TIBCO® Graph Database Query Guide

Version 3.1

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TIBCO Graph Database Query Language

Introduction

TIBCO Graph Database (TGDB) query language is a functional, data-flow language that enables users to succinctly express complex traversals on (or queries of) their application's property graph. The query language is derived from Apache Tinkerpop's graph traversal language "Gremlin". TGDB's query language is also referred to as the ***Gremlin Query Language*** (GQL).
Every Gremlin traversal is composed of a sequence of potentially nested steps. A step performs an atomic operation on the data stream.
Every step can be categorized into one of the following steps:

- Map step:- transforming the objects in the stream
- Filter step:- removing objects from the stream
- SideEffect step:- computing statistics about the stream

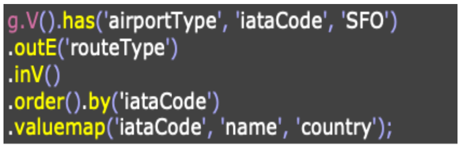
The Gremlin step library extends on these 3-fundamental operations to provide you a rich collection of steps that you can compose in order to ask any conceivable question you may have of their data for Gremlin is Turing-complete.

TGDB also supports/implements the functional API form of Gremlin Query in Java. In Programming languages like Java, Go, Python, typically the Connection object has executeQuery or createQuery methods that take a string representation of the Gremlin Query. The string is of the URI form "`gremlin://…`". This tells the query engine to interpret the string sequence as a Gremlin Query.

The current industry of Graph is evolving and query standards are being developed and refined. Providing a URI form helps end-user investment and quickly adapt to the new standards to avail the efficiency and benefits and changing the code as per the demands.

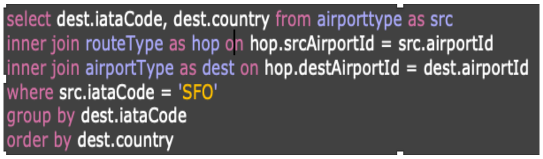
Functional & Declarative Languages

A GQL is a functional language, that is, an imperative language instructing the engine how to proceed in each step of the traversal. For instance, the imperative traversal on the right first places a traverser at the airport denoting "SFO". That traverser then splits itself across all of Gremlin's collaborators that are not Gremlin himself. Next, the traversers walk to the managers of those collaborators to ultimately be grouped into a manager name count distribution. This traversal is imperative in that it tells the traversers to "go here and then go there" in an explicit, procedural manner.



```
g.V().has('airportType', 'iataCode', 'SFO')
.outE('routeType')
.inV()
.order().by('iataCode')
.valuemap('iataCode', 'name', 'country');
```

Declarative language is a non-imperative style of language in which programs describe their desired results without explicitly listing commands or steps that must be performed. For instance, the SQL statement on the right window declares what to project, and the conditions to be met for the projection. It does not tell or spit out the instruction order as in the functional or imperative style. The query engine decides the best possible algorithm and execution model to execute the query.



```
select dest.iataCode, dest.country from airporttype as src
inner join routeType as hop on hop.srcAirportId = src.airportId
inner join airportType as dest on hop.destAirportId = dest.airportId
where src.iataCode = 'SFO'
group by dest.iataCode
order by dest.country
```

Each style has its own advantages and disadvantages. SQL style is well suited for traditional relational databases, is matured, and is good at expressing relational joins across 2 to 3 tables. But, when it comes to expressing a Graph traversal “cyclic” and “hierarchical”, it becomes very difficult to define and execute. GQL is built for Graph Traversal and Transformation. TIBCO Graph Database adopted GQL for its expressive prowess and simplicity in understanding.

The book provides various examples of GQL and attempts how a SQL variant could potentially solve the same problem. You can notice that as the complexity increases, GQL provides an easier way to express compared to the SQL variant.

TIBCO Graph Database also supports the Gremlin Functional Interface in Java, so code written for other Gremlin providers can easily be ported to the TIBCO provider by configuration settings.

Example Database for GQL

GQL helps you navigate the vertices and edges of a graph. It is the query language to graph databases, as SQL is the query language to relational databases. To tell Gremlin how it should "traverse" the graph (i.e., what you want your query to do) you need a way to provide commands in the language TGDB understands — and, of course, that language is called "Gremlin Query Language".

Prerequisites

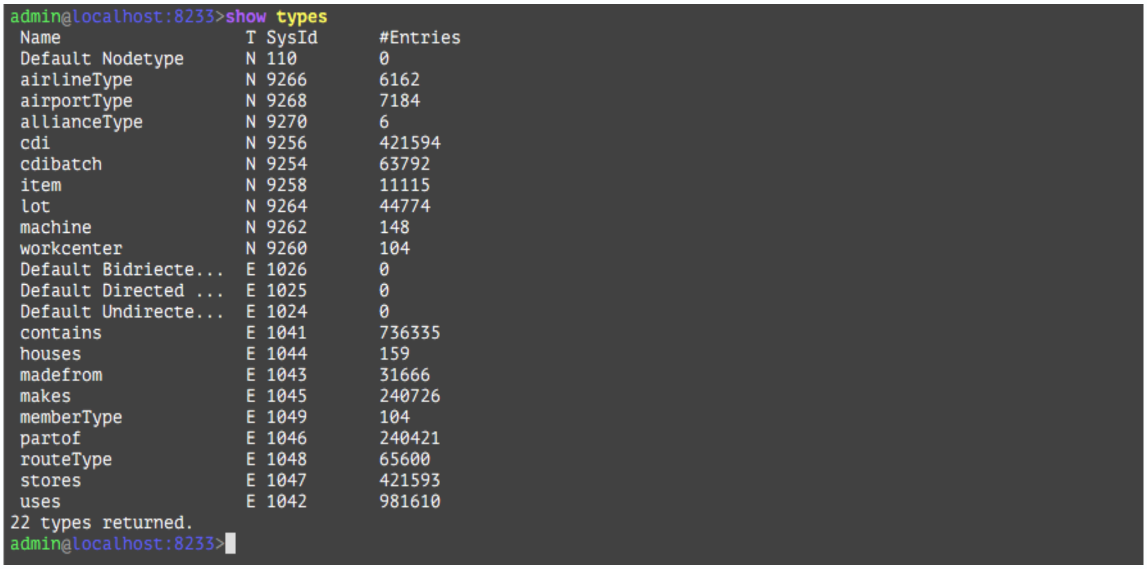
You installed TIBCO Graph Database 3.1.0, and followed the basic instructions as set in the Getting Started guide.

Installing the Example Database

Download the database from Github
[https://github.com/TIBCOSoftware/tgdb-client/tree/master/examples/database/gqt]
Follow the instructions:

1. Copy or download the database/gqt directory copied to <tgdb_home>/examples/
2. Make sure to extract the *import.zip* file. After extracting the archive, you should have <tgdb_home>/examples/gqt/import
3. <tgdb_home> specifies the path for the TGDB home directory. For Example,
   a. on MacOSX: /home/tibco/tgdb/3.1
   b. on Windows: C:/home/tibco/tgdb/3.1
4. Adjust configuration files:
   a. Copy *tgdb-init.conf* file into <tgdb_home>/bin directory
   b. Open *tgdb-init.conf* and locate the [databases] section. Make sure that the gqtdb database is not commented out.
   c. Open *../examples/gqt/gqtdb.conf* and locate the [import] section. Make sure that this section is not commented out.
   d. Open *<tgdb_home>/bin/tgdb.conf* and locate the databases section. Add gqtdb conf file path in this section. For example, gqtdb = ../examples/gqt/gqtdb.conf
5. Init database and import GQT data:
   a. Navigate to directory <tgdb_home>/bin to execute any of the following commands.
   b. Windows: tgdb -i -f -c tgdb-init.conf
   c. MacOSX/linux: ./tgdb -i -f -c tgdb-init.conf
6. Start database
   a. Windows: tgdb -s -c tgdb.conf
   b. MacOSX/linux: ./tgdb -s -c tgdb.conf
7. Launch an Admin console and connect to the TGDB server
   a. Navigate to <tgdb_home>/bin in a new command prompt window and execute following
   b. Windows: tgdb-admin
   c. MacOSX/linux: ./tgdb-admin
8. Use the database name as `gqtdb` and userid and password as default `admin/admin`

9. Execute a 'show types' command and make sure entries are present



```
admin@localhost:8233>show types
 Name                  T SysId      #Entries
 Default Nodetype      N 110        0
 airlineType           N 9266       6162
 airportType           N 9268       7184
 allianceType          N 9270       6
 cdi                   N 9256       421594
 cdibatch              N 9254       63792
 item                  N 9258       11115
 lot                   N 9264       44774
 machine               N 9262       148
 workcenter            N 9260       104
 Default Bidriecte...  E 1026       0
 Default Directed ...  E 1025       0
 Default Undirecte...  E 1024       0
 contains              E 1041       736335
 houses                E 1044       159
 madefrom              E 1043       31666
 makes                 E 1045       240726
 memberType            E 1049       104
 partof                E 1046       240421
 routeType             E 1048       65600
 stores                E 1047       421593
 uses                  E 1042       981610
22 types returned.
admin@localhost:8233>
```

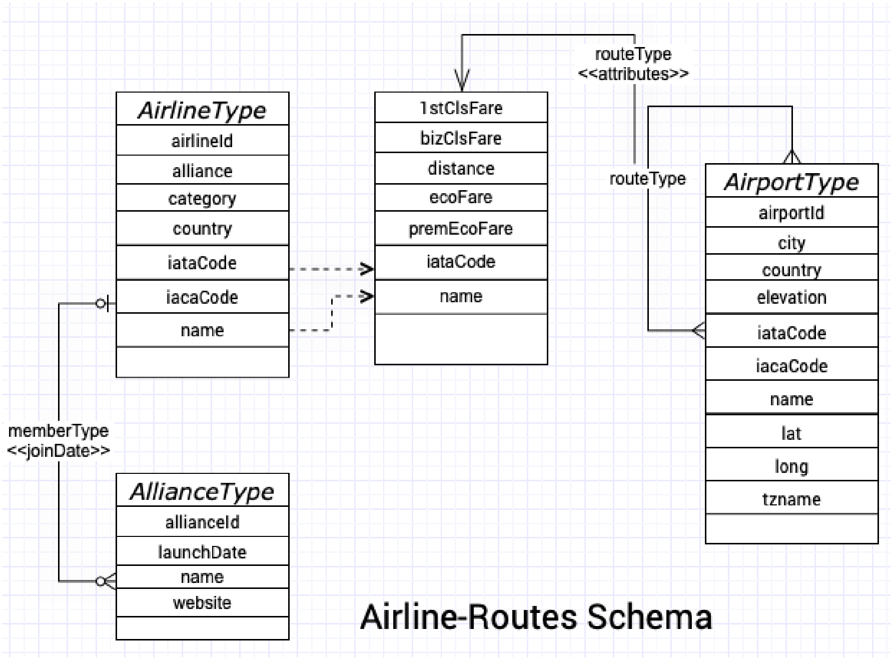
Database Schema

This book provides many examples of GQL queries. They require data, and model so that the queries are reasonable and have an application sense to today's work environment. The book comes with an Example database that can be downloaded from Github
Example database consists of two independent schemas

1. Airline Routes schema
2. Caliper Manufacturing schema

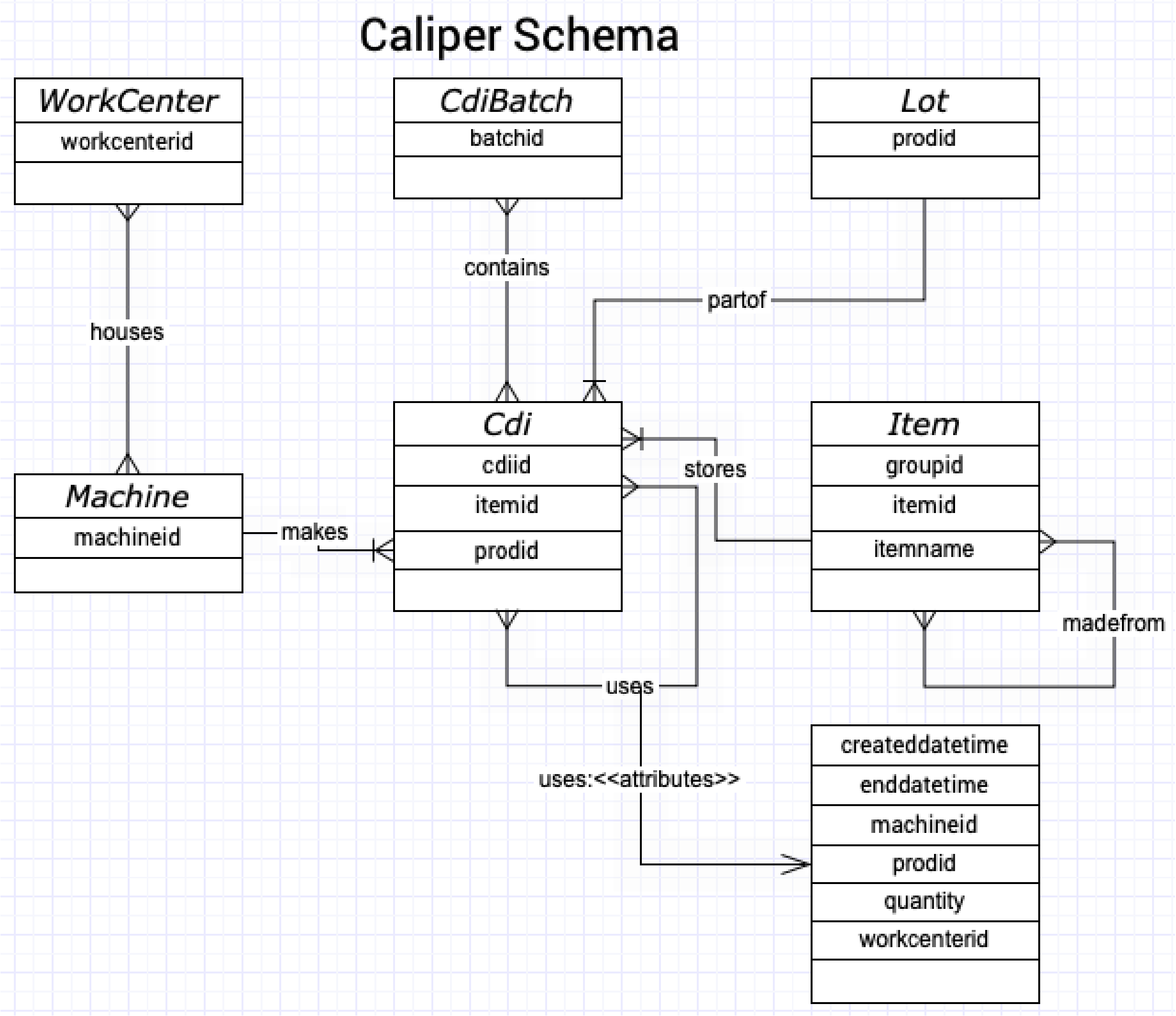
In the following E-R diagram, the entities are specified with both name and its attributes. The relationship between entities captures the name of the relationship and also the attributes for the relationships.

Airline-Routes schema provides an exhaustive set of Routes serviced by different airlines between any 2 airports.It also provides a class Fare for airline servicing the route.
It is important to note that the *RouteType* relationship is a self join of *AirportType* Entity and has attributes in which the *iataCode* is the key into the *AirlineType*



Airline-Routes Schema

Caliper model captures entities and relationship between foundry, manufactured parts and source materials. Data captured by this model provides traceability of each manufactured part in its manufacturing process



Schema Elements

The schema element consists of

- Attribute Descriptors,
- NodeTypes,
- EdgeTypes,
- Indices,
- Principals and Roles
- Stored Procedures

This chapter describes the key schema elements that are used throughout the book. One can run the *show types* command in Administrator and get all the information.

Node Types

CDI	A container or box contains a specific ‘Item’ A CDI can use other CDIs to make its ‘Item’
CDIBatch	Each batch contains multiple CDIs Each CDI can belong to multiple batches
Item	The actual part/item contained in a CDI An item can be made from one or more items
Lot	Each CDI is part of a lot Lot id is the ‘prodid’ in the data file A lot can contain more than one CDI
Workcenter	The place when the corresponding CDI is manufactured It contains one or more machines
Machine	The machine used to manufacture the item in the CDI

Edge Types

contains	A CDIBatch has a one to many ‘contains’ relationship to CDI
uses	A CDI can use other CDI during the manufacturing process It’s a many to many relationship
madefrom	Similar to the ‘uses’ relationship but it’s between ‘Item’ to ‘Item’
houses	A workcenter ‘houses’ one or more machines
partof	A CDI is ‘part of’ a lot It’s a many to one relationship
stores	A CDI has one and only one particular ‘item’ in it

GQL Anatomy

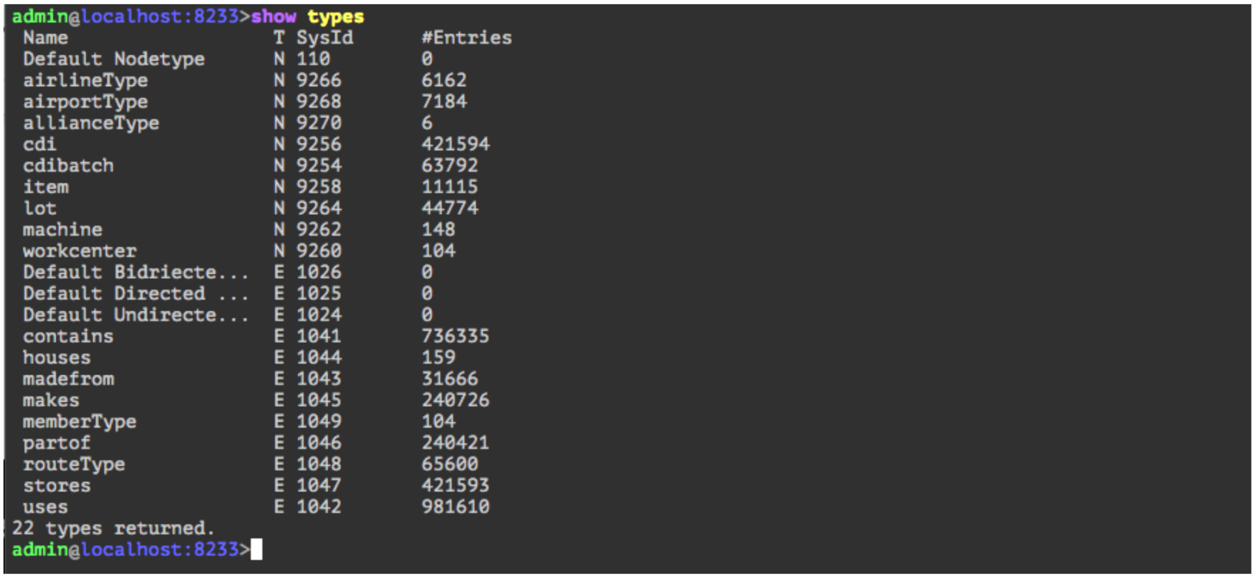
GQL Basics

This section introduces the GQL basics which helps you start working on GQL quickly.

Use the `tgdb-admin` console to help navigate the vertices and edge of a graph. The `tgdb-admin` is the tool equivalent to `pl/sql` of Oracle and GQL is the query language to graph database as SQL is the query language to the relational database.

At this point, it is assumed that the Example database has been loaded and is running. If you have not done that, please refer to Installing the Example Database section and complete that.

The first command to run is “`show types`”. See the following command output. It shows all the NodeTypes and EdgeTypes, their system id, along with the number of instances of that particular type. It is equivalent to executing a “`show tables`” on mysql.



```
admin@localhost:8233>show types
 Name                 T SysId      #Entries
 Default Nodetype     N 110        0
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 partof               E 1046       240421
 routeType            E 1048       65600
 stores               E 1047       421593
 uses                 E 1042       981610
22 types returned.
admin@localhost:8233>
```
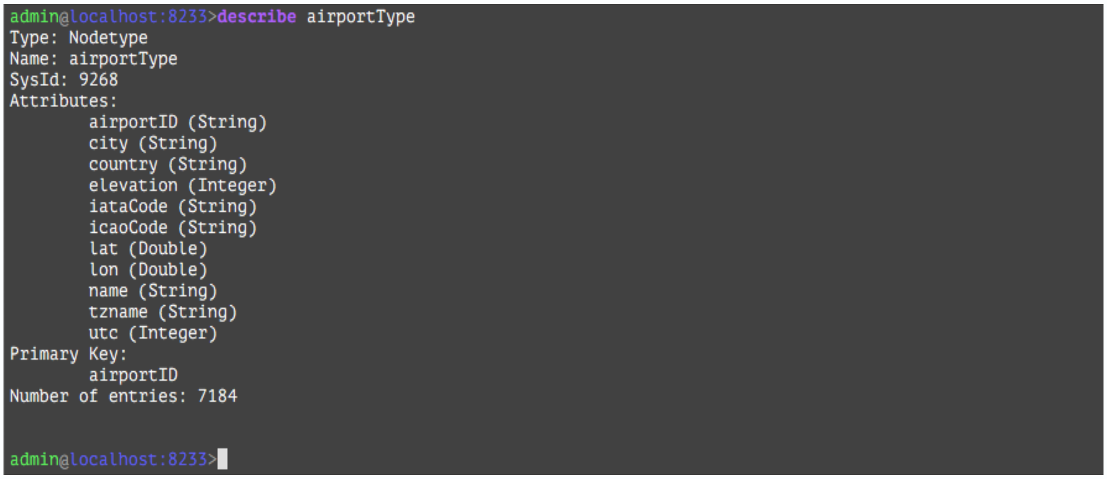

The database has a collection of nodes and edges which forms a graph. However just having a graph isn’t enough to traverse the graph, we need a TraversalSource. The TraversalSource provides additional information to Gremlin (such as the traversal strategies to apply and the traversal engine to use) which provides guidance on how to execute the trip around the graph.

In this short primer, see how to explore and search available flights from San Francisco airport to Paris airport in one or more hops. Then narrow the search by using United Airlines to reach the destination.

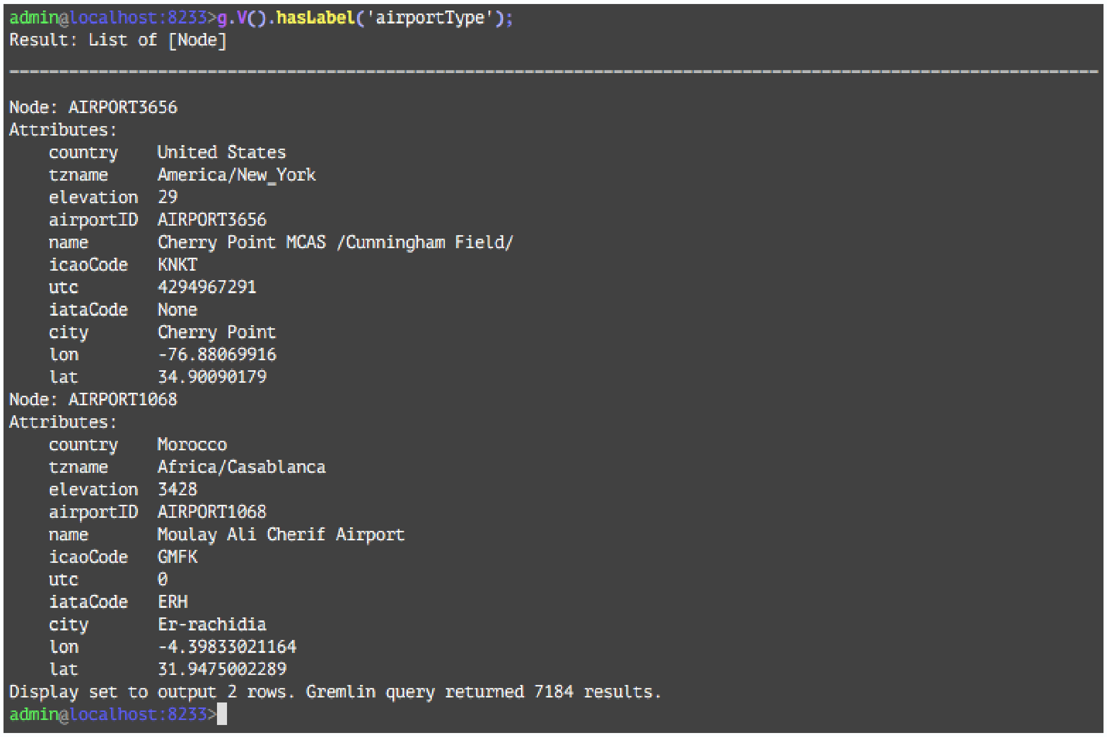
The admin console `“tgdb-admin”` comes with a built-in TraversalSource `“g”`. Use that to traverse the graph.

1. Let’s get the information on `‘airportType’,` and also set the display result set to 2 rows



```
admin@localhost:8233>describe airportType
Type: Nodetype
Name: airportType
SysId: 9268
Attributes:
        airportID (String)
        city (String)
        country (String)
        elevation (Integer)
        iataCode (String)
        icaoCode (String)
        lat (Double)
        lon (Double)
        name (String)
        tzname (String)
        utc (Integer)
Primary Key:
        airportID
Number of entries: 7184


admin@localhost:8233>
```

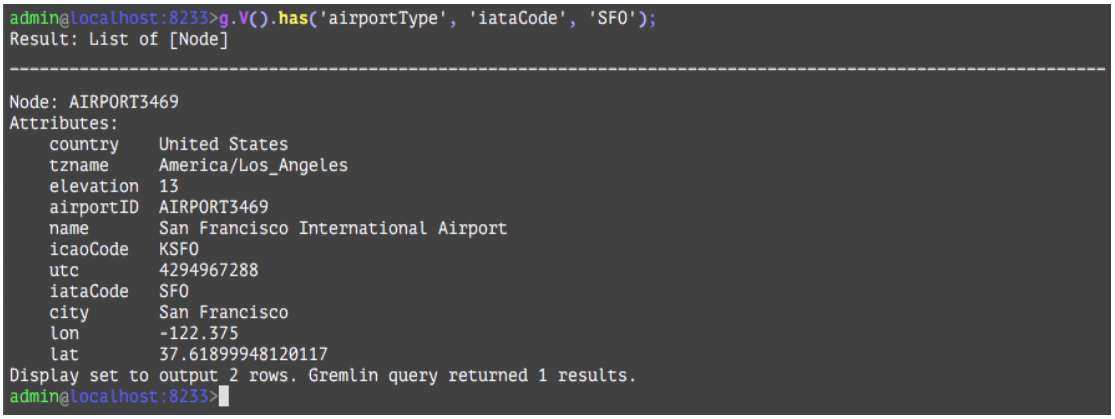
2. Get all the nodes of Node Type `airportType`



```
admin@localhost:8233>g.V().hasLabel('airportType');
Result: List of [Node]

--------------------------------------------------------------------------------------------------------------

Node: AIRPORT3656
Attributes:
    country    United States
    tzname     America/New_York
    elevation  29
    airportID  AIRPORT3656
    name       Cherry Point MCAS /Cunningham Field/
    icaoCode   KNKT
    utc        4294967291
    iataCode   None
    city       Cherry Point
    lon        -76.88069916
    lat        34.90090179
Node: AIRPORT1068
Attributes:
    country    Morocco
    tzname     Africa/Casablanca
    elevation  3428
    airportID  AIRPORT1068
    name       Moulay Ali Cherif Airport
    icaoCode   GMFK
    utc        0
    iataCode   ERH
    city       Er-rachidia
    lon        -4.39833021164
    lat        31.9475002289
Display set to output 2 rows. Gremlin query returned 7184 results.
admin@localhost:8233>
```

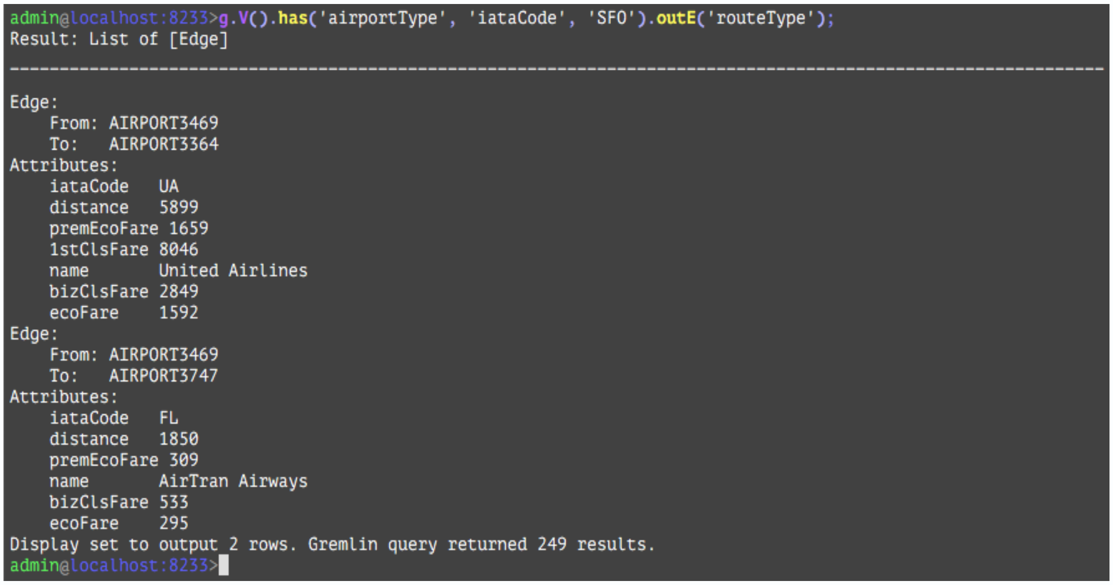
You can see that there are 7184 node instances of `airportType` in the database, and the result displayed 2 rows with all its attributes. The sql equivalent is `select * from airportType.`

3. Get the Airport Type node whose attribute `iataCode` value is `'SFO'` airport.



```
admin@localhost:8233>g.V().has('airportType', 'iataCode', 'SFO');
Result: List of [Node]
-----------------------------------------------------------------------------------------------------------------

Node: AIRPORT3469
Attributes:
    country    United States
    tzname     America/Los_Angeles
    elevation  13
    airportID  AIRPORT3469
    name       San Francisco International Airport
    icaoCode   KSFO
    utc        4294967288
    iataCode   SFO
    city       San Francisco
    lon        -122.375
    lat        37.61899948120117
Display set to output 2 rows. Gremlin query returned 1 results.
admin@localhost:8233>
```

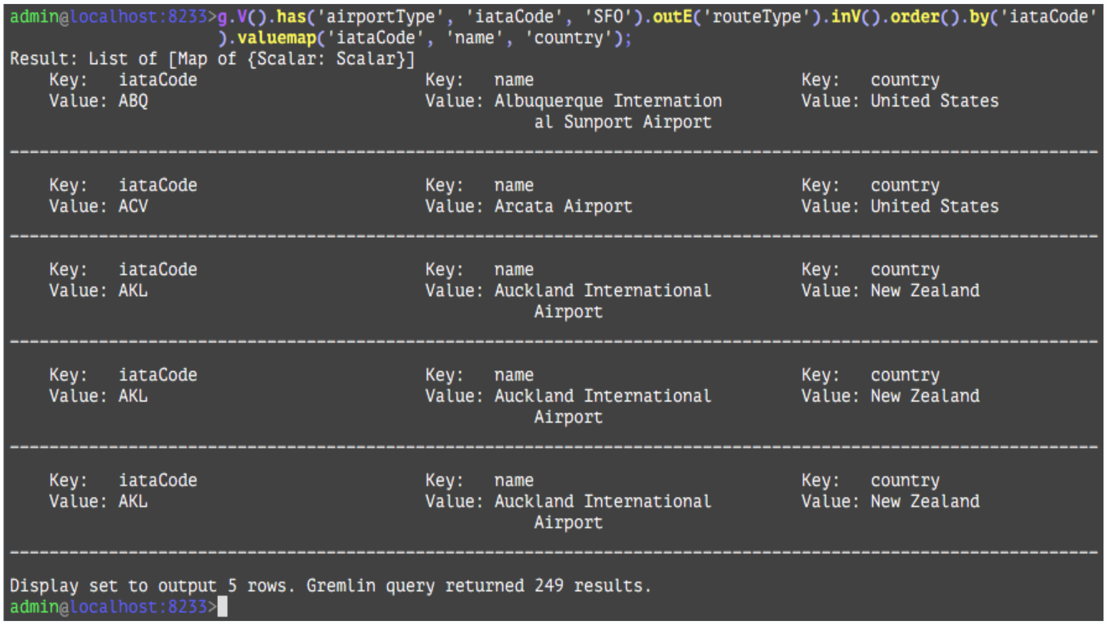
4. Get All the Routes from San Francisco airport i.e. Get the edges with the label 'routeType' for the vertex identified by its attribute 'iataCode' equal to 'SFO'.



```
admin@localhost:8233>g.V().has('airportType', 'iataCode', 'SFO').outE('routeType');
Result: List of [Edge]
-----------------------------------------------------------------------------------------------------------------

Edge:
    From: AIRPORT3469
    To:   AIRPORT3364
Attributes:
    iataCode   UA
    distance   5899
    premEcoFare 1659
    1stClsFare 8046
    name       United Airlines
    bizClsFare 2849
    ecoFare    1592
Edge:
    From: AIRPORT3469
    To:   AIRPORT3747
Attributes:
    iataCode   FL
    distance   1850
    premEcoFare 309
    name       AirTran Airways
    bizClsFare 533
    ecoFare    295
Display set to output 2 rows. Gremlin query returned 249 results.
admin@localhost:8233>
```

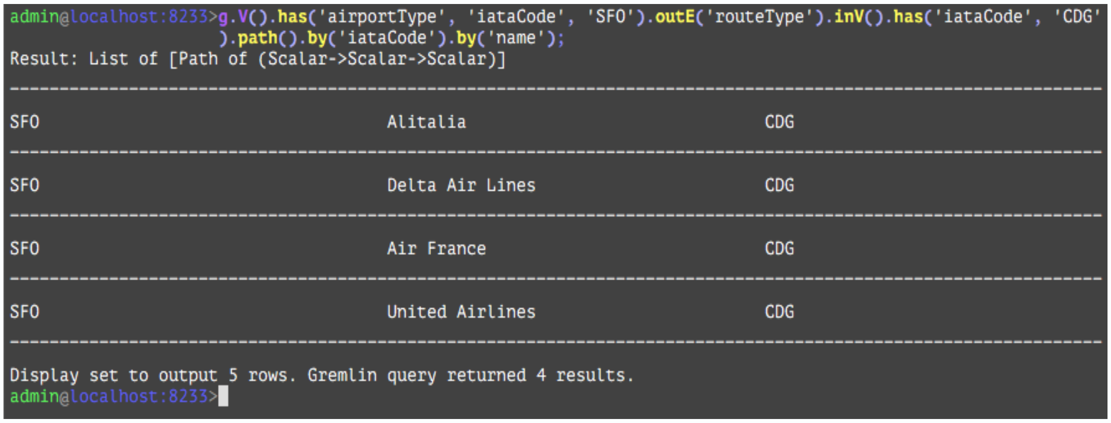
The routeType Edge is a cyclical edge and has various attributes. The `iataCode` whose value is `'UA'` is the airline code servicing between these 2 airports.

5. Get all the airport nodes that the vertex whose iataCode is SFO has connections to. This is also saying give me all the airports, and country that SFO is connected to directly or serviced by airlines ordered by the iataCode



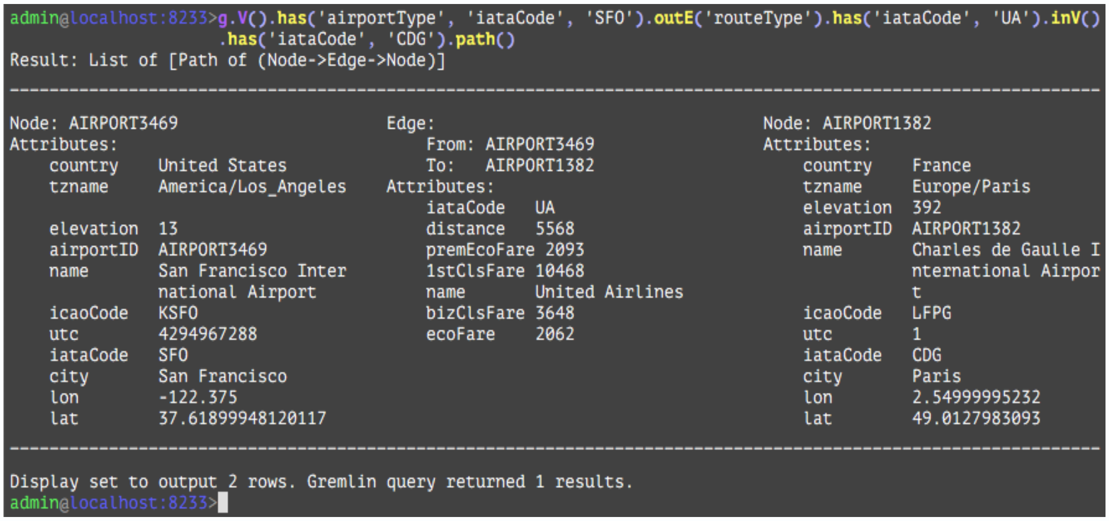
```
admin@localhost:8233>g.V().has('airportType', 'iataCode', 'SFO').outE('routeType').inV().order().by('iataCode'
                     ).valuemap('iataCode', 'name', 'country');
Result: List of [Map of {Scalar: Scalar}]
    Key:   iataCode                      Key:   name                          Key:   country
    Value: ABQ                           Value: Albuquerque Internation       Value: United States
                                                al Sunport Airport

--------------------------------------------------------------------------------------------------------------

    Key:   iataCode                      Key:   name                          Key:   country
    Value: ACV                           Value: Arcata Airport                Value: United States

--------------------------------------------------------------------------------------------------------------

    Key:   iataCode                      Key:   name                          Key:   country
    Value: AKL                           Value: Auckland International        Value: New Zealand
                                                Airport

--------------------------------------------------------------------------------------------------------------

    Key:   iataCode                      Key:   name                          Key:   country
    Value: AKL                           Value: Auckland International        Value: New Zealand
                                                Airport

--------------------------------------------------------------------------------------------------------------

    Key:   iataCode                      Key:   name                          Key:   country
    Value: AKL                           Value: Auckland International        Value: New Zealand
                                                Airport

--------------------------------------------------------------------------------------------------------------

Display set to output 5 rows. Gremlin query returned 249 results.
admin@localhost:8233>
```

6. Now, try to get the number of airlines servicing directly from SFO to CDG(Paris).



```
admin@localhost:8233>g.V().has('airportType', 'iataCode', 'SFO').outE('routeType').inV().has('iataCode', 'CDG'
                     ).path().by('iataCode').by('name');
Result: List of [Path of (Scalar->Scalar->Scalar)]
--------------------------------------------------------------------------------------------------------------

SFO                                    Alitalia                               CDG

--------------------------------------------------------------------------------------------------------------

SFO                                    Delta Air Lines                        CDG

--------------------------------------------------------------------------------------------------------------

SFO                                    Air France                             CDG

--------------------------------------------------------------------------------------------------------------

SFO                                    United Airlines                        CDG

--------------------------------------------------------------------------------------------------------------

Display set to output 5 rows. Gremlin query returned 4 results.
admin@localhost:8233>
```

7. To get the UA flight to Paris.



```
admin@localhost:8233>g.V().has('airportType', 'iataCode', 'SFO').outE('routeType').has('iataCode', 'UA').inV()
                     .has('iataCode', 'CDG').path()
Result: List of [Path of (Node->Edge->Node)]
--------------------------------------------------------------------------------------------------------------

Node: AIRPORT3469                     Edge:                                 Node: AIRPORT1382
Attributes:                               From: AIRPORT3469                 Attributes:
    country    United States              To:   AIRPORT1382                     country    France
    tzname     America/Los_Angeles    Attributes:                               tzname     Europe/Paris
                                          iataCode   UA                         elevation  392
    elevation  13                         distance   5568                       airportID  AIRPORT1382
    airportID  AIRPORT3469                premEcoFare 2093                      name       Charles de Gaulle I
    name       San Francisco Inter        1stClsFare 10468                                 nternational Airpor
               national Airport           name       United Airlines                       t
    icaoCode   KSFO                       bizClsFare 3648                       icaoCode   LFPG
    utc        4294967288                 ecoFare    2062                       utc        1
    iataCode   SFO                                                              iataCode   CDG
    city       San Francisco                                                    city       Paris
    lon        -122.375                                                         lon        2.54999995232
    lat        37.61899948120117                                                lat        49.0127983093

--------------------------------------------------------------------------------------------------------------

Display set to output 2 rows. Gremlin query returned 1 results.
admin@localhost:8233>
```

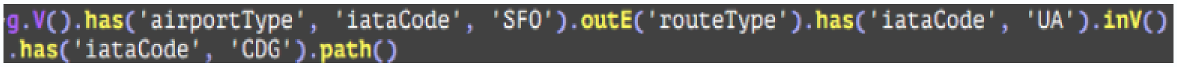
In 7 easy steps, you explored, searched, and traversed the Airline database.

GQL Components

TGDB query is a functional language composed of individual steps that make up the language. This section describes the component parts of the query that make a traversal work. It provides a foundational framework for:

a. Reading and dissecting GQL of arbitrary complexity.
b. Easily identify traversal patterns, and
c. Enables users to craft better, and efficient traversals.

The component parts of a Gremlin traversal can be all be identified from the following code (as in step 7 of the previous section:



```
g.V().has('airportType', 'iataCode', 'SFO').outE('routeType').has('iataCode', 'UA').inV()
.has('iataCode', 'CDG').path()
```

In plain English, we are listing all direct flights with their fares run by United Airlines (`‘UA’`) from SanFrancisco(`‘SFO’`) to Paris(`‘CDG’`). In the following sections, we will dissect the query into its individual components, and discuss in detail the functionality and any subtle differences between the TGDB GQL and Apache Gremlin

Graph Traversal Source

‘`g.`’ - It is in virtually every traversal you read in documentation, blog posts, or examples and is likely the start of most every traversal you will write in your own applications.
`‘g’` is a predefined GraphTraversalSource variable available in the `tgdb-admin` console, TGDB GQL query language in any of the API support. In Gremlin API support for Java, one can create an arbitrary GraphTraversalSource object and label it anything, but convention is to use g. The state of `‘g’` in TGDB is only for that query, and any subsequent query submission reinitializes the variable. This is a subtle deviation from the Apache Gremlin where the state management of `‘g’` is upto the provider, and is not clearly defined.
In TGDB, ‘g’ does not have any state, and is purely a functional decorator as of this release.
The subtle deviation between Apache and TGDB are as below

1. TGDB does not maintain any state on the default GraphTraversalSource object either in client or on the server. Apache Gremlin does define any protocol and requirements for the same.
2. Apache Gremlin defines certain configuration options that can be used with `‘g’` for `Strategies, Hints for Vertex Programs, A sack/bag` to be used throughout the execution lifecycle of query. TGDB uses “`QueryOptions`” parameters as configuration properties for query. See the Java API. So it does not support the `g.withStrategies, g.withComputer, and g.withSack` of the Apache Gremlin.
3. TGDB queries are executed on the server. Apache Gremlin is a functional interface between client and server and does not require or dictate its execution requirements.

Following ‘`g`’ are the `Start Steps` discussed in the next section.

Start Steps

`g` is a `GraphTraversalSource` and it spawns `GraphTraversal` instances with start steps. `V()` is one such start step, but there are others like `E()` for getting all the edges in the graph.
The start steps in Gremlin are tabled as below

`V()`	Reads vertices from the graph to start the traversal. Apache Gremlin defines this step to result in a list of vertices. However TGDB requires this step to be filtered by a Vertex Type or by a set of *ids*. It is similar to a relational query to say "select * from table <t>" unlike Apache Gremlin which mean "select * from table". TGDB will search for indices applicable for this vertex type and use the best possible index that narrows the result set. If no index is specified, and no primary key is defined, then it will use the internal index based on a internal "@id"
`E()`	Reads edges from the graph to start the traversal. TGDB reads edges from an Edge reference index. An Edge reference is a 40-byte object that maintains references of ***from*** and ***to*** vertex identifier, an 8-byte edge uniqueid, and edge page identifier if the edge has any properties. Note the edge index itself is a compressed index. Just like the V(), TGDB requires this step to be filtered by a Edge Type or by a set of *ids* As of this release, there is no support for user defined edge indices. This means a filtered set of edges is full scan on the edge reference index.

`addV()`
`addE()`
`inject()`
	These steps are not supported by TGDB in the current release. These steps are supported through the Transactional CRUD API available Java, Python, Go, REST in a different form. TGDB supports only the read-only query form of the Gremlin language.

Terminal Steps

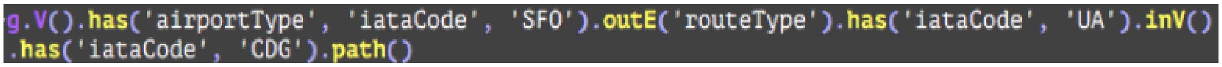
Terminal steps are steps that instruct the engine to execute the query and return results. These are not GraphTraversal steps. The examples of terminal steps include: hasNext(), toList(), and iterate().

TGDB supports only toList() and is the default terminal step when not specified. In the example used, toList is appended to the query and executed. TGDB query compiler raises syntax error for hasNext and iterate terminal steps.

Since the default terminal is always a List, the result set will always be enclosed in a List container. See ResultSet

Graph Traversal

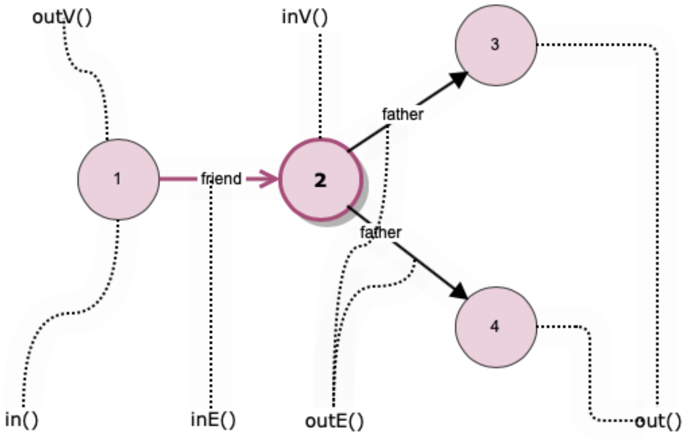
The start steps spawns the GraphTraversal. The GraphTraversal contains the steps that make up the Gremlin language. Each step returns a GraphTraversal so that the steps can be chained together in a fluent fashion. Revisiting the example again ‘has’, ‘outE’, ‘inV’, and ‘path’ are components of the GraphTraversal. The key to reading this Gremlin is to realize that the output of one step becomes the input to the next. Therefore, if you consider the start step of V() and realize that it returns vertices in the graph, the input to has() is going to be a Vertex. The has()-step is a filtering step and will take the vertices that are passed into it and block any that do not meet the criteria it has specified. In this case it will return vertex/vertices whose `iataCode` is SFO i.e output of has is a SFO vertex as input to outE. outE is a navigational step, in that it enables the traversal through the outgoing edges as the output. There are many navigational/vertex steps as we see in the next section.



```
g.V().has('airportType', 'iataCode', 'SFO').outE('routeType').has('iataCode', 'UA').inV()
.has('iataCode', 'CDG').path()
```

Vertex Steps

The real power of a graph comes into play when we start to walk or traverse the graph by looking at the connections (edges) between vertices. The term walking the graph is used to describe moving from one vertex to another vertex via an edge. Typically when using the phrase walking a graph the intent is to describe starting at a vertex traversing one or more vertices and edges and ending up at a different vertex or sometimes, back where you started in the case of a circular walk. It is very easy to traverse a graph in this way using Gremlin. The journey we take while on our walk is often referred to as our path. There are also cases when all you want to do is return edges or some combination of vertices and edges as the result of a query and Gremlin allows this as well. The figure and table below gives a brief summary of all the steps that can be used to walk or traverse a graph using Gremlin. More details on the steps and examples are presented in chapter Gremlin Steps.



Think of a graph traversal as moving through the graph from one place to one or more other places. These steps tell Gremlin which places to move to next as it traverses a graph for you.
In order to better understand these steps it is worth defining some terminology. One vertex is considered to be adjacent to another vertex if there is an edge connecting them. A vertex and an edge are considered incident if they are connected to each other.

The table below specifies all vertex steps and its meaning.

`out(string…)`	Move to the outgoing adjacent vertices given the edge labels.
`in(string…)`	Move to the incoming adjacent vertices given the edge labels.
`both(string…)`	Move to both the incoming and outgoing adjacent vertices given the edge labels
`outE(string…)`	Move to the outgoing incident edges given the edge labels.
`inE(string…)`	Move to the incoming incident edges given the edge labels
`bothE(string…)`	Move to both the incoming and outgoing incident edges given the edge labels.
`outV()`	Move to the outgoing vertex.
`inV()`	Move to the incoming vertex.
`bothV()`	Move to both vertices.
`otherV()`	Move to the vertex that was not the vertex that was moved from.

Aggregates, Filters and Predicates

GQL supports basic statistical steps such as calculating the amount of a particular item that is present in the graph, calculating the average (mean) of a set of values and calculating a maximum or minimum value. The table below summarizes the available steps.

count	Count how many of something exists.
sum	Sum (add up) a collection of values.
max	Find the maximum value in a collection of values.
min	Find the minimum value in a collection of values.
mean	Find the mean (average) value in a collection.
dedup	Distinct values in a collection
order	Sort the collection
group	Group the collection into smaller collection by organizing them based on certain functions or properties
groupcount	Same as group, but count them

The group step organizes the objects according to some function of the object. As traversers navigate across the graph as per the vertex steps defined above, some organizational collection may be required, group and groupcount are such steps that help organize. The organizational function may be qualified modulators as described in the Step Modulators section.

GQL provides steps that filter the output result using the “has” or “hasLabel” steps. In the context of Filter steps, the GQL supports functional expressions using Predicate steps. These steps are mathematical, logical, range related steps and are companion to the has or hasLabel.

and	Logical And
or	Logical Or
lt, lte	Less than, Less than equal to
gt, gte	Greater than, Greater than equal to
between	Value in between the range

Path Step

In the case of the example, path() step transforms the traverser as it moves through a series of steps within a traversal. The history of the traverser is realized by examining its path with path()-step. If edges are required in the path, then be sure to traverse those edges explicitly. It is possible to post-process the elements of the path in a round-robin fashion via by().

The behavior of the path step is influenced by the `‘by’` step.
The output of the path step can only be filtered by predicates or aggregates i.e it can only be followed by `has()` or by `count()`

Step Modulators

A modulator is a step that influences the behavior of the step that it is associated with. Examples of such modulator steps are `by` and `as`.
The `by` modulator steps are processed in a round robin fashion. If there are not enough modulators specified for the total number of elements in the path, Gremlin just loops back around to the first ‘`by’` step and so on. So even though there were three elements in the path that we wanted to have formatted, we only needed to specify two by modulators. This is because the first and third elements in the path are of the same type, namely airport vertices, and we wanted to use the same property name, code, in each of those cases. If we instead wanted to reference a different property name for each element of the path result, we would need to specify three explicit by modulator steps. This would be required if, for example, we wanted to reference the city property of the third element in the path rather than its code.

Flow Control

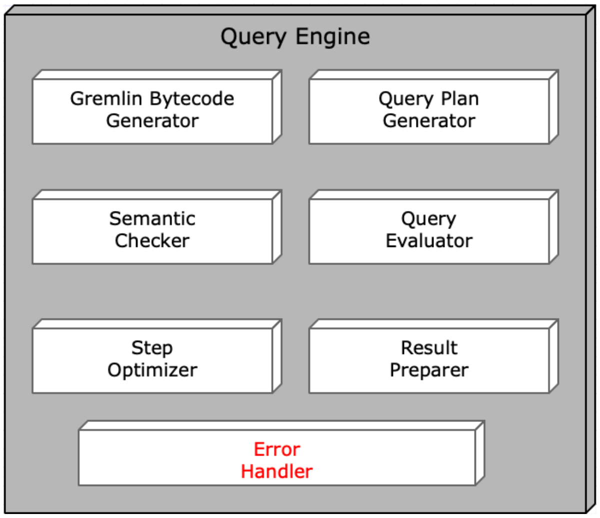
GQL provides steps to control the flow, repeat the number of times the same flow should be carried out either using a condition or using a count. These Flow Control steps are `repeat-pattern-emit-until` steps. These are usually used in a Path detection such as N-hops and the hop is the defined pattern. For instance in the example used if we were interested in 3 hops to Paris, we could use the Repeat step followed by the pattern and the terminating condition. As the Traverser is performing, one of the instructions could be collect the result set.

Query Engine Anatomy

The query engine is a component in TIBCO Graph Database Server that handles data retrieval of graph data from the database. Data retrieval request is expressed in the form of GQL. Requests can come from database clients or stored procedures. The requester roles and privileges are used to ensure data security. Concurrent requests are supported where data consistency is maintained for each request. TGDB also supports both unique and non-unique indexes. Query engine utilizes indexes to improve query performance.

Components

The below figure shows the components inside the Query Processor Engine.



Error Handler

If any errors are detected during processing of query request, the error handler is used to provide a common error handling and reporting mechanism to report errors to the query requester in the query response. TGDB client APIs provide interfaces to access information in the error message structure. Information captured in the structure includes the error type, error message and the server error code.

Gremlin Bytecode Generator

TGDB query engine supports Gremlin based query in its native language form such as Java and in string form as in GQL. Therefore, it processes Gremlin query requests in Gremlin bytecode form. When it receives a request in GQL, it first compiles GQL into Gremlin bytecode such that the query engine can understand. TGDB extends Apache Gremlin bytecode to include GQL specific extensions such as the ability to execute stored procedures. It means these extensions are not available to native language Gremlin query.

Semantic Checker

This checker validates any entity type and attribute names used in the query that actually exists in the system. It does additional checks to make sure that step sequence in the query is compatible and has the right input. In addition, it does explicit access control validation if types are specified in any of the filter conditions. Errors will be reported to the requester if any of these checks fail.

Step Optimizer

The optimizer analyzes the entire query step sequence to build an execution step sequence. It may combine multiple steps into a single step. For example, if multiple ‘has’ steps are used in a contiguous fashion, they are combined into a single logical step to be evaluated. The goal is to minimize the number of evaluations. The optimizer also determines how data should be maintained during query execution. Steps such as ‘dedup’, ‘order’ and ‘limit’ can affect how data are maintained. Queries which include ‘path’ steps are analyzed for different step execution models.

Query Plan Generator

The plan generator analyzes the starting ‘g.V()’ filter condition. If indexes or primary keys are defined for that node type(s), the generator tries to select the appropriate database index to retrieve the initial set of data from the database. If no indexes are defined or none matched for the filter condition, all the nodes of the given type(s) will be retrieved to be evaluated.

Query Evaluator

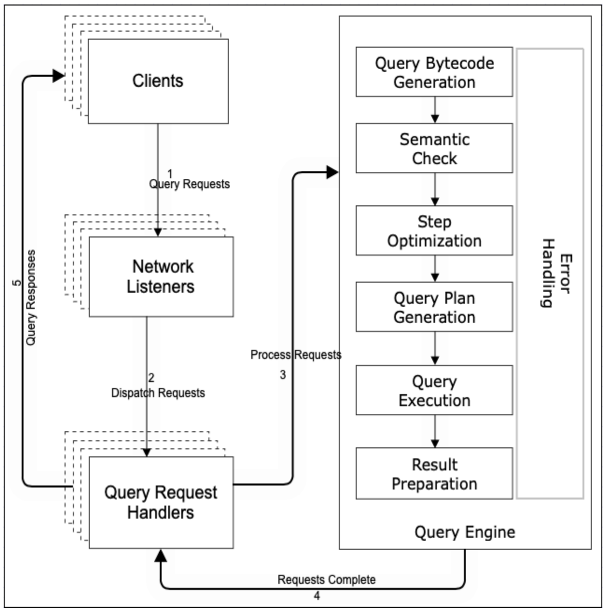
Evaluation starting with the initial data retrieval using the plan selected by the query plan generator. Subsequent evaluation is based on the step sequence constructed by the step optimizer. Another access control validation is done during the evaluation where explicit node or edge types are not specified in the query filter conditions. Any entities that failed the access control check will be automatically filtered out.

Result Preparer

Prepare query results in a result set structure. In addition to the results of the query, the preparer includes the result set annotation. In case of error, the preparer put the error information into the result set. At this point, the result is ready to be sent back to the requester.

Query Processing Sequence

Below figure describes a Client's Query Request and its processing sequence.



Step	Action
1	Client initiate a query request
2	Request received by one of the network listeners which validates the request and extracts the request type. Based on the request type, it dispatches the request to the query request handler.
3	One of the query request handlers picks up the request and extracts the request details from the incoming request. It uses the details to ask the query engine to process the query
4	Query engine processes the query request in the sequence shown in the diagram. After the last step, which is the result preparation step, is completed, it returns the results to the query requests handler.
5	Query request handler packages the results in the network format and sends them back to the client.

Network Listener

The query request sequence starts when a client sends a query to the server. Network listener is a component of the server responsible for handling client requests over the network. Query is one of such requests. Another example is transaction requests when a client makes changes to the database data. Network listener has various configurable properties such as maximum number of connections that can be configured in the server configuration file under the 'netlistener' section. Please refer to the server configuration guide for details.

Query Request Handler

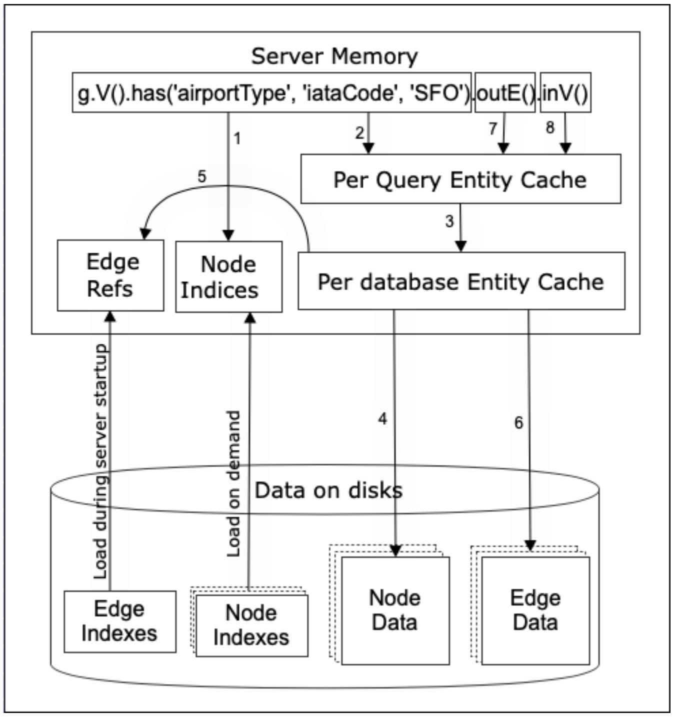
In order to handle various kinds of requests submitted over the network, the network listener delegates the request to different server components based on the request type. Query request handler is one of such components and it's responsible for handling queries. Transaction handler is another example which handles transactions. The delegation is done asynchronously such that requests are processed by the handler in a separate thread. The network listener is not blocked waiting for the request to be completed such that it can quickly return to service another request. Query request handler extracts details of a request and uses the query engine to process it. Once the query engine completes the request, this handler packages the response and sends it back to the client. Similar to the network listener, the number of query handlers can be configured in the database configuration file under the 'processors' section.

Query Engine

Once the query engine receives a query request, it processes it in the order shown in the diagram. What happens in each step is described in the component section.

Query Execution Data Flow

This section describes how a query processor executes a sample query `“g.V().has(‘airportType’, ‘iataCode’, ‘SFO’).outE().inV();”` It shows interaction between various server components such as memory, storage, page manager, network and others. The threading model of the Query Processor is based on the ‘`Actor`’ model. It has its own queue and thread to run. Query processor requests ‘read locks’ from the Page manager for entities that it requires to filter or process. Entities are reference counted as when the Query Processor deems it is needed for future processing or result preparations.



Indices

During server startup, edge id based edge index is loaded into server memory. For nodes, each node type can have multiple indexes besides their primary key indexes. Node indexes are loaded on demand into memory. The amount of memory allocated to the node indexes can be configured under the ‘cache’ section of the database configuration file.

Cache

Each database server can host multiple databases. Each database has its own entity cache. The purpose of the cache is to improve data access performance. The size of the cache can be configured under the ‘cache’ section of the database configuration file.

Query Entity Cache

In order to maintain a consistent view of database data during a query, each query has a temporary entity cache which guarantees data consistency by providing a snapshot view of the data while the same data may be modified by another transaction concurrently. The size of the query entity cache can be configured under the ‘cache’ section of the database configuration file.

Data Flow Sequence

Using the query example `g.V().has(‘airportType’,‘iataCode’,‘SFO’).outE().inV()` shown in the diagram above, the following table describes how query engine retrieves data relevant to the request.

Step	Action
1	The starting V step always attempts to use node indexes to retrieve node data from the database. For this query example, there is an index defined for ‘iataCode’ attribute which returns the id for ‘SFO’ airport node.
2	Query engine uses the node id to lookup the ‘SFO’ node from its query entity cache.
3	If the node is not found in the query cache, look it up from the database entity cache.
4	If the node is not found in the database cache, retrieve the node from the database and use the node id to lookup edge ids containing the node from the edge index(step 5). Retrieve the edges from the database cache. For any edges not in the cache, get them from the database(step 6). Include edge objects in the node object before putting it in the cache. Return the node object to the query cache. Query processing continues to the next step with the returned node.
7	Retrieve all outgoing edges in the SFO node which is done in step 6 already.
8	For each outgoing edge, retrieve the ‘to’ node from the query cache. And repeat from step 3 if necessary.

Working with Date, Time, DateTime and Timezones

TGDB supports Datetime and with Timezone attribute types as shown below. All Date, Time and its combination are indexable and their properties with the range values are tabled as below

Attribute Type	Format	Range	Storage	Description
Date	ISO-8601 Date ±YYYY-MM-DD	Year can be from -65535 to +65535	8-bytes	Standard Date. Representation/Format for Clients to exchange with the server. Clients can have specialized properties to help specify in locale specific style too.
Time	ISO-8601 Time hh:mm:ss.nnnnnnn	Upto 0.5 microsecond precision	8-bytes	Standard Time. Representation/Format for Clients to exchange with the server.
Timestamp	ISO-8601 Datetime ±YYYY-MM-DD hh:mm:ss.nnnnnnn	Date Range is the same as the Date field. Time precision is the same as for the Time field	8-bytes	Standard Date & Time specified together. Timezone is not saved in the database, and if the format string has a timezone specified, it will be dropped. Index lookup or comparison are done without any conversion, and compared on the values only.
ZonedTimestamp	ISO-8601 with TZ	Same as Timestamp	10-bytes	TGDB supports Timezone using the Olson Timezone facilities of the underlying Operating system it runs on. Source Timezone **id** is preserved, and the datetime is returned with the source timezone on query results. Source Data is converted to UTC timezone with its source timezone preserved and stored. Comparison and Index lookups are done at UTC timezone.Comparison strings are also converted to UTC. Query Results are converted from UTC to source timezone id and returned.
ZonedLocalTimestamp	ISO-8601 with TZ	Same as ZonedTimestamp	8-bytes	Source Timezone is not preserved. Source Data is converted to UTC timezone with its source timezone dropped. Comparison and Index lookups are done at UTC timezone.Comparison strings are also converted to UTC. Query Results are converted from UTC to local timezone id based on the session timezone properties either at Server or at Client whichever is applicable

Predicates steps often require to filter out data based on certain date/datetime values, or between some date. TGDB GQL supports date, time, and datetime fields to specify data in ISO-8601 formatted string as ‘`yyyy-mm-dd hh:mm:ss.nnn [TZname or Offset]`’. Optional Timezone and DST is supported also.

Datetime attributes can be part of the index components, and the query engine will lookup if it can use the index. Depending on the string and the attribute, timezone conversions will be applied on the input string and then compared and/or searched.

A simple example is provided below

```
g.V()
 .has('cdi','cdiid','039HDFJEYX87')
 .inE('uses')
 .has('createddatetime', gte('2018-02-07 17:13:02'))
 .has('createddatetime',lt('2018-02-0810:00:00'))
 .values('createddatetime')
 .dedup()
 .order();
```

Gremlin Steps

GQL is a functional language i.e imperative language instructing the engine how to proceed in each step of the traversal. Each traversal is composed of multiple steps and these steps are categorized into

- Projection
- Filter
- Aggregation
- Sorting
- Traversals
- Flow Control
- Stored Procedures.

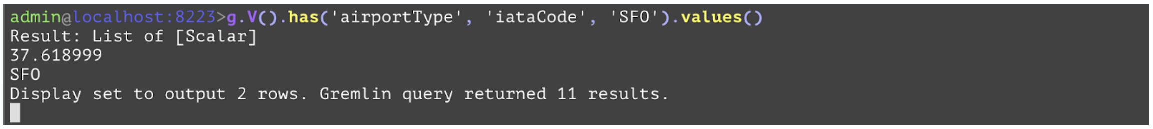
Each of these categories can have multiple steps depending on usages.

This chapter describes each `step`, the arguments needed for the `step`, a couple of examples, and potentially equivalent sql statements to help the reader map from GQL to SQL and vice-a-versa. This helps to understand the nuances and get familiarized with the GQL.
Note not all examples can be mapped to an SQL. Some of the SQL statements are very verbose, and inefficient in their execution even with indices defined. The SQL statements are run on a MySQL database.

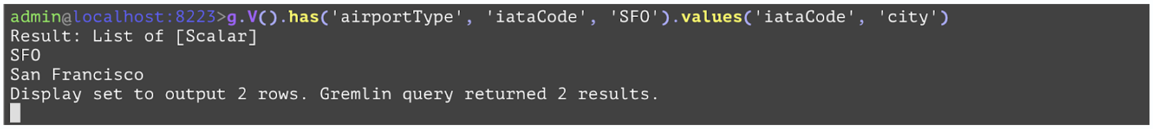
Projection

values

Gets all of the attribute's values for the current traversal. Extract from each entity (node or edge) the attribute values into a single list of attribute values that is piped to the next step. This is typically the last step in the query. In Example 1, we return all the attributes for the entity identified by SFO. In Example 2, we project only iataCode, and city.			
Args	Name	Type	Description
	attributes	string[]	Optionally the attributes of the entities to pass on to the next step. If not specified, then all of the attributes are used. Invalid or undefined attribute names will be ignored.

GQL	`gremlin://g.V().has('airportType', 'iataCode', 'SFO').values();`
	
	`admin@localhost:8223>g.V().has('airportType', 'iataCode', 'SFO').values()`
	`Result: List of [Scalar]`
	`37.618999`
	`SFO`
	`Display set to output 2 rows. Gremlin query returned 11 results.`		

	`gremlin://g.V().has('airportType', 'iataCode', 'SFO').values('iataCode', 'city');`		

```
admin@localhost:8223>g.V().has('airportType', 'iataCode', 'SFO').values('iataCode', 'city')
Result: List of [Scalar]
SFO
San Francisco
Display set to output 2 rows. Gremlin query returned 2 results.
```

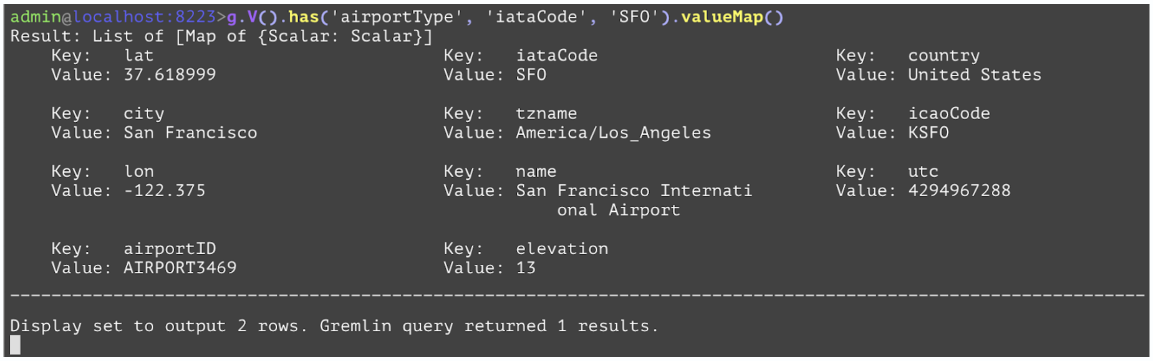
SQL	SELECT * FROM airportType WHERE iataCode='SFO';
	SELECT iataCode, city FROM airportType WHERE iataCode='SFO';

valueMap

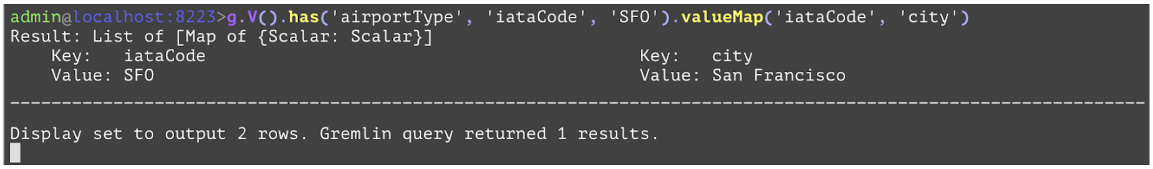
Gets each entity's attributes as a map with the key being the attribute name and the value being the attribute. This is typically a last step in the query. While there is no direct SQL analog, the examples below have analogs that retrieve the same information in a different format as shown below.

In the first example, the query will return a map of the attributes of the airport SFO. It would look something like this: `{'city': 'San Francisco', 'country': 'United States', 'airportId': 'AIRPORT3469', 'name': 'San Francisco Internal Airport', ...}`.
For the second example, this query will restrict the attributes down to just `{'city': 'San Francisco', 'iataCode': 'SFO'}`.

Args	Name	Type	Description
	attributes	string[]	Optionally the attributes of the entities to pass on to the next step. If not specified, then all of the attributes are used.

GQL	gremlin://g.V().has('airportType', 'iataCode', 'SFO').valueMap(); 

```
admin@localhost:8223>g.V().has('airportType', 'iataCode', 'SFO').valueMap()
Result: List of [Map of {Scalar: Scalar}]
    Key:   lat                          Key:   iataCode                    Key:   country
    Value: 37.618999                    Value: SFO                         Value: United States

    Key:   city                         Key:   tzname                      Key:   icaoCode
    Value: San Francisco                Value: America/Los_Angeles         Value: KSFO

    Key:   lon                          Key:   name                        Key:   utc
    Value: -122.375                     Value: San Francisco Internati     Value: 4294967288
                                              onal Airport

    Key:   airportID                    Key:   elevation
    Value: AIRPORT3469                  Value: 13
---------------------------------------------------------------------------------------------------------------

Display set to output 2 rows. Gremlin query returned 1 results.
```

	gremlin://g.V().has('airportType', 'iataCode', 'SFO').valueMap('iataCode', 'city'); 

```
admin@localhost:8223>g.V().has('airportType', 'iataCode', 'SFO').valueMap('iataCode', 'city')
Result: List of [Map of {Scalar: Scalar}]
    Key:   iataCode                                         Key:   city
    Value: SFO                                              Value: San Francisco
---------------------------------------------------------------------------------------------------------------

Display set to output 2 rows. Gremlin query returned 1 results.
```

SQL	SELECT * FROM airportType WHERE iataCode='SFO';
	SELECT iataCode, city FROM airportType WHERE iataCode='SFO';

Filter

has

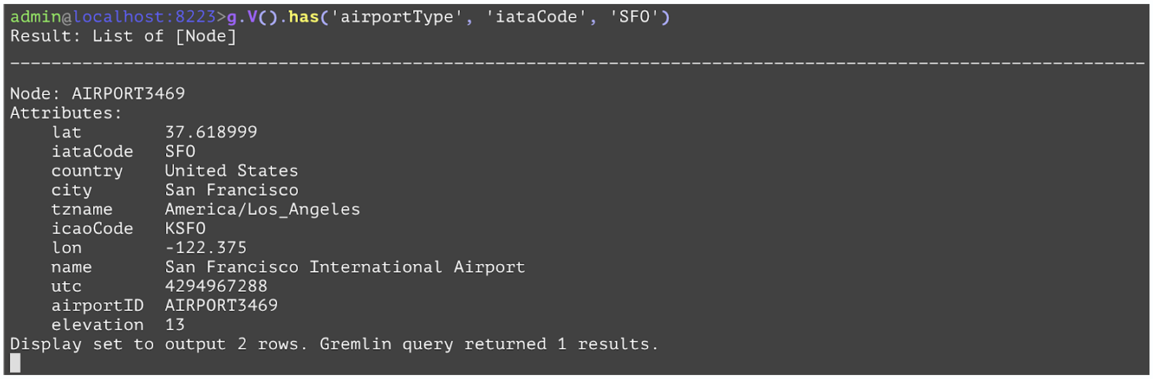
Only allows elements to pass this step if they meet the requirements specified in the arguments. Multiple "has" steps in sequence together form an implicit "and" condition.

The first example makes use of the optional typename first parameter to simplify what would otherwise be a lengthy hasLabel('airportType').has('iataCode', 'SFO') is simplified into the more manageable has('airportType', 'iataCode', 'SFO').
The second one operates on edges and does not specify the optional typename argument.

Args	Name	Type	Description
	typename	string	Optionally the type name (aka label) to filter out elements. When specified this step will act as a joint hasLabel(<typename>).has(<attrname>, <condition>).
	attrname	string	The name for the attribute to filter on.
	condition	string or expression	The value for that attribute must either be equal (if this argument is a string) or pass the condition of the expression (if this argument is a condition).

GQL

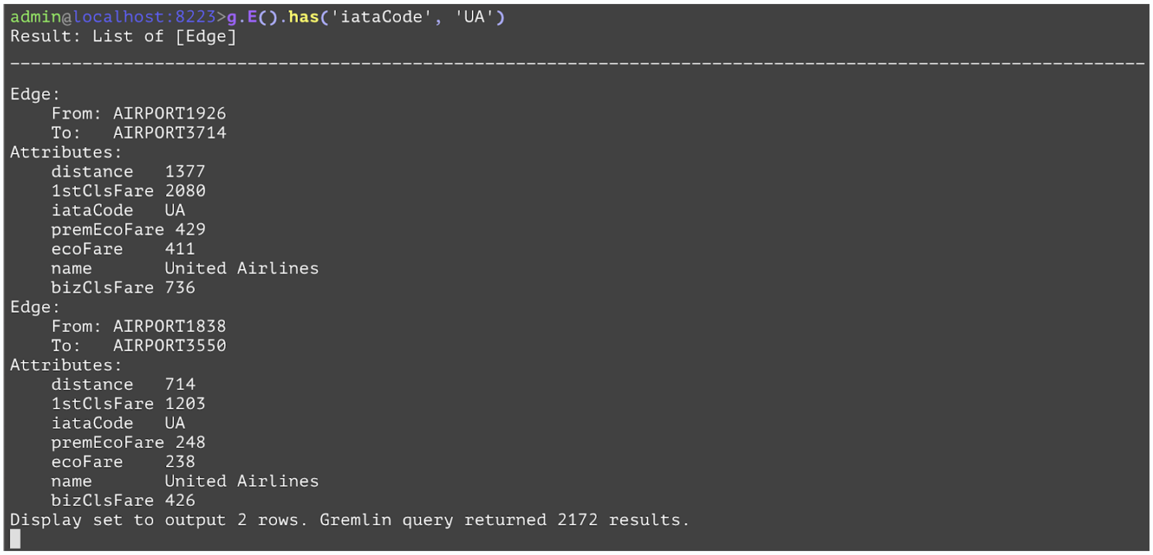
```
gremlin://g.V().has('airportType', 'iataCode', 'SFO');
```



```
admin@localhost:8223>g.V().has('airportType', 'iataCode', 'SFO')
Result: List of [Node]
--------------------------------------------------------------------------------------------------------------

Node: AIRPORT3469
Attributes:
    lat        37.618999
    iataCode   SFO
    country    United States
    city       San Francisco
    tzname     America/Los_Angeles
    icaoCode   KSFO
    lon        -122.375
    name       San Francisco International Airport
    utc        4294967288
    airportID  AIRPORT3469
    elevation  13
Display set to output 2 rows. Gremlin query returned 1 results.
```

```
gremlin://g.E().has('iataCode', 'UA');
```

Note: This query is a full scan of the global edge index. The server maintains a global Edge Index for fast lookup from a NodeType perspective. Calling E() is always a linear scan.



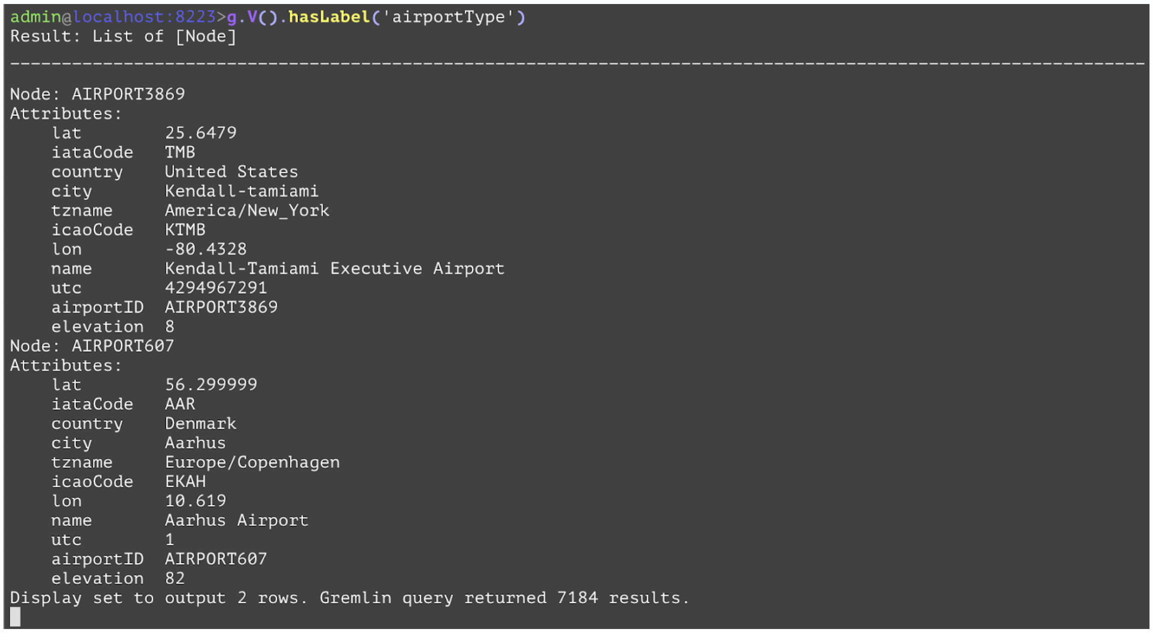
```
admin@localhost:8223>g.E().has('iataCode', 'UA')
Result: List of [Edge]
--------------------------------------------------------------------------------------------------------------
Edge:
    From: AIRPORT1926
    To:   AIRPORT3714
Attributes:
    distance   1377
    1stClsFare 2080
    iataCode   UA
    premEcoFare 429
    ecoFare    411
    name       United Airlines
    bizClsFare 736
Edge:
    From: AIRPORT1838
    To:   AIRPORT3550
Attributes:
    distance   714
    1stClsFare 1203
    iataCode   UA
    premEcoFare 248
    ecoFare    238
    name       United Airlines
    bizClsFare 426
Display set to output 2 rows. Gremlin query returned 2172 results.
```

SQL	`SELECT * FROM airportType WHERE iataCode='SFO';`
	`SELECT * FROM routeType WHERE iataCode='UA';`

hasLabel

<table>
<tr><td colspan="4">Only allows elements to pass this step if they have the typename (aka label) specified.
The example below will get all "airportType" nodes.</td></tr>
<tr><td rowspan="2">Args</td><td>Name</td><td>Type</td><td>Description</td></tr>
<tr><td>typename</td><td>string</td><td>The type name (aka label) to filter out arguments. Multiple can be specified in a comma-separated list to act as an "or" of the <typename> specified.</td></tr>
<tr><td>GQL</td><td colspan="3">

gremlin://g.V().hasLabel('airportType');



```
admin@localhost:8223>g.V().hasLabel('airportType')
Result: List of [Node]
---------------------------------------------------------------------------------------------------------------

Node: AIRPORT3869
Attributes:
    lat         25.6479
    iataCode    TMB
    country     United States
    city        Kendall-tamiami
    tzname      America/New_York
    icaoCode    KTMB
    lon         -80.4328
    name        Kendall-Tamiami Executive Airport
    utc         4294967291
    airportID   AIRPORT3869
    elevation   8
Node: AIRPORT607
Attributes:
    lat         56.299999
    iataCode    AAR
    country     Denmark
    city        Aarhus
    tzname      Europe/Copenhagen
    icaoCode    EKAH
    lon         10.619
    name        Aarhus Airport
    utc         1
    airportID   AIRPORT607
    elevation   82
Display set to output 2 rows. Gremlin query returned 7184 results.
```

</td></tr>
<tr><td><b>SQL</b></td><td colspan="3">SELECT * FROM airportType;</td></tr>
</table>

limit

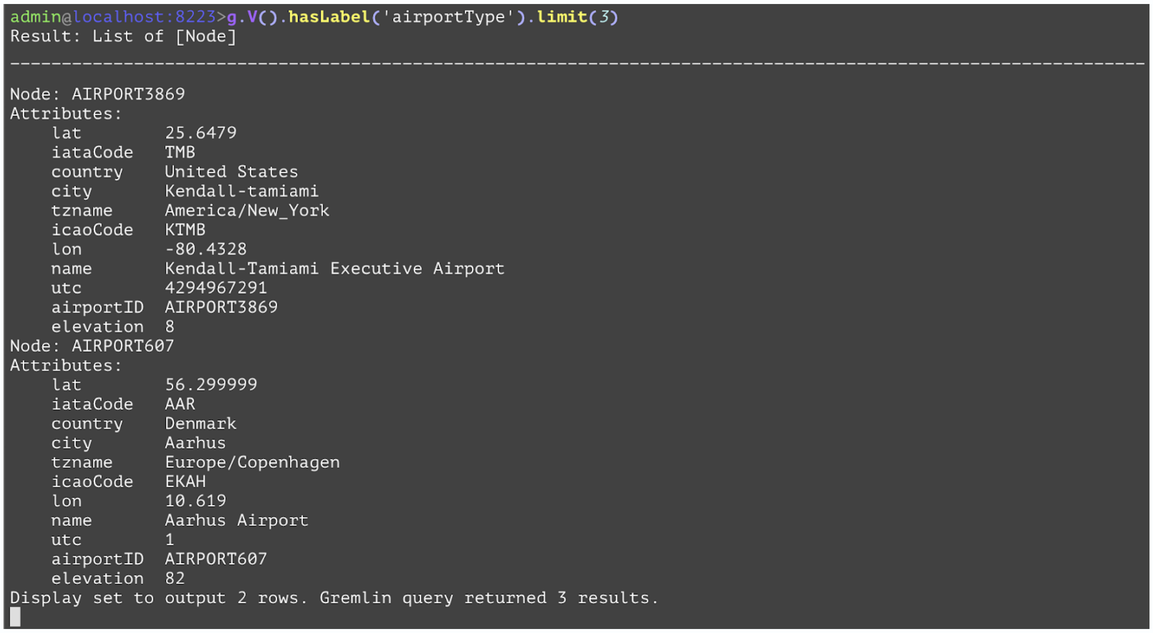
Only allows the first <traversal_limit> traversals to pass to the next step.

The following example will only allow three arbitrary airports to return from the query.

Args	Name	Type	Description
	traversal_limit	integer	The maximum number of traversals to pass on to the next step.

GQL

```
gremlin://g.V().hasLabel('airportType').limit(3);
```



```
admin@localhost:8223>g.V().hasLabel('airportType').limit(3)
Result: List of [Node]
---------------------------------------------------------------------------------------------------------------
Node: AIRPORT3869
Attributes:
    lat         25.6479
    iataCode    TMB
    country     United States
    city        Kendall-tamiami
    tzname      America/New_York
    icaoCode    KTMB
    lon         -80.4328
    name        Kendall-Tamiami Executive Airport
    utc         4294967291
    airportID   AIRPORT3869
    elevation   8
Node: AIRPORT607
Attributes:
    lat         56.299999
    iataCode    AAR
    country     Denmark
    city        Aarhus
    tzname      Europe/Copenhagen
    icaoCode    EKAH
    lon         10.619
    name        Aarhus Airport
    utc         1
    airportID   AIRPORT607
    elevation   82
Display set to output 2 rows. Gremlin query returned 3 results.
```

SQL

```
SELECT * FROM airportType LIMIT(3);
```

or

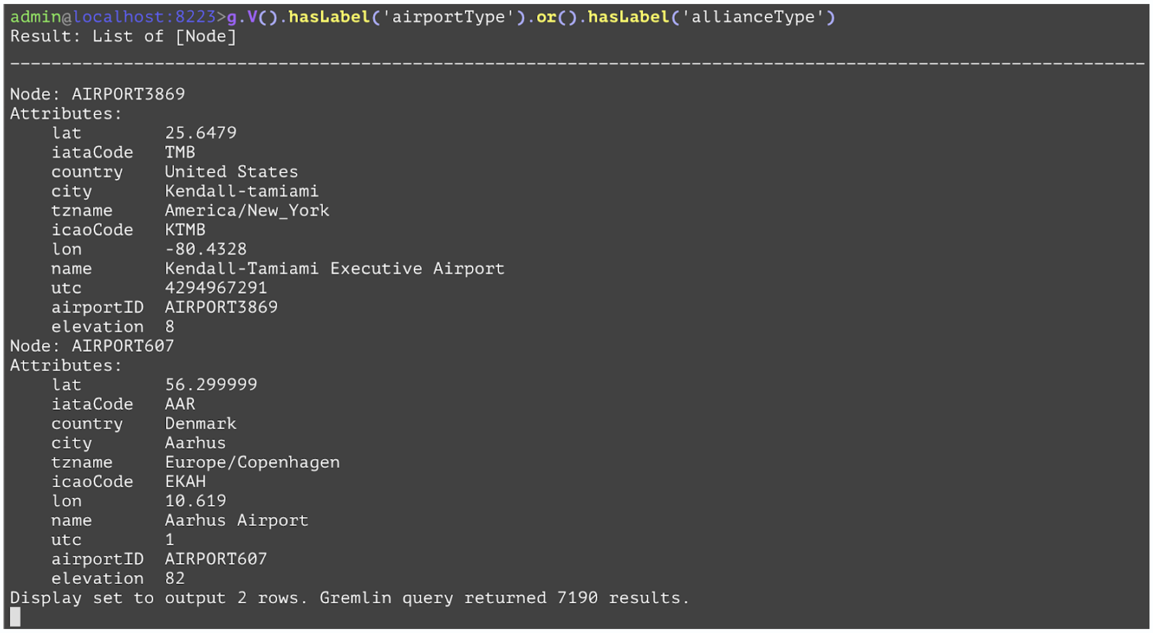
Allows the union of entities that pass the filters to pass on to the next step. This can be fairly useful when getting the union of distinct nodetypes.

In the following example all of the nodes of both the "`airportType`" and the "`allianceType`" are retrieved.

The SQL equivalent is again very verbose compared to its gremlin equivalent.

GQL

```
gremlin://g.V().hasLabel('airportType').or().hasLabel('allianceType');
```



```
admin@localhost:8223>g.V().hasLabel('airportType').or().hasLabel('allianceType')
Result: List of [Node]
----------------------------------------------------------------------------------------------------------------
Node: AIRPORT3869
Attributes:
    lat        25.6479
    iataCode   TMB
    country    United States
    city       Kendall-tamiami
    tzname     America/New_York
    icaoCode   KTMB
    lon        -80.4328
    name       Kendall-Tamiami Executive Airport
    utc        4294967291
    airportID  AIRPORT3869
    elevation  8
Node: AIRPORT607
Attributes:
    lat        56.299999
    iataCode   AAR
    country    Denmark
    city       Aarhus
    tzname     Europe/Copenhagen
    icaoCode   EKAH
    lon        10.619
    name       Aarhus Airport
    utc        1
    airportID  AIRPORT607
    elevation  82
Display set to output 2 rows. Gremlin query returned 7190 results.
```

SQL

```
SELECT airportId, city, country, elevation, iataCode, iacoCode, lat, lon, name, tzname, utc, null AS allianceID, null AS launchDate, null AS website FROM airportType UNION SELECT null AS airportId, null AS city, null AS country, null AS elevation, null AS iataCode, null AS iacoCode, null AS lat, null AS lon, name, null AS tzname, null AS utc, allianceID, launchDate, website FROM allianceType;
```

and

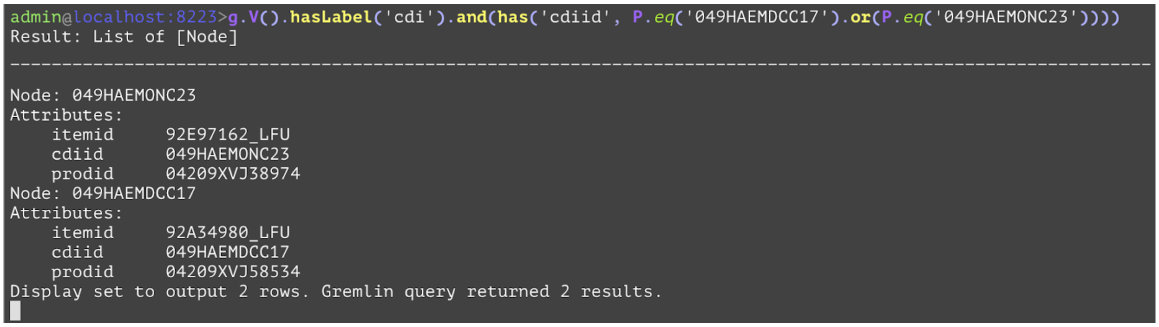
Allows the explicit `and`-ing of multiple has steps. Usually, this step is not required as multiple `”has”` steps in sequence are implicitly `and`-ed together.

For the following example, the `”and”` step acts as an explicit `”and”` to improve readability of the query.

Args	Name	Type	Description
	`traversal_steps`	steps or expression	The body of the `”and”` statement.

GQL

```
gremlin://g.V().hasLabel(‘cdi’).and(has(‘cdiid’,
P.eq(‘049HAEMDCC17’).or(P.eq(‘049HAEMONC23’))));
```



```
admin@localhost:8223>g.V().hasLabel('cdi').and(has('cdiid', P.eq('049HAEMDCC17').or(P.eq('049HAEMONC23'))))
Result: List of [Node]
---------------------------------------------------------------------------------------------------------------

Node: 049HAEMONC23
Attributes:
    itemid     92E97162_LFU
    cdiid      049HAEMONC23
    prodid     04209XVJ38974
Node: 049HAEMDCC17
Attributes:
    itemid     92A34980_LFU
    cdiid      049HAEMDCC17
    prodid     04209XVJ58534
Display set to output 2 rows. Gremlin query returned 2 results.
```

SQL

```
SELECT * FROM cdi WHERE cdiid=‘049HAEMDCC17’ OR cdiid=‘049HAEMONC23’;
```

dedup

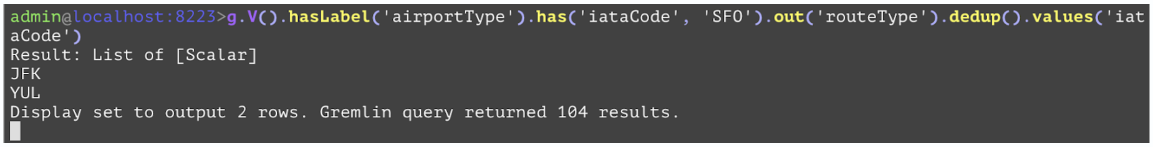
Removes duplicate elements from the traversals present at the current step. When acting on entities (nodes or edges) a proceeding "`by`" step can be specified to remove distinct entities that have overlapping attribute values (by specifying within the "`by`" step the attribute).

The first example removes duplicate airports from the arriving airports where the SFO airport is the departing airport.

In the second example, the "`dedup`" step is used on the "`uses`" edges that are inbound to the container with "`cdiid`" of "`049HDFJKKJ70`" and removes duplicates based on the "`workcenterid`" of those edges. While there is no direct SQL analog, one that retrieves the same information in a different format is shown below.

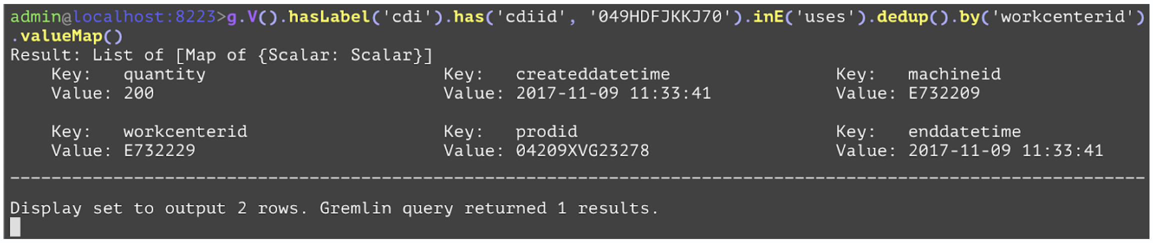
GQL

```
gremlin://g.V().hasLabel('airportType').has('iataCode',
'SFO').out('routeType').dedup().values('iataCode');
```



```
admin@localhost:8223>g.V().hasLabel('airportType').has('iataCode', 'SFO').out('routeType').dedup().values('iat
aCode')
Result: List of [Scalar]
JFK
YUL
Display set to output 2 rows. Gremlin query returned 104 results.
```

```
gremlin://g.V().hasLabel('cdi').has('cdiid',
'049HDFJKKJ70').inE('uses').dedup().by('workcenterid').valueMap();
```



```
admin@localhost:8223>g.V().hasLabel('cdi').has('cdiid', '049HDFJKKJ70').inE('uses').dedup().by('workcenterid')
.valueMap()
Result: List of [Map of {Scalar: Scalar}]
    Key:   quantity                          Key:   createddatetime               Key:   machineid
    Value: 200                               Value: 2017-11-09 11:33:41           Value: E732209

    Key:   workcenterid                      Key:   prodid                        Key:   enddatetime
    Value: E732229                           Value: 04209XVG23278                 Value: 2017-11-09 11:33:41
--------------------------------------------------------------------------------------------------------------

Display set to output 2 rows. Gremlin query returned 1 results.
```

SQL

```
SELECT DISTINCT(destAirport.iataCode) FROM airportType AS srcAirport INNER JOIN routeType AS hop ON
hop.srcAirportId=srcAirport.airportId INNER JOIN airportType AS destAirport ON
hop.destAirportId=destAirport.airportId WHERE srcAirport.iataCode='SFO';
```

```
SELECT DISTINCT(used.workcenterid), used.quantity, used.prodid, used.machineid, used.createddatetime,
used.enddatetime FROM cdi AS cd INNER JOIN uses AS used ON used.destCdiid=cd.cdiid WHERE
cd.cdiid='049HDFJKKJ70';
```

Predicates

eq

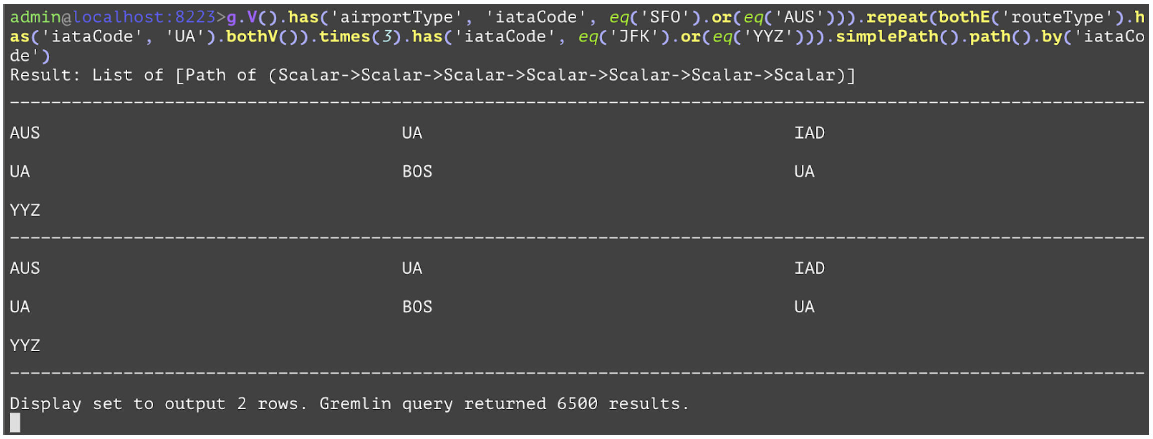
Compares the values, and if they are equal, the step will evaluate to True, otherwise False.

The "eq" inside of the example is used as a predicate to convert the raw values of "SFO", "AUS", "JFK", and "YYZ" for use by the "or" step predicate.

Args	Name	Type	Description
	value	string or number	The value for determining whether the filter step passes.

GQL

```
gremlin://g.V().has('airportType', 'iataCode',
eq('SFO').or(eq('AUS'))).repeat(bothE('routeType').has('iataCode',
'UA').bothV()).times(3).has('iataCode', eq('JFK').or(eq('YYZ'))).simplePath().path().by('iataCode');
```

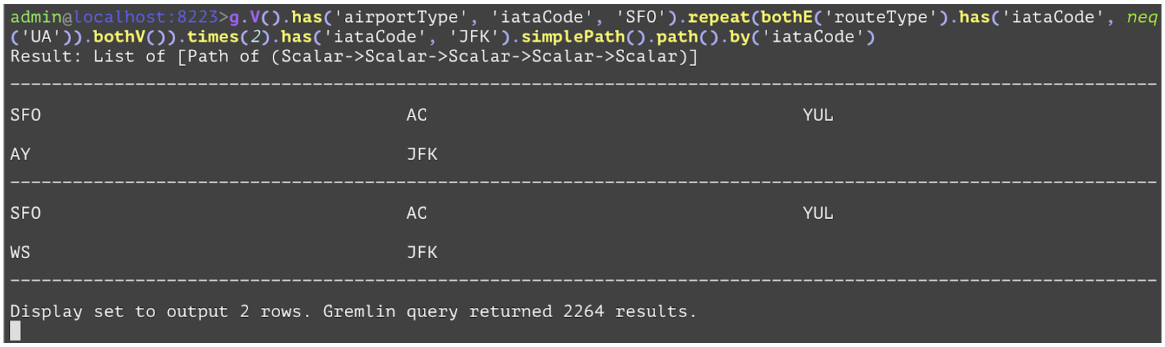


```
admin@localhost:8223>g.V().has('airportType', 'iataCode', eq('SFO').or(eq('AUS'))).repeat(bothE('routeType').h
as('iataCode', 'UA').bothV()).times(3).has('iataCode', eq('JFK').or(eq('YYZ'))).simplePath().path().by('iataCo
de')
Result: List of [Path of (Scalar->Scalar->Scalar->Scalar->Scalar->Scalar->Scalar)]
----------------------------------------------------------------------------------------------------------------
AUS                                    UA                                     IAD

UA                                     BOS                                    UA

YYZ
----------------------------------------------------------------------------------------------------------------
AUS                                    UA                                     IAD

UA                                     BOS                                    UA

YYZ
----------------------------------------------------------------------------------------------------------------
Display set to output 2 rows. Gremlin query returned 6500 results.
```

neq

<table>
<tr><td colspan="4">Compares the values, and if they are not equal, the step will evaluate to True, otherwise False.
The "neq" inside of the example is used as a predicate to prevent any "UA" from being included.</td></tr>
<tr><td rowspan="2">Args</td><td>Name</td><td>Type</td><td>Description</td></tr>
<tr><td>value</td><td>string or number</td><td>The value for determining whether the filter step passes.</td></tr>
<tr><td>GQL</td><td colspan="3">

```
gremlin://g.V().has('airportType', 'iataCode', 'SFO').repeat(bothE('routeType').has('iataCode',
neq('UA')).bothV()).times(2).has('iataCode', 'JFK').simplePath().path().by('iataCode');
```



```
admin@localhost:8223>g.V().has('airportType', 'iataCode', 'SFO').repeat(bothE('routeType').has('iataCode', neq
('UA')).bothV()).times(2).has('iataCode', 'JFK').simplePath().path().by('iataCode')
Result: List of [Path of (Scalar->Scalar->Scalar->Scalar->Scalar)]
---------------------------------------------------------------------------------------------------------------
SFO                                   AC                                    YUL

AY                                    JFK
---------------------------------------------------------------------------------------------------------------
SFO                                   AC                                    YUL

WS                                    JFK
---------------------------------------------------------------------------------------------------------------
Display set to output 2 rows. Gremlin query returned 2264 results.
```

</td></tr>
</table>

lt

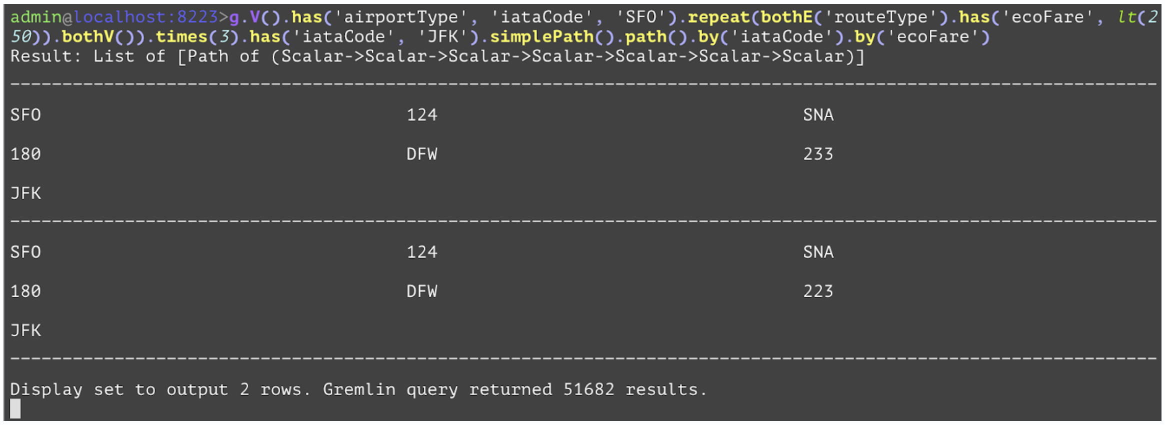
Compares the values, and if the current value is less than the value of the parameter, the step will evaluate to True, otherwise False.

The "`lt`" inside of the example is used to compare the route's economy fare and not include the route if the fare is over 250.

Args	Name	Type	Description
	value	string or number	The value for determining whether the filter step passes.

GQL

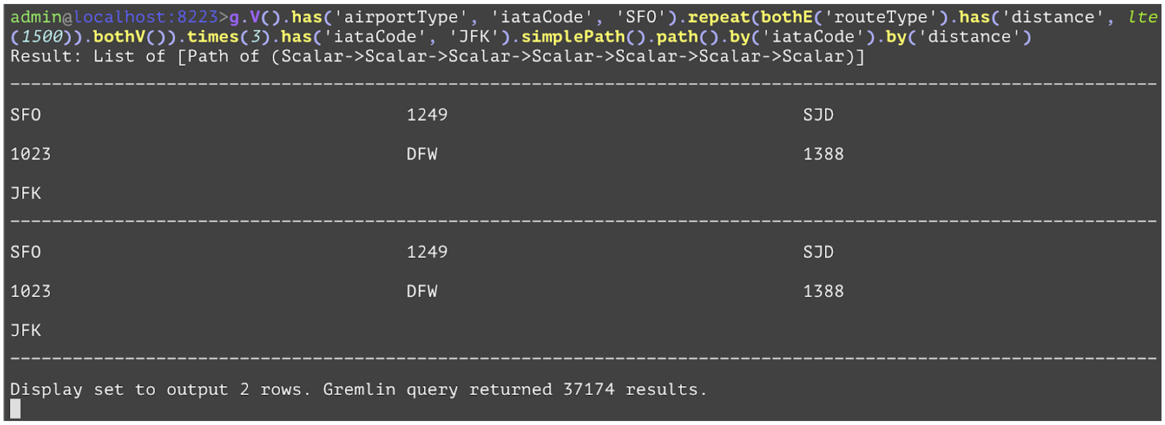
```
gremlin://g.V().has('airportType', 'iataCode', 'SFO').repeat(bothE('routeType').has('ecoFare', lt(250)).bothV()).times(3).has('iataCode', 'JFK').simplePath().path().by('iataCode').by('ecoFare');
```



```
admin@localhost:8223>g.V().has('airportType', 'iataCode', 'SFO').repeat(bothE('routeType').has('ecoFare', lt(2
50)).bothV()).times(3).has('iataCode', 'JFK').simplePath().path().by('iataCode').by('ecoFare')
Result: List of [Path of (Scalar->Scalar->Scalar->Scalar->Scalar->Scalar->Scalar)]
--------------------------------------------------------------------------------------------------------------
SFO                                   124                                   SNA

180                                   DFW                                   233

JFK
--------------------------------------------------------------------------------------------------------------
SFO                                   124                                   SNA

180                                   DFW                                   223

JFK
--------------------------------------------------------------------------------------------------------------
Display set to output 2 rows. Gremlin query returned 51682 results.
```

lte

<table>
<tr><td colspan="4">Compares the values, and if the current value is less than or equal to the value of the parameter, the step will evaluate to True, otherwise False.

The "<code>lte</code>" inside of the example is used as a way to only allow routes of distance less than or equal to 1500.</td></tr>
<tr><td rowspan="2">Args</td><td>Name</td><td>Type</td><td>Description</td></tr>
<tr><td>value</td><td>string or number</td><td>The value for determining whether the filter step passes.</td></tr>
<tr><td>GQL</td><td colspan="3">
<pre>
gremlin://g.V().has('airportType', 'iataCode', 'SFO').repeat(bothE('routeType').has('distance',
lte(1500)).bothV()).times(3).has('iataCode', 'JFK').simplePath().path().by('iataCode').by('distance');
</pre>

<pre>
admin@localhost:8223>g.V().has('airportType', 'iataCode', 'SFO').repeat(bothE('routeType').has('distance', lte
(1500)).bothV()).times(3).has('iataCode', 'JFK').simplePath().path().by('iataCode').by('distance')
Result: List of [Path of (Scalar->Scalar->Scalar->Scalar->Scalar->Scalar->Scalar)]

SFO   1249   SJD

1023   DFW   1388

JFK

SFO   1249   SJD

1023   DFW   1388

JFK

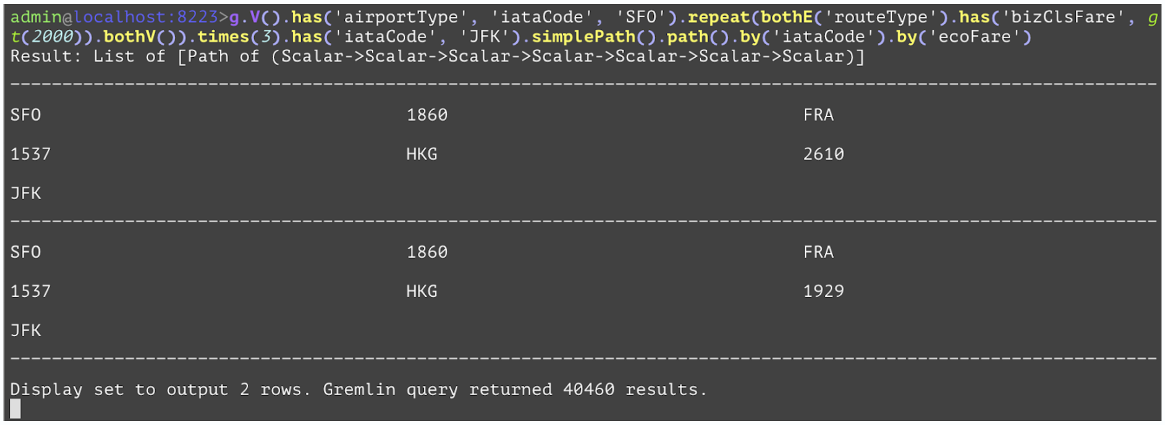
Display set to output 2 rows. Gremlin query returned 37174 results.
</pre>
</td></tr>
</table>

gt

<table>
<tr><td colspan="4">Compares the values, and if the current value is greater than the value of the parameter, the step will evaluate to True, otherwise False.

The "gt" inside of the example is used to only allow business class fares greater than 2000 into the returned query.</td></tr>
<tr><td>Args</td><td>Name</td><td>Type</td><td>Description</td></tr>
<tr><td></td><td>value</td><td>string or number</td><td>The value for determining whether the filter step passes.</td></tr>
<tr><td>GQL</td><td colspan="3">

```
gremlin://g.V().has('airportType', 'iataCode', 'SFO').repeat(bothE('routeType').has('bizClsFare',
gt(2000)).bothV()).times(3).has('iataCode', 'JFK').simplePath().path().by('iataCode').by('bizClsFare');
```



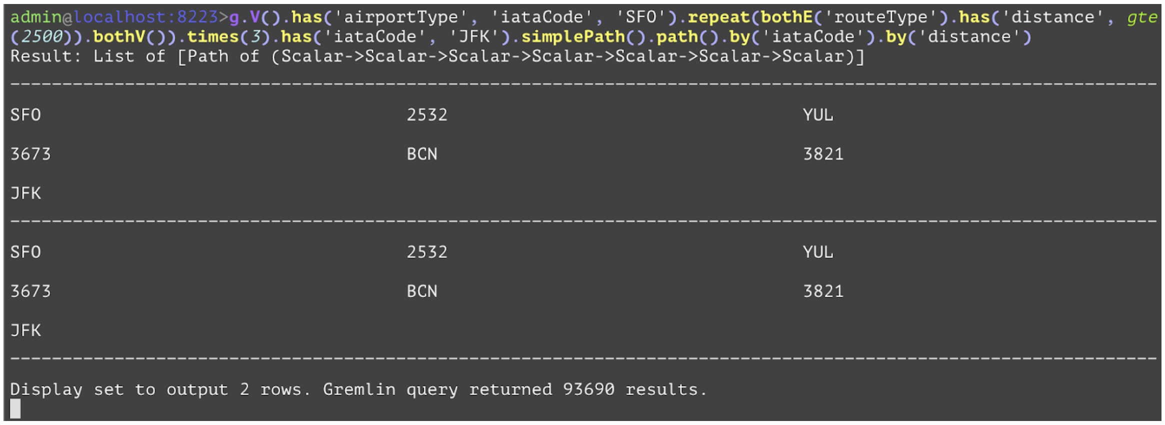
```
admin@localhost:8223>g.V().has('airportType', 'iataCode', 'SFO').repeat(bothE('routeType').has('bizClsFare', g
t(2000)).bothV()).times(3).has('iataCode', 'JFK').simplePath().path().by('iataCode').by('ecoFare')
Result: List of [Path of (Scalar->Scalar->Scalar->Scalar->Scalar->Scalar->Scalar)]
--------------------------------------------------------------------------------------------------------------
SFO                                   1860                                  FRA

1537                                  HKG                                   2610

JFK
--------------------------------------------------------------------------------------------------------------
SFO                                   1860                                  FRA

1537                                  HKG                                   1929

JFK
--------------------------------------------------------------------------------------------------------------
Display set to output 2 rows. Gremlin query returned 40460 results.
```

</td></tr>
</table>

gte

Compares the values, and if the current value is greater than or equal to the value of the parameter, the step will evaluate to True, otherwise False.

The "gte" inside of the example is used as a predicate to only allow routes with distance greater than or equal to 2500 to pass.

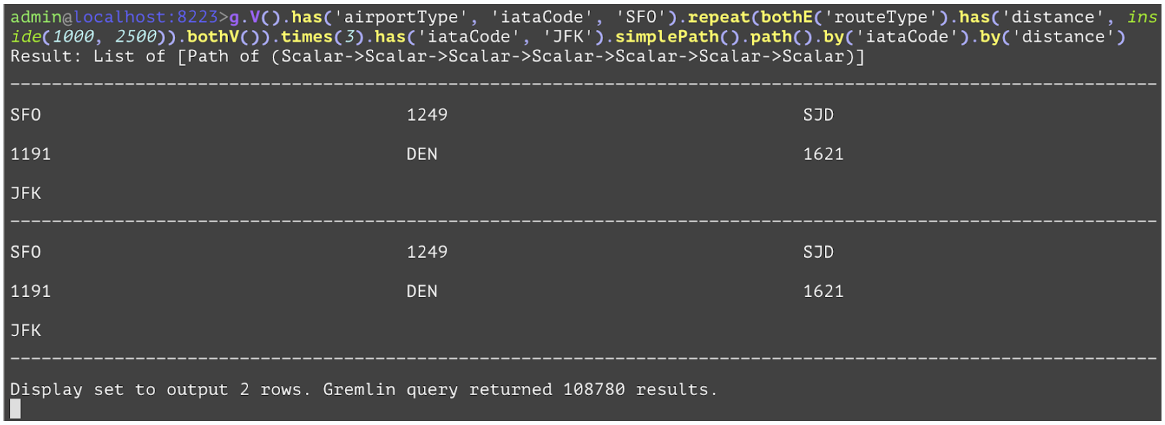
Args	Name	Type	Description
	value	string or number	The value for determining whether the filter step passes.
GQL	gremlin://g.V().has('airportType', 'iataCode', 'SFO').repeat(bothE('routeType').has('distance', gte(2500)).bothV()).times(3).has('iataCode', 'JFK').simplePath().path().by('iataCode').by('distance'); 		

```
admin@localhost:8223>g.V().has('airportType', 'iataCode', 'SFO').repeat(bothE('routeType').has('distance', gte
(2500)).bothV()).times(3).has('iataCode', 'JFK').simplePath().path().by('iataCode').by('distance')
Result: List of [Path of (Scalar->Scalar->Scalar->Scalar->Scalar->Scalar->Scalar)]
--------------------------------------------------------------------------------------------------------------
SFO                                    2532                                   YUL

3673                                   BCN                                    3821

JFK
--------------------------------------------------------------------------------------------------------------
SFO                                    2532                                   YUL

3673                                   BCN                                    3821

JFK
--------------------------------------------------------------------------------------------------------------
Display set to output 2 rows. Gremlin query returned 93690 results.
```

inside

Compares the values, and if the current value is greater than the first parameter and less than the second parameter, the step will evaluate to True, otherwise False.

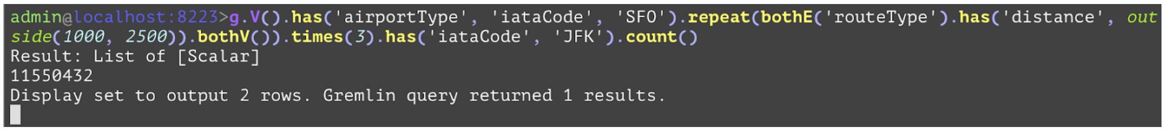
The "inside" inside of the example is used as a predicate to only allow distances between 1000 and 2500 past the filter.

Args	Name	Type	Description
	value1	string or number	The first value for determining whether the filter step passes.
	value2	string or number	The second value for determining whether the filter step passes.
GQL	gremlin://g.V().has('airportType', 'iataCode', 'SFO').repeat(bothE('routeType').has('distance', inside(1000, 2500)).bothV()).times(3).has('iataCode', 'JFK').simplePath().path().by('iataCode').by('distance'); 		

```
admin@localhost:8223>g.V().has('airportType', 'iataCode', 'SFO').repeat(bothE('routeType').has('distance', inside(1000, 2500)).bothV()).times(3).has('iataCode', 'JFK').simplePath().path().by('iataCode').by('distance')
Result: List of [Path of (Scalar->Scalar->Scalar->Scalar->Scalar->Scalar->Scalar)]
-------------------------------------------------------------------------------------------------------------
SFO                                  1249                                 SJD

1191                                 DEN                                  1621

JFK
-------------------------------------------------------------------------------------------------------------
SFO                                  1249                                 SJD

1191                                 DEN                                  1621

JFK
-------------------------------------------------------------------------------------------------------------
Display set to output 2 rows. Gremlin query returned 108780 results.
```

outside

Compares the values, and if the current value is less than the first parameter and greater than the second parameter, the step will evaluate to True, otherwise False. The "`outside`" inside of the example is used as a predicate to filter out any routes with distance between 1000 and 2500.			
Args	Name	Type	Description
	value1	string or number	The first value for determining whether the filter step passes.
	value2	string or number	The second value for determining whether the filter step passes.

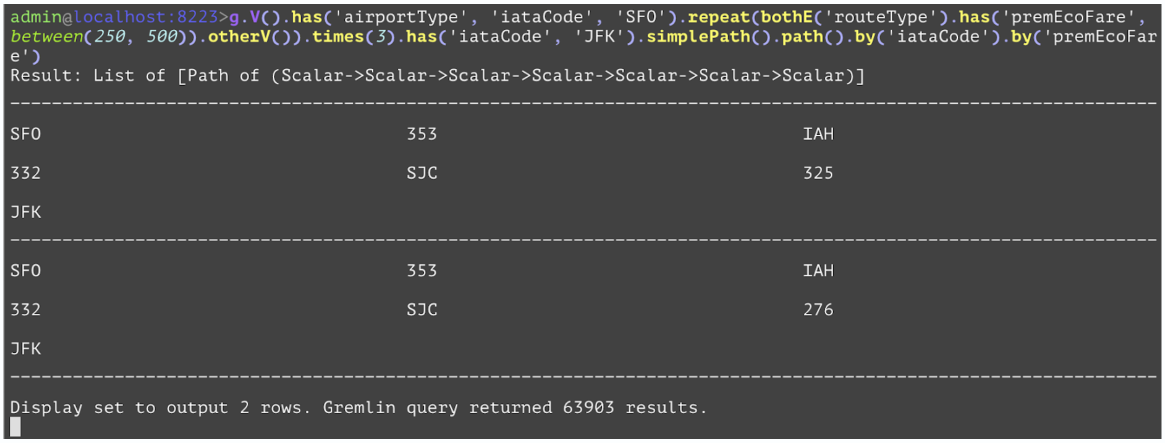
GQL	`gremlin://g.V().has('airportType', 'iataCode', 'SFO').repeat(bothE('routeType').has('distance', outside(1000, 2500)).bothV()).times(3).has('iataCode', 'JFK').count();`
	
	`admin@localhost:8223>g.V().has('airportType', 'iataCode', 'SFO').repeat(bothE('routeType').has('distance', out`
	`side(1000, 2500)).bothV()).times(3).has('iataCode', 'JFK').count()`
	`Result: List of [Scalar]`
	`11550432`
	`Display set to output 2 rows. Gremlin query returned 1 results.`		

between

<table>
<tr><td colspan="4">Compares the values, and if the current value is greater than or equal to the first parameter and less than the second parameter, the step will evaluate to True, otherwise False.

The "between" inside of the example is used as a predicate to only allow premium economy fares between 250 inclusive and 500 exclusive into the result.</td></tr>
<tr><td rowspan="3">Args</td><td>Name</td><td>Type</td><td>Description</td></tr>
<tr><td>value1</td><td>string or number</td><td>The first value for determining whether the filter step passes.</td></tr>
<tr><td>value2</td><td>string or number</td><td>The second value for determining whether the filter step passes.</td></tr>
<tr><td>GQL</td><td colspan="3">

```
gremlin://g.V().has('airportType', 'iataCode', 'SFO').repeat(bothE('routeType').has('premEcoFare',
between(250, 500)).otherV()).times(3).has('iataCode',
'JFK').simplePath().path().by('iataCode').by('premEcoFare');
```



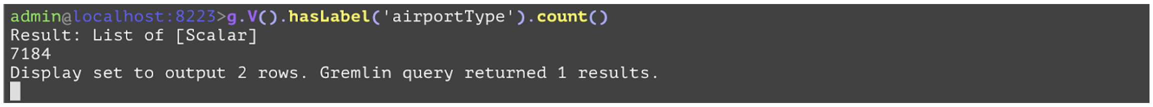
```
admin@localhost:8223>g.V().has('airportType', 'iataCode', 'SFO').repeat(bothE('routeType').has('premEcoFare',
between(250, 500)).otherV()).times(3).has('iataCode', 'JFK').simplePath().path().by('iataCode').by('premEcoFar
e')
Result: List of [Path of (Scalar->Scalar->Scalar->Scalar->Scalar->Scalar->Scalar)]
---------------------------------------------------------------------------------------------------------------
SFO                                   353                                   IAH

332                                   SJC                                   325

JFK
---------------------------------------------------------------------------------------------------------------
SFO                                   353                                   IAH

332                                   SJC                                   276

JFK
---------------------------------------------------------------------------------------------------------------
Display set to output 2 rows. Gremlin query returned 63903 results.
```

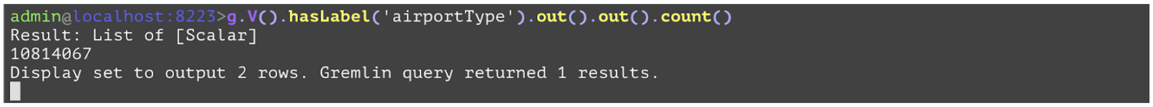
</td></tr>
</table>

Aggregation

count

Counts the number of traversals that get to this step. In example 1, it will get the number of airport type nodes in the database. For example 2, it will get the number of entries in a 2-join operation. The SQL equivalent is much more verbose for the second query when compared to the simple gremlin query.	

GQL	`gremlin://g.V().hasLabel('airportType').count();`
	
	`admin@localhost:8223>g.V().hasLabel('airportType').count()`
	`Result: List of [Scalar]`
	`7184`
	`Display set to output 2 rows. Gremlin query returned 1 results.`

	`gremlin://g.V().hasLabel('airportType').out().out().count();`
	
	`admin@localhost:8223>g.V().hasLabel('airportType').out().out().count()`
	`Result: List of [Scalar]`
	`10814067`
	`Display set to output 2 rows. Gremlin query returned 1 results.`

SQL	`SELECT COUNT(airportId) FROM airportType;`
	`SELECT COUNT(destAirport.airportId) FROM airportType AS srcAirport JOIN routeType AS firstHop ON firstHop.fromAirportId=srcAirport.airportId JOIN airportType AS interAirport ON firstHop.toAirportId=interAirport.airportId JOIN routeType AS secondHop ON secondHop.fromAirportId=interAirport.airportId JOIN airportType AS destAirport ON secondHop.toAirportId=destAirport;`

group

Groups together entities in the current traversal into a dictionary with keys being the attribute value specified in the first subsequent "by" step, and the values being a list of the entities that have the attribute with that value. Another "by" step would specify what each entity should be represented in the list.

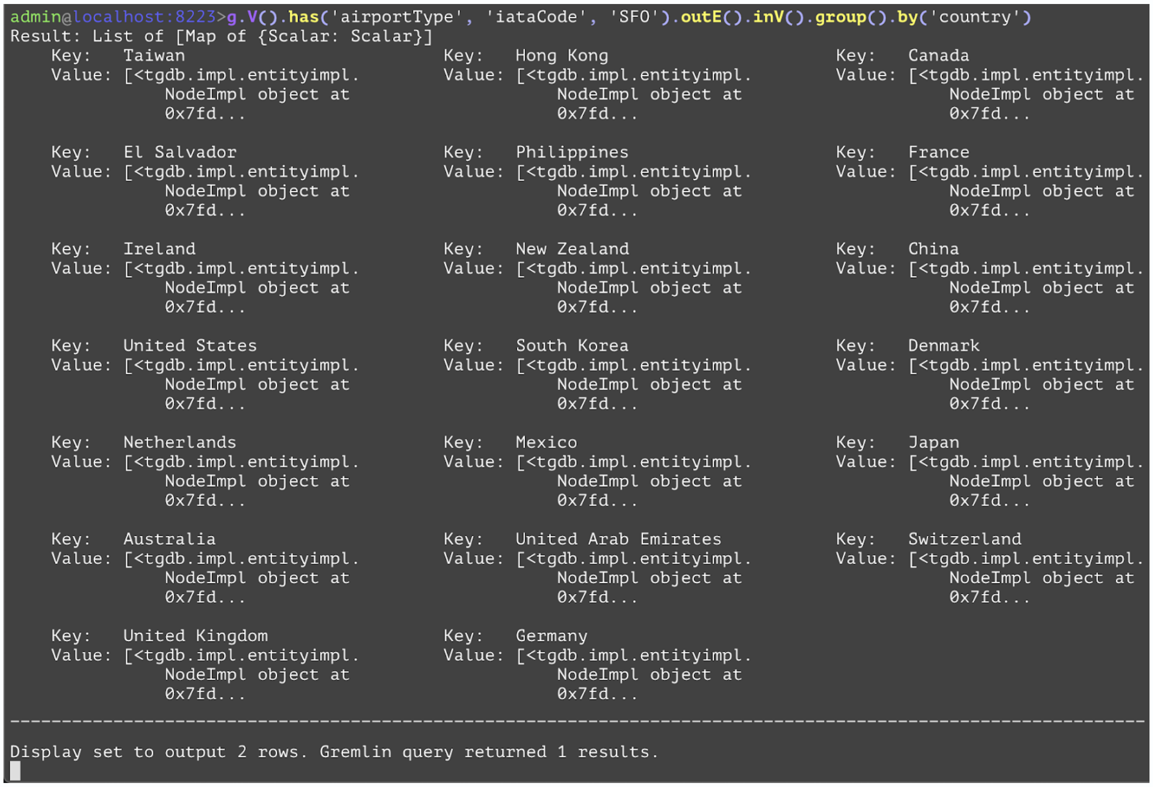
While there is no direct SQL analog, the examples below have analogs that retrieve the same information in a different format as shown below.

In the first example, this will group all outbound destinations from flights originating at the airport SFO based on the country of the destination.

In the second example, the list for each country will only contain the IATA codes for the airports within that country, instead of the entity objects. This can be used to reduce the amount of data sent over the network if all that is required are the IATA codes.

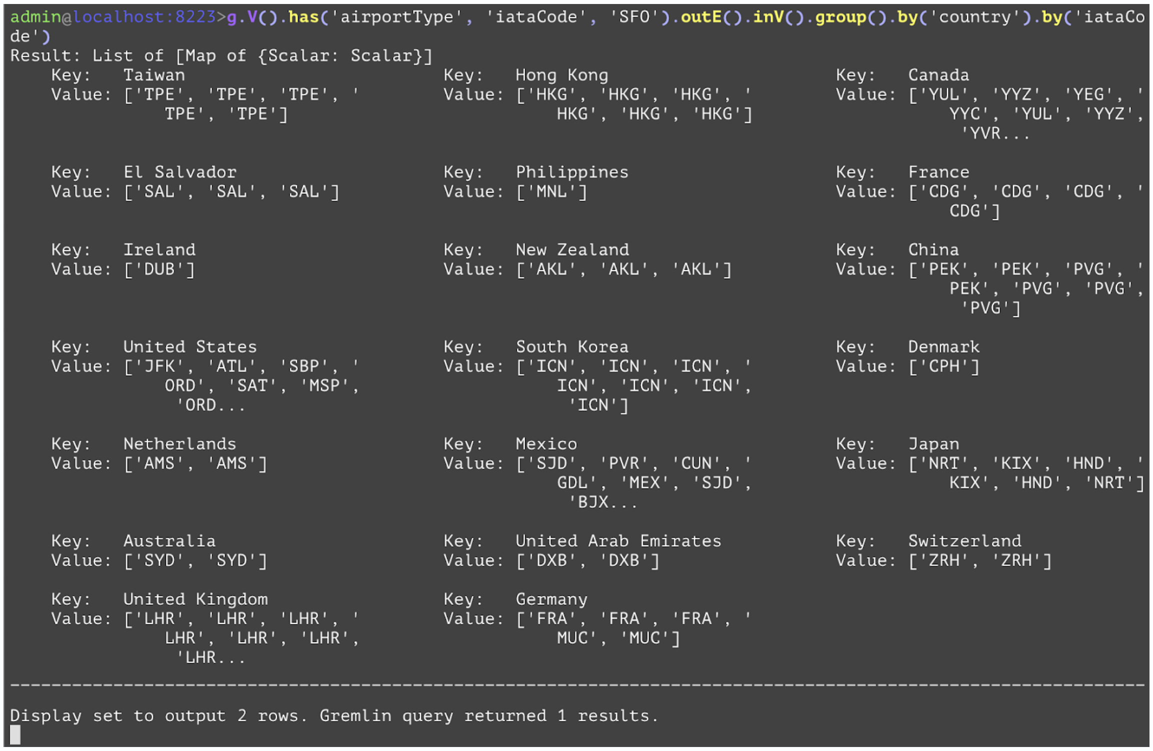
GQL

```
gremlin://g.V().has('airportType', 'iataCode', 'SFO').outE().inV().group().by('country');
```



```
admin@localhost:8223>g.V().has('airportType', 'iataCode', 'SFO').outE().inV().group().by('country')
Result: List of [Map of {Scalar: Scalar}]
    Key:   Taiwan                         Key:   Hong Kong                      Key:   Canada
    Value: [<tgdb.impl.entityimpl.        Value: [<tgdb.impl.entityimpl.        Value: [<tgdb.impl.entityimpl.
               NodeImpl object at                    NodeImpl object at                    NodeImpl object at
               0x7fd...                              0x7fd...                              0x7fd...

    Key:   El Salvador                    Key:   Philippines                    Key:   France
    Value: [<tgdb.impl.entityimpl.        Value: [<tgdb.impl.entityimpl.        Value: [<tgdb.impl.entityimpl.
               NodeImpl object at                    NodeImpl object at                    NodeImpl object at
               0x7fd...                              0x7fd...                              0x7fd...

    Key:   Ireland                        Key:   New Zealand                    Key:   China
    Value: [<tgdb.impl.entityimpl.        Value: [<tgdb.impl.entityimpl.        Value: [<tgdb.impl.entityimpl.
               NodeImpl object at                    NodeImpl object at                    NodeImpl object at
               0x7fd...                              0x7fd...                              0x7fd...

    Key:   United States                  Key:   South Korea                    Key:   Denmark
    Value: [<tgdb.impl.entityimpl.        Value: [<tgdb.impl.entityimpl.        Value: [<tgdb.impl.entityimpl.
               NodeImpl object at                    NodeImpl object at                    NodeImpl object at
               0x7fd...                              0x7fd...                              0x7fd...

    Key:   Netherlands                    Key:   Mexico                         Key:   Japan
    Value: [<tgdb.impl.entityimpl.        Value: [<tgdb.impl.entityimpl.        Value: [<tgdb.impl.entityimpl.
               NodeImpl object at                    NodeImpl object at                    NodeImpl object at
               0x7fd...                              0x7fd...                              0x7fd...

    Key:   Australia                      Key:   United Arab Emirates           Key:   Switzerland
    Value: [<tgdb.impl.entityimpl.        Value: [<tgdb.impl.entityimpl.        Value: [<tgdb.impl.entityimpl.
               NodeImpl object at                    NodeImpl object at                    NodeImpl object at
               0x7fd...                              0x7fd...                              0x7fd...

    Key:   United Kingdom                 Key:   Germany
    Value: [<tgdb.impl.entityimpl.        Value: [<tgdb.impl.entityimpl.
               NodeImpl object at                    NodeImpl object at
               0x7fd...                              0x7fd...
--------------------------------------------------------------------------------------------------------------

Display set to output 2 rows. Gremlin query returned 1 results.
```

```
gremlin://g.V().has('airportType', 'iataCode',
'SFO').outE().inV().group().by('country').by('iataCode');
```



```
admin@localhost:8223>g.V().has('airportType', 'iataCode', 'SFO').outE().inV().group().by('country').by('iataCo
de')
Result: List of [Map of {Scalar: Scalar}]
    Key:   Taiwan                         Key:   Hong Kong                     Key:   Canada
    Value: ['TPE', 'TPE', 'TPE', '        Value: ['HKG', 'HKG', 'HKG', '        Value: ['YUL', 'YYZ', 'YEG', '
               TPE', 'TPE']                           HKG', 'HKG', 'HKG']                  YYC', 'YUL', 'YYZ',
                                                                                            'YVR...

    Key:   El Salvador                    Key:   Philippines                   Key:   France
    Value: ['SAL', 'SAL', 'SAL']          Value: ['MNL']                        Value: ['CDG', 'CDG', 'CDG', '
                                                                                           CDG']

    Key:   Ireland                        Key:   New Zealand                   Key:   China
    Value: ['DUB']                        Value: ['AKL', 'AKL', 'AKL']          Value: ['PEK', 'PEK', 'PVG', '
                                                                                           PEK', 'PVG', 'PVG',
                                                                                            'PVG']

    Key:   United States                  Key:   South Korea                   Key:   Denmark
    Value: ['JFK', 'ATL', 'SBP', '        Value: ['ICN', 'ICN', 'ICN', '        Value: ['CPH']
               ORD', 'SAT', 'MSP',                   ICN', 'ICN', 'ICN',
                'ORD...                               'ICN']

    Key:   Netherlands                    Key:   Mexico                        Key:   Japan
    Value: ['AMS', 'AMS']                 Value: ['SJD', 'PVR', 'CUN', '        Value: ['NRT', 'KIX', 'HND', '
                                                     GDL', 'MEX', 'SJD',                   KIX', 'HND', 'NRT']
                                                      'BJX...

    Key:   Australia                      Key:   United Arab Emirates          Key:   Switzerland
    Value: ['SYD', 'SYD']                 Value: ['DXB', 'DXB']                 Value: ['ZRH', 'ZRH']

    Key:   United Kingdom                 Key:   Germany
    Value: ['LHR', 'LHR', 'LHR', '        Value: ['FRA', 'FRA', 'FRA', '
               LHR', 'LHR', 'LHR',                   MUC', 'MUC']
                'LHR...

--------------------------------------------------------------------------------------------------------------

Display set to output 2 rows. Gremlin query returned 1 results.
```

SQL

```
SELECT dest.* FROM airportType AS src INNER JOIN routeType AS hop ON hop.srcAirportId=src.airportId
INNER JOIN airportType AS dest ON hop.destAirportId=dest.airportId WHERE src.iataCode='SFO' GROUP BY
dest.airportId ORDER BY dest.country;
```

```
SELECT dest.iataCode, dest.country FROM airportType AS src INNER JOIN routeType AS hop ON
hop.srcAirportId=src.airportId INNER JOIN airportType AS dest ON hop.destAirportId=dest.airportId
WHERE src.iataCode='SFO' GROUP BY dest.iataCode ORDER BY dest.country;
```

groupCount

Groups together entities in the current traversal into a dictionary with keys being the attribute value specified in the first subsequent "by" if the current traversal is entities otherwise will group based on the values, and the values being an integer value for the number of times that value occurs.

While in practice both examples have the same result, the difference is that the first one has entities as that point in the traversal and requires a "by" step to reduce those entities into something that can be counted and grouped together.

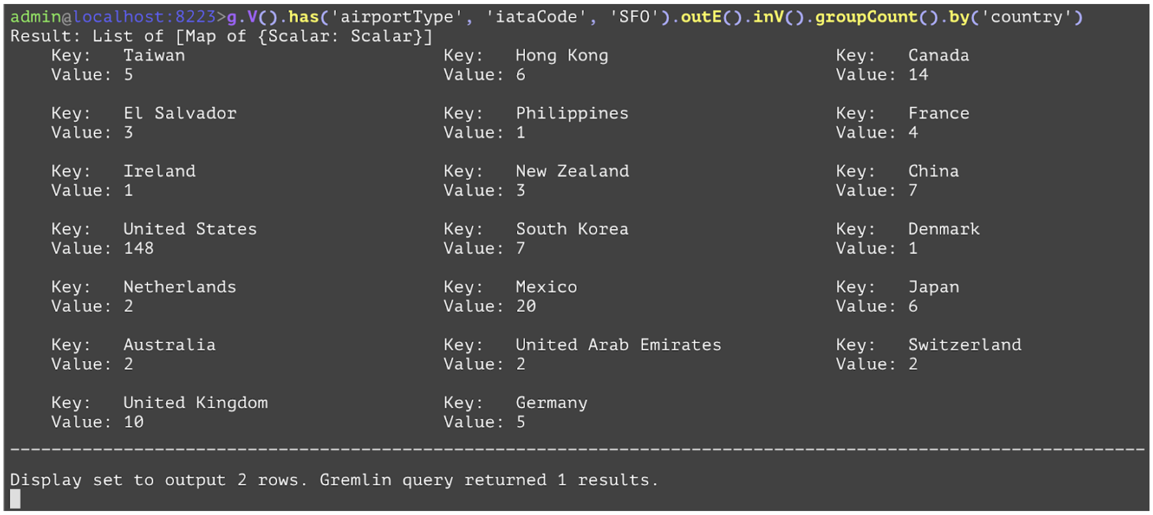
The second example, in contrast, reduces each airport entity into its country, and then passes that result onto the "groupCount" step which no longer requires a "by" step to reduce the airport entities to a simpler value.

Both examples count and display in a map the countries of the airports of the destination airports for flights originating from the SFO airport.

Both examples have a single similar SQL equivalent.

GQL

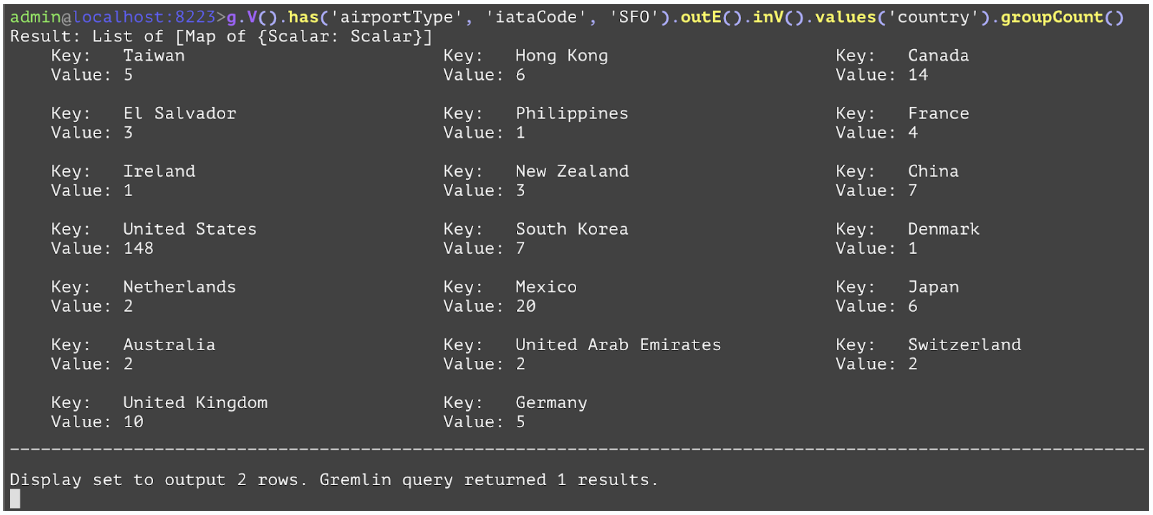
```
gremlin://g.V().has('airportType', 'iataCode', 'SFO').outE().inV().groupCount().by('country');
```



```
admin@localhost:8223>g.V().has('airportType', 'iataCode', 'SFO').outE().inV().groupCount().by('country')
Result: List of [Map of {Scalar: Scalar}]
    Key:   Taiwan                         Key:   Hong Kong                      Key:   Canada
    Value: 5                              Value: 6                              Value: 14

    Key:   El Salvador                    Key:   Philippines                    Key:   France
    Value: 3                              Value: 1                              Value: 4

    Key:   Ireland                        Key:   New Zealand                    Key:   China
    Value: 1                              Value: 3                              Value: 7

    Key:   United States                  Key:   South Korea                    Key:   Denmark
    Value: 148                            Value: 7                              Value: 1

    Key:   Netherlands                    Key:   Mexico                         Key:   Japan
    Value: 2                              Value: 20                             Value: 6

    Key:   Australia                      Key:   United Arab Emirates           Key:   Switzerland
    Value: 2                              Value: 2                              Value: 2

    Key:   United Kingdom                 Key:   Germany
    Value: 10                             Value: 5
--------------------------------------------------------------------------------------------------------------

Display set to output 2 rows. Gremlin query returned 1 results.
```

<table>
<tr>
<td></td>
<td>

```
gremlin://g.V().has('airportType', 'iataCode', 'SFO').outE().inV().values('country').groupCount();
```



```
admin@localhost:8223>g.V().has('airportType', 'iataCode', 'SFO').outE().inV().values('country').groupCount()
Result: List of [Map of {Scalar: Scalar}]
    Key:   Taiwan                         Key:   Hong Kong                      Key:   Canada
    Value: 5                              Value: 6                              Value: 14

    Key:   El Salvador                    Key:   Philippines                    Key:   France
    Value: 3                              Value: 1                              Value: 4

    Key:   Ireland                        Key:   New Zealand                    Key:   China
    Value: 1                              Value: 3                              Value: 7

    Key:   United States                  Key:   South Korea                    Key:   Denmark
    Value: 148                            Value: 7                              Value: 1

    Key:   Netherlands                    Key:   Mexico                         Key:   Japan
    Value: 2                              Value: 20                             Value: 6

    Key:   Australia                      Key:   United Arab Emirates           Key:   Switzerland
    Value: 2                              Value: 2                              Value: 2

    Key:   United Kingdom                 Key:   Germany
    Value: 10                             Value: 5
----------------------------------------------------------------------------------------------------------------

Display set to output 2 rows. Gremlin query returned 1 results.
```

</td>
</tr>
<tr>
<td>SQL</td>
<td>

```
SELECT destAirport.country, COUNT(destAirport.country) FROM airportType AS srcAirport INNER JOIN
routeType AS hop ON hop.fromAirportId=srcAirport.airportId INNER JOIN airportType AS destAirport ON
hop.toAirportId=destAirport.airportId WHERE srcAirport.iataCode='SFO' GROUP BY destAirport.country;
```

</td>
</tr>
<tr>
<td></td>
<td>

```
SELECT destAirport.country, COUNT(destAirport.country) FROM airportType AS srcAirport INNER JOIN
routeType AS hop ON hop.fromAirportId=srcAirport.airportId INNER JOIN airportType AS destAirport ON
hop.toAirportId=destAirport.airportId WHERE srcAirport.iataCode='SFO' GROUP BY destAirport.country;
```

</td>
</tr>
</table>

max

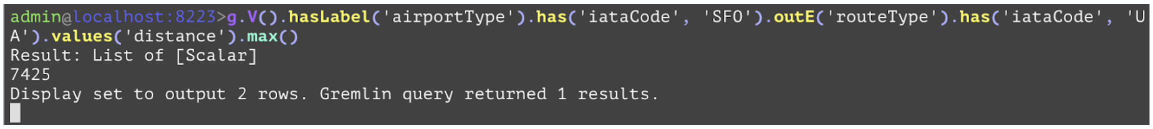
<table>
<tr>
<td colspan="2">

Gets the maximum element value out of the current traversal. Only works for numbers.

In the following example, the query gets the maximum distance flight where SFO is the departing airport.

</td>
</tr>
<tr>
<td>GQL</td>
<td>

```
gremlin://g.V().hasLabel('airportType').has('iataCode', 'SFO').outE('routeType').has('iataCode',
'UA').values('distance').max();
```



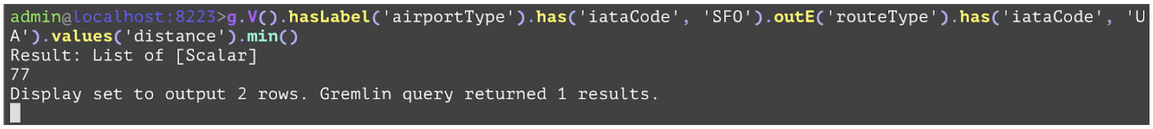
```
admin@localhost:8223>g.V().hasLabel('airportType').has('iataCode', 'SFO').outE('routeType').has('iataCode', 'U
A').values('distance').max()
Result: List of [Scalar]
7425
Display set to output 2 rows. Gremlin query returned 1 results.
```

</td>
</tr>
<tr>
<td>SQL</td>
<td>

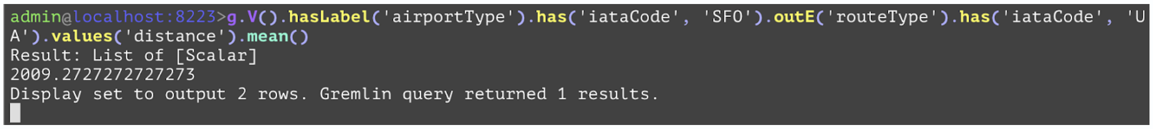
```
SELECT MAX(hop.distance) FROM airportType AS srcAirport INNER JOIN routeType AS hop ON
hop.fromAirportId=srcAirport.airportId WHERE srcAirport.iataCode='SFO';
```

</td>
</tr>
</table>

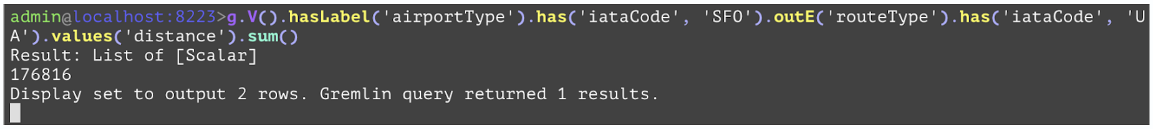
min

Gets the minimum element value out of the current traversal. Only works for numbers. In the following example, the query gets the minimum distance flight where SFO is the departing airport.	
GQL	gremlin://g.V().hasLabel('airportType').has('iataCode', 'SFO').outE('routeType').has('iataCode', 'UA').values('distance').min();  admin@localhost:8223>g.V().hasLabel('airportType').has('iataCode', 'SFO').outE('routeType').has('iataCode', 'U A').values('distance').min() Result: List of [Scalar] 77 Display set to output 2 rows. Gremlin query returned 1 results.
SQL	SELECT MIN(hop.distance) FROM airportType AS srcAirport INNER JOIN routeType AS hop ON hop.fromAirportId=srcAirport.airportId WHERE srcAirport.iataCode='SFO';

mean

Gets the arithmetic mean element value out of the current traversal. Only works for numbers. In the following example, the query gets the mean (average) distance flight where SFO is the departing airport.	
GQL	gremlin://g.V().hasLabel('airportType').has('iataCode', 'SFO').outE('routeType').has('iataCode', 'UA').values('distance').mean();  admin@localhost:8223>g.V().hasLabel('airportType').has('iataCode', 'SFO').outE('routeType').has('iataCode', 'U A').values('distance').mean() Result: List of [Scalar] 2009.2727272727273 Display set to output 2 rows. Gremlin query returned 1 results.
SQL	SELECT AVG(hop.distance) FROM airportType AS srcAirport INNER JOIN routeType AS hop ON hop.fromAirportId=srcAirport.airportId WHERE srcAirport.iataCode='SFO';

sum

Gets the sum of the elements at the current traversal. Only works for numbers. In the following example, the query gets the sum of all of the distances of flight where SFO is the departing airport.	
GQL	gremlin://g.V().hasLabel('airportType').has('iataCode', 'SFO').outE('routeType').has('iataCode', 'UA').values('distance').sum();  admin@localhost:8223>g.V().hasLabel('airportType').has('iataCode', 'SFO').outE('routeType').has('iataCode', 'U A').values('distance').sum() Result: List of [Scalar] 176816 Display set to output 2 rows. Gremlin query returned 1 results.
SQL	SELECT SUM(hop.distance) FROM airportType AS srcAirport INNER JOIN routeType AS hop ON hop.fromAirportId=srcAirport.airportId WHERE srcAirport.iataCode='SFO';

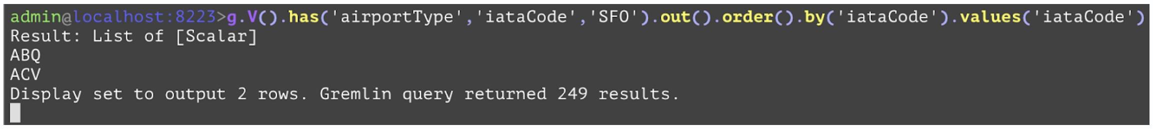
Sorting

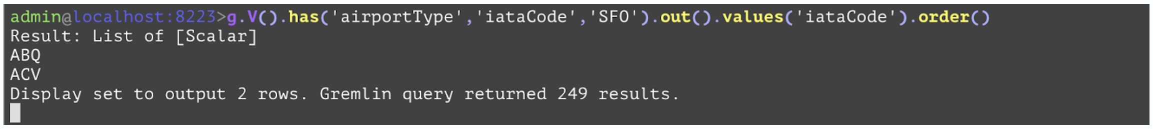
order

Sorts the preceding traversal based on the entity or value at the current step. A single successive "by" step to specify the attribute to sort on is required when the current traversal is an entity. A subsequent "by" step (or the second argument when specifying which attribute of an entity to sort on) can also specify the direction (either "asc" or "desc"), which by default is ascending.

Both examples accomplish the same result: sort all arriving airports by their IATA codes of flights departing from the SFO airport. However, they do this task differently. In the first example, this is accomplished by sorting the airport entities on their "iataCode" attribute, and then extracting the "iataCode" attribute of each entity. Whereas for the second example, the query first extracts the "iataCode" attribute from each entity, creating a list, and then sorting that list.

The SQL equivalent is shown below.

GQL	`gremlin://g.V().has('airportType','iataCode','SFO').out().order().by('iataCode').values('iataCode');`
	
	`admin@localhost:8223>g.V().has('airportType','iataCode','SFO').out().order().by('iataCode').values('iataCode')`
	`Result: List of [Scalar]`
	`ABQ`
	`ACV`
	`Display set to output 2 rows. Gremlin query returned 249 results.`

	`gremlin://g.V().has('airportType','iataCode','SFO').out().values('iataCode').order();`
	
	`admin@localhost:8223>g.V().has('airportType','iataCode','SFO').out().values('iataCode').order()`
	`Result: List of [Scalar]`
	`ABQ`
	`ACV`
	`Display set to output 2 rows. Gremlin query returned 249 results.`

SQL	`SELECT dest.iataCode FROM airportType AS src INNER JOIN routeType AS hop ON hop.srcAirportId=src.airportId INNER JOIN airportType AS dest ON hop.destAirportId=dest.airportId WHERE src.iataCode='SFO' ORDER BY dest.iataCode;`
	`SELECT dest.iataCode FROM airportType AS src INNER JOIN routeType AS hop ON hop.srcAirportId=src.airportId INNER JOIN airportType AS dest ON hop.destAirportId=dest.airportId WHERE src.iataCode='SFO' ORDER BY dest.iataCode;`

Traversal

out

Traverses to all nodes from the current traversal using all outbound edges. For a given node, this is equivalent to traversing to all of the outbound edges' `"to"` nodes that have the current node as a `"from"` vertex.

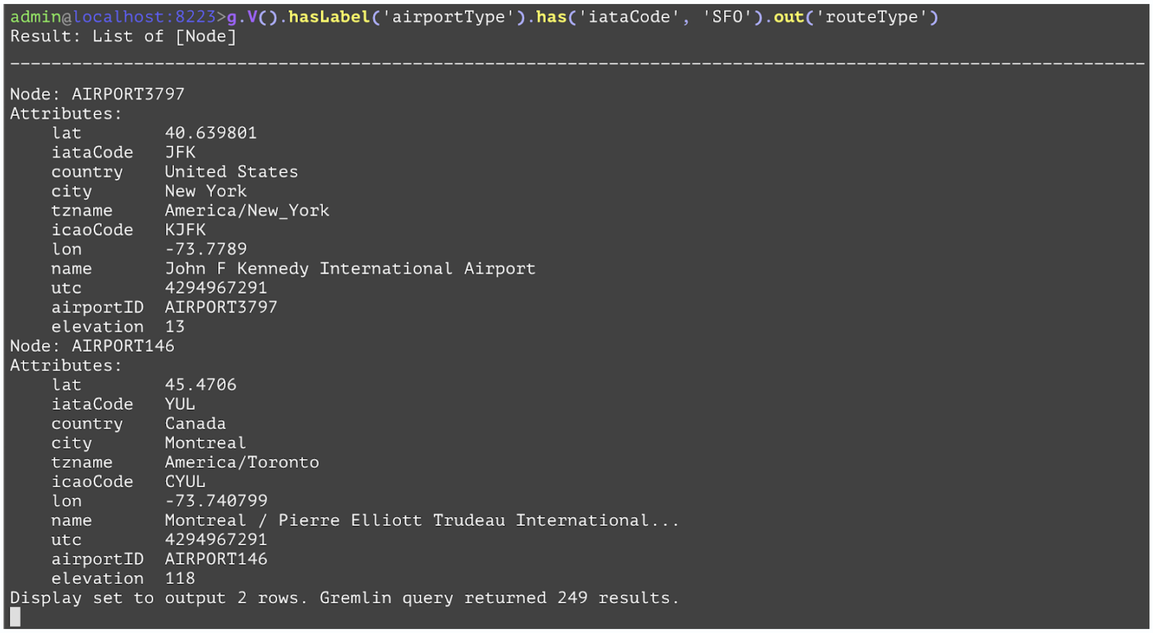
In the following example, the query is asking for all the destinations of all out-bound flights (departures) from the SFO airport.

The SQL equivalent is a bit verbose, and requires an inner join. Whilst this step is join-free in GQL.

Args	Name	Type	Description
	typenames	string[]	Optionally the edge type name(s) (aka edge label(s)) of the edges to traverse across. When specified, this will act as a joint outE().hasLabel(<typenames>).inV()

GQL

```
gremlin://g.V().hasLabel('airportType').has('iataCode', 'SFO').out('routeType');
```



```
admin@localhost:8223>g.V().hasLabel('airportType').has('iataCode', 'SFO').out('routeType')
Result: List of [Node]
------------------------------------------------------------------------------------------------------------

Node: AIRPORT3797
Attributes:
    lat         40.639801
    iataCode    JFK
    country     United States
    city        New York
    tzname      America/New_York
    icaoCode    KJFK
    lon         -73.7789
    name        John F Kennedy International Airport
    utc         4294967291
    airportID   AIRPORT3797
    elevation   13
Node: AIRPORT146
Attributes:
    lat         45.4706
    iataCode    YUL
    country     Canada
    city        Montreal
    tzname      America/Toronto
    icaoCode    CYUL
    lon         -73.740799
    name        Montreal / Pierre Elliott Trudeau International...
    utc         4294967291
    airportID   AIRPORT146
    elevation   118
Display set to output 2 rows. Gremlin query returned 249 results.
```

SQL

```
SELECT dest.* FROM airportType AS src INNER JOIN routeType AS hop ON hop.srcAirportId=src.airportId
INNER JOIN airportType AS dest ON hop.destAirportId=dest.airportId WHERE src.iataCode='SFO';
```

outE

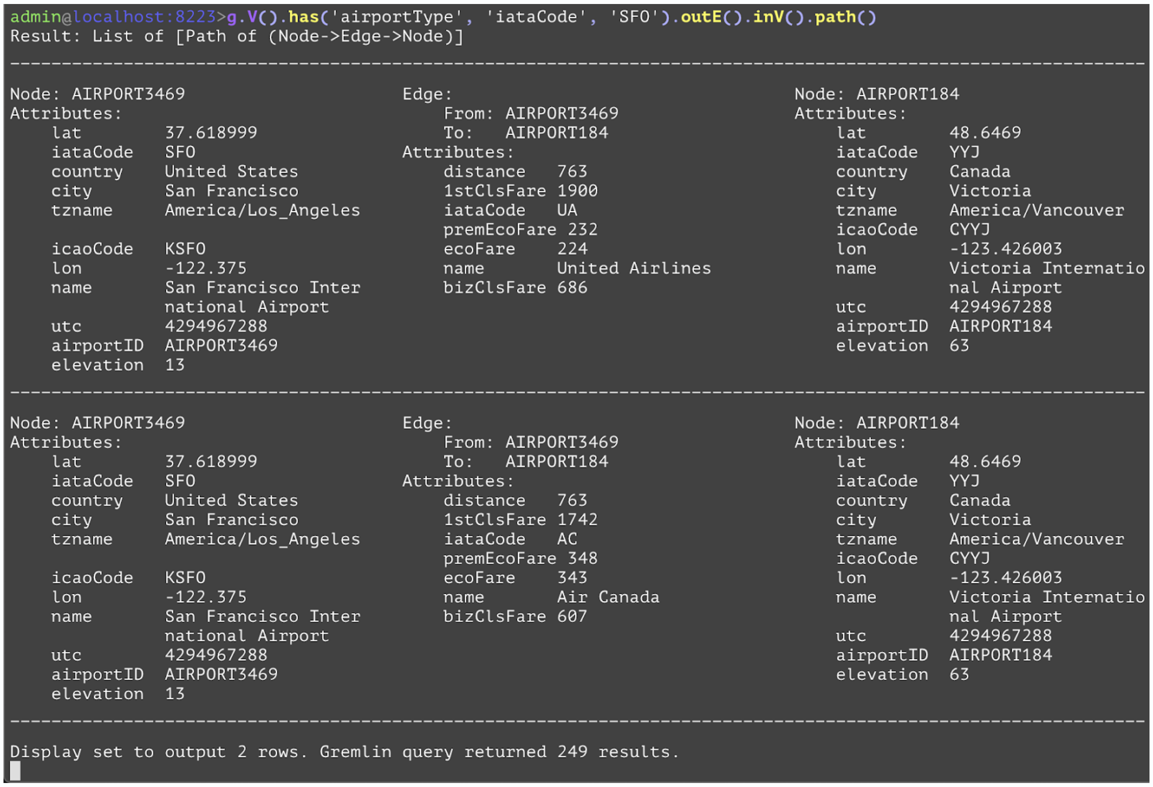
Traverses to all outbound edges from the current traversal. For a given node, this is equivalent to traversing to all of the edges that have the current node as a "`from`" vertex.

The following example uses the "`outE`" step to include the outbound flight edges and the destinations of the flights outbound (departing) from SFO and their destination airports, grouped within a single path element. This allows the user to acquire useful information from the edges, such as the distance of the flight or the fare's cost, while also getting both of the departing and arriving destinations.

Args	Name	Type	Description
	typenames	string[]	Optionally the edge type name(s) (aka edge label(s)) of the edges to traverse across. When specified, this will act as a joint outE().hasLabel(<typenames>)

GQL

```
gremlin://g.V().has('airportType', 'iataCode', 'SFO').outE().inV().path();
```



```
admin@localhost:8223>g.V().has('airportType', 'iataCode', 'SFO').outE().inV().path()
Result: List of [Path of (Node->Edge->Node)]
--------------------------------------------------------------------------------------------------------------

Node: AIRPORT3469                     Edge:                                 Node: AIRPORT184
Attributes:                               From: AIRPORT3469                 Attributes:
    lat        37.618999                  To:   AIRPORT184                      lat        48.6469
    iataCode   SFO                    Attributes:                               iataCode   YYJ
    country    United States              distance   763                        country    Canada
    city       San Francisco              1stClsFare 1900                       city       Victoria
    tzname     America/Los_Angeles        iataCode   UA                         tzname     America/Vancouver
                                          premEcoFare 232                       icaoCode   CYYJ
    icaoCode   KSFO                       ecoFare    224                        lon        -123.426003
    lon        -122.375                   name       United Airlines            name       Victoria Internatio
    name       San Francisco Inter        bizClsFare 686                                   nal Airport
               national Airport                                                 utc        4294967288
    utc        4294967288                                                       airportID  AIRPORT184
    airportID  AIRPORT3469                                                      elevation  63
    elevation  13
--------------------------------------------------------------------------------------------------------------

Node: AIRPORT3469                     Edge:                                 Node: AIRPORT184
Attributes:                               From: AIRPORT3469                 Attributes:
    lat        37.618999                  To:   AIRPORT184                      lat        48.6469
    iataCode   SFO                    Attributes:                               iataCode   YYJ
    country    United States              distance   763                        country    Canada
    city       San Francisco              1stClsFare 1742                       city       Victoria
    tzname     America/Los_Angeles        iataCode   AC                         tzname     America/Vancouver
                                          premEcoFare 348                       icaoCode   CYYJ
    icaoCode   KSFO                       ecoFare    343                        lon        -123.426003
    lon        -122.375                   name       Air Canada                 name       Victoria Internatio
    name       San Francisco Inter        bizClsFare 607                                   nal Airport
               national Airport                                                 utc        4294967288
    utc        4294967288                                                       airportID  AIRPORT184
    airportID  AIRPORT3469                                                      elevation  63
    elevation  13
--------------------------------------------------------------------------------------------------------------

Display set to output 2 rows. Gremlin query returned 249 results.
```

SQL

```
SELECT * FROM airportType AS src INNER JOIN routeType AS hop ON hop.srcAirportId=src.airportId INNER
JOIN airportType AS dest ON hop.destAirportId=dest.airportId WHERE src.iataCode='SFO';
```

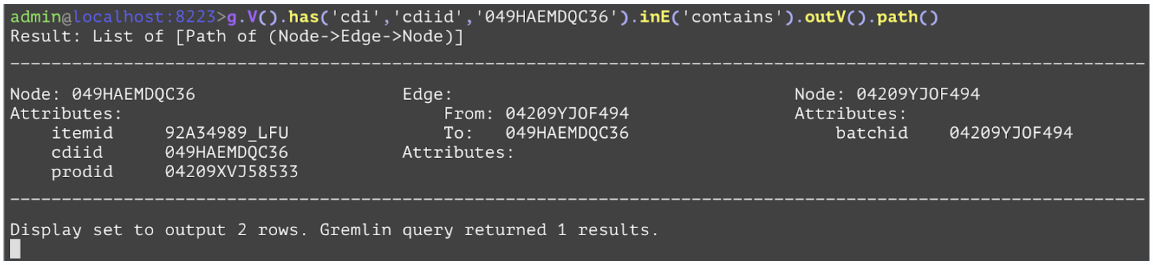
outV

Traverses to all outbound vertices from the current traversal. For a given edge, this is equivalent to traversing to its `"from"` node.

In the following example the `outV()` step is used to get the vertex that the `"contains"` edge is coming from. This gets all of the batches which contain the part with `"cdiid"` `"049HAEMDQC36"`.

GQL

```
gremlin://g.V().has('cdi','cdiid','049HAEMDQC36').inE('contains').outV().path();
```



```
admin@localhost:8223>g.V().has('cdi','cdiid','049HAEMDQC36').inE('contains').outV().path()
Result: List of [Path of (Node->Edge->Node)]
--------------------------------------------------------------------------------------------------------------

Node: 049HAEMDQC36                    Edge:                                 Node: 04209YJOF494
Attributes:                               From: 04209YJOF494                Attributes:
    itemid     92A34989_LFU               To:   049HAEMDQC36                    batchid    04209YJOF494
    cdiid      049HAEMDQC36           Attributes:
    prodid     04209XVJ58533

--------------------------------------------------------------------------------------------------------------

Display set to output 2 rows. Gremlin query returned 1 results.
█
```

SQL

```
SELECT * FROM cdi AS base INNER JOIN contains AS cont ON cont.destCdiid=base.cdiid INNER JOIN cdibatch
AS batch ON cont.srcBatchid=batch.batchid WHERE base.cdiid='049HAEMDQC36';
```

in

Traverses to all nodes from the current traversal using all inbound edges. For a given node, this is equivalent to traversing to all of the inbound edges' `"from"` nodes that have the current node as a `"to"` vertex.

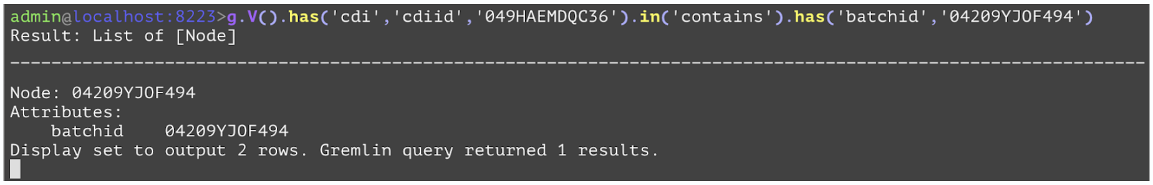
In the following example the `in()` is getting all of the batches which contain the part with `"cdiid"` of value `"049HAEMDQC36"`.

The SQL equivalent becomes verbose as the query does more traversals. It increases the number of joins.

Args	Name	Type	Description
	typenames	string[]	Optionally the edge type name(s) (aka edge label(s)) of the edges to traverse across. When specified, this will act as a joint inE().hasLabel(<typenames>).outV()

GQL

```
gremlin://g.V().has('cdi','cdiid','049HAEMDQC36').in('contains').has('batchid','04209YJOF494');
```



```
admin@localhost:8223>g.V().has('cdi','cdiid','049HAEMDQC36').in('contains').has('batchid','04209YJOF494')
Result: List of [Node]
--------------------------------------------------------------------------------------------------------------

Node: 04209YJOF494
Attributes:
    batchid    04209YJOF494
Display set to output 2 rows. Gremlin query returned 1 results.
█
```

SQL

```
SELECT batch.* FROM cdi AS base INNER JOIN contains AS cont ON cont.destCdiid=base.cdiid INNER JOIN
cdibatch AS batch ON cont.srcBatchid=batch.batchid WHERE base.cdiid='049HAEMDQC36' AND
batch.batchid='04209YJOF494';
```

inE

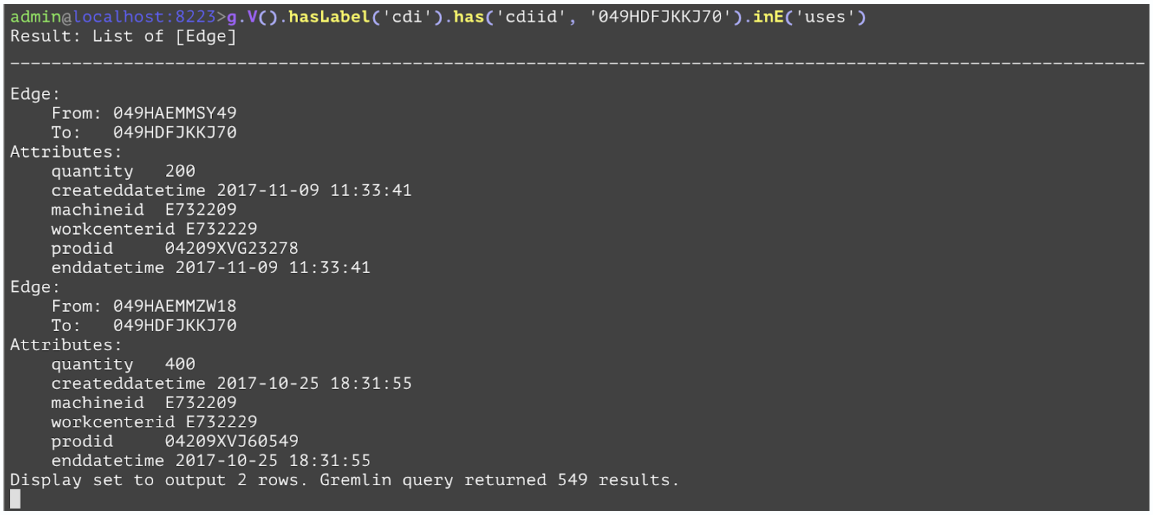
Traverses to all inbound edges from the current traversal. For a given node, this is equivalent to traversing to all of the edges that have the current node as a "to" vertex.

For the following example, the "inE" step is used to get the edge connection for the inbound edges of containers that use the container with "cdiid" of "049HDFJKKJ70".

Args	Name	Type	Description
	typenames	string[]	Optionally the edge type name(s) (aka edge label(s)) of the edges to traverse across. When specified, this will act as a joint inE().hasLabel(<typenames>)

GQL

```
gremlin://g.V().hasLabel('cdi').has('cdiid', '049HDFJKKJ70').inE('uses');
```



```
admin@localhost:8223>g.V().hasLabel('cdi').has('cdiid', '049HDFJKKJ70').inE('uses')
Result: List of [Edge]
----------------------------------------------------------------------------------------------------------------
Edge:
    From: 049HAEMMSY49
    To:   049HDFJKKJ70
Attributes:
    quantity   200
    createddatetime 2017-11-09 11:33:41
    machineid  E732209
    workcenterid E732229
    prodid     04209XVG23278
    enddatetime 2017-11-09 11:33:41
Edge:
    From: 049HAEMMZW18
    To:   049HDFJKKJ70
Attributes:
    quantity   400
    createddatetime 2017-10-25 18:31:55
    machineid  E732209
    workcenterid E732229
    prodid     04209XVJ60549
    enddatetime 2017-10-25 18:31:55
Display set to output 2 rows. Gremlin query returned 549 results.
```

SQL

```
SELECT firstUses.* FROM cdi AS base INNER JOIN uses AS firstUses ON firstUses.srcCdiid = base.cdiid
WHERE base.cdiid='049HDFJKKJ70';
```

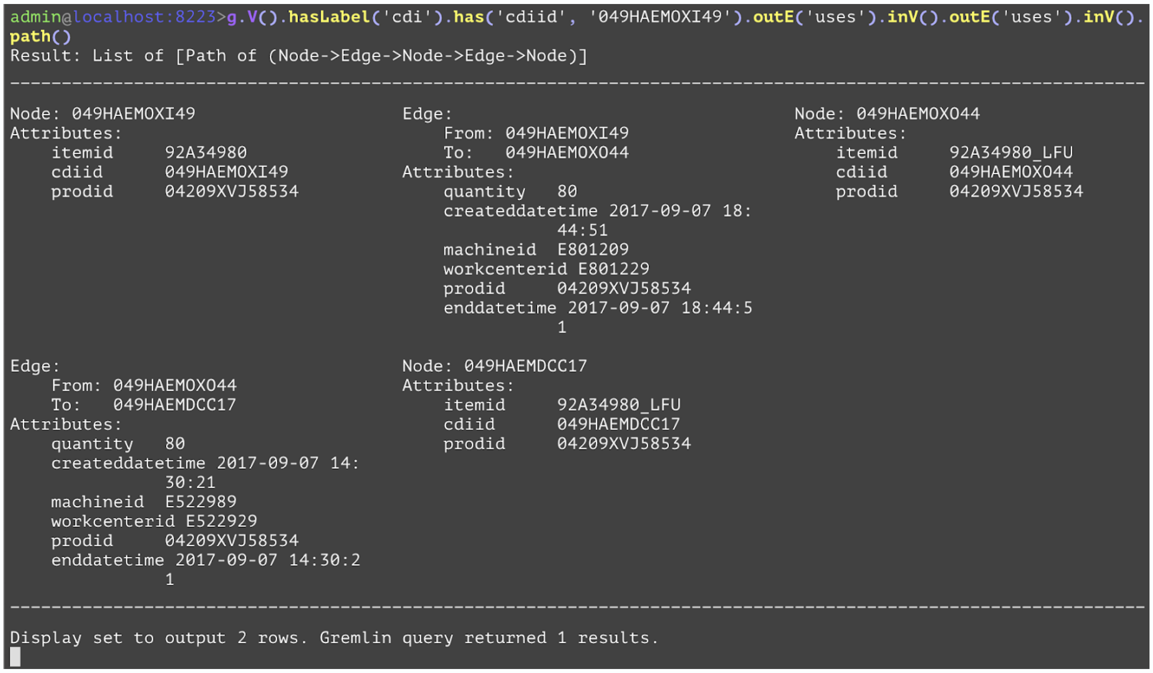
inV

Traverses to all inbound vertices from the current traversal. For a given edge, this is equivalent to traversing to its "`to`" node.

For the following example, the "`inV`" is used to get the containers which contain the container at the point in the traversal before the `outE('uses')`. The "`outE`" steps and "`inV`" are used in conjunction here to form a path with the included edges.

GQL

```
gremlin://g.V().hasLabel('cdi').has('cdiid',
'049HAEMOXI49').outE('uses').inV().outE('uses').inV().path();
```



```
admin@localhost:8223>g.V().hasLabel('cdi').has('cdiid', '049HAEMOXI49').outE('uses').inV().outE('uses').inV().
path()
Result: List of [Path of (Node->Edge->Node->Edge->Node)]
--------------------------------------------------------------------------------------------------------------

Node: 049HAEMOXI49                    Edge:                                 Node: 049HAEMOXO44
Attributes:                               From: 049HAEMOXI49                Attributes:
    itemid     92A34980                   To:   049HAEMOXO44                    itemid     92A34980_LFU
    cdiid      049HAEMOXI49           Attributes:                               cdiid      049HAEMOXO44
    prodid     04209XVJ58534              quantity   80                         prodid     04209XVJ58534
                                          createddatetime 2017-09-07 18:
                                                     44:51
                                          machineid  E801209
                                          workcenterid E801229
                                          prodid     04209XVJ58534
                                          enddatetime 2017-09-07 18:44:5
                                                     1

Edge:                                 Node: 049HAEMDCC17
    From: 049HAEMOXO44                Attributes:
    To:   049HAEMDCC17                    itemid     92A34980_LFU
Attributes:                               cdiid      049HAEMDCC17
    quantity   80                         prodid     04209XVJ58534
    createddatetime 2017-09-07 14:
               30:21
    machineid  E522989
    workcenterid E522929
    prodid     04209XVJ58534
    enddatetime 2017-09-07 14:30:2
               1

--------------------------------------------------------------------------------------------------------------

Display set to output 2 rows. Gremlin query returned 1 results.
█
```

SQL

```
SELECT * FROM cdi AS base INNER JOIN uses AS firstUses ON firstUses.srcCdiid=base.cdiid INNER JOIN cdi
AS inter ON firstUses.destCdiid=inter.cdiid INNER JOIN uses AS secondUses ON
secondUses.srcCdiid=inter.cdiid INNER JOIN cdi AS dest ON secondUses.destCdiid=dest.cdiid WHERE
src.cdiid='049HAEMOXI49';
```

both

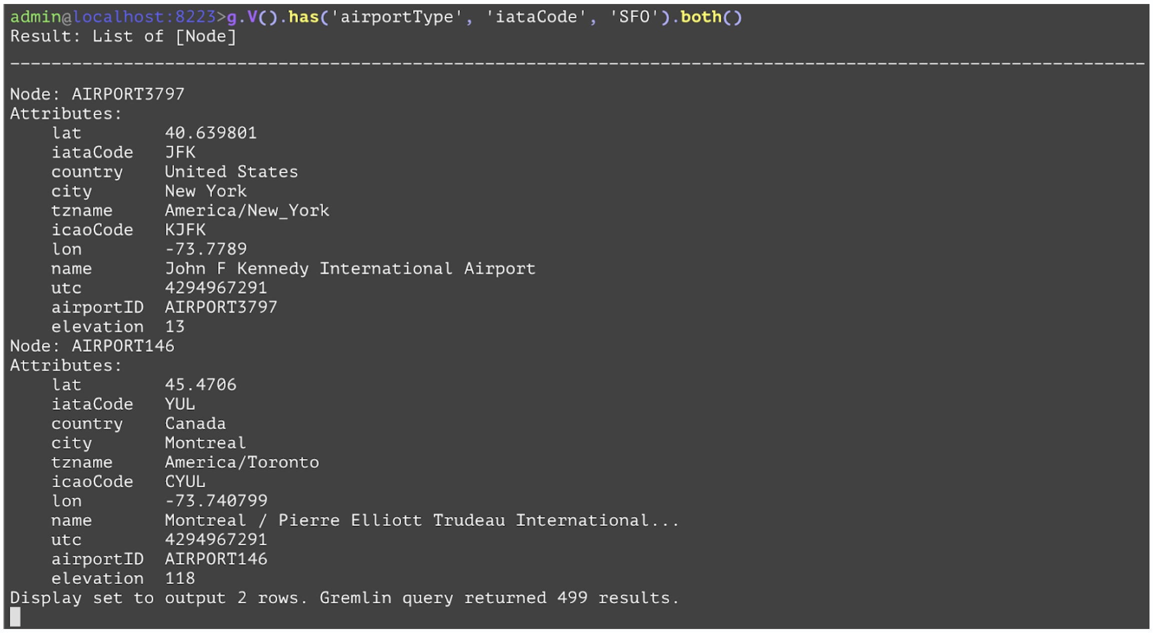
<table>
<tr><td colspan="4">

Traverses to all nodes from the current traversal using all edges. For a given node, this is equivalent to traversing to all of the edges' (both "from" and "to") nodes that have the current node as either a "from" or "to" vertex.

In the example below, the "both" step is getting all the other airports where SFO is either a departing or arriving airport.

</td></tr>
<tr><td rowspan="2">Args</td><td>Name</td><td>Type</td><td>Description</td></tr>
<tr><td>typename</td><td>string[]</td><td>Optionally the edge type name(s) (aka edge label(s)) of the edges to traverse across. When specified, this will act as a joint bothE().hasLabel(<typenames>).otherV()</td></tr>
<tr><td>GQL</td><td colspan="3">

gremlin://g.V().has('airportType', 'iataCode', 'SFO').both();

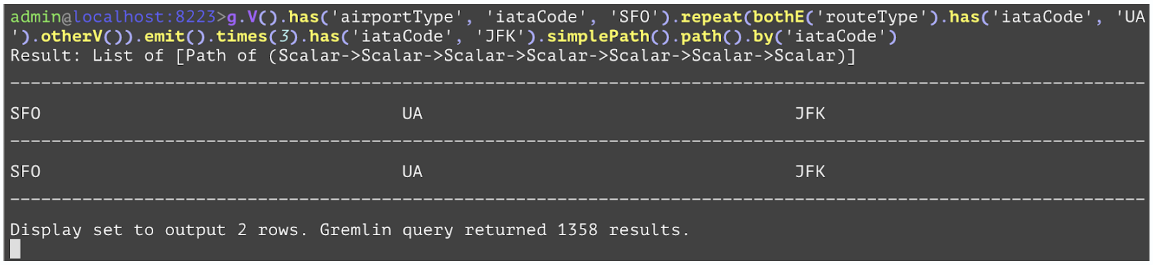


```
admin@localhost:8223>g.V().has('airportType', 'iataCode', 'SFO').both()
Result: List of [Node]
----------------------------------------------------------------------------------------------------------------

Node: AIRPORT3797
Attributes:
    lat         40.639801
    iataCode    JFK
    country     United States
    city        New York
    tzname      America/New_York
    icaoCode    KJFK
    lon         -73.7789
    name        John F Kennedy International Airport
    utc         4294967291
    airportID   AIRPORT3797
    elevation   13
Node: AIRPORT146
Attributes:
    lat         45.4706
    iataCode    YUL
    country     Canada
    city        Montreal
    tzname      America/Toronto
    icaoCode    CYUL
    lon         -73.740799
    name        Montreal / Pierre Elliott Trudeau International...
    utc         4294967291
    airportID   AIRPORT146
    elevation   118
Display set to output 2 rows. Gremlin query returned 499 results.
```

</td></tr>
<tr><td>SQL</td><td colspan="3">SELECT dest.* FROM airportType AS src INNER JOIN routeType AS hop ON hop.srcAirportId=src.airportId OR hop.destAirportId=src.airportId INNER JOIN airportType AS dest ON hop.srcAirportId=dest.airportId OR hop.destAirportId=dest.airportId WHERE src.iataCode='SFO';</td></tr>
</table>

bothE

<table>
<tr><td colspan="4">Traverses to all edges from the current traversal. For a given node, this is equivalent to traversing to all of the edges that have the current node as a vertex.

In the following example, the "bothE" step is used in conjunction with a "bothV" step to create a path with the edges included.</td></tr>
<tr><td rowspan="2">Args</td><td>Name</td><td>Type</td><td>Description</td></tr>
<tr><td>typename</td><td>string[]</td><td>Optionally the edge type name(s) (aka edge label(s)) of the edges to traverse across. When specified, this will act as a joint bothE().hasLabel(<typenames&gt;)</td></tr>
<tr><td>GQL</td><td colspan="3">gremlin://g.V().has('airportType', 'iataCode', 'SFO').repeat(bothE('routeType').has('iataCode', 'UA').otherV()).emit().times(3).has('iataCode', 'JFK').simplePath().path().by('iataCode');

admin@localhost:8223>g.V().has('airportType', 'iataCode', 'SFO').repeat(bothE('routeType').has('iataCode', 'UA
').otherV()).emit().times(3).has('iataCode', 'JFK').simplePath().path().by('iataCode')
Result: List of [Path of (Scalar->Scalar->Scalar->Scalar->Scalar->Scalar->Scalar)]

SFO   UA   JFK

SFO   UA   JFK

Display set to output 2 rows. Gremlin query returned 1358 results.</td></tr>
<tr><td>SQL</td><td colspan="3">No known SQL equivalent without using some form of a stored procedure.</td></tr>
</table>

bothV

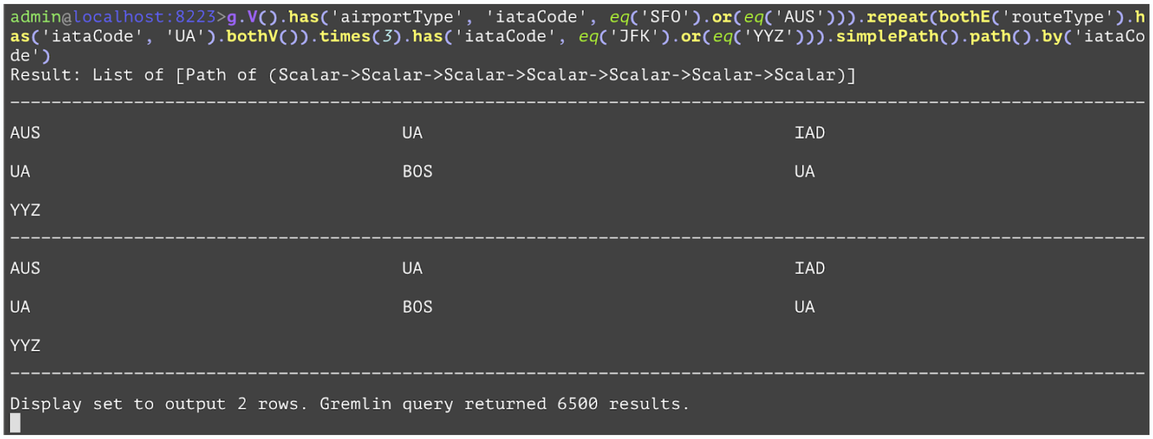
Traverses to all vertices from the current traversal. For a given edge, this is equivalent to traversing to both of its vertices.

The following example uses the "bothV" step to get both the arrival and departure airport of the current flight.

This example demonstrates the power of GQL in simple easy to understand functional language, and compare and contrast the verbose and complex SQL declarative counterpart. Besides the intuitive way of expression, the GQL query will be orders of magnitude faster in execution to its SQL parts.

GQL

```
gremlin://g.V().has('airportType', 'iataCode',
eq('SFO').or(eq('AUS'))).repeat(bothE('routeType').has('iataCode',
'UA').bothV()).times(3).has('iataCode', eq('JFK').or(eq('YYZ'))).simplePath().path().by('iataCode');
```



```
admin@localhost:8223>g.V().has('airportType', 'iataCode', eq('SFO').or(eq('AUS'))).repeat(bothE('routeType').h
as('iataCode', 'UA').bothV()).times(3).has('iataCode', eq('JFK').or(eq('YYZ'))).simplePath().path().by('iataCo
de')
Result: List of [Path of (Scalar->Scalar->Scalar->Scalar->Scalar->Scalar->Scalar)]
----------------------------------------------------------------------------------------------------------------
AUS                                     UA                                      IAD

UA                                      BOS                                     UA

YYZ
----------------------------------------------------------------------------------------------------------------
AUS                                     UA                                      IAD

UA                                      BOS                                     UA

YYZ
----------------------------------------------------------------------------------------------------------------
Display set to output 2 rows. Gremlin query returned 6500 results.
```

SQL

```
SELECT src.iataCode, firstHop.iataCode, inter1.iataCode, secondeHop.iataCode, inter2.iataCode,
thirdHop.iataCode, dest.iataCode FROM airportType AS src INNER JOIN routeType AS firstHop ON
firstHop.srcAirportId=src.airportId OR firstHop.destAirportId=src.airportId INNER JOIN airportType AS
inter1 ON firstHop.srcAirportId=inter1.airportId OR firstHop.destAirportId=inter1.airportId INNER JOIN
routeType AS secondHop ON secondHop.srcAirportId=inter1.airportId OR
secondHop.destAirportId=inter1.airportId INNER JOIN airportType AS inter2 ON
secondHop.srcAirportId=inter2.airportId OR secondHop.destAirportId=inter2.airportId INNER JOIN
routeType AS thirdHop ON thirdHop.srcAirportId=inter2.airportId OR
thirdHop.destAirportId=inter2.airportId INNER JOIN airportType AS dest ON
thirdHop.srcAirportId=dest.airportId OR thirdHop.destAirportId=dest.airportId WHERE
(src.iataCode='SFO' OR src.iataCode='AUS') AND firstHop.iataCode='UA' AND secondHop.iataCode='UA' AND
thirdHop.iataCode='UA' AND (dest.iataCode='JFK' OR dest.iataCode='YYZ') AND
src.airportId<>inter1.airportId AND src.airportId<>inter2.airportId AND src.airportId<>dest.airportId
AND inter1.airportId<>inter2.airportId AND inter1.airportId<>dest.airportId AND
inter2.airportId<>dest.airportId;
```

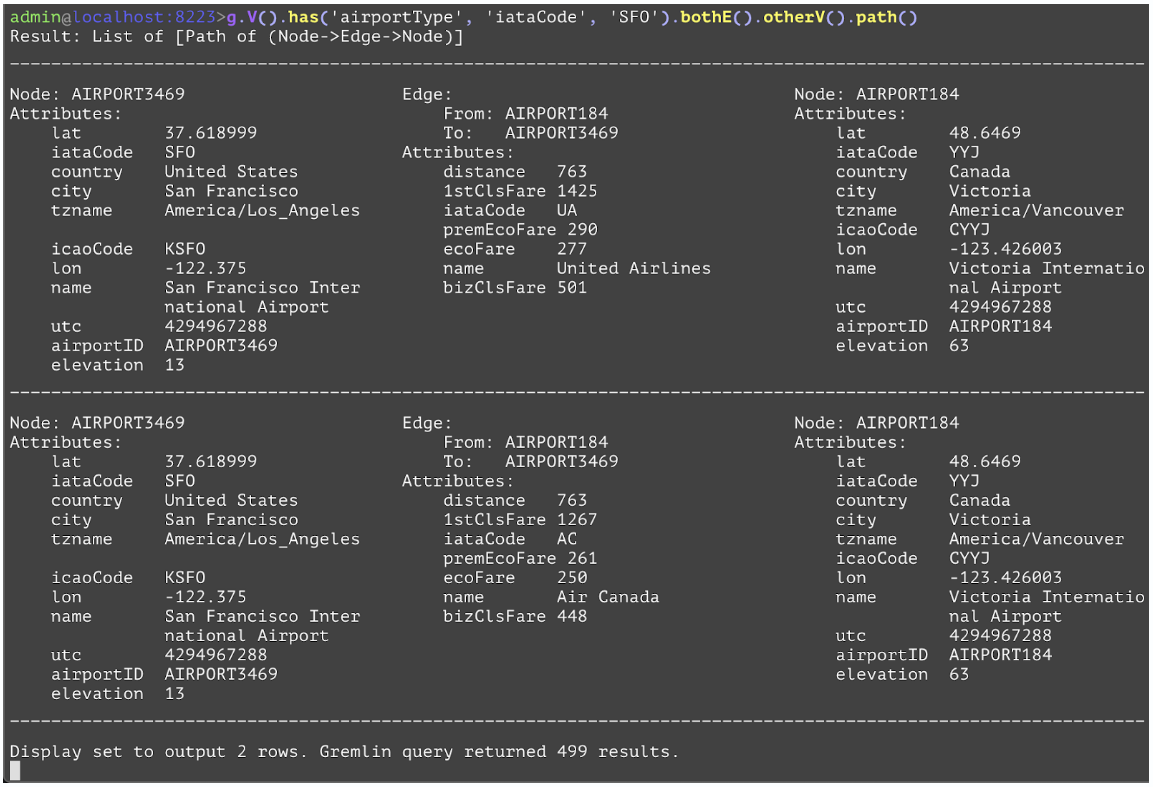
otherV

Traverses to the other vertex of this edge. For a given edge, this is equivalent to traversing to either vertex that has not been visited most recently by the traversal. It is extremely useful when used with `"bothE"` steps, as a `"bothV"` would also return the original vertex, while the `"otherV"` step will not.

In the following example, the `"otherV"` is used to prevent also including the SFO airport. The `"UNION"` of two almost similar, but slightly different SQL queries is necessary because `"otherV"` is a union of out-bound edge's in-bound vertices or in-bound edge's out-bound vertices.

GQL

```
gremlin://g.V().has('airportType', 'iataCode', 'SFO').bothE().otherV().path();
```



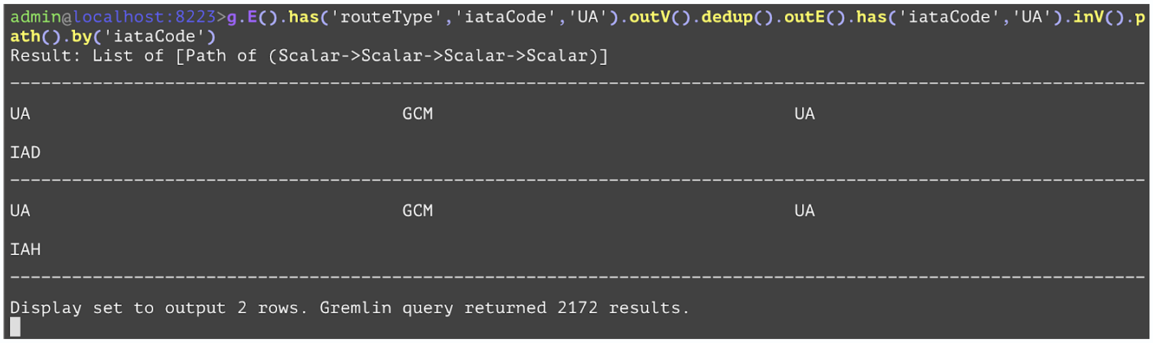
```
admin@localhost:8223>g.V().has('airportType', 'iataCode', 'SFO').bothE().otherV().path()
Result: List of [Path of (Node->Edge->Node)]
--------------------------------------------------------------------------------------------------------------
Node: AIRPORT3469                     Edge:                                 Node: AIRPORT184
Attributes:                               From: AIRPORT184                  Attributes:
    lat         37.618999                 To:   AIRPORT3469                     lat         48.6469
    iataCode    SFO                   Attributes:                               iataCode    YYJ
    country     United States             distance    763                       country     Canada
    city        San Francisco             1stClsFare 1425                       city        Victoria
    tzname      America/Los_Angeles       iataCode    UA                        tzname      America/Vancouver
                                          premEcoFare 290                       icaoCode    CYYJ
    icaoCode    KSFO                      ecoFare     277                       lon         -123.426003
    lon         -122.375                  name        United Airlines           name        Victoria Internatio
    name        San Francisco Inter       bizClsFare 501                                    nal Airport
                national Airport                                                utc         4294967288
    utc         4294967288                                                      airportID   AIRPORT184
    airportID   AIRPORT3469                                                     elevation   63
    elevation   13
--------------------------------------------------------------------------------------------------------------
Node: AIRPORT3469                     Edge:                                 Node: AIRPORT184
Attributes:                               From: AIRPORT184                  Attributes:
    lat         37.618999                 To:   AIRPORT3469                     lat         48.6469
    iataCode    SFO                   Attributes:                               iataCode    YYJ
    country     United States             distance    763                       country     Canada
    city        San Francisco             1stClsFare 1267                       city        Victoria
    tzname      America/Los_Angeles       iataCode    AC                        tzname      America/Vancouver
                                          premEcoFare 261                       icaoCode    CYYJ
    icaoCode    KSFO                      ecoFare     250                       lon         -123.426003
    lon         -122.375                  name        Air Canada                name        Victoria Internatio
    name        San Francisco Inter       bizClsFare 448                                    nal Airport
                national Airport                                                utc         4294967288
    utc         4294967288                                                      airportID   AIRPORT184
    airportID   AIRPORT3469                                                     elevation   63
    elevation   13
--------------------------------------------------------------------------------------------------------------
Display set to output 2 rows. Gremlin query returned 499 results.
```

SQL

```
SELECT * FROM airportType AS src INNER JOIN routeType AS hop ON hop.srcAirportId=src.airportId INNER
JOIN airportType AS dest ON hop.destAirportId=dest.airportId WHERE src.iataCode='SFO' UNION SELECT *
FROM airportType AS src INNER JOIN routeType AS hop ON hop.destAirportId=src.airportId INNER JOIN
airportType AS dest ON hop.srcAirportId=dest.airportId WHERE src.iataCode='SFO';
```

path

<table>
<tr><td colspan="2">Creates a tuple of the path over each entity in the traversal. Subsequent "by" steps specify what to extract from each entity as in the tuple. The "by" steps are applied in a loop, with the first element in the path converted to a value by the first "by", the second element converted to a value by the second, etc. until the "by" steps are used up. Let's say there are N "by" steps and M elements in the path with M > N, then the N+1th element is converted to a value by the first "by" step, etc. until all M elements of the path are converted. In addition, the "by" step need not contain an attribute name argument. In this case, the entity itself is included at that stage of the path.

In the example below, we get from all of the routes the ones with "iataCode" "UA", which is the code for United Airlines, their departing airports, and then gets the routes where those are the arrival airports that are also serviced by United Airlines, and finally get those second route's departing airports. Then, the "by" step reduces each of the entities in this path into its "iataCode" attribute.</td></tr>
<tr><td>GQL</td><td><pre>gremlin://g.E().has('routeType','iataCode','UA').outV().dedup().outE().has('iataCode','UA').inV().path
().by('iataCode');</pre>

<pre>admin@localhost:8223>g.E().has('routeType','iataCode','UA').outV().dedup().outE().has('iataCode','UA').inV().p
ath().by('iataCode')
Result: List of [Path of (Scalar->Scalar->Scalar->Scalar)]

UA   GCM   UA

IAD

UA   GCM   UA

IAH

Display set to output 2 rows. Gremlin query returned 2172 results.</pre></td></tr>
<tr><td>SQL</td><td><pre>SELECT firstHop.iataCode, firstAirport.iataCode, secondHop.iataCode, secondAirport.iataCode FROM
(SELECT DISTINCT(srcAirportId), iataCode FROM routeType) AS firstHop INNER JOIN airportType AS
firstAirport ON firstHop.srcAirportId=firstAirport.airportId INNER JOIN routeType AS secondHop ON
secondHop.destAirportId=firstAirport.airportId INNER JOIN airportType AS secondAirport ON
secondHop.srcAirportId=secondAirport.airportId WHERE firstHop.iataCode='UA' AND
secondHop.iataCode='UA';</pre></td></tr>
</table>

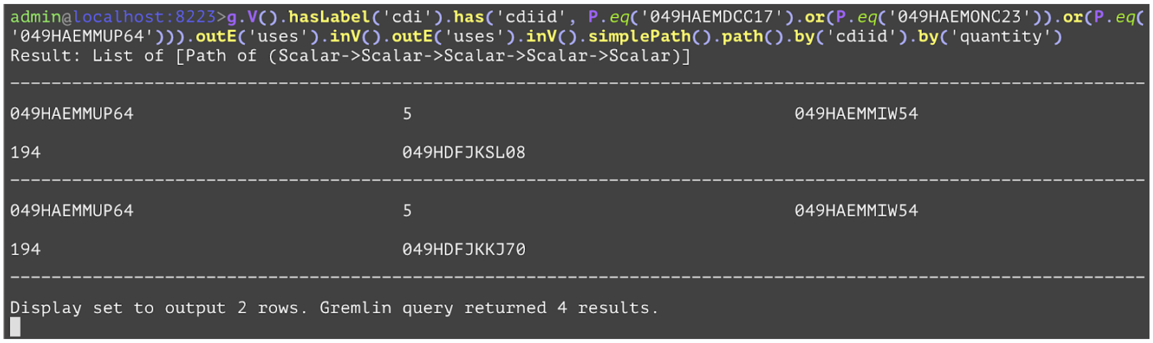
simplePath

Specifies to disallow cycles during a traversal. This can be used to improve performance of the query by preventing unwanted cycles within the results.

In the following example we want to get all of the contents of the containers and what those containers contain, and what those containers contain, the "`simplePath`" is used to prevent a container from containing itself, which it should not be able to do.

GQL

```
gremlin://g.V().hasLabel('cdi').has('cdiid',
P.eq('049HAEMDCC17').or(P.eq('049HAEMONC23')).or(P.eq('049HAEMMUP64'))).outE('uses').inV().outE('uses'
).inV().simplePath().path().by('cdiid').by('quantity');
```



```
admin@localhost:8223>g.V().hasLabel('cdi').has('cdiid', P.eq('049HAEMDCC17').or(P.eq('049HAEMONC23')).or(P.eq(
'049HAEMMUP64'))).outE('uses').inV().outE('uses').inV().simplePath().path().by('cdiid').by('quantity')
Result: List of [Path of (Scalar->Scalar->Scalar->Scalar->Scalar)]
---------------------------------------------------------------------------------------------------------------
049HAEMMUP64                          5                                     049HAEMMIW54

194                                   049HDFJKSL08
---------------------------------------------------------------------------------------------------------------
049HAEMMUP64                          5                                     049HAEMMIW54

194                                   049HDFJKKJ70
---------------------------------------------------------------------------------------------------------------
Display set to output 2 rows. Gremlin query returned 4 results.
```

SQL

```
SELECT outerMost.cdiid, firstUses.quantity, middle.cdiid, secondUses.quantity, innerMost.cdiid FROM
cdi AS outerMost INNER JOIN uses AS firstUses ON firstUses.srcCdiid=outerMost.cdiid INNER JOIN cdi AS
middle ON firstUses.destCdiid=middle.cdiid INNER JOIN uses AS secondUses ON
secondUses.srcCdiid=middle.cdiid INNER JOIN cdi AS innerMost ON secondUses.destCdiid=innerMost.cdiid
WHERE (outerMost.cdiid='049HAEMDCC17' OR outerMost.cdiid='049HAEMONC23' OR
outerMost.cdiid='049HAEMMUP64') AND (outerMost.cdiid<>middle.cdiid) AND
(outerMost.cdiid<>innerMost.cdiid) AND (middle.cdiid<>innerMost.cdiid);
```

Flow Control

emit

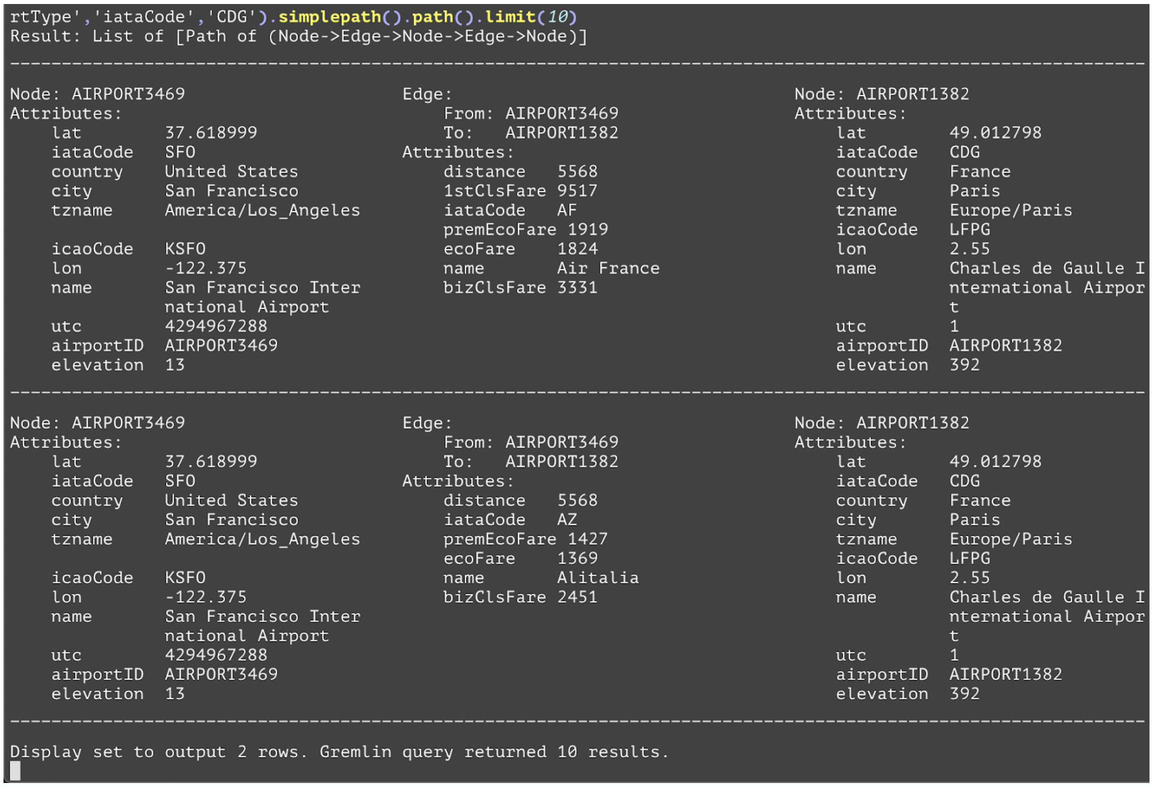
Acts as a step modulator for the repeat step. This step modulator will split the traversal at the end of each loop, one will continue to repeat (if it has not exceeded a `"times"` step), and the other will continue on to the next portion of the traversal.

In the following example, each traversal in the `"repeat"` step is emitted past the `times(2)` step on the first iteration of the loop to the `has('airportType','iataCode','CDG')` step, even though the looping portion (`outE().inV()`) has not yet looped twice.

Args	Name	Type	Description
	condition	expression	The condition to emit (pass on to next step).

GQL

```
gremlin://g.V().has('airportType','iataCode','SFO').repeat(outE().inV()).emit().times(2).has('airportType','iataCode','CDG').simplepath().path().limit(10);
```



```
rtType','iataCode','CDG').simplepath().path().limit(10)
Result: List of [Path of (Node->Edge->Node->Edge->Node)]
---------------------------------------------------------------------------------------------------------------

Node: AIRPORT3469                     Edge:                                 Node: AIRPORT1382
Attributes:                               From: AIRPORT3469                 Attributes:
    lat        37.618999                  To:   AIRPORT1382                     lat        49.012798
    iataCode   SFO                    Attributes:                               iataCode   CDG
    country    United States              distance   5568                       country    France
    city       San Francisco              1stClsFare 9517                       city       Paris
    tzname     America/Los_Angeles        iataCode   AF                         tzname     Europe/Paris
                                          premEcoFare 1919                      icaoCode   LFPG
    icaoCode   KSFO                       ecoFare    1824                       lon        2.55
    lon        -122.375                   name       Air France                 name       Charles de Gaulle I
    name       San Francisco Inter        bizClsFare 3331                                  nternational Airpor
               national Airport                                                            t
    utc        4294967288                                                       utc        1
    airportID  AIRPORT3469                                                      airportID  AIRPORT1382
    elevation  13                                                               elevation  392
---------------------------------------------------------------------------------------------------------------

Node: AIRPORT3469                     Edge:                                 Node: AIRPORT1382
Attributes:                               From: AIRPORT3469                 Attributes:
    lat        37.618999                  To:   AIRPORT1382                     lat        49.012798
    iataCode   SFO                    Attributes:                               iataCode   CDG
    country    United States              distance   5568                       country    France
    city       San Francisco              iataCode   AZ                         city       Paris
    tzname     America/Los_Angeles        premEcoFare 1427                      tzname     Europe/Paris
                                          ecoFare    1369                       icaoCode   LFPG
    icaoCode   KSFO                       name       Alitalia                   lon        2.55
    lon        -122.375                   bizClsFare 2451                       name       Charles de Gaulle I
    name       San Francisco Inter                                                         nternational Airpor
               national Airport                                                            t
    utc        4294967288                                                       utc        1
    airportID  AIRPORT3469                                                      airportID  AIRPORT1382
    elevation  13                                                               elevation  392
---------------------------------------------------------------------------------------------------------------

Display set to output 2 rows. Gremlin query returned 10 results.
```

SQL

No known SQL equivalent without using some form of a procedure.

by

A step modifier for specifying optional arguments to previous steps. The `"by"` steps can be applied to the `"group"`, `"groupCount"`, `"dedup"`, `"order"`, and `"path" steps.`

In the first example, the `"by"` step is used first (`by('country')`) to specify on what attribute to group the entities into, while the second `"by"` step (`by('iataCode')`) reduces each airport entity into its IATA code. There is no direct SQL equivalent due to the dictionary with values of lists that standard SQL does not support, although a similar one is shown below.

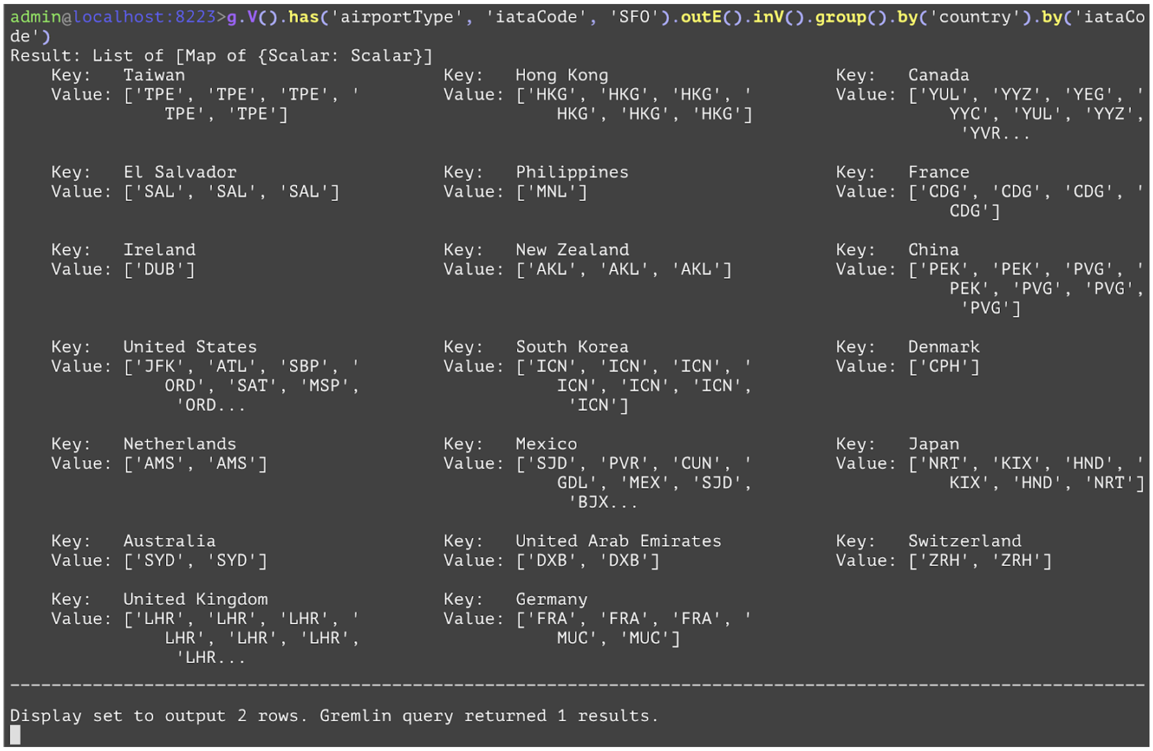
In the second example, the `"by"` step is used to reduce each element (airport or route) in a path to its IATA code. For a single iteration of the repeat step.

For the third example, the `"by"` step is used as a way to specify to the `"dedup"` step what attribute to deduplicate on. This query gets the iataCode of the airlines that have flights originating from the SFO airport.

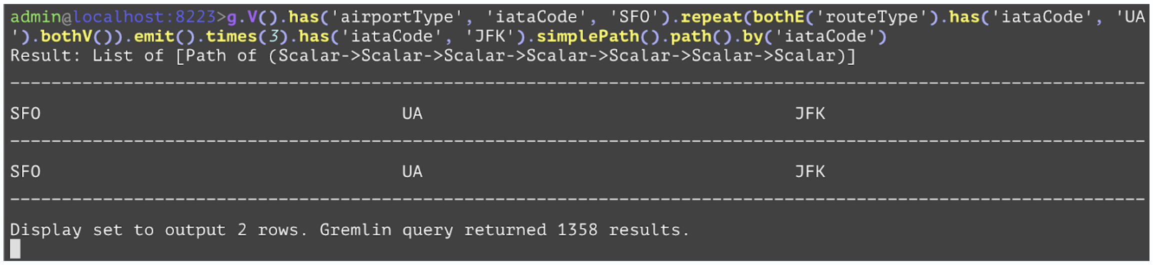
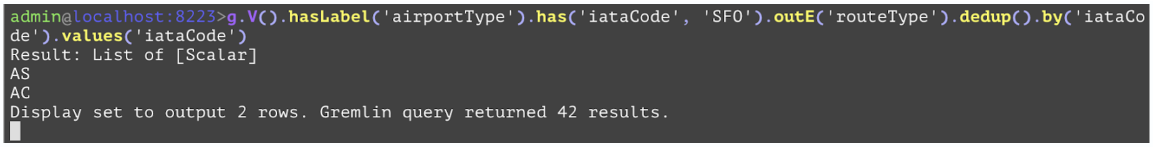
Args	Name	Type	Description
	step_modifier	string, expression, or sort order	Modifies the previous step. Can also be a <sort_order> which is one of "asc", "incr", "desc", or "decr".
	sort_order	sort order	Optional when following an order step. <sort_order> must be one of "asc", "incr", "desc", or "decr".

GQL

```
gremlin://g.V().has('airportType', 'iataCode',
'SFO').outE().inV().group().by('country').by('iataCode');
```



```
admin@localhost:8223>g.V().has('airportType', 'iataCode', 'SFO').outE().inV().group().by('country').by('iataCo
de')
Result: List of [Map of {Scalar: Scalar}]
    Key:   Taiwan                           Key:   Hong Kong                        Key:   Canada
    Value: ['TPE', 'TPE', 'TPE', '          Value: ['HKG', 'HKG', 'HKG', '          Value: ['YUL', 'YYZ', 'YEG', '
                TPE', 'TPE']                            HKG', 'HKG', 'HKG']                     YYC', 'YUL', 'YYZ',
                                                                                                 'YVR...

    Key:   El Salvador                      Key:   Philippines                      Key:   France
    Value: ['SAL', 'SAL', 'SAL']            Value: ['MNL']                          Value: ['CDG', 'CDG', 'CDG', '
                                                                                                CDG']

    Key:   Ireland                          Key:   New Zealand                      Key:   China
    Value: ['DUB']                          Value: ['AKL', 'AKL', 'AKL']            Value: ['PEK', 'PEK', 'PVG', '
                                                                                                PEK', 'PVG', 'PVG',
                                                                                                 'PVG']

    Key:   United States                    Key:   South Korea                      Key:   Denmark
    Value: ['JFK', 'ATL', 'SBP', '          Value: ['ICN', 'ICN', 'ICN', '          Value: ['CPH']
                ORD', 'SAT', 'MSP',                     ICN', 'ICN', 'ICN',
                 'ORD...                                 'ICN']

    Key:   Netherlands                      Key:   Mexico                           Key:   Japan
    Value: ['AMS', 'AMS']                   Value: ['SJD', 'PVR', 'CUN', '          Value: ['NRT', 'KIX', 'HND', '
                                                        GDL', 'MEX', 'SJD',                     KIX', 'HND', 'NRT']
                                                         'BJX...

    Key:   Australia                        Key:   United Arab Emirates             Key:   Switzerland
    Value: ['SYD', 'SYD']                   Value: ['DXB', 'DXB']                   Value: ['ZRH', 'ZRH']

    Key:   United Kingdom                   Key:   Germany
    Value: ['LHR', 'LHR', 'LHR', '          Value: ['FRA', 'FRA', 'FRA', '
                LHR', 'LHR', 'LHR',                     MUC', 'MUC']
                 'LHR...
--------------------------------------------------------------------------------------------------------------------

Display set to output 2 rows. Gremlin query returned 1 results.
```

	gremlin://g.V().has('airportType', 'iataCode', 'SFO').repeat(bothE('routeType').has('iataCode', 'UA').bothV()).emit().times(3).has('iataCode', 'JFK').simplePath().path().by('iataCode');  admin@localhost:8223>g.V().has('airportType', 'iataCode', 'SFO').repeat(bothE('routeType').has('iataCode', 'UA ').bothV()).emit().times(3).has('iataCode', 'JFK').simplePath().path().by('iataCode') Result: List of [Path of (Scalar->Scalar->Scalar->Scalar->Scalar->Scalar->Scalar)] -- SFO UA JFK -- SFO UA JFK -- Display set to output 2 rows. Gremlin query returned 1358 results.
	gremlin://g.V().hasLabel('airportType').has('iataCode', 'SFO').outE('routeType').dedup().by('iataCode').values('iataCode');  admin@localhost:8223>g.V().hasLabel('airportType').has('iataCode', 'SFO').outE('routeType').dedup().by('iataCo de').values('iataCode') Result: List of [Scalar] AS AC Display set to output 2 rows. Gremlin query returned 42 results.
SQL	SELECT destAirport.country, destAirport.iataCode FROM airportType AS srcAirport INNER JOIN routeType AS hop ON hop.fromAirportId=srcAirport.airportId INNER JOIN airportType AS destAirport ON hop.toAirportId=destAirport.airportId WHERE srcAirport.iataCode='SFO' GROUP BY destAirport.country;
	SELECT srcAirport.iataCode, route.iataCode, destAirport.iataCode FROM airportType AS srcAirport INNER JOIN routeType AS route ON route.srcAirportId=srcAirport.airportId INNER JOIN airportType AS destAirport ON route.destAirportId=destAirport.airportId WHERE srcAirport.iataCode='SFO' AND destAirport.iataCode='JFK' AND route.iataCode='UA';
	SELECT route.iataCode FROM airportType AS srcAirport INNER JOIN routeType AS route ON route.srcAirportId=srcAirport.airportID WHERE srcAirport.iataCode='SFO' GROUP BY route.iataCode;

times

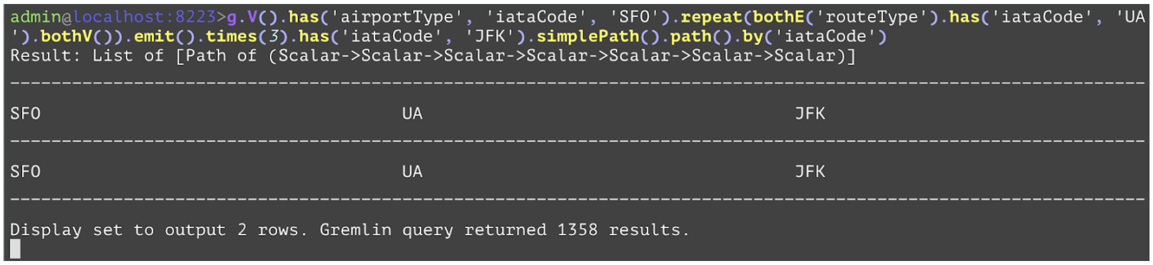
A step modifier for the "`repeat`" step that specifies the number of times the repeat is looped. The argument specifies the maximum number of times to loop within the "`repeat`" step.

The first example below gets all of the paths of flights (regardless of direction) between the SFO airport and the JFK airport with at most 3 flights and using only flights from the airline with iataCode UA (United Airlines).
In the second example, the query gets all paths (regardless of direction) made of flights between either of the SFO or AUS airports to either of the JFK or YYZ airports with at most 3 flights and using only flights from the airline with iataCode UA (United Airlines).

Args	Name	Type	Description
	num_times	integer	The number of times to loop.

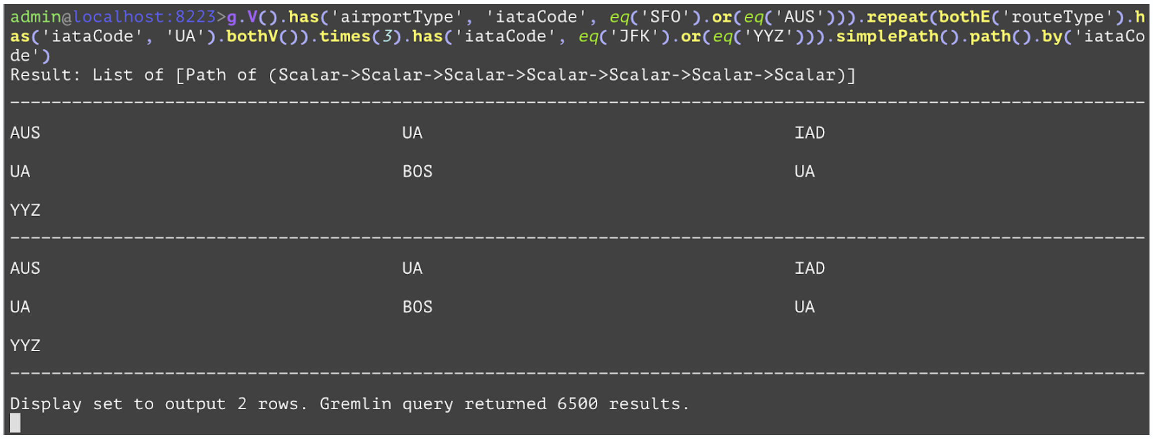
GQL

```
gremlin://g.V().has('airportType', 'iataCode', 'SFO').repeat(bothE('routeType').has('iataCode',
'UA').bothV()).emit().times(3).has('iataCode', 'JFK').simplePath().path().by('iataCode');
```



```
admin@localhost:8223>g.V().has('airportType', 'iataCode', 'SFO').repeat(bothE('routeType').has('iataCode', 'UA
').bothV()).emit().times(3).has('iataCode', 'JFK').simplePath().path().by('iataCode')
Result: List of [Path of (Scalar->Scalar->Scalar->Scalar->Scalar->Scalar->Scalar)]
-------------------------------------------------------------------------------------------------------------------
SFO                                     UA                                      JFK
-------------------------------------------------------------------------------------------------------------------
SFO                                     UA                                      JFK
-------------------------------------------------------------------------------------------------------------------
Display set to output 2 rows. Gremlin query returned 1358 results.
```

```
gremlin://g.V().has('airportType', 'iataCode',
eq('SFO').or(eq('AUS'))).repeat(bothE('routeType').has('iataCode',
'UA').bothV()).times(3).has('iataCode', eq('JFK').or(eq('YYZ'))).simplePath().path().by('iataCode');
```



```
admin@localhost:8223>g.V().has('airportType', 'iataCode', eq('SFO').or(eq('AUS'))).repeat(bothE('routeType').h
as('iataCode', 'UA').bothV()).times(3).has('iataCode', eq('JFK').or(eq('YYZ'))).simplePath().path().by('iataCo
de')
Result: List of [Path of (Scalar->Scalar->Scalar->Scalar->Scalar->Scalar->Scalar)]
-------------------------------------------------------------------------------------------------------------------
AUS                                     UA                                      IAD

UA                                      BOS                                     UA

YYZ
-------------------------------------------------------------------------------------------------------------------
AUS                                     UA                                      IAD

UA                                      BOS                                     UA

YYZ
-------------------------------------------------------------------------------------------------------------------
Display set to output 2 rows. Gremlin query returned 6500 results.
```

SQL

No known SQL equivalent without using some form of a procedure.

The second gremlin query is somewhat translated to a verbose SQL form using INNER joins, and execution times are order of magnitudes slower than its gremlin form of writing.

	The SQL below is equivalent to the gremlin query
	gremlin://g.V().has('airportType', 'iataCode', eq('SFO').or(eq('AUS'))).repeat(bothE('routeType').has('iataCode', 'UA').bothV()).times(3).has('iataCode', eq('JFK').or(eq('YYZ'))).simplePath().path().by('iataCode');
	
	SELECT src.iataCode, firstHop.iataCode, inter1.iataCode, secondeHop.iataCode, inter2.iataCode, thirdHop.iataCode, dest.iataCode FROM airportType AS src INNER JOIN routeType AS firstHop ON firstHop.srcAirportId=src.airportId OR firstHop.destAirportId=src.airportId INNER JOIN airportType AS inter1 ON firstHop.srcAirportId=inter1.airportId OR firstHop.destAirportId=inter1.airportId INNER JOIN routeType AS secondHop ON secondHop.srcAirportId=inter1.airportId OR secondHop.destAirportId=inter1.airportId INNER JOIN airportType AS inter2 ON secondHop.srcAirportId=inter2.airportId OR secondHop.destAirportId=inter2.airportId INNER JOIN routeType AS thirdHop ON thirdHop.srcAirportId=inter2.airportId OR thirdHop.destAirportId=inter2.airportId INNER JOIN airportType AS dest ON thirdHop.srcAirportId=dest.airportId OR thirdHop.destAirportId=dest.airportId WHERE (src.iataCode='SFO' OR src.iataCode='AUS') AND firstHop.iataCode='UA' AND secondHop.iataCode='UA' AND thirdHop.iataCode='UA' AND (dest.iataCode='JFK' OR dest.iataCode='YYZ') AND src.airportId<>inter1.airportId AND src.airportId<>inter2.airportId AND src.airportId<>dest.airportId AND inter1.airportId<>inter2.airportId AND inter1.airportId<>dest.airportId AND inter2.airportId<>dest.airportId;

repeat

Repeats the steps in the `<traversal_steps>` argument until it is either emitted or the number of times is reached. The `"repeat"` step can be modified with the `"times"` and `"emit"` steps. The `"times"` step specifies the maximum number of times the loop is repeated. The `"emit"` step splits the traversal at the end of each loop, one performs the loop, and the other exits the looping to continue with whatever is after the repeat steps. This is useful when multiple hops across a graph are desired but the exact number is not known.

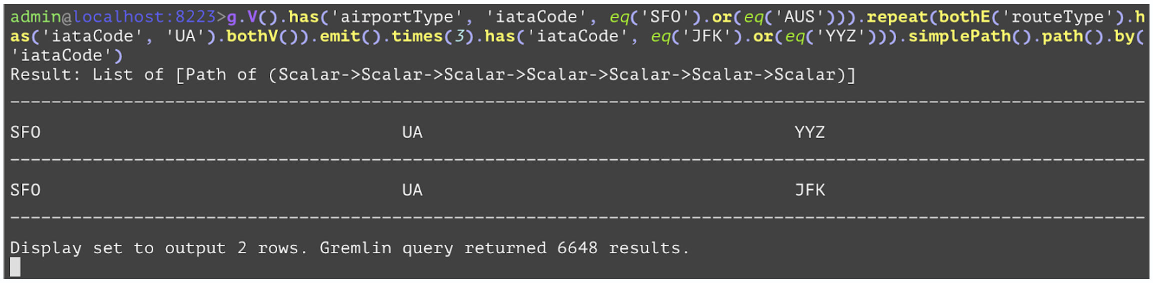
For the first example, the query returns the first 10 paths that have flights outbound from the SFO airport, stop at another airport, and then arrive at the CDG airport. The reason for the `outE().inV()` inside the `"repeat"` step instead of a simpler `out()` step is that the former will include the edges inside of the tuple returned by the `path()` step that will not be returned by the later.

For the second example, the `"repeat"` step has two separate conditions that cause it to exit: one is when the number of `times` is reached i.e (3 in this case) and the other is at the end of each section of the loop via the `emit()` step. The gist of this query is that it gets all paths (regardless of direction) made of flights between either of the SFO or AUS airports to either of the JFK or YYZ airports with at most 3 flights and using only flights from the airline with iataCode UA (United Airlines), and returns each of these entities by its `"iataCode"` attribute.

Args	Name	Type	Description
	traversal_steps	steps or expression	The body of the repeat loop. Repeat these steps until the loop is exited.

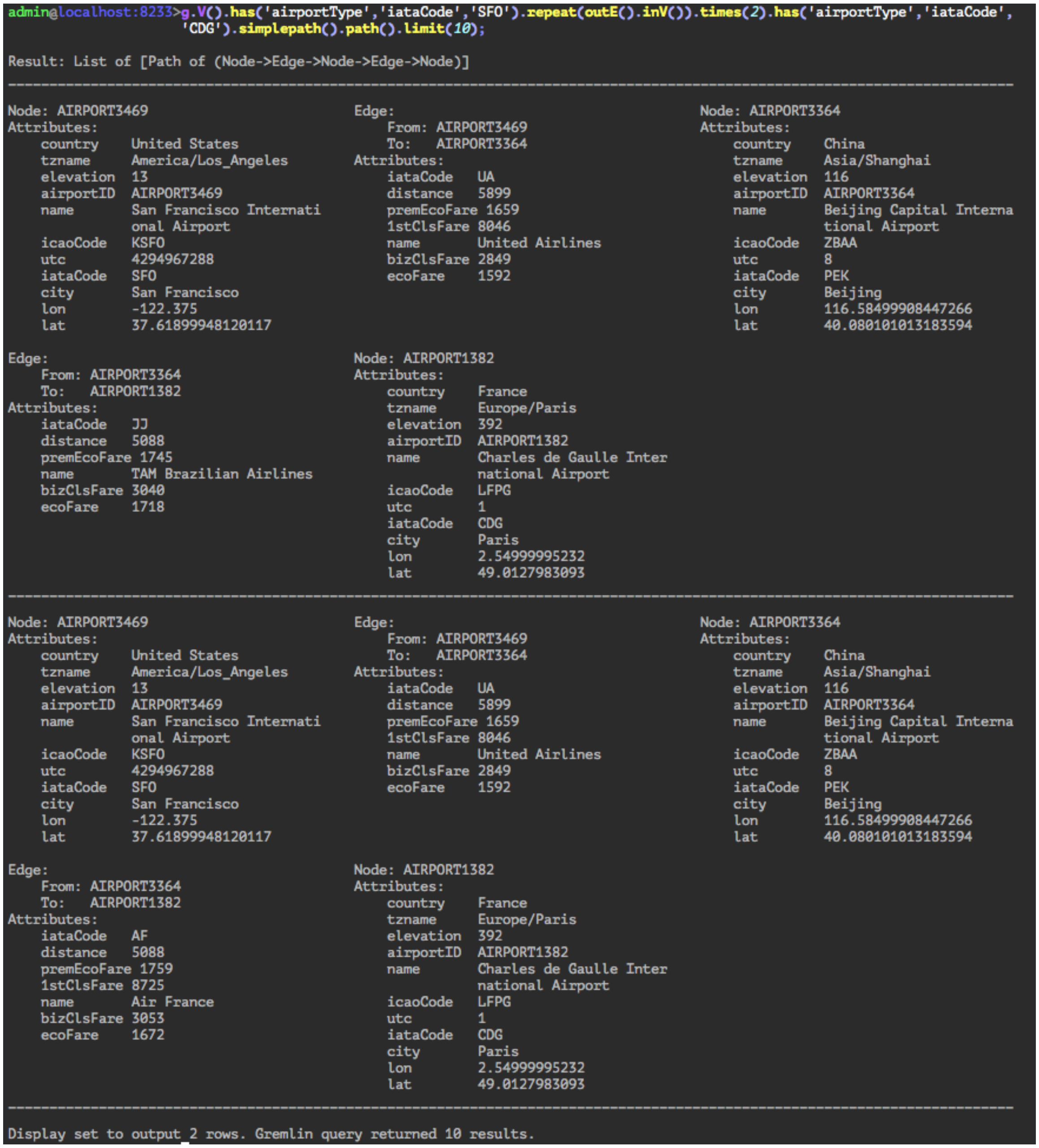
GQL

```
gremlin://g.V().has('airportType', 'iataCode',eq('SFO').or(eq('AUS'))).repeat(bothE('routeType')
.has('iataCode','UA').bothV()).emit().times(3).has('iataCode', eq('JFK').or(eq('YYZ')))
.simplePath().path().by('iataCode');
```



```
admin@localhost:8223>g.V().has('airportType', 'iataCode', eq('SFO').or(eq('AUS'))).repeat(bothE('routeType').h
as('iataCode', 'UA').bothV()).emit().times(3).has('iataCode', eq('JFK').or(eq('YYZ'))).simplePath().path().by(
'iataCode')
Result: List of [Path of (Scalar->Scalar->Scalar->Scalar->Scalar->Scalar->Scalar)]
--------------------------------------------------------------------------------------------------------------
SFO                                     UA                                      YYZ
--------------------------------------------------------------------------------------------------------------
SFO                                     UA                                      JFK
--------------------------------------------------------------------------------------------------------------
Display set to output 2 rows. Gremlin query returned 6648 results.
```

gremlin://g.V().has('airportType','iataCode','SFO').repeat(outE().inV()).times(2).has('airportType','iataCode','CDG').simplepath().path().limit(10);



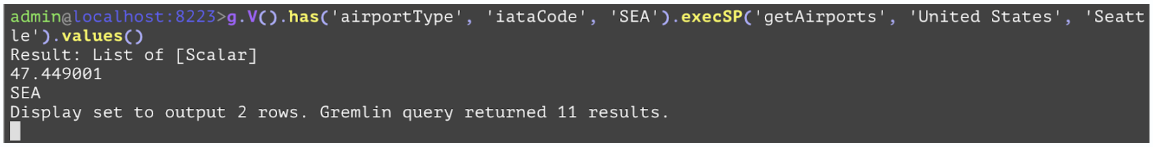
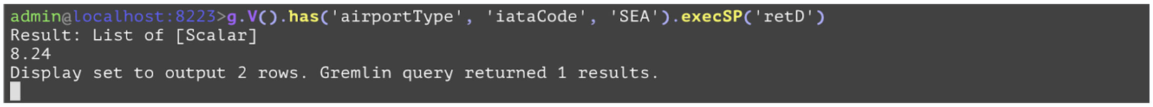
```
admin@localhost:8233>g.V().has('airportType','iataCode','SFO').repeat(outE().inV()).times(2).has('airportType','iataCode',
                     'CDG').simplepath().path().limit(10);

Result: List of [Path of (Node->Edge->Node->Edge->Node)]
-------------------------------------------------------------------------------------------------------------------------
Node: AIRPORT3469                         Edge:                                     Node: AIRPORT3364
Attributes:                                   From: AIRPORT3469                     Attributes:
    country    United States                  To:   AIRPORT3364                         country    China
    tzname     America/Los_Angeles        Attributes:                                   tzname     Asia/Shanghai
    elevation  13                             iataCode   UA                             elevation  116
    airportID  AIRPORT3469                    distance   5899                           airportID  AIRPORT3364
    name       San Francisco Internati        premEcoFare 1659                          name       Beijing Capital Interna
               onal Airport                   1stClsFare 8046                                      tional Airport
    icaoCode   KSFO                           name       United Airlines                icaoCode   ZBAA
    utc        4294967288                     bizClsFare 2849                           utc        8
    iataCode   SFO                            ecoFare    1592                           iataCode   PEK
    city       San Francisco                                                            city       Beijing
    lon        -122.375                                                                 lon        116.58499908447266
    lat        37.61899948120117                                                        lat        40.080101013183594

Edge:                                     Node: AIRPORT1382
    From: AIRPORT3364                     Attributes:
    To:   AIRPORT1382                         country    France
Attributes:                                   tzname     Europe/Paris
    iataCode   JJ                             elevation  392
    distance   5088                           airportID  AIRPORT1382
    premEcoFare 1745                          name       Charles de Gaulle Inter
    name       TAM Brazilian Airlines                    national Airport
    bizClsFare 3040                           icaoCode   LFPG
    ecoFare    1718                           utc        1
                                              iataCode   CDG
                                              city       Paris
                                              lon        2.54999995232
                                              lat        49.0127983093
-------------------------------------------------------------------------------------------------------------------------
Node: AIRPORT3469                         Edge:                                     Node: AIRPORT3364
Attributes:                                   From: AIRPORT3469                     Attributes:
    country    United States                  To:   AIRPORT3364                         country    China
    tzname     America/Los_Angeles        Attributes:                                   tzname     Asia/Shanghai
    elevation  13                             iataCode   UA                             elevation  116
    airportID  AIRPORT3469                    distance   5899                           airportID  AIRPORT3364
    name       San Francisco Internati        premEcoFare 1659                          name       Beijing Capital Interna
               onal Airport                   1stClsFare 8046                                      tional Airport
    icaoCode   KSFO                           name       United Airlines                icaoCode   ZBAA
    utc        4294967288                     bizClsFare 2849                           utc        8
    iataCode   SFO                            ecoFare    1592                           iataCode   PEK
    city       San Francisco                                                            city       Beijing
    lon        -122.375                                                                 lon        116.58499908447266
    lat        37.61899948120117                                                        lat        40.080101013183594

Edge:                                     Node: AIRPORT1382
    From: AIRPORT3364                     Attributes:
    To:   AIRPORT1382                         country    France
Attributes:                                   tzname     Europe/Paris
    iataCode   AF                             elevation  392
    distance   5088                           airportID  AIRPORT1382
    premEcoFare 1759                          name       Charles de Gaulle Inter
    1stClsFare 8725                                      national Airport
    name       Air France                     icaoCode   LFPG
    bizClsFare 3053                           utc        1
    ecoFare    1672                           iataCode   CDG
                                              city       Paris
                                              lon        2.54999995232
                                              lat        49.0127983093
-------------------------------------------------------------------------------------------------------------------------
Display set to output 2 rows. Gremlin query returned 10 results.
```

SQL	No known SQL equivalent without using some form of a stored procedure.
	SELECT * FROM airportType AS srcAirport INNER JOIN routeType AS firstHop ON firstHop.srcAirportId=srcAirport.airportId INNER JOIN airportType AS interAirport ON firstHop.destAirportId=interAirport.airportId INNER JOIN routeType AS secondHop ON

	secondHop.srcAirportId=interAirport.airportId INNER JOIN airportType AS destAirport ON secondHop.destAirportId=destAirport.airportId WHERE srcAirport.iataCode='SFO' AND destAirport.iataCode='CDG' AND srcAirport.airportId<>interAirport.airportId AND srcAirport.airportId<>destAirport.airportId AND interAirport.airportId<>destAirport.airportId LIMIT 10;

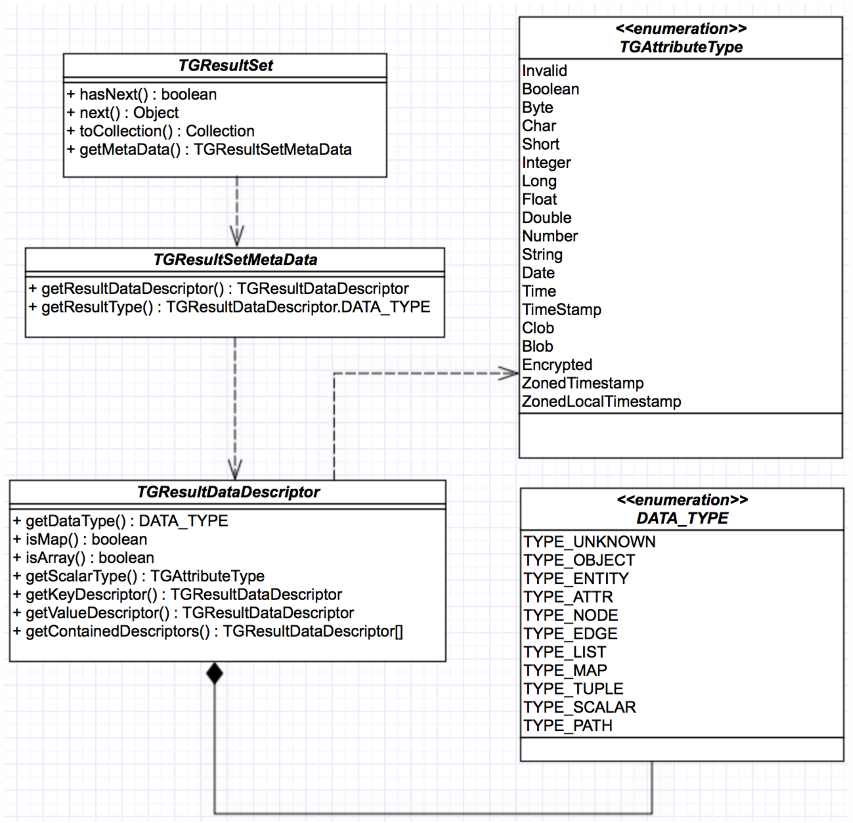
Stored Procedure

execSP

Executes a stored procedure that is currently registered in the database. In the first example, the `"getAirports"` stored procedure returns a list of all of the airports with the first parameter (in this case `United States`) as the country for that airport, and the second parameter (in this case `"Seattle"`) as the city for that airport. In the second example, the `"retD"` stored procedure simply returns a double value of 8.24. This stored procedure has no parameters needed.			
Args	Name	Type	Description
	stored_proc_name	string	The stored procedure to run.
	stored_proc_args	string[]	Optionally, the stored procedure arguments to pass in as parameters to the stored procedure. Can specify multiple arguments. Keyword arguments are specified within the string by using an equal sign between the argument name and value, like keyword_arg_name=keyword_arg_value.
GQL	gremlin://g.V().has('airportType', 'iataCode', 'SEA').execSP('getAirports', 'United States', 'Seattle').values();  admin@localhost:8223>g.V().has('airportType', 'iataCode', 'SEA').execSP('getAirports', 'United States', 'Seattle').values() Result: List of [Scalar] 47.449001 SEA Display set to output 2 rows. Gremlin query returned 11 results.		
	gremlin://g.V().has('airportType', 'iataCode', 'SEA').execSP('retD');  admin@localhost:8223>g.V().has('airportType', 'iataCode', 'SEA').execSP('retD') Result: List of [Scalar] 8.24 Display set to output 2 rows. Gremlin query returned 1 results.		

Query Result Set

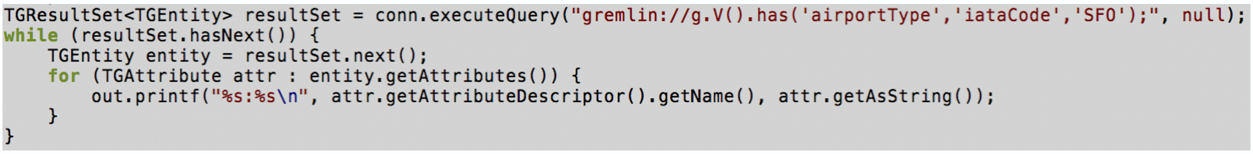
Result from a query is returned in the form of TGResultSet. Below shows a class diagram related to the TGResulSet. For more information, please see the Java API Reference



TGResultSet

This is the interface returned from a query. It implements an iterator interface. All the information about the result is accessed through TGResultSet.

Here is an example of retrieving query results.



```
TGResultSet<TGEntity> resultSet = conn.executeQuery("gremlin://g.V().has('airportType','iataCode','SFO');", null);
while (resultSet.hasNext()) {
    TGEntity entity = resultSet.next();
    for (TGAttribute attr : entity.getAttributes()) {
        out.printf("%s:%s\n", attr.getAttributeDescriptor().getName(), attr.getAsString());
    }
}
```

‘hasNext’ method is used to check any available data in the result. ‘Next’ is used to retrieve the result. In this example, the query returns the ‘SFO’ airport node which implements ‘TGEntity’ interface. Besides result data, metadata about the results can be retrieved using ‘TGResultSet’. ‘TGResultSetMetaData’ and ‘TGResultDataDescriptor’ maintain the result metadata.

TGResultSetMetaData

It serves as the starting point for retrieving metadata about the result. Since the query result is currently returned in a list, ‘getResultType’ of ‘TGResultSet’ always returns ‘TYPE_LIST’. ‘getResultDataDescriptor’ of ‘TGResultSet’ returns the ‘TGResultDataDescriptor’ which contains additional information about the data in the list.

TGResultDataDescriptor

The information presented in this interface is defined internally by data type annotations described in Annotation reference. This interface is recursive in nature because query results can contain complex objects such as a list of mixed data types of scalar data and entity objects. When stored procedures are used in a query, a stored procedure can return data which Python allows.
Here is an example of retrieving query metadata.

```
1  TGResultSet<TGEntity> resultSet = conn.executeQuery("gremlin://g.V().has('airportType','iataCode','SFO')." +
                                       "outE('routeType').inV().path().by('iataCode').by('distance').by();", null);
2  TGResultSetMetaData rsmd = resultSet.getMetaData();
3  TGResultDataDescriptor.DATA_TYPE dataType = rsmd.getResultType();
   out.printf("Result data type : %s\n", dataType);
4  TGResultDataDescriptor rsdd = rsmd.getResultDataDescriptor();
   System.out.printf("Type : %s, isArray : %b\n", rsdd.getDataType(), rsdd.isArray());
5  TGResultDataDescriptor[] ndd = rsdd.getContainedDescriptors();
   for (int i=0; i<ndd.length; i++) {
       System.out.printf("Type : %s, isArray : %b\n", ndd[i].getDataType(), ndd[i].isArray());
6      TGResultDataDescriptor[] pathdd = ndd[i].getContainedDescriptors();
       for (int j=0; j<pathdd.length; j++) {
           System.out.printf("   Type : %s, scalar type : %s\n", pathdd[j].getDataType(),
           pathdd[j].getDataType() == TYPE_SCALAR ? pathdd[j].getScalarType() : "none");
       }
   }
```

Step	Objective
1	Execute a query to return a list of paths representing routes from ‘SFO’. Each path contains three elements. Element types in each path are in the order of string, integer and node.
2	Retrieve the metadata object from the result set.
3	Retrieve the data type of the result set. Currently it is always of LIST type.
4	Retrieve the top level result data descriptor object which describes the result list. It also contains the descriptor objects of the data in the list.
5	In this example, there is only one element in the contained descriptor array because the result is a list of paths. Each data element in the query result list is a path.
6	Repeat the same ‘getContainedDescriptors’ call to get an array of data descriptors to find out what kind of data is captured in each path. In this example, each path is made up of three data elements, namely, a string, an integer and a node.

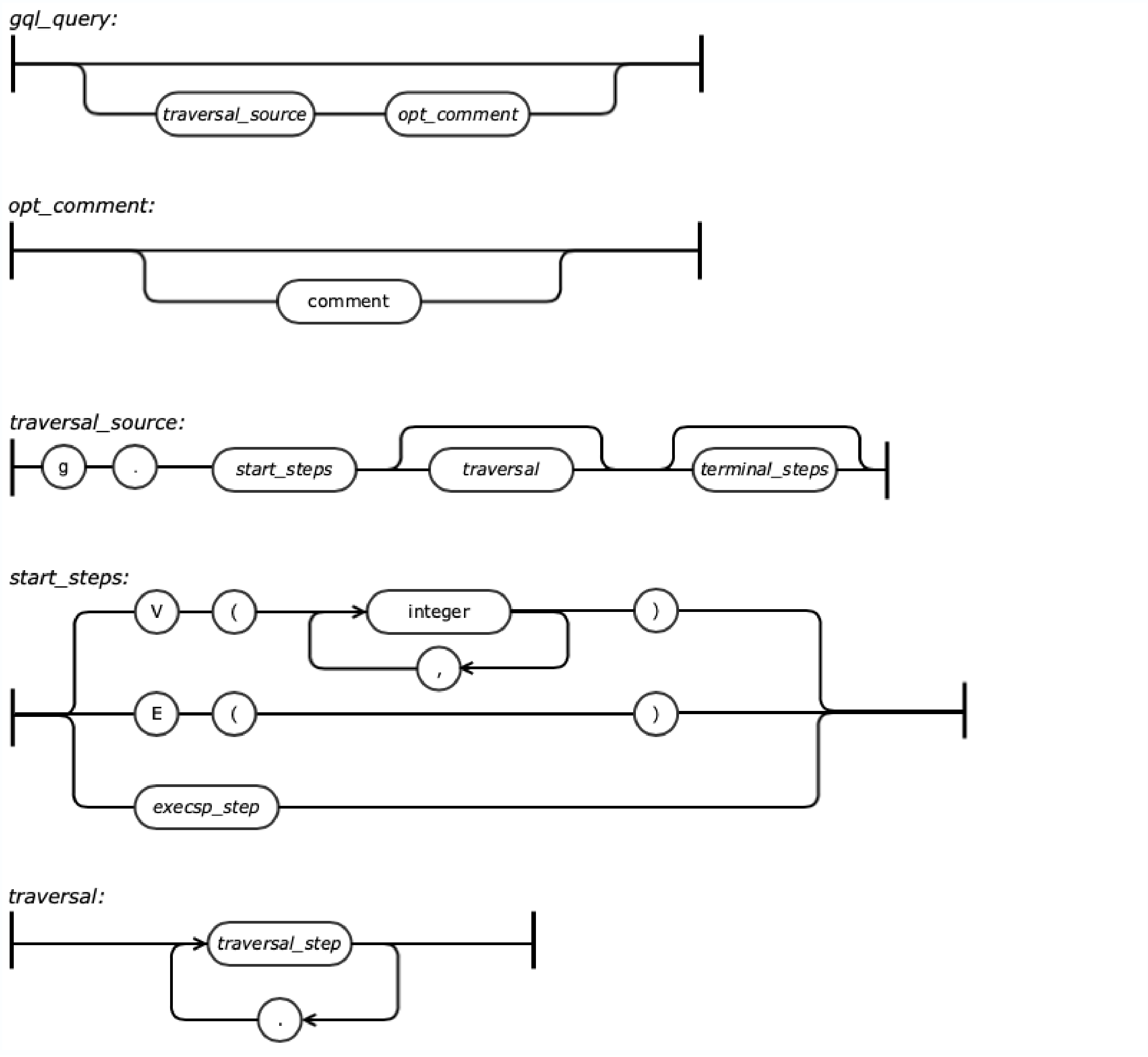
The output of the executed code is as below:

```
Result data type : TYPE_LIST
Type : TYPE_LIST, isArray : true
Type : TYPE_PATH, isArray : false
    Type : TYPE_SCALAR, scalar type : String
    Type : TYPE_SCALAR, scalar type : Integer
    Type : TYPE_NODE, scalar type : none
```

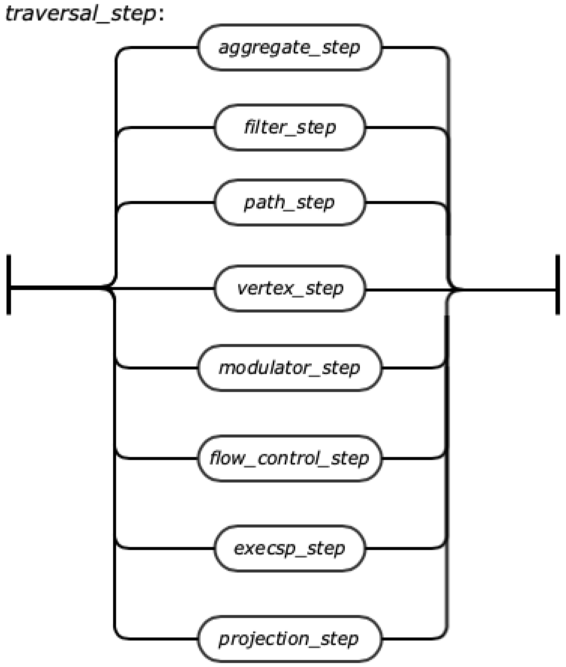
Appendices

Gremlin Query Language Syntax Diagram

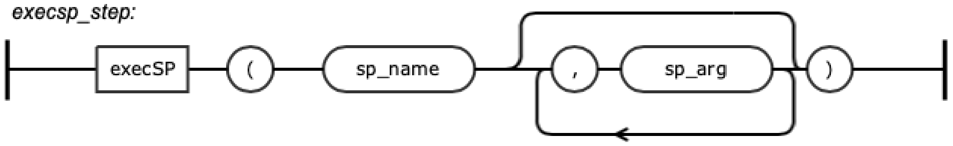
The syntax diagram for TGDB Gremlin Query is shown below.



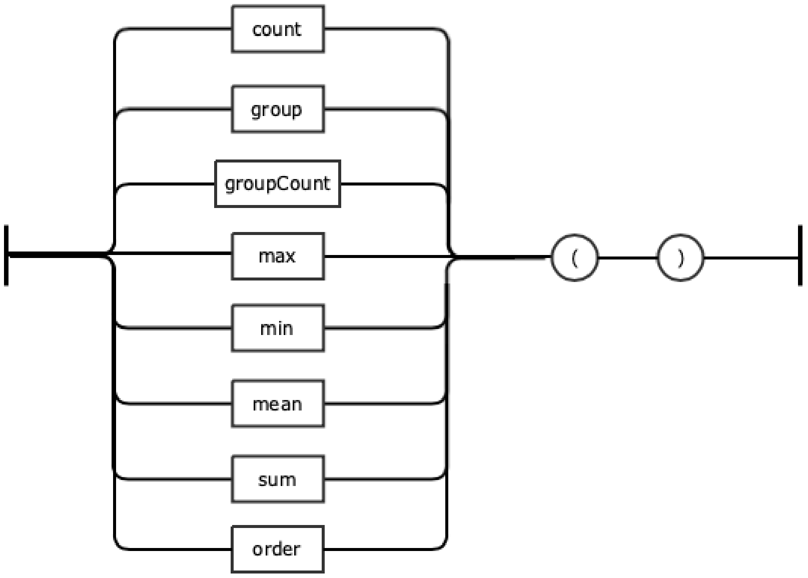
traversal_step:

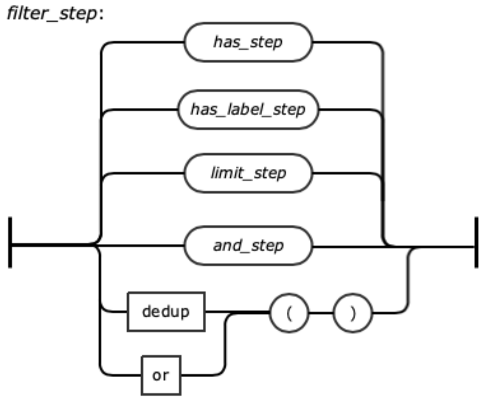


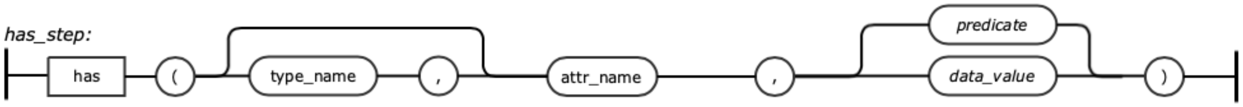
execsp_step:

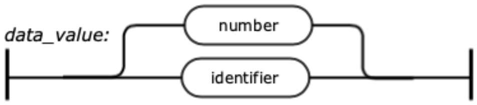


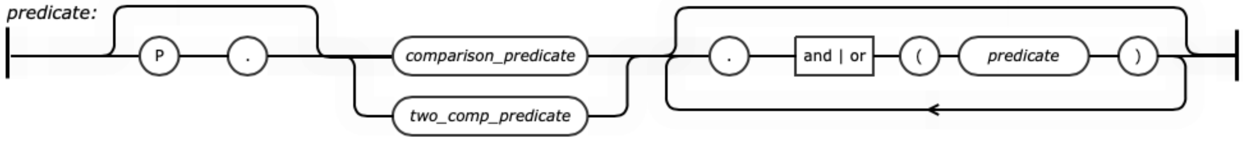
aggregate_step:

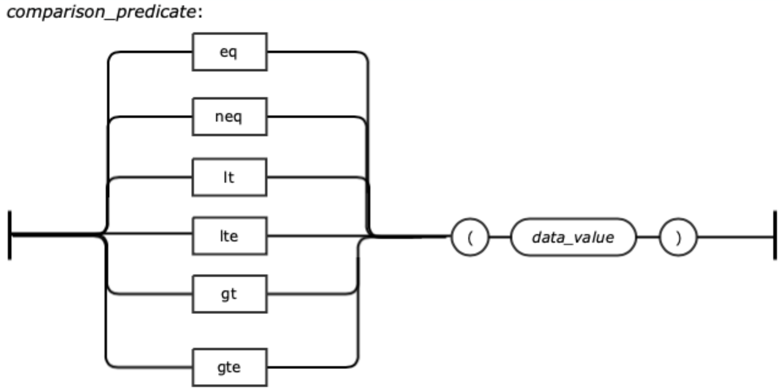


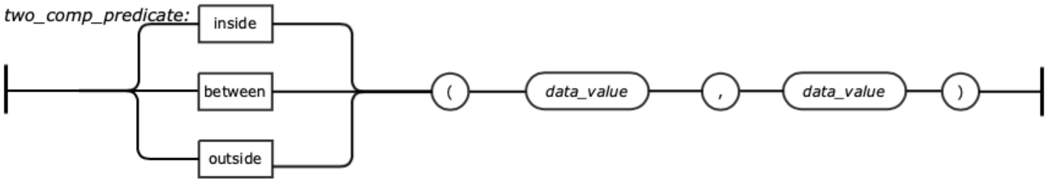

filter_step:
has_step
has_label_step
limit_step
and_step
dedup
or
(
)

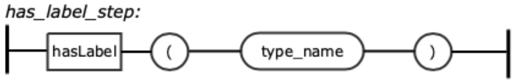

has_step:
has
(
type_name
,
attr_name
,
predicate
data_value
)

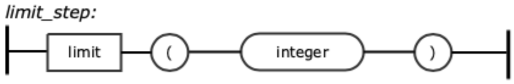

data_value:
number
identifier

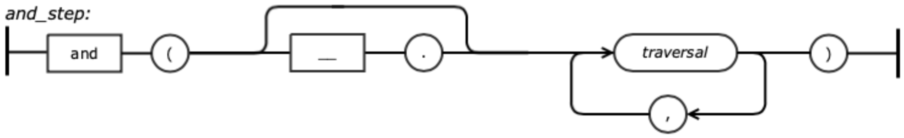

predicate:
P
.
comparison_predicate
two_comp_predicate
.
and | or
(
predicate
)


comparison_predicate:
eq
neq
lt
lte
gt
gte
(
data_value
)

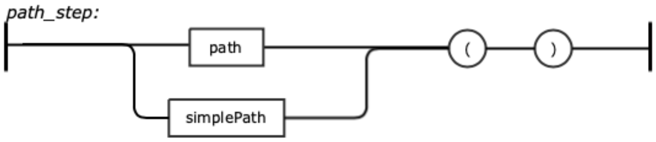

two_comp_predicate:
inside
between
outside
(
data_value
,
data_value
)

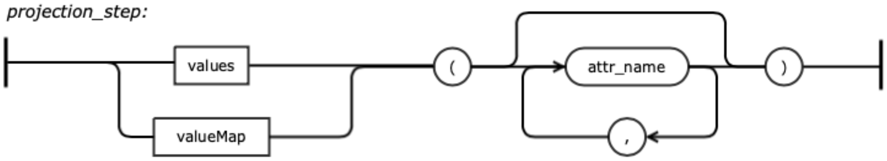

has_label_step:
hasLabel
(
type_name
)

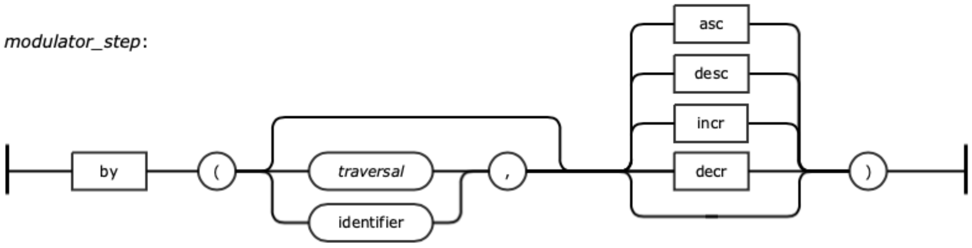

limit_step:
limit
(
integer
)



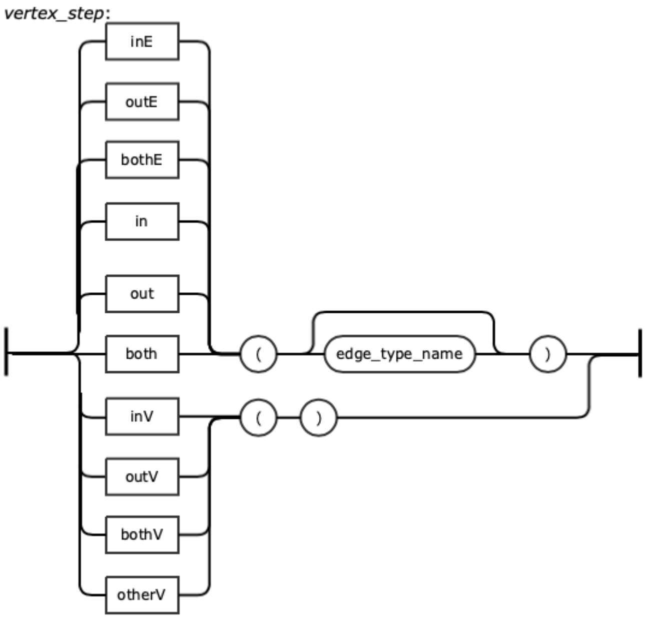
❗The and_step currently only allows ‘has’ step as argument. For correctness, we have shown traversal.







❗The modular_step currently only allows identifier as argument. For correctness, we have shown traversal.



Legend:

traversal_source	*Italics* text inside a rounded rectangle indicates a statement
)	small circle with a single text is a literal character terminal
sum	rectangle with a regular text is a string literal terminal
integer	Indicates an identifier terminal. See the rules for identifier terminal
Identifier Terminal	
edge_type_name	A valid edge type name in the database
type_name	A valid edge or node type name in the database
attr_name	A valid attribute descriptor name in the database
sp_name	A valid stored procedure name in the database
sp_arg	A stored procedure argument. If the argument is named argument, then it should be of the form ‘name=value’
number	any integer or decimal number. The regular expression for matching this is: -?[0-9]+(\.[0-9]+)?
integer	an integer. The regular expression for matching this is: -?[0-9]+
identifier	a single-quote enclosed string. The regular expression for matching this is: '(\\.|[^'\\])+'|‘(\\.|[^’\\])+’
comment	a comment used to document what a query does or how it works.Single line comments only. Comments starts with # Can be at the end of the query or at the beginning.

Annotation References

Annotation Codes that can be returned as a Sequence of characters as result of Query string or from an execution of a Stored Procedure.

Annotation Symbol	Annotation Type (Server-side)	Python Type	Description
""	void	--	def rVoid(g,...) -> "": pass
c	Char	str	def rChar(g,..) → "c" :
b	signed byte	bytes	
B *	unsigned byte		
?	Boolean	bool	
h	short.	int	Optionally specify the width using the ":" and size
H *	unsigned short		
i	int	int	
I *	unsigned int		
l	long	int	
L *	unsigned long		
f	float	float	
d	Double	float	
s	string	str	
n:size_t *	number with precision		
q *	long long (64 bit)		
Q *	unsigned long long (64)		
p *	Pointer (64 bit)		
G *	Graph		
P	Path	list	A path may be annotated as a generic path: "P". The list elements are limited to nodes, edges, entities, and scalar values. It may not include tuples, or otherwise nested objects - this is just for annotation purposes. If the path has a fixed number of elements it can be expressed as e.g. "P(V,E,V,V,E,V)" or "P(V,d,d,s,E,i)". Alternatively, path elements may be defined explicitly: If the path has a fixed number of elements it can be expressed as e.g. "P(V,E,V,V,E,V)" or "P(V,d,d,s,E,i)". For variable size paths, list annotation may be used, e.g. "P([s])" - any number of strings. P(d,[(s,V)]) means a path starts with a double and then with zero or more tuples of string and vertex combination. It means P(d,s,V) and P(d,s,V,s,V) are both represented by P(d,[(s,V)]). Path elements are restricted to scalar types, nodes, edges, and entities.
O *	Generic object		
S *	Scalar.		Primitive types and string
A *	Attribute		Any Generic TGDB Attribute

Annotation Symbol	Annotation Type (Server-side)	Python Type	Description
A:name *	Named Attribute		A valid TGDB attribute of the specified name def rAttributeAge(g:, ...) → "A:age"
T *	Node or Edge entity		This annotation previously included attribute as well - may need to revert in the future
V	Any Node Type	TGNode	
V:name *	Named Node Type		A Node of a specific type
E	Any Edge	TGEdge	
E:name *	Named Edge Type		A Edge of specific type

[ ]	A List of values.	list	The values can be any of types. It is an indefinite set and the count is only known at runtime.
			
			To specify a type use any of annotation symbol including "[]" for itself
			Examples:
			def rGenericList(g:, ...) → "[]"*
			def rListofNames(g:, ...) → "[s]"
			def rListofPeoples(g:, ...) → "[V:people]"

()	Declares a Tuple.	tuple	An ordered set of finite values. Finite set, count known at compile or pre-execution time. The values can be specified as any annotation symbol from the table including itself. def rTuple(g:, ...) → "(A:name, A:age, d:8)"
{K,V}	Set of unique (key, value) pairs	dict	A map of key and values. Key is one of the scalar or primitive types. i.e not a list, set, or a map

Differences between Apache Gremlin and TGDB GQL

This section tables the differences between the supported steps in Apache Gremlin and TIBCO Graph Database Gremlin Query Language. TGDB Query Language is based on the Apache Gremlin. Albeit, we strive to remain as consistent and completely at par with the Apache Gremlin, certain differences arise in the way of supporting steps due to design, security and time constraints. Some of the steps have workarounds, or have a better counterpart through elegant design. For instance TGDB supports Stored Procedures and also has built-in Graph Algorithms, they are all accessible via the `‘execsp’` command. This makes the VertexProgram of Gremlin completely redundant.
The table below outlines the differences between the two and should be used as reference. As TIBCO releases newer versions of TGDB, the product will aim to support as many as steps necessary to increase the end-user productivity and ease of use.

Step	Supported in TGDB	Apache Gremlin 3.5.2	Comments
Start Steps			
addE()	N	Y	TGDB supports a CRUD API in Java, Go, and Python separately from Gremlin. Gremlin is used for querying purpose only TGDB support a fast and efficient bulk operation
addV()	N	Y	
E()	Y	Y	
inject()	N	Y	
V()	Y	Y	
Terminal Steps			
fill()	N	Y	TGDB supports the default toList terminal step. Since the Gremlin is a functional API model, some of the steps aren’t appropriate. Also toBulkSet is supported through a fast and efficient bulk export mechanism.
hasNext()	N	Y	
iterate()	N	Y	
next()	N	Y	
toBulkSet()	N	Y	
toList()	Y	Y	
toSet()	N	Y	
tryNext()	N	Y	
Vertex Steps			
both	Y	Y	
bothE	Y	Y	
in	Y	Y	
inE	Y	Y	
inV	Y	Y	
otherV	Y	Y	
out	Y	Y	
outE	Y	Y	
outV	Y	Y	

Step	Supported in TGDB	Apache Gremlin 3.5.2	Comments
Projection Steps			
elementMap	N	Y	Other than Select, which is more than a Project Step as it is required to hold state vectors, the functionality of ElementMap, Properties, and PropertyMap are encapsulated in the default Entity object. Values and ValueMap helps to filter out the needed attributes
id	N	Y	
identity	N	Y	
key	N	Y	
label	N	Y	
project	N	Y	
properties	N	Y	
propertyMap	N	Y	
select	N	Y	
value	N	Y	
valueMap	Y	Y	
values	Y	Y	
Filter Steps			
and	Y	Y	
dedup	Y	Y	
has	Y	Y	
hasLabel	Y	Y	
is	N	Y	
limit	Y	Y	
none	N	Y	
not	N	Y	
or	Y	Y	
tail	N	Y	
timeLimit	N	Y	
FlowControl & Predicate Steps			
barrier	N	Y	Most of the unsupported steps can be worked around using stored procedures.
between	Y	Y	
choose	N	Y	
containing	N	Y	
emit	Y	Y	
endingWith	N	Y	
eq	Y	Y	
fold	N	Y	
gt	Y	Y	
gte	Y	Y	
inside	Y	Y	
local	N	Y	
loops	N	Y	
lt	Y	Y	
lte	Y	Y	
match	N	Y	

Step	Supported in TGDB	Apache Gremlin 3.5.2	Comments
neq	Y	Y	
notEndingWith	N	Y	
notStartingWith	N	Y	
option	N	Y	
optional	N	Y	
outside	Y	Y	
repeat	Y	Y	
sack	N	Y	
skip	N	Y	
startingWith	N	Y	
times	Y	Y	
unfold	N	Y	
until	N	Y	
where	N	Y	
Aggregation Steps			
aggregate	N	Y	
coalesce	N	Y	
count	Y	Y	
group	Y	Y	
groupcount	Y	Y	
max	Y	Y	
mean	Y	Y	
min	Y	Y	
order	Y	Y	
sum	Y	Y	
union	N	Y	
Path Steps			
cyclicPath	N	Y	Tree and Subgraph steps can be efficiently customized to the application needs using stored procedures.
path	Y	Y	
simplePath	Y	Y	
subgraph	N	Y	
tree	N	Y	
Modulator Steps			
as	N	Y	With step is supported using query options, since it is applicable only with ‘g.’
by	Y	Y	
from	N	Y	
to	N	Y	
with	N	Y	
write	N	Y	

Step	Supported in TGDB	Apache Gremlin 3.5.2	Comments
StoredProcedure Steps			
execSP	Y	N	This allows complex python code to be executed inline with the Gremlin query
Graph Analytics			
Betweenness Centrality	Y	N	Built-in stored procedures supports standard Vertex Programs and Graph Analytics
Closeness Centrality	Y	N	
PageRank	Y	Y	
Triangle Counts	Y	N	
Connected Components	Y	Y	
Peer Pressure	Y	Y	
Single Source/All Pairs Shortest Path	Y	Y	
Math Functions			
abs	N	Y	Workaround is to use stored procedures.
acos	N	Y	
asin	N	Y	
atan	N	Y	
cbrt	N	Y	
ceil	N	Y	
cos	N	Y	
cosh	N	Y	
exp	N	Y	
floor	N	Y	
log	N	Y	
log10	N	Y	
log2	N	Y	
sin	N	Y	
sinh	N	Y	
sqrt	N	Y	
tan	N	Y	
tanh	N	Y	
signum	N	Y	
Miscellaneous Functions			
Sample	N	Y	
Coin	N	Y	
Constant	N	Y	
Profile	N	Y	
Explain	N	Y	
Data Management Steps			
AddE	N	Y	TGDB supports transactional and bulk Data Management, Metadata Management operations using native API functionality. It does not rely on Gremlin's functional API semantics. The CRUD API is available on Java, Go, and Python. Transactional Update is not available on Gremlin, and relies on Drop followed by Add. Python supports High Performance bulk-io operations through the Panda framework.
AddProperty	N	Y	
AddV	N	Y	
Drop	N	Y	
Update	N	N	

Step	Supported in TGDB	Apache Gremlin 3.5.2	Comments
BulkIO	N	Y	

Gremlin Query Reserved Words

The following table lists the reserved words that are used by the Gremlin Query. Any identifier with the prefix ‘@’ is considered to be a system identifier.

__	bothV	group	inV	otherV	to
.	by	groupCount	is	out	to
(	choose	gt	key	outE	unfold
)	decr	gte	label	outside	until
@id	desc	hasKey	lt	outV	V
and	emit	hasNot	lte	range	valueMap
asc	execSP	id	match	repeat	values
barrier	explain	in	max	sum	where
between	fold	incr	mean	tail	with
both	from	inE	min	timeLimit	within
bothE	g	inside	or	times	without

References

1. PRACTICAL GREMLIN: An Apache Tinker Pop Tutorial - Kevin Lawrence http://kelvinlawrence.net/book/Gremlin-Graph-Guide.html
2. Gremlin's Anatomy - https://tinkerpop.apache.org/docs/current/tutorials/gremlins-anatomy/
3. SQL2Gremlin - http://sql2gremlin.com
4. Tinkerpop Gremlin Reference Documentation - https://tinkerpop.apache.org/docs/3.5.2/reference/

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Product-Specific Documentation

Documentation for TIBCO Graph Database is available on https://docs.tibco.com/products/tibco-graph-database-enterprise-edition-latest page.
This feature is available to both Enterprise edition and Community. The guidelines specified for Clustering is applicable only to Enterprise edition.
The following documents form the documentation set:

- *TIBCO® Graph Database Getting Started*: Read this manual before reading any other manual in the documentation set. This manual describes the terminology and concepts of the platform. The other manuals in the documentation set assume you are familiar with the information in this manual.
- *TIBCO Graph Database Administration* : Read this manual to learn how to manage the runtime and deploy and manage applications.
- *TIBCO® Graph Database Security Guidelines*: Read this manual to learn more about security guidelines and recommendations for TIBCO® Graph Database.
- *TIBCO Graph Database Release Notes*: Read this manual for a list of new and changed features, steps for migrating from a previous release, and lists of known issues and closed issues for the release.

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