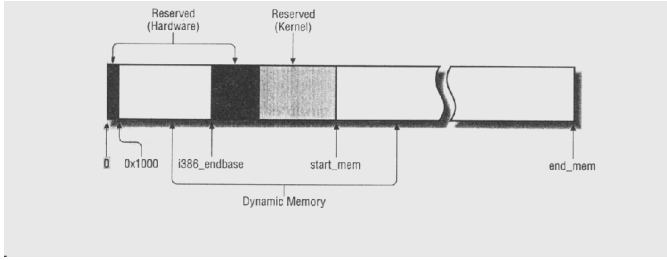
Ausgewählte Betriebssysteme

Memory

Memory Management

- Kernel
  - Page Frames
  - Buddy Allocator
  - Slab Allocators
  - Buffer Cache
  - Page Cache
- Process
  - Memory Regions

Memory Map



Page Frame

- kernel must keep track of state
  - kernel code, page cache, kernel data etc.
- which pages are available
- page descriptor for each frame
  - mem_map_t *mem_map
- linked into appropriate list if needed

Buddy

- robust, efficient kernel allocator
- contiguous page frames
- external fragmentation
  - paging
  - managing pages in a suitable way

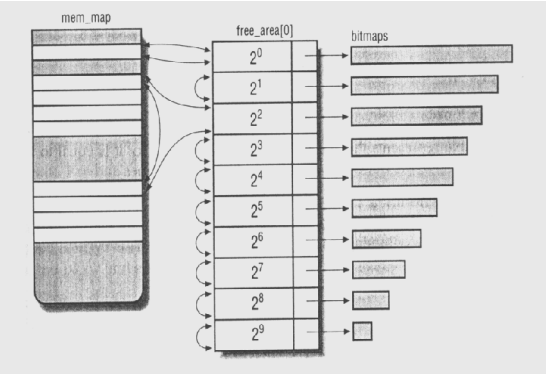
Why not paging

- sometimes physical contiguous pages required
  - DMA bypasses CPU paging circuitry
- paging modification deteriorate TLB efficiency
  - TLB flushing required for consistency

Buddy Allocator

- well-known buddy system algorithm
- free pages are grouped into 10 lists
  - 1 .. 512 contiguous pages
- apropriately aligned

Buddy in action



Buddy API

- get_free_page(pfp_mask);
- __get_free_pages(gfp_mask,order);
- free_page(addr);
- free_pages(addr,order);

Memory Area Management

- contiguous physical addresses
- arbitrary length (not necessarily multiple of page size)
  - feq tens or hundreds of bytes
- internal fragmentation
- 2.0 buddies for small requests
  - geometrically distributed size
  - not more than 50 % loss
- 2.2 Slab Allocator
  - first 1994 Solaris 2.4

Slab

- memory areas as objects
  - set of data structures
  - constructor and destructor
  - not used in Linux
- tendency of requesting and releasing same memory type repeatedly
  - e.g. process creation
  - keep memory in cache as long as possible

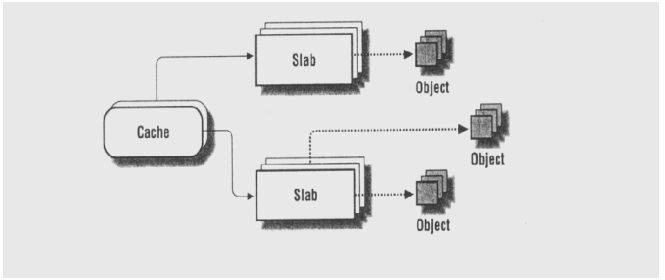
Slab

- if size not geometrically distributed, addresses are less prone to concentrate on physical addresses whose values are power of 2
  - better hardware cache usage
- frequent calls to the buddy allocator pollutes the cache

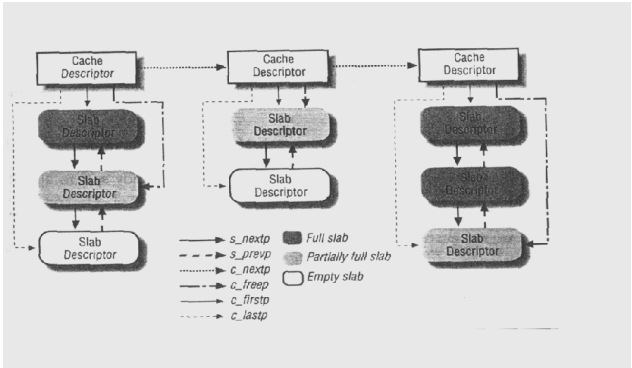
Caches

- object of same kind are stored in caches
  - e.g. file object upon open system call is stored in cache *filp* (file pointer)
  - /proc/slabinfo
- consist of several *slabs*
  - each slab consist of one or more contiguous page frames

Cache



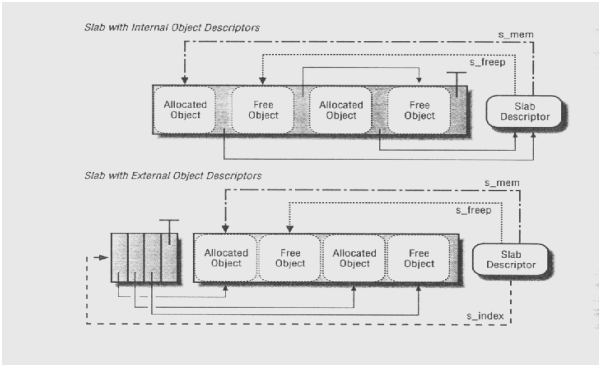
Caches and Slabs



General and Specific Caches

- general
- used only be the slab allocator for own purposses
  - cache descriptors (`cache_cache`)
  - slab descriptors (`cache_slabp`)
  - 13 caches for geometrically distributed memory areas
  - `kmem_cache_init()` ,`kmem_cache_sizes_init()`
- specific
  - `kmem_cache_create()`

Slabs and Objects

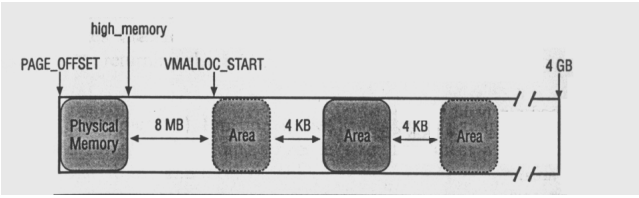


Noncontiguous Memory

- rarely used
- only for (hopefully) infrequent changed objects
  - data structures for active swap areas
  - space for modules
  - buffers for some I/O drivers

Noncontiguous Memory

- vmalloc
- vfree



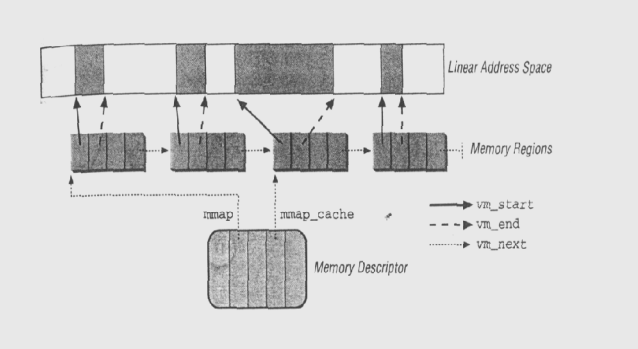
Linux 2.4 and Memory

- Buddies
  - 2.2 has two buddy systems (DMA and Non-DMA)
  - 2.4 adds a third for high physical memory
- Slabs
  - mostly unchanged
  - slab caches can be destroyed
    - modules are expected to do so

Process Address Space

- non-urgent
  - allocation does not mean access
- addressing errors must be caught
- set of linear address
  - memory region
- different access rights
- different for each process
- no relation among processes

Memory Regions



Memory Regions

- Situations for new regions
  - process creation
  - exec
  - memory map
  - stack growth
  - IPC shared memory
  - expand dynamic area (heap)

MM related system calls

- brk
- execve
- exit
- fork
- mmap
- munmap
- shmat
- shmdt

Memory Descriptor

- pointer to regions list
- pointer to Global Directory
- number of allocated pages
- address space size
- reference count
- possibly shared among lightweight processes

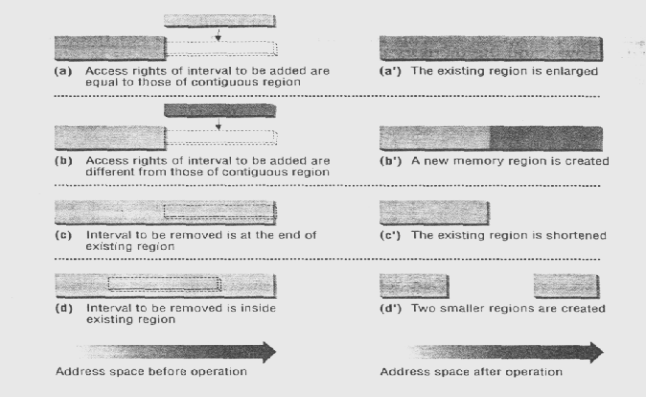
Memory Region

- vm_area_struct
- start of region
- end of region
- access rights
- all regions of a process are linked

Memory Region (2)

- find_vma()
- find_vma_intersection()
- get_unmapped_area()
- insert_vm_struct()
- do_map()
- do_unmap()

Changing Memory Regions



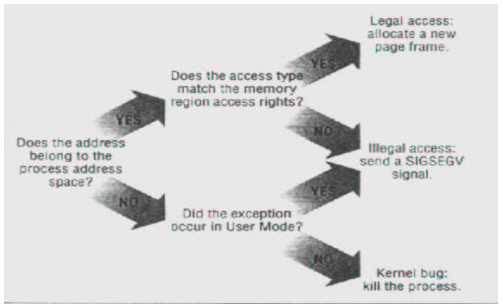
Page Faults

- programming errors
- missing page, though linear address belongs to the process address space
  - contained in some memory region
  - not invalid from process point of view
  - allocate page frame and have process continue

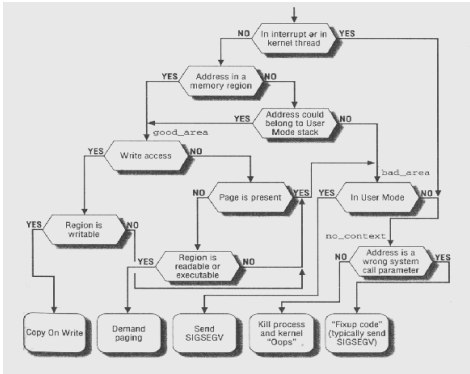
Page Fault

- handle_mm_fault()
  - allocates new pages
  - demand paging
    - do_no_page
      - vma->vm_ops->nopage handler loads page from disk
      - do_anonymous_page()
    - do_swap_page

Page Faults



Page Fault (2)



Copy On Write

- share pages
- duplicate on modification attempts
- handle_pte_fault()
  - allocate new page frame
  - adjust counter in frame descriptor
  - Copy content

Creating

- clone(), fork(), vfork()
- copy_mm()
  - copy_segments()
  - new_page_tables()
    - 0-3 GB clear
    - 3-4 GB initialized from swapper process
  - dup_mmap()
    - Duplicate memory regions
    - set up the copy-on-write mechanism

Heap

- C-library for user land
  - malloc, calloc, free, brk
  - only brk as system call
- brk syscall
  - check if request overlaps with current regions
  - maps/unmaps page

Disk Caches

- try to keep as much as possible in memory
- Buffer Cache
  - cache for buffer I/O operations
  - blocks of block devices
- Page Cache
  - content of files
  - not necessarily adjacent on disk

Operations related to disk caches

I/O Operation	Cache	System Call	Kernel Function
Read a block device file	Buffer	read()	block_read()
Write a block device file	Buffer	write()	block_write()
Read an Ext2 directory	Buffer	getdents()	ext2_bread()
Read an Ext2 regular file	Page	read()	generic_file_read()
Write an Ext2 regular file	Page, Buffer	write()	ext2_file_write()
Access to memory-mapped file	Page	None	file_map_nopage()
Access to swapped-out page	Page, Buffer	None	do_swap_page()

Finding Buffers

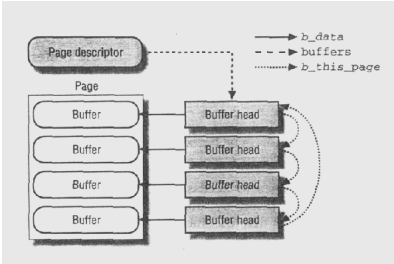
- buffer identified by device and block number
- `hash_table` helps to find buffer quickly
  - find_buffer()
  - insert_into_queues()
  - remove_from_queues()

getblk()

- main service routine for the buffer cache

Buffer Allocation

- not single memory objects for reasons of efficiency



Page Cache

- all accesses through `read()`,`write()`, and `mmap()` are handled by the page cache
- blocks contained in page don't need to be adjacent on disk
  - device and block number not identifying
- file inode and offset are unique

Page Cache Data Structures

- page hash table
  - `struct page **page_hash_table;`
  - identified by inode and offset
  - size depends on memory available
- inode queue
  - all pages of an inode

Page Cache