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(54) Title: DATABASE SYSTEMS WITH RE-ORDERED REPLICAS AND METHODS OF ACCESSING AND BACKING UP DATABASES

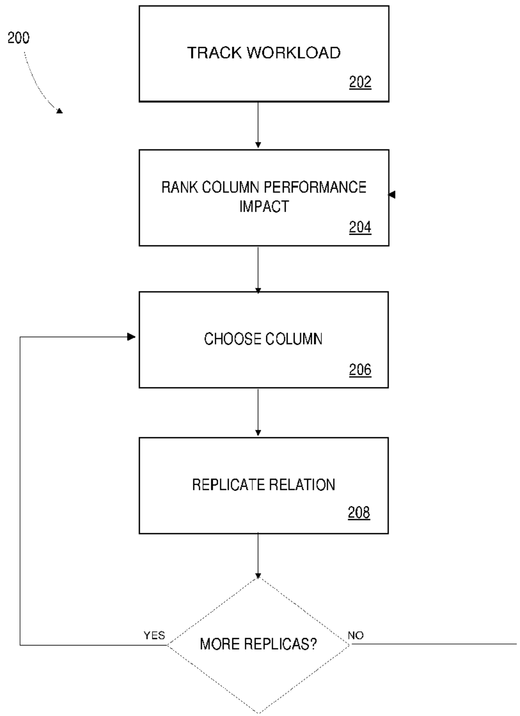

FIG.9

(57) Abstract: A database system comprises: a data store containing a database comprising records ordered according to a first key field, and a search index of the first key field. The database system also comprises a replica data store, containing a replica copy of the database, with the records ordered according a second key field, different from the first key field, and a search index of the second key field. A server is configured to receive a request to access the records, and to access the records using the replica copy if the request includes a criterion based on values of the second key field.

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DATABASE SYSTEMS WITH RE-ORDERED REPLICAS AND METHODS OF ACCESSING AND BACKING UP DATABASES

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This patent application claims priority to U.S. Patent Application No. 15/070,861, filed on March 15th, 2016 and entitled “DATABASE SYSTEMS WITH RE-ORDERED REPLICAS AND METHODS OF ACCESSING AND BACKING UP DATABASES”, which is hereby incorporated by reference herein as if reproduced in its entirety.

FIELD

[0002] This relates to databases, and in particular to replication systems and methods for databases.

BACKGROUND

[0003] In large databases, indexing data can speed up data access and filtering operations. Traditionally, databases may be indexed using search trees. Using search trees, queries or other data access requests can be performed by searching the tree, which, points to the relevant records that satisfy certain selection criteria, rather than by evaluating each record individually against the criteria.

[0004] Many types of search trees exist that can be used for indexing database contents. For example, some indexes may be binary search trees. Other indexes may be B-tree indexes. Such indexes can provide for fast access. Index performance may be greatest when database contents are ordered according to the indexed field or column, that is, when database records are stored in order of values of the indexed field.

[0005] Unfortunately, search indexes require extra storage space. In addition, certain database operations, particularly insertions, deletions and data updates, may necessitate updating of the index, and therefore, may be relatively slow.

[0006] Moreover, in many databases, data may need to be searched based on any of a plurality of fields. In such situations, space requirements for storing search index data may be particularly high. Likewise, data insertion and deletion may be particularly slow. Moreover, database contents may be such that some fields or columns cannot be indexed.

For example, if data is ordered on a first column, values in a second column may be randomly distributed and not suitable for indexing.

[0007] Modern database systems typically employ replication to maintain multiple copies of data in order to ensure availability even in the event of component failure. For example, many database systems store 2-3 copies of data. Copies may be exact replicas of one another, or copies with erasure encoding, such as in certain types of RAID (redundant array of inexpensive disks) storage. Generally, index data, such as B-tree index data is backed up along with database contents, to ensure accessibility of data and limit performance degradation in the event of a component failure.

SUMMARY

[0008] Disclosed herein is a database system comprising: a first server; a first data store at the first server containing a primary copy of a database comprising records, including at least first and second key fields, the records stored in a first order; a replica data store, containing a replica copy of the database, with the records stored in a second order different from the first order, according to values of the second key field, different from the first key field; the first server configured to receive a request to access the records, and access said records from the replica copy if the request includes a criterion based on values of the second key field. .

[0009] Also disclosed herein is a method of backing up database records ordered in a first order, comprising: selecting a key field; copying the database records to a data store to create a replica copy; and ordering the database records of the replica copy in a second order, different from the first order and according to values of the key field..

[0010] Also disclosed herein is a method of accessing database records on a database system comprising a primary database copy and at least one replica database copy, records of the replica copy ordered differently than records of the primary copy and based on a database field. The method comprises: receiving a request to access said database records, said request comprising a selection criterion based on a value of a queried database field; selecting one of said primary copy and said replica copy, said selected one of said primary copy and said replica copy ordered based on said queried database field; and returning database records by searching an index of said queried database field at the selected one of said primary copy and said replica copy.

[0011] Other aspects of the present disclosure will be apparent from the detailed description and figures.

BRIEF DESCRIPTION OF DRAWINGS

[0012] In the figures, which illustrate example embodiments:

[0013] FIG. 1 is a block diagram of a database system and client computing device;

[0014] FIG. 2 is a block diagram of a server of the database system of **FIG. 1**;

[0015] FIG. 3 is a diagram of software at the server of **FIG. 2**;

[0016] FIG. 4 is a diagram of components of the software of **FIG. 3**;

[0017] FIG. 5 is a schematic diagram of a database table of the database system of **FIG. 1**;

[0018] FIG. 6 is a schematic diagram of a workload log of the database system of **FIG. 1**;

[0019] FIGS. 7A-7B are schematic diagrams of indexes of the database table of **FIG. 5**;

[0020] FIGS. 8A and **8B** are schematic diagrams of replicas of the database system of **FIG. 1**;

[0021] FIG. 9 is a flow diagram of a process of creating a replica;

[0022] FIG. 10 is a flow diagram of a process of handling an access request;

[0023] FIG. 11 is a flow diagram of a process of updating data in a database; and

[0024] FIG. 12 is a flow diagram of a process of updating a replica.

DETAILED DESCRIPTION

[0025] FIG. 1 depicts an example database system **100**. Database system **100** includes a plurality of servers **102**, each with interconnected data storage **104**. Servers **102** may be interconnected via a network **106**, which may be an IPv4, IPv6, X.25, IPX compliant or similar network, including one or more wired or wireless access points. Network **106** may be a local-area network (LAN) or a wide-area network (WAN), such as the internet, and may be connected with other communications networks, such as GSM/GPRS/3G/4G/LTE networks. Each server **102** may host a database data in its interconnected data storage **104**. As depicted, database system **100** includes 3 servers **102-1**, **102-2**, **102-3** (individually and collectively, servers **102**), each with a respective data storage **104-1**, **104-2**, **104-3** (individually and collectively, data storage **104**). However, in other embodiments, more or fewer servers **102** and data storage **104** may be present.

[0026] Servers **102-1**, **102-2**, **102-3** may be physically separate machines, which may be located remotely from one another. Alternatively, servers **102-1**, **102-2**, **102-3** may be separate server instances running on a single machine. For example, servers **102-1**, **102-2**, **102-3** may be virtual machines or may be run on separate drives or partitions.

[0027] Database system **100** may be accessible by one or more client computing devices **110**. Client computing devices **110** may be connected directly to network **106**, or may be connected to network **106** by way of another network **112**, which may be a LAN or a WAN such as the internet. Client computing devices **110** may be, for example personal computers, smartphones, tablet computers, or the like, and may be based on any suitable operating system, such as Microsoft Windows, Apple OS X or iOS, Linux, Android, or the like.

[0028] **FIG. 2** is a block diagram of components of an example server **102**. As depicted, each server **102** includes a processor **114**, memory **116**, persistent storage **118**, network interface **120** and input/output interface **122**.

[0029] Processor **114** may be an Intel or AMD x86 or x64, PowerPC, ARM processor, or the like. Processor **114** may operate under control of software loaded in memory **116**. Network interface **120** connects server **102** to network **106**. I/O interface **122** connects server **102** to storage **104** and may further connect server **102** to one or more peripherals such as keyboards, mice, USB devices, disc drives, and the like.

[0030] Software may be loaded onto server **102** from peripheral devices or from network **106**. Such software may be executed using processor **114**.

[0031] **FIG**. **3** depicts a simplified arrangement of software at a server **102**. The software may include an operating system **116** and application software, such as database management system **117**. Database management system may be a system configured for compatibility with the relational database model using a language such as SQL.

[0032] Database management system **117** may itself have a number of components, as depicted in **FIG**. **4**. For example, database management system **117** may include a user interface **119**, a database engine **121**, a replication manager **124**, an access scheduler **126**

and a workload monitor **128**. Instances of database management system at different servers **102** may communicate with one another, for example, to send and receive instructions or data.

[0033] Database management system **117** may maintain a database **130** in storage **104**, e.g. a relational database comprising one or more tables with fields in columnar format. **FIG. 5** depicts a table representative of data in database **130**. Database engine **122** may allow database management system **117** to access the database **130** for the purpose of reading, creating, deleting, updating records and the like. As used herein, references to columns or rows of database **130** may relate to columns or rows of tables within database **130**. References herein to ordering or sorting based on a column mean ordering or sorting based on values of a field stored in that column. In other embodiments, database **130** may be another type of database, such as a document-oriented database or an object-oriented database. In such embodiments, database records may correspond to documents or objects, respectively. Columns may correspond to data fields in the objects or records. Rows may likewise correspond to documents or objects, such that references to ordering of rows may instead relate to ordering of documents or objects.

[0034] As depicted, database **130** includes a plurality of records **132** of sales data. Each record **132** contains values in a number of fields arranged in columns. As depicted, the values are associated with a sales transaction and may include values in an ID column **134**, a date column **136**, a price column **138**, a customer_ID column **140** and a Store_Location column **142**. However, as will be apparent, database **130** may have more or fewer columns that those depicted and may contain information other than sales information. Database **130** may optionally be stored on storage **104** such that entries in one of the columns **134**, **136**, **138**, **140**, **142** are in order or reverse order. As used herein, the "order" of storage refers to locations in a data store.

[0035] User interface **120** may be configured to receive requests for accessing data in database **130** and to return results. User interface **120** may be presented locally at server **102** for operation by a user. Alternatively, or additionally, user interface **120** may be presented remotely, e.g., through a web browser or application at a client computing device **110**.

[0036] Requests entered through user interface **120** may include record insertion, deletion or update, and queries based on one or more columns. For example, a user may request all records having value "New York" in Store_Location column **142** and a value greater than or equal to 50 in Price column **138.** User interface **120** may be operable to receive instructions from a user, e.g., by text entry or using a graphical menu, and convert those instructions to a database language, such as SQL. For example, a query for all records having value “New York” in Store_Location column **142** may be as follows:

SELECT * WHERE Store_Location = “New York” AND Price >= 50

[0037] Access requests received by database management system **117** may be logged by workload monitor **128**. In particular, workload monitor **128** may maintain a log of the number and frequency of access requests, and search criteria associated with such requests. For example, workload monitor **128** may log the number and frequency of requests which require searching on each column of database **130**. Workload monitor **128** may also log the time for each access request to be completed. As used herein, the “workload” of a database refers to the set of requests for access to the database.

[0038] FIG. 6 depicts an example workload log **146** stored by workload monitor **128**. As shown, workload monitor **128** maintains, for each column of database **130**, a log of the number of requests requiring a search on the column, frequency of such requests the average period, i.e. the average time elapsed, between requests, and performance data, such as the average time to execute such requests. Workload monitor **128** may determine, based on the data in workload log **146**, an estimate of the importance of each column on overall database performance. The performance impact may be a representation of the aggregate time spent searching on each column. For example, columns may be ranked based on a ratio of the average time to complete a query to the average period between queries. Other possibilities exist and will be apparent to skilled persons.

[0039] In an example, workload monitor **128** may also maintain weight scores in workload log **146**. Weight scores may, for example be initialized to a certain initial value for each column, and be incremented each time an operation is performed using a particular column. Weight scores may be adjusted to account for the amount of time required to perform operations using each column. For example, weight scores may be adjusted according to a scaling value proportional to the average time to execute requests.

[0040] Database engine **122** may also maintain an index **144** for data in database **130**, as depicted in **FIG. 7A**. Such indexing may improve performance of access requests. Indexing may be based on the expected workload of database system **100**.

[0041] Indexing may be based on fields, e.g. columns of database tables. That is, each index may be for searching based on values in a key field (e.g. a particular column). Indexes may contain key values corresponding to a particular database field and may map the keys to locations of corresponding records in storage. For the sake of illustration, **FIG. 7A** depicts a simple sequential index **144**. Entries in index **144** include a search key value **145**, namely a value in the indexed column from a database record **132**, and a pointer **147** to the record. Contents of index **144** may be searched, e.g., using a binary search algorithm, to identify records with the relevant search key values without individually scanning each record.

[0042] In other embodiments, the index may be a search tree, such as a binary tree or B-tree, for permitting a binary or similar search of values. For example, **FIG. 7B** depicts a representation of a B-tree index **144'**. B-tree index **144'** includes leaf nodes **149** and one or more layers of non-leaf nodes **151**. Each node contains a series of alternating search key values **145** and pointers **147**. Pointers **147** of leaf nodes **149** point to records having the adjacent search key value **145**. Pointers **147** of non-leaf nodes point to lower-layer nodes. Each pointer **147** in a non-leaf node **151** points to a node containing search key values **145** less than the search key value **145** following the pointer **147**, if any, and equal to or greater than the search key value **145** preceding the pointer **147**, if any.

[0043] Indexes may be clustered or non-clustered. In the case of a clustered index, the corresponding data records are stored in the order of the index. For example, as depicted in **FIG. 5**, records are stored in ascending order of values in ID column **134**. Likewise, index **144** uses column **134** as a key field. That is, index **144** uses ID values from column **134** as a search key. In the case of a non-clustered index, the records are stored in an order different than that of the index.

[0044] As depicted in **FIG. 7A**, index **144** includes a value for each corresponding record of database **130**. Alternatively, in other embodiments, records may be grouped, and index **144** may contain one entry for each group. In such embodiments, retrieving data may include searching for a relevant group, and then individually scanning the members of that group.

[0045] Typically, multiple indexes are stored for database **130**. Each index may enable searching based on a particular column of database **130**. For example, indexes may be created and maintained for each of ID column **134**, date column **136**, price column **138**, customer_ID column **140** and Store_Location column **142**. As will be apparent, no more than one index may be clustered. Additional indexes may be non-clustered.

[0046] Search performance may be fastest for clustered indexes. That is, if database **130** is stored as depicted in **FIG. 5**, searches based on an index of the ID column **134** may be faster than other columns, since data are stored in ID column order.

[0047] Database system **100** may store one or more replica copies of data in database **130** to protect against data loss, for example, due to failure of a hardware component. Referring again to **FIG. 1**, data store **104-1** of server **102-1** may store a primary copy of database **130**. Data stores **104-2**, **104-3** of servers **102-2**, **102-3** may store first and second replica copies.

[0048] Replication manager **124** (**FIG. 4**) may be responsible for updating the replica copies of database **126** and maintaining consistency between the primary copy and the replica copies (generally referred to herein as replication).

[0049] In some embodiments, replication manager **124** may log changes at the primary copy of database **126** and propagate those changes to replica copies. Specifically, replication manager **124** monitors for changes in the primary (master) copy of database **130** at server **102-1** and, when changes occur, replication manager **124** produces and sends instructions to each of servers **102-2**, **102-3** for replicating the changes in the replica copies. In such embodiments, the primary copy may be referred to as the master copy. Users may be permitted to make changes only in the master copy and conflicts between copies may therefore be avoided.

[0050] In other embodiments, users may be able to make changes on multiple copies of database **126**. In such embodiments, each user-editable copy may be treated as a master copy. Therefore, such embodiments may be said to employ “multi-master” replication. In multi-master embodiments, replication manager **124** may include processes and algorithms for resolving conflicts between database copies, for example, if a record is edited concurrently in two different database copies. In an example, transactions may be performed in an ansychronous mode, according to which changes are initially made on a first copy, and updates are subsequently propagated to other copies. Transactions may not be considered complete, and records may be locked against further editing until all updates are completed. Other mechanisms for maintaining consistency are will be apparent to skilled persons.

[0051] Replica copies of database **126** may include copies of indexes maintained with the primary copy. Thus, queries may be performed on any copy of database **126** and accelerated using indexes so that queries may be performed on servers **102-2**, **102-3** with substantially the same performance as server **102-1**. Accordingly, in the event of a failure of one of servers **102**, access requests may be directed to another server **102** with limited impact on performance.

[0052] As will be apparent, in some embodiments, Servers **102-1**, **102-2** and **102-3** may be at different physical or geographical locations. For example, servers **102-1**, **102-2**, **102-3** may be in different buildings, cities or continents. Servers **102** may likewise be accessed by client computing devices in a number of different locations. Access scheduler **126** may receive incoming access requests from client computing devices **110** and direct the requests to one of servers **102**. Requests may be directed based on, for example, physical proximity of the client computing device **110** to each server **102**, the activity level of each server **102**, or other factors.

[0053] Ordering of data in the replica copies at servers **102-2**, **102-3** may be controlled by replication manager **124**. In example embodiments, replication manager **124** may order data in the replica copies differently than in the primary copy. For example, as noted above, the primary copy of database **130** stored at server **102-1** is ordered according to values in its ID column **134**. The last record of database **130** has an ID value of n (hereinafter, referred to as the n^{th} record). As depicted in **FIG. 8A**, replica copy **130'** is stored in order of values of price column **138**. The n^{th} record has the second-highest price and is therefore stored second, i.e. in the second storage location. As depicted in **FIG. 8B**, replica copy **130''** is stored in order of values of Store_Location column **142**, and the n^{th} record is likewise stored second.

[0054] Indexes may be created and maintained for replica copies according to the ordering of records in those copies. For example, a clustered index of price column **138** may be created and maintained for replica copy **130'** and a clustered index of Store_Location column **142** may be created and maintained for replica copy **130''**.

[0055] Though replica copies **130'**, **130''** are ordered differently than the primary copy of database **130**, the replica copies contain all of the data in database **130** and therefore protect against data loss due to failure of server **102-1** which hosts database **130**. However, replica copies **130'**, **130''** may be hosted at servers **102-2**, **102-3** and used to perform searches. As compared to exact copies of database **130**, re-ordered replicas **130'**, **130''** may provide improved search performance.

[0056] Specifically, a database workload typically includes queries or selections formed using criteria on multiple different columns. For example, some searches may be based on an ID number, some searches may be based on a date, and some searches may be based on a combination thereof. Accordingly, in the absence of re-ordered replicas **130'**, **130''**, a workload may require additional non-clustered indexes to be maintained along with database **130**. For example, to provide for efficient searching based on ID column **134**, price column **138** and Store_Location **142**, indexes of all three columns would be required along with database **130**. If database **130** were to be backed up with exact copies, all of the indexes would typically be backed up as well.

[0057] Conversely, by backing up database **130** with re-ordered copies **130'**, **130''**, a single clustered index of the ID column **134** could be maintained with the primary copy of database **130**, while the non-clustered indexes could be reduced or eliminated. A single clustered index of the price column **138** could be maintained with replica copy **130'** and a single clustered index of the Store_Location column **142** could be maintained with replica copy **130''**.

[0058] As noted above, searching clustered indexes tends to be faster than searching non-clustered indexes. Accordingly, a workload including searches of each of the ID column **134**, the price column **138** and the Store_Location **142** may be completed more quickly using the primary copy of database **130** in combination with replicas **130'**, **130''**, relative to using database primary copy alone with indexes of all three columns. Indeed, the workload may complete more quickly using database **130** and copies **130'**, **130''** relative to three servers concurrently performing the search on identical copies of database **130**.

[0059] In addition, replica copies **130'**, **130''** may also have different non-clustered indexes, which may allow for index coverage of more columns, relative to a primary copy **130** and identical replicas. For instance, primary copy **130** may have a clustered index of ID column **134** and a non-clustered index of date column **136**. Back-up copy **130'** may have a clustered index of price column **138** and a non-clustered index of customer_ID column **140**, and back-up copy **130''** could have a clustered index of Store_Location column **142**, without any non-clustered indexes. Thus, between primary copy **130**, replica copy **130'** and replica copy **130''**, indexes are provided for each of the columns depicted in **FIG. 5**, however, no more than two indexes (one clustered and one non-clustered) are required to be stored at any server **102**.

[0060] Conversely, if database **130** were backed up with identical copies, in order to provide searchable indexes of all five columns, one clustered index and four non-clustered indexes would need to be provided with database **130**. All five indexes would typically be backed up along with the database **130** itself. Thus, re-ordered replicas **130'**, **130''** may allow for more columns to be indexed, and may reduce overall space taken by indexes, for the same number of columns.

[0061] Ordering and indexing of database **130** and replica copies **130'**, **130''** may be controlled based on information in workload log **146**. Specifically, replication manager **124** may be configured to choose ordering columns based on the performance impact of each column determined from workload log **146** (e.g., according to weighting values). Database **130** and replica copies **130'**, **130''** may be ordered on the columns with the highest performance impact, and clustered indexes be created for those columns. Additional non-clustered indexes may be provided for other columns in accordance with their respective performance impact.

[0062] Alternatively, ordering columns may be explicitly chosen by a database administrator, for example, based on information in workload log 146, or based on historical or test data.

[0063] Replication manager **124** and access scheduler **126** may be configured to accommodate replica copies **130'**, **130''** stored in orders different from primary copy **130** and with different indexes.

[0064] For example, access scheduler **126** maintains a record of ordering of primary copy **130** and replica copies **130'**, **130''** and available indexes at each server **102**. Access scheduler **126** may send a message comprising a query to database management system **117** at each other server **102**, which may respond with a messages indicating the ordering of replica copies **130'**, **130''**. Such messages may be exchanged on startup of a server **102**, at periodic time intervals, following a certain number of access requests, or according to any other suitable schedule.

[0065] When an access request is received, access scheduler **126** is configured to parse the request to determine selection criteria specified by the request and identify columns on which the selection criteria are based. Access scheduler **126** is further configured to compare the identified columns to the available indexes at each of servers **102-1**, **102-2**, **102-3**. If the search criteria match a clustered index at one of the servers **102**, access scheduler is configured to send the request to that server **102**. For example, all searches based on price column **138** (**FIG. 5**) may be directed to server **102**-**2**, which hosts replica copy **130'** and has a clustered index of the price column.

[0066] In other embodiments, access scheduler **126** may directly have access to ordering information of data at servers **102-1**, **102-2** and **102-3**, e.g. it may have access to a copy of each index. In such embodiments, access scheduler may simply retrieve the relevant records from server **102-2**, rather than directing the received query to server **102-2** for execution. In one such example, access scheduler **126** may be part of a catalog node in a database using Apache™ Hadoop™ technology.

[0067] If the search criteria do not match any clustered index, the search may be sent to a server with a non-clustered index corresponding to the search criteria. Alternatively, if no server has any index corresponding to the search criteria, the request may be directed to the nearest or least busy server **102**.

[0068] Replication manager **124** may be configured to propagate changes in database **130** to each of copies **130'**, **130''**. To do so, replication manager **124** is configured to optimize requests to create, update or delete requests. Received requests may be altered for better performance on replicas with particular indexes available. For example, in the SQL language, a received request may include an UPDATE statement which calls for data to be changed in records with certain criteria, e.g.:

```
UPDATE [table]
SET [data to be changed]
WHERE [selection criteria]
```

[0069] The request may, for example, specify data to be changed for all records with a particular ID number, e.g.:

```
UPDATE [table]
SET [data to be changed]
WHERE ID=0003
```

[0070] Such a statement could be efficiently carried out in primary copy **130**. However, if the same instruction was passed to servers **102**-**2**, **102**-**3** to be replicated in replica copies **130'**, **130''**, the resulting search would be less efficient, since replica copies **130'**, **130''** do not have a clustered index for ID column **134** and may not have any index for ID column **134**. In the absence of an index, carrying out the request may require scanning the value of ID column **134** in each record.

[0071] Accordingly, replication manager **124** may produce modified instructions which include selections based on indexed columns. For example, to propagate changes to server

102-2, which has a clustered index of Price column **138**, replication manager **124** may determine price values from the selected records and pass instructions to server **102**-**2** with selection criteria based on those price values. For example, as depicted in **FIG. 5**, the record with ID = 0003 has Price = 101.76. Accordingly, replication manager **124** may construct a request as follows:

```
UPDATE [table]
SET [data to be changed]
WHERE PRICE = 101.76 AND ID = 0003
```

[0072] Since Price=101.76 may not uniquely identify a record, the original search criteria may also be included. As will be apparent, executing the above request may require a search of the Price column, and testing each of the returned records for ID = 0003. Such instructions could be carried out relatively efficiently using the clustered index of price column **138** at server **102**-**2**.

[0073] Similarly, to propagate the same update to replica copy **130**" at server **102-3**, which has a clustered index of Store_Location column **142**, replication manager **124** determine Store_Location values from the selected records and pass instructions to server **102**-**3** with selection criteria based on those Store_Location values. For example, as depicted in **FIG. 5**, the record with ID = 0003 has Store_Location "Chicago". Accordingly, replication manager **124** may construct a request as follows:

```
UPDATE [table]
SET [data to be changed]
WHERE Store_Location = "Chicago" AND ID = 0003
```

[0074] Since Store_Location = "Chicago" may not uniquely identify a record, the original search criteria may also be included. As will be apparent, executing the above request may require a search of the Store_Location column, and testing each of the returned records for ID = 0003.Such instructions may be carried out relatively efficiently using the Store_Location index at server **102**-**3**.

[0075] **FIG**. **9** depicts a flow chart of a process **200** performed by a server **102** under control of database management system **117** to create a replica copy of database **130**.

[0076] At block **202**, workload monitor **128** monitors access requests received by server **102** and maintains a record of the requests in workload log **146**. Each time a request requires searching of a column, workload monitor **128** increments a count in a corresponding row of workload log **146**. Workload monitor **128** may track the search time, namely, the time elapsed between receipt of the access request and returning of the result, and search period, namely the time elapsed between successive searches on each column. In addition, workload monitor may track the average search time and search period.

[0077] At block **204**, workload monitor **128** may rank the columns according to their impact on search performance. The impact of a particular column may be a function of the product of the search time and the frequency of searches on the column.

[0078] At block **206**, replication manager **124** chooses a column identified as having high performance impact. The chosen column may be the column with the highest performance impact. Alternatively, if the column with the highest performance impact is the column on which the primary copy is ordered, the chosen column may be that with the next-highest performance impact.

[0079] At block **208**, replication manager **124** replicates the database **130** at a server **102**. If there are more replicas to be made, the process returns to block **206**, and the column with the next-highest performance impact is chosen. If no further replicas are to be made, the process returns to block **204**, and workload monitor **128** periodically or continuously tracks the workload of database **100** and the performance impact of each column. If there is a change in the columns with the highest performance impact, replication manager **124** may direct one or more replicas to be re-ordered based on a new column.

[0080] FIG. 10 depicts a flow chart of a process **212** of accessing data from database system **100**. At block **214**, a request to access database **130** is received at one of servers **102**. The access request may be, for example, a query.

[0081] At block **216**, access scheduler **126** parses the access request to identify the column or columns that need to be searched to perform the access request. Access scheduler **126** may, for example user, regular expression matching or other suitable algorithms to identify search operators in the access request and to identify columns to be searched.

[0082] At block **218**, access scheduler **126** compares the columns to be searched to the available clustered indexes associated with database **130** and each of its replica copies. If a clustered index exists for one of the key fields (e.g. columns) to be searched, access scheduler **126** selects the server with the relevant replica copy and index and, at block **220**, sends a message to that server containing the access request.

[0083] In some embodiments, the request may require searching on multiple columns of database **130** which have clustered indexes in servers **102**. in such cases, access scheduler **126** may send the access request to the closest server **102** with a relevant clustered index.

[0084] The access request is executed at the selected server. Specifically, database engine **121** searches the index for the record or records requested. The index points to the storage location or range of locations containing the relevant records.

[0085] At block **222**, the request result is loaded and returned to the client computing device **110**. An electronic message containing the query result may be sent directly from the server **102** performing the query to the client computing device **110** over networks **106**, **112**. In some embodiments, the client computing device **110** may be in communication with a different server **102** from the one performing the search. In such embodiments, an electronic message containing the request result may be sent to the client computing device **110** by way of another server **102**.

[0086] **FIG. 11** depicts a process **224** of adding, deleting or updating data in database system **100**. At block **226**, a server **102** receives a request from a client computing device **110**. The request may include an INSERT, DELETE or UPDATE request.

[0087] The request may include selection criteria based on values of one or more columns. For example, a request may instruct database system **100** to delete all records with value “Washington” in Store_Location column **142**. Alternatively, the request may instruct database system **100** to add one or more new records with value “Toronto” in Store_Location column **142**. As will be apparent, fulfilling such requests may involve searching one or more column indexes to determine the correct storage location or range of locations in which data should be inserted, deleted or changed, while maintaining the order of data.

[0088] At block **228**, access scheduler **126** parses the access request to identify the column or columns that need to be searched to perform the access request. Access scheduler **126** may, for example, use regular expression matching or other suitable algorithms to identify search operators in the access request and to identify columns to be searched.

[0089] At block **230**, access scheduler **126** compares the columns to be searched to the available clustered indexes associated with database **130** and each of its replica copies. If a clustered index exists for one of the columns to be searched, access scheduler **126** selects the server **102** with the relevant replica copy and index and, at block **232**, sends a message to that server **102** containing the access request. The server **102** searches the index to determine the appropriate storage location for writing or deleting and performs the necessary write or deletion. In some embodiments, the scheme for maintaining consistency between database 130 and its replicas may require that updates to database 130 and its replicas are performed concurrently. In such embodiments, requests may be sent simultaneously to database 130 and all replicas, rather than selecting an optimal database or replica in which to initially commit the change.

[0090] At block **236**, after the insertion, deletion or update of data, replication manager **124** of the server **102** that performed the read or write updates the clustered index and non-clustered indexes that are present.

[0091] Replication manager then sends one or more messages for causing updating of replica copies **130'**, **130''**. A process **238** for updating replicas is depicted in **FIG. 12**.

[0092] At block **240**, replication manager **124** compares the search criteria of the requested INSERT, DELETE or UPDATE operation to the available search indexes at the replicas. The request may be optimized for running at the server **102** hosting the replica. In particular, the request may be altered so that it identifies records to be updated, deleted or inserted based on values of columns that are indexed in the replica. For example, if the initial request is to update prices associated with all records having value “Chicago” in Store_Location column **142**, and the replica has an index of values in ID column **134**, the request may be modified as described above to select records with “Chicago” in Store_Location column **142** based on their corresponding values in ID column **134**.

[0093] At block **242**, the optimized request is sent to the replica server **242**. If more replicas need to be updated, the process returns to block **240**, and the original request is optimized for the next replica. Alternatively, if no further replicas need to be updated, the process ends.

[0094] As described above, database system **100** includes a database **130** and two replica copies **130'**, **130''**. In other embodiments, more or fewer replica copies may be provided. In addition, a database system may include both exact replicas and re-ordered replicas of a database. For example, a system could comprise a master database, one or more re-ordered replicas, and one or more identical replicas stored in the same order and having the same indexes as the master.

[0095] In some embodiments, the systems and methods disclosed herein may be used in a distributed database, wherein primary copy of database **130** is stored in parts spread among data stores at a plurality of servers. In such embodiments, replica copies **130'**, **130"** may likewise be stored in parts.

[0096] In some embodiments, a user may manually select columns on which primary copy of database **130** and replica copies **130'**, **130"** are ordered. The user may review the contents of workload log **146** to do so.

[0097] As described above, database **130** is a relational database including one or more tables, Records of database **130** (e.g. rows of the database tables) are ordered according to corresponding values in columns of the database tables. In other embodiments, the systems and methods described herein may be used in the context of other types of databases, such as document or object-oriented databases.

[0098] For example, in document-oriented databases, records may take the form of documents, The documents may contain fields of data, some of which may be common to the documents, Documents may be ordered according to values of certain fields. Replica database copies may have documents ordered according to values of fields different than those on which the primary copy is ordered. Alternatively, the primary copy may be randomly ordered, and replica copies may be ordered based on desired fields.

[0099] in object-oriented databases, records may take the form of object instances, The object instances may contain fields of data, some of which may be common, Object instances may be ordered according to values of certain fields. Replica database copies may have object instances ordered according to values of fields different than those on which the primary copy is ordered. Alternatively, the primary copy may be randomly ordered, and replica copies may be ordered based on desired fields.

[00100] In some embodiments, database **130** or its replica copies **130'**, **130"** may be randomly ordered or only semi-ordered on a particular key column.

[00101] In some embodiments, database **130** or its replica copies **130'**, **130"** may be ordered based on combined values of a plurality of columns, rather than a single column. For example, records may be ordered based on the sum of values in a plurality of fields, concatenated values of multiple fields, hash values generated from a plurality of fields, or the like.

[00102] As described above, database **130** and its replica copies **130'**, **130''** are ordered differently. Alternatively or additionally, in some embodiments, other properties of replica copies **130'**, **130''** may differ from those of database **130**. For example, data stored in one or more of database **130** and replica copies **130'**, **130''** may be compressed. Compression may be done using different algorithms for different copies. For example, replica copy **130'** may be compressed using an algorithm optimized for storage efficiency, and replica copy **130''** may be compressed using an algorithm optimized for speed or efficiency of decompression, or may not be compressed at all. In such embodiments, some access requests may be carried out using replica copy **130'** to limit bandwidth consumption and some access requests may be carried out using **130''** to limit computational load or decompression time.

[00103] In some embodiments, database **130** and replica copies **130'**, **130''** may be stored in different database formats, different file formats or different data formats. In such embodiments, access requests may be carried out based on the client from which they are received. For example, an access request may be received from a client which has native support for only a particular database or file format. Such a request may be carried out using a replica copy with a matching format, in order to avoid format conversion.

[00104] Although the embodiments have been described in detail, it should be understood that various changes, substitutions and alterations can be made herein.

[00105] Moreover, the scope of the present application is not intended to be limited to the particular embodiments of the process, machine, manufacture, composition of matter, means, methods and steps described in the specification. As one of ordinary skill in the art will readily appreciate from the disclosure of the present invention, processes, machines, manufacture, compositions of matter, means, methods, or steps, presently existing or later to be developed, that perform substantially the same function or achieve substantially the same result as the corresponding embodiments described herein may be utilized. Accordingly, the appended claims are intended to include within their scope such processes, machines, manufacture, compositions of matter, means, methods, or steps

[00106] As can be understood, the examples described above and illustrated are intended to be exemplary only. The invention is defined by the appended claims.

WHAT IS CLAIMED IS:

1. A database system comprising:

a first server;

a first data store at said first server containing a primary copy of a database comprising records including at least first and second key fields, said records stored in a first order;

a replica data store, containing a replica copy of said database, with said records ordered stored in a second order different from said first order, said second order according to values of said second key field;

said first server configured to receive a request to access said records, and configured to access said records from said replica copy if said request includes a criterion based on values of said second key field.

2. The database system of claim 1, wherein said first order is based on values of said first key field.

3. The database system of claim 2, wherein said first data store contains a search index comprising values in said first key field and said second data store contains a search index comprising values in said second key field.

4. The database system of claim 1, further comprising a second server, said replica data store interconnected with said second server.

5. The database system of claim 4, further comprising a third server and a second replica data store, said second replica data store containing a second replica copy of said database, with said records ordered according to values of a third key field, different from said first and second key fields, wherein said first server is configured to direct said request to said third server if said request includes a criterion based on values of said third key field.

6. The database system of claim 5, wherein said first, second and third servers are in communication over a network.

7. The database system of claim 4, wherein said second server is configured to receive a request to access said database records, and to direct said request to said first server if said request includes a criterion based on values of said first key field.

8. The database system of claim 4, wherein said first server is configured to replicate changes to said database in said replica copy, by modifying a request to change said database to create a modified request, and forwarding said modified request to said second server.

9. The database system of claim 8, wherein said modifying a request comprises executing a received request on a selected database record at said first data store and constructing a modified request based on a value of said second key field in said selected database record.

10. The database system of claim 1, wherein said first server is configured to select said second key field based on a set of received requests to access said database records.

11. The database system of claim 10, wherein said first server is configured to maintain a log of a set of received requests to access said database records and performance data associated with said set of received requests, and select said second key field based on said log.

12. The database system of claim 11, wherein said log comprises, for each field in said database, a count of requests comprising a criterion in that field, and performance measurements associated with said requests.

13. The database system of claim 1, wherein said second order is based on values of a plurality of fields, including said second key field.

14. The database system of claim 4, wherein said second server is physically separate from said first server.

15. The database system of claim 4, wherein said first and second servers are server instances on a single machine.

16. A method of backing up database records ordered in a first order, comprising:

selecting a key field ;

copying said database records to a data store to create a replica copy; and

ordering said database records of said replica copy in a second order, different from said first order and according to values of said key field.

17. The method of claim 16, wherein said key field is a second key field and said first order is based on values of a first key field.

18. The method of claim 16, comprising creating a search index comprising said values of said key field.

19. The method of claim 16, wherein said copying said database records comprises sending said database records from a first server to a second server.

20. The method of claim 17, comprising selecting a third key field different from said first and second key fields;

copying said database records to a second data store to create a second replica copy;

ordering said database records of said second replica copy according to values of said third key field;

creating a search index comprising said values of said third key field.

21. The method of claim 20, wherein said copying said database records comprises sending said database records to a server across a computer network.

22. The method of claim 16, further comprising receiving a request to access said database records, determining that said request includes a criterion based on values of said key field, and accessing said database records using said replica copy.

23. The method of claim 16, further comprising, in response to receiving a request to change at least one database records, modifying said request to include a selection of said at least one database record based on a value of said key field, and sending said modified request to a server for propagating said change to said replica copy.

24. The method of claim 16, further comprising maintaining a log of requests to access said database records and performance data associated with said requests, and selecting said key field based on said log.

25. The method of claim 24, wherein said maintaining a log comprises, for each field of said database records maintaining a count of requests comprising a criterion in that field, and performance measurements associated with said requests.

26. A method of accessing database records on a database system comprising a primary database copy and at least one replica database copy, records of said replica copy ordered differently than records of said primary copy and based on values of a database field, comprising:

receiving a request to access said database records, said request comprising a selection criterion based on a value of a queried database field;

selecting one of said primary copy and said replica copy, said selected one of said primary copy and said replica copy ordered based on said queried database field;

returning database records by searching an index of said queried database field at the selected one of said primary copy and said replica copy.

27. The method of claim 26, wherein said request comprises instructions to change at least one modified database record, the method further sending update instructions to the other of said primary copy and said replica copy, said update instructions comprising a modified criterion identifying the modified database record based on a value of a second database field, different from said queried database field.

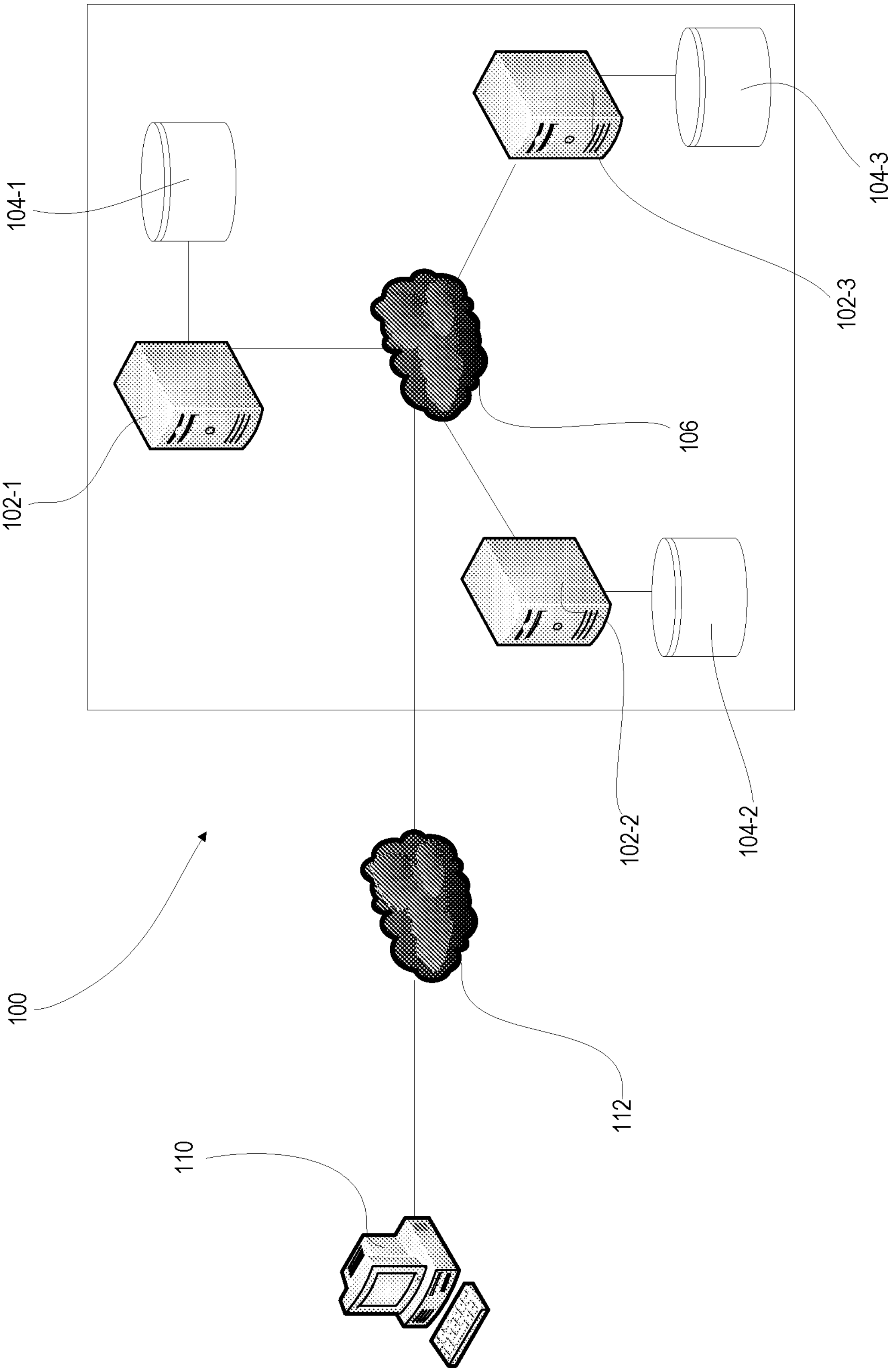


FIG.1

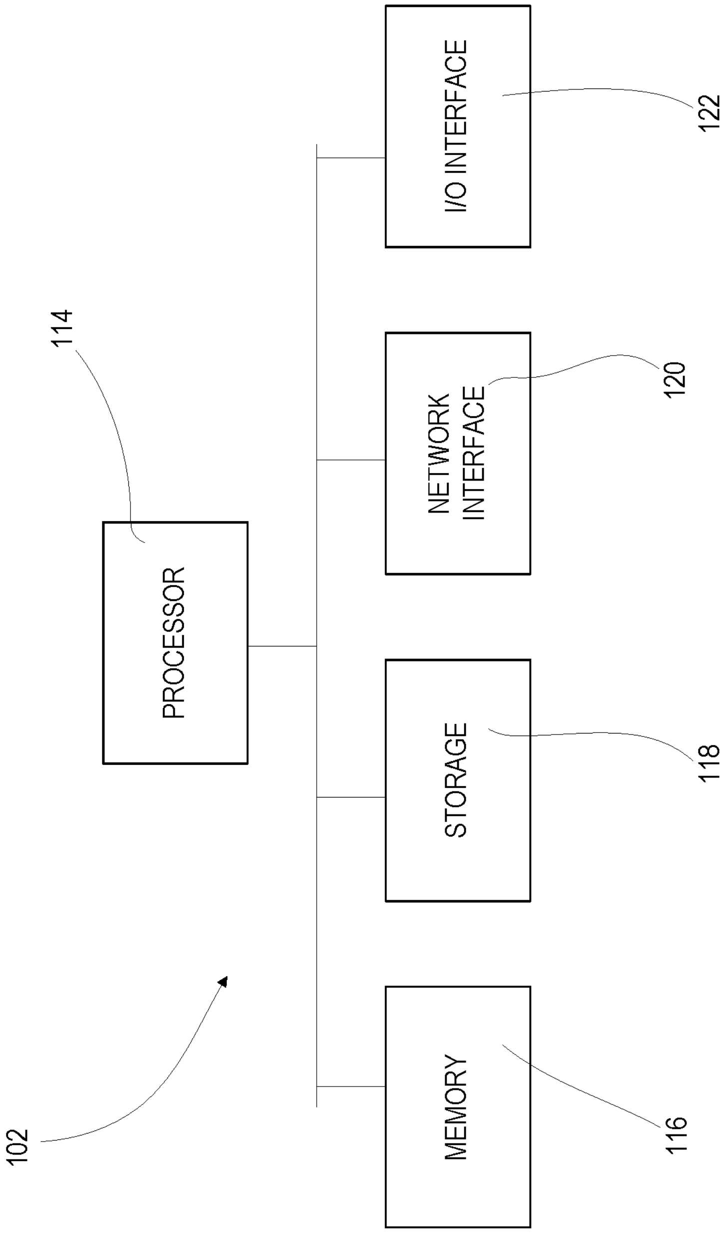

I/O INTERFACE
122
114
NETWORK INTERFACE
120
PROCESSOR
STORAGE
118
MEMORY
116
102

FIG.2

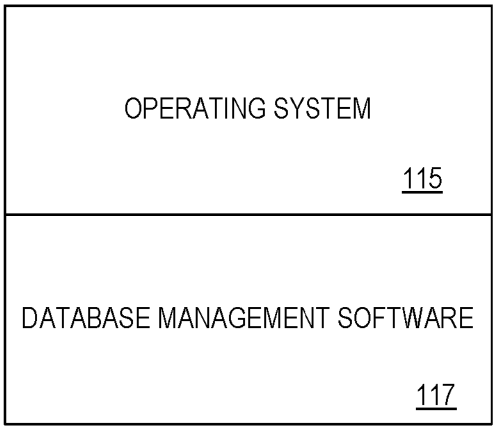


FIG.3

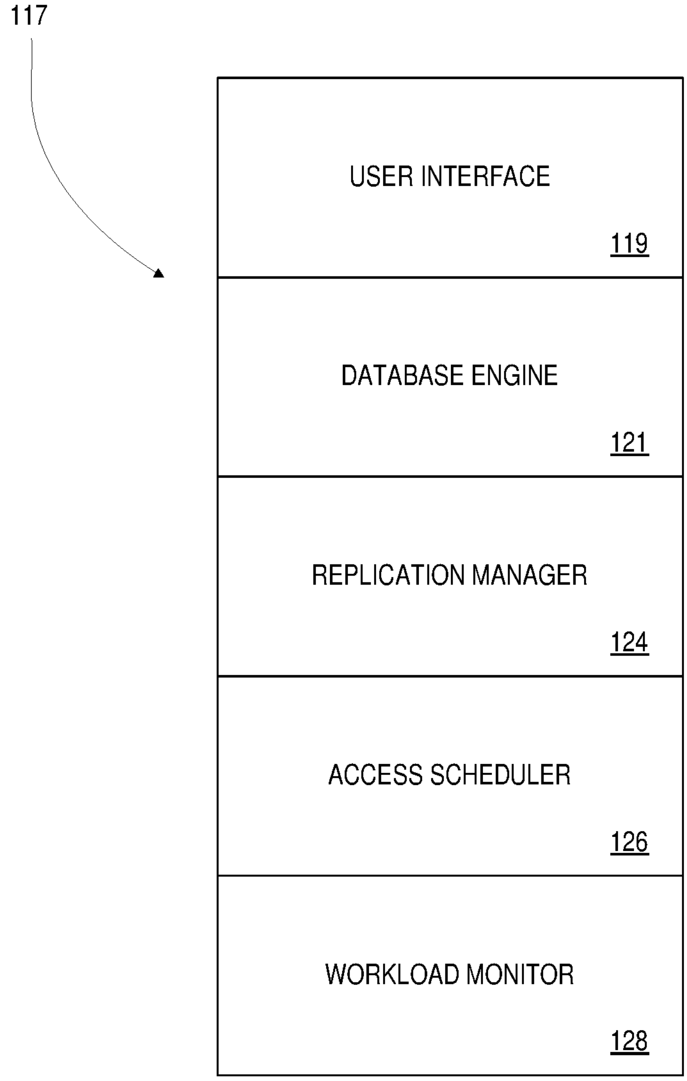
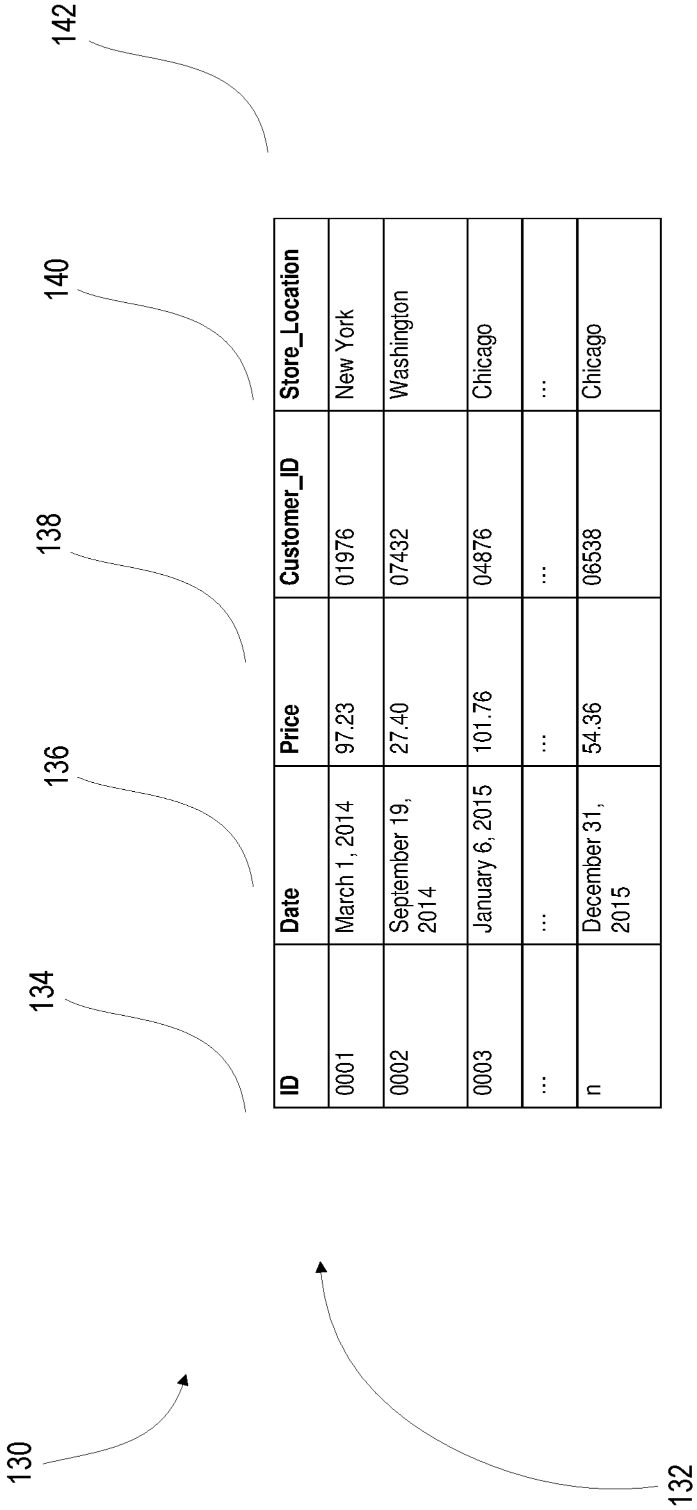

117
USER INTERFACE
119
DATABASE ENGINE
121
REPLICATION MANAGER
124
ACCESS SCHEDULER
126
WORKLOAD MONITOR
128

FIG.4



ID	Date	Price	Customer_ID	Store_Location
0001	March 1, 2014	97.23	01976	New York
0002	September 19, 2014	27.40	07432	Washington
0003	January 6, 2015	101.76	04876	Chicago
...	...	...	...	...
n	December 31, 2015	54.36	06538	Chicago

FIG.5

Column	Number of searches	Average period	Average search time
ID	…	…	…
DATE	…	…	…
PRICE	…	…	…
CUSTOMER_ID	…	…	…
STORE_LOCATION	…	…	…

FIG.6

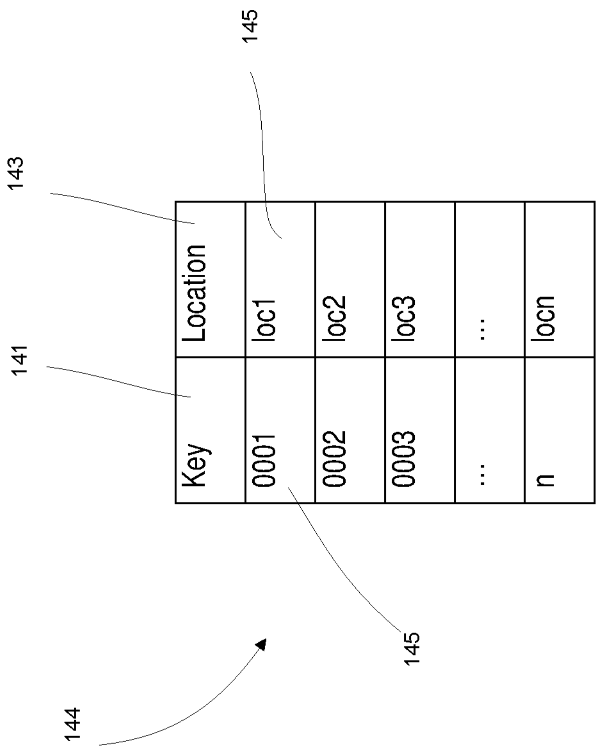

145
143
141
Key
Location
0001
loc1
0002
loc2
0003
loc3
...
...
n
locn
145
144

FIG.7A

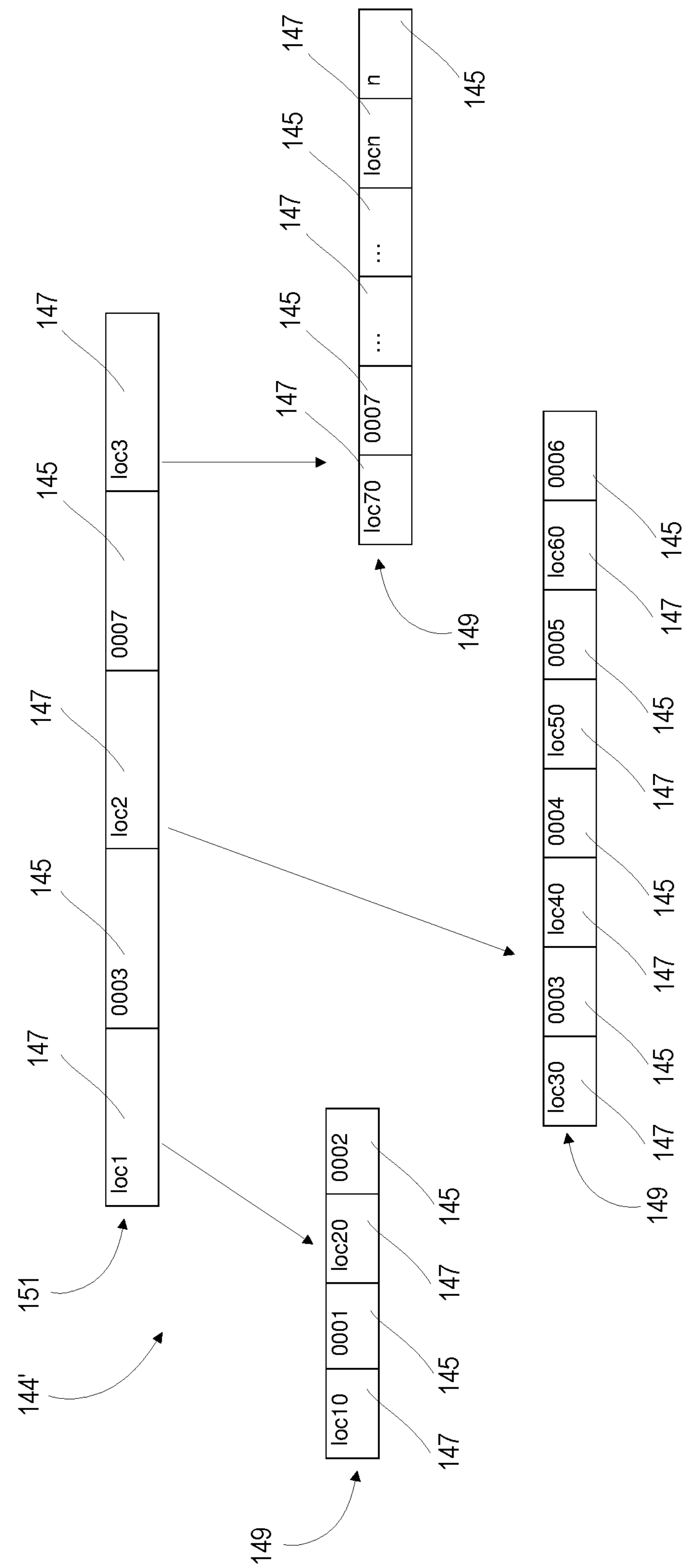

loc1
0003
loc2
0007
loc3
loc10
0001
loc20
0002
loc30
0003
loc40
0004
loc50
0005
loc60
0006
loc70
0007
...
...
locn
n
144'
151
149
145
147

FIG.7B

130'

134 136 138 140 142

132

ID	Date	Price	Customer_ID	Store_Location
0002	September 19, 2014	27.40	07432	Washington
n	December 31, 2015	54.36	06538	Chicago
...	...	...	...	...
0001	March 1, 2014	97.23	01976	New York
0003	January 6, 2015	101.76	04876	Chicago

FIG. 8A

130"

134 136 138 140 142

132

ID	Date	Price	Customer_ID	Store_Location
0003	January 6, 2015	101.76	04876	Chicago
n	December 31, 2015	54.36	06538	Chicago
0001	March 1, 2014	97.23	01976	New York
...	...	...	...	...
0002	September 19, 2014	27.40	07432	Washington

FIG. 8B

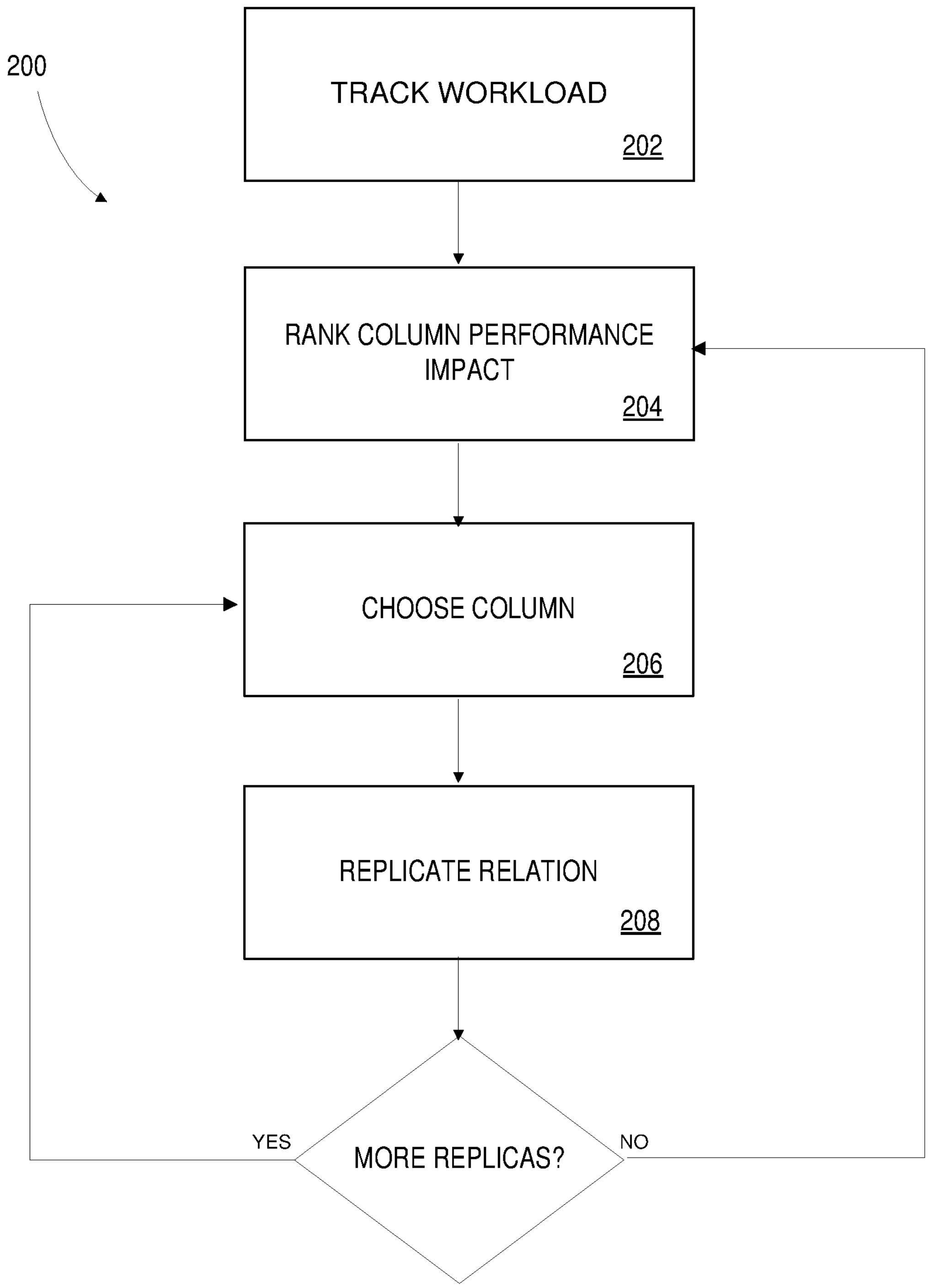

200
TRACK WORKLOAD
202
RANK COLUMN PERFORMANCE IMPACT
204
CHOOSE COLUMN
206
REPLICATE RELATION
208
MORE REPLICAS?
YES
NO

FIG.9

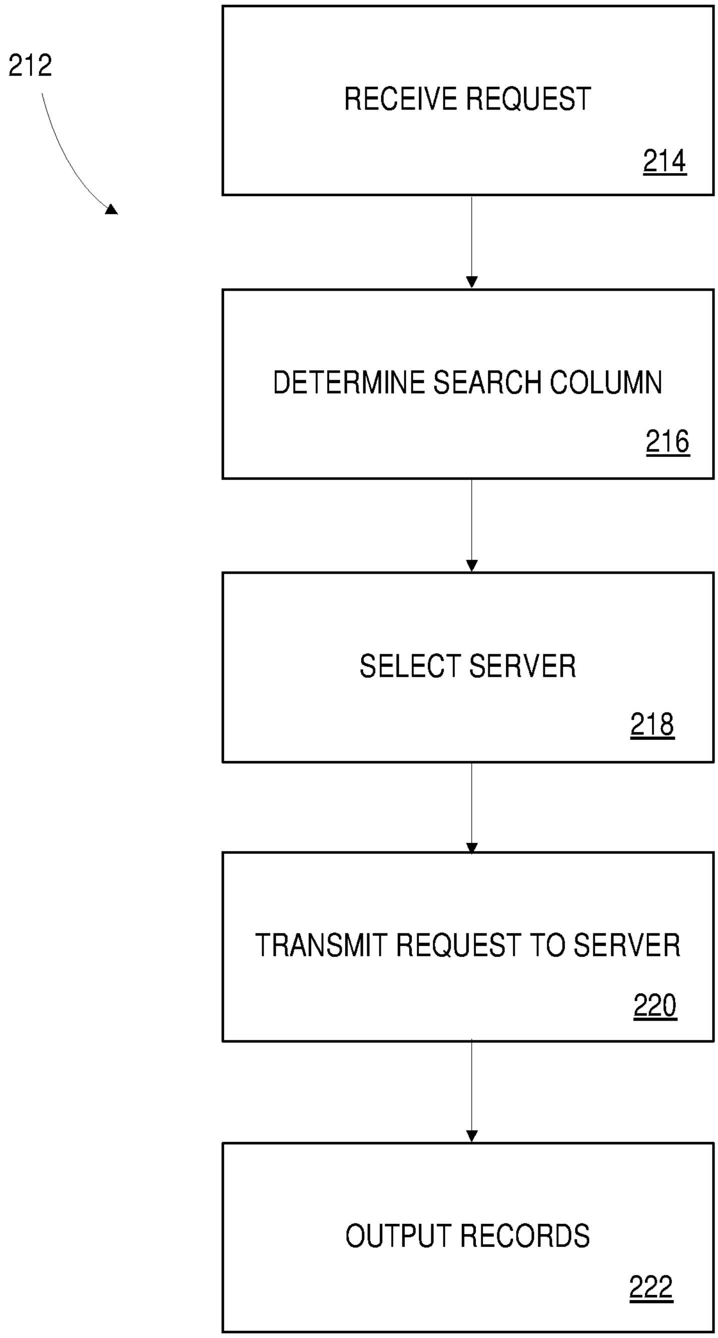

212
RECEIVE REQUEST
214
DETERMINE SEARCH COLUMN
216
SELECT SERVER
218
TRANSMIT REQUEST TO SERVER
220
OUTPUT RECORDS
222

FIG.10

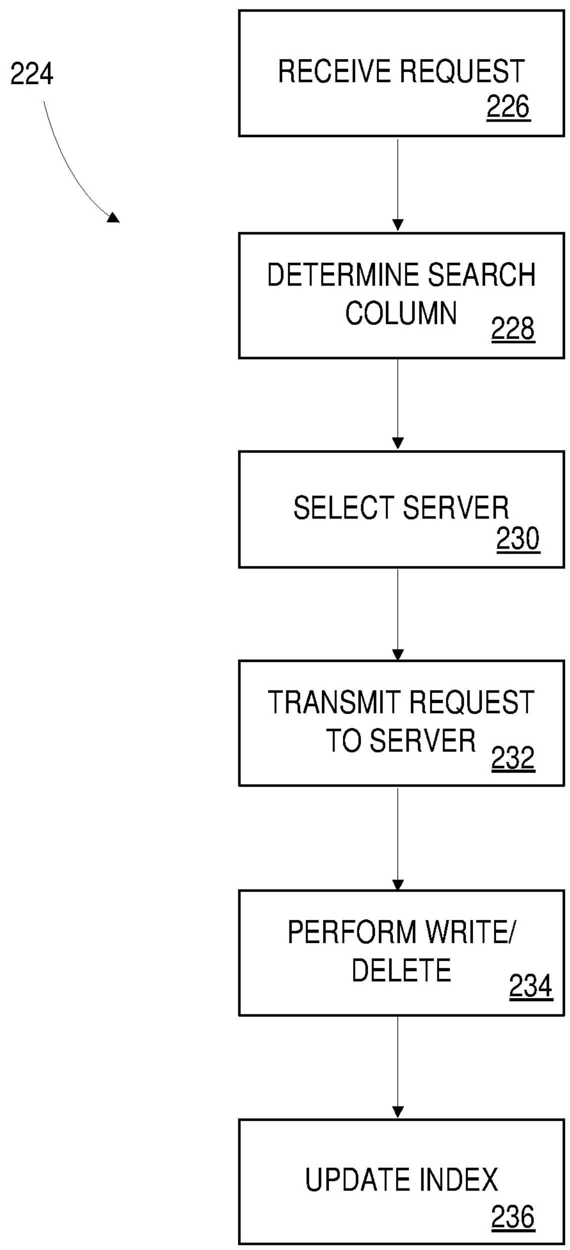

224
RECEIVE REQUEST 226
DETERMINE SEARCH COLUMN 228
SELECT SERVER 230
TRANSMIT REQUEST TO SERVER 232
PERFORM WRITE/ DELETE 234
UPDATE INDEX 236

FIG.11

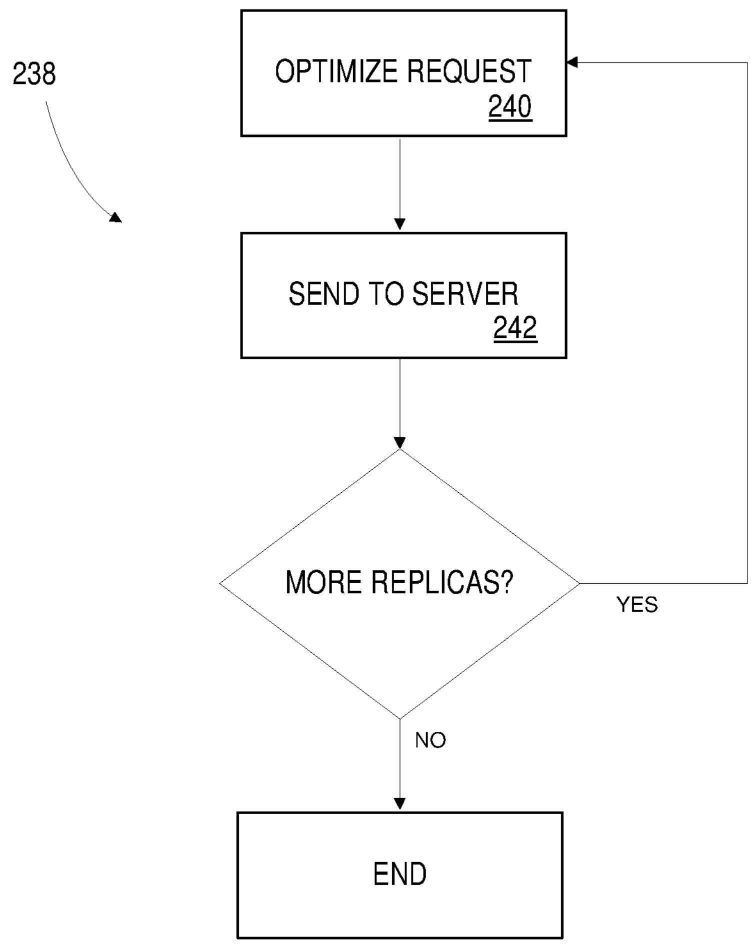

238
OPTIMIZE REQUEST
240
SEND TO SERVER
242
MORE REPLICAS?
YES
NO
END

FIG.12

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2016/081875

A. CLASSIFICATION OF SUBJECT MATTER

G06F 17/30(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G06F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

CNPAT,CNKI,WPI,EPODOC:database,table,column,key,item,order,replica+,duplica+,copy,backup,search,distributed

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2015/0378835 A1 (INTERNATIONAL BUSINESS MACHINES CORPORATION) 31 December 2015 (2015-12-31) paragraphs [0034]-[0063]	1-5，7-12，15-27
Y	US 2015/0378835 A1 (INTERNATIONAL BUSINESS MACHINES CORPORATION) 31 December 2015 (2015-12-31) paragraphs [0034]-[0063]	6，13-14
Y	US 2014/0012810 A1 (INTERNATIONAL BUSINESS MACHINES CORPORATION) 09 January 2014 (2014-01-09) paragraphs [0047]-[0060]，[0107]	6，13-14
A	CN 101866358 A (CHINESE ACAD SCI. COMPUTER TECHNOLOGY INSTITUTE) 20 October 2010 (2010-10-20) the whole document	1-27
A	US 2013/0346365 A1 (NEC CORPORATION) 26 December 2013 (2013-12-26) the whole document	1-27
A	US 2015/0347549 A1 (INTERNATIONAL BUSINESS MACHINES CORPORATION) 03 December 2015 (2015-12-03) the whole document	1-27

☐ Further documents are listed in the continuation of Box C.　　☑ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 November 2016	**14 December 2016**

Name and mailing address of the ISA/CN	Authorized officer
STATE INTELLECTUAL PROPERTY OFFICE OF THE P.R.CHINA **6, Xitucheng Rd., Jimen Bridge, Haidian District, Beijing 100088** **China**	**LIAO,Jiajia**
Facsimile No. **(86-10)62019451**	Telephone No. **(86-10)62413304**

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2016/081875

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
US	2015/0378835	A1	31 December 2015	CN	105446982	A	30 March 2016
US	2014/0012810	A1	09 January 2014	WO	2014000578	A1	03 January 2014
				CN	103514229	A	15 January 2014
				GB	2517885	A	04 March 2015
				DE	112013003205	T5	02 April 2015
CN	101866358	A	20 October 2010		None		
US	2013/0346365	A1	26 December 2013	WO	2012121316	A1	13 September 2012
				JP	5765416	B2	19 August 2015
US	2015/0347549	A1	03 December 2015		None		