CS 370: Operating Systems
[Memory Management]

Segmentation
A process is broken up
into *segments*

Each with its base and bounds
and different lengths

Each segment's
Stored contiguously
Though scattered
In physical memory

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Frequently asked questions from the previous class survey

- How do threads impact memory management?
- Address translation
  - Was address translation being performed even memory capacities were low?
  - Is address translation deterministic?
  - Does it need to be as fast as the CPU?
- How does the kernel decide *where* to place a process?
- What does "*managed by hardware*" (e.g. cache) mean?
  - Can the memory being referenced be in the cache?
- If two processes write to the same logical address, how are the accesses kept separate?
- Is having the OS reside in known regions of physical memory a security risk?

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Logical address spaces in action

```
#include <stdio.h>
#include <stdlib.h>
int main(int argc, char *argv[]) {
  printf("location of code : %p\n", main);
  printf("location of heap : %p\n", malloc(100e6));
  int x = 3;
  printf("location of stack: %p\n", &x);
  return x;
}
```

Output when run on a 64-bit Mac

```
location of code : 0x1095afe50
location of heap : 0x1096008c0
location of stack: 0x7fff691aea64
```


Topics covered in this lecture

- Contiguous memory allocations
- Fragmentations
  - External and Internal
- Segmentation
- Paging

WRAP-UP OF SWAPPING

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Factors constraining swapping besides swap time

- Process must be completely **idle**
  - No pending I/O
- Consider the case where the device is busy, so I/O is *queued*
  - Next, you swap out P_1 and swap in P_2
  - I/O operation may attempt to use P_2's memory
    - Solution 1: Never swap process with pending I/O
    - Solution 2: Execute I/O operations into OS buffers

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Swapping is not a reasonable memory management solution

- Too much swapping time; too little execution time
- Modification of swapping exists in many versions of UNIX
  - Swapping is normally disabled
  - Starts if many processes are running, and a set *threshold is breached*
  - Halted when system load reduces

Summarizing the pure Swapping based approach

- Bring in each process, in its *entirety*, into memory
- Run process for a while before eviction due to:
  - Space being needed for another process
  - Process becomes idle
    - Idle processes should not take up space in memory

Each process is contained in a single continuous section of memory

CONTIGUOUS MEMORY ALLOCATION

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Partitioning of memory

- Main memory needs to **accommodate** the OS and user processes
- Divided into two partitions
  - Resident OS
    - Usually low memory
  - User processes

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Memory Mapping and Protection

- Base register (also referred to as a *relocation* register)
  - Smallest physical address
- Limit register
  - Range of logical addresses

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Memory Mapping and Protection

- When CPU scheduler selects a process for execution
  - Base and limit registers reloaded as part of context switch
- Every address generated by the CPU
  - Checked against the relocation(base)/limit registers

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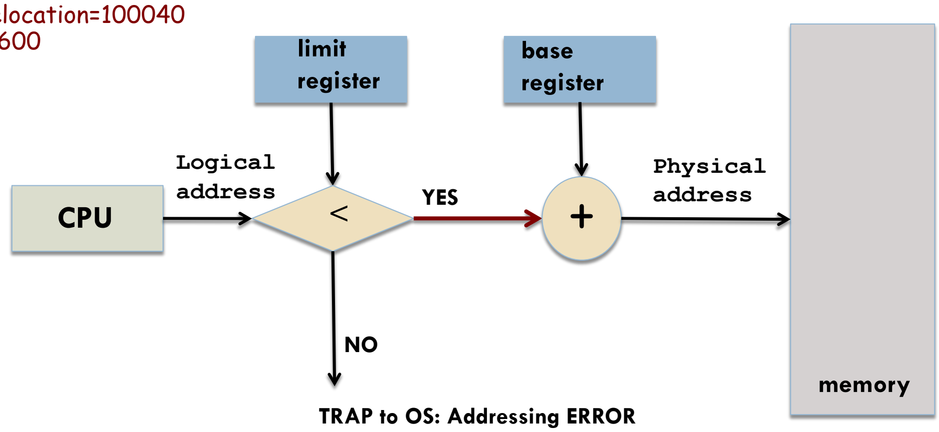
Memory Mapping and Protection

E.g.: base/relocation=100040
and limit=74600



Memory Allocation: Fixed Partition method

- **Divide** memory into several **fixed-size** partitions
  - Each partition contains exactly one process
- Degree of multiprogramming
  - Bound by the number of partitions

Memory allocation: Variable-partition method [1/2]

- Used in batch environments
- OS maintains table tracking memory utilization
  - What is available?
  - Which ones are occupied?
- Initially all memory is available
  - Considered a large **memory gap**
  - Eventually *many* memory gaps will exist

Memory allocation: Variable-partition method [2/2]

- OS orders processes according to the scheduling algorithm
- Memory allocated to processes until requirements of the next process cannot be met
  - *Wait* till a larger block is available
  - Check if smaller requirements of other processes can be met

Variable-partition method: Reclaiming spaces

- When process arrives, if space is too large
  - Split into two
- When process terminates?
  - If released memory is adjacent to other *memory gaps*
    - **Fuse** to form a larger space

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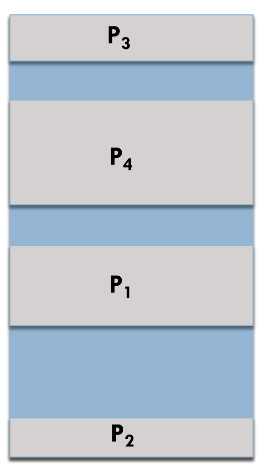
Splitting and Fusing Memory spaces



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Dynamic Storage Allocation Problem

- Satisfying a request of size ***n*** from the set of available spaces
  - First fit
  - Best fit
  - Worst fit

First fit

- Scan list of segments until you find a memory-gap that is big enough
- Gap is broken up into two pieces
  - One for the process
  - The other is unused memory

Best Fit

- Scan the entire list from beginning to the end
- Pick the smallest memory-gap that is adequate to host the process

Comparing Best Fit and First Fit

- Best fit is **slower** than first fit
- Surprisingly, best fit also results in more **wasted memory** than first fit
  - Tends to fill up memory with tiny, useless gaps

Worst fit

- How about going to the other extreme?
  - Always take the largest available memory-gap
  - Perhaps, the new memory-gap would be useful
- Simulations have shown that worst fit is not a good idea either

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Base and limits translation lacks many of the features needed to support modern programs

- Base and limits translation supports only **coarse-grained** protection at the level of the *entire* process
  - It is not possible to prevent a program from overwriting its own code, for example
  - It is also **difficult to share** regions of memory between two processes
  - Since the memory for a process needs to be contiguous …
    - Supporting dynamic memory regions, such as for heaps, thread stacks, or memory mapped files, becomes difficult to impossible

In our discussions so far …

- Logical/virtual memory is **one-dimensional**
  - Logical addresses go from 0 to some `max` value
- Many problems can benefit from having two or more **separate** logical address spaces

A compiler has many tables that are built up as compilation proceeds

- Source Text
- Symbol table
  - Names and attributes of variables
- Constants Table
  - Integer and floating point constants
- Parse tree
  - Syntactic analysis of program
- Stack
  - Procedure calls within the compiler

Grows continuously as compilation proceeds (Source Text, Symbol table, Constants Table, Parse tree)

Grows and shrinks in unpredictable ways during compilation (Stack)

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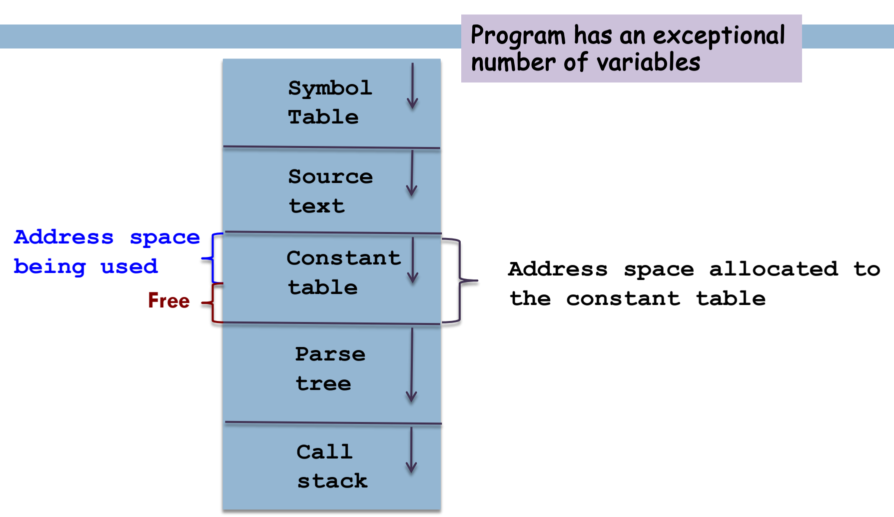
One dimensional address space with growing tables



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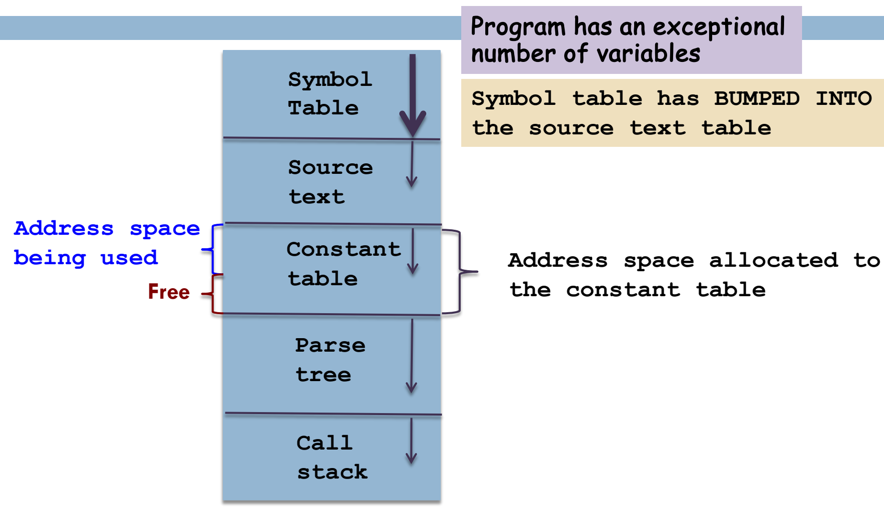
One dimensional address space with growing tables



Options available to the compiler

- Say that compilation cannot continue
  - Not cool
- Play Robin Hood
  - Take space from tables with room
  - Give to tables with little room

What would be really cool …

- Free programmer from having to manage expansion and contraction of tables

But how?

- Provide <u>many</u> completely **independent address spaces**
  - **Segments**

- Each segment has linear sequence of addresses
  - 0 to max

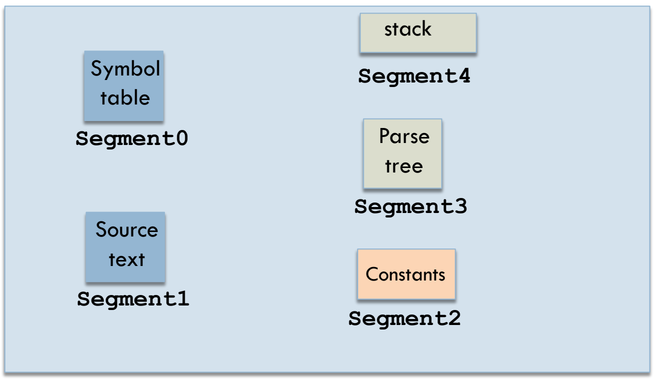
Segments and Base/Limit registers

- The hardware supports an **array** of pairs of base and bounds registers, for *each process*
  - **Segment Table**
- Each entry in the array controls a portion, or **segment**, of the virtual address space
- The physical memory for **each segment is stored contiguously**, but different segments can be stored at different locations
  - For example, code and data segments are not immediately adjacent to each other in either the virtual or physical address space

Other things about segments

- Different segments can and do have different lengths
- Segments grow and shrink independently without affecting each other; For example, consider a segment for the stack
  - Size increase: something pushed on stack segment
  - Size decrease: something popped off of stack segment

Segmentation allows users to view memory as a collection of variable-sized segments



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Segmentation

- Logical address space is a collection of segments
- Segments have name and length
- Addresses specify
  - Segment name
  - Offset within the segment
- Tuple: **`<segment-number, offset>`**

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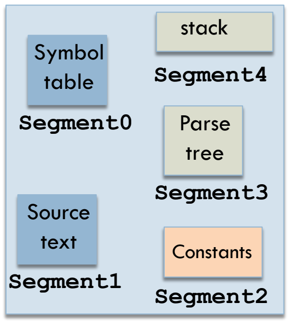
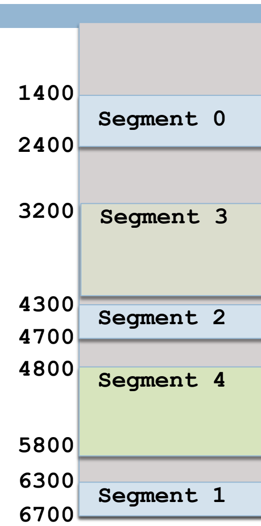
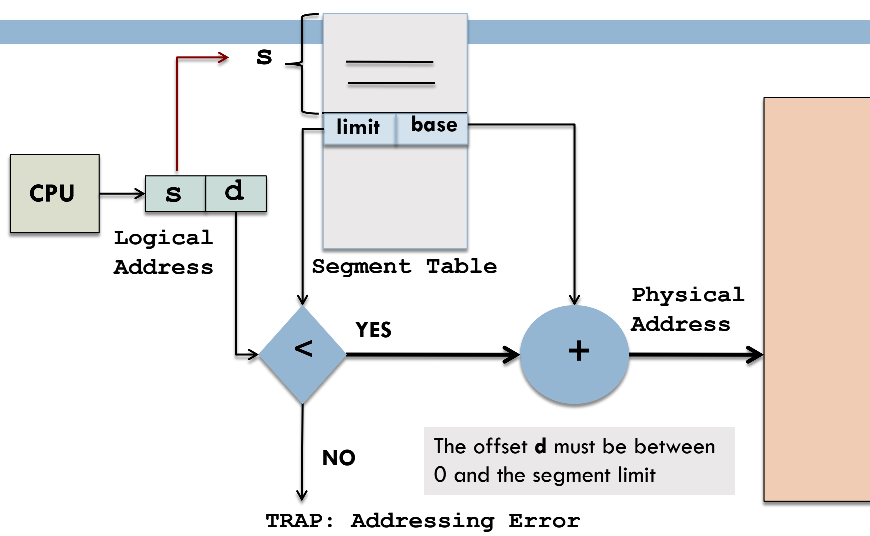
Segmentation Addressing Example



	Limit	Base
0	1000	1400
1	400	6300
2	400	4300
3	1000	3200
4	1000	4800



Segmentation Hardware



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Contiguous Memory Allocation: Fragmentation

- As processes (and segments) are loaded/removed from memory
  - Free memory space is **broken** into small pieces

- **External fragmentation**
  - Enough space to satisfy request; BUT
  - Available spaces are *not contiguous*

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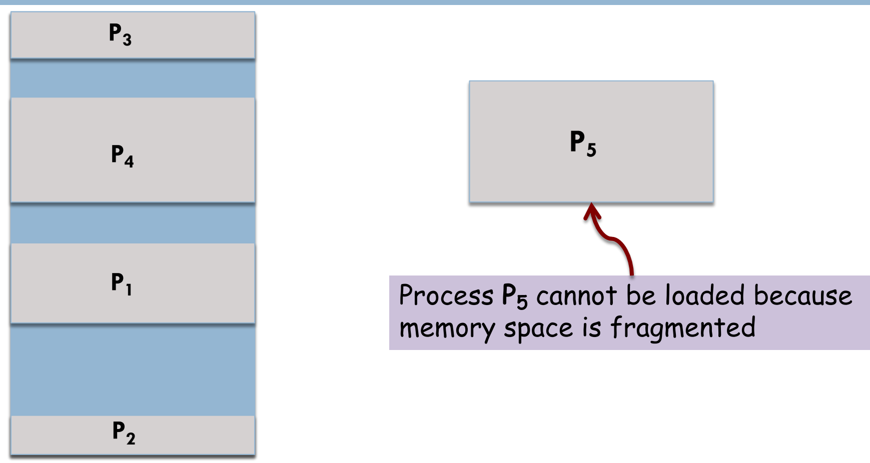
Fragmentation: Example



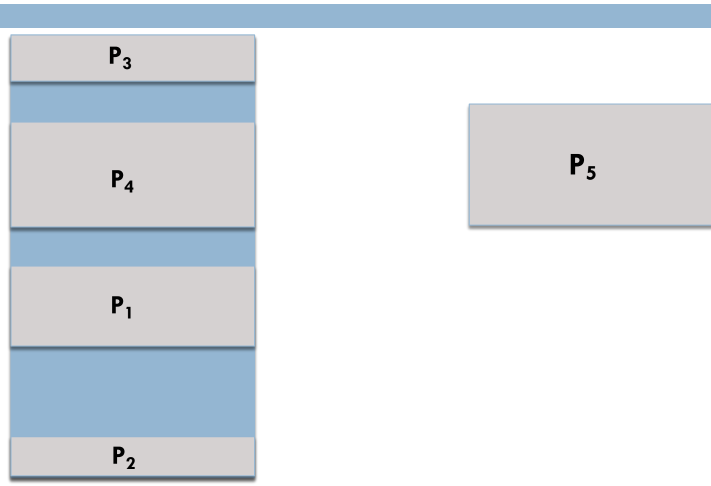
Fragmentation can be internal as well

- Memory allocated to process may be *slightly larger* than requested
- **Internal fragmentation**
  - Unused memory is internal to blocks

Compaction: Solution to external fragmentation

- **Shuffle** memory contents
  - Objective: Place free memory into large block
- Not possible if relocation is static
  - Load time
- Approach involves moving:
  1. Processes towards one end
  2. Gaps towards the other end

Compaction: Example

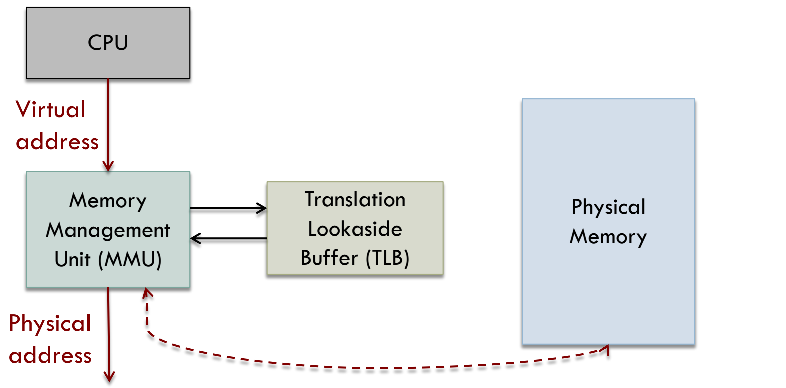


Memory compaction is time intensive and is usually not done

- Let's consider a machine with 1 GB of RAM
- The machine can copy 4 bytes in 20 nanoseconds
- Time to compact all the memory?
  10^9 x $(20\text{x}10^{-9}/4)$ = 5 seconds (approximately)
  Note: 1 GB is approximately 10^9 bytes

PAGING:
OVERVIEW OF THE MAPPING PROCESS

Overview of how mapping of logical and physical addresses is performed



MMU may access Physical Memory to perform translations
{PageTable may be stored there}

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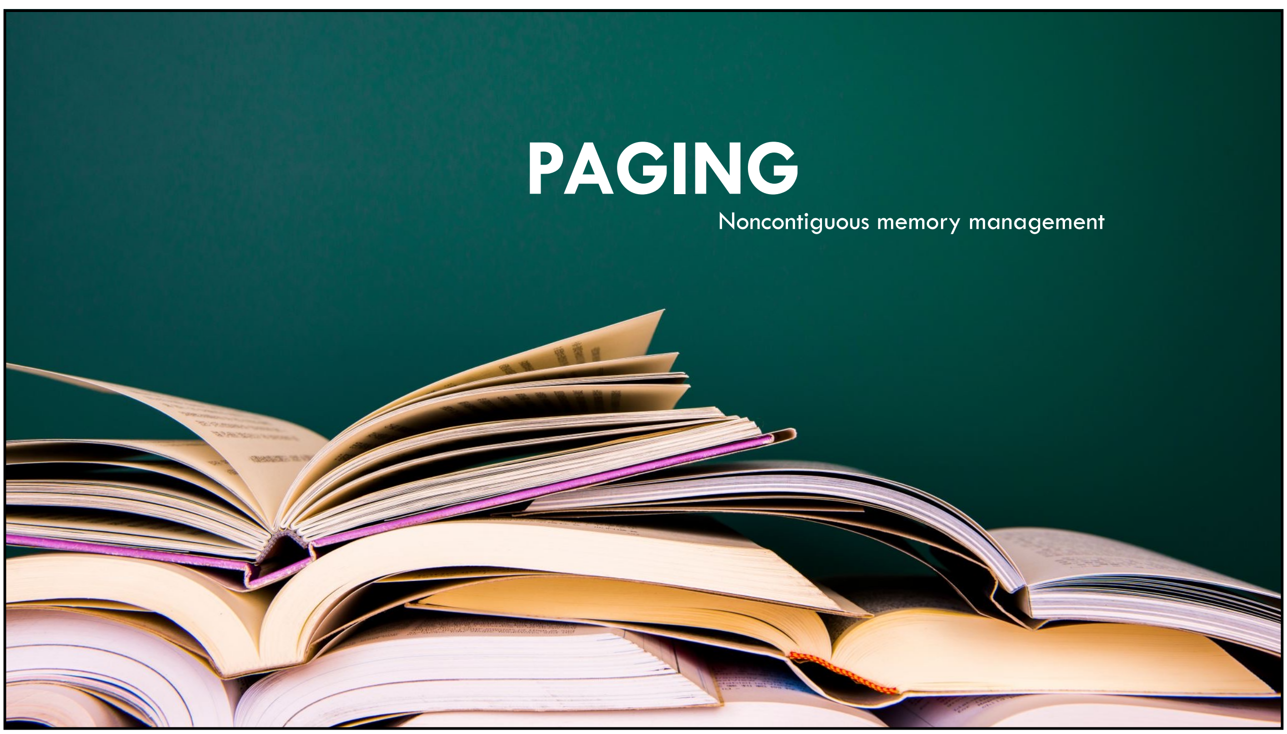

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The Paging memory management scheme

- Physical address space of process can be **non-contiguous**
- Solves problem of fitting variable-sized memory chunks to backing store
  - Backing store has fragmentation problem
    - Compaction is impossible

Basic method for implementing paging

- Break memory into **fixed-sized** blocks
  - Physical memory: **frames**
  - Logical memory: **pages**

  (frames and pages: **Same size**)
- Backing store is also divided the same way

The contents of this slide-set are based on the following references

- *Avi Silberschatz, Peter Galvin, Greg Gagne. Operating Systems Concepts, 9th edition. John Wiley & Sons, Inc. ISBN-13: 978-1118063330.* [Chapter 8]
- *Andrew S Tanenbaum and Herbert Bos. Modern Operating Systems. 4th Edition, 2014. Prentice Hall. ISBN: 013359162X/ 978-0133591620. [Chapter 3]*
- *Thomas Anderson and Michael Dahlin. Operating Systems Principles and Practice. 2nd Edition. Recursive Books. ISBN: 978-0985673529.* [Chapter 8]
- *Remzi Arpaci-Dusseau and Andrea Arpaci-Dusseau. Operating Systems: Three Easy Pieces. 1st edition. CreateSpace Independent Publishing Platform. ISBN-13: 978-1985086593. [Chapter 14]*