US012393551B2

(12) **United States Patent**
Deng et al.

(10) **Patent No.: US 12,393,551 B2**
(45) **Date of Patent: *Aug. 19, 2025**

(54) **SELECTING SUBSCRIBING COMPUTING NODE TO EXECUTE DATA STORAGE PLAN FOR DATA SHARD**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **18/600,583**

(22) Filed: **Mar. 8, 2024**

(65) **Prior Publication Data**

US 2024/0211440 A1 Jun. 27, 2024

Related U.S. Application Data

(63) Continuation of application No. 17/578,644, filed on Jan. 19, 2022, now Pat. No. 12,019,588.

(51) **Int. Cl.**
G06F 7/00 (2006.01)
G06F 16/17 (2019.01)
(Continued)

(52) **U.S. Cl.**
CPC ***G06F 16/172*** (2019.01); ***G06F 16/1734*** (2019.01); ***G06F 16/182*** (2019.01)

(58) **Field of Classification Search**
CPC .. G06F 16/172; G06F 16/1734; G06F 16/182; G06F 16/24552; G06F 16/278;
(Continued)

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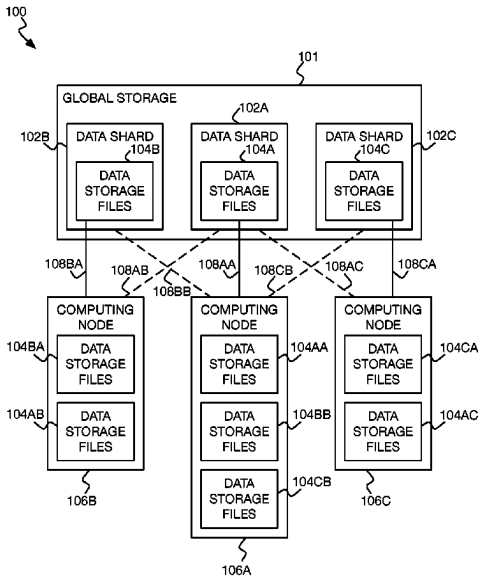
(57) **ABSTRACT**

A distributed database system maintains a database including a data shard for which a primary computing node is responsible. The primary computing node identifies a data storage plan for the data shard. The plan identifies a file subset of data storage files of the shard to be merged into a larger data storage file, and a node subset of computing nodes of the system that subscribe to the data shard. The primary node identifies which computing nodes of the node subset each have sufficient computing resources to execute the plan, as candidate computing nodes. The primary node identifies which files of the file subset each candidate computing node locally caches. The primary node selects one candidate computing node to execute the plan, based on the files of the file subset that each candidate computing node locally caches. The primary node causes the selected candidate computing node to execute the plan.

16 Claims, 6 Drawing Sheets



(51) **Int. Cl.**
G06F 16/172 (2019.01)
G06F 16/182 (2019.01)

(58) **Field of Classification Search**
CPC G06F 16/2471; H04L 67/109; H04L 67/1097
USPC 705/7.12, 7.13, 7.22, 7.25, 7.29, 7.31, 705/7.35, 28; 707/688, 705, 737, 769, 707/770, 802, 649, 661, 667, 741, 752, 707/823, 999.01, 999.204; 709/202, 203, 709/213, 219, 223, 224, 225, 226
See application file for complete search history.

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FIG 1

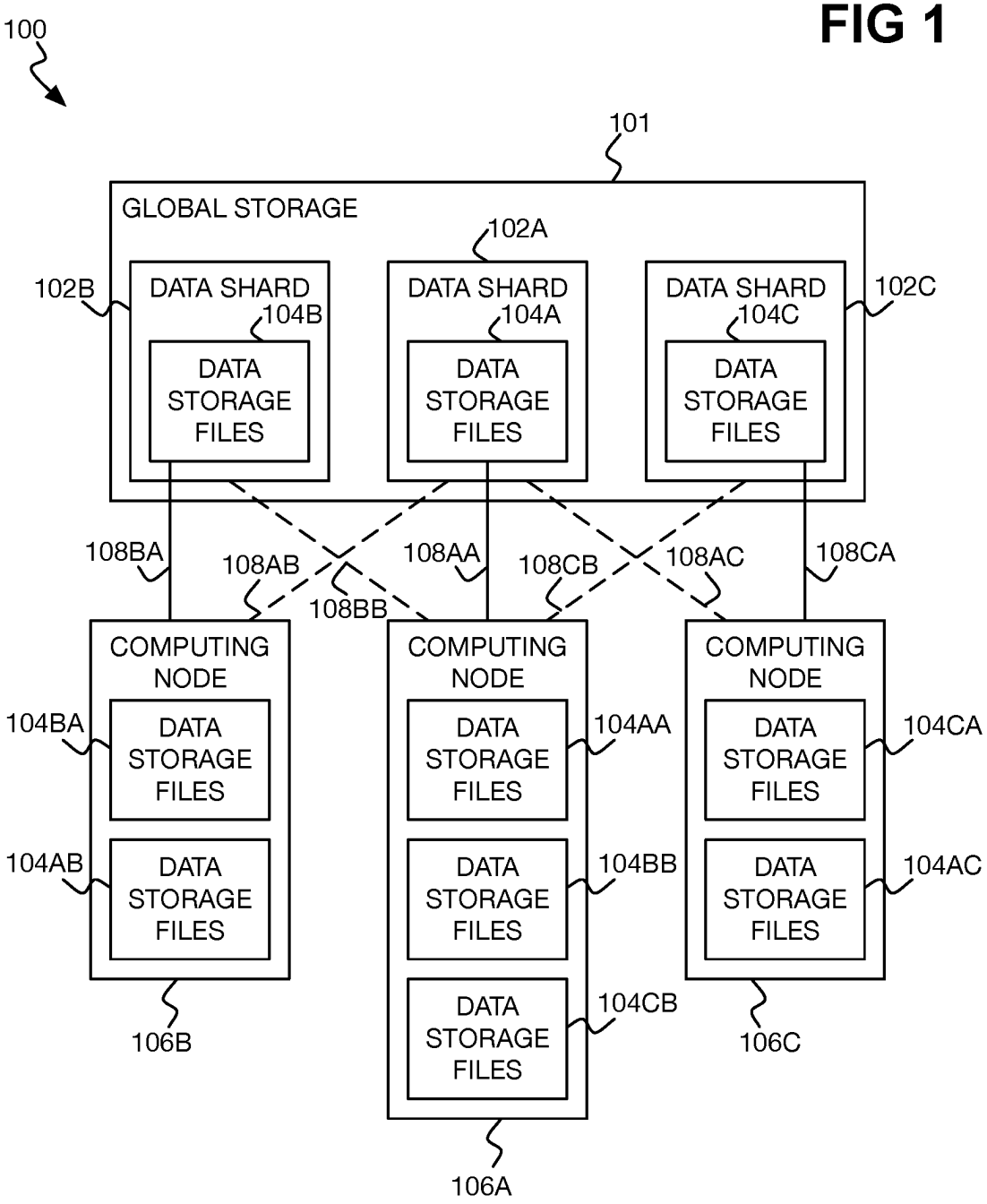

100
101
GLOBAL STORAGE
102A
102B
DATA SHARD
104B
DATA STORAGE FILES
DATA SHARD
104A
DATA STORAGE FILES
DATA SHARD
104C
DATA STORAGE FILES
102C
108BA
108AB
108BB
108AA
108CB
108AC
108CA
COMPUTING NODE
104BA
DATA STORAGE FILES
104AB
DATA STORAGE FILES
106B
COMPUTING NODE
DATA STORAGE FILES
104AA
DATA STORAGE FILES
104BB
DATA STORAGE FILES
104CB
106A
COMPUTING NODE
DATA STORAGE FILES
104CA
DATA STORAGE FILES
104AC
106C

FIG 2

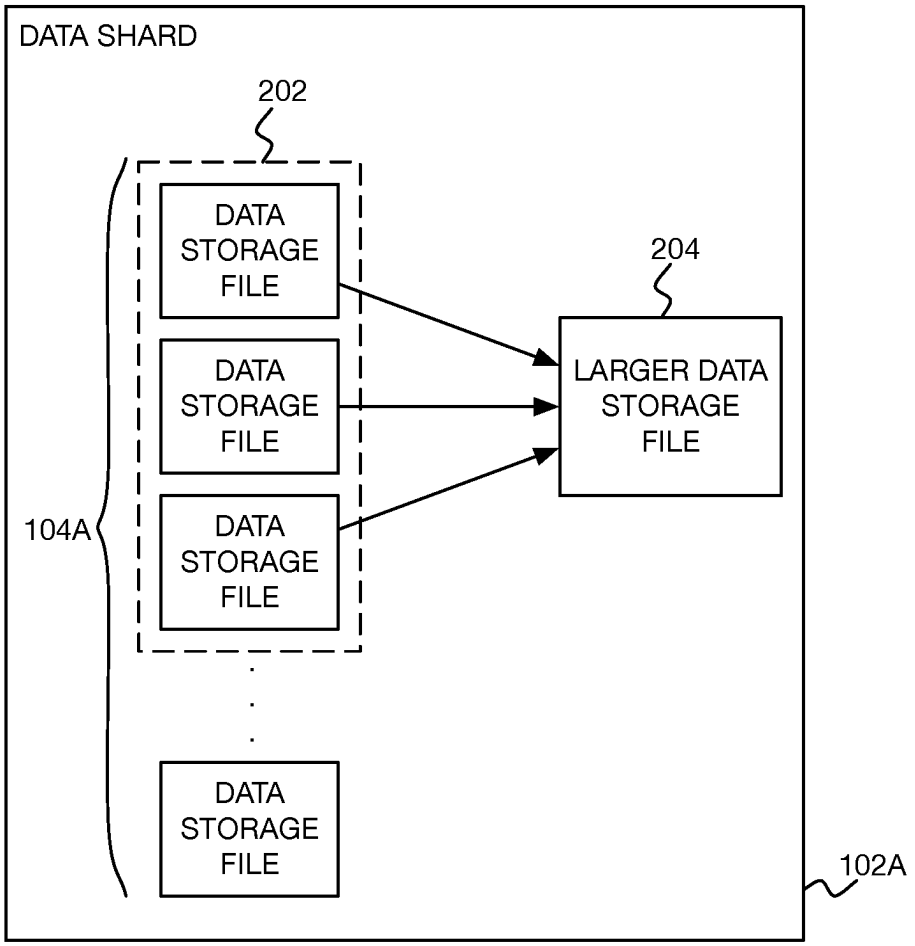

DATA SHARD
202
DATA STORAGE FILE
DATA STORAGE FILE
DATA STORAGE FILE
DATA STORAGE FILE
204
LARGER DATA STORAGE FILE
104A
102A

FIG 3

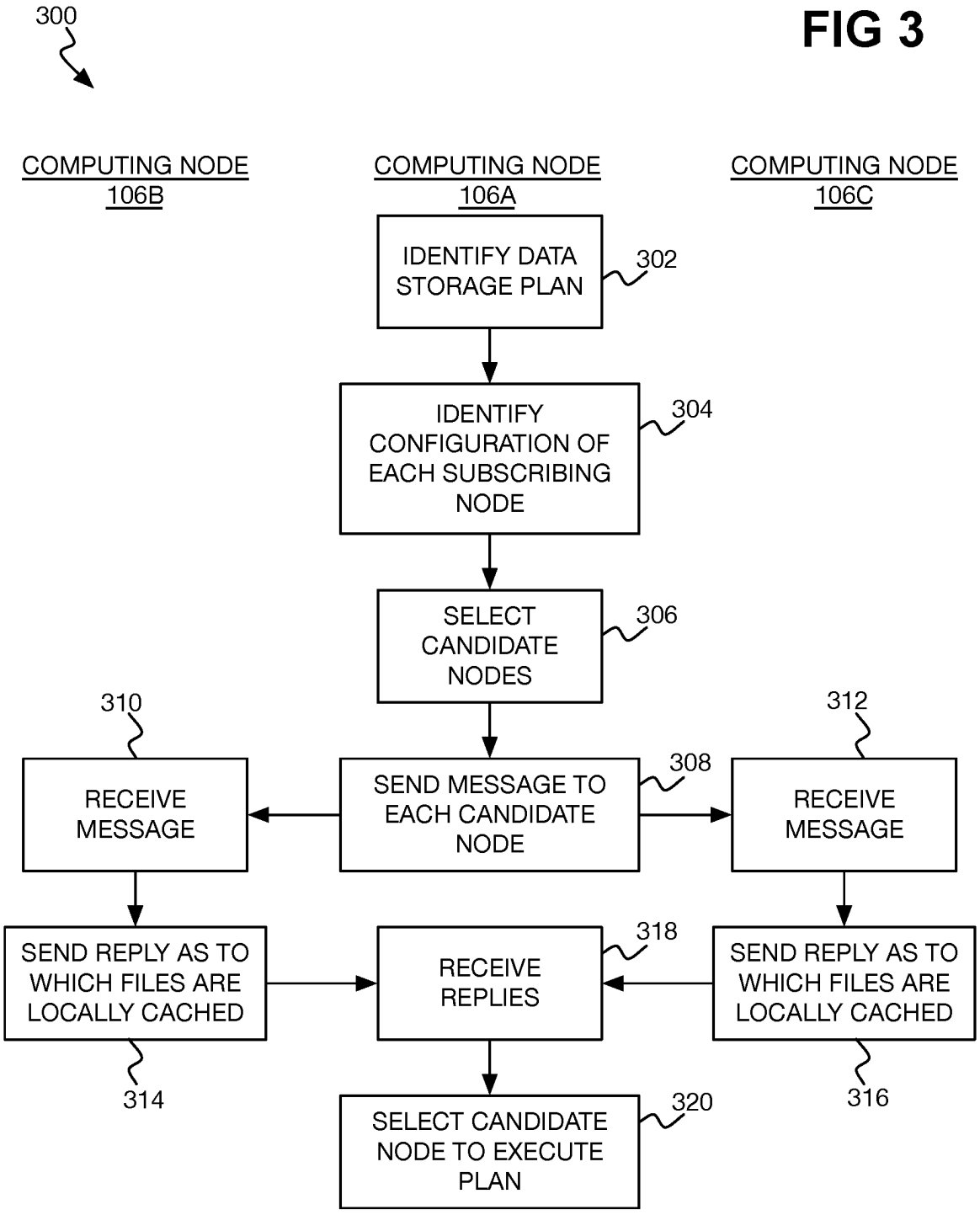

300
COMPUTING NODE 106B
COMPUTING NODE 106A
COMPUTING NODE 106C
IDENTIFY DATA STORAGE PLAN
302
IDENTIFY CONFIGURATION OF EACH SUBSCRIBING NODE
304
SELECT CANDIDATE NODES
306
310
312
RECEIVE MESSAGE
SEND MESSAGE TO EACH CANDIDATE NODE
308
RECEIVE MESSAGE
SEND REPLY AS TO WHICH FILES ARE LOCALLY CACHED
RECEIVE REPLIES
318
SEND REPLY AS TO WHICH FILES ARE LOCALLY CACHED
314
316
SELECT CANDIDATE NODE TO EXECUTE PLAN
320

FIG 4

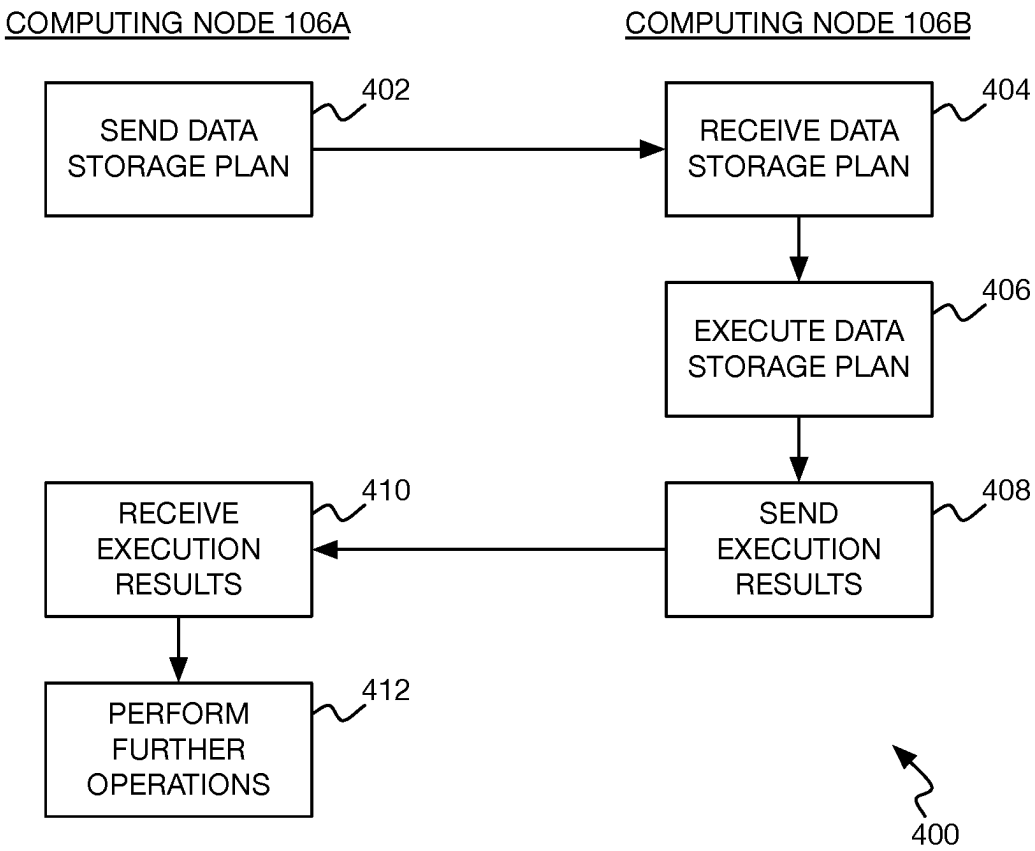

COMPUTING NODE 106A
COMPUTING NODE 106B
SEND DATA STORAGE PLAN
402
RECEIVE DATA STORAGE PLAN
404
EXECUTE DATA STORAGE PLAN
406
RECEIVE EXECUTION RESULTS
410
SEND EXECUTION RESULTS
408
PERFORM FURTHER OPERATIONS
412
400

FIG 5

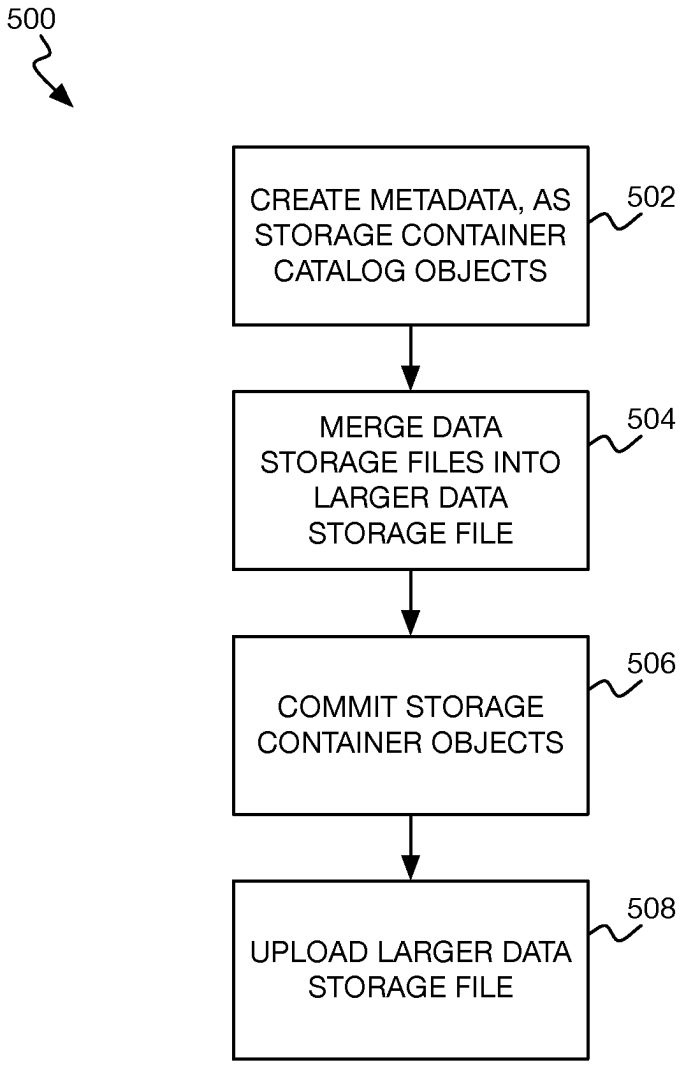
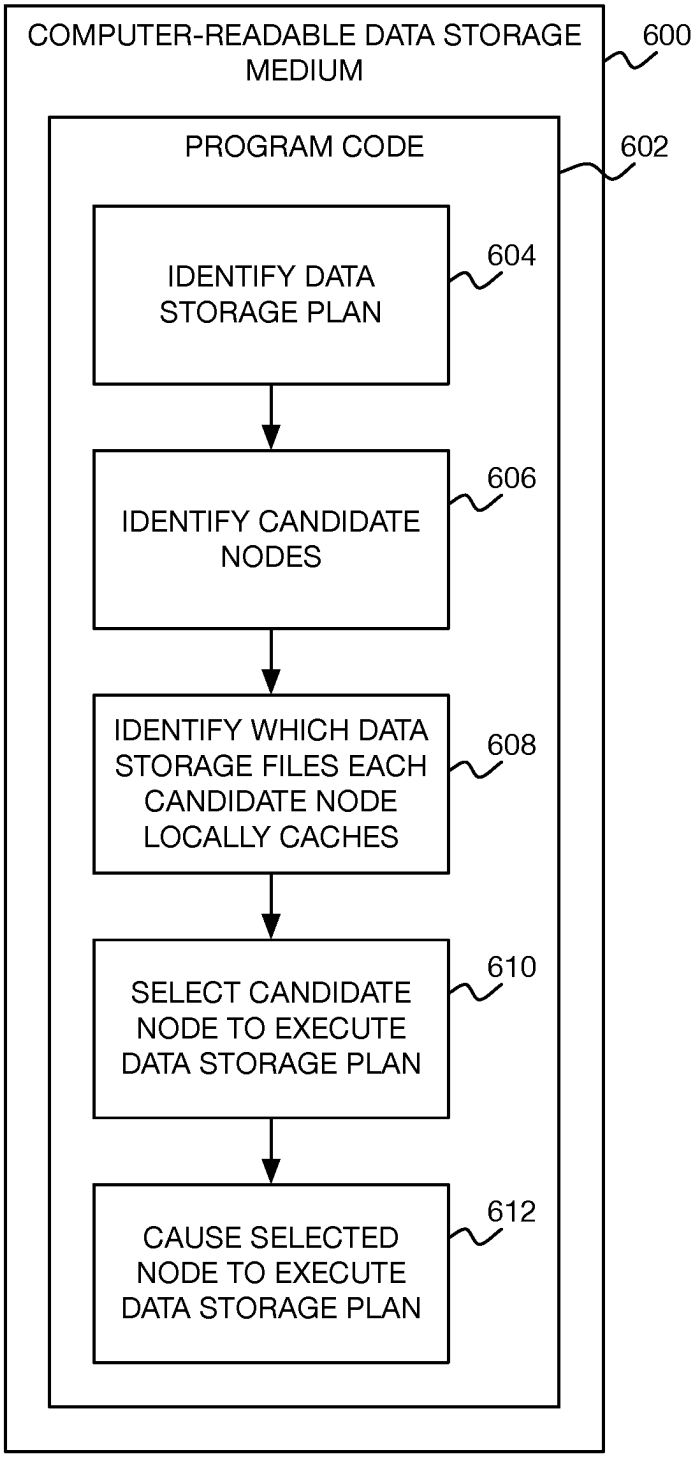

500
CREATE METADATA, AS STORAGE CONTAINER CATALOG OBJECTS
502
MERGE DATA STORAGE FILES INTO LARGER DATA STORAGE FILE
504
COMMIT STORAGE CONTAINER OBJECTS
506
UPLOAD LARGER DATA STORAGE FILE
508

FIG 6


COMPUTER-READABLE DATA STORAGE MEDIUM
600
PROGRAM CODE
602
IDENTIFY DATA STORAGE PLAN
604
IDENTIFY CANDIDATE NODES
606
IDENTIFY WHICH DATA STORAGE FILES EACH CANDIDATE NODE LOCALLY CACHES
608
SELECT CANDIDATE NODE TO EXECUTE DATA STORAGE PLAN
610
CAUSE SELECTED NODE TO EXECUTE DATA STORAGE PLAN
612

SELECTING SUBSCRIBING COMPUTING NODE TO EXECUTE DATA STORAGE PLAN FOR DATA SHARD

BACKGROUND

Data is the lifeblood of many entities like business and governmental organizations, as well as individual users. Large-scale storage of data in an organized manner is commonly achieved using databases. Databases are collections of information that are organized for easy access, management, and updating. Database systems, which may also be referred to as database management systems, are implemented by computing systems and used to create and manage databases.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram of an example distributed database system.

FIG. **2** is a diagram of example execution of a data storage plan for a data shard of a distributed database system.

FIG. **3** is a flowchart of an example method for selecting a subscribing computing node of a data shard of a distributed database system to execute a data storage plan for the data shard.

FIG. **4** is a flowchart of an example method for execution of a data storage plan for a data shard of a distributed database system by a subscribing computing node other than a primary computing node responsible for the data shard.

FIG. **5** is a flowchart of an example method for executing a data storage plan for a data shard of a distributed database system, in detail.

FIG. **6** is a diagram of an example non-transitory computer-readable data storage medium.

DETAILED DESCRIPTION

As noted in the background, databases created and managed by database systems store data. A database system may be a distributed database system that includes a global storage storing data shards of a database, where each data shard stores data storage files that include the data of the database. The data storage files stored by each data shard are different. That is, the data of the database stored in one data shard is not stored in any other data shard.

A distributed data system further includes computing nodes that have shared access to the global storage. Each computing node is responsible for maintaining a data shard, and each data shard is maintained by one computing node. The computing node that maintains a data shard is referred to as the primary computing node for the data shard. The primary computing node is considered as subscribing to the data shard for which it is responsible, and may locally cache the data storage files of the shard.

Other computing nodes may also subscribe to a data shard, in addition to the primary computing node. These other computing nodes similarly may locally cache the data storage files of the data shard. Therefore, each data shard has a subset of computing nodes that subscribe to the data shard and that can locally cache the data storage files of the shard. The subset of nodes includes at least the primary computing nodes and may also include one or more other of the computing nodes.

In a distributed database system, queries are performed against the database in a distributed manner by the computing nodes of the system. A query plan may be generated for a query. The query plan is executed to perform the query. That is, executing the query plan returns data of the database that satisfies the query.

As queries are performed, the data stored at each data shard may become fragmented over multiple data storage files. Therefore, at times the primary computing node for a data shard may generate a data storage plan to merge a subset of the data storage files into a single larger file for efficiency. The data storage plan is not to be confused with a query plan that is generated for and executed to perform a query. In general, the primary computing node for a data shard executes the data storage plan for this shard.

However, the primary computing node may not be the optimal subscribing computing node to execute the data storage plan. For example, the primary computing node may be currently processing queries, and therefore have insufficient computing resources to execute the plan, resulting in inefficient plan execution. As another example, the primary computing node may not be the subscribing computing node that maximally locally caches the subset of data storage files subject to the data storage plan, by number of files and/or by file size, which also results in inefficient plan execution.

Techniques described herein ameliorate these and other issues, by selecting the subscribing computing node of a data shard that is most efficiently able to execute a data storage plan for the data shard. The subscribing computing nodes of the data shard that have sufficient computing resources to execute the data storage plan are identified as candidate computing nodes. Which data storage files subject to the data storage plan each candidate computing node locally caches are identified, on which basis one of the selected candidate computing nodes is selected to execute the plan.

The computing node that executes a data storage plan for a data shard may thus be a computing node that subscribes to the shard other than the primary computing node for the data shard. The primary computing node identifies (e.g., generates) the data storage plan, and selects which subscribing computing node is to execute the data storage plan. If the selected subscribing computing node is not the primary computing node, the primary computing node provides the data storage plan to the selected node for execution.

FIG. **1** shows an example distributed database system **100**. The distributed database system **100** in one implementation may be the Vertica database management system available from Vertica Systems, of Cambridge, Mass., which is a subsidiary of Micro Focus International plc, of Newbury, U.K. The distributed database system **100** includes a global storage **101**, which may be implemented as a storage-array network (SAN) of storage devices like hard disk drives, or in another manner.

The global storage **101** stores data shards **102**A, **102**B, and **102**C, collectively referred to as the data shards **102** of a database. In the example of FIG. **1**, there are three data shards **102**, but more generally there is at least one data shard **102** and typically tens if not hundreds or more data shards **102**. The data shards **102**A, **102**B, and **102**C respectively store data storage files **104**A, **104**B, and **104**C, which are collectively referred to as the data storage files **104**.

More generally, each data shard **102** stores corresponding data storage files **104**. That is, the data storage files **104**A includes multiple such files, such as thousands, tens of thousands, or more, as do the data storage files **104**B and the data storage files **104**C. The data of the database maintained by the distributed database system **100** are stored in the data storage files **104** of the data shards **102**. The data stored at each data shard **102** is not stored at any other data shard **102**.

The distributed database system **100** also includes computing nodes **106**A, **106**B, and **106**C, collectively referred to as the computing nodes **106**. In the example of FIG. **1**, there are three computing nodes **106**, but more generally there is at least one computing node **106** and typically tens if not hundreds or more computing nodes **106**. In the example, the number of computing nodes **106** is equal to the number of data shards **102**, but in general, the number of computing nodes **106** may be less than, equal to, or greater than the number of data shards **102**.

Each computing node **106** can be a computing device, such as a server computing device, having one or multiple processors, memory, and its own local storage devices such as hard disk drives and solid-state drives (SSDs), among other types of hardware. The local storage devices of each computing node **106** may not be accessible by the other computing nodes **106**. Each computing node **106** is communicatively coupled to the global storage **101**, such as over a network.

Each data shard **102** has a primary computing node **106** that is responsible for maintaining the data storage files **104** stored on that data shard **102**. In the example, the computing node **106**A is the primary computing node for the data shard **102**A responsible for maintaining the data storage files **104**A, per solid line **108**AA. Similarly, the computing node **106**B is the primary computing node for the data shard **102**B responsible for maintaining the data storage files **104**B per solid line **108**BA, and the computing node **106**C is the primary computing node for the data shard **102**C responsible for maintaining the data storage files **104**C per solid line **108**CA.

More generally, however, a computing node **106** may be the primary computing node for zero or more data shards **102**. For example, a computing node may be the primary computing node for more than one data shard **102**, or may not be the primary computing node for any data shard **102**. However, each data shard **102** has just one primary computing node **106**, even if that computing node **106** is the primary computing node for one or more other data shards **102**.

The primary computing node **106** for a data shard **102** is a subscribing computing node of that shard **102**. Each computing node **106** can also be a subscribing computing node of one or more shards **102** for which it is not the primary computing node. For example, the computing node **106**A also subscribes to the data shard **102**B per the dashed line **108**BB and to the data shard **102**C per the dashed line **108**CB. Similarly, the computing nodes **106**B and **106**C also subscribe to the data shard **102**A per the dashed lines **108**AB and **108**AC, respectively.

Each computing node can locally cache the data storage files **104** of each data shard **102** to which it subscribes. For example, the computing node **106**A locally caches data storage files **104**AA, **104**BB, and **104**CB, which are subsets of the data storage files **104**A, **104**B, and **104**C of the data shards **102**A, **102**B, and **102**C, respectively. The computing node **106**B locally caches data storage files **104**BA and **104**AB, which are subsets of the data storage files **104**B of the data shards **102**B and **102**A, respectively. The computing node **106**C locally caches data storage files **104**CA and **104**AC, which are subsets of the data storage files **104**C and **104**A of the data shards **102**C and **102**A, respectively.

Stated another way, the data shard **102**A has three subscribing computing nodes **106**A, **106**B, and **106**C that locally cache different subsets of the data storage files **104**A of the shard **102**A, as the data storage files **104**AA, **104**AB, and **104**AC, respectively. The data shard **102**B has two subscribing computing nodes **106**B and **106**A that locally cache different subsets of the data storage files **104**B of the shard **102**B, as the data storage files **104**BA and **104**BB, respectively. The data shard **102**C has two subscribing computing nodes **106**C and **106**A that locally cache different subsets of the data storage files **104**C of the shard **102**C, as the data storage files **104**CA and **104**CB, respectively.

A query can be executed in a distributed fashion against the data of the database stored in the data storage files **104** of the data shards **102** by the computing nodes **106** that subscribe to the data shards **102** storing the data subject to the query. As queries are executed, data of the database may be fragmented into ever-smaller data storage files **104** within the data shards **102**. Therefore, periodically the primary computing node **106** for each data shard **102** may generate a data storage plan to merge a subset of smaller data storage files **104** of the data shard **102** into a single larger data storage file **104** for efficiency purposes.

FIG. **2** shows example execution of a data storage plan for the data shard **102**A having the primary computing node **106**A. The data shard **102**A includes multiple data storage files **104**A, of which the data storage files **202** are identified for merger by the data storage plan generated by the computing node **106**A. The data storage files **202** are a subset of the data storage files **104**A, which may be referred to as a file subset in this respect. The file subset can include all the data storage files **104**A.

Upon execution of the data storage plan, by any subscribing computing node **106** of the data shard **102**A (i.e., not necessarily the primary computing node **106**A), the data storage files **202** are merged into a single larger data storage file **204**. The data storage file **204** replaces the data storage files **202** within the data shard **102**A. That is, the data storage file **204** is one of the data storage files **104**A of the data shard **102**A, and the individual data storage files **202** that the data storage file **204** replaces are deleted after merger into the storage file **204**.

FIG. **3** shows an example method **300** for selecting a subscribing computing node **106** of a data shard **102** to execute a data storage plan for the data shard **102**. The method **300** is described in relation to a data storage plan for the data shard **102**A having subscribing computing nodes **106**A, **106**B, and **106**C, of which the computing node **106**A is the primary computing node. The parts of the method **300** in the left, center, and right columns are respectively performed by the computing nodes **106**B, **106**A, and **106**C.

The primary computing node **106**A first identifies the data storage plan (**302**). The computing node **106**A may generate the data storage plan, for instance, or otherwise receive the data storage plan. The data storage plan identifies the subset of the data storage files **104**A that are subject to the data storage plan, which are the data storage files **202** in the example.

The data storage plan also identifies the subscribing computing nodes **106** of the data shard **102**A. The subscribing computing nodes **106** are a subset of all the computing nodes **106** of the distributed database system **100**, which may be referred to as a node subset in this respect. In the example, the subscribing computing nodes **106** of the data shard **102**A are the computing nodes **106**A, **106**B, and **106**C. The node subset can thus include all the computing nodes **106** of the distributed database system **100**.

The primary computing node **106**A identifies the configuration of each subscribing computing node **106** of the data shard **102**A, including itself (**304**). The configuration of a computing node **106** may be identified within a resource pool of the distributed database system **100**, and specifies the

current utilization of that computing node **106**. The current utilization may be measurable by processor, memory, and/or network utilization of the computing node **106**, for instance.

The primary computing node **106**A then selects candidate computing nodes **106** from the subscribing computing nodes **106** of the data shard **102**A, which may include itself (**306**). The primary computing node **106**A may select as one of the candidate computing nodes **106** each subscribing computing node **106** having a current utilization that satisfies an availability criterion. For instance, if a subscribing computing node **106** has processor utilization, memory utilization, and network utilization less than respective thresholds, the computing node **106** may be selected as a candidate computing node **106**. In the example, it is assumed that each subscribing computing node **106**A, **106**B, and **106**C is selected as a candidate computing node **106**.

In this way, the primary computing node **106**A identifies which subscribing computing nodes **106** of the data shard **102**A have sufficient computing resources to execute the data storage plan. The computing node **106**A then has to select which of these candidate computing nodes **106** is to actually execute the data storage plan. This selection is based on the data storage files **202** of the data shard **102**A subject to the data storage plan that each candidate computing node **106** locally caches. The primary computing node **106**A already knows the data storage files **104**AA of the data storage files **104**A that it locally caches, and thus can identify which of the data storage files **202** that the computing node **106**A locally caches.

To identify which of the data storage files **202** of the data shard **102**A subject to the data storage plan that the other candidate computing nodes **106**B and **106**C respectively locally cache, the primary computing node **106**A sends messages to these other candidate computing nodes **106**B and **106**C (**308**). Specifically, the computing node **106**A sends a message to the computing node **106**B to receive information regarding which of the data storage files **202** are part of the data storage files **104**AB locally cached by the computing node **106**B, which receives this message (**310**). The computing node **106**A likewise sends a message to the computing node **106**C to receive information regarding which of the data storage files **202** are part of the data storage files **104**AC locally cached by the node **106**C, which receives this message (**312**).

The candidate computing node **106**B sends in reply the requested information regarding which of the data storage files **202** of the data shard **102**A that are subject to the data storage plan the computing node **106**B locally caches (**314**). Similarly, the candidate computing node **106**C sends in reply the requested information regarding which of the data storage files **202** of the data shard **102**A the computing node **106**C locally caches (**316**). The primary computing node **106**A thus receives these replies (**318**).

The information regarding which of the data storage files **202** of the data shard **102** that are subject to the data storage plan each candidate computing node **106** locally caches can include either or both of the following information. First, the information may include the number of the data storage files **202** that a candidate computing nodes **106** locally caches. Second, the information may include the size of the data storage files **202** that a candidate computing node **106** locally caches. For instance, the total size of the locally cached data storage files **202** may be provided by a candidate computing node **106**.

The primary computing node **106**A selects a candidate computing node **106** to execute the data storage plan based on which of the data storage files **202** of the data shard **102** that are subject to the data storage plan each candidate computing node **106** locally caches (**320**). In one implementation, the candidate computing node **106** locally caching the greatest number of the data storage files **202** is selected to execute the data storage plan. In another implementation, the candidate computing node **106** locally caching the largest size of the data storage files is selected to execute the data storage plan.

In a third implementation, the primary computing node **106**A may compute a score for each candidate computing node **106** based on both the number of and the size of the data storage files **202** that the candidate computing node **106** locally caches, and select the candidate computing node **106** having the highest score to execute the data storage plan. For example, the number of the data storage files **202** that a candidate computing node **106** locally caches may be divided by the total number of the data storage files **202**, and the resulting quotient normalized between 1 and 100. Likewise, the size of the data storage files **202** that the candidate computing node **106** locally caches may be divided by the size of all the data storage files **202**, and the resulting quotient normalized between 1 and 100.

In this example, the two quotients for each candidate computing node **106** may be added together or averaged to generate the score for the candidate computing node **106** in question. Before being added together or averaged, each quotient may be weighted by a respective weight. For example, the quotient pertaining to the number of the data storage files **202** that a candidate computing node **106** locally caches may be weighted higher or lower than the quotient pertaining to the size of the data storage files **202** that the candidate computing node **106** locally caches. In the former case, the number of the data storage files **202** that are locally cached contributes to the score for the candidate computing node **106** more than their size, whereas in the latter case, the size of the data storage files **202** that are locally cached contributes to the score more than their number.

If the primary computing node **106**A for the data shard **102**A is one of the candidate computing nodes **106**, then either the computing node **106**A or another candidate computing node **106** may be selected to execute the data storage plan. In the example, the candidate computing node **106**A, **106**B, or **106**C may thus be selected to execute the data storage plan. However, if the primary computing node **106**A were not one of the candidate computing nodes **106**, then the candidate computing node **106**B or **106**C is selected to execute the data storage plan.

FIG. **4** shows an example method **400** that is performed in the case in which the candidate computing node **106** that is selected to execute a data storage plan for a data shard **102** is not the primary computing node **106** for that shard **102**. The method **400** is described in relation to a data storage plan for the data shard **102**A having the primary computing node **106**A, where the subscribing computing node **106**B has been selected to execute the data storage plan. The parts of the method **300** in the left and right columns are respectively performed by the computing nodes **106**A and **106**B.

The primary computing node **106**A sends the data storage plan for execution to the selected computing node **106**B (**402**), which receives the data storage plan (**404**). The computing node **106**B then executes the data storage plan to merge the data storage files **202** of the data shard **102**A identified by the data storage plan into a single larger data storage file **204** (**406**). The computing node **106**B sends the results of data storage plan execution to the computing node **106**A (**408**), which receives the execution results (**410**). The

execution results may indicate whether or not execution of the data storage plan was successful, for instance, as well as metadata regarding the larger data storage file **204**.

The primary computing node **106**A may perform further operations regarding the data shard **102**A, based or depending on the data storage plan execution results (**412**). As one example, the primary computing node **106**A may transfer the larger data storage file **204** that was generated to other subscribing computing nodes **106** of the data shard **102**A besides the selected computing node **106** that executed the data storage plan. The data storage file **204** may be provided in a peer-to-peer manner, for instance.

FIG. **5** shows in detail an example method **500** for executing a data storage plan. The method **500** is described in relation to a data storage plan for the data shard **102**A. The primary computing node **106**A or another subscribing computing node **106**B or **106**C may perform the method **500**, depending on which subscribing computing node **106** was selected to execute the data storage plan. For instance, in the example of the method **400**, the computing node **106**B performs the method **500** in part **406**.

The method **500** includes creating metadata for the single larger data storage file **204** to be created upon merger of the data storage files **202** of the data shard **102**A that are subject to the data storage plan (**502**). The metadata may be created as storage container catalog objects that are stored within a database in the case in which the distributed database system **100** is the aforementioned Vertica database management system. The method **500** then includes merging the data storage files **202** together to create the data storage file **204** (**504**).

Once the data storage files **202** have been merged into the data storage file **204**, the method **500** includes committing the storage container objects containing the metadata regarding the data storage file **204** to the database (**506**). Such commitment effectively deletes or dereferences the now-duplicative data storage files **202** if still present. The method **500** concludes by uploading the data storage file **204** to the global storage **101** (**508**), where the data storage file **204** is part of the data shard **102**A and thus one of the data storage files **104**A of the shard **102**A. The other subscribing nodes **106** of the data shard **102**A are now able to access the data storage file **204**.

The parts of the method **500** may be performed in an order other than that which has is shown in FIG. **5**. For instance, part **504** may be performed first, and then part **502** may be performed. Finally, part **508** may be performed, and then part **506**.

FIG. **6** shows an example non-transitory computer-readable data storage medium **600** storing program code **602** executable by a primary computing node **106** for a data shard **102** to perform processing. The processing includes identifying a data storage plan for the data shard **102** (**604**). The data storage plan identifies a file subset of the data storage files **104** of the data shard **102** to be merged into a larger data storage file **204**. The data storage plan further identifies a node subset of the computing nodes **106** of the distributed database system **100** subscribing to the data shard **102**, including the primary computing node **106**.

The processing includes identifying which computing nodes **106** of the node subset each have sufficient computing resources to execute the data storage plan, as candidate computing nodes **106** (**606**). The processing includes identifying which data storage files **104** of the file subset each candidate computing node **106** locally caches (**608**). The processing includes selecting one of the candidate computing nodes **106** to execute the data storage plan, based on the data storage files **104** of the file subset that each candidate computing node locally **106** caches (**610**), and causing the selected one of the candidate computing nodes **106** to execute the data storage plan (**612**).

Techniques have been describing for selecting a subscribing computing node to execute a data storage plan for a data shard in such a way that the selected computing node may not necessarily be the primary computing node for the shard. Rather, the subscribing computing node is selected so that the data storage plan will be executed most efficiently. This means that overall performance of a distributed database system can improve, since background file maintenance tasks implemented by the data storage plans are performed more quickly and in a less burdensome manner on the system.

We claim:

1. A non-transitory computer-readable data storage medium storing program code executable by a primary computing node of a distributed database system to perform processing, the distributed database system maintaining a database that includes a data shard for which the primary computing node is responsible, the processing comprising:

receiving or generating a data storage plan for the data shard, the data storage plan identifying a file subset of a plurality of data storage files of the data shard to be merged into a larger data storage file, the data storage plan further identifying a node subset of a plurality of computing nodes of the distributed database system subscribing to the data shard, the subset including the primary computing node;

identifying which computing nodes of the node subset each have a current utilization satisfying an availability criterion, as candidate computing nodes, comprising:

identifying a configuration of each computing node of the node subset within a resource pool, the configuration specifying the current utilization of the computing node; and

selecting each computing node of which the current utilization satisfies the availability criterion, as one of the candidate computing nodes;

identifying which data storage files of the file subset each candidate computing node locally caches, comprising:

sending a message to the candidate computing node to receive information regarding the data storage files of the file subset that the candidate computing node locally caches; and

receiving a reply from the candidate computing node including the information regarding the data storage files of the file subset that the candidate computing node locally caches;

selecting one of the candidate computing nodes to execute the data storage plan, based on the data storage files of the file subset that each candidate computing node locally caches; and

causing the selected one of the candidate computing nodes to execute the data storage plan by merging the data storage files of the file subset into the larger data storage file and uploading the larger data storage file to a global shared storage accessible by the computing nodes of the distributed database system,

wherein execution of the data storage plan resolves fragmentation of data stored in the data shard resulting from queries being performed against the data.

2. The non-transitory computer-readable data storage medium of claim **1**, wherein the information comprises one or more of:

a number of the data storage files of the file subset that the candidate computing node locally caches; and

a size of the data storage files of the file subset that the candidate computing node locally caches.

3. The non-transitory computer-readable data storage medium of claim **1**, wherein selecting the one of the candidate computing nodes to execute the data storage plan, based on the data storage files of the file subset that each candidate computing node locally caches, comprises:

selecting the one of the candidate computing nodes to execute the data storage plan as the candidate computing node locally caching a greatest number of the data storage files of the file subset.

4. The non-transitory computer-readable data storage medium of claim **1**, wherein selecting the one of the candidate computing nodes to execute the data storage plan, based on the data storage files of the file subset that each candidate computing node locally caches, comprises:

selecting the one of the candidate computing nodes to execute the data storage plan as the candidate computing node locally caching a largest size of the data storage files of the file subset.

5. The non-transitory computer-readable data storage medium of claim **1**, wherein selecting the one of the candidate computing nodes to execute the data storage plan, based on the data storage files of the file subset that each candidate computing node locally caches, comprises:

for each candidate computing node, computing a score based on a number of the data storage files that the candidate computing node locally caches and based on a size of the data storage files that the candidate computing node locally caches;

selecting the one of the candidate computing nodes to execute the data storage plan as the candidate computing node having a highest score.

6. The non-transitory computer-readable data storage medium of claim **1**, wherein the selected one of the candidate computing nodes to execute the data storage plan is other than the primary computing node, and wherein causing the selected one of the candidate computing nodes to execute the data storage plan comprises:

sending the data storage plan to the selected one of the candidate computing nodes for execution.

7. The non-transitory computer-readable data storage medium of claim **6**, wherein the processing further comprises:

receiving data storage plan execution results from the selected one of the candidate computing nodes after execution of the data storage plan; and

performing further operations regarding the data shard, based on the data storage plan execution results.

8. The non-transitory computer-readable data storage medium of claim **1**, wherein the selected one of the candidate computing nodes to execute the data storage plan is the primary computing node, and wherein causing the selected one of the candidate computing nodes to execute the data storage plan comprises:

executing the data storage plan.

9. A method comprising:

receiving, by a computing node of a distributed database system maintaining a database including a data shard to which a node subset of a plurality of computing nodes of the distributed database system including the computing node and a primary computing node responsible for the data shard, a data storage plan identifying the node subset and a file subset of a plurality of data storage files of the data shard to be merged into a larger data storage file, the data storage plan received from the primary computing node;

executing, by the computing node, the data storage plan by merging the data storage files of the file subset into the larger data storage file and uploading the larger data storage file to a global shared storage accessible by the computing nodes of the distributed database system,

wherein execution of the data storage plan resolves fragmentation of data stored in the data shard resulting from queries being performed against the data,

and wherein the primary computing node:

identifies which computing nodes of the node subset each have a current utilization satisfying an availability criterion, as candidate computing nodes, the candidate computing nodes including the computing node, by:

identifying a configuration of each computing node of the node subset within a resource pool, the configuration specifying the current utilization of the computing node; and

selecting each computing node of which the current utilization satisfies the availability criterion, as one of the candidate computing nodes;

identifies which data storage files of the file subset each candidate computing node locally caches, comprising:

sending a message to the candidate computing node to receive information regarding the data storage files of the file subset that the candidate computing node locally caches; and

receiving a reply from the candidate computing node including the information regarding the data storage files of the file subset that the candidate computing node locally caches; and

selects the computing node to execute the data storage plan, based on the data storage files of the file subset that each candidate computing node locally cache.

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

receiving, by the computing node from the primary computing node, a message to send information regarding the data storage files of the file subset that the computing node locally caches; and

sending, by the computing node to the primary computing node, a reply including the information regarding the data storage files of the file subset that the computing node locally caches.

11. The method of claim **10**, wherein the information comprises:

a number of the data storage files of the file subset that the computing node locally caches.

12. The method of claim **10**, wherein the information comprises a size of the data storage files of the file subset that the candidate computing node locally caches.

13. A distributed database system comprising:

a plurality of computing nodes; and

a global storage storing a plurality of data shards of a database, each data shard including a plurality of data storage files and for which one of the computing nodes is a primary computing node responsible for the data shard,

wherein the primary computing node for each data shard is to:

receive or generate a data storage plan for the data shard, the data storage plan identifying a file subset of the data storage files of the data shard to be merged into a larger data storage file, the data storage

plan further identifying a node subset of the computing nodes subscribing to the data shard, the subset including the primary computing node;

identify which computing nodes of the node subset each have a current utilization satisfying an availability criterion, as candidate computing nodes, by:

identifying a configuration of each computing node of the node subset within a resource pool, the configuration specifying the current utilization of the computing node; and

selecting each computing node of which the current utilization satisfies the availability criterion, as one of the candidate computing nodes;

identify which data storage files of the file subset each candidate computing node locally caches, by:

sending a message to the candidate computing node to receive information regarding the data storage files of the file subset that the candidate computing node locally caches; and

receiving a reply from the candidate computing node including the information regarding the data storage files of the file subset that the candidate computing node locally caches;

select one of the candidate computing nodes to execute the data storage plan, based on the data storage files of the file subset that each candidate computing node locally caches; and

cause the selected one of the candidate computing nodes to execute the data storage plan by merging the data storage files of the file subset into the larger data storage file and uploading the larger data storage file to a global shared storage accessible by the computing nodes of the distributed database system,

wherein execution of the data storage plan resolves fragmentation of data stored in the data shard resulting from queries being performed against the data.

14. The distributed database system of claim **13**, wherein the information comprises a number of the data storage files of the file subset that the candidate computing node locally caches.

15. The distributed database system of claim **13**, wherein the information comprises a size of the data storage files of the file subset that the candidate computing node locally caches.

16. The distributed database system of claim **13**, wherein the primary node for each data shard is to select the one of the candidate computing nodes to execute the data storage plan, based on the data storage files of the file subset that each candidate computing node locally caches, by:

for each candidate computing node, computing a score based on a number of the data storage files that the candidate computing node locally caches and/or based on a size of the data storage files that the candidate computing node locally caches; and

selecting the one of the candidate computing nodes to execute the data storage plan as the candidate computing node having a highest score.

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