environment Block

- User mode data structure
- Context for image loader and various Windows DLLs
- View with !teb or dt nt!_teb



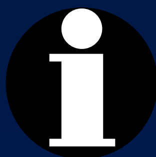
Thread-Related Performance Counters

Object: Counter	Function
Process: Priority Base	Base priority of process: starting priority for thread within process
Thread:%PrivilegedTime	Percentage of time that the thread was run in kernel mode
Thread:%ProcessorTime	Percentage of CPU time that the threads has used during specified interval %PrivilegedTime + %UserTime
Thread:%UserTime	Percentage of time that the thread has run in user mode
Thread: ElapsedTime	Total lifetime of thread in seconds
Thread: ID Process	PID – process IDs are re-used
Thread: ID Thread	Thread ID – re-used

Thread-Related Performance Counters (contd.)

Object: Counter	Function
Thread: Priority Base	Base priority of thread: may differ from the thread‘s starting priority
Thread: Priority Current	The thread‘s current dynamic priority
Thread: Start Address	The thread‘s starting virtual address (the same for most threads)
Thread: Thread State	Value from 0 through 7 – current state of thread
Thread: Thread Wait Reason	Value from 0 through 19 – reason why the thread is in wait state

Windows Thread APIs



- CreateThread
- CreateRemoteThread
- GetCurrentThreadId - returns global ID
- GetCurrentThread - returns handle
- SuspendThread/ResumeThread
- ExitThread – notifies DLLs
- TerminateThread - no DLL notification
- GetExitCodeThread
- GetThreadTimes
- Windows 2000 adds:
  - OpenThread
  - new thread pooling APIs

Birth of a Thread

CreateThread Function in Kernel32.dll:

1. Coverts API params to native flags and builds native OBJECT_ATTRIBUTES
2. Builds attribute lists of: client ID and TEB address (return after creation)
3. Call *NTCreateThreadEx* to create user-mode context, which calls *PspCreateThread* to create suspended ETHREAD object
    1. Create and initialize ETHREAD
    2. Set up the stack and context
    3. Allocate TEB for new thread
    4. Store start address in ETHREAD
    5. KeInitThread is called to set up the KTHREAD block

Birth of a Thread

6. *CreateThread* allocates activation stack and activates it
7. Notify Windows subsystems about the new thread
8. Thread handle and ID are returned
9. Thread is resumed and calls *KiThreadStartup* before calling the user specified start address

Thread Rundown Sequence

1. DLL notification
   - unless TerminateThread was used
2. All handles to Windows User and GDI objects are closed
3. Outstanding I/Os are cancelled
4. Thread stack is deallocated
5. Thread's exit code changes from STILL_ACTIVE to the specified exit code

```
BOOL GetExitCodeThread(
        HANDLE hThread,
        LPDWORD lpdwExitCode);
```

6. Thread kernel object becomes signaled
7. When handle and reference counts == 0, thread object deleted
8. If last thread in process, process exits

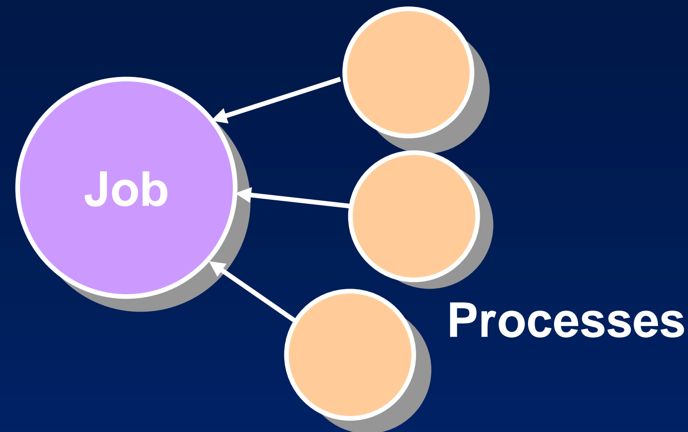
Start of Thread Wrapper

- All threads in all Windows processes appear to have one of just two different start addresses, regardless of the .EXE running
  - One for thread 0 (start of process wrapper), the other for all other threads (start of thread wrapper *RtlUserThreadStart* in Ntdll.dll)
- These “wrapper” functions are what Process Viewer shows as Thread Start Address for Windows apps
- Start of process & start of thread wrappers have same behavior
  - Provides default exception handling, access to debugger, etc.
  - Forces thread exit when thread function returns
- To find “real” Windows start address, use TLIST <processname> (or Kernel Debugger !thread command)

Tools for Obtaining Process & Thread Information

- Many overlapping tools (most show one item the others do not)
- Built-in tools in Windows XP + :
  - Task Manager, Performance Tool
  - Tasklist (new in XP)
- Support Tools
  - pviewer - process and thread details (GUI)
  - pmon - process list (character cell)
  - tlist - shows process tree and thread details (character cell)
- Resource Kit tools:
  - apimon - system call and page fault monitoring (GUI)
  - oh – display open handles (character cell)
  - pviewer - processes and threads and security details (GUI)
  - ptree – display process tree and kill remote processes (GUI)
  - pulist - lists processes and usernames (character cell)
  - pstat - process/threads and driver addresses (character cell)
  - qslice - can show process-relative thread activity (GUI)
- Tools from www.sysinternals.com
  - Process Explorer – super Task Manager – shows open files, loaded DLLs, security info, etc.
  - Pslist – list processes on local or remote systems
  - Ntpmon - shows process/thread create/deletes (and context switches on MP systems only)
  - Listdlls - displays full path of EXE & DLLs loaded in each process

Jobs



- Jobs are collections of processes
  - Can be used to specify limits on CPU, memory, and security
  - Enables control over some unique process & thread settings not available through any process or thread system call
    - E.g. length of thread time slice
- Job object is a nameable, secure and shareable kernel object
- Allows a group of processes to be managed and manipulated as a unit

Creation of Jobs

- How do processes become part of a job?
  - Job object has to be created (CreateJobObject)
  - Then processes are explicitly added (AssignProcessToJob)
    - Processes created by processes in a job automatically are part of the job
      - Unless restricted, processes can “break away” from a job
  - Then quotas and limits are defined (SetInformationJobObject)
    - Examples on next slide…

Job Settings

- Quotas and restrictions:
  - Quotas: total CPU time, # active processes, per-process CPU time, memory usage
  - Run-time restrictions: priority of all the processes in job; processors threads in job can run on
  - Security restrictions: limits what processes can do
    - Not acquire administrative privileges
    - Not accessing windows outside the job, no reading/writing the clipboard
  - Scheduling class: number from 0-9 (5 is default) - affects length of thread timeslice (or quantum)
    - E.g. can be used to achieve “class scheduling” (partition CPU)

Examples of Jobs

- Examples where Windows OS uses jobs:
  - Add/Remove Programs (“ARP Job”)
  - WMI provider
  - RUNAS service (SecLogon) uses jobs to terminate processes at log out
- Process Explorer highlights processes that are members of jobs
  - Color can be configured with Options->Configure Highlighting
  - For processes in a job, click on Job tab in process properties to see details

Further Reading

- Mark E. Russinovich, *et al.* Windows Internals, 5th Edition, Microsoft Press, 2005.
  - Chapter 5 - Processes, Thread, and Jobs (from pp. 335)
  - Process Internals (from pp. 335)
  - Flow of Create Process (from pp. 348)
  - Thread Internals (from pp. 370)

Lab: EPROCESS, KPROCESS and PEB blocks

- lkd> !dt _eprocess
- lkd> !dt _kprocess
- lkd> !process

Lab: Show Windows API

2013-9-30

Windows API

```
#include <Windows.h>
```

http://msdn.microsoft.com/en-US/

Hungarian notation (Wikipedia)

CreateProcess()

```
BOOL WINAPI CreateProcess(
  _In_opt_     LPCTSTR lpApplicationName,
  _Inout_opt_  LPTSTR lpCommandLine,
  _In_opt_     LPSECURITY_ATTRIBUTES lpProcessAttributes,
  _In_opt_     LPSECURITY_ATTRIBUTES lpThreadAttributes,
  _In_         BOOL bInheritHandles,
  _In_         DWORD dwCreationFlags,
  _In_opt_     LPVOID lpEnvironment,
  _In_opt_     LPCTSTR lpCurrentDirectory,
  _In_         LPSTARTUPINFO lpStartupInfo,
  _Out_        LPPROCESS_INFORMATION lpProcessInformation
);
```

TerminateProcess()

```
BOOL WINAPI TerminateProcess(
  _In_  HANDLE hProcess,
  _In_  UINT uExitCode
);
```

Lab: Start a process image

- Install a debugger to run instead of notepad.exe. We chose Solitaire (sol.exe – a standard tool on every Windows system).

  - start regedit.exe
  - create (insert) key at
    HKLM\Software\Microsoft\WindowsNT\CurrentVersion\Image File Execution Options\notepad.exe
  - insert value:
    Debugger (REG_SZ) C:\winnt\system32\sol.exe
  - start notepad (!)

Lab: Trace Process Startup

Lab: ETHREAD, KTHREAD and TEB

- lkd> dt nt!_ethread
- lkd> dt nt!_kthread