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(54) **REGULATING FILE ACCESS RATES ACCORDING TO FILE TYPE**

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See application file for complete search history.

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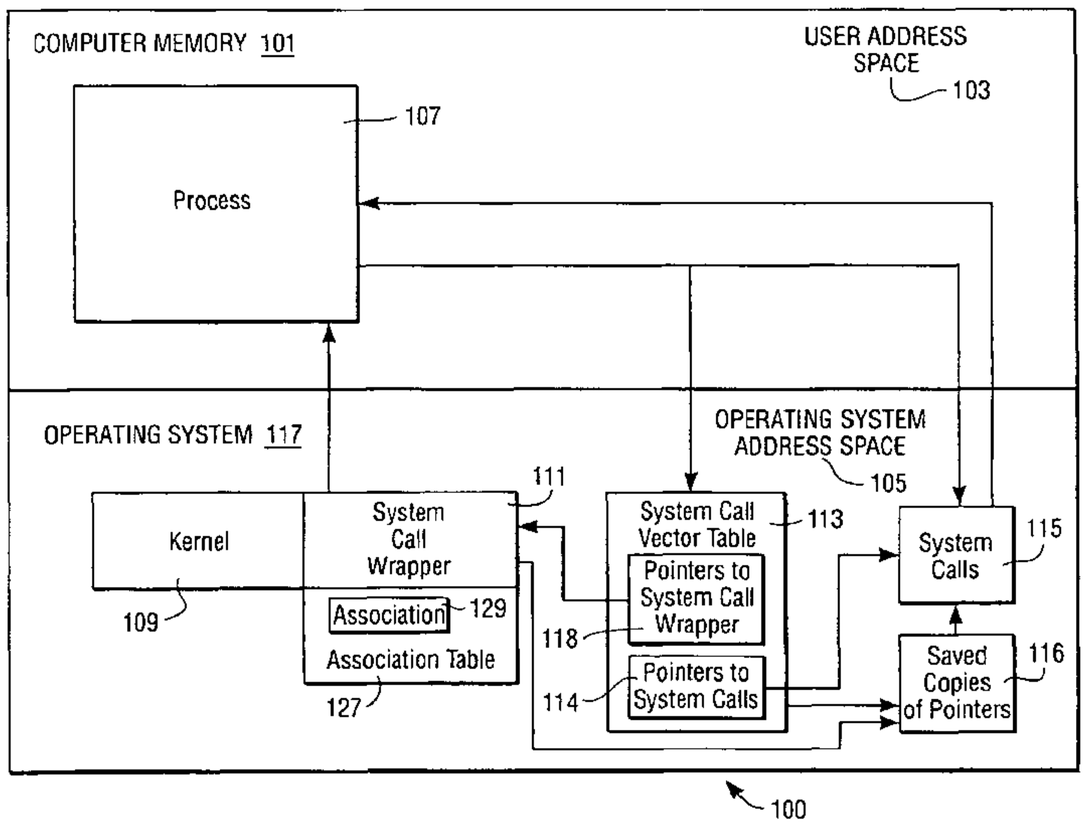
(57) **ABSTRACT**

File access rates of processes are regulated according to file type. An association table stores entries associating processes to be regulated with specific access rates for various file types. System calls that access files are intercepted, and a system call wrapper executes. The system call wrapper determines the type of file that is being accessed by the process. The system call wrapper examines the association table in order to determine if the calling process is associated with an access rate for the file type being accessed. If so, the system call wrapper regulates access to the file according to the appropriate rate.

21 Claims, 5 Drawing Sheets



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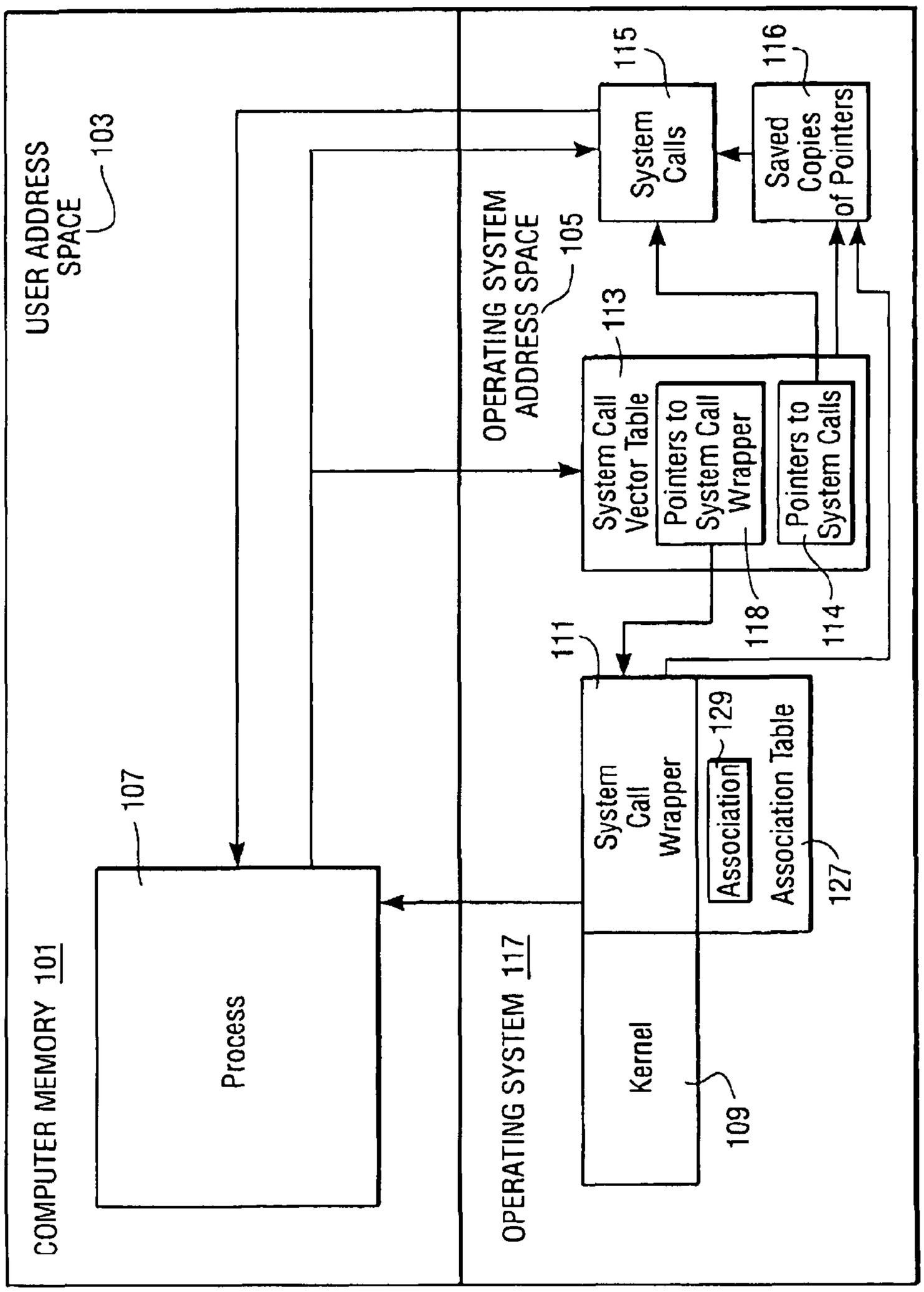
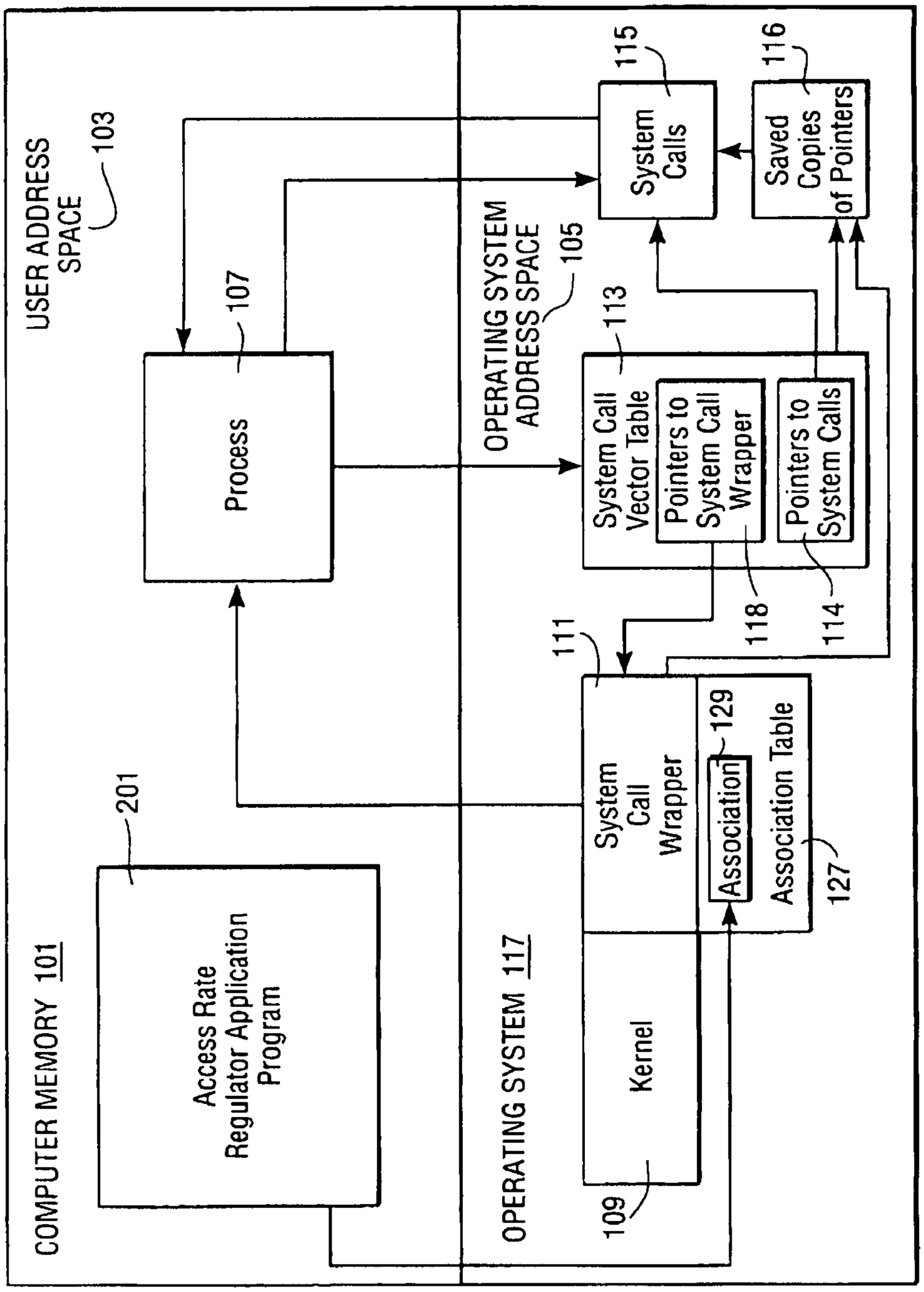

COMPUTER MEMORY 101
USER ADDRESS SPACE 103
Process
107
OPERATING SYSTEM 117
OPERATING SYSTEM ADDRESS SPACE 105
Kernel
109
System Calls
115
Saved Copies of Pointers
116
113
System Call Vector Table
Pointers to System Call Wrapper
Pointers to System Calls
118
114
111
System Call Wrapper
Association
129
Association Table
127
100

FIG. 1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USER ADDRESS SPACE 103
OPERATING SYSTEM ADDRESS SPACE 105
OPERATING SYSTEM 117
Process 107
Access Rate Regulator Application Program 201
System Calls 115
Saved Copies of Pointers 116
System Call Vector Table 113
Pointers to System Call Wrapper
Pointers to System Calls
118
114
111
System Call Wrapper
Association 129
Association Table 127
Kernel 109
200

FIG. 2

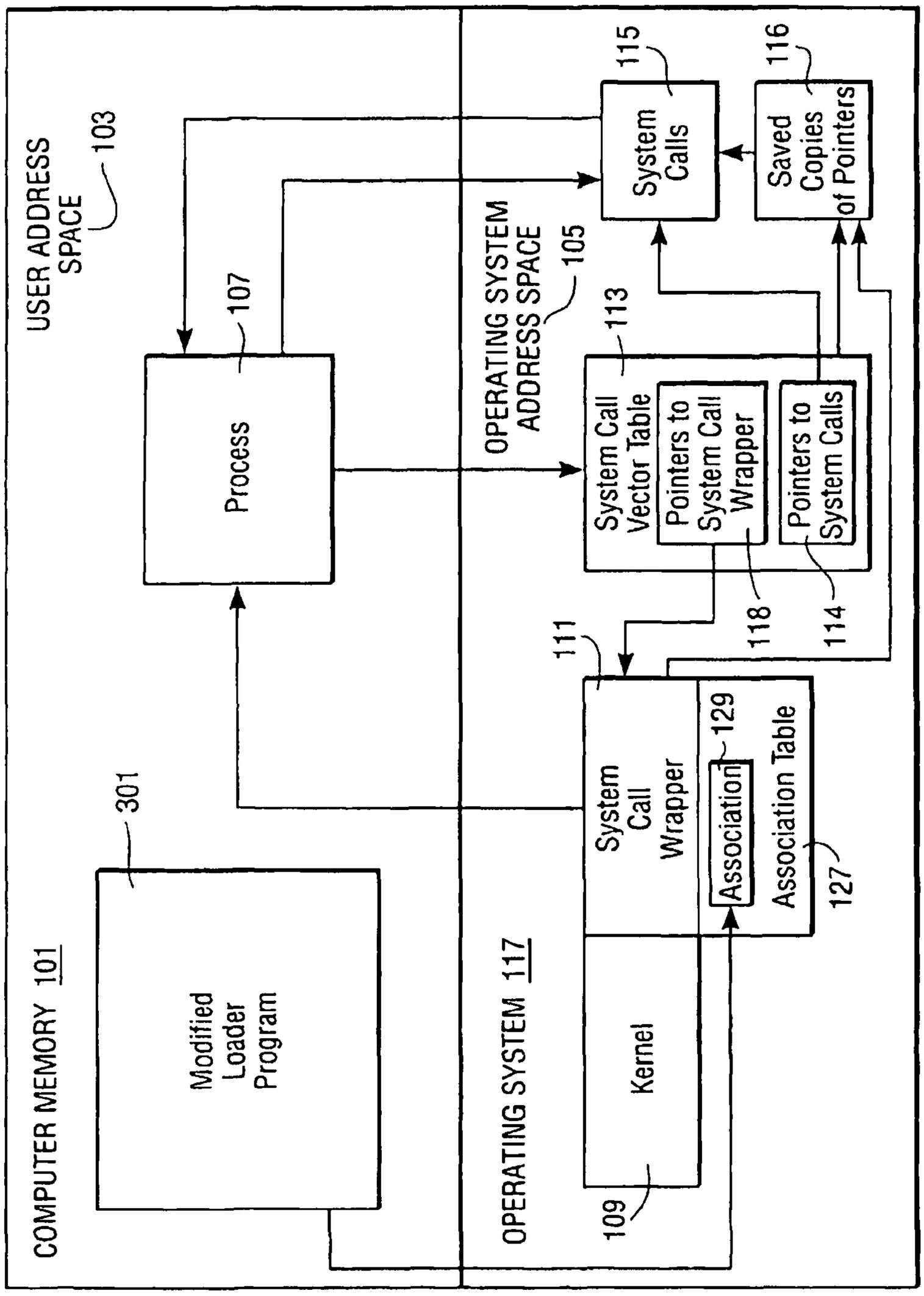
COMPUTER MEMORY 101
USER ADDRESS SPACE 103
Process 107
Modified Loader Program 301
OPERATING SYSTEM ADDRESS SPACE 105
System Calls 115
Saved Copies of Pointers 116
OPERATING SYSTEM 117
System Call Vector Table 113
Pointers to System Call Wrapper
Pointers to System Calls
118
114
111
System Call Wrapper
Association 129
Association Table 127
Kernel 109
300

FIG. 3

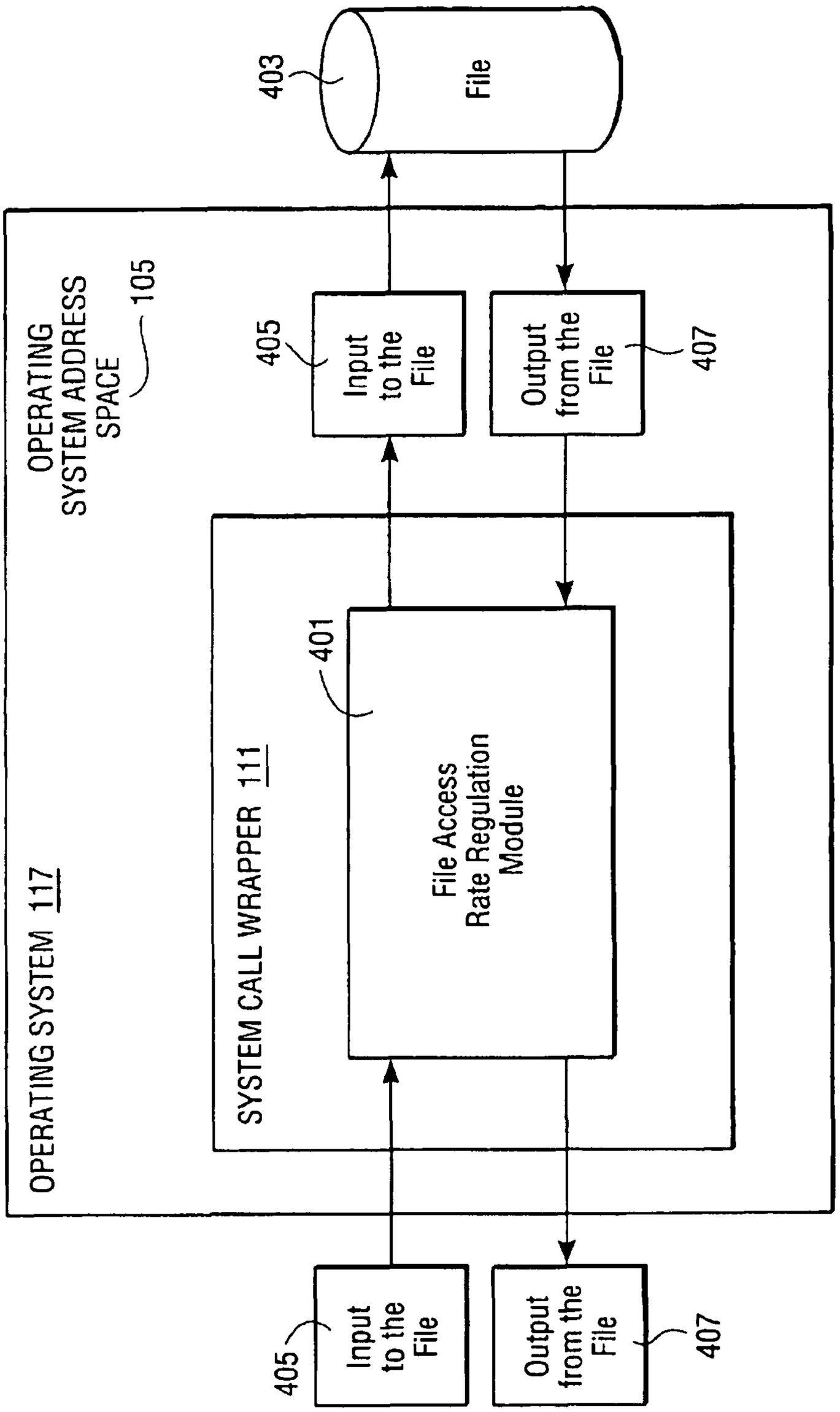
403
File
OPERATING SYSTEM ADDRESS SPACE 105
405
Input to the File
Output from the File
407
400
401
File Access Rate Regulation Module
SYSTEM CALL WRAPPER 111
OPERATING SYSTEM 117
405
Input to the File
Output from the File
407

FIG. 4

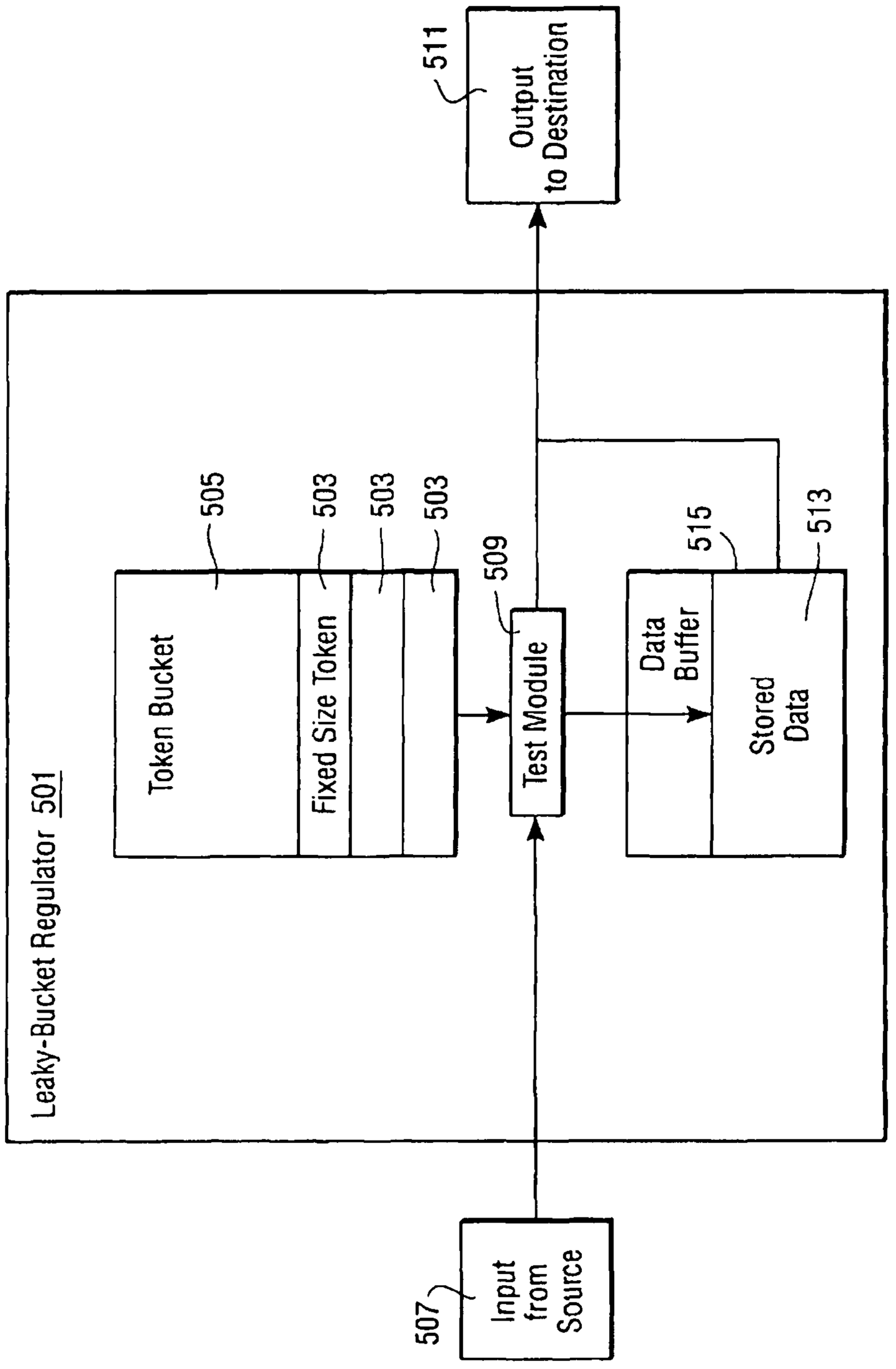
Leaky-Bucket Regulator 501
Token Bucket
505
Fixed Size Token
503
503
503
509
Test Module
Data Buffer
515
Stored Data
513
511
Output to Destination
507
Input from Source

FIG. 5

REGULATING FILE ACCESS RATES ACCORDING TO FILE TYPE

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

CROSS REFERENCE TO RELATED APPLICATIONS

This application *is a reissue application for U.S. Pat. No. 6,907,421, issued from U.S. patent application Ser. No. 09/572,672 filed on May 16, 2000, which* incorporates by reference the entirety of the following patent applications: U.S. patent application Ser. No. 09/500,212, now U.S. Pat. No. 6,560,613 entitled "Disambiguating File Descriptors," filed on Feb. 8, 2000; U.S. patent application Ser. No. 09/499,098, now U.S. Pat. No. 6,529,985 entitled "Selective Interception of System Calls," filed on Feb. 4, 2000; and U.S. patent application Ser. No. 09/452,286, now pending entitled "Providing Quality of Service Guarantees to Virtual Hosts," filed on Nov. 30, 1999. The incorporated applications have the same assignee as the present application.

BACKGROUND

1. Field of Invention

The present invention relates generally to regulating access rates in a computer system, and specifically to regulating file access rates of software processes according to file type.

2. Background of Invention

Multitasking operating systems such as UNIX® and Microsoft WINDOWS NT®are widely utilized in commercial computing systems. Among their many commercial uses, these operating systems are commonly deployed on Internet and other network server computers. With the popularity and success of the Internet, server computer operating systems are currently of great commercial importance.

One function of a multitasking operating system is to allocate system resources to the multiple software processes that simultaneously execute under the control of the operating system. Control over the allocation of system resources by an operating system is commercially useful for a number of reasons. Multitasking operating system are commonly used on Internet web servers by Internet Service Providers (ISP's). Where an ISP provides host services to multiple customers on a single physical computer, it is desirable to allot to each virtual host a specific amount of computer resources appropriate to the needs of the customer, and preferably based upon the amount paid for the services.

For example, suppose two customers purchase host services from an ISP. The first customer is a large corporation providing financial services to thousands of clients internationally. The financial services host requires fast file access, as well as prompt response time to all client requests. Of course, the first customer is willing to compensate the ISP appropriately for providing such a level of host services. The second customer is a sole proprietorship that sells floral arrangements locally. The second customer has a very limited budget, but only requires minimal computer resources. Clearly, it is desirable for the ISP to allocate different percentages of the system resources to the two separate virtual hosts provided by the ISP for the two separate customers.

In the example above, the ISP may wish to provide the financial services host with the ability to access files at the rate

of 1,000 bytes per second, but to allow the florist to access files at the rate of only 150 bytes per second. These different access rates would be based upon the different needs of the two customers, and the corresponding different compensation schemes of each. As multitasking operating systems operate today, it would be impossible for the ISP to regulate the file access rates of the different customers. Each process associated with either virtual host simply accesses the file system at the same unregulated rate, and thus it is impossible for the ISP to guarantee or restrict access rates based upon customer need and corresponding financial arrangement. What is needed is a method that facilitates the regulation of the rate at which individual processes access the file system of a multitasking operating system.

Many commercially popular operating systems such as UNIX® and Microsoft WINDOWS NT® treat communication channels as files. In such an operating system, when a process instructs the operating system to create a communication channel, the operating system returns a file descriptor. The communication channel is subsequently accessed via the file descriptor, in a similar manner as a file stored on media.

Communication channels and files stored on media are inherently different, despite the fact that both are accessed via file descriptors. It is often desirable to for an ISP to allow a single process to access files stored on media at one rate, and to access communication channels at another. For example, a customer of the ISP may need to receive and respond to client requests very quickly, but need only an average access time for files stored on the system storage device(s). Such a customer would require (and be willing to pay for) a fast communication channel access rate, but only need (and be willing to pay for) a slower access rate to files stored on media.

Multitasking operating systems today are not capable of regulating the file access rates of different processes generally, much less facilitating different access rates for specific processes based on file type. Currently, each process accesses both files stored on media and communication channels at unregulated rates, not controlled by the operating system. Thus, it is impossible for the ISP to provide customers with different access rates for files stored on media and for communication channels, based upon customer need and corresponding financial arrangement. What is further needed is a method that not only facilitates the regulation of the rate at which individual processes access the file system of a multitasking operating system, but which also allows processes to be regulated to different access rates for different file types.

It is further desirable to not only be able to set separate access rates for communication channels and files stored on media, but to be able set separate access rates for file types generally. Under some operating systems, entities other than communication channels and files stored on media are treated as files, and hence need separate access rates. For example, under the UNIX® operating system, hardware devices are treated as files. For the same reasons that it is desirable to set separate access rates for communication channels and files stored on media, it is further desirable to be able to set a separate access rate for any type of file. Accordingly, what is needed is a method to set separate access rates for individual processes according to file type.

SUMMARY OF INVENTION

The present invention allows regulation of the file access rates of processes according to file type. An association data structure stores associations between processes to be regulated and specific access rates for various file types. In order to regulate processes to their associated access rates, system

calls that access files are intercepted. When a process to be regulated makes a system call that accesses a file, the system call is intercepted, and a system call wrapper executes instead. The system call wrapper determines the type of file that is being accessed by the process. The system call wrapper examines the association table in order to determine if the calling process is associated with an access rate for that file type. If not, then the process is not to be regulated for that file type, in which case the system call wrapper simply allows the file access to proceed. Otherwise, the system call wrapper regulates the rate of the access to the file according to the appropriate rate.

The features and advantages described in this summary and the following detailed description are not all-inclusive, and particularly, many additional features and advantages will be apparent to one of ordinary skill in the art in view of the drawings, specification, and claims hereof. Moreover, it should be noted that the language used in the specification has been principally selected for readability and instructional purposes, and may not have been selected to delineate or circumscribe the inventive subject matter, resort to the claims being necessary to determine such inventive subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram providing a high level overview of a system for regulating file access rates of processes based upon file type, according to one embodiment of the present invention.

FIG. **2** is a block diagram illustrating a system for managing an association table by an access rate regulator program, according to one embodiment of the present invention.

FIG. **3** is a block diagram illustrating a system for managing an association table by a modified loader program, according to another embodiment of the present invention.

FIG. **4** is a block diagram illustrating a system for regulating file access rate, according to one embodiment of the present invention.

FIG. **5** is a block diagram illustrating a leaky-bucket regulator according to one embodiment of the present invention.

The figures depict embodiments of the present invention for purposes of illustration only. One skilled in the art will readily recognize from the following discussion that alternative embodiments of the structures and methods illustrated herein may be employed without departing from the principles of the invention described herein.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

I. System Overview

FIG. **1** illustrates a high level overview of a system **100** for regulating file access rates of processes **107** based upon file type according to one embodiment of the present invention. A computer memory **101** includes user address space **103** and operating system address space **105**. A process **107** executes in user address space **103**. Although FIG. **1** illustrates only a single process **107** executing in user address space **103**, it is to be understood that within a given computer memory **101**, multiple processes **107** can execute simultaneously.

Preferably, a data structure for storing associations **129** between processes **107** and access rates for file types is inserted into the operating system **117**. In one embodiment, the data structure is an association table **127**, but in other embodiments other data structures are utilized, for example a linked list. In one embodiment, the association table **127** (or other data structure) is dynamically loaded into the operating system kernel **109**, while the kernel **109** is active. In another embodiment, the association table **127** is stored in user address space **103**. The maintenance and use of the association table **127** is discussed in detail below.

In order to regulate file access rates, system calls **115** that access files are intercepted. A system call wrapper **111** is utilized in order to intercept system calls **115**. In one embodiment, the system call wrapper **111** is dynamically loaded into the operating system kernel **109**, while the kernel **109** is active. In another embodiment, the system call wrapper is loaded in user address space **103**. The system call wrapper **111** is preferably in the form of object code, the functional features of which are described in detail below.

Pointers **114** to system calls **115** are located in an operating system call vector table **113**. It is to be understood that the term "system call vector table" as used herein denotes an area in operating system address space **105** in which there are stored the addresses of system calls. In the UNIX® operating system, this part of the operating system is called the "system call vector table," and that term is used in this specification. Other operating systems employ different terminology to denote the sane system component. A system call vector table by any other name is still within the scope of the present invention.

A copy **116** is made of a pointer **114** to each system call **115** to be intercepted. These copies **116** of pointers **114** are preferably stored in operating system address space **105**, but in an alternative embodiment are stored in user address space **103**. Once the copies **116** have been made and saved, the pointers **114** in the system call vector table **113** to the system calls **115** to be intercepted are replaced with pointers **118** to the system call wrapper **111**, such that when a system call **115** to be intercepted is made, the system call wrapper **111** executes instead. In one embodiment, this copying, storing, and replacing of pointers is performed by the system call wrapper **111**. In other embodiments, copying, storing, and replacing of pointers is performed by a pointer management module executing in either operating system address space **105** or user address space **103** as desired. The pointer management module can either be a stand alone program, or a component of a larger application program as desired.

Executing alternative code when a system call **115** is made comprises intercepting the system call **115**. The steps of inserting a system call wrapper **111** into the operating system **117**, making a copy **116** of an operating system pointer **114** to a system call **115**, and replacing the operating system pointer **114** with a pointer **118** to the system call wrapper **111** facilitate interception of a system call **115**. When a system call **115** to be intercepted is made, the operating system **117** uses the pointer **118** in the system call vector table **113** to the system call wrapper **111** to execute the system call wrapper **111**.

It is to be understood that only system calls **115** that access files need be intercepted, and thus only pointers **114** to system calls **115** to be intercepted are replaced with pointers **118** to the system call wrapper **111**. Pointers **114** to system calls **115** which are not to be intercepted are not replaced. Thus, when a non-intercepted system call **115** is made, the system call **115** executes, not the system call wrapper **111**.

In one embodiment, a single system call wrapper **111** is loaded into operating system address space **105**. Thus, whenever any process **107** makes a system call **115** to be intercepted, the system call wrapper **111** executes. In another embodiment, techniques described in the "Selective Interception of System Calls" application are used to associate a specific system call wrapper **111** with each process to be regulated.

Processes **107** execute in user address space **103** under control of the operating system **117**, and make system calls **115**. When a process makes a system call **115** that accesses a file, the system call wrapper **111** determines the type of the file being accessed. The system call wrapper **111** also examines the association table **127** to determine whether the process **107** that made the system call **115** is associated with an access rate for that file type. If so, the system call wrapper **111** regulates the file access rate appropriately. Otherwise, the access is allowed to proceed normally. Note that even in the embodiment in which processes **107** to be regulated are associated with individual system call wrappers **111**, the system call wrapper still determines if the process **107** is associated with a rate for the file type being accessed, because an individual process **107** may be regulated for some file types and not for others.

II. Storing Associations by a Regulator Program

FIG. **2** illustrates one embodiment of a system **200** for regulating file access rates of processes **107** based upon file type. In the embodiment illustrated by FIG. **2**, the association table **127** is managed by an access rate regulator program **201**.

The access rate regulator program **201** modifies the operating system **117** of the computer to include the association table **127**. Preferably, the regulator program **201** loads the association table **127** into the kernel **109** of the operating system **117** while the kernel is active.

For each process **107** to be regulated, the regulator program **201** stores, in the association table **127**, an association **129** between the process **107** and an access rate for at least one file type. For example, suppose a process **107** associated with a financial services host is to be regulated to 1,000 bytes per second for files stored on media, and to 1,400 bytes per second for communication channels. The regulator program **201** would store two associations for the process **107**, the first indicating the access rate for files stored on media (1,000 bytes per second), and the second the access rate for communication channels (1,400 bytes per second). Of course, the regulator program **201** can add, modify, and delete associations **129** from the association table **127**, as desired.

III. Storing Associations by a Loader Program

FIG. **3** illustrates another embodiment of a system **300** for regulating file access rates of processes **107** based upon file type. In the embodiment illustrated by FIG. **3**, processes **107** to be regulated are loaded by the modified loader program **301**, which also stores the associations **129**.

A loader program is an operating system utility that is used to execute computer programs that are stored on static media. Typically, a loader program loads an executable image from static media into user address space **103** of computer memory **101**, and then initiates execution of the loaded image by transferring execution to the first instruction thereof.

Like a standard loader program, the modified loader **301** loads executable images from static media into user address space **103**. Additionally, the modified loader program **301** stores, in the association table **127**, at least one association **129** between the process **107** and a file access rate. Thus, whenever a process **107** to be regulated is loaded, the association table **127** is updated as needed.

In other embodiments, in addition to storing associations, the modified loader program **301** uses methodology described in detail in the "Selective Interception of System Calls" application in order to associate an individual system call wrapper **111** with the loaded process **107**. In different embodiments, the system call wrapper **111** associated with the process is loaded into process address space of the process, user address space **103**, or operating system address space **105** as described in the "Selective Interception of System Calls" application. In each of these embodiments, whenever the process **107** makes a system call **115** to be intercepted (i.e., a system call **115** that accesses a file) the system call wrapper **111** associated with the process **107** executes, and proceeds to manage the regulation of the file access rate. Regulation of file access rate by system call wrappers **111** generally is discussed in detail below.

IV. Determining the File Type

When a system call wrapper **111** executes, the system call wrapper determines the type of the file being accessed. Once the file type has been determined, the system call wrapper **111** examines the association table **127** to determine whether the process **107** that made the system call **115** is associated with an access rate for that file type. If so, the system call wrapper **111** regulates the file access rate appropriately. Otherwise, access of files of that type by the process **107** is not to be regulated, so the access is allowed to proceed normally. In one embodiment, the determination is made using methodology described in the "Disambiguating File Descriptors" application. Other techniques such as file extension or file name can also be used as desired.

V. Regulating the Access Rate

FIG. **4** illustrates one embodiment of a system **400** for regulating file access rate. After determining the file type being accessed, the system call wrapper **111** executes a file access rate regulation module **401** in order to regulate the access rate of the file **403** by the process **107**. In one embodiment, the file access rate regulation module **401** executes in operating system address space **105**, as illustrated in FIG. **4**. In another embodiment, the file access rate regulation module **401** executes in user address space **103**. The file access rate regulation module **401** can either be a section of the system call wrapper (as illustrated), a stand alone program, or a component of a larger application program as desired. In any case, the file access rate regulation module **401** applies a known rate regulation technique to the access of the file **403** by the process **107**. More specifically, data being written to the file **403** by the process (input to the file **405**) is routed through the file access rate regulation module **401**. The file access rate regulation module **401** controls the rate at which the input **405** is sent to the file **403** by the process. Likewise, data read by the process **107** from the file (output from the file **407**) is also routed through the file access rate regulation module **401**, which controls the rate at which the output **407** is sent to the process **107**.

Many techniques for regulating access rate are known. In one embodiment, the file access rate regulation module **401** uses a leaky-bucket regulator to regulate the access rate. A leaky-bucket regulator is one specific example of a technique for regulating access rates. A leaky-bucket regulator is described in An Engineering Approach to Computer Networking, Srinivasan Keshav, 1997, Addison Wesley, Chapter 7, at pp 403-405, which is incorporated herein by reference.

FIG. **5** illustrates a leaky-bucket regulator **501**. As illustrated in FIG. **5**, the leaky-bucket regulator **501** stores fixed sized tokens **503** in a data structure known as a token (or leaky) bucket **505**. Each token **503** constitutes permission for the regulator **501** to send a certain number of bits to a destination. The regulator **501** adds tokens **503** to the bucket **505** at

a fixed rate, R. The bucket **505** overflows if the number of tokens **503** crosses some threshold, called its depth, D.

Data arrives at the regulator **501** as input **507** from a source. A test module **509** examines the bucket **505**, to determine the sum of the sizes of the tokens **503** therein. The regulator **501** only sends the data as output to a destination **511** if the sum equals or exceeds the size of the data. When data is sent as output **511**, the regulator **501** removes tokens **503** corresponding to the output **511** size from the token bucket **505**.

If the sum is less than the size of the input **507**, the input **507** is held as stored data **513** in a data buffer **515**. Once the bucket **505** contains sufficient tokens **503**, the stored data **513** is sent as output **511**.

A leaky-bucket regulator **501** limits the size of a burst of output **511** to a little more D. The size can be slightly greater than D because tokens **503** may be added to the bucket **505** while output **511** equal in size to D is being sent. Over the long term, the rate at which output **511** is sent by the regulator **501** is limited by the rate R at which tokens **503** are added to the bucket **505**. Thus, the leaky-bucket regulator **501** can be used to regulate a process **107** to an access rate for a file type by setting R to that access rate.

For example, suppose the system call wrapper **111** determines that the file access write for a process **107** is 1,000 bytes per second. The system call wrapper passes the rate to the leaky-bucket regulator **501**, which proceeds to set R to the rate. Thus, the regulator **501** adds 1,000 byte tokens **503** to a bucket **505** at a rate of once per second. The system call wrapper **111** then routes the communication between the process **107** and the file through the regulator **501**, which regulates the access rate to 1,000 bytes per second.

Note that if the process **107** is writing data to a file **403**, the input to the file **405** becomes the input **507** to the leaky bucket regulator **501**, and the output **511** from the leaky bucket regulator **501** is sent to the file **403**. On the other hand, if the process **107** is reading data from a file **403**, the output from the file **407** becomes the input **507** to the leaky bucket regulator **501**, and the output **511** from the leaky bucket regulator **501** is sent to the process **107**.

In other embodiments, other access rate techniques are employed by the file access rate regulation module **401**, for example moving average, jumping average, or peak rate.

As will be understood by those familiar with the art, the invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. Likewise, the particular capitalization or naming of the modules, protocols, features, attributes or any other aspect is not mandatory or significant, and the mechanisms that implement the invention or its features may have different names or formats. Accordingly, the disclosure of the present invention is intended to be illustrative, but not limiting, of the scope of the invention, which is set forth in the following claims.

What is claimed is:

1. A computer-implemented method for regulating file access rates of processes according to file type, the computer-implemented method comprising:

intercepting a system call that attempts to access a file;

determining whether a process that made the intercepted system call is associated with an access rate corresponding to a type of the file being accessed;

in response to the attempt to access the file by the process, determining the associated access rate for the type of the file being accessed; and

regulating the process to access of the file at the determined rate.

2. The method of claim **1** further comprising:

storing an association between a selected process and the access rate for at least one file type.

3. The method of claim **2** wherein:

storing the association is performed by a process executing in user address space.

4. The method of claim **1** further comprising:

selecting a process to associate with an access rate for at least one file type;

loading the selected process into process address space by a modified loader program; and

storing, by the modified loader program, an association between the selected process and the access rate for at least one file type.

5. The method of claim **1** further comprising:

associating at least two different access rates with a single process, each access rate corresponding to a different file type.

6. The method of claim **1** further comprising:

associating at least two different access rates with at least two different processes.

7. The method of claim **1** wherein:

in response to the determination that the process is associated with the access rate, regulating the process to access of the file at the associated rate.

8. The method of claim **1**, further comprising:

determining the type of the file being accessed.

9. The method of claim **1**, further comprising:

associating at least one process with the access rate for at least one file access type.

10. A computer-readable program product for regulating file rates of processes according to file type, the computer-readable program product comprising:

program code for intercepting a system call that attempts to access a file;

program code for determining whether a process that made the intercepted system call is associated with an access rate corresponding to a type of the file being accessed;

program code for, in response to the attempt to access the file by the process, determining the associated access rate for the type of the file being accessed;

program code for regulating the process to access of the file at the determined rate; and

a computer readable medium on which the program codes are stored.

11. The computer-readable program product of claim **10** further comprising:

program code for storing an association between a selected process and an access rate for at least one file type.

12. The *non-transitory* computer-readable **[**program product**]** *medium* of claim **10** further comprising:

program code for selecting a process to associate with the access rate for at least one file type;

program code for loading the selected process into process address space; and

program code for storing an association between the selected process and the access rate for at least one file type.

13. The *non-transitory* computer-readable **[**program product**]** *medium* of claim **10** further comprising:

program code for associating at least two different access rates with a single process, each access rate corresponding to a different file type.

14. The *non-transitory* computer-readable **[**program product**]** *medium* of claim **10** further comprising:

program code for associating at least two different access rates with at least two different processes.

15. The *non-transitory* computer-readable [program product] *medium* of claim 10 further comprising:

program code for, in response to the determination that the process is associated with the access rate, regulating the process to access of the file at the associated rate.

16. The *non-transitory* computer-readable [program product] *medium* of claim 10 further comprising:

program code for determining the type of the file being accessed.

17. The computer-readable program product of claim 10 further comprising:

program code for associating at least one process with the access rate for at least one file type.

18. A computer implemented system for regulating file access rates of processes according to file type, the system comprising:

an interception module, for intercepting system calls that access files, the interception module being coupled to a determination module;

at least one system call wrapper, for determining whether a process that made an intercepted system call is associated with an access rate corresponding to a type of the file being accessed, the system call wrapper being coupled to the interception module;

the determination module for, in response to an attempt to access a file by the process, determining the associated access rate for the type of the file being accessed; and

coupled to the determination module, a file access rate regulation module, for regulating the process to access of the file at the determined rate.

19. The computer system of claim 18 further comprising:

a selection module for selecting the process to associate with the access rate for at least one file type, the selection module being coupled to the determination module; and

a modified loader program for loading the selected process into process address space, and for storing the association between the selected process and the access rate for at least one file type, the modified loader program being coupled to the selection module.

20. The computer system of claim 18 further comprising:

a storage module, for storing the association between a selected process and the access rate for at least one file type, the storage module being coupled to the determination module.

21. A computer-implemented method for regulating file access rates of processes according to file type, the method comprising:

associating processes with rates for accessing files of specific types;

detecting attempts by processes to access files by intercepting system calls that access files;

determining associated access rates for the types of files being accessed; and

regulating processes to access [of] the files at the associated rates.

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