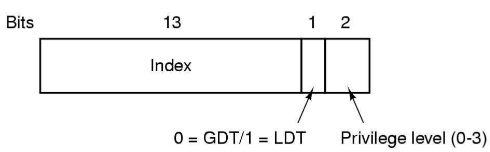
Windows 2000 and Linux Memory Management

Segmentation with paging: Pentium (1)

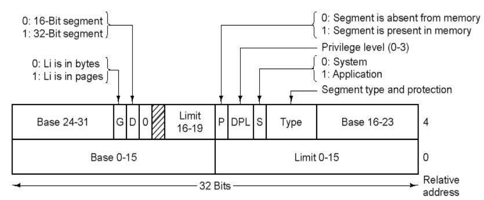
- Has 16K independent segments, each holding up to 1 billion 32-bit words
- Heart of virtual memory
  - Local descriptor table (LDT): describes segments local to one program
  - Global descriptor table (GDT): describes system segments including OS itself

Segmentation with Paging: Pentium (2)



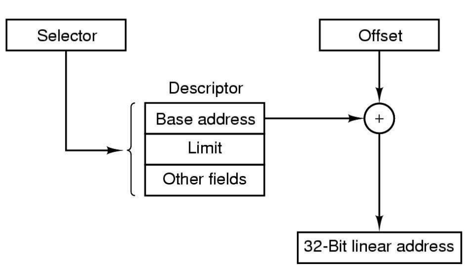
A Pentium selector

Segmentation with Paging: Pentium (3)



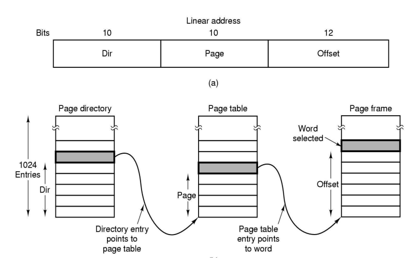
- Pentium code segment descriptor
- Data segments differ slightly

Segmentation with Paging: Pentium (4)



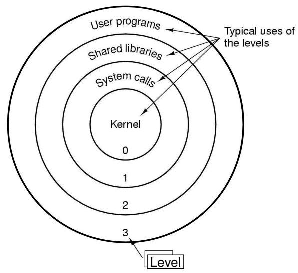
Conversion of a (selector, offset) pair to a linear address

Segmentation with Paging: Pentium (5)



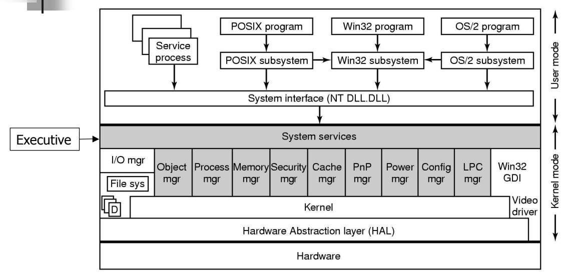
Mapping of a linear address onto a physical address

Segmentation with Paging: Pentium (6)



Protection on the Pentium

Windows 2000 OS structure

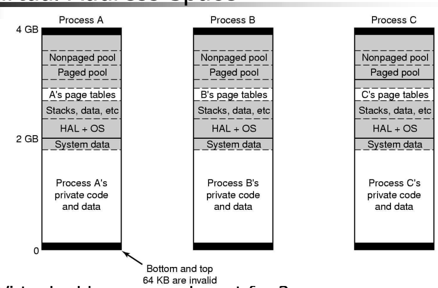


- Executive is architecture independent part of the OS
- Memory Manager is one part of this executive

Memory Management

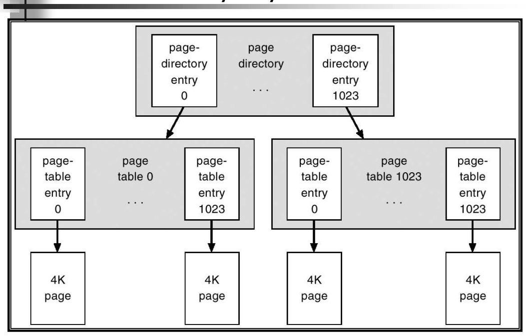
- Sophisticated virtual memory (VM) management
  - Assumption is that underlying hardware supports virtual-to-physical address translation, paging, and other VM features
- The VM manager in 2000 uses a page-based management scheme with a page size of 4 KB
- VM manager uses 32 bit addresses, so each process has a 4 GB virtual address space
  - Upper 2 GB are identical for each process and lower 2 GB are distinct for each process
- Two-step memory allocation procedure
  1. Reservation a portion of the process' address space
  2. Commitment of the allocation by assigning space in the OS paging file

Virtual Address Space



- Virtual address space layout for 3 user processes
- White areas are private per process
- Shaded areas are shared among all processes

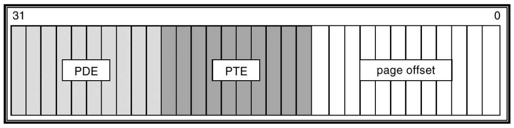
Virtual-Memory Layout



Virtual Memory Manager (Cont.)

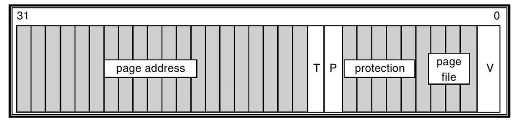
- The virtual address translation in 2000 uses several data structures.
  - Each process has a *page directory* that contains 1024 *page directory entries* of size 4 bytes.
  - Each page directory entry points to a *page table* which contains 1024 *page table entries* (PTEs) of size 4 bytes.
  - Each PTE points to a 4 KB *page frame* in physical memory.
- A 10-bit integer can represent all the values form 0 to 1023, therefore, can select any entry in the page directory, or in a page table.
- This property is used when translating a virtual address pointer to a bye address in physical memory.
- A page can be in one of six states: valid, zeroed, free standby, modified and bad.

Virtual-to-Physical Address Translation



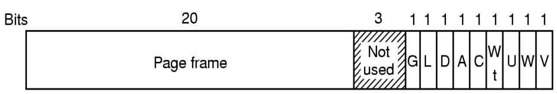
- 10 bits for page directory entry, 10 bits for page table entry, and 12 bits for byte offset in page.

Page File Page-Table Entry



- 5 bits for page protection, 20 bits for page frame address, 4 bits to select a paging file, and 3 bits that describe the page state. V = 0

Page File Page-Table Entry

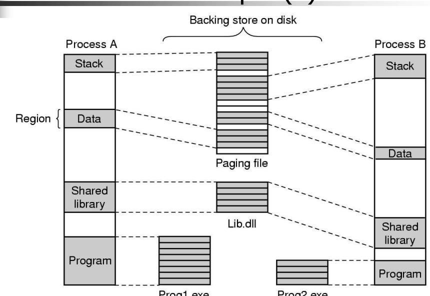


G: Page is global to all processes
L: Large (4-MB) page
D: Page is dirty
A: Page has been accessed

Wt: Write through (no caching)
U: Page is accessible in user mode
W: Writing to the page permitted
V: Valid page table entry

A page table entry for a mapped page on the Pentium

Fundamental Concepts (2)



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

Memory Management System Calls

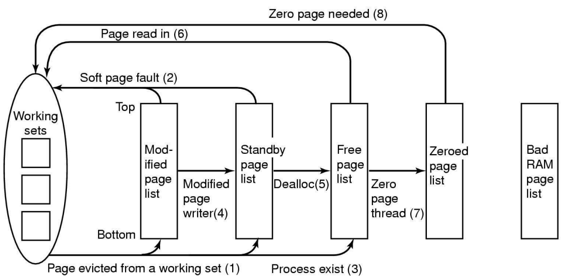
Win32 API function	Description
VirtualAlloc	Reserve or commit a region
VirtualFree	Release or decommit a region
VirtualProtect	Change the read/write/execute protection on a region
VirtualQuery	Inquire about the status of a region
VirtualLock	Make a region memory resident (i.e., disable paging for it)
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

The principal Win32 API functions for mapping virtual memory in Windows 2000

Programmer Interface - Memory Management

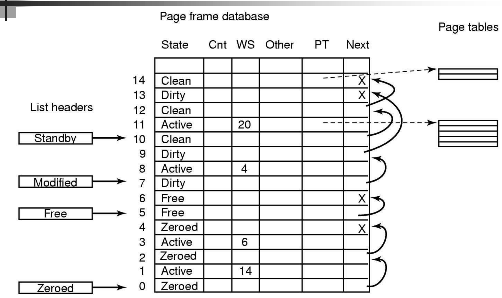
- Virtual memory:
  - `VirtualAlloc` reserves or commits virtual memory.
  - `VirtualFree` decommits or releases the memory.
  - These functions enable the application to determine the virtual address at which the memory is allocated.
- An application can use memory by memory mapping a file into its address space.
  - Multistage process.
  - Two processes share memory by mapping the same file into their virtual memory.

Physical Memory Management (1)



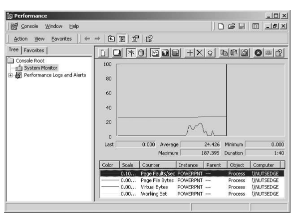
The various page lists and the transitions between them

Physical Memory Management (2)

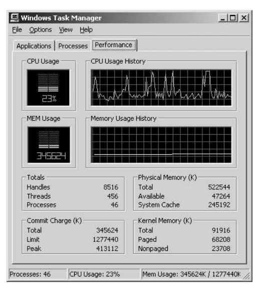


Some of the major fields in the page frame data base for a valid page

Win2K tools



perfmon

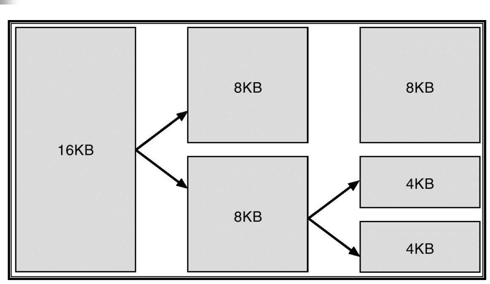


Task Manager

Linux Memory Management

- Linux's physical memory-management system deals with allocating and freeing pages, groups of pages, and small blocks of memory.
- It has additional mechanisms for handling virtual memory, memory mapped into the address space of running processes.

Splitting of Memory in a Buddy Heap



Managing Physical Memory

- The page allocator allocates and frees all physical pages; it can allocate ranges of physically-contiguous pages on request.
- The allocator uses a *buddy-heap* algorithm to keep track of available physical pages.
  - Each allocatable memory region is paired with an adjacent partner.
  - Whenever two allocated partner regions are both freed up they are combined to form a larger region.
  - If a small memory request cannot be satisfied by allocating an existing small free region, then a larger free region will be subdivided into two partners to satisfy the request.
- Memory allocations in the Linux kernel occur either statically (drivers reserve a contiguous area of memory during system boot time) or dynamically (via the page allocator).

Virtual Memory

- The VM system maintains the address space visible to each process: It creates pages of virtual memory on demand, and manages the loading of those pages from disk or their swapping back out to disk as required.
- The VM manager maintains two separate views of a process's address space:
  - A logical view describing instructions concerning the layout of the address space.
    The address space consists of a set of nonoverlapping regions, each representing a continuous, page-aligned subset of the address space.
  - A physical view of each address space which is stored in the hardware page tables for the process.

Virtual Memory (Cont.)

- Virtual memory regions are characterized by:
  - The backing store, which describes from where the pages for a region come; regions are usually backed by a file or by nothing (*demand-zero* memory)
  - The region's reaction to writes (page sharing or copy-on-write).
- The kernel creates a new virtual address space
  1. When a process runs a new program with the **exec** system call
  2. Upon creation of a new process by the **fork** system call

Virtual Memory (Cont.)

- On executing a new program, the process is given a new, completely empty virtual-address space; the program-loading routines populate the address space with virtual-memory regions.
- Creating a new process with **fork** involves creating a complete copy of the existing process's virtual address space.
  - The kernel copies the parent process's VMA descriptors, then creates a new set of page tables for the child.
  - The parent's page tables are copied directly into the child's, with the reference count of each page covered being incremented.
  - After the fork, the parent and child share the same physical pages of memory in their address spaces.

Virtual Memory (Cont.)

- The VM paging system relocates pages of memory from physical memory out to disk when the memory is needed for something else.
- The VM paging system can be divided into two sections:
  - The pageout-policy algorithm decides which pages to write out to disk, and when.
  - The paging mechanism actually carries out the transfer, and pages data back into physical memory as needed.

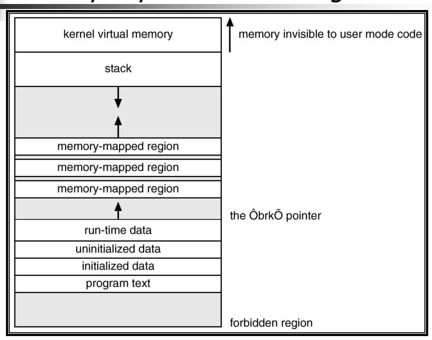
Virtual Memory (Cont.)

- The Linux kernel reserves a constant, architecture-dependent region of the virtual address space of every process for its own internal use.
- This kernel virtual-memory area contains two regions:
  - A static area that contains page table references to every available physical page of memory in the system, so that there is a simple translation from physical to virtual addresses when running kernel code.
  - The reminder of the reserved section is not reserved for any specific purpose; its page-table entries can be modified to point to any other areas of memory.

Executing and Loading User Programs

- Linux maintains a table of functions for loading programs; it gives each function the opportunity to try loading the given file when an exec system call is made.
- The registration of multiple loader routines allows Linux to support both the ELF and **a.out** binary formats.
- Initially, binary-file pages are mapped into virtual memory; only when a program tries to access a given page will a page fault result in that page being loaded into physical memory.
- An ELF-format binary file consists of a header followed by several page-aligned sections; the ELF loader works by reading the header and mapping the sections of the file into separate regions of virtual memory.

Memory Layout for **ELF** Programs



Static and Dynamic Linking

- A program whose necessary library functions are embedded directly in the program's executable binary file is *statically* linked to its libraries.
- The main disadvantage of static linkage is that every program generated must contain copies of exactly the same common system library functions.
- *Dynamic* linking is more efficient in terms of both physical memory and disk-space usage because it loads the system libraries into memory only once.

Acknowledgements

1. Silberschatz, et al., *Operating System Concepts,* 6th Edition, John Wiley & Sons, Inc, 2003.
2. Tanenbaum, Andew., *Modern Operating Systems,* 2nd Edition, Prentice Hall, 2001.