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**Hensley**

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(54) **EMULATED READ-WRITE DISK DRIVE USING A PROTECTED MEDIUM**

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(58) **Field of Classification Search** ..... 703/25, 703/24; 719/322, 326; 707/205, 202  
See application file for complete search history.

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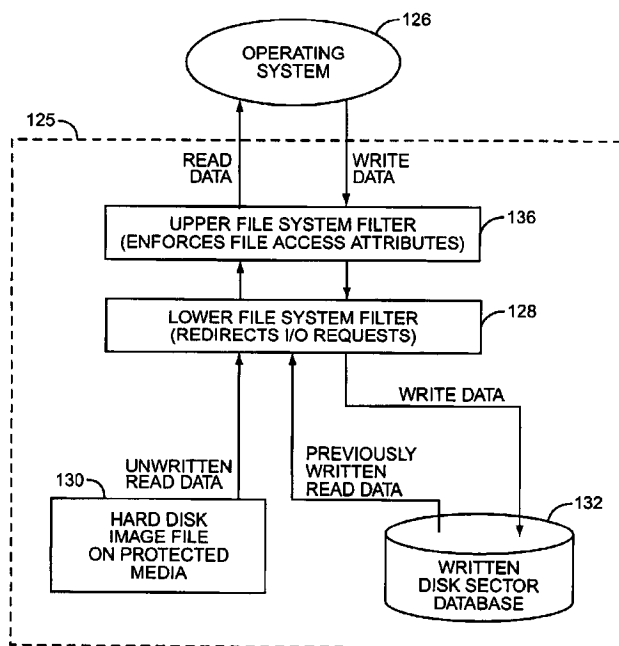
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(57) **ABSTRACT**

A read-write hard disk drive is emulated using a hard disk drive image file on a protected medium such as a CD-ROM, a written disk sector database, and file system filters. A file system filter intercepts file I/O requests from the operating system. Initial read requests are serviced from the hard disk drive image file. Write operations are directed to a database, such as in RAM. Subsequent read requests for previously written data are serviced from the database. Another file system filter monitors attempts to alter the file access attributes, and prevents pre-existing read-only files on the emulated drive from being written or deleted. The maximum size of the written disk sector database is the sum of sectors on the hard disk drive image file allocated to read-write files and free space. The emulated read-write hard disk drive allows for the execution of programs requiring a read-write native media.

**15 Claims, 7 Drawing Sheets**



# US 6,999,913 B2

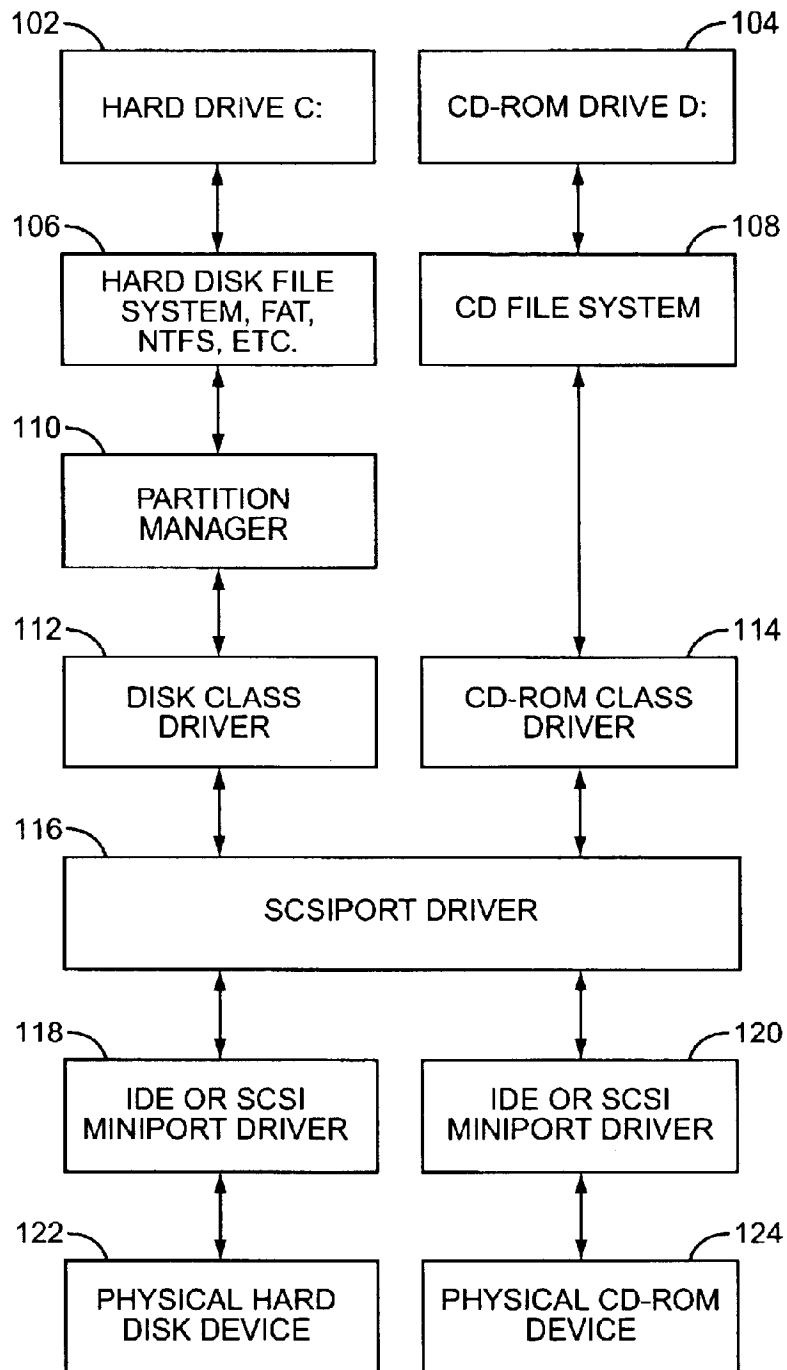
Page 2

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**FIG. 1**  
**(PRIOR ART)**

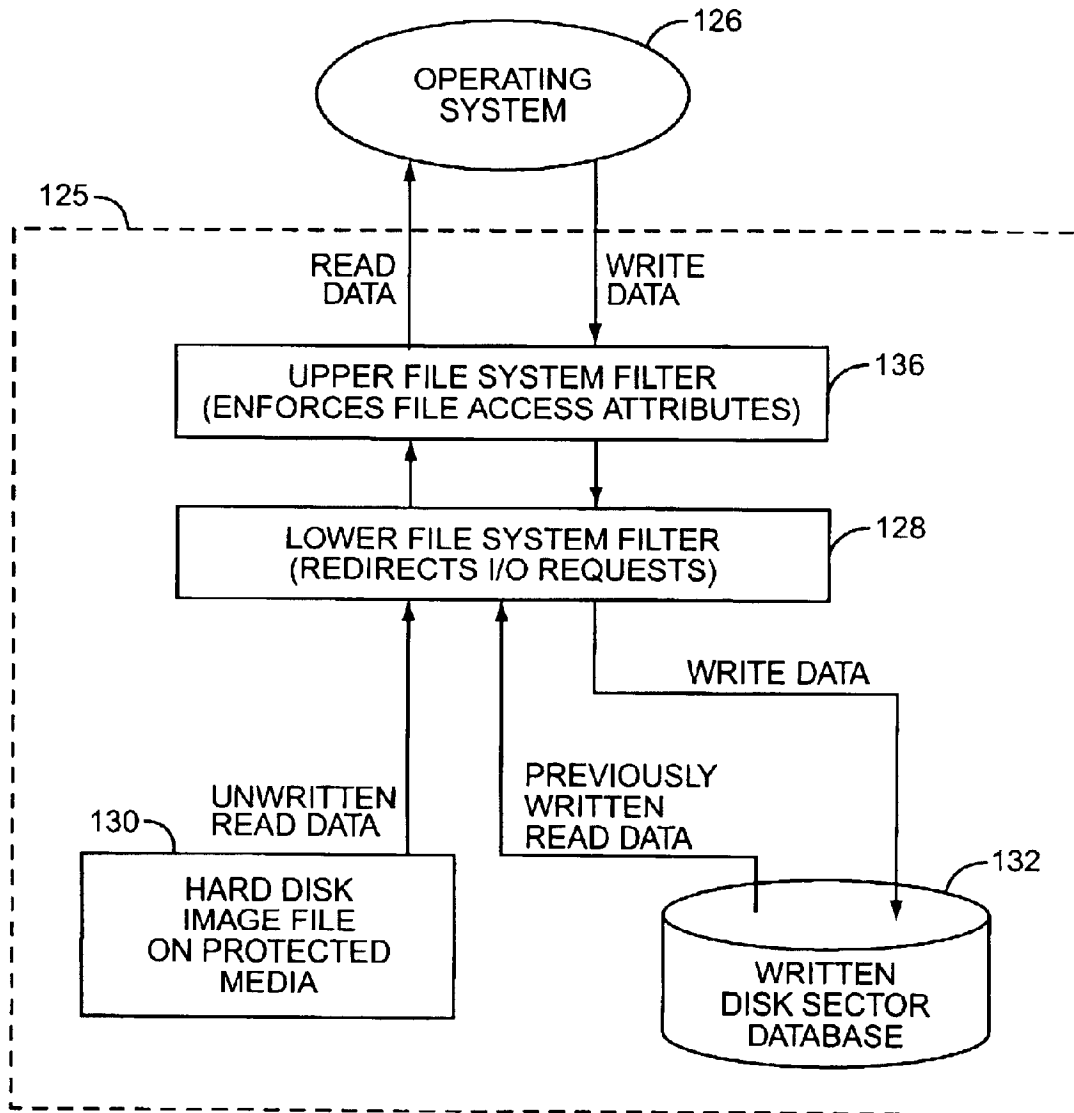


FIG. 2

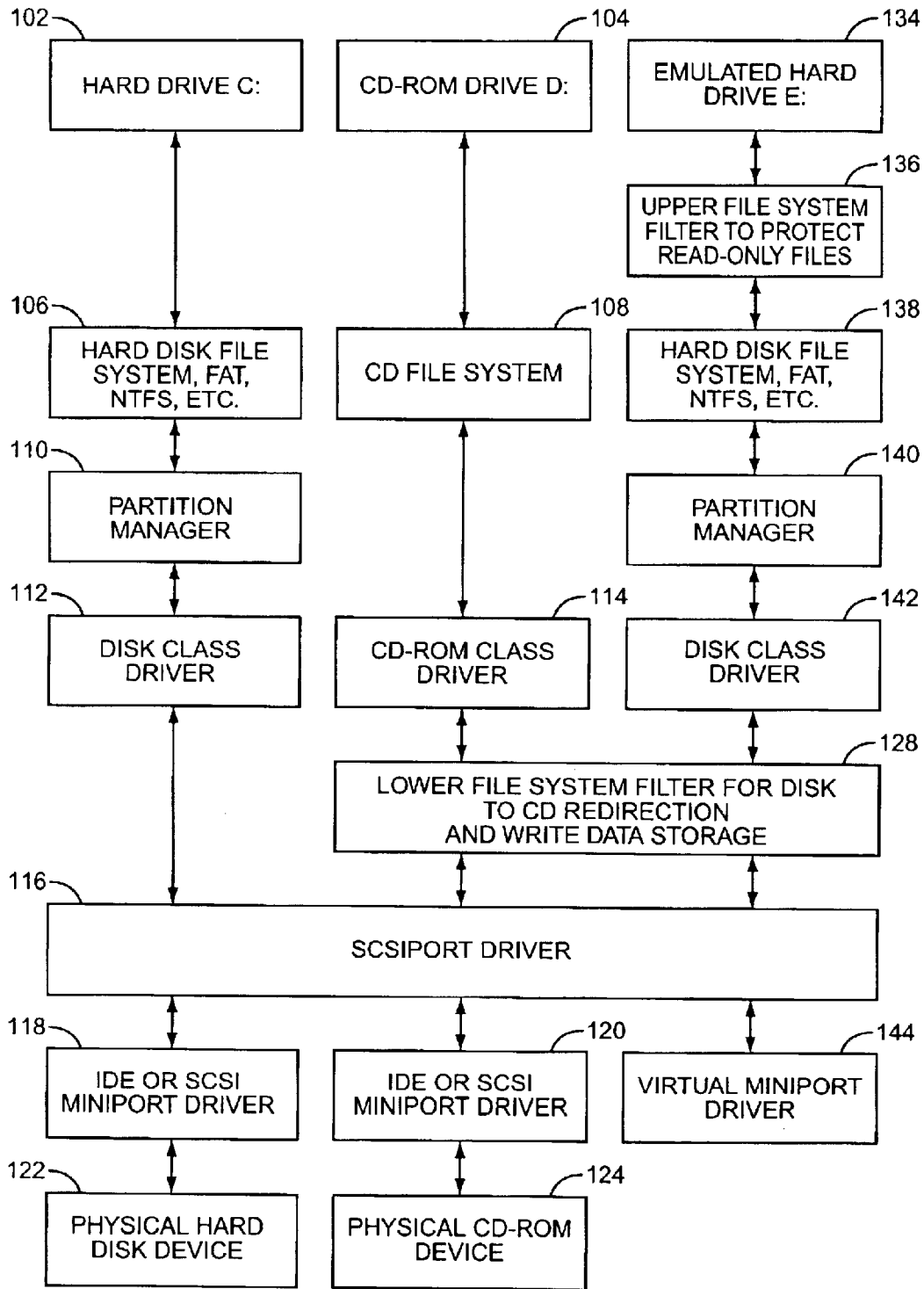


FIG. 3

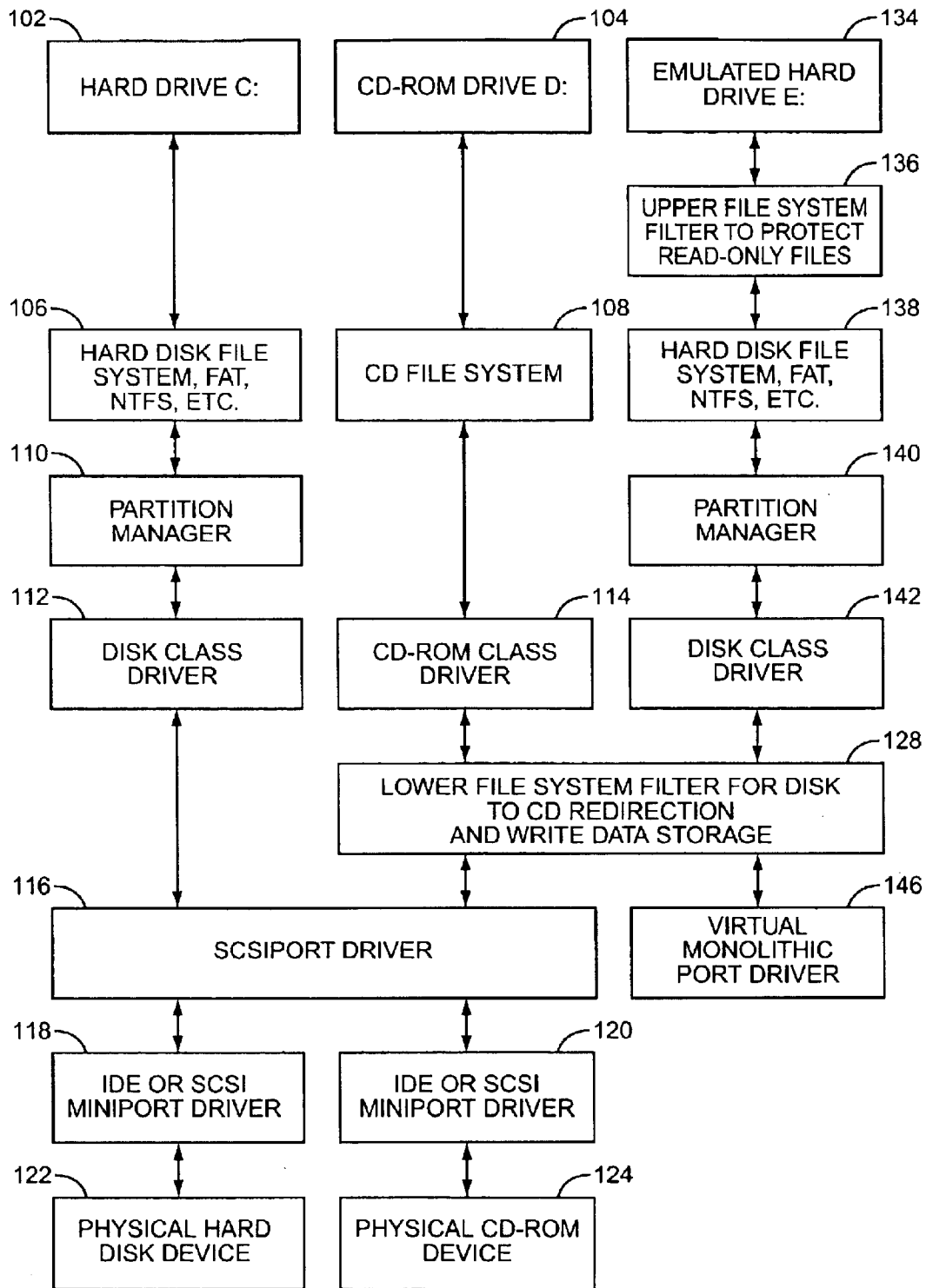


FIG. 4

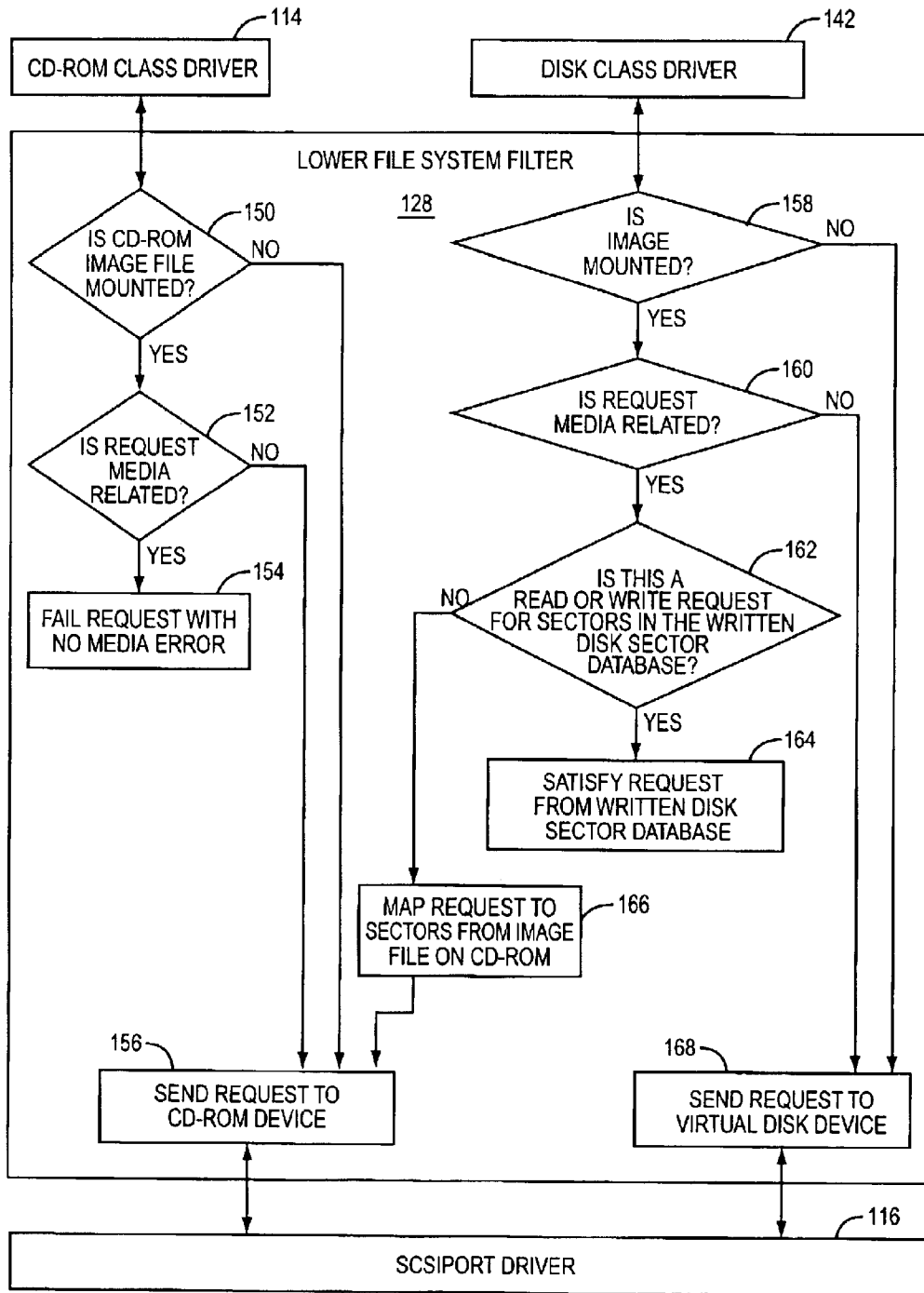


FIG. 5

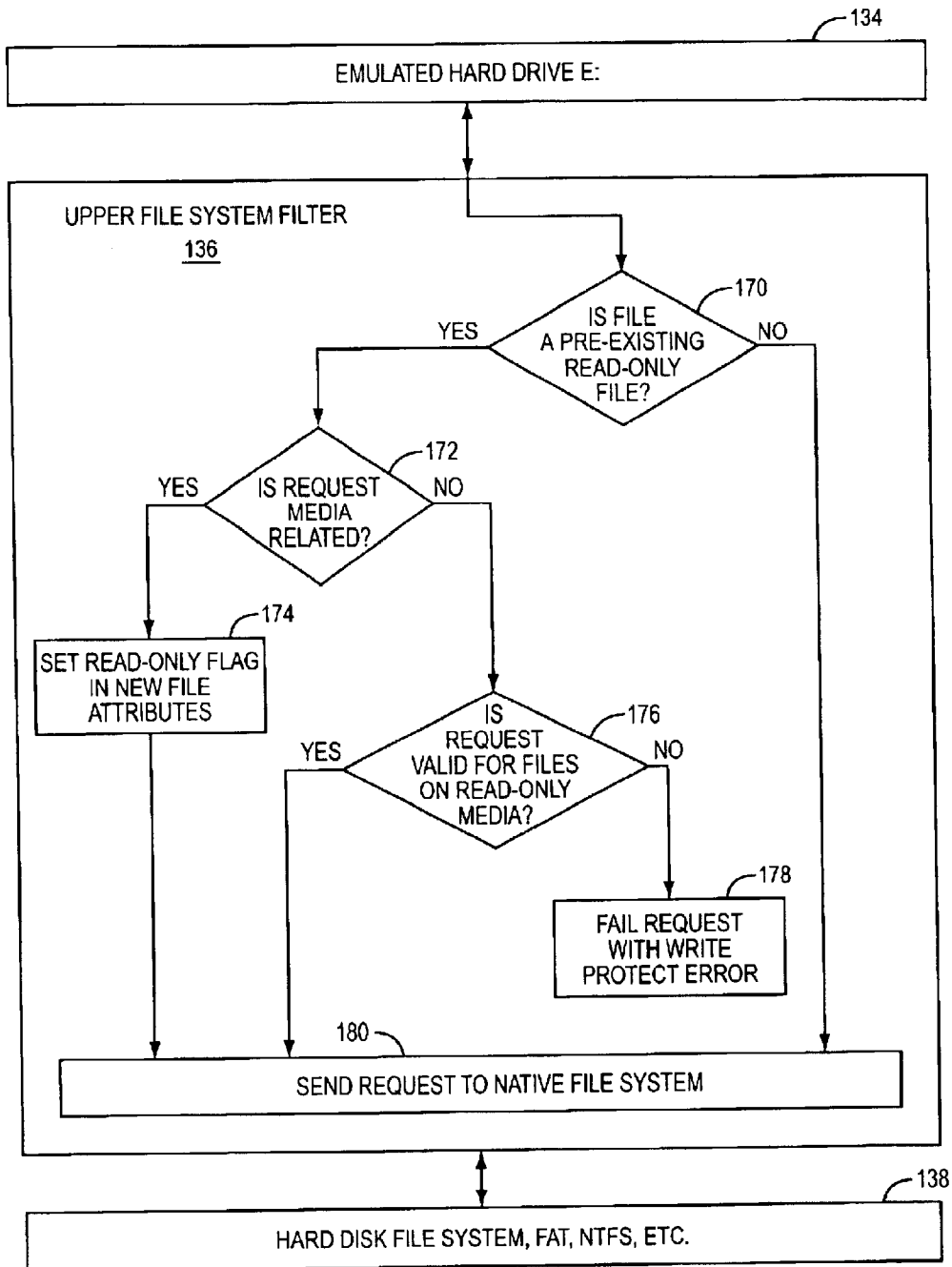


FIG. 6



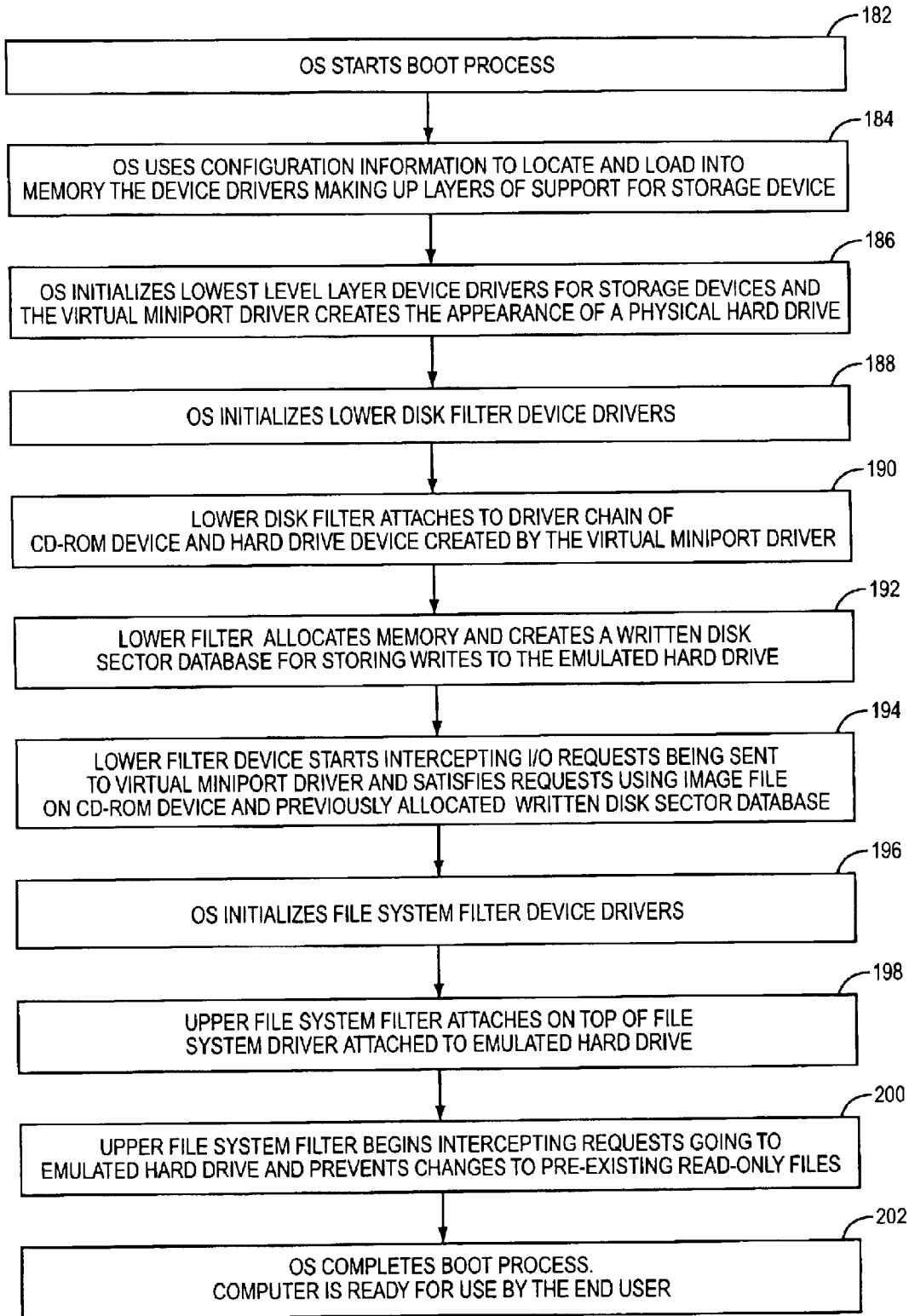


FIG. 7

## EMULATED READ-WRITE DISK DRIVE USING A PROTECTED MEDIUM

### BACKGROUND OF THE INVENTION

The present invention relates generally to the field of computers, and specifically to an emulated read-write disk drive implemented using a protected medium.

Protected, or read-only media devices, such as CD-ROM and DVD-ROM, have become ubiquitous parts of modern computer systems, with a CD-ROM and/or DVD-ROM drive standard equipment on the vast majority of computers. In addition, CD-ROM and DVD-ROM "burners," or drives capable of writing data to these traditionally read-only media, have proliferated to the extent that nearly all personal computer manufacturers offer a CD-ROM burner or DVD-ROM burner as standard equipment on the machines they sell. The drives are additionally available as peripheral equipment, communicating with the computer via a variety of interfaces such as IDE, SCSI, and the like.

A cost effective means for a computer user to safely archive large quantities of computer programs and data is to use a CD-ROM or DVD-ROM burner and save the data onto Write Once Read Many (WORM) media, or alternatively, a "re-writable" media. In either case, after data has been burned onto the CD-ROM or DVD-ROM and the media session has been closed, the data is protected from any changes and will appear as a read-only disk to the computer's host operating system and to the computer user.

While archiving data in a read-only format on protected media is cost effective, it imposes fundamental limitations on the way the archived data may be used. The standard file-system formats used on CD-ROM and DVD-ROM media were designed with characteristics specific to read-only media. For example, they limit direct use of data archived on the media to computer programs that were explicitly written to work with read-only files. As such, programs that rely on native file-system security features unable to directly use files archived on protected media. The read-only characteristics of protected media also preclude many executable programs from running directly from the media. For example, an executable program may need to write temporary files to the directory from which it was started, such as for scratch space, semaphores to synchronize with other programs or threads, alterations to the operating system registry, or the like. As one consequence of the inability of many executable programs to run directly from protected media, most modern computer operating systems, which were designed to operate natively on a read-write storage device such as a hard drive, are unable to load and execute from a protected medium.

Methods are known in the art that allow data on protected, or read-only, media to be dynamically modified. These methods intercept file and directory read and write requests before they reach the operating system's native CD-ROM file-system driver, and dynamically change the appearance of the data in the directories and files located on the protected media. Such methods are useful, for example in "patching" a bug in a file distributed on a CD-ROM, without the necessity to send the user an updated CD-ROM disk. The file and directory access requests to effect the modifications must be intercepted before they reach the operating system's native CD-ROM file-system driver, because the native CD-ROM file-system driver typically does not normally support write operations and will fail such requests. These prior art methods change only the appearance of the

directories, files and data on the protected media as seen by the operating system, and not the characteristics of the native file-system. That is, the operating system, and application programs, will still see a read-only device, with read-only files and directories; the modification changes only the appearance of the data returned.

Other prior art methods, such as those used in Embedded XP product from Microsoft Corporation, use device drivers to emulate a read-write hard drive, using the image of a hard drive on a CD-ROM or other protected media device, in combination with a write cache to emulate write operations to the emulated hard drive. Such methods provide the operating system with a device that has all of the characteristics of a read-write hard drive device. This method of providing read-write functionality using a protected media presents several disadvantages. The method dispenses with some advantages of the protected media, such as the enforcement of read-only file attributes. By emulating a generic read-write device, a user may remove the read-only attribute from a file and then delete that file. This would give the appearance of the file being deleted and of additional free space being created on the emulated hard drive. A related disadvantage of emulating a generic read-write device in this manner is that there is no way to accurately predict in advance the total amount writeable storage that will be needed (i.e., the size of the write cache is not bounded), and thus available resources may be exceeded. For example, a CD-ROM may hold an image file of a 650 megabyte read-write hard drive; if such a device is emulated on a personal computer that has only 128 megabytes of writeable memory available, the system may run out of write space.

### SUMMARY OF THE INVENTION

The present invention relates to a method of emulating a computer storage device having read and write capabilities using a protected media having read-only access. A computer storage device image file including at least one file having a file access attribute is provided on a protected media. A written disk sector database is provided, such as in RAM. A file system filter intercepts file access requests from the operating system. For write requests to files having a read-write access attribute, the write data are directed to the written disk sector database. For read requests, data is supplied from the written disk sector database if the file has previously been written, and is supplied from a corresponding file on the protected media if the file has not previously been written. For write requests, delete requests, or requests to change file access attributes to files having a read-only attribute, the requests are failed.

### BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a diagram of prior art file system hierarchical filters and drivers.

FIG. 2 is a functional block diagram of the emulated read-write hard disk drive of the present invention.

FIG. 3 is a diagram of a file system of a computer implementing one embodiment of the emulated read-write hard disk drive of the present invention.

FIG. 4 is a diagram of a computer file system according to a different embodiment of the emulated read-write hard disk drive of the present invention.

FIG. 5 is a flow diagram representation of a lower file system filter.

FIG. 6 is a flow diagram representation of an upper file system filter.

FIG. 7 is a flow diagram of a boot process by which the emulated read-write hard disk drive of the present invention may be implemented and initialized.

### DETAILED DESCRIPTION OF THE INVENTION

The present invention relates to the use of protected media to emulate a read-write disk drive. As used herein, the term "protected media" refers to computer-readable data storage media that has or enforces read-only characteristics at the time of the hard disk emulation of the present invention. Traditional CD-ROM and DVD-ROM discs are examples of protected media, as are ROM, PROM, EEPROM, and similar read-only solid-state memories. The term also applies to CD-R and CD-RW media (as well as DVD+R, DVD+RW, and other optical storage media of any size, capacity, or format), which may be written one or more times, but at the close of such media session, have the characteristics of read-only media. Protected media also include magnetic storage media that have been rendered read-only, at the time of disk emulation according to the present invention, by the use of a "write protect" feature. The term is to be construed broadly.

Computer systems access data from, and store data to, a variety of data storage devices, or drives. Modern operating systems provide a layered hierarchy of support for, and access to, the storage devices, as depicted in FIG. 1. The various layers of device and file system drivers are typically loaded into memory and initialized during a system initialization, or boot, procedure. The layered approach allows the operating system, and other programs running within the operating system environment, to access files stored on the underlying storage media without specific knowledge of the underlying file system or hardware protocols. The use of a layered driver model in modern operating systems enhances the portability of programs, allows programs to execute on a wide range of hardware configurations, and allows for the incorporation of new storage technology into existing computers without the need to update all applications to take advantage of the new hardware. As discussed more fully herein, the layered driver model also makes it possible to change the apparent characteristics of a physical or virtual storage device, or of files located on a storage medium, by providing appropriate filters and drivers in the layer hierarchy.

As used herein, the term "file system filter" refers to filters, device drivers, or other software modules anywhere within the layered hierarchy as depicted in FIGS. 1, 2, 3, and 4. Note that some such filters at the lower levels, i.e., next to the hardware devices, may be independent of any specific file system, and may operate on a block I/O level. This allows the emulated read-write disk drive of the present invention to be implemented on a variety of systems, independent of the specific file system(s) the systems support. Such lower level filters are referred to herein as "file system filters" for consistency; the term is meant to be construed inclusively, and is not limited to filters operating within, or aware of, only certain specific file systems.

FIG. 1 depicts a functional hierarchy of system components and device drivers that translate operating system views of storage devices (i.e., C: or D: drives) to the corresponding physical drive devices. The operating system provides standard interfaces to storage devices for use by application programs, such as the hard drive C: **102** and CD-ROM drive D: **104**. Additional drive interfaces such as floppy drives, tape units, and the like are not shown; also, the

use of a CD-ROM drive in this explanation is representative of a protected media drive, and is not limiting. The operating system standard drive interfaces **102**, **104** allow programs running within the operating system environment to access files on the underlying media. The disk file system driver **106** and CD-ROM file system driver **108** provide services for accessing individual files within the respective file systems on the respective underlying media. The partition manager **110** provides access to data within each of a plurality of partitions that may exist on the hard disk. The disk class driver **112** and CD-ROM class driver **114** provide a means of accessing features that are specific to the underlying devices. The SCSIport driver **116** converts I/O requests into a standard format that is understood by the underlying miniport drivers **118** and **120**. The miniport drivers **118**, **120** understand the controllers on which the physical devices **122**, **124** are attached, and process I/O requests from the SCSIport driver **116**. Finally, the physical hard disk drive device **122** and CD-ROM drive device **124** read data from (and, in the case of the hard disk drive **122**, store data to) non-volatile magnetic or optical data storage media, respectively.

FIG. 2 depicts, in functional block diagram form, an emulated read-write hard disk drive **125** on which file attributes are preserved, according to the present invention. From the point of view of the operating system **126**, the emulated read-write disk drive is indistinguishable from a physical hard disk drive (such as logical disk drive **102**, implemented by physical hard disk drive **122** and the intervening layered file system and device drivers as depicted in FIG. 1). Both an upper file system filter **136** and a lower file system filter **128**, as described in greater detail below, are inserted within the layered hierarchy of file system and device drivers (not shown) associated with the emulated read-write hard disk drive **125**. The lower file system filter **128** intercepts read and write requests directed to the emulated drive **125**. Initial read requests, that is, read requests directed to files or data not previously written, are serviced from a hard disk image file **130** residing on protected media, such as a CD-ROM. Write requests directed to the emulated hard disk drive **125** are intercepted by the lower file system filter **128**, and directed to a written disk sector database **132**. The written disk sector database **132** may reside in system memory or alternatively on any read-write storage device, and is capable of storing a quantity of write data corresponding to all read-write files and free space on the hard disk image file **130**. The lower file system **128** services subsequent read requests, that is, read requests to files or data that have previously been written to the emulated hard disk drive **125**, from the written disk sector database **132**.

The upper file system filter **136** monitors and enforces access attributes associated with files and directories on the hard disk image file **130**. For example, requests from the operating system **126** to change a read-only file attribute to read-write (which would allow the file to subsequently be deleted, giving the appearance of increasing the amount of free space available on the emulated hard disk drive **125**) are intercepted and the operation prevented. In this manner, the total (ultimate) size of the written disk sector database **132** is constrained.

The written disk sector database **132** may be maintained on any available read-write computer data storage device, and is preferably maintained as a logical structure in system memory. The written disk sector database **132** may be organized in any logical structure as necessary or desired, but is preferably implemented as a succession of data

5

storage locations, or “bins,” each of a sufficient capacity to store one sector of the hard disk image file **130**. Because the maximum size of the written disk sector database **132** is known or calculable (i.e., all read-write files and free space on the hard disk image file **130**), the entire written disk sector database **132** may be allocated in advance (such as for example, during system initialization). Alternatively, the written disk sector database **132** may be dynamically constructed, with memory or other storage resources allocated only as data is written.

The written disk sector database **132** is similar in some respects to a disk cache. Disk caches are well known in the art. A disk cache improves perceived I/O performance, reducing the average latency of disk accesses by maintaining recently accessed data in a high-speed hierarchical memory level. Disk caches are populated with data in response to both read and write requests. Disk caches are typically of a fixed size, and when the available storage locations, or bins, are fully utilized, the older or less recently used bins are reallocated to store more recent data. When a reallocated bin contains write data, the underlying storage medium must be updated at some time to reflect the changed data that was written to the cache.

The written disk sector database **132** of the present invention differs from a disk cache in many important respects. The written disk sector database **132** is not populated with data in response to read requests. Rather, it contains only write data; that is, data associated with a write request directed to the emulated read-write hard disk drive **125** (read requests directed to previously written data are serviced from the written disk sector database **132**, however, the database **132** is never populated with data in response to a read request). Since the ultimate size of the written disk sector database **132** is known, the storage locations or bins associated with a particular disk sector of the hard drive image file **130** are preferably not reallocated. That is, once a disk sector of a read-write file or free space on the hard disk image file **130** is written, the bin of the written disk sector database **132** allocated to that sector is not subsequently reallocated to another sector of the image file **130**. Finally, the written disk sector database **132** does not maintain write data coherency with any underlying mass storage device. In other words, the written disk sector database **132** is the final destination of data written to the emulated read-write hard disk drive **125** of the present invention.

FIG. **3** depicts one implementation of the emulated read-write hard disk drive **125**, within the layered hierarchy of file system drivers and devices previously described. In this embodiment, a virtual miniport driver **144** is added. The virtual miniport driver **144** emulates the basic functionality of a hard disk device by simulating sector read and write operations that are directed to it by the SCSIport driver **116**. Also added to the file system hierarchy is the lower file system filter **128**. The lower filter **128** intercepts file system requests directed to the virtual miniport driver **144** and provides read-write hard drive emulation. The lower filter **128** accomplishes this by redirecting write operations to the written disk sector database **132** as described previously. The lower filter **128** additionally redirects initial (i.e., not previously written) read requests to the CD-ROM drive, where the read data is retrieved from a hard drive image file **130** located on a protected medium.

Other file system components associated with the emulated read-write hard disk drive **125**, such as the operating system interface **134**, file system drivers **138**, partition manager **140**, and disk class driver **142** function in a manner directly analogous to those of a physical hard drive, as well known in the art, and as described above with reference to FIG. **1**.

6

The emulated read-write hard disk drive **125** additionally includes an upper file system filter **136**. The upper filter **136** enforces file system attributes on the emulated drive **125**. That is, the upper file system **136** intercepts all read and write requests directed to the emulated read-write disk drive **125**, and prevents changes to pre-existing read-only files on the emulated drive **125**.

As depicted in FIG. **3**, the logical structure and operational flow of data to and from the emulated read-write hard disk drive **125** are independent of those relating to a physical hard disk drive, such as drive **122**. Thus, the emulated read-write hard disk drive **125** of the present invention may be implemented on a computer that lacks a physical hard disk drive **122**, or for which an existing hard disk drive **122** is damaged or otherwise unavailable. The emulated read-write hard disk drive **125** of the present invention may thus find particular utility in disaster recovery, such as recovering from a physical hard disk drive crash, severe virus infection, or the like.

FIG. **4** depicts an alternative embodiment of the emulated read-write hard disk drive **125** of the present invention. In this embodiment, a virtual monolithic port driver **146** replaces both the SCSIport driver **116** (in the chain of the emulated read-write hard disk drive **125**) and the virtual miniport driver **144**. The virtual monolithic port driver **146** provides the functionality of both the SCSIport driver **116** and the virtual mini port driver **144**.

FIG. **5** demonstrates the operation of the lower file system filter **128** via a flow diagram. File I/O requests directed to the CD-ROM drive from the CD-ROM class driver **114** are intercepted by the lower file system filter **128**. When a hard drive image file **130** is not being used to implement the emulated read-write hard disk drive **125**, as determined at step **150**, the file I/O requests are passed to the CD-ROM device at step **156**. When the emulated read-write hard disk drive **125** is enabled, all I/O requests directed to the CD-ROM drive **124** are examined at step **152** to determine if the I/O request is media related. If so, the request is failed with a “no media” error code at step **154**. If the I/O request is not media related, it is passed on to the CD-ROM drive **124** at step **156**.

The lower file system filter **128** additionally intercepts requests directed to the emulated read-write disk drive **125**, as they flow from the disk class driver **142**. Whether hard drive emulation is enabled is determined at step **158**, and if not, all I/O requests are directed to the lower disk driver layers at step **168**. These I/O requests will eventually be processed by the virtual miniport driver **144**, or the virtual monolithic port driver **146**. If the emulated read-write hard disk drive **125** is enabled, the I/O request is then examined at step **160** to determine whether it is media related. If the I/O request is not media related, it is passed to the lower disk driver layers at step **168**. If the I/O request is media related, it is then examined to determine whether it can be serviced from the written disk sector database **132**. That is, a determination is made whether the I/O request is a write operation, or a read operation directed to data that has previously been written. If so, the I/O request is satisfied from the written disk sector database **132** at step **164**. If not, that is, if the I/O request is an initial read request (i.e., a read request directed to data that has not been previously written), then the read request is mapped to appropriate sector(s) of the hard disk image file **130** at step **166**, and the read request is sent to the CD-ROM device at step **156**.

FIG. **6** depicts the operation of the upper file system filter **136** via a flow diagram. The upper file system filter **136**

enforces file attributes of pre-existing files on the emulated read-write hard disk drive **125** by intercepting I/O requests directed to the emulated drive **125** by the operating system interface **134**. The upper file system filter **136** first examines the I/O request to determine if it is for one of the pre-existing files on the emulated drive **125** (i.e., if the file exists on the hard disk image file **130**), and if the file needs to be protected, at step **170**. Whether the requested file needs to be protected may be determined at step **170** in a variety of ways, such as:

- using a pre-created list of fully qualified file names;
- using the file attributes;
- using the file date/time stamp;
- using the file location within the directory hierarchy; or
- any combination of these methods.

If the intercepted I/O request is directed to a file that is not identified as a protected file, the request is passed on to the lower level file system drivers at step **180**. If the I/O request is directed to a file identified as one in need of protection, then the request is further examined at step **172** to determine if it is a request to change the access attributes of the file. If the request would alter the read-only attribute for the protected file, then the request packet is altered at step **174** to force the read-only attribute to ON in order to preserve the read-only property associated with the file. The altered I/O request is then sent to the lower file system drivers at step **180**. If a determination is made at step **172** that the I/O request will not alter the access attributes of the protected file, then the request is further examined at step **176** to determine if the request is valid for files on a read-only media. If the request is valid, it is sent on to the lower level file system drivers at step **180**. If the I/O request is determined to be not valid for a file on a read-only media (e.g., a request to delete the file), then the request is failed at step **178** with an error code signaling an attempt to write to a write-protected media.

FIG. 7 depicts a method by which a computer system may be configured to implement an emulated read-write hard disk drive **125** according to the present invention. The operating system boot process (step **182**) begins when the POST (Power On Self Test) routine in the ROMBIOS reads a boot sector containing bootstrap code into memory, and then transfers control of the CPU to the bootstrap code. The operating system bootstrap code reads configuration information from the boot device and uses this information to locate and load all of the device drivers that make up the layers of support for the storage devices (step **184**). The operating system initializes each device driver layer, starting with the layer closest to the physical storage device (step **184**). During this initialization step, the virtual SCSI miniport driver **144** (FIG. 3) or virtual monolithic port driver **146** (FIG. 4) reports finding a physical hard drive, and then emulates the functionality of a physical hard drive to satisfy requests from the operating system to the virtual device. The operating system then initializes the lower file system filter **128** (step **188**) and attaches the filter **128** to the file system chain of the CD-ROM drive and the virtual hard disk drive (step **190**). The lower file system filter **128** then creates the written disk sector database **132** by allocating space in writeable random access memory or on other writeable storage medium (step **192**). If desired, the written disk sector database **132** may be fully allocated at this point, as its total size is known or may be calculated as the sum of sectors on the hard disk image file **130** allocated to either read-write files or free space. Alternatively, the written disk sector database **132** may be initialized, with memory allocated to

it dynamically on an as-needed basis. The lower file system filter **128** begins intercepting I/O requests directed to the emulated read-write hard disk drive **125** (step **194**) and processes the I/O requests using sectors from the hard disk image file **130** on the CD-ROM drive in combination with the written disk sector database **132**, as described above. The operating system continues to initialize file system device drivers (step **196**), and eventually attaches the upper file system filter **136** into the I/O request path for the emulated read-write hard disk drive **125** (step **198**). When the upper file system filter **136** has been initialized and attached to the emulated hard drive **125**, it begins intercepting requests to the emulated hard drive **125** (step **200**) and prevents changes to pre-existing read-only files on the emulated drive **125**. The operating system then completes the boot process, and the computer system is ready for use by the user (step **202**).

Although the present invention has been described herein with respect to particular features, aspects and embodiments thereof, it will be apparent that numerous variations, modifications, and other embodiments are possible within the broad scope of the present invention, and accordingly, all variations, modifications and embodiments are to be regarded as being within the scope of the invention. The present embodiments are therefore to be construed in all aspects as illustrative and not restrictive and all changes coming within the meaning and equivalency range of the appended claims are intended to be embraced therein.

What is claimed is:

1. A method of emulating a computer storage device having read and write capabilities using a protected media having read-only access, comprising:
  - providing a computer storage device image file on said protected media, said image file including at least one file having a file access attribute;
  - providing a written disk sector database;
  - intercepting file access requests from the operating system of said computer; and
  - for write requests to read-write files, directing the write data to said written disk sector database;
  - for read requests to files, providing data from said written disk sector database if said file has previously been written, and providing data from a corresponding file on said protected media if said file has not previously been written; and
  - for write requests, delete requests, or requests to change file access attributes to read-only files, failing said requests.
2. The method of claim 1 wherein said written disk sector database is maintained in memory in said computer.
3. The method of claim 1 wherein said computer storage device image file includes elements selected from the group consisting of read-only files, read-write files, and free space.
4. The method of claim 1 wherein said written disk sector database comprises a plurality of records, each record corresponding to a sector of said computer storage device image file and operative to store at least the amount of data of said corresponding sector.
5. The method of claim 4 wherein said written disk sector database comprises a number of said records at least as large as the number of disk sectors allocated to read-write files and free space on said computer storage device image file.
6. The method of claim 1 wherein said read-write files and read-only files are determined by a method selected from the group consisting of using a pre-created list of fully qualified file names, using the file attributes, using the file date/time stamp, and using the file location within the directory hierarchy.

7. An emulated mass storage device for a computer, comprising:

a computer storage device image file on a protected medium operative to supply data from read-only files, data from the initial state of read-write files, and free space for said emulated mass storage device; and

a written disk sector database operative to store data written to read-write files and free space on said emulated mass storage device, and operative to supply data previously written to read-write files on said emulated mass storage device, said written disk sector database constrained in size to the total number of sectors allocated to read-write files and free space on said computer storage device image file, without reallocating any storage among said sectors.

8. The emulated mass storage device of claim 7, further comprising a file system filter operative to intercept file system requests from the operating of said computer directed to said emulated mass storage device.

9. The emulated mass storage device of claim 8 wherein said file system filter diverts write data for write requests to files with read-write attributes to said written disk sector database.

10. The emulated mass storage device of claim 8 wherein said file system filter satisfies read requests to files with read-write attributes from said written disk sector database if said files have previously been written, and if said files have not previously been written, satisfies said read requests from said computer storage device image file.

11. The emulated mass storage device of claim 8 wherein said file system filter fails requests to write, to delete, or to

alter the file access attributes, of files having a read-only access attribute.

12. A computer, comprising:

an operating system; and

an emulated mass storage device comprising:

a computer storage device image file on a protected medium, said image file including data organized into a plurality of files, each file having an access attribute;

a fixed-size, non-reallocating written disk sector database operative to store data written to said emulated mass storage device; and

a file system filter operative to intercept file access requests from said operating system and to service said requests via said written disk sector database and said computer storage device image file, said file system filter enforcing said access attributes by failing requests to write, delete, or change the access attributes of read-only files.

13. The computer of claim 12 wherein said written disk sector database has a predetermined maximum size.

14. The computer of claim 13 wherein the predetermined size of said written disk sector database corresponds to the number of sectors in said computer storage device image file that are allocated to files with a read-write attribute or free space.

15. The computer of claim 12 wherein storage locations in said written disk sector database are not reallocated.

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