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(54) **RANSOMWARE DETECTION USING I/O PATTERNS**

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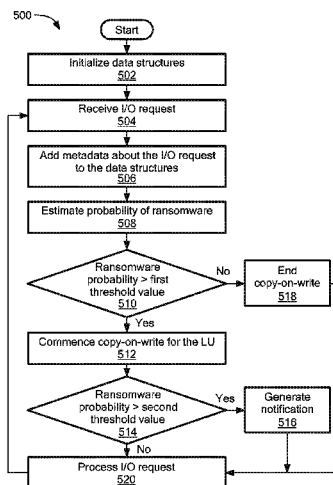
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(57) **ABSTRACT**

A computer program product, system, and method for generating coded fragments comprises initializing historical I/O activity data structures and recent I/O activity data structures associated with a logical unit (LU) of storage; receiving an I/O request from a host, the I/O request associated with one or more chunks within the LU; adding metadata about the I/O request to the recent I/O activity data structures; generating a ransomware probability by comparing the recent I/O activity data structures to the historical I/O activity data structures; and if the ransomware probability exceeds a first threshold value, taking one or more first actions to mitigate the effects of ransomware within the host.

**18 Claims, 6 Drawing Sheets**



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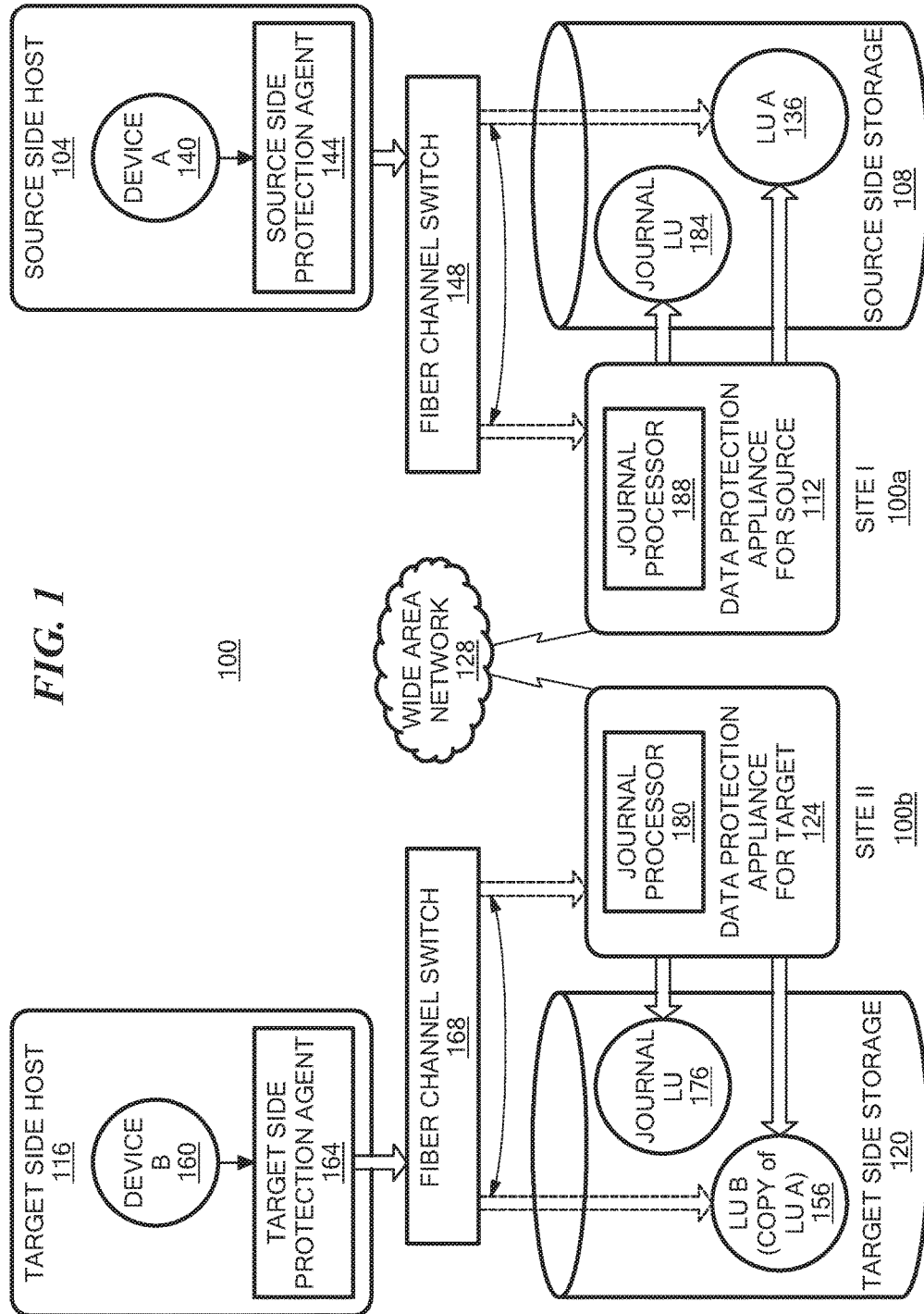
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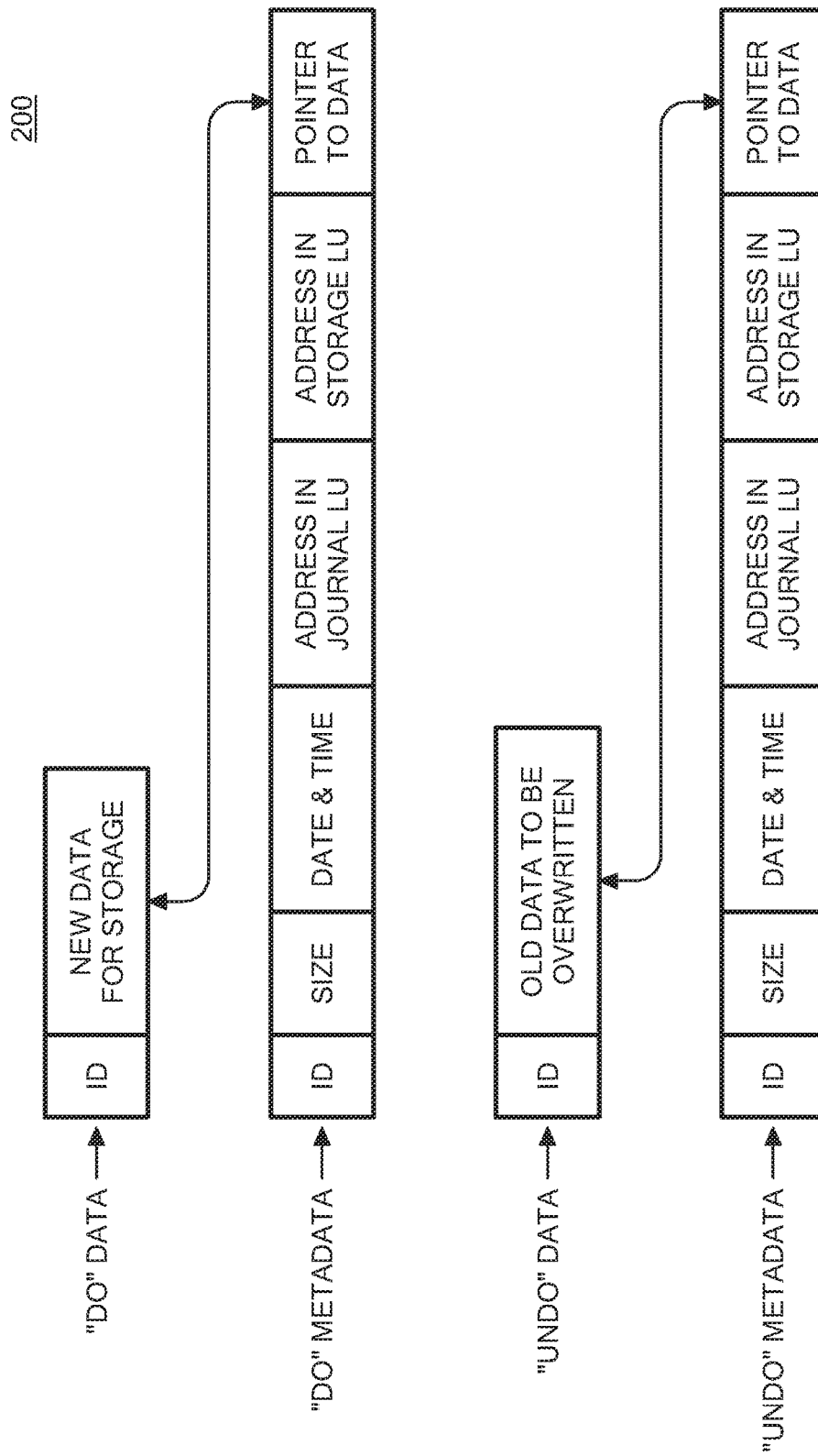
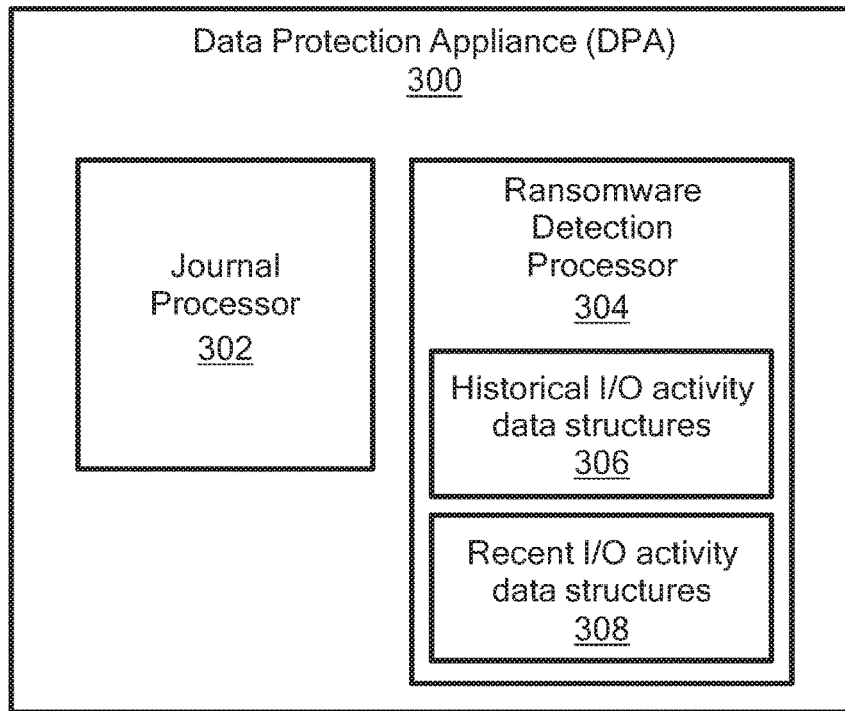


FIG. 2

**FIG. 3**

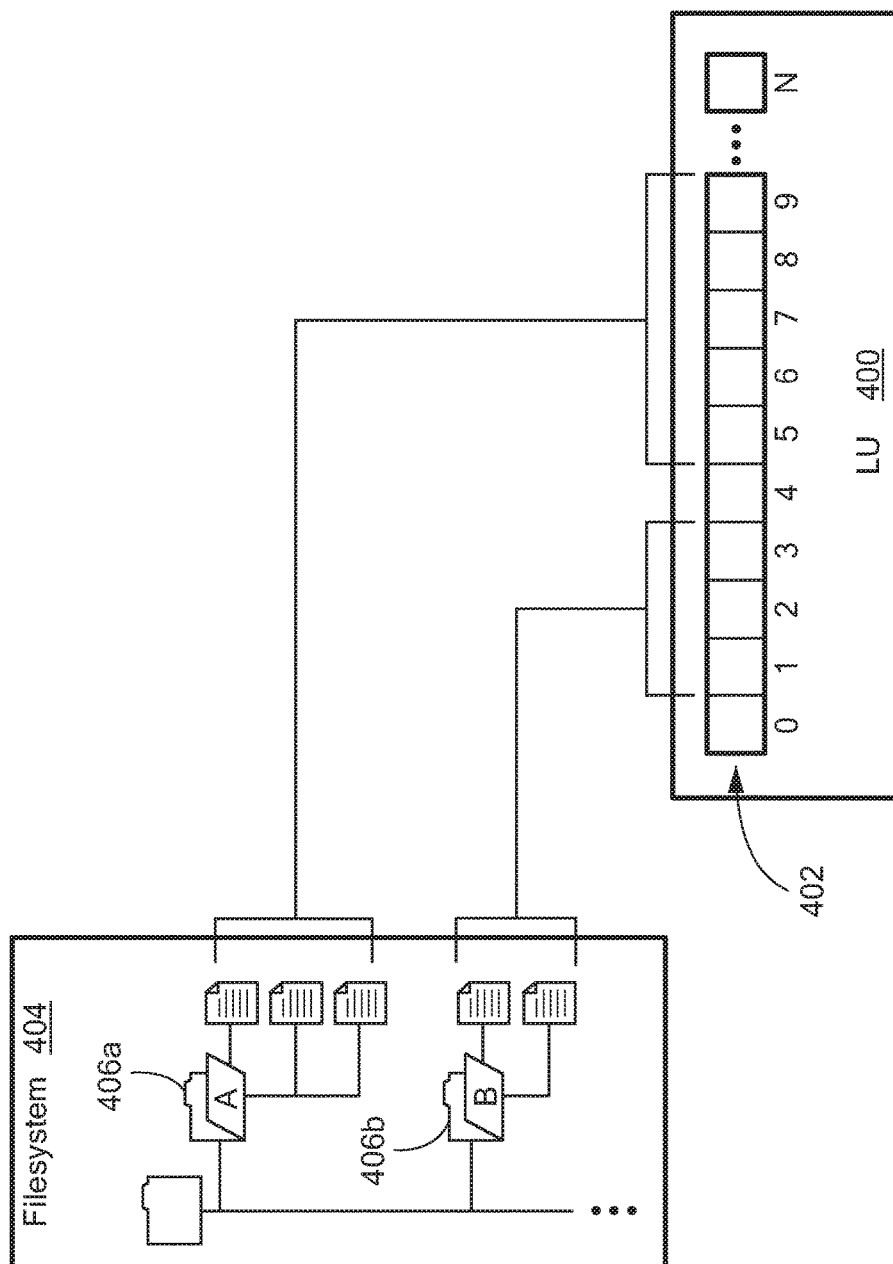
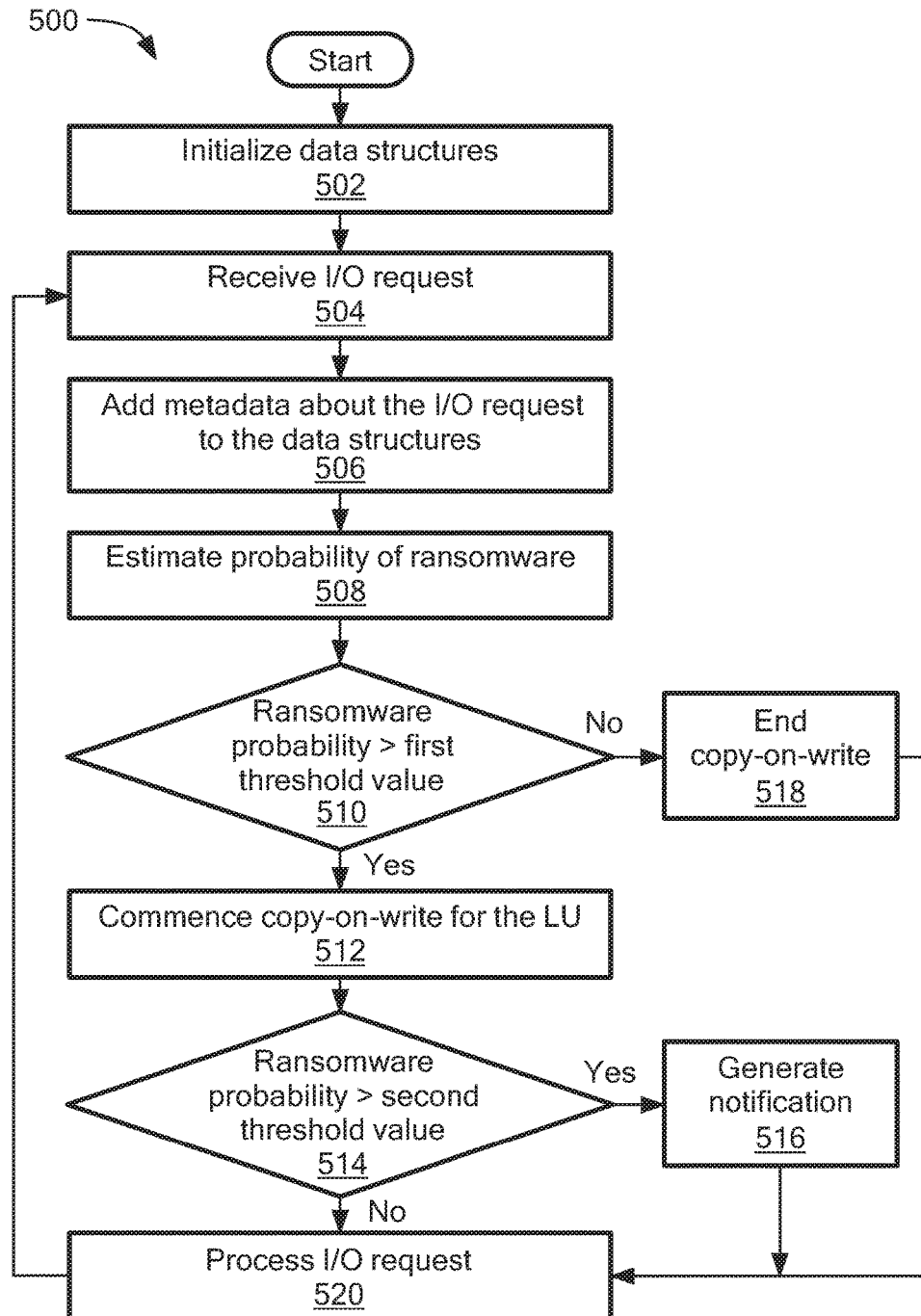
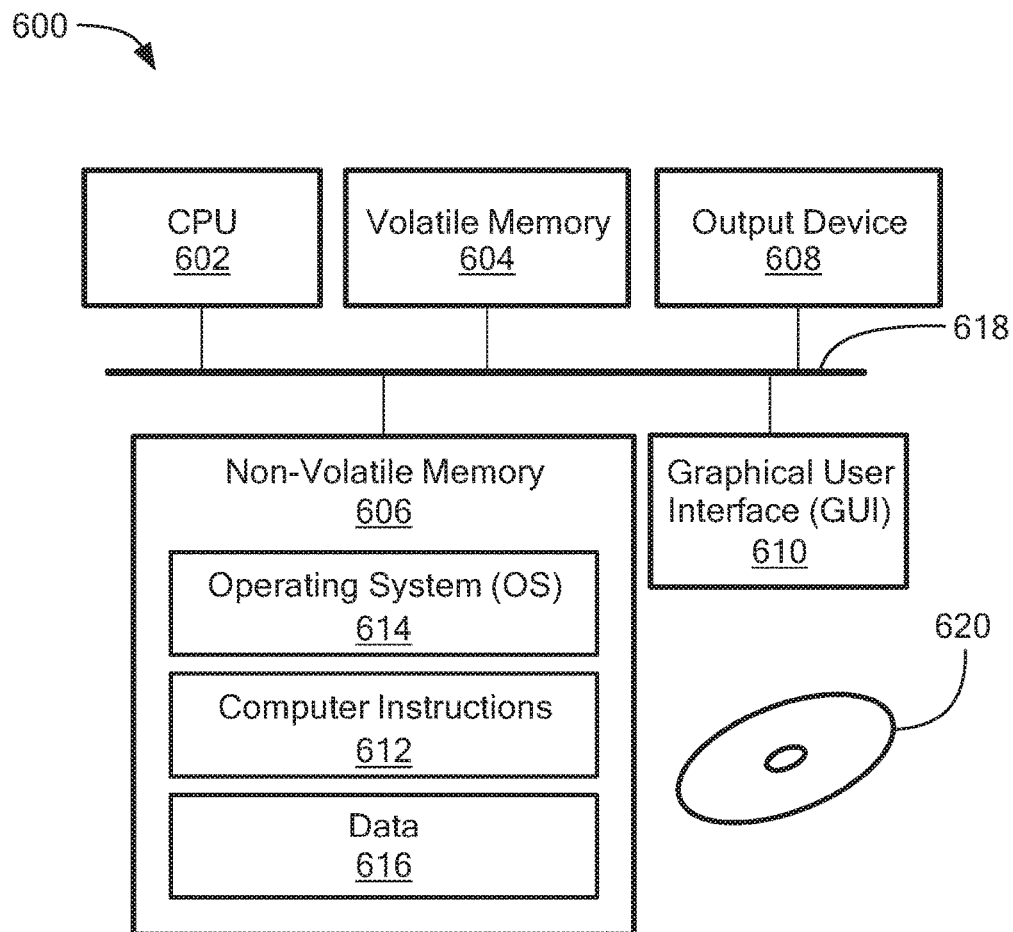


FIG. 4

**FIG. 5**



**FIG. 6**

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## RANSOMWARE DETECTION USING I/O PATTERNS

### BACKGROUND

Computer data is vital to today's organizations and a significant part of protection against disasters is focused on data protection. Existing data protection systems may provide continuous data protection, meaning that every change made to data is backed up.

Ransomware attacks are increasing prevalent. In a typical attack, the attacker installs a virus on a victim host (e.g., a desktop or server computer) that replaces files on the host with encrypted versions of those files. If strong encryption is used, the original files can practically only be recovered using a secret key held by the attacker. The attacker may demand payment in exchange for the secret key.

### SUMMARY

Described herein are embodiments of systems and methods for detecting ransomware using I/O patterns.

According to one aspect of the disclosure, a method comprises: initializing historical I/O activity data structures and recent I/O activity data structures associated with a logical unit (LU) of storage; receiving an I/O request from a host, the I/O request associated with one or more chunks within the LU; adding metadata about the I/O request to the recent I/O activity data structures; generating a ransomware probability by comparing the recent I/O activity data structures to the historical I/O activity data structures; and if the ransomware probability exceeds a first threshold value, taking one or more first actions to mitigate the effects of ransomware within the host.

In various embodiments, the method further comprises if the ransomware probability exceeds a second threshold value, taking one or more second actions to mitigate the effects of ransomware within the host, wherein the second threshold value is greater than the first threshold value. In one embodiment, the one or more first actions include commencing copy-on-write (COW) for the LU and wherein the one or more second actions include generating a notification of suspected ransomware. In certain embodiments, generating a ransomware probability comprises using at least one of the following heuristics: the number of times the chunks have been recently accessed according to the recent I/O activity data structures, the probability of the chunks being accessed according to the historical I/O activity data structures, whether the chunks have been recently read from and then overwritten according to the recent I/O activity data structures, the probability of the chunks being read from and then overwritten according to the historical I/O activity data structures, whether the chunks are within a range of chunks that have been recently accessed according to the recent I/O activity data structures, and the probability of the chunks being accessed sequentially according to the historical I/O activity data structures.

In some embodiments, the method further comprises if the ransomware probability is less than the third threshold value less than or equal to the first threshold value, ending copy-on-write for the LU. In various embodiments, ending copy-on-write for the LU includes erasing copy-on-write chunk versions from the storage. In one embodiment, commencing COW for the LU comprises creating a snapshot of the LU. In certain embodiments, commencing COW for the

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LU comprises making a copy, in storage, of any data that will be overwritten by subsequent I/O requests.

### BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing features may be more fully understood from the following description of the drawings in which:

FIG. 1 is a block diagram of a data protection system, according to one embodiment of the disclosure;

FIG. 2 is a diagram illustrating a journal history of write transactions for a storage system, according to one embodiment of the disclosure;

FIG. 3 is a block diagram of a data protection appliance, according to another embodiment of the disclosure;

FIG. 4 is a diagram illustrating a logical unit (LU) wherein contents of a filesystem are stored, according to an embodiment of the disclosure;

FIG. 5 is flow diagram of a method for detecting and mitigating ransomware attacks, according to embodiments of the disclosure; and

FIG. 6 is a block diagram of a computer on which the method of FIG. 5 may be implemented, according to an embodiment of the disclosure.

The drawings are not necessarily to scale, or inclusive of all elements of a system, emphasis instead generally being placed upon illustrating the concepts, structures, and techniques sought to be protected herein.

### DETAILED DESCRIPTION

Before describing embodiments of the concepts, structures, and techniques sought to be protected herein, some terms are explained. In some embodiments, the term "I/O request" or simply "I/O" may be used to refer to an input or output request. In some embodiments, an I/O request may refer to a data read or write request.

Referring to the embodiment of FIG. 1, a data protection system 100 includes two sites: Site I 100a and Site II 100b. Under normal operation Site I 100a may correspond to a source side (i.e., the transmitter within a data replication workflow) of system 100 and Site II 100b may be the target side (i.e., the receiver within a data replication workflow) of the system, as shown in FIG. 1. Thus, during normal operations, the direction of replicate data flow may go from Site I 100a to Site II 100b.

In certain embodiments, Site I and Site II may be remote from one another. In other embodiments, the two sites may be local to one another. In particular embodiments, Site I and Site II may be connected via a local area network (LAN). In other embodiments, the two sites may be connected via a wide area network (WAN), such as the Internet.

In particular embodiments, the data protection system may include a failover mode of operation, wherein the direction of replicated data flow is reversed. In such embodiments, Site I may behave as a target side and Site II may behave as the source side. In some embodiments, failover may be triggered manually (e.g., by a user) or automatically. In many embodiments, failover may be performed in the event of a disaster at Site I. In some embodiments, both Site I and Site II may behave as source side for some stored data and may behave simultaneously as a target site for other stored data. In certain embodiments, a portion of stored data may be replicated from one site to the other, and another portion may not be replicated.

In some embodiments, Site I corresponds to a production site (e.g., a facility where one or more hosts run data processing applications that write data to a storage system

and read data from the storage system) and Site II corresponds to a backup or replica site (e.g., a facility where replicated production site data is stored). In such embodiments, Site II may be responsible for replicating production site data and may enable rollback of Site I data to an earlier point in time. In many embodiments, rollback may be used in the event of data corruption of a disaster, or alternatively in order to view or to access data from an earlier point in time.

Referring again to FIG. 1, Site I **100a** includes a source host **104**, a source storage system (or “storage array”) **108**, and a source data protection appliance (DPA) **112** coupled via a first storage area network (SAN). Similarly, Site II **100b** includes a target host **116**, a target storage system **120**, and a target DPA **124** coupled via a second SAN. Each SAN may include one or more devices (or “nodes”) that may be designated an “initiator,” a “target,” or both. In the embodiment of FIG. 1, the first SAN includes a first fiber channel switch **148** and the second SAN includes a second fiber channel switch **168**. Communication links between each host **104**, **116** and its corresponding storage system **108**, **120** may be any appropriate medium suitable for data transfer, such as fiber communication channel links. In many embodiments, a host communicates with its corresponding storage system using SCSI commands.

Referring back to FIG. 1, hosts **104** and **116** may each correspond to one computer, a plurality of computers, or a network of distributed computers. In some embodiments, a host may include a processor, volatile memory, non-volatile memory, a data bus, an I/O interface, a display interface and a network interface. In certain embodiments, a host may run at least one data processing application, such as a database application and an e-mail server.

Referring again to FIG. 1, each storage system **108**, **120** may include storage devices for storing data, such as disks or arrays of disks. In some embodiments, the storage systems may be target nodes. In certain embodiments, in order to enable initiators to send requests to a storage system, the storage system may expose one or more logical units (LU) to which commands are issued. In many embodiments, the storage systems may be SAN entities that provide multiple LUs for access by multiple SAN initiators. In many embodiments, an LU is a physical or virtual logical entity provided by a storage system for accessing data stored therein. In some embodiments, a LU may be identified by a unique logical unit number (LUN).

In the embodiment of FIG. 1, storage system **108** exposes a logical unit **136**, designated as LU A, and storage system **120** exposes a logical unit **156**, designated as LU B. LU B may be used for replicating LU A. As such, LU B may be generated as a copy of LU A. In one embodiment, LU B may be configured so that its size is identical to the size of LU A.

Referring back to FIG. 1, the source host **104** generates a host device **140** (“Device A”) corresponding to LU A and the source host **116** generates a host device **160** (“Device B”) corresponding to LU B. In many embodiments, a host device is a logical entity within a host through which the host may access a LU. In some embodiments, an operating system of a host may generate a host device for each logical unit exposed by a storage system in the host SAN.

Referring again to FIG. 1, the source host **104** is configured to act as a SAN initiator that issues I/O requests through host device **140** to LU **136** (“LU A”). In some embodiments, the I/O requests include SCSI commands. In many embodiments, an I/O request includes an address that includes a specific device identifier, an offset within the device, and a data size.

Referring back to FIG. 1, the source DPA **112** and target DPA **124** may perform various data protection services, such as data replication of a storage system, and journaling of I/O requests issued by the hosts **104**, **116**. When acting as a target DPA, a DPA may also enable rollback of data to an earlier point-in-time (PIT), and processing of rolled back data at the target site. Each DPA **112**, **124** may be a physical device, a virtual device running, or may be a combination of a virtual and physical device.

In some embodiments, a DPA may be a cluster of such computers. In many embodiments, a cluster may ensure that if a DPA computer is down, then the DPA functionality switches over to another computer. In some embodiments, computers within a DPA cluster may communicate with one another using at least one communication link suitable for data transfer via fiber channel or IP based protocols, or such other transfer protocol. In certain embodiments, one computer from the DPA cluster may serve as the DPA leader that coordinates other computers in the cluster, and may also perform other tasks that require coordination between the computers, such as load balancing.

In certain embodiments, a DPA may be a standalone device integrated within a SAN. In other embodiments, a DPA may be integrated into a storage system. In some embodiments, the DPAs communicate with their respective hosts through communication lines such as fiber channels using, for example, SCSI commands or any other protocol.

In various embodiments, the DPAs may be configured to act as initiators in the SAN. For example, the DPAs may issue I/O requests using to access LUs on their respective storage systems. In some embodiments, each DPA may also be configured with the necessary functionality to act as targets, e.g., to reply to I/O requests, such as SCSI commands, issued by other initiators in the SAN, including their respective hosts. In certain embodiments, the DPAs, acting as target nodes, may dynamically expose or remove one or more LUs.

Referring again to FIG. 1, as described herein above, Site I and Site II may each behave simultaneously as a production site and a backup site for different logical units. As such, DPA **112** and DPA **124** may each behave as a source DPA for some LUs, and as a target DPA for other LUs, at the same time.

In the embodiment of FIG. 1, hosts **104** and **116** include protection agents **144** and **164**, respectively. Protection agents **144** and **164** are configured to intercept SCSI commands issued by their respective hosts to LUs via host devices (e.g. host devices **140** and **160**). A protection agent may act on an intercepted SCSI command issued to a logical unit, in one of the following ways: send the SCSI commands to its intended LU; redirect the SCSI command to another LU; split the SCSI command by sending it first to the respective DPA and, after the DPA returns an acknowledgement, send the SCSI command to its intended LU; fail a SCSI command by returning an error return code; and delay a SCSI command by not returning an acknowledgement to the respective host. A protection agent **144**, **164** may handle different SCSI commands, differently, according to the type of the command. For example, a SCSI command inquiring about the size of a certain LU may be sent directly to that LU, whereas a SCSI write command may be split and sent first to a DPA within the host’s site.

In various embodiments, a protection agent may change its behavior for handling SCSI commands, for example as a result of an instruction received from the DPA. In certain embodiments, the behavior of a protection agent for a certain host device may depend on the behavior of its associated

DPA with respect to the LU of the host device. In some embodiments, when a DPA behaves as a source site DPA for a certain LU, then during normal course of operation, the associated protection agent may split I/O requests issued by a host to the host device corresponding to that LU. In particular embodiments, when a DPA behaves as a target device for a certain LU, then during normal course of operation, the associated protection agent fails I/O requests issued by the host to the host device corresponding to that LU.

Referring back to FIG. 1, communication between a protection agent 144, 164 and its respective DPA 112, 124 may use any protocol suitable for data transfer within a SAN, such as fiber channel, or SCSI over fiber channel. The communication may be direct, or via a logical unit exposed by the DPA.

In certain embodiments, protection agents may be drivers located in their respective hosts. In other embodiments, a protection agent may be located in a fiber channel switch or in any other device situated in a data path between a host and a storage system or on the storage system itself. In a virtualized environment, the protection agent may run at the hypervisor layer or in a virtual machine providing a virtualization layer.

Referring again to FIG. 1, the target storage system 120 exposes a journal LU 176 for maintaining a history of write transactions made to LU 156, referred to herein as a “journal.” The journal may be used to provide access to storage at specified points in time, as discussed further below in conjunction with FIG. 2. In some embodiments, the journal may be stored across multiple LUs (e.g., using striping).

In the embodiment of FIG. 1, the target DPA 124 includes a journal processor 180 for managing the journal within LU 176. The journal processor 180 is configured to manage the journal entries of LU B 156. Specifically, journal processor 180 may enter write transactions received by the target DPA 124 from the source DPA 112 into the journal by writing them into the journal LU 176, read the undo information for the transaction from LU B 156, update the journal entries in the journal LU 176 with undo information, apply the journal transactions to LU B 156, and remove already-applied transactions from the journal.

In one embodiment, the journal processor 180 is configured to perform processing described in the patent titled “METHODS AND APPARATUS FOR OPTIMAL JOURNALING FOR CONTINUOUS DATA REPLICATION” and with U.S. Pat. No. 7,516,287, issued Apr. 7, 2009, which is hereby incorporated by reference.

Embodiments of the data replication system may be provided as physical systems for the replication of physical LUs, or as virtual systems for the replication of virtual LUs. In one embodiment, a hypervisor may consume LUs and may generate a distributed file system on the logical units such as VMFS, for example, generates files in the file system and exposes the files as LUs to the virtual machines (each virtual machine disk is seen as a SCSI device by virtual hosts). In another embodiment, a hypervisor may consume a network based file system and exposes files in the NFS as SCSI devices to virtual hosts.

Referring back to FIG. 1, in normal operation (sometimes referred to as “production mode”), the DPA 112 acts as a source DPA for LU 136 (“LU A”). Thus, protection agent 144 is configured to act as a source protection agent, specifically by splitting I/O requests to host device 140 (“Device A”). The protection agent 144 may send an I/O request to source DPA 112 and, after receiving an acknowledgement therefrom, may send the I/O request to LU 136.

After receiving a second acknowledgement from storage system 108, the host 104 may acknowledge that the I/O request has successfully completed.

When source DPA 112 receives a replicated I/O request from protection agent 144, source DPA 112 may transmit certain I/O information characterizing the write request, packaged as a “write transaction”, over WAN 128 to the target DPA 124 for journaling and for incorporation within target storage system 120. When applying write operations to storage system 120, the target DPA 124 may act as an initiator, and may send SCSI commands to LU 156 (“LU B”).

The source DPA 112 may send its write transactions to target DPA 124 using a variety of modes of transmission, including inter alia (i) a synchronous mode, (ii) an asynchronous mode, and (iii) a batch mode. In synchronous mode, the source DPA 112 may send each write transaction to the target DPA 124, may receive back an acknowledgement from the target DPA 124, and in turns may send an acknowledgement back to protection agent 144.

In synchronous mode, protection agent 144 may wait until receipt of such acknowledgement before sending the I/O request to LU 136. In asynchronous mode, the source DPA 112 may send an acknowledgement to protection agent 144 upon receipt of each I/O request, before receiving an acknowledgement back from target DPA 124.

In batch mode, the source DPA 112 may receive several I/O requests and combines them into an aggregate “batch” of write activity performed in the multiple I/O requests, and may send the batch to the target DPA 124, for journaling and for incorporation in target storage system 120. In batch mode, the source DPA 112 may send an acknowledgement to protection agent 144 upon receipt of each I/O request, before receiving an acknowledgement back from the target DPA 124.

As discussed above, in normal operation, LU B 156 may be used as a backup of LU A 136. As such, while data written to LU A by host 104 is replicated from LU A to LU B, the target host 116 should not send I/O requests to LU B. To prevent such I/O requests from being sent, protection agent 164 may act as a target side protection agent for host device B 160 and may fail I/O requests sent from host 116 to LU B 156 through host device B 160.

Still referring to FIG. 1, in recovery mode, the target DPA 124 may undo the write transactions in the journal LU 176 so as to restore the target storage system 120 to an earlier state.

In various embodiments, the source DPA 112 is configured to detect and mitigate the effects of ransomware within the source host 104. In some embodiments, the source DPA 112 uses structures and techniques described below in conjunction with FIGS. 3-5 to detect and mitigate the effects of ransomware.

Referring to the embodiment of FIG. 2, a write transaction 200 may be included within a journal and stored within a journal LU, in accordance with an embodiment. The write transaction 200 includes one or more identifiers; a time stamp indicating the date and time at which the transaction was received by the source DPA; a write size indicating the size of the data block; a location in the journal LU where the data is entered; a location in the target LU where the data is to be written; and the data itself.

Referring briefly to both FIGS. 1 and 2, the transaction 200 may correspond to a transaction transmitted from the source DPA 112 to target DPA 124. The target DPA 124 may record the write transaction 200 in the journal that includes four streams. A first stream, referred to as a “DO” stream,

includes a copy of the new data for writing to LU B 156. A second stream, referred to as a "DO METADATA" stream, includes metadata for the write transaction, such as an identifier, a date and time, a write size, the offset within LU B 156 where the new data is written, and a pointer to the offset in the DO stream where the corresponding data is located. A third stream, referred to as an "UNDO" stream, includes a copy of the data being overwritten within LU B 156 (referred to herein as the "old" data). A fourth stream, referred to as an "UNDO METADATA" stream, includes an identifier, a date and time, a write size, a beginning address in LU B 156 where data was (or will be) overwritten, and a pointer to the offset in the UNDO stream where the corresponding old data is located.

Since the journal contains the "undo" information necessary to rollback storage system 120, data that was stored in specific memory locations at a specified point in time may be obtained by undoing write transactions that occurred subsequent to such point in time.

Each of the four streams may hold a plurality of write transaction data. As write transactions are received dynamically by target DPA, the write transactions may be recorded at the end of the DO stream and the end of the DO METADATA stream, prior to committing the transaction.

In some embodiments, a metadata stream (e.g., UNDO METADATA stream or the DO METADATA stream) and the corresponding data stream (e.g., UNDO stream or DO stream) may be kept in a single stream by interleaving metadata and data.

Referring to FIG. 3, a data protection appliance (DPA) 300 includes a journal processor 302 and a ransomware detection processor 304, according to an embodiment of the disclosure. In some embodiments, the DPA may be the same as or similar to a DPA 112, 124 in FIG. 1. In certain embodiments, the journal processor 302 may be the same as or similar to a journal processor 188, 180 in FIG. 1.

In the embodiment of FIG. 3, ransomware detection processor 304 is configured to detect patterns of host I/O behavior that may result from ransomware and to mitigate the effects of ransomware on the host's data. In some embodiments, the ransomware detection processor detects ransomware that systematically traverses the host's filesystem, enumerating files in a directory-by-directory basis, and performing in-place encryption of files regardless of whether they are located within direct attached storage (DAS) and network attached storage (NAS). In many embodiments, the phrase "in-place encryption" refers to encrypting a file without changing the location or name of the file within the host's filesystem.

Referring to the embodiment FIG. 4, and also with reference to FIG. 3, a host may write data to a logical unit (LU) 400 within a storage array. As discussed above in conjunction with FIG. 1, a DPA 300 configured as a source DPA may receive I/O requests originating from the host before such requests are issued to the source-side LU 400. The LU 400 is logically divided into a plurality of chunks 402, and each chunk has a corresponding chunk number that is unique to the LU 400. The LU 400 includes N chunks having corresponding chunk numbers 0 . . . N. In some embodiments, all chunks have the same size (i.e., the LU may be divided into a plurality of equal-sized chunks).

Conventional filesystems (e.g., XFS for Linux and NTFS for MICROSOFT WINDOWS®) may locate files in the same directory (or "folder") together within storage. As illustrated in FIG. 4, a filesystem 404 includes a first directory 406a and a second directory 406b, each having a plurality of files. The files within the first directory 406a are

stored within chunks 1-3 and the files within the second directory 406b are stored within chunks 5-9.

In various embodiments, the ransomware detection processor takes advantage of the sequential (i.e., directory-by-directory) nature of ransomware and the spatial location of filesystems to detect ransomware. In some embodiments, the pattern of I/O requests resulting from ransomware encryption may be significantly different (e.g., statistically distinguishable) from I/O request patterns resulting from normal application usage within the host. In particular embodiments, ransomware encryption tends to access chunks in a sequential fashion. In the embodiment of FIG. 4, if ransomware encrypts all files within directory 406a, the resulting I/O pattern might look like: R1, R2, W1, W2, R2, W2, R2, R3, W3, where the notation "R#" denotes a read to a specified chunk number, and the notation "W#" denote writes to a specified chunk number. Moreover, chunks that are written to as a result of ransomware encryption tend to be written to less often compared with chunks that are written to as a result of normal application usage. This pattern results from that fact that encrypted files written by ransomware cannot be properly updated without access to the ransomware secret key. Stated differently, once a chunk is visited by ransomware, it tends to become useless to the host's users and applications, thereby making it unlikely that the chunk will be subsequently written to.

Referring back to the embodiment of FIG. 3, the ransomware detection processor 304 may maintain one or more data structures for historical I/O activity 306 and one or more data structures for recent I/O activity 308. In certain embodiments, each recent and historical I/O data structure is associated with a particular LU and a particular host (i.e., an activity data structure may include information about activity between a single host and a single LU).

Referring again to FIG. 3, recent I/O activity 308 includes information about I/O activity that has occurred in the recent past (e.g., over the past K seconds, minutes, or hours). In various embodiments, recent I/O activity includes a list of metadata about recent I/O requests issued from a particular host to an LU. In one embodiment, recent I/O activity may include a list of storage locations (e.g., chunk numbers) that have recently been read from, and a list of storage locations that have recently been written to. In some embodiments, recent I/O activity includes metadata about all I/O requests that occurred in the past K seconds, minutes, hours, etc. In other embodiments, recent I/O activity may include metadata about the last N I/O requests (e.g., a fixed-length data structure may be used).

Referring back to the embodiment of FIG. 3, historical I/O activity 306 includes information about common I/O access patterns over time between a host and an LU. In many embodiments, I/O access patterns include at least some of the following information: the probability that a storage location is read from in a given time period; the probability that a storage location is written to in a time period; the probability that a range of storage locations are read from sequentially, meaning the probability that the entire range (or a substantial portion thereof) is read within a time period; the probability that a range of storage locations is written to sequentially; the probability that a storage location is read from at random, meaning the probability that the storage location is read from in a non-sequential manner within a time period; the probability a storage location is written to at random; and the probability that a storage location is read from and then written to (i.e., overwritten) in a time period. In certain embodiments, historical I/O activity data may be collected over relatively long time periods (e.g., several

hours, days, or weeks) over which the probability that ransomware is running on the host is low. In some embodiments, historical I/O data structures may include heatmaps indicating how frequently storage locations are accessed.

Referring back to FIG. 3, the ransomware detection processor 304 compares recent I/O activity 308 to historical I/O activity 306 to determine if ransomware is running on the host. The ransomware detection processor uses statistical analysis to generate a probability that ransomware is running in the host ("the ransomware probability"). Non-limiting examples of heuristics that may be used to generate the ransomware probability include: (1) the number of times a storage location has been recently read from/written to versus the historic probability of that storage location being read/written within a given time period; (2) whether a storage location has recently been read from and then overwritten versus the historic probability of that occurring; (3) whether a range of storage locations has been recently read to/written from versus the historic probability of those storage locations being read/written sequentially; and (4) whether a storage location has been recently read to/written from in a random fashion versus the historic probability of that occurring.

Based on the ransomware probability, the ransomware detection processor may take different actions to mitigate the effects of the suspected ransomware. In some embodiments, if the ransomware probability is above a first threshold, the ransomware detection processor may cause the storage system to enter copy-on-write mode to prevent data loss. In certain embodiments, if the ransomware probability is above a second threshold (higher than the first threshold), then the ransomware detection processor may generate a notification (e.g., send an alert to a user of the suspected ransomware).

In the embodiment of FIG. 3, the ransomware detection processor 304 is located within a DPA 300. In other embodiments, the ransomware detection processor may be located within a storage array (e.g., storage array 108 in FIG. 1). In various embodiments, the ransomware detection processor is located external to the host such that ransomware running on the host is unable to disrupt the ransomware detection (e.g., some ransomware attempts to shutdown processes on the host before it begins encrypting host data).

FIG. 5 is a flow diagram showing illustrative processing that can be implemented within data protection system (e.g., data protection system 100 of FIG. 1). In some embodiments, at least a portion of the processing described herein may be implemented within a data protection appliance (e.g., DPA 300 of FIG. 3). In one embodiment, at least a portion of the processing described herein may be implemented within a ransomware detection processor (e.g., ransomware detection processor 304 of FIG. 3). Rectangular elements (typified by element 502), herein denoted "processing blocks," represent computer software instructions or groups of instructions. Diamond shaped elements (typified by element 510), herein denoted "decision blocks," represent computer software instructions, or groups of instructions, which affect the execution of the computer software instructions represented by the processing blocks.

Alternatively, the processing and decision blocks may represent steps performed by functionally equivalent circuits such as a digital signal processor (DSP) circuit or an application specific integrated circuit (ASIC). The flow diagrams do not depict the syntax of any particular programming language but rather illustrate the functional information one of ordinary skill in the art requires to fabricate circuits or to generate computer software to perform the processing required of the particular apparatus. It should be

noted that many routine program elements, such as initialization of loops and variables and the use of temporary variables may be omitted for clarity. The particular sequence of blocks described is illustrative only and can be varied without departing from the spirit of the concepts, structures, and techniques sought to be protected herein. Thus, unless otherwise stated, the blocks described below are unordered meaning that, when possible, the functions represented by the blocks can be performed in any convenient or desirable order.

Referring to FIG. 5, a method 500 can be used to detect and mitigate the effects of ransomware within a host. At block 502, one or more data structures for historical I/O activity and one or more data structures for recent I/O activity are initialized. In some embodiments, this includes allocating data structures in memory. In certain embodiments, initializing one or more historical I/O activity data structures includes fetching previously collected historical I/O data (e.g., from storage or memory). In various embodiments, the recent and historical I/O activity structures may be the same as or similar to those described above in conjunction with FIG. 3.

Referring back to FIG. 5, at block 504, an I/O request is received from a host. The I/O request may include a LUN identifying a LU, an offset within the LU, and a data length. The offset and data length can be used to determine one or more storage locations (e.g., chunk numbers) within the LU where the requested data should be read from or written to.

At block 506, metadata about the I/O request may be added to the recent I/O activity data structures. In some embodiments, such metadata includes an offset, data length, and/or storage locations associated with the I/O request. In particular embodiments, metadata about the I/O request may also be added to the historical I/O activity data structures.

Referring again to FIG. 5, at block 508, a probability of ransomware is generated by comparing recent I/O activity to historical I/O activity (i.e., information within the respective data structures initialized at block 502). In various embodiments, generating the ransomware probability includes using one or more of the heuristics described above in conjunction with FIG. 3.

Referring back to FIG. 5, at block 510, if the ransomware probability exceeds a first threshold value (e.g., a first predetermined value), then the storage system may begin using copy-on-write (COW) for the LU (block 512). In some embodiments, if the system is in COW mode, an I/O write causes a copy to be made of any data that will be overwritten by the write. In other embodiments, COW may be implemented by creating a point in time snapshot of the LU. Referring again to FIG. 5, in the event that the host is infected with ransomware, the user may recover data by requesting a rollback from the storage system. If the ransomware probability subsequently falls below the certain threshold value, then COW may be ended for the LU and any COW data copies may be erased from storage (block 518). In some embodiments, COW ends when the ransomware probability subsequently falls below the first threshold value. In other embodiments, COW ends when the ransomware probability subsequently falls below the third threshold value less than the first threshold value.

At block 514, if the ransomware probability exceeds a second threshold value (greater than the first threshold), then a notification of suspected ransomware is generated. In some embodiments, an alert is sent to a user notifying the user of suspected ransomware within the host. In one embodiment, the user may recover from a ransomware attack using COW data copies.

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Referring back to FIG. 5, at block 520 the I/O request is processed. In the event that COW mode was enabled for the LU and the I/O request is a write request, then processing the I/O request may include making a copy, in storage, of any data that will be overwritten by the write request. In the embodiment of FIG. 5, the I/O request is processed even if the ransomware probability exceeds the second threshold value. In other embodiments, the I/O request is not processed if the ransomware probability exceeds the second threshold value.

Referring again to FIG. 5, the process 500 may repeat from block 504, as shown.

FIG. 6 shows a computer 600 that can perform at least part of the processing described herein, according to one embodiment. The computer 600 may include a processor 602, a volatile memory 604, a non-volatile memory 606 (e.g., hard disk), an output device 608 and a graphical user interface (GUI) 610 (e.g., a mouse, a keyboard, a display, for example), each of which is coupled together by a bus 618. The non-volatile memory 606 may be configured to store computer instructions 612, an operating system 614, and data 616. In one example, the computer instructions 612 are executed by the processor 602 out of volatile memory 604. In one embodiment, an article 620 comprises non-transitory computer-readable instructions. In some embodiments, the computer 600 corresponds to a virtual machine (VM). In other embodiments, the computer 600 corresponds to a physical computer.

Processing may be implemented in hardware, software, or a combination of the two. In various embodiments, processing is provided by computer programs executing on programmable computers/machines that each includes a processor, a storage medium or other article of manufacture that is readable by the processor (including volatile and non-volatile memory and/or storage elements), at least one input device, and one or more output devices. Program code may be applied to data entered using an input device to perform processing and to generate output information.

The system can perform processing, at least in part, via a computer program product, (e.g., in a machine-readable storage device), for execution by, or to control the operation of, data processing apparatus (e.g., a programmable processor, a computer, or multiple computers). Each such program may be implemented in a high level procedural or object-oriented programming language to communicate with a computer system. However, the programs may be implemented in assembly or machine language. The language may be a compiled or an interpreted language and it may be deployed in any form, including as a stand-alone program or as a module, component, subroutine, or other unit suitable for use in a computing environment. A computer program may be deployed to be executed on one computer or on multiple computers at one site or distributed across multiple sites and interconnected by a communication network. A computer program may be stored on a storage medium or device (e.g., CD-ROM, hard disk, or magnetic diskette) that is readable by a general or special purpose programmable computer for configuring and operating the computer when the storage medium or device is read by the computer. Processing may also be implemented as a machine-readable storage medium, configured with a computer program, where upon execution, instructions in the computer program cause the computer to operate. The program logic may be run on a physical or virtual processor. The program logic may be run across one or more physical or virtual processors.

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Processing may be performed by one or more programmable processors executing one or more computer programs to perform the functions of the system. All or part of the system may be implemented as special purpose logic circuitry (e.g., an FPGA (field programmable gate array) and/or an ASIC (application-specific integrated circuit)).

All references cited herein are hereby incorporated herein by reference in their entirety.

Having described certain embodiments, which serve to illustrate various concepts, structures, and techniques sought to be protected herein, it will be apparent to those of ordinary skill in the art that other embodiments incorporating these concepts, structures, and techniques may be used. Elements of different embodiments described hereinabove may be combined to form other embodiments not specifically set forth above and, further, elements described in the context of a single embodiment may be provided separately or in any suitable sub-combination. Accordingly, it is submitted that the scope of protection sought herein should not be limited to the described embodiments but rather should be limited only by the spirit and scope of the following claims.

What is claimed is:

1. A method comprising:

receiving an I/O request from a host, the I/O request associated with one or more chunks within a logical unit (LU) of storage;  
adding metadata about the I/O request to recent I/O activity data structures associated with the LU;  
generating a ransomware probability by comparing the recent I/O activity data structures to the historical I/O activity data structures associated with the LU;  
if the ransomware probability exceeds a first threshold value, taking one or more first actions to mitigate the effects of ransomware within the host; and  
if the ransomware probability exceeds a second threshold value, taking one or more second actions to mitigate the effects of ransomware within the host, wherein the second threshold value is greater than the first threshold value;

wherein the one or more first actions include commencing copy-on-write (COW) for the LU and wherein the one or more second actions include generating a notification of suspected ransomware.

2. The method of claim 1 wherein generating a ransomware probability comprises using at least one of the following heuristics:

the number of times the chunks have been recently accessed according to the recent I/O activity data structures;  
the probability of the chunks being accessed according to the historical I/O activity data structures;  
whether the chunks have been recently read from and then overwritten according to the recent I/O activity data structures;  
the probability of the chunks being read from and then overwritten according to the historical I/O activity data structures;  
whether the chunks are within a range of chunks that have been recently accessed according to the recent I/O activity data structures; and  
the probability of the chunks being accessed sequentially according to the historical I/O activity data structures.

3. The method of claim 1 further comprising:

if the ransomware probability is less than a third threshold value, wherein the third threshold value is less than or equal to the first threshold value, ending copy-on-write for the LU.

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4. The method of claim 3 wherein ending copy-on-write for the LU includes erasing copy-on-write chunk versions from the storage.

5. The method of claim 1 wherein commencing COW for the LU comprises creating a snapshot of the LU.

6. The method of claim 1 wherein commencing COW for the LU comprises making a copy, in storage, of any data that will be overwritten by subsequent I/O requests.

7. A system comprising:

one or more processors;

a volatile memory; and

a non-volatile memory storing computer program code that when executed on the processor causes execution across the one or more processors of a process operable to perform the operations of:

receiving an I/O request from a host, the I/O request associated with one or more chunks within a logical unit (LU) of storage;

adding metadata about the I/O request to the recent I/O activity data structures associated with the LU;

generating a ransomware probability by comparing the recent I/O activity data structures to the historical I/O activity data structures associated with the LU;

if the ransomware probability exceeds a first threshold value, taking one or more first actions to mitigate the effects of ransomware within the host; and

if the ransomware probability exceeds a second threshold value, taking one or more second actions to mitigate the effects of ransomware within the host, wherein the second threshold value is greater than the first threshold value;

wherein the one or more first actions include commencing copy-on-write (COW) for the LU and wherein the one or more second actions include generating a notification of suspected ransomware.

8. The system of claim 7 wherein the computer program code causes execution of a process to generate a ransomware probability comprising using at least one of the following heuristics:

the number of times the chunks have been recently accessed according to the recent I/O activity data structures;

the probability of the chunks being accessed according to the historical I/O activity data structures;

whether the chunks have been recently read from and then overwritten according to the recent I/O activity data structures;

the probability of the chunks being read from and then overwritten according to the historical I/O activity data structures;

whether the chunks are within a range of chunks that have been recently accessed according to the recent I/O activity data structures; and

the probability of the chunks being accessed sequentially according to the historical I/O activity data structures.

9. The system of claim 7 wherein the computer program code causes execution of a process further operable to perform the operations of:

if the ransomware probability is less than a third threshold value, wherein the third threshold value is less than or equal to the first threshold value, ending copy-on-write for the LU.

10. The system of claim 9 wherein ending copy-on-write for the LU includes erasing copy-on-write chunk versions from the storage.

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11. The system of claim 7 wherein commencing COW for the LU comprises creating a snapshot of the LU.

12. The system of claim 7 wherein commencing COW for the LU comprises making a copy, in storage, of any data that will be overwritten by subsequent I/O requests.

13. A computer program product tangibly embodied in a non-transitory computer-readable medium, the computer-readable medium storing program instructions that are executable to:

receive an I/O request from a host, the I/O request associated with one or more chunks within a logical unit (LU) of storage;

add metadata about the I/O request to the recent I/O activity data structures associated with the LU;

generate a ransomware probability by comparing the recent I/O activity data structures to the historical I/O activity data structures associated with the LU;

if the ransomware probability exceeds a first threshold value, take one or more first actions to mitigate the effects of ransomware within the host; and

if the ransomware probability exceeds a second threshold value, taking one or more second actions to mitigate the effects of ransomware within the host, wherein the second threshold value is greater than the first threshold value;

wherein the one or more first actions include commencing copy-on-write (COW) for the LU and wherein the one or more second actions include generating a notification of suspected ransomware.

14. The computer program product of claim 13 further storing program instructions that are generating a ransomware probability comprising using at least one of the following heuristics:

the number of times the chunks have been recently accessed according to the recent I/O activity data structures;

the probability of the chunks being accessed according to the historical I/O activity data structures;

whether the chunks have been recently read from and then overwritten according to the recent I/O activity data structures;

the probability of the chunks being read from and then overwritten according to the historical I/O activity data structures;

whether the chunks are within a range of chunks that have been recently accessed according to the recent I/O activity data structures; and

the probability of the chunks being accessed sequentially according to the historical I/O activity data structures.

15. The computer program product of claim 13 further storing program instructions that are executable to:

if the ransomware probability is less than a third threshold value, wherein the third threshold value is less than or equal to the first threshold value, ending copy-on-write for the LU.

16. The computer program product of claim 15 wherein ending copy-on-write for the LU includes erasing copy-on-write chunk versions from the storage.

17. The computer program product of claim 13 wherein commencing COW for the LU comprises creating a snapshot of the LU.

18. The computer program product of claim 13 wherein commencing COW for the LU comprises making a copy, in storage, of any data that will be overwritten by subsequent I/O requests.