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(54) **METHOD FOR PERFORMING DATA QUERY USING A GRAPH ANALYTICS ENGINE AND RELATED APPARATUS**

(71) Applicant: **PuppyQuery Inc.**, Santa Clara, CA (US)

(72) Inventors: **Weimo LIU**, Santa Clara, CA (US); **Danfeng XU**, Belmont, CA (US); **Lei HUANG**, Fremont, CA (US)

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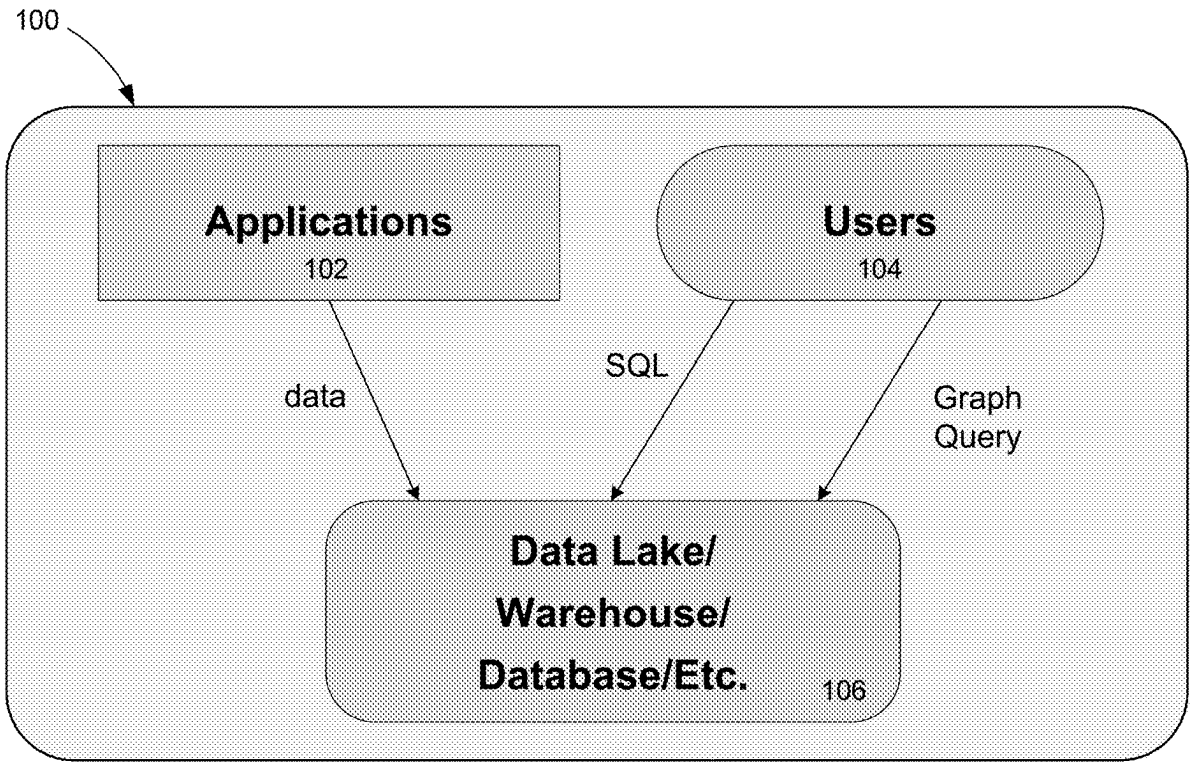
G06F 16/2453	(2019.01)

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

CPC ***G06F 16/24526*** (2019.01); ***G06F 16/2428*** (2019.01); ***G06F 16/24542*** (2019.01)

(57) **ABSTRACT**

This application is directed to data query. A data query method includes 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 output entries. Each output entry includes 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 vertices and 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 output entries.



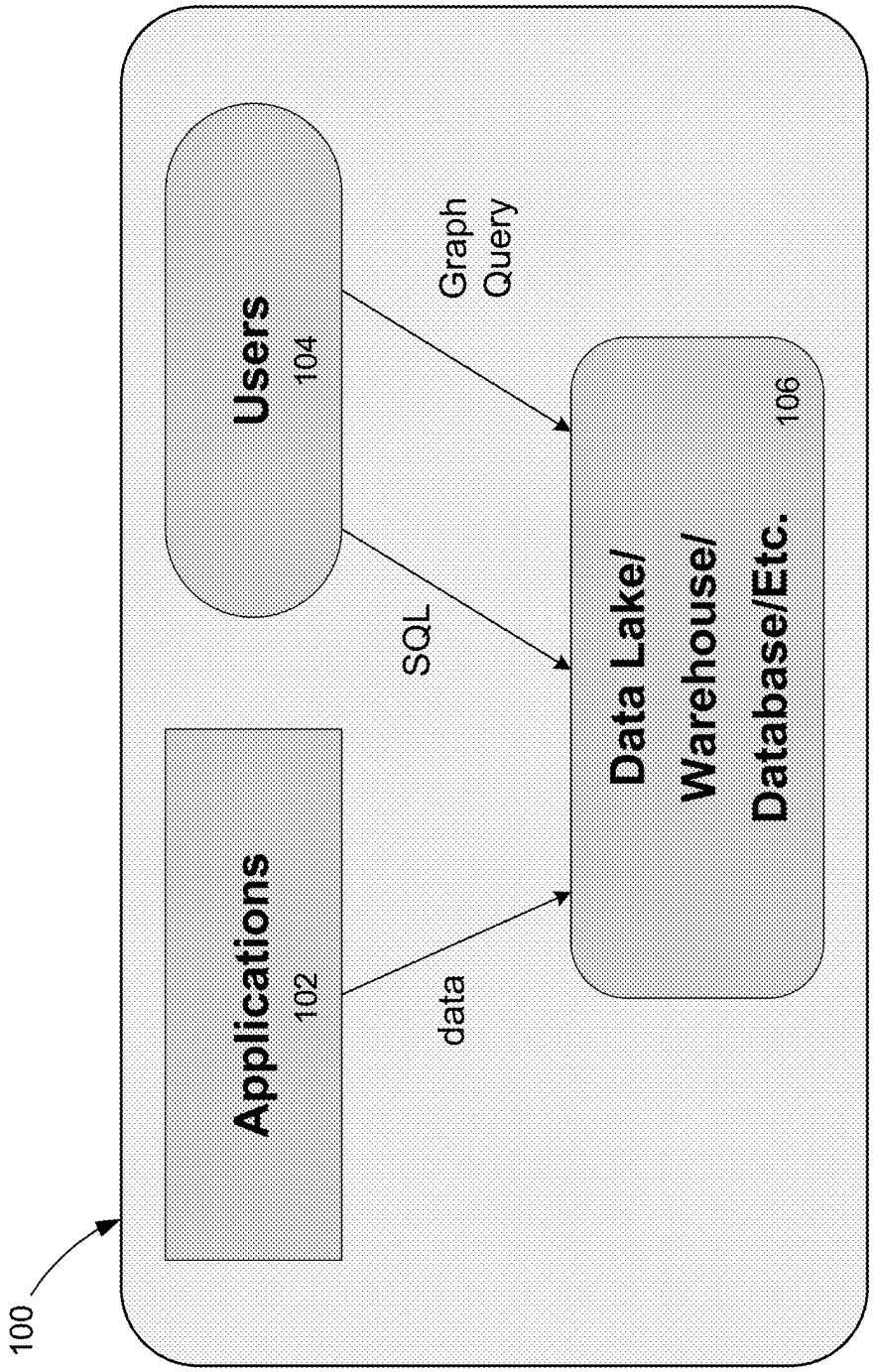

100
Applications
102
Users
104
Data Lake/
Warehouse/
Database/Etc.
106
data
SQL
Graph
Query

Figure 1

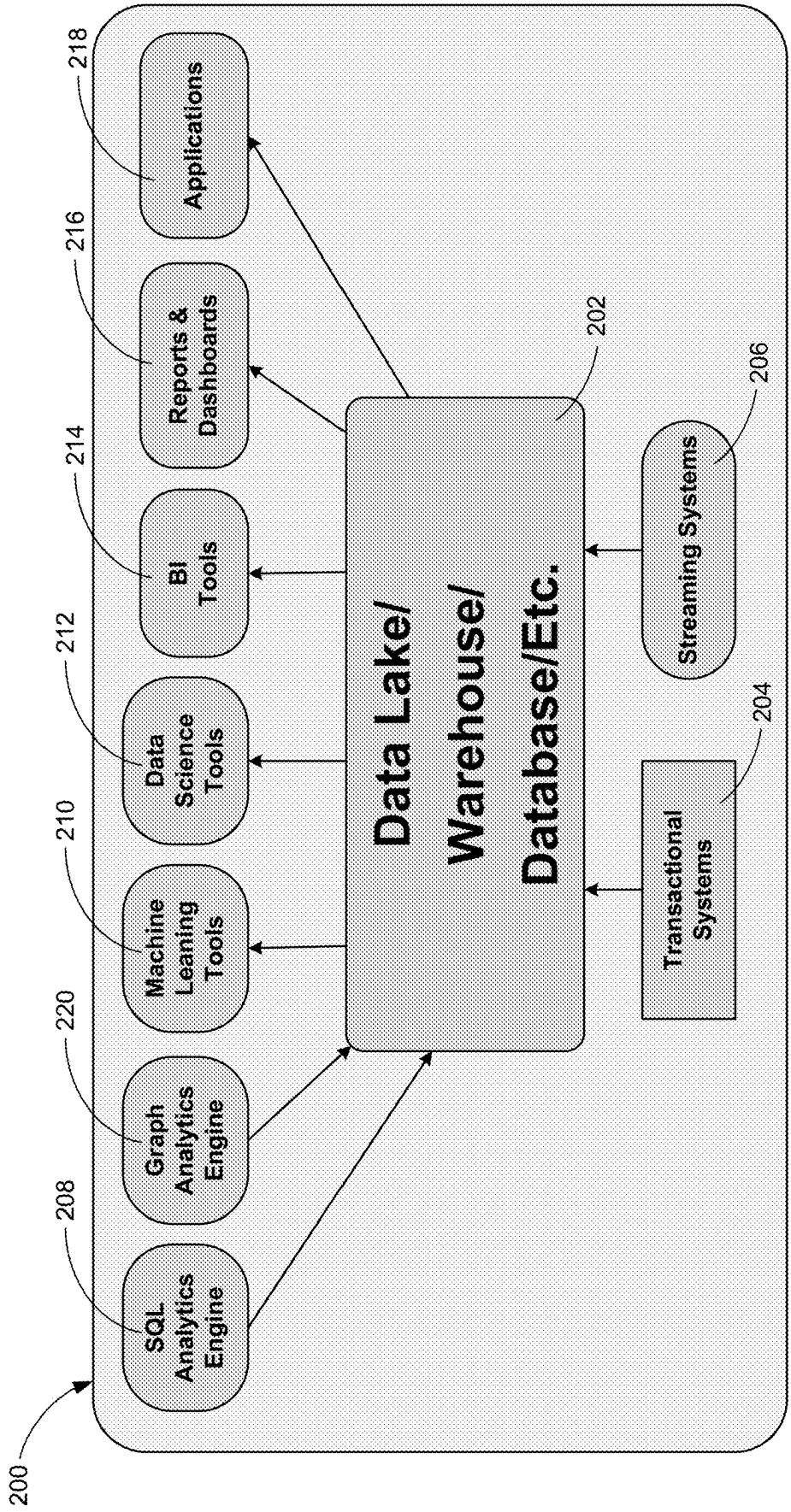

200
208
SQL Analytics Engine
220
Graph Analytics Engine
210
Machine Leaning Tools
212
Data Science Tools
214
BI Tools
216
Reports & Dashboards
218
Applications
Data Lake/ Warehouse/ Database/Etc.
202
Transactional Systems
204
Streaming Systems
206

Figure 2

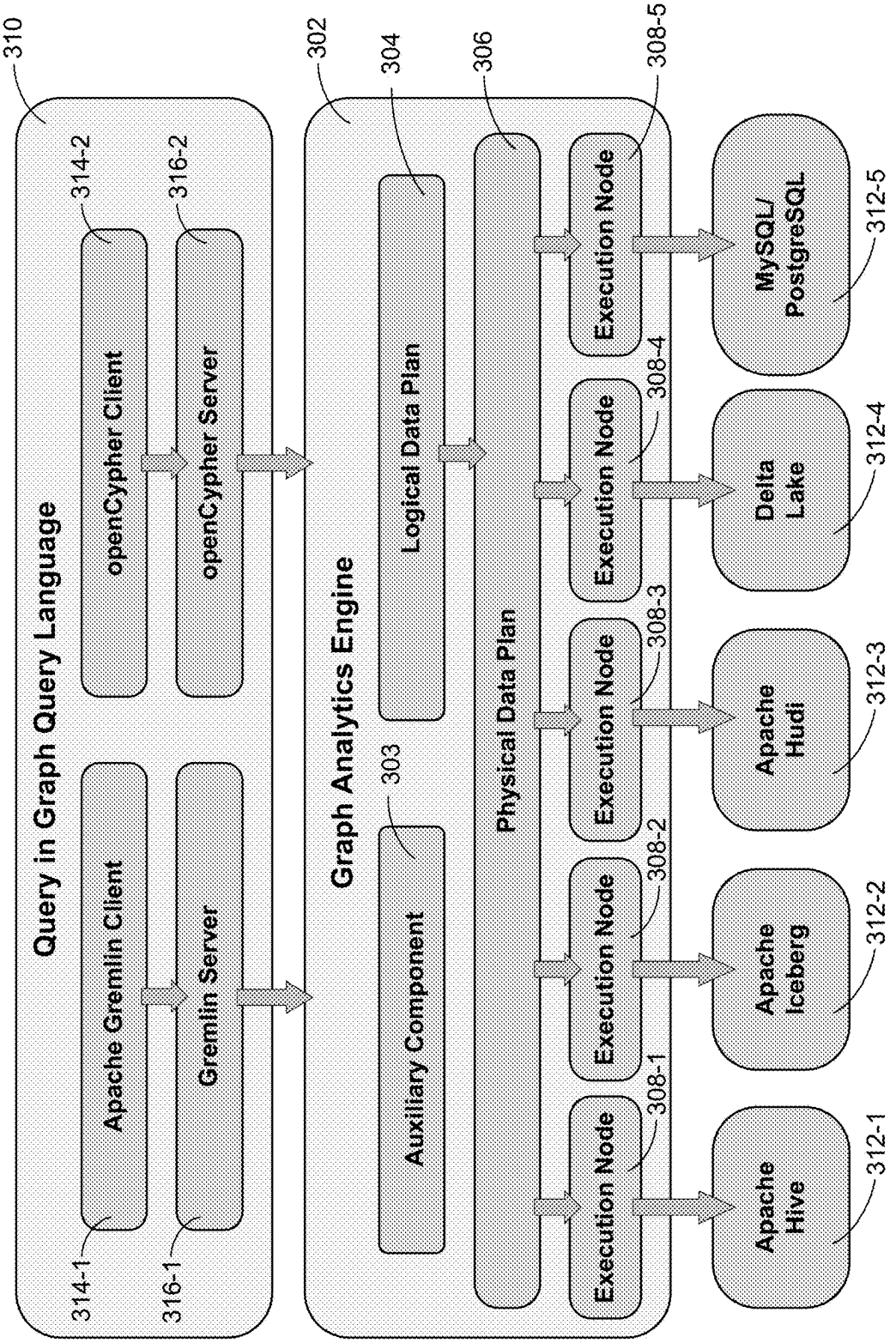
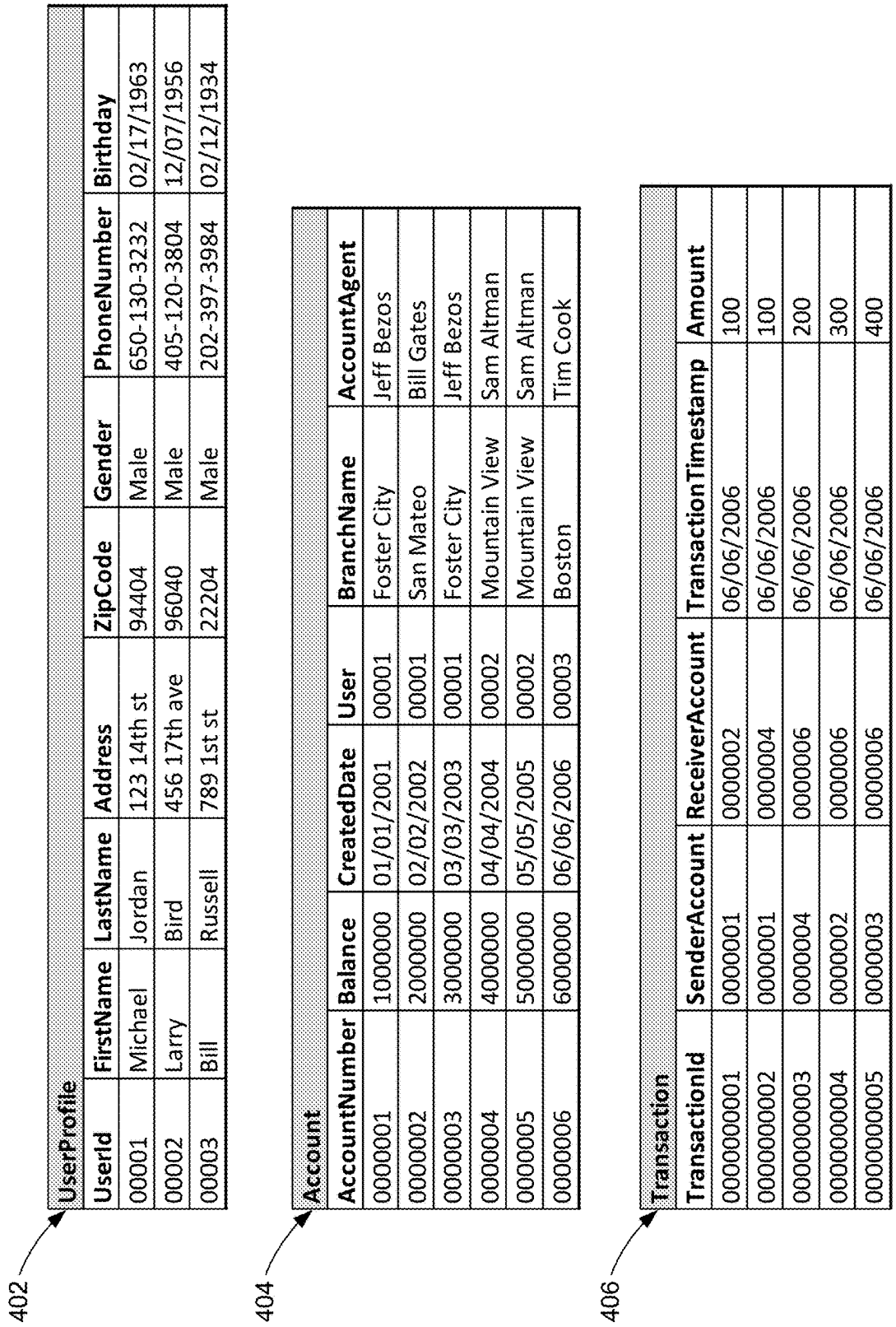

300
310
Query in Graph Query Language
314-2
openCypher Client
316-2
openCypher Server
Apache Gremlin Client
314-1
Gremlin Server
316-1
302
Graph Analytics Engine
304
Logical Data Plan
306
Physical Data Plan
303
Auxiliary Component
Execution Node
308-1
Execution Node
308-2
Execution Node
308-3
Execution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

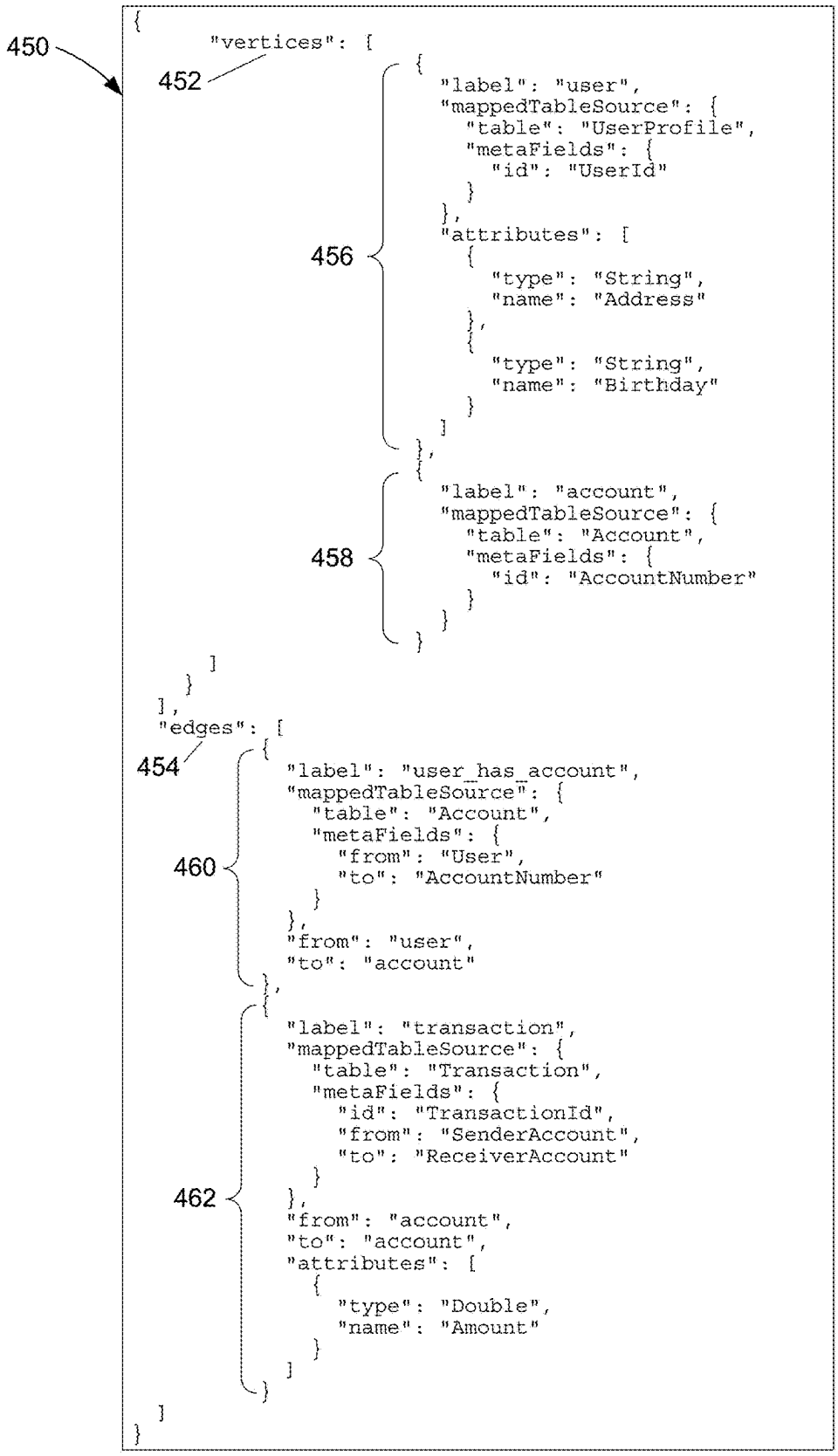

450
452
456
458
454
460
462
{
"vertices": [
{
"label": "user",
"mappedTableSource": {
"table": "UserProfile",
"metaFields": {
"id": "UserId"
}
},
"attributes": [
{
"type": "String",
"name": "Address"
},
{
"type": "String",
"name": "Birthday"
}
]
},
{
"label": "account",
"mappedTableSource": {
"table": "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

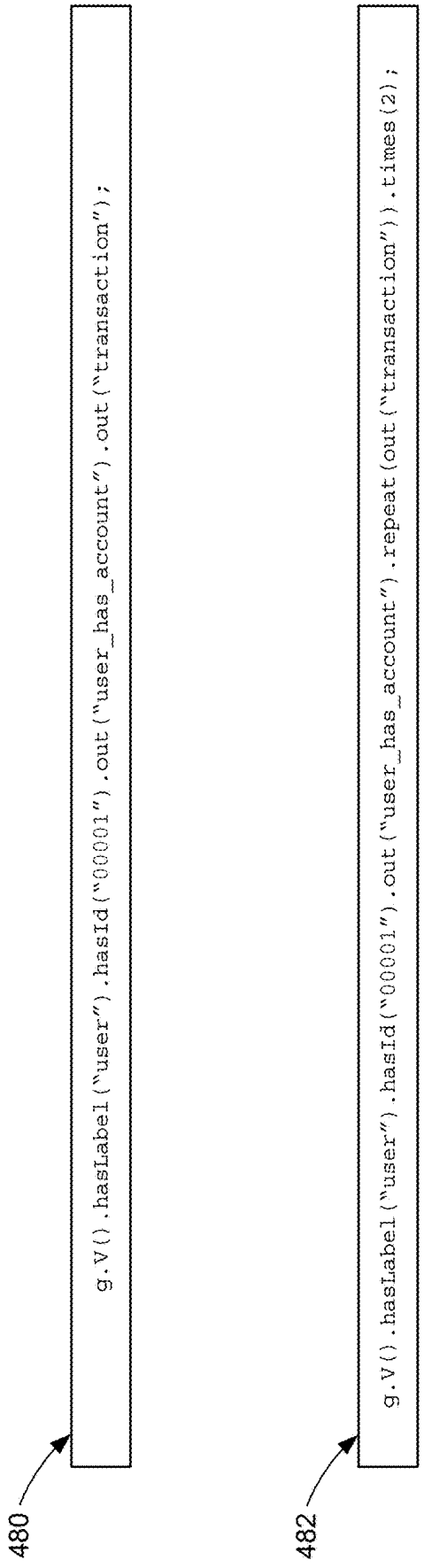

g.V().hasLabel("user").hasId("00001").out("user_has_account").out("transaction");
g.V().hasLabel("user").hasId("00001").out("user_has_account").repeat(out("transaction")).times(2);
480
482

Figure 4C


500
510
512
514
TABLE OVERVIEW
ACTIVITY
SNAPSHOTS
ACCESS CONTROL
SETTINGS
89.89 KB
0.0%
puppy_small_v_person
Table storing the records for every person in the social network
Not partitioned
Optional
id
long
The identifier of the person
firstName
string
The first name of the person
lastName
string
The last name of the person
gender
string
The gender of the person
birthday
timestamptz
The birthday of the person
creationDate
timestamptz
The date the person joined the social network
locationIP
string
The IP of the location from which the person was registered to the social network
browserUsed
string
The browser used when the person registered to the social network
language
string
The languages the person speaks
email
string
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

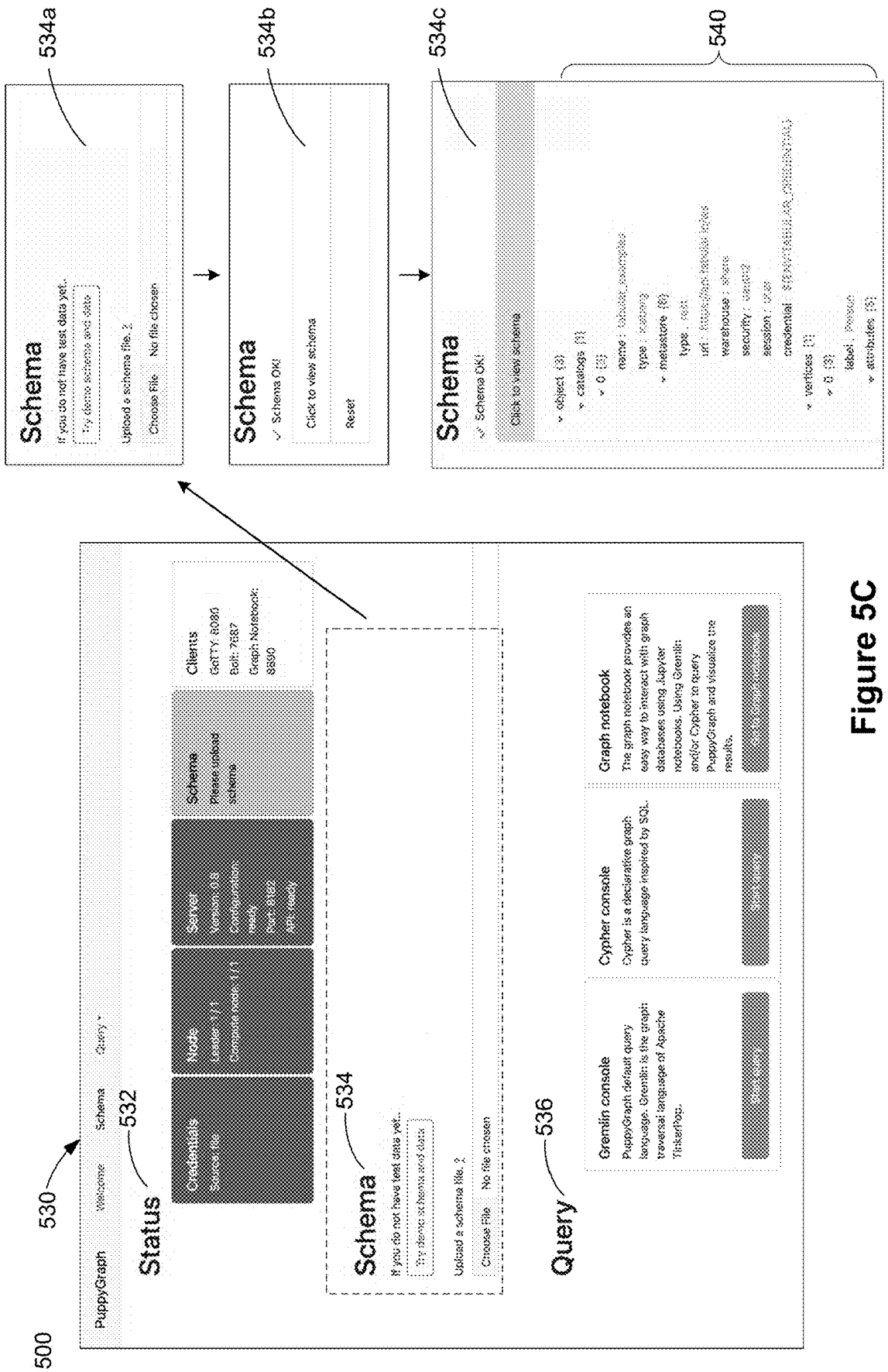

500
530
PuppyGraph
Welcome
Schema
Query *
Status
532
Credentials
Schema file
Nodes
Edges
Schema
Please upload schema
Clients
Gremlin console
PuppyGraph default query language. Gremlin is the graph traversal language of Apache TinkerPop.
Cypher console
Cypher is a declarative graph query language inspired by SQL.
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.
Schema
534
If you do not have test data yet..
Try demo schema and data
Upload a schema file. 2
Choose File
No file chosen
Query
536
Schema
534a
If you do not have test data yet..
Try demo schema and data
Upload a schema file. 2
Choose File
No file chosen
Schema
534b
Schema OK!
Click to view schema
Reset
Schema
534c
Schema OK!
Click to view schema
540

Figure 5C

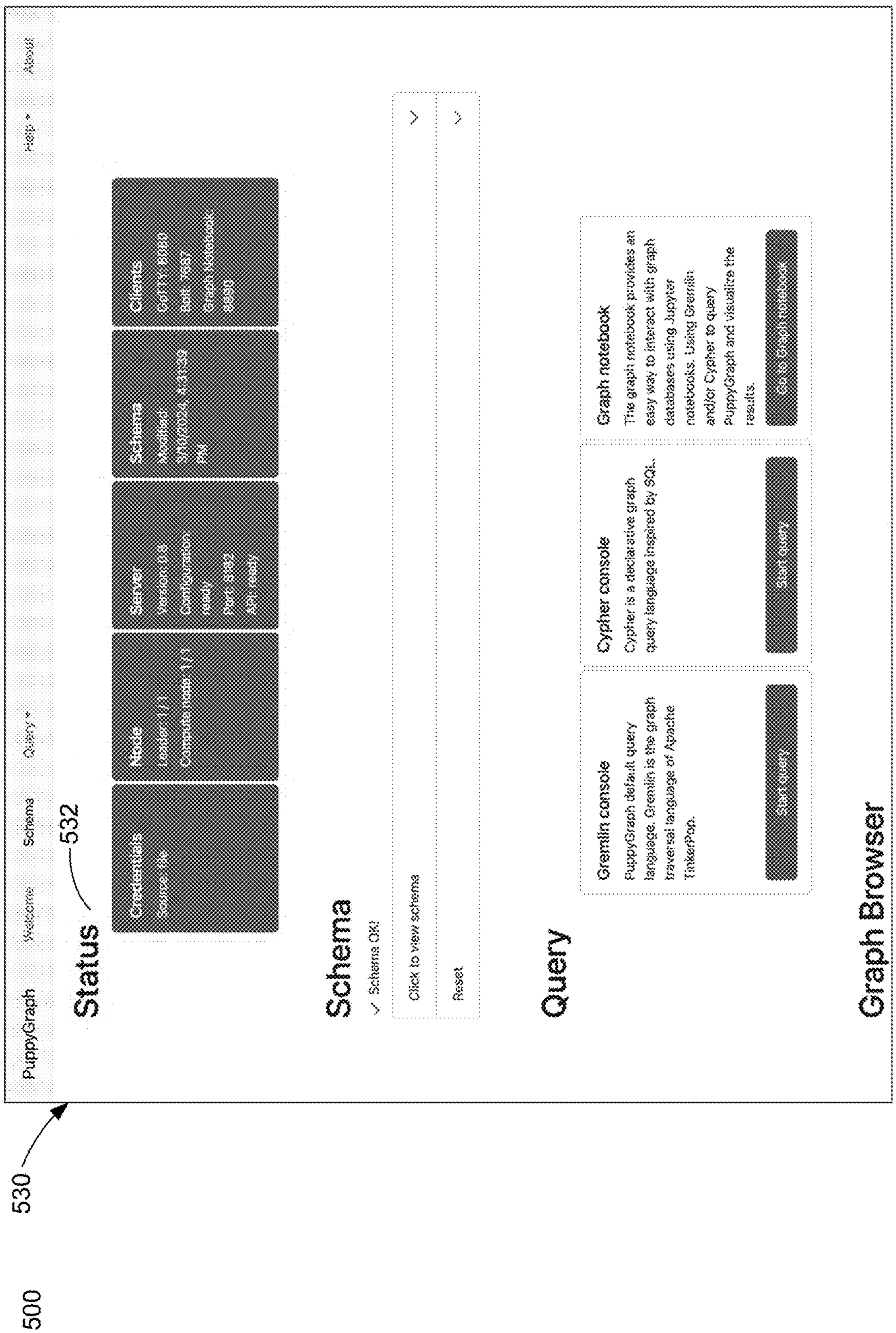

500
530
532
PuppyGraph
Welcome
Schema
Query
Help
About
Status
Credentials
Source file
Node
Leader 1/1
Compute node 1/1
Server
Version 0.8
Configuration ready
Port 8182
API ready
Schema
Modified
PM
Clients
Schema
Schema OK!
Click to view schemas
Reset
Query
Gremlin console
PuppyGraph default query language. 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
Graph Browser

Figure 5D

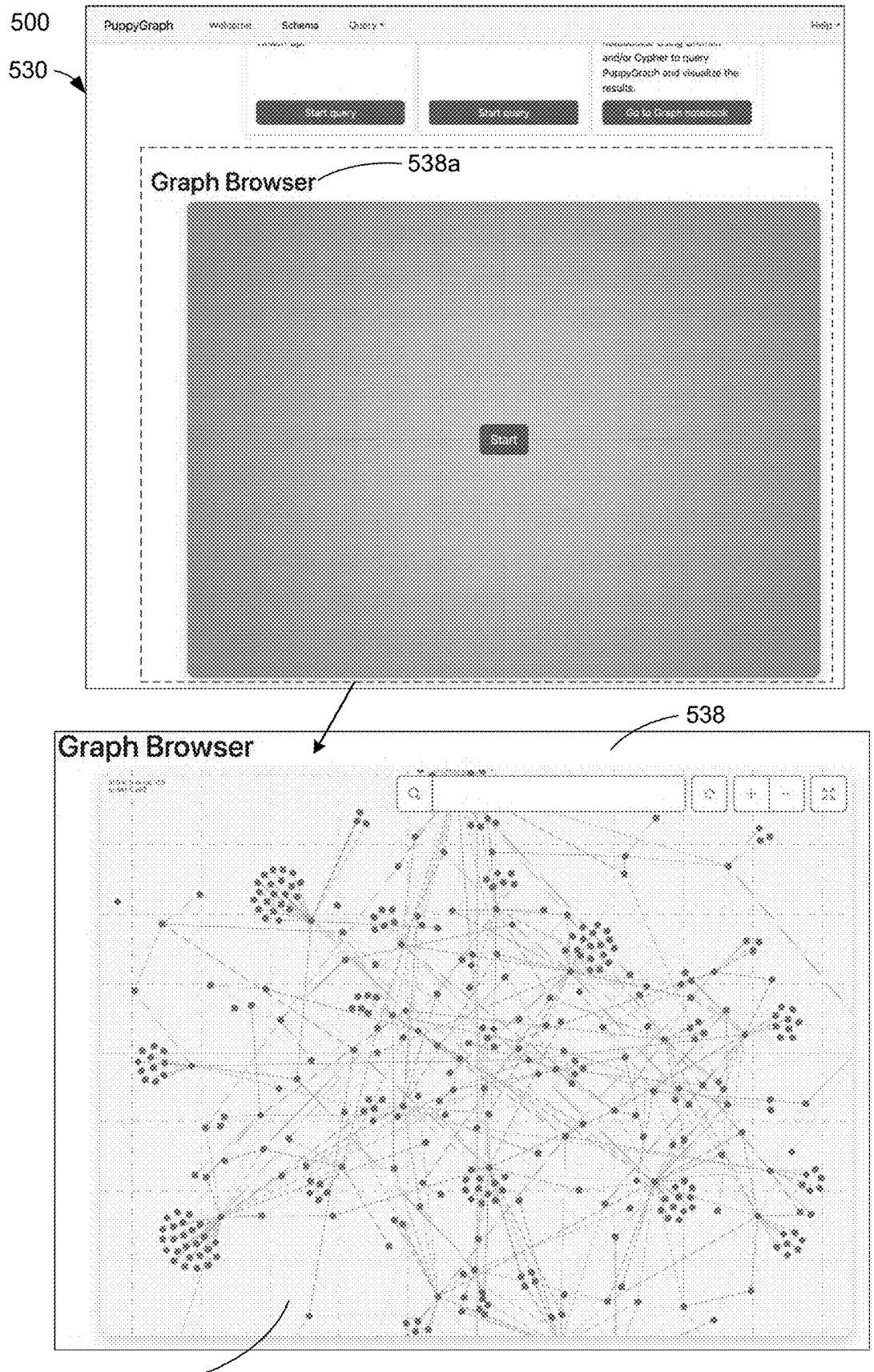

500
530
PuppyGraph
Welcome
Schema
Query
Help
and/or Cypher to query
PuppyGraph and visualize the
results.
Graph Browser
538a
Graph Browser
538
542

Figure 5E

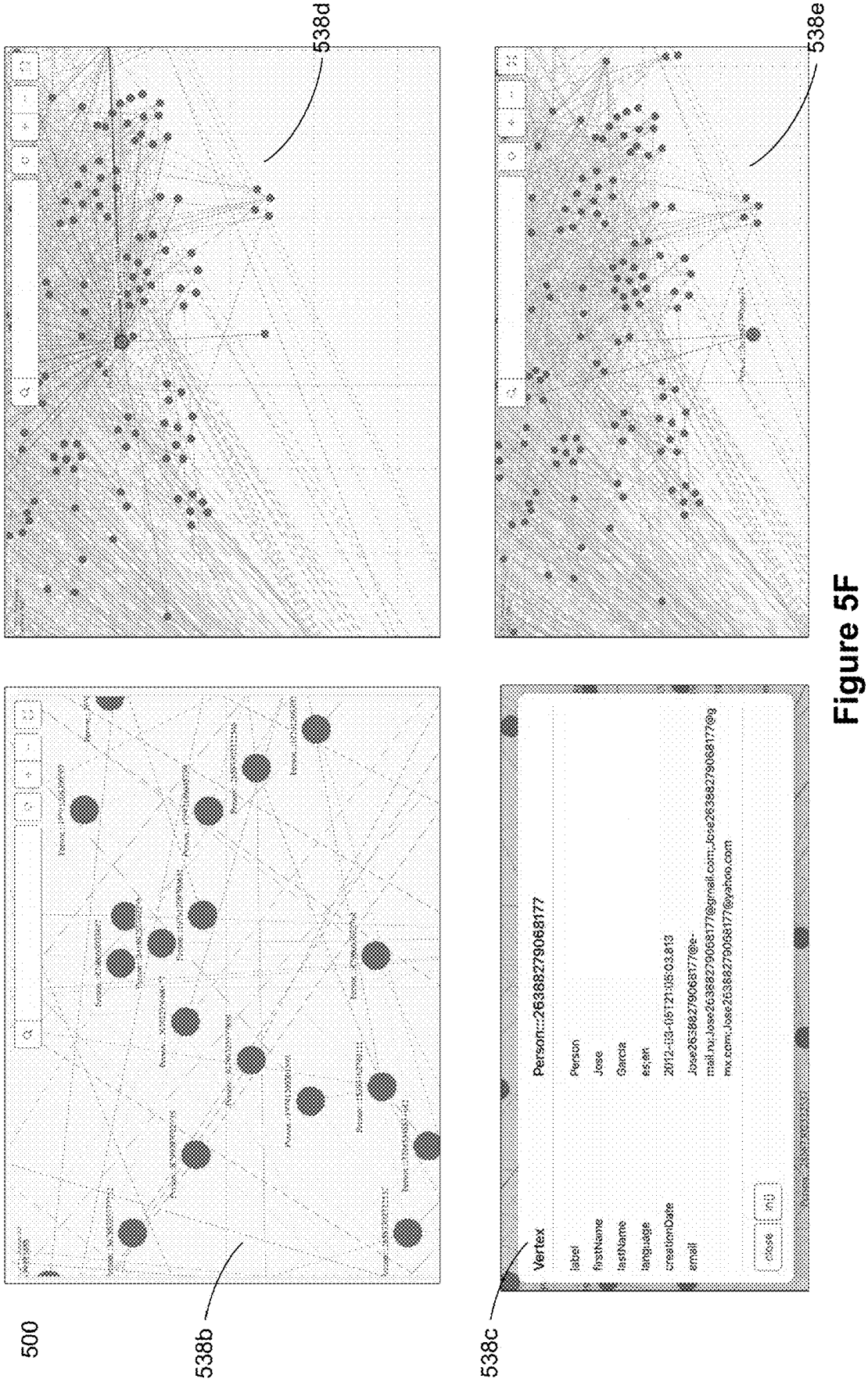
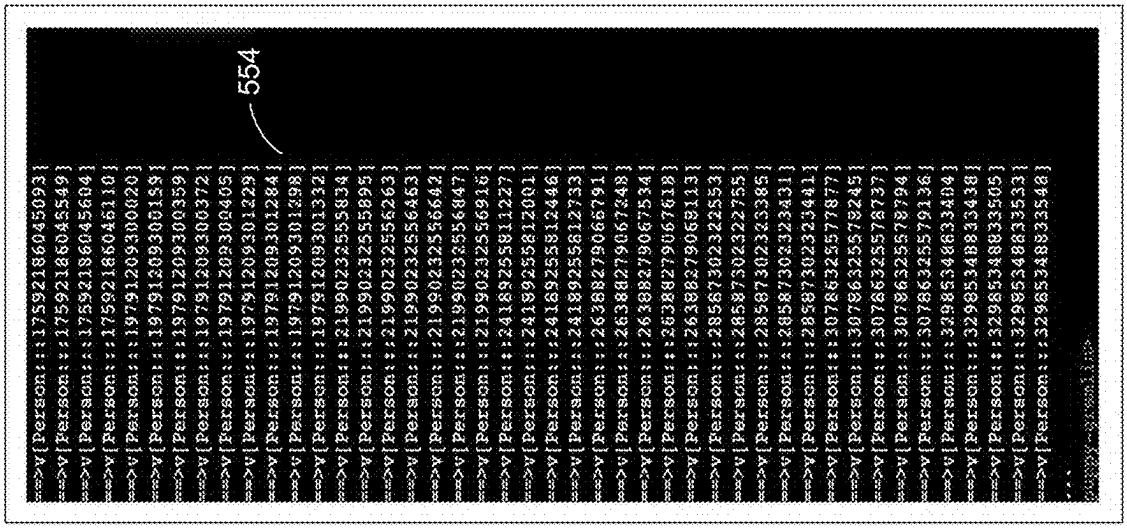

500
538b
538c
538d
538e
Vertex
Person:::2638827906817
label
Person
firstName
Jose
lastName
Garcia
language
es;en
creationDate
2012-03-05T21:05:03.813
email
Jose2638827906817@e-mail.xx;Jose2638827906817@gmail.com;Jose2638827906817@gmx.com;Jose2638827906817@yahoo.com
close
edit

Figure 5F


554

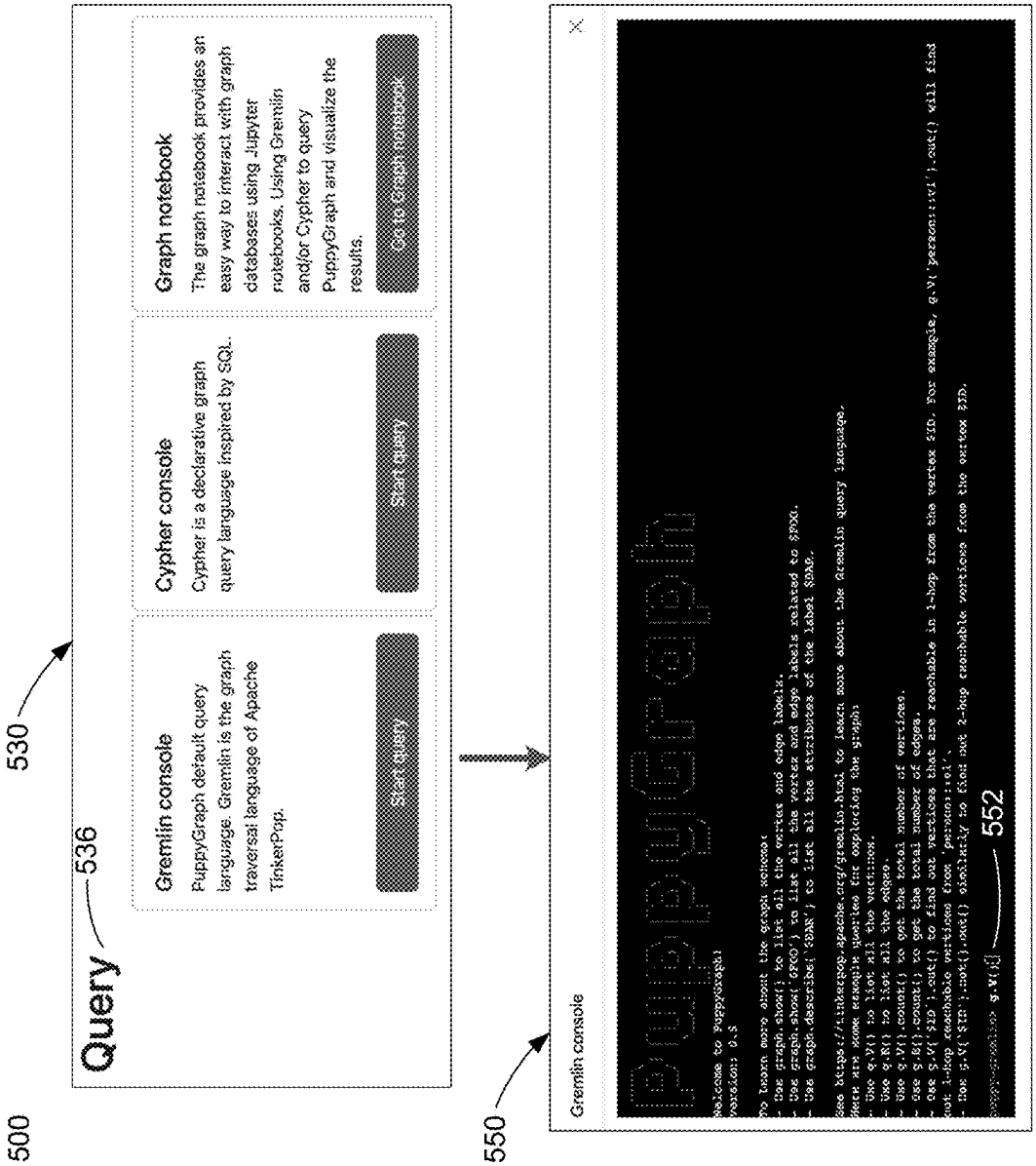

500
530
Query
536
Gremlin console
PuppyGraph default query language. Gremlin is the graph traversal language of Apache TinkerPop.
Start query
Cypher console
Cypher is a declarative graph query language inspired by SQL.
Start query
Graph notebook
The graph notebook provides an easy way to interact with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

Figure 5G

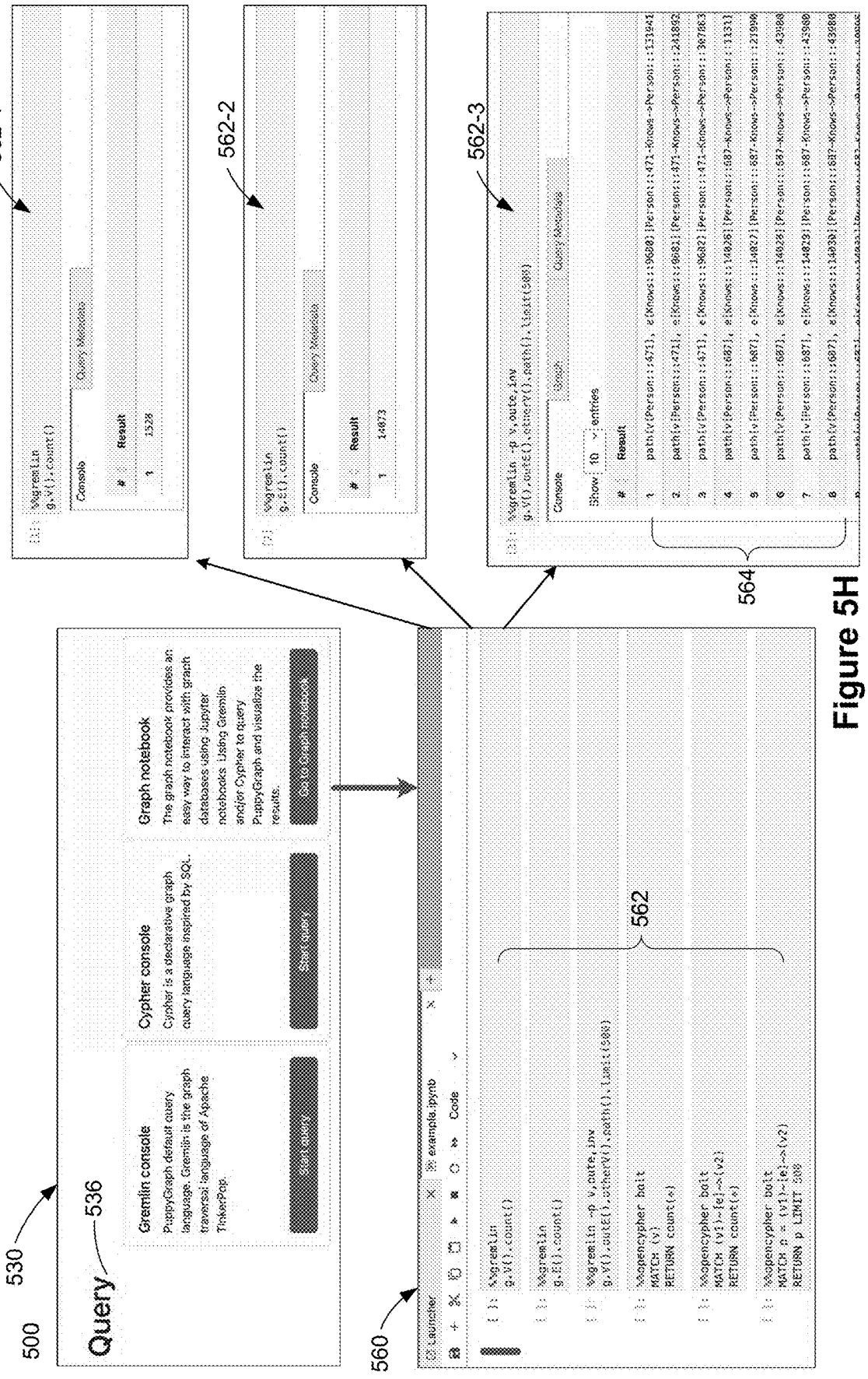
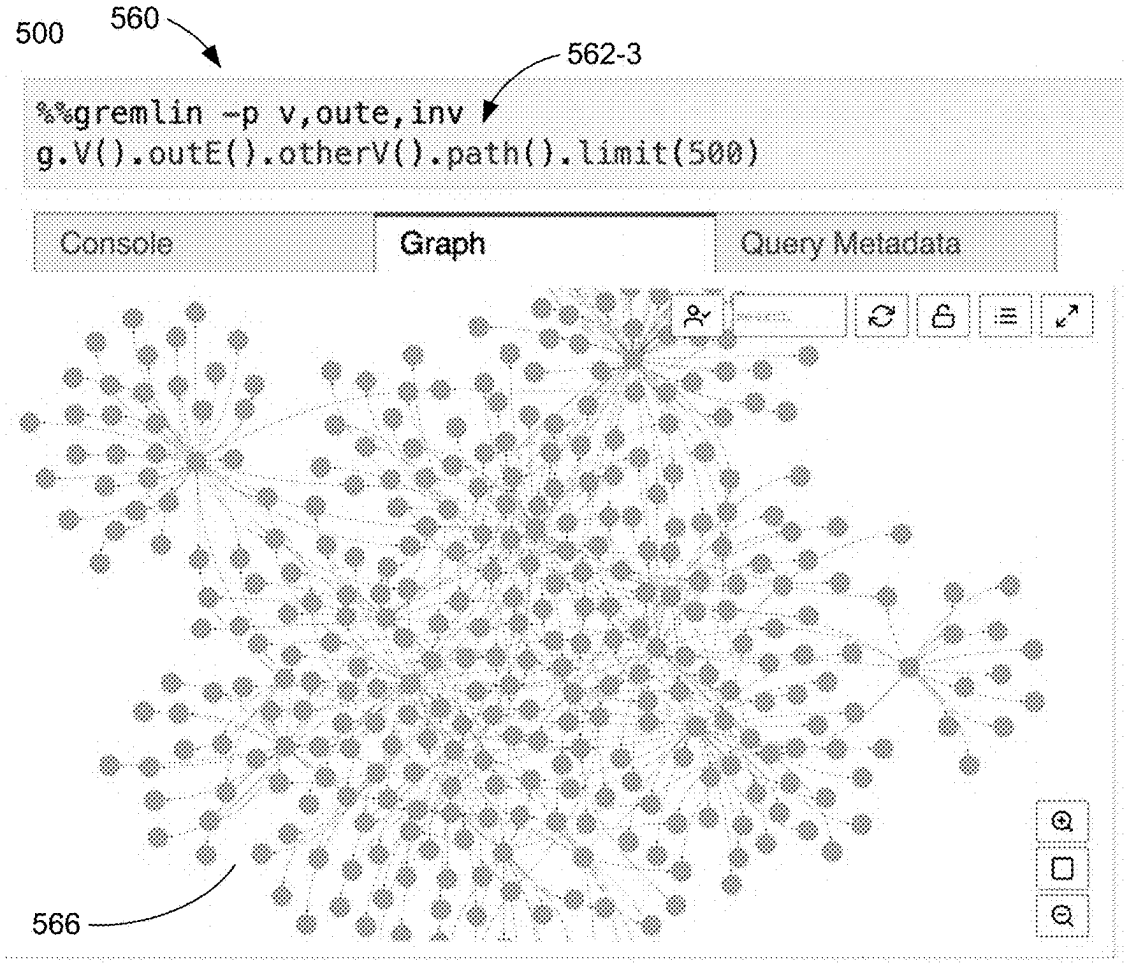

562-1
562-2
562-3
500
530
536
Query
Gremlin console
Cypher console
Graph notebook
562
564
560

Figure 5H


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

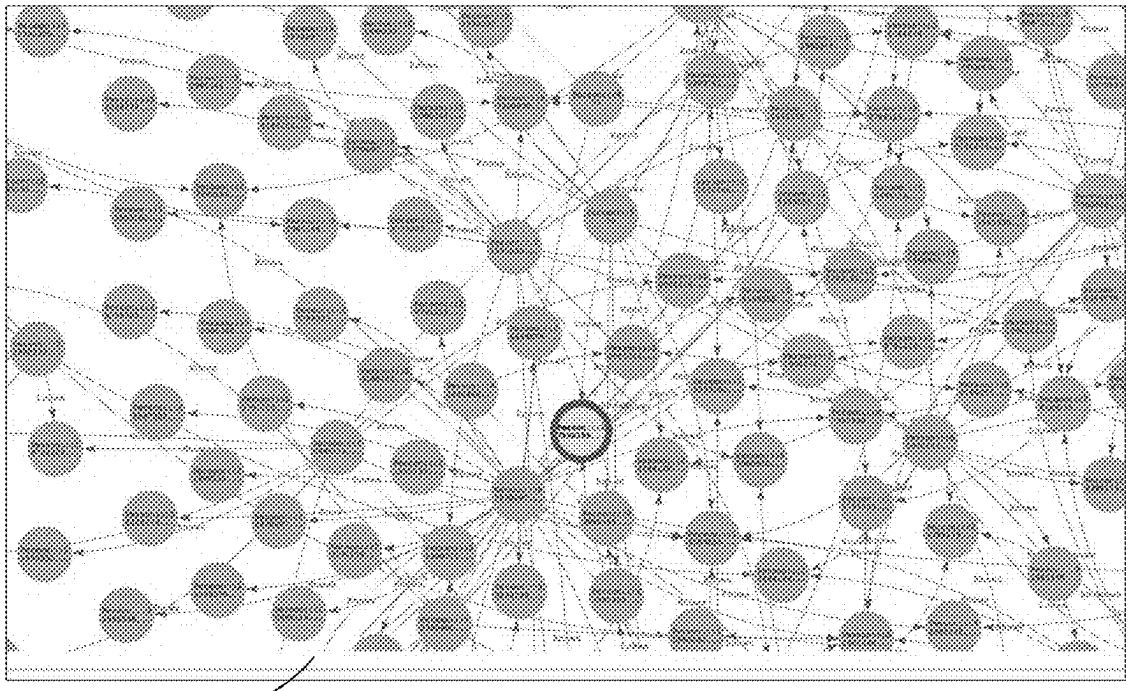

566a

Figure 5I

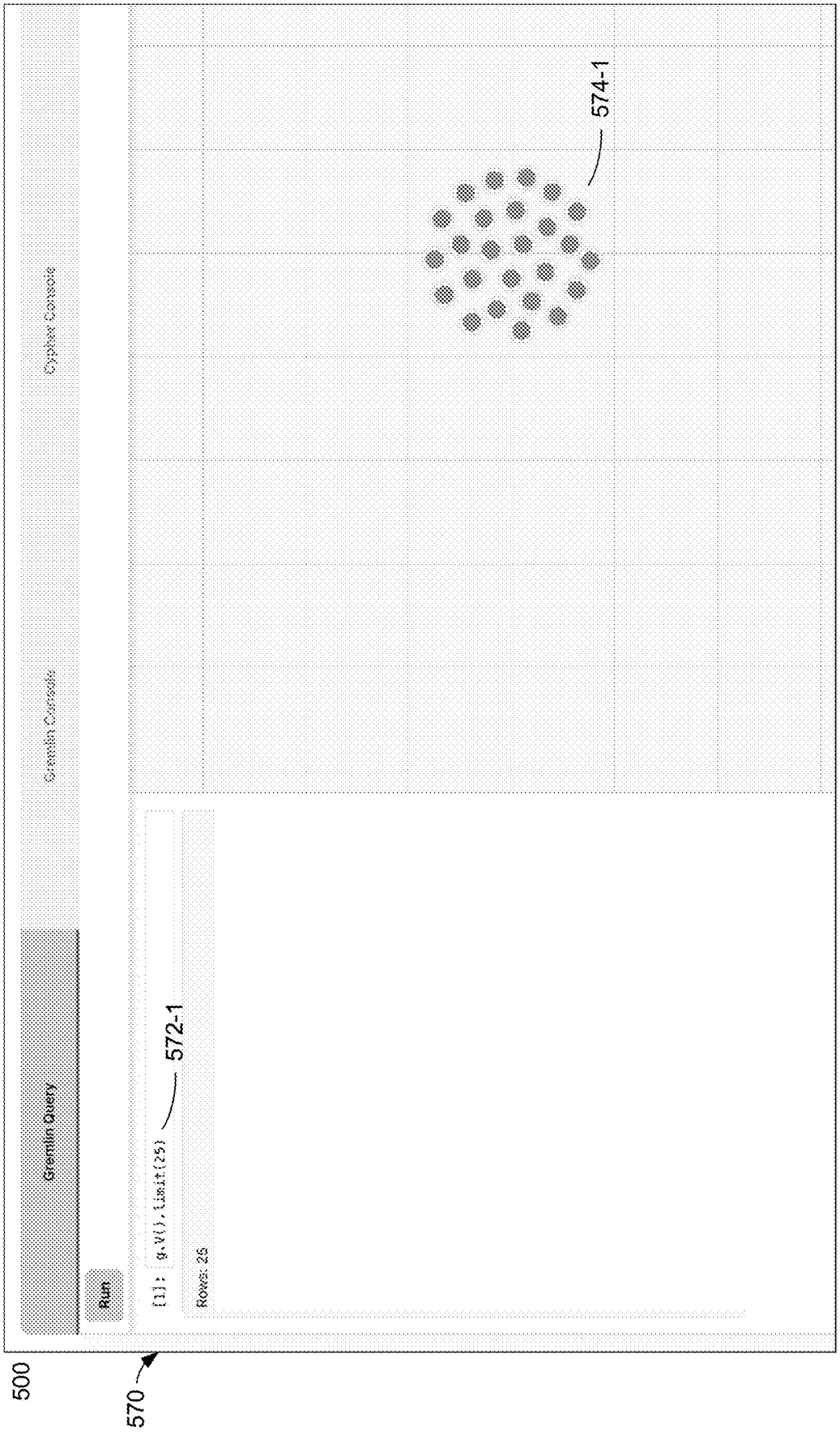

500
570
Gremlin Console
Cypher Console
Gremlin Query
Run
572-1
g.V().limit(25)
Rows: 25
574-1

Figure 5J

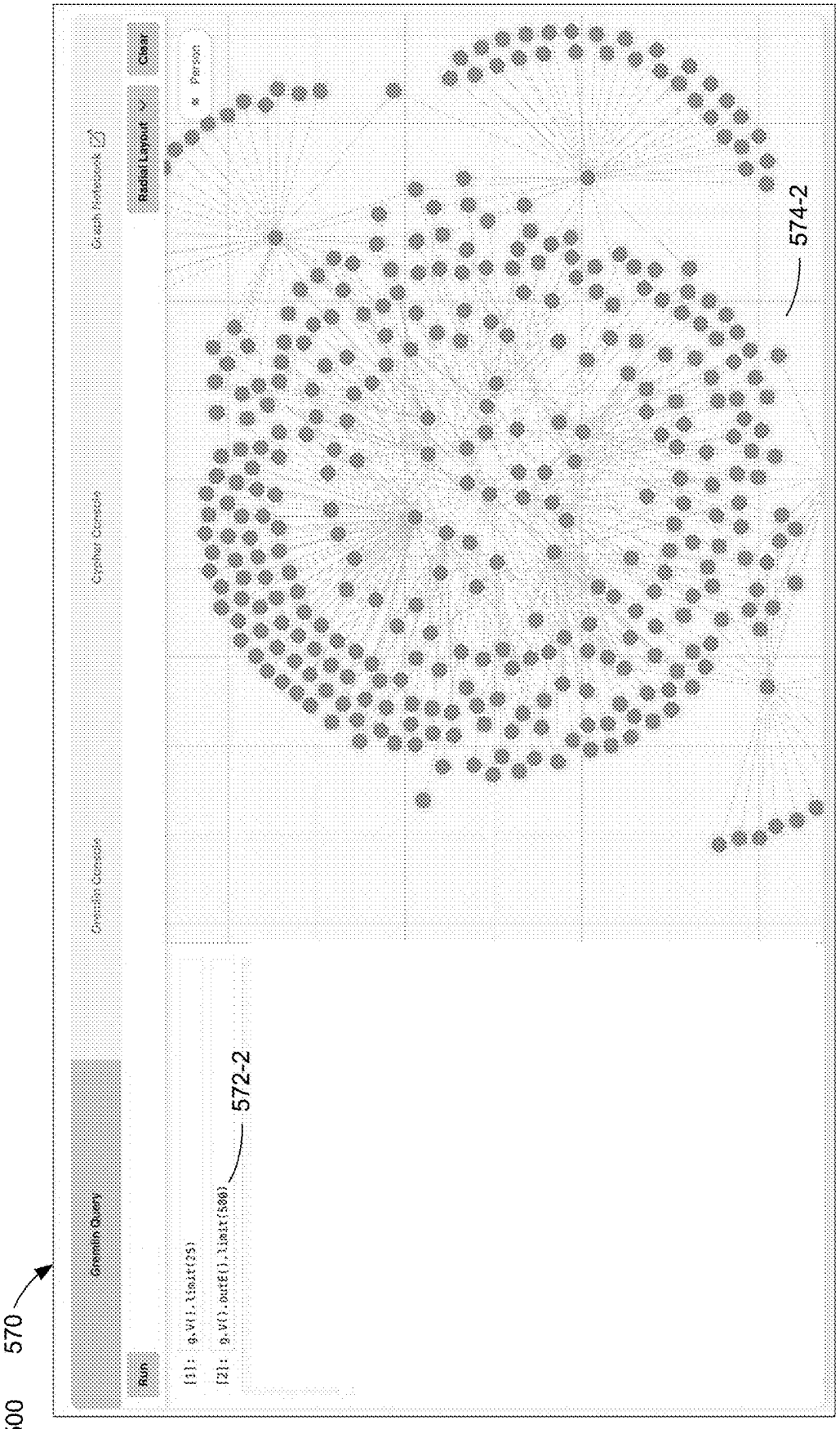

500
570
Gremlin Query
Cypher Console
Graph Notebook
Run
Radial Layout
Clear
Person
574-2
572-2

Figure 5K

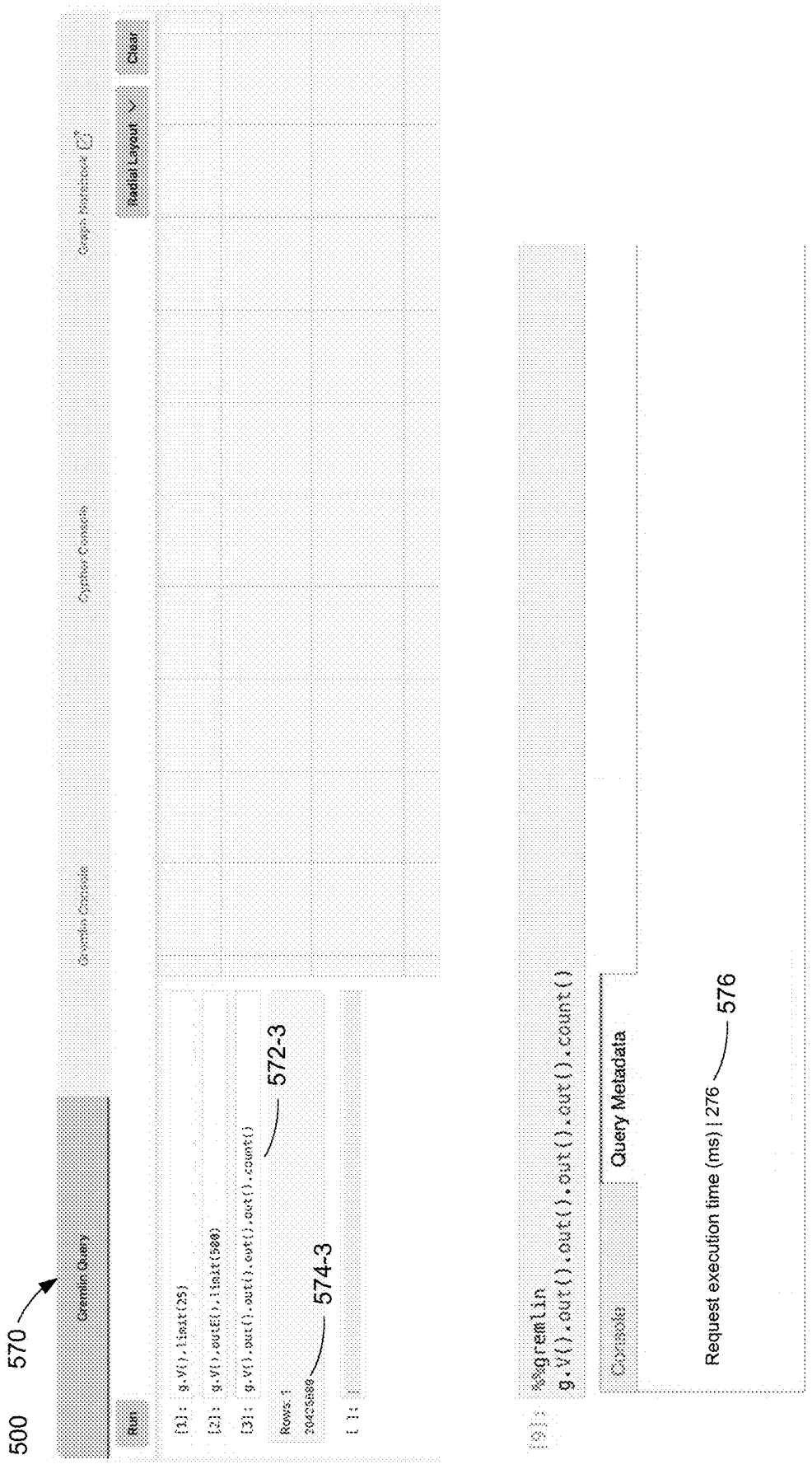

500
570
Gremlin Query
Graph Visualization
Radial Layout
Clear
Run
[1]: g.V().limit(25)
[2]: g.V().outE().limit(500)
[3]: g.V().out().out().out().out().count()
572-3
Rows: 1
20426888
574-3
[9]: %gremlin
g.V().out().out().out().out().count()
Console
Query Metadata
Request execution time (ms) | 276
576

Figure 5L

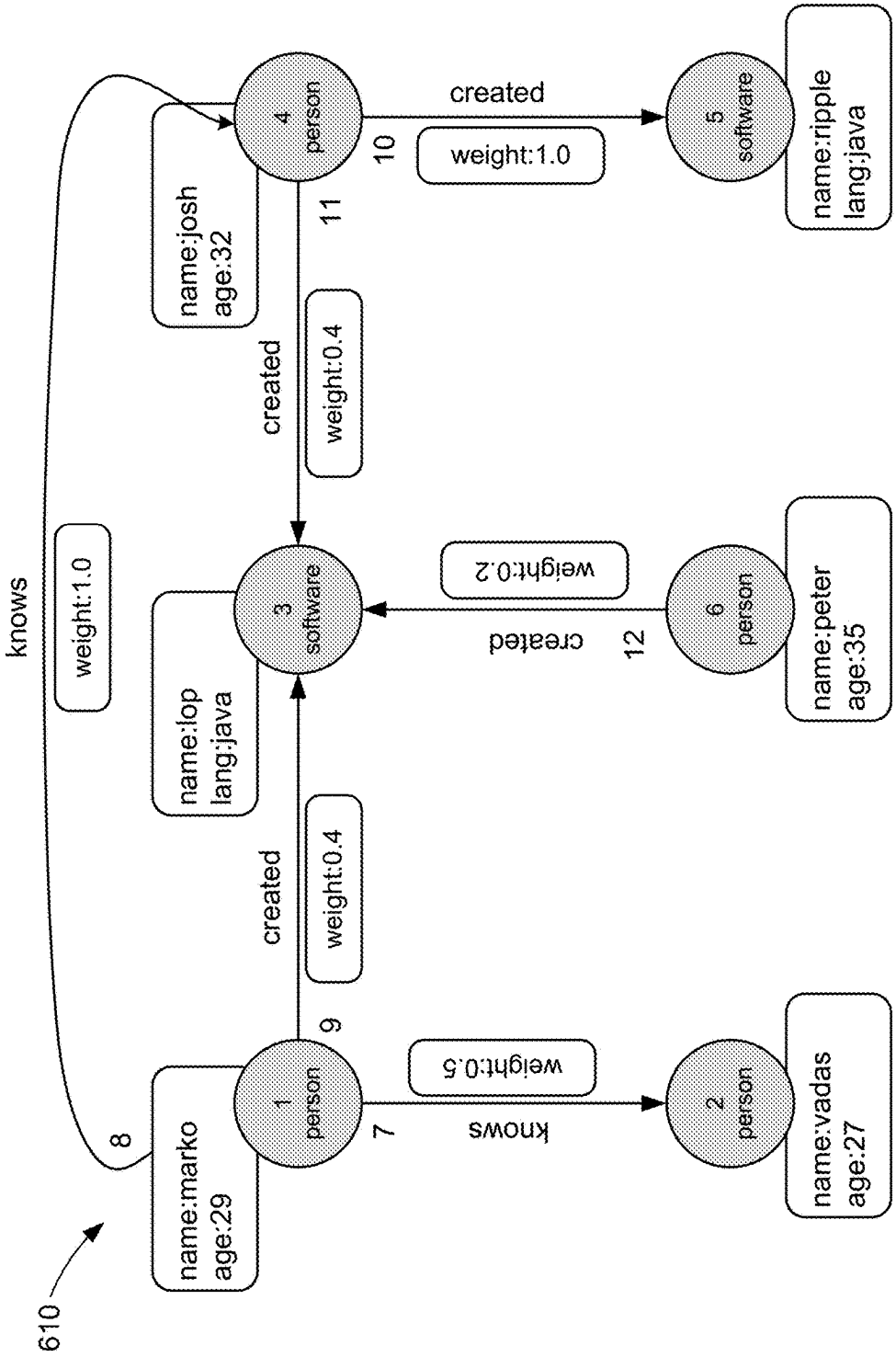

600
610
1 person
name:marko age:29
2 person
name:vadas age:27
3 software
name:lop lang:java
4 person
name:josh age:32
5 software
name:ripple lang:java
6 person
name:peter age:35
knows
weight:0.5
created
weight:1.0
created
weight:0.4
created
weight:0.4
knows
weight:1.0
created
weight:0.2
created
weight:1.0
7
8
9
10
11
12

Figure 6A

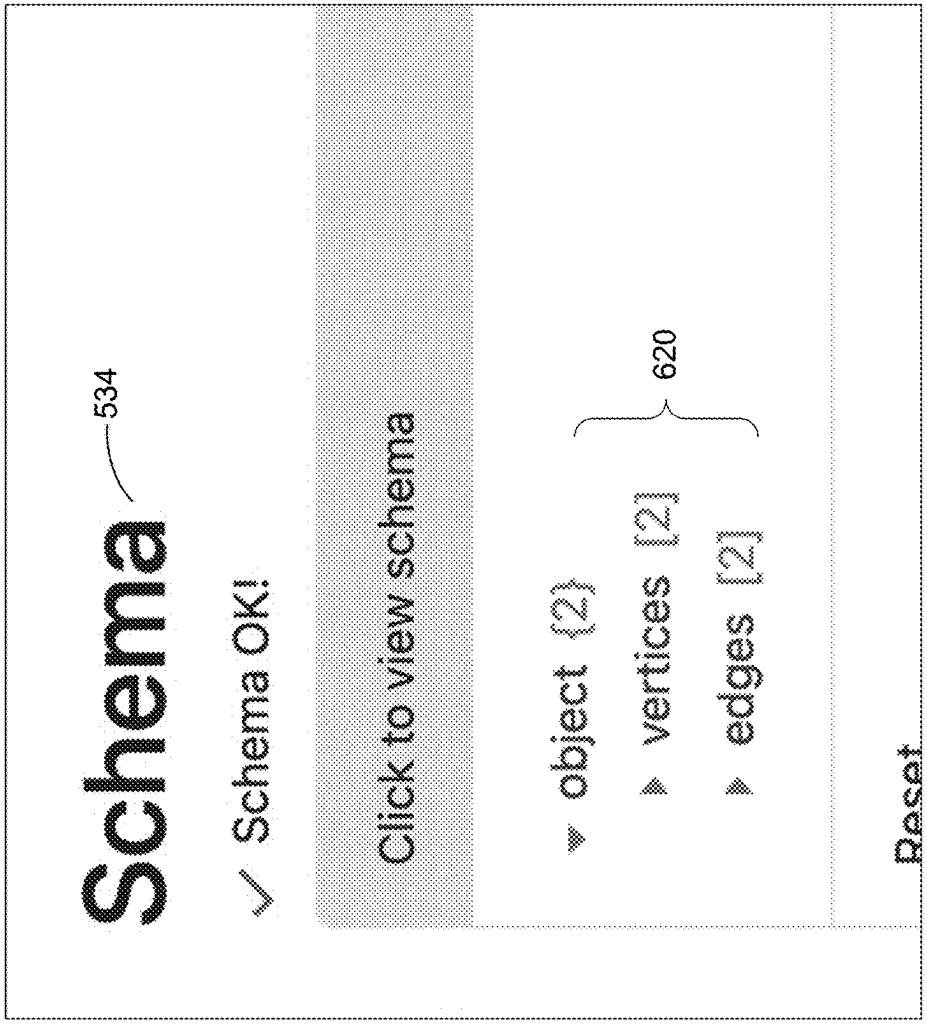


Figure 6B

600

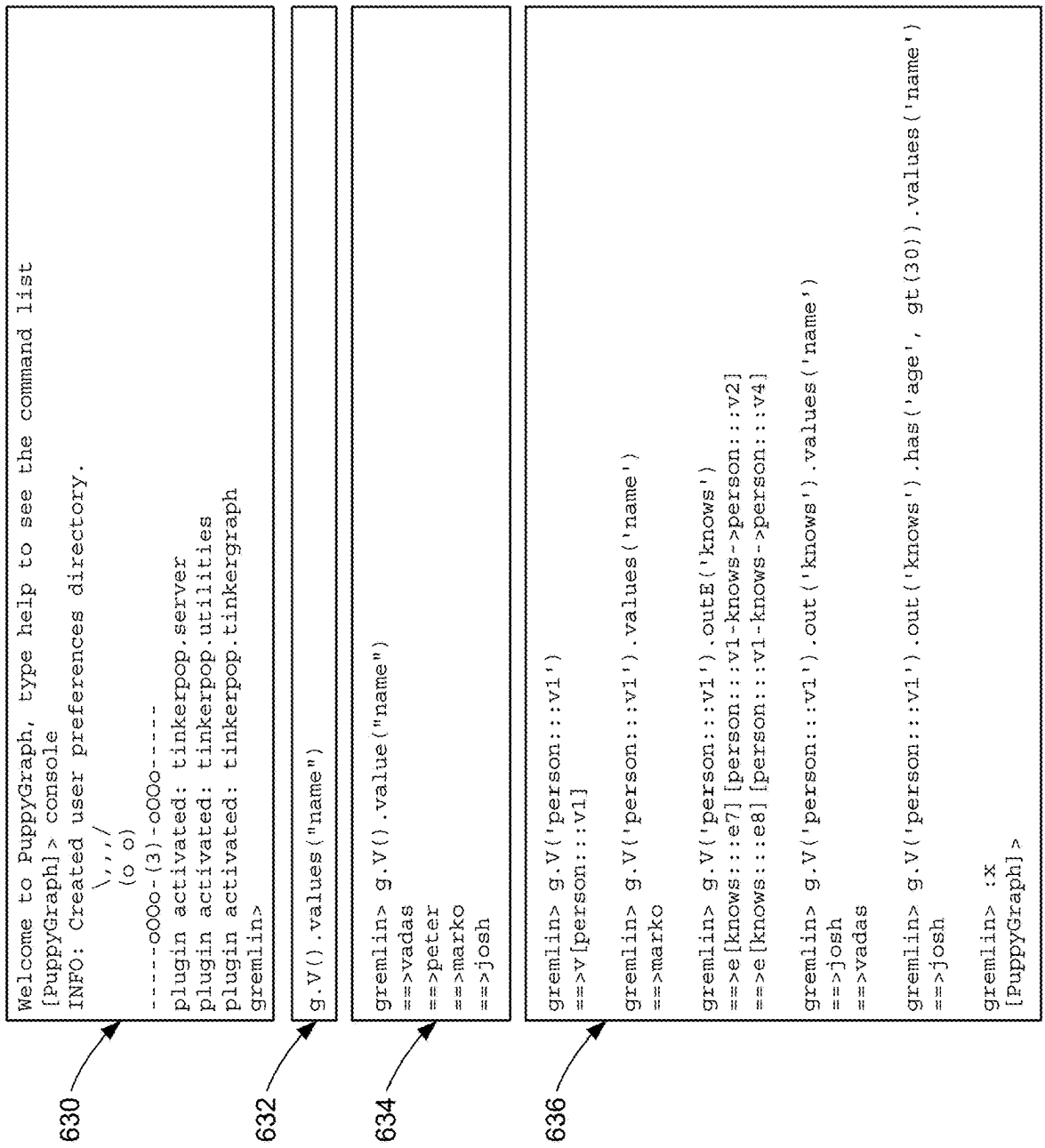

600
630
632
634
636
Welcome to PuppyGraph, type help to see the command list
[PuppyGraph]> console
INFO: Created user preferences directory.
\,,,/
(o o)
-----oOOo-(3)-oOOo-----
plugin activated: tinkerpop.server
plugin activated: tinkerpop.utilities
plugin activated: tinkerpop.tinkergraph
gremlin>
g.V().values("name")
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

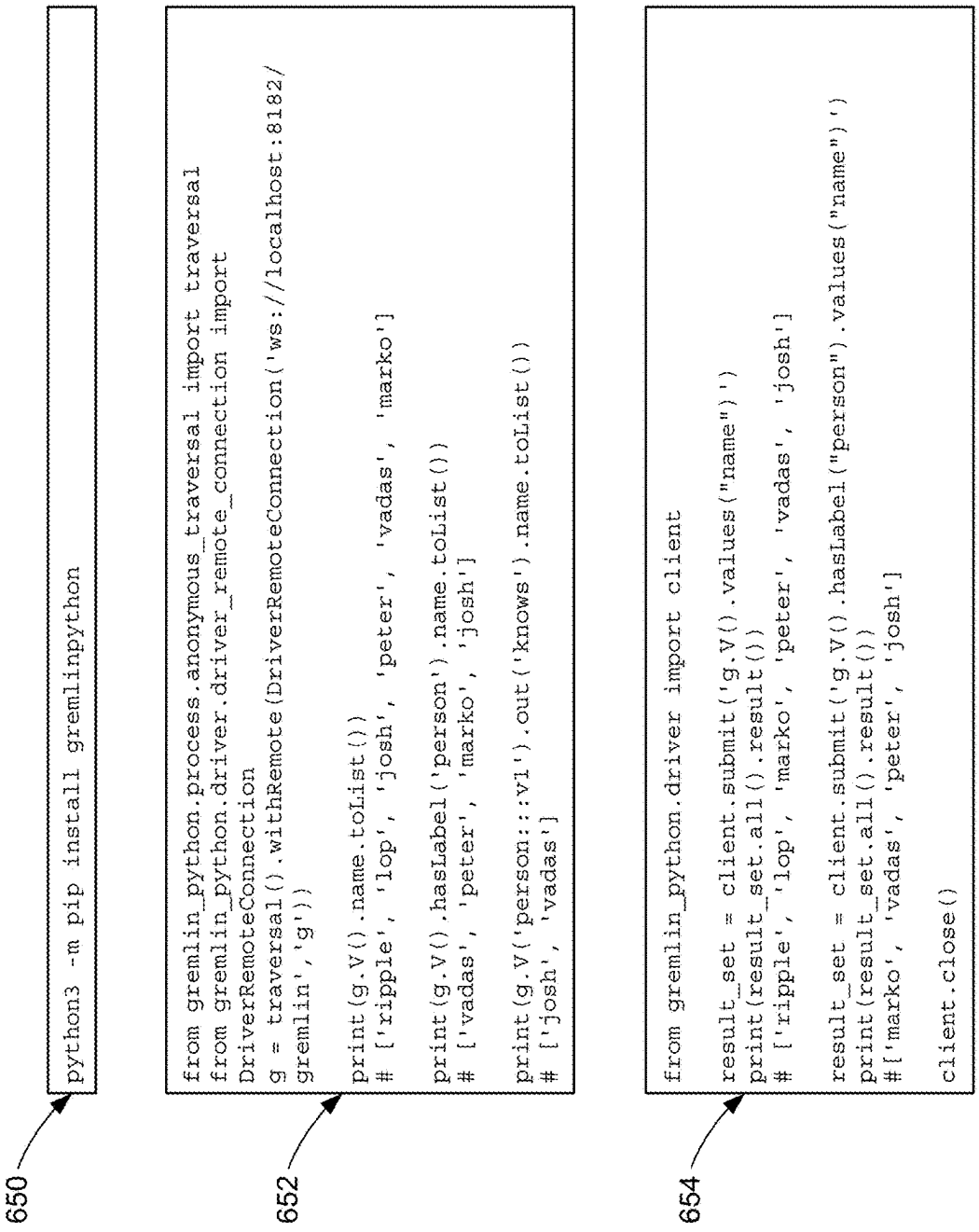

600
650
python3 -m pip install gremlinpython
652
from gremlin_python.process.anonymous_traversal import traversal
from gremlin_python.driver.driver_remote_connection import
DriverRemoteConnection
g = traversal().withRemote(DriverRemoteConnection('ws://localhost:8182/
gremlin','g'))
print(g.V().name.toList())
# ['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

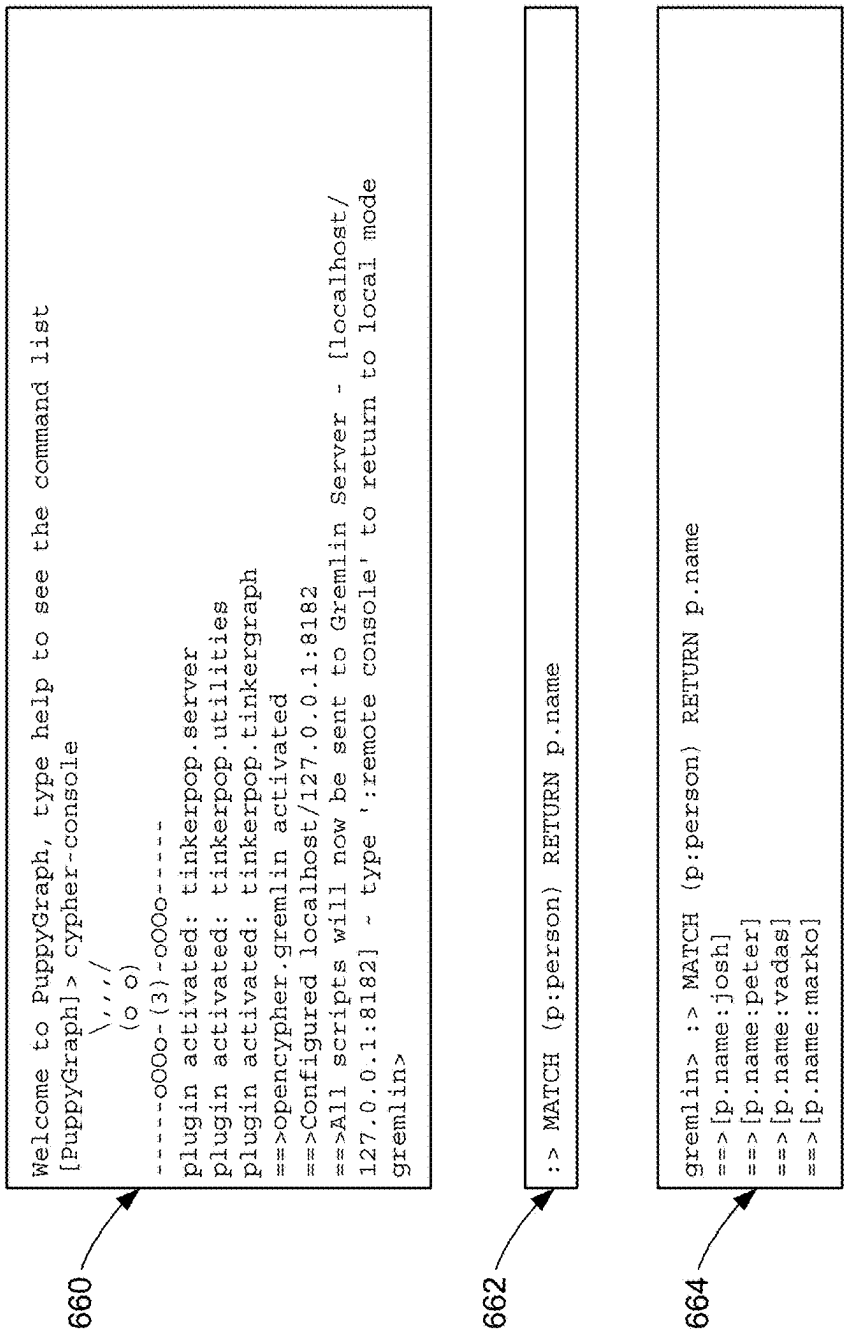


Figure 6F

600

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

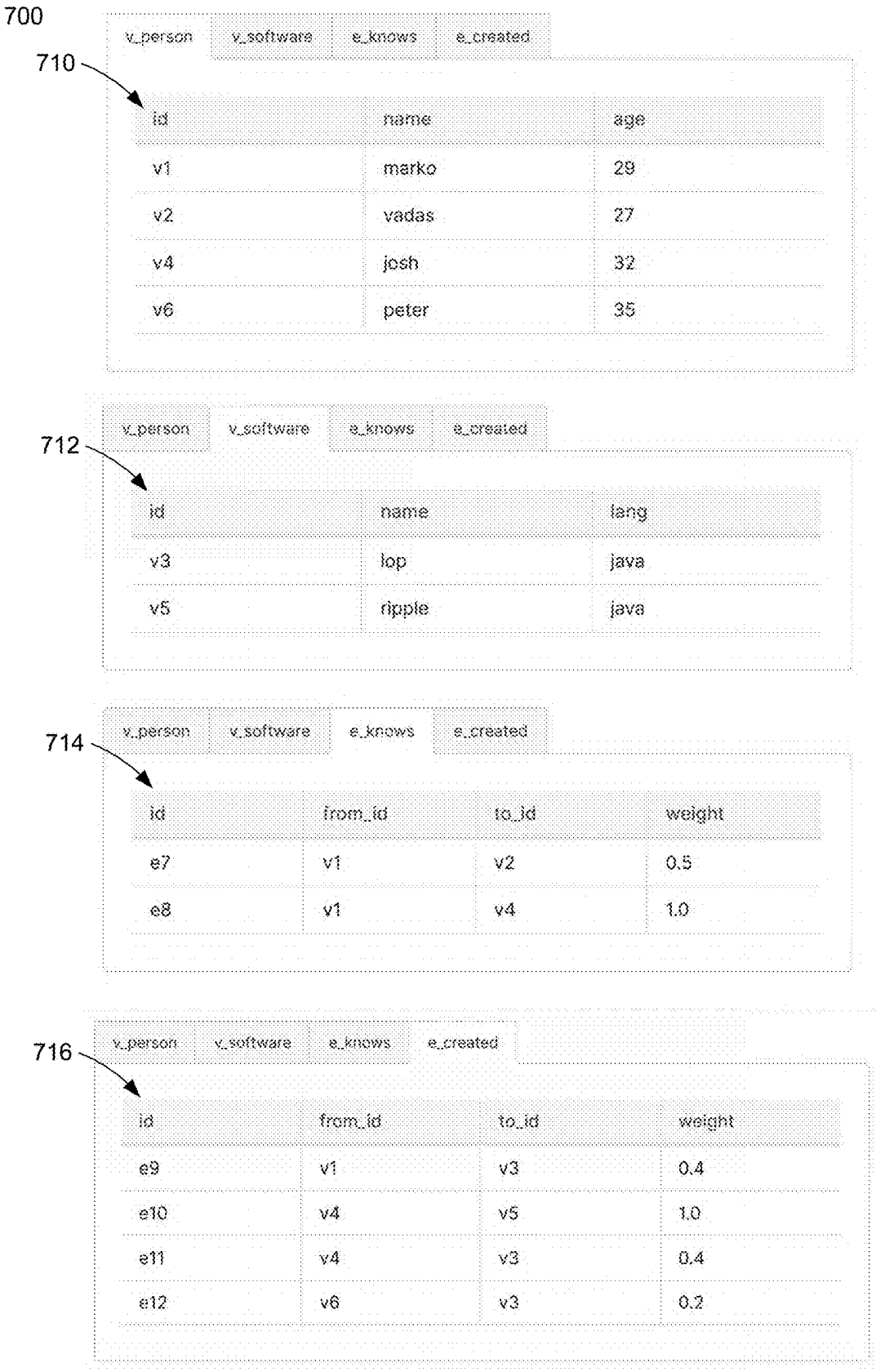

700
v_person
v_software
e_knows
e_created
710
id
name
age
v1
marko
29
v2
vadas
27
v4
josh
32
v6
peter
35
v_person
v_software
e_knows
e_created
712
id
name
lang
v3
lop
java
v5
ripple
java
v_person
v_software
e_knows
e_created
714
id
from_id
to_id
weight
e7
v1
v2
0.5
e8
v1
v4
1.0
v_person
v_software
e_knows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

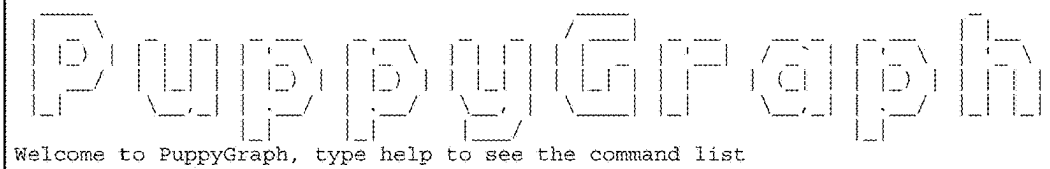
722

```
{"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

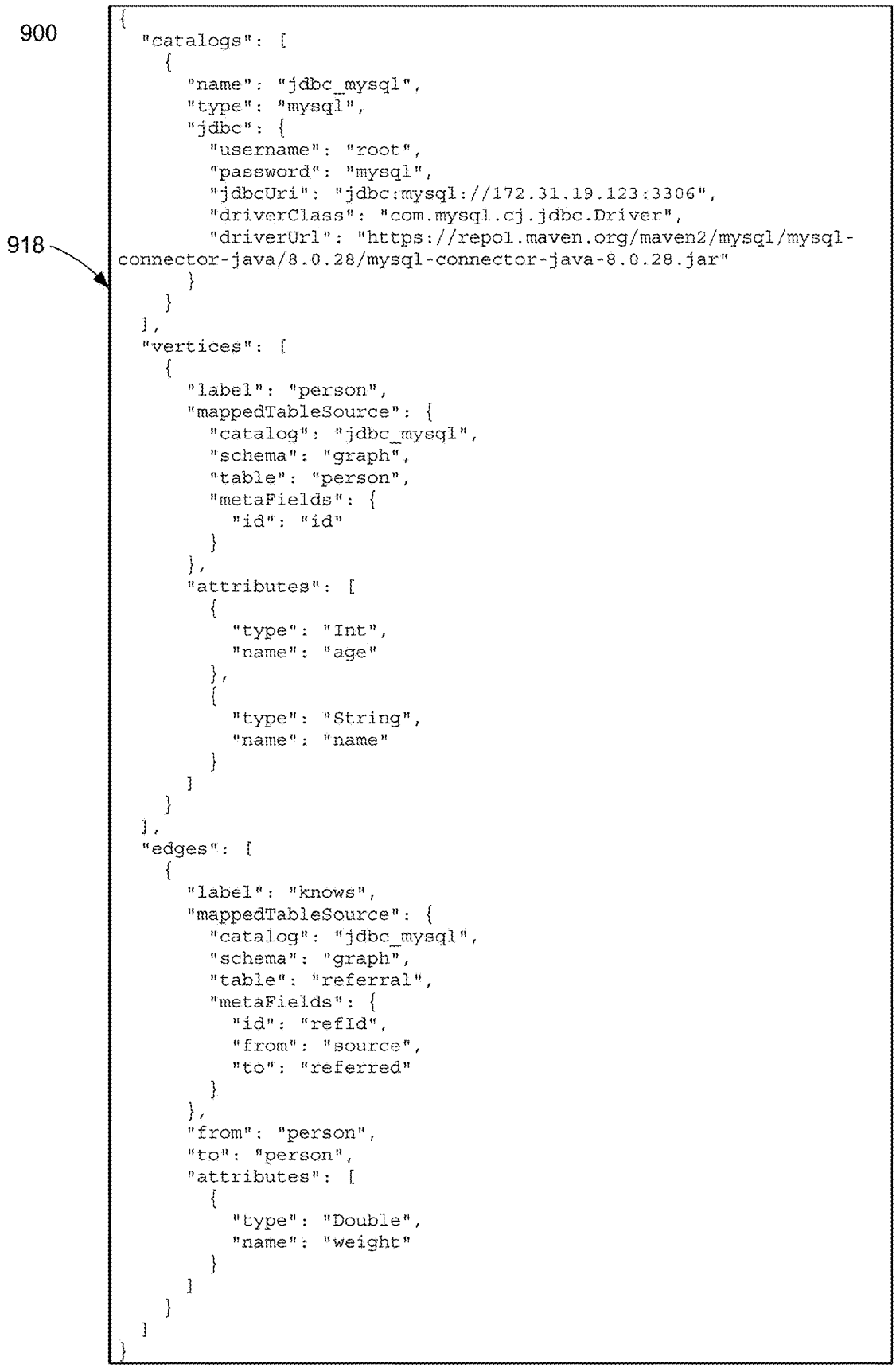
```
drop database if exists graph;
create database if not exists graph;
use graph;
create table person
(
    ID   varchar(128) not null,
    age  int,
    name varchar(128),
    PRIMARY KEY (ID)
);
insert into person values ('v1', 29, 'marko'), ('v2', 27, 'vadas');
create table referral
(
    refId 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

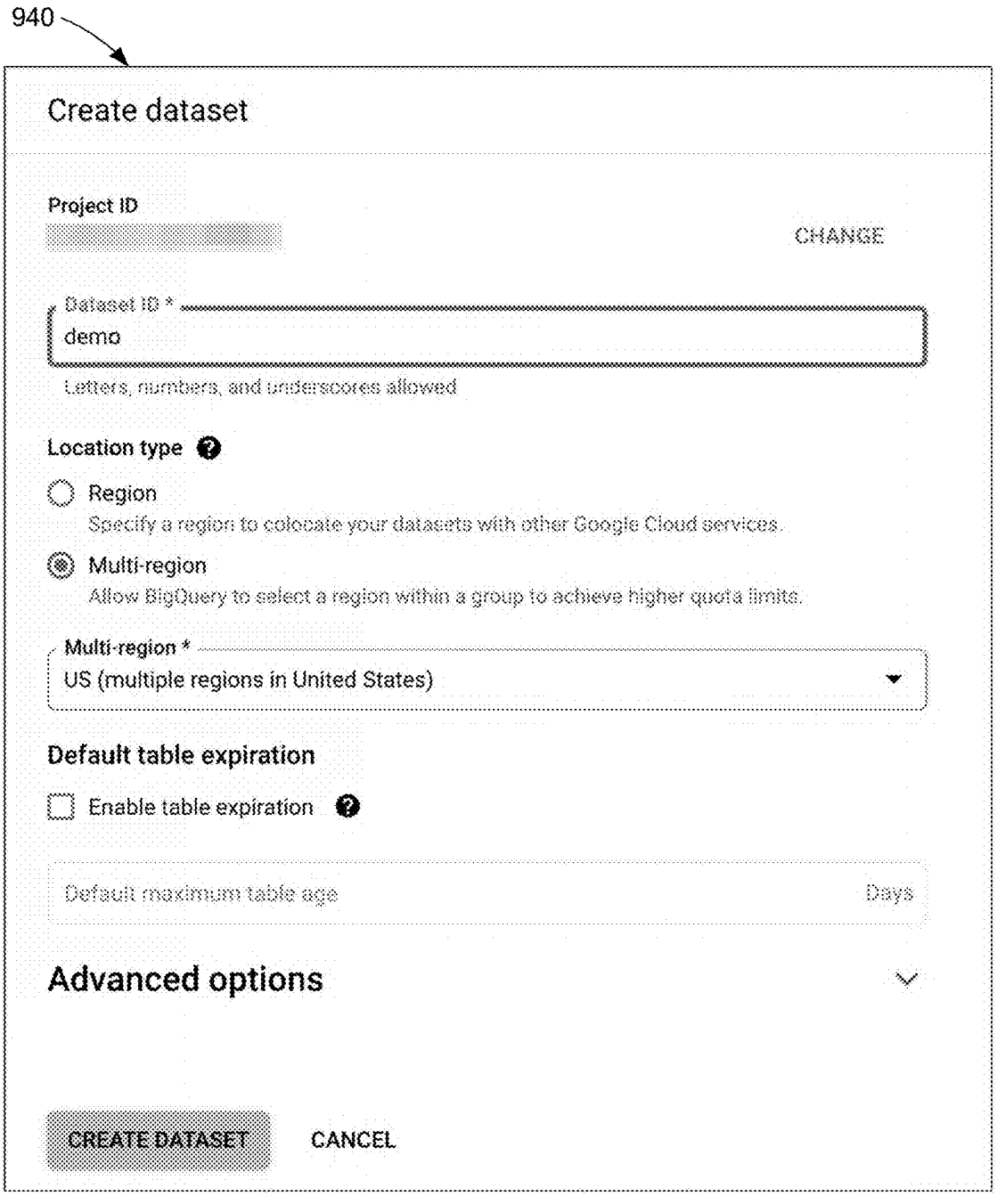


Figure 9G

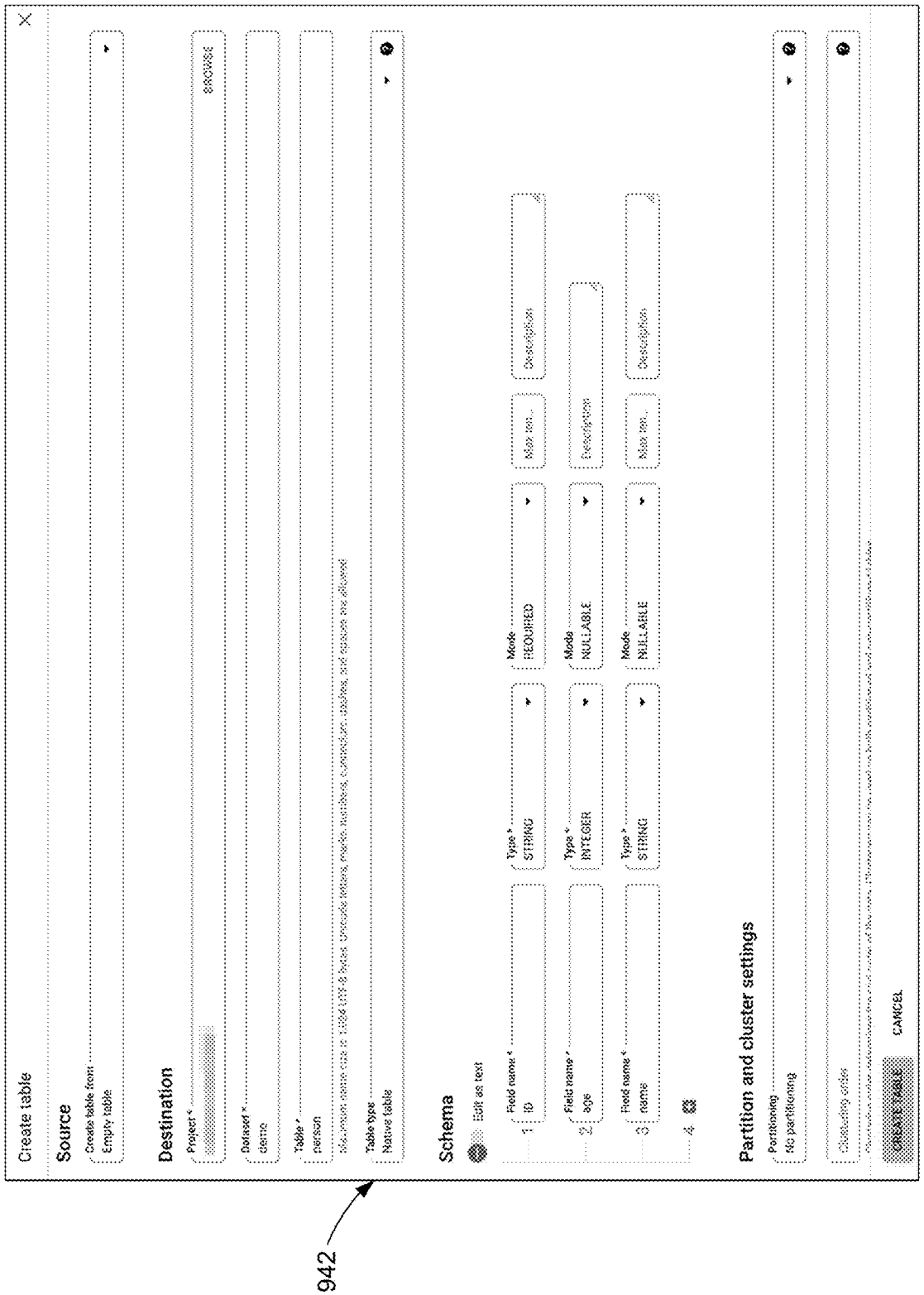

900
942
Create table
Source
Create table from
Empty table
Destination
Project *
BROWSE
Dataset *
demo
Table *
person
Table type
Native table
Schema
Edit as text
Field name *
id
Type *
STRING
Mode
REQUIRED
Make nul...
Description
Field name *
age
Type *
INTEGER
Mode
NULLABLE
Description
Field name *
name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

Figure 9H

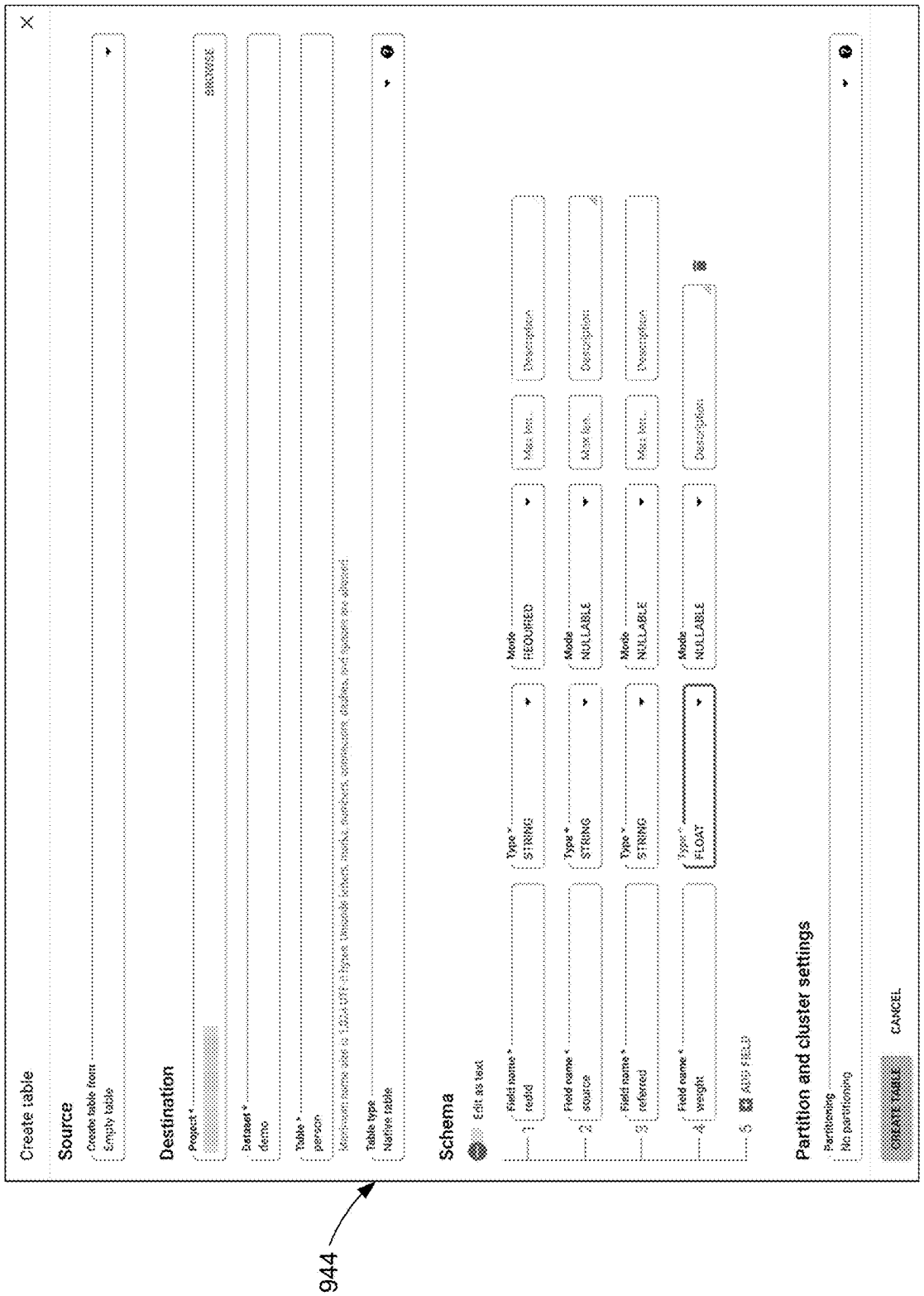

900
944
Create table
Source
Create table from
Empty table
Destination
Project *
BROWSE
Dataset *
demo
Table *
person
Table type
Native table
Schema
Edit as text
Field name *
1 redid
Type *
STRING
Mode
REQUIRED
Max len...
Description
Field name *
2 source
Type *
STRING
Mode
NULLABLE
Max len...
Description
Field name *
3 referred
Type *
STRING
Mode
NULLABLE
Max len...
Description
Field name *
4 weight
Type *
FLOAT
Mode
NULLABLE
Description
5 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

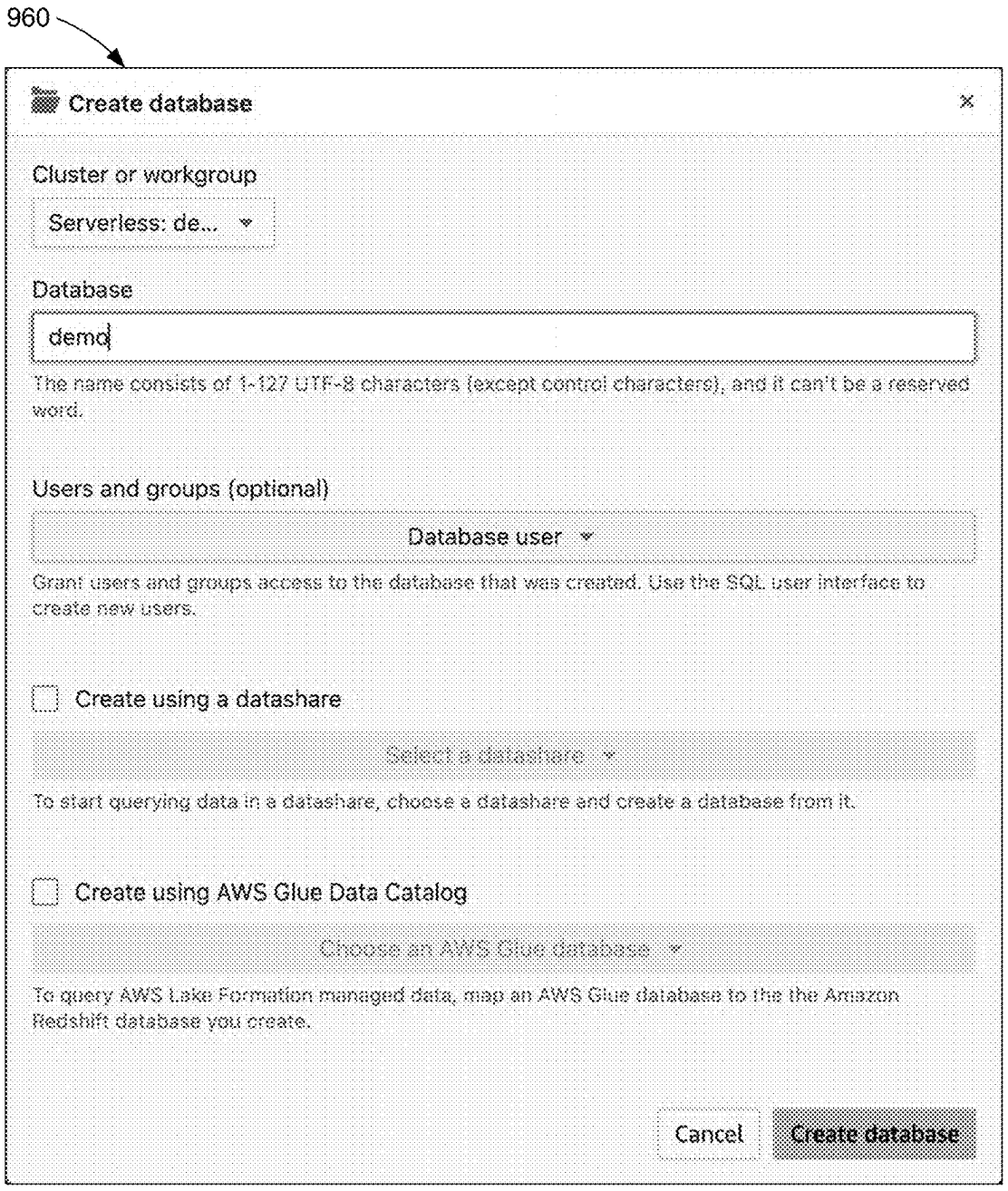


Figure 9L

900

962

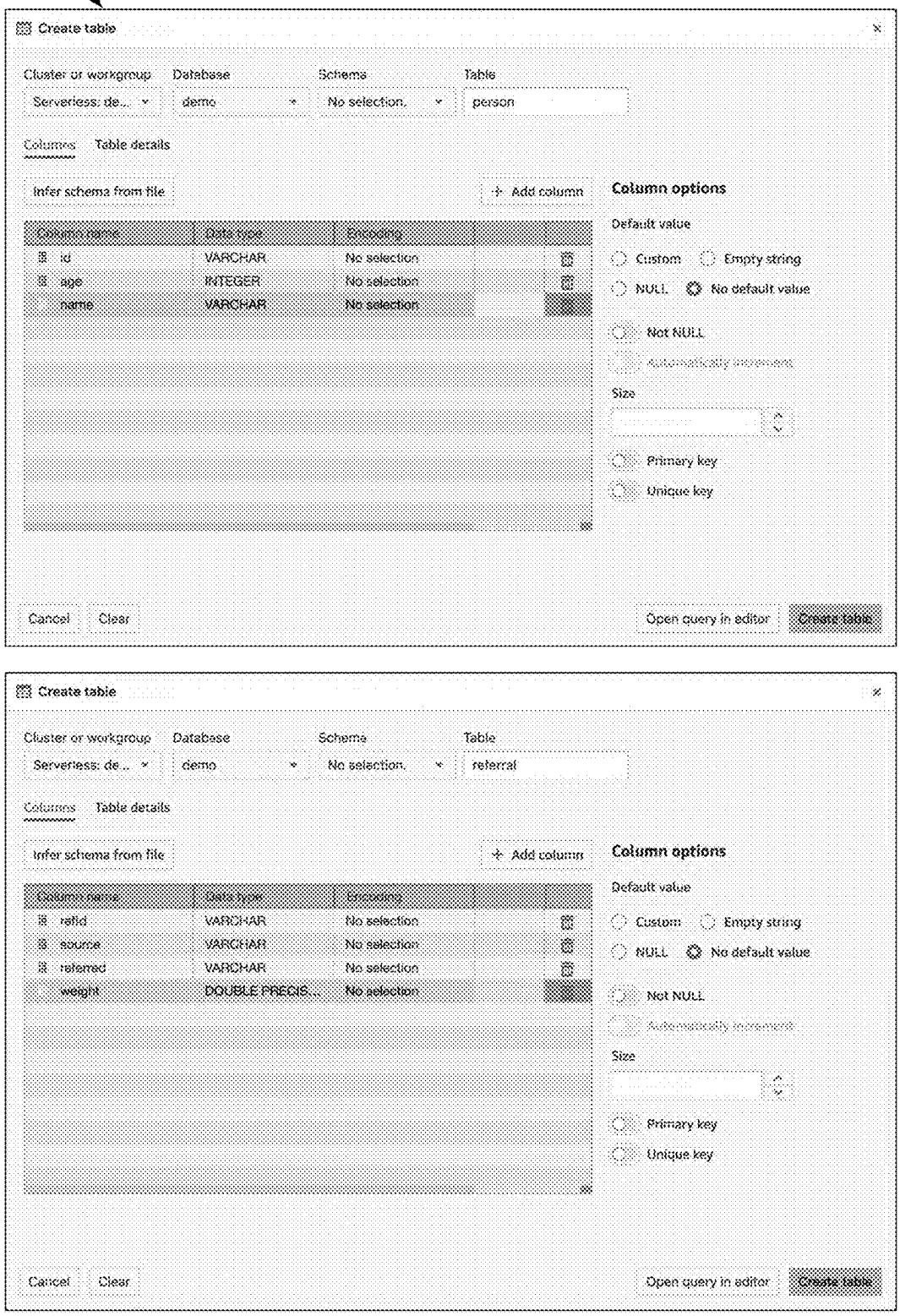


Figure 9M

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 9O

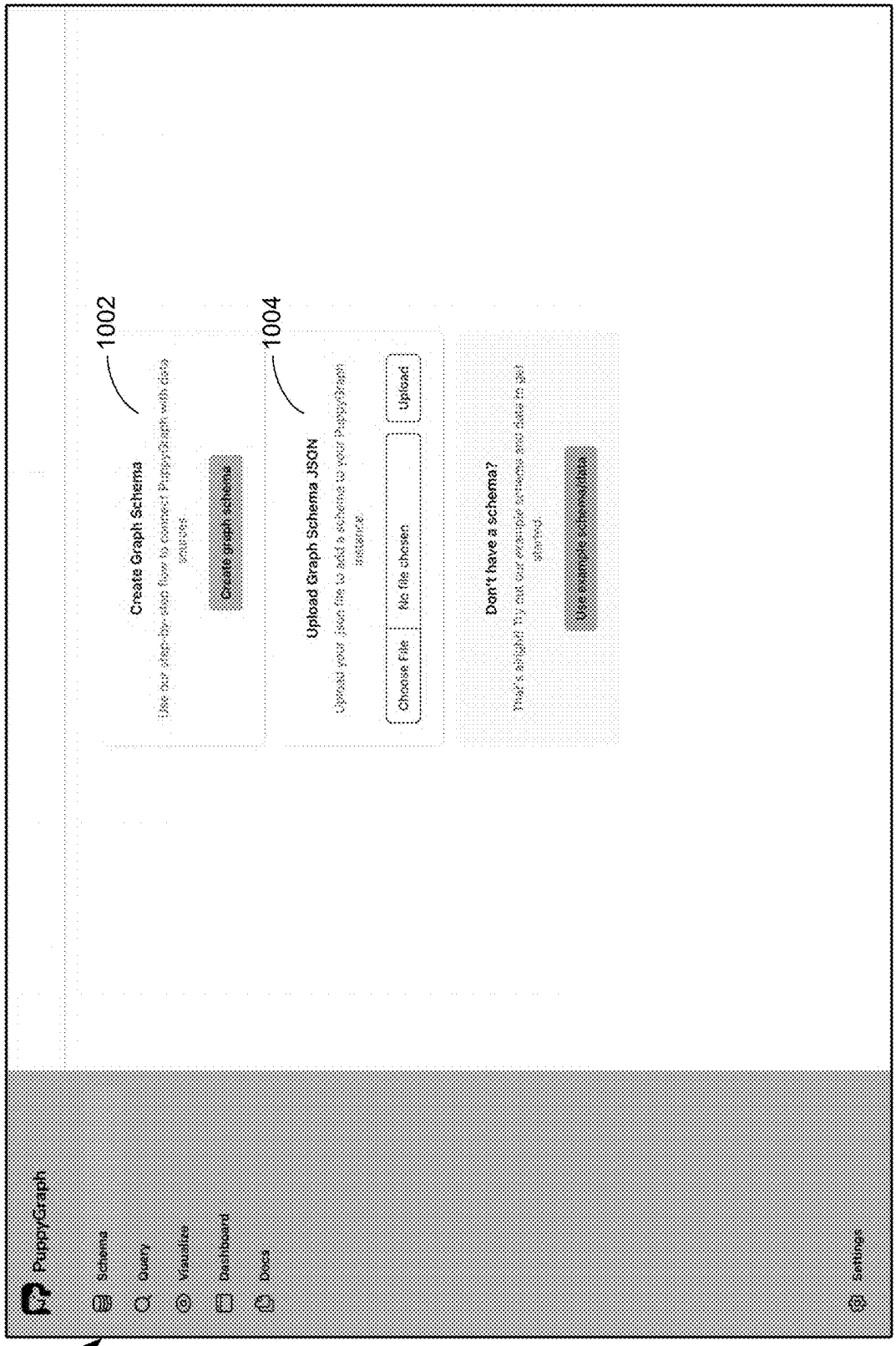

1000
PuppyGraph
Schema
Query
Visualize
Dashboard
Docs
Settings
1002
Create Graph Schema
Create graph schema
1004
Upload Graph Schema JSON
Choose File
No file chosen
Upload
Don't have a schema?
Use sample schema

Figure 10A

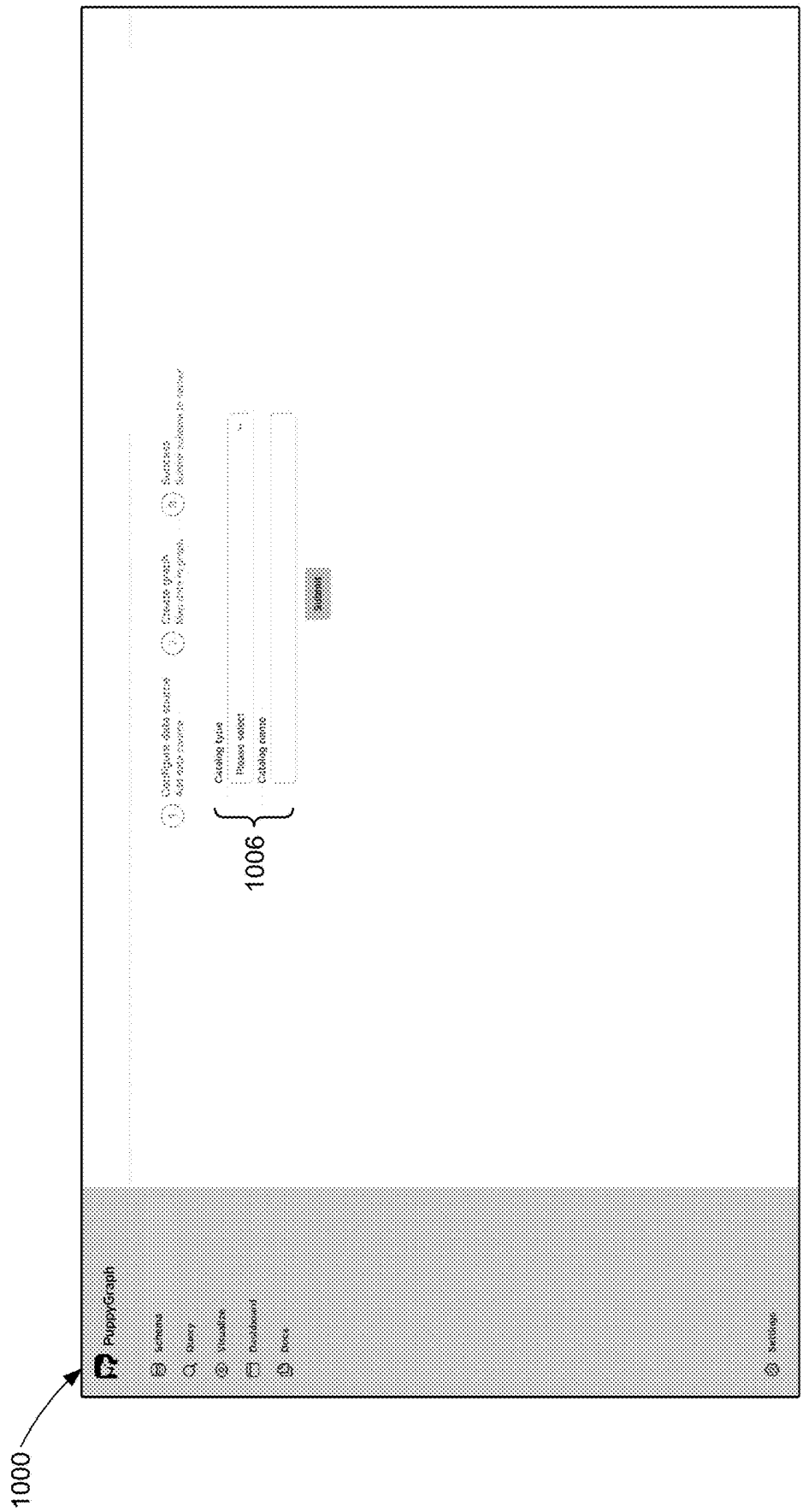

1000
PuppyGraph
Schema
Query
Visualize
Deployment
Docs
Settings
1006
Catalog type
Please select
Catalog name

Figure 10B

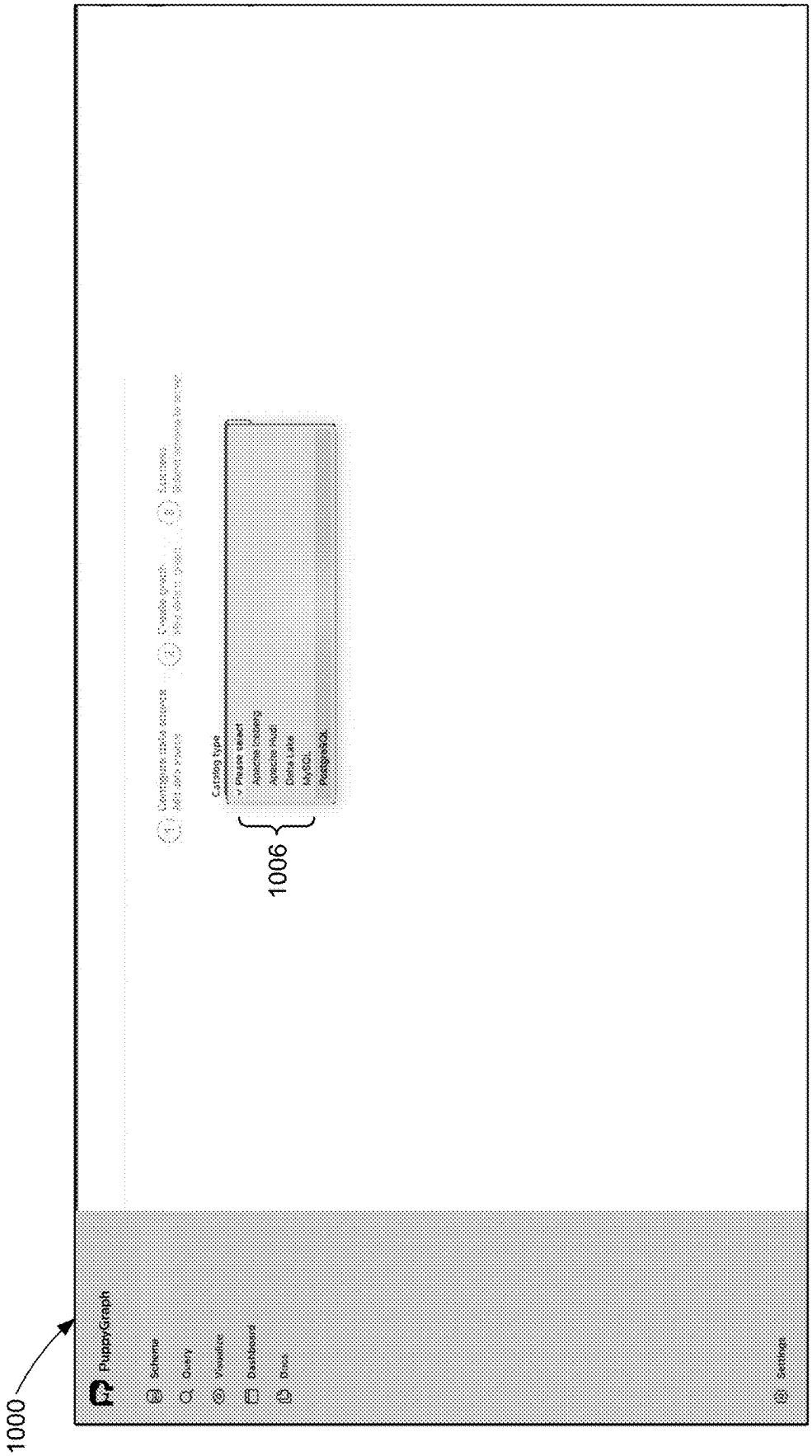

1000
PuppyGraph
Schema
Query
Visualize
Dashboard
Setting
Catalog type
Please select
Apache Iceberg
Apache Hudi
Delta Lake
MySQL
PostgreSQL
1006

Figure 10C

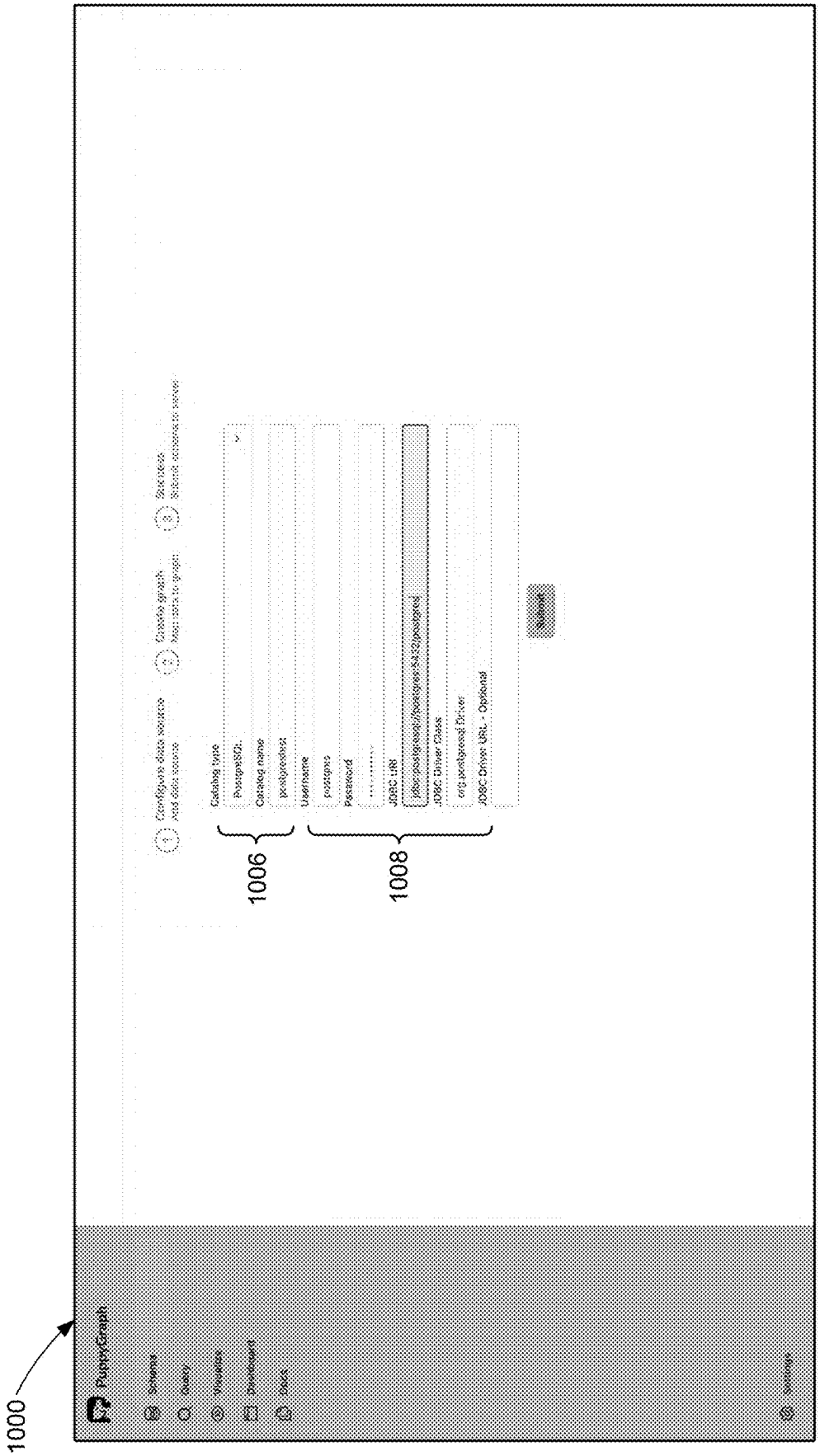

1000
PuppyGraph
Schema
Query
Visualize
Dashboard
Docs
Settings
1006
1008
Catalog type
PostgreSQL
Catalog name
postgresdest
Username
postgres
Password
JDBC URI
jdbc:postgresql://postgres:5432/postgres
JDBC Driver Class
org.postgresql.Driver
JDBC Driver URL - Optional
Submit

Figure 10D

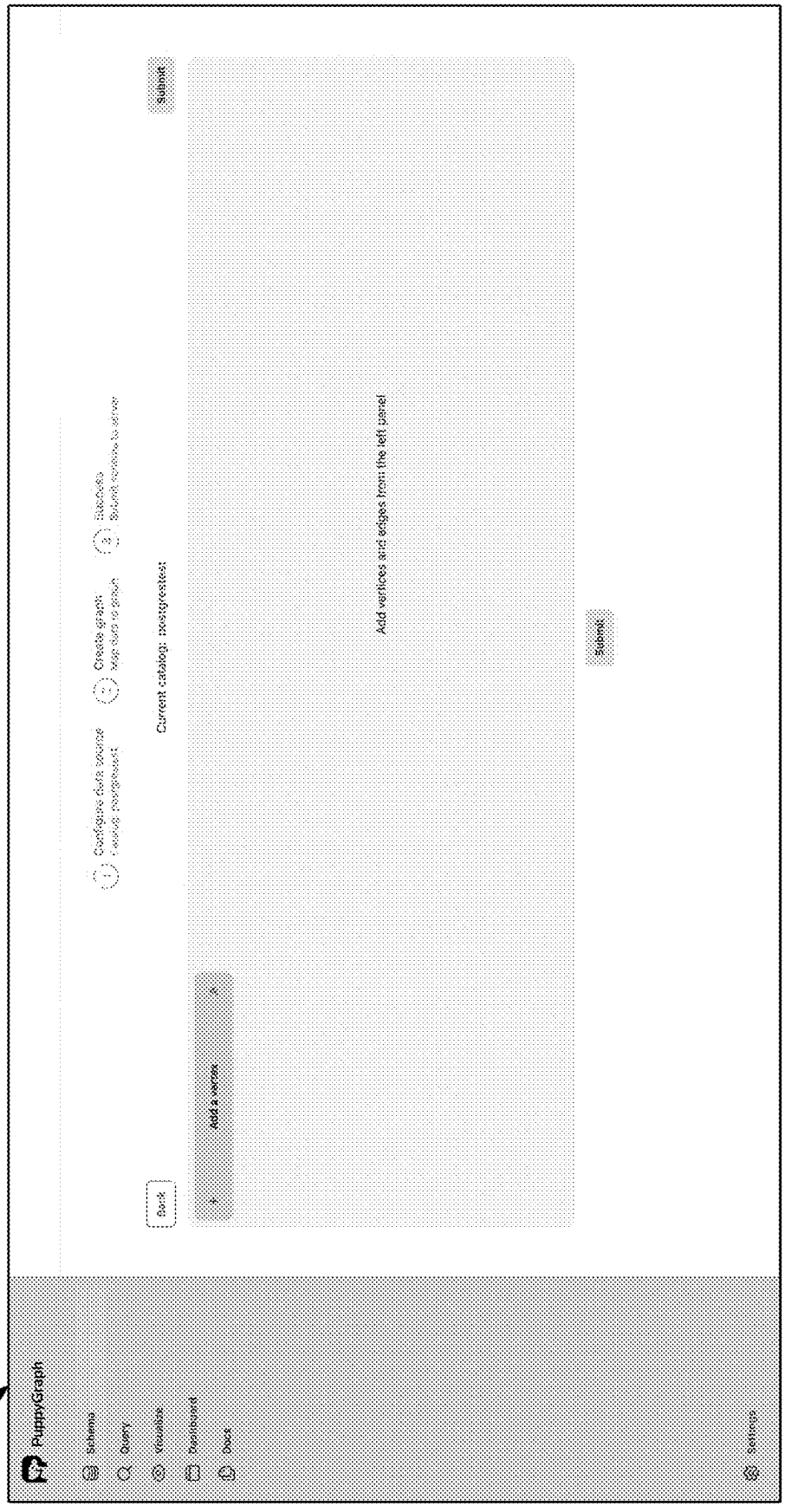

1000
PuppyGraph
Schema
Query
Visualize
Dashboard
Docs
Settings
Back
Submit
Current catalog: postgrestest
Add vertices and edges from the left panel
Submit

Figure 10E

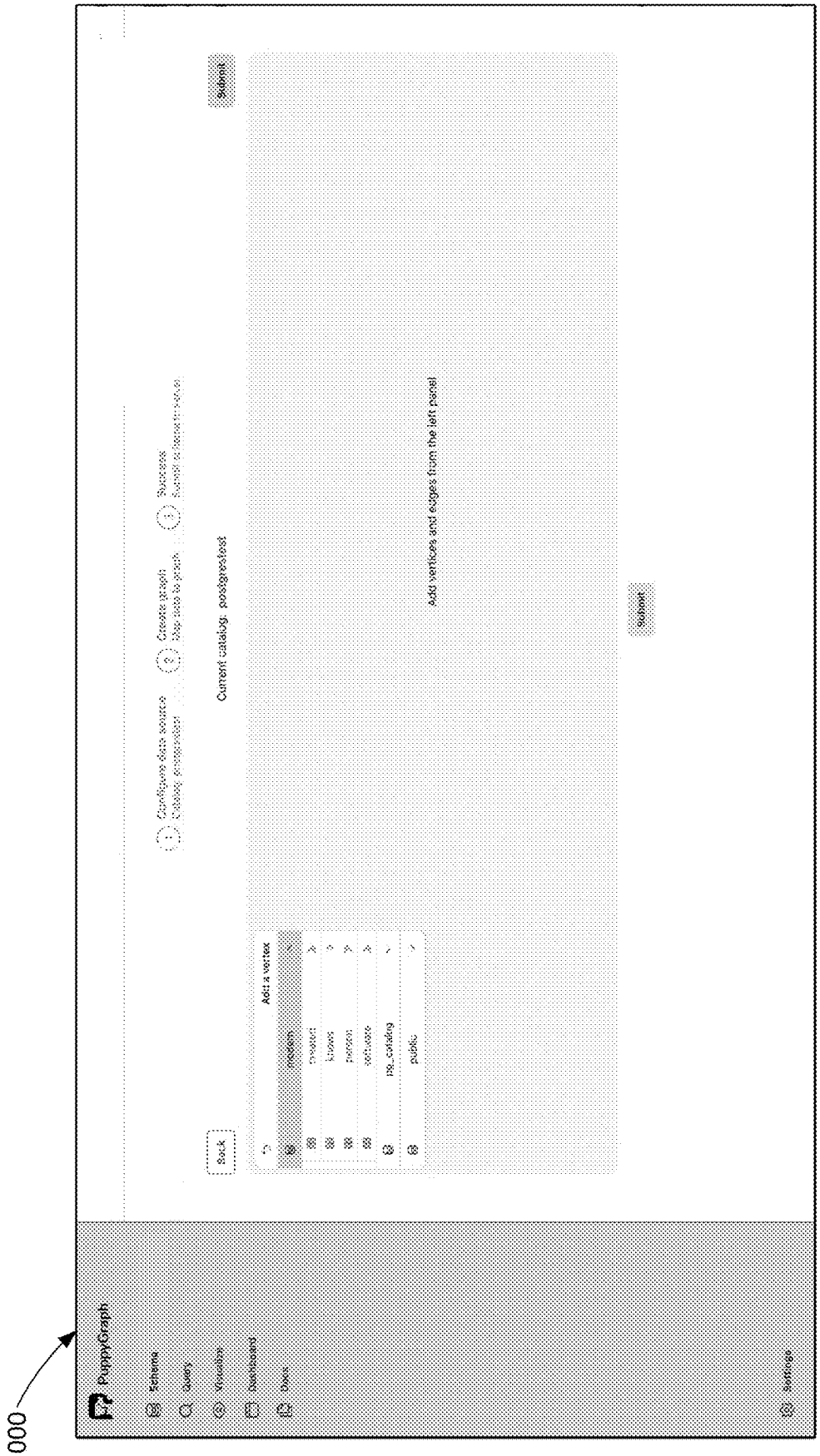

1000
PuppyGraph
Schema
Query
Visualize
Dashboard
Docs
Settings
Back
Submit
Current catalog: postgresfood
Add a vertex
Add vertices and edges from the left panel
Submit

Figure 10F

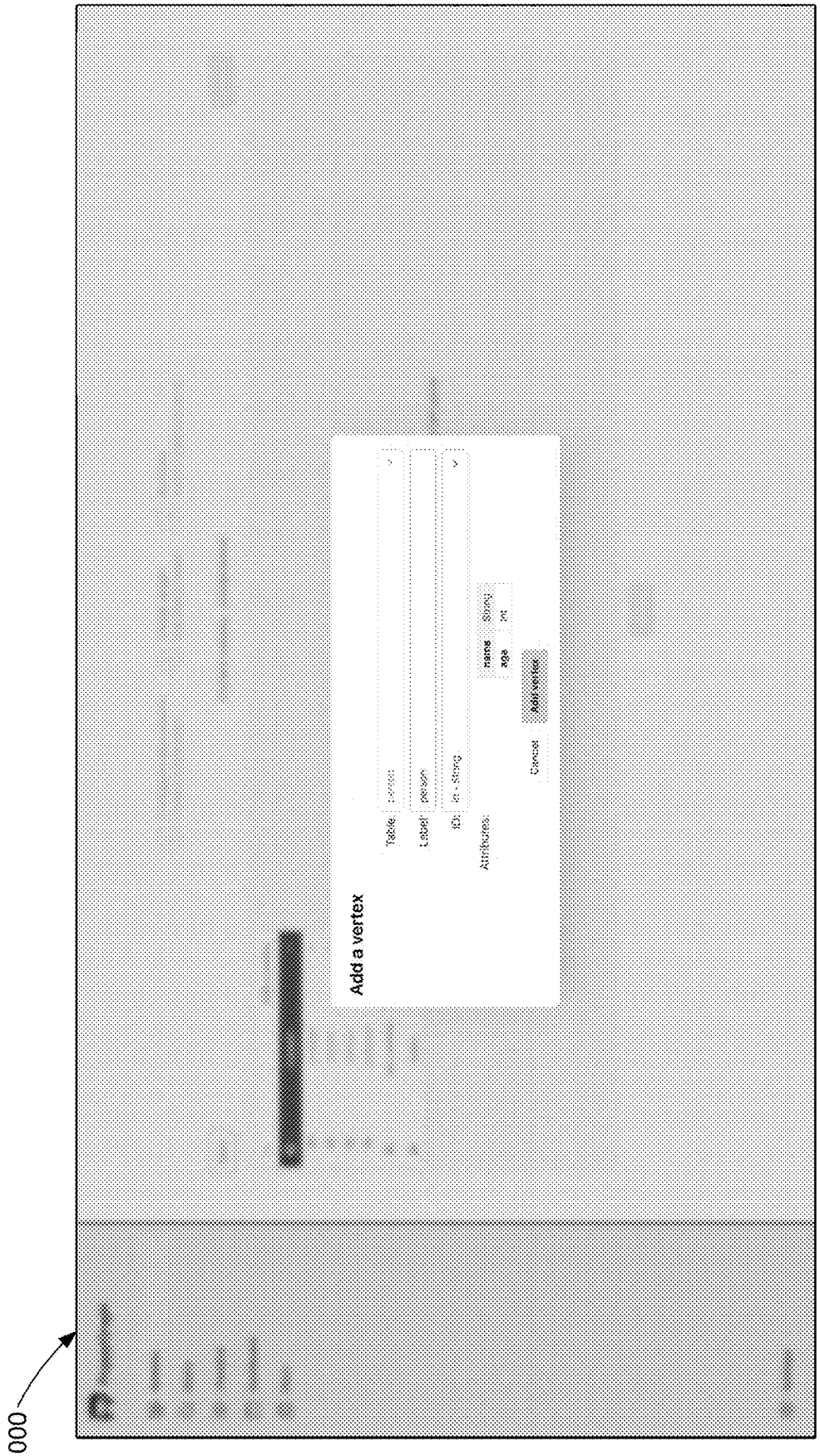

1000
Add a vertex
Table:
Label:
person
ID:
Attributes:
name
String
age
Cancel
Add vertex

Figure 10G

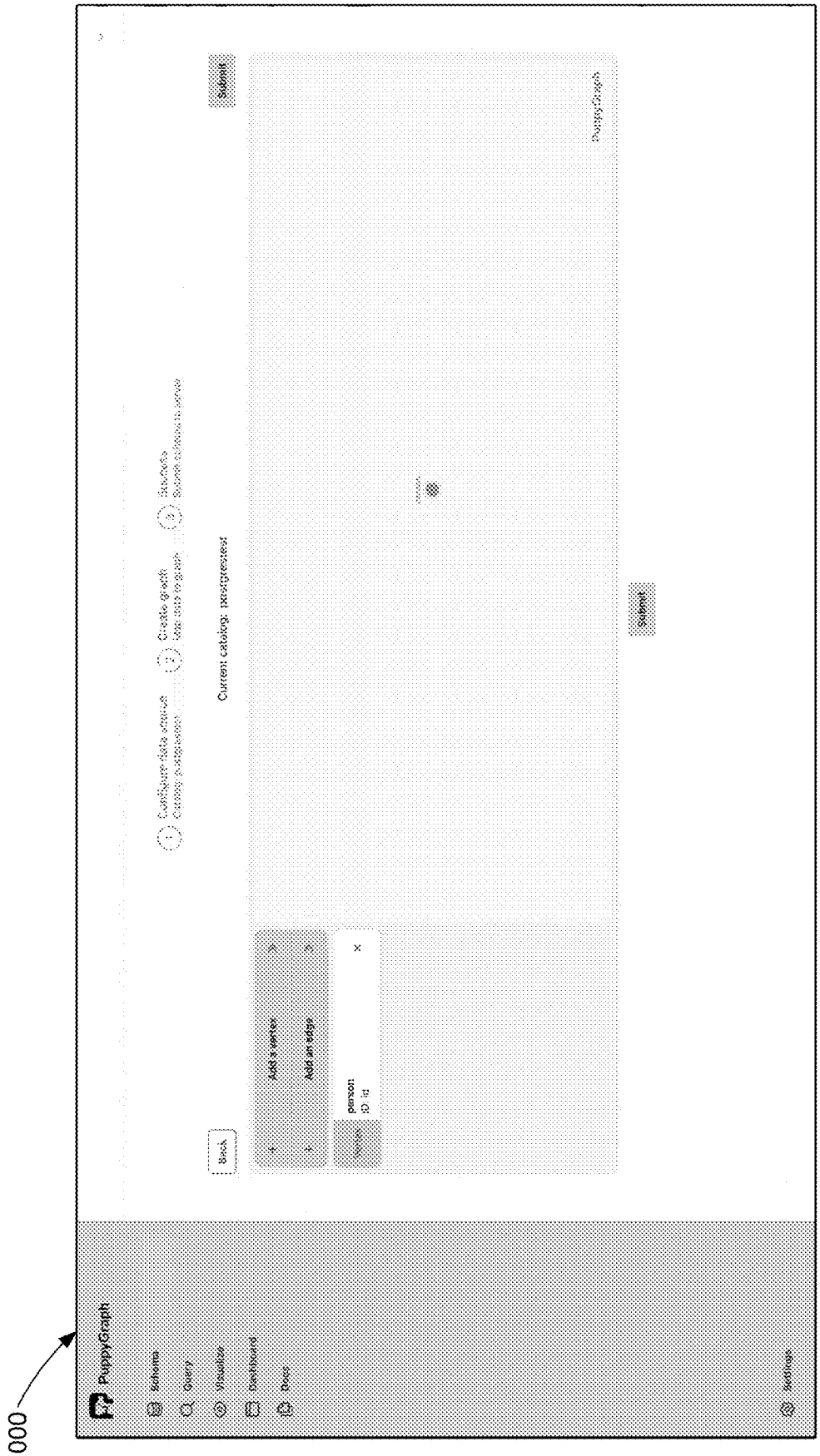

1000
PuppyGraph
Schema
Query
Visualize
Dashboard
Docs
Settings
Submit
Current catalog: postgrestest
Back
Add a vertex
Add an edge
person
ID: id
Submit

Figure 10H

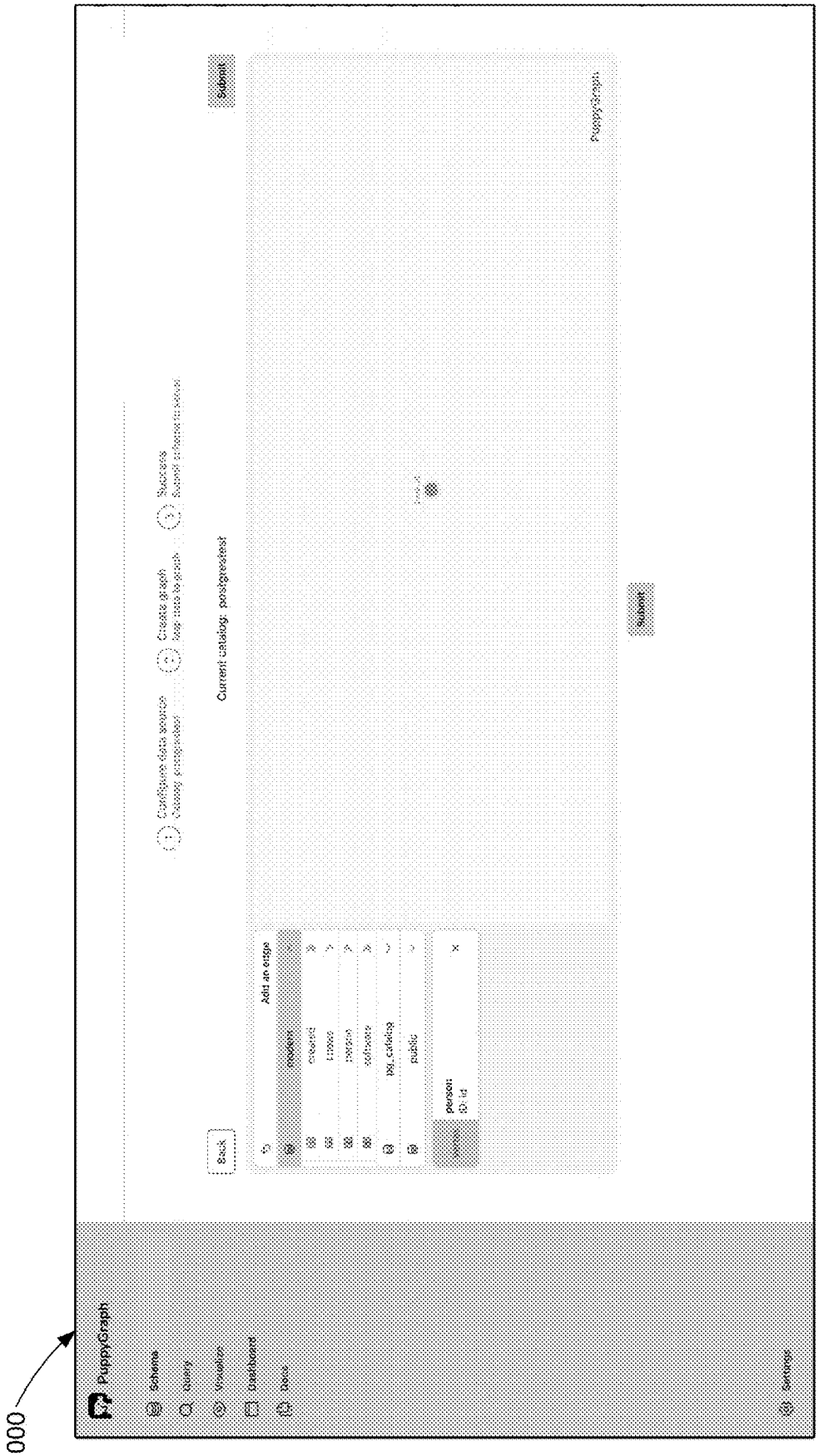

1000
PuppyGraph
Schema
Query
Visualizer
Dashboard
Docs
Settings
Submit
Current catalog: postgrestest
Back
Add an edge
Submit
PuppyGraph

Figure 10I

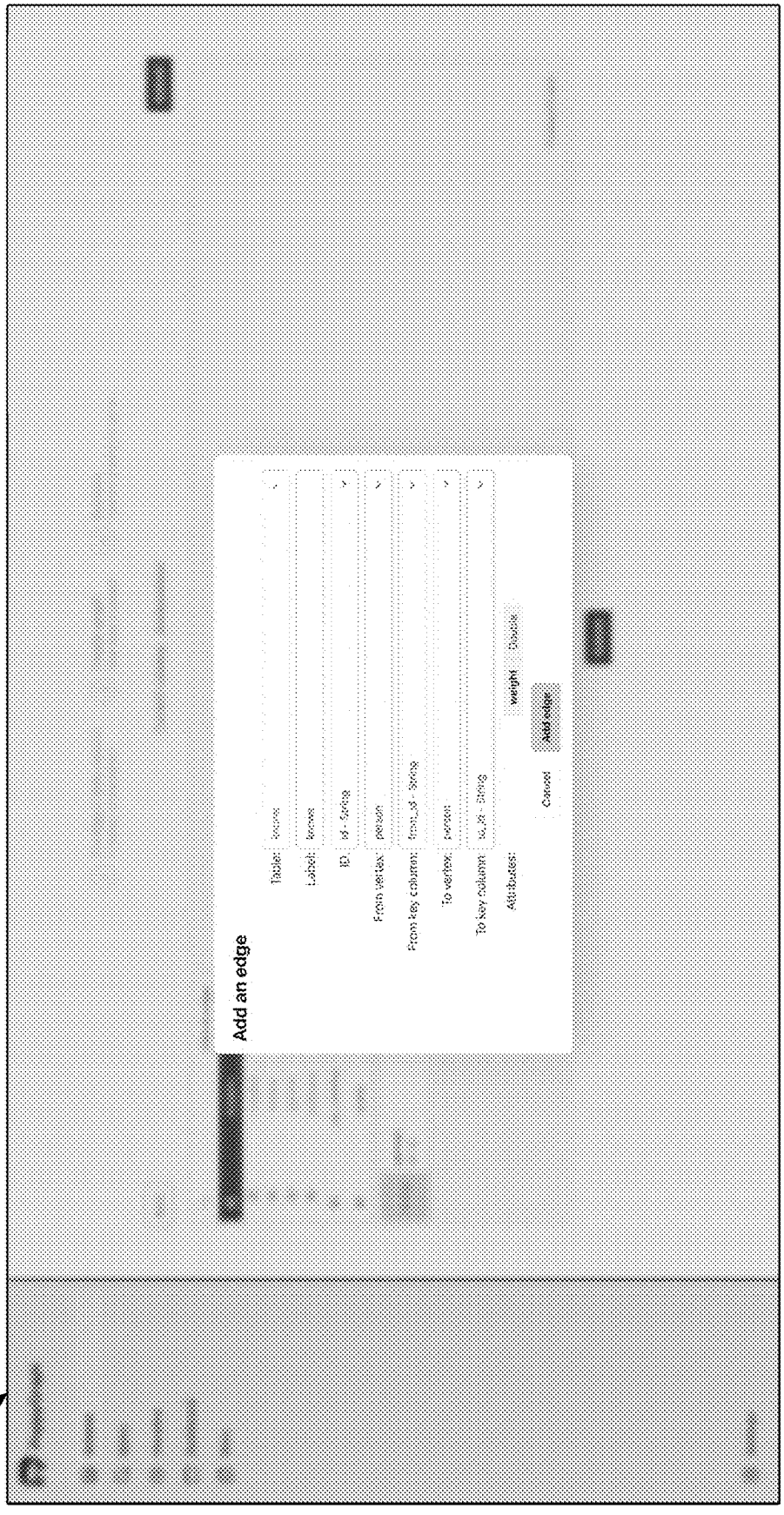

1000
Add an edge
Table:
Label:
ID:
From vertex:
From key column:
To vertex:
To key column:
Attributes:
weight
Double
Cancel
Add edge

Figure 10J

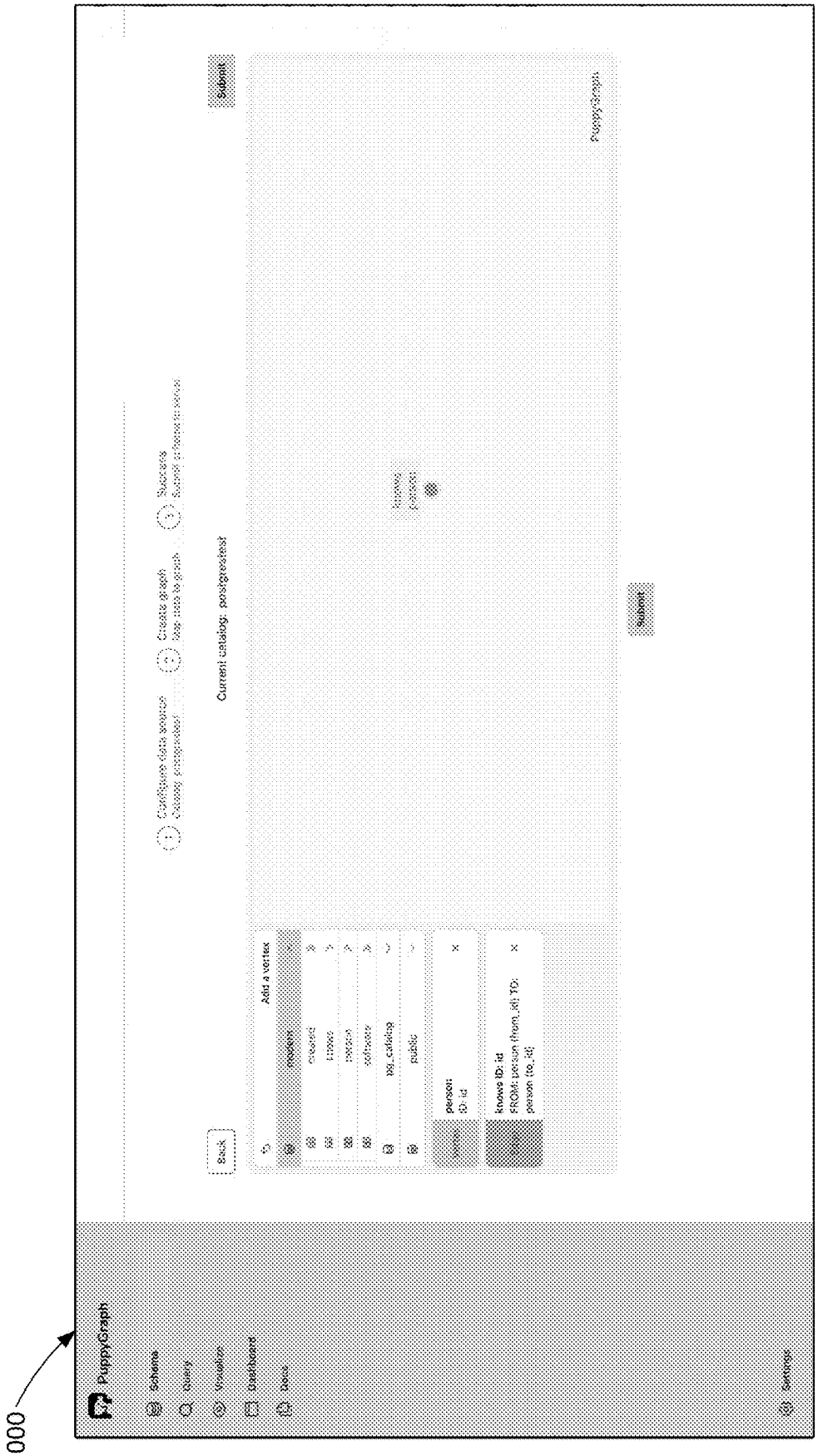

1000
PuppyGraph
Schema
Query
Visualizer
Dashboard
Docs
Settings
Back
Submit
Current catalog: postgrestest
Add a vertex
person
person:
ID: id
knows ID: id
FROM: person (from_id) TO: person (to_id)
Submit

Figure 10K

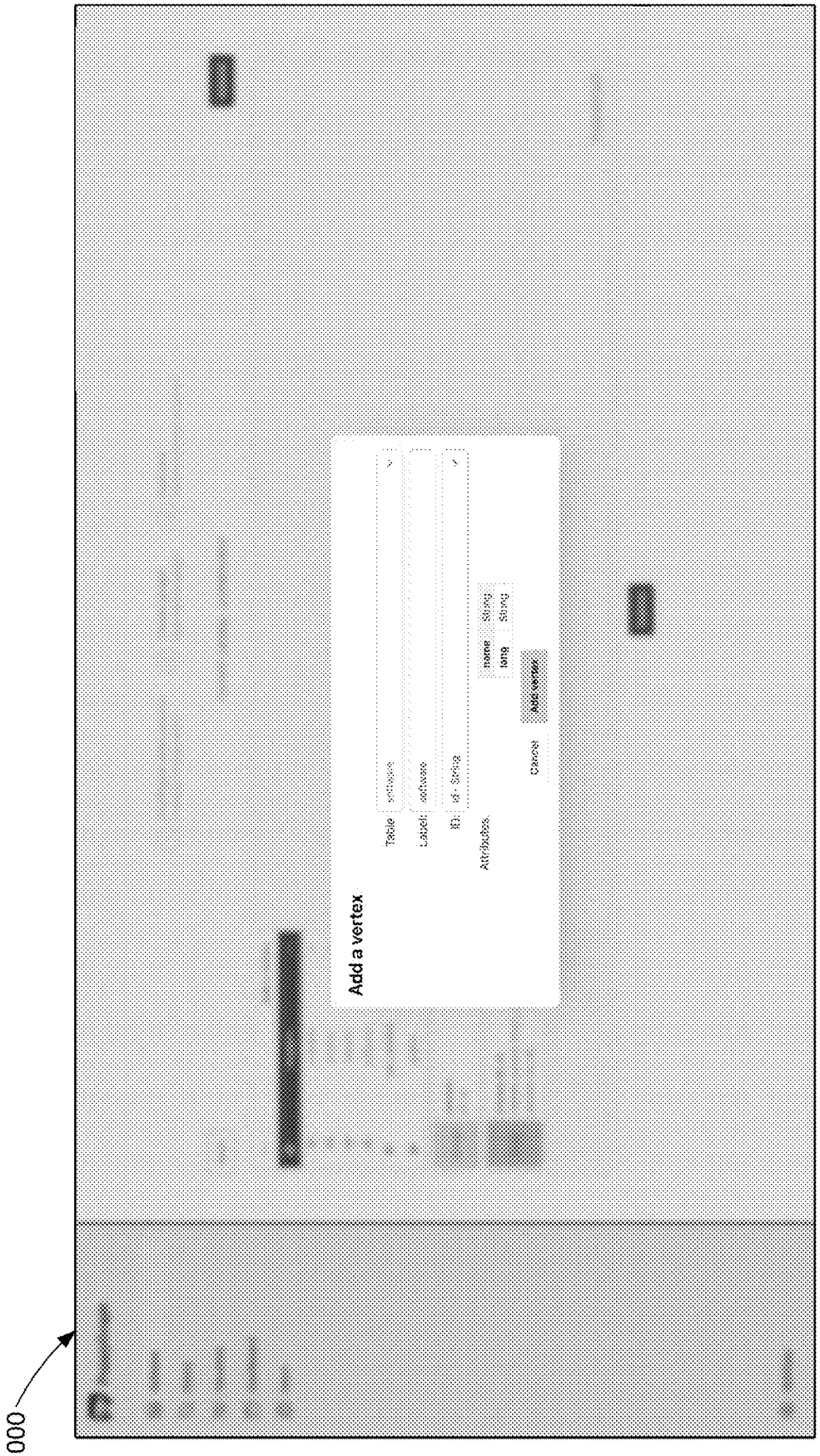

1000
Add a vertex
Table
Label
Attributes
name
lang
String
String
Add vertex
Cancel

Figure 10L

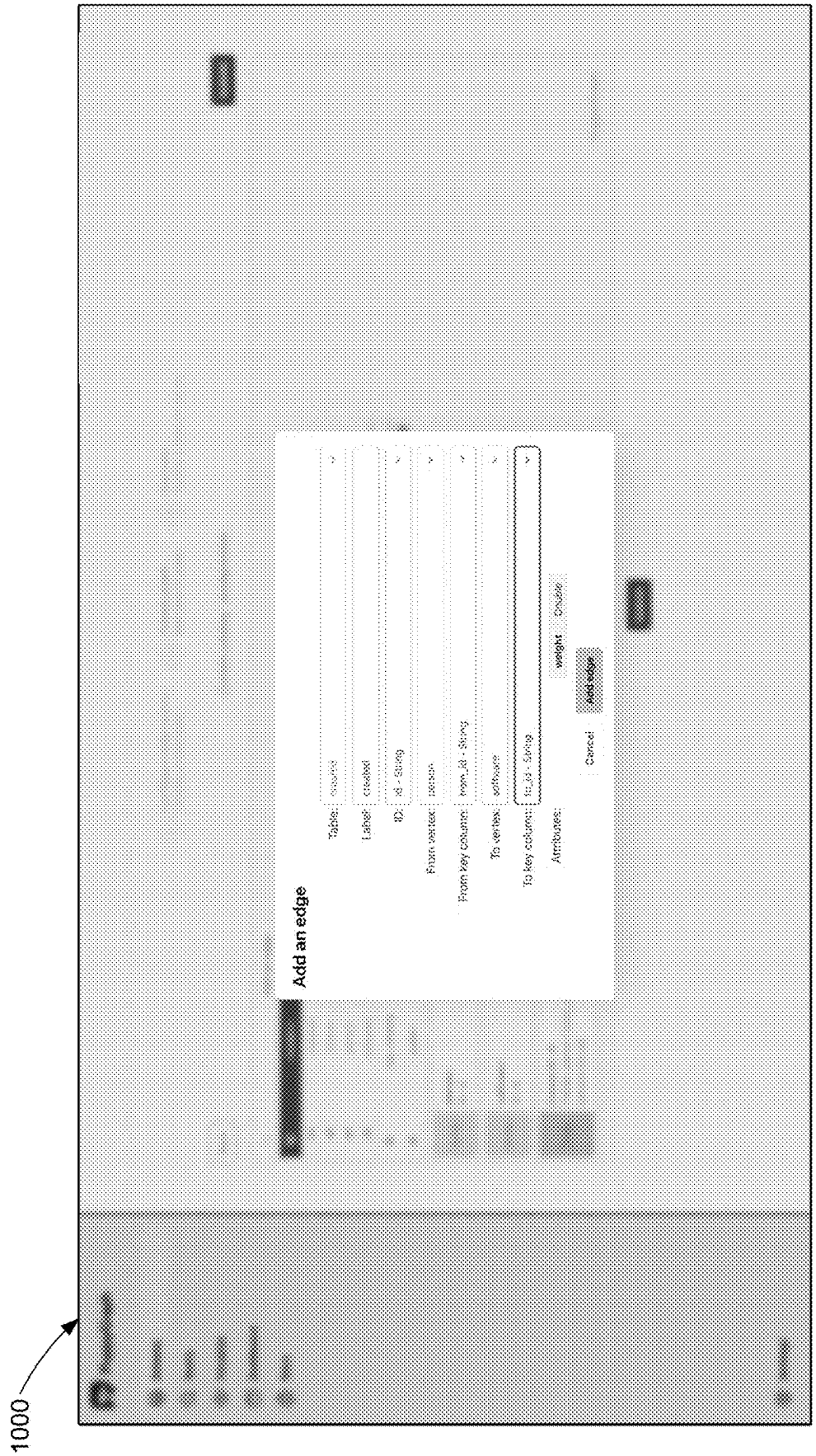

1000
Add an edge
Table:
Label:
ID:
From vertex:
From key column:
To vertex:
To key column:
Attributes:
weight
Double
Cancel
Add edge

Figure 10M

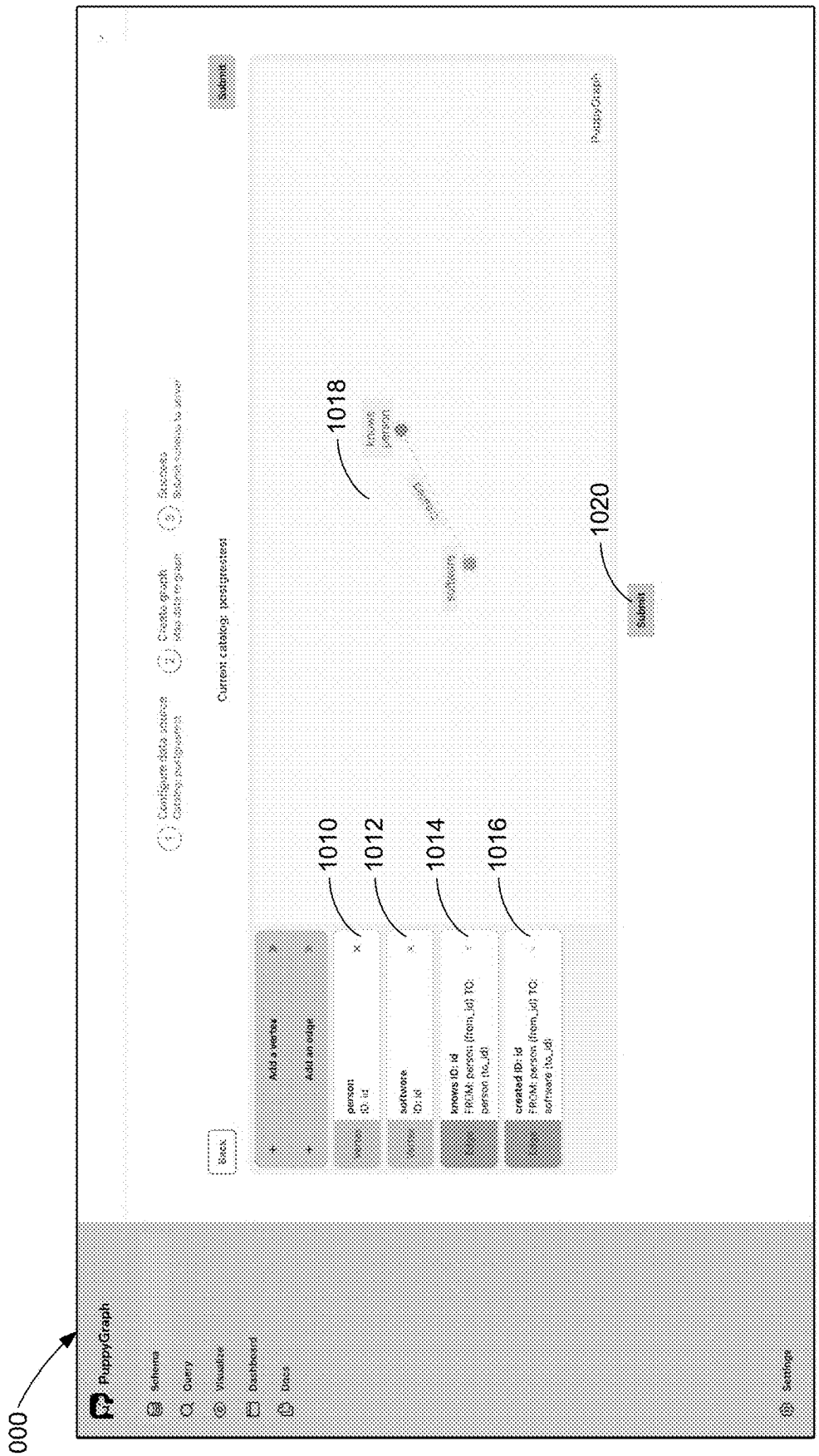

1000
PuppyGraph
Schema
Query
Visualize
Dashboard
Docs
Settings
Back
Submit
Current catalog: postgrestest
Add a vertex
Add an edge
person
ID: id
software
ID: id
knows ID: id
FROM: person (from_id) TO: person (to_id)
created ID: id
FROM: person (from_id) TO: software (to_id)
1010
1012
1014
1016
1018
1020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

Figure 10N

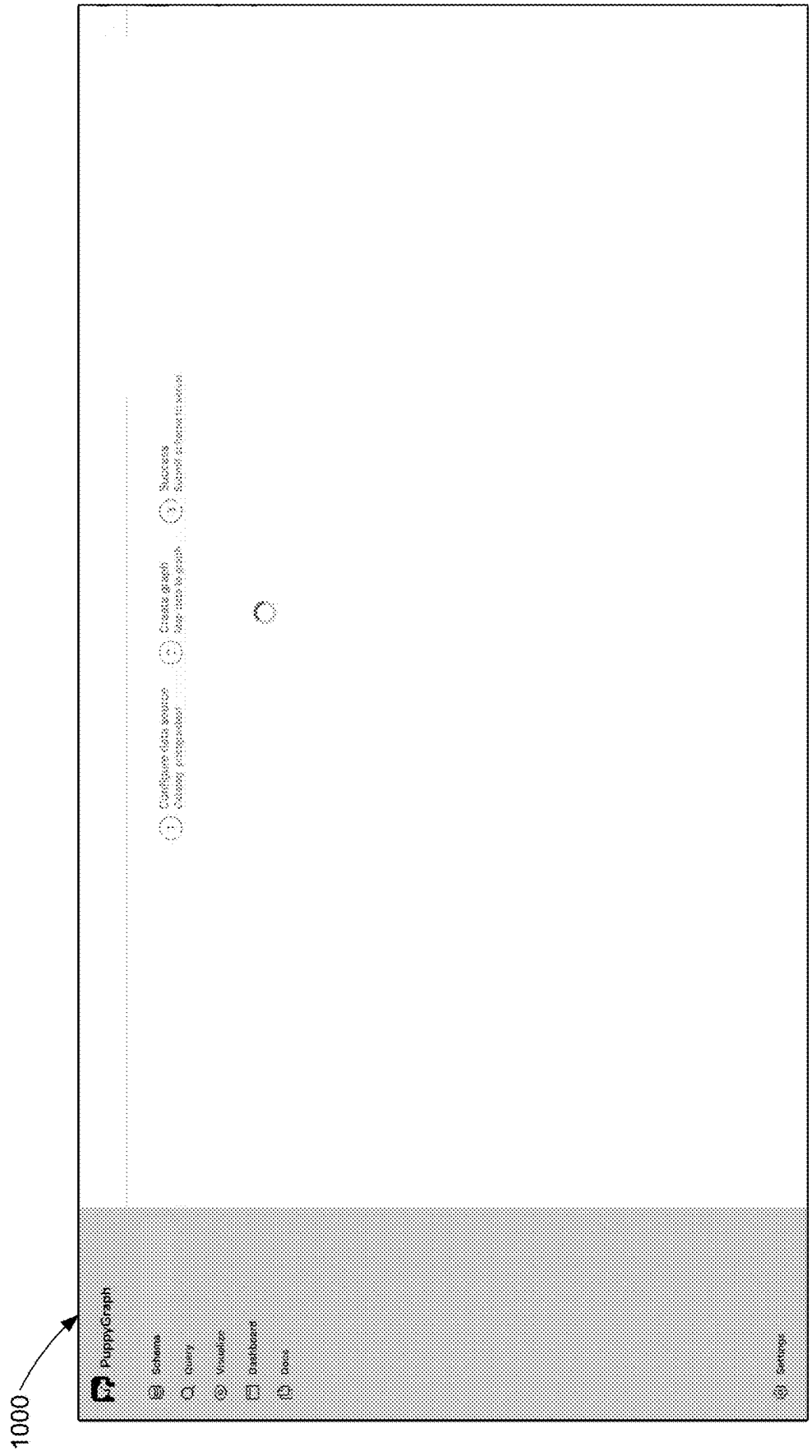

1000
PuppyGraph
Schema
Query
Visualizer
Dashboard
Docs
Settings

Figure 10O

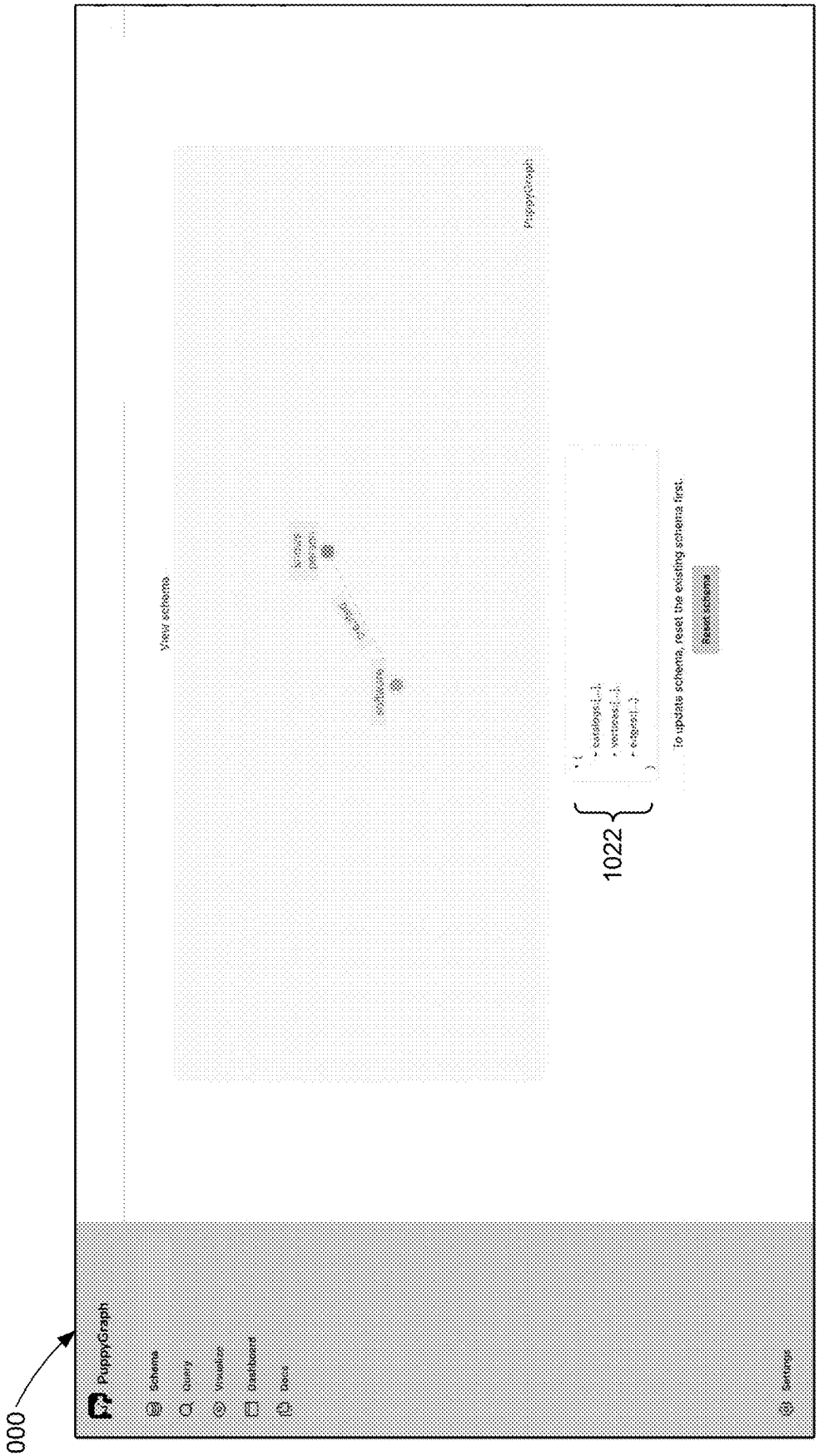

1000
PuppyGraph
Schema
Query
Visualize
Dashboard
Docs
Settings
View schema
PuppyGraph
1022
To update schema, reset the existing schema first.
Reset schema

Figure 10P

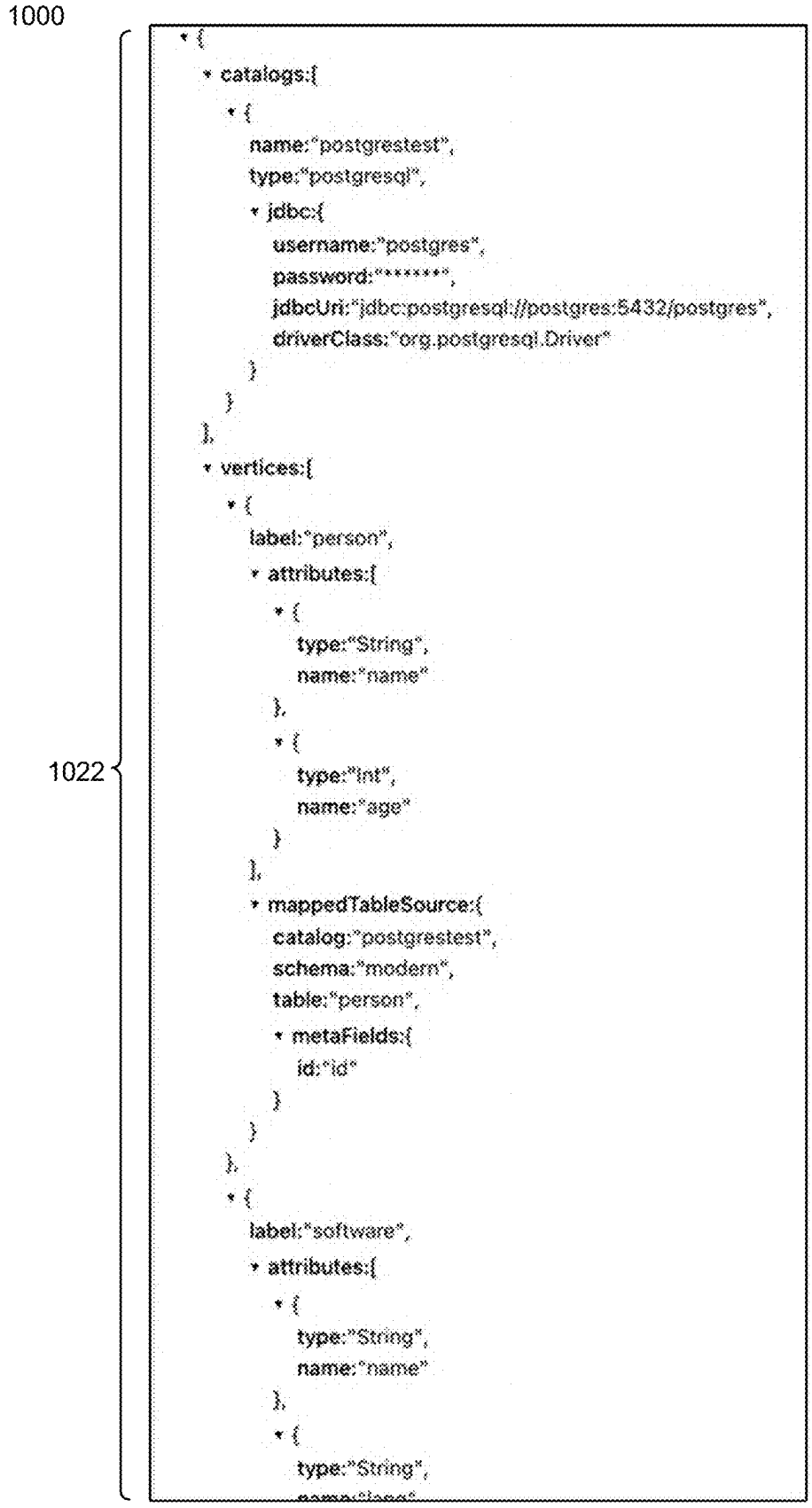

1000
1022
{
catalogs:[
{
name:"postgrestest",
type:"postgresql",
jdbc:{
username:"postgres",
password:"******",
jdbcUri:"jdbc:postgresql://postgres:5432/postgres",
driverClass:"org.postgresql.Driver"
}
}
],
vertices:[
{
label:"person",
attributes:[
{
type:"String",
name:"name"
},
{
type:"Int",
name:"age"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

Figure 10Q

1100

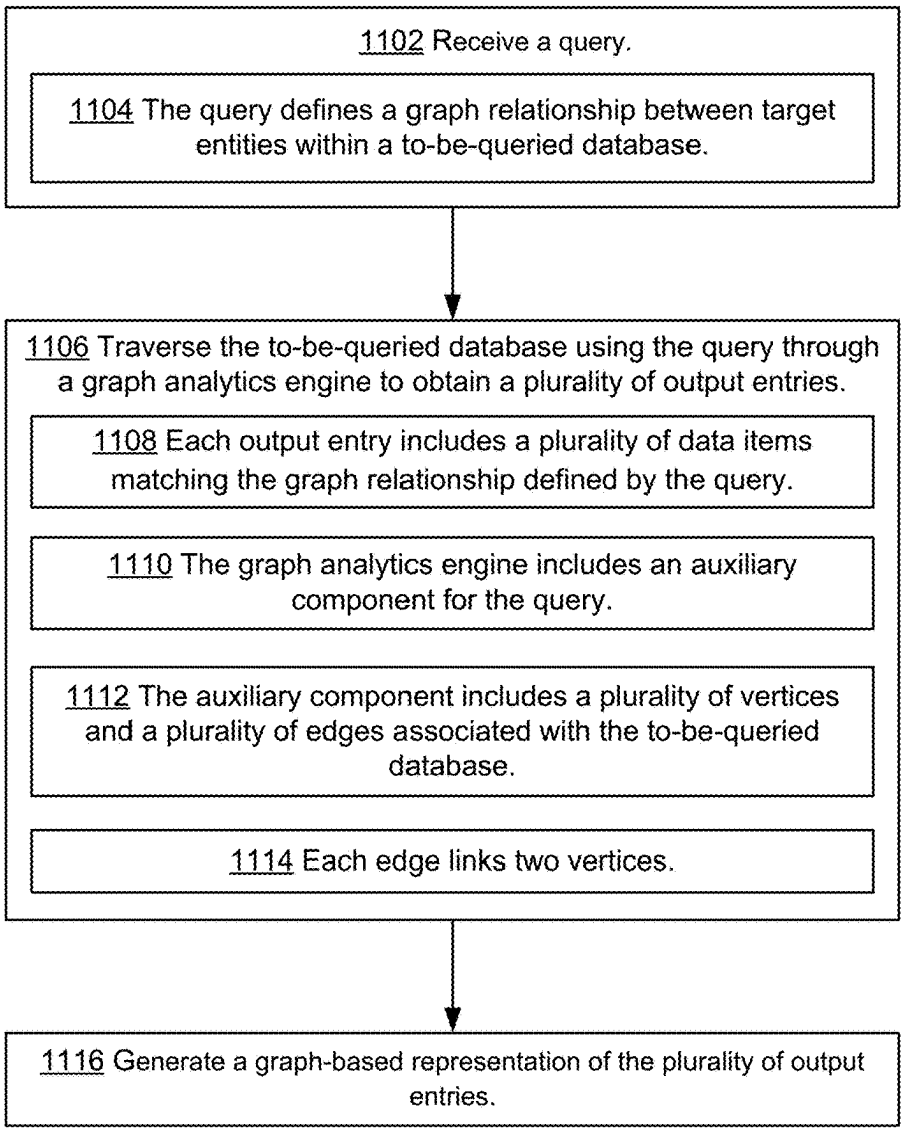


Figure 11

METHOD FOR PERFORMING DATA QUERY USING A GRAPH ANALYTICS ENGINE AND RELATED APPARATUS

TECHNICAL FIELD

[0001] This application relates generally to data query, including but not limited to techniques for performing data query using a graph analytics engine across diverse databases.

BACKGROUND

[0002] 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.

[0003] 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

[0004] Implementing a graph analytics engine 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.

[0005] In accordance with one aspect of the application, a data query method includes 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.

[0006] In another aspect of the application, a computer system includes one or more processes 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 for any of the methods described above.

[0007] In yet another aspect of the application, 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 for any of the methods described above.

[0008] 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.

[0009] Having summarized the above example aspects, a brief description of the drawings will now be presented.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] 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.

[0011] FIG. **1** illustrates a first example data query system based on a graph analytics engine, in accordance with some embodiments.

[0012] FIG. **2** illustrates a second example data query system based on the graph analytics engine, in accordance with some embodiments.

[0013] FIG. **3** illustrates an example graph query process based on an example graph analytics engine, in accordance with some embodiments.

[0014] 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.

[0015] FIGS. **5**A-**5**L illustrate a series of graph query steps associated with a first 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.

[0016] FIGS. **6**A-**6**F illustrate a series of graph query steps associated with a second example person_knows_person graph query that is performed based on the management UI of the graph analytics engine, in accordance with some embodiments.

[0017] 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.

[0018] FIG. **7**E illustrates an example graph query using the graph analytics engine with locally deployed PostgreSQL, in accordance with some embodiments.

[0019] FIG. **7**F illustrates an example graph query using the graph analytics engine with locally deployed DuckDB, in accordance with some embodiments.

[0020] FIGS. **8**A-**8**J illustrate an example graph query using the graph analytics engine with data lakes, in accordance with some embodiments.

[0021] FIGS. **9**A-**9**O illustrates an example graph query using the graph analytics engine with relational databases, in accordance with some embodiments.

[0022] 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.

[0023] FIG. **11** illustrates a flow diagram of an example data query method, in accordance with some embodiments.

[0024] 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

[0025] 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

[0026] FIG. **1** illustrates a first example data query system **100** based on a graph analytics engine, in accordance with some embodiments. As shown the first 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.

[0027] 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.

[0028] FIG. **2** illustrates a second 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.

[0029] 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**).

[0030] 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 submit 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 transfer 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.

[0031] 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.

[0032] In some embodiments, a graph query process based on the graph analytics engine supports data sources distributed across cloud platforms and regional networks.

[0033] 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**.

[0034] 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.

[0035] 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.

[0036] 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.

[0037] 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.

[0038] 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 bring several advantages, including parallel processing, scalability, and cost efficiency.

[0039] 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.

[0040] 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-**9**O). 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).

[0041] 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).

[0042] 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.

[0043] In some embodiments, a to-be-queried database includes a non-SQL (NoSQL) database.

Data Query with a JSON File

[0044] 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**).

[0045] 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 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 form of arrays.

[0046] FIGS. **4A-4C** 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.

[0047] FIG. **4A** 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.

[0048] FIG. **4B** 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**.

[0049] FIG. **4C** illustrates example graph query statements **480** and **482** for transaction traces. A first example graph query statement **480** and a second example graph query statement **482** is to obtain whom a User 00001 transfers to through a one-hop route and a two-hop route, respectively.

[0050] In the first 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."

[0051] The second example graph query statement **482** is similar to the first example graph query statement **480**, except that the second 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.

[0052] 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 define the vertices **452** and edges **454** in form of arrays. The user further generates the JSON file **450** based on the vertices **452** and edges **454**.

[0053] 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.

[0054] 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).

[0055] 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

[0056] FIGS. **5**A-**5**L illustrate a series of graph query steps **500** associated with a first 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 first 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.

[0057] 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**.

[0058] FIG. **5**B illustrates a JSON file **520** corresponding to the first 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**.

[0059] 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.

[0060] 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*, a drop-down list **540** then emerges and provides the processed information of the JSON file **520** related to catalogs, vertices, and edges.

[0061] FIG. **5**D illustrates the status section **532** after the process on the JSON file **520** is complete.

[0062] 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**.

[0063] 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**.

[0064] FIG. **5**G illustrates performing a first set of example graph query statements **552** of the first 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 first 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".

[0065] FIG. **5**H illustrates performing a second set of example graph query statements **562** of the first 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 second 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).

[0066] 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** provide more details of the output entries of the graph query **562-3** for obtaining paths between persons.

[0067] FIGS. **5**J-**5**L illustrate virtualizing output entries of graph queries from a third set of example graph query statements **572** of the first 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.

[0068] 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).

[0069] 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 first 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

[0070] FIGS. **6**A-**6**F illustrate a series of graph query steps **600** associated with a second 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.

[0071] 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.

[0072] 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**.

[0073] 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 second 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.

[0074] 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.

[0075] 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.

[0076] 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

[0077] 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 second example person_knows_person graph query in reference to FIG. **6**A.

[0078] 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.

[0079] 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**").

[0080] 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.

[0081] 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.

[0082] 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 obtain output entries **730**, as shown in FIG. **7**D.

Graph Analytics Engine with Locally Deployed PostgreSQL

[0083] 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 second 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.

[0084] 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.

[0085] 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).

[0086] 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

[0087] 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 second 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.

[0088] 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.

[0089] 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).

[0090] 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

[0091] FIGS. **8**A-**8**J illustrate an example graph query **800** using the graph analytics engine with data lakes, in accordance with some embodiments.

[0092] A user can query data by connecting to the data lakes, which include Apache Iceberg, Apache Hudi, Delta Lake, and Apache Hive.

[0093] 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

[0094] 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 **810** and the SparkSQL statements **812** is optional.

[0095] 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:

[0096] A catalog object named catalog_test defines an Iceberg data source. The hiveMetastoreUrl field matches the Hive Metastore URL.

[0097] 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.

[0098] The mappedTableSource object also refers to columns (e.g., attributes) in the tables.

[0099] An id field refers to a column storing identities for vertices ID and edges refId.

[0100] 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.

[0101] 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

[0102] 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 **830** and the SparkSQL query **832** is optional.

[0103] 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:

[0104] 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.

[0105] 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.

[0106] 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.

[0107] 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

[0108] 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.

[0109] 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:

[0110] 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.

[0111] 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.

[0112] 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.

[0113] 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

[0114] 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.

[0115] 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:

[0116] 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.

[0117] A type of the Hive Catalog is hive, and a metastore type of the Hive Catalog is HMS.

[0118] 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.

[0119] 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.

[0120] 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).

[0121] 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.

[0122] 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

[0123] FIGS. **9**A-**9**O illustrates an example graph query **900** using the graph analytics engine with relational databases, in accordance with some embodiments.

[0124] A user can query data by connecting to the relational databases, which include MySQL, PostgreSQL, DuckDB, BigQuery, and Redshift.

[0125] 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

[0126] 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.

[0127] 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:

- **[0128]** A catalog jdbc_mysql is added to specify remote data source in MySQL.
  - **[0129]** Set type to mysql.
  - **[0130]** 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.
  - **[0131]** Set driverUrl to provide a URL where the graph analytics engine finds the MySQL driver.
- **[0132]** 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.
- **[0133]** 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.

[0134] 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

[0135] 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.

[0136] 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:

- **[0137]** A catalog jdbc_postgres is added to specify remote data source in postgreSQL.
  - **[0138]** Set type to postgresql.
  - **[0139]** Set driverClass to org.postgresql.Driver.
  - **[0140]** Set driverUrl to provide a URL where the graph analytics engine finds the PostgreSQL driver.
- **[0141]** 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.
- **[0142]** 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.

[0143] 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

[0144] 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.

[0145] 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:

- **[0146]** A catalog jdbc_duckdb is added to specify remote data source in DuckDB.
  - **[0147]** Set type to duckdb.
  - **[0148]** Set driverClass to org.duckdb.DuckDBDriver.
  - **[0149]** Set driverUrl to provide a URL where the graph analytics engine finds the DuckDB driver.
- **[0150]** 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.
- **[0151]** 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.

[0152] 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

[0153] For creating tables and insert data to BigQuery, the user performs steps below as shown in screenshots (e.g., **940**, **942**, and **944**) of FIGS. **9**G-**9**I.

[0154] Create a dataset with multiple-region support in (e.g., the screenshot **940**).

[0155] Create tables using a web console (e.g., the screenshots **942** and **944**).

After that, the user opens a query table and execute 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.

[0156] Next, the user starts the graph analytics engine container named puppy through a key key.json command **948**, as illustrated in FIG. **9**J.

[0157] 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:

[0158] A catalog jdbc_bigquery is added to specify remote data source in BigQuery.

[0159] Set type to bigquery.

[0160] Set driverClass to com.simba.googlebigquery.jdbc.Driver.

[0161] Set driverUrl to provide a URL where the graph analytics engine finds the DuckDB driver.

[0162] jdbcUri needs to be set in accordance with the user's service account configuration.

[0163] Set ProjectId=PJID. PJID for service account project id.

[0164] Set OAuthServiceAcctEmail=for service account id.

[0165] Set OAuthPvtKeyPath=for a key file path in the docker container (e.g., /home/key.json).

[0166] 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.

[0167] 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.

[0168] 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

[0169] For creating tables and insert data to RedShift, the user follows steps below as shown in screenshots (e.g., **960** and **962**) in FIGS. **9**L-**9**M.

[0170] Create a database with a query editor (e.g., the screenshot **960**).

[0171] 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.

[0172] 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:

[0173] A catalog jdbc_redshift is added to specify remote data source in RedShift.

[0174] Replace username and password.

[0175] Replace jdbcUri with the user's JDBC URL.

[0176] 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.

[0177] 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.

[0178] 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.

[0179] 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.

[0180] 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

[0181] 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.

[0182] 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**.

[0183] 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.

[0184] 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.

[0185] 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**).

[0186] FIG. **11** illustrates a flow diagram of an example data query method **1100**, in accordance with some embodiments. In some embodiments, the example data query method **1100** is performed at a computer system. In some

embodiments, the example data query method **1100** 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.

[0187] In the example data query method **1100**, the computer system receives (**1102**) a query. The query defines (**1104**) a graph relationship between target entities within a to-be-queried database. The computer system traverses (**1106**) the to-be-queried database using the query through a graph analytics engine to obtain a plurality of output entries. Each output entry includes (**1108**) a plurality of data items matching the graph relationship defined by the query. The graph analytics engine includes (**1110**) an auxiliary component for the query. The auxiliary component includes (**1112**) a plurality of vertices and a plurality of edges associated with the to-be-queried database. Each edge links (**1114**) two vertices. The computer system generates (**1116**) a graph-based representation of the plurality of output entries.

[0188] In some embodiments, 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. Further, in some embodiments, the graph analytics engine includes a plurality of execution nodes. Each execution node is associated with a respective to-be-queried database.

[0189] In some embodiments, the query is written in a graph query language.

[0190] In some embodiments, 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.

[0191] In some embodiments, the to-be-queried database defines the graph relationship between the target entities in a tabular form.

[0192] In some embodiments, the to-be-queried database is compatible with structured query language (SQL).

[0193] In some embodiments, the to-be-queried database includes a non-SQL (NoSQL) database.

[0194] In some embodiments, 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. Moreover, in some embodiments, the auxiliary component is a human-readable file. 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), or Extensible Markup Language (XML). Further, in some embodiments, a respective edge linking two adjacent vertices of the plurality of vertices is directed or undirected. In some embodiments, the respective edge linking two adjacent vertices of the plurality of vertices includes a weight component. Additionally, in some embodiments, the auxiliary component is created through a user interface associated with the auxiliary component.

[0195] In some embodiments, 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.

[0196] In some embodiments, 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.

[0197] It should be understood that the particular order in which the operations in FIG. **10** 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 providing 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**-**10**Q. For brevity, these details are not repeated in the description herein.

[0198] 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.

[0199] 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.

[0200] 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.

[0201] 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 data query method, comprising:

receiving a query, the query defining a graph relationship between target entities within a to-be-queried database;

traversing the to-be-queried database using the query through a graph analytics engine to obtain a plurality of output entries, each output entry including a plurality of data items matching the graph relationship defined by the query, wherein:

the graph analytics engine includes an auxiliary component for the query, the auxiliary component including a plurality of vertices and a plurality of edges associated with the to-be-queried database, each edge linking two vertices; and

generating a graph-based representation of the plurality of output entries.

2. The data query method of claim **1**, wherein 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.

3. The data query method of claim **2**, wherein the graph analytics engine includes a plurality of execution nodes, each execution node being associated with a respective to-be-queried database.

4. The data query method of claim **1**, wherein the query is written in a graph query language.

5. The data query method of claim **1**, wherein the to-be-queried database is built in accordance with a data architecture, the data architecture including at least one of relational database, data warehouse, or data lake.

6. The data query method of claim **1**, wherein the to-be-queried database defines the graph relationship between the target entities in a tabular form.

7. The data query method of claim **1**, wherein the to-be-queried database is compatible with structured query language (SQL).

8. The data query method of claim **1**, wherein the to-be-queried database includes a non-SQL (NoSQL) database.

9. The data query method of claim **1**, wherein 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.

10. The data query method of claim **9**, wherein the auxiliary component is a human-readable file.

11. The data query method of claim **10**, wherein 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).

12. The data query method of claim **9**, wherein a respective edge linking two adjacent vertices of the plurality of vertices is directed or undirected.

13. The data query method of claim **12**, wherein the respective edge linking two adjacent vertices of the plurality of vertices includes a weight component.

14. The data query method of claim **9**, wherein the auxiliary component is created through a user interface associated with the auxiliary component.

15. The data query method of claim **1**, wherein 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.

16. The data query method of claim **1**, wherein the receiving, the traversing, and the generating are performed via an application or a user interface.

17. A computer system, comprising:

one or more processors; and

memory storing one or more programs, the one or more programs comprising instructions that, when executed by the one or more processors, cause the one or more processors to perform operations comprising:

receiving a query, the query defining a graph relationship between target entities within a to-be-queried database;

traversing the to-be-queried database using the query through a graph analytics engine to obtain a plurality of output entries, each output entry including a plurality of data items matching the graph relationship defined by the query, wherein:

the graph analytics engine includes an auxiliary component for the query, the auxiliary component including a plurality of vertices and a plurality of edges associated with the to-be-queried database, each edge linking two vertices; and

generating a graph-based representation of the plurality of output entries.

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 query, the query defining a graph relationship between target entities within a to-be-queried database;

traversing the to-be-queried database using the query through a graph analytics engine to obtain a plurality of output entries, each output entry including a plurality of data items matching the graph relationship defined by the query, wherein:

the graph analytics engine includes an auxiliary component for the query, the auxiliary component including a plurality of vertices and a plurality of edges associated with the to-be-queried database, each edge linking two vertices; and

generating a graph-based representation of the plurality of output entries.

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