US 20200117737A1

(19) United States
(12) Patent Application Publication
Gopalakrishnan et al.
(10) Pub. No.: US 2020/0117737 A1
(43) Pub. Date: Apr. 16, 2020

(54) FAST HETEROGENEOUS MULTI-DATA SOURCE SEARCH AND ANALYTICS

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(21) Appl. No.: **16/162,309**

(22) Filed: **Oct. 16, 2018**

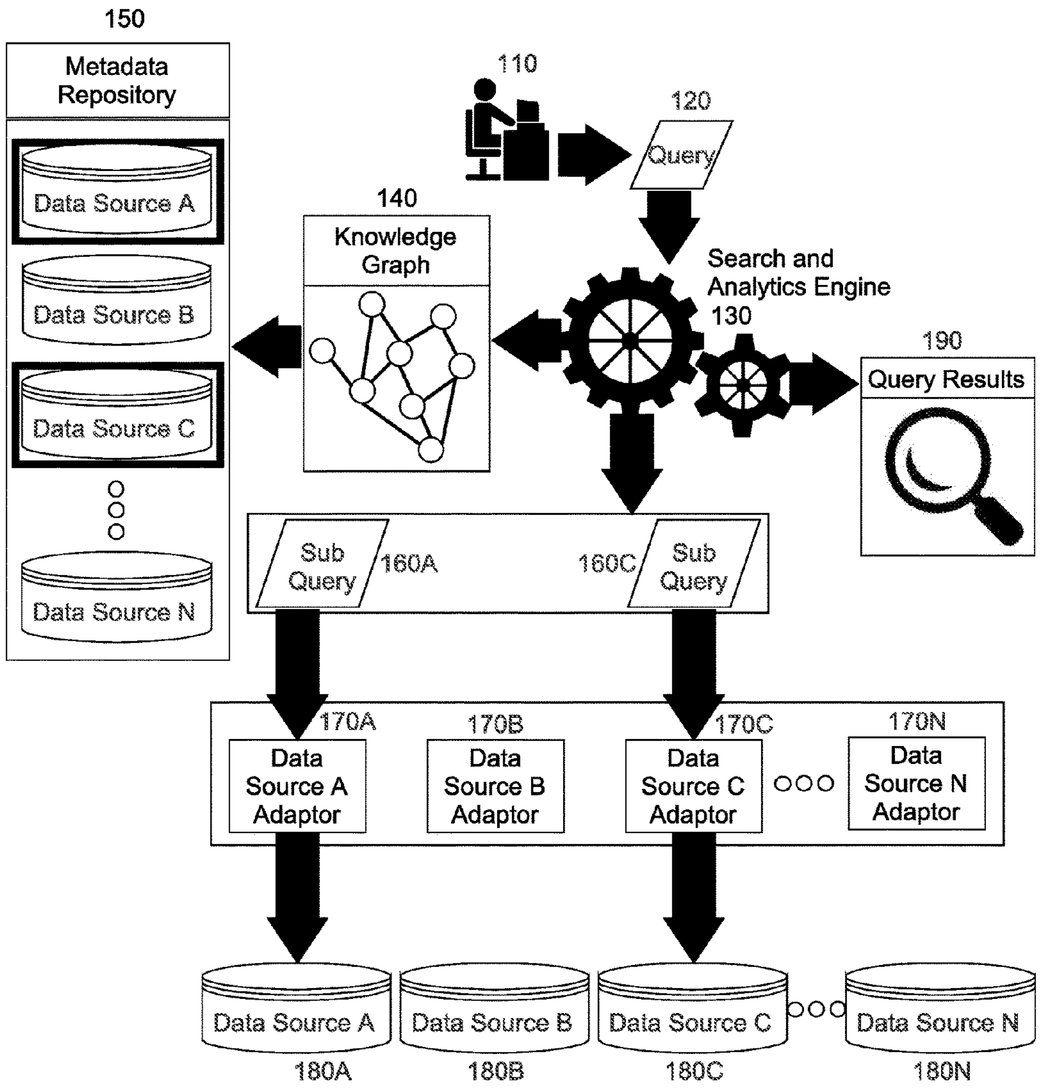
Publication Classification

(51) **Int. Cl.**
G06F 17/30 (2006.01)

(52) **U.S. Cl.**
CPC .. *G06F 17/30477* (2013.01); *G06F 17/30557* (2013.01); *G06F 17/30958* (2013.01); *G06F 17/30389* (2013.01); *G06F 17/30533* (2013.01); *G06F 17/30991* (2013.01)

(57) **ABSTRACT**

Embodiments of the present invention provide for a method, system and computer program product for fast heterogeneous multi-data source search and analytics. In an embodiment of the invention, a method includes receiving a specification of multiple different data sources in a search and analytics engine, establishing communicative links between the engine and the data sources, and identifying a data source type and corresponding data fields storing respective data for each data source. The method further includes specifying a multi-hop graph traversal query implicating data across the different data sources, decomposing the query into constituent components and mapping each of the constituent components to each of the data sources based upon the corresponding data fields. The method even further includes formulating a specific query for each of the data sources, transmitting each query to each data source and populating in a knowledge graph each result set received for each query.



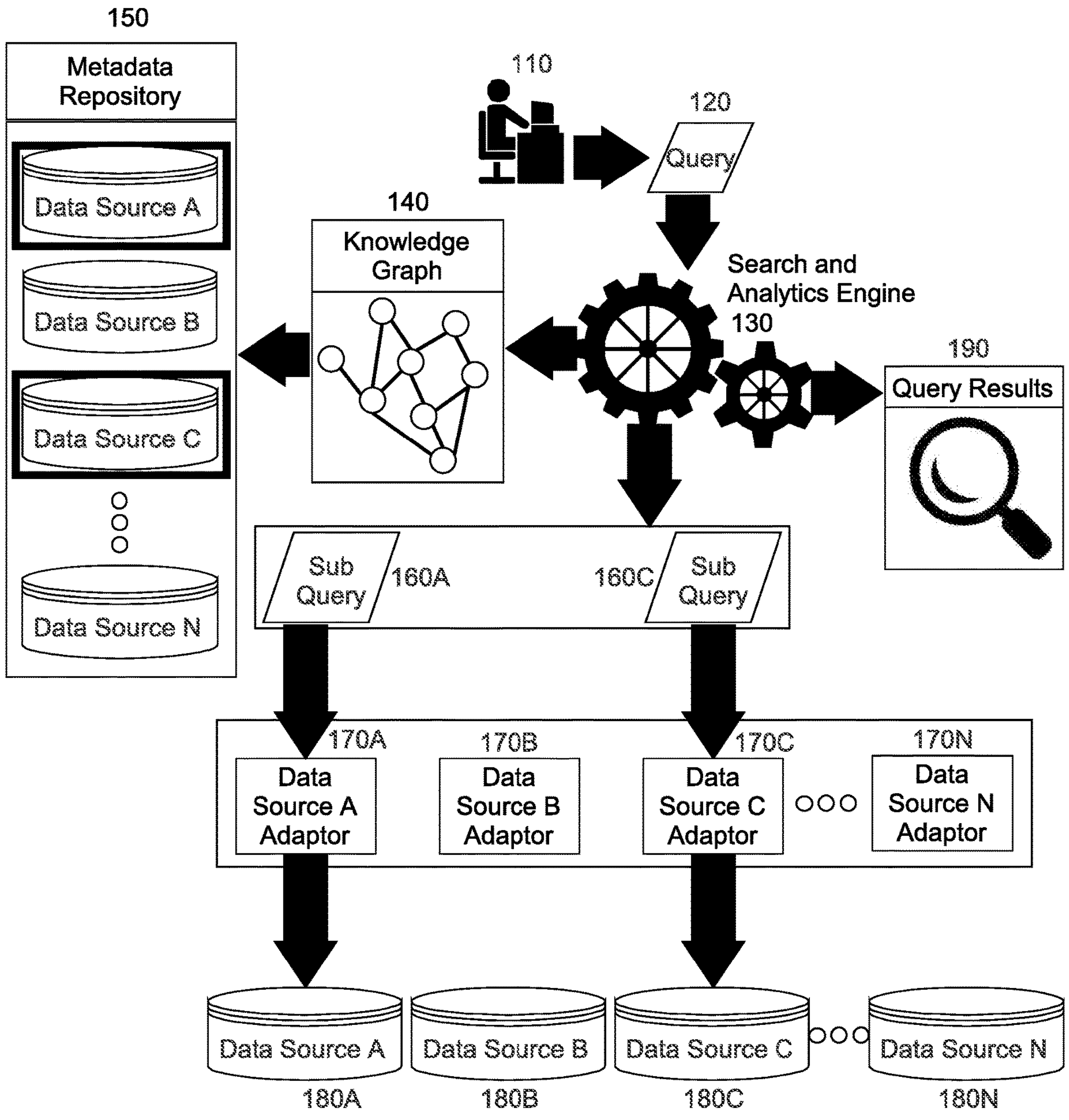

150
Metadata Repository
Data Source A
Data Source B
Data Source C
Data Source N
110
120
Query
140
Knowledge Graph
Search and Analytics Engine 130
190
Query Results
Sub Query 160A
160C Sub Query
170A
Data Source A Adaptor
170B
Data Source B Adaptor
170C
Data Source C Adaptor
170N
Data Source N Adaptor
Data Source A
180A
Data Source B
180B
Data Source C
180C
Data Source N
180N

FIG. 1

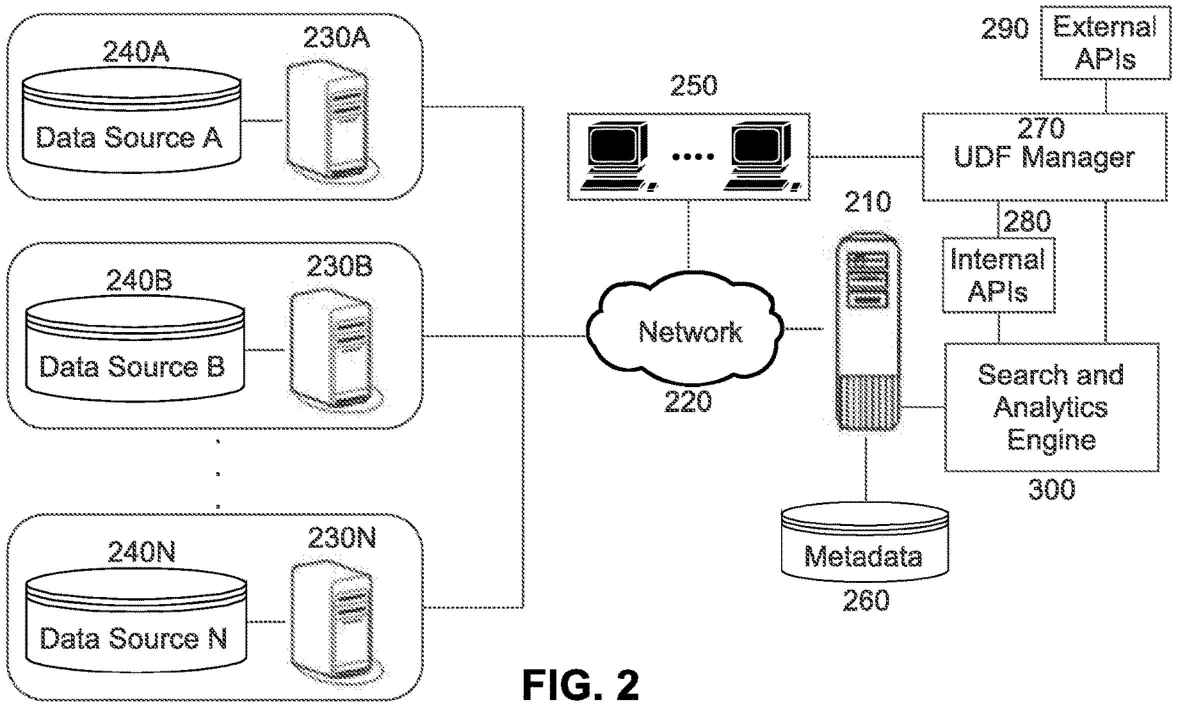

240A
230A
Data Source A
240B
230B
Data Source B
240N
230N
Data Source N
250
290
External APIs
270
UDF Manager
210
280
Internal APIs
Network
220
Search and Analytics Engine
300
Metadata
260

FIG. 2

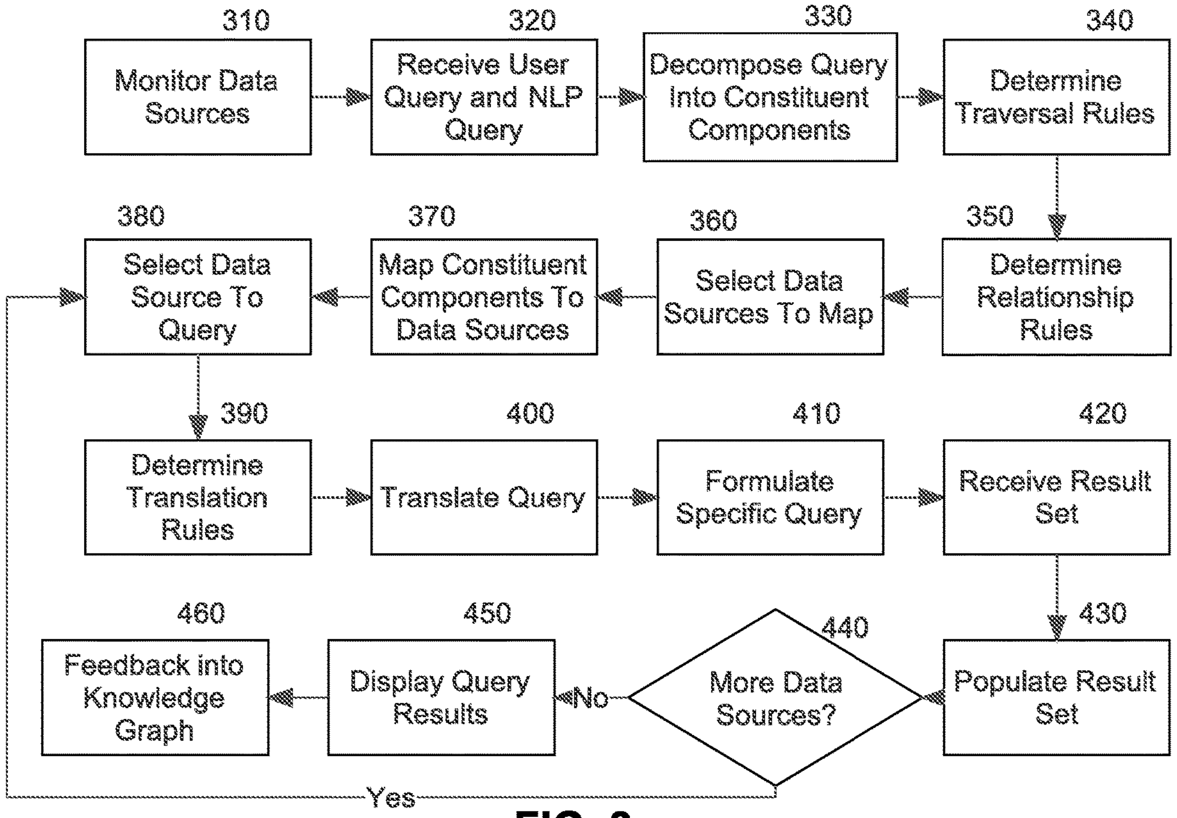

310
Monitor Data Sources
320
Receive User Query and NLP Query
330
Decompose Query Into Constituent Components
340
Determine Traversal Rules
350
Determine Relationship Rules
360
Select Data Sources To Map
370
Map Constituent Components To Data Sources
380
Select Data Source To Query
390
Determine Translation Rules
400
Translate Query
410
Formulate Specific Query
420
Receive Result Set
430
Populate Result Set
440
More Data Sources?
No
Yes
450
Display Query Results
460
Feedback into Knowledge Graph

FIG. 3

FAST HETEROGENEOUS MULTI-DATA SOURCE SEARCH AND ANALYTICS

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention relates to the field of data management and more particularly to data management of multiple heterogeneous data sources.

Description of the Related Art

[0002] A database is an organized collection of data and a database management system (DBMS) is often used to create, update, delete, query and generally administer the database. In order to properly query a database or data source, the data in the database is organized and indexed according to the preferred convention. Currently, there are many forms of database models that indicate how data is organized in the database, such as spreadsheets, relational databases based on Structured Query Language (SQL), NoSQL databases, Not Only SQL databases, object databases, etc. Within those database models, the schema used to organize data will differ between database models and schemas such as RDF, object, tabular, tuple, triplestores, graph, etc. may be used. Alternatively, data files may not be stored with any specific organization measures and may simply include JSON files, XML files, text files, spreadsheets or multimedia such as images, video, audio, etc. without an organization schema.

[0003] Tabular databases (relational, NoSQL, etc.) use indexes and logic tables to show the relational structure between elements in the database. Such databases are useful for quickly finding results but limited by the schema with which the database was built. A graph database is a specific type of database that is modeled based on graph theory where data is represented in a non-tabular fashion. Data is stored as nodes, defining the entities, and edges, defining the relationships between those entities. Thus, elements of a graph database are interconnected to depict how those elements are related to other elements in the database. A graph database is useful for determining complex relationships between elements and can be useful for easily developing new schemas; however, graph databases are significantly more complex than relational databases.

[0004] The ways in which an end user queries a database is dependent on the type of database being queried. Databases, or more specifically relational databases, most often use SQL in order to query data that are stored in tables. On the other hand, there is currently no universally accepted query language to query graph databases, although the Resource Description Framework (RDF) is commonly used in many cases. With advances in natural language processing (NLP), more simplified approaches to querying are being utilized to allow for less-structured searches involving text documents. Also, it is noted that a query may be different based on whether the end user wishes to query the metadata of the data or the instances of the data.

[0005] With the amount of different types of databases and associated data, due to legacy databases or based on the type of data required, multiple heterogenous databases often exist within large federated and disparate IT systems, spread across organizations. Additionally, with the advent of big data applications, oftentimes separate queries will have to be conducted for different data types for a single application. Not only are separate queries required, oftentimes the nodes or indices of a pre-built database require additional nodes or indices based on new knowledge in order to be of value to the query. Thus, end users must either spend a significant amount of time running multiple queries over multiple data types or spend a significant amount of time organizing and indexing data into a new, single schema, which is hard to predict in advance. Thus, the storage and analysis of data files based on specific organization of databases place significant limitations on big data applications, such as machine learning, as the data with different organizational measures cannot be easily compared.

BRIEF SUMMARY OF THE INVENTION

[0006] Embodiments of the present invention address deficiencies of the art in respect to database management of multiple heterogeneous databases and provide a novel and non-obvious method, system and computer program product for fast heterogeneous multi-data source search and analytics. In an embodiment of the invention, a method for fast heterogeneous multi-data source search and analytics is claimed. The method includes receiving a specification of multiple different data sources in a user interface to a search and analytics engine, establishing communicative links between the engine and each specified one of the data sources and identifying for a corresponding one of the data sources through a respective one of the communicative links, a data source type and corresponding data fields storing respective data. The method further includes specifying in the user interface, a multi-hop graph traversal query implicating data across the multiple different data sources, decomposing the query into constituent components and mapping each of the constituent components to a corresponding one of the data sources based upon the identified corresponding data fields of each of the data sources. The method even further includes formulating a specific query for each of the corresponding one of the data sources mapped to one of the constituent components, transmitting each formulated specific query to a corresponding one of the data sources, receiving in response a result set and populating in a single knowledge graph each result set received for each specific query transmitted to a corresponding one of the data sources.

[0007] In one aspect of the embodiment, the method further includes storing relationship data between the different data sources and wherein the mapping is based on the stored relationship data. In another aspect of the embodiment, the method further includes storing translation data between the multi-hop graph traversal query and the data source types of the different data sources and wherein the translation data is used to formulate the specific queries. In yet another aspect of the embodiment, the method further includes storing query relationship data between previous queries and corresponding previous result sets and wherein the mapping is based on learned rules determined from the stored relationship data. In even yet another aspect of the embodiment, the method further includes determining a pattern of usage of a user profile and selecting only the corresponding data sources based on the pattern of usage of the user profile performing the query, or across a pattern of usage from similar users. In a final aspect of the embodiment, the method further includes monitoring changes to data in each specified one of the data sources, determining rules based on the monitored changes in the data in the different data sources and wherein the mapping is based on the rules between the different data sources.

[0008] In another embodiment of the invention, a data processing system configured for fast heterogeneous multi-data source search and analytics has been claimed. The system includes a host computing platform comprising one or more computers, each with memory and at least one processor, multiple different data sources communicating with the host computing platform over a network, and a search and analytics engine executing in the memory of the host computing platform. The engine includes program code enabled upon execution in the host computing platform to receive in a user interface to a search and analytics engine, a specification of the multiple different data sources, to establish communicative links, each between the engine and each specified one of the data sources, and to identify for a corresponding one of the data sources through a respective one of the communicative links, a data source type and corresponding data fields storing respective data. The program code is further enabled to specify in the user interface, a multi-hop graph traversal query implicating data across the multiple different data sources, to decompose the query into constituent components and map each of the constituent components to a corresponding one of the data sources based upon the identified corresponding data fields of each of the data sources. The program code is even further enabled to formulate a specific query for each of the corresponding one of the data sources mapped to one of the constituent components, to transmit each formulated specific query to a corresponding one of the data sources, receive in response a result set and to populate in a single knowledge graph each result set received for each specific query transmitted to a corresponding one of the data sources.

[0009] Additional aspects of the invention will be set forth in part in the description which follows, and in part will be obvious from the description, or may be learned by practice of the invention. The aspects of the invention will be realized and attained by means of the elements and combinations particularly pointed out in the appended claims. It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the invention, as claimed.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0010] The accompanying drawings, which are incorporated in and constitute part of this specification, illustrate embodiments of the invention and together with the description, serve to explain the principles of the invention. The embodiments illustrated herein are presently preferred, it being understood, however, that the invention is not limited to the precise arrangements and instrumentalities shown, wherein:

[0011] FIG. **1** is a pictorial illustration of a process for fast heterogeneous multi-data source search and analytics;

[0012] FIG. **2** is a schematic illustration of a data processing system configured for fast heterogeneous multi-data source search and analytics; and

[0013] FIG. **3** is a flow chart illustrating a process for fast heterogeneous multi-data source search and analytics.

DETAILED DESCRIPTION OF THE INVENTION

[0014] Embodiments of the invention provide for fast heterogeneous multi-data source search and analytics. In accordance with an embodiment of the invention, a search and analytics engine may be connected over a network to multiple heterogeneous data sources. The data sources may be completely federated. An end user may then query data stored within the multiple different heterogenous data sources through a multi-hop graph traversal query. To that end, when the end user provides the query to the analytics engine, the analytics engine automatically determines the data sources to query based on stored metadata tags and metadata relationships between the data sources as defined as nodes and edges of a single knowledge graph. The analytics engine then formulates a specific query for each of the data sources relevant to the original query and translates the query based on the specific schema or custom schema of each of the data sources. The analytics engine then populates each of the results in a single result set and feeds the results back into the knowledge graph. In this way, a single knowledge graph populated by metadata that corresponds to data contained in multiple heterogeneous federated, graphical and/or non-graphical, data sources and the relationships between the data is utilized to generate query results from the heterogeneous data sources while the actual data remains at the sources. This is accomplished without needing an overarching master data model, as is often seen in Data Warehouse indexing, or a master index as is often seen in data lakes.

[0015] Optionally, in addition to the predefined translations between schemas, the analytics engine may translate the query based upon learned translation schema between different data schemas. Also, in addition to the predefined relationships between data sources and respective schema and namespaces, the analytics engine may store logically or statistically learned relationships and suggest probable relationships between different data sets in the heterogenous databases in order to provide better result sets to a query, recommended result sets to the query and optimize the traversal strategies of the analytics engine. The translation and relationship data may be metadata relationships about the joins across both graph, tabular & image-based data sources stored across the data sources. Machine learning and logical reasoning may be used in combination to develop the translation capabilities between the different schema and recommend relationships between heterogenous data sets. As well, the analytics engine may store predefined and learned relationships of data and data sources that each user or group of users are most probable to access based on their respective roles identified upon sign in, or their queries in order to optimize the recommendation and traversal strategies of the analytics engine. Thus, when a user is operating the engine their associated user traversal strategy is loaded in order to optimize their search. Similarly, the relationships between a user or a group of users and data may be utilized to recommend related result sets from similar users or groups of users. Thus, the corresponding data sources may be selected across a pattern of usage from similar users (a community of interest of sorts) where recommendations can be made from these learnings.

[0016] As a further option, the analytics engine may monitor changes to the data stored in the multiple heterogeneous data sources in order to develop fuzzy inference rules between changes in related data. In particular, the fuzzy inference rules probabilistically determine relationships between data points and can similarly be stored in cognitive data structures, so that when a user changes one portion of data, the related portion of data can automatically change or the user can be notified of the related data to change. All of these rules may be predefined rules, dynamic, learned rules or a combination thereof, in order to optimize the search results.

[0017] In even yet a further option, the metadata repository that stores the metadata that corresponds to data stored in the heterogenous databases and organized by the knowledge graph may be automatically merged and sorted to optimize search results. When the metadata is read from the respective data sources, the analytics engine may utilize the respective sort implementation of the connected data source and then perform either an on or off the disk merge within the metadata repository. As well, the results to a query may be automatically merged and sorted to optimize the search results with the respective relationships between the data sources. Furthermore, the end user may define scripts or domain-specific languages to automatically schedule and run queries within the analytics engine.

[0018] In further illustration, FIG. **1** pictorially shows a process for fast heterogeneous multi-data source search and analytics. As shown in FIG. **1**, search and analytics engine **130** communicates with multiple heterogenous data sources **180**A, **180**B, **180**C, **180**N. The communicative links may be virtualized. Search and analytics engine **130** receives a specification of each of the multiple heterogenous data sources **180**A, **180**B, **180**C, **180**N. Data sources **180**A, **180**B, **180**C, **180**N may be completely federated. Search and analytics engine **130** is able to identify the data source types, schema, namespaces, etc. for the corresponding data fields of each of the data sources **180**A, **180**B, **180**C, **180**N. Search and analytics engine **130** is driven by knowledge graph **140** that defines the nodes and edges of the metadata stored in metadata repository **150** that corresponds to the data stored in each of the data sources **180**A, **180**B, **180**C, **180**N. Thus, the relationships between the data sources are defined in knowledge graph **140** and stored in the metadata repository **150**. In order to maintain the federated nature of the data, search and analytics engine **130** may read data sources **180**A, **180**B, **180**C, **180**N and read/write the data in the knowledge graph **140** and metadata repository **150**.

[0019] End user **110** can input or automatically schedule a query **120** into the search and analytics engine **130**. The query **120** may be a multi-hop graph traversal query in order to apply a graph query to graph and non-graph data sources. Furthermore, an end user may input a different query type, such as a graph query, a relational query, natural language query, etc., and the search and analytics engine **130** may translate the query to the required query type using the respective translation or natural language processing technique. Thus, a user can input their desired query format and the search and analytics engine **130** will still be able to perform the multi-hop graph traversal query against graph and non-graph data sources.

[0020] Subsequent to the translation of the end user's query **120** to a multi-hop graph traversal query, the query is decomposed to its constituent components of the original query and mapped to each of the respective data types of the data fields in the each of the relevant data sources **180**A, **180**B, **180**C, **180**N. As can be seen, in the example shown in FIG. **1**, query **120** is decomposed and mapped to data source A **180**A and data source C **180**C resulting in sub-queries **160**A and **160**C. In doing so, data source B **180**B, as well as the rest of the data sources **180**N are traversed resulting in a more efficient query process. The mapping of the decomposed query to the respective data sources is based on the predefined and learned relationships between the data sources, as contained in the metadata repository **150** and defined by the knowledge graph **140**.

[0021] The mapping of the query to the respective data sources may be based on predefined and learned query-data source relationship and traversal rules, as well as predefined and learned user-data source relationship and traversal rules. The query-data source rules may be based on the relationships between the data sources **180**A, **180**B, **180**C, **180**N as stored in the knowledge graph **140** and metadata repository **150**. Additionally, the query-data source rules may be learned rules from previous queries and resulting data sets. Furthermore, the query-data source rules may be based on fuzzy logic rules that develop a correlation between monitored changes in related data sets. The user-data source rules may be predefined rules based on a user profile of the end user **110**, or a profile for a group of users, and may include information such as job type and available data sources. The user-data source rules may also be based on learned patterns of the user or group of users. Thus, in using query-data source relationship and traversal rules and user-data source relationship and traversal rules, the search and analytics engine may provide collaborative filtering of data sources to be searched, recommendations of related data, as well as general traversal strategies of specific data sources.

[0022] As can be seen, based on the relationships between the user **110** inputting the query, the query **120**, the data sources **180**A, **180**B, **180**C, **180**N as contained in the metadata repository **150** and defined by the knowledge graph **140**, the constituent components are mapped to each respective data types of the data fields in data sources **180**A and **180**C resulting in sub-queries **160**A and **160**C. Search and analytics engine **130** may automatically translate the queries for the respective data type, schema, namespace, etc. of the data sources **180**A and **180**C or sub-queries **160**A and **160**C may be fed through a data source adaptor **170**A and **170**C to translate the query. The translation of the sub-queries **160**A and **160**C may be based on predefined and learned translation rules. The translation rules may be based on predefined translations between data type, schema, namespace, etc., which logically specifies the translation between different data structures in the heterogenous data sources. As such, data source adaptor **170**A, **170**B, **170**C, **170**N may be defined for custom data storage. The translation rules may also be based on learned translation rules from previous query result sets as determined from the knowledge graph **140** and metadata repository **150**. Thus, the formulation of specific queries by translating the queries allows for queries of single or multiple different namespaces. Furthermore, if the data type includes multimedia, such as audio, video, or images, computer vision and natural language processing may be utilized to search or query any data type.

[0023] Furthermore, data source adaptors **170**A, **170**B, **170**C, **170**N allow the sub-queries to be performed independently, as well as the subsequent responses to the sub-queries, translation back into the desired schema and display to the end user. This allows the search and analytics engine

130 to receive, translate and display results from different underlying data processing architectures of the heterogeneous data sources. For example, data source A **180**A may allow for processing under Lambda architecture and data source C **180**C may allow for processing under Kappa architecture. In that case, data source adaptor **170**A may act as a read adaptor for the batch layer and may also in turn display the results from the speed layer in result set **190** through a serving layer as the data is still processing. As the search and analytics engine **130** allows for multiple serving layers, the batch layer does not need to be a single data store and it is possible to have different levels of random access speeds and parallel processing of data.

[0024] Following the transmission of the translated sub-queries **160**A and **160**C to each respective data source **180**A and **180**C, a result set is received for each sub-query and the result sets are populated in a single query result **190**. The query result **190**, along with the results sets from previous and subsequent queries, are input into the knowledge graph **140** and stored in metadata repository **150** and used to drive the search index. Thus, the results of the specific query are stored in a single ontology of the knowledge graph **140**, so that the results can be further processed under the single ontology. The knowledge graph defining the nodes and edges of the metadata repository **150** allows for an efficient way to utilize the computational graph architecture to apply machine learning to the data contained in the federated data sources **180**A, **180**B, **180**C, **180**N. The result set **190** may include data of data sources **180**A, **180**B, **180**C, **180**N, metadata of the data, persisted instance information, or any result of the query **120**, sub-queries **160**A and **160**C or real time view thereof. The result sets are translated, based on similar translation rules as mentioned above, into a desired result set schema for the end user. The desired schema may be in tabular form or graph form. The query results **190** of the query **120** that include the results of the different sub-queries **160**A and **160**C are displayed to the end user. Finally, all of the above-mentioned results are fed back into the search and analytics engine **130** in order to optimize the search and analytics engine **130**.

[0025] The process described in connection with FIG. **1** can be implemented in a data processing system. In yet further illustration, FIG. **2** schematically shows a data processing system configured for fast heterogeneous multi-data source search and analytics. The system can include a computing system **210** of one or more servers each with memory and at least one processor, collectively configured to support the execution of a data processing system that communicates with, and may monitor, multiple heterogenous data sources **240**A, **240**B, **240**N. The heterogenous data sources **240**A, **240**B, **240**N may be federated and have their own respective servers **230**A, **230**B, **230**N or may be directly connected to the host computing system **210**. The data sources **240**A, **240**B, **240**N may also reside in network servers that communicate with the host computing system **210** over the internet. The host server computing system **210** can be configured for communicatively coupling to different client computers **250** over computer communications network **220** such that requests to access the data processing system can be received in the host computing system **210** from applications executing in respective ones of the client computers **210**.

[0026] Importantly, a search and analytics engine **300** can be coupled to the data processing system **210**. The search and analytics engine **300** communicates with data sources **240**A, **240**B, **240**N through the host computing system **210**.The search and analytics engine **300** may also monitor data changes in the data sources **240**A, **240**B, **240**N through the host computing system **210**. The search and analytics engine **300** maintains a specification of the data sources **240**A, **240**B, **240**N and also maintains relationship data between the data sources. The relationship data may be predefined rules or learned rules between the data in the respective data sources **240**A, **240**B, **240**N, queries and end users, as stored in a knowledge graph of metadata repository **260**.

[0027] The search and analytics engine **300** receives a query from an end user input through a user interface of a client computer **250**. The search and analytics engine **300** translates the query then decomposes the query into its constituent components and maps the constituent components to each of the types of data in the respective data sources **240**A, **240**B, **240**N based on the relationships stored in metadata repository **260**. The search and analytics engine **300** may then formulate a specific query for each data type of the data sources **240**A, **240**B, **240**N, transmit each specific query to each data source, and receive a result set from each data source in response to the specific query. The search and analytics engine **300** populates each of the results in a single result set for the end user and may display the search results to the end user in a user interface of the client computer **250**. The results of the query are stored in the knowledge graph in metadata repository **260** in order to optimize the search and analytics engine **300**.

[0028] Search and analytics engine **300** may also be connected to a user-defined function ("UDF") manager **270**. The query from an end user may be input through a user interface of a client computer **250** to the search and analytics engine **300** directly, through the UDF manager **270**, or may be automatically scheduled through the UDF manager **270**. The query input through the UDF manager **270** may be in communication with the search and analytics engine **300** directly or one or more internal Application Programming Interfaces ("APIs") or scripts or plugins **280** to input the query through the search and analytics engine **300**. The internal APIs or scripts or plugins **280** may be in communication with the search and analytics engine **300** directly or the metadata repository **260** directly in order to optimize the query and/or results and select the data sources to be queried based on the desired specifications of the query. The UDF manager **270** may also be extended with external APIs or scripts or plugins **290** in order to allow the end user optimize their query and/or results using external APIs or scripts or plugins. The external APIs or scripts or plugins **290** may be in communication with search and analytics engine **300** or the metadata repository **260** directly in order to optimize the query and select the data sources to be queried directly. Thus, internal and external APIs or scripts or plugins **280** and **290** through the UDF manager **270** may be utilized so that an end user can optimize and design queries to their desired specifications.

[0029] In yet further illustration of the process performed by the program code of the search and analytics engine **300**, FIG. **3** is a flow chart illustration a process for fast heterogeneous multi-data source search and analytics. Beginning in block **310**, the search and analytics engine monitors the data sources for changes and maintains a specification of each of the data sources defining the schema, data types, namespaces and metadata of the data in each of the data sources. In block **320**, a user query is received, translated into a multi-hop graph traversal query and, in block **330**, the query is decomposed into its constituent components. In block **340**, the predefined and learned traversal rules for the query, data sources and user performing the query are determined. In block **350**, the predefined and learned relationships between query, data sources, and user performing the query are determined. Applying the rules of blocks **340** and **350**, in block **360**, data sources are selected to be queried. In block **370**, the constituent components of the original query are mapped to the selected data sources.

[0030] In block **380**, the first data source is selected to query and, in block **390**, the predefined and learned translation rules for the data type of that data source are determined. In block **400**, the query is translated for the data of the data source and, in block **410**, a specific query is formulated for that data source. In response to that specific query, in block **420**, a result set from that data source is received, translated and populated into a single result set in block **430**. In block **440**, if there are more data sources, the process repeats from block **380** until there are no more data sources to query. After specific queries for all of the data source are completed, in block **450**, the search results may be displayed for the end user. The user may also be provided a real time view of the search results while the queries are processing at different random access speeds. Finally, in block **460**, the results from the query are stored in a metadata repository as a single knowledge graph in order to optimize the search and analytics engine.

[0031] The present invention may be embodied within a system, a method, a computer program product or any combination thereof. The computer program product may include a computer readable storage medium or media having computer readable program instructions thereon for causing a processor to carry out aspects of the present invention. The computer readable storage medium can be a tangible device that can retain and store instructions for use by an instruction execution device. The computer readable storage medium may be, for example, but is not limited to, an electronic storage device, a magnetic storage device, an optical storage device, an electromagnetic storage device, a semiconductor storage device, or any suitable combination of the foregoing.

[0032] Computer readable program instructions described herein can be downloaded to respective computing/processing devices from a computer readable storage medium or to an external computer or external storage device via a network. The computer readable program instructions may execute entirely on the user's computer, partly on the user's computer, as a stand-alone software package, partly on the user's computer and partly on a remote computer or entirely on the remote computer or server. Aspects of the present invention are described herein with reference to flowchart illustrations and/or block diagrams of methods, apparatus (systems), and computer program products according to embodiments of the invention. It will be understood that each block of the flowchart illustrations and/or block diagrams, and combinations of blocks in the flowchart illustrations and/or block diagrams, can be implemented by computer readable program instructions.

[0033] These computer readable program instructions may be provided to a processor of a general purpose computer, special purpose computer, or other programmable data processing apparatus to produce a machine, such that the instructions, which execute via the processor of the computer or other programmable data processing apparatus, create means for implementing the functions/acts specified in the flowchart and/or block diagram block or blocks. These computer readable program instructions may also be stored in a computer readable storage medium that can direct a computer, a programmable data processing apparatus, and/or other devices to function in a particular manner, such that the computer readable storage medium having instructions stored therein includes an article of manufacture including instructions which implement aspects of the function/act specified in the flowchart and/or block diagram block or blocks.

[0034] The computer readable program instructions may also be loaded onto a computer, other programmable data processing apparatus, or other device to cause a series of operational steps to be performed on the computer, other programmable apparatus or other device to produce a computer implemented process, such that the instructions which execute on the computer, other programmable apparatus, or other device implement the functions/acts specified in the flowchart and/or block diagram block or blocks.

[0035] The flowchart and block diagrams in the Figures illustrate the architecture, functionality, and operation of possible implementations of systems, methods, and computer program products according to various embodiments of the present invention. In this regard, each block in the flowchart or block diagrams may represent a module, segment, or portion of instructions, which includes one or more executable instructions for implementing the specified logical function(s). In some alternative implementations, the functions noted in the block may occur out of the order noted in the figures. For example, two blocks shown in succession may, in fact, be executed substantially concurrently, or the blocks may sometimes be executed in the reverse order, depending upon the functionality involved. It will also be noted that each block of the block diagrams and/or flowchart illustration, and combinations of blocks in the block diagrams and/or flowchart illustration, can be implemented by special purpose hardware-based systems that perform the specified functions or acts or carry out combinations of special purpose hardware and computer instructions.

[0036] Finally, the terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. As used herein, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "includes" and/or "including," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

[0037] The corresponding structures, materials, acts, and equivalents of all means or step plus function elements in the claims below are intended to include any structure, material, or act for performing the function in combination with other claimed elements as specifically claimed. The description of the present invention has been presented for purposes of illustration and description, but is not intended to be exhaustive or limited to the invention in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art without departing from the scope and spirit of the invention. The embodiment was chosen and described in order to best explain the principles of the invention and the practical application, and to enable others of ordinary skill in the art to understand the invention for various embodiments with various modifications as are suited to the particular use contemplated.

[0038] Having thus described the invention of the present application in detail and by reference to embodiments thereof, it will be apparent that modifications and variations are possible without departing from the scope of the invention defined in the appended claims as follows:

We claim:

1. A method for fast heterogeneous multi-data source search and analytics comprising:

receiving in a user interface to a search and analytics engine, a specification of multiple different data sources;

establishing communicative links, each between the engine and each specified one of the data sources;

identifying for a corresponding one of the data sources through a respective one of the communicative links, a data source type and corresponding data fields storing respective data;

specifying in the user interface, a multi-hop graph traversal query implicating data across the multiple different data sources;

decomposing the query into constituent components and mapping each of the constituent components to a corresponding one of the data sources based upon the identified corresponding data fields of each of the data sources;

formulating a specific query for each of the corresponding one of the data sources mapped to one of the constituent components;

transmitting each formulated specific query to a corresponding one of the data sources and receiving in response a result set; and,

populating in a single knowledge graph each result set received for each specific query transmitted to a corresponding one of the data sources.

2. The method of claim **1**, further comprising:

storing relationship data between the different data sources and wherein the mapping is based on the stored relationship data.

3. The method of claim **1**, further comprising:

storing translation data between the multi-hop graph traversal query and the data source types of the different data sources and wherein the translation data is used to formulate the specific queries.

4. The method of claim **1**, further comprising:

storing query relationship data between previous queries and corresponding previous result sets and wherein the mapping is based on learned rules determined from the stored relationship data.

5. The method of claim **1**, further comprising:

determining a pattern of usage of a user profile and selecting only the corresponding data sources based on the pattern of usage of the user profile performing the query.

6. The method of claim **1**, further comprising:

monitoring changes to data in each specified one of the data sources, determining rules based on the monitored changes in the data in the different data sources and wherein the mapping is based on the rules between the different data sources.

7. A data processing system configured for fast heterogeneous multi-data source search and analytics comprising:

a host computing platform comprising one or more computers, each with memory and at least one processor;

multiple different data sources communicating with the host computing platform over a network;

and a search and analytics engine executing in the memory of the host computing platform, the engine comprising program code enabled upon execution in the host computing platform to receive in a user interface to a search and analytics engine, a specification of the multiple different data sources, to establish communicative links, each between the engine and each specified one of the data sources, to identify for a corresponding one of the data sources through a respective one of the communicative links, a data source type and corresponding data fields storing respective data, to specify in the user interface, a multi-hop graph traversal query implicating data across the multiple different data sources, to decompose the query into constituent components and map each of the constituent components to a corresponding one of the data sources based upon the identified corresponding data fields of each of the data sources, to formulate a specific query for each of the corresponding one of the data sources mapped to one of the constituent components, to transmit each formulated specific query to a corresponding one of the data sources and receive in response a result set and to populate in a single knowledge graph each result set received for each specific query transmitted to a corresponding one of the data sources.

8. The system of claim **7**, wherein the program code is further enabled to store relationship data between the different data sources and wherein the mapping is based on the stored relationship data.

9. The system of claim **7**, wherein the program code is further enabled to store translation data between the multi-hop graph traversal query and the data source types of the different data sources and wherein the translation data is used to formulate the specific queries.

10. The system of claim **7**, wherein the program code is further enabled to store query relationship data between previous queries and corresponding previous result sets and wherein the mapping is based on learned rules determined from the stored relationship data.

11. The system of claim **7**, wherein the program code is further enabled to determine a pattern of usage of a user profile and select only the corresponding data sources based on the pattern of usage of the user profile performing the query.

12. The system of claim **7**, wherein the program code is further enabled to monitor changes to data in each specified one of the data sources, determine rules based on the monitored changes in the data in the different data sources and wherein the mapping is based on the rules between the different data sources.

13. A computer program product for fast heterogeneous multi-data source search and analytics, the computer program product comprising a computer readable storage medium having program instructions embodied therewith, the program instructions executable by a device to cause the device to perform a method comprising:

receiving in a user interface to a search and analytics engine, a specification of multiple different data sources;

establishing communicative links, each between the engine and each specified one of the data sources;

identifying for a corresponding one of the data sources through a respective one of the communicative links, a data source type and corresponding data fields storing respective data;

specifying in the user interface, a multi-hop graph traversal query implicating data across the multiple different data sources;

decomposing the query into constituent components and mapping each of the constituent components to a corresponding one of the data sources based upon the identified corresponding data fields of each of the data sources;

formulating a specific query for each of the corresponding one of the data sources mapped to one of the constituent components;

transmitting each formulated specific query to a corresponding one of the data sources and receiving in response a result set; and,

populating in a single knowledge graph each result set received for each specific query transmitted to a corresponding one of the data sources.

14. The computer program product of claim **13**, wherein the method further comprises:

storing relationship data between the different data sources and wherein the mapping is based on the stored relationship data.

15. The computer program product of claim **13**, wherein the method further comprises:

storing translation data between the multi-hop graph traversal query and the data source types of the different data sources and wherein the translation data is used to formulate the specific queries.

16. The computer program product of claim **13**, wherein the method further comprises:

storing query relationship data between previous queries and corresponding previous result sets and wherein the mapping is based on learned rules determined from the stored relationship data.

17. The computer program product of claim **13**, wherein the method further comprises:

determining a pattern of usage of a user profile and selecting only the corresponding data sources based on the pattern of usage of the user profile performing the query.

18. The computer program product of claim **13**, wherein the method further comprises:

monitoring changes to data in each specified one of the data sources, determining rules based on the monitored changes in the data in the different data sources and wherein the mapping is based on the rules between the different data sources.

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