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Qiao et al.

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(54) **UPGRADING REPLICATED DATABASES WITH SMALL DOWNTIME**

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(51) **Int. Cl.**

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G06F 3/06	(2006.01)
G06F 16/21	(2019.01)

(52) **U.S. Cl.**

CPC ***G06F 16/27*** (2019.01); ***G06F 3/0607*** (2013.01); ***G06F 3/064*** (2013.01); ***G06F 3/065*** (2013.01); ***G06F 3/0683*** (2013.01); ***G06F 16/21*** (2019.01)

(58) **Field of Classification Search**

CPC G06F 16/27; G06F 16/21; G06F 3/0607; G06F 3/064; G06F 3/065; G06F 3/0683

See application file for complete search history.

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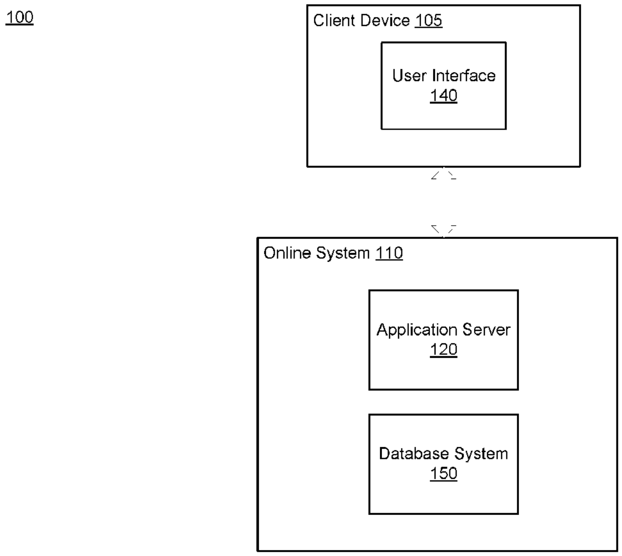
Primary Examiner — Irete F Ehichioya
Assistant Examiner — Ken Hoang

(57) **ABSTRACT**

An online system performs upgrades of replicated databases. The online system stores data in a primary site and a secondary site. The primary site comprising databases used to process client requests and a secondary site comprising databases used as standby. The online system upgrades databases of both sites by upgrading the secondary site, switching client requests to the secondary site while using the databases of primary site as standby databases. The online system then upgrades the primary site. The process allows the online system to upgrade databases with small down time.

18 Claims, 16 Drawing Sheets



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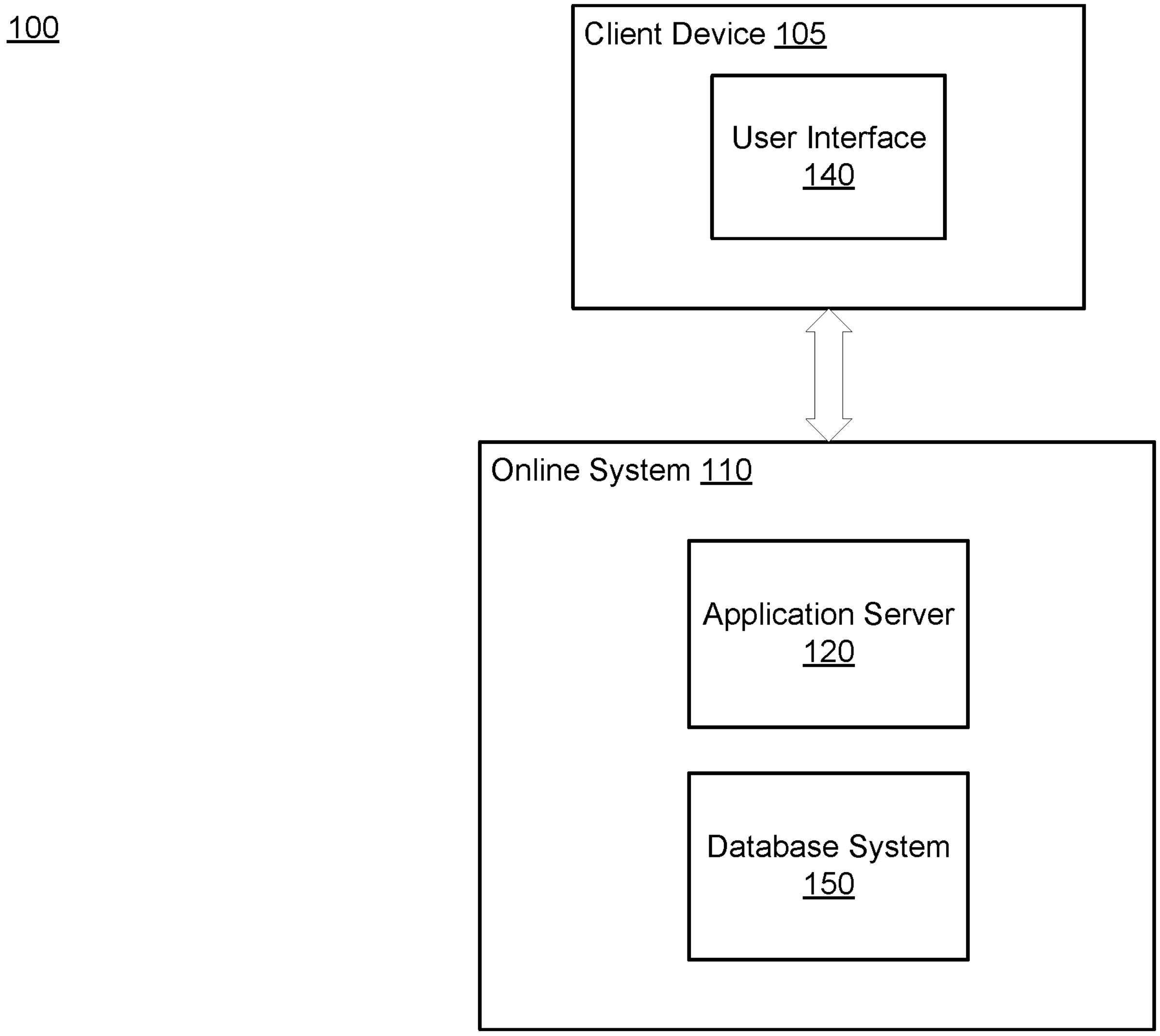
100
Client Device 105
User Interface 140
Online System 110
Application Server 120
Database System 150

FIG. 1

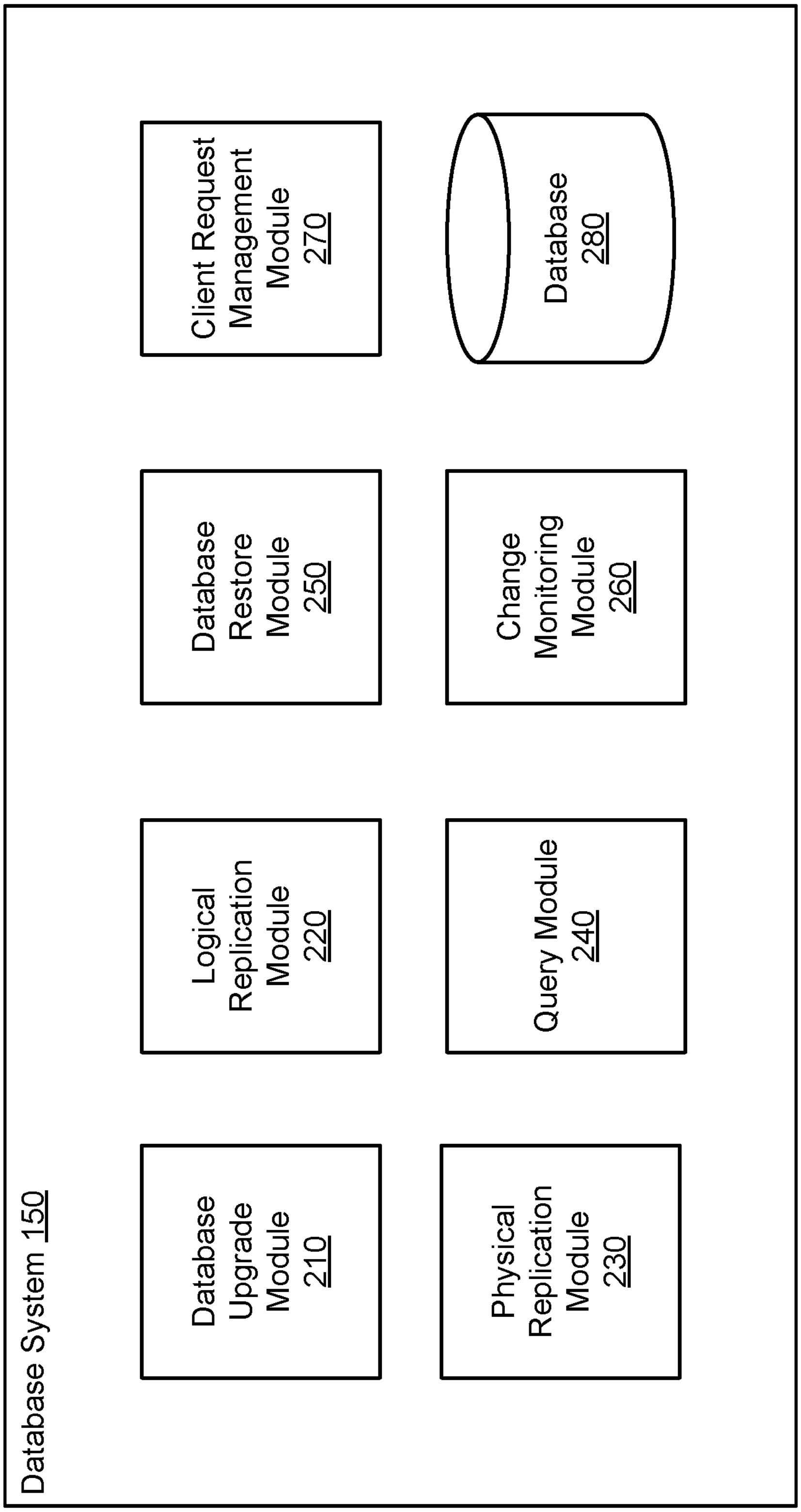
Database System 150
Database Upgrade Module 210
Logical Replication Module 220
Database Restore Module 250
Client Request Management Module 270
Physical Replication Module 230
Query Module 240
Change Monitoring Module 260
Database 280

FIG. 2

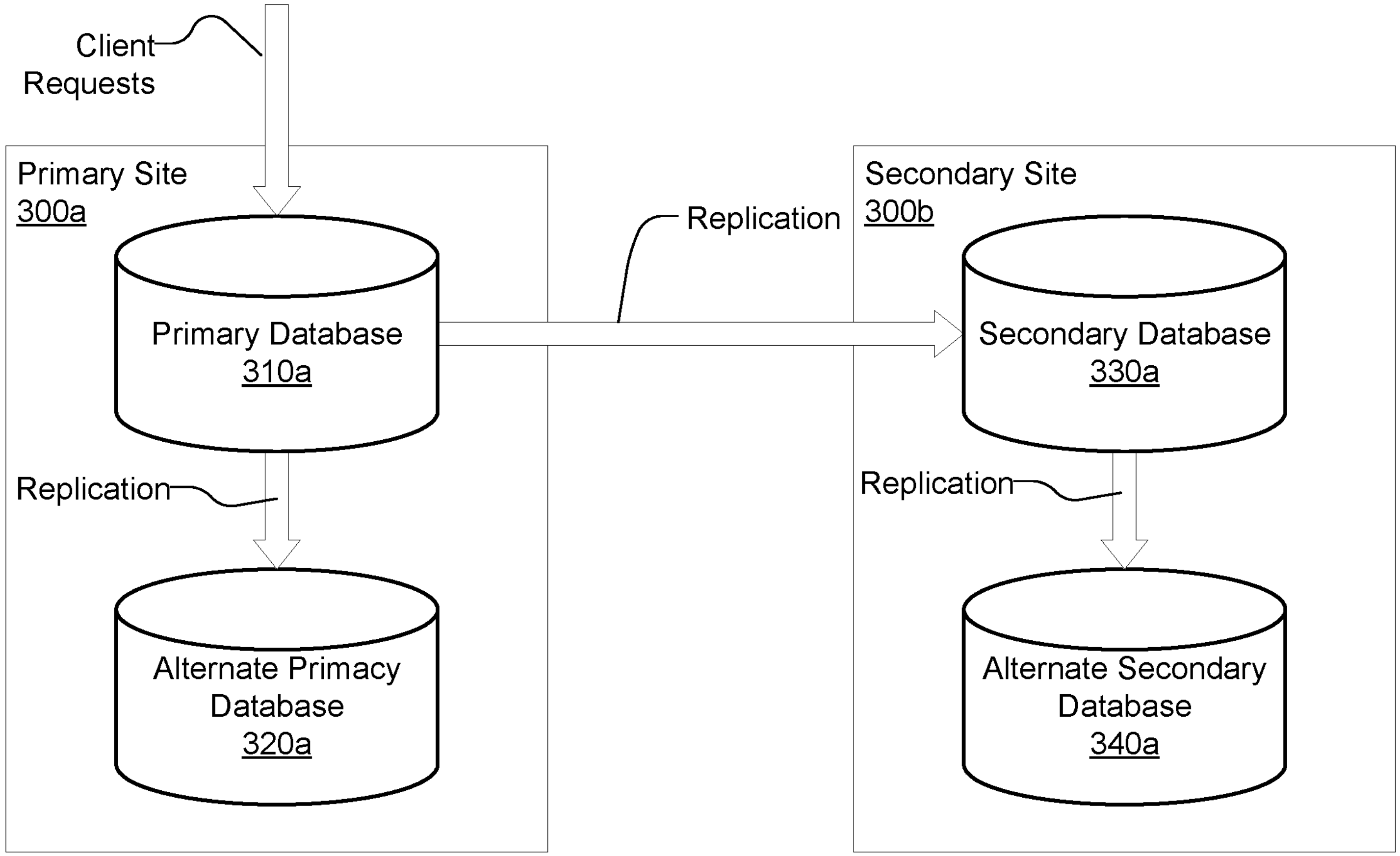
Client Requests
Primary Site
300a
Primary Database
310a
Replication
Alternate Primacy Database
320a
Replication
Secondary Site
300b
Secondary Database
330a
Replication
Alternate Secondary Database
340a

FIG. 3

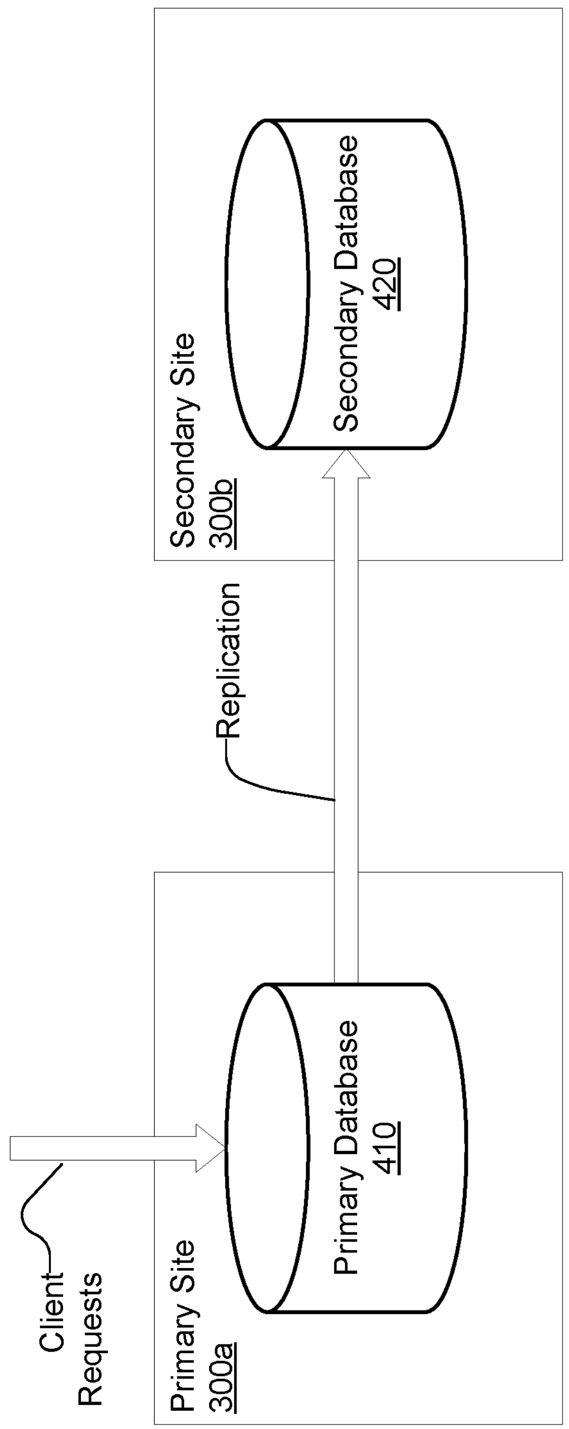
Client Requests
Primary Site
300a
Primary Database
410
Replication
Secondary Site
300b
Secondary Database
420

FIG. 4

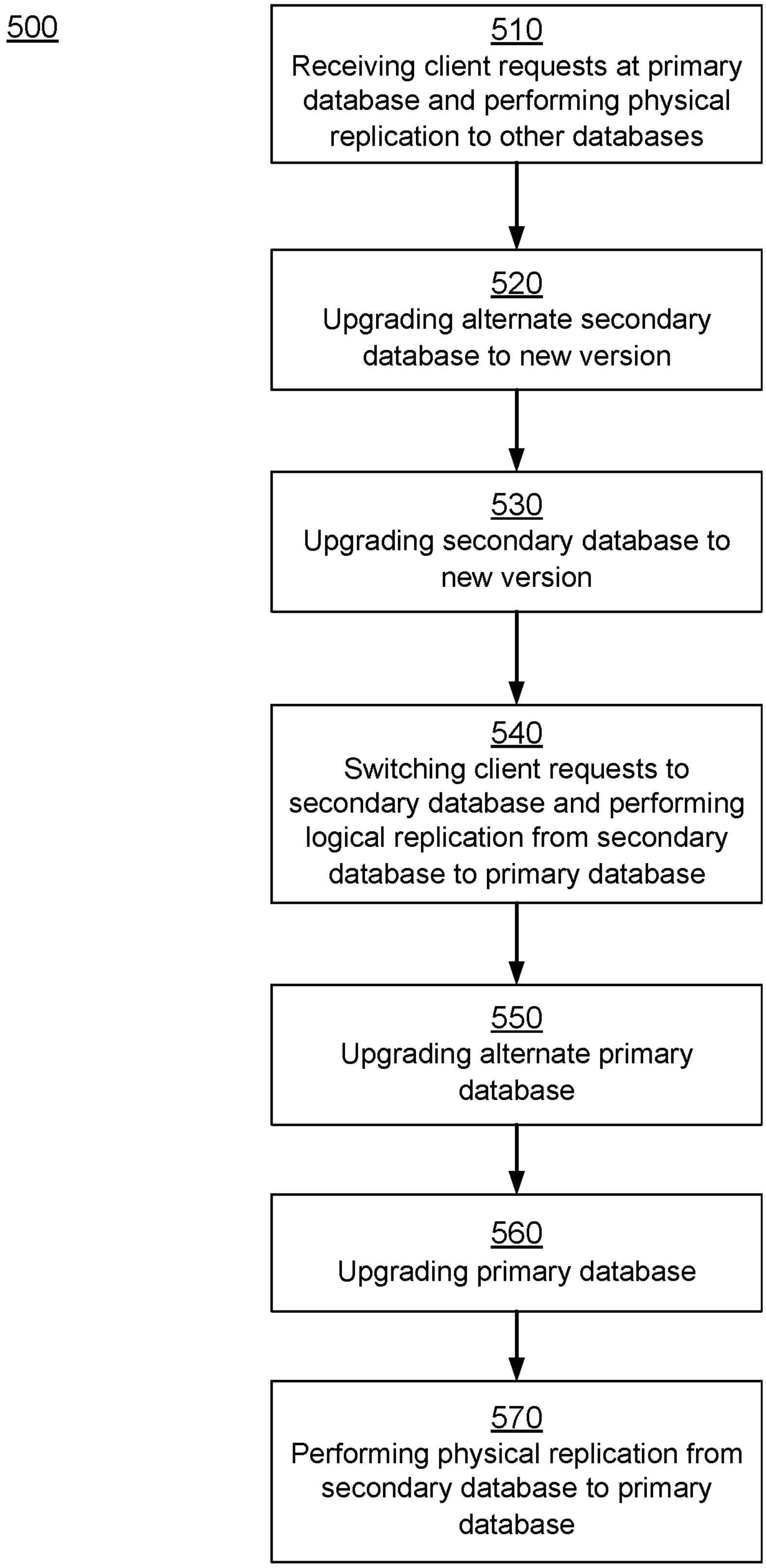
500
510
Receiving client requests at primary database and performing physical replication to other databases
520
Upgrading alternate secondary database to new version
530
Upgrading secondary database to new version
540
Switching client requests to secondary database and performing logical replication from secondary database to primary database
550
Upgrading alternate primary database
560
Upgrading primary database
570
Performing physical replication from secondary database to primary database

FIG. 5

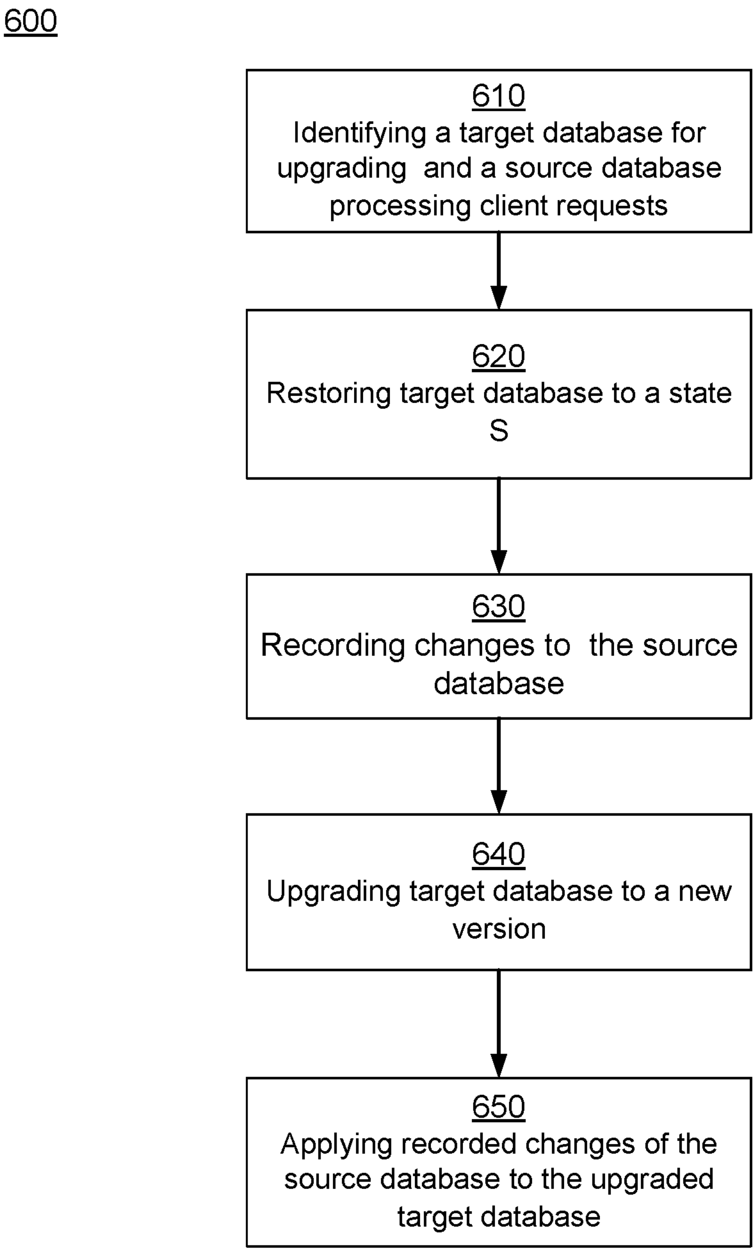
600
610
Identifying a target database for upgrading and a source database processing client requests
620
Restoring target database to a state S
630
Recording changes to the source database
640
Upgrading target database to a new version
650
Applying recorded changes of the source database to the upgraded target database

FIG. 6

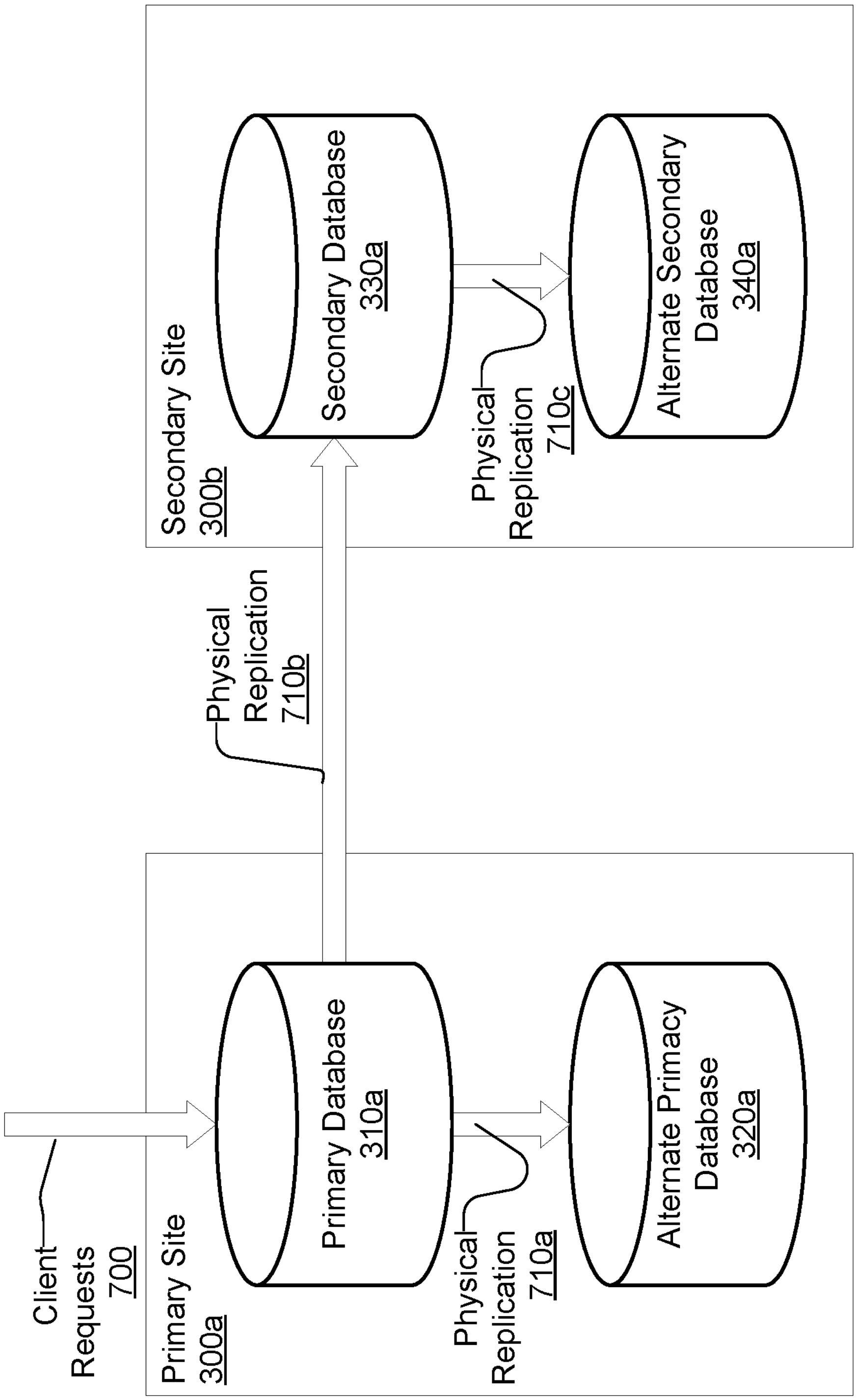
Client Requests 700
Primary Site 300a
Primary Database 310a
Physical Replication 710a
Alternate Primacy Database 320a
Physical Replication 710b
Secondary Site 300b
Secondary Database 330a
Physical Replication 710c
Alternate Secondary Database 340a

FIG. 7A

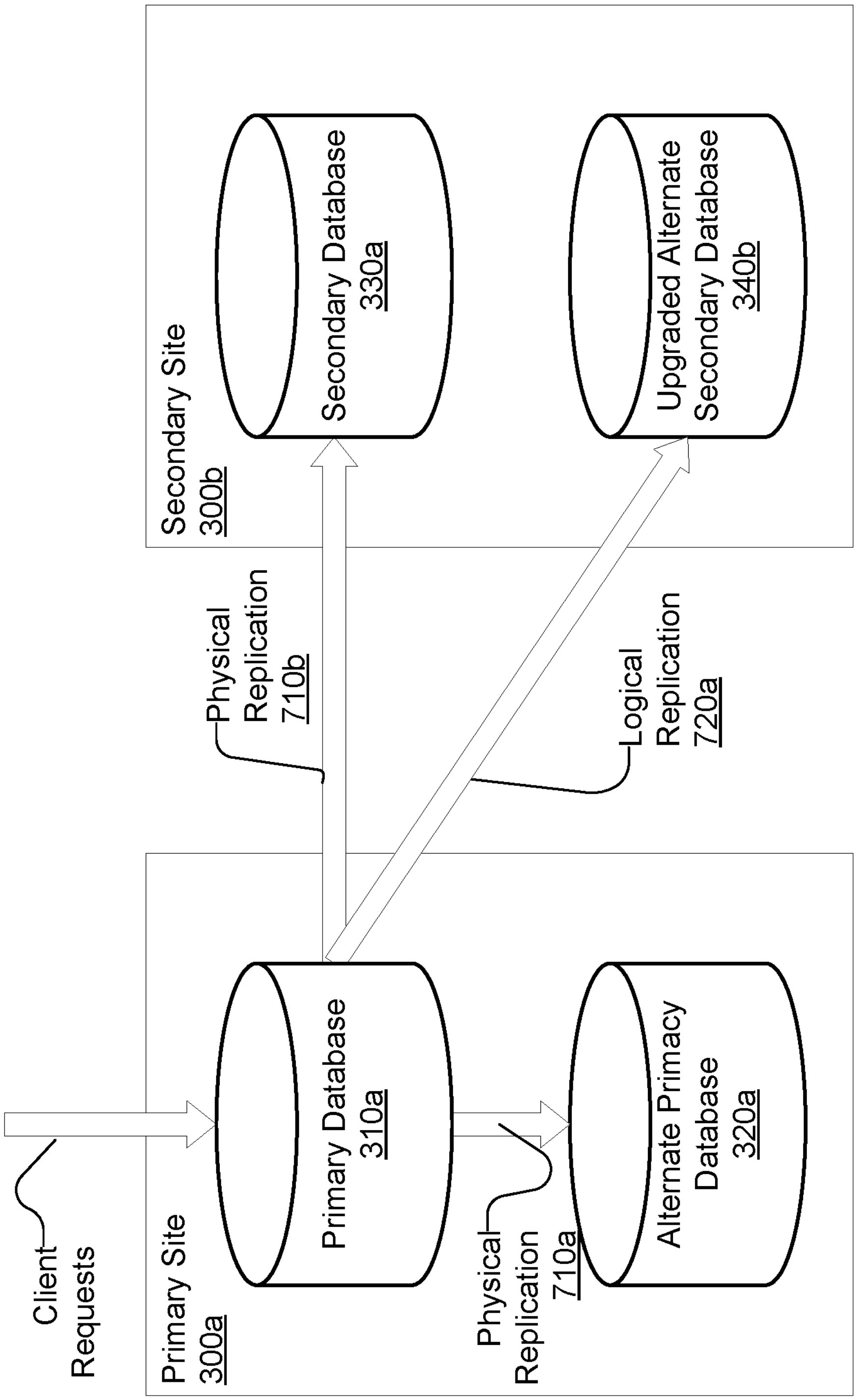
Client Requests
Primary Site 300a
Primary Database 310a
Physical Replication 710a
Alternate Primacy Database 320a
Physical Replication 710b
Logical Replication 720a
Secondary Site 300b
Secondary Database 330a
Upgraded Alternate Secondary Database 340b

FIG. 7B

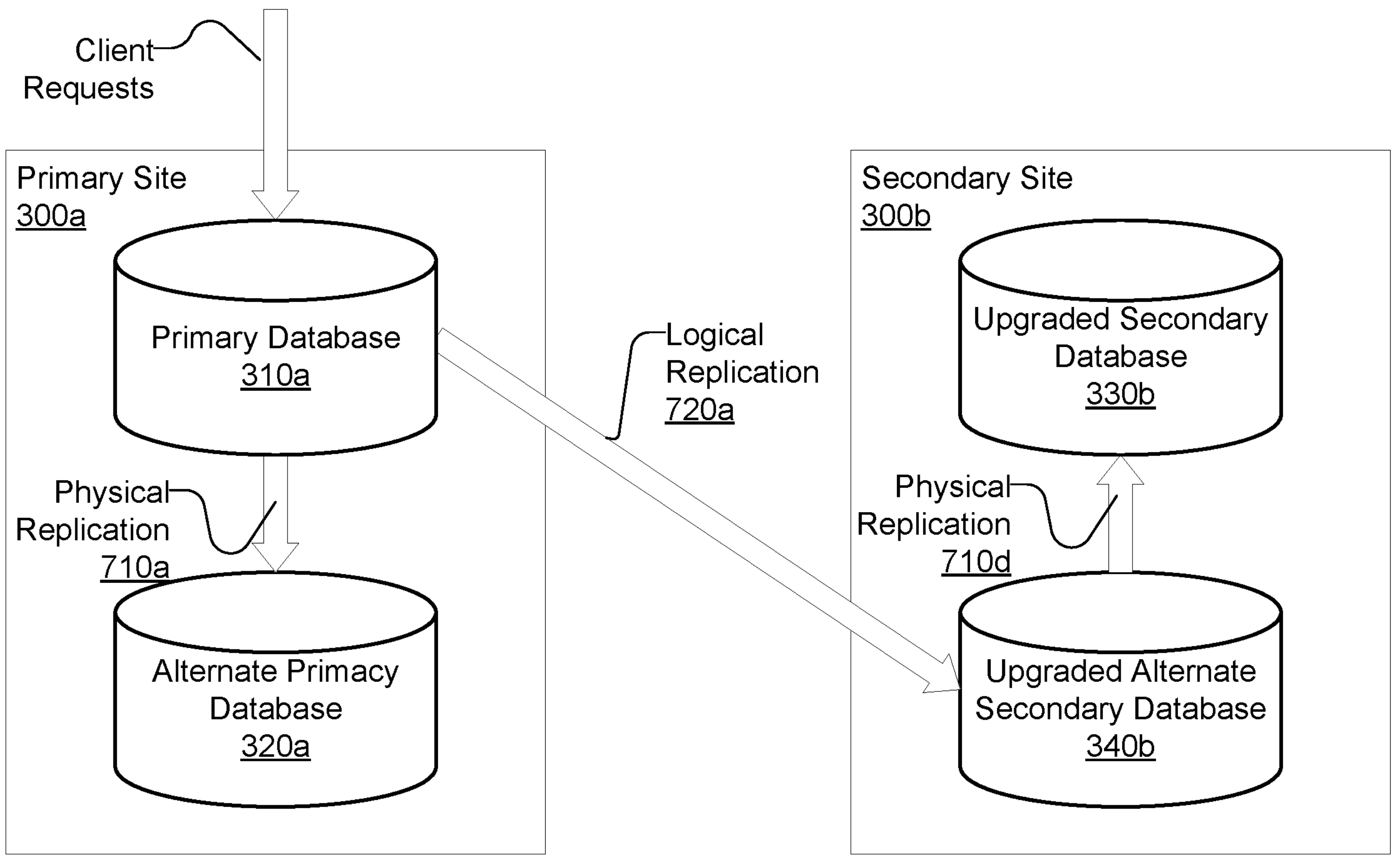
Client Requests
Primary Site
300a
Primary Database
310a
Physical Replication
710a
Alternate Primacy Database
320a
Logical Replication
720a
Secondary Site
300b
Upgraded Secondary Database
330b
Physical Replication
710d
Upgraded Alternate Secondary Database
340b

FIG. 7C

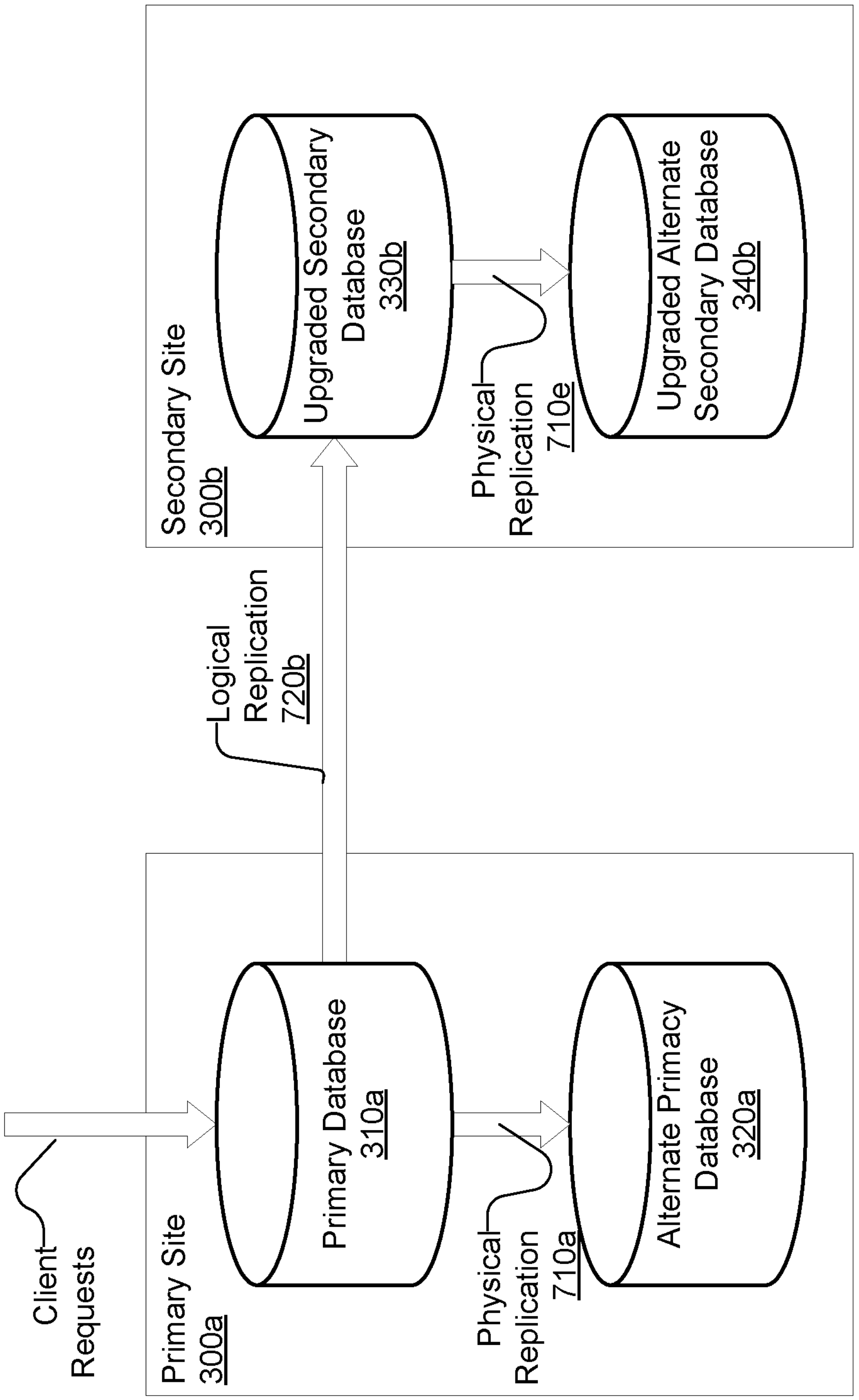
Client Requests
Primary Site 300a
Primary Database 310a
Physical Replication 710a
Alternate Primacy Database 320a
Logical Replication 720b
Secondary Site 300b
Upgraded Secondary Database 330b
Physical Replication 710e
Upgraded Alternate Secondary Database 340b

FIG. 7D

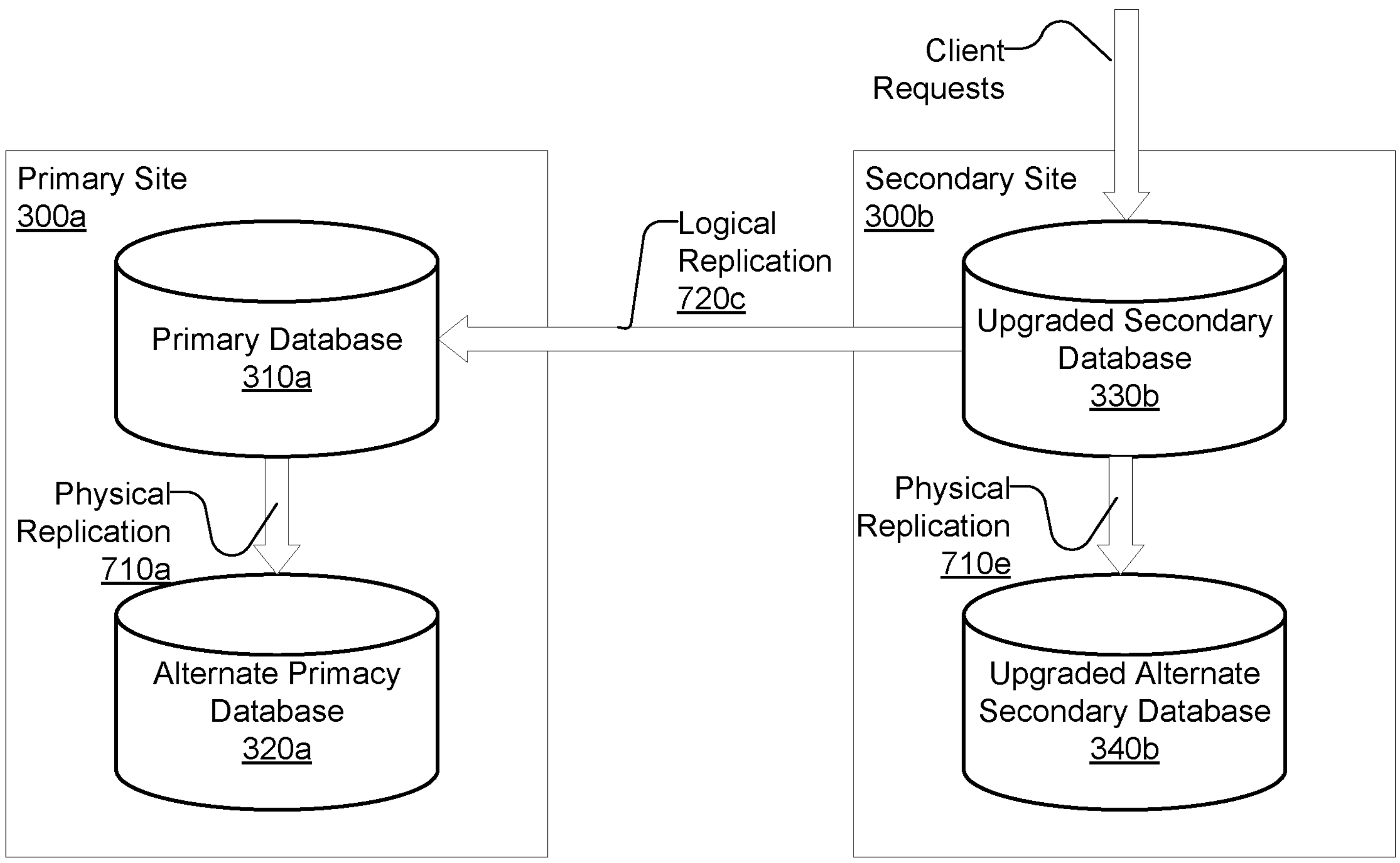
Client
Requests
Primary Site
300a
Primary Database
310a
Physical
Replication
710a
Alternate Primacy
Database
320a
Logical
Replication
720c
Secondary Site
300b
Upgraded Secondary
Database
330b
Physical
Replication
710e
Upgraded Alternate
Secondary Database
340b

FIG. 7E

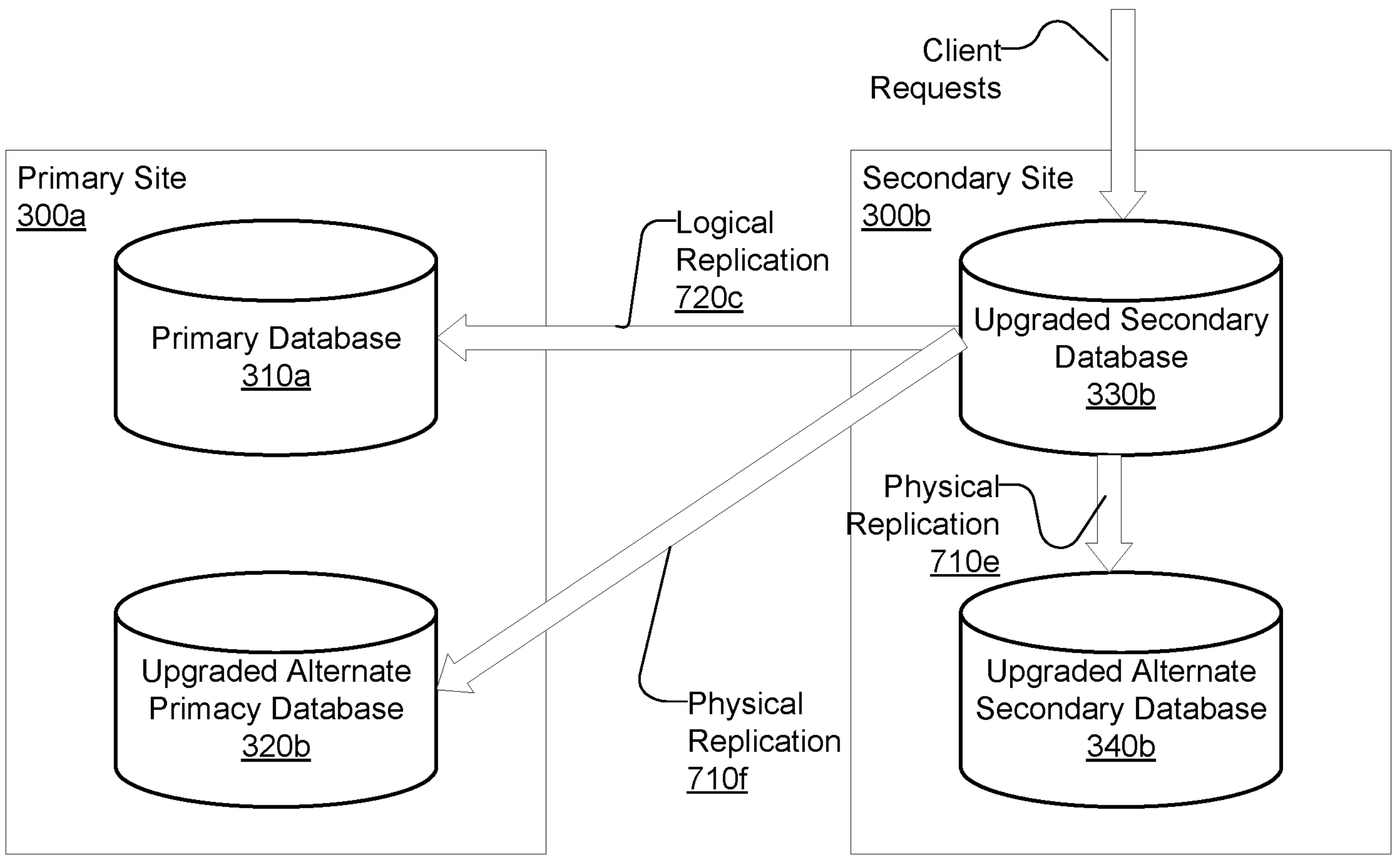
Client Requests
Primary Site
300a
Primary Database
310a
Upgraded Alternate Primacy Database
320b
Logical Replication
720c
Physical Replication
710f
Secondary Site
300b
Upgraded Secondary Database
330b
Physical Replication
710e
Upgraded Alternate Secondary Database
340b

FIG. 7F

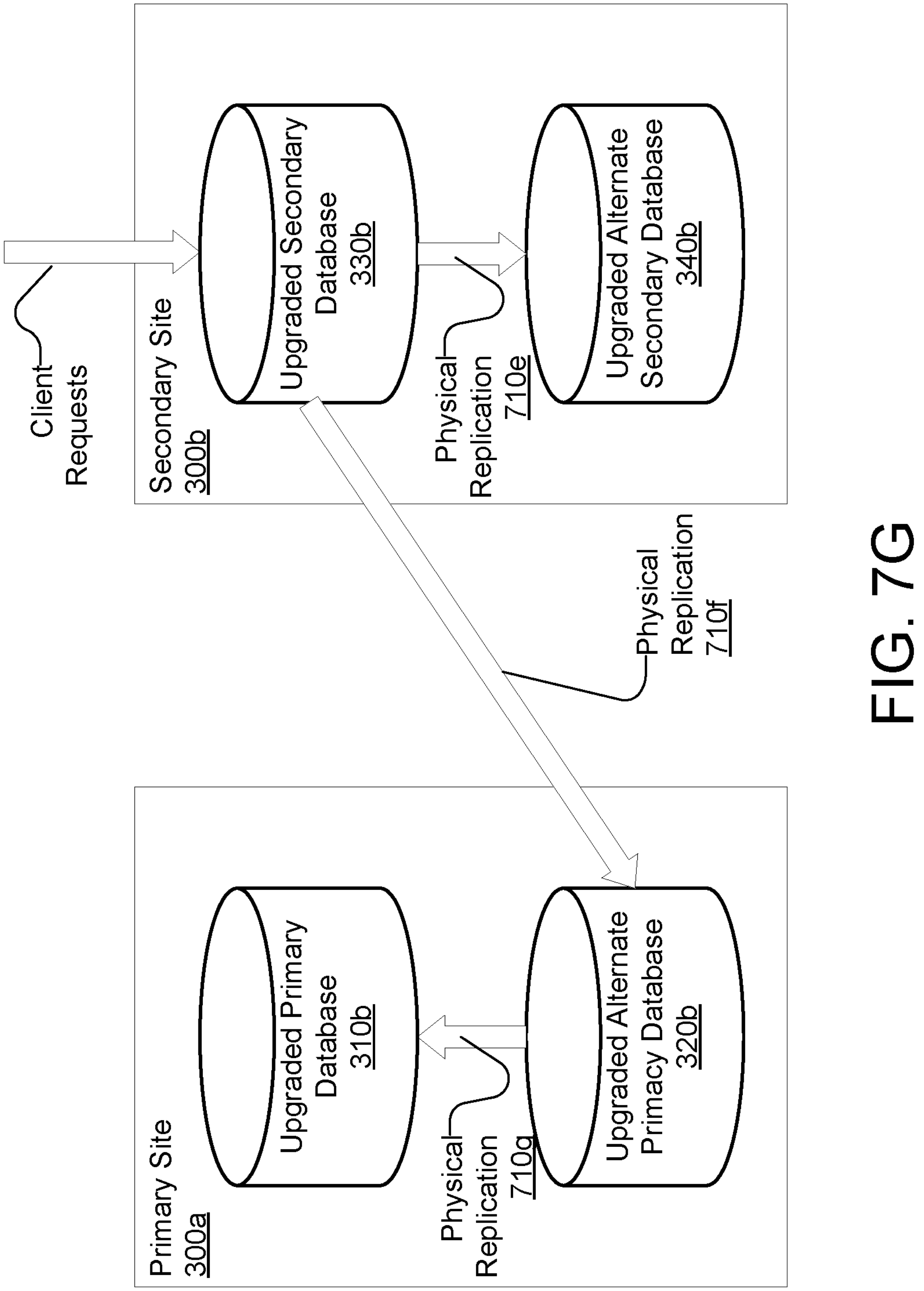
Secondary Site
300b
Client
Requests
Upgraded Secondary
Database
330b
Physical
Replication
710e
Upgraded Alternate
Secondary Database
340b
Physical
Replication
710f
Primary Site
300a
Upgraded Primary
Database
310b
Physical
Replication
710g
Upgraded Alternate
Primacy Database
320b

FIG. 7G

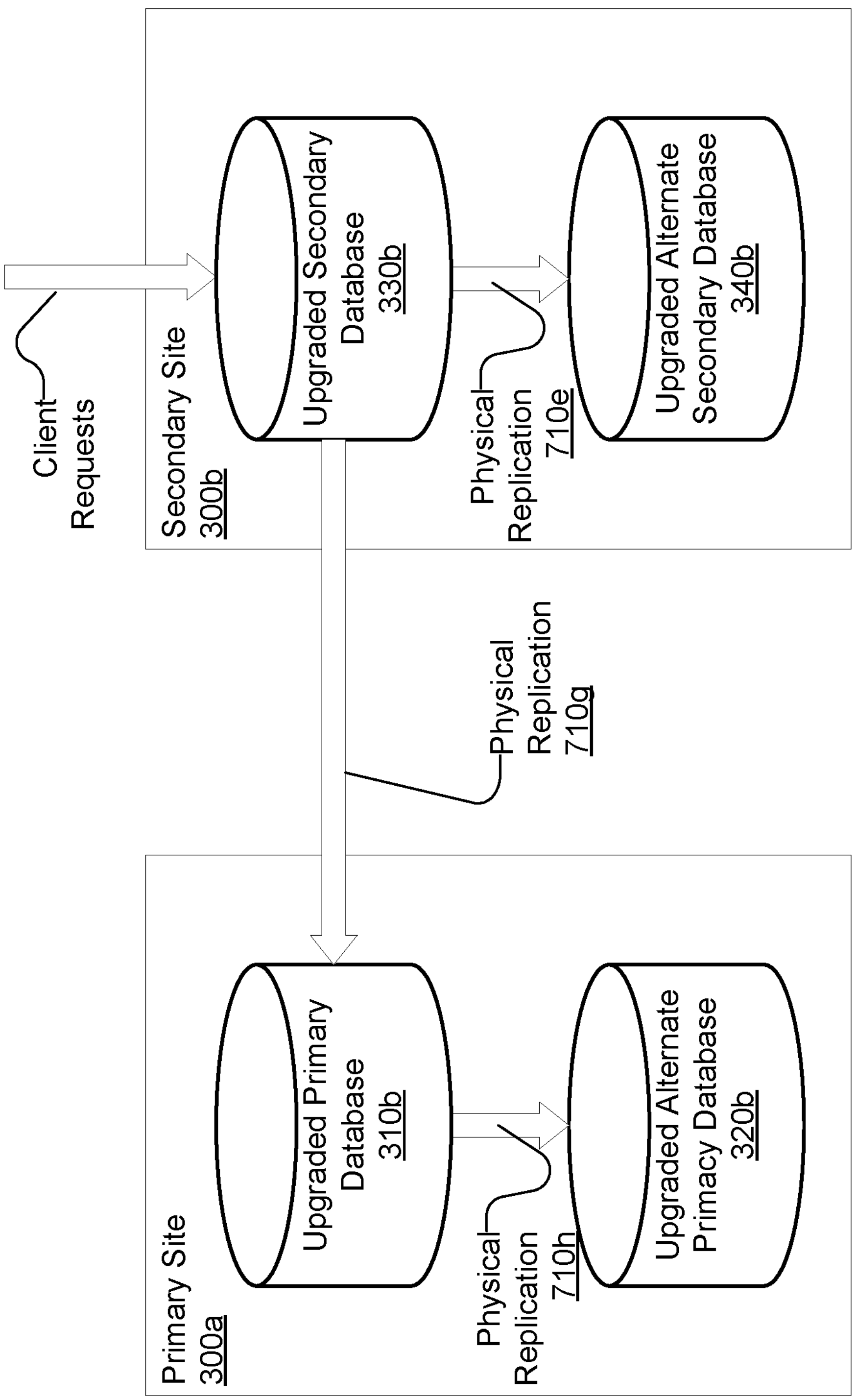
Client Requests
Secondary Site
300b
Upgraded Secondary Database
330b
Physical Replication
710e
Upgraded Alternate Secondary Database
340b
Physical Replication
710g
Primary Site
300a
Upgraded Primary Database
310b
Physical Replication
710h
Upgraded Alternate Primacy Database
320b

FIG. 7H

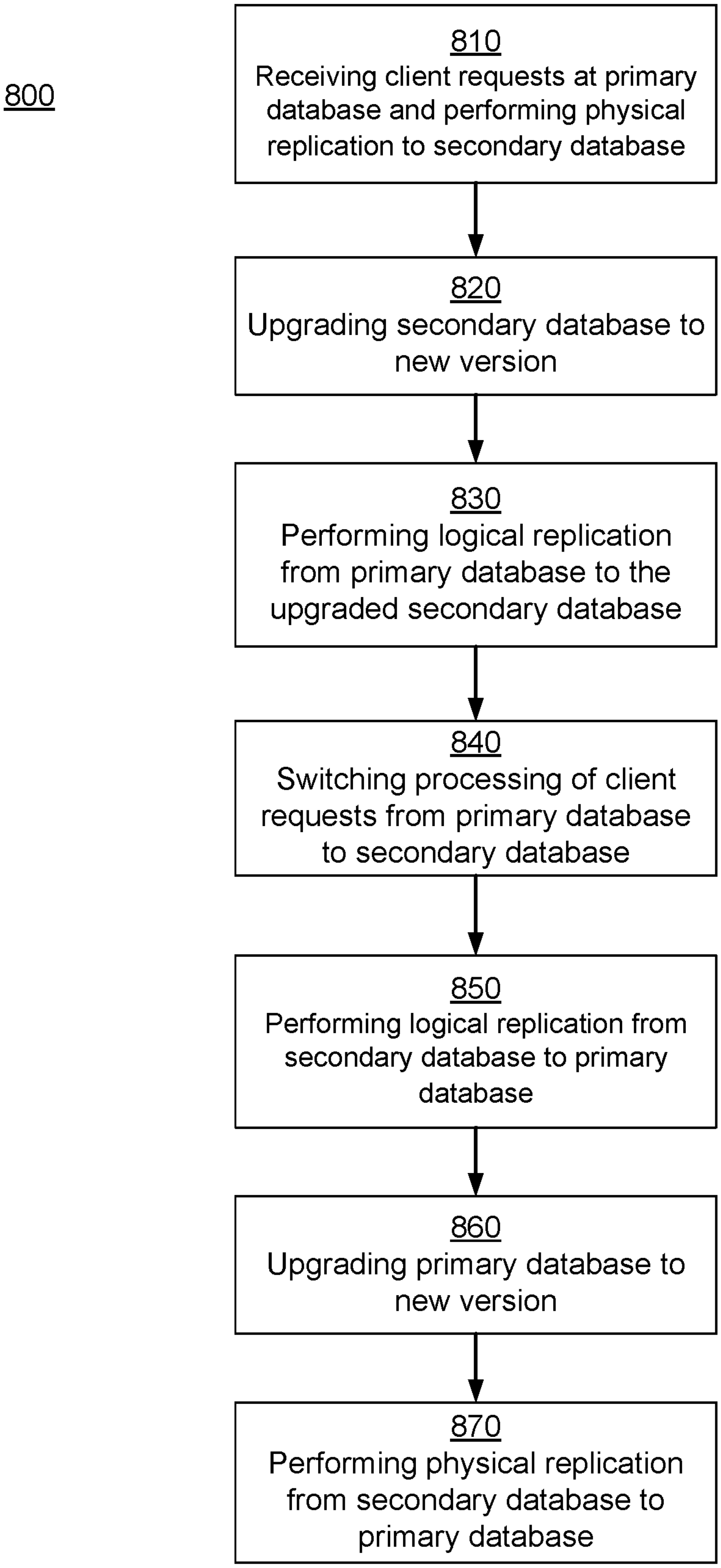
800
810
Receiving client requests at primary database and performing physical replication to secondary database
820
Upgrading secondary database to new version
830
Performing logical replication from primary database to the upgraded secondary database
840
Switching processing of client requests from primary database to secondary database
850
Performing logical replication from secondary database to primary database
860
Upgrading primary database to new version
870
Performing physical replication from secondary database to primary database

FIG. 8

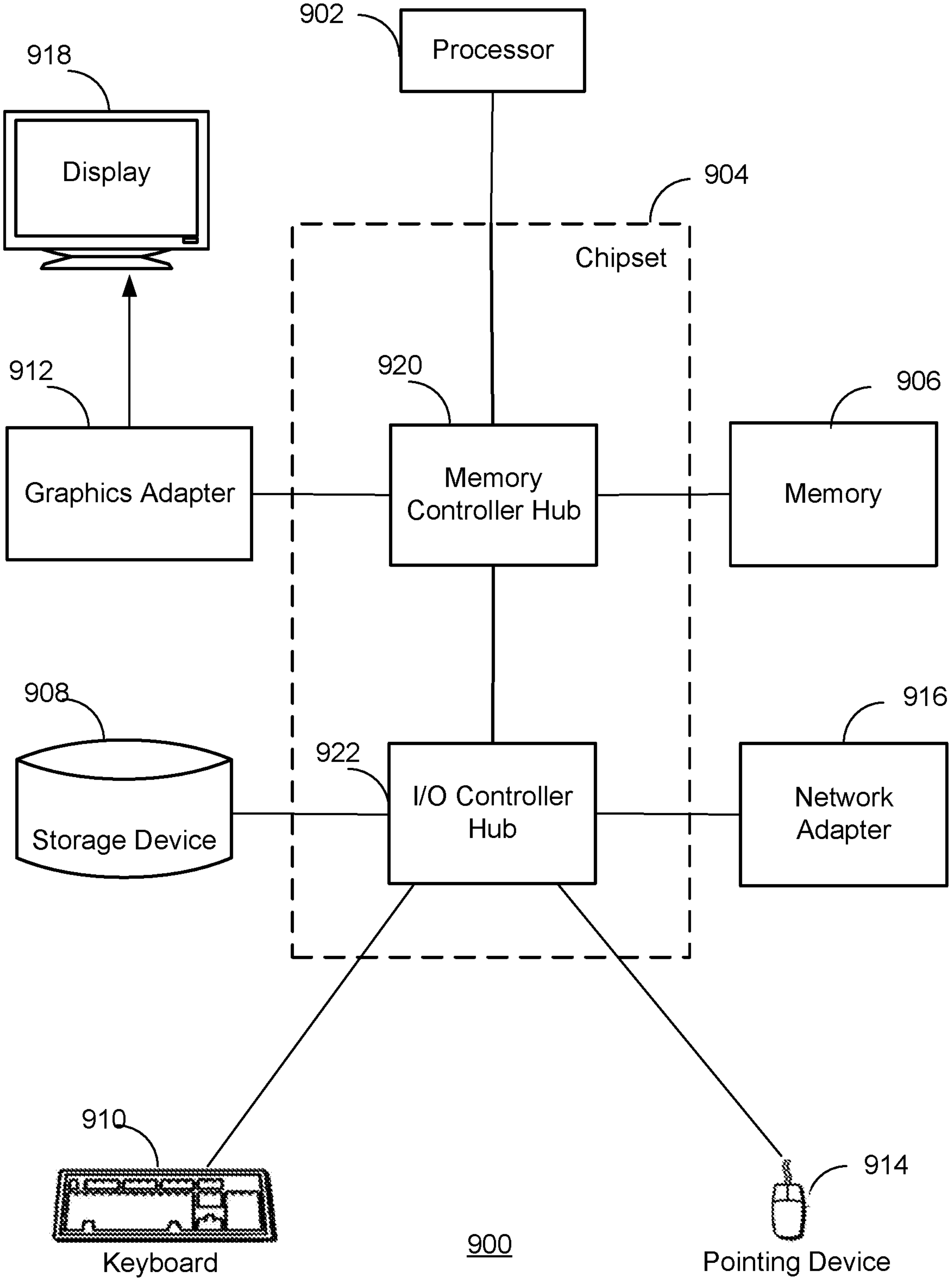
902
Processor
918
Display
904
Chipset
912
920
906
Graphics Adapter
Memory Controller Hub
Memory
908
916
922
Storage Device
I/O Controller Hub
Network Adapter
910
914
Keyboard
900
Pointing Device

FIG. 9

UPGRADING REPLICATED DATABASES WITH SMALL DOWNTIME

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims a benefit of U.S. Patent Application Ser. No. 62/989,531, filed Mar. 13, 2020, the contents of which are incorporated by reference herein.

BACKGROUND

Field of Art

This disclosure relates in general to replicated databases used by online systems such as multi-tenant systems and in particular to performing upgrade of replicated databases used by the online system with small downtime of the online system.

Description of the Related Art

Online systems typically store data in a database, for example, user information, information describing different types of objects, information describing activities such as online transactions performed by the online system. The amount of data stored in a database of an online system can be several terabytes. Online system such as multi-tenant systems store data of multiple enterprises in a database or in multiple databases. Accordingly, the amount of data stored in a database can be several hundred terabytes. Furthermore, the multi-tenant system may store data in several databases, each database storing data of multiple tenants of the multi-tenant system. Online systems often use database replication to store copies of the same data. For example, each database maybe replicated to store the data in multiple databases for supporting disaster recovery or for performing backup and restore operations.

An online system may have to perform upgrades of their databases. This may be required, for example, if the database vendor ships a newer version that supports new features, security fixes, reduced bugs, improved performance, and so on. Upgrading such large databases can take several hours and even days. If the online system encounters certain issues during the upgrade, for example, unexpected defects in the code, the delay caused by the upgrade can be significantly larger, for example, several days or weeks. A multi-tenant system can perform several thousand database transactions per second and over a billion transactions in a day. If the database is not available for several hours or days, users are unable to perform these transactions. Such large amount of downtime is unacceptable for several applications.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a block diagram of a system environment **100** illustrating use of an online system that uses a database, according to one embodiment.

FIG. **2** is a block diagram illustrating architecture of a database system, according to one embodiment.

FIG. **3** is a block diagram illustrating architecture of a database replicated across multiple sites, according to one embodiment.

FIG. **4** is a block diagram illustrating architecture of a database replicated across multiple sites, according to another embodiment.

FIG. **5** is a flow chart illustrating the process for performing a database upgrade for the online system, according to one embodiment.

FIG. **6** is a flow chart illustrating the process for upgrading a particular database, according to one embodiment.

FIGS. **7**A-H illustrate various steps of a database upgrade for an online system, according to one embodiment.

FIG. **8** is a flow chart illustrating the process for performing a database upgrade for the online system, according to another embodiment.

FIG. **9** is a block diagram illustrating a functional view of a typical computer system for use in the environment of FIG. **1** according to one embodiment.

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

The figures use like reference numerals to identify like elements. A letter after a reference numeral, such as "**115***a*," indicates that the text refers specifically to the element having that particular reference numeral. A reference numeral in the text without a following letter, such as "**115**," refers to any or all of the elements in the figures bearing that reference numeral.

DETAILED DESCRIPTION

An online system performs upgrades of replicated databases with small downtime. Embodiments of the invention perform database upgrades with downtime reduced to few minutes when the client requests are redirected from one database to another database. This is a significant improvement compared to conventional techniques that cause the database to be down during the entire duration of the database upgrade that can be several hours or days. Accordingly, embodiments of the invention increase availability of databases during an upgrade process.

According to an embodiment, the online system stores data in (1) a primary site comprising a primary set of databases processing client requests, and (2) a secondary site comprising a secondary set of databases used as standby databases. The online system; receives a request to upgrade databases of both sites to a new version. The online system upgrades the secondary site, switches client requests to the secondary set of databases using the primary set of databases as standby databases, and then upgrades the primary site.

The online system upgrades the secondary site as follows. The online system identifies a database (D**1**) of the secondary site for upgrading and restores the first database to a target state T**1**. The online system records changes to a database (Dp) of the primary set starting from a state corresponding to the target state T**1**. The online system upgrades the database D**1** and applies the recorded changes of the database Dp to the upgraded database D**1**.

The online system upgrades the primary site as follows. The online system identifies a database (D**2**) of the primary site for upgrading. The online system restores the database D**2** to a second target state. The online system records changes to a database (Ds) of the secondary site starting from a state corresponding to the second target state T**2**. The online system upgrades the database D**2** and applies the recorded changes of the database Ds to the upgraded database D**2**.

In an embodiment, responsive to switching client requests to the secondary set of databases, client request are directed to a secondary database of the secondary set of databases. Accordingly, changes to the secondary database are replicated to a database of the primary set of databases using a logical replication platform.

In an embodiment, before upgrading database of the secondary set of databases, client request are directed to a primary database of the primary set of databases and changes to the primary database are replicated to a database of the secondary set of databases using physical replication that performs storage block level replication.

In an embodiment, after upgrading database of the secondary site, client request are directed to a secondary database and changes to the secondary database are replicated to a database of the primary set of databases using physical replication.

In an embodiment, the primary set of databases further includes an alternate primary database and the secondary set of databases further includes an alternate secondary database, wherein replication is used to copy data across databases within each set of databases.

In an embodiment, the set of databases of the secondary site comprises a plurality of databases. After upgrading the secondary database to the new version, the online system upgrades one or more other databases from the set of databases of the secondary site to the new version. Switching client requests to the secondary set of databases comprises directing the requests to one of the upgraded databases from the set of databases of the secondary site.

In an embodiment, the online system is a multi-tenant system and each database from the primary and secondary sets of databases stores data of a plurality of tenants.

Overall System Environment

FIG. **1** is a block diagram of a system environment **100** illustrating use of an online system that uses a database, according to one embodiment. The system environment **100** comprises an online system **110** and one or more client devices **105**. In other embodiments, the system environment **100** may include other more or fewer components, for example, there may be third party systems that interact with the online system **110**.

The online system **110** comprises one or more application servers **120** and a database system **150**. The online system **110** may include other modules than those shown in FIG. **1**. Functionality indicated as being performed by a particular module as described herein may be performed by other modules. The application servers **120** comprises instructions for various applications executing on the online system **110** that users can access via client devices **105**.

In some embodiments, the online system **110** is a multi-tenant system. Each tenant may be an enterprise. Each tenant may represent a customer of the multi-tenant system that has multiple users that interact with the multi-tenant system via client devices **105**.

A multi-tenant system stores data for multiple tenants in the same physical database. However, the database is configured so that data of one tenant is kept logically separate from that of other tenants so that one tenant does not have access to another tenant's data, unless such data is expressly shared. It is transparent to tenants that their data may be stored in a table that is shared with data of other customers. A database table may store rows for a plurality of tenants. Accordingly, in a multi-tenant system, various elements of hardware and software of the system may be shared by one or more tenants. For example, the multi-tenant system may execute an application server that simultaneously processes requests for a number of tenants. However, the multi-tenant system enforces tenant-level data isolation to ensure that jobs of one tenant do not access data of other tenants.

The database system **150** manages data that is processed by the online system **110**. In embodiments where the online system is a multi-tenant system, the database system **150** stores data for various tenants of the multi-tenant system. The database system **150** may store data for different tenants in separate physical structures, for example, separate database tables or separate databases. Alternatively, the database system **150** may store data of multiple tenants in a shared structure. For example, user accounts for all tenants may share the same database table. However, the multi-tenant system stores additional information to logically separate data of different tenants. The details of the database system **150** are shown in FIG. **2** and described in connection with FIG. **2**

In one embodiment, the online system **110** is a multi-tenant system that implements a web-based customer relationship management (CRM) system and the application server **120** provides users access to applications configured to implement and execute CRM software applications.

The client device **105** comprises a user interface **140** that may be provided by an application executing on the client device **105**, for example, a browser application. A user may use the user interface **140** to interact with the online system **110**. For example, the user may execute an application in connection with an interaction with one or more other users to complete a transaction.

Each component shown in FIG. **1** represents one or more computing devices. A computing device can be a conventional computer system executing, for example, a Microsoft™ Windows™-compatible operating system (OS), Apple™ OS X, and/or a Linux distribution. A computing device can also be a client device having computer functionality, such as a personal digital assistant (PDA), mobile telephone, video game system, etc. Each computing device stores software modules storing instructions.

The interactions between the various components of the system environment **100** are typically performed via a network, not shown in FIG. **1**. In one embodiment, the network uses standard communications technologies and/or protocols. In another embodiment, the entities can use custom and/or dedicated data communications technologies instead of, or in addition to, the ones described above.

Although the system architecture and the processes described herein are illustrated using a multi-tenant system, the techniques disclosed are not limited to multi-tenant systems but can be executed by any online system, for example, an online system used by a single enterprise.

System Architecture

The database system **150** may store data on multiple databases that are stored in one site of different sites. A site may refer to a physical location in which computing resources are kept. For example, a site may be a data center comprising hardware including processors and storage devices.

FIG. **2** is a block diagram illustrating architecture of a database system, according to one embodiment. The database system **150** comprises a database upgrade module **210**, a logical replication module **220**, a physical replication module **230**, a query module **240**, a database restore module **250**, a change monitoring module **260**, a client request management module **270**, and a database **280**. Other embodiments can have different and/or other components than the ones described here, and the functionalities can be distributed among the components in a different manner.

The database **280** stores data and allows users to perform queries that may access data as well as modify the data. For example, the database **280** may store records comprising fields and a query may insert new records, update existing records, and delete records. A query may request fields of records. The database is typically replicated. For a multi-tenant system, the database **280** may store data for multiple enterprises, each enterprise representing a tenant of the multi-tenant system.

The query module **240** processes user queries to process data stored in database **280**. In an embodiment, the query module **240** processes queries in a particular query language, for example, structured query language (SQL). A query may be used to perform an action using the database, for example, update a record, add new record, or delete a record. The query may be used to access information, for example, values stored in one or more records.

The database upgrade module **210** performs upgrades of database **280**. The upgrade of a database upgrades both the instructions executed for processing data of the database as well as the data stored in the database. The instructions of the database may be stored as libraries of executable instructions, for example, binary files. As an example, the database **280** may have a version V1 and the database upgrade module **210** upgrades the database **280** to a newer version V2. An upgrade may update one or more libraries storing instructions of the database, for example, to add new features or to fix certain known defects in the instructions.

The physical replication module **230** performs replication by copying storage blocks. The physical replication module **230** performs replication of data from a source database to a target database. Accordingly, if there are changes in the storage blocks of the source database, the physical replication module **230** propagates the changes to the target database by sending information describing the storage blocks that changed. The physical replication is performed only if the source database and the target database have the same version. Physical replication cannot be performed across two databases having different versions.

The logical replication module **220** performs logical replication from a source database to a target database. The logical replication module **220** identifies high level operations performed in the source database and performs the same operations in the target database. For example, if a transaction is performed in the source database that updates a set of records, the logical replication module **220** performs the same transaction in the target database, thereby causing the corresponding sets of records of the target database to be updated. In an embodiment, the logical replication module **220** identifies query statements corresponding to the changes performed on the source database and executes the same query statements on the target database.

The database restore module **250** restores the database to a particular state. In an embodiment, the database system **150** identifies a state of the database by a system change number and provides the system change number as input to the database restore module **250**. The database restore module **250** modifies the state of the database so that the state of the database is restored to the input state corresponding to the system change number.

The change monitoring module **260** monitors changes performed in a source database and stores information describing these changes. The database system **150** can apply the stored information describing the changes to a target database. In an embodiment, the information describing changes to a source database are represented as change logs.

The client request management module **270** directs requests received from client devices of users to a database for processing. In an embodiment, the client request management module **270** directs the requests to a particular site storing a set of databases. One of the database from the set is used for processing the requests and one or more other databases may be used as standby databases. A standby database does not process client requests directly but receives changes performed by a database that does process client requests. Accordingly, data of the standby database is kept in sync with the database that processes client requests. The standby database may be used for processing client requests if necessary, for example, if a failure occurs in the database that is currently processing client requests.

Replicated Database Configurations

FIG. **3** is a block diagram illustrating architecture of a database replicated across multiple sites, according to one embodiment. FIG. **3** shows two sites, a primary site **300***a* and a secondary site **300***b*. Each site may be a data center having a physical location on which computing resources are located for storing one or more databases. The primary site **300***a* comprises a primary database **310***a* and an alternate primary database **320***a*. The data of the primary database **310***a* is replicated to the alternate primary database **320***a*. The secondary site **300***b* comprises a secondary database **330***a* and an alternate secondary database **340***a*. The data of the secondary database **330***a* is replicated to the alternate secondary database **340***a*. The client requests are directed by the client request management module **270** to the primary site **300***a*. In particular, the client request management module **270** directs client requests to the primary database **310***a*. The data of the primary database **310***a* is replicated to the secondary database **330***a*.

In an embodiment, the alternate primary database uses less powerful hardware compared to the primary database. Accordingly, the client requests are processed by the primary database and the alternate primary database is used for performing tasks other than processing of client requests, such as backups. Similarly, the alternate secondary database uses less powerful hardware compared to the secondary database. Accordingly, if the secondary site is used for processing client requests, the client requests are processed by the secondary database and the alternate secondary database is used for performing tasks other than processing of client requests, such as backups.

FIG. **4** is a block diagram illustrating architecture of a database replicated across multiple sites, according to another embodiment. FIG. **4** also shows two sites, a primary site **300***a* and a secondary site **300***b*. The primary site **300***a* comprises a primary database **410***a* and the secondary site **300***b* comprises a secondary database **420***a*. The client requests are directed by the client request management module **270** to the primary site **300***a*. In particular, the client request management module **270** directs client requests to the primary database **310***a*. The data of the primary database **410***a* is replicated to the secondary database **420***a*.

Processes

FIGS. **5-8** show various flowcharts illustrating processes executed by the database system **150**. Various embodiments can perform the steps of the processes in different orders than those indicated herein. Moreover, other embodiments can include different and/or additional steps than the ones described herein.

FIG. **5** is a flow chart illustrating the process for performing a database upgrade for the online system, according to one embodiment. The process applies to the replicated database configuration illustrated in FIG. **3** but can be applied to other configurations as well, for example, a database configuration in which there are more than two replicated databases corresponding to each database at each site. FIG. **7**A-H illustrate various steps of a database upgrade for an online system, according to one embodiment. The steps of the flowchart of FIG. **5** are illustrated using the steps shown in FIGS. **7**A-H.

The database system **150** receives **510** client requests **700** at the primary database **310***a*. The databases at the secondary site act as standby databases. As illustrated in FIG. **7**H, the changes to the primary database are replicated **710***b* to secondary database **330***a* using physical replication. The changes to the primary database are also replicated **710***a* to the alternate primary database **320***a* using physical replication. The change to the secondary database **330***a* are replicated **710***c* to the alternate secondary database **340***a* using physical replication. The online system **110** may have several databases that are similar to primary database **310***a* at a particular site and are replicated across the same site as well as across other sites using a configuration similar to that shown in FIG. **7**A. The databases **310***a*, **320***a*, **330***a*, and **340***a* all have a current version, for example, version V1.

The database system **150** receives a request to upgrade the databases to a new version, for example, version V2. The details of the upgrade process for a particular database are illustrated in FIG. **6**. The database system **150** starts by upgrading the databases of a secondary site, i.e., any site that is not processing client requests and is used for standby purposes. The database system **150** selects a database from the set of databases of the secondary site for upgrade. In an embodiment, the database system **150** first selects the alternate secondary database **340***b* for upgrade and upgrades **520** the alternate secondary database **340***a* to obtain the upgraded alternate secondary database **340***b*.

The database system **150** may build a tree representation of the databases where each node represents a database and an edge exists between a node representing a database D**1** and a node representing a database D**2** if the data of database D**1** is replicated to database D**2**. The database system **150** upgrades databases of a site in an order that starts from leaf nodes of such a tree and traverses up the tree towards the root node. Accordingly, the database system **150** starts by upgrading the database that is not being replicated to any other database and is the destination of replication from another database. Accordingly, the database system **150** upgrades a leaf node and then upgrades a parent of the leaf node. The database system **150** reverses the direction of replication between the database corresponding to the leaf node and the database corresponding to the parent of leaf node by replicating changes to the database corresponding to the leaf node to the database corresponding to the parent of the leaf node.

FIG. **7**B illustrates a configuration in which the alternate secondary database **340***a* has been upgraded to the new version to obtain the upgraded alternate secondary database **340***b*. The database system **150** also continues physical replication **710***b* from the primary database **310***a* to the secondary database **330***a*. The database system **150** stops physical replication **710***c* from the secondary database **330***a* to the alternate secondary database **340***a*. The database system **150** starts logical replication **720***a* from the primary database **310***a* to the upgraded alternate secondary database **340***b*. The database system **150** performs logical replication **720***a* instead of physical replication from the primary database **310***a* to the upgraded alternate secondary database **340***b* since the versions of the two databases are different.

The database system **150** next selects the secondary database **330***a* for upgrade and upgrades **530** the secondary database **330***a* to obtain the upgraded secondary database **330***b*. FIG. **7**C illustrates a configuration in which the alternate secondary database **340***a* has been upgraded to the new version to obtain the upgraded alternate secondary database **340***b*. As shown in FIG. **7**C, the database system **150** continues logical replication **720***a* from the primary database **310***a* to the upgraded alternate secondary database **340***b*. The database system **150** stops physical replication **710***b* from the primary database **310***a* to the secondary database **330***a*. The database system **150** starts physical replication **710***d* from the alternate secondary database **340***b* to the secondary database **330***b*.

In an embodiment, the database system starts performing logical replication **720***b* from the primary database **310***a* to the upgraded secondary database **330***b* as illustrated in FIG. **7**D. The database system starts performing physical replication **710***e* from upgraded secondary database **330***b* to the upgraded alternate secondary database **340***b*. The physical replications **710***a* continues as shown in FIG. **7**C.

The database system **150** switches **540** client requests **700** from primary site **300***a* to the secondary site **300***b*. Accordingly, all client requests **700** are sent to a database selected from the set of databases of the secondary site **300***b*. In an embodiment, the client requests **700** are now being processed by the upgraded secondary database **330***b* as shown in FIG. **7**E. As shown in FIG. **7**E, logical replication **720***c* is performed from the upgraded secondary database **330***b* to primary database **310***a*. The physical replications **710***a* and **710***e* continue as illustrated in FIG. **7**D.

The database system **150** upgrades **550** the alternate primary database **320***a* to obtain the upgraded alternate primary database **320***b* as illustrated in FIG. **7**F. As shown in FIG. **7**F, before upgrading the alternate primary database **320***a*, the database system **150** stops the physical replication **710***a* from the primary database **310***a* to the alternate primary database **320***a*. As shown in FIG. **7**F, the database system **150** continues logical replication **720***c* from upgraded secondary database **330***b* to the primary database **720***c*. The database system **150** starts physical replication **710***f* from the upgraded secondary database **330***b* to the upgraded alternate primary database **320***b*.

The database system **150** upgrades **560** the primary database **310***a* to obtain the upgraded primary database **310***b* as illustrated in FIG. **7**G. As illustrated in FIG. **7**G, the database system **150** continues the physical replication **710***f* The database system **150** starts the physical replication **710***g* from upgraded alternate primary database **320***b* to the upgraded primary database **310***b*. The database system **150** continues the physical replication **710***e* as shown in FIG. **7**F.

At this stage all databases are upgraded to the new version. The database system starts performing **570** physical replication **710***g* from upgraded secondary database **330***b* to the upgraded primary database **310***b*. The database system **150** continues the physical replication **710***e* as shown in FIG. **7**G. The database system **150** starts physical replication **710***h* from the updated primary database **310***b* to the upgraded alternate primary database **320***b* as shown in FIG. **7**F. The configuration shown in FIG. **7**H mirrors the configuration shown in FIG. **7**A except that the client requests are processed by the upgraded secondary database **330***b* and the physical replication **710***g* is performed from the upgraded secondary database **330***b* to the upgraded primary database **310***b*.

In an embodiment, the database system may switch client requests to the primary site **300***a* again to obtain a configuration matching FIG. **7**A.

FIG. **6** is a flow chart illustrating the process for upgrading a particular database, according to one embodiment. The database system **150** upgrades a database to a new version by upgrading the binary files that stores instructions as well as the data. For example, a new version of data may store data using a different format, or use metadata that is different from the metadata of the previous version. The database system **150** executes upgrade instructions, for example, an upgrade script that modifies the data and metadata to conform to the new version.

The database system **150** identifies a target database for upgrading and a source database that is processing client requests. For example, as illustrated in FIG. 7B, for upgrading he alternate secondary database **340***a*, the database system **150** identifies the target database as the alternate secondary database **340***a* and the source database as the primary database **310***a* that is processing the client requests. Similarly, in FIG. 7E, for upgrading the alternate primary database **320***a*, the database system **150** identifies the target database as the alternate primary database **320***a* and the source database as the secondary database **330***b* that is processing the client requests.

The database system **150** identifies a state S of the target database and restores **620** of the state of the target database to state S. In an embodiment, the state S is selected as a recent consistent state of the target database. The restore operation may be performed by the database restore module **250**. The source system has a state S' corresponding to state S. The database system records **630** all changes made to the source database from state S' onwards. These changes may be stored by the change monitoring module **260** as change logs. The database system **150** shuts down the target database system and upgrades the target database system to the new version. The database system **150** applies all recorded **630** changes to the upgraded target database to bring the state of the target database to a state close to the latest state of the source database system.

FIG. **8** is a flow chart illustrating the process for performing a database upgrade for the online system, according to another embodiment. The database system **150** is configured as shown in FIG. **5** such that each site **300** has a database, the primary site **300***a* comprising a primary database **410** and he secondary site comprising a secondary database **420**. The database system receives **810** client requests at the primary database **410**. The database system **150** performs physical replication from the primary database **410** to the secondary database **420**.

The database system **150** receives a request to upgrade the databases. The database system **150** upgrades **820** the secondary database **420** to obtain an upgraded secondary database. The database system **150** upgrades **820** the secondary database **420***a* using the process described in FIG. **6** wherein the source database is the primary database **410** and the target database is the secondary database **420**. The database system **150** performs logical replication from the primary database to the upgraded secondary database. The database system **150** switches the processing of the client requests from the primary site to the secondary site. More specifically the database system **150** switches the processing of the client requests from the primary database to the upgraded secondary database. After switching the client requests to the secondary database, the database system **150** performs logical replication from the upgraded secondary database to the primary database. The database system **150** upgrades the primary database to an upgraded primary database using the process illustrated in FIG. **6** wherein the source database is the upgraded secondary database and the target database is the primary database. The database system **150** starts physical replication from the upgraded secondary database to the upgraded primary database. In an embodiment, the database system **150** may switch the client requests back to the primary site to have a configuration similar to that shown in FIG. **6** except for the primary and secondary databases being upgraded.

Computer Architecture

FIG. **9** is a high-level block diagram illustrating a functional view of a typical computer system for use as one of the entities illustrated in the environment **100** of FIG. **1** according to an embodiment. Illustrated are at least one processor **902** coupled to a chipset **904**. Also coupled to the chipset **904** are a memory **906**, a storage device **908**, a keyboard **910**, a graphics adapter **912**, a pointing device **914**, and a network adapter **916**. A display **918** is coupled to the graphics adapter **912**. In one embodiment, the functionality of the chipset **904** is provided by a memory controller hub **920** and an I/O controller hub **922**. In another embodiment, the memory **906** is coupled directly to the processor **902** instead of the chipset **904**.

The storage device **908** is a non-transitory computer-readable storage medium, such as a hard drive, compact disk read-only memory (CD-ROM), DVD, or a solid-state memory device. The memory **906** holds instructions and data used by the processor **902**. The pointing device **914** may be a mouse, track ball, or other type of pointing device, and is used in combination with the keyboard **910** to input data into the computer system **200**. The graphics adapter **912** displays images and other information on the display **918**. The network adapter **916** couples the computer system **900** to a network.

As is known in the art, a computer **900** can have different and/or other components than those shown in FIG. **9**. In addition, the computer **900** can lack certain illustrated components. For example, a computer system **900** acting as an online system **110** may lack a keyboard **910** and a pointing device **914**. Moreover, the storage device **908** can be local and/or remote from the computer **900** (such as embodied within a storage area network (SAN)).

The computer **900** is adapted to execute computer modules for providing the functionality described herein. As used herein, the term "module" refers to computer program instruction and other logic for providing a specified functionality. A module can be implemented in hardware, firmware, and/or software. A module can include one or more processes, and/or be provided by only part of a process. A module is typically stored on the storage device **908**, loaded into the memory **906**, and executed by the processor **902**.

The types of computer systems **900** used by the entities of FIG. **1** can vary depending upon the embodiment and the processing power used by the entity. For example, a client device **104** may be a mobile phone with limited processing power, a small display **918**, and may lack a pointing device **914**. The online system **110** in contrast, may comprise multiple blade servers working together to provide the functionality described herein.

ADDITIONAL CONSIDERATIONS

The particular naming of the components, capitalization of terms, the attributes, data structures, or any other programming or structural aspect is not mandatory or significant, and the mechanisms that implement the embodiments described may have different names, formats, or protocols. Further, the systems may be implemented via a combination of hardware and software, as described, or entirely in hardware elements. Also, the particular division of functionality between the various system components described herein is merely exemplary, and not mandatory; functions performed by a single system component may instead be performed by multiple components, and functions performed by multiple components may instead performed by a single component.

Some portions of above description present features in terms of algorithms and symbolic representations of operations on information. These algorithmic descriptions and representations are the means used by those skilled in the data processing arts to most effectively convey the substance of their work to others skilled in the art. These operations, while described functionally or logically, are understood to be implemented by computer programs. Furthermore, it has also proven convenient at times, to refer to these arrangements of operations as modules or by functional names, without loss of generality.

Unless specifically stated otherwise as apparent from the above discussion, it is appreciated that throughout the description, discussions utilizing terms such as "processing" or "computing" or "calculating" or "determining" or "displaying" or the like, refer to the action and processes of a computer system, or similar electronic computing device, that manipulates and transforms data represented as physical (electronic) quantities within the computer system memories or registers or other such information storage, transmission or display devices.

Certain embodiments described herein include process steps and instructions described in the form of an algorithm. It should be noted that the process steps and instructions of the embodiments could be embodied in software, firmware or hardware, and when embodied in software, could be downloaded to reside on and be operated from different platforms used by real-time network operating systems.

The embodiments described also relate to apparatuses for performing the operations herein. An apparatus may be specially constructed for the required purposes, or it may comprise a general-purpose computer selectively activated or reconfigured by a computer program stored on a computer readable medium that can be accessed by the computer. Such a computer program may be stored in a non-transitory computer readable storage medium, such as, but is not limited to, any type of disk including floppy disks, optical disks, CD-ROMs, magnetic-optical disks, read-only memories (ROMs), random access memories (RAMs), EPROMs, EEPROMs, magnetic or optical cards, application specific integrated circuits (ASICs), or any type of media suitable for storing electronic instructions, and each coupled to a computer system bus. Furthermore, the computers referred to in the specification may include a single processor or may be architectures employing multiple processor designs for increased computing capability.

The algorithms and operations presented herein are not inherently related to any particular computer or other apparatus. Various general-purpose systems may also be used with programs in accordance with the teachings herein, or it may prove convenient to construct more specialized apparatus to perform the required method steps. The required structure for a variety of these systems will be apparent to those of skill in the, along with equivalent variations. In addition, the present embodiments are not described with reference to any particular programming language. It is appreciated that a variety of programming languages may be used to implement the teachings of the embodiments as described herein.

The embodiments are well suited for a wide variety of computer network systems over numerous topologies. Within this field, the configuration and management of large networks comprise storage devices and computers that are communicatively coupled to dissimilar computers and storage devices over a network, such as the Internet.

Finally, it should be noted that the language used in the specification has been principally selected for readability and instructional purposes, and may not have been selected to delineate or circumscribe the inventive subject matter. Accordingly, the disclosure of the embodiments is intended to be illustrative, but not limiting.

We claim:

1. A method for upgrading databases, comprising:

storing, by an online system, data in (1) a primary site comprising a primary set of databases processing client requests, the primary set of databases comprising a primary database and an alternate primary database that is a physical replication of the primary database, and (2) a secondary site comprising a secondary set of databases used as standby databases, the secondary set of databases comprising a secondary database and an alternate secondary database that is a physical replication of the secondary database;

upgrading the secondary site, comprising:

upgrading the alternate secondary database to an upgraded alternate secondary database;

after the upgrading of the alternate secondary database, applying recorded changes of the primary database of the primary set to the upgraded alternate secondary database, causing the upgraded alternate secondary database to be a logical replication of the primary database;

upgrading the secondary database to an upgraded secondary database, causing the secondary database to be a physical replication of the upgraded alternate secondary database;

after upgrading the secondary site, switching client requests to the secondary set of databases and using the primary set of databases as standby databases;

upgrading the primary site, comprising:

upgrading the alternate primary database to an upgraded alternate primary database, causing the upgraded alternate primary database to be a physical replication of the upgraded secondary database; and

upgrading the primary database to an upgraded primary database, causing the upgraded primary database to be a physical replication of the upgraded alternate primary database.

2. The method of claim **1**, wherein the primary and secondary sites represent respective physical locations.

3. The method of claim **1**, wherein responsive to switching client requests to the secondary set of databases, client requests are directed to the secondary database and changes to the secondary database are replicated to a database of the primary set of databases using a logical replication platform.

4. The method of claim **1**, wherein before upgrading databases of the secondary set of databases, client requests are directed to the primary database and changes to the primary database are replicated to a database of the secondary set of databases using physical replication that performs storage block level replication.

5. The method of claim **1**, wherein after upgrading databases of the secondary site, client requests are directed to the secondary databases and changes to the secondary database are replicated to a database of the primary set of databases using physical replication.

6. The method of claim **1**, wherein the online system is a multi-tenant system and each database from the primary set of databases and the secondary set of databases stores data of a plurality of tenants.

7. The method of claim **1**, wherein replication is used to copy data across databases within each set of the primary and secondary sets of databases.

8. The method of claim **1**, wherein, after the upgrading of the secondary database, the method further comprising:

upgrading one or more other databases from the secondary set of databases of the secondary site; and

wherein the switching of client requests to the secondary set of databases comprises directing client requests to the secondary database.

9. The method of claim **1**, wherein the switching of client requests to the secondary set of databases comprises directing client requests to the secondary database.

10. A non-transitory computer readable storage medium for storing instructions that when executed by a computer processor cause the computer processor to perform steps comprising:

storing, by an online system, data in (1) a primary site comprising a primary set of databases processing client requests, the primary set of databases comprising a primary database and an alternate primary database that is a physical replication of the primary database, and (2) a secondary site comprising a secondary set of databases used as standby databases, the secondary set of databases comprising a secondary database and an alternate secondary database that is a physical replication of the secondary database;

upgrading the secondary site, comprising:

upgrading the alternate secondary database to an upgraded alternate secondary database; and

after the upgrading of the alternate secondary database, applying recorded changes of the primary database of the primary set to the upgraded alternate secondary database, causing the upgraded alternate secondary database to be a logical replication of the primary database;

upgrading the secondary database to an upgraded secondary database, causing the secondary database to be a physical replication of the upgraded alternate secondary database;

after upgrading the secondary site, switching client requests to the secondary set of databases and using the primary set of databases as standby databases;

upgrading the primary site, comprising:

upgrading the alternate primary database to an upgraded alternate primary database, causing the upgraded alternate primary database to be a physical replication of the upgraded secondary database; and

upgrading the primary database to an upgraded primary database, causing the upgraded primary database to be a physical replication of the upgraded alternate primary database.

11. The non-transitory computer readable storage medium of claim **10**, wherein the primary and secondary sites represent respective physical locations.

12. The non-transitory computer readable storage medium of claim **10**, wherein responsive to switching client requests to the secondary set of databases, client requests are directed to the secondary database and changes to the secondary database are replicated to a database of the primary set of databases using a logical replication platform.

13. The non-transitory computer readable storage medium of claim **10**, wherein before upgrading databases of the secondary set of databases, client requests are directed to the primary database and changes to the primary database are replicated to a database of the secondary set of databases using physical replication that performs storage block level replication.

14. The non-transitory computer readable storage medium of claim **10**, wherein after upgrading database of the secondary site, client requests are directed to the secondary database and changes to the secondary database are replicated to a database of the primary set of databases using physical replication.

15. The non-transitory computer readable storage medium of claim **10**, wherein replication is used to copy data across databases within each set of the primary and secondary sets of databases.

16. The non-transitory computer readable storage medium of claim **10**, wherein the steps further comprise, after the upgrading of the secondary database:

upgrading one or more other databases from the secondary set of databases of the secondary site; and

wherein the switching of client requests to the secondary set of databases comprises directing client requests to the secondary database.

17. The non-transitory computer readable storage medium of claim **10**, wherein the switching of client requests to the secondary set of databases comprises directing client requests to the secondary database.

18. A computer system comprising:

a computer processor; and

a non-transitory computer readable storage medium for storing instructions that when executed by a computer processor cause the computer processor to perform steps comprising:

storing, by an online system, data in (1) a primary site comprising a primary set of databases processing client requests, the primary set of databases comprising a primary database and an alternate primary database that is a physical replication of the primary database, and (2) a secondary site comprising a secondary set of databases used as standby databases, the secondary set of databases comprising a secondary database and an alternate secondary database that is a physical replication of the secondary database;

upgrading the secondary site, comprising:

upgrading the alternate secondary database to an upgraded alternate secondary database;

after the upgrading of the alternate secondary database, applying recorded changes of the primary database of the primary set to the upgraded alternate secondary database, causing the upgraded alternate secondary database to be a logical replication of the primary database;

upgrading the secondary database to an upgraded secondary database, causing the secondary database to be a physical replication of the upgraded alternate secondary database;

after upgrading the secondary site, switching client requests to the secondary set of databases and using the primary set of databases as standby databases;

upgrading the primary site, comprising:

upgrading the alternate primary database to an upgraded alternate primary database, causing the upgraded alternate primary database to be a physical replication of the upgraded secondary database; and

upgrading the primary database to an upgraded primary database, causing the upgraded primary database to be a physical replication of the upgraded alternate primary database.

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