CSE 4733/6733 - Operating System 1

S. Torri, T. Ritter

Mississippi State University

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Linear Page Tables

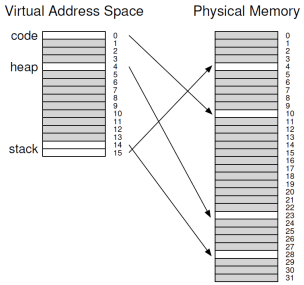

Figure 20.1: **A 16KB Address Space With 1KB Pages**

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1. Can we just make the page bigger, to make the table smaller?
   - Waste within pages - IE. Internal fragmentation
   - End up with MANY fewer jobs in-memory and memory quickly fills up
   - This is a tuneable parameter for a kernel
   - Not that simple...

Linear Page Tables

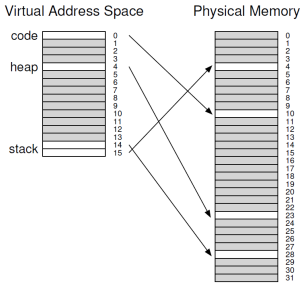
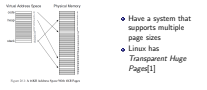


Figure 20.1: **A 16KB Address Space With 1KB Pages**

- Have a system that supports multiple page sizes
- Linux has *Transparent Huge Pages*[1]

Linear Page Tables



1. Complications?
   - A single TLB entry will map to a much larger amount of virtual memory in turn reducing the TLB misses.
   - Now use a *khugepaged* daemon to scan memory and collapse sequences of std pages into huge pages
   - Might be worth the effort for a database or other special purpose system, that why we have the libraries in Linux[2]
   - Virtual memory management becomes more complicated, latency spikes as OS moves data around and updates page entries...

Hybrid Page Table

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- User address space broken into a number of segments, with each segment into pages
- Both have strengths, paging to remove external fragmentation, segmentation lends itself to protection and sharing

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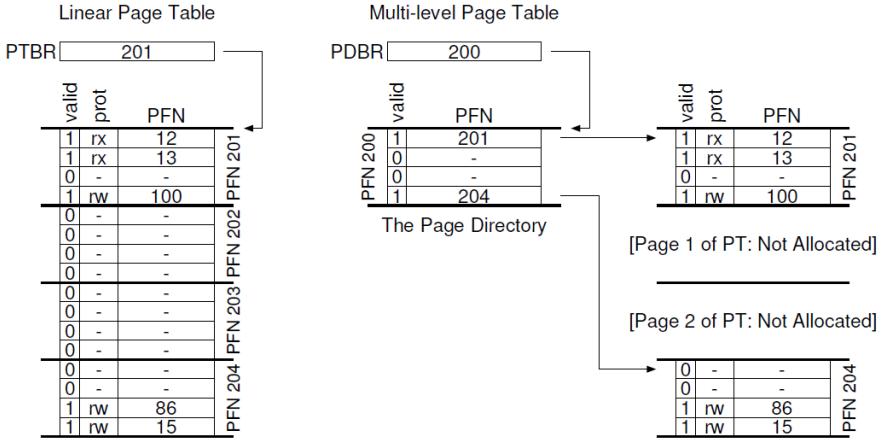
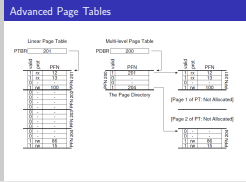
1. Comments
   - Easy base address and length calculation to protect memory bounds
   - Combined segmentation and paging has advantages, but brings back external fragmentation

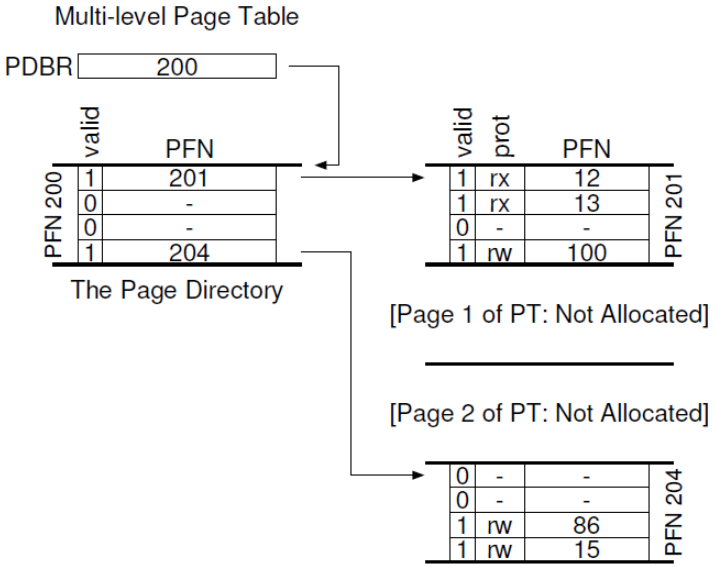
Advanced Page Tables

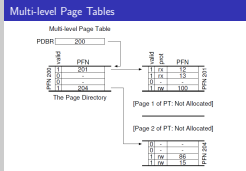




1. Note: Divide the page table into page sized chunks
   - We now have a valid flag, and a protection flag
   - If an entire page of page-table entries (PTEs) is invalid, save memory and don't allocate that page of the page table.
   - The page directory data structure results in a multi-level design with a much smaller memory footprint
   - Page directory contains either where the page table is, or if an entire page of the page table has no valid pages

Multi-level Page Tables





1. Note: Classic Trade-Off
   - We created a OS data structure with a smaller memory footprint
   - We see that a TLB *MISS* is more expensive than before
   - More page table levels are possible, what if the Page Directory is too large for a single page???
   - Supports sparse address spaces well, and page-table space is proportional to address space
   - Subtle note, valid flag in a Page Pirectory mean there is at least one page entry valid in the page where it points, unlike in the page table itself
   - More complexity in the design...

Inverted Page Table

- Create a *single* OS page table that has one entry for each real memory frame (physical page)
- Entry contains PID and what virtual page maps to that frame
- Create a simple hash function to speed up the linear search
- Inverted since the table in indexed by real memory frames, not virtual
- Page tables are a data structure that allows for trade-offs

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1. Requirements
   - Table requires PID of the process with the frame
   - Table requires control bits for valid, modified (dirty), protection, etc.
   - Table requires a chain pointer since your hash may point to the same entry as another virtual address

Swapping

- Multiprogramming, large jobs all drive an OS to support swapping
- Swap space is secondary storage, typically a disk address/chunk of space
- Need another flag - a *present bit* to determine if a page is in memory or swap
- The terminology of swapping - A *page fault* is when the OS wants to accesse a page that is not in memory

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1. Comments
   - Page faults are expected, really more of a page miss
   - Hardware will raise an exception, and the OS will have to swap the page requested into memory
   - The OS will have a page-fault handler to service page faults

Swapping

- Swapping is by nature a *slow* process compared to memory access times, the TLB is a memory cache
- This is not a hardware function, rather the OS is going to do it
- When memory is full, you have to have a Page Replacement Policy

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Swapping

- Kernel parameters of: *high watermark (HW) and low watermark (LW)*
- Linux has a *kswapd* to swap pages as needed
- When low watermark is reached then kswapd wakes to reclaim memory in the background.
- It stays awake until free memory reaches the high watermark.

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1. Comments
   - Linux kernel tuning is a complicated enterprise [3] eg. sysctl -a
   - The article quoted 49 Virtual Memory parameters out of 1,200 you can tune
   - Linux has a 3-level page table memory managment scheme and is complex
   - Swapping is normal, but low memory can make a machine work at the speed of disk I/O rather than memory I/O

References I


Free Software Foundation.
Transparent hugepage support, 2023.


Erik Rigtorp.
Using huge pages on linux, 2020.


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Fine tuning linux virtual memory, 2022.

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