Computer Science 162, Fall 2014

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Midterm 2

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Name	
SID	
Login	
TA Name	
Section Time	

This is a closed book exam with one 2-sided page of notes permitted. It is intended to be a 80 minute exam. You have 80 minutes to complete it. The number at the beginning of each question indicates the points for that question. Write all of your answers directly on this paper. Make your answers as concise as possible. If there is something in a question that you believe is open to interpretation, please raise your hand to request clarification. When told to open the exam, put your login on every page and check that you have them all. (Final page is for reference.)

By my signature below, I swear that this exam is my own work. I have not obtained answers or partial answers from anyone. Furthermore, if I am taking the exam early, I promise not to discuss it with anyone prior to completion of the regular exam, and otherwise I have not discussed it with anyone who took the early alternate exam.

X_______________________________________

Grade Table (for instructor use only)

Question	Points	Score
1	25	
2	25	
3	25	
4	25	
Total:	100	

1. (25 points) **Operating Systems Concepts**

   (a) (20 points) Choose **either** true or false for the below questions. You do not need to provide justifications.

      i. (2 points) A thread that wants to signal other threads upon completion of a critical section should do so with a Condition Variable after releasing the lock.
         ◯ True
         [✓ **False**]

      ii. (2 points) By using an atomic read-modify-write instruction, a user thread can acquire a lock without entering the operating system.
         [✓ **True**]
         ◯ False

      iii. (2 points) With paged virtual address translation threads only share state when they are within the same process.
         ◯ True
         [✓ **False**]

      iv. (2 points) With paged virtual memory, an process can be started with none of its code or data pages being resident in memory.
         [✓ **True**]
         ◯ False

      v. (2 points) The size of page tables is always much smaller than the size of physical memory.
         ◯ True
         [✓ **False**]

      vi. (2 points) The offset within the page of a data element is the same in virtual memory page and physical memory page, regardless of whether a single level or multi-level page table is used.
         [✓ **True**]
         ◯ False

      vii. (2 points) With multi-level page tables, the TLB holds translations for each of the level.
         ◯ True
         [✓ **False**]

      viii. (2 points) In a Unix-style system user access rights are checked on file read and file write operations.
         ◯ True
         [✓ **False**]

      ix. (2 points) Compared to FIFO, disk scheduling using shortest-seek-time first reduces average seek time but also reduces fairness.
         [✓ **True**]
         ◯ False

      x. (2 points) If all the operations in a transaction are durably recorded in the log, the transaction can be applied to the disk store, before the final commit marker is placed in the log.
         ◯ True
         [✓ **False**]

(b) (5 points) Which of the following is true about File System operation? Select **all** the choices that apply.

- √ **The directory structure can be searched on Open and need not be examined on Read or Write.**
- ◯ The user FILE * object contains information about how the file is stored on disk.
- ◯ SCAN has shorter average seek distance than C-SCAN because it services requests while the head is moving in either direction.
- √ **If the transaction log is stored on disk, requests must be written in order, as with FIFO scheduling.**
- ◯ File Index structures are optimized to handle small and large files in the same manner.

2. (25 points) **Page Tables**
The following figure (Figure 1) shows the relevant state of a machine with 32-bit virutal address space supported by a two-level page table with 4 KB pages. The contents of several of the frames of physical memory are shown on the right with physical addresses. On the left are several machine registers, including the PC and the page table base register, which contains the physical frame number of the root page table. A 4-entry, fully associative TLB is initially all empty. Page table entries have the valid flag as the most siginificant bit and the physical frame number of valid entries in the low order bits. Other flags can be assumed to be zero for this problem.

You are to step through the three instructions whose address and dis-assembly is shown in the figure.

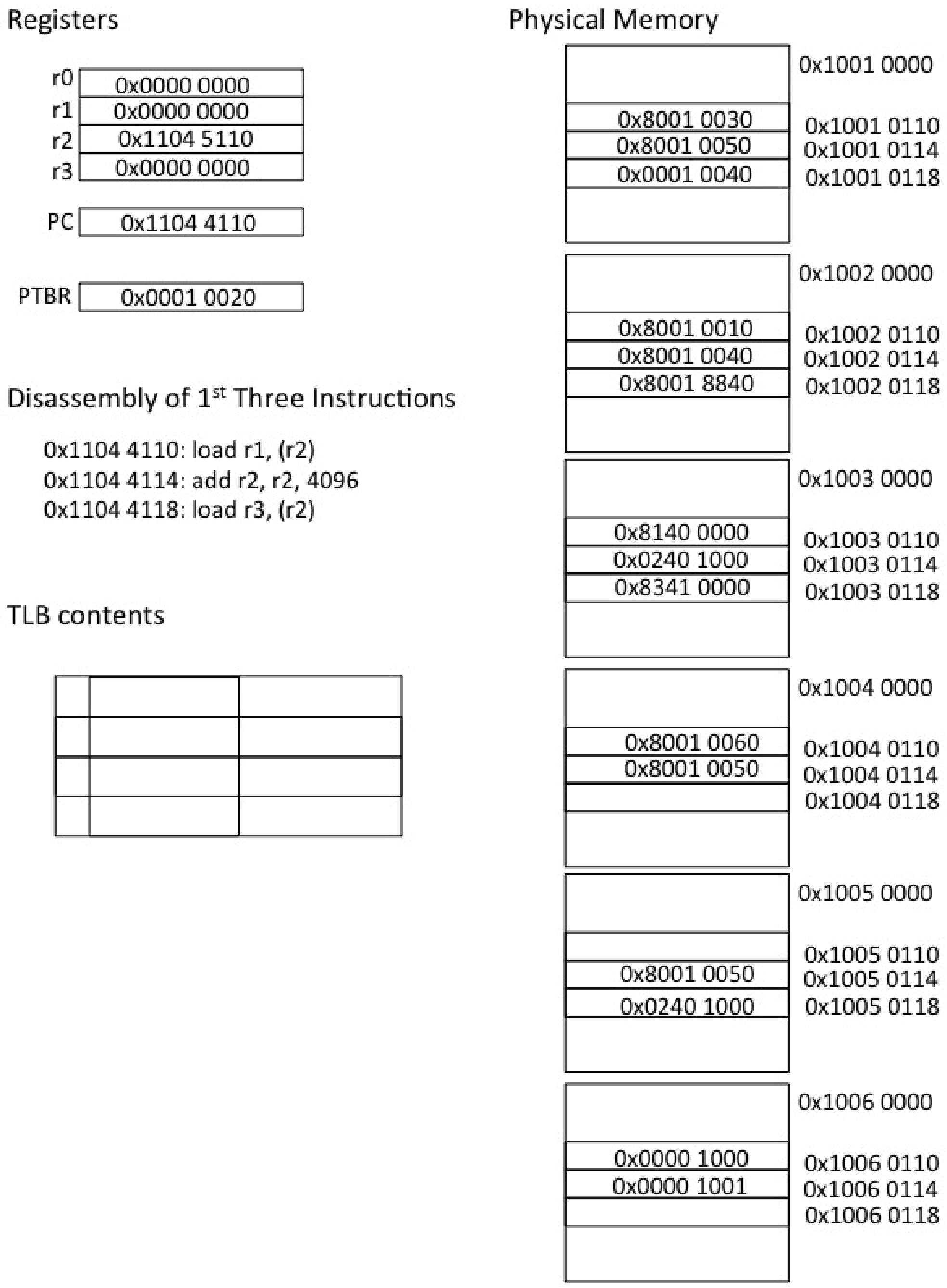
(a) (9 points) Describe which bits of the 32-bit virtual address are used for each part of the virtual address translation.

For the address of the first instruction, 0x1104 4110, show the value of each of these bit fields.

For each of the page table accesses, what is the byte offset of the page table entry that is accessed?

Solution: Bits 31-22 is the index into the root page table. The entry, if valid contains the frame number of the second level page table
Bits 21-12 is the index into the second level page table. The entry, if valid contains the frame number of the data page.
Bits 11-0 is the byte index of the data element in the data page.
In binary this is 0001 0001 0000 0100 0100 0001 0001 000
So the fields are 0001 0001 00 = 00 0100 0100 = 0x044 00 0100 0100 = 0x044 0001 0001 000 = 0x110
Each page table entry is 4 bytes in size, so the offset for both is is
0001 0001 0000 = 0x110

(b) (16 points) In the space provided below, you should write down the operation, address, and value associated with every memory operation associated with the three instructions. (You will notice that the page table entries are word aligned, 32-bit objects, hence the byte offset is 4 times the index.) Also, update the state of the memory, registers, and TLB by over-writing the figure. Identify any exceptions that are generated (but do not worry about handling them).



r0	0x0000 0000
r1	0x0000 0000
r2	0x1104 5110
r3	0x0000 0000
PC	0x1104 4110
PTBR	0x0001 0020

Disassembly of 1st Three Instructions

```
0x1104 4110: load r1, (r2)
0x1104 4114: add r2, r2, 4096
0x1104 4118: load r3, (r2)
```

TLB contents

Physical Memory

	0x1001 0000
0x8001 0030	0x1001 0110
0x8001 0050	0x1001 0114
0x0001 0040	0x1001 0118
	0x1002 0000
0x8001 0010	0x1002 0110
0x8001 0040	0x1002 0114
0x8001 8840	0x1002 0118
	0x1003 0000
0x8140 0000	0x1003 0110
0x0240 1000	0x1003 0114
0x8341 0000	0x1003 0118
	0x1004 0000
0x8001 0060	0x1004 0110
0x8001 0050	0x1004 0114
	0x1004 0118
	0x1005 0000
	0x1005 0110
0x8001 0050	0x1005 0114
0x0240 1000	0x1005 0118
	0x1006 0000
0x0000 1000	0x1006 0110
0x0000 1001	0x1006 0114
	0x1006 0118

Figure 1: Figure for question 2.

operation	address	value	comment
root PT fetch	`0x1002 0110`	`0x8001 0010`	Read valid PTE for 2nd level page

Solution:

operation	address	value	comment
root PT fetch	0x1002 0110	0x8001 0010	read valid PTE for 2nd level page
PT fetch	0x1001 0110	0x8001 0030	read valid PTE for data page
TLB add			TLB entry: 0x11044 => 0x10030
i fetch	0x1003 0110	0x8140 0000	fetch first instruction
		ld r1,(r2)	
root PT fetch	0x1002 0110	0x8001 0010	read valid PTE for 2nd level page
PT fetch	0x1000 0114	0x8001 0050	read valid PTE for data page
TLB add			TLB entry: 0x11045 => 0x10050
load	0x1005 0110	0x0040 1000	read data word
Reg WB			r1 <= 0040 1000
TLB hit			ifetch 0x1104 4114
i fetch	0x1003 0114	0x0240 1000	fetch 2nd instruction
		add r2, r2, 4096	
TLB hit			ifetch 0x1104 4118
i fetch	0x1003 0118	0x8341 0000	fetch 3rd instruction
		load r3, (r2)	
TLB miss			0x1104 6110
root PT fetch	0x1002 0110	0x8001 0010	read valid PTE for 2nd level page
PT fetch	0x1001 0118	0x0001 0040	read not-valid PTE for data page
Page Fault			VA 0x1104 6110

Grade Rubric:

2	Root PT Fetch - occurs three times
2	Second Level PT Fetch - occurs three times
2	Add Translation to the TLB - twice
2	TLB hit - occurs twice
2	TLB miss - occurs three time
2	Page Fault
1	Reg write-back
1	instruction fetch - twice
2	data load - once

3. (25 points) **File Sytems**

Consider the following file system code drawn from Pintos. You may assume all the code is run on intel x86 **32** bit architechture.

```
#define BLOCK_SIZE 4096

/* Block device that contains the file system. */
struct block *fs_device;

/* Reads sector SECTOR from BLOCK into BUFFER */
void block_read (struct block *block, block_sector_t sector, void *buffer);

/* Write sector SECTOR to BLOCK from BUFFER, mark block as not free */
void block_write (struct block *block, uint32_t sector, const void *buffer)

/* Returns one free block */
long get_free_block();

/* Marks given block as free */
void free_block(long bnum);


/* On-disk inode.
   Must be exactly BLOCK_SIZE bytes long. */
struct inode_disk
  {
    uint32_t start;                     /* First data sector. */
    long length;                        /* File size in bytes. */
    unsigned int magic;                 /* Magic number. */
    uint32_t unused[1021];               /* Not used. */
  };

/* In-memory inode. */
struct inode
  {
    struct list_elem elem;              /* Element in inode list. */
    uint32_t sector;              /* Sector number of disk location. */
    int open_cnt;                       /* Number of openers. */
    bool removed;                       /* True if deleted, false otherwise. */
    int deny_write_cnt;                 /* 0: writes ok, >0: deny writes. */
    struct inode_disk data;             /* Inode content. */
  };
```

(a) (4 points) **In fifteen words or less**, what can you say about how files are allocated on disk in this file system.
Solutions longer than 15 words will receive no credit

Solution: A file must be allocated contiguously on disk.

(b) (2 points) Recall that in the unix file system inodes had both direct and indirect block pointers. We decide in our file system we want our inodes to always be in one of two modes: either the maximum amount of direct block pointers or the maximum amount of singly indirect block pointers, but never mixed. Please modify the struct definitions below to allow that behavior. We have added the mode field for you. You may delete fields

Make the minimum number of modificatins necessary for proper functionality, extraneous modifications will incur a loss of points

```
 /* On-disk inode.
    Must be exactly BLOCK_SIZE bytes long. */
struct inode_disk
  {
    uint32_t mode;                      /* direct or indirect mode */

    ________________________________;

    ________________________________;

    ________________________________;

    long length;                        /* File size in bytes. */
    unsigned int magic;                 /* Magic number. */
    uint32_t unused[1021];               /* Not used. */
  };

/* In-memory inode. */
struct inode
  {
    struct list_elem elem;              /* Element in inode list. */
    uint32_t sector;                    /* Sector number of disk location. */
    int open_cnt;                       /* Number of openers. */
    bool removed;                       /* True if deleted, false otherwise. */
    int deny_write_cnt;                 /* 0: writes ok, >0: deny writes. */
    struct inode_disk data;             /* Inode content. */

    ________________________________;

    ________________________________;

    ________________________________;

    ________________________________;
  };
```

Solution:

```
 /* On-disk inode.
    Must be exactly BLOCK_SIZE bytes long. */
struct inode_disk
```

```
  {
    uint32_t mode;
    uint32_t data[1021];
    long length;                         /* File size in bytes. */
    unsigned int magic;                  /* Magic number. */
  };

/* In-memory inode. */
struct inode
  {
    struct list_elem elem;               /* Element in inode list. */
    uint32_t sector;                     /* Sector number of disk location. */
    int open_cnt;                        /* Number of openers. */
    bool removed;                        /* True if deleted, false otherwise. */
    int deny_write_cnt;                  /* 0: writes ok, >0: deny writes. */
    struct inode_disk data;              /* Inode content. */
  };
```

(c) (2 points) What is the maximum theoretical file size in this file system now?

Solution: 1021*1024*4096 bytes

(d) (5 points) Implement the function `fblock_to_dblock`. We have given you a skeleton. You need to complete the error checking and the operational parts.

```
/* Converts file_block_num (a block offset into the file)  to an absolute disk_block_num to
   returns -1 in the case of error.
*/
long
fblock_to_dblock (struct inode *inode, int file_block_num)
{
   long bnum;
   if ( inode->data.mode ) {

       if (_______________________________ &&

           __________________________________) {

           bnum = _______________________________________________________;

       } else {
           return -1;
       }
   } else {
       if (___________________________________ &&

           ______________________________________) {

           ______________________________________________;

           _______________________________________________;

           ______________________________________________;

           block_read(__________________________________________________);

           bnum = _______________________________________________________;

       } else {
          return -1;
       }
   }
   return bnum;
}
```

Solution:

```
 int
 fblock_to_dblock (struct inode *inode, int file_block_num, int err*)
{
    int bnum;
    if (inode->data.mode){
        if (file_block_num <= 1021 &&
            file_block_num <= inode->data->length/BLOCK_SIZE) {
            bnum = inode->data[file_block_num]
        } else {
            return -1
        }
    } else {
        if (file_block_num <= 1021*1024) {
            int indirect_bnum = file_block_num/1024;
            int offset = file_block_num % 1024;
            block_read(fs_device, indirect_bnum, buffer);
            bnum = ((uint32_t*) buffer)[offset]
        } else {
            return -1
        }
    }
    return bnum;
}
```

(e) (4 points) Now implement `inode_block_read` to support the above implementation. You may assume `fblock_to_dblock` is implemented correctly.

```
/* Tries to read BLOCK_SIZE bytes from INODE into BUFFER from file_block_num
   Returns the number of bytes actually read, which may be less
   than BLOCK_SIZE if end of file or and error is reached.
   err is filled when an error occurs
   */
long
inode_block_read (struct inode *inode, void *buffer_, int file_block_num, int* err)
{
    long bytes_read = BLOCK_SIZE;
    long sector_idx = fblock_to_dblock(inode, file_block_num);

    if (_____________________________) {

        ________________________________;

        return 0;
    }

    if (_________________________________________) {

        bytes_read = _______________________________;
    }
    block_read (fs_device, sector_idx, buffer);
    return bytes_read;
}
```

Solution:

```
/* Tries to read BLOCK_SIZE bytes from INODE into BUFFER from file_block_num
   Returns the number of bytes actually read, which may be less
   than BLOCK_SIZE if end of file or and error is reached.
   err is filled when an error occurs
   */
long
inode_block_read (struct inode *inode, void *buffer_, int file_block_num, int* err)
{
    long sector_idx = fblock_to_dblock(inode, file_block_num);
    long bytes_read = BLOCK_SIZE;

    if (sector_idx < 0) {
        *err = 1;
        return 0;
    }
    if (inode->data->length/BLOCK_SIZE == file_block_num) {
        bytes_read = inode->data->length%BLOCK_SIZE;
    }
    block_read (fs_device, sector_idx, buffer);
    return bytes_read;
}
```

(f) (4 points) Consider the below implementation of `inode_block_write`.

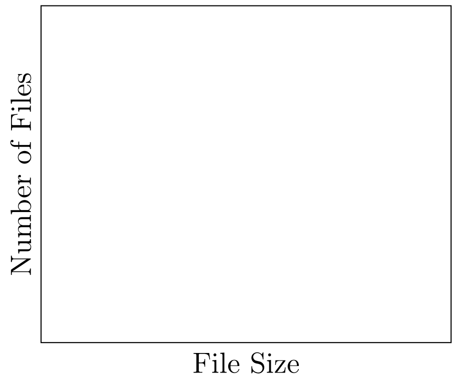
```
/* Writes BLOCK_SIZE bytes from BUFFER into INODE, starting at  file_block_num*BLOCK_SIZE
all inputs are assumed to be valid and in bounds. Zero pads if file_block_num is greater
than file size.
*/

void inode_write_block (struct inode *inode, const void *buffer_, int file_block_num, int er
{

    long bnum = fblock_to_dblock(inode, file_block_num);
    if (file_block_num > inode->data.length/BLOCK_SIZE) {
        void* zeros = calloc(BLOCK_SIZE,1);
        for (int i = inode->data.length/BLOCK_SIZE + 1; i < file_block_num; ++i){
            block_write(fs, fblock_to_dblock(inode, i), zeros);
        }
    }
    block_write(fs_device, bnum, buffer);
    inode_recalc_length(inode); // updates length field if necessary.
}
```

Assuming all inputs to `inode_write_block` are valid and in bounds, **In forty words or less**, state whether the above implementation is correct (no explanation necessary), or precisely describe the steps necessary to fix the above implementation.

Solution: Check if the `file_block_num` is greater than 1021, if so change the mode of the file, and copy all the direct block pointers into an indirect block.

(g) (4 points) Given that our superblock has a fixed size inode region $2MB$ in size Draw a histogram on the graph below to reflect the usage pattern that this file system is optimized for. Remember to label the values one ach axis so we can interpret your graph properly. Particularly consider the maximum attainable values on either axis.

Solution: We were looking for a bimodal graph with two peaks at 1021*4096 and 1021*1024*4096 bytes. The peaks should be less than $\frac{2^{21}}{2^{12}}$



4. (25 points) **Syscall Implementation**

This question requires you to implement the `dup2()` syscall.

According to the man page, `dup2(int oldfd, int newfd)` makes newfd become the copy of oldfd, closing newfd first if necessary. After a successful return the old and new file descriptors may be used interchangeably. If oldfd is not a valid file descriptor, the call fails and newfd is not closed. If oldfd is a valid file descriptor and newfd has the same value as oldfd, then dup2() does nothing. On success, these system calls return the new descriptor. On error, -1 is returned.

(a) (3 points) Below is a simple **Linux** C program which uses the `dup2()` syscall to redirect `stdin` so that executed process greps the word "cs162" from the file "cs162.txt". Fill in the blanks. Assume calls to `open` `close` and `execvp` succeed.

```
#include <stdio.h>
#include <unistd.h>
#include <fcntl.h>
#include <sys/types.h>
#include <sys/stat.h>


int main(int argc, char **argv)
{
  char *grep_args[] = {"grep", "cs162", NULL};
  int in = open("cs162.txt", O_RDONLY);

  // replace standard input with input file

  dup2(_________________________________);

  close(in);                    // close unused file descriptors
  execvp("grep", grep_args);     // execute grep
}
```

Solution:

```
 // replace standard input with input file
  dup2(in, 0);
```

(b) (5 points) Suppose you have to implement `dup2` in **Pintos**. The following code provides a framework for the **Pintos** implementation of `dup2`. You may assume `fs_lock` is properly initialized. Read it and answer the questions following.

```
struct thread
  {
    ...  /* Other members as in your pintos projects */

    /* Owned by syscall.c. */
    struct list fds;            /* List of open file descriptors. */
    int next_handle;       /* Look at the sys_open and sys_close code
                                          in the appendix to figure out its purpose */

  };
```

```
/* A file descriptor, for binding a file handle to a file object. */
struct file_descriptor
{
     struct list_elem elem;      /* List element */
     struct file *file;          /* File object */
     int handle;                 /* File handle */
};

/* Returns the file descriptor associated with the given handle.
   Returns NULL if HANDLE is not associated with an
   open file. */

static struct file_descriptor *lookup_fd (int handle) {
  struct thread *cur = thread_current ();
  struct list_elem *e;

  for (e = list_begin (&cur->fds); e != list_end (&cur->fds);
       e = list_next (e))
    {
      struct file_descriptor *fd;
      fd = list_entry (e, struct file_descriptor, elem);
      if (fd->handle == handle)
        return fd;
    }
  return NULL;
}
static struct lock fs_lock;
```

For reference on how these structures can be used to implement the syscalls `open` and `close`, refer to the appendix.

i. (3 points) What is the purpose of the lock in the functions `sys_open` and `sys_close` (given in the appendix?)

> **Solution:** To isolate this instance of open and close from all other file system calls since they might manipulate the file descriptor data structure.

ii. (2 points) What is `next_handle` member in `struct thread`?

> **Solution:** The next free file handle number.

(c) (15 points) Given this setup, implement the `dup2` system call using the skeleton below. Assume that the global syscall table calls the required functions, and copies the returned value to the eax register. You do not have to set `errno`. Make sure your code has no memory leaks. You are NOT allowed to write more lines of code than the blanks given. Assume calls to `malloc` succeed, and user programs are single-threaded. (Do not worry about modifying or bound-checking `next_handle` in this system call).

```
static int sys_dup2(int oldfd, int newfd)
   {
        /* Variable initialization
            nfd : new file_descriptor
            ofd : old file_decriptor
         */
        struct file_descriptor *nfd, *ofd;

        if (newfd == oldfd) return newfd;    /* handle special case */


        ofd = _______________________________;

        if (ofd == NULL ) {

        _____________________________________;

        }

        nfd = _______________________________;

        if (nfd == NULL ) {

        _____________________________________;

        _____________________________________;

        _____________________________________;

        } else {

        _____________________________________;

        _____________________________________;

        _____________________________________;

        }

        _____________________________________;


        return newfd;
    }
```

Solution:

```
Grading:
1. Lock acquire and release
2. Use lookup to get ofd.
```

```
3. If oldfd is not a valid file descriptor,
   then the call fails, and newfd is not closed.
4. Determine if newfd is a valid file descriptor with lookup
5. if new dup2() makes newfd be the copy of oldfd, the original newfd must be closed
6. if newfd is yet unallocated, allocate.
7. Make new same as old
All are 2 points, except 6 is 3.

static int
   sys_dup2(int oldfd, int newfd)
   {
        struct file_descriptor *nfd, *ofd;

        if (newfd == oldfd)  return newfd;

        ofd = lookup_fd(oldfd);

        if (ofd == NULL)  { /* if not a valid file descriptor, return error */
            return -1;
        }
        nfd = lookup_fd(newfd);
        if (nfd == NULL)   {
        /* Allocate a new file_descriptor.
        Push it into current thread's file descriptor table */
            nfd = malloc(sizeof(struct file_descriptor));
            nfd->handle = newfd;
            list_push_front (&thread_current ()->fds, &nfd->elem);
        } else {

            lock_acquire(&fs_lock);
   file_close (nfd->file);
   lock_release(&fs_lock);
         }

        nfd->file = ofd->file;              /* Make new file same as old file */

        return newfd;
}
```

(d) (2 points) Consider the user program in part(a) running in Pintos as well as Linux. Why does this program work as expected (i.e grep has its input redirected from cs162.txt) in Linux but not in Pintos ? (Assume that `execvp` is replaced by `exec` in Pintos, and the arguments to `exec` are valid)

Solution: Pintos : File descriptors are not maintained across exec(). Linux : File descriptors remain . Only process image is modified.

```
/************Reference Syscall Implementation **********************/

static int sys_open (const char *ufile) {
    // Copy userspace pointer to kernel space
    char *kfile = copy_in_string (ufile);
    struct file_descriptor *fd;
    int handle = -1;

    fd = malloc (sizeof *fd);
    if (fd != NULL) {
        lock_acquire (&fs_lock);
        fd->file = filesys_open (kfile);
        if (fd->file != NULL)
          {
            struct thread *cur = thread_current ();
            handle = fd->handle = cur->next_handle++;
            list_push_front (&cur->fds, &fd->elem);
          }
        else
          free (fd);
        lock_release (&fs_lock);
      }
    palloc_free_page (kfile);
    return handle;
}

/* Close system call. */
static int
sys_close (int handle){
  struct file_descriptor *fd = lookup_fd (handle);
  lock_acquire (&fs_lock);
  file_close (fd->file);
  lock_release (&fs_lock);
  list_remove (&fd->elem);
  free (fd);
  return 0;
}


/**************************** String Processing ****************/
char *strcpy(char *dest, const char *src);
char *strncpy(char *dest, const char *src, size_t n);

pid_t wait(int *status);
pid_t waitpid(pid_t pid, int *status, int options);
```

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DO NOT WRITE ANSWERS ON THIS PAGE