12.15 Consider a file system on a disk that has both logical and physical block sizes of 512 bytes. Assume that the information about each file is already in memory. For each of the three allocation strategies (contiguous, linked, and indexed), answer these questions:

a. How is the logical-to-physical address mapping accomplished in this system? (For the indexed allocation, assume that a file is always less than 512 blocks long.)

b. If we are currently at logical block 10 (the last block accessed was block 10) and want to access logical block 4, how many physical blocks must be read from the disk?

12.16 Consider a file system that uses inodes to represent files. Disk blocks are 8 KB in size, and a pointer to a disk block requires 4 bytes. This file system has 12 direct disk blocks, as well as single, double, and triple indirect disk blocks. What is the maximum size of a file that can be stored in this file system?

12.17 Fragmentation on a storage device can be eliminated by recompaction of the information. Typical disk devices do not have relocation or base registers (such as those used when memory is to be compacted), so how can we relocate files? Give three reasons why recompacting and relocation of files are often avoided.

12.18 Assume that in a particular augmentation of a remote-file-access protocol, each client maintains a name cache that caches translations from file names to corresponding file handles. What issues should we take into account in implementing the name cache?

12.19 Explain why logging metadata updates ensures recovery of a file system after a file-system crash.

12.20 Consider the following backup scheme:

- **Day 1**. Copy to a backup medium all files from the disk.
- **Day 2**. Copy to another medium all files changed since day 1.
- **Day 3**. Copy to another medium all files changed since day 1.

This differs from the schedule given in Section 12.7.4 by having all subsequent backups copy all files modified since the first full backup. What are the benefits of this system over the one in Section 12.7.4? What are the drawbacks? Are restore operations made easier or more difficult? Explain your answer.

Programming Problems

The following exercise examines the relationship between files and inodes on a UNIX or Linux system. On these systems, files are represented with inodes. That is, an inode is a file (and vice versa). You can complete this exercise on the Linux virtual machine that is provided with this text. You can also complete the exercise on any Linux, UNIX, or

Mac OS X system, but it will require creating two simple text files named `file1.txt` and `file3.txt` whose contents are unique sentences.

12.21 In the source code available with this text, open `file1.txt` and examine its contents. Next, obtain the inode number of this file with the command

```
ls -li file1.txt
```

This will produce output similar to the following:

```
16980 -rw-r--r-- 2 os os 22 Sep 14 16:13 file1.txt
```

where the inode number is boldfaced. (The inode number of `file1.txt` is likely to be different on your system.)

The UNIX `ln` command creates a link between a source and target file. This command works as follows:

```
ln [-s] <source file> <target file>
```

UNIX provides two types of links: (1) **hard links** and (2) **soft links**. A hard link creates a separate target file that has the same inode as the source file. Enter the following command to create a hard link between `file1.txt` and `file2.txt`:

```
ln file1.txt file2.txt
```

What are the inode values of `file1.txt` and `file2.txt`? Are they the same or different? Do the two files have the same—or different—contents?

Next, edit `file2.txt` and change its contents. After you have done so, examine the contents of `file1.txt`. Are the contents of `file1.txt` and `file2.txt` the same or different?

Next, enter the following command which removes `file1.txt`:

```
rm file1.txt
```

Does `file2.txt` still exist as well?

Now examine the `man` pages for both the `rm` and `unlink` commands. Afterwards, remove `file2.txt` by entering the command

```
strace rm file2.txt
```

The `strace` command traces the execution of system calls as the command `rm file2.txt` is run. What system call is used for removing `file2.txt`?

A soft link (or symbolic link) creates a new file that "points" to the name of the file it is linking to. In the source code available with this text, create a soft link to `file3.txt` by entering the following command:

```
ln -s file3.txt file4.txt
```

After you have done so, obtain the inode numbers of `file3.txt` and `file4.txt` using the command

```
ls -li file*.txt
```

Are the inodes the same, or is each unique? Next, edit the contents of `file4.txt`. Have the contents of `file3.txt` been altered as well? Last, delete `file3.txt`. After you have done so, explain what happens when you attempt to edit `file4.txt`.

Bibliographical Notes

The MS-DOS FAT system is explained in [Norton and Wilton (1988)]. The internals of the BSD UNIX system are covered in full in [McKusick and Neville-Neil (2005)]. Details concerning file systems for Linux can be found in [Love (2010)]. The Google file system is described in [Ghemawat et al. (2003)]. FUSE can be found at http://fuse.sourceforge.net.

Log-structured file organizations for enhancing both performance and consistency are discussed in [Rosenblum and Ousterhout (1991)], [Seltzer et al. (1993)], and [Seltzer et al. (1995)]. Algorithms such as balanced trees (and much more) are covered by [Knuth (1998)] and [Cormen et al. (2009)]. [Silvers (2000)] discusses implementing the page cache in the NetBSD operating system. The ZFS source code for space maps can be found at http://src.opensolaris.org/source/xref/onnv/onnv-gate/usr/src/uts/common/fs/zfs/space_map.c.

The network file system (NFS) is discussed in [Callaghan (2000)]. NFS Version 4 is a standard described at http://www.ietf.org/rfc/rfc3530.txt. [Ousterhout (1991)] discusses the role of distributed state in networked file systems. Log-structured designs for networked file systems are proposed in [Hartman and Ousterhout (1995)] and [Thekkath et al. (1997)]. NFS and the UNIX file system (UFS) are described in [Vahalia (1996)] and [Mauro and McDougall (2007)]. The NTFS file system is explained in [Solomon (1998)]. The Ext3 file system used in Linux is described in [Mauerer (2008)] and the WAFL file system is covered in [Hitz et al. (1995)]. ZFS documentation can be found at http://www.opensolaris.org/os/community/ZFS/docs.

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[Hitz et al. (1995)] D. Hitz, J. Lau, and M. Malcolm, "File System Design for an NFS File Server Appliance", Technical report, NetApp (1995).