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Lazier

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(54) **LAYERED DATA REDUNDANCY CODING TECHNIQUES FOR LAYER-LOCAL DATA RECOVERY**

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G06F 11/10 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H03M 13/2942*** (2013.01); ***G06F 1/266*** (2013.01); ***G06F 1/3268*** (2013.01); ***G06F 3/06*** (2013.01); ***G06F 11/1008*** (2013.01); ***G06F 11/1068*** (2013.01); ***G06F 11/1072*** (2013.01); ***G06F 11/1076*** (2013.01); ***G06F 11/1088*** (2013.01); ***G06F 11/1446*** (2013.01); ***G06F 11/167*** (2013.01); ***G06F 17/30073*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC G06F 11/1068; G06F 11/1072; G06F 11/1076; G06F 11/1088; G06F 17/30073; G06F 3/06; G06F 11/1446; G06F 11/167; G06F 2211/1028; G06F 2211/104; G06F 17/30371; G06F 17/30997; G06F 21/6218; G06F 21/6209; G06F 21/606; G06F 11/1008; G06F 1/266; G06F 1/3268; H04L 67/10; H04L 67/1097; H04L 63/08; H03M 13/2942; H03M 13/373; H03M 13/1102; H03M 13/3761; H03M 13/1515
USPC 714/774, 769, 763, 770, 6.22, 6.24, 6.12, 714/48, 54; 711/114, 129, 148
See application file for complete search history.

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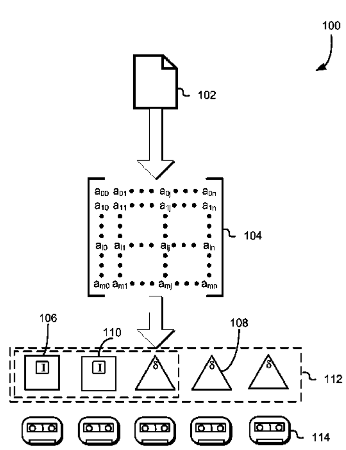
(74) *Attorney, Agent, or Firm* — Davis Wright Tremaine LLP

(57) **ABSTRACT**

Techniques and methods for generating and implementing multiple layers of redundancy coded data are disclosed. For example, a redundancy coding scheme may include data elements that include data that is unencoded relative to the input, yet may still fully participate in providing redundancy to any data element in a given set. In a layered scheme, the input may include a bundle or group of encoded (or unencoded) data elements, thereby nesting two or more layers of redundancy coding. The specific amount of redundancy generated by such a scheme may be adjusted and adapted to failure characteristics of the entity on which the data elements are stored.

20 Claims, 20 Drawing Sheets



(51) **Int. Cl.**

G06F 17/30	(2006.01)
G06F 11/14	(2006.01)
G06F 11/16	(2006.01)
G06F 3/06	(2006.01)
H04L 29/08	(2006.01)
G06F 21/62	(2013.01)
G06F 21/60	(2013.01)
H04L 29/06	(2006.01)
H03M 13/37	(2006.01)
H03M 13/11	(2006.01)
H03M 13/15	(2006.01)
G06F 1/26	(2006.01)
G06F 1/32	(2006.01)

(52) **U.S. Cl.**
CPC .. ***G06F 17/30371*** (2013.01); ***G06F 17/30997*** (2013.01); ***G06F 21/606*** (2013.01); ***G06F 21/6209*** (2013.01); ***G06F 21/6218*** (2013.01); ***H03M 13/1102*** (2013.01); ***H03M 13/1515*** (2013.01); ***H03M 13/373*** (2013.01); ***H03M 13/3761*** (2013.01); ***H04L 63/08*** (2013.01); ***H04L 67/10*** (2013.01); ***H04L 67/1097*** (2013.01); *G06F 2211/104* (2013.01); *G06F 2211/1028* (2013.01)

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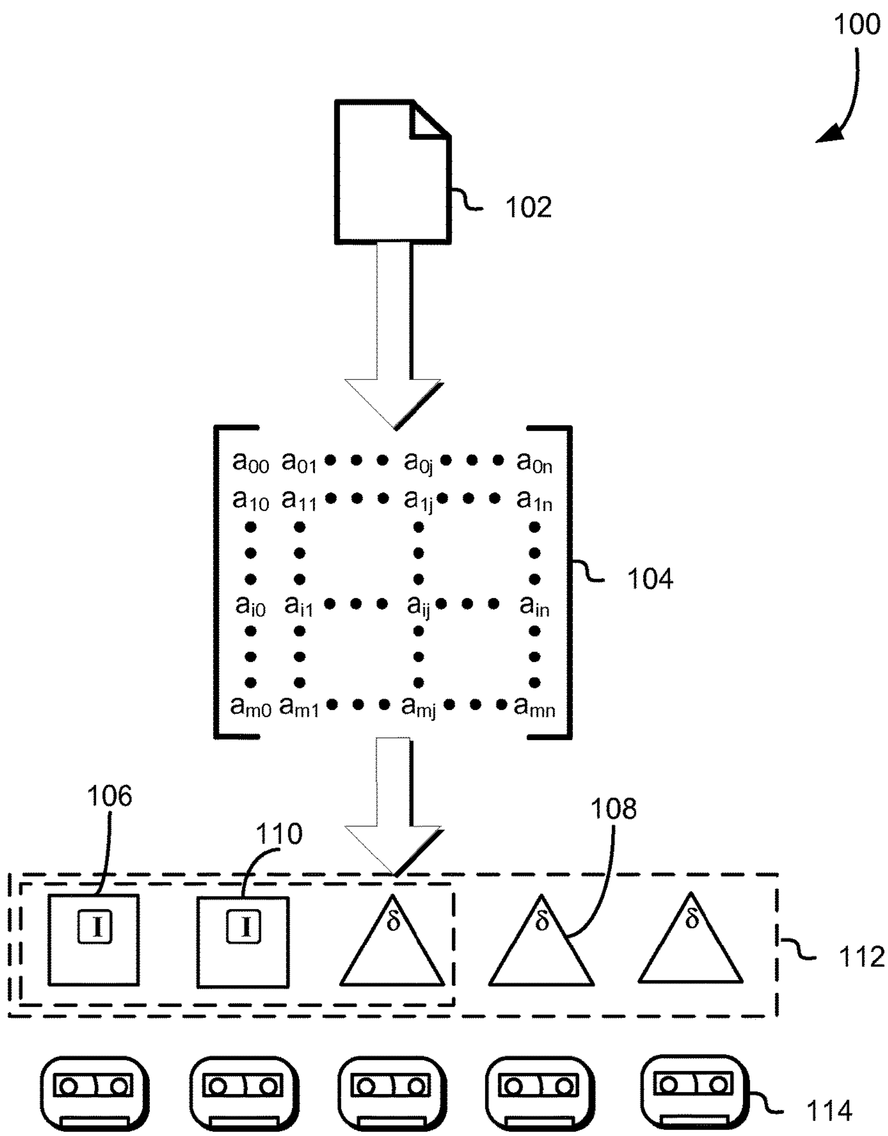
100
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FIG. 1

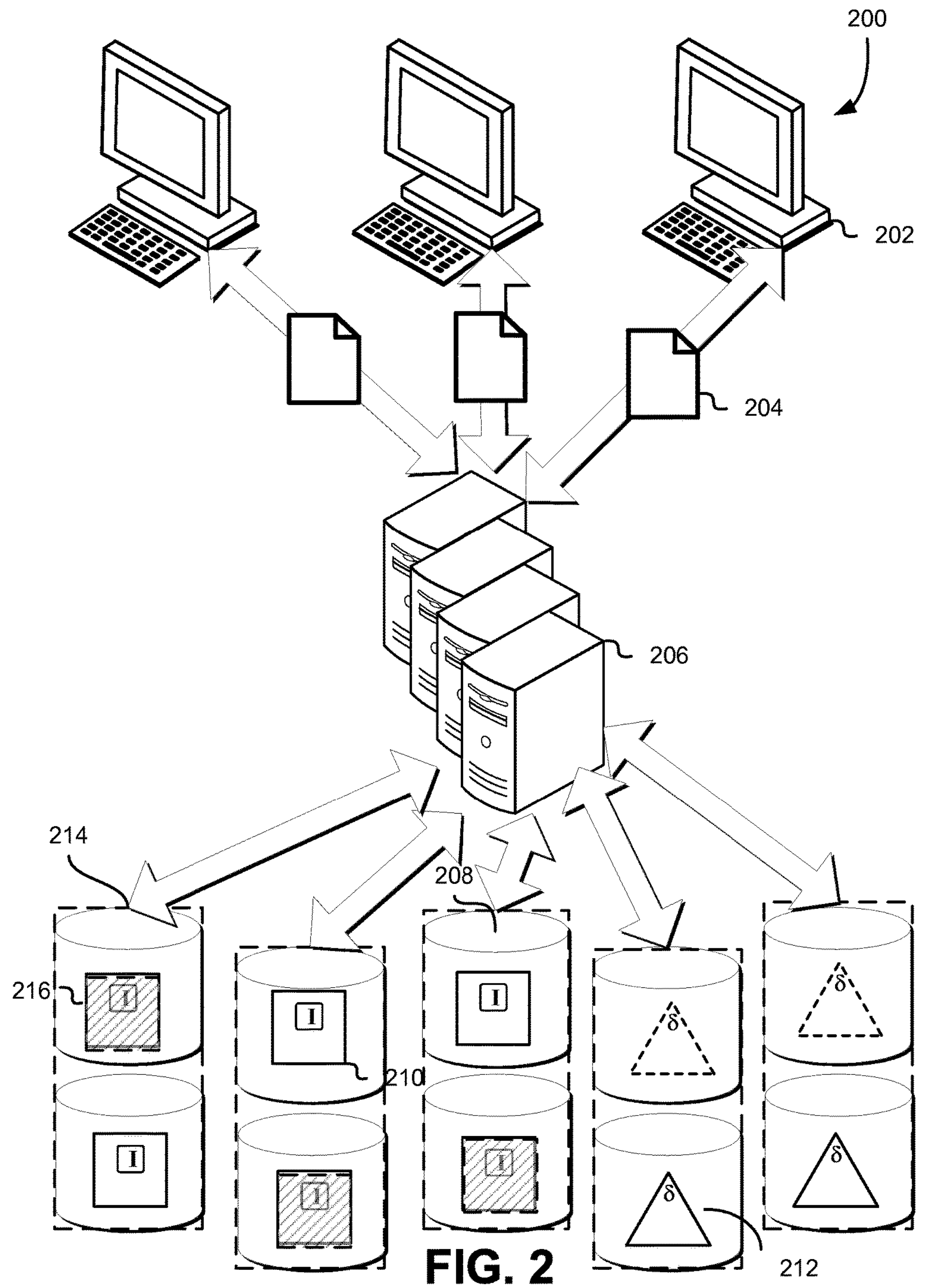


FIG. 2

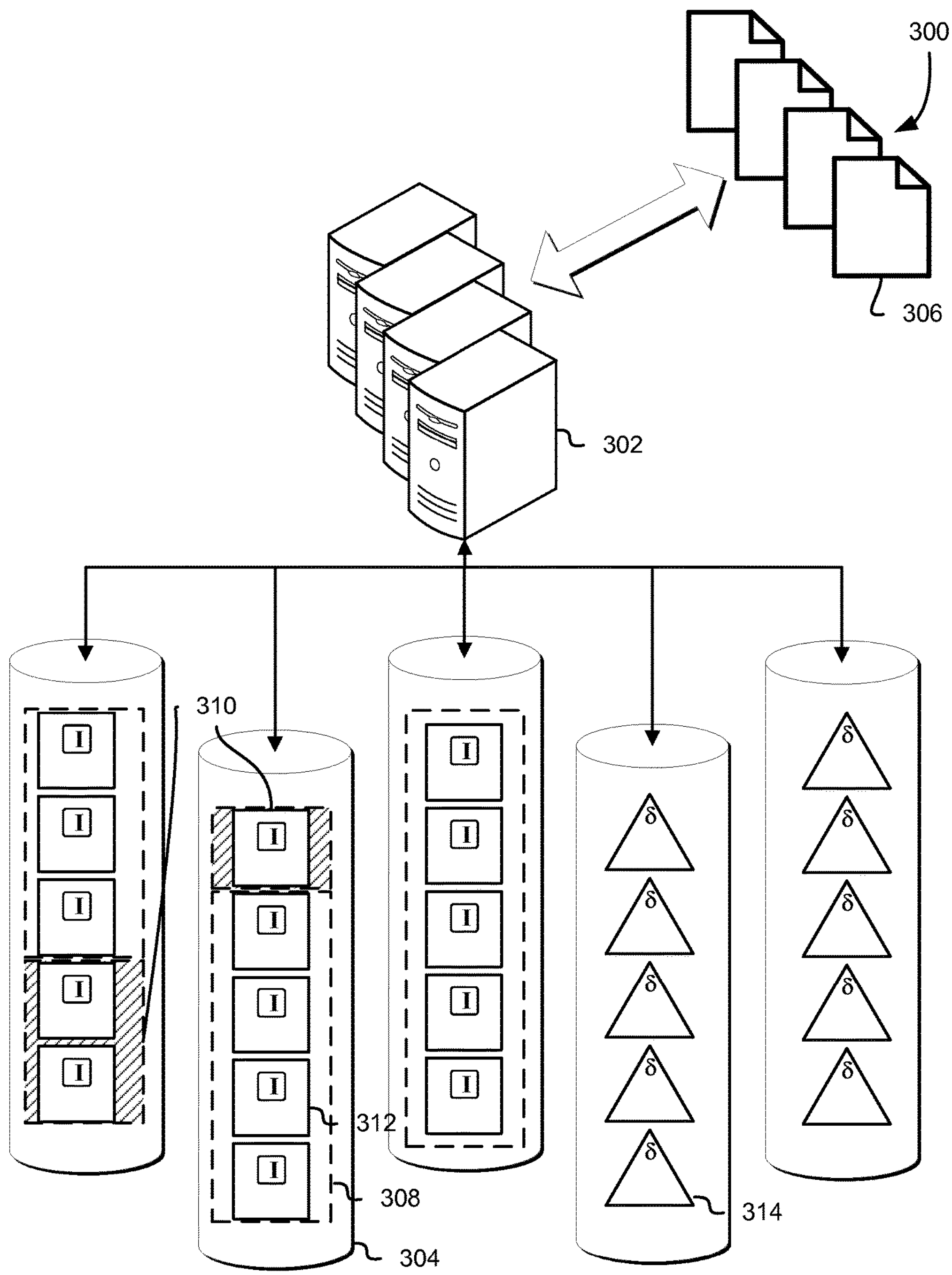
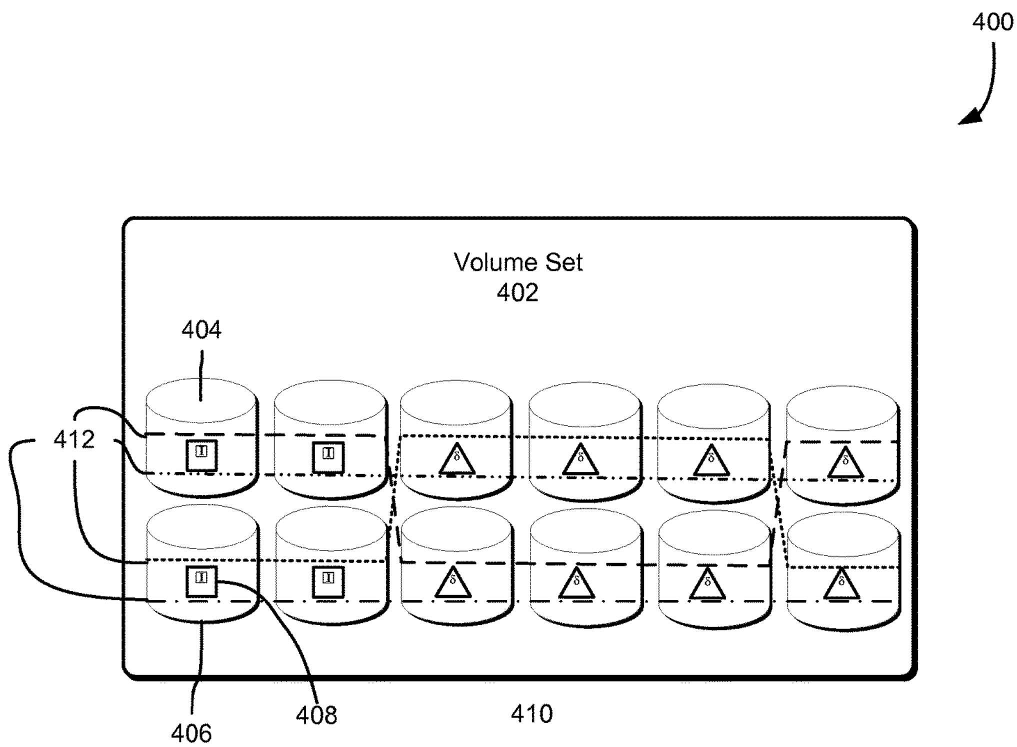


FIG. 3



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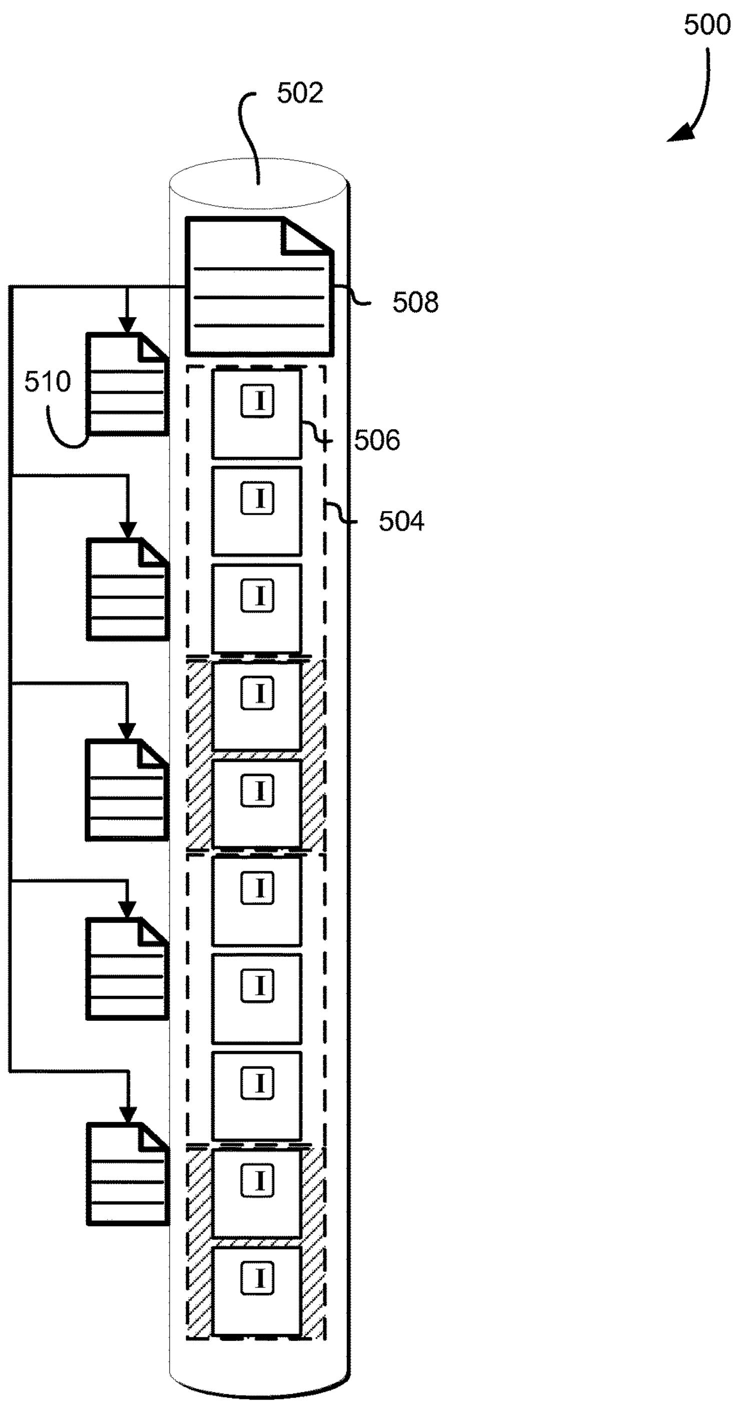

FIG. 5

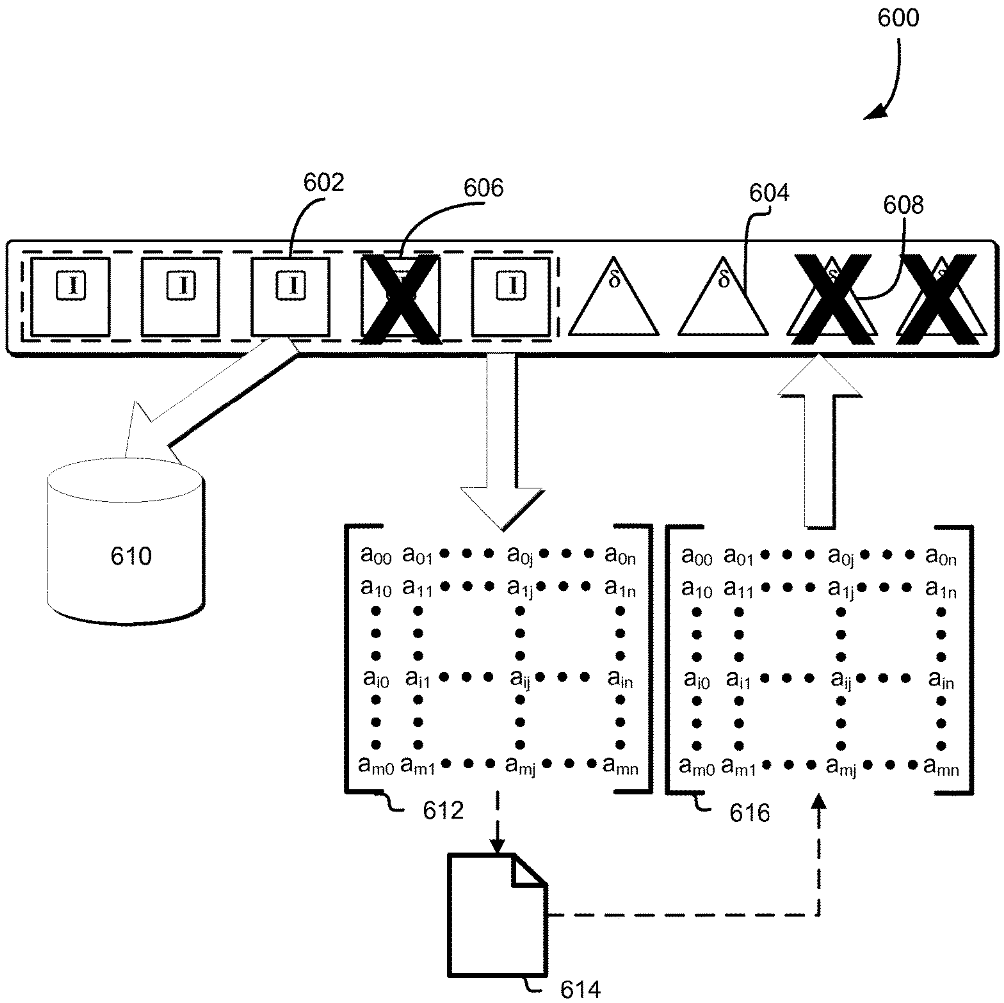

FIG. 6

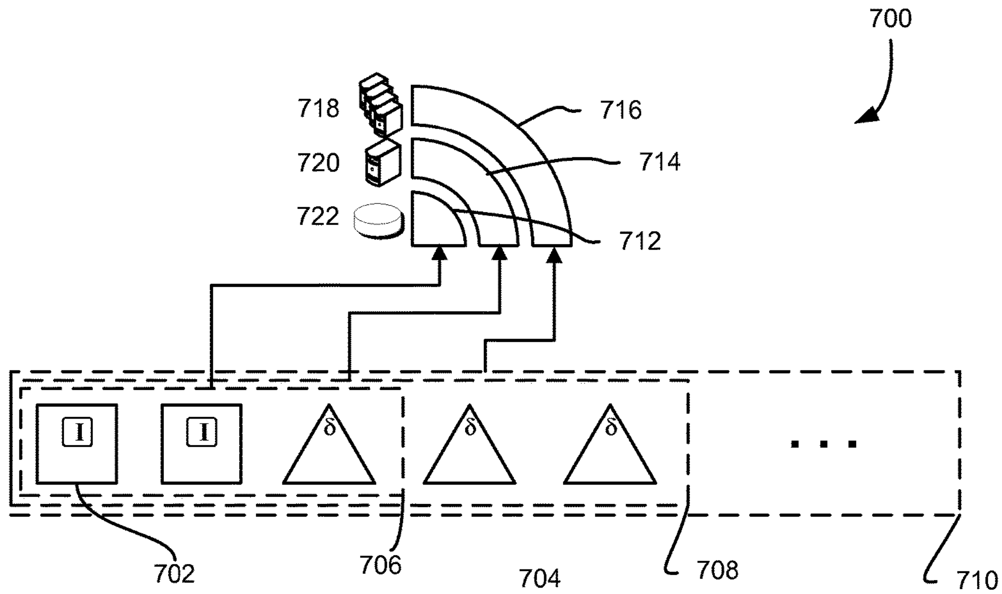

FIG. 7

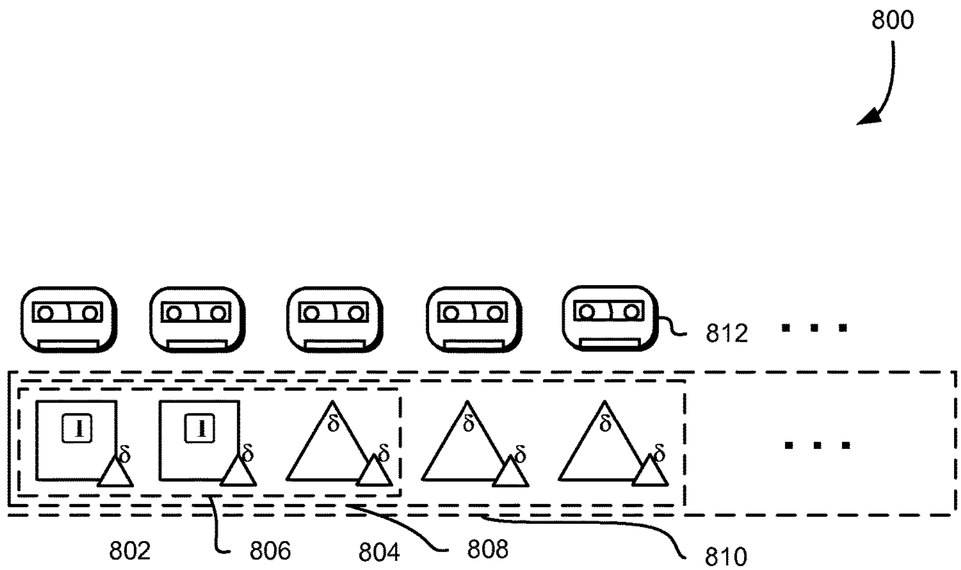

FIG. 8

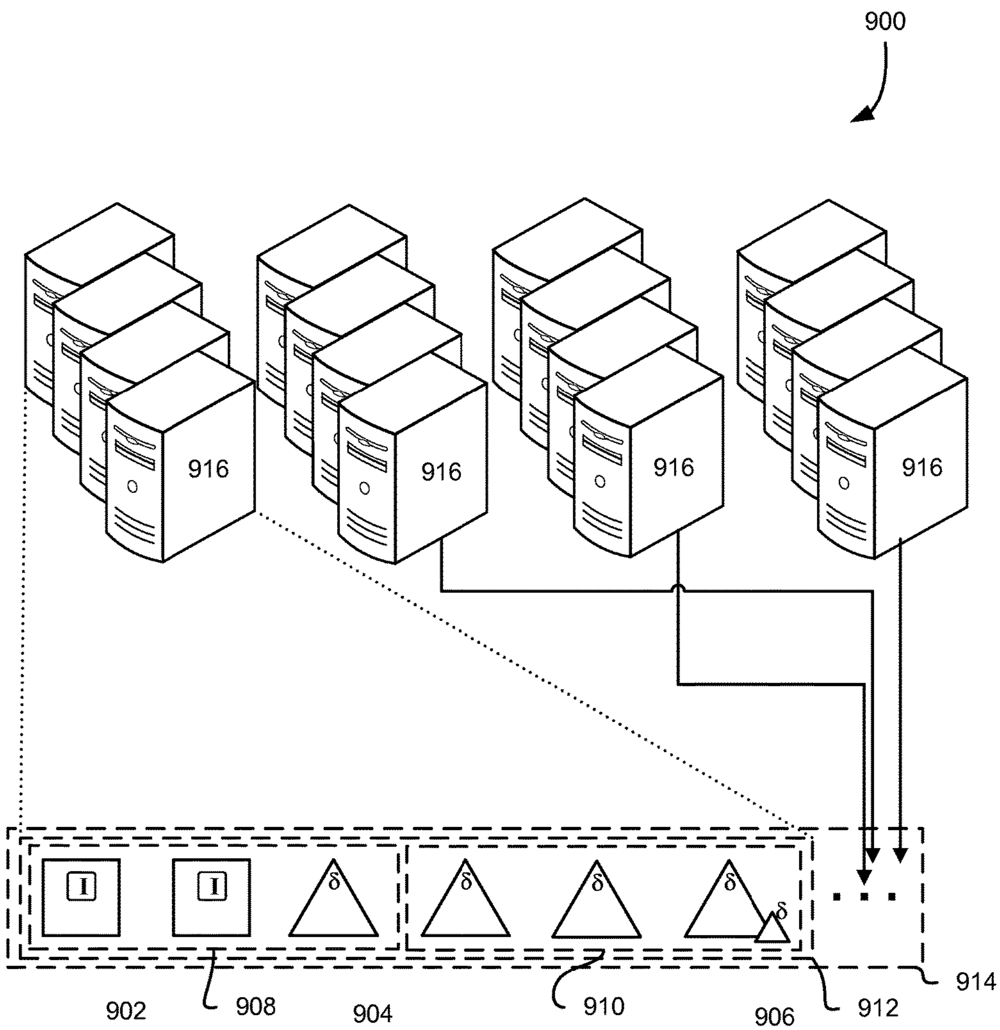

FIG. 9

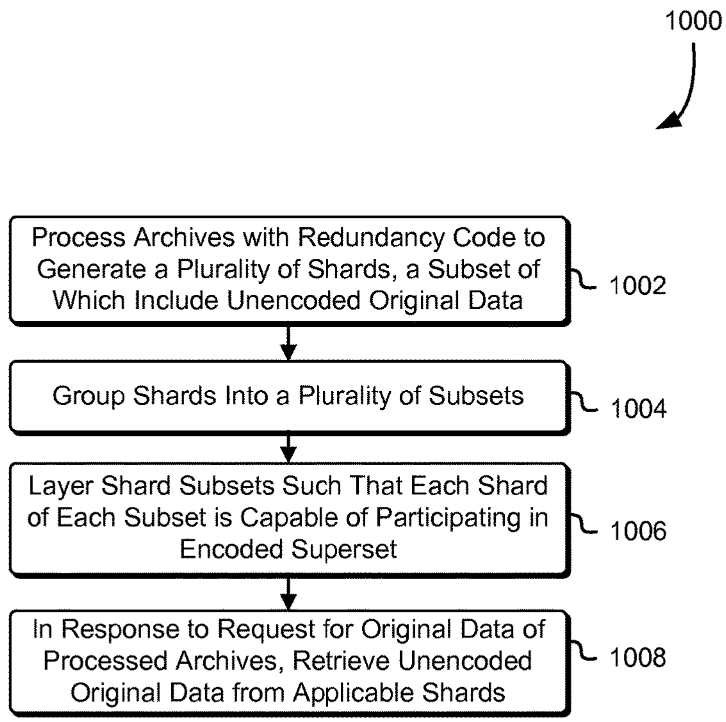
1000
Process Archives with Redundancy Code to Generate a Plurality of Shards, a Subset of Which Include Unencoded Original Data
1002
Group Shards Into a Plurality of Subsets
1004
Layer Shard Subsets Such That Each Shard of Each Subset is Capable of Participating in Encoded Superset
1006
In Response to Request for Original Data of Processed Archives, Retrieve Unencoded Original Data from Applicable Shards
1008

FIG. 10

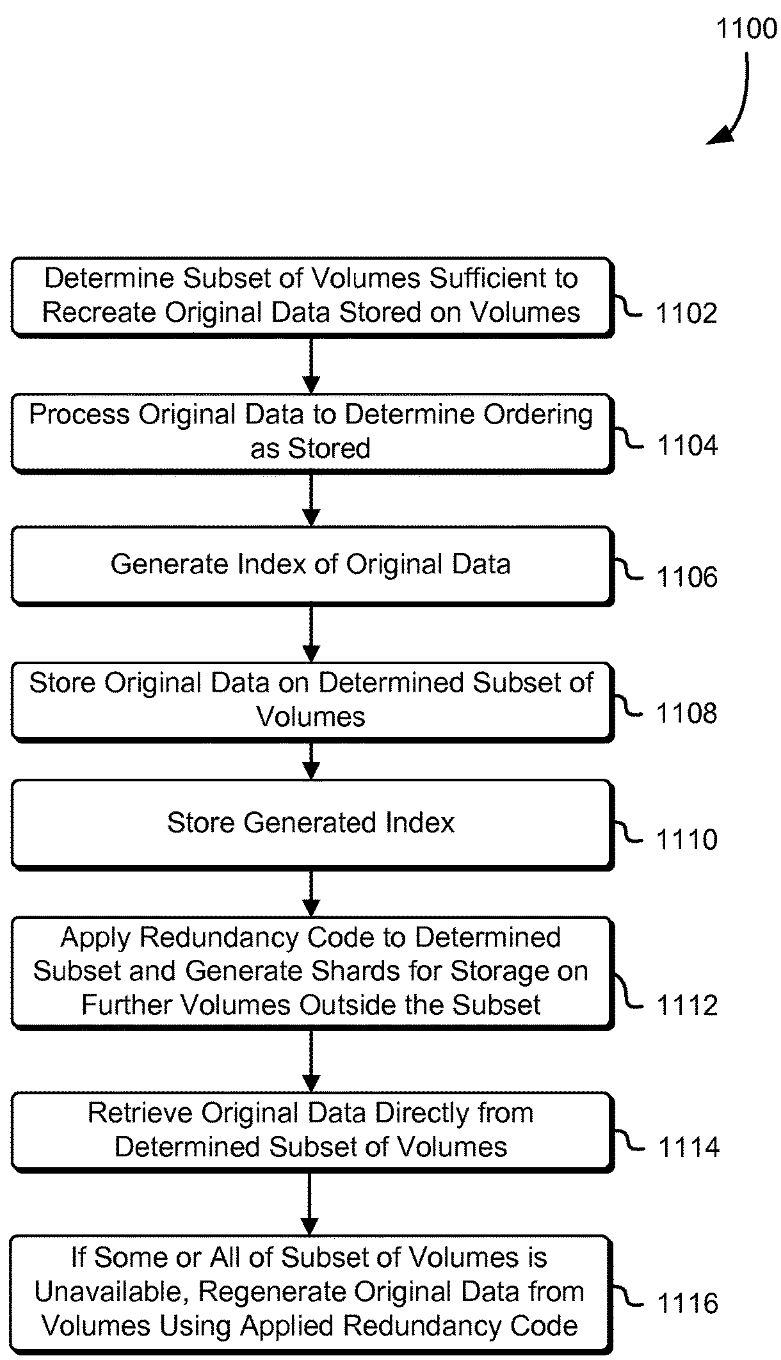
1100
Determine Subset of Volumes Sufficient to Recreate Original Data Stored on Volumes
1102
Process Original Data to Determine Ordering as Stored
1104
Generate Index of Original Data
1106
Store Original Data on Determined Subset of Volumes
1108
Store Generated Index
1110
Apply Redundancy Code to Determined Subset and Generate Shards for Storage on Further Volumes Outside the Subset
1112
Retrieve Original Data Directly from Determined Subset of Volumes
1114
If Some or All of Subset of Volumes is Unavailable, Regenerate Original Data from Volumes Using Applied Redundancy Code
1116

FIG. 11

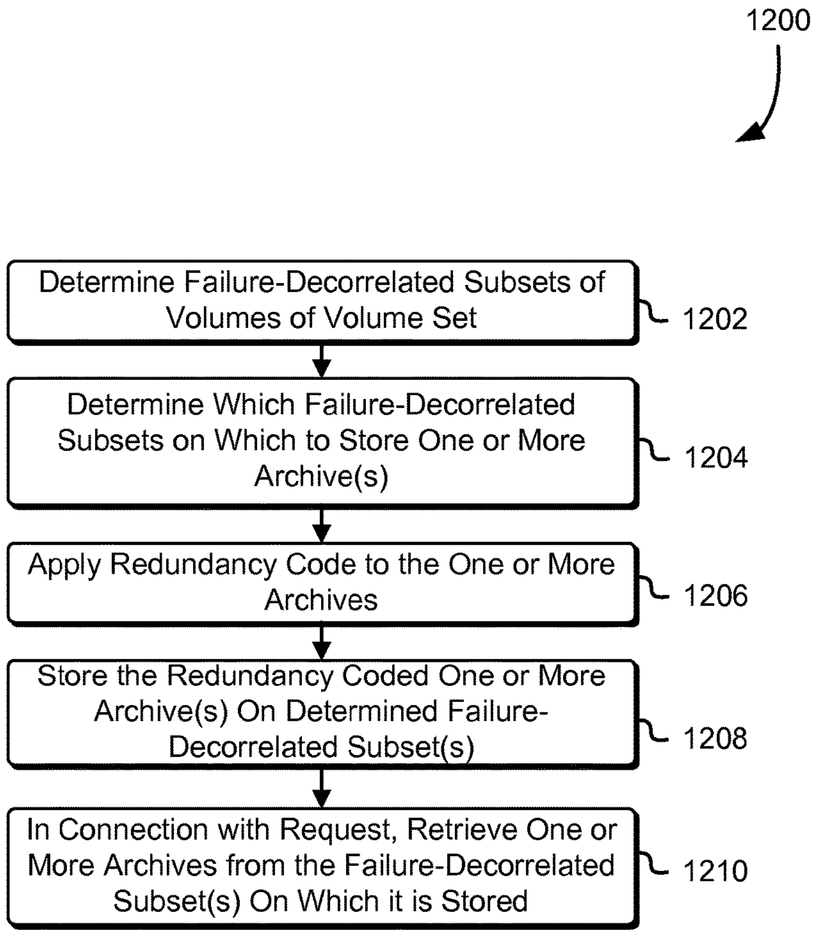
1200
Determine Failure-Decorrelated Subsets of Volumes of Volume Set
1202
Determine Which Failure-Decorrelated Subsets on Which to Store One or More Archive(s)
1204
Apply Redundancy Code to the One or More Archives
1206
Store the Redundancy Coded One or More Archive(s) On Determined Failure-Decorrelated Subset(s)
1208
In Connection with Request, Retrieve One or More Archives from the Failure-Decorrelated Subset(s) On Which it is Stored
1210

FIG. 12

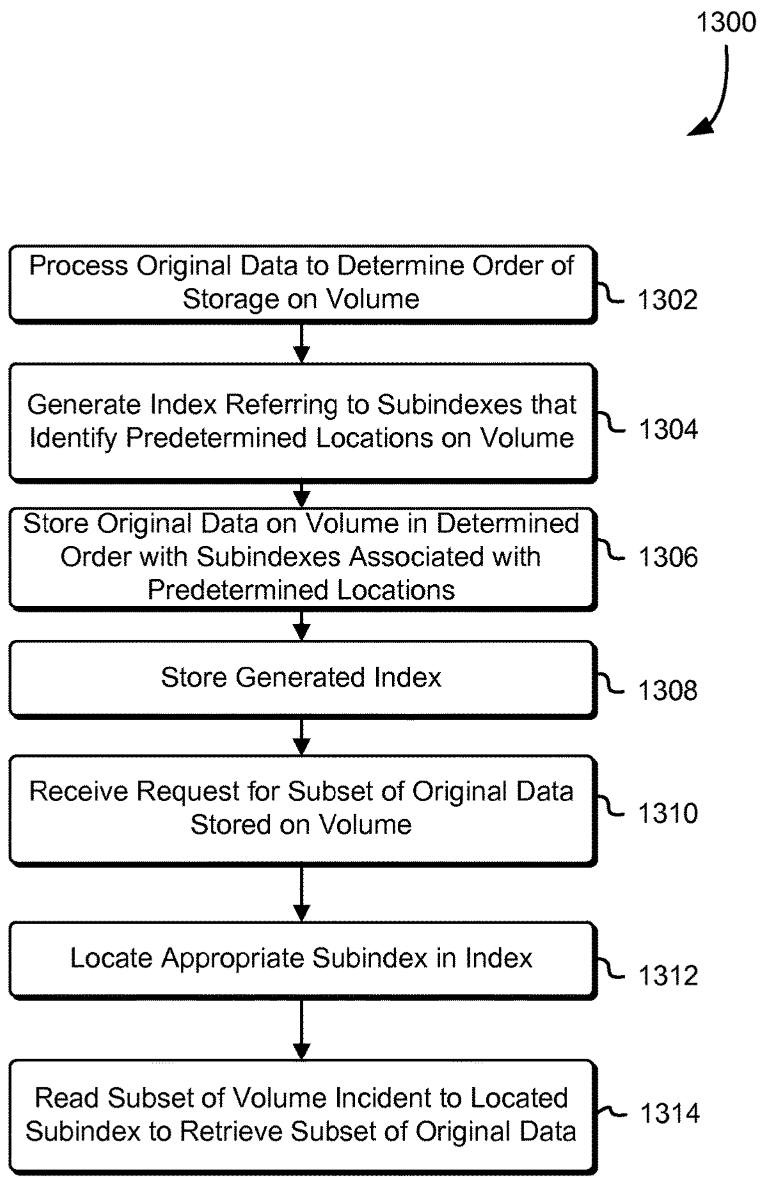
1300
Process Original Data to Determine Order of Storage on Volume
1302
Generate Index Referring to Subindexes that Identify Predetermined Locations on Volume
1304
Store Original Data on Volume in Determined Order with Subindexes Associated with Predetermined Locations
1306
Store Generated Index
1308
Receive Request for Subset of Original Data Stored on Volume
1310
Locate Appropriate Subindex in Index
1312
Read Subset of Volume Incident to Located Subindex to Retrieve Subset of Original Data
1314

FIG. 13

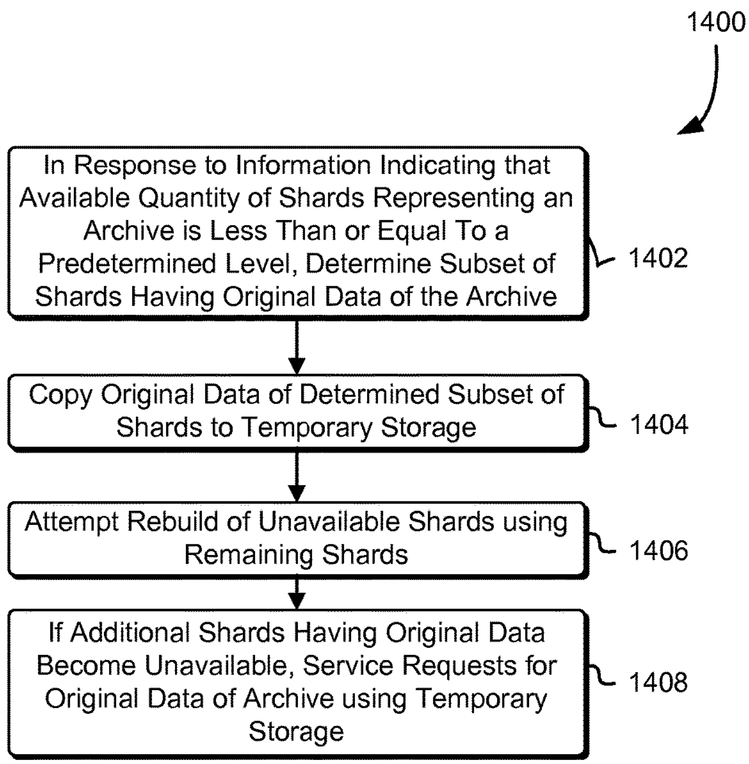
1400
In Response to Information Indicating that Available Quantity of Shards Representing an Archive is Less Than or Equal To a Predetermined Level, Determine Subset of Shards Having Original Data of the Archive
1402
Copy Original Data of Determined Subset of Shards to Temporary Storage
1404
Attempt Rebuild of Unavailable Shards using Remaining Shards
1406
If Additional Shards Having Original Data Become Unavailable, Service Requests for Original Data of Archive using Temporary Storage
1408

FIG. 14

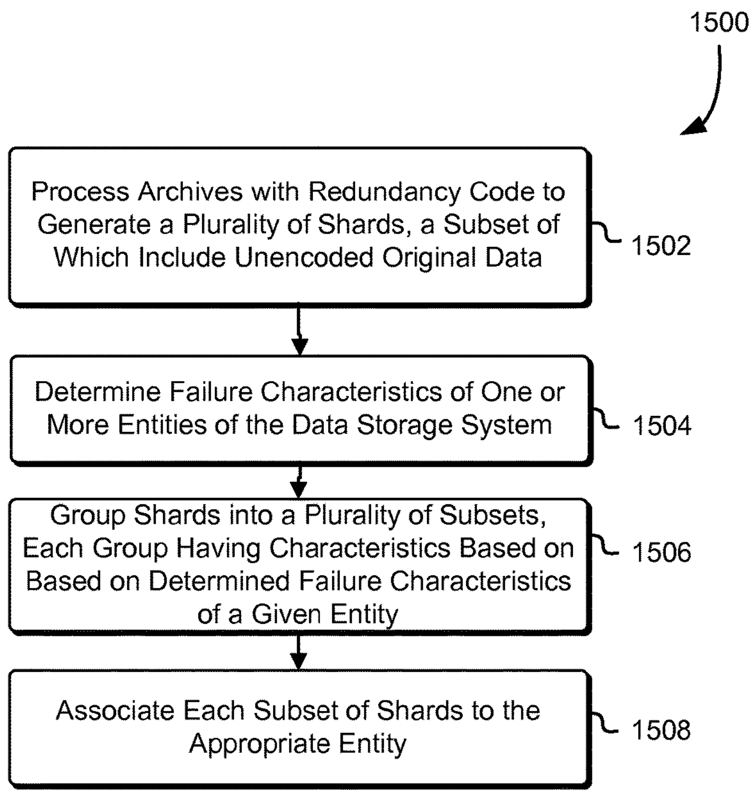
1500
Process Archives with Redundancy Code to Generate a Plurality of Shards, a Subset of Which Include Unencoded Original Data
1502
Determine Failure Characteristics of One or More Entities of the Data Storage System
1504
Group Shards into a Plurality of Subsets, Each Group Having Characteristics Based on Based on Determined Failure Characteristics of a Given Entity
1506
Associate Each Subset of Shards to the Appropriate Entity
1508

FIG. 15

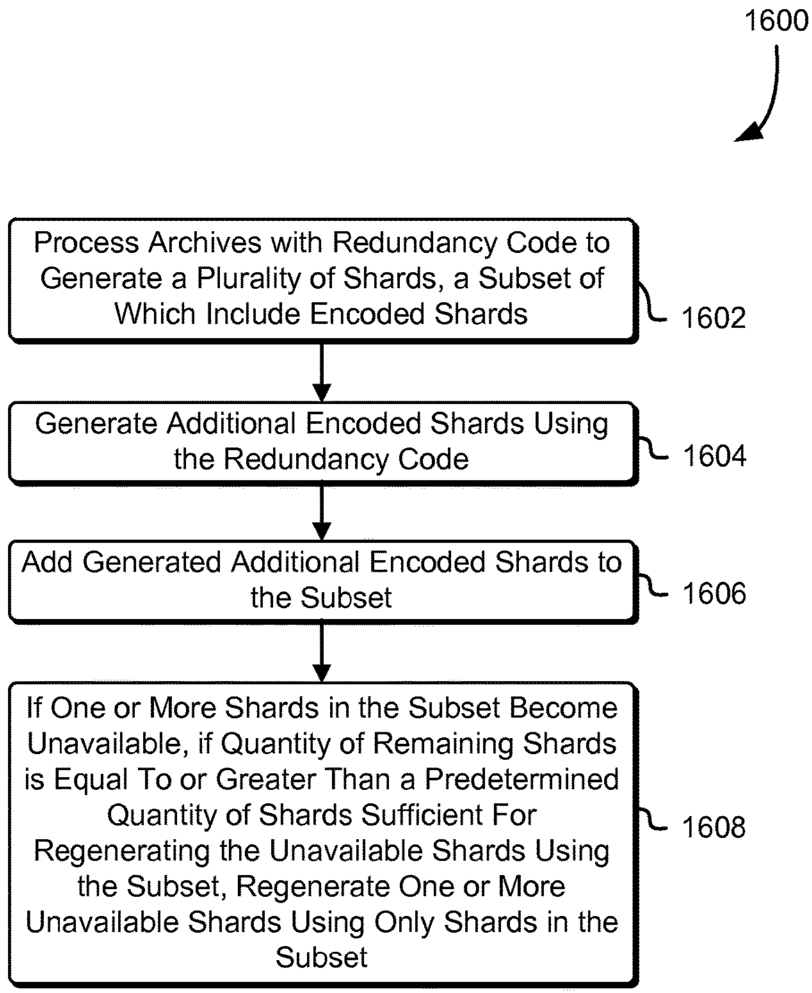
1600
Process Archives with Redundancy Code to Generate a Plurality of Shards, a Subset of Which Include Encoded Shards
1602
Generate Additional Encoded Shards Using the Redundancy Code
1604
Add Generated Additional Encoded Shards to the Subset
1606
If One or More Shards in the Subset Become Unavailable, if Quantity of Remaining Shards is Equal To or Greater Than a Predetermined Quantity of Shards Sufficient For Regenerating the Unavailable Shards Using the Subset, Regenerate One or More Unavailable Shards Using Only Shards in the Subset
1608

FIG. 16

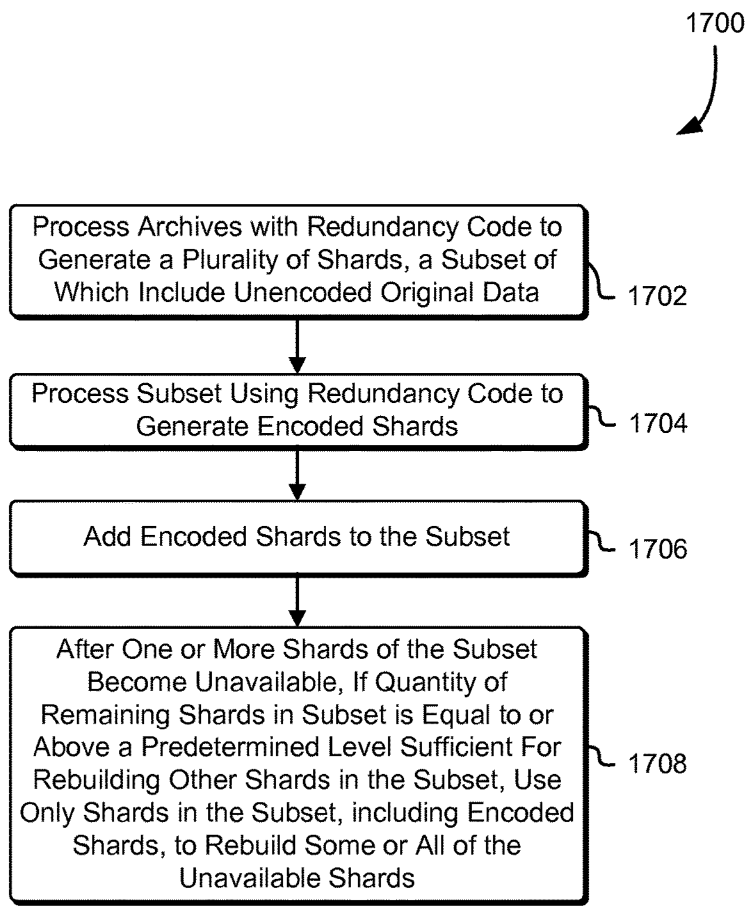
1700
Process Archives with Redundancy Code to Generate a Plurality of Shards, a Subset of Which Include Unencoded Original Data
1702
Process Subset Using Redundancy Code to Generate Encoded Shards
1704
Add Encoded Shards to the Subset
1706
After One or More Shards of the Subset Become Unavailable, If Quantity of Remaining Shards in Subset is Equal to or Above a Predetermined Level Sufficient For Rebuilding Other Shards in the Subset, Use Only Shards in the Subset, including Encoded Shards, to Rebuild Some or All of the Unavailable Shards
1708

FIG. 17

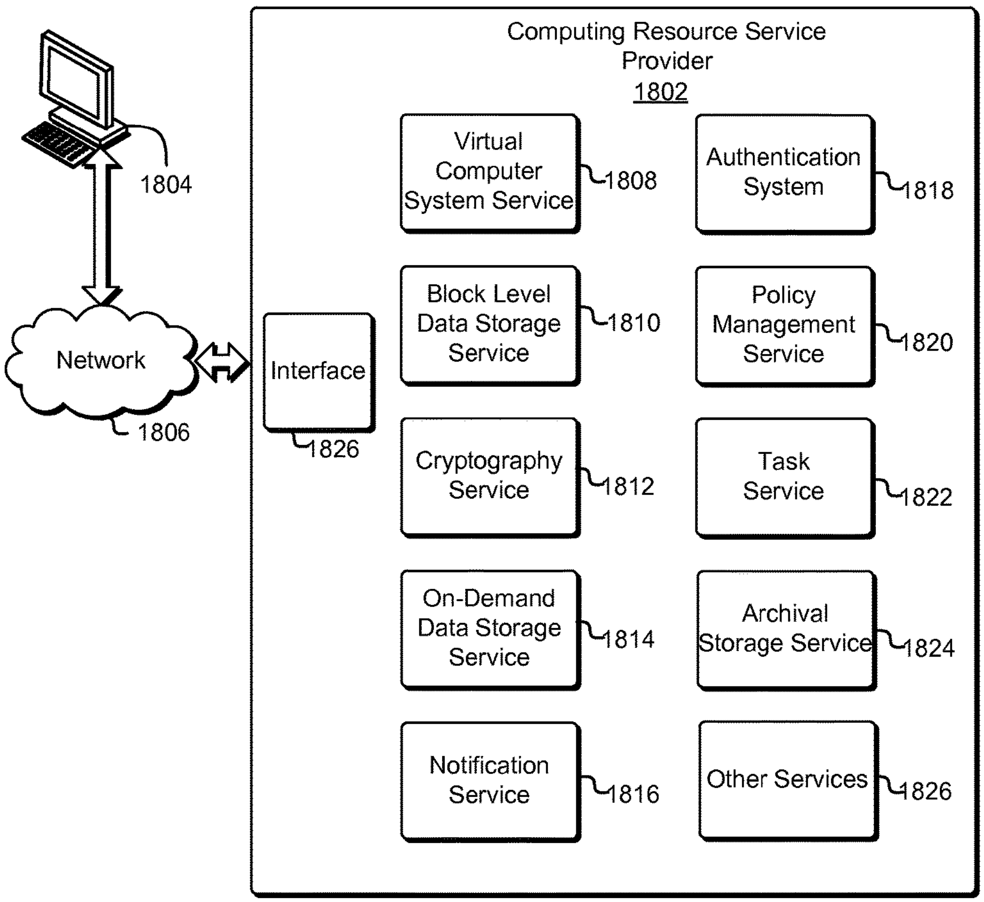
Computing Resource Service Provider
1802
Virtual Computer System Service
1808
Authentication System
1818
Block Level Data Storage Service
1810
Policy Management Service
1820
Cryptography Service
1812
Task Service
1822
On-Demand Data Storage Service
1814
Archival Storage Service
1824
Notification Service
1816
Other Services
1826
Interface
1826
Network
1806
1804

FIG. 18

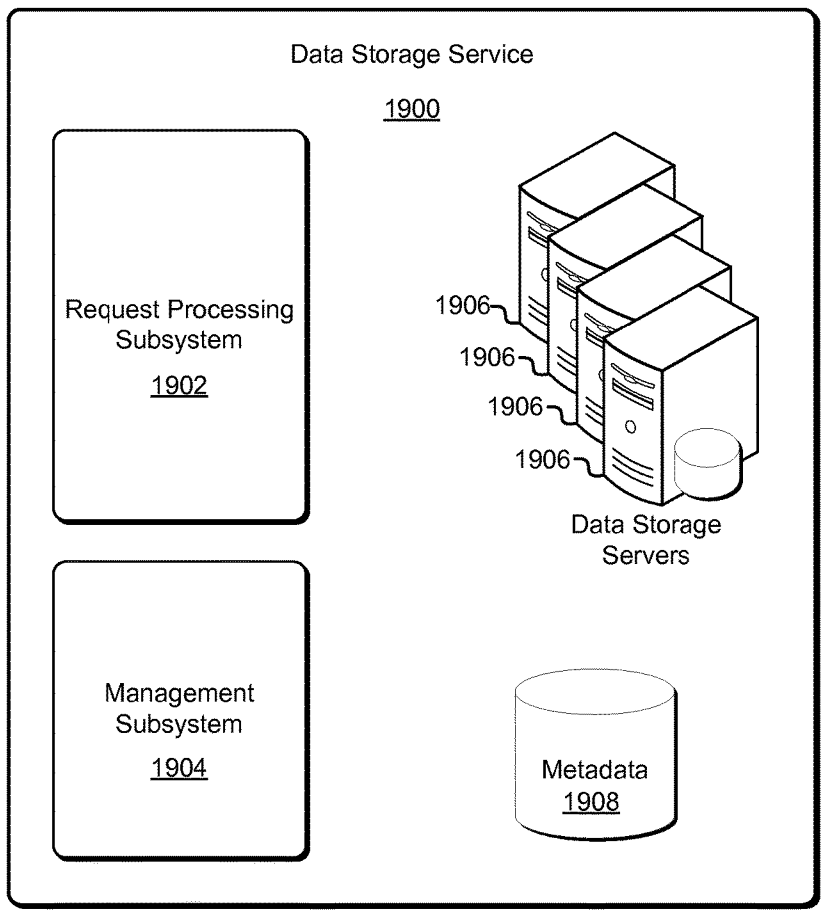
Data Storage Service
1900
Request Processing Subsystem
1902
Management Subsystem
1904
1906
1906
1906
1906
Data Storage Servers
Metadata
1908

FIG. 19

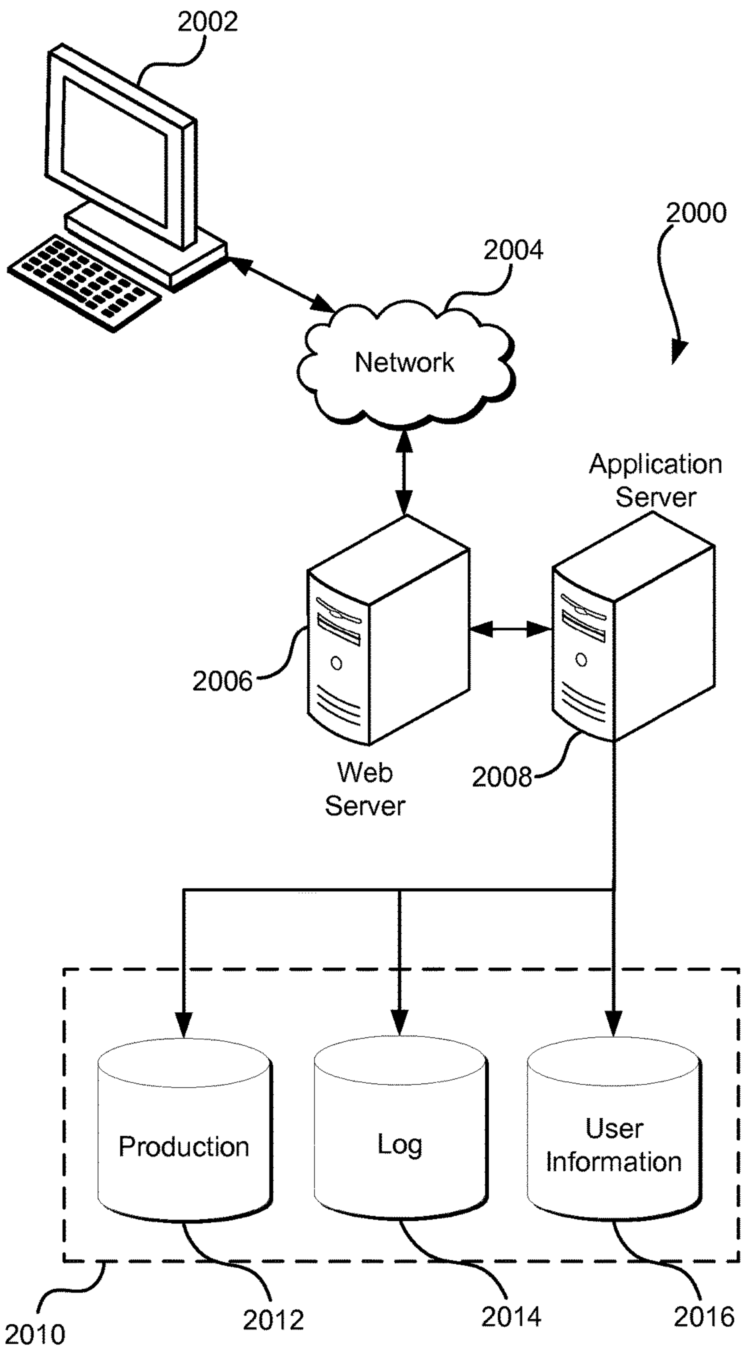
2002
2000
2004
Network
Application
Server
2006
Web
Server
2008
Production
Log
User
Information
2010
2012
2014
2016

FIG. 20

LAYERED DATA REDUNDANCY CODING TECHNIQUES FOR LAYER-LOCAL DATA RECOVERY

CROSS REFERENCE TO RELATED APPLICATIONS

This application incorporates by reference for all purposes the full disclosure of co-pending U.S. patent application Ser. No. 14/741,402, filed on Jun. 16, 2015, entitled "MULTI-LAYERED DATA REDUNDANCY CODING TECHNIQUES," co-pending U.S. patent application Ser. No. 14/741,403, filed on Jun. 16, 2015, entitled "LAYERED REDUNDANCY CODING FOR ENCODED PARITY DATA," co-pending U.S. patent application Ser. No. 14/741,407, filed on Jun. 16, 2015, entitled "FAILURE MODE-SENSITIVE LAYERED REDUNDANCY CODING TECHNIQUES," and co-pending U.S. patent application Ser. No. 14/741,409, filed on Jun. 16, 2015, entitled "ADAPTIVE DATA LOSS MITIGATION FOR REDUNDANCY CODING SYSTEMS."

BACKGROUND

The use of network computing and storage has proliferated in recent years. The resources for network computing and storage are often provided by computing resource providers who leverage large-scale networks of computers, servers and storage drives to enable clients, including content providers, online merchants and the like, to host and execute a variety of applications and web services. Content providers and online merchants, who traditionally used on-site servers and storage equipment to host their websites and store and stream content to their customers, often forego on-site hosting and storage and turn to using the resources of the computing resource providers. The usage of network computing allows content providers and online merchants, among others, to efficiently and to adaptively satisfy their computing needs, whereby the computing and storage resources used by the content providers and online merchants are added or removed from a large pool provided by a computing resource provider as need and depending on their needs.

The proliferation of network computing and storage, as well as the attendant increase in the number of entities dependent on network computing and storage, has increased the importance of optimizing data performance and integrity on network computing and storage systems. Data archival systems and services, for example, may use various types of error correcting and error tolerance schemes, such as the implementation of redundancy coding and data sharding. Furthermore, capacity and cost of persisting increasing quantities of data may be mitigated by the use of data storage devices or media that is considerably faster at sequential storage than random access storage, relative to other data storage devices.

BRIEF DESCRIPTION OF THE DRAWINGS

Various embodiments in accordance with the present disclosure will be described with reference to the drawings, in which:

FIG. **1** schematically illustrates example workflows for layering redundancy coded data in groups, in accordance with some embodiments;

FIG. **2** schematically illustrates an environment in which original data of archives may be stored on a data storage system implementing a redundancy code, in accordance with some embodiments;

FIG. **3** schematically illustrates various workflows for storing original data of archives on a plurality of data stores of a data storage system, in accordance with some embodiments;

FIG. **4** schematically illustrates various workflows for storing data in failure-decorrelated subsets of a volume set, in accordance with some embodiments;

FIG. **5** schematically illustrates various workflows for indexing and locating data stored on a data storage system in accordance with some embodiments;

FIG. **6** schematically illustrates various workflows for mitigating data loss in systems using volume-level redundancy coding techniques, in accordance with some embodiments;

FIG. **7** schematically illustrates various workflows for associating layered groups of redundancy coded data to layers of data storage entities, in accordance with some embodiments;

FIG. **8** schematically illustrates various workflows for providing additional redundancy to redundancy coded data, in accordance with some embodiments;

FIG. **9** schematically illustrates various workflows for enabling regeneration and/or repair for redundancy coded data stored within a data storage facility in a multi-facility environment, in accordance with some embodiments;

FIG. **10** schematically illustrates an example process for layering redundancy coded data, in accordance with some embodiments;

FIG. **11** schematically illustrates an example process for processing, indexing, storing, and retrieving data stored on a data storage system, in accordance with some embodiments;

FIG. **12** schematically illustrates an example process for determining failure-decorrelated volume subsets and storing/retrieving data thereto, in accordance with some embodiments;

FIG. **13** schematically illustrates an example process for indexing original data stored on a redundancy coded data storage system, in accordance with some embodiments;

FIG. **14** schematically illustrates an example process for mitigating data loss in redundancy coded data, in accordance with some embodiments;

FIG. **15** schematically illustrates an example process for grouping redundancy coded data according to failure characteristics of a data storage system, in accordance with some embodiments;

FIG. **16** schematically illustrates an example process for adjusting redundancy of encoded shards associated with redundancy coded data, in accordance with some embodiments;

FIG. **17** schematically illustrates an example process for adjusting redundancy associated with original data in redundancy coded systems, in accordance with some embodiments;

FIG. **18** schematically illustrates an environment, including a computing resource service provider, in which data storage and indexing techniques may be implemented, in accordance with some embodiments;

FIG. **19** schematically illustrates a data storage service capable of implementing various data storage and indexing techniques, in accordance with some embodiments; and

FIG. **20** illustrates an environment in which various embodiments can be implemented.

DETAILED DESCRIPTION

In the following description, various embodiments will be described. For purposes of explanation, specific configurations and details are set forth in order to provide a thorough understanding of the embodiments. However, it will also be apparent to one skilled in the art that the embodiments may be practiced without the specific details. Furthermore, well-known features may be omitted or simplified in order not to obscure the embodiment being described.

In the following description, various embodiments will be described. For purposes of explanation, specific configurations and details are set forth in order to provide a thorough understanding of the embodiments. However, it will also be apparent to one skilled in the art that the embodiments may be practiced without the specific details. Furthermore, well-known features may be omitted or simplified in order not to obscure the embodiment being described.

Techniques described and suggested herein include systems and methods for storing original data of data archives ("archives") on data storage systems using redundancy coding techniques. For example, redundancy codes, such as erasure codes, may be applied to incoming archives (such as those received from a customer of a computing resource service provider implementing the storage techniques described herein) so as allow the storage of original data of the individual archives available on a minimum of volumes, such as those of a data storage system, while retaining availability, durability, and other guarantees imparted by the application of the redundancy code.

In some embodiments, archives, such as customer archives containing any quantity and nature of data, are received from customers of a computing resource service provider through a service, such as an archival storage service, provided by one or more resources of the computing resource service provider. The archives may be sorted according to one or more common attributes, such as the identity of the customer, the time of upload and/or receipt by, e.g., the archival storage service. Such sorting may be performed so as to minimize the number of volumes on which any given archive is stored. In some embodiments, the original data of the archives is stored as a plurality of shards across a plurality of volumes, the quantity of which (either shards or volumes, which in some cases may have a one to one relationship) may be predetermined according to various factors, including the number of total shards sufficient to reconstruct the original data using a redundancy code.

In some embodiments, the volumes may be grouped into volume sets, and in some of such embodiments, the volume sets may be apportioned into failure-decorrelated subsets of volumes (or "cohorts"). A given volume set may include, depending on the redundancy coding scheme used, volumes that store original data of incoming archives, as well as volumes that store derived data (e.g., with mathematical transformations applied according to the implementing redundancy coding scheme). The volume set may include more volumes than is necessitated by the implemented redundancy coding scheme. In such embodiments, a quantity of failure-decorrelated subsets of the volume set is determined such that the number of volumes in each failure-decorrelated subset corresponds to the number of volumes necessitated by the implemented redundancy coding scheme. In some embodiments, the failure-decorrelated subsets are implemented such that incoming archives to be stored in a given volume set are committed to different failure-decorrelated subsets, according to some apportionment scheme (e.g., based on an attribute of the incoming data itself, in a predetermined sequence, etc.)

In some embodiments, one or more indices may be generated in connection with, e.g., the order in which the archives are to be stored, as determined in connection with the sorting mentioned immediately above. An index may, in some embodiments, be generated for each volume of the plurality, and in such embodiments, may reflect the archives stored on the respective volume to which it applies. The indices may be of any appropriate type, and may include sparse indices. In embodiments where sparse indices are used, the index (e.g., for a given volume) may point to a subset of archives stored or to be stored on, e.g., that volume. The subset may be selected on any basis and for any appropriate interval. Examples may include the identification of the archives located at an interval of x blocks or bytes of the volume, or the identification of the archives at an interval of n archives, where x or n may be predetermined by, e.g., the archival storage service or an administrator thereof.

In some embodiments, the sparse indexes are used in connection with information relating to the sort order of the archives so as to locate archives without necessitating the use of dense indexes, e.g., those that account for every archive on a given volume. Such sort order-related information may reside on the volume(s) or, in some embodiments, on an entity separate from the volume(s). Similarly, the indexes may be stored on the same volume(s) to which they apply, or, in some embodiments, separately from such volume(s). In embodiments where the sort order-related information and/or the indexes are stored on the applicable volumes, they may be included with the original data of the archives and stored therewith as shards, as previously mentioned.

In some embodiments, the original data of the archives (and, in embodiments where the indices are stored on the volumes, the indices) is processed by an entity associated with, e.g., the archival storage service, using a redundancy code, such as an erasure code, so as to generate redundancy coded shards that may be used to regenerate the original data and, if applicable, the indices. In some embodiments, the redundancy code may utilize a matrix of mathematical functions (a "generator matrix"), a portion of which may include an identity matrix. In some of such embodiments, the redundancy coded shards may correspond, at least in part, to the portion of the generator matrix that is outside of the identity matrix. Redundancy coded shards so generated may be stored in further volumes. The total number of volumes may include the volumes bearing the original data (and indices) as well as the volumes containing the redundancy coded shards.

In some embodiments, the volumes bearing the original data may themselves be identity shards that are peers (i.e., are capable of fully participating in redundancy code-based regeneration) with the redundancy coded shards (encoded or derived shards). In such embodiments, bundles (groups) of shards of one or both types may be layered amongst one another, in some cases hierarchically. For example, rather than bearing only original data, one or more identity shards may be treated as a group of other shards, which may include additional identity shards, encoded shards, and/or some combination thereof. In some implementations, all shards, regardless of group/layer membership and/or hierarchy, may be peers and therefore freely interchangeable in terms of their ability to participate in reconstructing data represented across a system.

As may be contemplated, many benefits and unique properties arise from layered redundancy coding techniques. For example, layers/groups of shards may be correlated with physical, logical, or arbitrary layers of an implementing data storage system. In some embodiments, redundancy levels for each layer are adjusted according to one or more failure characteristics of the intended data storage system layer to which it is associated. The layers themselves may be individually, internally redundant in accordance with such failure characteristics. In other words, a data storage system layer may locally recover from the failure or other unavailability of up to a quantity of shards in an assigned shard group without necessitating the participation of other data storage system layers and/or shard groups.

In some embodiments, identity shards may themselves include encoded data, such as groups of encoded shards, which may allow for encoded shards in a given shard group to be locally regenerable, e.g., by a data storage system entity or layer to which it is associated. A given shard group may be extended and/or modified to include additional encoded shards, or remove shards, in accordance with failure characteristics of the data storage system entity or layer. Such additional shards may be generated using the same redundancy code as was used create the shards of the parent group, or, in some embodiments, may use a different redundancy code (e.g., in implementations where local redundancy for stored shards is the primary objective, rather than cross-compatibility of shards across data storage system layers).

The implementation of layered redundancy coding techniques may, in some embodiments, enable higher storage efficiency, increased failure recovery speed and efficacy, greater durability and reliability of data storage, and reduced costs, in particular when implemented in multi-located data storage systems. For example, a given data storage facility of a multi-facility data storage system implementing layered redundancy coding techniques may locally repair any shard associated therewith, but in the case that it is incapable of doing so, shards in other data storage facilities of the same data storage system may be used to recover the shard as a last resort.

In some embodiments, redundancy coding schemes configured to store original data in at least some of the shards generated therefrom may impart an implementing system the ability to mitigate data loss even if a minimum quorum quantity of shards representing archive data is unavailable or corrupt. For example, if an implementing data storage system detects that a number of available shards approaches, equals, or drops below the minimum quorum quantity sufficient for reconstruction, the data storage system may prioritize the retrieval of the original data in, e.g., the identity shards and temporarily (or permanently) store them in a different data storage entity as part of the regeneration and/or recovery process. The original data thus stored may be made available to requesting customers, e.g., on demand, used to aid regeneration of the unavailable shards, or exist to provide additional durability guarantees, e.g., to customers of an implementing data storage system.

In some embodiments, retrieval of an archive stored in accordance with the techniques described herein may be requested by an entity, such as a client device under control of a customer of the computing resource service provider and/or the archival storage service provided therefrom, as described in further detail throughout this disclosure. In response to the request, the data storage system (e.g., the system including the aforementioned volumes, and providing the archival storage service) may locate, based on information regarding the sort order of the archives as stored on the volumes, the specific volume on which the archive is located. Thereafter, the index or indices may be used to locate the specific volume, whereupon it is read from the volume and provided to the requesting entity. In embodiments where sparse indexes are employed, the sort order information may be used to locate the nearest location (or archive) that is sequentially prior to the requested archive, whereupon the volume is sequentially read from that location or archive until the requested archive is found.

In some embodiments, if one of the volumes or a shard stored thereon is detected as corrupt, missing, or otherwise unavailable, a new shard may be generated using the redundancy code applied to generate the shard(s) in the first instance. In some embodiments, the new shard may be a replication of the unavailable shard, such as may be the case if the shard includes original data of the archive(s). In some embodiments, the new shard may be selected from a set of potential shards as generated by, e.g., a generator matrix associated with the redundancy code, so as to differ in content from the unavailable shard (such as may be the case if the unavailable shard was a shard generated from the redundancy code, and therefore contains no original data of the archives). In such cases, in certain embodiments, an entirely new volume may be generated, rather than a shard.

FIG. **1** schematically illustrates example workflows for layering redundancy coded data in groups, in accordance with some embodiments. One or more archives **102**, which may include any quantity of data in any format, are described in further detail below, are processed using one or more redundancy codes **104** to generate shards **106**, **108**. The shards **106**, **108**, which are described in further detail below, represent portions of the data of the archives **102**, and are usable, e.g., by reprocessing through one or more aspects of the redundancy code(s) **104** to regenerate the original data of the archives **102** and/or some or all of the shards **106**, **108** that require replacement due to, e.g., failure, unavailability, corruption, and the like. Parameters of the redundancy code(s) **104** may be set so as to manipulate the minimum quantity (quorum quantity, described in more detail below) of the shards **106**, **108** relative to the total number of shards **106**, **108** used to represent the archive(s) **102**.

As illustrated, the shards **106**, **108** may include identity shards **106** and encoded (derived) shards **108**, in accordance with one or more techniques (e.g., volume-level encoding techniques) described in further detail below. As described in further detail below, identity shards **106** may include data that is unchanged relative to the corresponding input data, e.g., of archive(s) **102** through redundancy code(s) **104**. As may be contemplated, identity shards **106** may also represent data other than original data of the archives **102**. For example, the identity shards **106** may include a group, or bundle, of other shards, other identity shards **106**, other encoded shards **108**, and the like. The encoded shards **108** include data that is transformed, e.g., by the redundancy code(s) **104**, relative to the input. Examples, more of which are provided throughout this disclosure, include parity data associated with the input, XOR transformation output, erasure code outputs, and the like.

Also as illustrated, the shards may be grouped **110**, **112**, e.g., in a hierarchical manner. The shards may be grouped such that each individual group may itself be redundant in some manner, e.g., where the minimum quorum quantity for a given group is less than the total number of shards in that group. In the illustrated example, the group **110** of shards may be encoded such that the original data, or any of the shard in the group **110**, may be regenerated using two of the three shards in the group **110**. The illustrated group **110** is part of the group **112**, which includes two additional encoded shards **108** and, for example, may be configured such that the minimum quorum quantity of the group **112** is three shards of the five total shards, including any of the three in the group **110**. It is contemplated that, in some embodiments, shards in a given group may be configured such that may be usable to participate in regeneration of a subgroup, but not necessarily others in that group. For example, in the illustrated group **112**, the two shards outside of group **110** may in some cases only be usable to rebuild the shards inside the group **110**, as may be the case if the two shards outside of the group **110** are parity shards (e.g., exclusive or (XOR) transformations of the original data) derived from the shards of group **110**.

As with other examples given herein, the immediately preceding example is not limiting. Any number or configuration of groups, as well as any configuration of shards (e.g., minimum quorum quantities, mixtures and/or configurations of identity shards and/or encoded shards), may be implemented as appropriate for a given system. In some embodiments, various configurations and/or parameters of the groups **110**, **112** and/or the shards **106**, **108** may be adjusted and/or adapted, either statically or dynamically, to alter the performance, efficiency, durability, and/or redundancy characteristics of each group. Such adjustment and/or adaptation may be in response to various parameters and/or characteristics of the data storage system (or layers and/or entities thereof), the archives and/or associated data, customer requests, and the like.

Durability may be measured in terms of annualized failure rate ("AFR"), daily failure rate ("DFR"), hourly failure rate ("HFR"), and the like. As used herein, the durability of a data object may be understood to be an estimate of the probability that the data object will not unintentionally become irretrievable (also referred to herein as "unavailable"). This durability is an estimated probability and is generally expressed as a percentage (e.g., 99.9999 percent). This durability is based on assumptions of probabilities of certain failures (e.g., the AFR of devices used to store the data) and may be based on an average failure rate, a maximum failure rate, a minimum failure rate, a mean failure rate, or some other such failure rate. The durability may be based on a statistical average of the failure over a collection of drives when there are many different drives and/or when there are many different types of drives. The durability may also be based on historical measurements of the failure of drives and/or statistical sampling of the historical measurements of the failure of drives. The durability may also be correlated with the probability that a data object will not unintentionally become unavailable such as, for example, basing the durability on the probability that a data object will unintentionally become unavailable. As may be contemplated, the methods of determining durability of data described herein are merely illustrative examples and other such methods of determining durability of data may be considered as within the scope of the present disclosure.

Durability may be calculated as a composite of failure rates associated with all layers, actions, and/or components of a given chain of entities associated with storing data for which durability is calculated. For example, a storage device may have a two percent (0.02) annual failure rate ("AFR"). Over the first hour that the data may be stored on that storage device there is, on average, a 0.00023 percent chance that the block storage device will fail (i.e., the block storage device may be 99.99977 percent reliable for the first hour). Similarly, the storage device may be 99.9945 percent reliable for the first day and 99.989 percent reliable through the second day. If it is desired that the data be 99.999 percent reliable (also referred to herein as having "five 9's" of durability), the data should be removed from the storage device with a two percent AFR before approximately four hours have passed (0.00023 percent chance of data loss per hour). If it is desired that the data be 99.99 percent reliable (also referred to herein as having "four 9's" of durability), the data should be removed from the storage device with a two percent AFR before two days have passed (0.0055 percent chance of data loss per day). As may be contemplated, the composite durability or AFR may be affected by the data storage device or other entity to which the data is being moved.

As such data generally may become less volatile over the first hour, or the first day, or the first two days, the data can then be moved to a more durable redundant storage system where the desired durability (e.g., four 9's, five 9's, or more) may be achieved by the durability of the data storage medium as well as by one or more redundancy encoding techniques such as those described herein.

As discussed further below, each of the shards of the group may be stored on a volume **114**, in some cases on a one-to-one basis. The volumes **114** may include physical data storage entities, such as data storage devices (e.g., tapes, optical devices, hard disk drives, solid state disk devices, and the like), and may be heterogenous or homogenous relative to one another. For example, different groups may be assigned to different types of data storage entities, and the groups may be configured so as to be sensitive to the particular characteristics (e.g., failure characteristics) of the specific data storage entities chosen.

FIG. **2** schematically illustrates an environment in which original data of archives may be stored on a data storage system implementing a redundancy code, in accordance with some embodiments. One or more client entities **202**, such as those under control of a customer of a computing resource service provider, submit archive(s) **204** to a data storage system **206** for storage. The client entities **202** may be any entity capable of transacting data with a data storage system, such as over a network (including the Internet). Examples include physical computing systems (e.g., servers, desktop computers, laptop computers, thin clients, and handheld devices such as smartphones and tablets), virtual computing systems (e.g., as may be provided by the computing resource service provider using one or more resources associated therewith), services (e.g., such as those connecting to the data storage system **206** via application programming interface calls, web service calls, or other programmatic methods), and the like.

The data storage system **206** may be any computing resource or collection of such resources capable of processing data for storage, and interfacing with one or more resources to cause the storage of the processed data. Examples include physical computing systems (e.g., servers, desktop computers, laptop computers, thin clients, and handheld devices such as smartphones and tablets), virtual computing systems (e.g., as may be provided by the computing resource service provider using one or more resources associated therewith), services (e.g., such as those connecting to the data storage system **206** via application programming interface calls, web service calls, or other programmatic methods), and the like. In some embodiments, the resources of the data storage system **206**, as well as the data storage system **206** itself, may be one or more resources of a computing resource service provider, such as that described in further detail below. In some embodiments, the data storage system **206** and/or the computing resource service provider provides one or more archival storage services and/or data storage services, such as those described in further below, through which the client entities **202** may transact data such as the archives **204**.

The archives **204** may include any quantity of data in any format. For example, the archives **204** may be single files, or, in some embodiments, may include several files. The archives **204** may be encrypted by, e.g., the client device(s) **202**, or, in some embodiments, may be encrypted by a component of the data storage system **206** after receipt of the archives **204**, such as on the request of a customer of the data storage system **206** and/or the computing resource service provider.

The data storage system **206** may sort the archives **204** according to one or more criteria (and in the case where a plurality of criteria is used for the sort, such criteria may be sorted against sequentially and in any order appropriate for the implementation). Such criteria may be attributes common to some or all of the archives, and may include the identity of the customer, the time of upload (e.g., by the client device **202**) and/or receipt (by the data storage system **206**), archive size, expected volume and/or shard boundaries relative to the boundaries of the archives (e.g., so as to minimize the number of archives breaking across shards and/or volumes), and the like. As mentioned, such sorting may be performed so as to minimize the number of volumes on which any given archive is stored. Such techniques may be used, e.g., to optimize storage in embodiments where the overhead of retrieving data from multiple volumes is greater than the benefit of parallelizing the retrieval from the multiple volumes. Information regarding the sort order may be persisted, e.g., by the data storage system **206**, for use in techniques described in further detail herein.

As previously discussed, in some embodiments, one or more indices may be generated in connection with, e.g., the order in which the archives are to be stored, as determined in connection with the sorting mentioned immediately above. The index may be a single index or may be a multipart index, and may be of any appropriate architecture and may be generated according to any appropriate method. For example, the index may be a bitmap index, dense index, sparse index, or a reverse index. Embodiments where multiple indices are used may implement different types of indices according to the properties of, e.g., the archives **204** to be stored via the data storage system **206**. For example, a data storage system **206** may generate a dense index for archives over a specified size (as the size of the index itself may be small relative to the number of archives stored on a given volume), and may also generate a sparse index for archives under that specified size (as the ratio of index size to archive size increases).

The data storage system **206** is connected to or includes one or more volumes **208** on which the archives **204**, and in some embodiments, the generated indices, are stored. The volumes **208** may be any container, whether logical or physical, capable of storing or addressing data stored therein. In some embodiments, the volumes **208** may map on a one-to-one basis with the data storage devices on which they reside (and, in some embodiments, may actually be the data storage devices themselves). In some embodiments, the size and/or quantity of the volumes **208** may be independent of the capacity of the data storage devices on which they reside (e.g., a set of volumes may each be of a fixed size such that a second set of volumes may reside on the same data storage devices as the first set). The data storage devices may include any resource or collection of resources, such as those of a computing resource service provider, that are capable of storing data, and may be physical, virtual, or some combination of the two.

As previously described, one or more indices may, in some embodiments, be generated for each volume **208** of the plurality, and in such embodiments, may reflect the archives stored on the respective volume **208** to which it applies. In embodiments where sparse indices are used, a sparse index for a given volume may point to a subset of archives **204** stored or to be stored on that volume **208**, such as those archives **204** which may be determined to be stored on the volume **208** based on the sort techniques mentioned previously. The subset of volumes to be indexed in the sparse index may be selected on any appropriate basis and for any appropriate interval. For example, the sparse index may identify the archives to be located at every x blocks or bytes of the volume (e.g., independently of the boundaries and/or quantity of the archives themselves). As another example, the sparse index may identify every nth archive to be stored on the volume **208**. As may be contemplated, the indices (whether sparse or otherwise), may be determined prior to actually storing the archives on the respective volumes. In some embodiments, a space may be reserved on the volumes so as to generate and/or write the appropriate indices after the archives **204** have been written to the volumes **208**.

In some embodiments, the sparse indexes are used in connection with information relating to the sort order of the archives so as to locate archives without necessitating the use of dense indexes, e.g., those that account for every archive **204** on a given volume **208**. Such sort order-related information may reside on the volume(s) **208** or, in some embodiments, on an entity separate from the volume(s) **208**, such as in a data store or other resource of a computing resource service provider. Similarly, the indexes may be stored on the same volume(s) **208** to which they apply, or, in some embodiments, separately from such volume(s) **208**.

As mentioned, the archives **204** are stored, bit for bit (e.g., the "original data" of the archives), on a subset of the plurality of volumes **208**. Also as mentioned, appropriate indices may also be stored on the applicable subset of the plurality of volumes **208**. The original data of the archives is stored as a plurality of shards across a plurality of volumes, the quantity of which (either shards or volumes, which in some cases may have a one to one relationship) may be predetermined according to various factors, including the number of total shards sufficient to reconstruct the original data using a redundancy code. In some embodiments, the number of volumes used to store the original data of the archives is the quantity of shards sufficient to reconstruct the original data from a plurality of shards generated by a redundancy code from the original data. As an example, FIG. **2** illustrates five volumes, three of which contain original data **210** and two of which contain derived data **212**, such as redundancy coded data. In the illustrated example, the redundancy code used may require any three shards to regenerate original data, and therefore, a quantity of three volumes may be used to write the original data (even prior to any application of the redundancy code).

The volumes **208** bearing the original data **210** may each contain or be considered as shards unto themselves. In embodiments where the sort order-related information and/or the indexes are stored on the applicable volumes **208**, they may be included with the original data of the archives and stored therewith as shards, as previously mentioned. In the illustrated example, the original data **210** is stored as three shards (which may include the respective indices) on three associated volumes **208**. In some embodiments, the original data **210** (and, in embodiments where the indices are stored on the volumes, the indices) is processed by an entity associated with, e.g., the archival storage service, using a redundancy code, such as an erasure code, so as to generate the remaining shards, which contain encoded information rather than the original data of the archives. The original data **210** may be processed using the redundancy code at any time after being sorted, such as prior to being stored on the volumes, contemporaneously with such storage, or after such storage.

Such encoded information may be any mathematically computed information derived from the original data, and depends on the specific redundancy code applied. As mentioned, the redundancy code may include erasure codes (such as online codes, Luby transform codes, raptor codes, parity codes, Reed-Solomon codes, Cauchy codes, Erasure Resilient Systematic Codes, regenerating codes, or maximum distance separable codes) or other forward error correction codes. In some embodiments, the redundancy code may implement a generator matrix that implements mathematical functions to generate multiple encoded objects correlated with the original data to which the redundancy code is applied. In some of such embodiments, an identity matrix is used, wherein no mathematical functions are applied and the original data (and, if applicable, the indexes) are allowed to pass straight through. In such embodiments, it may be therefore contemplated that the volumes bearing the original data (and the indexes) may correspond to objects encoded from that original data by the identity matrix rows of the generator matrix of the applied redundancy code, while volumes bearing derived data correspond to other rows of the generator matrix. In the example illustrated in FIG. **2**, the five volumes **208** include three volumes that have shards (e.g., identity shards) corresponding to the original data of the archives **210**, while two have encoded shards corresponding to the derived data **212**. In this example, the applied redundancy code may result in the data being stored in a 3:5 scheme, wherein any three shards of the five stored shards may be used to regenerate the original data, regardless of whether the selected three shards contain the original data or the derived data.

In some embodiments, if one of the volumes **208** or a shard stored thereon is detected as corrupt, missing, or otherwise unavailable, a new shard may be generated using the redundancy code applied to generate the shard(s) in the first instance. The new shard may be stored on the same volume or a different volume, depending, for example, on whether the shard is unavailable for a reason other than the failure of the volume. The new shard may be generated by, e.g., the data storage system **206**, by using a quantity of the remaining shards sufficient to regenerate the original data (and the index, if applicable) stored across all volumes, regenerating that original data, and either replacing the portion of the original data corresponding to that which was unavailable (in the case that the unavailable shard contains original data), or reapplying the redundancy code so as to provide derived data for the new shard.

As previously discussed, in some embodiments, the new shard may be a replication of the unavailable shard, such as may be the case if the unavailable shard includes original data of the archive(s). In some embodiments, the new shard may be selected from a set of potential shards as generated by, e.g., a generator matrix associated with the redundancy code, so as to differ in content from the unavailable shard (such as may be the case if the unavailable shard was a shard generated from the redundancy code, and therefore contains no original data of the archives). As discussed throughout this disclosure, the shards and/or volumes may be grouped and/or layered.

In some embodiments, retrieval of an archive stored in accordance with the techniques described herein may be requested by an entity, such as a client entity **202** under control of a customer of the computing resource service provider and/or the archival storage service provided therefrom, as described in further detail throughout this disclosure. In response to the request, the data storage system **206** may locate, based on information regarding the sort order of the archives **204** as stored on the volumes **208**, the specific volume **208** on which the archive **204** is located. Thereafter, the index or indices may be used to locate the specific archive, whereupon it is read from the volume and provided to the requesting client entity **202**. In embodiments where sparse indexes are employed, the sort order information may be used to locate the nearest location (or archive) that is sequentially prior to the requested archive, whereupon the volume is sequentially read from that location or archive until the requested archive is found. In embodiments where multiple types of indices are employed, the data storage system **206** may initially determine which of the indices includes the most efficient location information for the request archive based on assessing the criteria used to deploy the multiple types of indices in the first instance. For example, if archives under a specific size are indexed in a sparse index and archives equal to or over that size are indexed in a parallel dense index, the data storage system **206** may first determine the size of the requested archive, and if the requested archive is larger than or equal to the aforementioned size boundary, the dense index may be used so as to more quickly obtain the precise location of the requested archive.

In some embodiments, the volumes **208** may be grouped such that each given volume **208** has one or more cohorts **214**. In such embodiments, a volume set (e.g., all of the illustrated volumes **208**) may be implemented that incoming archives to be stored on the volumes are apportioned to one or more failure-decorrelated subsets of the volume set. The failure-decorrelated subsets may be some combination of the volumes **208** of the volume subset, where the quantity of volumes correlates to a number of shards required or sufficient for the implemented redundancy code. In the illustrated example, the overall volume set may comprise two failure-decorrelated subsets (volumes in a horizontal row) where a given constituent volume **208** is paired with a cohort (e.g., **214**). In some embodiments, the incoming archives are apportioned to one or more of the cohorts in the failure-decorrelated subset according to, for example, a predetermined sequence, based on one or more attributes of the incoming archives, and the like.

The illustrated example shows, for clarity, a pair-wise cohort scheme, though other schemes are contemplated as within scope of this disclosure, some of which are outlined in greater detail herein. In the illustrated example, some of the volumes of the volume set store original data of incoming archives (e.g., **210**, **216**), while others store derived data (e.g., **212**). The system (e.g., **206**), may implement a number of failure-decorrelated subsets to which to store the incoming archives, and in the pair-wise scheme pictured, the volumes used for a given archive may differ based on some arbitrary or predetermined pattern. As illustrated, some archives may be apportioned to volumes of a given cohort that are assigned to one pattern, or failure-decorrelated subset (e.g., as shown by shaded archives and derived data **216**), while others are apportioned to volumes in a different pattern (e.g., solid archives and derived data **210**). The patterns, as mentioned, may be arbitrary, predefined, and/or in some cases, sensitive to attributes of the incoming data. In some embodiments, patterns may not be used at all, and the member volumes of a given failure-decorrelated subset may be selected randomly from a pool of volumes in the volume set.

FIG. **3** schematically illustrates various workflows for storing original data of archives on a plurality of data stores of a data storage system, in accordance with some embodiments. A data storage system **302**, which in some embodiments may be similar to the data storage system **306** described above in connection with FIG. **2**, includes or is connected to a plurality of volumes **304**, which may be similar to the volumes **308**, also described above in connection with FIG. **2**. Archives **306**, such as those received from client entities **302** described in connection with FIG. **2**, are processed by the data storage system **302** according to the techniques described in further detail herein.

As previously discussed, the data storage system **302** may sort the archives **306** according to one or more criteria (and in the case where a plurality of criteria is used for the sort, such criteria may be sorted against sequentially and in any order appropriate for the implementation). Such criteria may be attributes common to some or all of the archives, and may include the identity of the customer, abstractions defined by the customer (e.g., larger data objects associated with multiple archives of the same customer), the time of upload and/or receipt, archive size, expected volume and/or shard boundaries relative to the boundaries of the archives (e.g., so as to minimize the number of archives breaking across shards and/or volumes), unique identifiers of the archives themselves, and the like. As previously mentioned, such sorting may be performed so as to minimize the number of volumes on which any given archive is stored. For example, larger archives may be sorted based on expected volume size, such that larger archives are stored earlier in the volume and increasingly smaller archives are stored later in the volume. Such techniques may be used, e.g., to optimize storage in embodiments where the overhead of retrieving data from multiple volumes is greater than the benefit of parallelizing the retrieval from the multiple volumes. For example, devices using removable media may incur significant latency penalties when the media are physically changed, and the sort order may concatenate and apportion archives so as to minimize the number of removable media sufficient for the retrieval of the archives. As previously mentioned, information regarding the sort order may be persisted, e.g., by the data storage system **302**, for use in techniques described in further detail herein.

In some embodiments, the data storage system **302** may sort the archives **306** two or more times, at least one of which may correspond to the various characteristics of the data storage system **302** and/or the volume **304** itself. For example, a first sort may include one or more of the criteria delineated above, and a second sort may, incident to actual storage of the archives **306** on one or more volumes **304**, re-sort the sorted archives according to boundaries, storage space, and other volume characteristics, so as to optimize the storage of the archives **306**.

As previously described (e.g., in connection with FIG. **2**), one or more indices, of one or more types may, in some embodiments, be generated for each volume **304** of the plurality, and in such embodiments, may reflect the archives stored on the respective volume **304** to which it applies. In some embodiments, the indexes are used in connection with information relating to the sort order of the archives **306** so as to locate archives without necessitating the use of dense indexes, e.g., those that account for every archive **304** on a given volume **308**. Such sort order-related information may reside on the volume(s) **304** or, in some embodiments, on an entity separate from the volume(s) **304**, such as in a data store or other resource of a computing resource service provider. Similarly, the indexes may be stored on the same volume(s) **304** to which they apply, or, in some embodiments, separately from such volume(s) **304**.

As mentioned, the original data **312** of archives **306** are stored on a subset of the plurality of volumes **304**, and the quantity of the subset of volumes may be equal to the minimum number of shards required by or sufficient for the redundancy code to regenerate the original data. Also as mentioned, appropriate indices may also be stored on the applicable subset of the plurality of volumes **308**, in connection with the original data **312** of the stored archives **308**. The original data of the archives is stored as a plurality of shards across a plurality of volumes, the quantity of which (either shards or volumes, which in some cases may have a one to one relationship) may be predetermined according to various factors, including the number of total shards sufficient to reconstruct the original data using a redundancy code.

As an example, FIG. **3** illustrates five volumes, three of which contain original data **312** of stored archives **308** (corresponding to the incoming archives **306**), and two of which contain data **314** derived from mathematical functions of the applied redundancy code. In the illustrated example, the redundancy code used may require any three shards to regenerate original data, and therefore, a quantity of three volumes may be used to write the original data (prior to any application of the redundancy code). As discussed further herein, though a single set of five volumes **304** is illustrated, the volumes and/or shards may be grouped and/or layered in any configuration, including hierarchically.

Similarly to previously discussed, the volumes **304** storing the original data **312** of the stored archives **308** are processed, at a volume level, by an entity associated with, e.g., the archival storage service, using a redundancy code, such as an erasure code, so as to generate the remaining shards **314**, which contain encoded information rather than the original data of the archives. As previously mentioned, the original data **312** may be processed using the redundancy code at any time after being sorted, such as prior to being stored on the volumes, contemporaneously with such storage, or after such storage. As illustrated by the shaded archive **310**, a given archive may, in certain cases, break between two (or possibly more) volumes **304**, due to size, placement, and the like. In embodiments where the redundancy code is applied at a volume level (e.g., the entirety of the contents of the volumes bearing the original data of the archives being considered as a single data object to be processed by the redundancy code), failure of one of the two volumes (or shards) on which the original data of the illustrated archive **310** resides may not necessitate rebuilding of both volumes, but only the volume that is unavailable.

The encoded information **314** may be any mathematically computed information derived from the original data **312**, and depends on the specific redundancy code applied. In some embodiments, the redundancy code may implement a generator matrix that implements mathematical functions to generate multiple encoded objects correlated with the original data to which the redundancy code is applied. In some of such embodiments, an identity matrix is used, wherein no mathematical functions are applied and the original data (and, if applicable, the indexes) are allowed to pass straight through. It may be therefore contemplated that the volumes bearing the original data (and the indexes) **308** may correspond to objects encoded from that original data by the identity matrix rows of the generator matrix of the applied redundancy code, while volumes bearing derived data **314** correspond to other rows of the generator matrix.

Similarly to previously discussed, if one of the volumes **304** or a shard stored thereon is detected as corrupt, missing, or otherwise unavailable, a new shard may be generated using the redundancy code applied to generate the shard(s) in the first instance. The new shard may be stored on the same volume or a different volume, depending, for example, on whether the shard is unavailable for a reason other than the failure of the volume. The new shard may be generated by, e.g., the data storage system **302**, by using a quantity of the remaining shards sufficient to regenerate the original data (and the index, if applicable) stored across all volumes, regenerating that original data, and either replacing the portion of the original data corresponding to that which was unavailable (in the case that the unavailable shard contains original data), or reapplying the redundancy code so as to provide derived data for the new shard. In embodiments where layered redundancy coding is used, in some of such embodiments, a subset (e.g., group) of the shards may be used to locally regenerate a given volume **304** and/or shard from shards within that particular subset, and if such local regeneration is not feasible, shards from outside a given subset may be used (e.g., those shards part of a higher hierarchical layer or other group).

As previously discussed, in some embodiments, the new shard may be a replication of the unavailable shard, such as may be the case if the unavailable shard includes original data of the archive(s). In some embodiments, the new shard may be selected from a set of potential shards as generated by, e.g., a generator matrix associated with the redundancy code, so as to differ in content from the unavailable shard (such as may be the case if the unavailable shard was a shard generated from the redundancy code, and therefore contains no original data of the archives).

FIG. **4** schematically illustrates various workflows for storing data in failure-decorrelated subsets of a volume set, in accordance with some embodiments. A volume set **402** includes a plurality of volumes **404**, which may in some instances be similar in implementation and characteristics to the volumes (e.g., **308**) described in at least FIGS. **2** and **3** above. As pictured, the volumes **404** may be grouped such that each given volume **404** has one or more cohorts **406**. In such embodiments, the volume set **402** may be implemented that incoming archives to be stored on the volumes are apportioned to one or more failure-decorrelated subsets **412** of the volume set (depicted illustratively by four generally horizontal traces). The failure-decorrelated subsets may be some combination of the volumes **404**, **406** of the volume subset **402**, where the quantity of volumes in each failure-decorrelated subset **412** correlates to a number of shards required by or sufficient for the implemented redundancy code.

As depicted, some of the volumes of the volume set **402** are designated as storing original data **408** of archives to be stored, and others are designated as storing derived data **410**, such as may be the case when a redundancy code and volume-level encoding techniques such as described elsewhere herein are implemented. However, other storage mechanisms and schemes are contemplated hereby, including object-level encoding techniques. As previously mentioned, and in the illustrated example, the overall volume set **402** may comprise multiple failure-decorrelated subsets (volumes along one of the four horizontal traces depicted) where a given constituent volume **404** is paired with one or more cohort (e.g., **406**). In some embodiments, the incoming archives are apportioned to one or more of the cohorts participating in one or more of the failure-decorrelated subsets **412** according to, for example, a predetermined sequence, based on one or more attributes of the incoming archives, and the like.

The illustrated example shows, for clarity, a pair-wise cohort scheme, though other schemes are contemplated as within scope of this disclosure, some of which are outlined in greater detail herein. As mentioned, in the illustrated example, some of the volumes **404**, **406**, **408** of the volume set **402** store original data of incoming archives (e.g., **406**), while others store derived data (e.g., **410**). The system may implement a number of failure-decorrelated subsets **412** to which to store the incoming archives, and in the pair-wise scheme pictured, the volumes used for a given archive may differ based on some arbitrary or predetermined pattern (such as those depicted by the horizontal traces **412**). As illustrated, some archives may be apportioned to volumes of a given cohort that are assigned to one pattern or failure-decorrelated subset **412**, while others are apportioned to volumes in a different pattern **412**. The size of a given failure-decorrelated subset **412** may be adjusted, in some embodiments, to account for the characteristics of the expected incoming archives, the volumes themselves, or a combination. For example, the failure-decorrelated subsets **412** may be configured to have an arbitrary byte-size boundary (e.g., may contain X bytes), an object quantity boundary (e.g., may include X objects), or be a value derived from the quantity of failure-decorrelated subsets **412** desired.

The patterns, as mentioned, may be arbitrary, predefined, and/or in some cases, sensitive to attributes of the incoming data. For example, in the planar representation shown, the patterns **412** may be selected such that each of the volumes selected for the patterns are evenly allocated and/or accessed, with few or none of the members of each given cohort (e.g., vertical pair) over- or underrepresented in a given pattern. The patterns **412** may be predefined, e.g., independently of the attributes of the incoming data and selected to optimize some operational parameter, e.g., mean time between failure or annualized failure rate of each volume or device thereon, performance of each volume and/or device thereon, minimization of slack space, power-on time, and the like, and each pattern may be used and reused in some sequence and/or at some interval. For example, each N number of archives are stored to a given failure-decorrelated subset **412** before the following N archives are stored to the next failure-decorrelated subset in the sequence, and so on.

In other examples, attributes of the incoming archives may be used to apportion archives having those attributes to a given failure-decorrelated subset **412**. For example, an identity value (or hash thereof), either unique to the incoming archive or a customer thereof, may be mapped such that a given range of values within the possible extent of values is mapped to a given sequence. In some embodiments, as a result, a customer may be able to have partial or full control over the specific failure-decorrelated subset to which their archives are stored.

In some embodiments, patterns may not be used at all, and the member volumes of a given failure-decorrelated subset may be selected randomly from a pool of volumes in the volume set. For example, the patterns **412** may be constructed out of random or pseudorandom combinations of eligible volumes (e.g., with the correct number of volumes capable of storing original data **404** and the correct number of volumes capable of storing derived data **410**, according to the specific redundancy coding used.

FIG. **5** schematically illustrates various workflows for indexing and locating data stored on a data storage system in accordance with some embodiments. A representative volume **502**, which in some embodiments is similar to the volumes described above in connection with FIGS. **1** and **2**, stores a plurality of archives **504**, including the original data **506** as, e.g., received from a customer, such as that of a data storage system or other resource and/or service of a computing resource service provider to which the data storage system is attached. The archives **504** may have been sorted in connection with one of the techniques described above in connection with FIGS. **2** and **3**, and information regarding the sort order may be persisted by, e.g., a resource directly or indirectly connected with the volume **502**. The volume **502** may reside on (or consist of) one or more storage devices that are optimized for sequential data access, relative to random data access.

As previously discussed, in some embodiments, one or more indices **508** may be generated in connection with, e.g., the order in which the archives are to be stored, as determined in connection with the sorting mentioned previously. The index may be a single index or may be a multipart index, and may be of any appropriate architecture and may be generated according to any appropriate method. For example, the index may be a bitmap index, dense index, sparse index, or a reverse index. Embodiments where multiple indices are used may implement different types of indices according to the properties of, e.g., the archives **504** to be stored in the volume **502**. For example, the volume **502** may utilize a dense index for archives over a specified size (as the size of the index itself may be small relative to the number of archives stored on a given volume), and may also generate a sparse index for archives under that specified size (as the ratio of index size to archive size increases).

In embodiments where sparse indices are used, a sparse index **508** for a given volume may point to subindexes **510**, which in turn mark representative locations on the volume. The subindexes **510** may be an abstraction that points to data that resides at a predetermined interval. In some embodiments, the subindexes **510** may be additional data or metadata that is stored in connection with (or in some embodiments, directly upon) the volume, and at a predetermined interval. In such embodiments, it may be contemplated that the subindexes **510** may be stored as part of the shard on the volume, in a similar fashion as described in connection with FIGS. **1** and **2** above for the index and the original data of the archives.

In some embodiments, the predetermined interval may be in blocks, bytes, or other units of data. For example, the subindexes may identify the archives to be located at every x blocks or bytes of the volume (e.g., independently of the boundaries and/or quantity of the archives themselves). In some embodiments, the predetermined interval may be delinated by number of volumes. For example, the subindex may point to every nth archive to be stored on the volume **502**. As may contemplated, the sparse index **508** (and in some embodiments, the subindexes **510**) may be generated and/or written at a time before the storage of the archives **504**, contemporaneously with such storage, or after such storage. In some embodiments, the sparse index **508** and the subindexes **510** may be stored in a reserved space on the volume, e.g., after the archives **504** have been stored.

In some embodiments, the sparse index **508** is used in connection with information relating to the predetermined sort order of the archives **504** so as to locate specific archives. As previously mentioned, such sort order-related information may reside on the volume(s) **502** or, in some embodiments, on an entity separate from the volume(s) **502**, such as in a data store or other resource of a computing resource service provider. An entity requesting a given archive stored on the volume **502** may determine, based on the sort order-related information and by reading the index **508**, the nearest subindex that is sequentially prior to the requested archive on the volume **502**. The requesting entity may then cause the volume **502** to be sequentially read from the location of that subindex **510** until the requested archive is located and fully read.

In embodiments where multiple types of indices are employed, the requesting entity may initially determine which of the indices includes the most efficient location information for the requested archive based on assessing the criteria used to deploy the multiple types of indices in the first instance. For example, if archives under a specific size are indexed in a sparse index and archives equal to or over that size are indexed in a parallel dense index, the requesting entity may first determine the size of the requested archive, and if the requested archive is larger than or equal to the aforementioned size boundary, may use the dense index in favor of the sparse index as to more quickly obtain the precise location of the requested archive.

FIG. **6** schematically illustrates various workflows for mitigating data loss in systems using volume-level redundancy coding techniques, in accordance with some embodiments. In some embodiments, a group, layer, or set of redundancy coded shards representing one or more archives may be encoded such that the set includes identity shards **602** having some or all of the original data of the archives and encoded shards **604** including information derived from the original data, e.g., through one or more redundancy codes. In the case that some of the shards become unavailable **606**, **608**, various regeneration techniques, such as those described herein, may be initiated so as to attempt to bring those unavailable shards online. In some embodiments, if the total number of available shards drops to or below a predetermined level, such as one determined in connection with the minimum quorum quantity for the group of shards, the regeneration process may be initiated by first copying (or copying in parallel with other portions of the regeneration process) some or all of the available identity shards **602** to a data store **610**, such as a cache, a data storage device, or other data storage entity to which the implementing data storage system has access. The data store **610** may be a part of the implementing data storage system, or, in some embodiments, may be separate from it.

As may be contemplated, in some cases, at the time at which the copying process is initiated, the actual number of available shards may be less than the minimum quorum quantity, or, in some cases, may drop below that minimum quorum quantity during part of the copying or the regeneration process. Under such circumstances, the shard set cannot be fully rebuilt, but by virtue of copying some or all of the identity shards to temporary storage, some of the represented data may be recovered.

The identity shards **602** copied to the data store **610** may be used for a variety of purposes while resident therein. For example, customer request for data represented by an otherwise unviable shard set may be serviced using original data stored in the data store **610**. Additionally, the identity shards **602** may be used to aid the regeneration process. For example, if the number of available shards in the set drops below the minimum quorum quantity, e.g., during the regeneration process, if one or more of the identity shards was copied to the data store **610** prior to becoming unavailable, it may, in some cases, allow regeneration to continue. As another example, the original data contained in the identity shards **610** stored in the data store may be used to create a new shard set, even if the data represented is incomplete, so as to preserve redundancy for what original data remains.

The regeneration process (e.g., by decoding the available shards into the original data **614** using a decode matrix **612**, then re-encoding the original data **614** using a generator matrix **616** so as to generate new shards to stand in for those that are unavailable) may be similar to analogous process described elsewhere herein. As previously mentioned, the copying process to the data store **610** may be performed at the outset of the regeneration process, prior to the regeneration process, or in parallel with the regeneration process. After the regeneration process is complete, the data stored in the data store **610** may be flushed, in some cases after a delay (e.g., so as to ascertain that the shard set will remain stably available after regeneration.

FIG. **7** schematically illustrates various workflows for associating layered groups of redundancy coded data to layers of data storage entities, in accordance with some embodiments. As previously discussed, e.g., in connection with FIG. **1**, shards **702**, **704** may be arranged into any number groups **706**, **708**, **710**, which may in turn be arranged in any appropriate fashion (e.g., hierarchically, etc.). As previously discussed, some or all of the shards may be part of one or more groups, and in some cases where a given shard is part of more than one group, it may be so allocated as a result of being a member of two non-hierarchical group (i.e., participates in two partially overlapping groups). As previously discussed, some of the shards may be identity shards **702**, which include original data of the archives from which they are generated, and other shards may be encoded shards **704**, which may be redundancy coded data portions generated using one or more redundancy codes applied to the original data (or, in some cases, the identity shards themselves). The encoded shards **704** may include, in some embodiments, parity data for other shards (identity shards or other encoded shards) in the same or different group, and thus may only be usable to regenerate the shards from which the parity data was derived.

In some embodiments, a given group of shards may be assigned to one or more failure-correlated layers **712**, **714**, **716**. Each failure-correlated layer may correspond to one or more hardware, software, facility, or other entities for which one or more failure characteristics have been established and/or correlated. For example, a given failure-correlated layer may be designated by using one or more failure probability mechanisms, such as the application of Markov chain modeling, probabilistic binomial theorem, and the like, to various failure characteristics of one or more components of a given data storage system or service. Such failure probability mechanisms and/or failure characteristics may include failure rates, annualized failure rates, mean time to failure, mean time between failures, mean time to error, mean time to resolution, mean time to repair, and the like.

In the illustrated example, failure-correlated layers **712**, **714**, and **716**, are associated with a data storage device layer **722**, a host layer **720**, and a data center or cluster layer **718**, respectively. In such an example, the failure characteristics of each of the physical (or other) layers **718**, **720**, **722** are calculated modeled, using one or more of the characteristics detailed above, to associate them into arbitrarily defined failure-correlated layers **712**, **714**, **716**, for which an entity (e.g., some entity of the data storage system itself) may determine an optimal configuration of assigned shard groups **706**, **708**, **710**, as well as an optimal configuration of the contents therein (e.g., number of encoded shards **704** and/or identity shards **702**, redundancy code(s) used, tuning of the quorum quantity of shards required or sufficient to rebuild the group, as well as the total number of shards in the group, etc.). As may be contemplated, such optimal group and shard configurations may change as the failure characteristics of the underlying physical (or other) layers change, and in some embodiments, the configuration of the failure-correlated layers **712**, **714**, **716** and/or that of the groups of shards may change in response. In some embodiments, these changes may be made manually, and in some embodiments, such adjustments may be preemptive, adaptive, and/or dynamic (e.g., by usage of a monitor or listening entity of the data storage system).

FIG. **8** schematically illustrates various workflows for providing additional redundancy to redundancy coded data, in accordance with some embodiments. As previously discussed, in some embodiments, identity shards (e.g., **802**) may themselves include encoded data, such as groups of encoded shards **806**, which may allow for encoded shards (e.g. **804**) in a given shard group to be locally regenerable, e.g., by a data storage system entity or layer to which it is associated. A given shard group may be extended and/or modified to include additional encoded shards, or remove shards, in accordance with failure characteristics of the data storage system entity or layer. Such additional shards may be generated using the same redundancy code as was used create the shards of the parent group, or, in some embodiments, may use a different redundancy code (e.g., in implementations where local redundancy for stored shards is the primary objective, rather than cross-compatibility of shards across data storage system layers).

In the illustrated example, identity shards **802** include encoded data, which, as previously discussed, may be in the form of other encoded shards. A redundancy code, which may be the same or different than the redundancy code used to encode, e.g., the encoded shard in the first instance, is applied to the encoded data so as to generate a doubly encoded shard **804**. In some embodiments, the redundancy code used to generate the doubly encoded shard **804** may include parity mechanisms (e.g., the application of exclusive or (XOR)). In such embodiments, as may be contemplated, such doubly encoded shards **804** may not be able to participate in regeneration of shards outside of the group of shards from which they are derived. However, in other embodiments, such as those implementing erasure codes or other types of redundancy codes relate to those used to generate shards in other groups, a doubly encoded shard **804** may be usable to regenerate shards in one or more other groups.

For example, as illustrated, some or all of the groups **806**, **808**, **810** may be hierarchically organized, and each group may include encoded data in identity shards **802**, (doubly) encoded shards **804**, and so forth. In some embodiments, all shards in the superset (e.g., **810**) may participate in regeneration of shards both inside and outside of the group to which it directly belongs, but, as may be contemplated, each group may have a different minimum quorum quantity. For example, the shards **802**, **804** having encoded data may be rebuilt using any two of the three shards **802**, **804** in group **806**. However, if two shards of the group **806** become unavailable, one or more shards in the group **808** may be used interchangeably to rebuild the missing shards. Similarly, shards of the group **808** may be regenerated using any of the five total shards in groups **806** and **808**.

While the illustrated example of FIG. **8** shows groups arranged in a hierarchical fashion, as previously discussed, some embodiments may group together shards only partially hierarchically, or not at all hierarchically. As one example, a given shard (e.g., doubly encoded shard **804**) may belong to two separate and non-hierarchical groups (e.g., the overlap between the two groups is incomplete but includes at least one shared shard. In such embodiments, such a shared shard may be used to generate the other shards in the group(s) to which it belongs at a local level (e.g., both may have independent minimum quorum quantities, such as the two-of-three scheme previously discussed for the group **806**).

FIG. **9** schematically illustrates various workflows for enabling regeneration and/or repair for redundancy coded data stored within a data storage facility in a multi-facility environment, in accordance with some embodiments.

As previously mentioned, the implementation of layered redundancy coding techniques may, in some embodiments, enable higher storage efficiency, increased failure recovery speed and efficacy, greater durability and reliability of data storage, and reduced costs, in particular when implemented in multi-located data storage systems. For example, a given data storage facility (e.g., as illustrated, one group of the four illustrated data storage facilities **916**) of a multi-facility data storage system (e.g., **916**, collectively) implementing layered redundancy coding techniques may locally repair any shard associated therewith. For example, the leftmost illustrated data storage facility **916** may store or otherwise be responsible for the storage of two groups **908**, **910** of shards **902**, **904**, **906**, while the remaining data storage facilities store other groups of shards (which may or may not be similar in configuration as the group(s) stored in the leftmost data storage facility **916**. Such groups may be layered such that a first group **908** includes identity shards **902** having original data and an encoded shard **904** that provides redundancy, such as using a redundancy code, as described elsewhere herein. Under ordinary circumstances, even if a number of shards (i.e., the total number of shards in the group minus the minimum quorum quantity for that group) becomes unavailable, the data storage facility **916** may regenerate the unavailable shard(s) using only the remaining shards of the group **908** to which it belongs.

In the case that too few shards in the group **908** remain available to rebuild the unavailable shards within the group **908**, in some embodiments where the shards in other groups (e.g., group **910**) stored on or otherwise under control of the same data storage facility **916** are usable to rebuild shards in the group **908**, one or more of such shards (e.g., of the group **910**, or other group under control of the same data storage facility **916**) may be used to regenerate the unavailable shards. As previously discussed, any number and/or configuration of shards and groups may be stored or otherwise controlled by a given data storage facility **916**. As may be contemplated, in some embodiments, unavailable shards may thus be regenerated using only shards under control of the same data storage facility **916**, i.e., without necessitating retrieval of shards in other data storage facilities **916**. However, if an entire data storage facility **916** becomes unavailable, the shards in other data storage facilities of the same data storage system may be used to recover the unavailable shards as a last resort.

As may be contemplated, many benefits and unique properties arise from layered redundancy coding techniques. For example, layers/groups of shards may be correlated with physical, logical, or arbitrary layers of an implementing data storage system. In some embodiments, redundancy levels for each layer are adjusted according to one or more failure characteristics of the intended data storage system layer to which it is associated. The layers themselves may be individually, internally redundant in accordance with such failure characteristics. In other words, a data storage system layer may locally recover from the failure or other unavailability of up to a quantity of shards in an assigned shard group without necessitating the participation of other data storage system layers and/or shard groups.

FIG. **10** schematically illustrates an example process for layering redundancy coded data, in accordance with some embodiments. At step **1002**, a resource of an implementing data storage system, such as that implementing a redundancy code to store archives, processes incoming archives (such as those received from a customer of, e.g., a data storage system or a computing resource service provider as described in further detail above in connection with at least FIGS. **1-9**) to generate a plurality of shards. As previously discussed, the shards may be generated such that a subset includes unencoded original data of the archives (e.g., identity shards), while other shards include encoded forms of such data, such as may be generated by application of a redundancy code.

At step **1004**, a resource of the data storage system, such as the same or different resource that generated the shard(s) in the first instance, groups shards into a plurality of subsets (groups). As previously discussed, some or all of the groups of shards may be configured such that as long as a minimum quorum quantity of shards remain in a given group, unavailable shards with that group may be regenerated using the available shards with that group. In some embodiments, as previously discussed, some groups may include doubly derived shards, such as may be the case if a group is generated in connection with another group (e.g. a group of parity shards associated with an erasure coded group).

At step **1006**, the shard subsets (groups) are layered by a resource of the data storage system such that shards in disparate groups may participate in regeneration of at least some of the shards outside of the group to which it immediately belongs. As previously discussed, such layering may enable otherwise unavailable groups of shards to be regenerated using shards of other groups.

At step **1008**, in response to a request, e.g., of a customer to which a given archive belongs, for original data processed and stored in accordance with steps **1002-1006** above, the original data may directly be retrieved, e.g., from the identity shards bearing the unencoded original data. As such, such retrieval requests may be serviced in a way that only groups including the relevant identity shards need be retrieved and processed, thereby increasing efficiency of retrieval of the data.

FIG. **11** schematically illustrates an example process for processing, indexing, storing, and retrieving data stored on a data storage system, in accordance with some embodiments. At step **1102**, a resource of a data storage system, such as that implementing a redundancy code to store archives, determines which subset (e.g., quantity) of a plurality of volumes is sufficient, based on, e.g., a redundancy code to be applied to the archives, to recreate the original data to be stored. For example, in accordance with the techniques described above in connection with at least FIGS. **2** and **3**, such information may be derived from predetermining the parameters of an erasure code with a specified ratio of shards sufficient to regenerate the original data from which they derive to the total number of shards generated from the application of the erasure code.

At step **1104**, original data, such as original data of archives received from customers of, e.g., a data storage system or a computing resource service provider as described in further detail above in connection with at least FIGS. **1**-**9** above, is sorted by, e.g., the data storage system or associated entity. For example, as previously described, the sort order may be implemented on one or more attributes of the incoming data.

At step **1106**, one or more indices, such as sparse indices, are generated by, e.g., the data storage system, for the original data. As previously discussed in connection with at least FIGS. **1** through **9**, there may be more than one index for a given volume, and such parallel indices may be of different types depending on the nature of the archives and/or original data being stored.

At step **1108**, the original data is stored, e.g., by the data storage system, on the subset of volumes determined in connection with step **1102**, and in the order determined in step **1104**. Additionally, at step **1110**, the index generated in step **1106** is stored, e.g., by the data storage system, on an appropriate entity. As previously discussed, the index may be stored as part of a shard on which the original data is stored, or, in some embodiments, may be stored on a separate resource from that which persists the volume.

At step **1112**, the redundancy code is applied, e.g., by the data storage system, to the determined subset of volumes (e.g., shards, as previously discussed in connection with FIGS. **1** through **3**), and additional shards containing data derived from the application of the redundancy code are stored on a predetermined quantity of volumes outside the subset determined in connection with step **1102**. For example, as previously discussed, the ratio of volumes (e.g., shards) storing the original data to the overall quantity of volumes (including those storing the derived data generated in this step **1112**) may be prescribed by the recovery/encoding ratio of the redundancy code applied herein.

At step **1114**, in normal operation, requested data may be retrieved, e.g., by the data storage system, directly from the subset of volumes storing the original data, without necessitating retrieval and further processing (e.g., by the redundancy code) from the volumes storing the derived data generated in step **1112**. However, at step **1116**, if any of the volumes are determined, e.g., by the data storage system, to be unavailable, a replacement shard may be generated by the data storage system by reconstructing the original data from a quorum of the remaining shards, and re-encoding using the redundancy code to generate the replacement shard. As previously discussed in connection with FIGS. **2**-**5**, the replacement shard may be the same or different from the shard detected as unavailable.

FIG. **12** schematically illustrates an example process for determining failure-decorrelated volume subsets and storing/retrieving data thereto, in accordance with some embodiments. At step **1202**, the quantity, configuration, and/or size of failure-decorrelated subsets of a volume set are determined by, e.g., an implementing data storage system or computing resource service provider as described below. As mentioned in connection with at least FIG. **4**, such quantity, configuration, and/or size of failure-decorrelated subsets may be tuned and/or adjusted according to the system characteristics desired. Also as mentioned, the number of cohorts from which a given failure-decorrelated subset is selected may also be adjusted or adjustable as sufficient.

At step **1204**, the system determines which failure-decorrelated subset(s) to store archives incoming to the system. As previously mentioned, the determination may be made on any appropriate basis, such as using the attributes of the incoming archives, attributes of the volumes and/or the failure-decorrelated subset(s), and the like.

At step **1206**, a redundancy code, such as a forward error correction code or erasure code, may be applied to the archives by the system. As previously discussed, such application may be made prior to, after, or in connection with the storage of original data of the archives to be stored (and in some embodiments, may result generation of shards of derived data as well as shards of original data.

At step **1208**, some or all of the results of the encoding of step **1206** are stored by the system on an appropriate failure-decorrelated subset for the given archive as determined in steps **1202** and **1204**. As mentioned, in some embodiments, such storage may be performed using volume-encoding techniques, and thus the original data may be directly stored and/or retrieved from some or all of the volumes without necessitating decoding unless such volumes become unavailable.

At step **1210**, in connection with, e.g., a request from an owner or customer of the stored archives, the system locates the appropriate failure-decorrelated subset and retrieves the archives. The manner in which the system locates the appropriate failure-decorrelated subset may differ depending on how such failure-decorrelated subsets (and archives) are apportioned. For example, if the sequence of failure-decorrelated subsets is predetermined and keyed to a given attribute of the archive, the archive attribute may be used to identify which of the failure-decorrelated subsets is storing the data.

FIG. **13** schematically illustrates an example process for indexing original data stored on a redundancy coded data storage system, in accordance with some embodiments. At step **1302**, similarly to step **1104** of process **1100** described in connection with FIG. **11**, original data is processed by, e.g., a data storage system, to determine the order of storage of archives containing the original data on a volume. Information regarding the sort order may be persisted on, e.g., the volume, or a separate entity from the volume, as discussed above.

At step **1304**, one or more indices, such as sparse indices, are generated by, e.g., the data storage system, and point to subindexes that identify predetermined locations on the volume. The locations may be predetermined based on the parameters of the specific implementation, such as the size of the volume, the speed of reading and/or writing the volume (e.g., sequentially), the number of archives per volume, and the like. As previously discussed, the subindexes may be abstractions, or, in some embodiments, may be data or metadata elements stored on or in connection with the volume.

At step **1306**, the original data sorted in step **1302** is stored by the data storage system on the volume, with subindexes associated with, pointing to, or stored at predetermined locations mentioned in step **1304**. The index generated in step **1304** is stored, at step **1308**, by the data storage system on a resource associated with volume, or, in some embodiments, on the volume itself, according to the techniques described above.

At step **1310**, a request, such as from a client entity or other entity connected to the data storage system and/or the volume, for a subset of the original data stored on the volume, is received by the volume or the data storage system associated with the volume. The data storage system and/or the requesting entity may, as previously discussed, have access to information regarding the sort order of the original data as determined in step **1302**, and, in embodiments utilizing sparse indexes, may use the index to locate an appropriate subindex at step **1312**. As previously discussed, in some embodiments, the appropriate subindex is the nearest location, marked by the subindex, that is sequentially prior to the requested subset of original data as stored on the volume. Once the subindex is determined in step **1312**, at step **1314**, the volume is sequentially read (e.g., by the data storage system or the storage device on which the volume is implemented) from the location denoted by the appropriate subindex, until the requested subset of original data is located and retrieved.

FIG. **14** schematically illustrates an example process for mitigating data loss in redundancy coded data, in accordance with some embodiments. At step **1402**, in response to receiving information indicating that an available quantity of shards representing one or more archives is less than, equal to, or approaching a predetermined level, an entity associated with the data storage system responsible for the associated shards determines which subset of the shards includes the unencoded, original data associated with the one or more archives. As previously discussed, the entity may include a listener or other type of resource capable of monitoring the whereabouts and/or status of the shards. The subset of the shards determined in this step **1402** may include one or more groups of shards that include identity shards. The predetermined level may be set in advance, determined dynamically, and/or adjusted manually, and may be predetermined in connection with one or more minimum quorum quantities of one or more groups of shards associated with the archive(s).

At step **1404**, the subset of shards determined in step **1402** is copied to a storage entity associated with the data storage system. As previously discussed, the storage entity may be a storage device, a storage service, a cache, or other resource capable of at least temporarily storing the data. In some embodiments, also as previously discussed, the storage entity may be configured such that it is capable of "standing in" or otherwise temporarily replacing one or more components or resources used by the data storage system in ordinary data retrieval and storage operations.

At step **1406**, the data storage system or associated resource(s) attempt to regenerate, using techniques described elsewhere in this disclosure, the unavailable shards associated with the archive(s). In some embodiments, the regeneration of this step **1406** may be performed in parallel with the copying operation of step **1404**. In some embodiments, however, the copying process of step **1404** may be prioritized, either temporally or by allocation of system resources dedicated to related operations, so as to minimize the chance that additional shards and/or original data are lost after the information is received in step **1402**.

At step **1408**, in the cases where the original data becomes unavailable (e.g., the shards having such original data become unavailable) during any of the preceding steps **1402-1406**, some or all of the requests associated with the archive(s) associated with that original data are directed to the temporary storage to which the original data was copied in step **1404**, if the original data was successfully copied. In some embodiments, all requests for the original data are redirected to the temporary storage until such time as the quantity of shards representing such original data has been restored to a level equal to or above the predetermined level mentioned in connection with step **1402**.

FIG. **15** schematically illustrates an example process for grouping redundancy coded data according to failure characteristics of a data storage system, in accordance with some embodiments. At step **1502**, a resource of an implementing data storage system, such as that implementing a redundancy code to store archives, processes incoming archives (such as those received from a customer of, e.g., a data storage system or a computing resource service provider as described in further detail above in connection with at least FIGS. **1-14**) to generate a plurality of shards. As previously discussed, the shards may be generated such that a subset includes unencoded original data of the archives (e.g., identity shards), while other shards include encoded forms of such data, such as may be generated by application of a redundancy code.

At step **1504**, an entity associated with the data storage system determines failure characteristics of one or more other entities of the data storage system. For example, the entity may gather and process failure rate information for hardware, software, and other layers of the data storage system, such as that of physical storage devices, datacenters and other data storage facilities, servers/hosts, and the like, and may group them in any appropriate way. As may be contemplated, the combined failure-correlated layers may have composite failure characteristics.

At step **1506**, the data storage system (e.g., using the same or different entity responsible for processing the archives in step **1502**) groups the shards generated in step **1502** into a plurality of shard subsets (groups) in accordance with the failure characteristics determined at step **1504**. As previously discussed, the groups may include a quantity of shards, and/or a minimum quorum quantity, that is specific to the failure characteristics of the particular layer to which it is associated. In some embodiments, the configuration of such groups may dynamically change in accordance with detected changes in failure characteristics. At step **1508**, after the shards are grouped in accordance with such failure characteristics, the groups determined in step **1502** are associated with the appropriate entity or entities (e.g., layers).

FIG. **16** schematically illustrates an example process for adjusting redundancy of encoded shards associated with redundancy coded data, in accordance with some embodiments. At step **1602**, a resource of an implementing data storage system, such as that implementing a redundancy code to store archives, processes incoming archives (such as those received from a customer of, e.g., a data storage system or a computing resource service provider as described in further detail above in connection with at least FIGS. **1-9**) to generate a plurality of shards. As previously discussed, the subset includes encoded shards, such as may be generated by application of a redundancy code.

At step **1604**, the data storage system resource generates additional encoded shards using the redundancy code. Such encoded shards may be generated using the same redundancy code used to generate the existing encoded shards in step **1602**. In some embodiments, a different redundancy code may be used. In some embodiments, the encoded shards may be used as an input for the redundancy code, and doubly encoded shards may be generated in this step **1604**.

At step **1606**, the encoded shards generated in step **1604** is added to the subset generated in step **1602** (or an associated subset). As previously discussed, such subsets may include shared encoded shards, such as may be the case if the subsets are arranged hierarchically. At step **1608**, if one of the encoded shards generated in step **1602** or, in some cases, at step **1604**, becomes unavailable, if the number of total remaining available shards generated in steps **1602-1606** remains above a predetermined level (which may be connected with the minimum quorum quantity for the overall superset of shards generated in steps **1602-1606**), the unavailable encoded shards are regenerated, using one or more appropriate resources of the data storage system, using only the encoded shards generated in connection with steps **1602-1606**.

FIG. **17** schematically illustrates an example process for adjusting redundancy associated with original data in redundancy coded systems, in accordance with some embodiments. At step **1702**, a resource of an implementing data storage system, such as that implementing a redundancy code to store archives, processes incoming archives (such as those received from a customer of, e.g., a data storage system or a computing resource service provider as described in further detail above in connection with at least FIGS. **1-9**) to generate a plurality of shards. As previously discussed, the subset of the generated shards includes identity shards, which may include unencoded original data of the archives.

At step **1704**, the data storage system resource generates encoded shards using the redundancy code. Such encoded shards may be generated using the same redundancy code used to generate the shards in step **1702**. In some embodiments, a different redundancy code may be used. In some embodiments, the encoded shards may be used as an input for the redundancy code, and doubly encoded shards may be generated in this step **1704**.

At step **1706**, the encoded shards generated in step **1704** is added to the subset generated in step **1702** (or an associated subset). As previously discussed, such subsets may include shared encoded shards, such as may be the case if the subsets are arranged hierarchically. At step **1708**, if one of the shards generated in step **1702** or, in some cases, at step **1704**, becomes unavailable, if the number of total remaining available shards generated in steps **1702-1706** remains above a predetermined level (which may be connected with the minimum quorum quantity for the overall superset of shards generated in steps **1702-1706**), the unavailable shards are regenerated, using one or more appropriate resources of the data storage system, using only the encoded shards generated in connection with steps **1702-1706**.

FIG. **18** shows an example of a customer connected to a computing resource service provider in accordance with at least one embodiment. The computing resource service provider **1802** may provide a variety of services to the customer **1804** and the customer **1804** may communicate with the computing resource service provider **1802** via an interface **1826**, which may be a web services interface or any other type of customer interface. While FIG. **18** shows one interface **1826** for the services of the computing resource service provider **1802**, each service may have its own interface and, generally, subsets of the services may have corresponding interfaces in addition to or as an alternative to the interface **1826**. The customer **1804** may be an organization that may utilize one or more of the services provided by the computing resource service provider **1802** to maintain and deliver information to its employees, which may be located in various geographical locations. Additionally, the customer **1804** may be an individual that utilizes the services of the computing resource service provider **1802** to deliver content to a working group located remotely. As shown in FIG. **18**, the customer **1804** may communicate with the computing resource service provider **1802** through a network **1806**, whereby the network **1806** may be a communication network, such as the Internet, an intranet or an Internet service provider (ISP) network. Some communications from the customer **1804** to the computing resource service provider **1802** may cause the computing resource service provider **1802** to operate in accordance with one or more embodiments described or a variation thereof.

The computing resource service provider **1802** may provide various computing resource services to its customers. The services provided by the computing resource service provider **1802**, in this example, include a virtual computer system service **1808**, a block-level data storage service **1810**, a cryptography service **1812**, an on-demand data storage service **1814**, a notification service **1816**, an authentication system **1818**, a policy management service **1820**, a task service **1822** and one or more other services **1824**. It is noted that not all embodiments described include the services **1808-1824** described with reference to FIG. **18** and additional services may be provided in addition to or as an alternative to services explicitly described. As described, each of the services **1808-1824** may include one or more web service interfaces that enable the customer **1804** to submit appropriately configured API calls to the various services through web service requests. In addition, each of the services may include one or more service interfaces that enable the services to access each other (e.g., to enable a virtual computer system of the virtual computer system service **1808** to store data in or retrieve data from the on-demand data storage service **1814** and/or to access one or more block-level data storage devices provided by the block level data storage service **1810**).

The virtual computer system service **1808** may be a collection of computing resources configured to instantiate virtual machine instances on behalf of the customer **1804**. The customer **1804** may interact with the virtual computer system service **1808** (via appropriately configured and authenticated API calls) to provision and operate virtual computer systems that are instantiated on physical computing devices hosted and operated by the computing resource service provider **1802**. The virtual computer systems may be used for various purposes, such as to operate as servers supporting a website, to operate business applications or, generally, to serve as computing power for the customer. Other applications for the virtual computer systems may be to support database applications, electronic commerce applications, business applications, and/or other applications. Although the virtual computer system service **1808** is shown in FIG. **18**, any other computer system or computer system service may be utilized in the computing resource service provider **1802**, such as a computer system or computer system service that does not employ virtualization or instantiation and instead provisions computing resources on dedicated or shared computers/servers and/or other physical devices.

The block-level data storage service **1810** may comprise one or more computing resources that collectively operate to store data for a customer **1804** using block-level storage devices (and/or virtualizations thereof). The block-level storage devices of the block-level data storage service **1810** may, for instance, be operationally attached to virtual computer systems provided by the virtual computer system service **1808** to serve as logical units (e.g., virtual drives) for the computer systems. A block-level storage device may enable the persistent storage of data used/generated by a corresponding virtual computer system where the virtual computer system service **1808** may only provide ephemeral data storage.

The computing resource service provider **1802** also includes a cryptography service **1812**. The cryptography service **1812** may utilize one or more storage services of the computing resource service provider **1802** to store keys of the customers in encrypted form, whereby the keys may be usable to decrypt customer **1812** keys accessible only to particular devices of the cryptography service **1812**.

The computing resource service provider **1802** further includes an on-demand data storage service **1814**. The on-demand data storage service **1814** may be a collection of computing resources configured to synchronously process requests to store and/or access data. The on-demand data storage service **1814** may operate using computing resources (e.g., databases) that enable the on-demand data storage service **1814** to locate and retrieve data quickly, to allow data to be provided in responses to requests for the data. For example, the on-demand data storage service **1814** may maintain stored data in a manner such that, when a request for a data object is retrieved, the data object can be provided (or streaming of the data object can be initiated) in a response to the request. As noted, data stored in the on-demand data storage service **1814** may be organized into data objects. The data objects may have arbitrary sizes except, perhaps, for certain constraints on size. Thus, the on-demand data storage service **1814** may store numerous data objects of varying sizes. The on-demand data storage service **1814** may operate as a key value store that associates data objects with identifiers of the data objects that may be used by the customer **1804** to retrieve or perform other operations in connection with the data objects stored by the on-demand data storage service **1814**.

In the environment illustrated in FIG. **18**, a notification service **1816** is included. The notification service **1816** may comprise a collection of computing resources collectively configured to provide a web service or other interface and browser-based management console. The management console can be used to configure topics for which customers seek to receive notifications, configure applications (or people), subscribe clients to the topics, publish messages, or configure delivery of the messages over clients' protocol of choice (i.e., hypertext transfer protocol (HTTP), e-mail and short message service (SMS), among others). The notification service **1816** may provide notifications to clients using a "push" mechanism without the need to check periodically or "poll" for new information and updates. The notification service **1816** may further be used for various purposes such as monitoring applications executing in the virtual computer system service **1808**, workflow systems, time-sensitive information updates, mobile applications, and many others.

As illustrated in FIG. **18**, the computing resource service provider **1802**, in various embodiments, includes an authentication system **1818** and a policy management service **1820**. The authentication system **1818**, in an embodiment, is a computer system (i.e., collection of computing resources) configured to perform operations involved in authentication of users of the customer. For instance, one of the services **1808-1816** and **1820-1824** may provide information from a user to the authentication system **1818** to receive information in return that indicates whether the user requests are authentic.

The policy management service **1820**, in an embodiment, is a computer system configured to manage policies on behalf of customers (such as customer **1804**) of the computing resource service provider **1802**. The policy management service **1820** may include an interface that enables customers to submit requests related to the management of policy. Such requests may, for instance, be requests to add, delete, change, or otherwise modify policy for a customer or for other administrative actions, such as providing an inventory of existing policies and the like.

The computing resource service provider **1802**, in various embodiments, is also equipped with a task service **1822**. The task service **1822** is configured to receive a task package from the customer **1804** and enable executing tasks as dictated by the task package. The task service **1822** may be configured to use any resource of the computing resource service provider **1802**, such as one or more instantiated virtual machines or virtual hosts, for executing the task. The task service **1824** may configure the one or more instantiated virtual machines or virtual hosts to operate using a selected operating system and/or a selected execution application in accordance with a requirement of the customer **1804**.

The computing resource service provider **1802** additionally maintains one or more other services **1824** based at least in part on the needs of its customers **1804**. For instance, the computing resource service provider **1802** may maintain a database service for its customers **1804**. A database service may be a collection of computing resources that collectively operate to run one or more databases for one or more customers **1804**. The customer **1804** may operate and manage a database from the database service by utilizing appropriately configured API calls. This, in turn, may allow a customer **1804** to maintain and potentially scale the operations in the database. Other services include, but are not limited to, object-level archival data storage services, services that manage and/or monitor other services.

The computing resource service provider **1802** further includes an archival storage service **1824**. The archival storage service **1824** may comprise a collection of computing resources that collectively operate to provide storage for data archiving and backup of customer data. The data may comprise one or more data files that may be combined to form an archive. The archival storage service **1824** may be configured to persistently store data that may be infrequently accessed and for which long retrieval times are acceptable to a customer utilizing the archival storage service **1824**. A customer may interact with the archival storage service **1824** (for example, through appropriately configured API calls made to the archival storage service **1824**) to generate one or more archives, upload and retrieve the one or more archives or monitor the generation, upload or retrieval of the one or more archives.

The computing resource service provider **1802** additionally maintains one or more other services **1826** based at least in part on the needs of its customers **1804**. For instance, the computing resource service provider **1802** may maintain a database service for its customers **1804**. A database service may be a collection of computing resources that collectively operate to run one or more databases for one or more customers **1804**. The customer **1804** may operate and manage a database from the database service by utilizing appropriately configured API calls. This, in turn, may allow a customer **1804** to maintain and potentially scale the operations in the database. Other services include, but are not limited to, object-level archival data storage services, services that manage and/or monitor other services.

FIG. **19** shows an illustrative example of a data storage service in accordance with various embodiments. The data storage service **1900** may be a service of a computing resource provider used to operate an on-demand data storage service such as described above in connection with FIG. **18**. As illustrated in FIG. **19**, the data storage service **1900** includes various subsystems such as a request processing subsystem **1902** and a management subsystem **1904**. The data storage service **1900** may also include a plurality of data storage servers **1906** and a metadata storage **1908**, which may store metadata about various data objects stored among the data storage servers **1906** as described. In an embodiment, the request processing subsystem **1902** is a collection of computing resources, such as webservers and application servers, collectively configured to process requests submitted to the data storage service **1900**. The request processing subsystem **1902**, for example, may include one or more webservers that provide a web service interface to enable customers of the data storage service **1900** to submit requests to be processed by the data storage service **1900**. The request processing subsystem **1902** may include computers systems configured to make various determinations in connection with the processing of requests, such as whether policy allows fulfillment of a request, whether requests are authentic (e.g., electronically signed using a suitable cryptographic key) and otherwise.

Components of the request processing subsystem may interact with other components of the data storage service **1900** (e.g., through network communications). For example, some requests submitted to the request processing subsystem **1902** may involve the management of computing resources which may include data objects stored by the data storage servers **1906**. The request processing subsystem **1902**, for example, may receive and process requests to modify computing resources. For instance, in some examples, data objects are logically organized into logical data containers. Data objects associated with a logical data container may, for example, be said to be in the logical data container. Requests to the data processing subsystem **1902** may include requests for creating logical data containers, deleting logical data containers, providing an inventory of a logical data container, providing or updating access control policy with respect to one or more logical data containers and the like.

The requests may be processed by the management subsystem **1904** upon receipt by the request processing subsystem **1902**. If applicable, various requests processed by the request processing subsystem **1902** and/or management subsystem **1904**, may result in the management subsystem **1904** updating metadata associated with data objects and logical data containers stored in the metadata store **1908**. Other requests that may be processed by the request processing subsystem **1902** include requests to perform operations in connection with data objects. The requests, for example, may include requests to upload data objects to the data storage service **1900**, to download data objects from the data storage service **1900**, to delete data objects stored by the data storage service **1900** and/or other operations that may be performed.

Requests processed by the request processing subsystem **1902** that involve operations on data objects (upload, download, delete, e.g.) may include interaction between the request processing subsystem **1902** and one or more data storage servers **1906**. The data storage servers **1906** may be computer system communicatively coupled with one or more storage devices for the persistent of data objects. For example, in order to process a request to upload a data object, the request processing subsystem may transmit data to a data storage server **1906** for persistent storage. It is noted, however, that in some embodiments, client (e.g., customer) computer systems may transmit data directly to the data storage servers **1906** instead of through severs in the request processing subsystem.

In some embodiments, the request processing subsystem **1902** transmits data to multiple data storage servers **1906** for the purposes of redundantly storing the data to allow the retrievability of data in the event of failure of an individual data storage server **1906** and/or associated data storage device. For example, in some embodiments, the request processing subsystem uses a redundancy in coding scheme such as erasure coding to deconstruct a data object into multiple parts that are stored among the data storage servers **1906**. The parts may be configured such that if access to a certain number of parts is lost, the data object may nevertheless be reconstructible from the remaining parts that remain accessible.

To enable efficient transfer of data between the request processing subsystem **1902** and the data storage servers **1906** and/or generally to enable quick processing of requests, the request processing subsystem **1902** may include one or more databases that enable the location of data among the data storage servers **1906**. For example, the request processing subsystem **1902** may operate a key value store that serves to associate identifiers of data objects with locations among the data storage servers **1906** for accessing data of the data objects.

FIG. **20** illustrates aspects of an example environment **2000** for implementing aspects in accordance with various embodiments. As will be appreciated, although a web-based environment is used for purposes of explanation, different environments may be used, as appropriate, to implement various embodiments. The environment includes an electronic client device **2002**, which can include any appropriate device operable to send and/or receive requests, messages, or information over an appropriate network **2004** and, in some embodiments, convey information back to a user of the device. Examples of such client devices include personal computers, cell phones, handheld messaging devices, laptop computers, tablet computers, set-top boxes, personal data assistants, embedded computer systems, electronic book readers, and the like. The network can include any appropriate network, including an intranet, the Internet, a cellular network, a local area network, a satellite network or any other such network and/or combination thereof. Components used for such a system can depend at least in part upon the type of network and/or environment selected. Protocols and components for communicating via such a network are well known and will not be discussed herein in detail. Communication over the network can be enabled by wired or wireless connections and combinations thereof. In this example, the network includes the Internet, as the environment includes a web server **2006** for receiving requests and serving content in response thereto, although for other networks an alternative device serving a similar purpose could be used as would be apparent to one of ordinary skill in the art.

The illustrative environment includes at least one application server **2008** and a data store **2010**. It should be understood that there can be several application servers, layers or other elements, processes or components, which may be chained or otherwise configured, which can interact to perform tasks such as obtaining data from an appropriate data store. Servers, as used herein, may be implemented in various ways, such as hardware devices or virtual computer systems. In some contexts, servers may refer to a programming module being executed on a computer system. As used herein, unless otherwise stated or clear from context, the term "data store" refers to any device or combination of devices capable of storing, accessing and retrieving data, which may include any combination and number of data servers, databases, data storage devices and data storage media, in any standard, distributed, virtual or clustered environment. The application server can include any appropriate hardware, software and firmware for integrating with the data store as needed to execute aspects of one or more applications for the client device, handling some or all of the data access and business logic for an application. The application server may provide access control services in cooperation with the data store and is able to generate content including, but not limited to, text, graphics, audio, video and/or other content usable to be provided to the user, which may be served to the user by the web server in the form of HyperText Markup Language ("HTML"), Extensible Markup Language ("XML"), JavaScript, Cascading Style Sheets ("CSS") or another appropriate client-side structured language. Content transferred to a client device may be processed by the client device to provide the content in one or more forms including, but not limited to, forms that are perceptible to the user audibly, visually and/or through other senses including touch, taste, and/or smell. The handling of all requests and responses, as well as the delivery of content between the client device **2002** and the application server **2008**, can be handled by the web server using PHP: Hypertext Preprocessor ("PHP"), Python, Ruby, Perl, Java, HTML, XML or another appropriate server-side structured language in this example. It should be understood that the web and application servers are not required and are merely example components, as structured code discussed herein can be executed on any appropriate device or host machine as discussed elsewhere herein. Further, operations described herein as being performed by a single device may, unless otherwise clear from context, be performed collectively by multiple devices, which may form a distributed and/or virtual system.

The data store **2010** can include several separate data tables, databases, data documents, dynamic data storage schemes and/or other data storage mechanisms and media for storing data relating to a particular aspect of the present disclosure. For example, the data store illustrated may include mechanisms for storing production data **2012** and user information **2016**, which can be used to serve content for the production side. The data store also is shown to include a mechanism for storing log data **2014**, which can be used for reporting, analysis or other such purposes. It should be understood that there can be many other aspects that may need to be stored in the data store, such as page image information and access rights information, which can be stored in any of the above listed mechanisms as appropriate or in additional mechanisms in the data store **2010**. The data store **2010** is operable, through logic associated therewith, to receive instructions from the application server **2008** and obtain, update or otherwise process data in response thereto. The application server **2008** may provide static, dynamic, or a combination of static and dynamic data in response to the received instructions. Dynamic data, such as data used in web logs (blogs), shopping applications, news services and other such applications may be generated by server-side structured languages as described herein or may be provided by a content management system ("CMS") operating on, or under the control of, the application server. In one example, a user, through a device operated by the user, might submit a search request for a certain type of item. In this case, the data store might access the user information to verify the identity of the user and can access the catalog detail information to obtain information about items of that type. The information then can be returned to the user, such as in a results listing on a web page that the user is able to view via a browser on the user device **2002**. Information for a particular item of interest can be viewed in a dedicated page or window of the browser. It should be noted, however, that embodiments of the present disclosure are not necessarily limited to the context of web pages, but may be more generally applicable to processing requests in general, where the requests are not necessarily requests for content.

Each server typically will include an operating system that provides executable program instructions for the general administration and operation of that server and typically will include a computer-readable storage medium (e.g., a hard disk, random access memory, read only memory, etc.) storing instructions that, when executed by a processor of the server, allow the server to perform its intended functions. Suitable implementations for the operating system and general functionality of the servers are known or commercially available and are readily implemented by persons having ordinary skill in the art, particularly in light of the disclosure herein.

The environment, in one embodiment, is a distributed and/or virtual computing environment utilizing several computer systems and components that are interconnected via communication links, using one or more computer networks or direct connections. However, it will be appreciated by those of ordinary skill in the art that such a system could operate equally well in a system having fewer or a greater number of components than are illustrated in FIG. **20**. Thus, the depiction of the system **2000** in FIG. **20** should be taken as being illustrative in nature and not limiting to the scope of the disclosure.

The various embodiments further can be implemented in a wide variety of operating environments, which in some cases can include one or more user computers, computing devices or processing devices which can be used to operate any of a number of applications. User or client devices can include any of a number of general purpose personal computers, such as desktop, laptop or tablet computers running a standard operating system, as well as cellular, wireless and handheld devices running mobile software and capable of supporting a number of networking and messaging protocols. Such a system also can include a number of workstations running any of a variety of commercially-available operating systems and other known applications for purposes such as development and database management. These devices also can include other electronic devices, such as dummy terminals, thin-clients, gaming systems and other devices capable of communicating via a network. These devices also can include virtual devices such as virtual machines, hypervisors and other virtual devices capable of communicating via a network.

Various embodiments of the present disclosure utilize at least one network that would be familiar to those skilled in the art for supporting communications using any of a variety of commercially-available protocols, such as Transmission Control Protocol/Internet Protocol ("TCP/IP"), User Datagram Protocol ("UDP"), protocols operating in various layers of the Open System Interconnection ("OSI") model, File Transfer Protocol ("FTP"), Universal Plug and Play ("UpnP"), Network File System ("NFS"), Common Internet File System ("CIFS") and AppleTalk. The network can be, for example, a local area network, a wide-area network, a virtual private network, the Internet, an intranet, an extranet, a public switched telephone network, an infrared network, a wireless network, a satellite network, and any combination thereof.

In embodiments utilizing a web server, the web server can run any of a variety of server or mid-tier applications, including Hypertext Transfer Protocol ("HTTP") servers, FTP servers, Common Gateway Interface ("CGI") servers, data servers, Java servers, Apache servers, and business application servers. The server(s) also may be capable of executing programs or scripts in response to requests from user devices, such as by executing one or more web applications that may be implemented as one or more scripts or programs written in any programming language, such as Java®, C, C# or C++, or any scripting language, such as

Ruby, PHP, Perl, Python or TCL, as well as combinations thereof. The server(s) may also include database servers, including without limitation those commercially available from Oracle®, Microsoft®, Sybase® and IBM® as well as open-source servers such as MySQL, Postgres, SQLite, MongoDB, and any other server capable of storing, retrieving, and accessing structured or unstructured data. Database servers may include table-based servers, document-based servers, unstructured servers, relational servers, non-relational servers or combinations of these and/or other database servers.

The environment can include a variety of data stores and other memory and storage media as discussed above. These can reside in a variety of locations, such as on a storage medium local to (and/or resident in) one or more of the computers or remote from any or all of the computers across the network. In a particular set of embodiments, the information may reside in a storage-area network ("SAN") familiar to those skilled in the art. Similarly, any necessary files for performing the functions attributed to the computers, servers or other network devices may be stored locally and/or remotely, as appropriate. Where a system includes computerized devices, each such device can include hardware elements that may be electrically coupled via a bus, the elements including, for example, at least one central processing unit ("CPU" or "processor"), at least one input device (e.g., a mouse, keyboard, controller, touch screen or keypad) and at least one output device (e.g., a display device, printer or speaker). Such a system may also include one or more storage devices, such as disk drives, optical storage devices and solid-state storage devices such as random access memory ("RAM") or read-only memory ("ROM"), as well as removable media devices, memory cards, flash cards, etc.

Such devices also can include a computer-readable storage media reader, a communications device (e.g., a modem, a network card (wireless or wired), an infrared communication device, etc.), and working memory as described above. The computer-readable storage media reader can be connected with, or configured to receive, a computer-readable storage medium, representing remote, local, fixed, and/or removable storage devices as well as storage media for temporarily and/or more permanently containing, storing, transmitting, and retrieving computer-readable information. The system and various devices also typically will include a number of software applications, modules, services or other elements located within at least one working memory device, including an operating system and application programs, such as a client application or web browser. It should be appreciated that alternate embodiments may have numerous variations from that described above. For example, customized hardware might also be used and/or particular elements might be implemented in hardware, software (including portable software, such as applets) or both. Further, connection to other computing devices such as network input/output devices may be employed.

Storage media and computer readable media for containing code, or portions of code, can include any appropriate media known or used in the art, including storage media and communication media, such as, but not limited to, volatile and non-volatile, removable and non-removable media implemented in any method or technology for storage and/or transmission of information such as computer readable instructions, data structures, program modules or other data, including RAM, ROM, Electrically Erasable Programmable Read-Only Memory ("EEPROM"), flash memory or other memory technology, Compact Disc Read-Only Memory ("CD-ROM"), digital versatile disk (DVD) or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices or any other medium which can be used to store the desired information and which can be accessed by the system device. Based on the disclosure and teachings provided herein, a person of ordinary skill in the art will appreciate other ways and/or methods to implement the various embodiments.

The specification and drawings are, accordingly, to be regarded in an illustrative rather than a restrictive sense. It will, however, be evident that various modifications and changes may be made thereunto without departing from the broader spirit and scope of the invention as set forth in the claims.

Other variations are within the spirit of the present disclosure. Thus, while the disclosed techniques are susceptible to various modifications and alternative constructions, certain illustrated embodiments thereof are shown in the drawings and have been described above in detail. It should be understood, however, that there is no intention to limit the invention to the specific form or forms disclosed, but on the contrary, the intention is to cover all modifications, alternative constructions and equivalents falling within the spirit and scope of the invention, as defined in the appended claims.

The use of the terms "a" and "an" and "the" and similar referents in the context of describing the disclosed embodiments (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. The terms "comprising," "having," "including" and "containing" are to be construed as open-ended terms (i.e., meaning "including, but not limited to,") unless otherwise noted. The term "connected," when unmodified and referring to physical connections, is to be construed as partly or wholly contained within, attached to or joined together, even if there is something intervening. Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein and each separate value is incorporated into the specification as if it were individually recited herein. The use of the term "set" (e.g., "a set of items") or "subset" unless otherwise noted or contradicted by context, is to be construed as a nonempty collection comprising one or more members. Further, unless otherwise noted or contradicted by context, the term "subset" of a corresponding set does not necessarily denote a proper subset of the corresponding set, but the subset and the corresponding set may be equal.

Conjunctive language, such as phrases of the form "at least one of A, B, and C," or "at least one of A, B and C," unless specifically stated otherwise or otherwise clearly contradicted by context, is otherwise understood with the context as used in general to present that an item, term, etc., may be either A or B or C, or any nonempty subset of the set of A and B and C. For instance, in the illustrative example of a set having three members, the conjunctive phrases "at least one of A, B, and C" and "at least one of A, B and C" refer to any of the following sets: {A}, {B}, {C}, {A, B}, {A, C}, {B, C}, {A, B, C}. Thus, such conjunctive language is not generally intended to imply that certain embodiments require at least one of A, at least one of B and at least one of C each to be present.

Operations of processes described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. Processes described herein (or variations and/or combinations thereof) may be performed under the control of one or more computer systems configured with executable instructions and may be implemented as code (e.g., executable instructions, one or more computer programs or one or more applications) executing collectively on one or more processors, by hardware or combinations thereof. The code may be stored on a computer-readable storage medium, for example, in the form of a computer program comprising a plurality of instructions executable by one or more processors. The computer-readable storage medium may be non-transitory.

The use of any and all examples, or exemplary language (e.g., "such as") provided herein, is intended merely to better illuminate embodiments of the invention and does not pose a limitation on the scope of the invention unless otherwise claimed. No language in the specification should be construed as indicating any non-claimed element as essential to the practice of the invention.

Embodiments of this disclosure are described herein, including the best mode known to the inventors for carrying out the invention. Variations of those embodiments may become apparent to those of ordinary skill in the art upon reading the foregoing description. The inventors expect skilled artisans to employ such variations as appropriate and the inventors intend for embodiments of the present disclosure to be practiced otherwise than as specifically described herein. Accordingly, the scope of the present disclosure includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the scope of the present disclosure unless otherwise indicated herein or otherwise clearly contradicted by context.

All references, including publications, patent applications, and patents, cited herein are hereby incorporated by reference to the same extent as if each reference were individually and specifically indicated to be incorporated by reference and were set forth in its entirety herein.

What is claimed is:

1. A computer-implemented method, comprising:

processing archives to be stored on a set of volumes, by at least:

applying a redundancy code to the archives to generate a plurality of shards, a first subset of which include original data of the archives, and a second subset of which includes encoded shards derived from the original data;

layering the plurality of shards into a plurality of groups such that:

a first group of the plurality of groups includes a portion of the first subset of shards and a portion of the second portion of shards; and

a second group that includes at least a portion of a remainder of the plurality of shards not in the first group;

associating the first group with a first subset of the set of volumes, the first subset of the set of volumes being associated with a first data storage facility of a plurality of data storage facilities;

associating the second group with at least a second subset of the set of volumes, the second subset of the set of volumes being associated with a second data storage facility of the plurality of data storage facilities; and

applying a redundancy code to the first group to generate additional shards;

adding the additional shards to the first group; and

storing the first group, including the additional shards, and the second group on the first subset of the set of volumes and the second subset of the set of volumes, respectively, to enable regeneration of any shard in the first group using only shards stored in the first data storage facility.

2. The computer-implemented method of claim **1**, wherein contents of the first group are modified so as to replace a subset of the shards of the first group with the additional shards.

3. The computer-implemented method of claim **1**, wherein contents of the second group are modified so as to add shards generated from the second group to the second group.

4. The computer-implemented method of claim **1**, further comprising, after receiving information that one or more shards of the first group are unavailable, regenerating the unavailable shards using other shards in the first group.

5. A system, comprising:

at least one computing device that implements one or more services, wherein the one or more services at least:

group a plurality of redundancy coded shards associated with archives into a plurality of groups such that:

a first group of the plurality of groups includes a first subset of the shards to be stored on a first data storage entity, and

a second group of the plurality of groups includes a second subset of the shards to be stored on at least a second data storage entity; and

process the first group of shards by applying a redundancy code to the shards so as to generate additional shards; and

store the first group of shards with the additional shards on the first data storage entity to enable the first data storage entity to rebuild any unavailable shards of the first group of shards without the use of any of the second group of shards.

6. The system of claim **5**, wherein the one or more services further generate the plurality of redundancy coded shards in response to receiving the archives.

7. The system of claim **5**, wherein the first subset of the shards includes at least one shard containing original data of the archives.

8. The system of claim **5**, wherein the first group includes a plurality of subgroups, each subgroup of which is encoded to be capable of regenerating a quantity of shards of the same subgroup.

9. The system of claim **5**, wherein the first data storage entity and the second data storage entity are a first data storage facility and a second data storage facility, respectively, of a plurality of data storage facilities.

10. The system of claim **9**, wherein the plurality of redundancy coded shards are distributed across each data storage facility of the plurality of data storage facilities.

11. The system of claim **5**, wherein the one or more services further analyze one or more failure characteristics of the first data storage entity so as to determine a quantity of the additional shards to generate.

12. The system of claim **5**, wherein the redundancy code is the same redundancy code used to generate the redundancy coded shards.

13. A non-transitory computer-readable storage medium having stored thereon executable instructions that, upon execution by one or more processors of a computer system, cause the computer system to at least:

layer a plurality of redundancy coded shards associated with archives into a plurality of groups, of which a first group includes a first subset of the shards to be stored on a first data storage entity, and of which a second group includes a second subset of the shards to be stored on a second data storage entity;

process, based at least in part on the shards of the first group of shards, the first group of shards to generate additional shards;

add the additional shards to the first group;

store the first group of shards including the additional shards on the first data storage entity, and the second group of shards on the second data storage entity, such that the first data storage entity is capable of regenerating unavailable shards of the first group using only the first group of shards including the additional shards.

14. The non-transitory computer-readable storage medium of claim **13**, wherein the instructions further comprise instructions that, upon execution by the one or more processors, cause the computer system to generate the redundancy coded shards in response to receiving the archives.

15. The non-transitory computer-readable storage medium of claim **14**, wherein the instructions further comprise instructions that, upon execution by the one or more processors, cause the computer system to process the first group of shards such that any shard of the first group, including the additional shards, is capable of being used to regenerate any shard of the first group and the second group.

16. The non-transitory computer-readable storage medium of claim **13**, wherein the redundancy code applied to the shards is the same redundancy code used to generate the redundancy coded shards from original data of the archives.

17. The non-transitory computer-readable storage medium of claim **13**, wherein the redundancy code is an erasure code.

18. The non-transitory computer-readable storage medium of claim **13**, wherein a subset of the plurality of redundancy coded shards includes original data of the archives.

19. The non-transitory computer-readable storage medium of claim **18**, wherein the at least one shard of the subset of the plurality of redundancy coded shards includes the original data of a plurality of the archives.

20. The non-transitory computer-readable storage medium of claim **13**, wherein the instructions further comprise instructions that, upon execution by the one or more processors, cause the computer system to analyze failure characteristics of the first data storage entity so as to determine a quantity of the additional shards to generate.

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