CSE 451
Autumn 2003

November 13 Section

Questions from Lecture?

Questions from the Project?

Questions from the Exam?

Questions from Homework?

- 9.11: what is the effect of have two entries in a *page table* point at the same physical page
  - not two entries in *two* page tables
- Aliasing
  - Same memory shows up twice
  - Changing a byte in one view changes the other
- Copying
  - Can implement copy by just remapping
  - Need to make both copies read-only, do copy when one changes to get copy semantics

Memory Protection

- 9.9: How do operating systems prevent processes from seeing other memory?
  - Common answer: valid/invalid bit
  - Correct answer:
    - Every address a process uses is translated by the page table
    - A process has no *language* to talk about memory other than its own
  - How can we implement this?
    - Share a physical page between two PTEs
    - Provide a system call to read/write memory in other processes

Project 3 - Virtual Memory

- Experiments
  - Have a hypothesis
    - "Big pages are better"
    - "Algorithm y is better"
    - "Prefetching will reduce the number of page faults"
    - "If we understand why x happens, we can fix it"

Running experiments

- Two steps
  - Control: what is the baseline?
    - What happens with existing page sizes / page replacement algorithms / no prefeching
  - New test: what happens with the new system
    - Try to change just one aspect of the system to isolate the difference

Some ideas

- What is the ideal page size for this trace under different amount of main memory?
- How much better is page replacement algorithm x then LRU
  - e.g. 2Q, ARC (currently best known techniques)
- How close can we come to LRU without doing any work between page faults?
  - e.g. no scanning, constant work per page fault
- How important is recency vs. frequency in predicting page re-use?

No so good ideas

- What kind of music is made when I set the convert the address trace to notes?
- Can I make a fractal out of this data?

Today's Topic: Optional

- Memory Management in Linux

- High level:
  - 3 level page tables
  - common kernel heap allocator ("kmalloc", "slab")
  - Virtual memory areas
  - Physical memory regions

Page Tables

- PGD = top level pointer
  - Points to a page of PMDs (page middle directory)
- PMD = middle level
  - Can have just one entry for two-level hardware
  - Points to a page of PTEs
- PTE = page table
  - Translates a single virtual page into a physical page

Page Frame Database

```
• struct page {
  address_space * mapping;
   unsigned long index; // offset in mapping
   struct page * next_hash;
   struct page * prev_hash;
   unsigned long flags;
   atomic_t count; // usage count
   struct list_head lru; // pageout list
   void * virtual; // virtual address of this
  page in kernel memory map
   struct buffer_head * buffers;
}
```

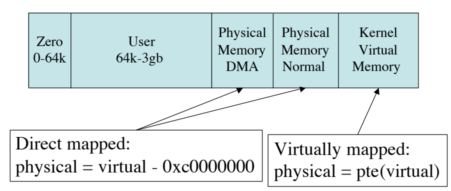
Page Flags

```
PG_locked
PC_error
PG_referenced
PG_uptodate
PG_dirty
PG_unused
PG_lru
PG_active
PG_slab
PG_highmem
PG_checked
…
```

Physical Memory Zones

- ZONE_DMA - used for DMA to antique devices, < 16 MB
- ZONE_NORMAL: 16-896 MB
- ZONE_HIGHMEM: > 896 MB

Linux Memory Picture



Page Replacement

- Triggered by low memory during allocation
- kswapd daemon also triggers swapping
  - wakes up every second when few pages available
- `try_to_free_pages()` finds pages to release (many)
  - walks through each memory type and asks it to release some pages

Page replacement (2)

- Two lists of memory
  - active pages: currently actively in use
  - inactive pages: candidates for swapping
- Pages are moved from active to inactive using clock algorithm
  - active list scanned for non-referenced pages
  - unused pages put on inactive list

Page replacement (3)

- Inactive list scanned for pages to swap out
  - Put pages that have been referenced back on active list
  - Leave behind pages locked for I/O
  - Try to free buffers in buffer cache using the page
- Keep swapping out pages until enough have been freed

Issues

- How do you check reference bits on shared pages?
- What happens if the swapper needs to allocate memory?
- What happens if part of the swapper code is swapped out?

Slab Allocator

- Goal:
  - Locality
  - Fast
  - Keep similar types together
    - Can create a heap for a specific type
  - Non-blocking synchronization
    - Uses atomic instructions instead of locks

Slab Allocator Design

- struct page knows what cache holds memory
  - Makes free easy - no need to specify/locate cache
- Heaps allocate from chunks called "slabs"
  - 3 types:
    - fully used - not used for allocation
    - partially used - used first
    - empty - reserved until no partially full
  - Can span multiple page sizes
    - optimized to reduce wastage

Page allocator

- Used for requesting contiguous chunks of physical memory
  - Can specify zone (DMA, normal, highmem)
  - Only allocates powers of 2 pages
  - Used for I/O - need contigous physical memory or for single pages
- Uses buddy allocator
  - coalesces adjacent pages into powers of 2
- Triggers swapper when memory runs low
  - Can wait until memory is available

Virtual Memory Areas

- Used when contiguous virtual address is needed
  - e.g. allocating memory for dynamically loaded kernel code
- Kernel maintains sorted linked-list of areas in use
  - traverses list to find free space
  - allocate PMT/PTE/pages for the space

Page Fault Handler

- in arch/i386/mm/fault.c: do_page_fault()
  - Looks up faulting address in virtual memory area list to see what kind of memory it is
- Checks common fault cases:
  - usermode/kernel mode
  - write protect / invalid
  - stack growth
  - lazy synchronization of page table
- Resolutions:
  - call handle_mm_fault
  - send SIGSEGV
  - panic()