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(54) **METHOD FOR AUTOMATED GRAPH SCHEMA GENERATION AND RELATED APPARATUS**

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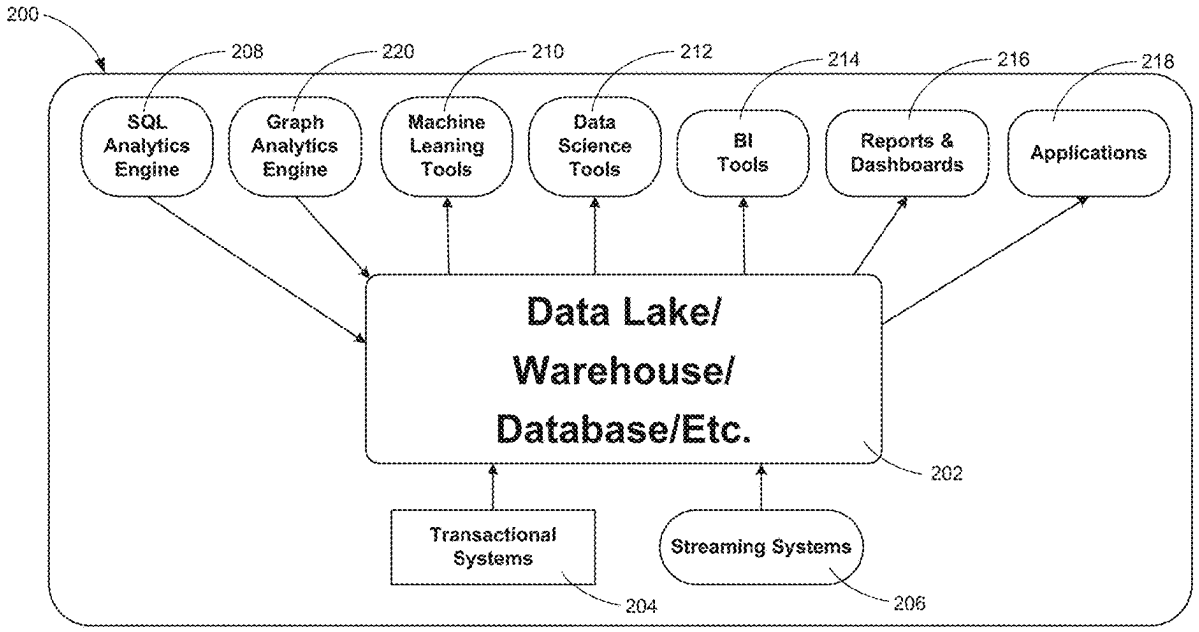
G06F 16/28	(2019.01)
G06F 16/901	(2019.01)

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

CPC ***G06F 16/211*** (2019.01); ***G06F 16/283*** (2019.01); ***G06F 16/9024*** (2019.01)

(57) **ABSTRACT**

This application is directed to automated graph schema generation. A schema generation method includes receiving a graph schema having vertices and edges associated with a plurality of data tables. The method also includes automatically generating, based on the plurality of data tables and the graph schema, one or more suggestions using a computational model. The one or more suggestions identify one or more vertices and/or one or more edges. The one or more suggestions include a respective suggestion that identifies a respective subset of the one or more vertices and/or the one or more edges. The method further includes receiving a first user input that is a selection of the respective suggestion from the one or more suggestions. The method further includes updating, based on the first user input, the graph schema. The method further includes outputting the updated graph schema.



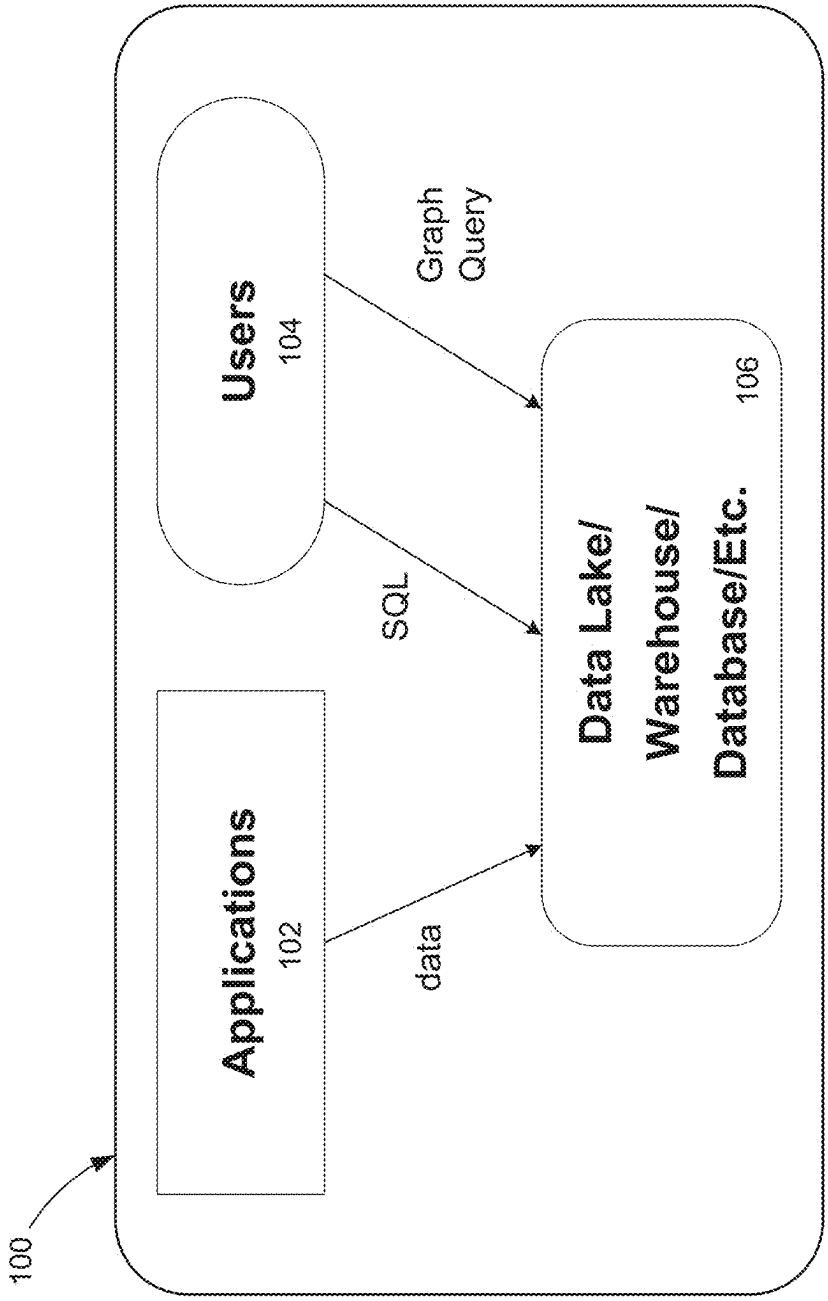

100
Applications
102
Users
104
Data Lake/
Warehouse/
Database/Etc.
106
data
SQL
Graph
Query

Figure 1

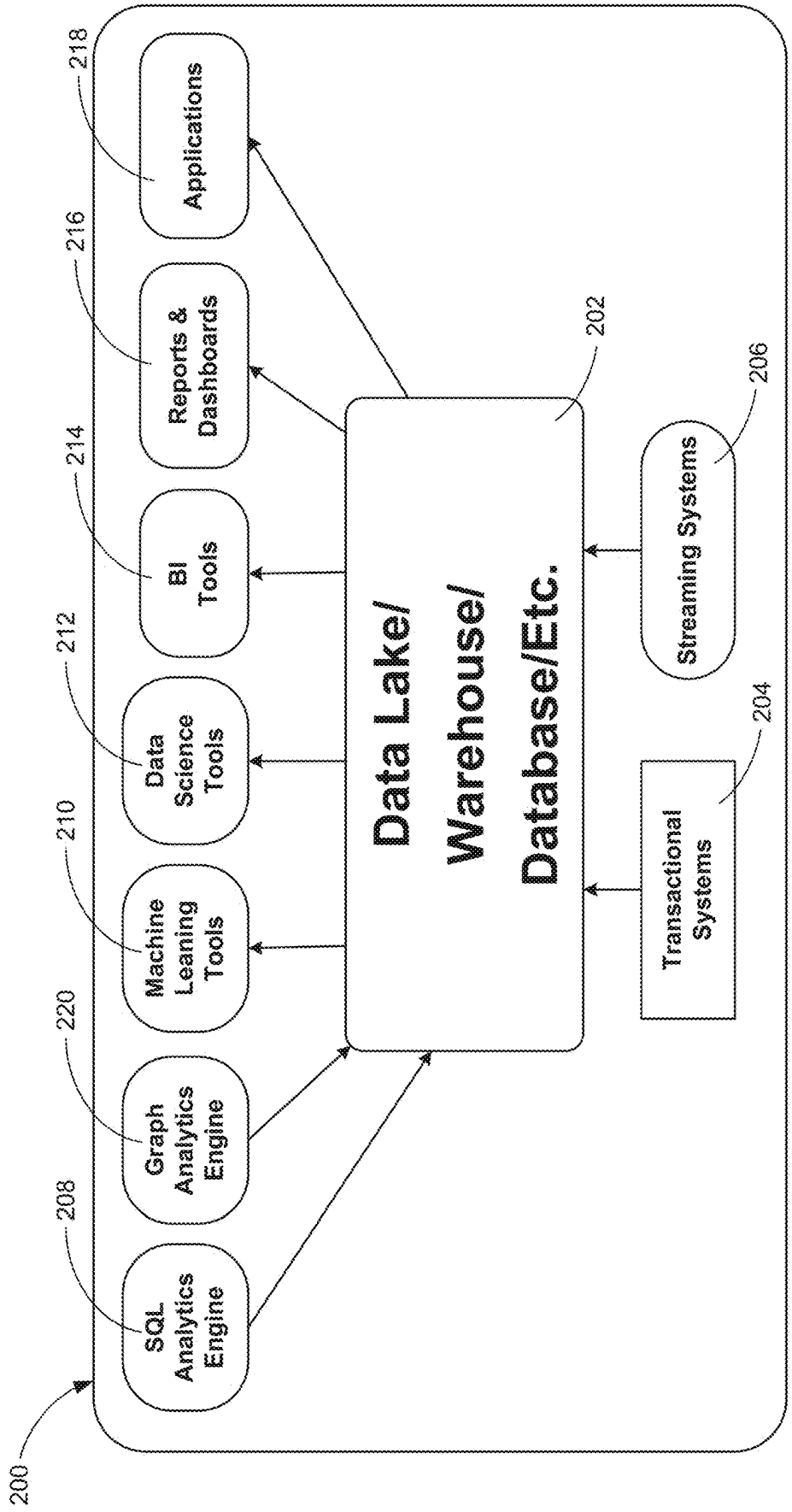

200
208
SQL Analytics Engine
220
Graph Analytics Engine
210
Machine Leaning Tools
212
Data Science Tools
214
BI Tools
216
Reports & Dashboards
218
Applications
Data Lake/ Warehouse/ Database/Etc.
202
Transactional Systems
204
Streaming Systems
206

Figure 2

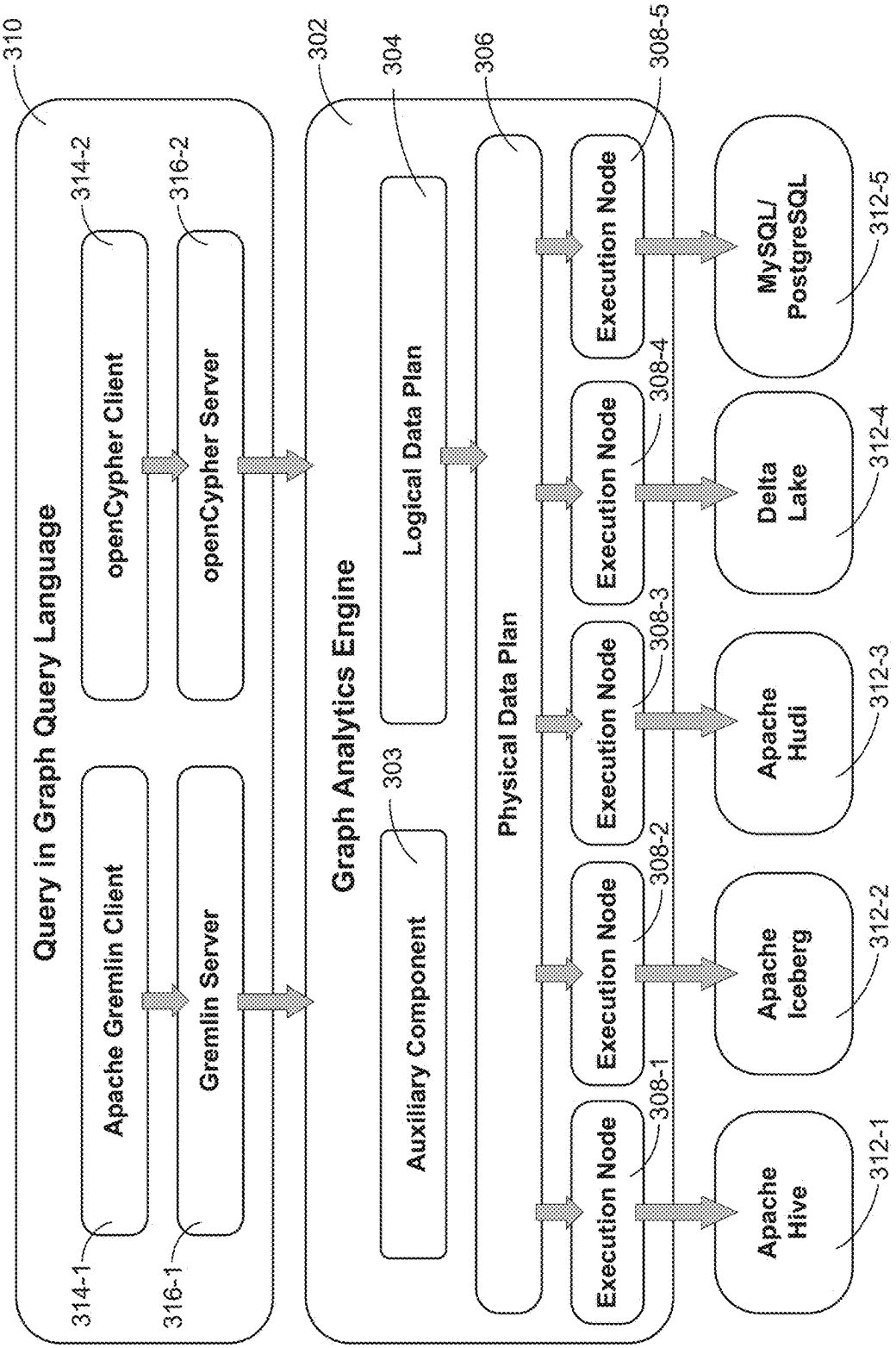
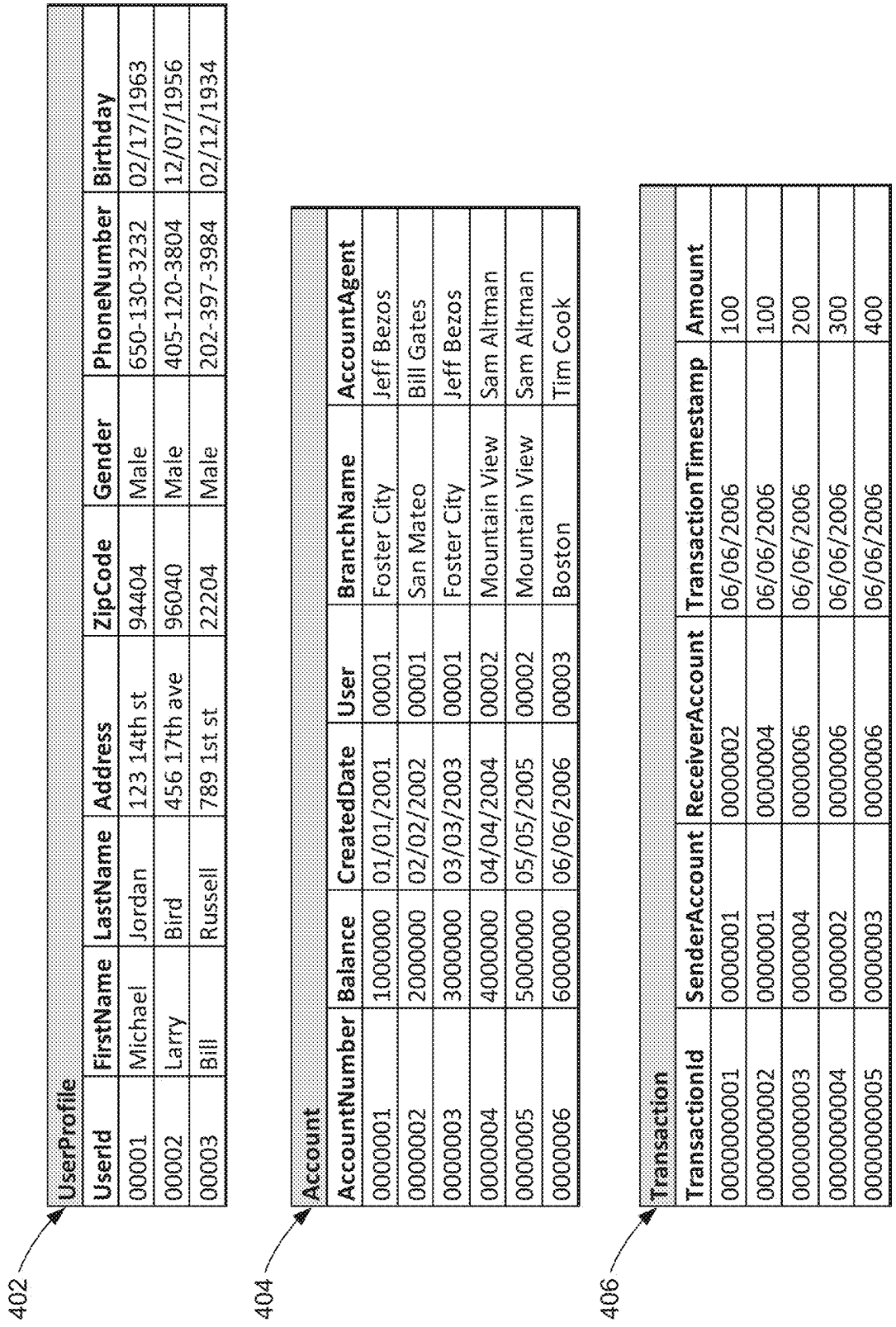

300
310
Query in Graph Query Language
Apache Gremlin Client
Gremlin Server
openCypher Client
openCypher Server
314-1
316-1
314-2
316-2
302
Graph Analytics Engine
Auxiliary Component
303
Logical Data Plan
304
Physical Data Plan
306
Execution Node
Execution Node
Execution Node
Execution Node
Execution Node
308-1
308-2
308-3
308-4
308-5
Apache Hive
Apache Iceberg
Apache Hudi
Delta Lake
MySQL/ PostgreSQL
312-1
312-2
312-3
312-4
312-5

Figure 3



UserProfile

UserId	FirstName	LastName	Address	ZipCode	Gender	PhoneNumber	Birthday
00001	Michael	Jordan	123 14th st	94404	Male	650-130-3232	02/17/1963
00002	Larry	Bird	456 17th ave	96040	Male	405-120-3804	12/07/1956
00003	Bill	Russell	789 1st st	22204	Male	202-397-3984	02/12/1934

Account

AccountNumber	Balance	CreatedDate	User	BranchName	AccountAgent
0000001	1000000	01/01/2001	00001	Foster City	Jeff Bezos
0000002	2000000	02/02/2002	00001	San Mateo	Bill Gates
0000003	3000000	03/03/2003	00001	Foster City	Jeff Bezos
0000004	4000000	04/04/2004	00002	Mountain View	Sam Altman
0000005	5000000	05/05/2005	00002	Mountain View	Sam Altman
0000006	6000000	06/06/2006	00003	Boston	Tim Cook

Transaction

TransactionId	SenderAccount	ReceiverAccount	TransactionTimestamp	Amount
0000000001	0000001	0000002	06/06/2006	100
0000000002	0000001	0000004	06/06/2006	100
0000000003	0000004	0000006	06/06/2006	200
0000000004	0000002	0000006	06/06/2006	300
0000000005	0000003	0000006	06/06/2006	400

Figure 4A

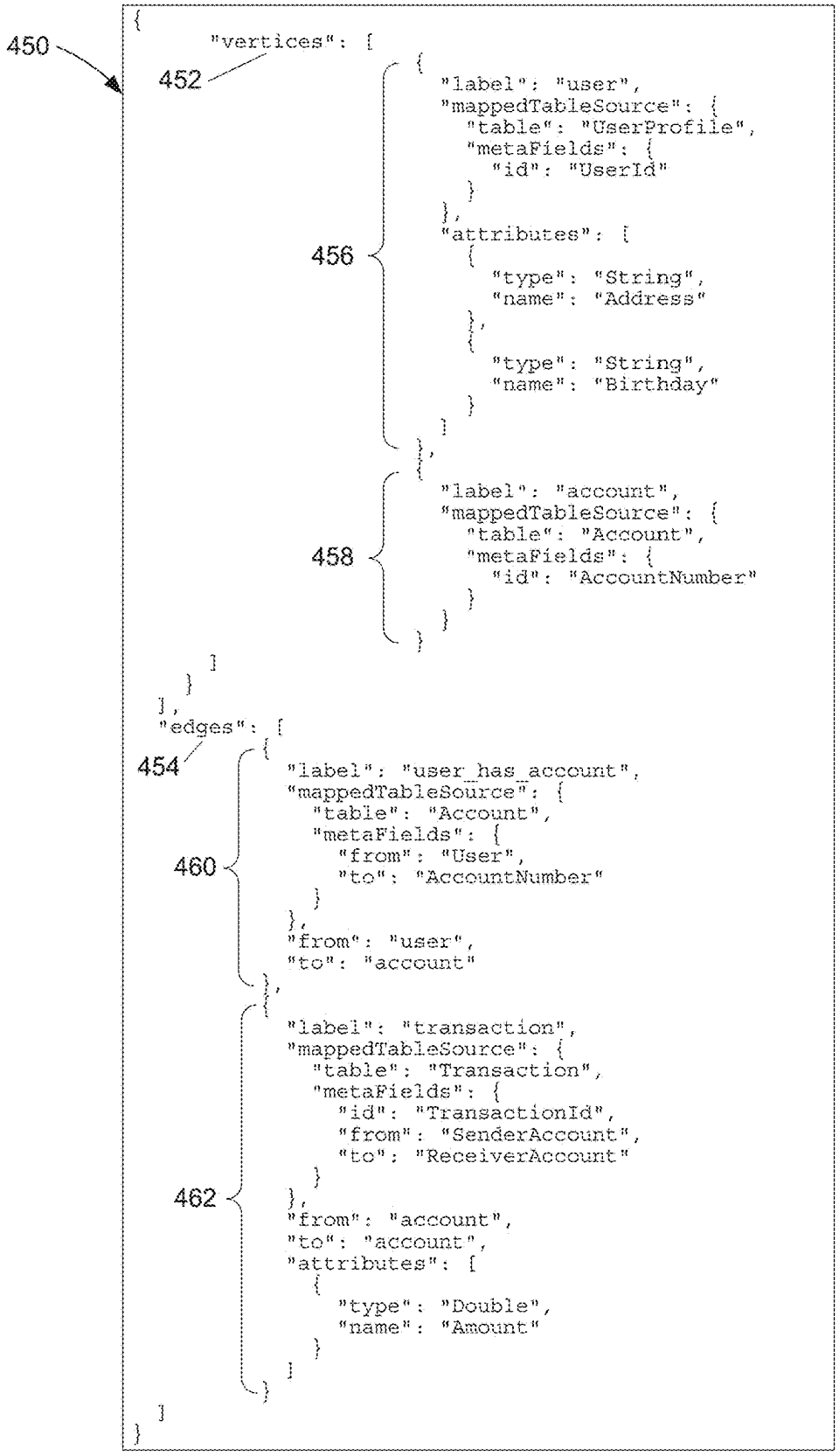

450
452
456
458
454
460
462
{
"vertices": [
{
"label": "user",
"mappedTableSource": {
"table": "UserProfile",
"metaFields": {
"id": "UserId"
}
},
"attributes": [
{
"type": "String",
"name": "Address"
},
{
"type": "String",
"name": "Birthday"
}
]
},
{
"label": "account",
"mappedTableSource": {
"table": "Account",
"metaFields": {
"id": "AccountNumber"
}
}
}
]
}
],
"edges": [
{
"label": "user_has_account",
"mappedTableSource": {
"table": "Account",
"metaFields": {
"from": "User",
"to": "AccountNumber"
}
},
"from": "user",
"to": "account"
},
{
"label": "transaction",
"mappedTableSource": {
"table": "Transaction",
"metaFields": {
"id": "TransactionId",
"from": "SenderAccount",
"to": "ReceiverAccount"
}
},
"from": "account",
"to": "account",
"attributes": [
{
"type": "Double",
"name": "Amount"
}
]
}
]
}

Figure 4B

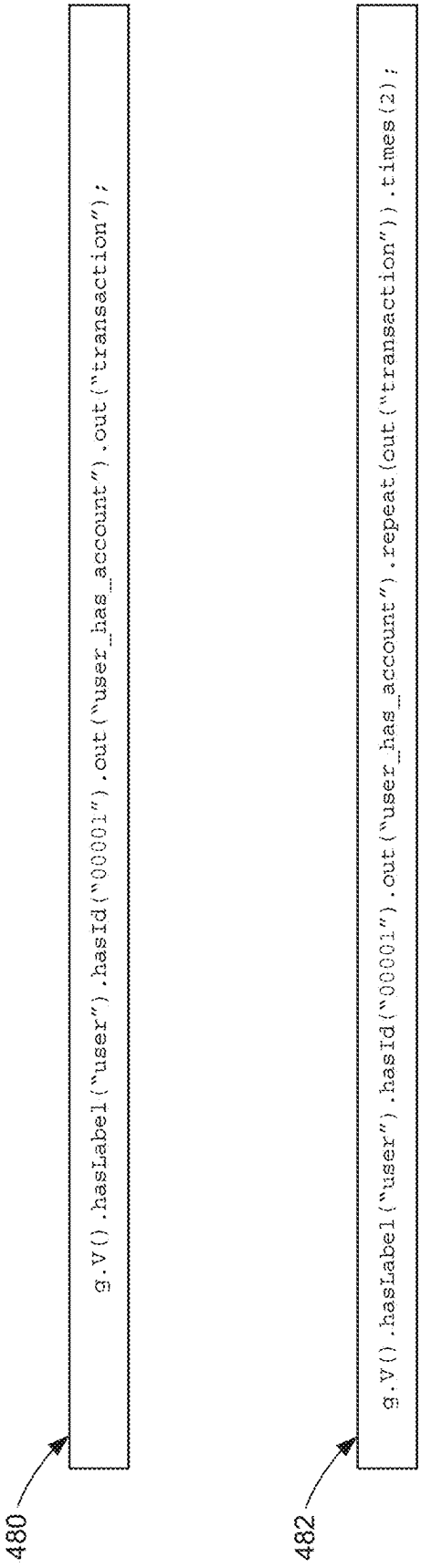

g.V().hasLabel("user").hasId("00001").out("user_has_account").out("transaction");
480
g.V().hasLabel("user").hasId("00001").out("user_has_account").repeat(out("transaction")).times(2);
482

Figure 4C

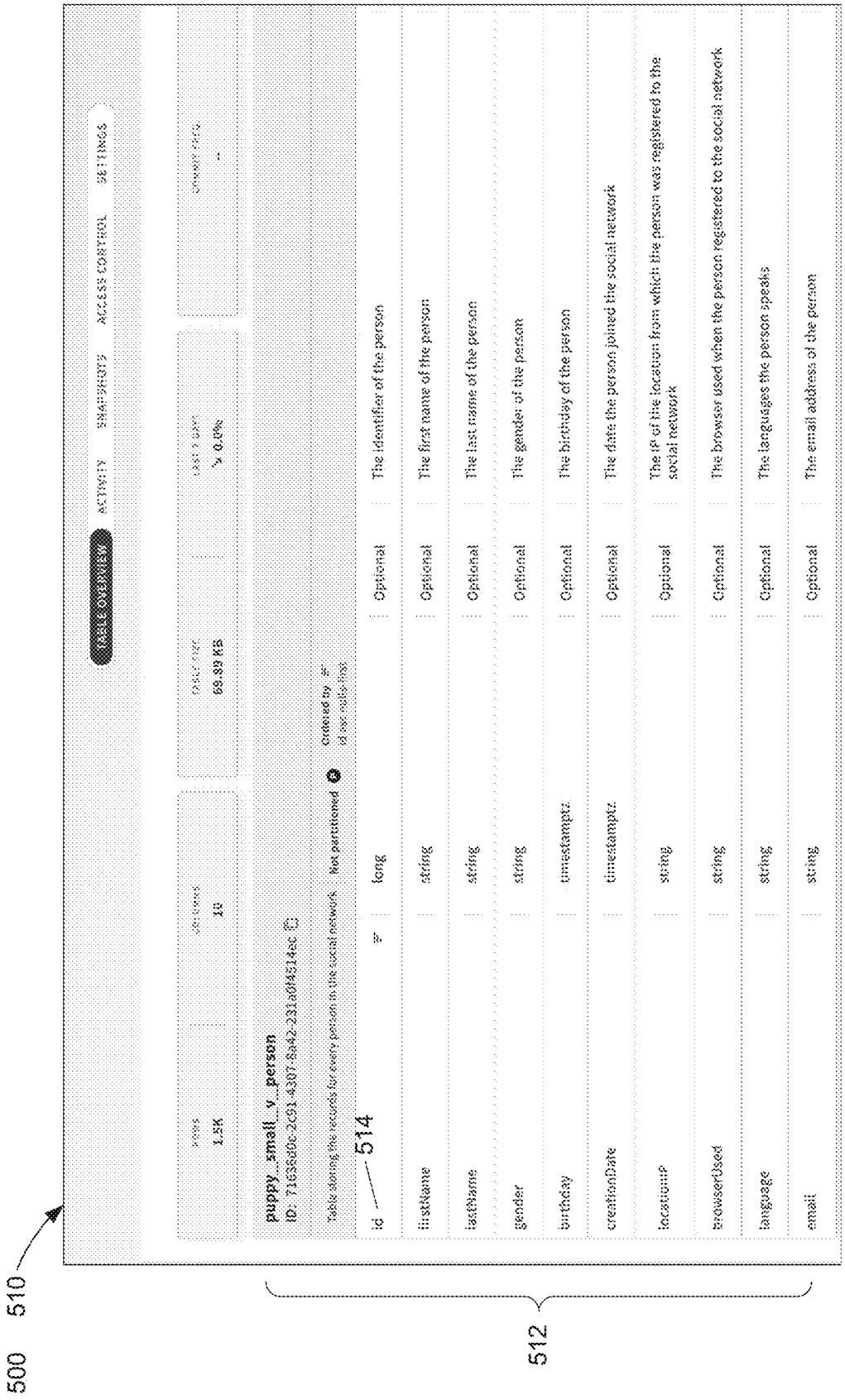

500
510
512
514
puppy_small_v_person
id
long
firstName
string
lastName
string
gender
string
birthday
timestamptz
creationDate
timestamptz
locationIP
string
browserUsed
string
language
string
email
string
Optional
The identifier of the person
The first name of the person
The last name of the person
The gender of the person
The birthday of the person
The date the person joined the social network
The IP of the location from which the person was registered to the social network
The browser used when the person registered to the social network
The languages the person speaks
The email address of the person

Figure 5A

500

520

schema.json

```
{
  "catalogs": [
    {
      "name": "tabular_examples",
      "type": "iceberg",
      "metastore": {
        "type": "rest",
        "uri": "https://api.tabular.io/ws",
        "warehouse": "share",
        "security": "oauth2",
        "session": "user",
        "credential": "${ENV:TABULAR_CREDENTIAL}"
      }
    }
  ],
  "vertices": [
    {
      "label": "Person",
      "mappedTableSource": {
        "catalog": "tabular_examples",
        "schema": "puppygraph",
        "table": "puppy_small_v_person",
        "metaFields": {
          "id": "id"
        }
      },
      "attributes": [
        {
          "name": "creationDate",
          "type": "DateTime"
        },
        {
          "name": "firstName",
          "type": "String"
        },
        {
```

Figure 5B

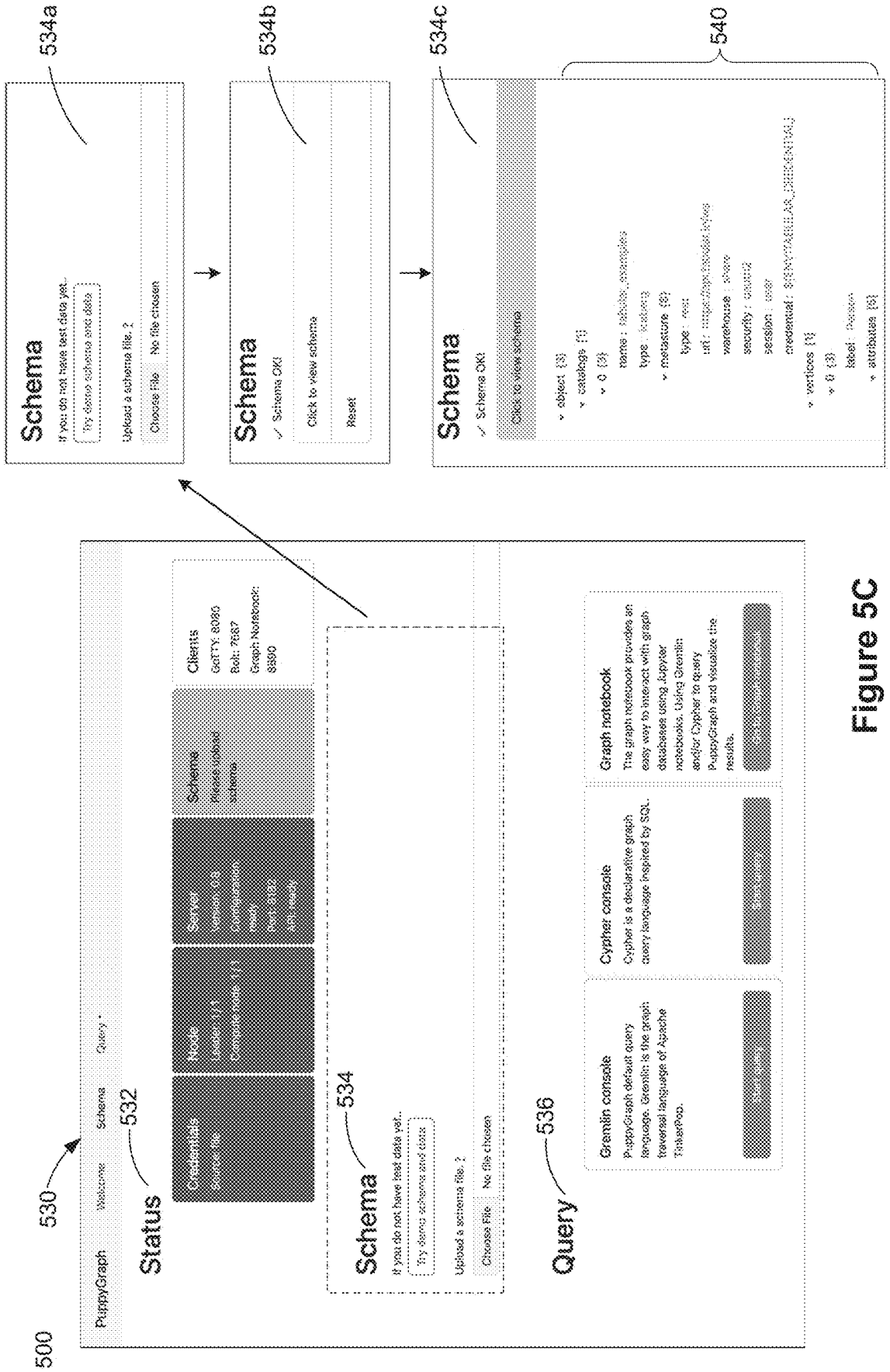

500
530
PuppyGraph
Welcome
Schema
Query
532
Status
Credentials
Nodes
Edges
Clients
534
Schema
If you do not have test data yet.
Try demo schema and data
Upload a schema file. ?
Choose File
No file chosen
536
Query
Gremlin console
Cypher console
Graph notebook
534a
Schema
534b
Schema
Click to view schema
Reset
534c
Schema
540

Figure 5C

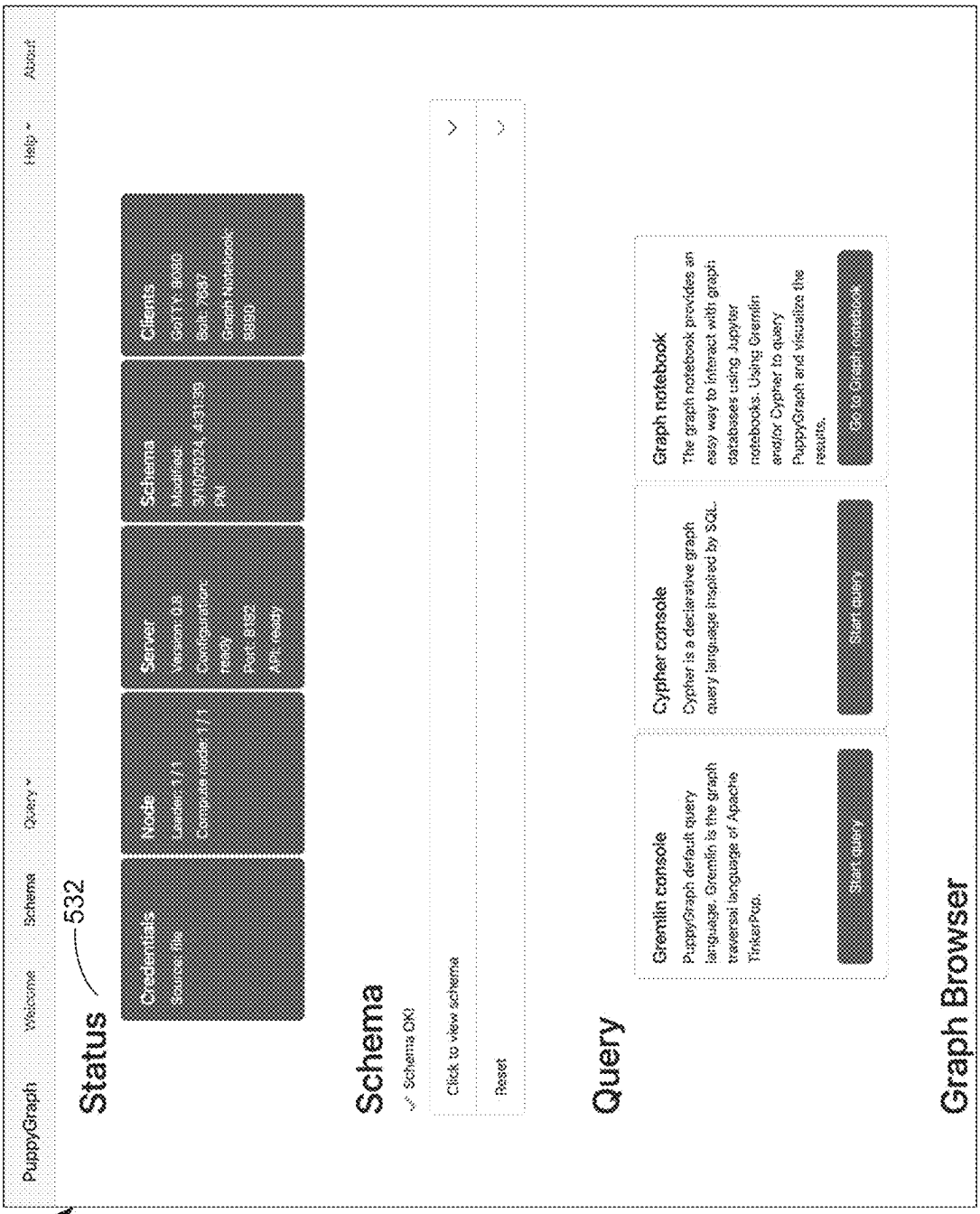

500
530
PuppyGraph
Welcome
Schema
Query
Help
About
Status
532
Credentials
Server
Node
Schema
Clients
Schema
Click to view schema
Reset
Query
Gremlin console
Cypher console
Graph notebook
Graph Browser

Figure 5D

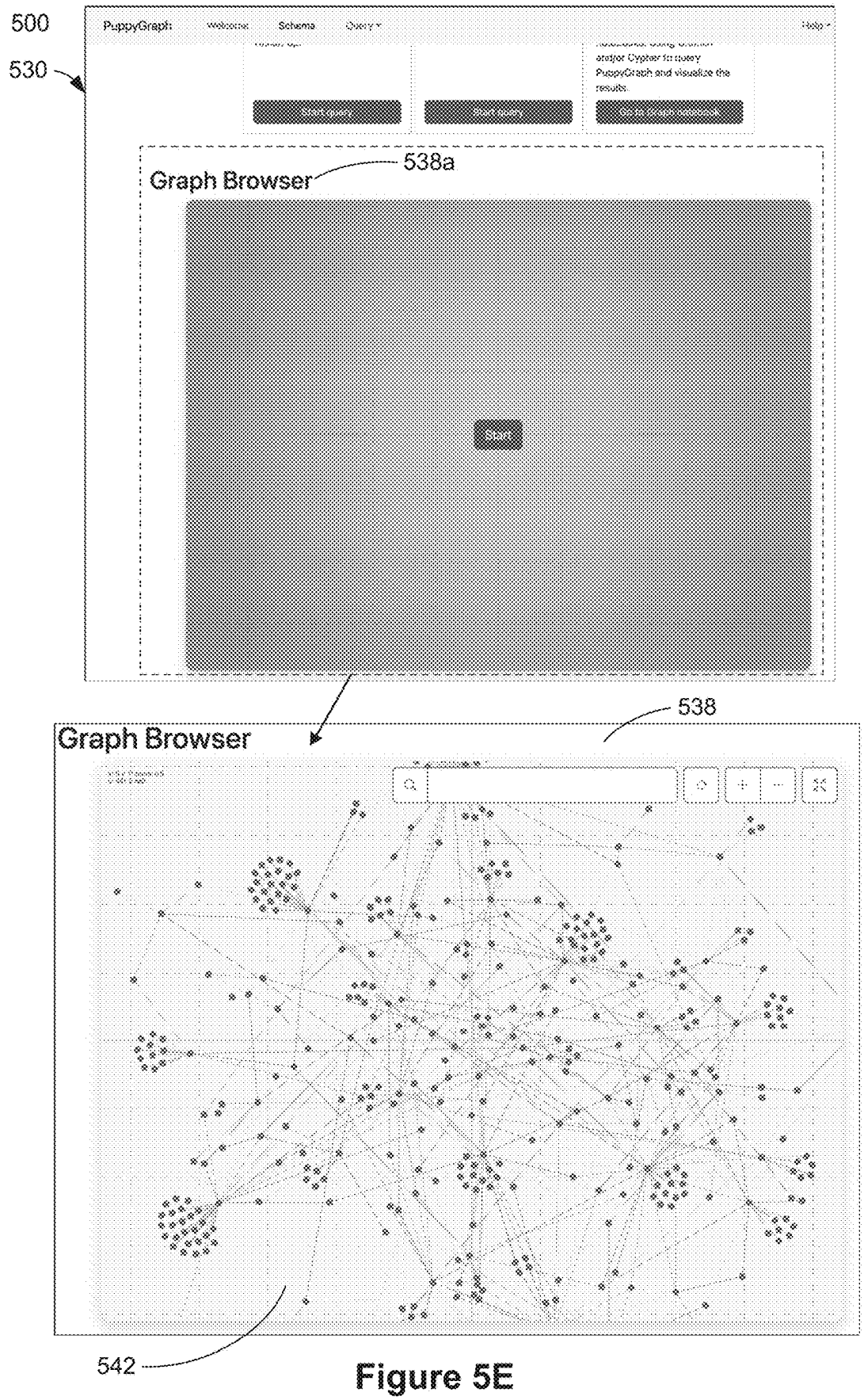

500
530
PuppyGraph:
Welcome
Schema
Query
Help
and/or Cypher to query
PuppyGraph and visualize the
results.
Graph Browser
538a
Graph Browser
538
542

Figure 5E

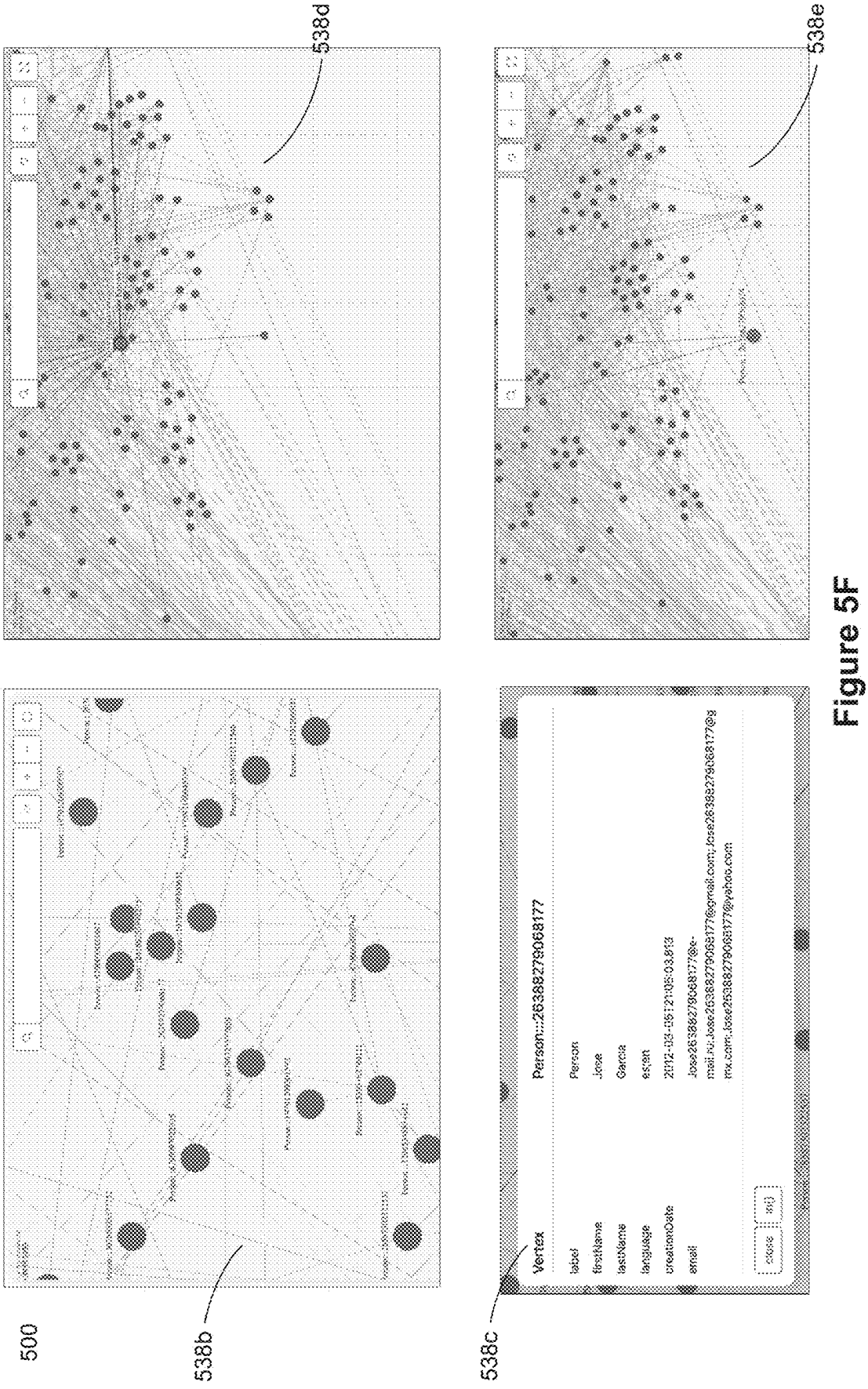
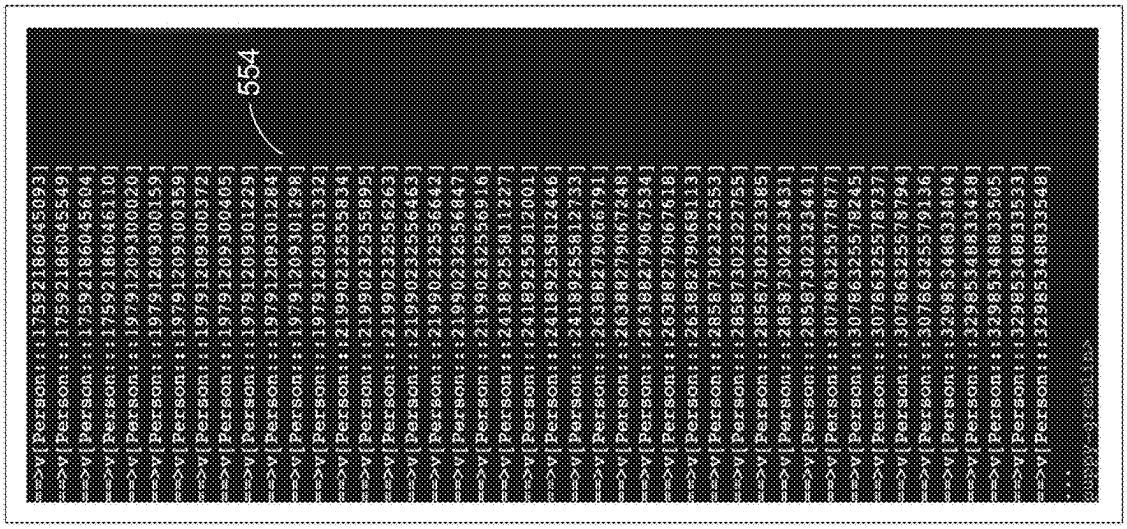

500
538b
538c
538d
538e
Vertex
Person:::263882790681777
label
Person
firstName
Jose
lastName
Garcia
language
esp
creationDate
2012-03-05T21:05:03.813
email
Jose263882790681777@e-mail.ru;Jose263882790681777@gmail.com;Jose263882790681777@gmx.com;Jose263882790681777@yahoo.com
close
Info

Figure 5F


554

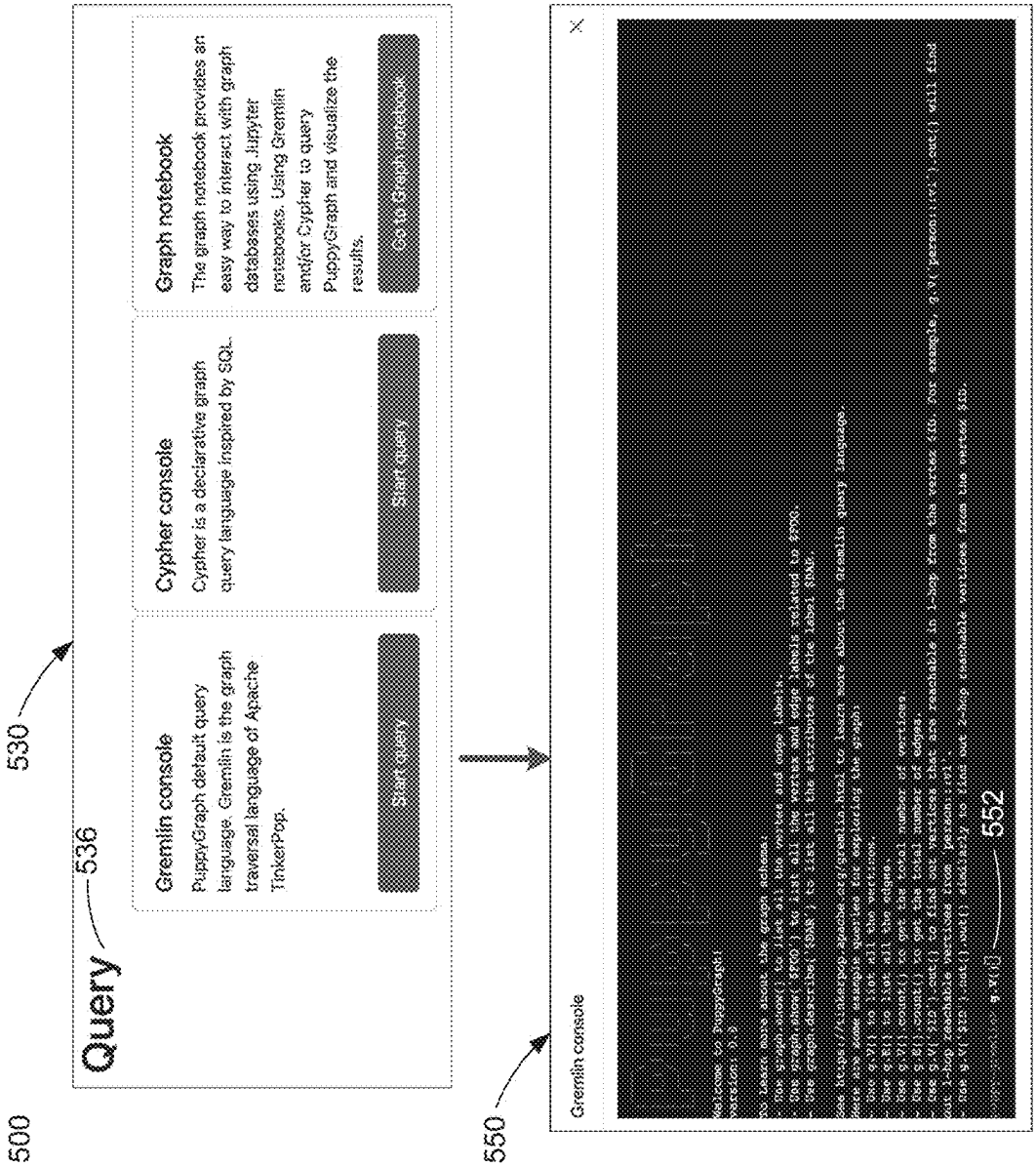

500
530
Query
536
Gremlin console
PuppyGraph default query language. Gremlin is the graph traversal language of Apache TinkerPop.
Start query
Cypher console
Cypher is a declarative graph query language inspired by SQL.
Start query
Graph notebook
The graph notebook provides an easy way to interact with graph databases using Jupyter notebooks. Using Gremlin and/or Cypher to query PuppyGraph and visualize the results.
Go to Graph notebook
550
Gremlin console
552

Figure 5G

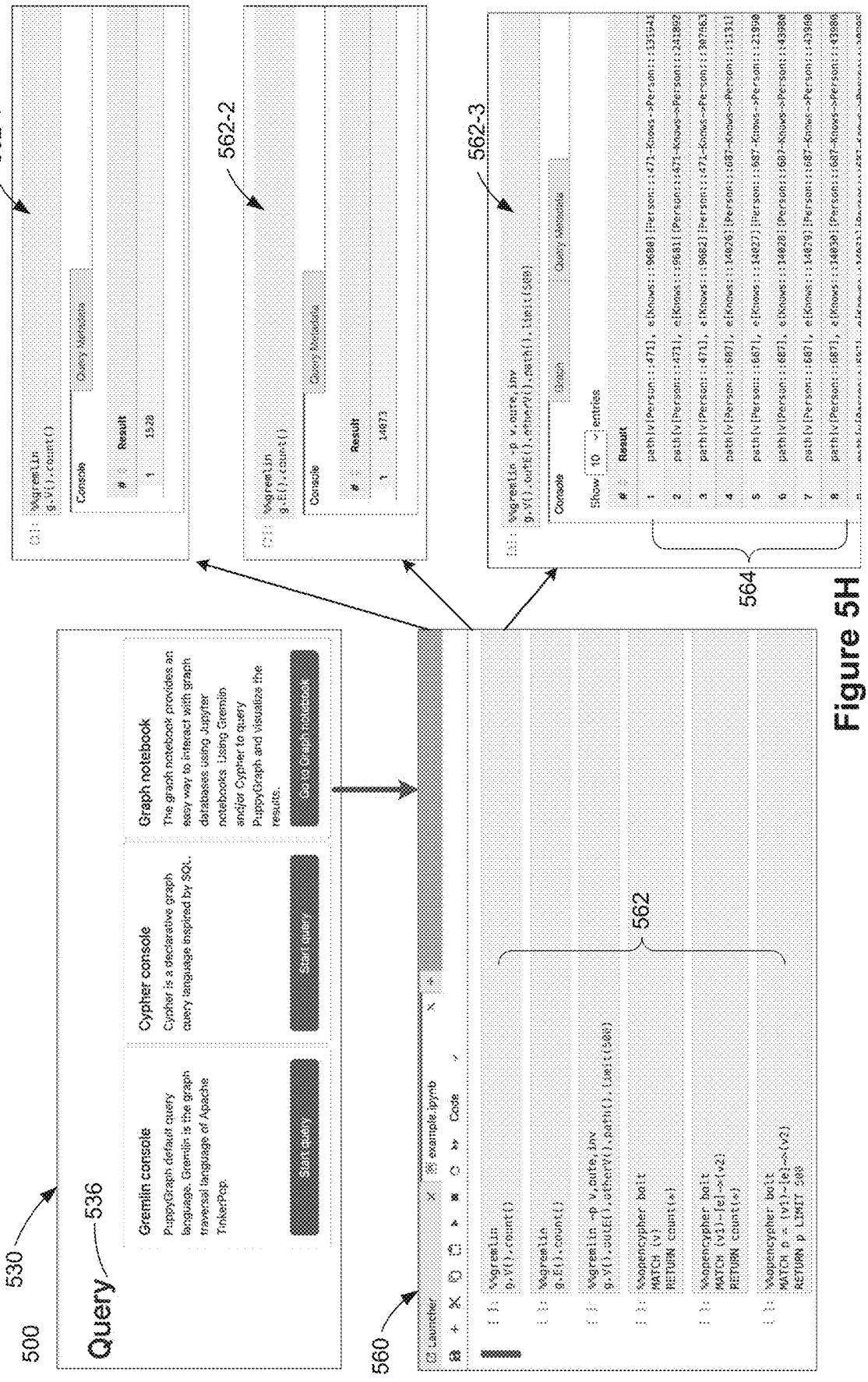
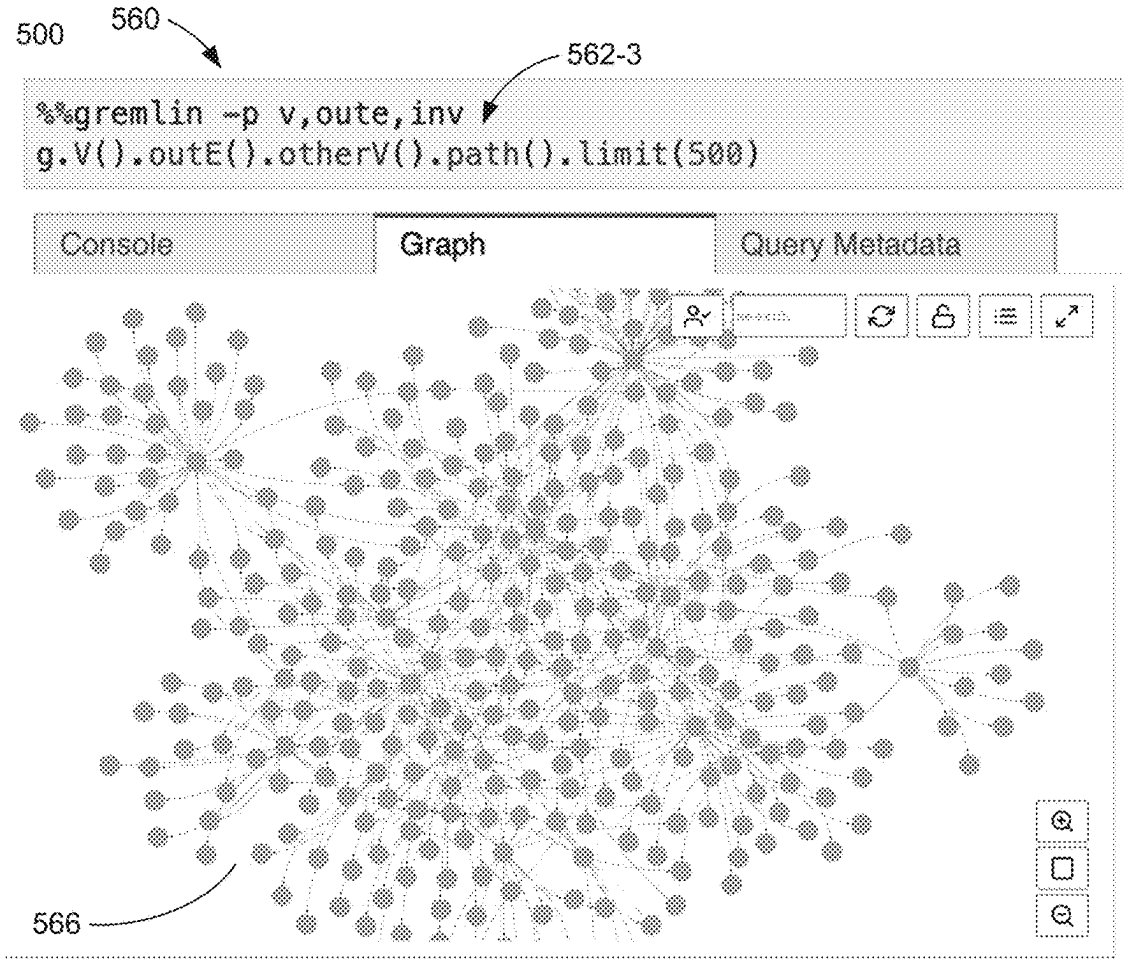

562-1
562-2
562-3
500
530
536
Query
Gremlin console
Cypher console
Graph notebook
562
564
560

Figure 5H


500
560
562-3
%%gremlin -p v,oute,inv
g.V().outE().otherV().path().limit(500)
Console
Graph
Query Metadata
566

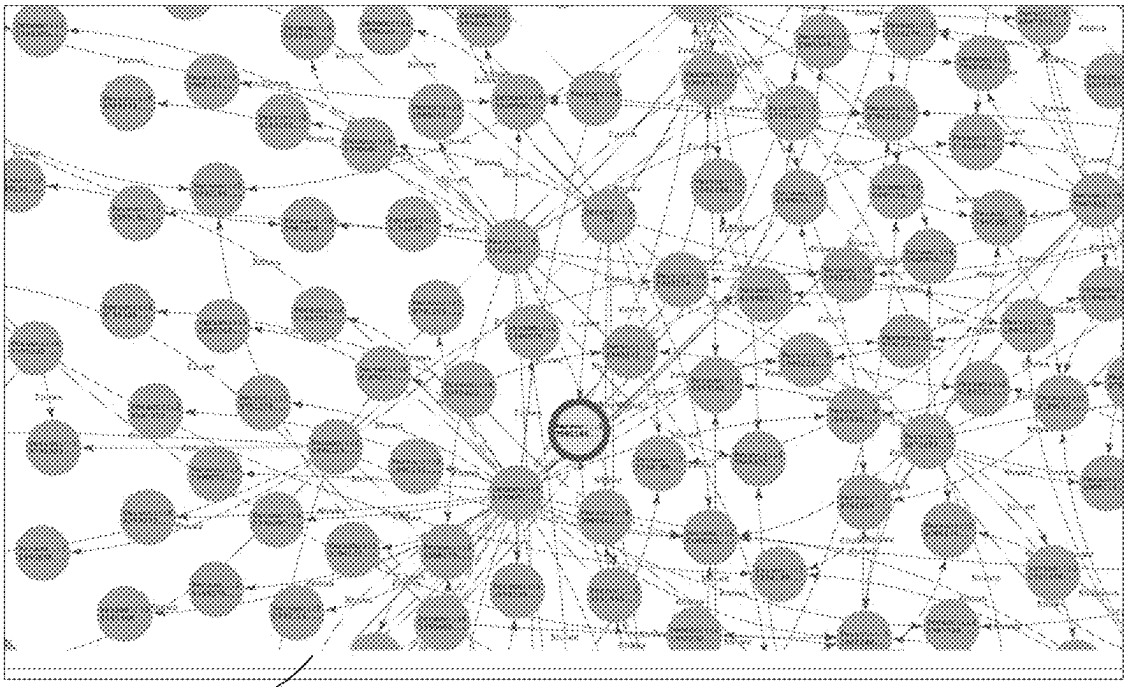

566a

Figure 5I

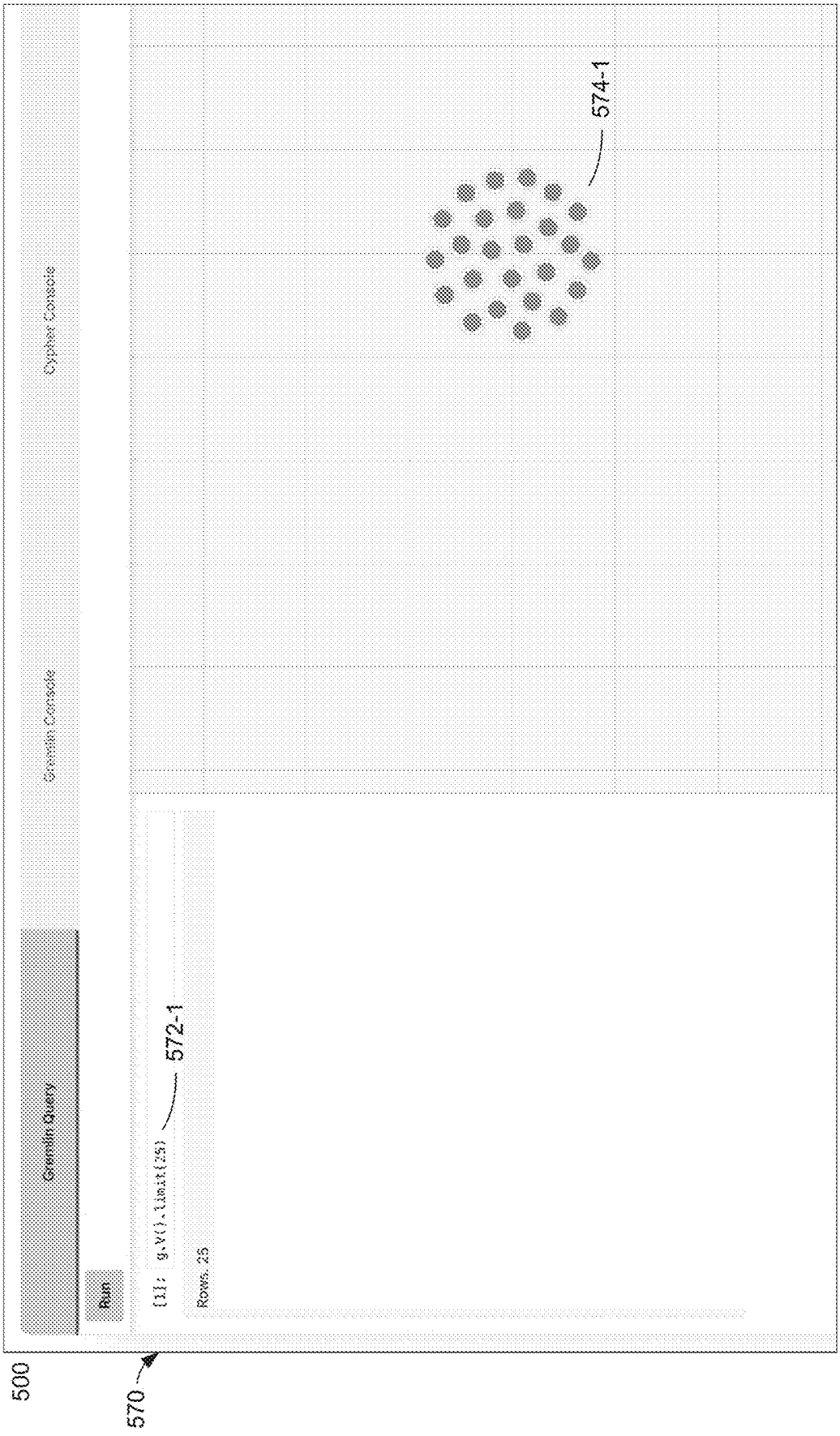

500
570
Gremlin Query
Run
Gremlin Console
Cypher Console
572-1
Rows: 25
574-1

Figure 5J

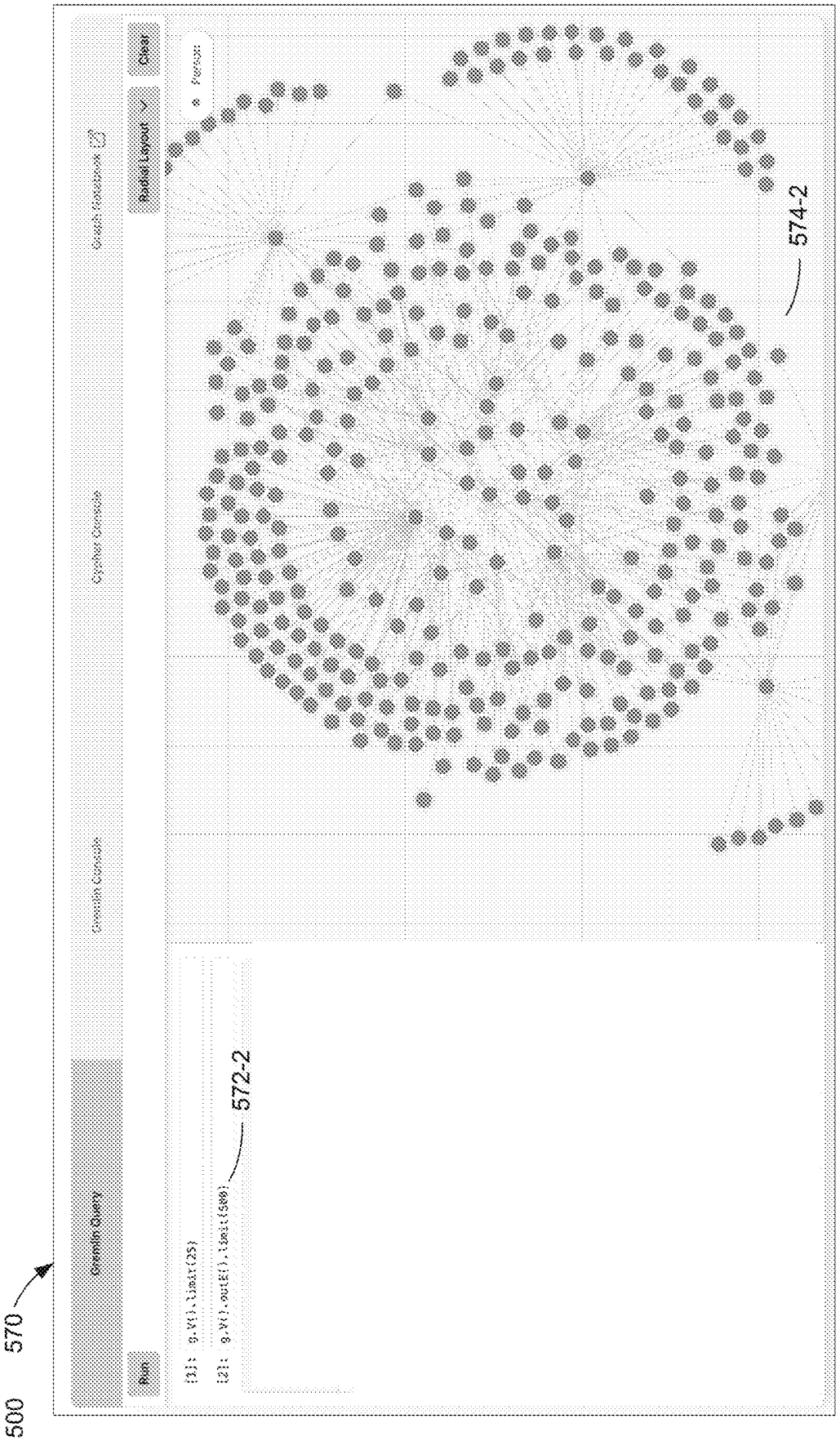

500
570
Run
Cypher Query
Cypher Console
Graph Console
Graph Database
Radial Layout
Clear
Person
574-2
572-2

Figure 5K

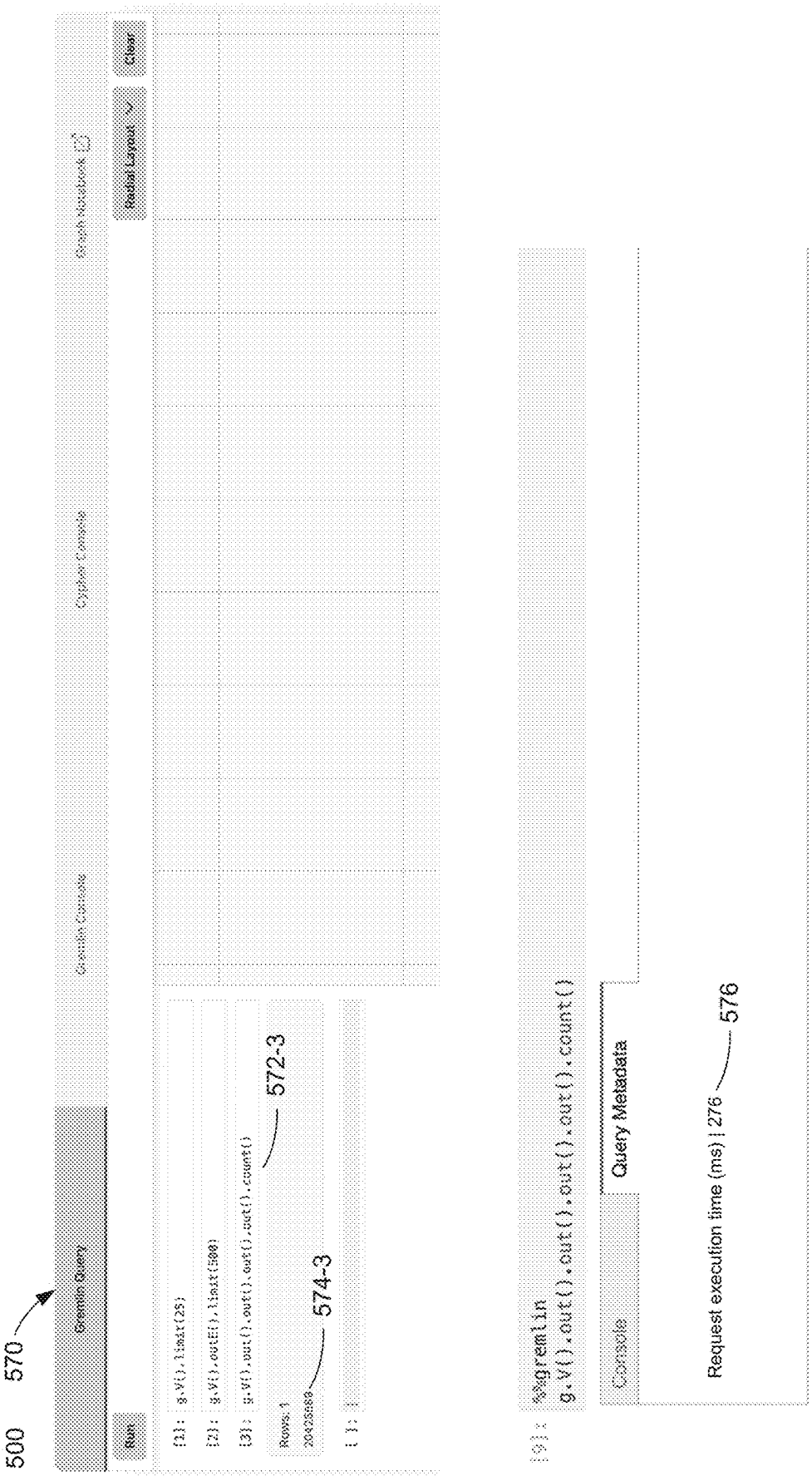

500
570
Gremlin Query
Gremlin Console
Cypher Console
Graph Notebook (?)
Run
Radial Layout
Clear
[1]: g.V().limit(25)
[2]: g.V().outE().limit(500)
[3]: g.V().out().out().out().count()
Rows: 1
20428868
574-3
572-3
[ ]:
[9]: %%gremlin
g.V().out().out().out().count()
Console
Query Metadata
Request execution time (ms) | 276
576

Figure 5L

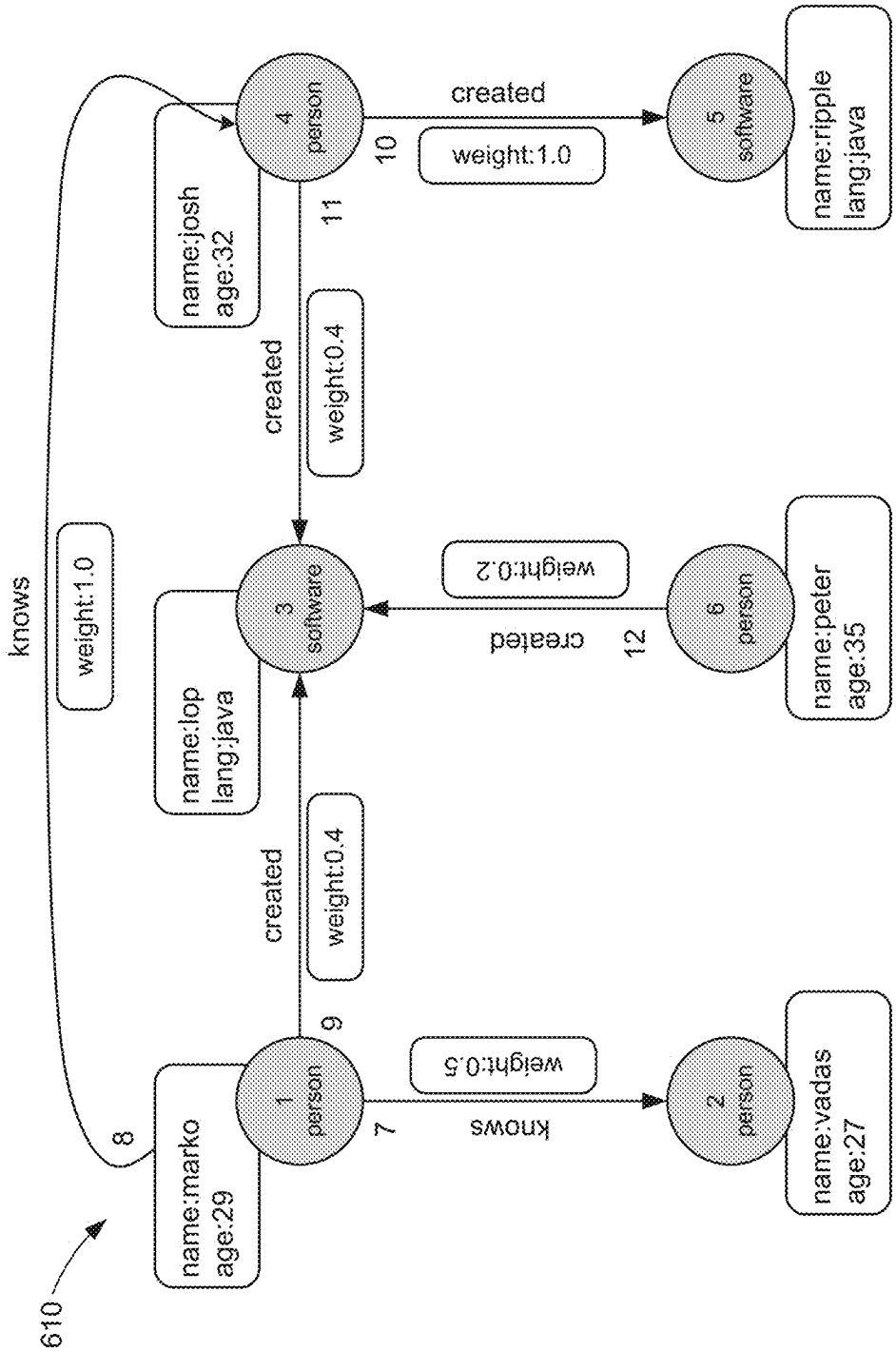

610
1 person
name:marko age:29
2 person
name:vadas age:27
3 software
name:lop lang:java
4 person
name:josh age:32
5 software
name:ripple lang:java
6 person
name:peter age:35
knows
weight:0.5
created
weight:1.0
created
weight:0.4
created
weight:0.4
created
weight:0.2
knows
weight:1.0
7
8
9
10
11
12

Figure 6A

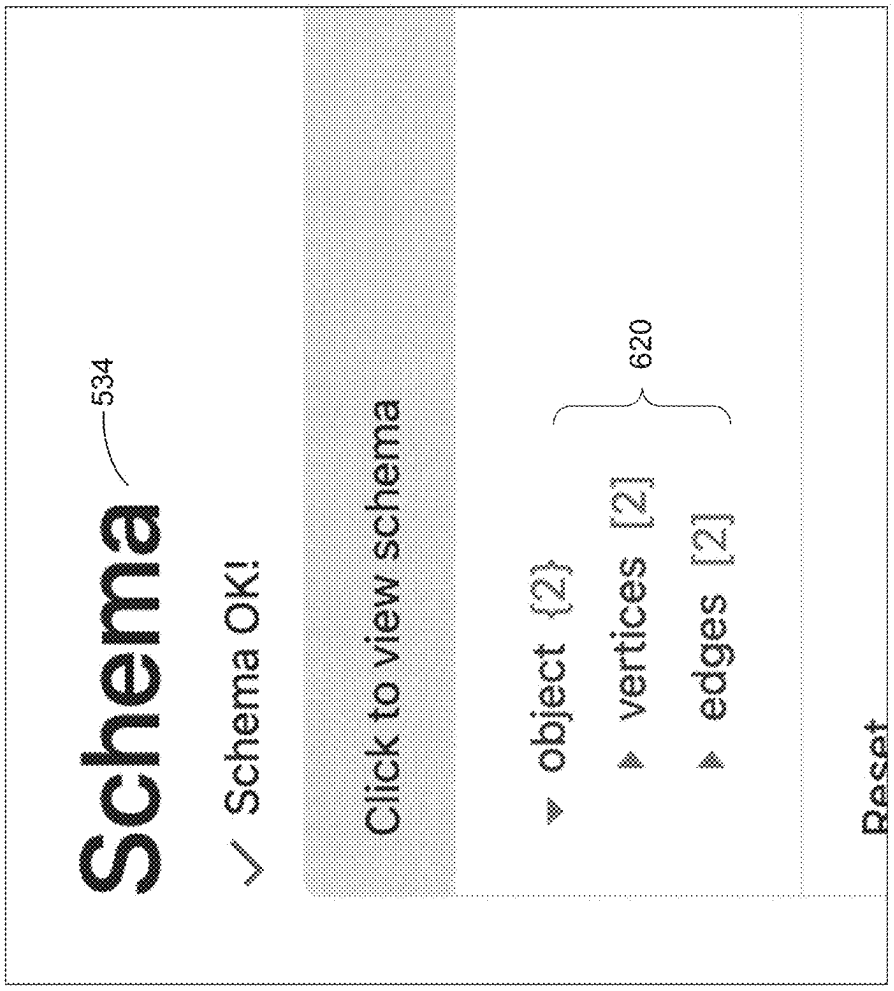

Schema
534
Schema OK!
Click to view schema
object {2}
vertices [2]
edges [2]
620
Reset

Figure 6B

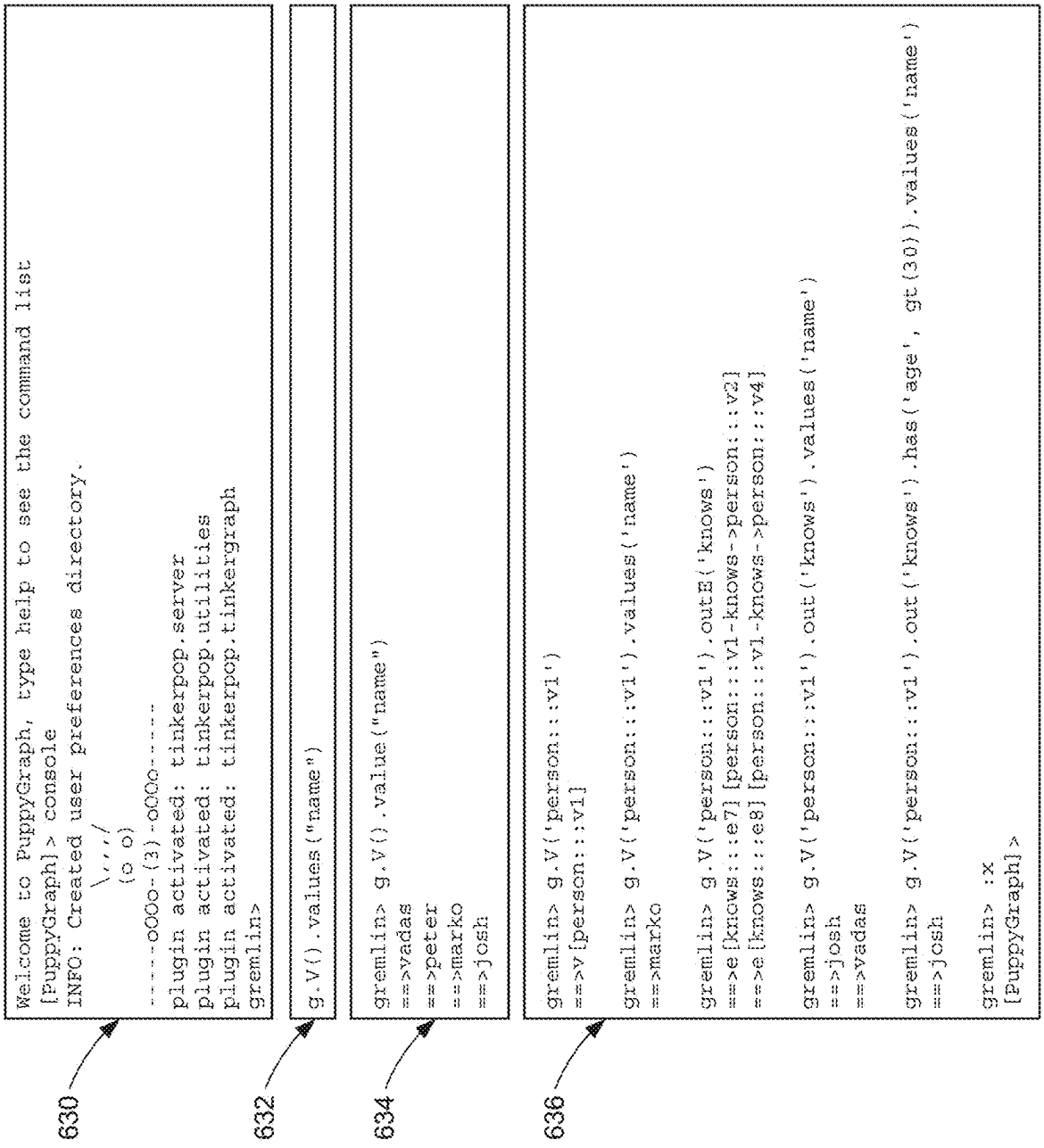

600
630
632
634
636
Welcome to PuppyGraph, type help to see the command list
[PuppyGraph]> console
INFO: Created user preferences directory.
\,,,/
(o o)
-----oOOo-(3)-oOOo-----
plugin activated: tinkerpop.server
plugin activated: tinkerpop.utilities
plugin activated: tinkerpop.tinkergraph
gremlin>
g.V().values("name")
gremlin> g.V().value("name")
==>vadas
==>peter
==>marko
==>josh
gremlin> g.V('person::v1')
==>v[person::v1]
gremlin> g.V('person::v1').values('name')
==>marko
gremlin> g.V('person::v1').outE('knows')
==>e[knows::e7][person::v1-knows->person::v2]
==>e[knows::e8][person::v1-knows->person::v4]
gremlin> g.V('person::v1').out('knows').values('name')
==>josh
==>vadas
gremlin> g.V('person::v1').out('knows').has('age', gt(30)).values('name')
==>josh
gremlin> :x
[PuppyGraph]>

Figure 6C

600

640

```
<dependency>
    <groupId>org.apache.tinkerpop</groupId>
    <artifactId>gremlin-core</artifactId>
    <version>3.6.0</version>
</dependency>
<dependency>
    <groupId>org.apache.tinkerpop</groupId>
    <artifactId>gremlin-driver</artifactId>
    <version>3.6.0</version>
</dependency>
<dependency>
    <groupId>org.apache.tinkerpop</groupId>
    <artifactId>gremlin-server</artifactId>
    <version>3.6.0</version>
</dependency>
```

642

```
public class TestGraphBinaryMessageSerializerV1 {
    public static void main(String[] args) throws Exception {
        Cluster cluster =
Cluster.build().addContactPoint("127.0.0.1").create();
        Client client = cluster.connect();

        GraphTraversalSource g = AnonymousTraversalSource.traversal()
                .withRemote(DriverRemoteConnection.using(client, "g"));

        System.out.println(g.V().count().next());
        System.out.println(g.E().count().next());
        System.out.println(g.V("person:::v1").values("name").next(10));

        g.close();
        client.close();
        cluster.close();
        return;
    }
}
```

Figure 6D

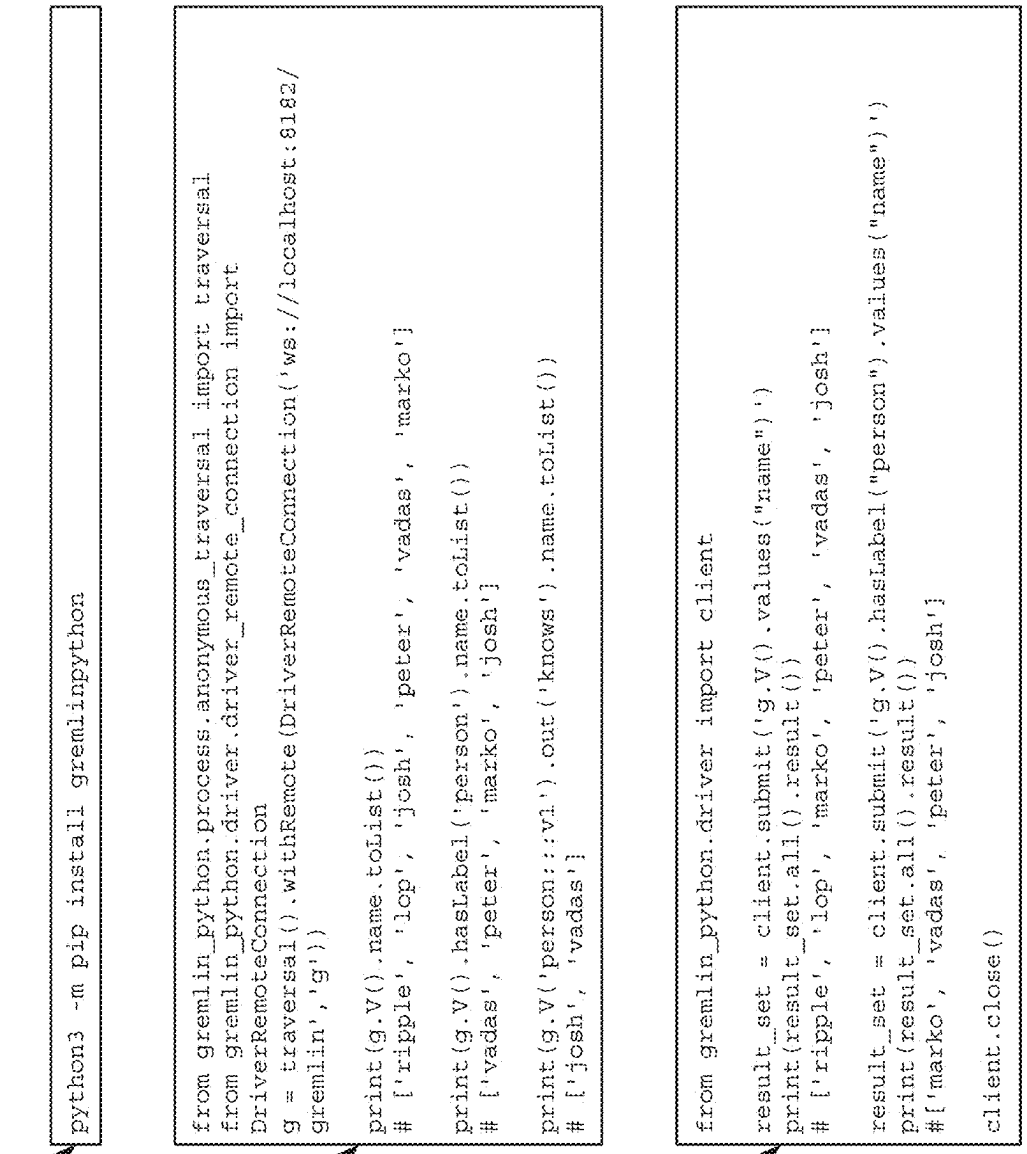

600
650
python3 -m pip install gremlinpython
652
from gremlin_python.process.anonymous_traversal import traversal
from gremlin_python.driver.driver_remote_connection import
DriverRemoteConnection
g = traversal().withRemote(DriverRemoteConnection('ws://localhost:8182/
gremlin','g'))
print(g.V().name.toList())
# ['ripple', 'lop', 'josh', 'peter', 'vadas', 'marko']
print(g.V().hasLabel('person').name.toList())
# ['vadas', 'peter', 'marko', 'josh']
print(g.V('person::v1').out('knows').name.toList())
# ['josh', 'vadas']
654
from gremlin_python.driver import client
result_set = client.submit('g.V().values("name")')
print(result_set.all().result())
# ['ripple', 'lop', 'marko', 'peter', 'vadas', 'josh']
result_set = client.submit('g.V().hasLabel("person").values("name")')
print(result_set.all().result())
#['marko', 'vadas', 'peter', 'josh']
client.close()

Figure 6E

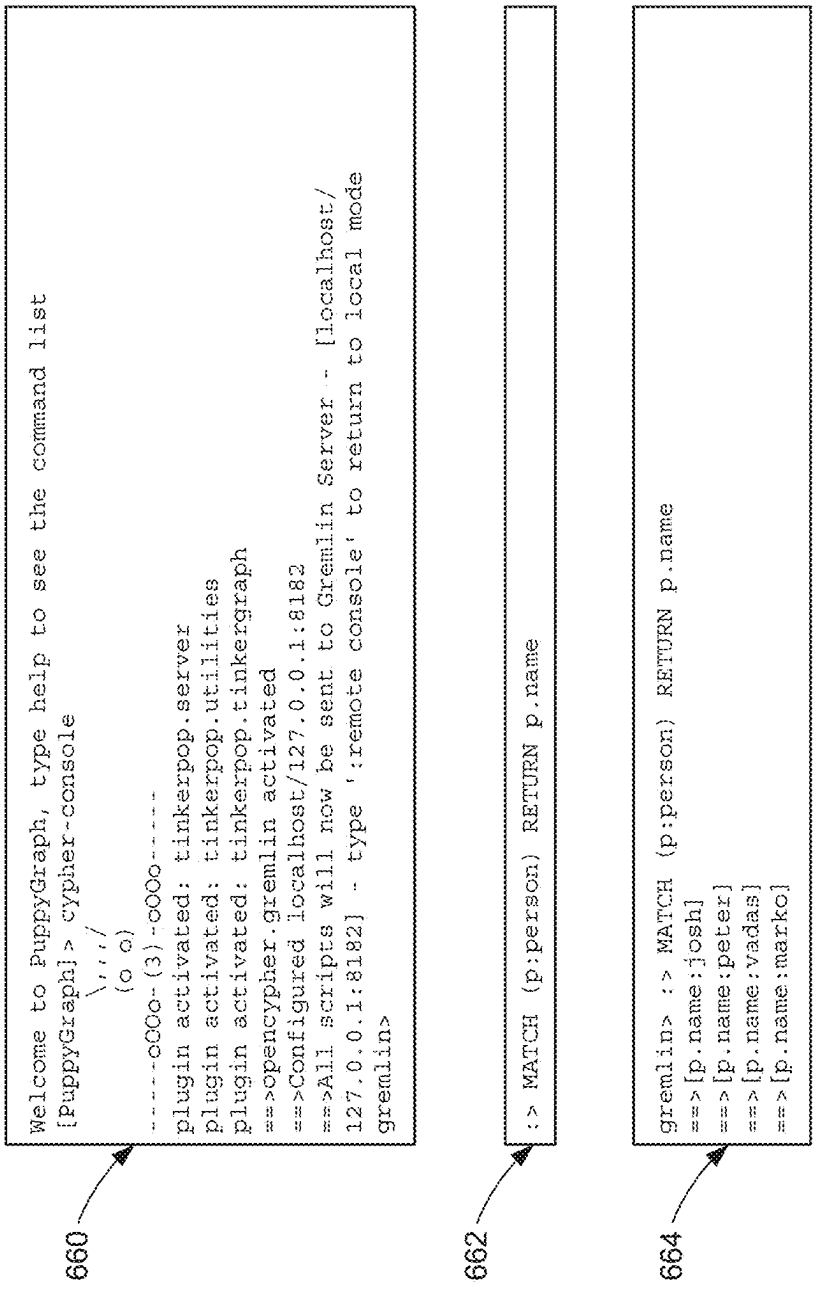

600
660
Welcome to PuppyGraph, type help to see the command list
[PuppyGraph]> cypher-console
\ ,,,/
(o o)
-----oCCo-(3)-oCCo-----
plugin activated: tinkerpop.server
plugin activated: tinkerpop.utilities
plugin activated: tinkerpop.tinkergraph
==>opencypher.gremlin activated
==>Configured localhost/127.0.0.1:8182
==>All scripts will now be sent to Gremlin Server - [localhost/
127.0.0.1:8182] - type ':remote console' to return to local mode
gremlin>
662
:> MATCH (p:person) RETURN p.name
664
gremlin> :> MATCH (p:person) RETURN p.name
==>[p.name:josh]
==>[p.name:peter]
==>[p.name:vadas]
==>[p.name:marko]

Figure 6F

700

```
docker compose up -d

[+] Running 6/6
 ✓ Network puppy-iceberg          Created
 ✓ Container minio                Started
 ✓ Container mc                   Started
 ✓ Container iceberg-rest         Started
 ✓ Container spark-iceberg        Started
 ✓ Container puppygraph           Started
```

702

704

```
docker exec -it spark-iceberg spark-sql
```

706

```
spark-sql ()>
```

708

```
CREATE DATABASE demo.modern;

CREATE EXTERNAL TABLE demo.modern.v_person (
  id string,
  name string,
  age int
) USING iceberg;

INSERT INTO demo.modern.v_person VALUES
  ('v1', 'marko', 29),
  ('v2', 'vadas', 27),
  ('v4', 'josh', 32),
  ('v6', 'peter', 35);

CREATE EXTERNAL TABLE demo.modern.v_software (
  id string,
  name string,
  lang string
) USING iceberg;

INSERT INTO demo.modern.v_software VALUES
  ('v3', 'lop', 'java'),
  ('v5', 'ripple', 'java');

CREATE EXTERNAL TABLE demo.modern.e_created (
  id string,
  from_id string,
  to_id string,
  weight double
) USING iceberg;

INSERT INTO demo.modern.e_created VALUES
  ('e9', 'v1', 'v3', 0.4),
  ('e10', 'v4', 'v5', 1.0),
  ('e11', 'v4', 'v3', 0.4),
  ('e12', 'v6', 'v3', 0.2);

CREATE EXTERNAL TABLE demo.modern.e_knows (
  id string,
  from_id string,
  to_id string,
  weight double
) USING iceberg;

INSERT INTO demo.modern.e_knows VALUES
  ('e7', 'v1', 'v2', 0.5),
  ('e8', 'v1', 'v4', 1.0);
```

Figure 7A

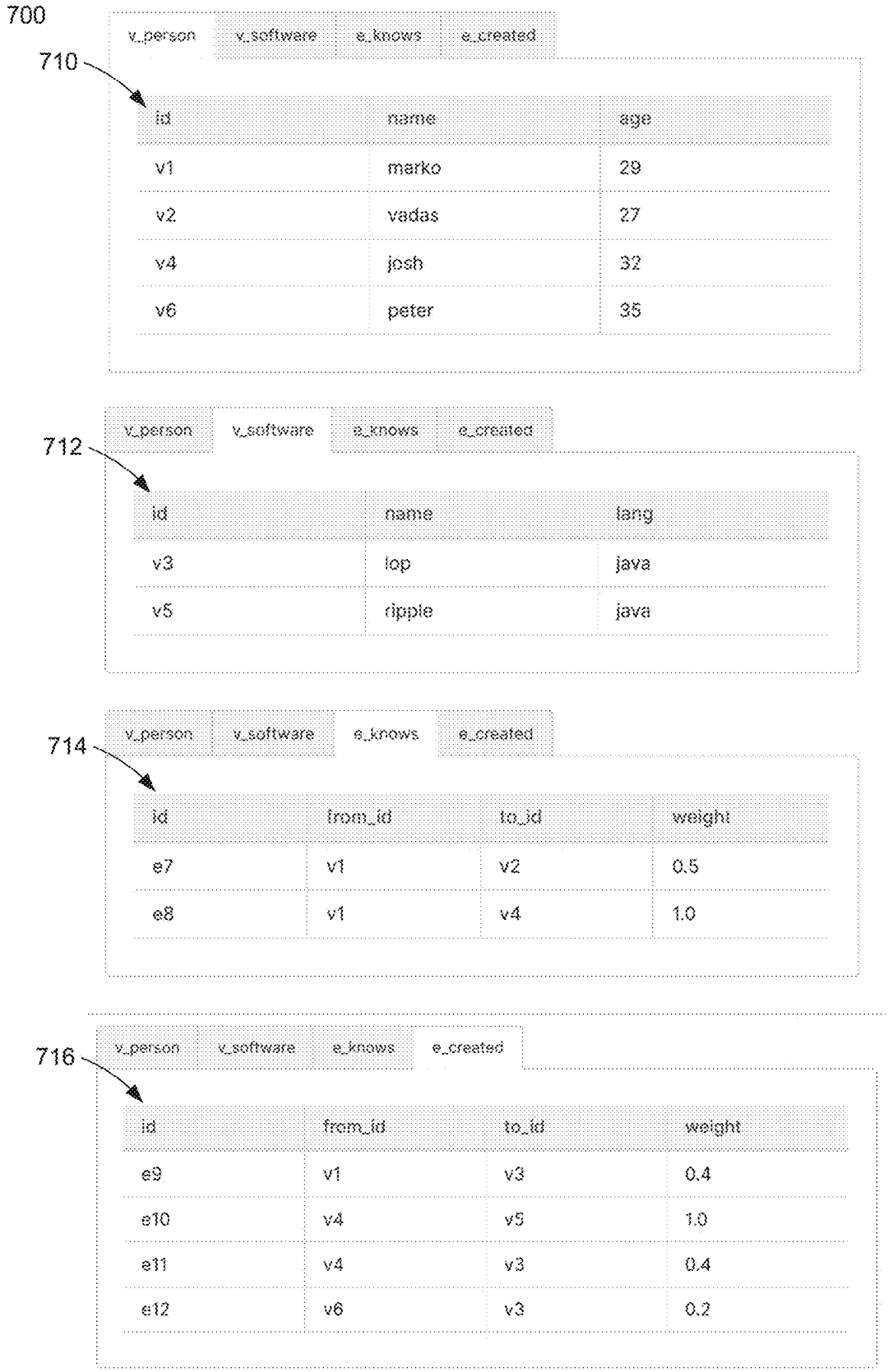

700
v_person
v_software
e_knows
e_created
710
id
name
age
v1
marko
29
v2
vadas
27
v4
josh
32
v6
peter
35
v_person
v_software
e_knows
e_created
712
id
name
lang
v3
lop
java
v5
ripple
java
v_person
v_software
e_knows
e_created
714
id
from_id
to_id
weight
e7
v1
v2
0.5
e8
v1
v4
1.0
v_person
v_software
e_knows
e_created
716
id
from_id
to_id
weight
e9
v1
v3
0.4
e10
v4
v5
1.0
e11
v4
v3
0.4
e12
v6
v3
0.2

Figure 7B

700

720

```
curl -XPOST -H "content-type: application/json" --data-binary @./
iceberg.json --user "puppygraph:888888" localhost:8081/schema
```

722

```
{"Status":"OK","Message":"Schema uploaded and gremlin server restarted"}
```

724

```
docker exec -it puppygraph ./bin/puppygraph
```

726

```
Welcome to PuppyGraph, type help to see the command list
[PuppyGraph]> console
```

728

```
g.V()
g.E()
g.V().count()
g.E().count()
g.V().outE().otherV().path()
g.V().elementMap()
g.E().elementMap()
```

Figure 7C

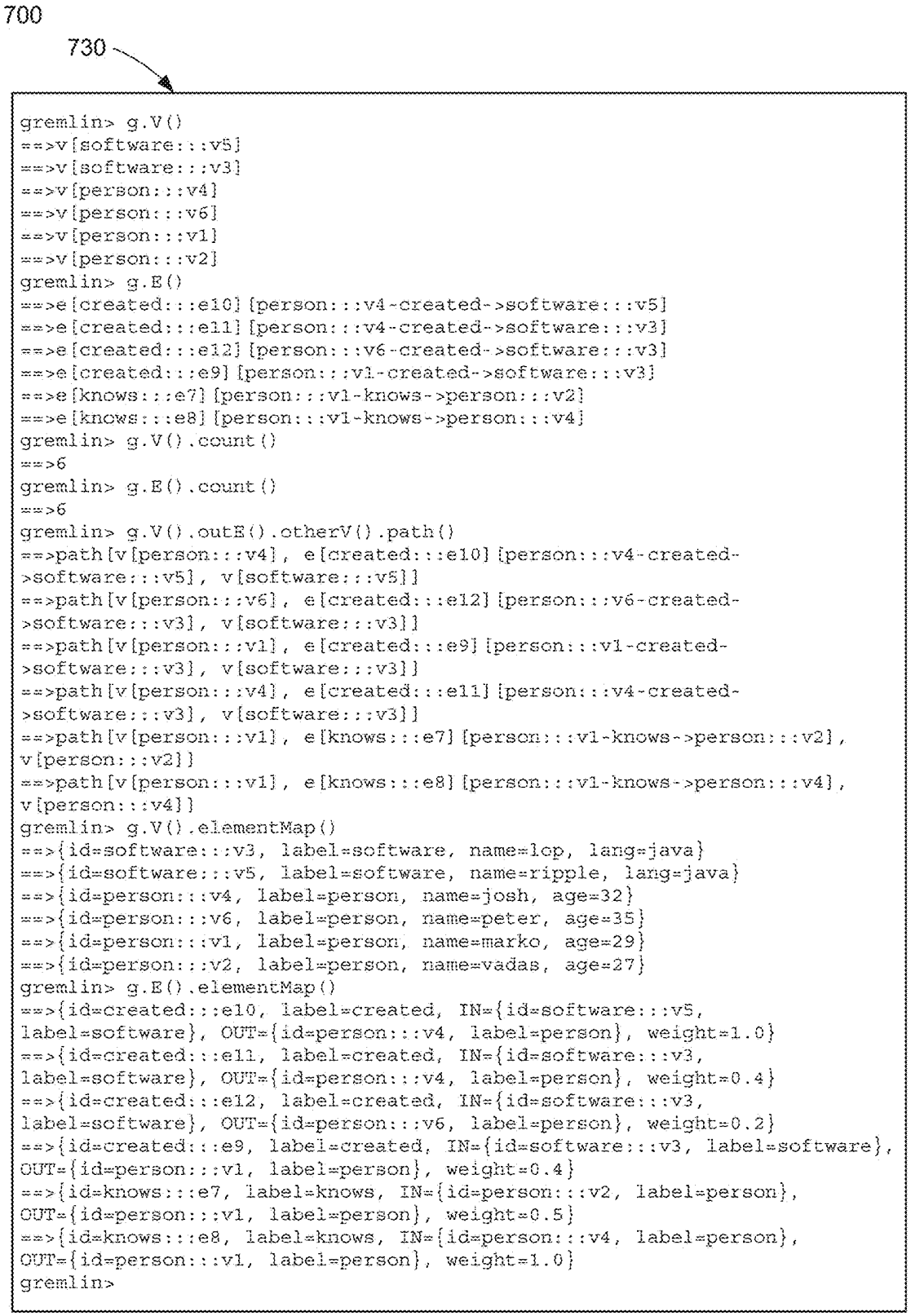

700
730
gremlin> g.V()
==>v[software:::v5]
==>v[software:::v3]
==>v[person:::v4]
==>v[person:::v6]
==>v[person:::v1]
==>v[person:::v2]
gremlin> g.E()
==>e[created:::e10][person:::v4-created->software:::v5]
==>e[created:::e11][person:::v4-created->software:::v3]
==>e[created:::e12][person:::v6-created->software:::v3]
==>e[created:::e9][person:::v1-created->software:::v3]
==>e[knows:::e7][person:::v1-knows->person:::v2]
==>e[knows:::e8][person:::v1-knows->person:::v4]
gremlin> g.V().count()
==>6
gremlin> g.E().count()
==>6
gremlin> g.V().outE().otherV().path()
==>path[v[person:::v4], e[created:::e10][person:::v4-created-
>software:::v5], v[software:::v5]]
==>path[v[person:::v6], e[created:::e12][person:::v6-created-
>software:::v3], v[software:::v3]]
==>path[v[person:::v1], e[created:::e9][person:::v1-created-
>software:::v3], v[software:::v3]]
==>path[v[person:::v4], e[created:::e11][person:::v4-created-
>software:::v3], v[software:::v3]]
==>path[v[person:::v1], e[knows:::e7][person:::v1-knows->person:::v2],
v[person:::v2]]
==>path[v[person:::v1], e[knows:::e8][person:::v1-knows->person:::v4],
v[person:::v4]]
gremlin> g.V().elementMap()
==>{id=software:::v3, label=software, name=lop, lang=java}
==>{id=software:::v5, label=software, name=ripple, lang=java}
==>{id=person:::v4, label=person, name=josh, age=32}
==>{id=person:::v6, label=person, name=peter, age=35}
==>{id=person:::v1, label=person, name=marko, age=29}
==>{id=person:::v2, label=person, name=vadas, age=27}
gremlin> g.E().elementMap()
==>{id=created:::e10, label=created, IN={id=software:::v5,
label=software}, OUT={id=person:::v4, label=person}, weight=1.0}
==>{id=created:::e11, label=created, IN={id=software:::v3,
label=software}, OUT={id=person:::v4, label=person}, weight=0.4}
==>{id=created:::e12, label=created, IN={id=software:::v3,
label=software}, OUT={id=person:::v6, label=person}, weight=0.2}
==>{id=created:::e9, label=created, IN={id=software:::v3, label=software},
OUT={id=person:::v1, label=person}, weight=0.4}
==>{id=knows:::e7, label=knows, IN={id=person:::v2, label=person},
OUT={id=person:::v1, label=person}, weight=0.5}
==>{id=knows:::e8, label=knows, IN={id=person:::v4, label=person},
OUT={id=person:::v1, label=person}, weight=1.0}
gremlin>

Figure 7D

740

742

```
docker compose up -d

[+] Running 1/1
 ✓ puppygraph Pulled
[+] Running 3/3
 ✓ Network puppy-postgres  Created
 ✓ Container postgres      Started
 ✓ Container puppygraph    Started
```

744

```
docker exec -it postgres psql -h postgres -U postgres
```

746

```
psql (14.1)
Type "help" for help.

postgres=#
```

748

```
create schema modern;
create table modern.person (id text, name text, age
integer);
insert into modern.person values
                              ('v1', 'marko', 29),
                              ('v2', 'vadas', 27),
                              ('v4', 'josh', 32),
                              ('v6', 'peter', 35);

create table modern.software (id text, name text, lang
text);
insert into modern.software values
                               ('v3', 'lop', 'java'),
                               ('v5', 'ripple', 'java');

create table modern.created (id text, from_id text, to_id
text, weight double precision);
insert into modern.created values
                              ('e9', 'v1', 'v3', 0.4),
                              ('e10', 'v4', 'v5', 1.0),
                              ('e11', 'v4', 'v3', 0.4),
                              ('e12', 'v6', 'v3', 0.2);

create table modern.knows (id text, from_id text, to_id
text, weight double precision);
insert into modern.knows values
                             ('e7', 'v1', 'v2', 0.5),
                             ('e8', 'v1', 'v4', 1.0);
```

Figure 7E

750

752

```
docker compose up -d

[+] Running 1/1
 ✓ puppygraph Pulled
[+] Running 4/4
 ✓ Network puppy-duckdb    Created
 ✓ Volume "puppy-duckdb"   Created
 ✓ Container puppygraph    Started
 ✓ Container duckdb        Started
```

754

```
docker exec -it duckdb duckdb /home/share/demo.db
```

756

```
v0.9.2 3c695d7ba9
Enter ".help" for usage hints.
D
```

758

```
create schema modern;
create table modern.person (id text, name text, age
integer);
insert into modern.person values
                              ('v1', 'marko', 29),
                              ('v2', 'vadas', 27),
                              ('v4', 'josh', 32),
                              ('v6', 'peter', 35);

create table modern.software (id text, name text, lang
text);
insert into modern.software values
                               ('v3', 'lop', 'java'),
                               ('v5', 'ripple', 'java');

create table modern.created (id text, from_id text, to_id
text, weight double precision);
insert into modern.created values
                              ('e9', 'v1', 'v3', 0.4),
                              ('e10', 'v4', 'v5', 1.0),
                              ('e11', 'v4', 'v3', 0.4),
                              ('e12', 'v6', 'v3', 0.2);

create table modern.knows (id text, from_id text, to_id
text, weight double precision);
insert into modern.knows values
                             ('e7', 'v1', 'v2', 0.5),
                             ('e8', 'v1', 'v4', 1.0);
```

Figure 7F

800

802

Person Table | Referral Table

ID	Age	Name
v1	29	marko
v2	27	vadas

804

Person Table | Referral Table

RefID	Source	Referred	Weight
e1	v1	v2	0.5

Figure 8A

800

810

```
spark-sql --packages org.apache.iceberg:iceberg-spark-runtime-
3.3_2.12:1.1.0 --conf spark.hadoop.fs.defaultFS=hdfs://
172.31.19.123:9000 --conf spark.sql.warehouse.dir=hdfs://
172.31.19.123:9000/spark-warehouse --conf
spark.sql.extensions=org.apache.iceberg.spark.extensions.IcebergSpa
rkSessionExtensions --conf
spark.sql.catalog.spark_catalog=org.apache.iceberg.spark.SparkSessi
onCatalog --conf spark.sql.catalog.spark_catalog.type=hive --conf
spark.sql.catalog.puppy_iceberg=org.apache.iceberg.spark.SparkCatal
og --conf spark.sql.catalog.puppy_iceberg.type=hive --conf
spark.sql.catalog.puppy_iceberg.uri=thrift://172.31.31.125:9083
```

812

```
CREATE DATABASE puppy_iceberg.onhdfs;
USE puppy_iceberg.onhdfs;
CREATE EXTERNAL TABLE person (id string, age int, name string)
using iceberg;
INSERT INTO person VALUES ('v1', 29, 'marko'), ('v2', 27, 'vadas');
CREATE EXTERNAL TABLE referral (refId string, source string,
referred string, weight double) using iceberg;
INSERT INTO referral VALUES ('e1', 'v1', 'v2', 0.5);
```

814

```
curl -XPOST -H "content-type: application/json" --data-binary @./
iceberg.json --user "puppygraph:888888" localhost:8081/schema
```

Figure 8B

800

816

```
{
  "catalogs": [
    {
      "name": "catalog_test",
      "type": "iceberg",
      "metastore": {
        "type": "HMS",
        "hiveMetastoreUrl": "thrift://172.31.31.125:9083"
      }
    }
  ],
  "vertices": [
    {
      "label": "person",
      "mappedTableSource": {
        "catalog": "catalog_test",
        "schema": "onhdfs",
        "table": "person",
        "metaFields": {
          "id": "id"
        }
      },
      "attributes": [
        {
          "type": "Int",
          "name": "age"
        },
        {
          "type": "String",
          "name": "name"
        }
      ]
    }
  ],
  "edges": [
    {
      "label": "knows",
      "mappedTableSource": {
        "catalog": "catalog_test",
        "schema": "onhdfs",
        "table": "referral",
        "metaFields": {
          "id": "refId",
          "from": "source",
          "to": "referred"
        }
      },
      "from": "person",
      "to": "person",
      "attributes": [
        {
          "type": "Double",
          "name": "weight"
        }
      ]
    }
  ]
}
```

Figure 8C

800

830

```
spark-sql --packages org.apache.hudi:hudi-spark3.3-
bundle_2.12:0.13.0 \
--conf spark.hadoop.fs.defaultFS=hdfs://172.31.19.123:9000 \
--conf spark.sql.warehouse.dir=hdfs://172.31.19.123:9000/spark-
warehouse \
--conf
spark.sql.extensions=org.apache.spark.sql.hudi.HoodieSparkSessionEx
tension \
--conf
spark.serializer=org.apache.spark.serializer.KryoSerializer \
--conf
spark.sql.catalog.spark_catalog=org.apache.spark.sql.hudi.catalog.H
oodieCatalog \
--conf spark.sql.catalog.spark_catalog.type=hive \
--conf
spark.sql.catalog.puppy_hudi=org.apache.spark.sql.hudi.catalog.Hood
ieCatalog \
--conf spark.sql.catalog.puppy_hudi.type=hive \
--conf spark.sql.catalog.puppy_hudi.uri=thrift://172.31.31.125:9083
```

832

```
CREATE DATABASE hudi_onhdfs;
USE hudi_onhdfs;
CREATE EXTERNAL TABLE person (
   ID string,
   age int,
   name string
) using hudi
tblproperties (
   primaryKey = 'ID'
);
INSERT INTO person VALUES ('v1', 29, 'marko'), ('v2', 27, 'vadas');

CREATE EXTERNAL TABLE referral (
   refId string,
   source string,
   referred string,
   weight double
) using hudi
tblproperties (
   primaryKey = 'refId'
);
INSERT INTO referral VALUES ('e1', 'v1', 'v2', 0.5);
```

834

```
curl -XPOST -H "content-type: application/json" --data-binary @./
hudi.json --user "puppygraph:888888" localhost:8081/schema
```

Figure 8D

800

836

```
{
  "catalogs": [
    {
      "name": "catalog_test",
      "type": "hudi",
      "metastore": {
        "type": "HMS",
        "hiveMetastoreUrl": "thrift://172.31.31.125:9083"
      }
  ],
  "vertices": [
    {
      "label": "person",
      "mappedTableSource": {
        "catalog": "catalog_test",
        "schema": "hudi_onhdfs",
        "table": "person",
        "metaFields": {
          "id": "id"
        }
      },
      "attributes": [
        {
          "type": "Int",
          "name": "age"
        },
        {
          "type": "String",
          "name": "name"
        }
      ]
    }
  ],
  "edges": [
    {
      "label": "knows",
      "mappedTableSource": {
        "catalog": "catalog_test",
        "schema": "hudi_onhdfs",
        "table": "referral",
        "metaFields": {
          "id": "refId",
          "from": "source",
          "to": "referred"
        }
      },
      "from": "person",
      "to": "person",
      "attributes": [
        {
          "type": "Double",
          "name": "weight"
        }
      ]
    }
  ]
}
```

Figure 8E

800

850

```
spark-sql \
--packages io.delta:delta-core_2.12:2.3.0 \
--conf
spark.sql.extensions=io.delta.sql.DeltaSparkSessionExtension \
--conf spark.hadoop.fs.defaultFS=hdfs://172.31.19.123:9000 \
--conf spark.sql.warehouse.dir=hdfs://172.31.19.123:9000/spark-
warehouse \
--conf
spark.sql.catalog.spark_catalog=org.apache.spark.sql.delta.catalog.
DeltaCatalog \
--conf spark.sql.catalog.spark_catalog.type=hive \
--conf
spark.sql.catalog.puppy_delta=org.apache.spark.sql.delta.catalog.De
ltaCatalog \
--conf spark.sql.catalog.puppy_delta.type=hive \
--conf spark.sql.catalog.puppy_delta.uri=thrift://
172.31.31.125:9083
```

852

```
CREATE DATABASE puppy_delta.onhdfs;
USE puppy_delta.onhdfs;
CREATE EXTERNAL TABLE person (ID string, age int, name string)
using delta;
INSERT INTO person VALUES ('v1', 29, 'marko'), ('v2', 27, 'vadas');
CREATE EXTERNAL TABLE referral (refId string, source string,
referred string, weight double) using delta;
INSERT INTO referral VALUES ('e1', 'v1', 'v2', 0.5);
```

854

```
curl -XPOST -H "content-type: application/json" --data-binary @./
deltalake.json --user "puppygraph:888888" localhost:8081/schema
```

Figure 8F

800

856

```
{
  "catalogs": [
    {
      "name": "catalog_test",
      "type": "deltalake",
      "metastore": {
        "type": "HMS",
        "hiveMetastoreUrl": "thrift://172.31.31.125:9083"
      }
    }
  ],
  "vertices": [
    {
      "label": "person",
      "mappedTableSource": {
        "catalog": "catalog_test",
        "schema": "onhdfs",
        "table": "person",
        "metaFields": {
          "id": "id"
        }
      },
      "attributes": [
        {
          "type": "Int",
          "name": "age"
        },
        {
          "type": "String",
          "name": "name"
        }
      ]
    }
  ],
  "edges": [
    {
      "label": "knows",
      "mappedTableSource": {
        "catalog": "catalog_test",
        "schema": "onhdfs",
        "table": "referral",
        "metaFields": {
          "id": "refId",
          "from": "source",
          "to": "referred"
        }
      },
      "from": "person",
      "to": "person",
      "attributes": [
        {
          "type": "Double",
          "name": "weight"
        }
      ]
    }
  ]
}
```

Figure 8G

800

870

```
/opt/hive/bin/beeline -u 'jdbc:hive2://localhost:10000/'
```

872

```
CREATE DATABASE hive_onhdfs;
CREATE TABLE hive_onhdfs.person (ID string, age int, name string);
CREATE TABLE hive_onhdfs.referral (refId string, source string,
referred string, weight double);
INSERT INTO hive_onhdfs.person VALUES ('v1', 29, 'marko'), ('v2',
27, 'vadas');
INSERT INTO hive_onhdfs.referral VALUES ('e1', 'v1', 'v2', 0.5);
```

874

```
{
  "name": "hive_hdfs",
  "type": "hive",
  "metastore": {
    "type": "HMS",
    "hiveMetastoreUrl": "thrift://localhost:9083"
  }
}
```

876

```
curl -XPOST -H "content-type: application/json" --data-binary @./
hive_hdfs.json --user "puppygraph:888888" localhost:8081/schema
```

Figure 8H

800

878

```
{
  "catalogs": [
    {
      "name": "hive_hdfs",
      "type": "hive",
      "metastore": {
        "type": "HMS",
        "hiveMetastoreUrl": "thrift://localhost:9083"
      }
    }
  ],
  "vertices": [
    {
      "label": "person",
      "mappedTableSource": {
        "catalog": "hive_hdfs",
        "schema": "hive_onhdfs",
        "table": "person",
        "metaFields": {
          "id": "id"
        }
      },
      "attributes": [
        {
          "type": "Int",
          "name": "age"
        },
        {
          "type": "String",
          "name": "name"
        }
      ]
    }
  ],
  "edges": [
    {
      "label": "knows",
      "mappedTableSource": {
        "catalog": "hive_hdfs",
        "schema": "hive_onhdfs",
        "table": "referral",
        "metaFields": {
          "id": "refId",
          "from": "source",
          "to": "referred"
        }
      },
      "from": "person",
      "to": "person",
      "attributes": [
        {
          "type": "Double",
          "name": "weight"
        }
      ]
    }
  ]
}
```

Figure 8I

800

880

```
[PuppyGraph]> console
         \,,,/
         (o o)
-----oOOo-(3)-oOOo-----
plugin activated: tinkerpop.server
plugin activated: tinkerpop.utilities
plugin activated: tinkerpop.tinkergraph
```

882

```
gremlin> g.V().hasLabel("person").out("knows").values("name")
==>vadas
```

Figure 8J

900

910

```
docker volume rm mysql-data
docker volume create mysql-data
docker run -p 3306:3306 -itd --name mysql-server -v mysql-data:/
var/lib/mysql -e MYSQL_ROOT_PASSWORD= --restart=always mysql:8.0.33
```

912

```
# username = root
# passwd = mysql
mysql -h 127.0.0.1 -P3306 -uroot -p
```

914

```
drop database if exists graph;
create database if not exists graph;
use graph;
create table person
(
    ID   varchar(128) not null,
    age  int,
    name varchar(128),
    PRIMARY KEY (ID)
);
insert into person values ('v1', 29, 'marko'), ('v2', 27, 'vadas');
create table referral
(
    refId    varchar(128) not null,
    `source` varchar(128),
    referred varchar(128),
    weight   double,
    PRIMARY KEY (refId)
);
insert into referral values ('e1', 'v1', 'v2', 0.5);
```

916

```
curl -XPOST -H "content-type: application/json" --data-binary @./
mysql.json --user "puppygraph:888888" localhost:8081/schema
```

Figure 9A

900

```
{
  "catalogs": [
    {
      "name": "jdbc_mysql",
      "type": "mysql",
      "jdbc": {
        "username": "root",
        "password": "mysql",
        "jdbcUri": "jdbc:mysql://172.31.19.123:3306",
        "driverClass": "com.mysql.cj.jdbc.Driver",
        "driverUrl": "https://repo1.maven.org/maven2/mysql/mysql-
connector-java/8.0.28/mysql-connector-java-8.0.28.jar"
      }
    }
  ],
  "vertices": [
    {
      "label": "person",
      "mappedTableSource": {
        "catalog": "jdbc_mysql",
        "schema": "graph",
        "table": "person",
        "metaFields": {
          "id": "id"
        }
      },
      "attributes": [
        {
          "type": "Int",
          "name": "age"
        },
        {
          "type": "String",
          "name": "name"
        }
      ]
    }
  ],
  "edges": [
    {
      "label": "knows",
      "mappedTableSource": {
        "catalog": "jdbc_mysql",
        "schema": "graph",
        "table": "referral",
        "metaFields": {
          "id": "refId",
          "from": "source",
          "to": "referred"
        }
      },
      "from": "person",
      "to": "person",
      "attributes": [
        {
          "type": "Double",
          "name": "weight"
        }
      ]
    }
  ]
}
```


Figure 9B

900

920

```
docker volume rm postgres-data
docker volume create postgres-data
docker run -p 5432:5432 --name postgres-server -v postgres-data:/
var/lib/postgresql/data -e POSTGRES_PASSWORD=postgres -d --
restart=always postgres:15.3
```

922

```
# username = postgres
# passwd = postgres
psql -h 127.0.0.1 -p 5432 -U postgres -W
```

924

```
drop table if exists person, referral;
create table if not exists person
(
    ID   varchar(128) not null,
    age  int,
    name varchar(128),
    PRIMARY KEY (ID)
);
insert into person values ('v1', 29, 'marko'), ('v2', 27, 'vadas');
create table if not exists referral
(
    refId    varchar(128) not null,
    source   varchar(128),
    referred varchar(128),
    weight   double precision,
    PRIMARY KEY (refId)
);
insert into referral values ('e1', 'v1', 'v2', 0.5);
```

926

```
curl -XPOST -H "content-type: application/json" --data-binary @./
postgres.json --user "puppygraph:888888" localhost:8081/schema
```

Figure 9C

900

928

```
{
  "catalogs": [
    {
      "name": "jdbc_postgres",
      "type": "postgresql",
      "jdbc": {
        "username": "postgres",
        "password": "postgres",
        "jdbcUri": "jdbc:postgresql://172.31.19.123:5432/postgres",
        "driverClass": "org.postgresql.Driver",
        "driverUrl": "https://repo1.maven.org/maven2/org/
postgresql/postgresql/42.3.3/postgresql-42.3.3.jar"
      }
    }
  ],
  "vertices": [
    {
      "label": "person",
      "mappedTableSource": {
        "catalog": "jdbc_postgres",
        "schema": "public",
        "table": "person",
        "metaFields": {
          "id": "id"
        }
      },
      "attributes": [
        {
          "type": "Int",
          "name": "age"
        },
        {
          "type": "String",
          "name": "name"
        }
      ]
    }
  ],
  "edges": [
    {
      "label": "knows",
      "mappedTableSource": {
        "catalog": "jdbc_postgres",
        "schema": "public",
        "table": "referral",
        "metaFields": {
          "id": "refId",
          "from": "source",
          "to": "referred"
        }
      },
      "from": "person",
      "to": "person",
      "attributes": [
        {
          "type": "Double",
          "name": "weight"
        }
      ]
    }
  ]
}
```

Figure 9D

900

930

```
docker run --name duckdb -v duckdb-data:/home/share -d --
restart=always puppygraph/duckdb-ubuntu:latest
```

932

```
docker exec -it duckdb duckdb /home/share/demo.db
```

934

```
CREATE SCHEMA graph;
CREATE TABLE graph.person
(
    ID   VARCHAR,
    age  INTEGER,
    name VARCHAR
);
INSERT INTO graph.person(ID, age, name) VALUES  ('v1', 29,
'marko'), ('v2', 27, 'vadas');
CREATE TABLE graph.referral
(
    refId    VARCHAR,
    source   VARCHAR,
    referred VARCHAR,
    weight   DOUBLE
);
INSERT INTO graph.referral(refId, source, referred, weight) VALUES
('e1', 'v1', 'v2', 0.5);
```

936

```
curl -XPOST -H "content-type: application/json" --data-binary @./
duckdb.json --user "puppygraph:888888" localhost:8081/schema
```

Figure 9E

900

938

```
{
  "catalogs": [
    {
      "name": "jdbc_duckdb",
      "type": "duckdb",
      "jdbc": {
        "jdbcUri": "jdbc:duckdb:/home/share/demo.db",
        "driverClass": "org.duckdb.DuckDBDriver",
        "driverUrl": "https://repo1.maven.org/maven2/org/duckdb/
duckdb_jdbc/0.9.1/duckdb_jdbc-0.9.1.jar"
      }
    }
  ],
  "vertices": [
    {
      "label": "person",
      "mappedTableSource": {
        "catalog": "jdbc_duckdb",
        "schema": "graph",
        "table": "person",
        "metaFields": {
          "id": "\"ID\""
        }
      },
      "attributes": [
        {
          "type": "Int",
          "name": "age"
        },
        {
          "type": "String",
          "name": "name"
        }
      ]
    }
  ],
  "edges": [
    {
      "label": "knows",
      "mappedTableSource": {
        "catalog": "jdbc_duckdb",
        "schema": "graph",
        "table": "referral",
        "metaFields": {
          "id": "\"refId\"",
          "from": "source",
          "to": "referred"
        }
      },
      "from": "person",
      "to": "person",
      "attributes": [
        {
          "type": "Double",
          "name": "weight"
        }
      ]
    }
  ]
}
```

Figure 9F

900

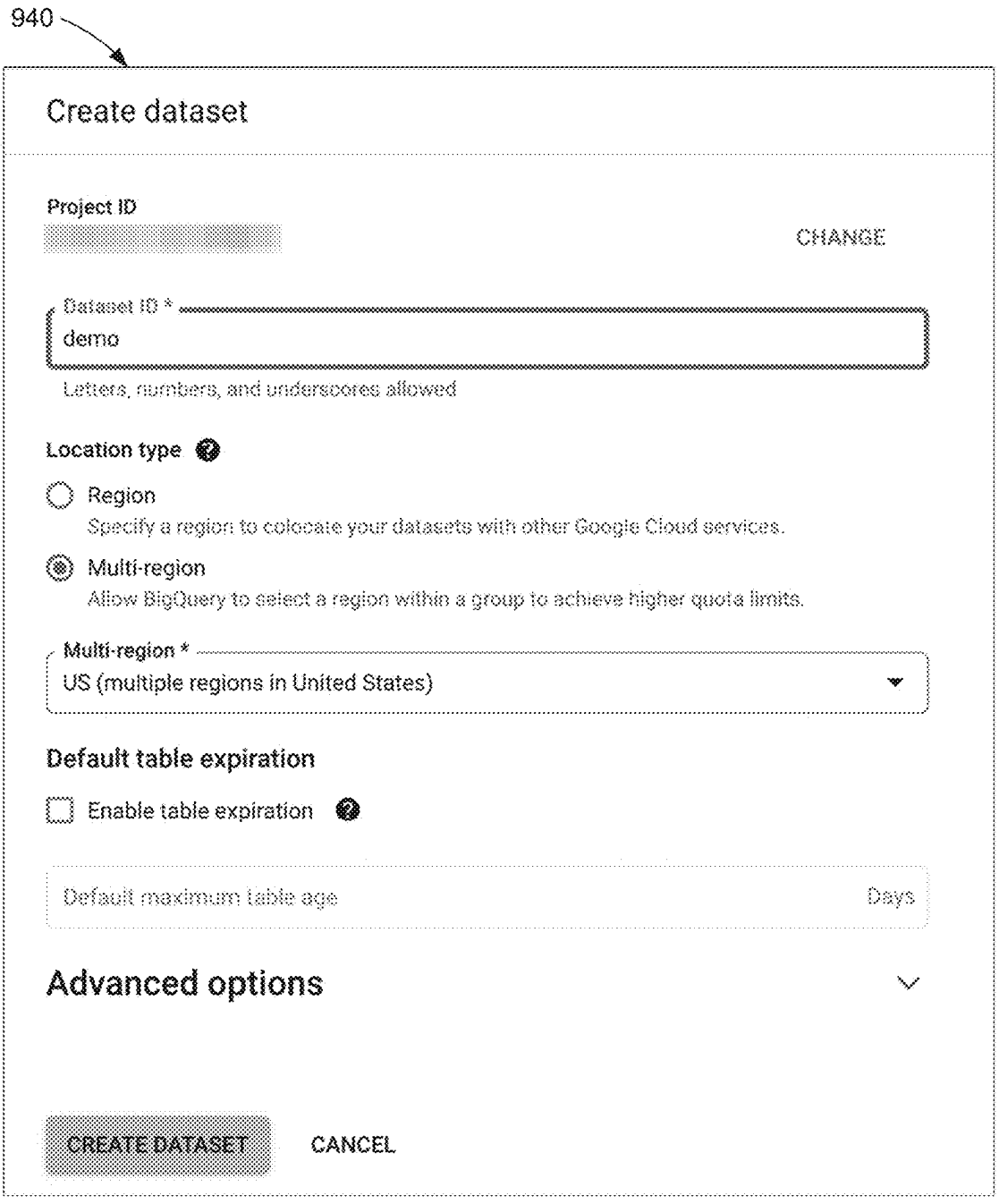


Figure 9G

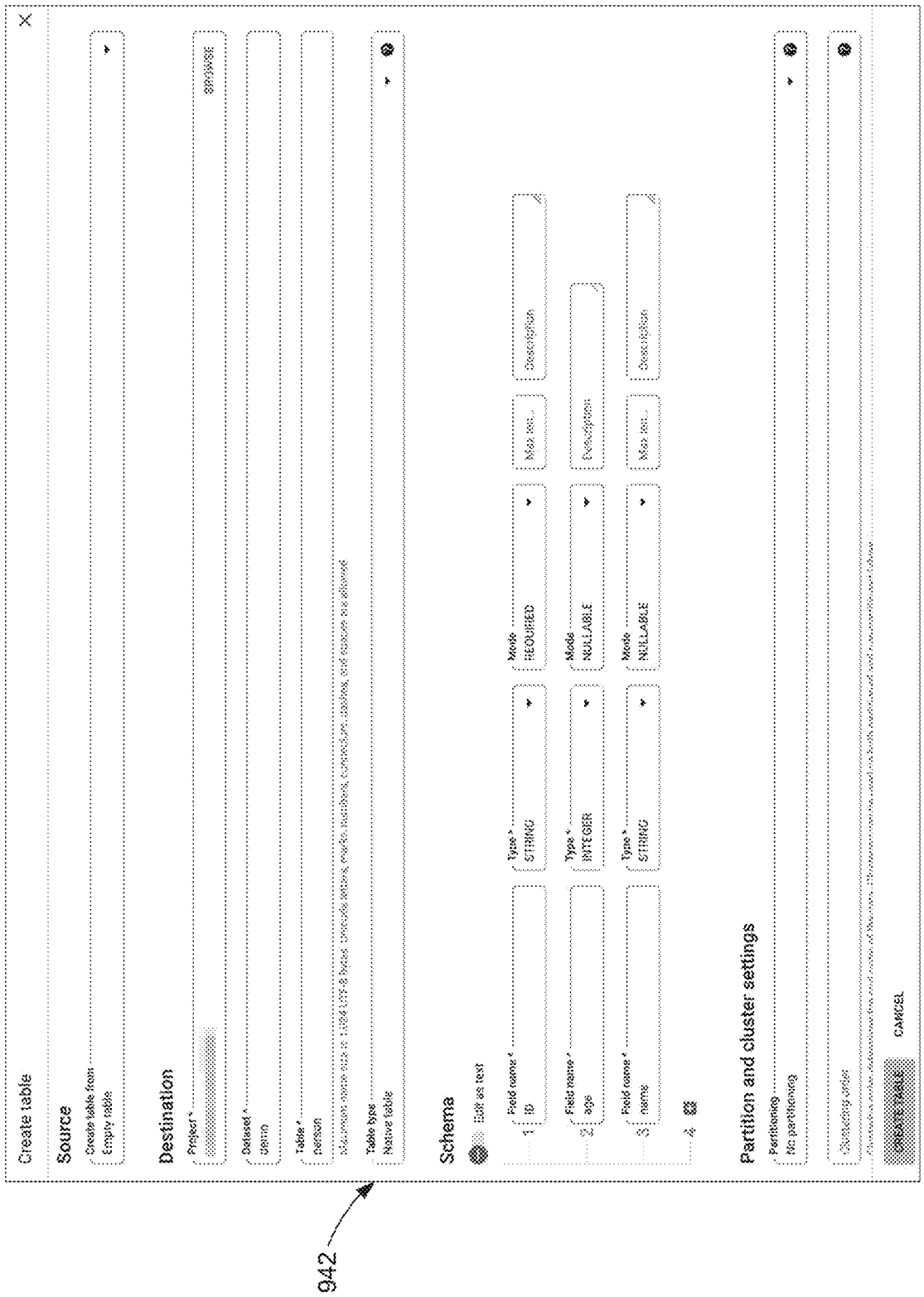

900
942
Create table
Source
Create table from
Empty table
Destination
Project *
BROWSE
Dataset *
demo
Table *
person
Table type
Native table
Schema
Edit as text
Field name *
id
Type *
STRING
Mode
REQUIRED
Description
Field name *
age
Type *
INTEGER
Mode
NULLABLE
Description
Field name *
name
Type *
STRING
Mode
NULLABLE
Description
Partition and cluster settings
Partitioning
No partitioning
Clustering order
CREATE TABLE
CANCEL

Figure 9H

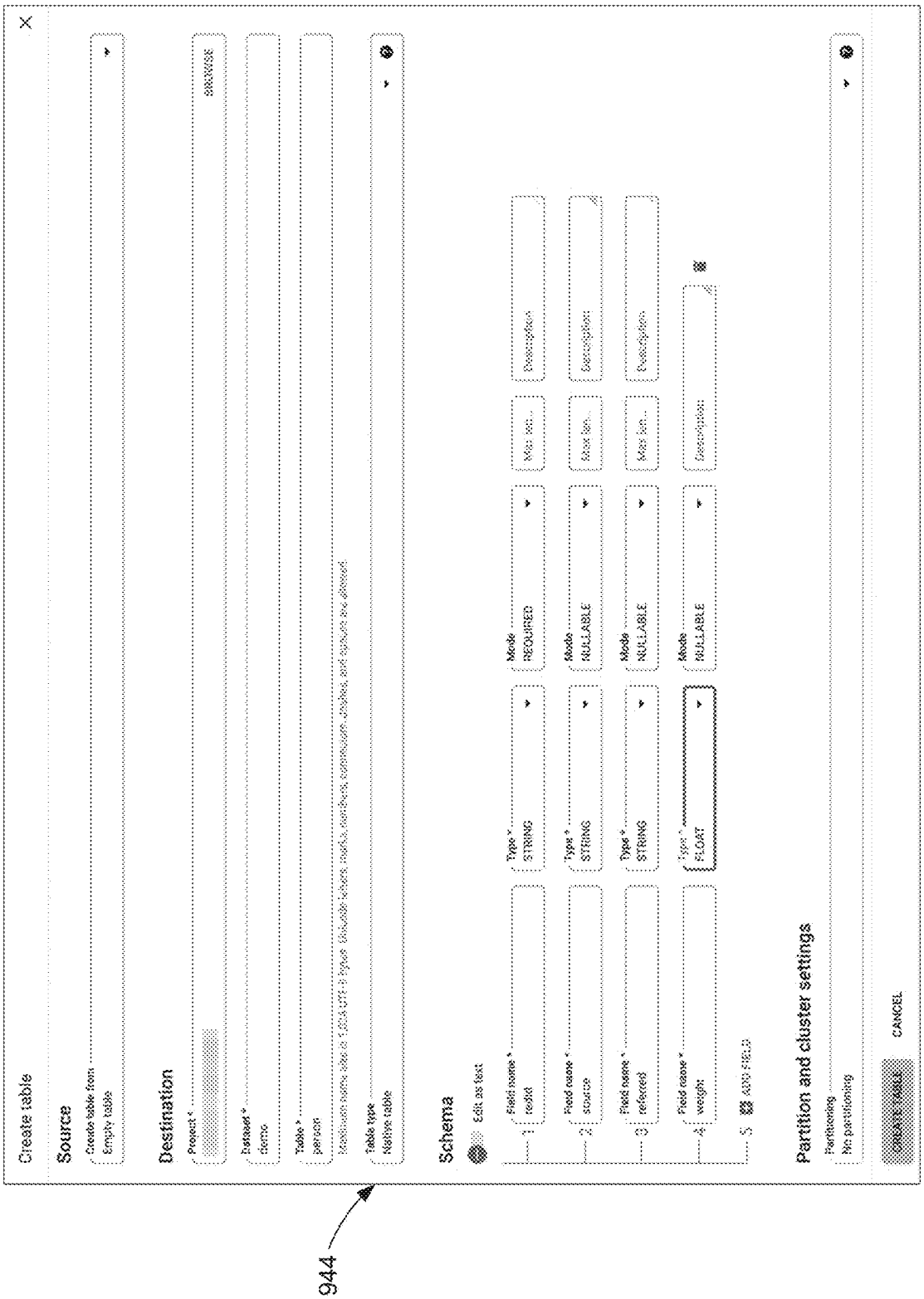

900
944
Create table
Source
Create table from
Empty table
Destination
Project *
BROWSE
Dataset *
demo
Table *
person
Table type
Native table
Schema
Edit as text
Field name *
restht
Type *
STRING
Mode
REQUIRED
Description
Field name *
source
Type *
STRING
Mode
NULLABLE
Description
Field name *
referred
Type *
STRING
Mode
NULLABLE
Description
Field name *
weight
Type *
FLOAT
Mode
NULLABLE
Description
ADD FIELD
Partition and cluster settings
Partitioning
No partitioning
CREATE TABLE
CANCEL

Figure 9I

900

946

```
insert into `demo.person` values ('v1', 29, 'marko'), ('v2', 27,
'vadas');
insert into `demo.referral` values ('e1', 'v1', 'v2', 0.5);
```

948

```
docker cp key.json puppy:/home/key.json
```

950

```
curl -XPOST -H "content-type: application/json" --data-binary @./
bigquery.json --user "puppygraph:888888" localhost:8081/schema
```

Figure 9J

900

952

```
{
  "catalogs": [
    {
      "name": "jdbc_bigquery",
      "type": "bigquery",
      "jdbc": {
        "jdbcUri": "jdbc:bigquery://https://www.googleapis.com/
bigquery/
v2:443;ProjectId=PJID;OAuthType=0;OAuthServiceAcctEmail=bigquery-
sa@PJID.iam.gserviceaccount.com;OAuthPvtKeyPath=/home/
key.json;EnableSession=1;",
        "driverClass": "com.simba.googlebigquery.jdbc.Driver"
      }
    }
  ],
  "vertices": [
    {
      "label": "person",
      "mappedTableSource": {
        "catalog": "jdbc_bigquery",
        "schema": "demo",
        "table": "person",
        "metaFields": {
          "id": "ID"
        }
      },
      "attributes": [
        {
          "type": "Long",
          "name": "age"
        },
        {
          "type": "String",
          "name": "name"
        }
      ]
    }
  ],
  "edges": [
    {
      "label": "knows",
      "mappedTableSource": {
        "catalog": "jdbc_bigquery",
        "schema": "demo",
        "table": "referral",
        "metaFields": {
          "id": "refId",
          "from": "source",
          "to": "referred"
        }
      },
      "from": "person",
      "to": "person",
      "attributes": [
        {
          "type": "Double",
          "name": "weight"
        }
      ]
    }
  ]
}
```

Figure 9K

900

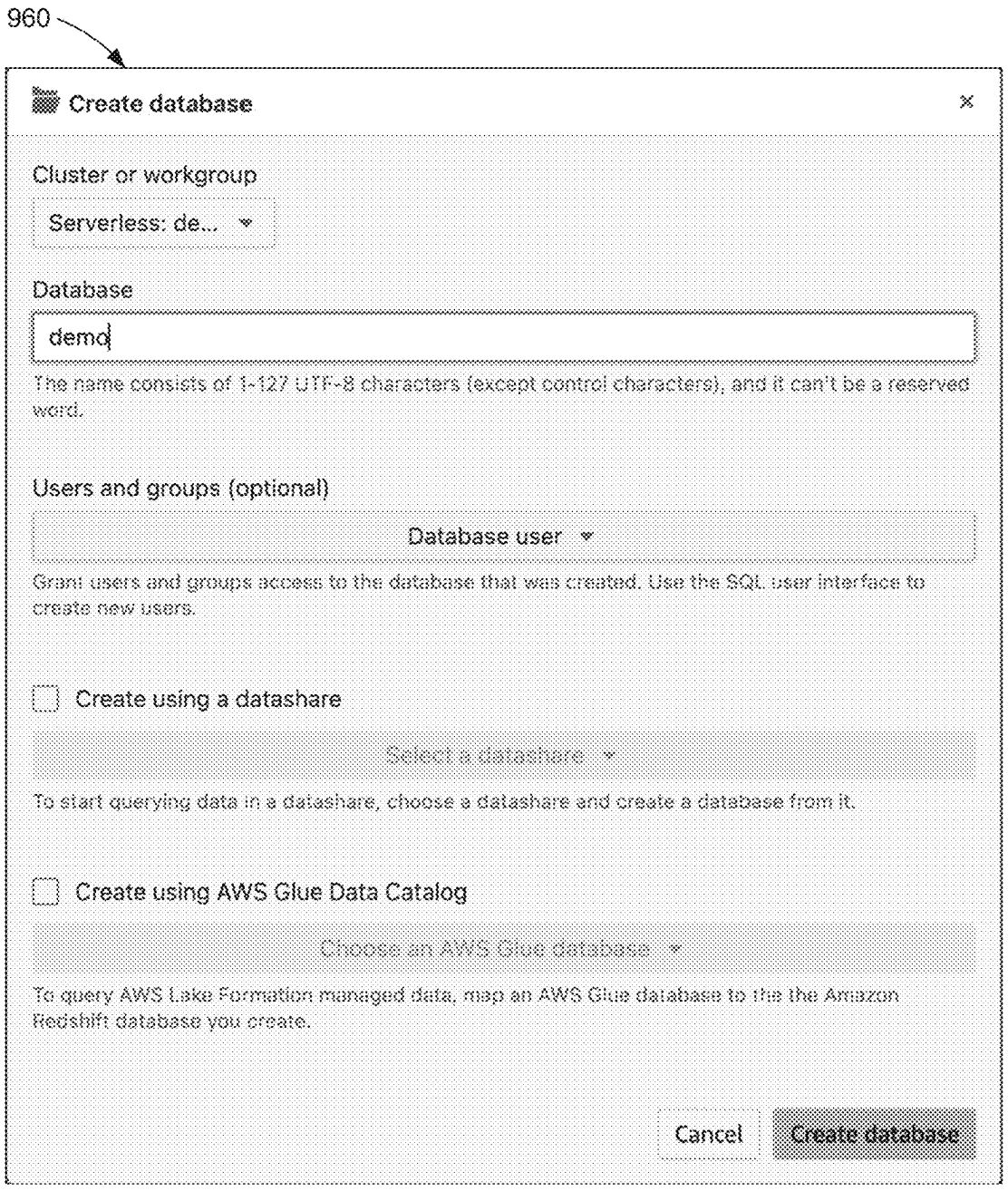


Figure 9L

900

962

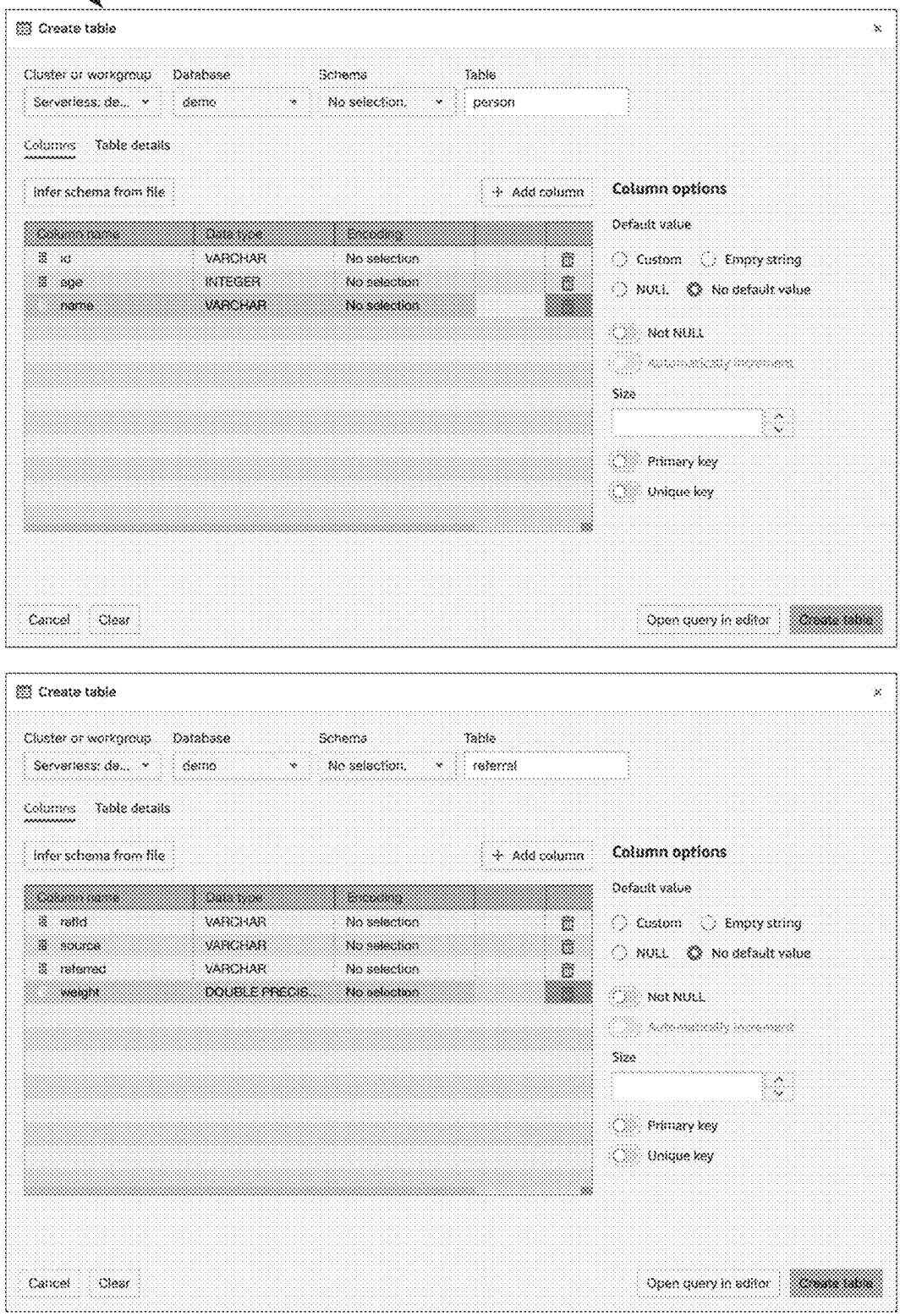


Figure 9M

900

964

```
insert into demo.public.person values ('v1', 29, 'marko'), ('v2',
27, 'vadas');
insert into demo.public.referral values ('e1', 'v1', 'v2', 0.5);
```

966

```
curl -XPOST -H "content-type: application/json" --data-binary @./
redshift.json --user "puppygraph:888888" localhost:8081/schema
```

Figure 9N

900

968

```
{
  "catalogs": [
    {
      "name": "jdbc_redshift",
      "type": "redshift",
      "jdbc": {
        "username": "puppy",
        "password": "puppy",
        "jdbcUri": "jdbc:redshift://
[group_name].[account_id].[region].redshift-
serverless.amazonaws.com:5439/demo",
        "driverClass": "com.amazon.redshift.Driver"
      }
    }
  ],
  "vertices": [
    {
      "label": "person",
      "mappedTableSource": {
        "catalog": "jdbc_redshift",
        "schema": "public",
        "table": "person",
        "metaFields": {
          "id": "id"
        }
      },
      "attributes": [
        {
          "type": "Int",
          "name": "age"
        },
        {
          "type": "String",
          "name": "name"
        }
      ]
    }
  ],
  "edges": [
    {
      "label": "knows",
      "mappedTableSource": {
        "catalog": "jdbc_redshift",
        "schema": "public",
        "table": "referral",
        "metaFields": {
          "id": "refid",
          "from": "source",
          "to": "referred"
        }
      },
      "from": "person",
      "to": "person",
      "attributes": [
        {
          "type": "Double",
          "name": "weight"
        }
      ]
    }
  ]
}
```

Figure 90

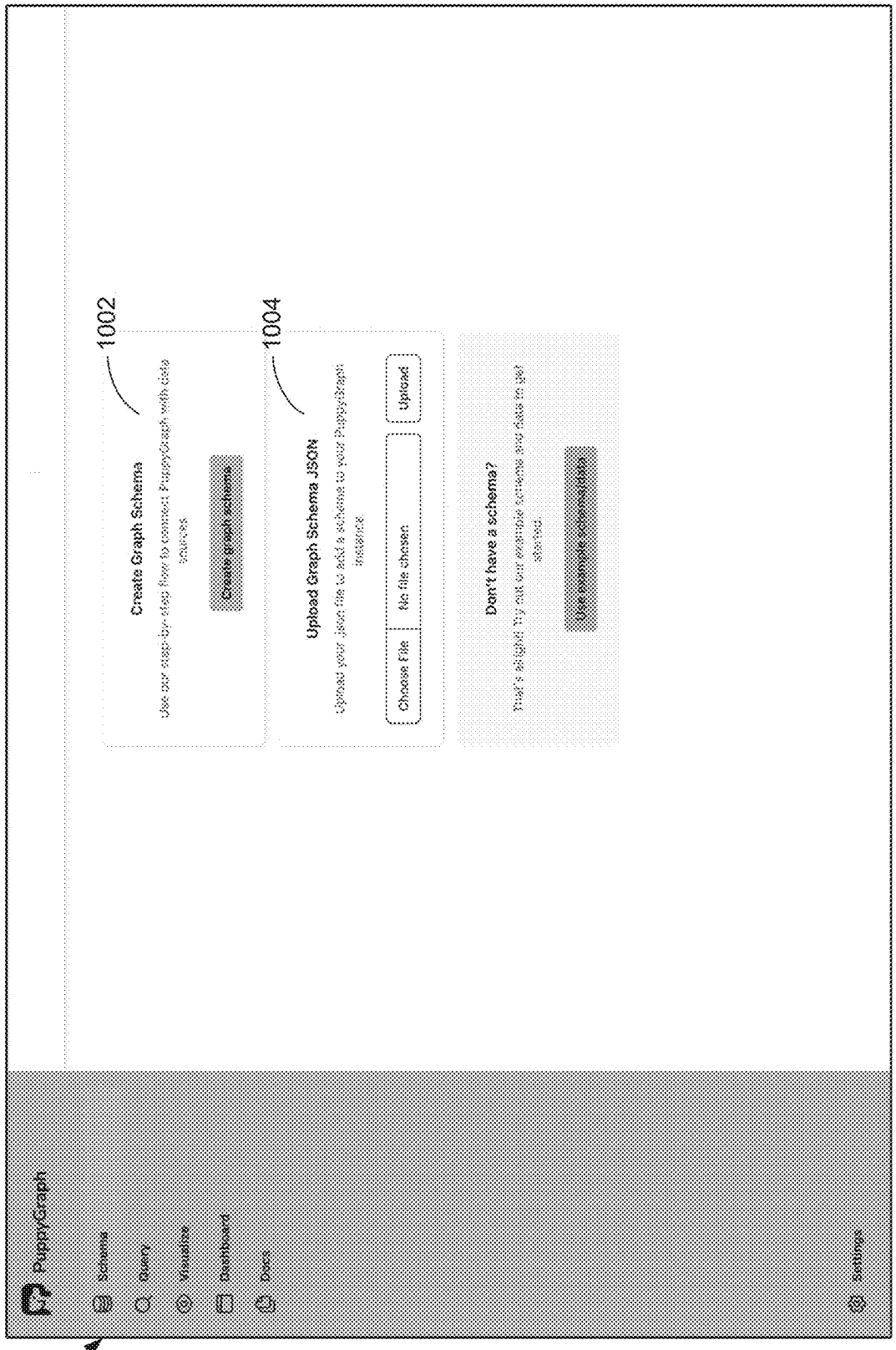

1000
PuppyGraph
Schema
Query
Visualize
Dashboard
Docs
Settings
1002
Create Graph Schema
Use our step-by-step flow to connect PuppyGraph with data sources
Create graph schema
1004
Upload Graph Schema JSON
Upload your json file to add a schema to your PuppyGraph instance
Choose File
No file chosen
Upload
Don't have a schema?
That's alright! Try out our example schema and data to get started
Use example schema

Figure 10A

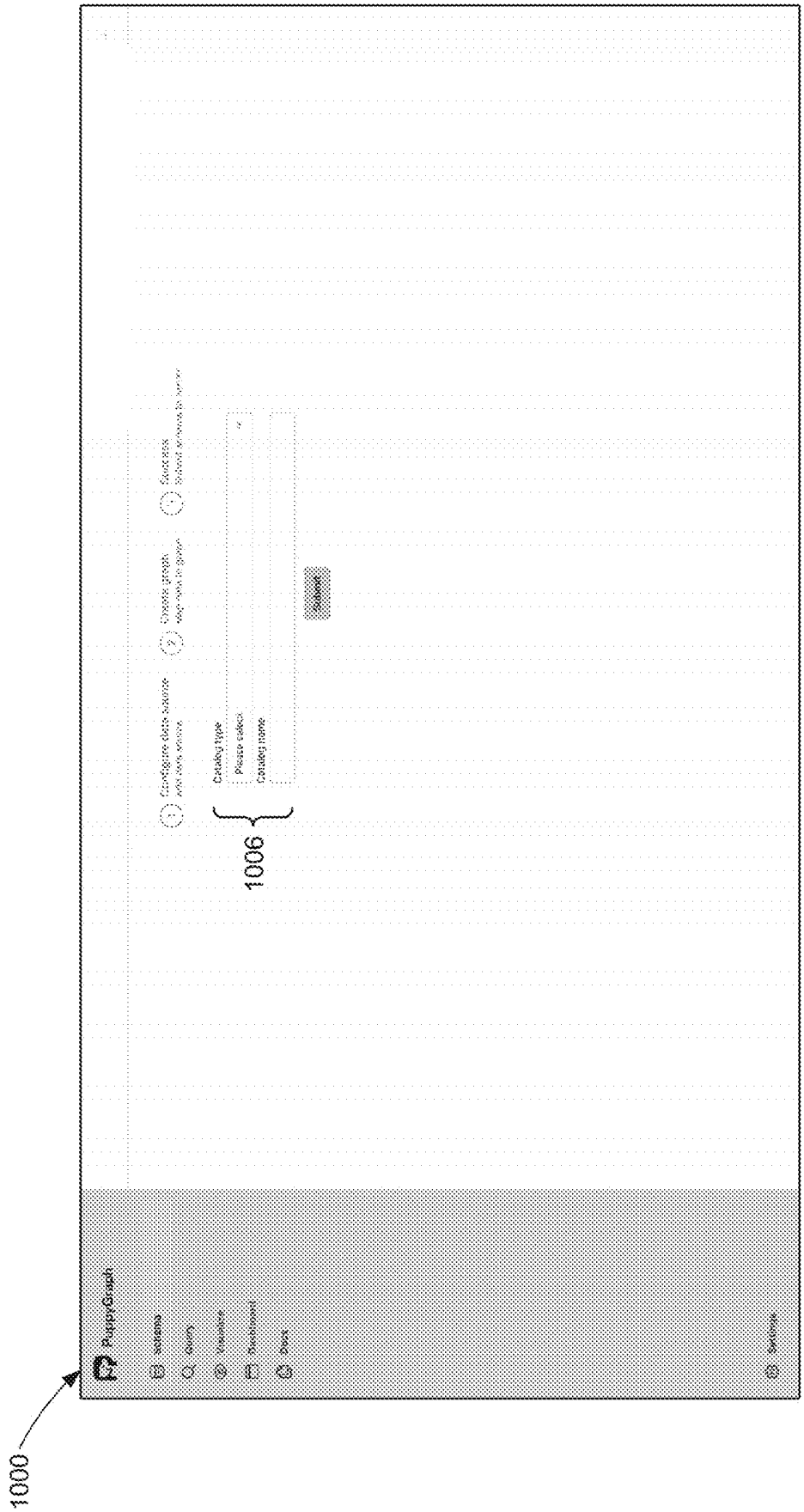

1000
PuppyGraph
Schema
Query
Visualize
Dashboard
Docs
Settings
Configure data source
Add new source
Choose graph
Map data to graph
Success
Submit schema to server
Catalog type
Please select
Catalog name
Submit
1006

Figure 10B

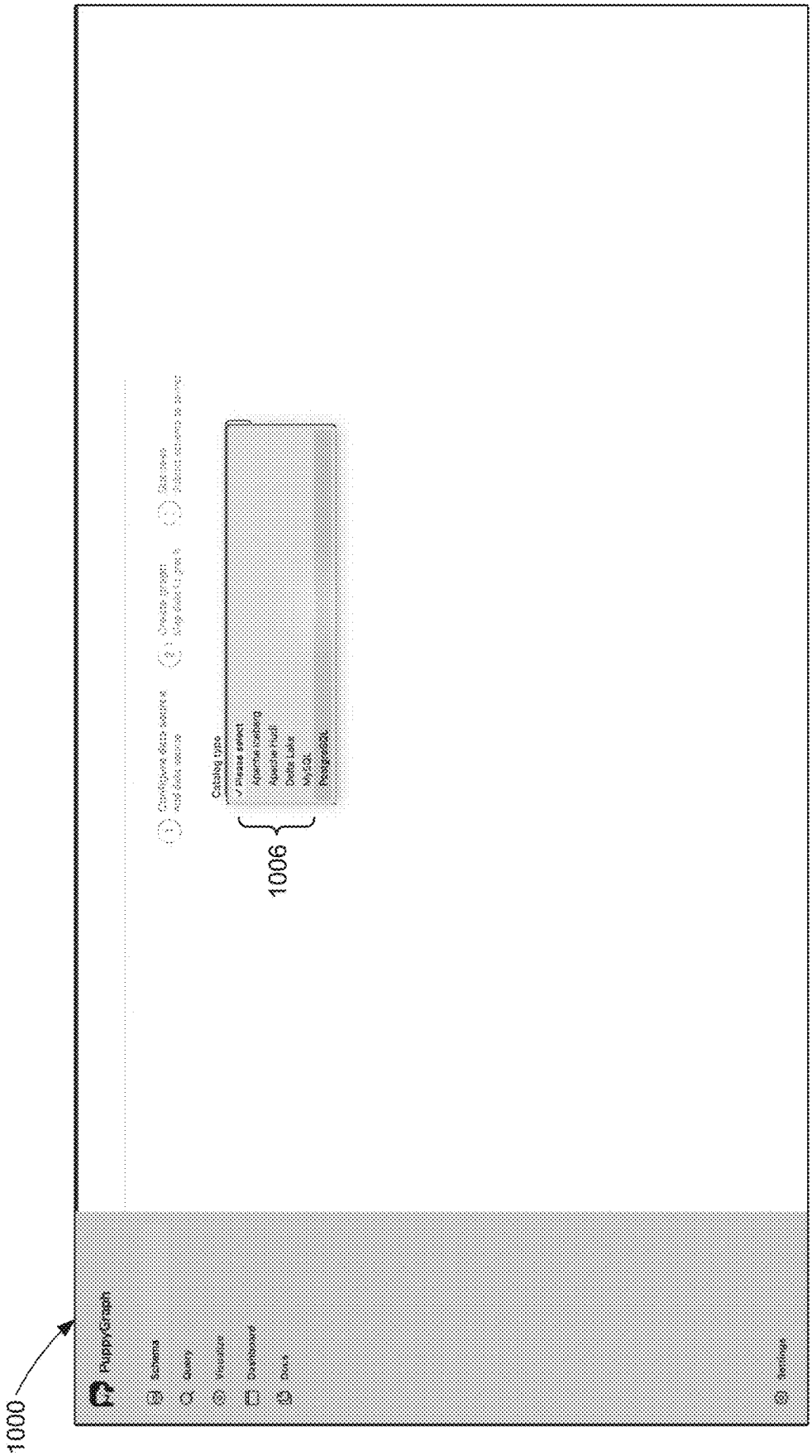

1000
PuppyGraph
Schema
Query
Visualize
Dashboard
Docs
Configure data source
Add data source
Choose graph
Start query
Catalog type
Please select
Apache Hudi
Delta Lake
MySQL
PostgreSQL
1006

Figure 10C

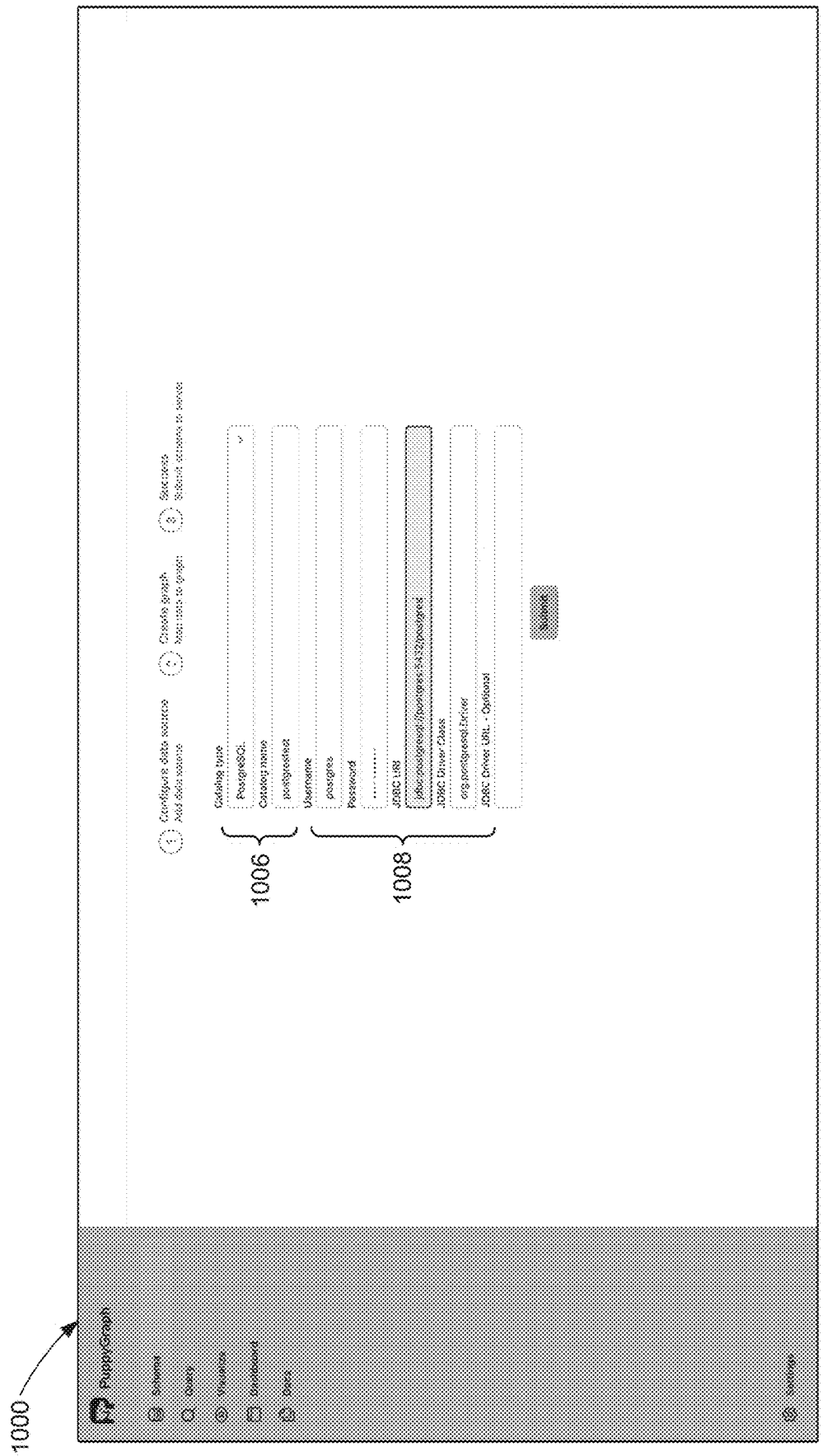

1000
PuppyGraph
Schema
Query
Visualize
Dashboard
Docs
Settings
1006
1008
Catalog type
PostgreSQL
Catalog name
postgresdest
Username
postgres
Password
JDBC URI
JDBC Driver Class
org.postgresql.Driver
JDBC Driver URL - Optional
Save

Figure 10D

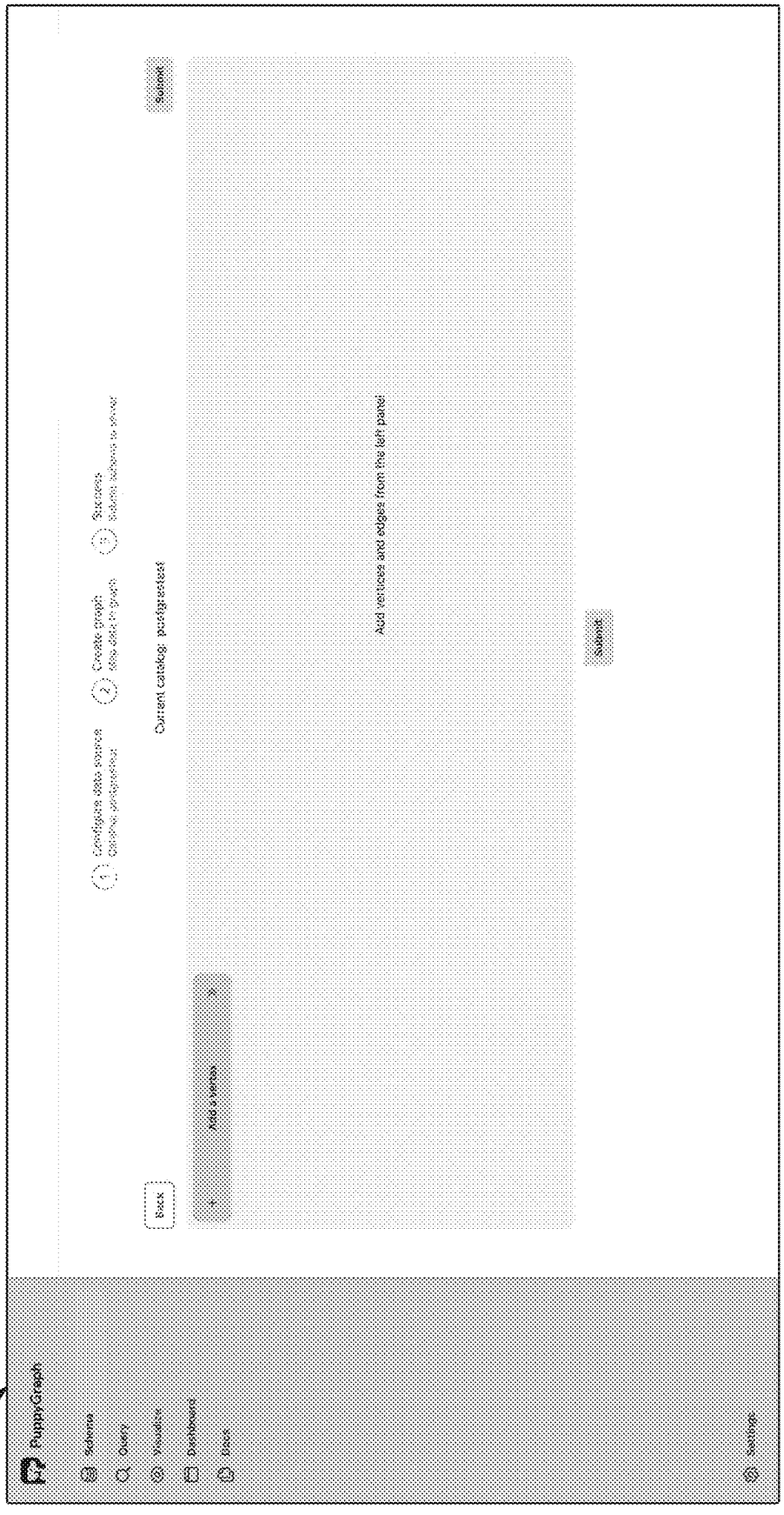

1000
PuppyGraph
Schema
Query
Visualize
Dashboard
Docs
Settings
Back
Add a vertex
Submit
Current catalog: postgrestest
Add vertices and edges from the left panel
Submit

Figure 10E

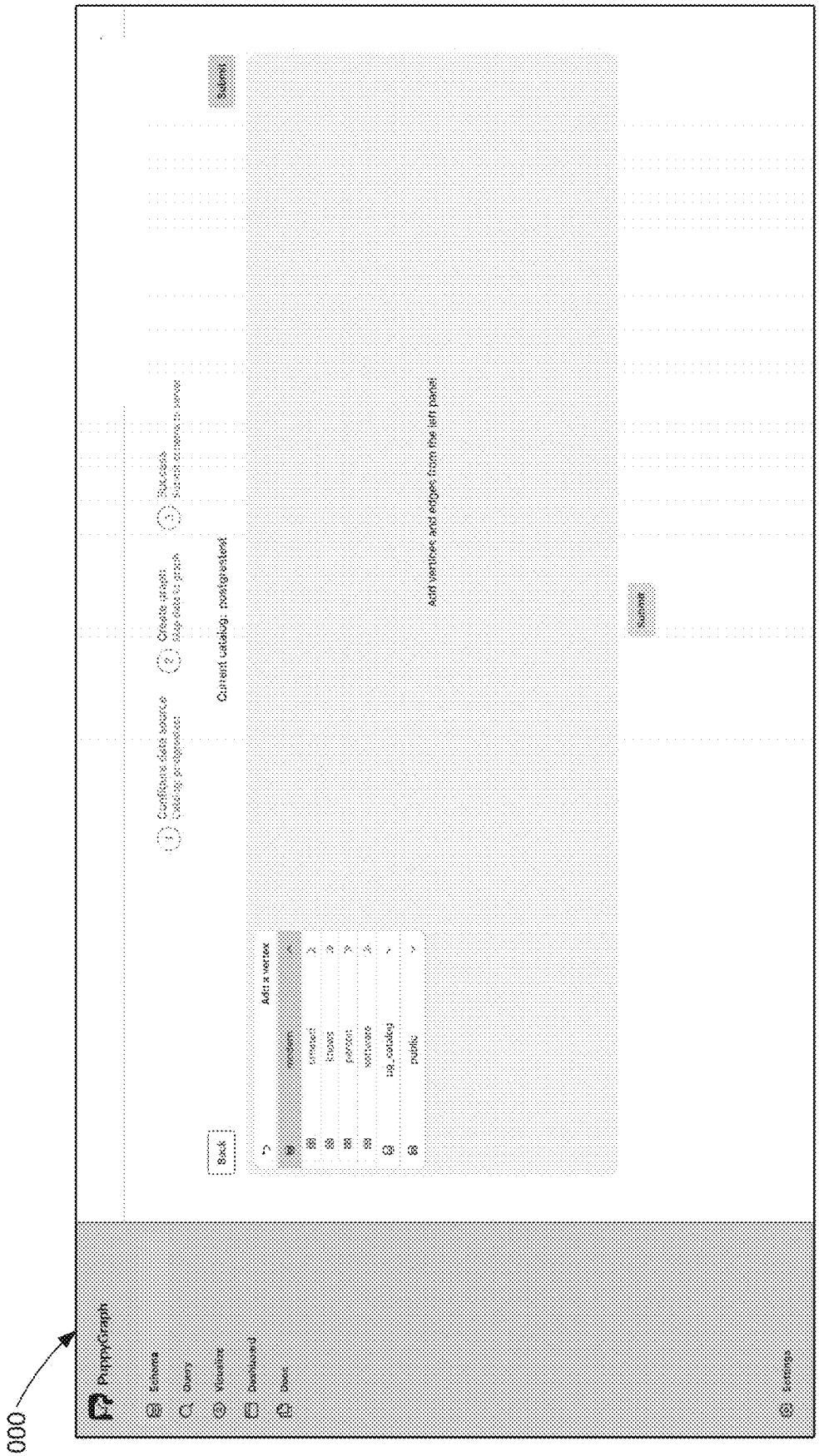

1000
PuppyGraph
Explore
Query
Visualize
Dashboard
Save
Settings
Back
Submit
Current catalog: postgresfarest
Add a vertex
Add vertices and edges from the left panel
Solve

Figure 10F

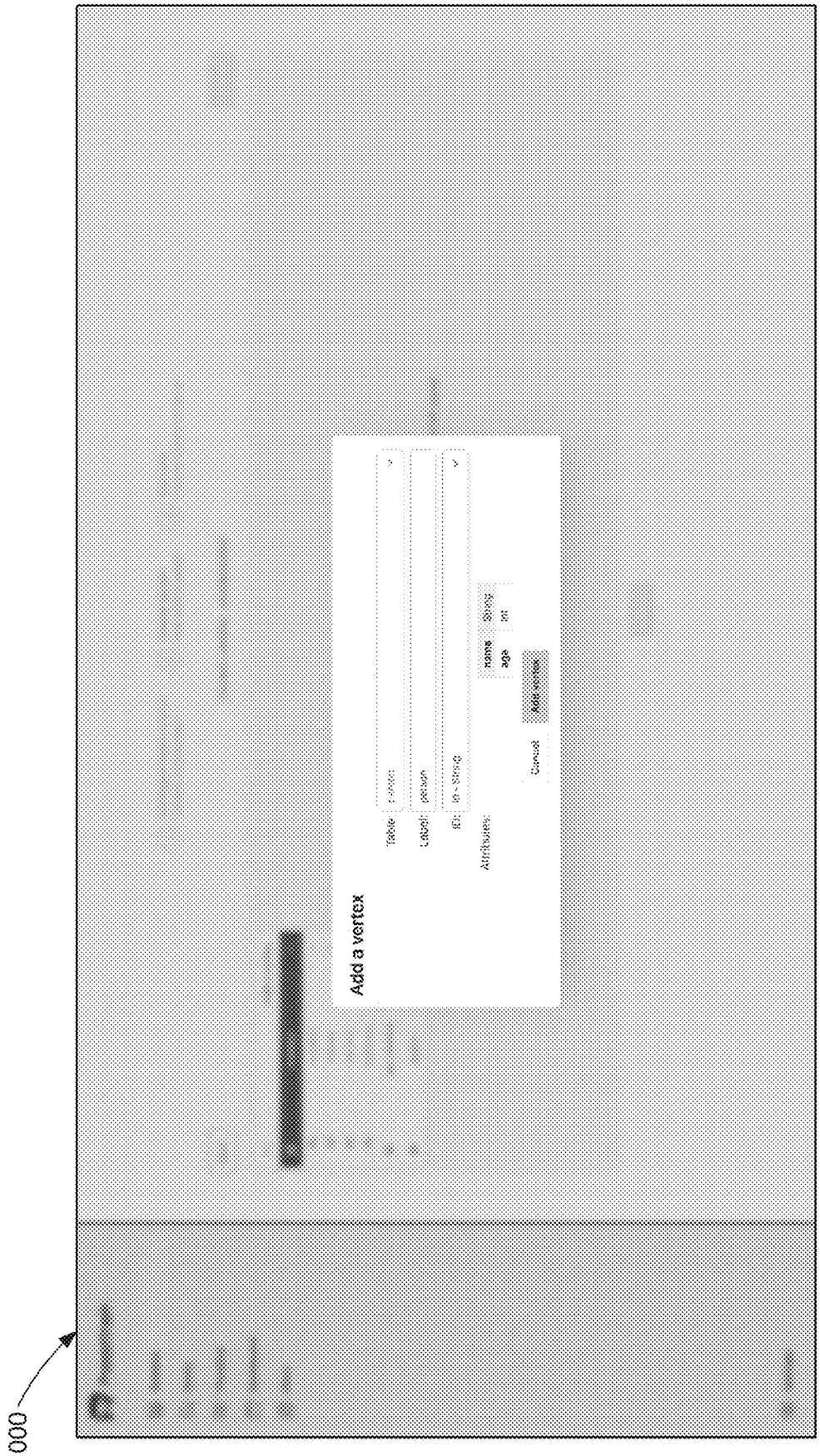

1000
Add a vertex
Table
Label
person
Attributes
name
String
age
Add vertex
Cancel

Figure 10G

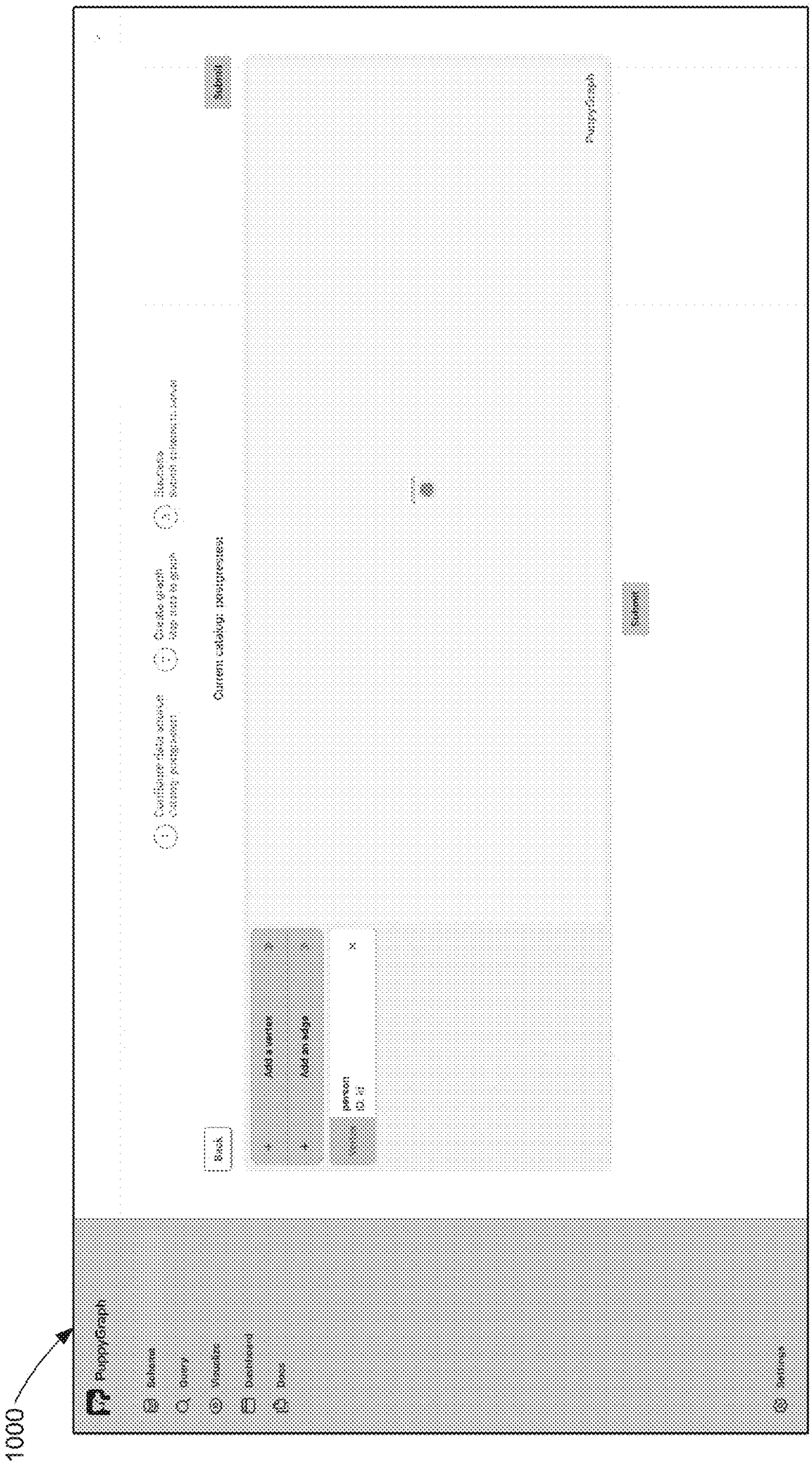


Figure 10H

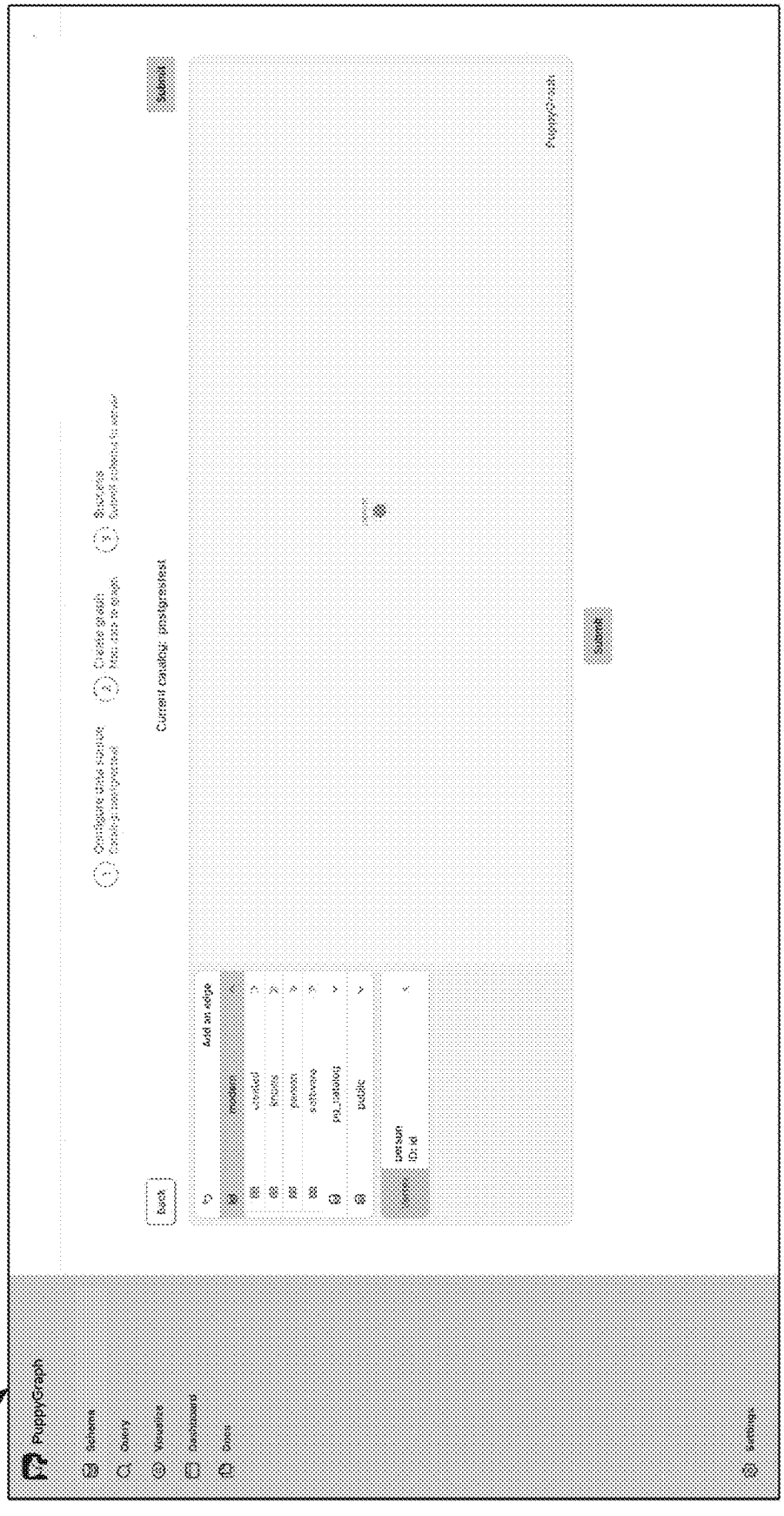

1000
PuppyGraph
Schema
Query
Visualize
Dashboards
Docs
Settings
Back
Submit
Current catalog: postgrestest
Add an edge
Submit

Figure 10I

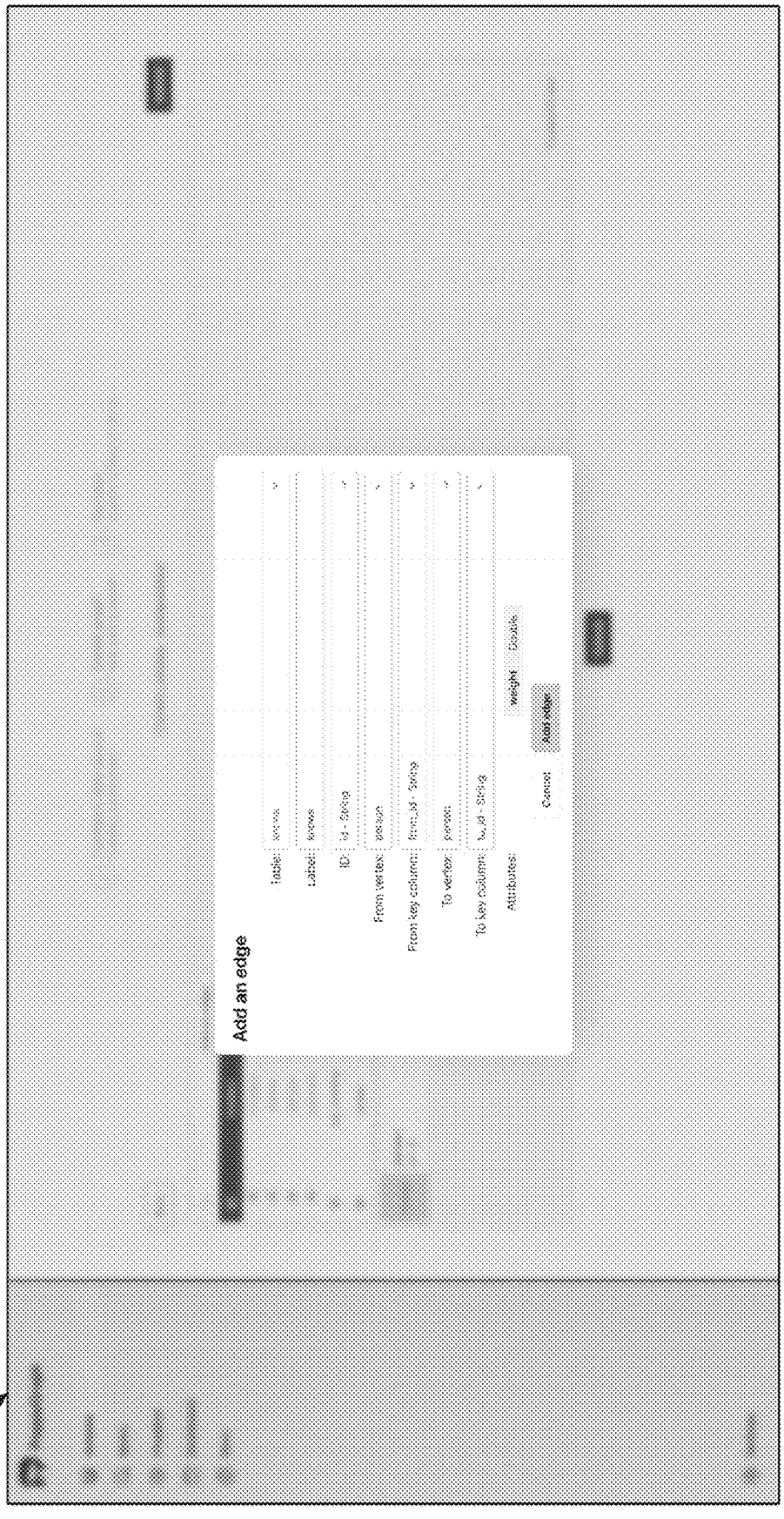

1000
Add an edge
Table:
Label:
ID:
From vertex:
From key column:
To vertex:
To key column:
Attributes:
weight
Double
Cancel
Add edge

Figure 10J

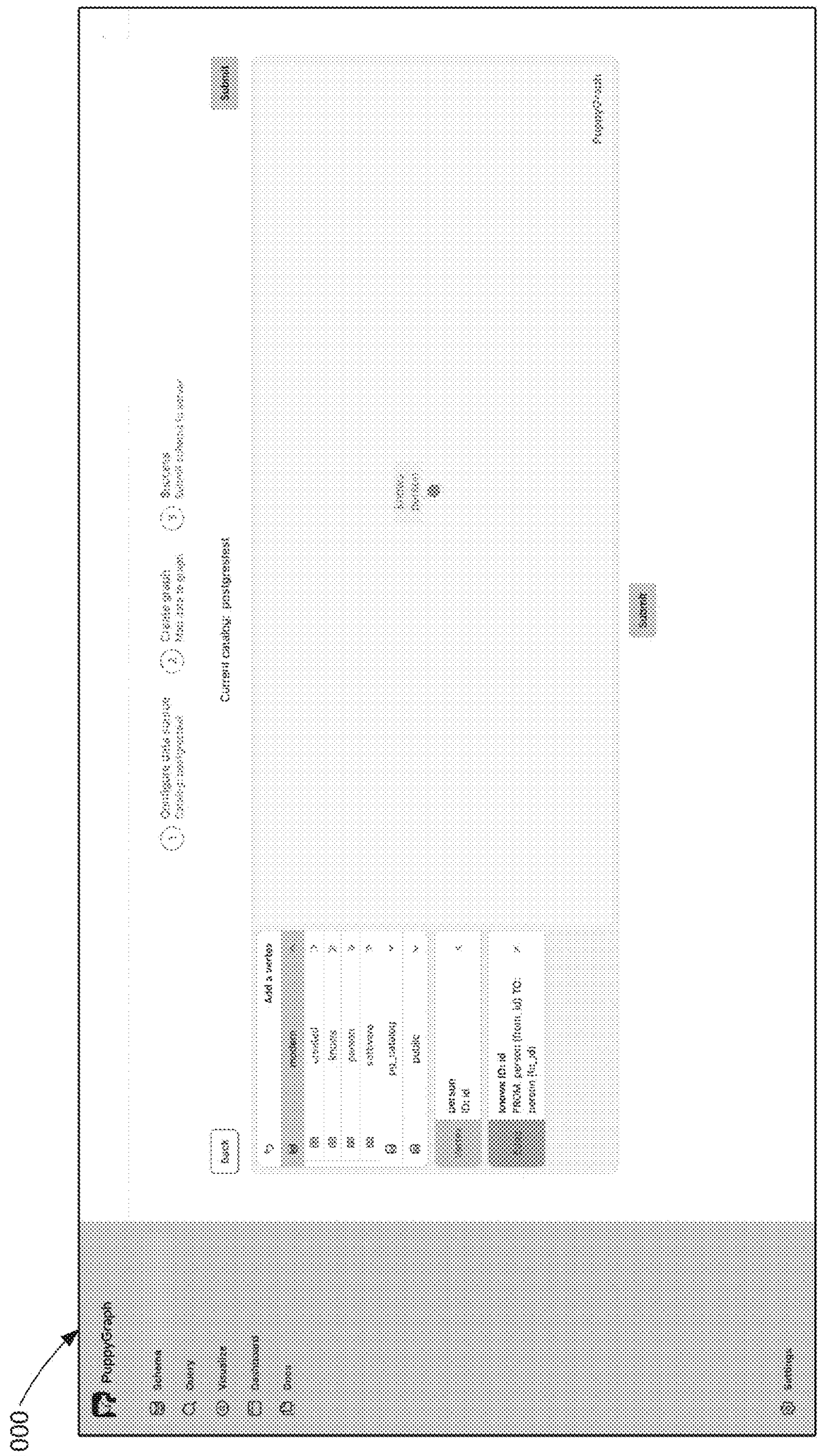

1000
PuppyGraph
Back
Submit
Current catalog: postgrestest
Add a vertex
public
person
ID: id

Figure 10K

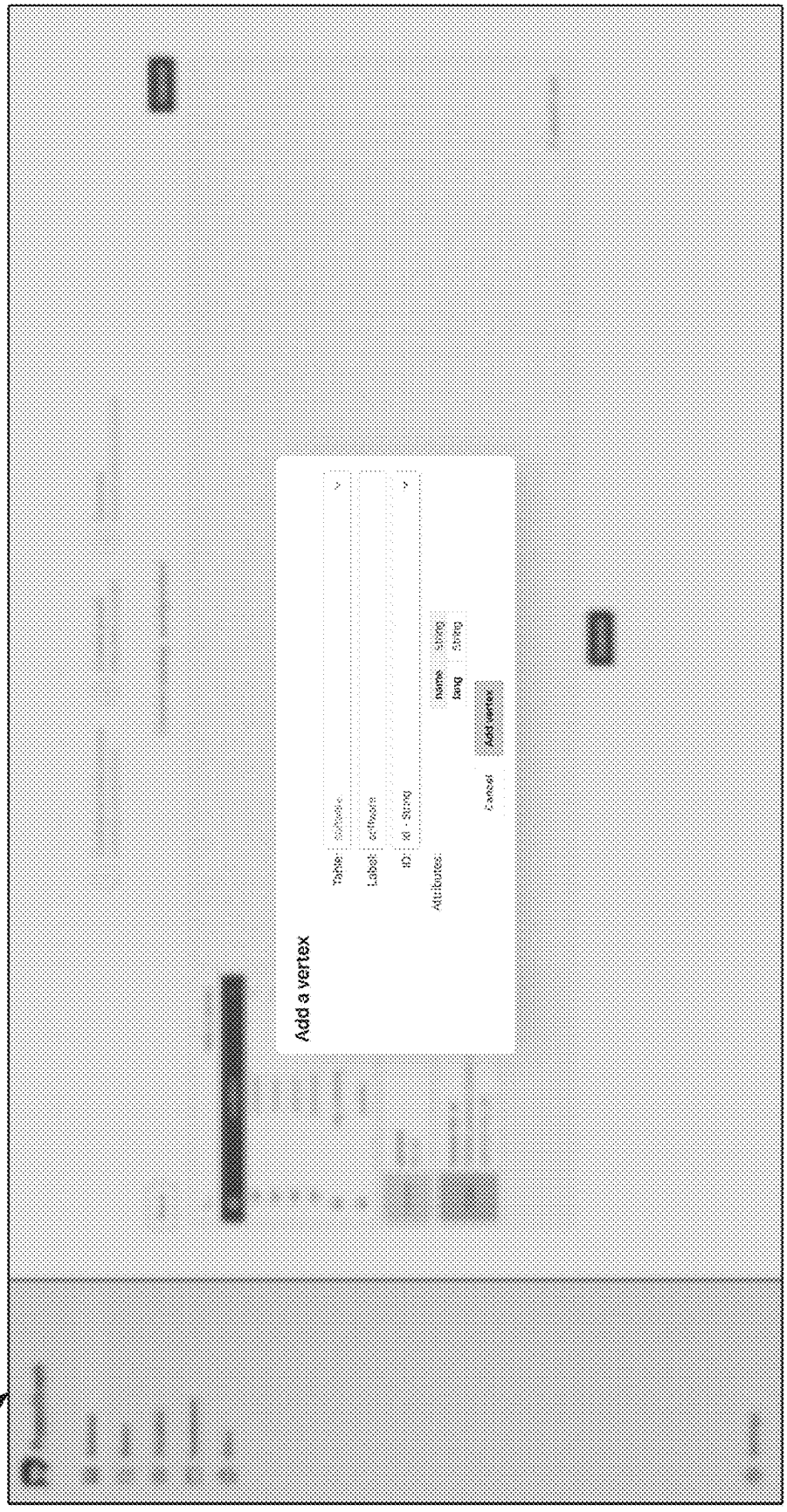

1000
Add a vertex
Table:
Label:
ID:
Attributes:
name
lang
String
String
Cancel
Add vertex

Figure 10L

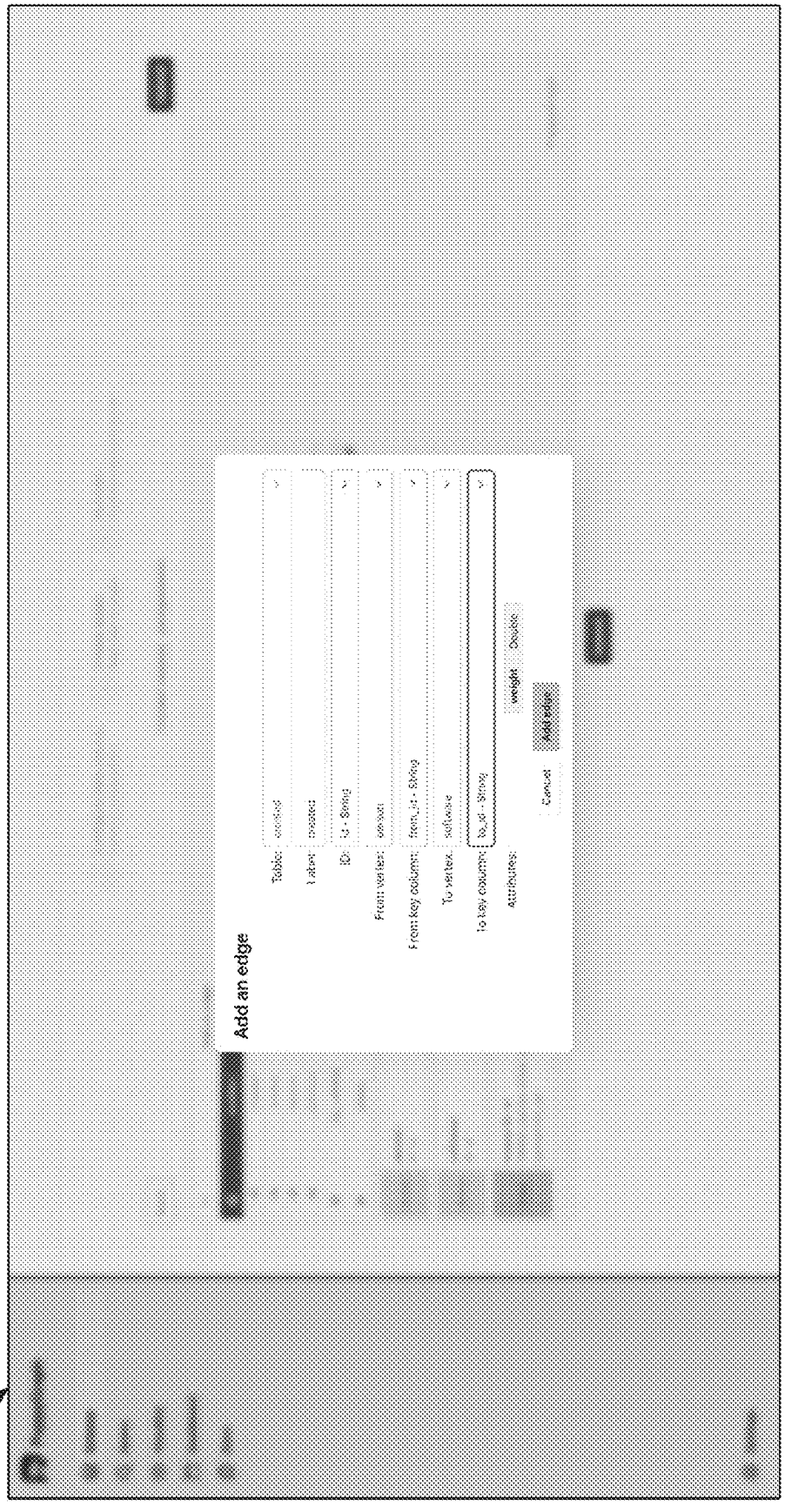

1000
Add an edge
Table:
Label:
ID:
From vertex:
From key column:
To vertex:
To key column:
Attributes:
weight
Double
Cancel
Add edge

Figure 10M

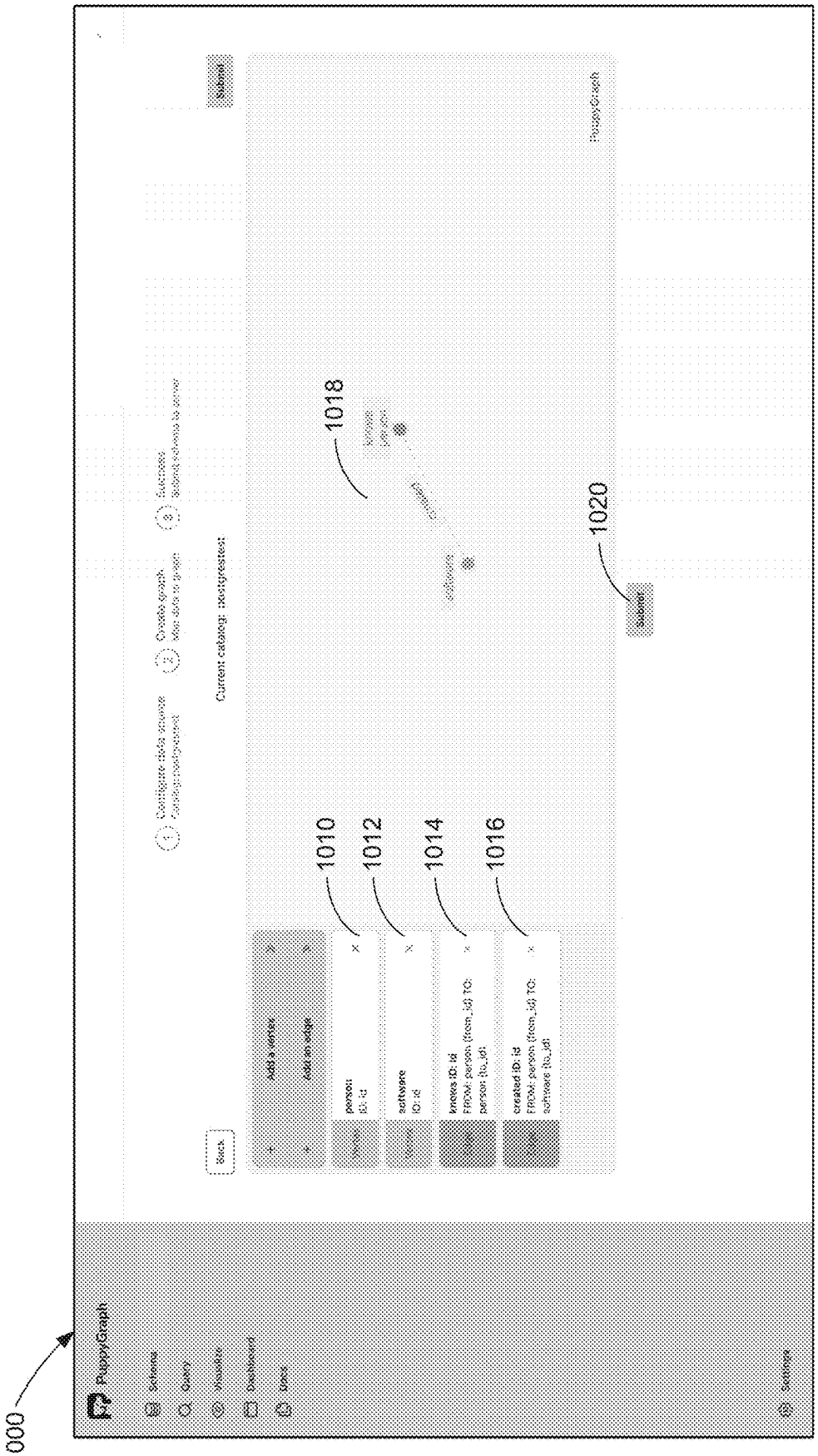

1000
PuppyGraph
Schema
Query
Visualize
Dashboard
Docs
Settings
Current catalog: mostgrestest
Back
Submit
Add a vertex
Add an edge
person
id: id
software
id: id
knows id: id
FROM: person (from_id) TO: person (to_id)
created id: id
FROM: person (from_id) TO: software (to_id)
1010
1012
1014
1016
1018
1020

Figure 10N

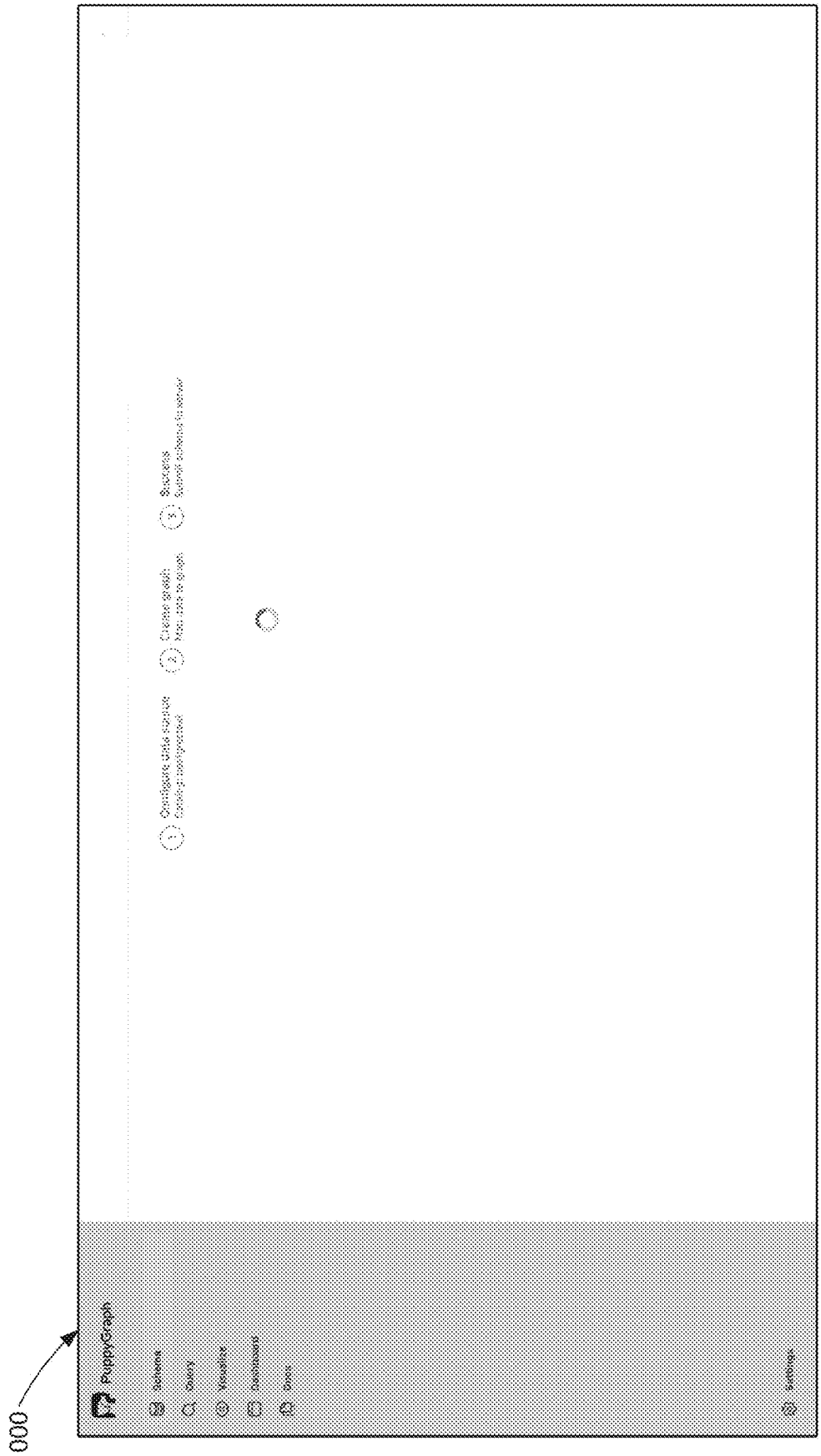

1000
PuppyGreen
Schema
Query
Visualize
Dashboards
Query
Schema

Figure 100

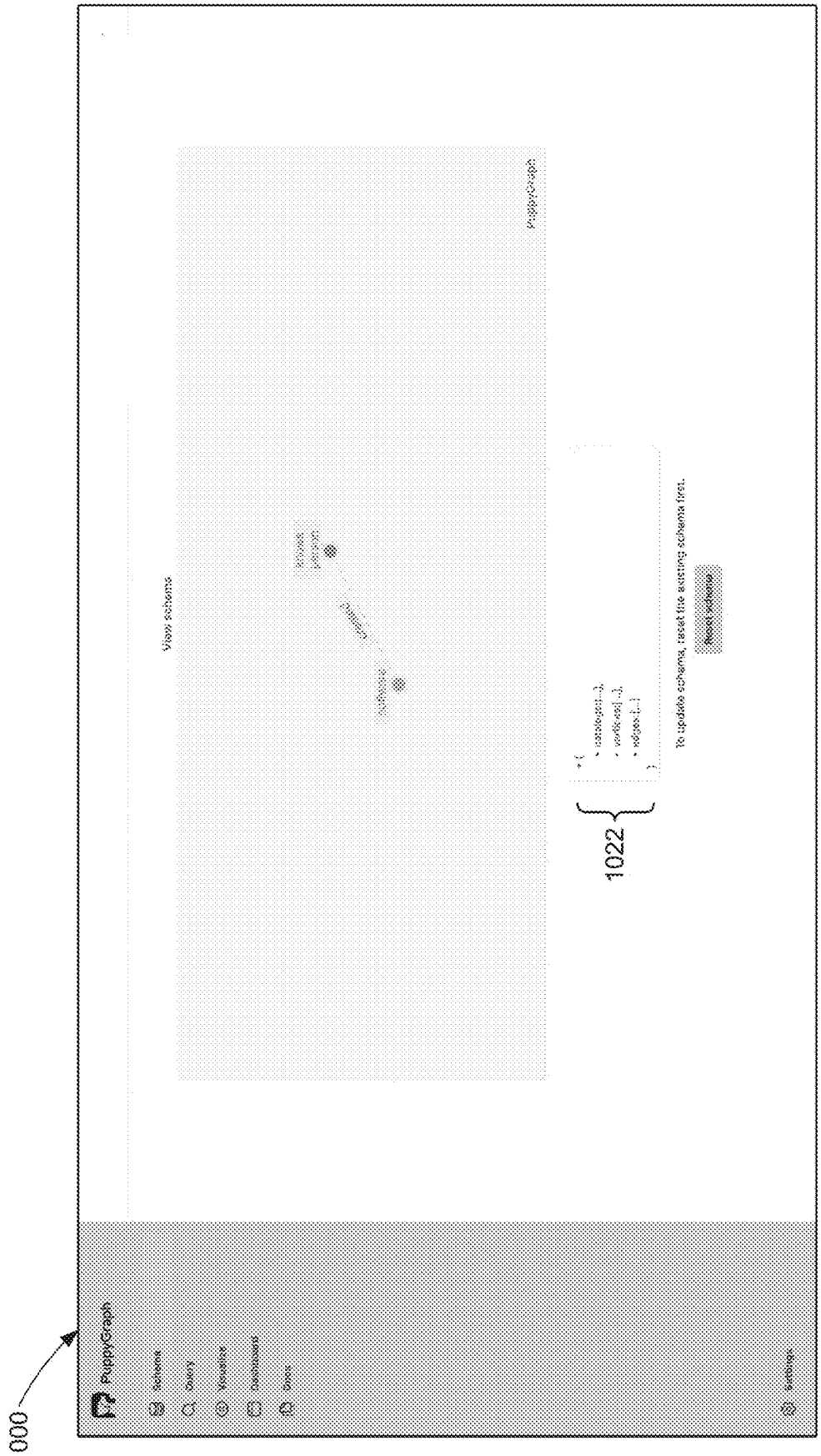

1000
PuppyGraph
Schema
Query
Visualize
Dashboards
Docs
Settings
View schema
PuppyGraph
1022
To update schema, reset the existing schema first.
Reset schema

Figure 10P

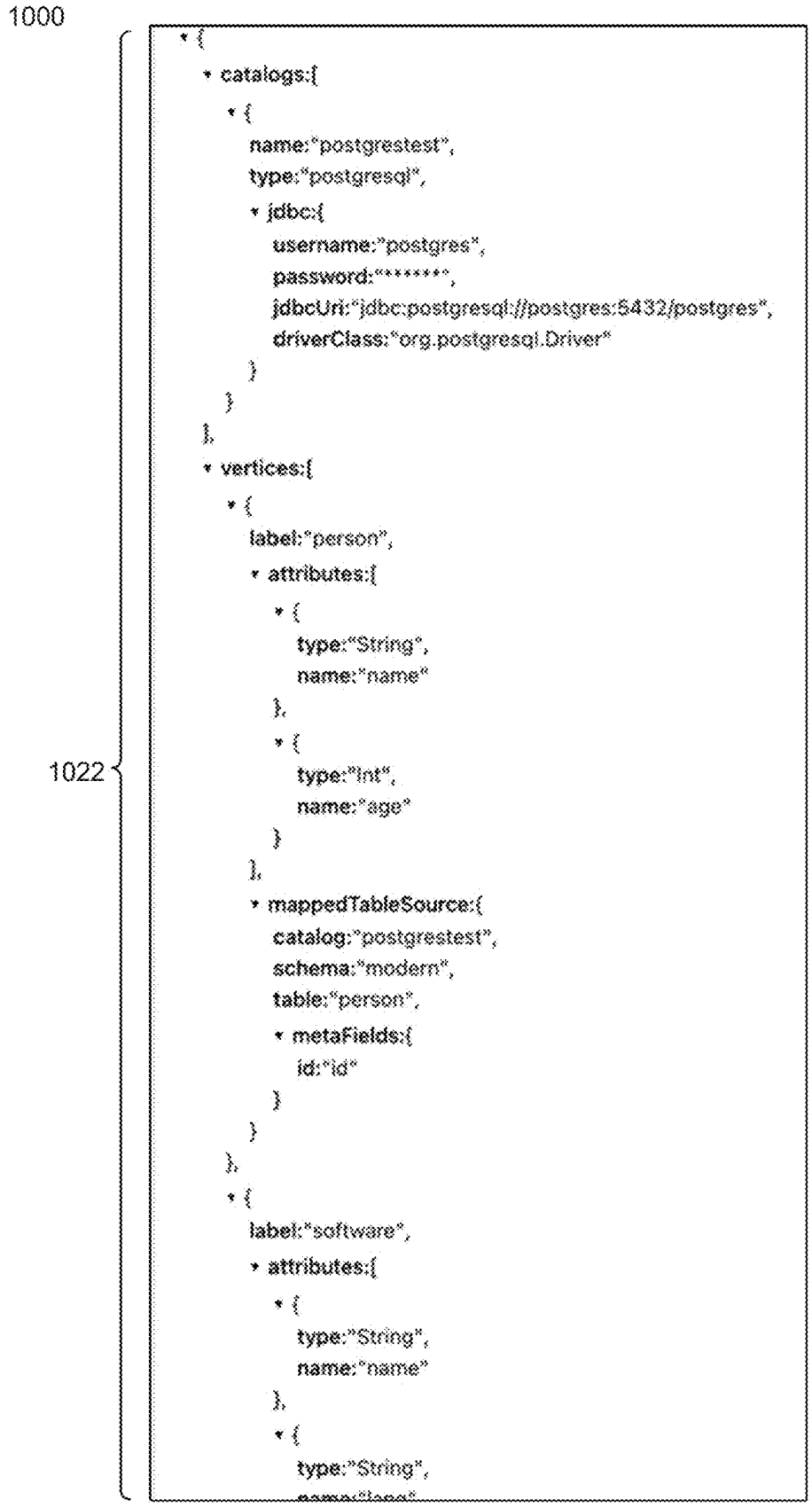

1000
1022
{
catalogs:[
{
name:"postgrestest",
type:"postgresql",
jdbc:{
username:"postgres",
password:"******",
jdbcUri:"jdbc:postgresql://postgres:5432/postgres",
driverClass:"org.postgresql.Driver"
}
}
],
vertices:[
{
label:"person",
attributes:[
{
type:"String",
name:"name"
},
{
type:"Int",
name:"age"
}
],
mappedTableSource:{
catalog:"postgrestest",
schema:"modern",
table:"person",
metaFields:{
id:"id"
}
}
},
{
label:"software",
attributes:[
{
type:"String",
name:"name"
},
{
type:"String",

Figure 10Q

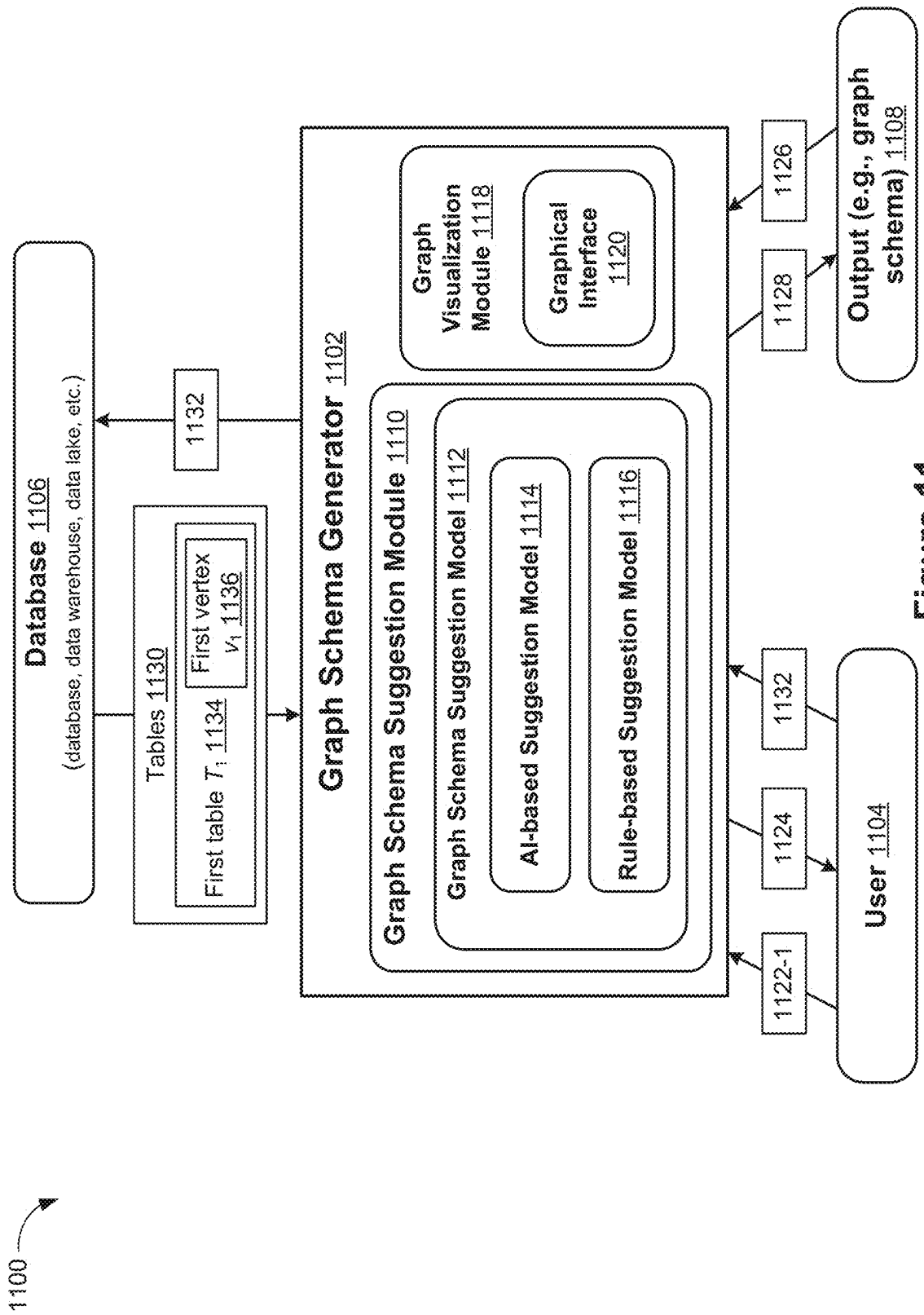

1100
Database 1106
(database, data warehouse, data lake, etc.)
Tables 1130
First table T_1 1134
First vertex v_1 1136
1132
Graph Schema Generator 1102
Graph Schema Suggestion Module 1110
Graph Schema Suggestion Model 1112
AI-based Suggestion Model 1114
Rule-based Suggestion Model 1116
Graph Visualization Module 1118
Graphical Interface 1120
1122-1
1124
1132
1126
1128
User 1104
Output (e.g., graph schema) 1108

Figure 11

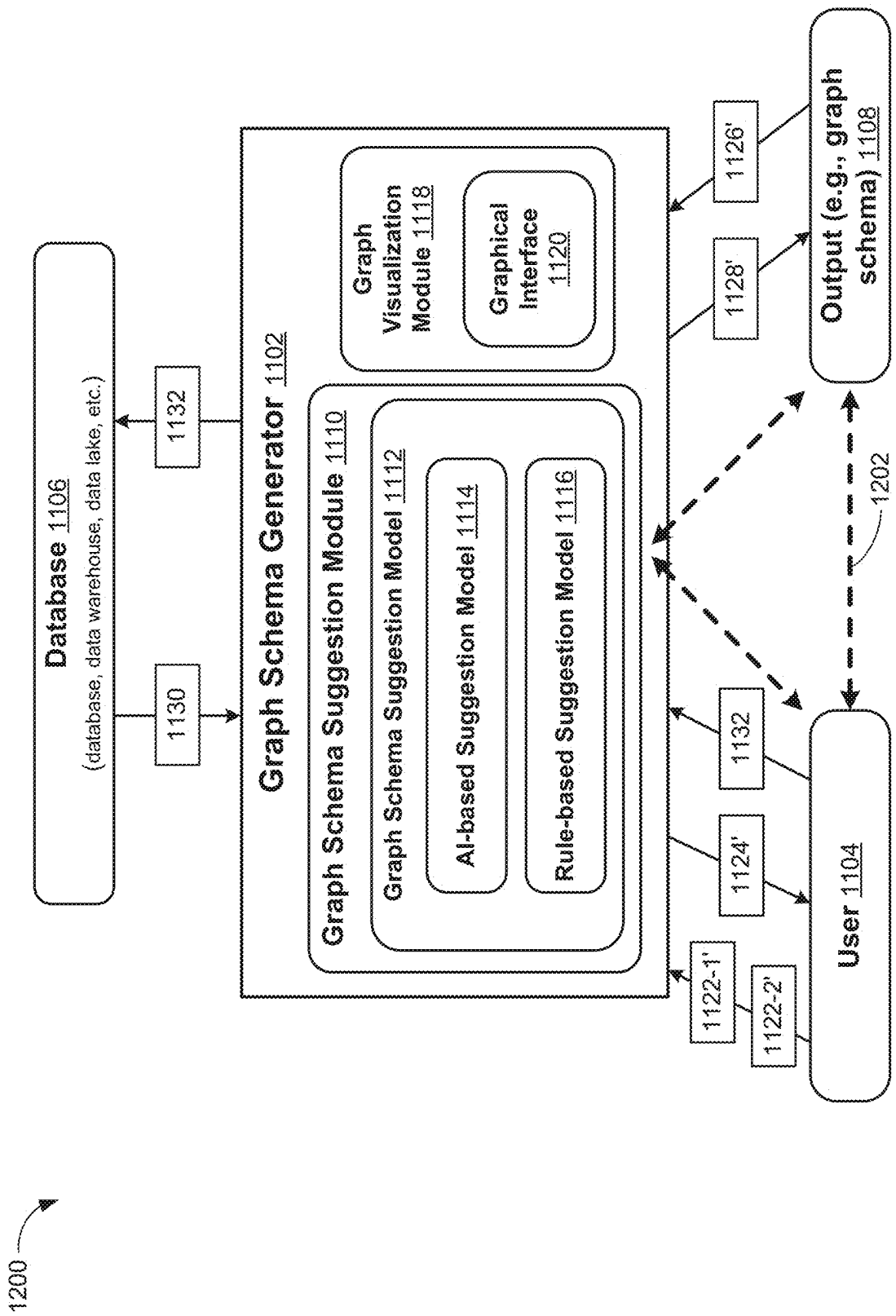

1200
Database 1106
(database, data warehouse, data lake, etc.)
1130
1132
Graph Schema Generator 1102
Graph Schema Suggestion Module 1110
Graph Schema Suggestion Model 1112
AI-based Suggestion Model 1114
Rule-based Suggestion Model 1116
Graph Visualization Module 1118
Graphical Interface 1120
1122-1'
1122-2'
1124'
1126'
1128'
User 1104
Output (e.g., graph schema) 1108
1202

Figure 12

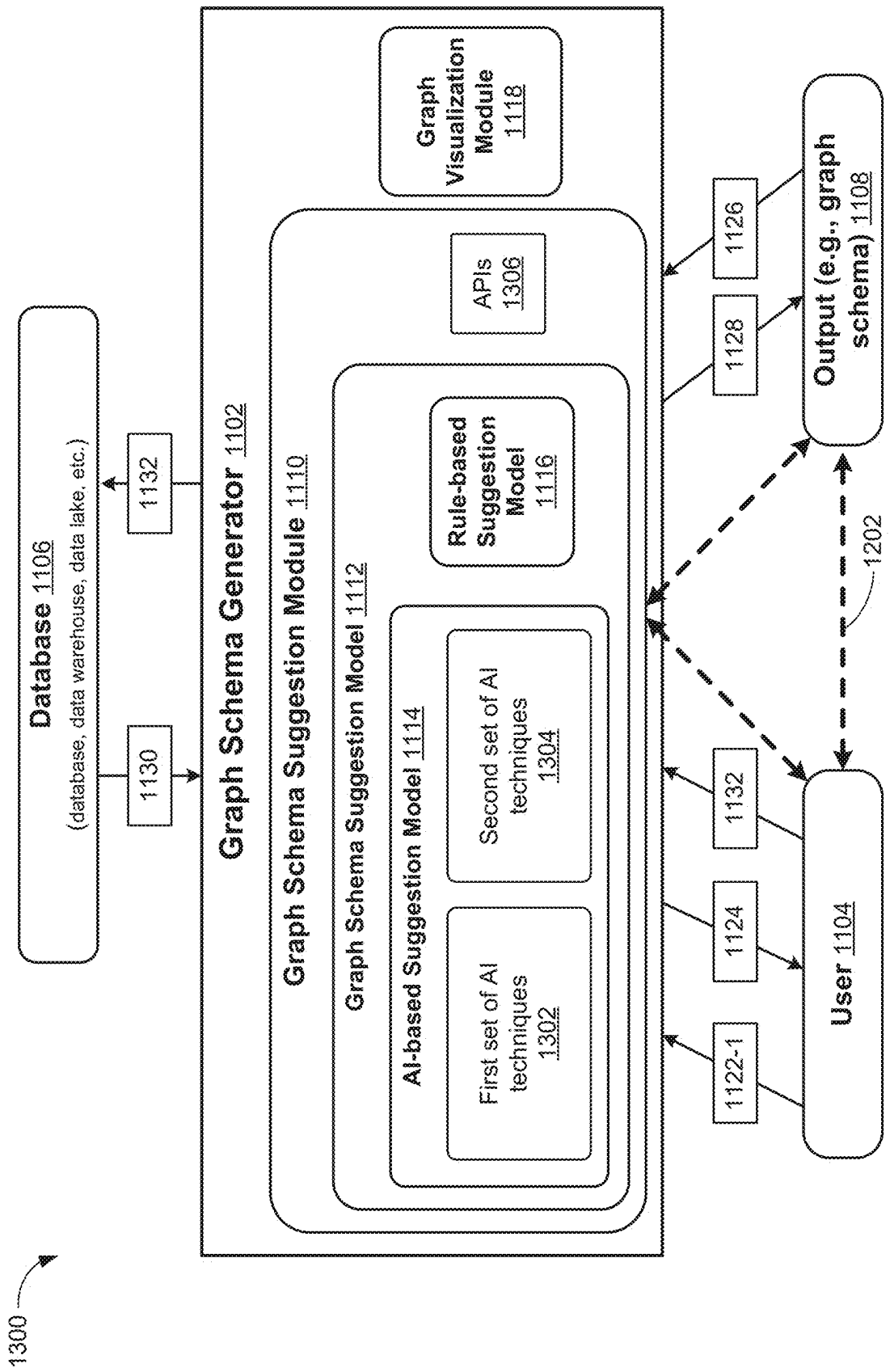

1300
Database 1106
(database, data warehouse, data lake, etc.)
1130
1132
Graph Schema Generator 1102
Graph Schema Suggestion Module 1110
Graph Schema Suggestion Model 1112
AI-based Suggestion Model 1114
First set of AI techniques 1302
Second set of AI techniques 1304
Rule-based Suggestion Model 1116
APIs 1306
Graph Visualization Module 1118
1122-1
1124
1126
1128
1132
User 1104
Output (e.g., graph schema) 1108
1202

Figure 13

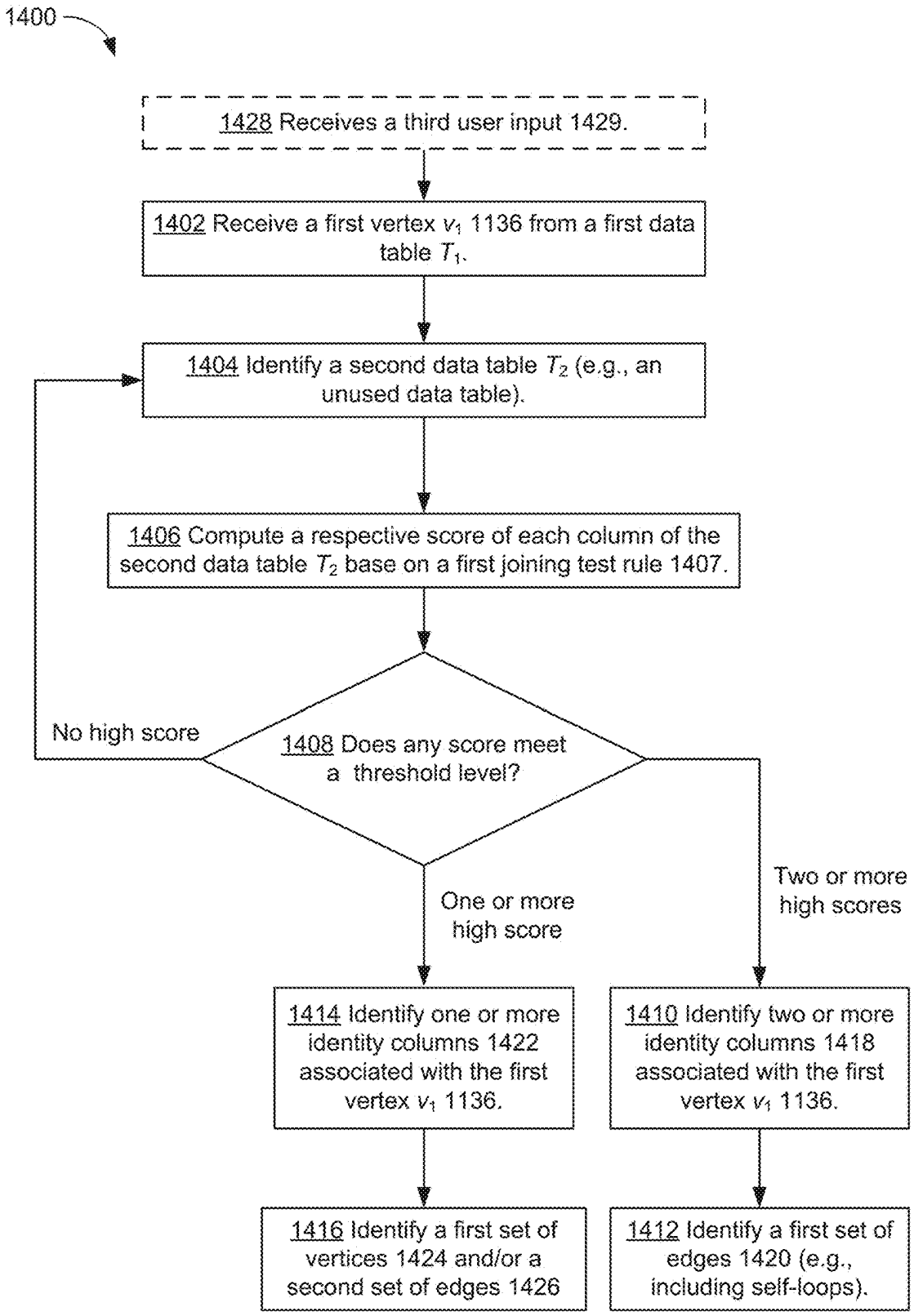

1400
1428 Receives a third user input 1429.
1402 Receive a first vertex v_1 1136 from a first data table T_1.
1404 Identify a second data table T_2 (e.g., an unused data table).
1406 Compute a respective score of each column of the second data table T_2 base on a first joining test rule 1407.
1408 Does any score meet a threshold level?
No high score
One or more high score
Two or more high scores
1414 Identify one or more identity columns 1422 associated with the first vertex v_1 1136.
1410 Identify two or more identity columns 1418 associated with the first vertex v_1 1136.
1416 Identify a first set of vertices 1424 and/or a second set of edges 1426
1412 Identify a first set of edges 1420 (e.g., including self-loops).

Figure 14A

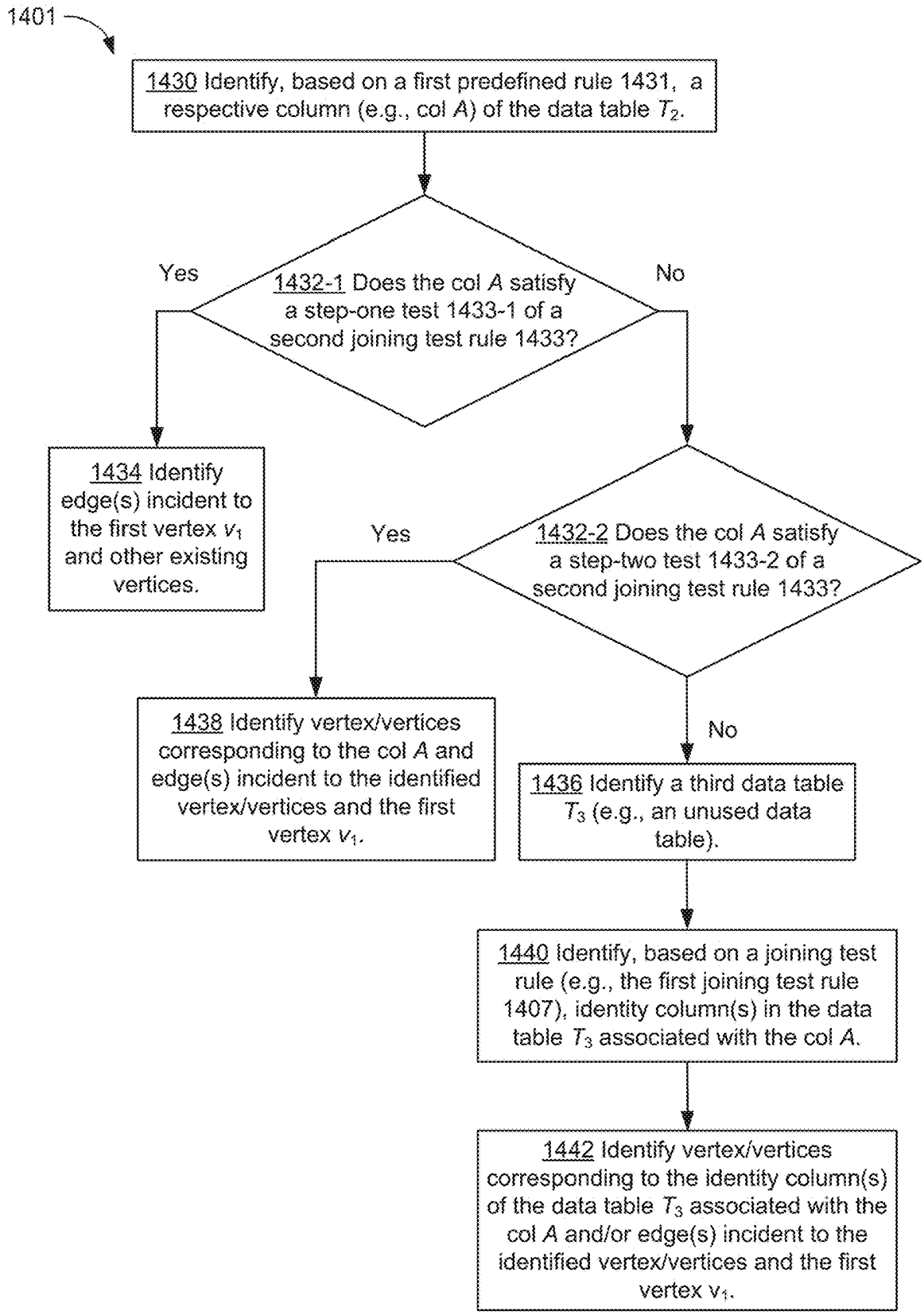
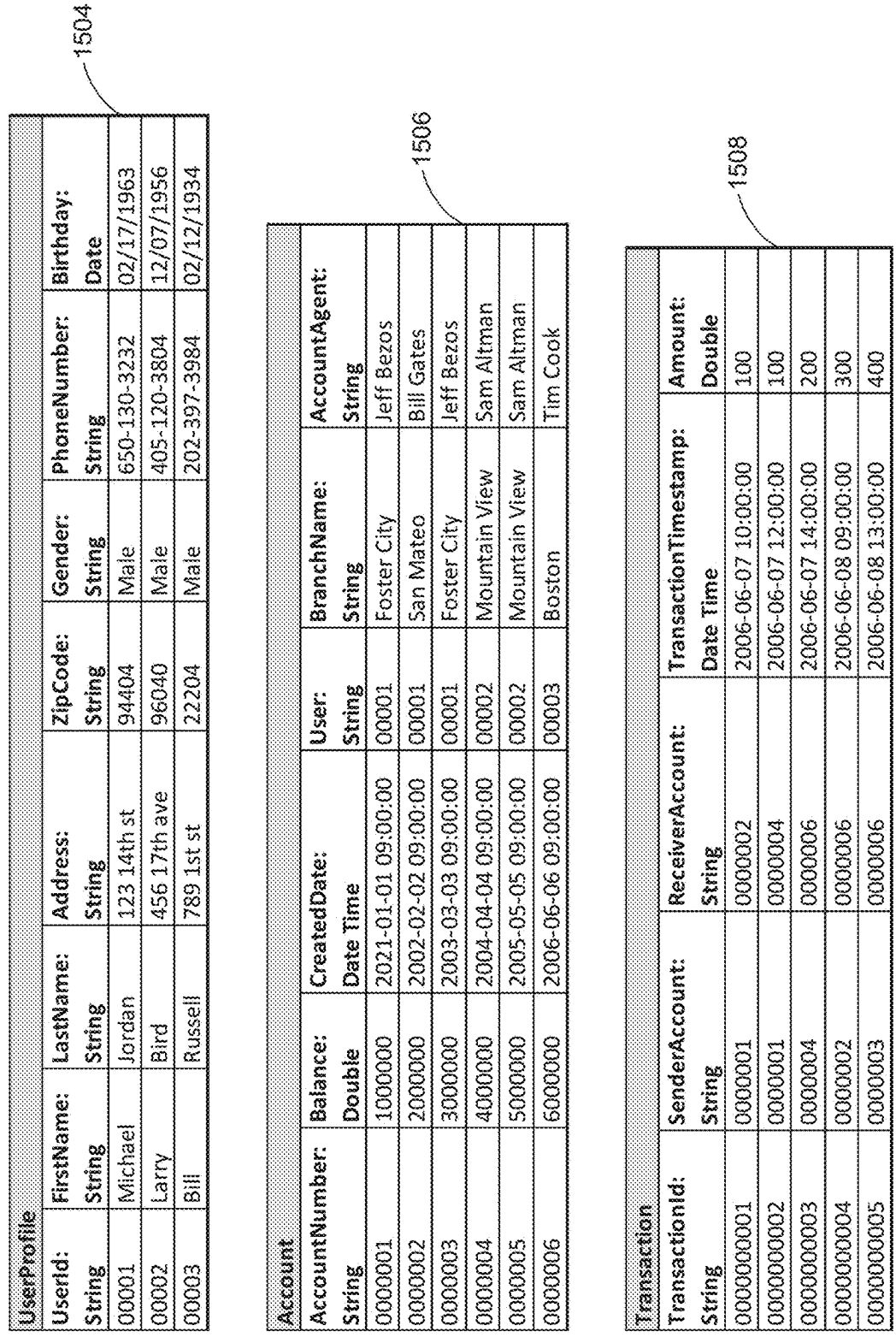

1401
1430 Identify, based on a first predefined rule 1431, a respective column (e.g., col A) of the data table T_2.
1432-1 Does the col A satisfy a step-one test 1433-1 of a second joining test rule 1433?
Yes
No
1434 Identify edge(s) incident to the first vertex v_1 and other existing vertices.
1432-2 Does the col A satisfy a step-two test 1433-2 of a second joining test rule 1433?
Yes
No
1438 Identify vertex/vertices corresponding to the col A and edge(s) incident to the identified vertex/vertices and the first vertex v_1.
1436 Identify a third data table T_3 (e.g., an unused data table).
1440 Identify, based on a joining test rule (e.g., the first joining test rule 1407), identity column(s) in the data table T_3 associated with the col A.
1442 Identify vertex/vertices corresponding to the identity column(s) of the data table T_3 associated with the col A and/or edge(s) incident to the identified vertex/vertices and the first vertex v_1.

Figure 14B



UserProfile

UserId: String	FirstName: String	LastName: String	Address: String	ZipCode: String	Gender: String	PhoneNumber: String	Birthday: Date
00001	Michael	Jordan	123 14th st	94404	Male	650-130-3232	02/17/1963
00002	Larry	Bird	456 17th ave	96040	Male	405-120-3804	12/07/1956
00003	Bill	Russell	789 1st st	22204	Male	202-397-3984	02/12/1934

Account

AccountNumber: String	Balance: Double	CreatedDate: Date Time	User: String	BranchName: String	AccountAgent: String
0000001	1000000	2021-01-01 09:00:00	00001	Foster City	Jeff Bezos
0000002	2000000	2002-02-02 09:00:00	00001	San Mateo	Bill Gates
0000003	3000000	2003-03-03 09:00:00	00001	Foster City	Jeff Bezos
0000004	4000000	2004-04-04 09:00:00	00002	Mountain View	Sam Altman
0000005	5000000	2005-05-05 09:00:00	00002	Mountain View	Sam Altman
0000006	6000000	2006-06-06 09:00:00	00003	Boston	Tim Cook

Transaction

TransactionId: String	SenderAccount: String	ReceiverAccount: String	TransactionTimestamp: Date Time	Amount: Double
0000000001	0000001	0000002	2006-06-07 10:00:00	100
0000000002	0000001	0000004	2006-06-07 12:00:00	100
0000000003	0000004	0000006	2006-06-07 14:00:00	200
0000000004	0000002	0000006	2006-06-08 09:00:00	300
0000000005	0000003	0000006	2006-06-08 13:00:00	400

Figure 15A

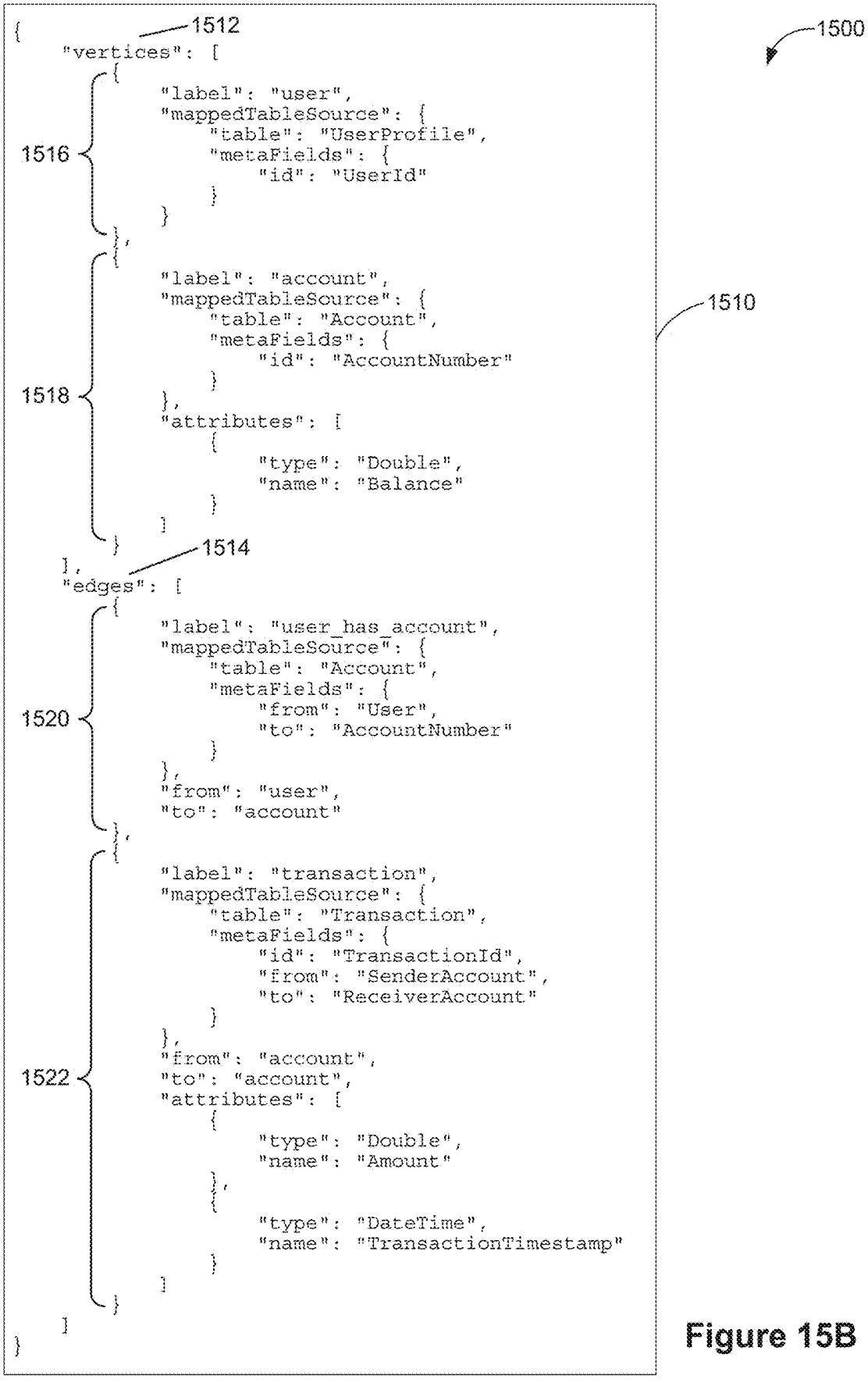

1500
1510
1512
1514
1516
1518
1520
1522
{
"vertices": [
{
"label": "user",
"mappedTableSource": {
"table": "UserProfile",
"metaFields": {
"id": "UserId"
}
}
},
{
"label": "account",
"mappedTableSource": {
"table": "Account",
"metaFields": {
"id": "AccountNumber"
}
},
"attributes": [
{
"type": "Double",
"name": "Balance"
}
]
}
],
"edges": [
{
"label": "user_has_account",
"mappedTableSource": {
"table": "Account",
"metaFields": {
"from": "User",
"to": "AccountNumber"
}
},
"from": "user",
"to": "account"
},
{
"label": "transaction",
"mappedTableSource": {
"table": "Transaction",
"metaFields": {
"id": "TransactionId",
"from": "SenderAccount",
"to": "ReceiverAccount"
}
},
"from": "account",
"to": "account",
"attributes": [
{
"type": "Double",
"name": "Amount"
},
{
"type": "DateTime",
"name": "TransactionTimestamp"
}
]
}
]
}

Figure 15B

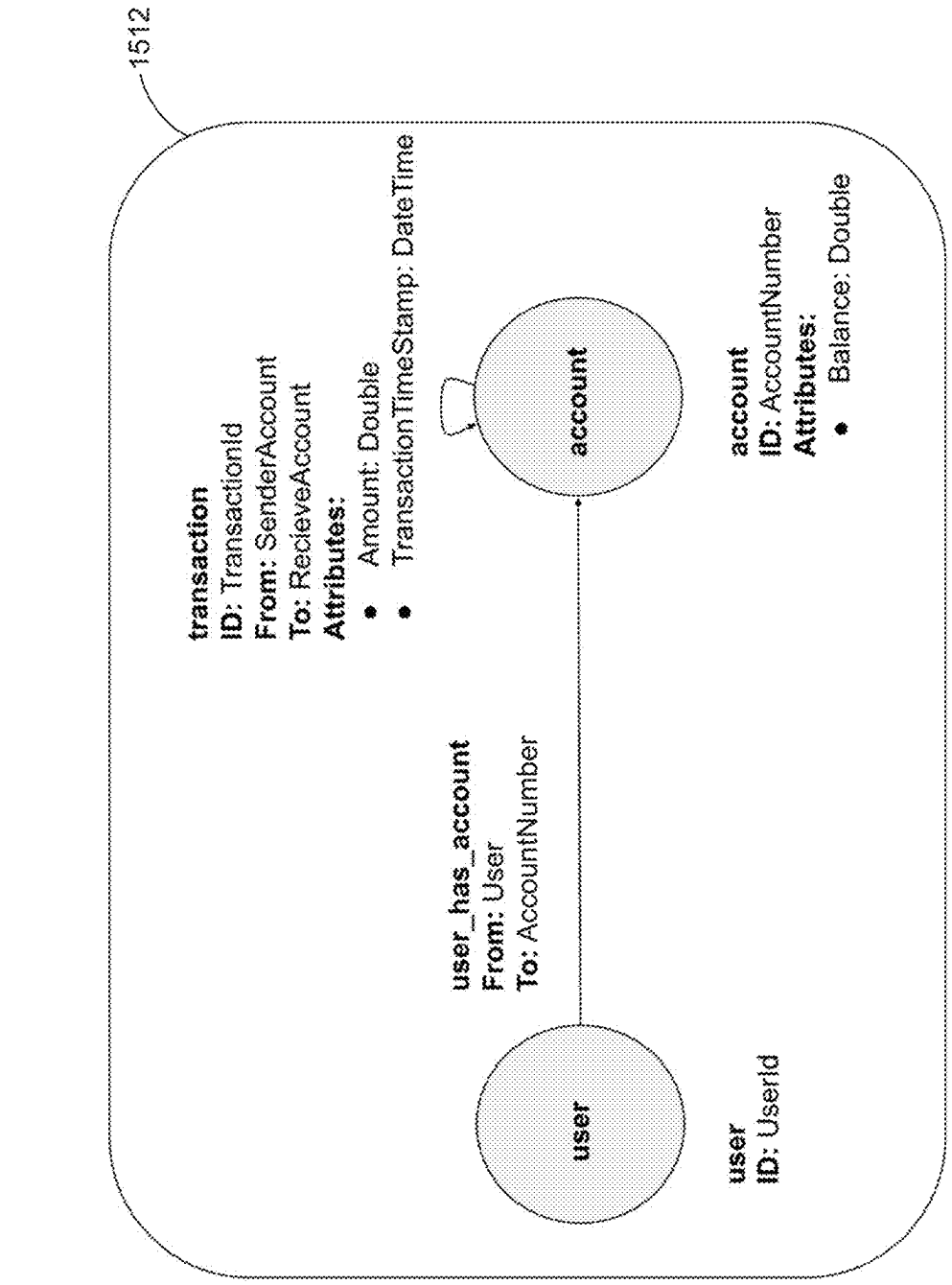

1500
1512
transaction
ID: TransactionId
From: SenderAccount
To: RecieveAccount
Attributes:
Amount: Double
TransactionTimeStamp: DateTime
user_has_account
From: User
To: AccountNumber
user
account
user
ID: UserId
account
ID: AccountNumber
Attributes:
Balance: Double

Figure 15C

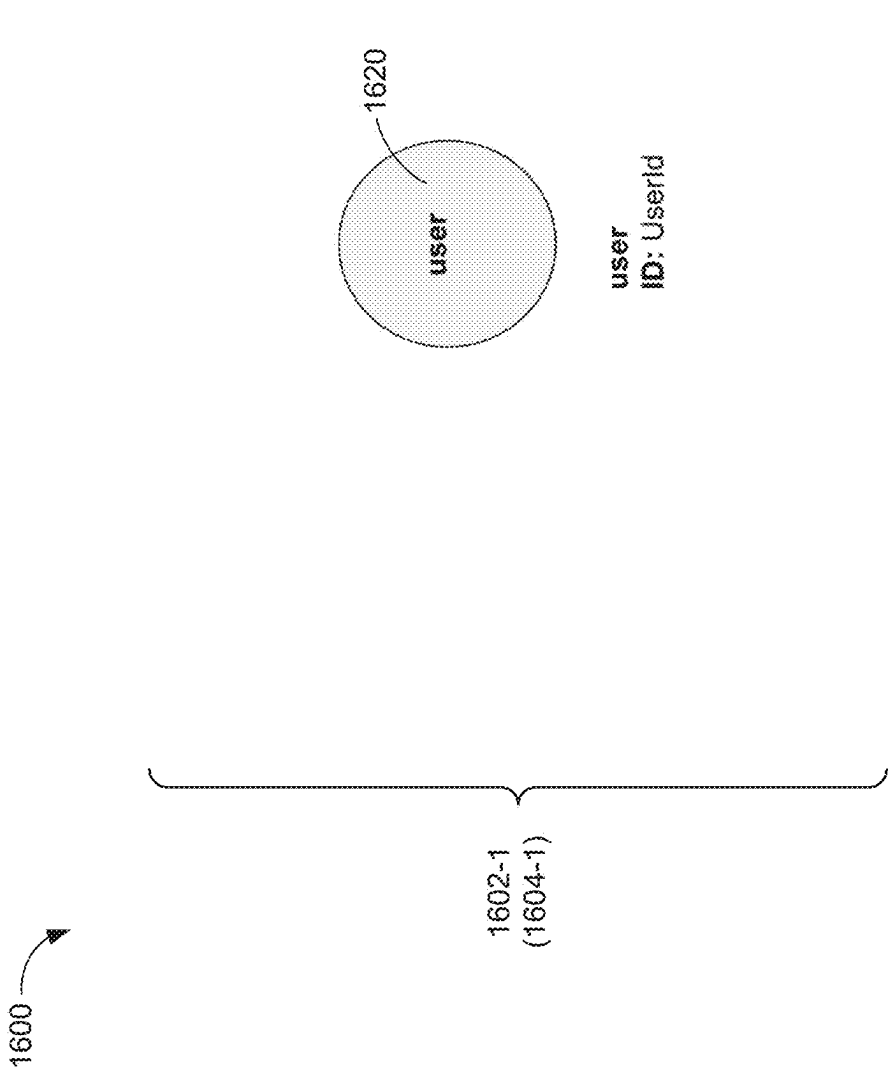


Figure 16A

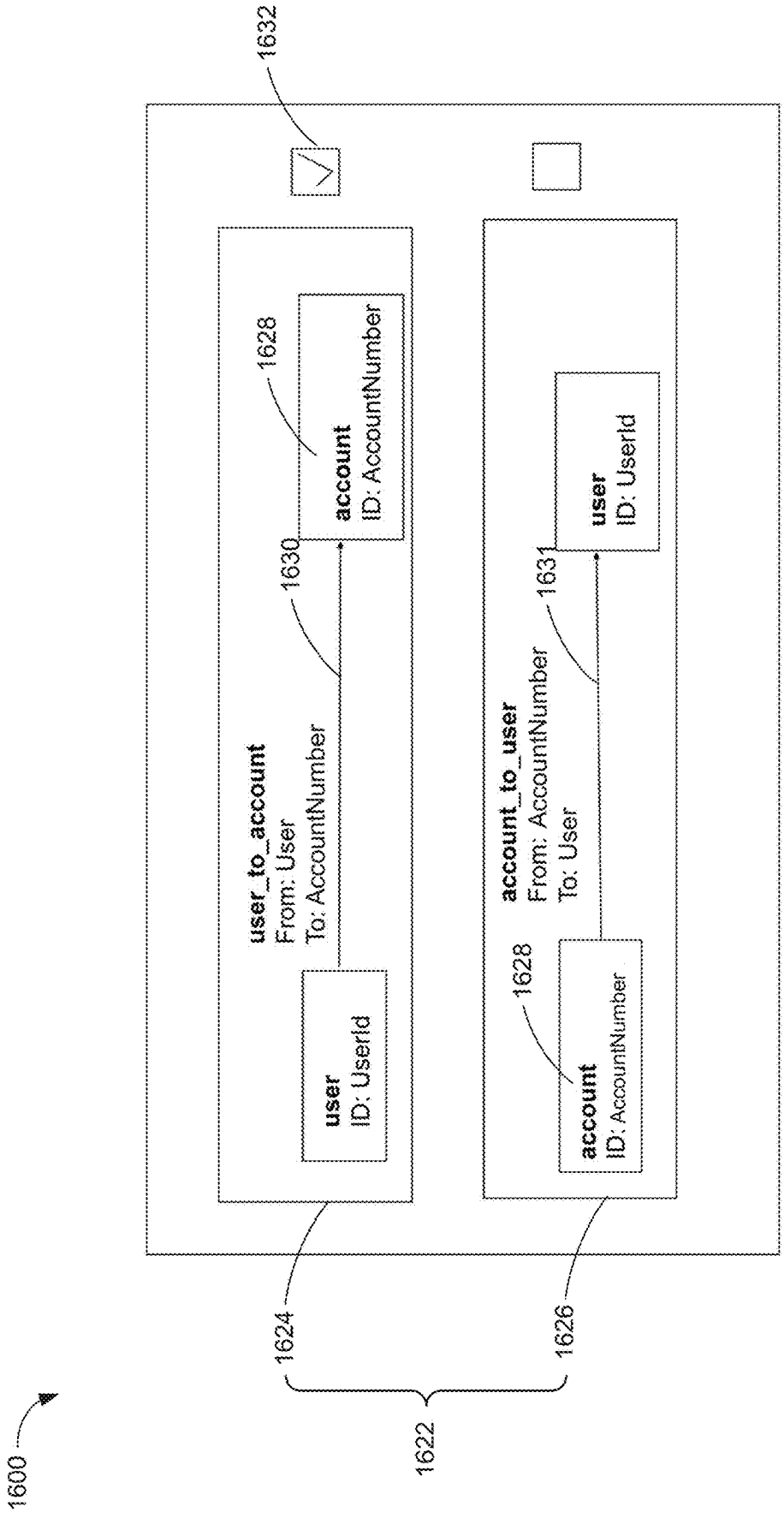

1600
1622
1624
1626
1628
1630
1631
1632
user
ID: UserId
user_to_account
From: User
To: AccountNumber
account
ID: AccountNumber
account_to_user
From: AccountNumber
To: User
user
ID: UserId
account
ID: AccountNumber

Figure 16B

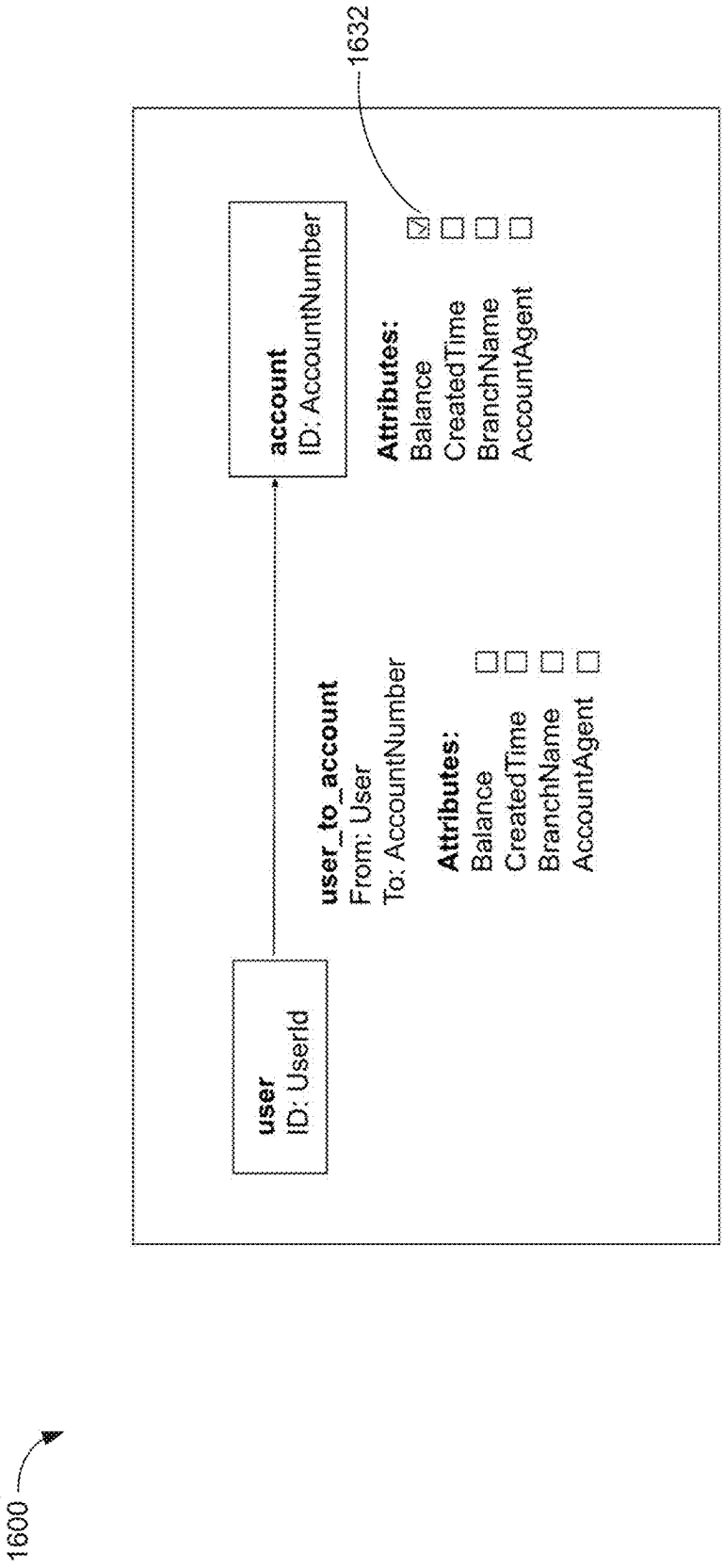

1600
1632
user
ID: UserId
user_to_account
From: User
To: AccountNumber
Attributes:
Balance
CreatedTime
BranchName
AccountAgent
account
ID: AccountNumber
Attributes:
Balance
CreatedTime
BranchName
AccountAgent

Figure 16C

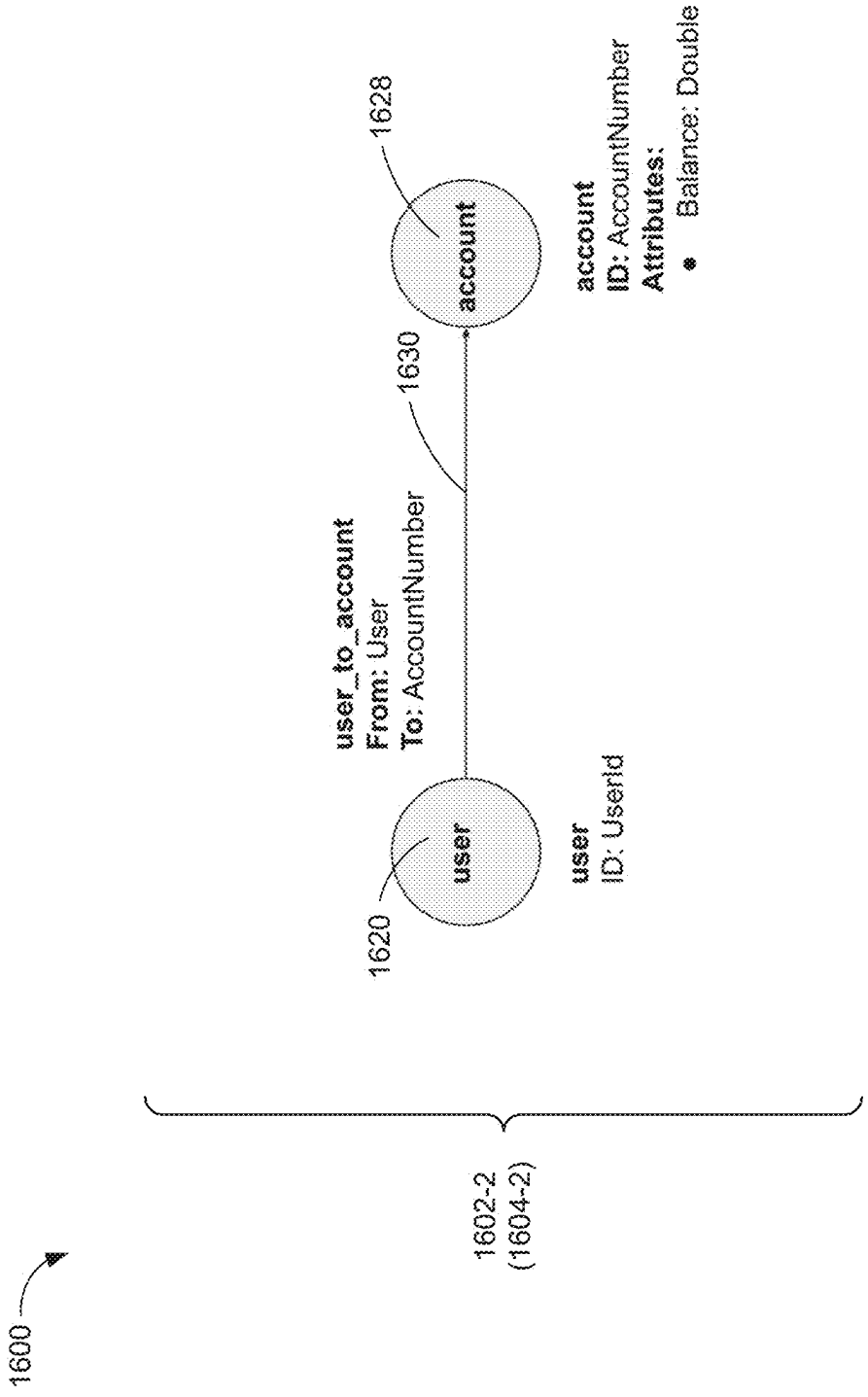

1600
1602-2
(1604-2)
1620
user
user
ID: UserId
user_to_account
From: User
To: AccountNumber
1630
1628
account
account
ID: AccountNumber
Attributes:
• Balance: Double

Figure 16D

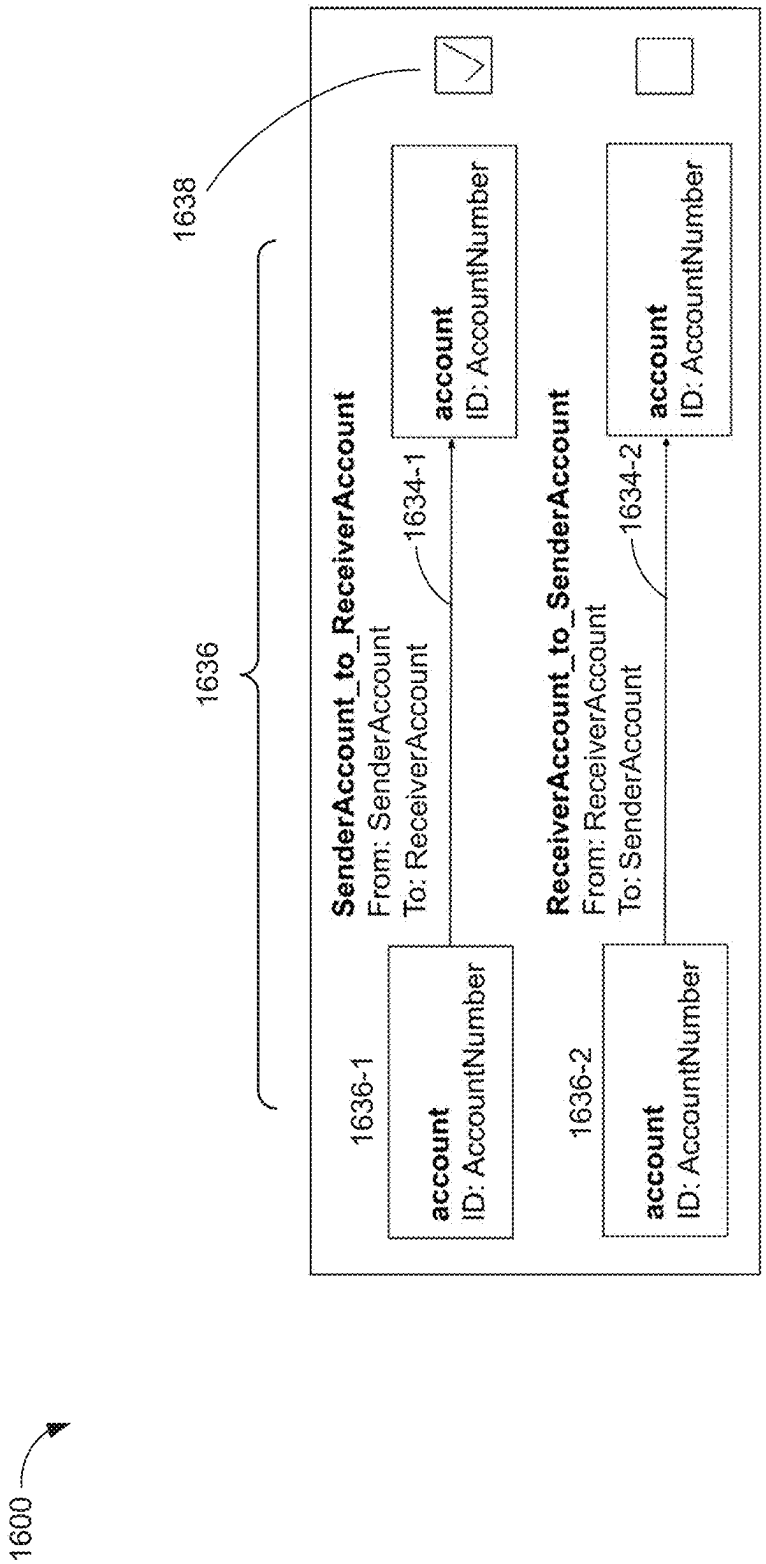

1600
1636
1638
1636-1
account
ID: AccountNumber
SenderAccount_to_ReceiverAccount
From: SenderAccount
To: ReceiverAccount
1634-1
account
ID: AccountNumber
1636-2
account
ID: AccountNumber
ReceiverAccount_to_SenderAccount
From: ReceiverAccount
To: SenderAccount
1634-2
account
ID: AccountNumber

Figure 16E

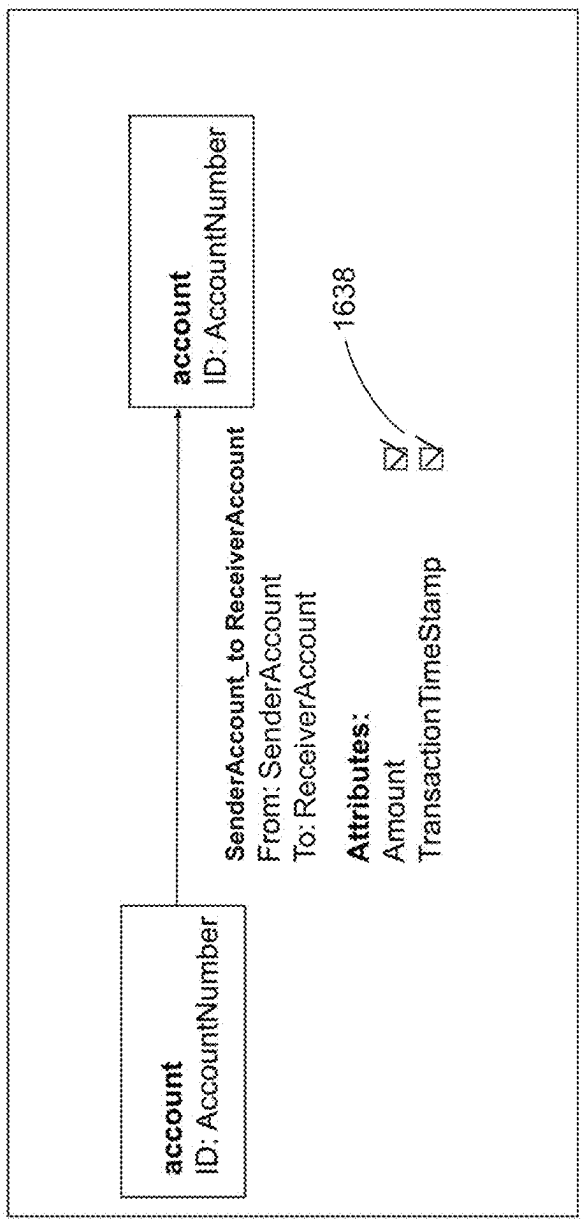

account
ID: AccountNumber
SenderAccount_to ReceiverAccount
From: SenderAccount
To: ReceiverAccount
Attributes:
Amount
TransactionTimeStamp
account
ID: AccountNumber
1638
1600

Figure 16F

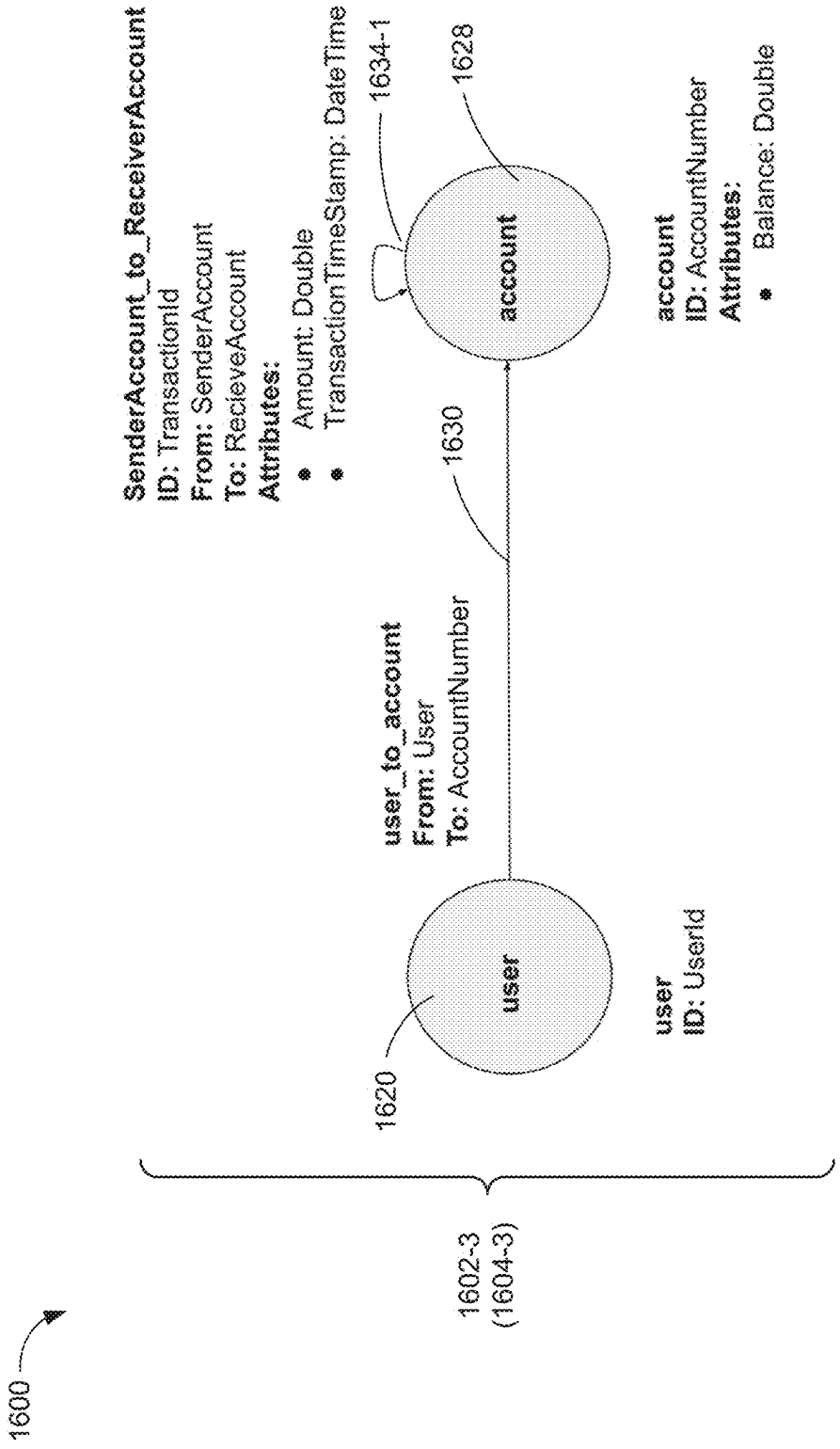

1600
1602-3
(1604-3)
1620
user
ID: UserId
1630
user_to_account
From: User
To: AccountNumber
1628
account
account
ID: AccountNumber
Attributes:
Balance: Double
1634-1
SenderAccount_to_ReceiverAccount
ID: TransactionId
From: SenderAccount
To: RecieveAccount
Attributes:
Amount: Double
TransactionTimeStamp: DateTime

Figure 16G

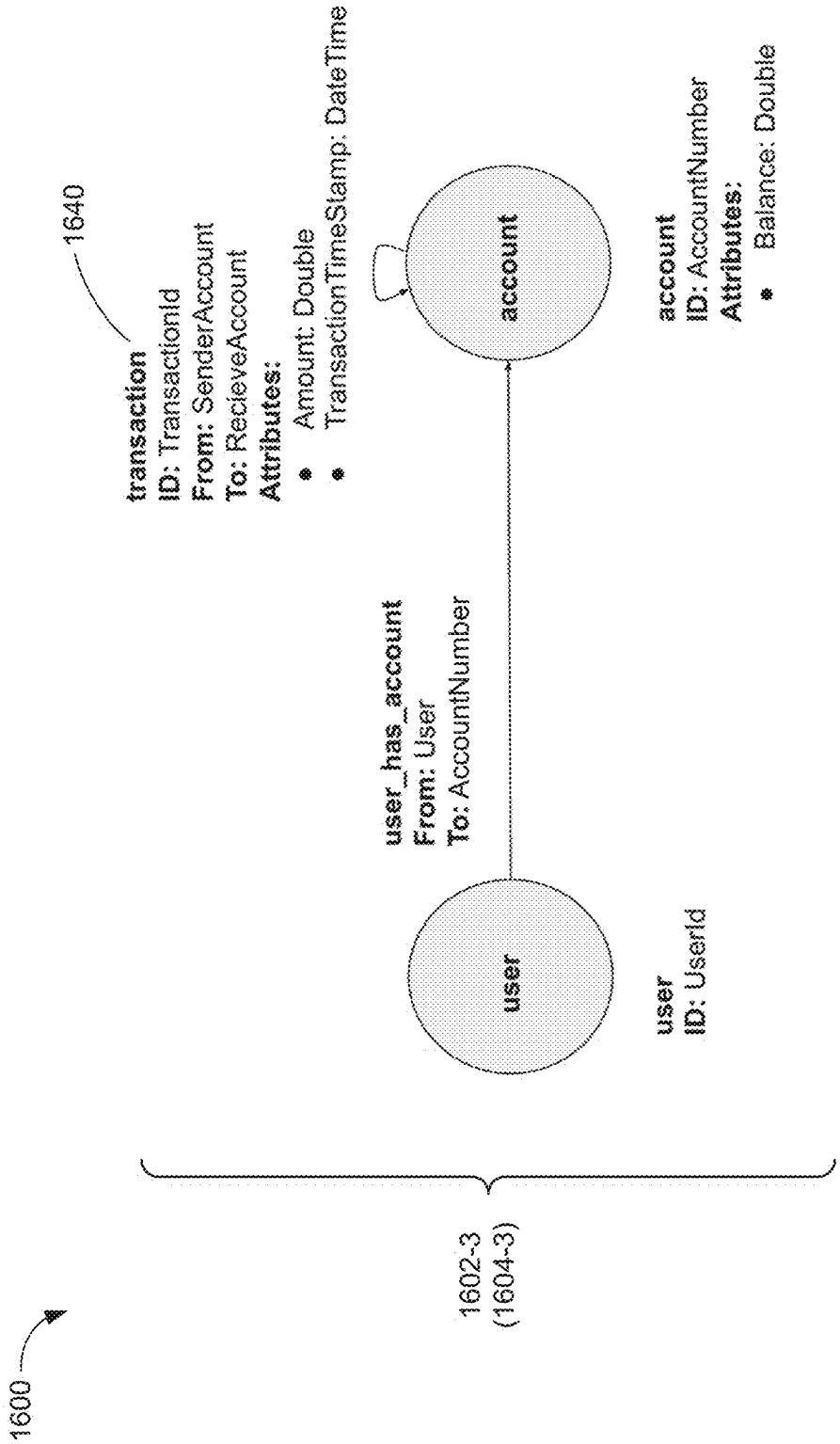

1600
1602-3
(1604-3)
1640
transaction
ID: TransactionId
From: SenderAccount
To: RecieveAccount
Attributes:
Amount: Double
TransactionTimeStamp: DateTime
user_has_account
From: User
To: AccountNumber
user
ID: UserId
account
account
ID: AccountNumber
Attributes:
Balance: Double

Figure 16H

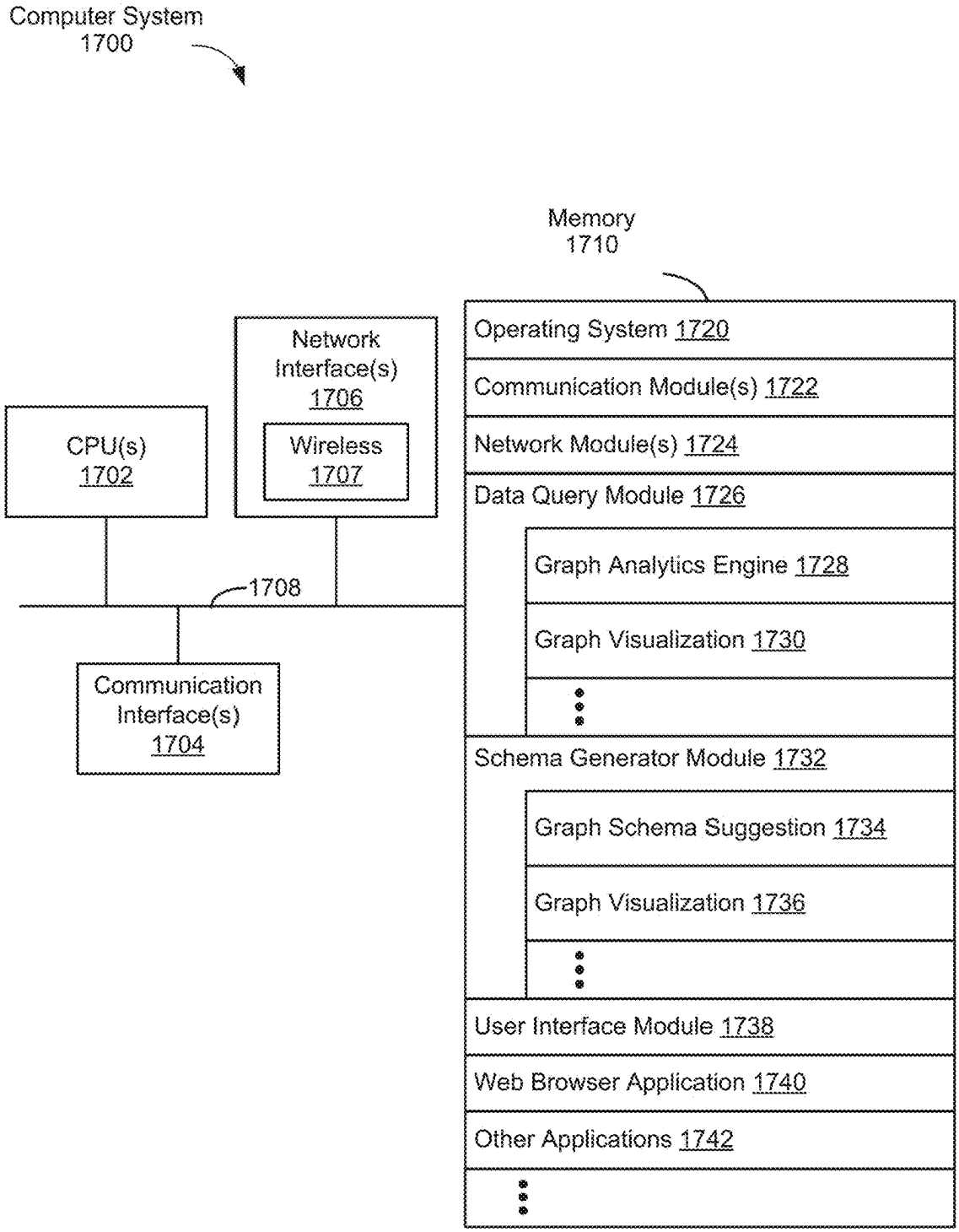

Computer System
1700
Memory
1710
Operating System 1720
Communication Module(s) 1722
Network Module(s) 1724
Data Query Module 1726
Graph Analytics Engine 1728
Graph Visualization 1730
Schema Generator Module 1732
Graph Schema Suggestion 1734
Graph Visualization 1736
User Interface Module 1738
Web Browser Application 1740
Other Applications 1742
Network Interface(s) 1706
Wireless 1707
CPU(s) 1702
1708
Communication Interface(s) 1704

Figure 17

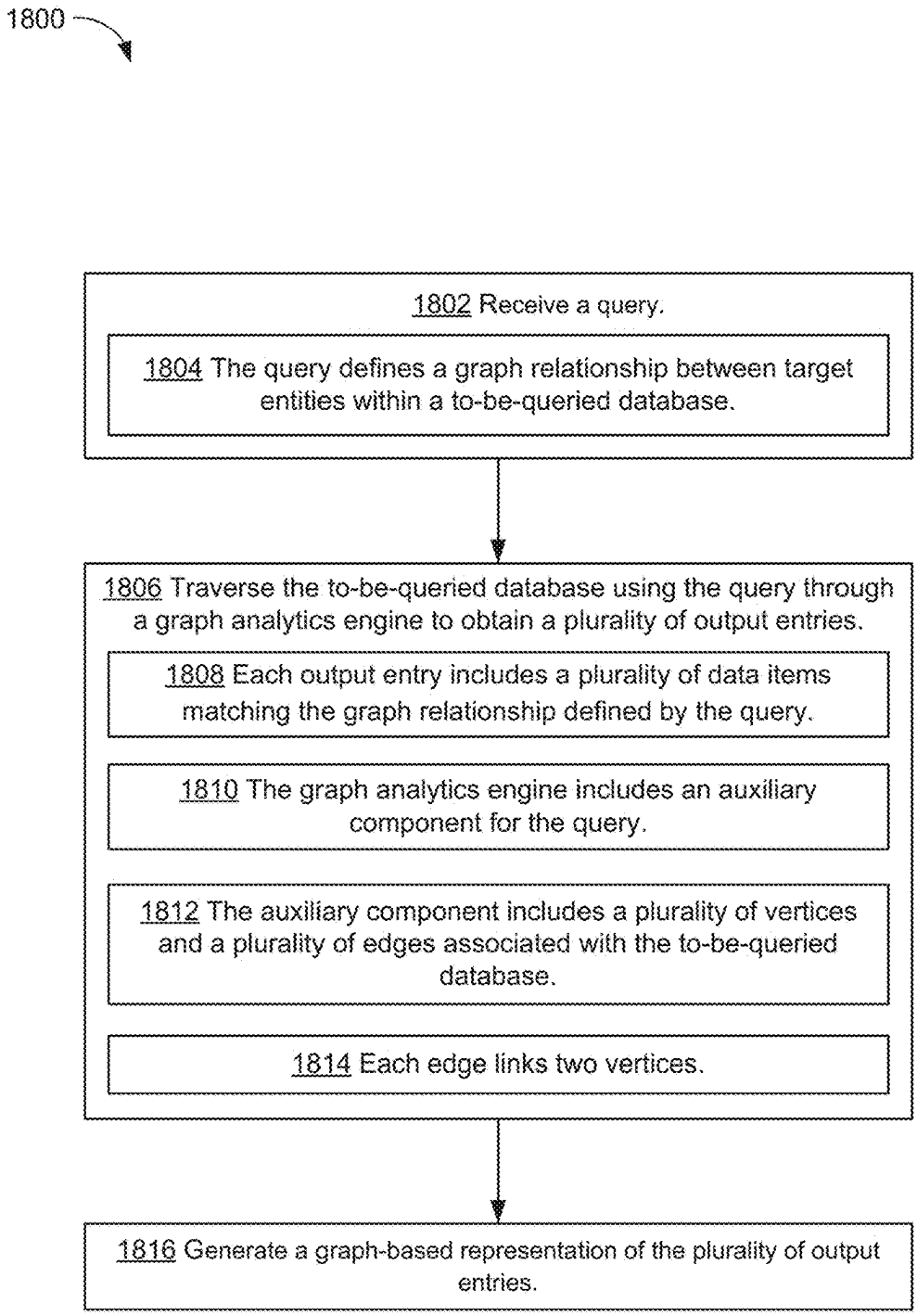

1800
1802 Receive a query.
1804 The query defines a graph relationship between target entities within a to-be-queried database.
1806 Traverse the to-be-queried database using the query through a graph analytics engine to obtain a plurality of output entries.
1808 Each output entry includes a plurality of data items matching the graph relationship defined by the query.
1810 The graph analytics engine includes an auxiliary component for the query.
1812 The auxiliary component includes a plurality of vertices and a plurality of edges associated with the to-be-queried database.
1814 Each edge links two vertices.
1816 Generate a graph-based representation of the plurality of output entries.

Figure 18

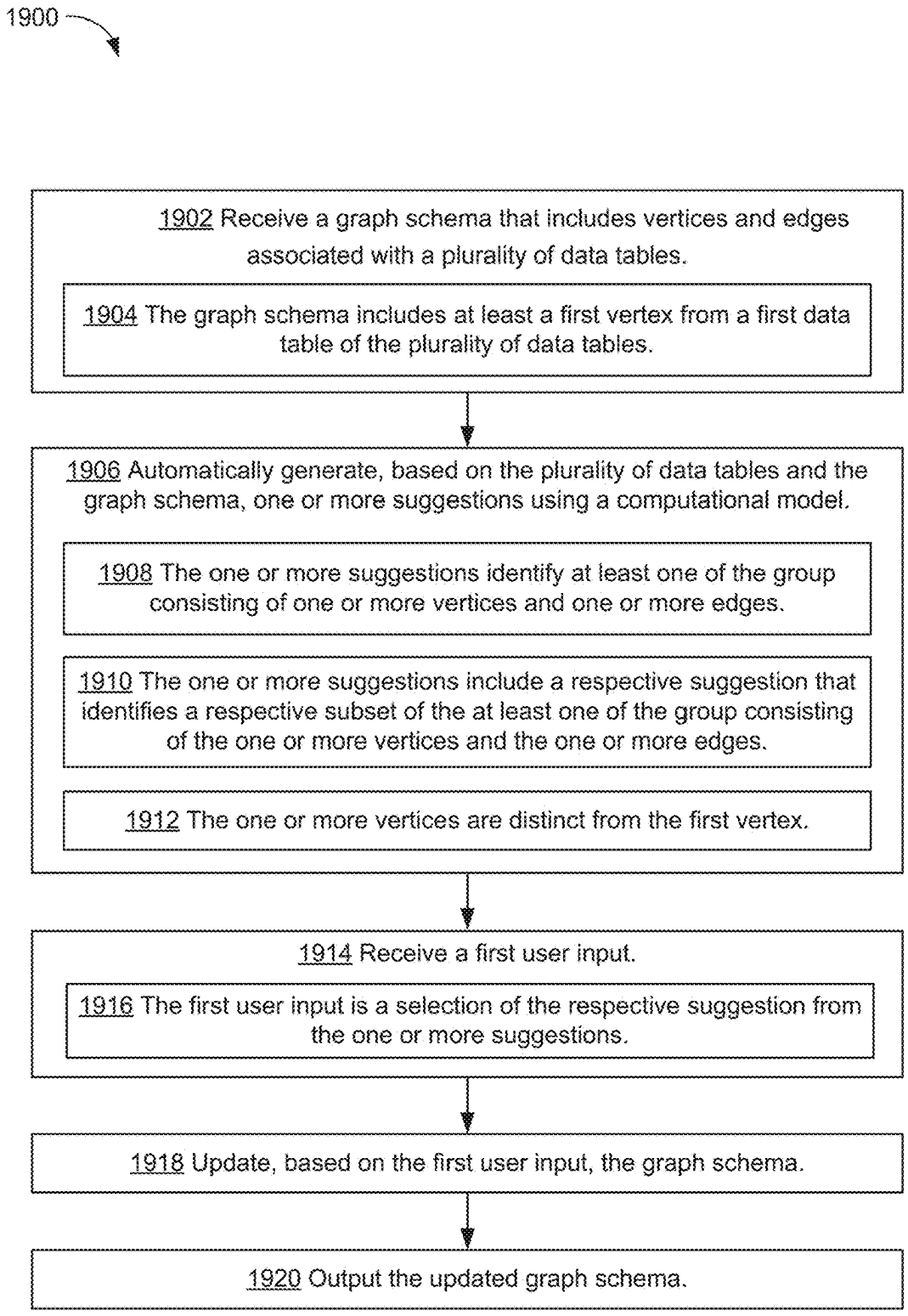

1900
1902 Receive a graph schema that includes vertices and edges associated with a plurality of data tables.
1904 The graph schema includes at least a first vertex from a first data table of the plurality of data tables.
1906 Automatically generate, based on the plurality of data tables and the graph schema, one or more suggestions using a computational model.
1908 The one or more suggestions identify at least one of the group consisting of one or more vertices and one or more edges.
1910 The one or more suggestions include a respective suggestion that identifies a respective subset of the at least one of the group consisting of the one or more vertices and the one or more edges.
1912 The one or more vertices are distinct from the first vertex.
1914 Receive a first user input.
1916 The first user input is a selection of the respective suggestion from the one or more suggestions.
1918 Update, based on the first user input, the graph schema.
1920 Output the updated graph schema.

Figure 19

METHOD FOR AUTOMATED GRAPH SCHEMA GENERATION AND RELATED APPARATUS

RELATED APPLICATION

[0001] This application is a continuation-in-part application of U.S. patent application Ser. No. 18/442,085, entitled "Method for Performing Data Query Using a Graph Analytics Engine and Related Apparatus" filed Feb. 14, 2024, which is incorporated by reference herein in its entirety.

TECHNICAL FIELD

[0002] This application relates generally to data query, including but not limited to techniques for performing data query and generating graph schema.

BACKGROUND

[0003] Data querying serves as a fundamental building block of data management and analytics. Continuous advancements in data querying technologies and methodologies are required to keep pace with users' demands. Challenges in data querying spans various aspects, including query optimization, query scalability, and complexity of traversing interconnected data. In particular, large-scale graph-based data querying requires an efficient graph processing and an effective integration into expandable databases. Moreover, balancing trade-offs between query complexity and computational efficiency remains an ongoing challenge in this domain.

[0004] Additionally, databases (e.g., graph databases) have become popular for their ability to represent and manage highly interconnected data in various fields. Data stored in databases often contain complex, interrelated information that can be more intuitively understood when visualized using graphs. Therefore, it is important to create graph schema(s) that defines structure and organization of data within a database. Moreover, a graph schema of a database specifies types of edges and vertices (e.g., nodes), their properties, and relationships between them. The graph schema enables efficient querying, traversal, and analysis of data within the database. In some circumstances, creating a graph schema for querying a database is often a time-consuming process. A user needs to create the graph schema (e.g., by manually writing a graph schema) in a data format to specify edges and vertices and their mappings to associated tables/attributes stored in the database.

[0005] As such, there is a need to address one or more of the above-identified challenges. A brief summary of solutions to the issues noted above are described below.

SUMMARY

[0006] Various embodiments of this application are directed to implementing a graph analytics engine that brings a unique solution to data querying and provides a robust data querying platform for accessing large-scale databases. This approach brings several advantages. First, an "Extract, Transform, and Load" (ETL) Process is no longer required. Users can query tables to obtain graphs based on existing tabular databases. The existing tabular databases can be built on Apache Hive, Apache Iceberg, Apache Hudi, Delta Lake, MySQL/Postgre SQL, or other forms that support database connectivity. Second, auto-scaling becomes achievable, as scalability is no longer a concern for graphs. This is because data are auto-sharded, with computation and storage being separately distributed. Third, exceptional performance can be achieved with low latency for complex data queries (e.g., queries for 10-hop neighbors). Fourth, a data querying platform based on the graph analytics engine can be easily migrated because of its compatibility with existing query languages (e.g., Apache Gremlin and OpenCypher) and established data lakes (e.g., Apache Iceberg, Apache Hudi, and Delta Lake). Fifth, data management is streamlined, because there is no need to create additional persisted data copies, which simplifies retention obligations. This simplification of data management process can be further achieved by leveraging existing data lake permissions. Lastly, a data querying platform based on the graph analytics engine empowers users to maintain complete control of their data within data centers that are seamlessly integrated into their cloud-native infrastructure.

[0007] Additionally, various embodiments of this application are directed to implementing an automated graph schema generation system to create graph schemas from tables (e.g., relational data tables) stored in relational databases. The automated graph schema generation system leverages data analysis techniques and artificial intelligence (AI), thereby significantly reducing the need for manual interventions. In particular, the automated graph schema generation system constructs graph-based data models (e.g., rule-based suggestion model, AI-based suggestion model) for processing data (e.g., relational data). For example, automated graph schema generation system automatically identifies and generates vertices (e.g., nodes) and edges from user-provided relational data, allowing real-time interaction between a user and a graphical user interface to dynamically create a graph schema based on auto-generated suggestions. This approach significantly reduces mental and physical effort required to navigate large relational tables, e.g., enabling a user to simply click and select from suggested vertices and edges, streamlining a graph-building process in a short amount time. In some embodiments, the automated graph schema generation system simplifies and streamlines a schema generation process by implementing a schema suggestion generator having a computational model. In some embodiments, the schema suggestion generator iteratively expands a graph schema using the computational model by allowing a user to select respective suggested edges and vertices. In some embodiments, the computational model includes a rule-based suggestion model (e.g., for rule-based suggestions) and an intelligence model (e.g., for AI-based suggestions). The intelligence model executes large language models (LLMs). In some embodiments, both rule-based suggestion model and intelligence model provide user-computer interaction, allowing the user to guide suggestions provided by the computational model. In some embodiments, the schema suggestion generator selects, based on the user's input, between the rule-based suggestion model and the intelligence model based on available resources and data. In some embodiments, selecting the rule-based suggestion model is a preferred option (e.g., when resources are limited and no LLM is available). In some embodiments, selecting the intelligence model is a preferred option (e.g., when a database has comprehensive information, such as documentation or specification files, when an LLM or an associated application programming interface (API) is accessible). The schema suggestion generator receives the user's input(s) based on natural language

and guides the user to generate the graph schema. In some embodiments, the schema suggestion generator combines the rule-based suggestion model and intelligence model for graph scheme generation (e.g., the schema suggestion generator switches from one model to another after generating a partial graph schema). In some embodiments, the schema suggestion generator includes a graphical interface (e.g., a graph visualization tool) for displaying, in real-time, graph-based representations for generated graph schemas. In some embodiments, the automated graph schema generation system brings advantages of (i) significantly minimizing user effort by requiring user selection from suggestions and thereby removing the need to manually write complex schema files, (ii) maximizing usage of data (e.g., graph data, metadata, documentation files, specification files, etc.) to enhance accuracy in graph schema generation, and (iii) providing flexibility in selecting and combining models (e.g., the rule-based suggestion model and the intelligence model) based on available resources (e.g., computation power, LLMs, other AI-based resources, etc.).

[0008] In accordance with some embodiments, a data query method comprises receiving a query that defines a graph relationship between target entities within a to-be-queried database. The data query method further includes traversing the to-be-queried database using the query through a graph analytics engine to obtain a plurality of output entries. Each output entry includes a plurality of data items matching the graph relationship defined by the query. The graph analytics engine includes an auxiliary component for the query. The auxiliary component further includes a plurality of vertices and a plurality of edges associated with the to-be-queried database, and each edge links two vertices. The data query method further includes generating a graph-based representation of the plurality of output entries.

[0009] In accordance with some embodiments, a computer device performs a schema generation method by performing a set of operations. The computer device receives a graph schema that includes vertices and edges associated with a plurality of data tables. The graph schema includes at least a first vertex from a first data table of the plurality of data tables. The computer device then automatically generates, based on the plurality of data tables and the graph schema, one or more suggestions using a computational model. The one or more suggestions identify at least one of the group consisting of one or more edges and one or more vertices. The one or more suggestions include a respective suggestion that identifies a respective subset of the at least one of the group consisting of the one or more vertices and the one or more edges. The one or more vertices are distinct from the first vertex. The computer device further receives a first user input. The first user input is a selection of the respective suggestion from the one or more suggestions. The computer device further updates, based on the first user input, the graph schema. The schema generation method further includes outputting the updated graph schema.

[0010] In accordance with some embodiments, a computer system comprises one or more processes and memory storing one or more programs. The one or more programs are configured to be executed by the one or more processors. The one or more programs include instructions for any of the methods described above.

[0011] In accordance with some embodiments, a non-transitory computer-readable storage medium stores one or more programs. The one or more programs comprise instructions that, when executed by a computer system that includes one or more processors, cause the one or more processors to perform operations for any of the methods described above.

[0012] The features and advantages described in the specification are not necessarily all inclusive and, in particular, certain additional features and advantages will be apparent to one of ordinary skill in the art in view of the drawings, specification, and claims. Moreover, it should be noted that the language used in the specification has been principally selected for readability and instructional purposes.

[0013] Having summarized the above example aspects, a brief description of the drawings will now be presented.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] For a better understanding of the various described embodiments, reference should be made to the Detailed Description below, in conjunction with the following drawings in which like reference numerals refer to corresponding parts throughout the figures.

[0015] FIG. **1** illustrates an example data query system based on a graph analytics engine, in accordance with some embodiments.

[0016] FIG. **2** illustrates an example data query system based on the graph analytics engine, in accordance with some embodiments.

[0017] FIG. **3** illustrates an example graph query process based on an example graph analytics engine, in accordance with some embodiments.

[0018] FIGS. **4**A-**4**C illustrate an example transaction trace graph query based on the graph analytics engine for a to-be-queried tabular database, in accordance with some embodiments.

[0019] FIGS. **5**A-**5**L illustrate a series of graph query steps associated with an example person_knows_person graph query that is performed based on a management user interface (UI) of the graph analytics engine, in accordance with some embodiments.

[0020] FIGS. **6**A-**6**F illustrate a series of graph query steps associated with an example person_knows_person graph query that is performed based on the management UI of the graph analytics engine, in accordance with some embodiments.

[0021] FIGS. **7**A-**7**D illustrate an example graph query using the graph analytics engine with locally deployed Apache Iceberg, in accordance with some embodiments.

[0022] FIG. **7**E illustrates an example graph query using the graph analytics engine with locally deployed PostgreSQL, in accordance with some embodiments.

[0023] FIG. **7**F illustrates an example graph query using the graph analytics engine with locally deployed DuckDB, in accordance with some embodiments.

[0024] FIGS. **8**A-**8**J illustrate an example graph query using the graph analytics engine with data lakes, in accordance with some embodiments.

[0025] FIGS. **9**A-**9**O illustrates an example graph query using the graph analytics engine with relational databases, in accordance with some embodiments.

[0026] FIGS. **10**A-**10**Q illustrate a series of screenshots of an example schema creation UI for creating an example person_knows_person_UI graph schema, in accordance with some implementations.

[0027] FIG. **11** illustrates an example schema generation system that performs automated graph schema generation, in accordance with some embodiments.

[0028] FIG. **12** illustrates an example schema generation system that iteratively expands vertices and edges of a graph schema based on automated graph schema generation, in accordance with some embodiments.

[0029] FIG. **13** illustrates an example schema generation system that includes an AI-based suggestion model with various functionalities for generating suggestions associated with a graph schema, in accordance with some embodiments.

[0030] FIG. **14**A is a flow chart of a rule-based suggestion model that expands vertices and edges associated with a graph schema, in accordance with some embodiments.

[0031] FIG. **14**B is a flow chart of the rule-based suggestion model that further illustrates an operation of the flow chart of FIG. **14**A, in accordance with some embodiments.

[0032] FIGS. **15**A-**15**C illustrate an example transaction trace used for generating schema graphs.

[0033] FIGS. **16**A-**16**H illustrate an example schema generation using the example transaction trace of FIGS. **15**A-**15**C, in accordance with some embodiments.

[0034] FIG. **17** is a block diagram illustrating a computer system that supports a data query system and a schema generation system, in accordance with some embodiments.

[0035] FIG. **18** illustrates a flow diagram of an example data query method, in accordance with some embodiments.

[0036] FIG. **19** illustrates a flow diagram of an example schema generation method, in accordance with some embodiments.

[0037] These illustrative aspects are mentioned not to limit or define the disclosure, but to provide examples to aid understanding thereof. Additional embodiments are discussed in the Detailed Description, and further description is provided there.

DETAILED DESCRIPTION

[0038] Reference will now be made in detail to embodiments, examples of which are illustrated in the accompanying drawings. In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of the various described embodiments. However, it will be apparent to one of ordinary skill in the art that the various described embodiments may be practiced without these specific details. In other instances, well-known methods, procedures, components, and networks have not been described in detail so as not to unnecessarily obscure aspects of the embodiments.

System Architectures

[0039] FIG. **1** illustrates an example data query system **100** based on a graph analytics engine, in accordance with some embodiments. As shown in the example graph query system **100**, applications (e.g., software, networks, user interfaces, or open-source projects) **102** are configured to create and manage a to-be-queried database **106**. The to-be-queried database **106** is created in accordance with a data architecture that includes at least one of a relational database, a data warehouse, a data lake, or other forms. In particular, the to-be-queried database **106** includes non-graph relationships between non-graph entities and/or graph relationships between graph entities. A user **104** creates a non-graph query that defines a non-graph relationship between the non-graph entities and/or generates a graph query that defines a graph relationship between the graph entities. The user **104** traverses the to-be-queried database **106** using the non-graph query via structured query language (SQL) to obtain output non-graph entries for the non-graph query. Alternatively, the user **104** traverses the to-be-queried database **106** using the graph query through the graph analytics engine (described below in reference to FIG. **2**) to obtain output graph entries for the graph query, where each output graph entry for the graph query includes data items matching the graph relationship defined by the graph query.

[0040] In some embodiments, for querying a to-be-queried database, a user no longer needs to choose between a SQL-based data model or a graph-based data model. For instance, as shown in FIG. **1**, the to-be-queried database **106** can be constructed using SQL-based data models and/or graph-based data models, and it can then be accessed by a data query via the graph analytics engine.

[0041] FIG. **2** illustrates an example data query system **200** based on the graph analytics engine **220**, in accordance with some embodiments. A to-be-queried database **202** is built in accordance with a data architecture that includes at least one of relational database, data warehouse, data lake, or other forms. In some embodiments, the to-be-queried database **202** includes a non-SQL (NoSQL) database. The to-be-queried database **202** includes non-graph data and graph data, which are received from transactional systems **204** (e.g., storage devices) and/or streaming systems **206** (e.g., cloud storages). In particular, the non-graph data and graph data in the to-be-queried database **202** can be stored in formats compatible with SQL. A SQL analytics engine **208** is configured to traverse the to-be-queried database **202** using non-graph queries (e.g., written in SQL). On the other hand, the graph analytics engine **220** is configured to traverse the to-be-queried database **202** using both graph queries (e.g., written in graph languages) and non-graph queries (e.g., written in non-graph languages). Then, output entries obtained from the non-graph and/or graph queries are sent to accessory tools for data processing and/or visualization. For instance, the accessory tools include machine learning tools **210**, data science tools **212**, business intelligence tools **214**, reports and dashboards **216**, and applications **218** in other forms.

[0042] In some embodiments, the graph analytics engine is configured to generate a graph-based representation of output entries obtained from a data query. The graph-based representation can be a network diagram (e.g., network graph, neural network diagram, mesh topology diagram, or other forms). For instance, as shown in FIG. **2**, it is optional that the graph analytics engine **220** also includes features for data processing and/or visualization, similar to features provided by the accessory tools (e.g., **210**, **212**, **214**, **216**, and **218**).

[0043] FIG. **3** illustrates an example graph query process **300** based on an example graph analytics engine **302**, in accordance with some embodiments. The example graph analytics engine **302** is an example of the graph analytics engine **220**. The example graph analytics engine **302** includes an auxiliary component **303**, a logical data plan **304**, a physical data plan **306**, and one or more execution nodes **308**. In the example graph query process **300**, a user first creates a graph query and then traverses one or more to-be-queried databases **312** using the graph query through

the graph analytics engine **302**. Specifically, the user starts from creating the graph query on a platform **310** (e.g., software, network, user interface, or open-source project). The graph query defines a graph relationship between target entities within the one or more to-be-queried databases **312**. The user can choose to create the graph query using an open-source project that is written in a graph query language. For instance, the user creates the graph query on a client portal of Apache Gremlin **314-1** and submits the graph query to a server portal of Apache Gremlin **316-1**. In another instance, the user generates the graph query on a client portal of openCypher **314-2** and transfers the graph query to a server portal of openCypher **316-2**. After the graph query is created, the user imports the graph query from the platform **310** to the example graph analytics engine **302**. Next, the example graph analytics engine **302** is configured to map the graph query to the logical data plan **304** in accordance with a defined hierarchy of the target entities being stored in the auxiliary component **303** (described with more details below in reference to FIGS. **4**A-**4**C). The example graph analytics engine **302** is further configured to translate the logical data plan **304** to the physical data plan **306**. Then, the example graph analytics engine **302** is further configured to query, based on the physical data plan **306**, the one or more to-be-queried databases **312** through the one or more execution nodes **308** for obtaining output graph entries. Each output graph entry includes data items that match the graph relationship defined by the graph query.

[0044] Additionally, as shown in FIG. **3**, each execution node of the one or more execution nodes **308** is associated with a respective to-be-queried database of the one or more to-be-queried databases **312**. The example graph analytics engine **302** includes five execution nodes (e.g., **308-1**, **308-2**, **308-3**, **308-4**, and **308-5**), which are associated with five to-be-queried databases Apache Hive **312-1**, Apache Iceberg **312-2**, Apache Hudi **312-3**, Delta Lake **312-4**, and MySQL/Postgre SQL **312-5**, respectively.

[0045] In some embodiments, a graph query process based on the graph analytics engine supports data sources distributed across cloud platforms and regional networks.

[0046] In some embodiments, the graph analytics engine includes an auxiliary component for a data query (e.g., a non-graph query and/or a graph query). The auxiliary component includes vertices and edges that are associated with a to-be-queried database, where each edge links two vertices. For instance, as shown in FIG. **3**, the example graph analytics engine **302** includes the auxiliary component **303**.

[0047] In some embodiments, traversing a to-be-queried database using a query through the graph analytics engine includes mapping the query into a logical data plan in accordance with an auxiliary component. Traversing the to-be-queried database using the query through the graph analytics engine includes translating the logical data plan to a physical data plan. Traversing the to-be-queried database using the query through the graph analytics engine further includes querying, based on the physical data plan, the to-be-queried database through an execution node. For instance, as shown in FIG. **3**, the example graph analytics engine **302** is configured to receive the graph query from the platform **310** and map the graph query into the logical data plan **304** in accordance with the defined hierarchy of the target entities being stored in the auxiliary component **303**. In an example, the defined hierarchy of the target entities reflects the graph relationship of the target entities. Next, the example graph analytics engine **302** is further configured to translate the logical data plan **304** to the physical data plan **306**. Then, the example graph analytics engine **302** is configured to query, based on the physical data plan **306**, the one or more to-be-queried databases **312** through execution nodes **308**. Lastly, the example graph analytics engine **302** is configured to obtain output graph entries and generate a graph-based representation of the output entries, e.g., visualization using a network diagram.

[0048] In some embodiments, a logical data plan is a high-level structured representation of a data query (e.g., a non-graph query or a graph query). The logical data plan can be implemented based on a structural framework, e.g., tree architectures.

[0049] In some embodiments, a physical data plan is a low-level structured representation of a data query (e.g., a non-graph query or a graph query). The physical data plan defines physical storage structures (e.g., access methods and indexing) for data models and queries.

[0050] In some embodiments, the graph analytics engine includes a plurality of execution nodes, and each execution node is associated with a respective to-be-queried database. For instance, as shown in FIG. **3**, the example graph analytics engine **302** includes five execution nodes (e.g., **308-1**, **308-2**, **308-3**, **308-4**, and **308-5**). The execution nodes **308-1** to **308-5** are associated with the to-be-queried databases Apache Hive **312-1**, Apache Iceberg **312-2**, Apache Hudi **312-3**, Delta Lake **312-4**, and MySQL/Postgre SQL **312-5**, respectively.

[0051] In some embodiments, the graph analytics engine includes a plurality of execution nodes, and one or more respective execution nodes of the plurality of execution nodes are associated with a respective to-be-queried database. For instance, the graph analytics engine can include two execution nodes that are associated with a respective to-be-queried data lake. As a result, the graph analytics engine can traverse the respective to-be-queried data lake through either one of the two execution nodes or through the two execution nodes simultaneously. Offering multiple execution nodes for one respective to-be-queried database brings several advantages, including parallel processing, scalability, and cost efficiency.

[0052] In some embodiments, a data query is written in a graph query language. For instance, as shown in FIG. **3**, the data query can be written in Gremlin or openCypher. In some embodiments, the data query is written in a non-graph query language. For instance, as shown in FIG. **1**, the data query can be written in SQL. Specifically, the graph analytics engine is not confined to particular query languages and can support a wide range of query languages.

[0053] In some embodiments, a to-be-queried database is built in accordance with a data architecture that includes at least one of relational database, data warehouse, data lake, or other forms. For instance, as shown in FIG. **3**, the one or more to-be-queried databases **312** include various kinds: Apache Hive **312-1**, Apache Iceberg **312-2**, Apache Hudi **312-3**, Delta Lake **312-4**, and MySQL/Postgre SQL **312-5**. In another instance, the to-be-queried database is a relational database, e.g., MySQL, PostgreSQL, DuckDB, BigQuery, or Redshift (described below in reference to FIGS. **9**A-**90**). In yet another instance, the to-be-queried database is a data lake, e.g., Apache Iceberg, Apache Hudi, Delta Lake, or Apache Hive (described below in reference to FIGS. **8**A-**8**J).

[0054] In some embodiments, a to-be-queried database defines a graph relationship between target entities in a tabular form. For instance, the to-be-queried database stores tabular forms that include the graph relationship of the target entities, e.g., person-knows-person (described below in reference to FIGS. **4**A, **7**B and **8**A).

[0055] In some embodiments, a to-be-queried database is compatible with SQL. In particular, the to-be-queried database can be a SQL database. For instance, as shown in FIG. **3**, Apache Hive **312-1** is compatible with SQL and MySQL/Postgre SQL **312-5** is a SQL database. The graph analytics engine **302** is configured to traverse Apache Hive **312-1** and MySQL/Postgre SQL **312-5** using the graph query created by the platform **310** through the execution nodes **308-1** and **308-5**, respectively.

[0056] In some embodiments, a to-be-queried database includes a non-SQL (NoSQL) database.

Data Query with a JSON File

[0057] The graph analytics engine includes an auxiliary component for a query (e.g., a non-graph query and/or a graph query). The auxiliary component is a schema that defines a hierarchy of target entities. The hierarchy reflects a graph relationship of the target entities within a to-be-queried database. In particular, the auxiliary component includes vertices and edges that are associated with the to-be-queried database. Each edge links two vertices. After receiving the query (e.g., a graph query), the graph analytics engine is configured to map the query to a logical data plan in accordance with the defined hierarchy of the target entities being stored in the auxiliary component (described above in reference to FIG. **3**). In some embodiments, the graph query is received from a platform, e.g., software, network, user interface, open-source project (described above in reference to FIG. **3**).

[0058] Specifically, to create the auxiliary component for querying a tabular to-be-queried database, a user first obtains table catalogs, table schemas, and table attributes, based on a graph relationship between target entities within the tabular to-be-queried database. Next, the user defines vertices and edges in the form of arrays based on the table catalogs, table schemas, and table attributes, where each edge links two vertices. The vertices and edges reflect a hierarchy of the target entities within the tabular to-be-queried database, and include information of the table catalogs, table schemas, and table attributes. Then, the user generates the auxiliary component based on the vertices and edges in the form of arrays.

[0059] FIGS. **4**A-**4**C illustrate an example transaction trace graph query **400** based on the graph analytics engine for a to-be-queried tabular database **401**, in accordance with some embodiments. The example transaction trace graph query **400** is to obtain whom a User 00001 transfers to through a one-hop route or a two-hop route. More details of graph analytics engine architectures are described above in references to FIGS. **1**-**3**. When querying transaction traces, a user first generates a JavaScript Object Notation (JSON) file **450** in accordance with graph relationships between target entities within the to-be-queried tabular database **401**. Next, the user creates a graph query script (e.g., graph query statements) written in a graph query language. Then, the user queries the to-be-queried tabular database **401** using the JSON file **450** and the graph query script via the graph analytics engine.

[0060] FIG. **4**A illustrates the to-be-queried tabular database **401** for transactions traces. The to-be-queried tabular database **401** includes three catalogs: a UserProfile catalog **402**, an Account catalog **404**, and a Transaction catalog **406**. Specifically, the UserProfile catalog **402** includes (i) three records corresponding to three users (e.g., Users 00001, 00002, and 00003), and (ii) eight attributes (e.g., UserId, FirstName, LastName, Address, ZipCode, Gender, PhoneNumber, and Birthday). The Account catalog **404** includes (i) six records corresponding to six accounts (e.g., Accounts 0000001, 0000002, 0000003, 0000004, 0000005, and 0000006), and (ii) six attributes (e.g., AccountNumber, Balance, CreatedDate, User, BranchName, and AccountAgent). The Transaction catalog **406** includes (i) five records corresponding to five transactions (e.g., Transactions 0000000001, 0000000002, 0000000003, 0000000004, 0000000005), and (ii) six attributes (e.g., TransactionId, SenderAccount, ReceiverAccount, TransactionTimestamp, and Amount). The three catalogs **402**, **404**, and **406** are stored in a tabular format.

[0061] FIG. **4**B illustrates the JSON file **450** associated with the to-be-queried tabular database **401** for transactions traces. The JSON file **450** for transaction traces defines a hierarchy of the target entities. As discussed, the example transaction trace graph query **400** is to obtain whom a User **00001** transfers to through a one-hop route or a two-hop route. As a result, the target entities of the example transaction trace graph query **400** can include several attributes of the UserProfile catalog **402** (e.g., UserId, Address, and Birthday), several attributes of the Account catalog **404** (e.g., AccountNumber and User), and several attributes of the Transaction catalog **406** (e.g., TransactionId, SenderAccount ReceiverAccount, and Amount). In particular, the JSON file **450** includes a "vertices" array **452** that defines vertices and a "edges" array **454** that defines edges. The "vertices" array **452** includes an "user" object **456** and an "account" object **458**. The "user" object **456** further includes respective attributes (e.g., "User Id," "Address," "Birthday," and "User") listed in the catalogs **402**, **404**, and **406**. Similarly, the "account" object **458** further includes respective attributes (e.g., "AccountNumber") listed in the catalogs **402**, **404**, and **406**. On the other hand, the "edges" array **454** includes an "user has account" object **460** and an "transaction" object **462**. The "user has account" object **460** further includes attributes (e.g., "User" and "AccountNumber") listed in the catalogs **402**, **404**, and **406**. Similarly, the "transaction" object **462** further includes attributes (e.g., "TransactionId," "SenderAccount," "ReceiverAccount,", and "Amount") listed in the catalogs **402**, **404**, and **406**.

[0062] FIG. **4**C illustrates example graph query statements **480** and **482** for transaction traces. The example graph query statement **480** and the example graph query statement **482** are to obtain whom a User **00001** transfers to through a one-hop route and a two-hop route, respectively.

[0063] In the example graph query statement **480**, a step of .hasLabel("user") obtains a first set of vertices with a label of "user" (e.g., the "user" object **456**), and a step of .hasId("00001") further filters the first set of vertices to obtain a second set of vertices that includes a specified "UserId" of "00001." Next, .out("user has account") traverses edges with a label of "user has account" (e.g., the "user has account" object **460**) from the second set of vertices and reach a third set of vertices through the edges with the label of "user has account." Then, a step of .out("transaction") continues to traverse edges with the label

of "transaction" from the third set of vertices and reach a fourth set of vertices through the edges with the label of "transaction."

[0064] The example graph query statement **482** is similar to the example graph query statement **480**, except that the example graph query statement **482** includes a step of .repeat and with .time(2). The step of .repeat repeats .out("transaction") twice by traversing one level deeper from the fourth set of vertices.

[0065] In some embodiments, traversing a to-be-queried database using a query through the graph analytics engine includes obtaining catalogs, schemas, and attributes, based on a graph relationship between target entities. Traversing the to-be-queried database using the query through the graph analytics engine includes defining a plurality of vertices and a plurality of edges in form of arrays, based on the catalogs, schemas, and attributes. Traversing the to-be-queried database using the query through the graph analytics engine further includes generating an auxiliary component, based on the plurality of vertices and the plurality of edges. For instance, as shown in FIGS. **4**A-**4**B, the user obtains the table catalogs, table schemas, and table attributes from the to-be-queried tabular database **401** and defines the vertices **452** and edges **454** in the form of arrays. The user further generates the JSON file **450** based on the vertices **452** and edges **454**.

[0066] In some embodiments, an auxiliary component is a human-readable file. For instance, as shown in FIG. **4**B, the JSON file **450** is a human-readable file. Further, in some embodiments, the human-readable file is in a standard text-based format, including at least one of JavaScript Object Notation (JSON), Human-Optimized Config Object Notation (HOCON), Extensible Markup Language (XML), or other forms.

[0067] In some embodiments, a respective edge linking two adjacent vertices of a plurality of vertices is directed or undirected. The respective edge that is directed represents an asymmetric relation between the two adjacent vertices, while the respective edge that is undirected represents a symmetric relation between two adjacent vertices. For instance, as shown in the Transaction catalog **406** of FIG. **4**A, edges associated with transactions between accounts can be directed (e.g., the first record of the Transaction catalog **406** shows a transaction from a SenderAccount of 0000001 to a ReceiverAccount 0000002). In another instance, edges associated with a scenario that person knows person can be undirected (described below in reference to FIGS. **5**A-**5**L). Further, in some embodiments, the respective edge linking two adjacent vertices of the plurality of vertices includes a weight component. For instance, a query can be defined to find paths along respective edges with a certain sum of weights or a largest sum of weights (described below in reference to FIG. **6**A).

[0068] In some embodiments, an auxiliary component is created through a user interface associated with the auxiliary component (described below in reference to FIGS. **10**A-**10**Q).

Management User Interface of Graph Analytics Engine

[0069] FIGS. **5**A-**5**L illustrate a series of graph query steps **500** associated with an example puppy_small_v_person graph query that is performed based on a management user interface (UI) **530** of the graph analytics engine, in accordance with some embodiments. The management UI **530** of the graph analytics engine also generates graph-based representations of output entries from the example puppy_small_v_person graph query. In some embodiments, the management UI **530** of the graph analytics engine supports both graph queries and non-graph queries.

[0070] FIG. **5**A illustrates creating a to-be-queried puppy_small_v_person tabular database **512** (e.g., a tabular table named "puppy_small_v_person") using a first tabular database UI **510** (e.g., applications, open-source projects, etc.). As shown in the first tabular database UI **510**, the to-be-queried puppy_small_v_person tabular database **512** includes table schemas **514** associated with target entities of the to-be-queried puppy_small_v_person tabular database **512**.

[0071] FIG. **5**B illustrates a JSON file **520** corresponding to the example puppy_small_v_person graph query based on the to-be-queried puppy_small_v_person tabular database **512**. The JSON file **520** (e.g., "schema.JSON") defines a hierarchy of the target entities of the to-be-queried puppy_small_v_person tabular database **512**.

[0072] FIG. **5**C illustrates uploading the JSON file **520** to the graph analytics engine through the management UI **530** of the graph analytics engine. In some embodiments, the graph analytics engine is stored on a server. The management UI **530** of the graph analytics engine includes a status section **532**, a schema section **534**, and a query section **536**. The status section **532** shows a current status of an associated schema file (e.g., a JSON file). The schema section **534** processes the associated schema file (e.g., a JSON file). The query section **536** illustrates example resources (e.g., consoles, open-source projects, etc.) that are used to create graph queries in graph query languages.

[0073] As shown in a first zoomed view **534***a* of the schema section **534**, a user selects the JSON file **520** (e.g., "schema.JSON") and uploads it. Then, the server performs a process (e.g., a check) on the uploaded JSON file **520** to obtain processed information of the JSON file **520**. After the process is complete, the schema section **534** presents "Scheme OK!" as shown in a second zoomed view **534***b* of the schema section **534**. The schema section **534** also provides an option for the user to inspect the uploaded JSON file **520** by clicking "Click to view schema." Then, as shown in a third zoomed view **534***c* of the schema section **534**, a drop-down list **540** then emerges and provides the processed information of the JSON file **520** related to catalogs, vertices, and edges.

[0074] FIG. **5**D illustrates the status section **532** after the process on the JSON file **520** is complete.

[0075] FIG. **5**E illustrates generating graph representations of the vertices and edges. The management UI **530** of the graph analytics engine includes a graph browser section **538**. To visualize the vertices and edges, the user clicks "Start" to generate a graph-based representation **542** (e.g., a network graph) of the vertices and edges, as shown in a first zoomed view **538***a* of the graph browser section **538**.

[0076] FIG. **5**F illustrates a second to a fifth zoomed views **538***b*-**538***e* of the graph browser section **538** that further show the graph-based representation **542** of the vertices and edges. The user may zoom in a portion of the graph-based representation **542**, as shown in the second zoomed view **538***b* of the graph browser section **538**. The user may click on vertices to check their attributes, as shown in the third zoomed view **538***c* of the graph browser section **538**. The user may also explore the graph-based representation **542**

along different edges, and obtain respective neighboring vertices and different paths between the respective neighboring vertices, as shown in the fourth and fifth zoomed views **538***d*-**538***e* of the graph browser section **538**.

[0077] FIG. **5**G illustrates performing a set of example graph query statements **552** of the example puppy_small_v_person graph query. The user enters a first console UI **550** by clicking "Start query" associated with the first console UI **550** in the query section **536** of the management UI **530** of the graph analytics engine. Then, the user provides the set of example graph query statements to obtain output entries. For instance, the user can type g. V ( ) and obtain a list **554** of vertices for "Persons".

[0078] FIG. **5**H illustrates performing a set of example graph query statements **562** of the example puppy_small_v_person graph query. The user enters a second console UI **560** by clicking "Go to Graph notebook" associated with the second console UI **560** in the query section **536** of the management UI **530** of the graph analytics engine. As shown in the second console UI **560**, the set of example graph query statements **562** includes a graph query **562-1** for obtaining a count of the vertices, a graph query **562-3** for obtaining a count of the edges, and a graph query **562-3** for obtaining paths between persons. Output entries of the graph queries **562-1** to **562-3** can be printed out (e.g., a print-out **564** of the output entries of the graph query **562-3** for obtaining paths between persons).

[0079] FIG. **5**I illustrates virtualizing the output entries of the graph query **562-3** for obtaining paths between persons in the second console UI **560**. A visualization is realized in an example graph-based representation **566** (e.g., a network graph) of the output entries of the graph query **562-3** for obtaining paths between persons. A zoomed view **566***a* of the example graph-based representation **566** provides more details of the output entries of the graph query **562-3** for obtaining paths between persons.

[0080] FIGS. **5**J-**5**L illustrate virtualizing output entries of graph queries from a third set of example graph query statements **572** of the example puppy_small_v_person graph query through a first visualization UI **570**. FIG. **5**J illustrates a graph query **572-1** of the third set of example graph query statements **572** that randomly picks **25** vertices and a corresponding graph-based representation **574-1** of the picked **25** vertices. Similarly, in FIG. **5**K, the user submits a graph query **572-2** of the third set of example graph query statements **572** that randomly picks **500** edges and then creates a corresponding graph-based representation **574-2** of the picked **500** edges. Moreover, respective attributes and neighbors of edges can be visualized by leveraging functions of the first visualization UI **570**. FIG. **5**L illustrates a graph query **572-3** of the third set of example graph query statements **572** for obtaining a count **574-3** of four-hop paths. As shown in FIG. **5**L, the count **574-3** of the four-hop paths is 20,425,889, which is computed within a total execution time **576** less than 300 milliseconds.

[0081] In some embodiments, generating a graph-based representation of a plurality of output entries includes obtaining a respective graph relationship of the plurality of output entries. Generating the graph-based representation of the plurality of output entries further includes optimizing the respective graph relationship of the plurality of output entries for scalability. Generating the graph-based representation of the plurality of output entries further includes visualizing the optimized respective graph relationship of the plurality of output entries. For instance, as shown in FIGS. **5**I-**5**L, the graph-based representations of the output entries from the graph queries (e.g., **562** and **572**) can be optimized and scaled based on different UI functions (e.g., scripts, embedded UI features).

[0082] In some embodiments, receiving a graph query, traversing a to-be-queried database, and generating a graph-based representation of output entries are performed via an application or a user interface. For instance, as shown in FIGS. **5**A-**5**L, the example puppy_small_v_person graph query is performed based on the management UI **530** of the graph analytics engine. In particular, the management UI **530** of the graph analytics engine can be built as a cloud-native application. To facilitate graph-based representations of output entries from graph queries, additional graphical features can be incorporated within the management UI **530** of the graph analytics engine.

Data Query Using Graph Analytics Engine

[0083] FIGS. **6**A-**6**F illustrate a series of graph query steps **600** associated with an example person_knows_person graph query that is performed based on the management UI **530** of the graph analytics engine, in accordance with some embodiments.

[0084] A user can access the graph analytics engine in a browser page with the URL http://<hostname>:8081. For instance, a locally deployed graph analytics engine is available at http://localhost:8081.

[0085] The user logins the graph analytics engine with a default username and a default password. Then, the user refreshes the browser page to restart the graph analytics engine. After logging in with the username and password, the user sees the management UI **530** of the graph analytics engine (in reference to FIGS. **5**C-**5**E). As discussed, the management UI **530** of the graph analytics engine includes the status section **532**, the schema section **534**, the query section **536**, and the graph browser section **538**.

[0086] The user first creates a graph (e.g., a to-be-queried database) and loads it into the graph analytics engine. In some embodiments, the graph can be stored within internal data sources (e.g., local drivers) or external data sources (e.g., data lakes or databases). FIG. **6**A illustrates an example person-knows-person graph **610** for the example person_knows_person graph query. In some embodiments, a respective edge that links two adjacent vertices is directed or undirected (e.g., an asymmetric or symmetric relation between two adjacent vertices). In some embodiments, the respective edge that links two adjacent vertices includes a weight component. For instance, as shown in FIG. **6**A, an edge linking vertices "person 1" and "person 2" includes a weight of 0.5.

[0087] Next, the user creates a schema (e.g., a JSON file) that defines a hierarchy of target entities within the graph. After creating the schema, the user views the schema on the management UI **530** of the graph analytics engine, as shown in FIG. **6**B. FIG. **6**B illustrates a drop-down list **620** in the schema section **534**. The drop-down list **620** provides that the graph has two vertex types and two edge types.

[0088] Then, the user queries the graph using graph query languages (e.g., Gremlin and Cypher). To query the graph using Gremlin, the user may use an embedded Gremlin console (in reference to FIG. **5**G) in the graph analytics engine. FIG. **6**C illustrates a start **630** of the embedded Gremlin console, a sample query **632** asking for all names

of the vertices in the graph, an output **634** of the sample query **632**. FIG. **6**C further illustrates additional example queries and their corresponding outputs **636**. The user may alternatively use Java Client. FIG. **6**D illustrates dependencies **640** to be added into Java dependency for connecting with Java Client. FIG. **6**D further illustrates an example connection with Gremlin Server **642**. In addition, the user may alternatively use Python Client. FIG. **6**E illustrates a portion **650** of a script for connecting official gremlin-python client and a query to a local Gremlin server **652** using a native driver. It is optional to submit a query directly via Python Client such that the query string is consistent with the one used in the embedded Gremlin console, as shown in an example script **654** of FIG. **6**E.

[0089] Instead of Gremlin, the user can query the graph using Cypher. The user may use an embedded Cypher console (e.g., clicking "Start Query" under a "Cypher console" subsection of the query section **536** in reference to FIG. **5**C) provided by the graph analytics engine. FIG. **6**F illustrates a start **660** of the embedded Cypher console, a sample query **662** asking for all names of the vertices in the graph, an output **664** of the sample query **662**.

Graph Analytics Engine with Locally Deployed Apache Iceberg

[0090] FIGS. **7**A-**7**D illustrate an example graph query **700** using the graph analytics engine with locally deployed Apache Iceberg, in accordance with some embodiments. The example graph query **700** is based on the example person-knows-person graph **610** for the example person_knows_person graph query in reference to FIG. **6**A.

[0091] A user creates a file docker-compose.yaml with content "docker-compose.yaml." The user then runs command **702** to start Iceberg and graph analytics engine services, as illustrated in FIG. **7**A.

[0092] To prepare data on Iceberg, the user runs command **704** to start a Spark-SQL shell **706** to access Iceberg for creating database, as illustrated in FIG. **7**A. The user then executes SQL statements **708** in the Spark-SQL shell, as illustrated in FIG. **7**A, to create tables and insert data. The SQL statements **708** create Iceberg tables (e.g., a "v_person" table **710**, a "v software" table **712**, a "e_knows" table **714**, and a "e_created" table **716**").

[0093] Then, the user defines a schema in accordance with the created Iceberg tables. The user creates a graph schema file iceberg.json with content "iceberg.json" based on the example person-knows-person graph **610**. The user runs command **720** to upload the graph schema file iceberg.json, as illustrated in FIG. **7**C. A response **722** shows that the graph schema file iceberg.json is uploaded, as illustrated in FIG. **7**C.

[0094] After the graph schema file iceberg.json is uploaded, the user queries the example person-knows-person graph **610** through a web-based Gremlin console embedded in the graph analytics engine. To access a command-line interface (CLI) of the graph analytics engine, the user runs command **724**, as illustrated in FIG. **7**C. In the CLI of the graph analytics engine, the user types "console" to start the embedded Gremlin console **726**, as illustrated in FIG. **7**C.

[0095] The user then queries the example person-knows-person graph **610** using Gremlin query language. For instance, the user creates graph queries **728**, as shown in FIG. **7**C, and obtains output entries **730**, as shown in FIG. **7**D.

Graph Analytics Engine with Locally Deployed PostgreSQL

[0096] FIG. **7**E illustrates an example graph query **740** using the graph analytics engine with locally deployed PostgreSQL, in accordance with some embodiments. The example graph query **740** is based on the example person-knows-person graph **610** for the example person_knows_person graph query in reference to FIG. **6**A. A major portion of the example graph query **740** with the locally deployed PostgreSQL is substantially similar to the example graph query **700** with the locally deployed Apache Iceberg.

[0097] A user creates a file docker-compose.yaml with content "docker-compose.yaml." The user then runs command **742** to start Postgres and graph analytics engine services, as illustrated in FIG. **7**E.

[0098] To prepare data on Iceberg, the user runs command **744** to start a PostgreSQL shell **746** to access PostgreSQL for creating database, as illustrated in FIG. **7**E. The user then executes SQL statements **748** in the PostgreSQL shell, as illustrated in FIG. **7**E, to create tables and insert data. The SQL statements **748** create PostgreSQL tables (e.g., similar to Iceberg tables in reference to FIG. **7**B).

[0099] Then, the user defines a graph schema file in accordance with the created PostgreSQL tables, upload graph schema file to the graph analytics engine, and queries the example person-knows-person graph **610** using Gremlin query language.

Graph Analytics Engine with Locally Deployed DuckDB

[0100] FIG. **7**F illustrates an example graph query **750** using the graph analytics engine with locally deployed DuckDB, in accordance with some embodiments. The example graph query **750** is based on the example person-knows-person graph **610** for the example person_knows_person graph query in reference to FIG. **6**A. Similarly, the example graph query **750** with locally deployed DuckDB involves steps that closely resemble those for the locally deployed PostgreSQL and Apache Iceberg.

[0101] A user creates a file docker-compose.yaml with content "docker-compose.yaml." The user then runs command **752** to start DuckDB and graph analytics engine services, as illustrated in FIG. **7**F.

[0102] To prepare data on Iceberg, the user runs command **754** to create a database file/home/share/demo.db and start a DuckDB shell **756** to access DuckDB for creating database, as illustrated in FIG. **7**F. The user then executes SQL statements **758** in the DuckDB shell, as illustrated in FIG. **7**F, to create tables and insert data. The SQL statements **758** create DuckDB tables (e.g., similar to Iceberg tables in reference to FIG. **7**B).

[0103] Then, the user defines a graph schema file in accordance with the created DuckDB tables, upload graph schema file to the graph analytics engine, and queries the example person-knows-person graph **610** using Gremlin query language.

Query Data Lakes

[0104] FIGS. **8**A-**8**J illustrate an example graph query **800** using the graph analytics engine with data lakes, in accordance with some embodiments.

[0105] A user can query data by connecting to the data lakes, which include Apache Iceberg, Apache Hudi, Delta Lake, and Apache Hive.

[0106] In the example graph query **800** with the data lakes, the user creates example person-referral tables (e.g., a person table **802** and a referral table **804**) in the data lakes, as shown in FIG. **8**A.

Query Data Lakes: Apache Iceberg

[0107] The user runs shell command **810** to start a Spark SQL shell for data preparation. A spark-sql executable is in a bin folder of a Spark directory, as illustrated in FIG. **8**B. The shell command **810** assumes data are stored on Hadoop Distributed File System (HDFS) at 172.31.19.123:9000 and that Hive Metastore is at 172.31.31.125:9083. Then, the user runs Spark-SQL statements **812** to create the example person-referral tables **802** and **804** in Iceberg database onhdfs and insert data, as illustrated in FIG. **8**B. A catalog name puppy_iceberg is specified in the shell command **810**. In some embodiments, running the shell command **810** and the Spark-SQL statements **812** is optional.

[0108] The user then defines a graph before querying the graph by creating a schema file iceberg.json **816**, as shown in FIG. **8**C. The schema file iceberg.json **816** requires:

[0109] A catalog object named catalog_test defines an Iceberg data source. The hiveMetastoreUrl field matches the Hive Metastore URL.

[0110] Labels of vertices and edges may not be the same as names of tables in Iceberg. A mappedTableSource object in each vertex or edge type specifies a schema and/or database name onhdfs and a table name referral.

[0111] The mappedTableSource object also refers to columns (e.g., attributes) in the tables.

[0112] An id field refers to a column storing identities for vertices ID and edges refId.

[0113] Fields from and to refer to two columns in the tables as ends of edges. Values of these two columns match the id field of the vertices. In the example graph query **800** with the data lakes, each row in the referral table models an edge in the graph from source to referred.

[0114] Once the schema file iceberg.json **816** is created, the user uploads it to the graph analytics engine with shell command **814**, as shown in FIG. **8**B.

Query Data Lakes: Apache Hudi

[0115] The user runs shell command **830** to start a SparkSQL instance for data preparation, as illustrated in FIG. **8**D. The shell command **830** assumes delta lake data are stored on HDFS at 172.31.19.123:9000 and that Hive Metastore is at 172.31.31.125:9083. Then, the user runs SparkSQL query **832** to create the example person-referral tables **802** and **804** in delta lake database hudi_onhdfs and insert data, as illustrated in FIG. **8**D. A catalog name puppy_delta is specified in the shell command **830**. In some embodiments, running the shell command **830** and the SparkSQL query **832** is optional.

[0116] The user then defines a graph before querying the graph by creating a schema file hudi.json **836**, as illustrated in FIG. **8**E. The schema file hudi.json **836** requires:

[0117] A catalog object named catalog_test specifies remote data source in Apache Hudi. A hiveMetastoreUrl field has the same value as the one used to create data.

[0118] Labels of vertices and edges may not be the same as names of tables in Apache Hudi. A mappedTableSource object in each vertex or edge type specifies a schema and/or database name onhdfs and a table name referral.

[0119] The mappedTableSource object remarks meta columns (e.g., attributes) in the tables. For instance, fields from and to refer to two columns that form endpoints of the edges.

[0120] Once the schema file hudi.json **836** is created, the user uploads it to the graph analytics engine with shell command **834**, as shown in FIG. **8**D.

Query Data Lakes: Delta Lake

[0121] The user runs shell command **850** to start a SparkSQL instance for data preparation, as illustrated in FIG. **8**F. The shell command **850** assumes delta lake data are stored on HDFS at 172.31.19.123:9000 and that Hive Metastore is at 172.31.31.125:9083. Then, the user runs SparkSQL query **852** to create the example person-referral tables **802** and **804** in Delta Lake database onhdfs and insert data, as illustrated in FIG. **8**F. A catalog name puppy_delta is specified in the shell command **850**. In some embodiments, running the shell **850** and the SparkSQL query **852** is optional.

[0122] The user then defines a graph before querying the graph by creating a schema file deltalake.json **856**, as illustrated in FIG. **8**G. The schema file deltalake.json **856** requires:

[0123] A catalog object named catalog_test specifies remote data source in Delta Lake. A hiveMetastoreUrl field has the same value as the one used to create data.

[0124] Labels of vertices and edges may not be the same as names of tables in Delta Lake. A mappedTableSource object in each vertex or edge type specifies a schema and/or database name onhdfs and a table name referral.

[0125] The mappedTableSource object marks meta columns (e.g., attributes) in the tables. For instance, fields from and to refer to two columns that form endpoints of the edges.

[0126] Once the schema file deltalake.json **856** is created, the user uploads it to the graph analytics engine with shell command **854**, as shown in FIG. **8**F.

Query Data Lakes: Apache Hive

[0127] The user runs command **870** to use Hive beeline client to connect to Hive Server, as illustrated in FIG. **8**H. A Hive home path is /opt/hive. If the Hive Server is not at a localhost, the user changes URL accordingly. Then, the user creates tables by statements **872** in Hive beeline console, as illustrated in FIG. **8**H. In some embodiments, running the command **870** and the statements **872** is optional.

[0128] The user then defines a graph before querying the graph by creating a schema file hive_hdfs.json **878**, as illustrated in FIG. **8**I. The schema file hive_hdfs.json defines a Hive Catalog **874**, as illustrated in FIG. **8**H. The schema file hive_hdfs.json **878** requires:

[0129] The name hive_hdfs defines a reference within the hive_hdfs.json schema. The name hive_hdfs is used by definition of vertices and edges.

[0130] A type of the Hive Catalog is hive, and a metastore type of the Hive Catalog is HMS.

[0131] A metastore.hiveMetastoreUrl specifies URL of a Hive Metastore Service. The user can change a hostname accordingly if the Hive Metastore Service is not deployed at the localhost.

[0132] Once the schema file hive_hdfs.json **878** is created, the user uploads it to the graph analytics engine with shell command **876**, as shown in FIG. **8**H.

[0133] In some embodiments, the graph analytics engine supports querying Iceberg, Hudi, and Delta Lake with metastore (e.g., Hive metastore, AWS Glue) and with storage (e.g., HDFS, AWS S3, MinIO).

[0134] To query the data based on the data lakes (e.g., Apache Iceberg, Apache Hudi, Delta Lake, and Apache Hive) discussed above, the user connects to the graph analytics engine at http://localhost:8081 and start the embedded Gremlin console UI **550** (e.g., in reference to FIG. **5**G) through the management UI **530** of the graph analytics engine.

[0135] After connecting to the embedded Gremlin Console, the user starts to query the graph. For instance, the user submits an example graph query **880** for checking names of people known by a person and subsequently receives corresponding output entries **882**, as shown in FIG. **8**J.

Query Relational Databases

[0136] FIGS. **9**A-**90** illustrates an example graph query **900** using the graph analytics engine with relational databases, in accordance with some embodiments.

[0137] A user can query data by connecting to the relational databases, which include MySQL, PostgreSQL, DuckDB, BigQuery, and Redshift.

[0138] In the example graph query **900** with the relational databases, the user creates example person-referral tables (e.g., a person table **802** and a referral table **804** in reference to FIG. **8**A) in the relational databases.

Querying Relational Databases: MySQL

[0139] The user starts a MySQL container through Docker by command **910**, as illustrated in FIG. **9**A, and writes data to MySQL. An IP address of a machine that runs the MySQL container is assumed to be 172.31.19.123. After waiting for the MySQL container to start, the user connects through MySQL client **912**, as illustrated in FIG. **9**A. Then, the user creates a database and a data table by statements **914**, as illustrated in FIG. **9**A, and writes the data to MySQL. In some embodiments, running the command **910** and the statements **914** is optional.

[0140] The user then defines a schema file mysql.json **918** before querying the table, as illustrated in FIG. **9**B. The schema file mysql.json **918** requires:

- **[0141]** A catalog jdbc_mysql is added to specify remote data source in MySQL.
  - **[0142]** Set type to mysql.
  - **[0143]** Set driverClass to com.mysql.jdbc. Driver for MySQL v5.x and earlier. Alternatively, set driverClass to com.mysql.cj.jdbc. Driver for MySQL v6.x and later.
  - **[0144]** Set driverUrl to provide a URL where the graph analytics engine finds the MySQL driver.
- **[0145]** Labels of vertices and edges may not be the same as names of tables in MySQL. A mappedTableSource object in each vertex or edge type specifies a schema name graph and a table name referral.
- **[0146]** The mappedTableSource object remarks meta columns (e.g., attributes) in the tables. For instance, fields from and to refer to two columns that form endpoints of the edges.

[0147] Once the schema file mysql.json **918** is created, the user uploads it to the graph analytics engine at localhost with shell command **916**, as shown in FIG. **9**A.

Querying Relational Databases: PostgreSQL

[0148] The user starts a PostgreSQL container through Docker by command **920**, as illustrated in FIG. **9**C, and writes data to PostgreSQL. An IP address of a machine that runs the PostgreSQL container is assumed to be 172.31.19.123. After waiting for the PostgreSQL container to start, the user connects through PostgreSQL client **922**, as illustrated in FIG. **9**C. Then, the user creates a database and a data table by statements **924**, as illustrated in FIG. **9**C, and writes the data to PostgreSQL. In some embodiments, running the command **920** and the statements **924** is optional.

[0149] The user then defines a schema file postgres.json **928** before querying the table, as illustrated in FIG. **9**D. The schema file postgres.json **928** requires:

- **[0150]** A catalog jdbc_postgres is added to specify remote data source in postgreSQL.
  - **[0151]** Set type to postgresql.
  - **[0152]** Set driverClass to org.postgresql.Driver.
  - **[0153]** Set driverUrl to provide a URL where the graph analytics engine finds the PostgreSQL driver.
- **[0154]** Labels of vertices and edges may not be the same as names of tables in PostgreSQL. A mappedTableSource object in each vertex or edge type specifies a schema name public and a table name referral.
- **[0155]** The mappedTableSource object marks meta columns (e.g., attributes) in the tables. For instance, fields from and to refer to two columns that form endpoints of the edges.

[0156] Once the schema file mysql.json **928** is created, the user uploads it to the graph analytics engine at localhost with shell command **926**, as shown in FIG. **9**C.

Querying Relational Databases: DuckDB

[0157] The user starts a DuckDB container through Docker by command **930**, as illustrated in FIG. **9**E, and writes data to DuckDB. After waiting for the DuckDB container to start, the user runs command **932** to start DuckDB interactive shell, as illustrated in FIG. **9**E. Then, the user creates a database and a data table by statements **934**, as illustrated in FIG. **9**E, and writes the data to DuckDB. After writing the data to DuckDB, the user stops the DuckDB interactive shell by typing.exit to close the DuckDB client. This is to avoid a conflict with other programs (e.g., the graph analytics engine). In some embodiments, running the commands **930** and **932** and the statements **934** is optional.

[0158] The user then defines a schema file duckdb.json **938** before querying the table, as illustrated in FIG. **9**F. The schema file duckdb.json **938** requires:

- **[0159]** A catalog jdbc_duckdb is added to specify remote data source in DuckDB.
  - **[0160]** Set type to duckdb.
  - **[0161]** Set driverClass to org.duckdb.DuckDBDriver.
  - **[0162]** Set driverUrl to provide a URL where the graph analytics engine finds the DuckDB driver.
- **[0163]** Labels of vertices and edges may not be the same as names of tables in DuckDB. A mappedTableSource object in each vertex or edge type specifies a schema name graph and a table name referral.

[0164] The mappedTableSource object marks meta columns (e.g., attributes) in the tables. For instance, fields from and to refer to two columns that form endpoints of the edges.

[0165] Once the schema file duckdb.json **938** is created, the user uploads it to the graph analytics engine at localhost with shell command **936**, as shown in FIG. **9**E.

Querying Relational Databases: BigQuery

[0166] For creating tables and inserting data to BigQuery, the user performs steps below as shown in screenshots (e.g., **940**, **942**, and **944**) of FIGS. **9**G-**9**I.

[0167] Create a dataset with multiple-region support in (e.g., the screenshot **940**).

[0168] Create tables using a web console (e.g., the screenshots **942** and **944**).

After that, the user opens a query table and executes SQL statements **946**, as illustrated in FIG. **9**J. In some embodiments, performing steps shown in FIGS. **9**G-**9**I and executing SQL statements **946** are optional. In some embodiments, a BigQuery Authentication is required.

[0169] Next, the user starts the graph analytics engine container named puppy through a key key.json command **948**, as illustrated in FIG. **9**J.

[0170] Then, the user defines a schema file bigquery.json **952** before querying the table, as illustrated in FIG. **9**K. The schema file bigquery.json **952** requires:

[0171] A catalog jdbc_bigquery is added to specify remote data source in BigQuery.

[0172] Set type to bigquery.

[0173] Set driverClass to com.simba.googlebigquery.jdbc.Driver.

[0174] Set driverUrl to provide a URL where the graph analytics engine finds the DuckDB driver.

[0175] jdbcUri needs to be set in accordance with the user's service account configuration.

[0176] Set ProjectId=PJID. PJID for service account project id.

[0177] Set OAuthServiceAcctEmail=for service account id.

[0178] Set OAuthPvtKeyPath=for a key file path in the docker container (e.g., /home/key.json).

[0179] Labels of vertices and edges may not be the same as names of tables in BigQuery. A mappedTableSource object in each vertex or edge type specifies a schema name demo and a table name referral.

[0180] The mappedTableSource object marks meta columns (e.g., attributes) in the tables. For instance, fields from and to refer to two columns that form endpoints of the edges.

[0181] Once the schema file bigquery.json **952** is created, the user uploads it to the graph analytics engine at localhost with shell command **950**, as shown in FIG. **9**J.

Querying Relational Databases: RedShift

[0182] For creating tables and inserting data to RedShift, the user follows steps below as shown in screenshots (e.g., **960** and **962**) in FIGS. **9**L-**9**M.

[0183] Create a database with a query editor (e.g., the screenshot **960**).

[0184] Create tables in the database (e.g., the screenshot **962**).

After that, the user executes SQL statements **964** to insert data into the tables, as illustrated in FIG. **9**N. In some embodiments, performing steps shown in FIGS. **9**L-**9**M and executing SQL statements **964** are optional.

[0185] Then, the user defines a schema file redshift.json **968** before querying the table, as illustrated in FIG. **9**O. The schema file redshift.json **968** requires:

[0186] A catalog jdbc_redshift is added to specify remote data source in RedShift.

[0187] Replace username and password.

[0188] Replace jdbcUri with the user's JDBC URL.

[0189] Labels of vertices and edges may not be the same as names of tables in RedShift. A mappedTableSource object in each vertex or edge type specifies a schema name public and a table name referral.

[0190] The mappedTableSource object marks meta columns (e.g., attributes) in the tables. For instance, fields from and to refer to two columns that form endpoints of the edges.

[0191] Once the schema file redshift.json **968** is created, the user uploads it to the graph analytics engine at localhost with shell command **966**, as shown in FIG. **9**N.

[0192] To query the data based on the relational databases (e.g., MySQL, PostgreSQL, DuckDB, BigQuery, and Redshift) discussed above, the user connects to the graph analytics engine at http://localhost:8081 and start the embedded Gremlin console UI **550** (e.g., in reference to FIG. **5**G) through the management UI **530** of the graph analytics engine.

[0193] After connecting to the embedded Gremlin Console, the user starts to query the graph. For instance, the user submits an example graph query **880** for checking names of people known by a person and subsequently receives corresponding output entries **882**, as shown in FIG. **8**J.

Schema Creation User Interfaces

[0194] FIGS. **10**A-**10**Q illustrate a series of screenshots of an example schema creation UI **1000** for creating an example person_knows_person_UI graph schema **1022**, in accordance with some implementations. The example schema creation UI **1000** allows a user to create graph schemas (e.g., JSON files) by UI features provided by the example schema creation UI **1000** such that there is no need for the user to upload separate JSON files.

[0195] FIG. **10**A illustrates a "Create Graph Schema" section **1002** and a "Upload Graph Schema JSON" section **1004** within the example schema creation UI **1000**. The user can choose the "Create Graph Schema" section **1002** to initiate a schema creation process using UI features provided by the example schema creation UI **1000**.

[0196] FIGS. **10**B-**10**D illustrate the user's selection of respective catalog information **1006** and respective to-be-queried database information **1008** in accordance with the example person_knows_person_UI graph schema.

[0197] FIGS. **10**E-**10**N illustrate a series of steps of creating respective vertices (e.g., **1010** and **1012**) and respective edges (**1014** and **1016**) of the example person_knows_person_UI graph schema. In addition, FIG. **10**N illustrates a respective graph representation of the respective vertices (e.g., **1010** and **1012**) and respective edges (**1014** and **1016**). The user clicks "Submit" **1020** to start processing the respective vertices (e.g., **1010** and **1012**) and respective edges (**1014** and **1016**) for generating a respective graph schema, as shown in FIGS. **10**N-**10**O.

[0198] FIGS. **10**P-**10**Q illustrate the example person_knows_person_UI graph schema **1022** generated by the example schema creation UI **1000** in accordance with the respective vertices (e.g., **1010** and **1012**) and respective edges (**1014** and **1016**).

Automated Graph Schema Generation

[0199] FIG. **11** illustrates an example schema generation system **1100** that performs automated graph schema generation, in accordance with some embodiments. The example schema generation system **1100** includes a graph schema generator **1102** configured to interact with a user **1104** and a database **1106** and automatically generate an output **1108** (e.g., a graph schema in a JSON file). The graph schema generator **1102** includes a graph schema suggestion module **1110** that executes a graph schema suggestion model **1112** (e.g., a computational model) configured to generate suggestion(s) that identifies new vertices and/or new edges as potential candidates for generating graph schemas. In some embodiments, the graph schema suggestion model **1112** includes an AI-based suggestion model **1114** and a rule-based suggestion model **1116**. The AI-based suggestion model **1114** implements AI techniques (e.g., machine learning models, LLMs, etc.), and the rule-based suggestion model **1116** implements predefined rules and heuristics (e.g., joining test rules, dependency rules, validation rules, matching rules, conditional join rules, etc.). In some embodiments, the graph schema generator **1102** includes a graph visualization module **1118** (e.g., a schema graph visualization tool) that executes a graphical interface **1120** for displaying visual graph-based representations of graph schemas. The graph visualization module **1118** helps users understand and refine graph schemas by displaying potential candidates of vertices and/or edges based on the suggestion(s). In some embodiments, the database **1106** includes a relational database, a data warehouse, and/or a data lake, each of which having data table(s), metadata, and/or other essential inputs. In some embodiments, the database **1106** includes documents, specifications, reports, and/or other types of files, each of which having data table(s) and/or other essential inputs. The more detailed and canonical the documents are, the more accurate the suggestion(s) will be. In some embodiments, graph schemas are utilized in a variety of applications, such as data analysis and knowledge representation. In some embodiments, the graph schema generator **1102** is configured to generate the auxiliary component **303**, the graph schema file(s), and/or other graph schema(s) described above in reference to FIGS. **1**-**10**Q. In some embodiments, in a graph schema, vertices define individual objects (e.g., data points), and edges defines connections/relationships between vertices.

[0200] In some embodiments, the example schema generation system **1100** automatically generates graph schema (s) based on input(s) from the user **1104** and data tables received from the database **1106**. The graph schema generator **1102** receives a graph schema **1126** (e.g., a partial graph schema that defines a subset of vertices and edges associated with data tables) that includes vertices and edges associated with a plurality of data tables **1130** (e.g., relational data tables) of the database **1106**. The graph schema **1126** includes at least a first vertex v_1 **1136** from a first data table T_1 **1134** of the plurality of data tables **1130**. The graph schema generator **1102** further automatically generates, based on the plurality of data tables **1130** and the graph schema **1126**, one or more suggestions **1124** using the graph schema suggestion model **1112**. The one or more suggestions **1124** identifies at least one of the group consisting of one or more vertices and one or more edges. The one or more suggestions **1124** includes a respective suggestion that identifies a respective subset of the at least one of the group consisting of the one or more vertices and the one or more edges. The one or more vertices are distinct from the first vertex v_1 **1136**. For example, the one or more suggestions **1124** identifies new vertices and/or new edges, which are not currently present in the graph schema **1126**, as potential candidates to be added into the graph schema **1126**. In another example, the one or more suggestions **1124** (e.g., S_1, S_2, S_3, . . . , S_k; k is an integer greater than 1) identify the one or more vertices (e.g., v_1, v_2, v_3, . . . , v_m; m is an integer greater than 1) and/or the one or more edges (e.g., e_1, e_2, e_3, . . . , e_n; n is an integer greater than 1). The respective suggestion (e.g., S_2) of the one or more suggestions **1124** identifies the vertex v_2 and/or the edge e_2, which is the respective subset of the one or more vertices (e.g., v_1, v_2, v_3, . . . , v_n) and/or the one or more edges (e.g., e_1, e_2, e_3, . . . , e_m). The graph schema generator **1102** further receives a first user input **1122-1** from the user **1104**. In particular, the first user input **1122-1** is a selection of the respective suggestion from the one or more suggestions **1124** (e.g., the user **1104** selects the respective suggestion from the one or more suggestions **1124**). For example, the user **1104** reviews and refines the one or more suggestions **1124** for the graph schema **1126**. The user **1104** further provides the first user input **1122-1** as feedback to the graph schema generator **1102** by confirming new vertices and/or new edges, which are not currently present in the graph schema **1126**. In particular, the first user input **1122-1** helps to fine-tune the graph schema **1126** according to specific requirements and insights of the user **1104**. The graph schema generator **1102** further updates, based on the first user input **1122-1** (e.g., the selection of the respective suggestion), the graph schema **1126**. The graph schema generator **1102** further outputs the updated graph schema **1128** (e.g., creating a JSON file). In some embodiments, the one or more suggestions **1124** include a plurality of suggestions. Each suggestion of the plurality of suggestions identify one or more vertices (e.g., v_1, v_2, v_3, . . . , v_m; m is an integer greater than 1) and/or one or more edges (e.g., e_1, e_2, e_3, . . . , e_n; n is an integer greater than 1). In some embodiments, when the one or more vertices and/or the one or more edges identified by the one or more suggestions **1124** are unwanted (e.g., as later shown FIG. **16**E, a subset of a plurality of suggestions **1636** is unwanted by the user **1104**), the user **1104** creates the first user input **1122-1** to select a respective suggestion from the plurality of suggestions **1636**, thereby eliminating the unwanted suggestion(s) from the updated graph schema **1128**. In some embodiments, when the one or more vertices and/or the one or more edges identified by the one or more suggestions **1124** are invalid (e.g., disconnected vertex, redundant edge, edge with undefined vertices, etc.), the user **1104** creates the first user input **1122-1** to remove the one or more suggestions **1124**, prompting the graph schema generator **1102** to regenerate suggestions, thereby ensuring the accuracy and relevance of graph schema(s) (e.g., graph schema **1126**, updated graph schema **1128**). In some embodiments, suggestion(s) generated by the rule-based suggestion model **1116** of the graph schema suggestion model **1112** is unlikely to create invalid vertex/vertices

and/or edge(s). For example, invalid vertex/vertices and/or edge(s) are rejected and filtered out based on predefined rules and heuristics of the rule-based suggestion model **1116**.

[0201] In some embodiments, the plurality of data tables **1130** are randomly selected from original data tables (e.g., data tables used for generating graph schemas and performing graph queries) stored in the database **1106** to form a subset (e.g., a segment) of the original data tables. For example, when the original data tables are significantly large (e.g., several gigabytes (GBs) in size), the graph schema generator **1102** is configured to partially select a subset of the original data tables, thereby reducing memory usage and increasing processing efficiency. In some embodiments, the plurality of data tables **1130** include metadata of original data tables (e.g., data tables used for generating graph schemas and performing graph queries) stored in the database **1106**. In some circumstances, when the original data tables stored in the database **1106** are significantly large (e.g., several gigabytes (GBs) in size), the graph schema generator **1102** is configured to receive the metadata instead of the entire original data tables, thereby reducing memory usage and increasing processing efficiency. In some embodiments, the metadata of the original data tables stored in the database **1106** include maximum and/or minimum value(s) of each column of the original data tables. The maximum and/or minimum value(s) can be used to quickly retrieve the metadata from the database **1106**. In some circumstances, the maximum and/or minimum value(s) of each column of the original data tables are predetermined.

[0202] In some embodiments, updating the graph schema **1126** includes adding the respective subset of the at least one of the group consisting of the one or more vertices (e.g., v_1, v_2, v_3, . . . , v_m; m is an integer greater than 1) and the one or more edges (e.g., e_1, e_2, e_3, . . . , e_n; n is an integer greater than 1) into the graph schema **1126**. For example, the respective suggestion (e.g., S_2) of the one or more suggestions **1124** identifies the vertex v_2 and/or the edge e_2, which is the respective subset of the one or more vertices (e.g., v_1, v_2, v_3, . . . , v_n) and/or the one or more edges (e.g., e_1, e_2, e_3, . . . , e_m). The graph schema generator **1102** adds the vertex v_2 and/or the edge e_2 that are identified by the respective suggestion into the graph schema **1126** to form the updated graph schema **1128**.

[0203] In some embodiments, a user request (e.g., pressing/clicking a button on a graphical user interface, speaking a command to a microphone, selecting an option from a dropdown menu, tapping an icon on a touchscreen device, etc.) is required to initiate the automated graph schema generation. The graph schema generator **1102** receives a user request **1132** from the user **1104** for accessing data tables. The graph schema generator **1102** further sends the user request **1132** to the database **1106**. In response to the user request **1132**, the database **1106** sends the plurality of data tables **1130** to the graph schema generator **1102**.

[0204] In some embodiments, the graph visualization module **1118** displays, via the graphical interface **1120**, the one or more suggestions **1124** for the user **1104** to select a respective suggestion for expanding vertices and edges and updating the graph schema **1126**. In some embodiments, the graph visualization module **1118** displays, via the graphical interface **1120** and based on at least one of the graph schema **1126** or the updated graph schema **1128**, a graph-based representation to the user **1104**. In some embodiments, the user **1104** determines, based on the graph-based representation of the graph schema **1126** or the updated graph schema **1128**, that a respective suggestion for expanding a vertex or an edge is invalid (e.g., disconnected vertex, redundant edge, edge with undefined vertices, etc.). In this circumstance, the user **1104** interrupts the graph schema generator **1102** and manually fixes the graph schema **1126** or the updated graph schema **1128**. As discussed above, in some embodiments, suggestion(s) generated by the rule-based suggestion model **1116** of the graph schema suggestion model **1112** is unlikely to create invalid vertex/vertices and/or edge(s). For example, invalid vertex/vertices and/or edge(s) are rejected and filtered out based on predefined rules and heuristics of the rule-based suggestion model **1116**.

[0205] In some embodiments, the operations (e.g., receiving the plurality of data tables **1130**, receiving the graph schema **1126**, generating the one or more suggestions **1124**, the receiving the first user input **1122-1**, updating the graph schema **1126**, and outputting the updated graph schema **1128**) executed by the graph schema generator **1102** are performed via an application or a user interface. For example, as later shown in FIGS. **16**A-**16**H, a user interface allows the user **1104** to provide user inputs in response to suggestions generated by the graph schema generator **1102**. In some embodiments, the application and/or the user interface are communicatively coupled to external resources through APIs.

[0206] FIG. **12** illustrates an example schema generation system **1200** that iteratively expands vertices and edges of a graph schema based on automated graph schema generation, in accordance with some embodiments. The example schema generation system **1200** includes a plurality of iterations **1202** to expand vertices and edges associated with a graph schema. In particular, the graph schema generator **1102** expands the graph schema by adding vertices and their associated edges. The plurality of iterations **1202** proceed as new edges and vertices are suggested, evaluated, and incorporated into the graph schema. In some embodiments, the iterative process ensures that the graph schema meets required criteria (e.g., scalability, redundancy minimization, normalization, etc.) and is optimized for various applications (e.g., fraud detection, recommendation system, social network analysis, supply chain management, bioinformatics, etc.). In some embodiments, the graph schema generator **1102** is configured to generate the auxiliary component **303**, the graph schema file(s), and/or other graph schema(s) described above in reference to FIGS. **1**-**10**Q.

[0207] More specifically, in some embodiments, the graph schema generator **1102** iteratively receives a respective graph schema **1126'** (e.g., a partial graph schema that defines a subset of vertices and edges associated with the plurality of data tables **1130**). The graph schema generator **1102** further automatically generates a respective suggestion **1124'** that identifies respective vertex/vertices and/or respective edge(s). The graph schema generator **1102** further receives a respective first user input **1122-1'**. In particular, the respective first user input **1122-1'** is a user selection of the respective suggestion **1124'** to confirm the respective vertex/vertices and/or respective edge(s) be added into the respective graph schema **1126'**. The graph schema generator **1102** further updates the respective graph schema **1126'** for the plurality of iterations **1202** to expand vertices and edges associated with the respective graph schema **1126'**. Each

iteration of the plurality of iterations **1202** corresponds to a respective updated graph schema **1128'**, where each edge links two vertices.

[0208] In some embodiments, the graph schema suggestion model **1112** (e.g., a computational model) of the graph schema suggestion module **1110** includes a plurality of models (e.g., the AI-based suggestion model **1114** and the rule-based suggestion model **1116**). In each iteration of the plurality of iterations **1202**, the graph schema generator **1102** receives a respective second user input **1122-2'** for selecting a respective model (e.g., the AI-based suggestion model **1114** or the rule-based suggestion model **1116**) from the plurality of models. In response to the respective second user input **1122-2'**, the graph schema generator **1102** automatically generates, based on the plurality of data tables **1130** and the respective graph schema **1126'**, the respective suggestion **1124'** using the respective model. For example, during one iteration of the plurality of iterations **1202**, the user **1104** decides to switch from the AI-based suggestion model **1114** to the rule-based suggestion model **1116** after reviewing a visual graph-based representation of the respective graph schema **1126'**. In response to the respective second user input **1122-2'** that indicates the determination of the user **1104**, the graph schema generator **1102** executes the rule-based suggestion model **1116** instead of the AI-based suggestion model **1114** to automatically generate the respective suggestion **1124'**.

[0209] FIG. **13** illustrates an example schema generation system **1300** that includes an AI-based suggestion model **1114** with various functionalities for generating suggestions associated with a graph schema, in accordance with some embodiments. The AI-based suggestion model **1114** is configured to generate the one or more suggestions **1124** associated with the graph schema **1126** using various AI techniques. The AI-based suggestion model **1114** of the example schema generation system **1300** includes a first set of AI techniques **1302** and a second set of AI techniques **1304**. In some embodiments, the graph schema generator **1102** is configured to generate the auxiliary component **303**, the graph schema file(s), and/or other graph schema(s) described above in reference to FIGS. **1-10**Q.

[0210] More specifically, in some embodiments, the first set of AI techniques **1302** is configured to execute multimodal large language models (e.g., MLLMs). In particular, the MLLMs are fine-tuned to improve accuracy and relevance for generating the one or more suggestions **1124**. In some embodiments, the MLLMs implement AI techniques, such as retrieval-augmented generation and prompt engineering, to integrate capabilities of multiple modalities, thereby enhancing the ability of the AI-based suggestion model **1114** to process the data tables **1130** and generate more precise and comprehensive suggestions. In some embodiments, the graph schema suggestion model **1112** of the graph schema generator **1102** includes APIs **1306** communicatively coupled to external computation resources (e.g., external MLLMs). In particular, the AI-based suggestion model **1114** is configured to access the external computation resources via the APIs **1306**. In some embodiments, developing custom-built MLLMs is a preferred option as it allows for capabilities such as fine-tuning. In some embodiments, executing external computation resources (e.g., external MLLMs) via the APIs **1306** is a preferred option because of cost efficiency.

[0211] More specifically, in some embodiments, the second set of AI techniques **1304** is configured to execute various supplementary algorithms to generate the one or more suggestions **1124**. In some embodiments, the supplementary algorithms include a natural language processing (NLP) (e.g., relationship extraction, knowledge graph construction) configured to identify and map relationships within the data tables **130**. In some embodiments, the supplementary algorithms further include a keyword-based search technique configured to extract relevant information and context from the data tables **130**. In some embodiments, the supplementary algorithms of the second set of AI techniques **1304** work in conjunction with the MLLMs of the first set of AI techniques **1302** to provide a robust and multi-faceted approach to generate the one or more suggestions **1124**.

[0212] FIG. **14**A is a flow chart **1400** of the rule-based suggestion model **1116** that expands vertices and edges associated with a graph schema, in accordance with some embodiments. In particular, the flow chart **1400** illustrates the plurality of iterations **1202** to automatically generate the one or more suggestions **1124** to the user **1104** and update the graph schema **1126** by adding new vertices and edges based on the first user input **1122-1**. In some embodiments, the rule-based suggestion model **1116** implements a plurality of predefined rules (e.g., joining test rules, dependency rules, validation rules, matching rules, conditional join rules, etc.). In some embodiments, the plurality of predefined rules of the rule-based suggestion model **1116** includes a first joining test rule **1407** that determines whether records, attributes, and/or fields of different tables meet criteria (e.g., matching criteria) when joined or compared. In particular, the first joining test rule **1407** includes comparing data types, comparing column names, and tests of joining for tables.

[0213] In some embodiments, the rule-based suggestion model **1116** receives (operation **1402**) the first vertex v_1 **1136** from the first data table T_1 **1134** of the plurality of data tables **1130**. The rule-based suggestion model **1116** further identifies (operation **1404**) a second data table T_2 (e.g., an unused data table) of the plurality of data tables **1130**. The second data table T_2 is distinct from the first data table T_1 **1134**. The rule-based suggestion model **1116** further receives columns of the second data table T_2, which are critical components for identifying relationships between vertices and edges. The rule-based suggestion model **1116** further computes (operation **1406**), for each column of the second data table T_2 and based on the first joining test rule **1407**, a respective score (e.g., based on points, percentages, or other types of scoring mechanisms). The rule-based suggestion model **1116** further determines (operation **1408**) whether a respective score for each column of the second data table T_2 meets a threshold level (e.g., a point level, a percentage level, or other types of threshold levels). In particular, the rule-based suggestion model **1116** determines whether a respective column of the second data table T_2 is an identity column associated with the first vertex v_1 **1136**. In accordance with a determination that the second data table T_2 includes no column having scores that meet the threshold level, the rule-based suggestion model **1116** identifies no identity column associated with the first vertex v_1 **1136**. In particular, the rule-based suggestion model **1116** takes no further action on the second data table T_2 and identifies (operation **1404**) another table (e.g., another unused data table) of the plurality of data tables **1130**, distinct from the first data table T_1 and

the second data table T_2. Moreover, in accordance with a determination that the second data table T_2 includes two or more columns having scores that meet the threshold level, the rule-based suggestion model **1116** identifies (operation **1410**) two or more identity columns **1418** associated with the first vertex v_1 **1136**. The rule-based suggestion model **1116** further identifies (operation **1412**), based on at least the two or more identity columns **1418** of the second data table T_2, a first set of edges **1420** (e.g., including self-loops) for the first vertex v_1 **1136** to automatically form a first suggestion corresponding to the identified first set of edges **1420**. In some embodiments, the first set of edges **1420** includes self-loop(s) (e.g., edge **1634-1** in reference to FIG. **16**G). For example, when two identity columns of the second data table T_2 are associated with the first vertex v_1 **1136**, the graph schema generator **1102** determines that these two identity columns form a self-loop based on the first vertex v_1 **1136**. Further, in accordance with a determination that the second data table T_2 includes one or more columns having scores that meet the threshold level, the rule-based suggestion model **1116** identifies (operation **1414**) one or more identity columns **1422** associated with the first vertex v_1 **1136**. The rule-based suggestion model **1116** further identifies (operation **1416**), based on at least the one or more identity columns **1422** columns of the second data table T_2, a first set of vertices **1424** and/or a second set of edges **1426** to automatically form a second suggestion corresponding to the identified first set of vertices **1424** and/or second set of edges **1426**. The first set of vertices **1424** is distinct from the first vertex v_1 **1136**.

[0214] In some embodiments, the rule-based suggestion model **1116** determines whether the identified first set of vertices **1424** and/or second set of edges **1426** are already in the graph schema **1126**. In accordance with a determination that the identified first set of vertices **1424** and/or second set of edges **1426** are not in the graph schema **1126**, the rule-based suggestion model **1116** adds the first set of vertices **1424** and/or the second set of edges **1426** to the first vertex v_1 **1136**. In some embodiments, an identity column (e.g., an identity column of the second data table T_2 associated with the first vertex v_1 **1136**) refers to a unique identifier or a primary key for each record or row within a data table of the polarity of the data tables **1130**. The unique identifier is distinct and easily retrievable.

[0215] In some embodiments, the rule-based suggestion model **1116** of the graph schema generator **1102** receives (operation **1428**) a third user input **1429** for identifying an initial vertex (e.g., the first vertex v_1) from the plurality of data tables **1130**. In response to the third user input **1429**, the graph schema generator **1102** automatically generates the graph schema **1126** including the initial vertex (e.g., the first vertex v_1). Receiving the third user input **1429** is to ensure that the graph schema **1126** includes at least one vertex for iterative expansion of vertices and edges. In some embodiments, receiving the third user input **1429** is optional.

[0216] FIG. **14**B is a flow chart **1401** of the rule-based suggestion model **1116** that further illustrates the operation **1416** of the flow chart **1400**, in accordance with some embodiments. In particular, the flow chart **1401** illustrates a process of identifying the first set of vertices **1424** and/or the second set of edges **1426** to be added into the graph schema **1126**. In some embodiments, the plurality of predefined rules of the rule-based suggestion model **1116** includes a first predefined rule **1431** and a second joining test rule **1433**. The first predefined rule **1431** determines whether a respective column has a predefined data type or name. Stated another way, in some embodiments, the first predefined rule **1431** determines whether a respective column is an identity column that indicates a vertex, not an edge. The second joining test rule **1433** determines whether records, attributes, and/or fields of different tables meet criteria (e.g., matching criteria) when joined or compared. In particular, the second joining test rule **1433** includes comparing columns of a data table with existing vertex identities and comparing data types and names. In some embodiments, the second joining test rule **1433** includes a step-one test **1433-1** and a step-two test **1433-2** (discussed below).

[0217] In some embodiments, the rule-based suggestion model **1116** identifies (operation **1430**), based the first predefined rule **1431**, a respective column (e.g., a column A) of the second data table T_2. The column A is distinct from the one or more identity columns (e.g., identified in the operation **1414**). The rule-based suggestion model **1116** further determines (operation **1432-1**) whether the column A satisfies the step-one test **1433-1** (e.g., by comparing data types and/or names of a vertex (e.g., v_2) based on the column A with existing vertex/vertices including the first vertex v_1 **1136** in the graph schema **1126**) of the second joining test rule **1433**. In accordance with a determination that the column A satisfies the step-one test **1433-1** of the second joining test rule **1433**, the rule-based suggestion model **1116** further identifies (operation **1434**) edge(s), which is incident to (e.g., associated with) the first vertex v_1 **1136** and other existing vertices in the graph schema **1126**, to automatically form a suggestion (e.g., the second suggestion) corresponding to the identified edge(s). In this circumstance, the edge(s) (e.g., identified through the operation **1434**) for the graph schema **1126** is identified based on the second data table T_2. In some embodiments, the edge(s) identified through the operation **1434** is part of the second set of edges **1426**. In accordance with a determination that the column A does not satisfy the step-one test **1433-1** of the second joining test rule **1433**, the rule-based suggestion model **1116** further determines (operation **1432-2**) whether the column A satisfies the step-two test **1433-2** of the second joining test rule **1433**. In particular, the step-two test **1433-2** of the second joining test rule **1433** determines whether a suggestion for a vertex (e.g., v_2) corresponding to the column A can be formed based on the second data table T_2. In accordance with a determination that the column A satisfies the step-two test **1433-2** of the second joining test rule **1433**, the rule-based suggestion model **1116** further identifies (operation **1438**) vertex/vertices corresponding to the column A and edge(s) incident to (e.g., associated with) the identified vertex/vertices and the first vertex v_1 to automatically form a suggestion (e.g., the second suggestion). In this circumstance, the vertex/vertices and edge(s) (e.g., identified through the operation **1438**) for the graph schema **1126** are identified based on the second data table T_2. In accordance with a determination that the column A does not satisfy the step-two test **1433-2** of the second joining test rule **1433**, the rule-based suggestion model **1116** further identifies (operation **1436**) a third data table T_3 (e.g., an unused data table) of the plurality of data tables **1130**. Specifically, in some embodiments, the rule-based suggestion model **1116** enumerates all data tables of the plurality of data tables **1130** (e.g., by checking metadata of each data table of the plurality of data tables **1130** except the first data table T_1 and the

second data table T_2) to identify the third data table T_3. The rule-based suggestion model **1116** further identifies (operation **1440**), based on a joining test rule (e.g., the first joining test rule **1407**), identity column(s) (e.g., different from the one or more identity columns **1422**) of the third data table T_3 associated with the column A. The rule-based suggestion model **1116** further identifies (operation **1442**) vertex/vertices corresponding to the identity column(s) of the third data table T_3 associated with the column A and edges incident to (e.g., associated with) the identified vertex/vertices and the first vertex v_1 to automatically form a suggestion (e.g., the second suggestion). In this circumstance, the vertex/vertices and/or edge(s) (e.g., identified through the operation **1442**) for the graph schema **1126** are identified based on the third data table T_3. In some embodiments, the vertex/vertices and/or edge(s) identified through the operation **1442** are part of the first set of vertices **1424** and/or the second set of edges **1426**. In some embodiments, the vertex/vertices and edge(s) identified through the operation **1438** are part of the first set of vertices **1424** and/or the second set of edges **1426**. In some embodiments, the flow chart **1401** is repeated for remaining columns (e.g., including the column A) of the second data table T_2 that are distinct from the one or more identity columns **1422**. This is to ensure that all potential relationships within the second data table T_2 are explored to update the graph schema **1126**. In some embodiments, in operations **1436** and/or **1438**, the rule-based suggestion model **1116** enumerates all data tables and/or all metadata of the plurality of data tables **1130**. In some embodiment, the rule-based suggestion model **1116** subsequently or concurrently performs operation **1436** even when the column A satisfies the step-two test **1433-2** of the second joining test rule **1433**, such that the rule-based suggestion model **1116** enumerates all data tables and/or all metadata of the plurality of data tables **1130**.

[0218] FIGS. **15**A-**15**C illustrate an example transaction trace **1500** used for generating schema graphs, in accordance with some embodiments. In particular, FIG. **15**A illustrates a plurality of transaction trace data tables **1502** from a relational database, FIG. **15**B illustrates a graph schema **1510** associated with the plurality of transaction trace data tables **1502**, and FIG. **15**C illustrates a visual graph-based representation **1512** of the graph schema **1510**. In some embodiments, the visual graph-based representation **1512** illustrates relationships between entities defined in the graph schema **1510**.

[0219] In some embodiments, the plurality of transaction trace data tables **1502** includes three data tables: a UserProfile data table **1504**, an Account data table **1506**, and a Transaction data table **1508**. Specifically, the UserProfile data table **1504** includes (i) three records corresponding to three users (e.g., Users 00001, 00002, and 00003, as account holders), and (ii) eight columns with different data types (e.g., UserId [String], FirstName [String], LastName [String], Address [String], ZipCode [String], Gender [String], PhoneNumber [String], and Birthday [Date], as information associated with the account holders). The Account data table **1506** includes (i) six records corresponding to six accounts (e.g., Accounts 0000001, 0000002, 0000003, 0000004, 0000005, and 0000006, as account numbers), and (ii) six columns with different data types (e.g., AccountNumber [String], Balance [Double], CreatedDate [DateTime], User [String], BranchName [String], and AccountAgent [String], as information associated with the account numbers). The Transaction data table **1508** includes (i) five records corresponding to five transactions (e.g., Transactions 0000000001, 0000000002, 0000000003, 0000000004, and 0000000005, as transaction numbers), and (ii) five columns with data types (e.g., TransactionId [String], SenderAccount [String], ReceiverAccount [String], TransactionTimestamp [DateTime], and Amount [Double], as information associated with the transaction numbers). In some embodiments, the UserProfile data table **1504**, the Account data table **1506**, and the Transaction data table **1508** are stored in a tabular format.

[0220] In some embodiments, the graph schema **1510** is a JSON file defining a hierarchy of target entities. The target entities of the example transaction trace **1500** include selected attributes from the UserProfile data table **1504**, the Account data table **1506**, and the Transaction data table **1508**. Specifically, the graph schema **1510** includes a "vertices" array **1512** that defines vertices and an "edges" array **1514** that defines edges. The "vertices" array **1512** includes a "user" object **1516** and an "account" object **1518**. The "user" object **1516** has an identity that corresponds to the UserId column of the UserProfile data table **1504** and does not include attributes. The "account" object **1518** has an identity that corresponds to the AccountNumber column of the Account data table **1506** and includes a "Balance" attribute that corresponds to the Balance column of the Account data table **1506**. The "edges" array **1514** defines relationships between vertices. The "edges" array **1514** includes a "user_has_account" object **1520** and a "transaction" object **1522**. The "user_has_account" object **1520** represents relationships between the users (e.g., three users named Users 00001, 00002, and 00003) and their accounts. The "user_has_account" object **1520** includes a plurality of directions identifying respective transactions from respective users to respective accounts. The respective users and the respective accounts correspond to the User column and the AccountNumber column of the Account data table **1506**, respectively. The "user_has_account" object **1520** does not include attributes. The "transaction" object **1522** represents transactions between accounts, defining respective directions from respective sender accounts to respective receiver accounts. The respective sender accounts and the respective receiver accounts correspond to the SenderAccount column and the ReceiverAccount column of the Transaction data table **1508**. The "transaction" object **1522** includes an "Amount" attribute and a "TransactionTimestamp" attribute that corresponds to the Amount column and the TransactionTimestamp column of the Transaction data table **1508**, respectively.

[0221] FIGS. **16**A-**16**H illustrate an example schema generation **1600** using the example transaction trace **1500**, in accordance with some embodiments. The example schema generation **1600** is performed using the rule-based suggestion model **1116**. In particular, for a plurality of iterations, the rule-based suggestion model **1116** automatically and systematically generates suggestions to the user **1104** that identify new vertices and edges for a graph schema, and updates the graph schema based on the user input (e.g., the respective first user input **1122-1**') by expanding vertices and edges. In some embodiments, the schema generation process based on iterations ensures comprehensive and accurate representation of relationships between vertices and edges associated with data tables (e.g., the plurality of data tables **1130**).

[0222] As shown in FIG. **16**A, the rule-based suggestion model **1116** receives (e.g., the operation **1402**) a first vertex "user" **1620** from the UserProfile data table **1504** of the plurality of transaction trace data tables **1502**. The first vertex "user" **1620** corresponds to the UserId column of the UserProfile data table **1504**. In particular, the graph schema generator **1102** automatically generates an initial graph schema **1602-1** including the first vertex "user" **1620** and displays, based on the initial graph schema **1602-1** and via the graphical interface **1120**, an initial graph-based representation **1604-1**. In some embodiments, the rule-based suggestion model **1116** receives (e.g., the operation **1428**) a user input (e.g., the third user input **1429**) for identifying the first vertex "user" **1620** from the plurality of transaction trace data tables **1502**. In response to the user input, the graph schema generator **1102** automatically generates the initial graph schema **1602-1** including the first vertex "user" **1620**. In some embodiments, receiving the first vertex "user" **1620** through the user input is to ensure that the graph schema **1126** includes at least one vertex for iterative expansion of vertices and edges associated with the plurality of transaction trace data tables **1502**. In some embodiments, receiving the user input for identifying the first vertex "user" **1620** is optional.

[0223] Moreover, the rule-based suggestion model **1116** identifies (e.g., the operation **1404**) the Transaction data table **1508** (e.g., an unused data table) of the plurality of transaction trace data tables **1502**. The Transaction data table **1508** is distinct from the UserProfile data table **1504**. In some embodiments, the Transaction data table **1508** is automatically identified (e.g., selected) by the rule-based suggestion model **1116** from the plurality of transaction trace data tables **1502**. The rule-based suggestion model **1116** further computes (e.g., the operation **1406**), for each column (e.g., TransactionId column, SenderAccount column, ReceiverAccount column, TransactionTimestamp column, and Amount column) of the Transaction data table **1508** and based on the first joining test rule **1407**, a respective score (e.g., pass, no pass, etc.). The rule-based suggestion model **1116** further determines (e.g., the operation **1408**) whether a respective score for each column of the Transaction data table **1508** meets a threshold level (e.g., a point level, a percentage level, or other types of threshold levels). No column of the Transaction data table **1508** achieves a high score to meet the threshold level, because the columns of the Transaction data table **1508** do not match the UserId column of the UserProfile data table **1504** associated with the first vertex "user" **1620** by comparing data types, column names, or strings. In accordance with a determination that the Transaction data table **1508** includes no column having scores that meet the threshold level, the rule-based suggestion model **1116** identifies no identity column associated with the vertex "user" **1620**. The rule-based suggestion model **1116** takes no further action on the Transaction data table **1508**.

[0224] Further, the rule-based suggestion model **1116** identifies (e.g., the operation **1404**) the Account data table **1506** (e.g., another unused data table) of the plurality of transaction trace data tables **1502**. The Account data table **1506** is distinct from the UserProfile data table **1504** and the Transaction data table **1508**. In some embodiments, the Account data table **1506** is automatically identified (e.g., selected) by the rule-based suggestion model **1116** from the plurality of transaction trace data tables **1502**. The rule-based suggestion model **1116** further computes (e.g., the operation **1406**), for each column (e.g., AccountNumber, Balance, CreatedDate, User, BranchName, and AccountAgent) of the Account data table **1506** and based on the first joining test rule **1407**, a respective score (e.g., pass, no pass, etc.). The rule-based suggestion model **1116** further determines (e.g., the operation **1408**) whether a respective score for each column of the Account data table **1506** meet a threshold level (e.g., a point level, a percentage level, or other types of threshold levels). The User column achieves the highest score among scores of other columns, because only the User column passes rules (e.g., type checking, name checking, and/or other tests of joining with the User column of the UserProfile data table **1504**) of the first joining test rule **1407**. The remaining columns of the Account data table **1506** do not achieve scores meeting the threshold level. In accordance with a determination that the Account data table **1506** includes one column (e.g., the User column) having a respective score that meet the threshold level, the rule-based suggestion model **1116** identifies (e.g., the operation **1414**) the User column as an identity column associated with the first vertex "user" **1620**. The rule-based suggestion model **1116** further identifies (e.g., the operation **1416**), based on at least the User column, vertex/vertices and/or edge(s) to automatically form a suggestion to the user **1104**. The identified vertex/vertices is distinct from the first vertex "user" **1620**.

[0225] More specifically, since only one identity column (e.g., the User column), the rule-based suggestion model **1116** moves to the operation **1430**. The rule-based suggestion model **1116** identifies (e.g., the operation **1430**), based on a first predefined rule (e.g., type of a column is numeric string), the AccountNumber column (e.g., "column A") of the Account data table **1506**. The AccountNumber column is distinct from the identity column (e.g., the User column). The rule-based suggestion model **1116** further determines (e.g., the operation **1432-1**) whether the AccountNumber column satisfies the step-one test **1433-1** of the second joining test rule **1433** (e.g., by comparing data types and/or names of a vertex based on the AccountNumber column with existing vertex/vertices including the first vertex "user" **1620** in the initial graph schema **1602-1**). The AccountNumber column does not satisfy the step-one test **1433-1** of the second joining test rule **1433**, because it does not pass type checking, name checking, and/or other tests of joining with the existing identity column (e.g., the User column). The rule-based suggestion model **1116** further determines (e.g., the operation **1432-2**) whether the AccountNumber column satisfies the step-two test **1433-2** of the second joining test rule **1433** (e.g., whether a suggestion for a vertex corresponding to the AccountNumber column can be formed based on the Account data table **1506**). In accordance with a determination that the AccountNumber column satisfies the step-two test **1433-2** of the second joining test rule **1433**, the rule-based suggestion model **1116** further identifies (e.g., the operation **1438**) a vertex corresponding to the AccountNumber column and an edge incident to (e.g., associated with) the identified vertex and the first vertex "user" **1620** to form a suggestion. Subsequently or concurrently, the rule-based suggestion model **1116** further identifies (e.g., operation **1436**) another unused data table from the plurality of transaction trace data tables **1502**. For example, the Transaction data table **1508** is identified as an unused data table in the operation **1436** (e.g., the Transaction data table **1508**

was used in the operations **1404**, **1406**, and **1408** for identifying identity column(s) based on the first vertex "user" **1620**, but the Transaction data table **1508** has not been used in operations associated with the AccountNumber column (e.g., "column A") of the Account data table **1506**). The rule-based suggestion model **1116** further identifies (operation **1440**), based on a joining test rule (e.g., the first joining test rule **1407**), identity column(s) of the Transaction data table **1508** associated with the AccountNumber column. In accordance with a determination that the Transaction data table **1508** includes no identity column associated with the AccountNumber column, the rule-based suggestion model **1116** takes no further action on the Transaction data table **1508**. For example, neither the SenderAccount column nor the ReceiveAccount column of the Transaction data table **1508** is an identity column, because each column includes redundant elements (e.g., Account 0000001 appears twice in the SenderAccount column, Account 0000006 appears three times in the ReceiveAccount column). In some embodiments, the operations **1430** and **1432** (e.g., operations **1432-1** and/or **1432-2**) are repeated for the remaining columns (e.g., including the AccountNumber column) of the Account data table **1506** that are distinct from the User column. This is to ensure that all potential relationships within the Account data table **1506** are explored to update the initial graph schema **1602-1**.

[0226] In some embodiments, as shown in FIG. **16**B, the rule-based suggestion model **1116** automatically generates, based on the vertices corresponding to the User column, a plurality of suggestions **1622** including a "user_to_account" suggestion **1624** and an "account_to_user" suggestion **1626**. The "user_to_account" suggestion **1624** identifies a vertex "account" **1628** (e.g., corresponding to the AccountNumber column of the Account data table **1506**) and a "user_to_account" edge **1630** incident to the vertex "account" **1628** and the first vertex "user" **1620**. Informative indicatives "From: User" and "To: AccountNumber" in the "user_to_account" suggestion **1624** indicate that the "user_to_account" suggestion **1624** provides an edge (e.g., the "user_to_account" edge **1630**) making a connection from the first vertex "user" **1620** to the vertex "account" **1628**. Similarly, the "account_to_user" suggestion **1626** identifies the vertex "account" **1628** and an "account_to_user" edge **1631** incident to the vertex "account" **1628** and the first vertex "user" **1620**. Informative indicatives "From: AccountNumber" and "To: User" in the "account_to_user" suggestion **1626** indicate that the "account_to_user" suggestion **1626** provides an edge (e.g., the "account_to_user" edge **1631**) making a connection from the vertex "account" **1628** to the first vertex "user" **1620**. Moreover, the informative indicatives "From: User" and "To: User" correspond to the column name of the User column of the Account data table **1506**. The informative indicatives "From: AccountNumber" and "To: AccountNumber" correspond to the column name of the AccountNumber column of the Account data table **1506**. Additionally, as shown in FIG. **16**B, the graph schema generator **1102** automatically displays the "user_to_account" suggestion **1624** and the "account_to_user" suggestion **1626** via the graphical interface **1120** to the user **1104**. The user **1104** generates a user input **1632** (e.g., the respective first user input **1122-1'**) to select a respective suggestion from the "user_to_account" suggestion **1624** and the "account to user" suggestion **1626**. In this circumstance, the user input **1632** is a selection of the "user_to_account" suggestion **1624**.

[0227] In some embodiments, the user input **1632** further includes a respective selection of attribute(s) corresponding to the selected respective suggestion. As shown in FIG. **16**C, the user **1104** selects a "Balance" attribute from a plurality of attributes associated with the selected "user_to_account" suggestion **1624**.

[0228] In some embodiments, as shown in FIG. **16**D, the rule-based suggestion model **1116** updates, based on the user input **1628**, the initial graph schema **1602-1** to form a second graph schema **1602-2** (e.g., the updated initial graph schema **1602-1**) including the vertex "account" **1628**, the first vertex "user" **1620**, and the "user_to_account" edge **1630**. The graph schema generator **1102** automatically generates, based on the second graph schema **1602-2** and via the graphical interface **1120**, a second graph-based representation **1604-2**. In some embodiments, the graph schema generator **1102** outputs the second graph schema **1602-2** (e.g., creating a JSON file).

[0229] In some embodiments, the vertex "account" **1628** becomes a vertex for starting a new iteration for expanding vertices and edges and updating the second graph schema **1602-2**. More specifically, in the new iteration, the rule-based suggestion model **1116** receives (e.g., the operation **1402**) the vertex "account" **1628** from the Account data table **1506** of the plurality of transaction trace data tables **1502**. The rule-based suggestion model **1116** further identifies (e.g., the operation **1404**) the Transaction data table **1508** (e.g., an unused data table in the new iteration) of the plurality of transaction trace data tables **1502**. The rule-based suggestion model **1116** further computes (e.g., the operation **1406**), for each column (e.g., TransactionId column, SenderAccount column, ReceiverAccount column, TransactionTimestamp column, and Amount column) of the Transaction data table **1508** and based on the first joining test rule **1407**, a respective score (e.g., pass, no pass, etc.). The rule-based suggestion model **1116** further determines (e.g., the operation **1408**) whether a respective score for each column of the Transaction data table **1508** meets a threshold level (e.g., a point level, a percentage level, or other types of threshold levels). In accordance with a determination that the Transaction data table **1508** includes two columns, the SenderAccount column and the ReceiverAccount column, having scores that meet the threshold level, the rule-based suggestion model **1116** further identifies (e.g., the operation **1410**) the SenderAccount column and the ReceiverAccount column as two identity columns. As shown in FIG. **16**E, the rule-based suggestion model **1116** further identifies (e.g., the operation **1412**), based on at least the two identity columns, edges **1634-1** and **1634-2** (e.g., including self-loops) for the vertex "account" **1628** to automatically form a plurality of suggestions **1636**. Moreover, as shown in FIG. **16**E, the graph schema generator **1102** automatically displays the plurality of suggestions **1636** (e.g., "SenderAccount_to_ReceiverAccount" and "ReceiverAccount_to_SenderAccount") via the graphical interface **1120** to the user **1104**. The user **1104** generates a user input **1638** (e.g., the respective first user input **1122-1'**) to select a respective suggestion from the plurality of suggestions **1636**. In this circumstance, the user input **1632** is a selection of the "SenderAccount_to_ReceiverAccount" suggestion **1636-1** associated with the "SenderAccount_to_ReceiverAccount" edge **1634-1**. In

some embodiments, the edges **1634-1** and **1634-2** are part of a set of edges identified by the rule-based suggestion model **1116** including "SenderAccount_to_ReceiverAccount," "ReceiverAccount_to_SenderAccount," "account_to_SenderAccount," "account_to_ReceiverAccount," "SenderAccount_to_account," and Receiver to account."

[0230] In some embodiments, the user input **1638** further includes a respective selection of attribute(s) corresponding to the selected respective suggestion. As shown in FIG. **16**F, the user **1104** selects an "Amount" attribute and a "TransactionTimeStamp" attribute from a plurality of attributes associated with the selected "SenderAccount_to_ReceiverAccount" suggestion **1636-1**.

[0231] In some embodiments, as shown in FIG. **16**G, the rule-based suggestion model **1116** updates, based on the user input **1638**, the second graph schema **1602-2** to form a third graph schema **1602-3** (e.g., the updated second graph schema **1602-2**) including the vertex "account" **1628**, the first vertex "user" **1620**, the "user_to_account" edge **1630**, and the "SenderAccount_to_ReceiverAccount" edge **1634-1**. The graph schema generator **1102** automatically generates, based on the third graph schema **1602-3** and via the graphical interface **1120**, a third graph-based representation **1604-3**. In some embodiments, the graph schema generator **1102** outputs the third graph schema **1602-3** (e.g., creating a JSON file).

[0232] In some embodiments, as shown in FIG. **16**H, the user **1104** modifies labels of the vertices and edges of the third graph-based representation **1604-3** displayed via the graphical interface **1120**. For example, the user **1104** modifies a title label **1640** from "SenderAccount_to_ReceiverAccount" to "transaction."

[0233] FIG. **17** is a block diagram illustrating a computer system **1700** that supports the data query system (e.g., the example data query systems **100** and **200**, in references to FIGS. **1-2**) and the schema generation system (e.g., the example schema generation systems **1100**, **1200**, and **1300**, in reference to FIGS. **11-13**), in accordance with some embodiments. The computer system **1700** includes one or more central processing units (CPU(s), i.e., processors or cores) **1702**, one or more communication interfaces **1704**, one or more network interfaces **1706**, memory **1710**, and one or more communication buses **1708** for interconnecting these components. The communication buses **1708** optionally include circuitry (e.g., a chipset) that interconnects and controls communications between system components.

[0234] In some embodiments, the one or more network interfaces **1706** include wireless and/or wired interfaces for communicating with databases (e.g., the to-be-queried databases **106** and **202**, the database **1106**, etc.) and other external resources (e.g., APIs, external data resources, external computation resources, etc.). In some embodiments, data communications are carried out using any of a variety of custom or standard wireless protocols (e.g., NFC, RFID, IEEE 802.117.4, Wi-Fi, ZigBee, 6LoWPAN, Thread, Z-Wave, Bluetooth, ISA100.11a, WirelessHART, MiWi, etc.). Furthermore, in some embodiments, data communications are carried out using any of a variety of custom or standard wired protocols (e.g., USB, Firewire, Ethernet, etc.). For example, the one or more network interfaces **1706** include a wireless interface **1707** for enabling wireless data communications with databases (e.g., the to-be-queried databases **106** and **202**, the database **1106**, etc.) and other external resources (e.g., APIs, external data resources, external computation resources, etc.). Furthermore, in some embodiments, the wireless interface **1707** (or a different communications interface of the one or more network interfaces **1706**) enables data communications with other WLAN-compatible components (e.g., devices, servers, clouds, and/or other types) for displaying data, storing data, processing data, or other purposes related to data query.

[0235] Memory **1710** includes high-speed random-access memory, such as DRAM, SRAM, DDR RAM, or other random-access solid-state memory devices; and may include non-volatile memory, such as one or more magnetic disk storage devices, optical disk storage devices, flash memory devices, or other non-volatile solid-state storage devices. Memory **1710** may optionally include one or more storage devices remotely located from the CPU(s) **1702**. Memory **1710**, or alternately, the non-volatile memory solid-state storage devices within memory **1710**, includes a non-transitory computer-readable storage medium. In some embodiments, memory **1710** or the non-transitory computer-readable storage medium of memory **1710** stores the following programs, modules, and data structures, or a subset or superset thereof:

- **[0236]** an operating system **1720** that includes procedures for handling various basic system services and for performing hardware-dependent tasks;
- **[0237]** communication module(s) **1722** for transmitting data, handling protocols (e.g., authentication/encryption), detecting error, and/or other functions;
- **[0238]** network module(s) **1724** for connecting the data query system and the schema generation system to databases and other external resources, via the one or more network interfaces **1706** (wired or wireless);
- **[0239]** a data query module **1726** associated with the data query system (e.g., the example data query systems **100** and **200**, in references to FIGS. **1-2**); In some embodiments, the data query module **1726** also includes the following sub-module(s), or a subset or superset thereof:
  - **[0240]** a graph analytics engine sub-module **1728**;
  - **[0241]** a graph visualization sub-module **1730**;
- **[0242]** a schema generator module **1732** associated with the graph schema generator **1102**; In some embodiments, the schema generation module **1732** also includes the following sub-module(s), or a subset or superset thereof:
  - **[0243]** a graph schema suggestion sub-module **1734**;
  - **[0244]** a graph visualization sub-module **1736**;
- **[0245]** a user interface module **1738** that receives commands and/or inputs from a user via a user interface (e.g., from an input device) and provides outputs for display on the user interface (e.g., to an output device);
- **[0246]** a web browser application **1740** for accessing, viewing, and interacting with web sites; and
- **[0247]** other applications **1742**, such as applications for word processing, calendaring, mapping, weather, time keeping, virtual digital assistant, presenting, number crunching (spreadsheets), drawing, instant messaging, e-mail, telephony, video conferencing, photo management, video management, and/or other purposes.

[0248] Each of the above identified modules stored in memory **1710** corresponds to a set of instructions for performing a function described herein. The above identified modules or programs (i.e., sets of instructions) need not be implemented as separate software programs, procedures, or

modules, and thus various subsets of these modules may be combined or otherwise re-arranged in various embodiments. Likewise, although shown as stored in a single memory, the above-identified modules may be stored on physically separate memories and/or executed on physically separate (e.g., remote) devices. In some embodiments, memory **1710** optionally stores a subset or superset of the respective modules and data structures identified above. Furthermore, memory **1710** optionally stores additional modules and data structures not described above.

[0249] FIG. **18** illustrates a flow diagram of an example data query method **1800**, in accordance with some embodiments. In some embodiments, the example data query method **1800** is performed at a computer system. In some embodiments, the data query method **1800** is governed by instructions that are stored in a non-transitory computer-readable storage medium and that are executed by one or more processors of the computer system.

[0250] (A1) The method **1800** includes receiving (operation **1802**) a query. The query defines (operation **1804**) a graph relationship between target entities within a to-be-queried database. The method **1800** further includes traversing (operation **1806**) the to-be-queried database using the query through a graph analytics engine to obtain a plurality of output entries. Each output entry includes (operation **1808**) a plurality of data items matching the graph relationship defined by the query. The graph analytics engine includes (operation **1810**) an auxiliary component for the query. The auxiliary component includes (operation **1812**) a plurality of vertices and a plurality of edges associated with the to-be-queried database. Each edge links (operation **1814**) two vertices. The method **1800** further includes generating (operation **1816**) a graph-based representation of the plurality of output entries.

[0251] (A2) In some embodiments of A1, traversing the to-be-queried database using the query through the graph analytics engine further comprises: mapping the query into a logical data plan in accordance with the auxiliary component; translating the logical data plan to a physical data plan; and querying, based on the physical data plan, the to-be-queried database through an execution node.

[0252] (A3) In some embodiments of A1-A2, the graph analytics engine includes a plurality of execution nodes. Each execution node is associated with a respective to-be-queried database.

[0253] (A4) In some embodiments of A1-A3, the query is written in a graph query language.

[0254] (A5) In some embodiments of A1-A4, the to-be-queried database is built in accordance with a data architecture. The data architecture includes at least one of relational database, data warehouse, or data lake.

[0255] (A6) In some embodiments of A1-A5, the to-be-queried database defines the graph relationship between the target entities in a tabular form.

[0256] (A7) In some embodiments of A1-A6, the to-be-queried database is compatible with structured query language (SQL).

[0257] (A8) In some embodiments of A1-A7, the to-be-queried database includes a non-SQL (NoSQL) database.

[0258] (A9) In some embodiments of A1-A8, traversing the to-be-queried database using the query through the graph analytics engine further comprises: obtaining catalogs, schemas, and attributes, based on the graph relationship between the target entities; defining the plurality of vertices and the plurality of edges in form of arrays, based on the catalogs, schemas, and attributes; and generating the auxiliary component, based on the plurality of vertices and the plurality of edges.

[0259] (A10) In some embodiments of A1-A9, the auxiliary component is a human-readable file.

[0260] (A11) In some embodiments of A1-A10, the human-readable file is in a standard text-based format, including at least one of JavaScript Object Notation (JSON), Human-Optimized Config Object Notation (HOCON), or Extensible Markup Language (XML).

[0261] (A12) In some embodiments of A1-A11, a respective edge linking two adjacent vertices of the plurality of vertices is directed or undirected.

[0262] (A13) In some embodiments of A1-A12, the respective edge linking two adjacent vertices of the plurality of vertices includes a weight component.

[0263] (A14) In some embodiments of A1-A13, the auxiliary component is created through a user interface associated with the auxiliary component.

[0264] (A15) In some embodiments of A1-A14, generating the graph-based representation of the plurality of output entries further comprises: obtaining a respective graph relationship of the plurality of output entries; optimizing the respective graph relationship of the plurality of output entries for scalability; and visualizing the optimized respective graph relationship of the plurality of output entries.

[0265] (A16) In some embodiments of A1-A15, the receiving the graph query, the traversing the to-be-queried database using the query through the graph analytics engine to obtain the plurality of output entries, and the generating the graph-based representation of the plurality of output entries are performed via an application or a user interface.

[0266] (B1) In accordance with some embodiments, a computer system comprises one or more processors and memory storing one or more programs The one or more programs include instructions that, when executed by the one or more processors, cause the one or more processors to perform operations corresponding to any of A1-A16.

[0267] (C1) In accordance with some embodiments, a non-transitory computer readable storage medium stores one or more programs. The one or more programs include instructions that, when executed by a computer system that includes one or more processors, cause the one or more processors to perform operations corresponding to any of A1-A16.

[0268] FIG. **19** illustrates a flow diagram of an example schema generation method **1900**, in accordance with some embodiments. In some embodiments, the example schema generation method **1900** is performed at a computer system. In some embodiments, the example schema generation method **1900** is governed by instructions that are stored in a non-transitory computer-readable storage medium and that are executed by one or more processors of the computer system.

[0269] (D1) The method **1900** includes receiving (operation **1902**) a graph schema that includes vertices and edges associated with a plurality of data tables. The

graph schema includes (operation **1904**) at least a first vertex from a first data table of the plurality of data tables. The schema generation method **1900** further includes automatically generating (operation **1906**), based on the plurality of data tables and the graph schema, one or more suggestions using a computational model. The one or more suggestions identify (operation **1908**) at least one of the group consisting of one or more vertices and one or more edges. The one or more suggestions include (operation **1910**) a respective suggestion that identifies a respective subset of the at least one of the group consisting of the one or more vertices and the one or more edges. The one or more vertices are (operation **1912**) distinct from the first vertex. The schema generation method **1900** further includes receiving (operation **1914**) a first user input. The first user input is (operation **1916**) a selection of the respective suggestion from the one or more suggestions. The schema generation method **1900** further includes updating (operation **1918**), based on the first user input, the graph schema. The schema generation method **1900** further includes outputting (operation **1920**) the updated graph schema.

[0270] (D2) In some embodiments of D1, the schema generation method **1900** further includes iteratively receiving a respective graph schema, automatically generating a respective suggestion, receiving a respective first user input, and updating the respective graph schema for a plurality of iterations to expand vertices and edges associated with the respective graph schema. Each iteration of the plurality of iterations corresponds to a respective updated graph schema. Each edge links two vertices.

[0271] (D3) In some embodiments of D1-D2, the computational model includes a plurality of models. Iteratively receiving the respective graph schema, automatically generating the respective suggestion, receiving the respective first user input, and updating the respective graph schema for the plurality of iterations to expand vertices and edges associated with the respective graph schema includes: in each iteration, receiving a respective second user input for selecting a respective model from the plurality of models and in response to the respective second user input, automatically generating, based on the plurality of data tables and the respective graph schema, the respective suggestion using the respective model.

[0272] (D4) In some embodiments of D1-D3, the computational model includes a rule-based suggestion model corresponding to a predefined rule.

[0273] (D5) In some embodiments of D1-D4, the computational model includes an intelligence model for executing large language models.

[0274] (D6) In some embodiments of D1-D5, the predefined rule includes a joining test rule. Automatically generating the one or more suggestions using the computational model includes identifying a second data table from the plurality of data tables. The second data table is distinct from the first data table. Automatically generating the one or more suggestions using the computational model further includes computing, for each column of the second data table and based on the joining test rule, a respective score. Automatically generating the one or more suggestions using the computational model further includes in accordance with a determination that the second data table includes two or more columns having scores that meet a threshold level, identifying, based on at least the second data table, a first set of edges to form a first suggestion. Automatically generating the one or more suggestions using the computational model further includes in accordance with a determination that the second data table includes one or more columns having scores that meet the threshold level, identifying, based on at least the second data table, a second set of edges and/or a first set of vertices to form a second suggestion. The first set of vertices is distinct from the first vertex.

[0275] (D7) In some embodiments of D1-D6, updating the graph schema includes adding the respective subset of the at least one of the group consisting of the one or more vertices and the one or more edges into the graph schema.

[0276] (D8) In some embodiments of D1-D7, the schema generation method **1900** further includes receiving a third user input for identifying an initial vertex from the plurality of data tables. The schema generation method **1900** further includes in response to the third user input, automatically generating the graph schema including the initial vertex.

[0277] (D9) In some embodiments of D1-D8, the schema generation method **1900** further includes receiving a user request. The schema generation method **1900** further includes in response to the user request, receiving the plurality of data tables.

[0278] (D10) In some embodiments of D1-D9, the schema generation method **1900** further includes displaying the one or more suggestions via a graphical interface.

[0279] (D11) In some embodiments of D1-D10, the schema generation method **1900** further includes displaying, based on at least one of the graph schema or the updated graph schema, a graph-based representation via a graphical interface.

[0280] (D12) In some embodiments of D1-D11, the plurality of data tables are relational data tables.

[0281] (D13) In some embodiments of D1-D12, the plurality of data tables are stored in at least one of the group consisting of relational database, data warehouse, and data lake.

[0282] (D14) In some embodiments of D1-D13, the receiving the graph schema, the automatically generating the one or more suggestions, the receiving the first user input, the updating the graph schema, and the outputting the updated graph schema are performed via an application or a user interface.

[0283] (E1) In accordance with some embodiments, a computer system comprises one or more processors and memory storing one or more programs. The one or more are configured to be executed by the one or more processors. The one or more programs include instructions corresponding to any of D1-D14.

[0284] (F1) In accordance with some embodiments, a non-transitory computer readable storage medium stores one or more programs. The one or more programs include instructions that, when executed by a computer system that includes one or more processors, cause the one or more processors to perform operations corresponding to any of D1-D14.

[0285] It should be understood that the particular order in which the operations in FIGS. **18** and **19** have been described are merely exemplary and are not intended to indicate that the described order is the only order in which the operations could be performed. One of ordinary skill in the art would recognize various ways to provide a computer system for performing data queries. It is also noted that more details on the data query method are explained above with reference to FIGS. **1-17**. For brevity, these details are not repeated in the description herein.

[0286] It will be understood that, although the terms "first," "second," etc. may be used herein to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another.

[0287] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the claims. As used in the description of the embodiments and the appended claims, the singular forms "a," "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will also be understood that the term "and/or" as used herein refers to and encompasses any and all possible combinations of one or more of the associated listed items. It will be further understood that the terms "comprises" and/or "comprising," 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.

[0288] As used herein, the term "if" can be construed to mean "when" or "upon" or "in response to determining" or "in accordance with a determination" or "in response to detecting," that a stated condition precedent is true, depending on the context. Similarly, the phrase "if it is determined [that a stated condition precedent is true]" or "if [a stated condition precedent is true]" or "when [a stated condition precedent is true]" can be construed to mean "upon determining" or "in response to determining" or "in accordance with a determination" or "upon detecting" or "in response to detecting" that the stated condition precedent is true, depending on the context.

[0289] The foregoing description, for purpose of explanation, has been described with reference to specific embodiments. However, the illustrative discussions above are not intended to be exhaustive or to limit the claims to the precise forms disclosed. Many modifications and variations are possible in view of the above teachings. The embodiments were chosen and described in order to best explain principles of operation and practical applications, to thereby enable others skilled in the art.

What is claimed is:

1. A schema generation method, comprising:

receiving a graph schema that includes vertices and edges associated with a plurality of data tables, the graph schema including at least a first vertex from a first data table of the plurality of data tables;

automatically generating, based on the plurality of data tables and the graph schema, one or more suggestions using a computational model, wherein the one or more suggestions identify at least one of the group consisting of one or more vertices and one or more edges, the one or more suggestions including a respective suggestion that identifies a respective subset of the at least one of the group consisting of the one or more vertices and the one or more edges, the one or more vertices distinct from the first vertex;

receiving a first user input, wherein the first user input is a selection of the respective suggestion from the one or more suggestions;

updating, based on the first user input, the graph schema; and

outputting the updated graph schema.

2. The schema generation method of claim **1**, including:

iteratively receiving a respective graph schema, automatically generating a respective suggestion, receiving a respective first user input, and updating the respective graph schema for a plurality of iterations to expand vertices and edges associated with the respective graph schema, each iteration of the plurality of iterations corresponding to a respective updated graph schema, each edge linking two vertices.

3. The schema generation method of claim **2**, wherein:

the computational model includes a plurality of models; and

iteratively receiving the respective graph schema, automatically generating the respective suggestion, receiving the respective first user input, and updating the respective graph schema for the plurality of iterations to expand vertices and edges associated with the respective graph schema includes:

in each iteration:

receiving a respective second user input for selecting a respective model from the plurality of models; and

in response to the respective second user input, automatically generating, based on the plurality of data tables and the respective graph schema, the respective suggestion using the respective model.

4. The schema generation method of claim **1**, wherein the computational model includes a rule-based suggestion model corresponding to a predefined rule.

5. The schema generation method of claim **1**, wherein the computational model includes an intelligence model for executing large language models.

6. The schema generation method of claim **4**, wherein:

the predefined rule includes a joining test rule; and

automatically generating the one or more suggestions using the computational model includes:

identifying a second data table from the plurality of data tables, the second data table distinct from the first data table;

computing, for each column of the second data table and based on the joining test rule, a respective score;

in accordance with a determination that the second data table includes two or more columns having scores that meet a threshold level:

identifying, based on at least the second data table, a first set of edges to form a first suggestion; and

in accordance with a determination that the second data table includes one or more columns having scores that meet the threshold level:

identifying, based on at least the second data table, a second set of edges and/or a first set of vertices to form a second suggestion, the first set of vertices distinct from the first vertex.

7. The schema generation method of claim 1, wherein:
updating the graph schema includes adding the respective subset of the at least one of the group consisting of the one or more vertices and the one or more edges into the graph schema.

8. The schema generation method of claim 1, including:
receiving a third user input for identifying an initial vertex from the plurality of data tables; and
in response to the third user input, automatically generating the graph schema including the initial vertex.

9. The schema generation method of claim 1, including:
receiving a user request; and
in response to the user request, receiving the plurality of data tables.

10. The schema generation method of claim 1, including:
displaying the one or more suggestions via a graphical interface.

11. The schema generation method of claim 1, including:
displaying, based on at least one of the graph schema or the updated graph schema, a graph-based representation via a graphical interface.

12. The schema generation method of claim 1, wherein the plurality of data tables are relational data tables.

13. The schema generation method of claim 1, wherein the plurality of data tables are stored in at least one of the group consisting of relational database, data warehouse, and data lake.

14. The schema generation method of claim 1, wherein the receiving the graph schema, the automatically generating the one or more suggestions, the receiving the first user input, the updating the graph schema, and the outputting the updated graph schema are performed via an application or a user interface.

15. A computer system, comprising:
one or more processors; and
memory storing one or more programs, wherein the one or more programs are configured to be executed by the one or more processors, the one or more programs including instructions for:
receiving a plurality of data tables, wherein the plurality of data tables have vertices and edges;
receiving a graph schema that includes at least a first vertex from a first data table of the plurality of data tables;
automatically generating, based on the plurality of data tables and the graph schema, a suggestion using a computational model, wherein the suggestion identifies at least one of the group consisting of one or more edges and one or more vertices, the one or more vertices distinct from the first vertex;
receiving a first user input corresponding to the suggestion;
updating, based on the first user input, the graph schema; and
outputting the updated graph schema.

16. The computer system of claim 15, wherein the one or more programs include instructions for:
iteratively receiving a respective graph schema, automatically generating a respective suggestion, receiving a respective first user input, and updating the respective graph schema for a plurality of iterations to expand vertices and edges associated with the respective graph schema, each iteration of the plurality of iterations corresponding to a respective updated graph schema, each edge linking two vertices.

17. The computer system of claim 16, wherein:
the computational model includes a plurality of models; and
iteratively receiving the respective graph schema, automatically generating the respective suggestion, receiving the respective first user input, and updating the respective graph schema for the plurality of iterations to expand vertices and edges associated with the respective graph schema includes:
in each iteration:
receiving a respective second user input for selecting a respective model from the plurality of models; and
in response to the respective second user input, automatically generating, based on the plurality of data tables and the respective graph schema, the respective suggestion using the respective model.

18. A non-transitory computer-readable storage medium storing one or more programs, the one or more programs comprising instructions that, when executed by a computer system that includes one or more processors, cause the one or more processors to perform operations, comprising:
receiving a plurality of data tables, wherein the plurality of data tables have vertices and edges;
receiving a graph schema that includes at least a first vertex from a first data table of the plurality of data tables;
automatically generating, based on the plurality of data tables and the graph schema, a suggestion using a computational model, wherein the suggestion identifies at least one of the group consisting of one or more edges and one or more vertices, the one or more vertices distinct from the first vertex;
receiving a first user input corresponding to the suggestion;
updating, based on the first user input, the graph schema; and
outputting the updated graph schema.

19. The non-transitory computer-readable storage medium of claim 18, wherein the one or more programs include instructions that, when executed by the computer system, cause the computer system to perform operations, including:
iteratively receiving a respective graph schema, automatically generating a respective suggestion, receiving a respective first user input, and updating the respective graph schema for a plurality of iterations to expand vertices and edges associated with the respective graph schema, each iteration of the plurality of iterations corresponding to a respective updated graph schema, each edge linking two vertices.

20. The non-transitory computer-readable storage medium 19, wherein:
the computational model includes a plurality of models; and
iteratively receiving the respective graph schema, automatically generating the respective suggestion, receiving the respective first user input, and updating the respective graph schema for the plurality of iterations to expand vertices and edges associated with the respective graph schema includes:
in each iteration:

receiving a respective second user input for selecting a respective model from the plurality of models; and

in response to the respective second user input, automatically generating, based on the plurality of data tables and the respective graph schema, the respective suggestion using the respective model.

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