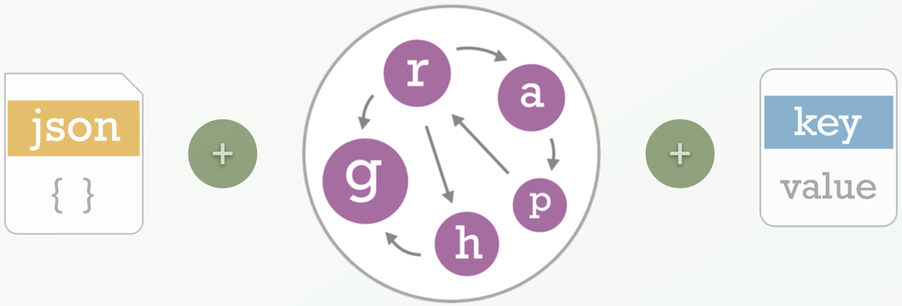
ArangoDB

Graph Course for Freshers:
*The **Shortest Path** to first graph skills*



2019 Edition

Welcome on board

This is a short journey for developers, data scientists and all other interested folks. In this course you will learn how to get started with ArangoDB's graph related features and some other bits and pieces.

If you are new to ArangoDB, don't be afraid – we will start with the basic things. Don't mind the number of pages too much, there are plenty of illustrations.

We will use real world data of domestic flights and airports in the US.
The structure of the data should be easy to understand and enable you to write many interesting queries to answer a variety of questions.

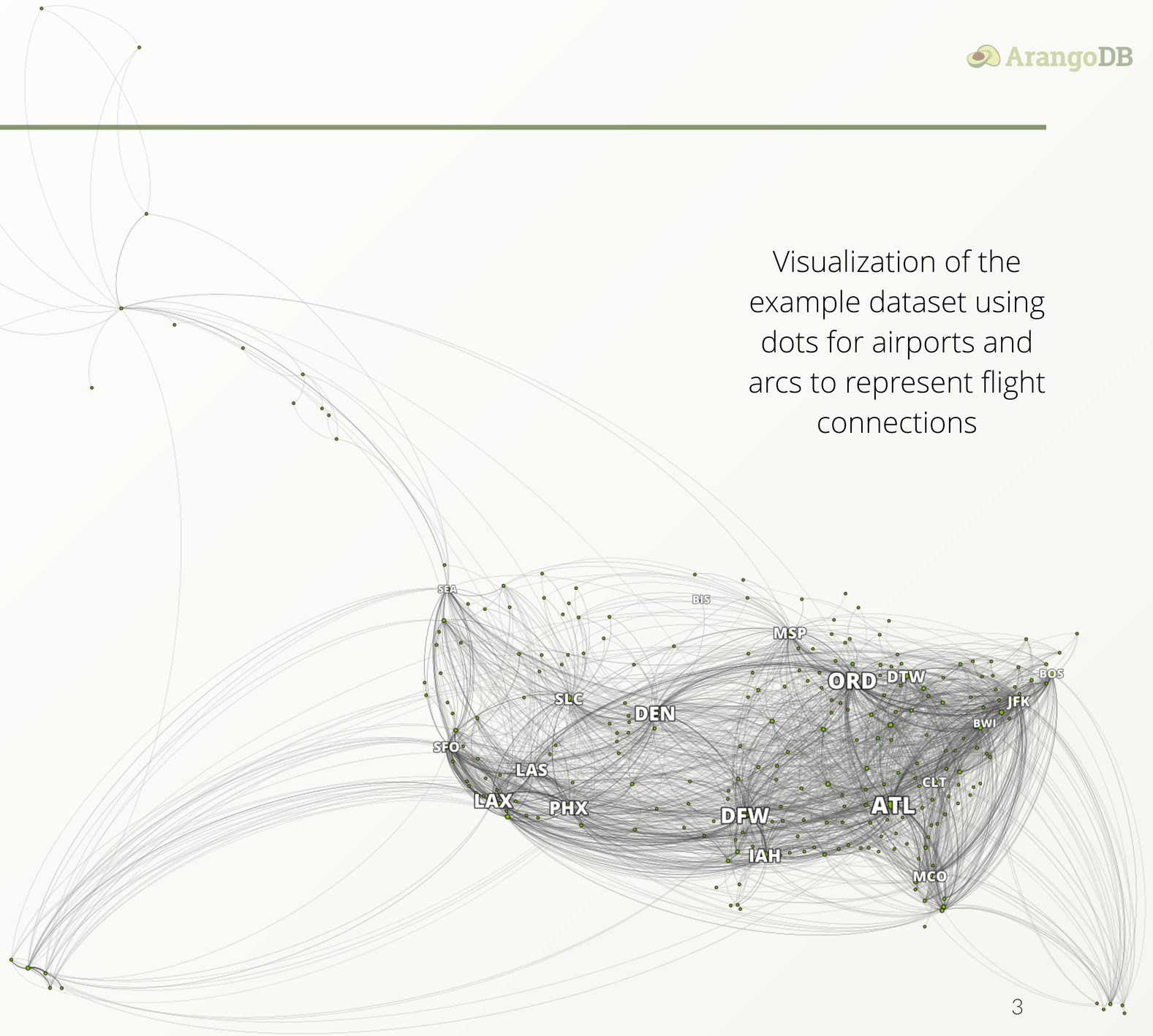
Already familiar? Feel free to get right to importing the dataset on page 24.

We hope you will enjoy the course!

Special thanks to @darkfrog *for his feedback to the beta version and to thousands of enthusiastic downloaders of this course!*

What you will learn

- Basics about graphs,
  in general and in ArangoDB
- Architecture of ArangoDB
  and what **multi-model** is
- How to import
  (graph) data
- Doing queries in ArangoDB's
  query language **AQL**
  - Data retrieval with filtering,
    sorting and more
  - Simple graph queries
  - Traversing through a graph
    with different options
  - Shortest path queries



Visualization of the example dataset using dots for airports and arcs to represent flight connections

Usability hint

ArangoDB

The symbol below indicates a link.

If you read this course in a browser, click on links with the middle-mouse button to open a new tab!

Graph Course page

The same goes for underlined links.

Table of Content

Takeoff

Graph Basics

&

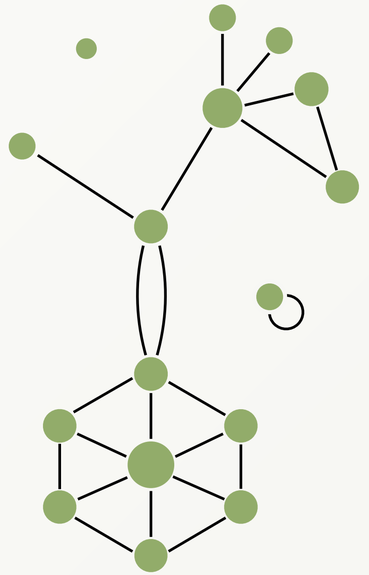
The Example Dataset

Graph Basics

ArangoDB

What is a graph? There are multiple definitions and types. A brief overview:

In discrete mathematics, a graph is defined as **set of vertices and edges**. In computing it is considered an **abstract data type** which is really good to represent connections or relations – unlike the tabular data structures of relational database systems, which are ironically very limited in expressing relations.



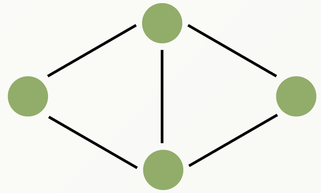
A good metaphor for graphs is to think of nodes as **circles** and edges as **lines** or **arcs**. The terms *node* and *vertex* are used interchangeably here. Usually vertices are connected by edges, making up a graph. Vertices don't have to be connected, but they may also be connected with more than one other vertex via multiple edges. You may also find vertices connected to themselves.

Graph Basics

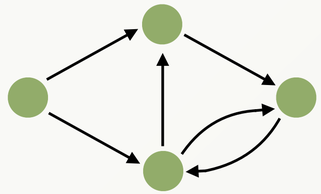
ArangoDB

Important types of graphs:

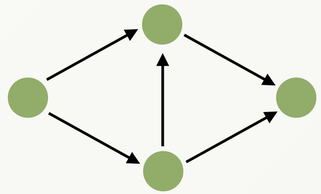
- **Undirected** – edges connect pairs of nodes without having a notion of direction

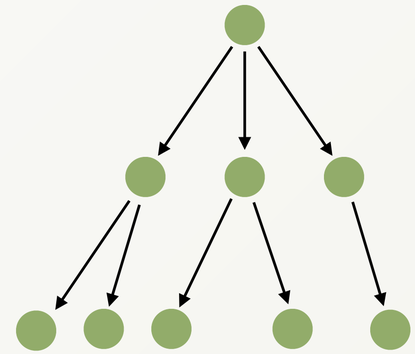


- **Directed** – edges have a direction associated with them (the lines/arcs have arrow heads in depictions)



- **DAG** – *Directed Acyclic Graph*: edges have a direction and their are no loops. In the most simple case, this means that if you have vertices A and B and an edge from A to B, then there must not be another edge from B to A. One example for a DAG is a tree topology.

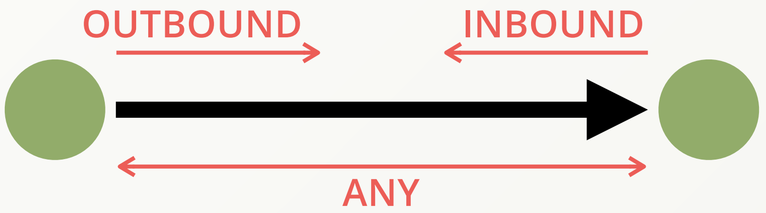




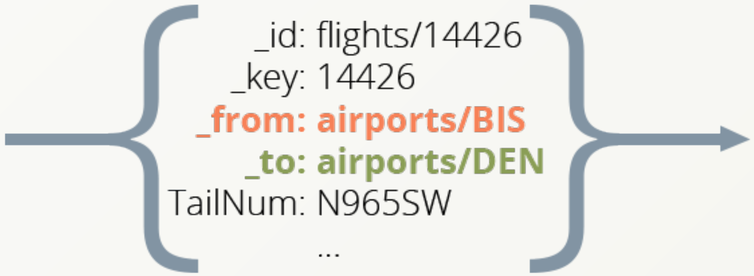
Graph Basics

In ArangoDB, each edge has a single direction, it can't point both ways at once. This model is also known as *oriented* graph.

Moreover, **edges are always directed**, but you can ignore the direction (follow in ANY direction) when you walk through the graph, or follow edges in reverse direction (INBOUND) instead of going in the direction they actually point to (OUTBOUND). Walking through a graph is called *traversal*.



ArangoDB allows you to store all kinds of graphs in different shapes and sizes, with and without cycles. You can save one or more edges between two vertices or even the same vertex. Also note that edges are **full-fledged JSON documents**, which means you can store as much information on the edges as you want!



Graph Basics

ArangoDB

A few examples of what can be answered by graph queries with the example dataset in mind:

- Give me all flights departing from JFK (airport in New York)
- Give me all flights landing in LAX (airport in Los Angeles) on January 5th
- Which airports can I reach with up to one stopover?
  (From one or multiple starting airports)

- Shortest Path:
  - What is the minimum amount of stopovers to fly from BIS
    (Bismarck Municipal Airport in North Dakota) to LAX and where is the stopover?

- Pattern Matching:
  - Departing from BIS, which flight to JFK with one stopover
    (at least 20 minutes time for the transit) is the quickest and via which airport?

Graph Basics

ArangoDB

Typical **use cases for graph databases** and "graphy" queries are:

- 360° View (Market Data, Customer, User, ...)
- Artificial Intelligence
- Dependency Management
- Fraud Detection
- Identity & Access Management
- Knowledge Graph
- Master Data Management
- Network Infrastructure
- Recommendation Engine
- Risk Management
- Social Media Management

Whenever the depth of your search is unknown (how many edges to follow), then graph queries are easier to write and more efficient to compute compared to other query patterns.

The Example Dataset

ArangoDB

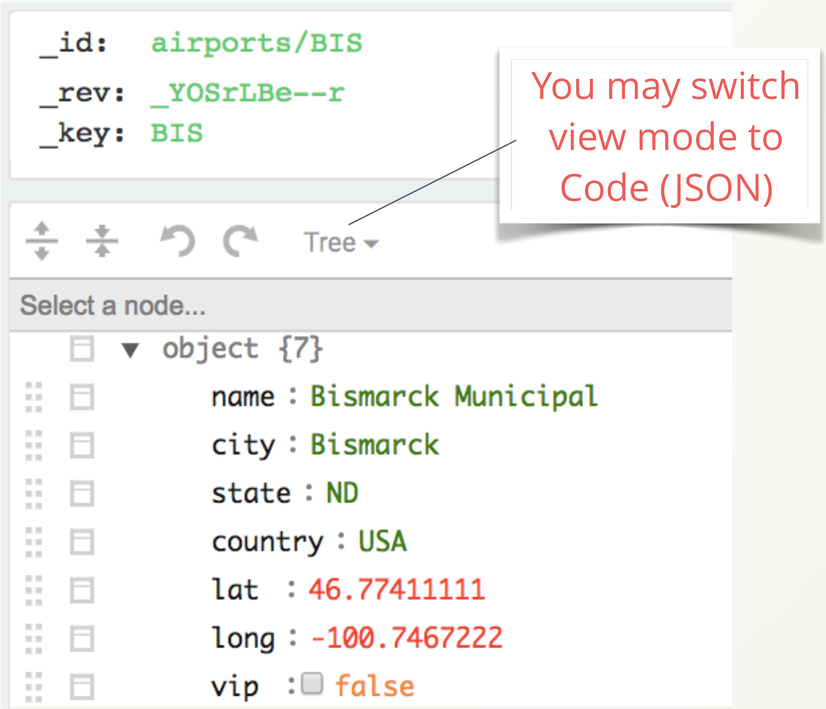
We took a dataset of US airports and flights, augmented and simplified it. Included are more than 3,000 airports and roughly 300,000 flights from January 1st to 15th, 2008.

Data structure of airport documents:

Attribute	Description
_key	international airport abbreviation code
_id	collection name + "/" + _key (computed property)
name	full name of the airport
city	name of the associated city
country	name of the country it is in
lat	latitude portion of the geographic location
long	longitude portion of the geographic location
state	name of the US state it is in
vip	airport with premium lounge? (true or false) *

* We marked a few airports randomly for example queries shown later

Example airport as shown in the document editor of the web interface:



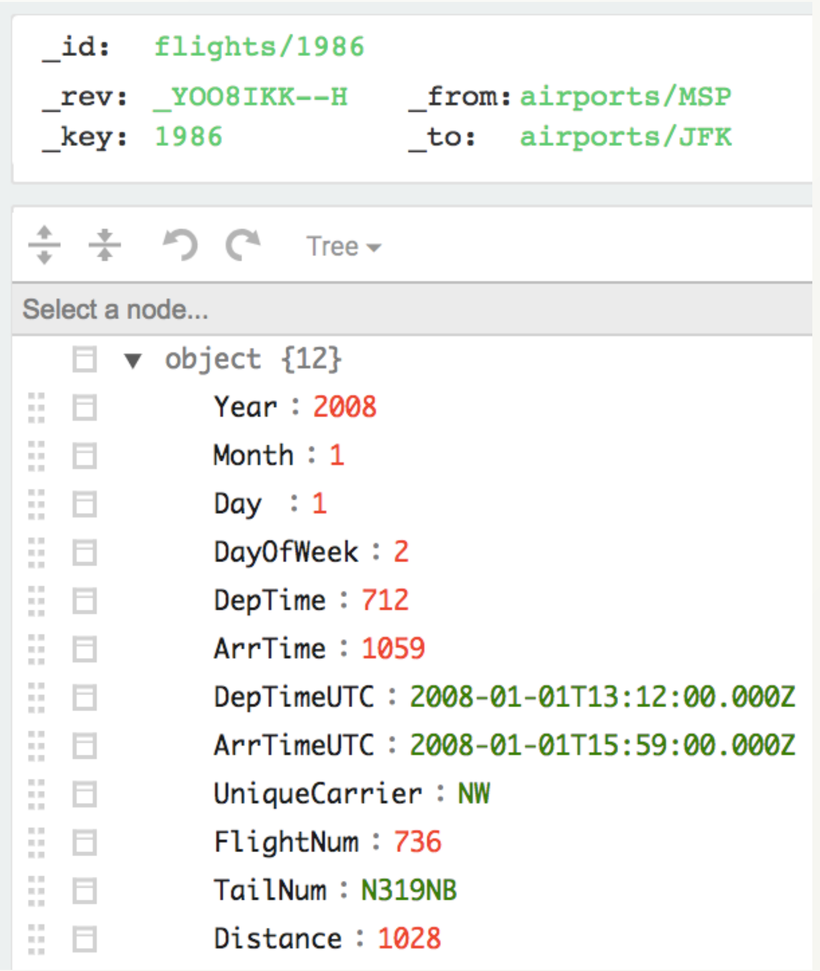
The Example Dataset

ArangoDB

Data structure of flights documents:

Attribute	Description
_from	Origin (airport _id)
_to	Destination (airport _id)
Year	Year of flight (here: 2008)
Month	Month of flight (1..12)
Day	Day of flight (1..31)
DayOfWeek	Weekday (1 = Monday .. 7 = Sunday)
DepTime	Actual departure time (local, *hhmm* as number)
ArrTime	Actual arrival time (local, *hhmm* as number)
DepTimeUTC	Departure time (coord. universal time, ISO string)
ArrTimeUTC	Arrival time (coordinated universal time, ISO string)
FlightNum	Flight number
TailNum	Plane tail number
UniqueCarrier	Unique carrier code
Distance	Travel distance in miles

Example flight as shown in the document editor of the web interface:



The Example Dataset

ArangoDB

Here are some example documents from both collections (JSON view mode):

airports


```
{
  "_key": "JFK",
  "_id": "airports/JFK",
  "_rev": "_YOO08KG-_T",
  "name": "John F Kennedy Intl",
  "city": "New York",
  "state": "NY",
  "country": "USA",
  "lat": 40.63975111,
  "long": -73.77892556,
  "vip": true
}
```



```
{
  "_key": "BIS",
  "_id": "airports/BIS",
  "_rev": "_YOSrLBe--r",
  "name": "Bismarck Municipal",
  "city": "Bismarck",
  "state": "ND",
  "country": "USA",
  "lat": 46.77411111,
  "long": -100.7467222,
  "vip": false
}
```


flights


```
{
  "_key": "25471",
  "_id": "flights/25471",
  "_from": "airports/BIS",
  "_to": "airports/MSP",
  "_rev": "_YOO8JXG--f",
  "Year": 2008,
  "Month": 1,
  "Day": 2,
  "DayOfWeek": 3,
  "DepTime": 1055,
  "ArrTime": 1224,
  "DepTimeUTC": "2008-01-02T16:55:00.000Z",
  "ArrTimeUTC": "2008-01-02T18:24:00.000Z",
  "UniqueCarrier": "9E",
  "FlightNum": 5660,
  "TailNum": "85069E",
  "Distance": 386
}
```



```
{
  "_key": "71374",
  "_id": "flights/71374",
  "_from": "airports/JFK",
  "_to": "airports/DCA",
  "_rev": "_YOO8LYG--N",
  "Year": 2008,
  "Month": 1,
  "Day": 4,
  "DayOfWeek": 5,
  "DepTime": 1604,
  "ArrTime": 1724,
  "DepTimeUTC": "2008-01-04T21:04:00.000Z",
  "ArrTimeUTC": "2008-01-04T22:24:00.000Z",
  "UniqueCarrier": "MQ",
  "FlightNum": 4755,
  "TailNum": "N854AE",
  "Distance": 213
}
```

Concepts of ArangoDB

What is Multi-Model?

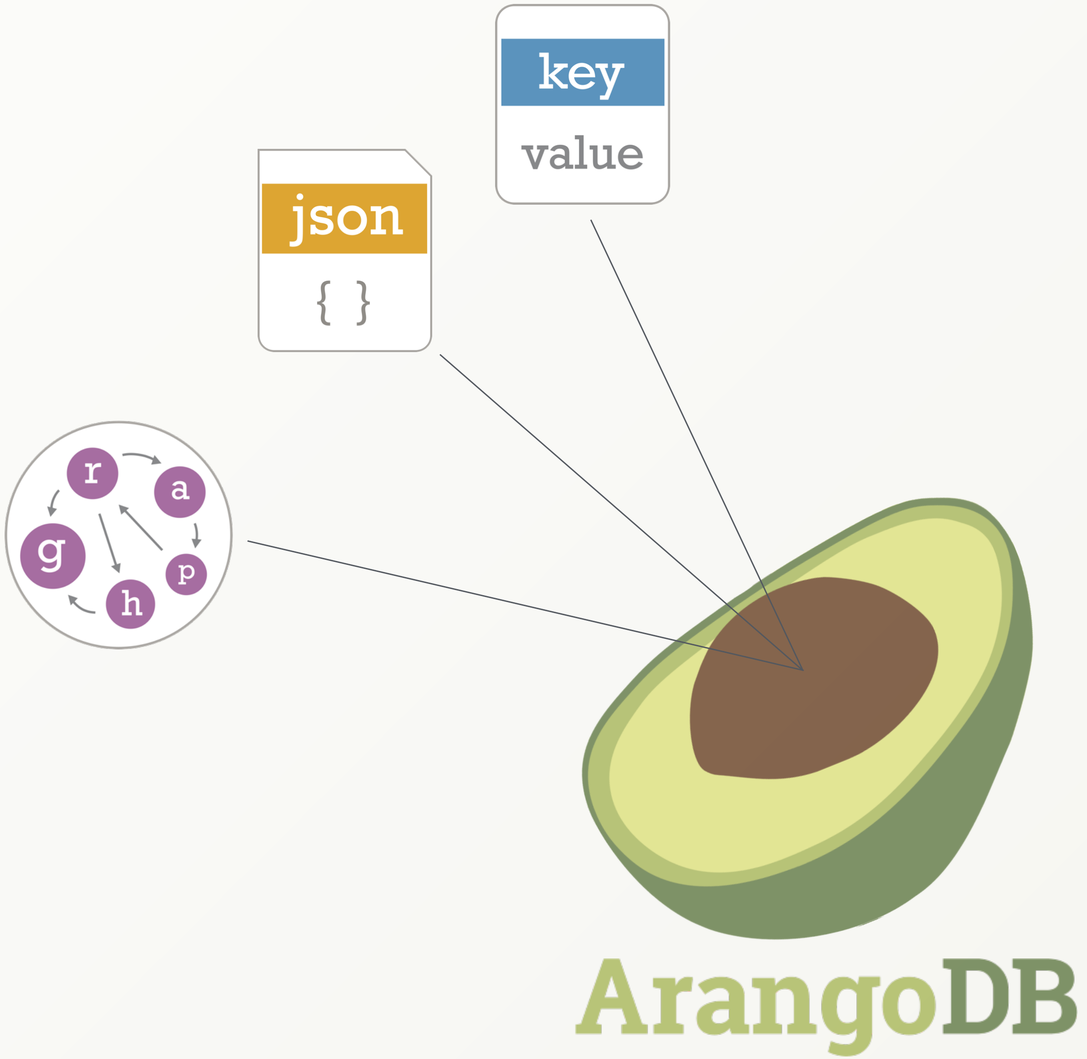
&

ArangoDB Architecture

What is Multi-Model?

- ArangoDB is a **native multi-model** database
  - **Multi-Model**: ArangoDB supports three major NoSQL data models
  - **Native**: Supports all data models with one database core and one query language (AQL)

- Unique features of AQL:
  - Possibility to combine all 3 data models in a single query
  - combine joins, traversals, filters, geo-spatial operations and aggregations in your queries



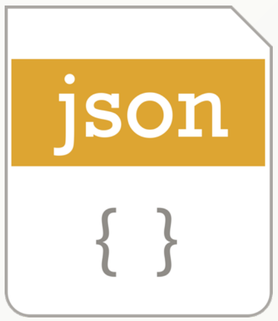
What is Multi-Model?

ArangoDB

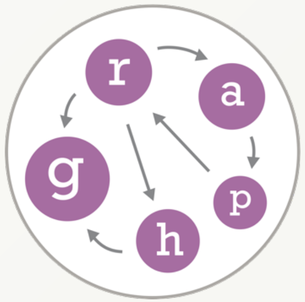
How is multi-model possible at all?

If you store a JSON document and treat it as opaque value under a primary key then you have a key/value store.

ArangoDB is a document-oriented data store using primary keys



Special *_from* and *_to* attributes in edge documents pointing to other documents make up your graph in ArangoDB



What is Multi-Model?

ArangoDB

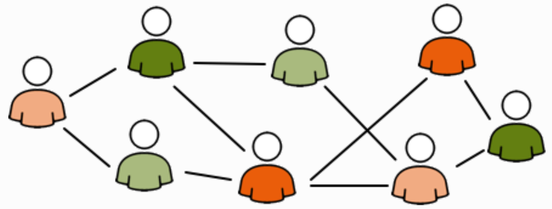
Benefits of ArangoDB's **NATIVE MULTI-MODEL** approach

Documents - JSON

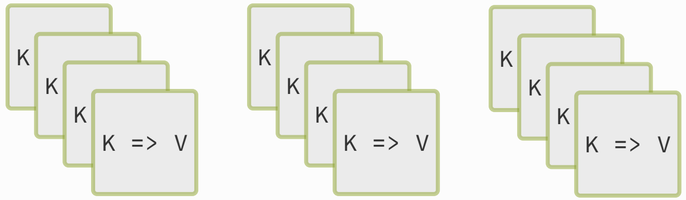
```
{
 "type":      "pants",
 "waist":     "32",
 "length":    "34",
 "color":     "blue",
 "material":  "cotton"
}
```

```
{
 "type":               "television",
 "diagonal size":      "46",
 "hdmi inputs":        "3",
 "wall mountable":     "true",
 "built-in tuner":     "true",
 "dynamic contrast":   "50,000:1",
 "Resolution":         "1920x1080"
}
```

Graphs



Key Values



no data-model lock-in

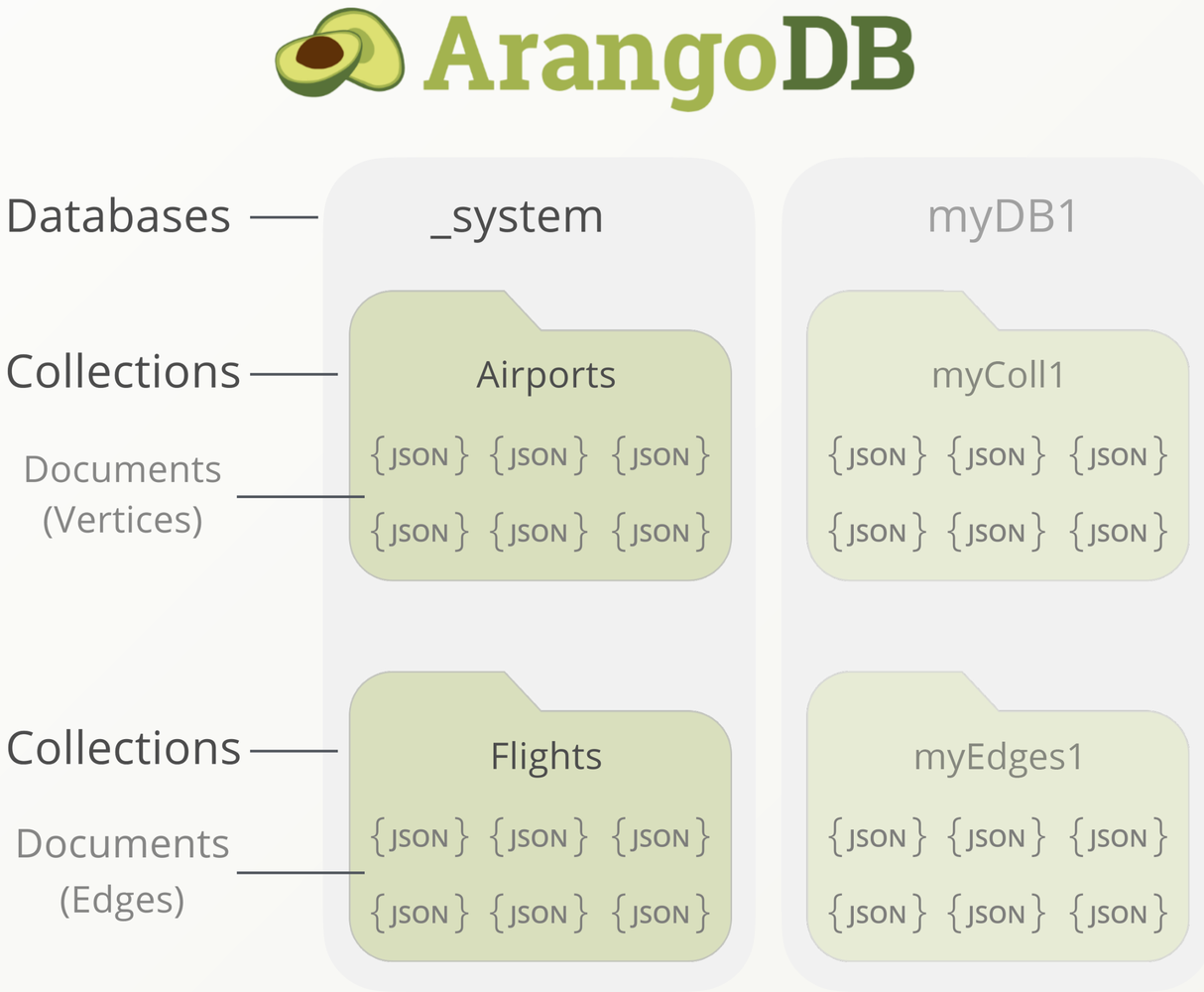
simpler development

larger solution-space
than relational model

ArangoDB Architecture

ArangoDB has a storage hierarchy like other databases have too:

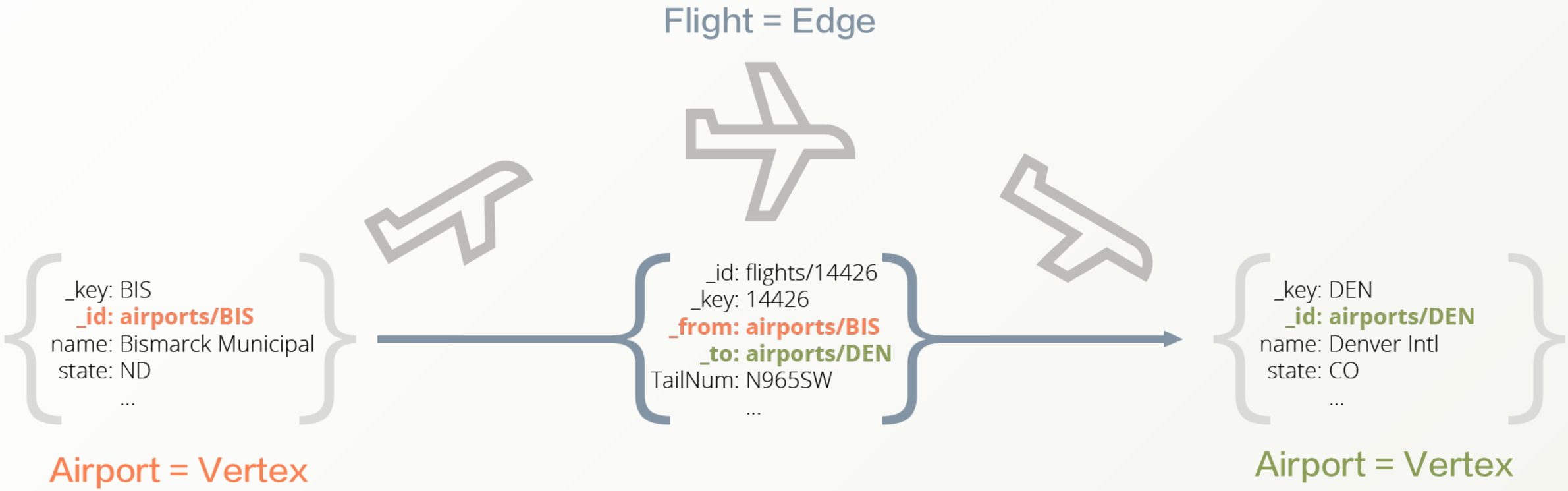
- You can create different **Databases** which can hold an arbitrary number of collections. There is a default database called *_system*
- **Collections** can hold arbitrary amounts of documents. There are two collection types: document and edge collections
- **Documents** are stored in **JSON** format. A document is a JSON object at the top-level, whose attribute names are strings and the values can be null, true, false, numbers, strings, arrays and nested objects. There are also system attributes (*_key*, *_id*, *_rev*, for edges also *_from*, *_to*)



ArangoDB Architecture

How do airports & flights form a graph?

Airports are the vertices, flights are the edges. The *_id* attribute of airport documents is used for the *_from* and *_to* attributes in the edge documents to link airports together by flights.



ArangoDB Architecture

The two collection types in summary:

Document collections

- Contain documents
  Each document is a JSON object
- Built-in primary index
  Each document has a unique *_key*
  by which it can be found quickly
- Documents can be vertices
  if they are used as nodes in a graph

Edge collections

- Contain documents, but with special edge attributes
  _from: *_id* value of the source vertex
  _to: *_id* value of the target vertex
- Built-in edge index for every edge collection
- Place to hold relations
  Comparable with many-to-many relations in SQL database systems (cross tables)

Preparations for this Course

Download and Install ArangoDB

&

Import the Dataset

Download and Install ArangoDB

- Go to arangodb.com/download/ to find the latest *Community* or *Enterprise Edition* for your operating system. Follow the instructions on how to download and install it for your OS. We recommend to set a password for the default user *root*. Further details can be found here: arangodb.com/docs/stable/installation.html
- Once the server is booted up, open **http://localhost:8529** in your browser to access *Aardvark*, the ArangoDB WebUI
- Login with your credentials, e.g. as *root*.
  If you did not set a password, then leave the password field empty.
- Next, select a database, e.g. the default *_system* database.

Import the Dataset – Airports

ArangoDB

- Download the example dataset here:
  arangodb.com/arangodb_graphcourse_demodata/
- Unpack it to a folder of your choice.
  After unpacking you should see two .csv files named airports.csv and flights.csv
- Import the airports with ArangoDB's import tool *arangoimport*.
  Run the following on your command line (single line):

```
arangoimport --file path to airports.csv on your machine
--collection airports --create-collection true --type csv
```

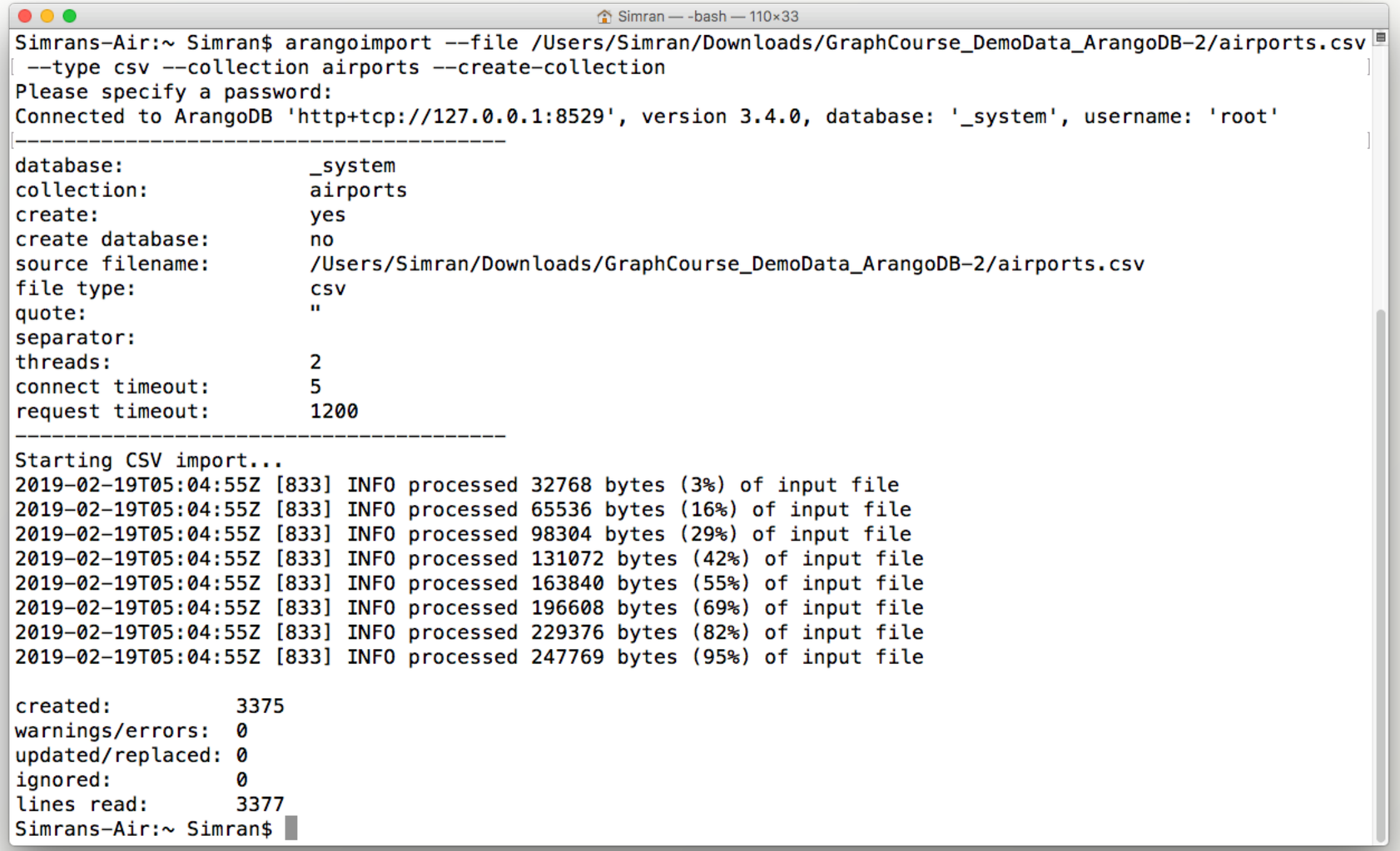
You can specify **`--server.username name`** to use another user than *root*.
If you did not set a password or if the server has authentication disabled then just hit return when asked for a password.

If ArangoDB is in your *PATH* environment variable, then you can run the binaries by their name from any working directory. Otherwise specify the full path.

Import the Dataset – Airports

ArangoDB

You should see something like this in your console after putting in the import command:



Import the Dataset – Airports

ArangoDB

What did *arangoimport* do?

- Created a new *document* collection (airports) with a primary index on *_key*
- Created one document for each line of the CSV file (except the first line and last, empty line)
- The first line is the header defining the attribute names

Note:

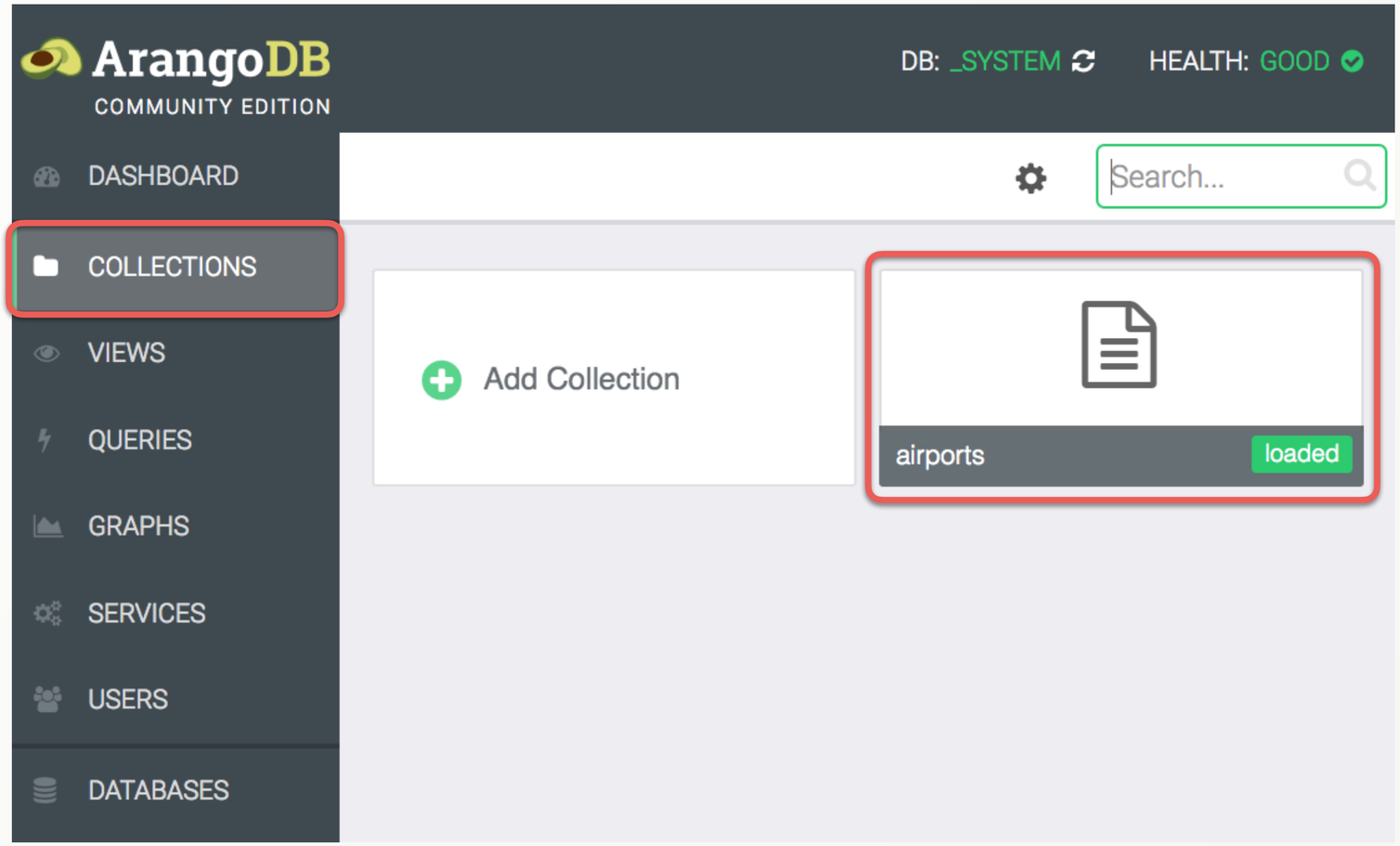
- Airport codes are provided as *_key* attribute in the CSV file
- The *_key* attribute is the primary key which uniquely identifies documents within a collection. Therefore, we will be able to retrieve airports via their airport code utilizing the primary index

airports.csv

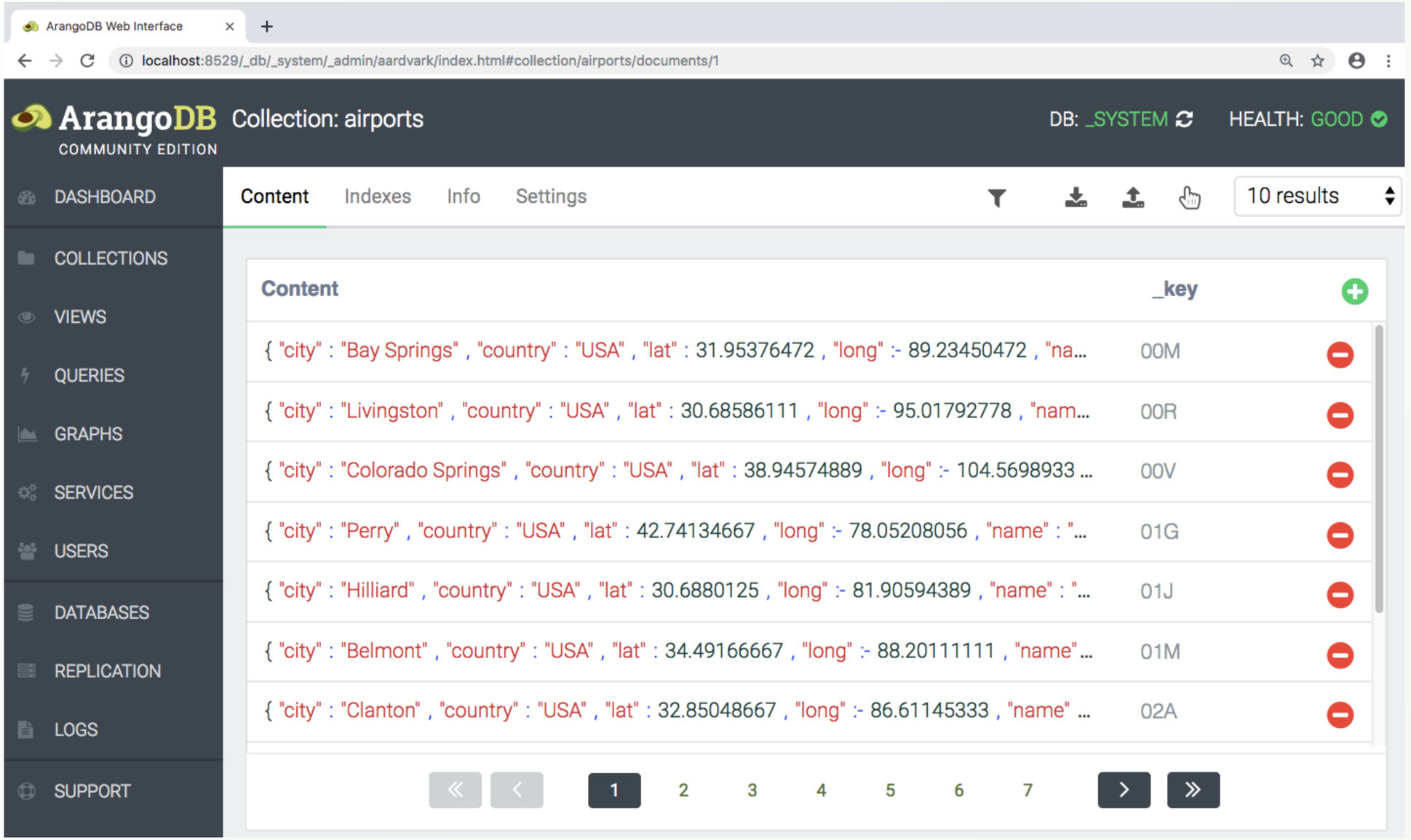
```
"_key","name","city","state","country","lat","long","vip"
"00M","Thigpen ","Bay Springs","MS","USA",31.95376472,-89.23450472,false
"00R","Livingston Municipal","Livingston","TX","USA",30.68586111,-95.01792778,false
"00V","Meadow Lake","Colorado Springs","CO","USA",38.94574889,-104.5698933,false
"01G","Perry-Warsaw","Perry","NY","USA",42.74134667,-78.05208056,false
"01J","Hilliard Airpark","Hilliard","FL","USA",30.6880125,-81.90594389,false
"01M","Tishomingo County","Belmont","MS","USA",34.49166667,-88.20111111,false
"02A","Gragg-Wade ","Clanton","AL","USA",32.85048667,-86.61145333,false
"02C","Capitol","Brookfield","WI","USA",43.08751,-88.17786917,false
"02G","Columbiana County","East Liverpool","OH","USA",40.67331278,-80.64140639,false
"03D","Memphis Memorial","Memphis","MO","USA",40.44725889,-92.22696056,false
"04M","Calhoun County","Pittsboro","MS","USA",33.93011222,-89.34285194,false
"04Y","Hawley Municipal","Hawley","MN","USA",46.88384889,-96.35089861,false
"05C","Griffith-Merrillville ","Griffith","IN","USA",41.51961917,-87.40109333,false
"05F","Gatesville - City/County","Gatesville","TX","USA",31.42127556,-97.79696778,false
"05U","Eureka","Eureka","NV","USA",39.60416667,-116.0050597,false
"06A","Moton  Municipal","Tuskegee","AL","USA",32.46047167,-85.68003611,false
"06C","Schaumburg","Chicago/Schaumburg","IL","USA",41.98934083,-88.10124278,false
"06D","Rolla Municipal","Rolla","ND","USA",48.88434111,-99.62087694,false
"06M","Eupora Municipal","Eupora","MS","USA",33.53456583,-89.31256917,false
"06N","Randall ","Middletown","NY","USA",41.43156583,-74.39191722,false
"06U","Jackpot/Hayden ","Jackpot","NV","USA",41.97602222,-114.6580911,false
"07C","Dekalb County","Auburn","IN","USA",41.30716667,-85.06433333,false
"07F","Gladewater Municipal","Gladewater","TX","USA",32.52883861,-94.97174556,false
"07G","Fitch H Beach","Charlotte","MI","USA",42.57450861,-84.81143139,false
"07K","Central City Municipal","Central City","NE","USA",41.11668056,-98.05033639,false
"08A","Wetumpka Municipal","Wetumpka","AL","USA",32.52943944,-86.32822139,false
"08D","Stanley Municipal","Stanley","ND","USA",48.30079861,-102.4063514,false
"08K","Harvard State","Harvard","NE","USA",40.65138528,-98.07978667,false
"08M","Carthage-Leake County","Carthage","MS","USA",32.76124611,-89.53007139,false
"09A","Butler-Choctaw County","Butler","AL","USA",32.11931306,-88.1274625,false
"09J","Jekyll Island","Jekyll Island","GA","USA",31.07447222,-81.42777778,false
"09K","Sargent Municipal","Sargent","NE","USA",41.63695083,-99.34038139,false
"09M","Charleston Municipal","Charleston","MS","USA",33.99150222,-90.078145,false
"09W","South Capitol Street","Washington","DC","USA",38.86872333,-77.00747583,false
"0A3","Smithville Municipal","Smithville","TN","USA",35.98531194,-85.80931806,false
"0A8","Bibb County","Centreville","AL","USA",32.93679056,-87.08888306,false
"0A9","Elizabethton Municipal","Elizabethton","TN","USA",36.37094306,-82.17374111,false
"0AK","Pilot Station","Pilot Station","AK","USA",61.93396417,-162.8929358,false
"0B1","Col. Dyke ","Bethel","ME","USA",44.42506444,-70.80784778,false
"0B4","Hartington Municipal","Hartington","NE","USA",42.60355556,-97.25263889,false
"0B5","Turners Falls","Montague","MA","USA",42.59136361,-72.52275472,false
```

Import the Dataset – Airports

- Go to ArangoDB WebUI (**http://localhost:8529** in your browser) and click on *COLLECTIONS* in the menu
- Collection "airports" should be there now
- The icon indicates that it is a **document** collection
- Click on the collection to browse its documents



Import the Dataset – Airports



Import the Dataset – Flights

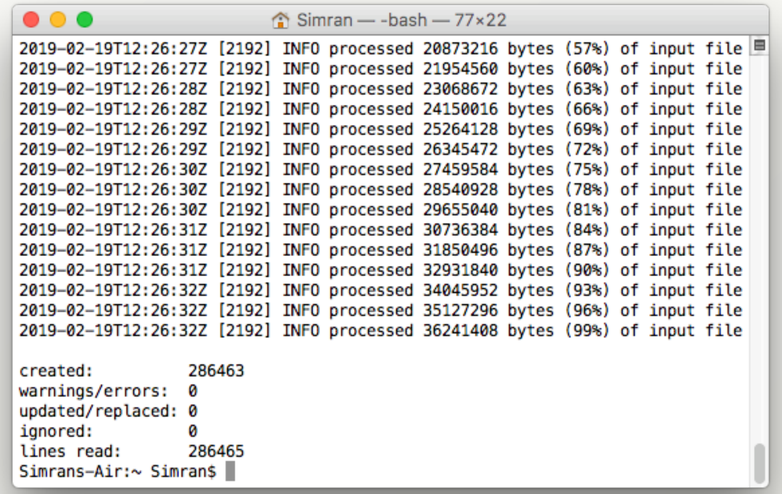
ArangoDB

The imported *airports* are the vertices of our graph. To complete our graph dataset, we also need edges to connect the vertices. In our case the edges are *flights*.

- Import the flights into an edge collection with *arangoimport*.
  Run the following in your command line (single line):

```
arangoimport --file path to flights.csv on your machine
--collection flights --create-collection true --type csv
--create-collection-type edge
```

Importing *flights.csv* might take a few moments to complete.
On a decent computer with at least 4 GB of memory and an SSD drive it should take less than a minute.



Import the Dataset – Flights

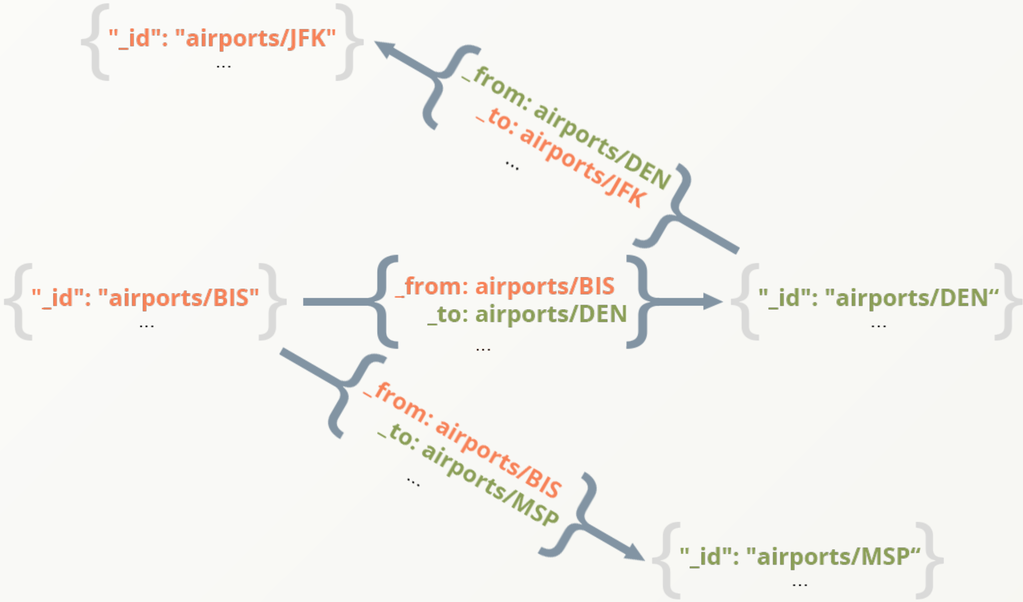
ArangoDB

What did *arangoimport* do?

- Created a new edge collection (flights) with a primary index on attribute *_key* and an edge index on *_from* and *_to*
- Created one edge document for each line of the CSV file (except the header and the last line)

Note:

- The *_from* and *_to* attributes form the graph by referencing document *_id*s of departure and arrival airports
- No *_key* is provided, thus it gets auto-generated

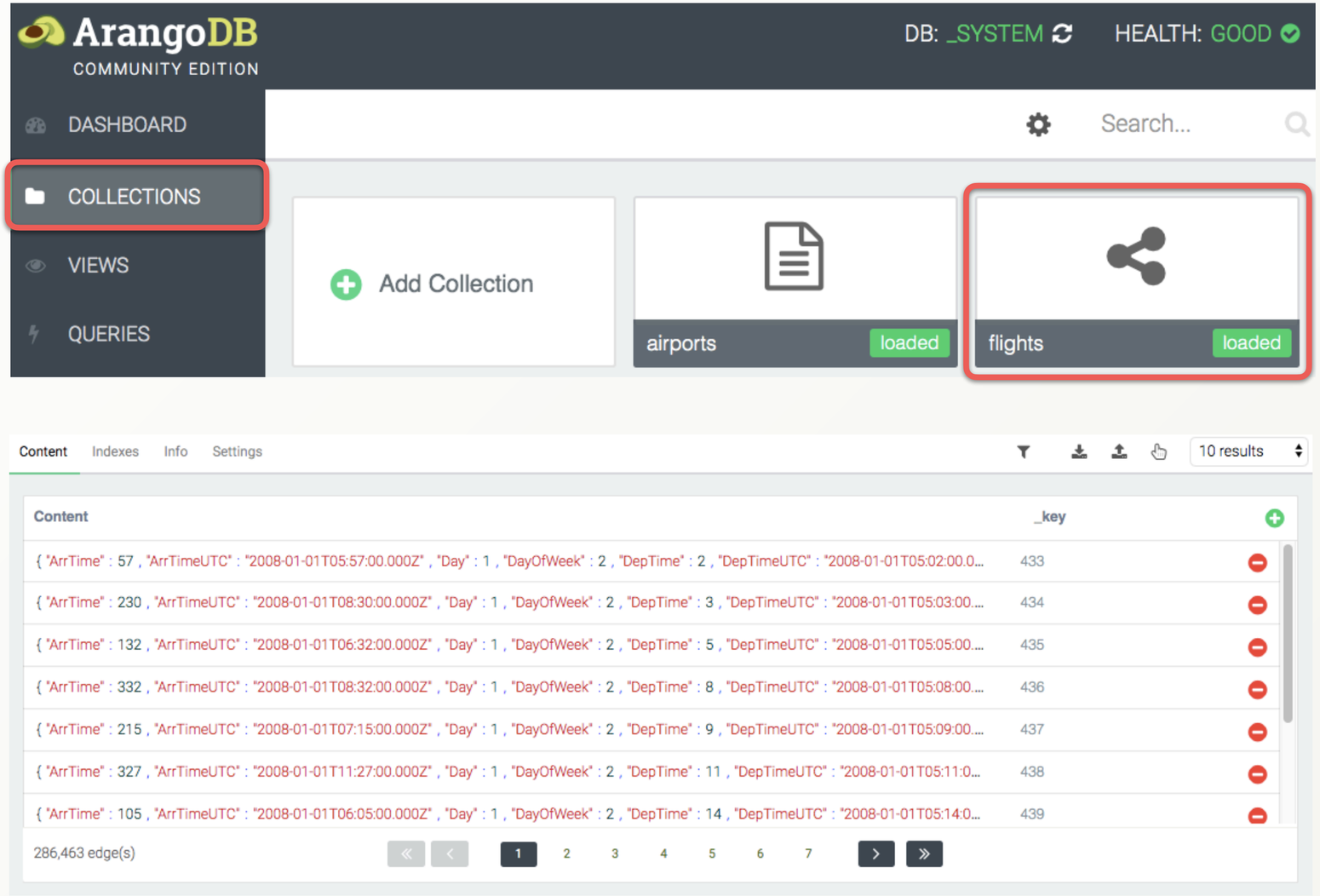


flights.csv

```
1  "_from","_to","Year","Month","Day","DayOfWeek","DepTime","ArrTime","DepTimeUTC","ArrTimeUTC","UniqueCarrier","FlightNum","TailNum","Distance"
2  "airports/ATL","airports/CHS",2008,1,1,2,2,57,"2008-01-01T05:02:00.000Z","2008-01-01T05:57:00.000Z","FL",579,"N937AT",259
3  "airports/CLE","airports/SAT",2008,1,1,2,3,230,"2008-01-01T05:03:00.000Z","2008-01-01T08:30:00.000Z","XE",2895,"N14158",1241
4  "airports/IAD","airports/CLE",2008,1,1,2,5,132,"2008-01-01T05:05:00.000Z","2008-01-01T06:32:00.000Z","YV",7185,"N592ML",288
5  "airports/JFK","airports/PBI",2008,1,1,2,8,332,"2008-01-01T05:08:00.000Z","2008-01-01T08:32:00.000Z","B6",859,"N505JB",1028
```

Import the Dataset – Flights

- Go to ArangoDB WebUI and click on COLLECTIONS in the menu
- Edge Collection "flights" should be there now
- The type of the collection is indicated by a different icon for **edge** collections
- Click on the flights collection to browse its edge documents



Starting with the dataset

AQL Query Editor

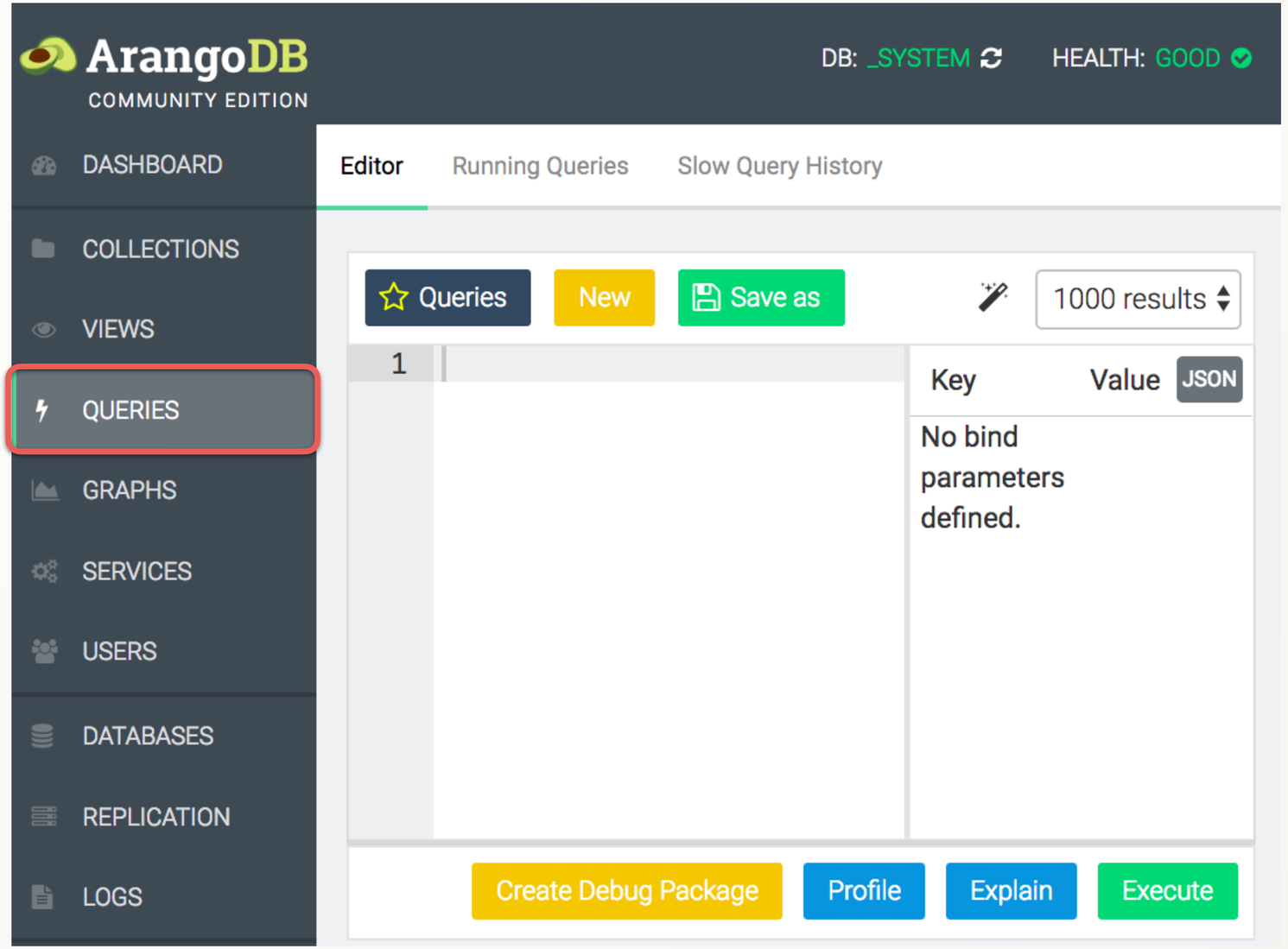
&

First AQL Queries

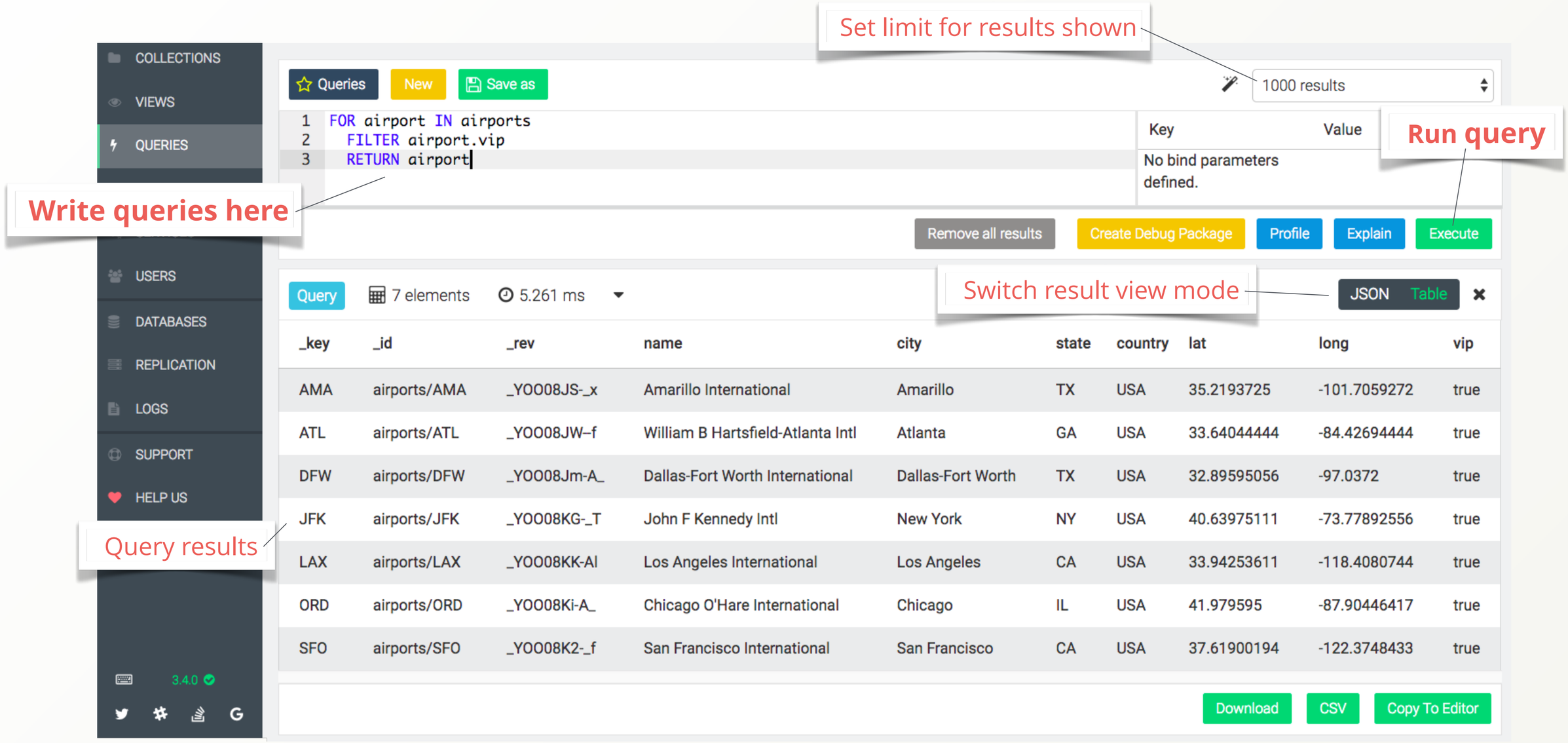
ArangoDB Query Editor

Now that we have demo data in ArangoDB, let us start to write AQL queries!

- Click on *QUERIES* in the ArangoDB WebUI
- It brings up the AQL query editor to write, execute and profile queries
- It supports syntax highlighting and allows you to save and manage queries



ArangoDB Query Editor



_key	_id	_rev	name	city	state	country	lat	long	vip
AMA	airports/AMA	_YOO08JS-_x	Amarillo International	Amarillo	TX	USA	35.2193725	-101.7059272	true
ATL	airports/ATL	_YOO08JW–f	William B Hartsfield-Atlanta Intl	Atlanta	GA	USA	33.64044444	-84.42694444	true
DFW	airports/DFW	_YOO08Jm-A_	Dallas-Fort Worth International	Dallas-Fort Worth	TX	USA	32.89595056	-97.0372	true
JFK	airports/JFK	_YOO08KG-_T	John F Kennedy Intl	New York	NY	USA	40.63975111	-73.77892556	true
LAX	airports/LAX	_YOO08KK-Al	Los Angeles International	Los Angeles	CA	USA	33.94253611	-118.4080744	true
ORD	airports/ORD	_YOO08Ki-A_	Chicago O'Hare International	Chicago	IL	USA	41.979595	-87.90446417	true
SFO	airports/SFO	_YOO08K2-_f	San Francisco International	San Francisco	CA	USA	37.61900194	-122.3748433	true

First AQL Queries – Hands on

ArangoDB

- Fetch John F. Kennedy airport by *_id* using the DOCUMENT() function, which will look up the document utilizing the primary index:

```
RETURN DOCUMENT("airports/JFK")
```

- Use a FOR loop to iterate over the airports collection, filter by *_key* and return the Kennedy airport document. This pattern gets optimized automatically to utilize the primary index as well:

```
FOR airport IN airports
  FILTER airport._key == "JFK"
  RETURN airport
```

- This construct can be used for complex filter criteria. Various operators are available.

```
FOR airport IN airports
  FILTER airport.city == "New York"
     AND airport.state == "NY"
  RETURN airport
```

- You can SORT the results by one or multiple conditions in ascending (default) and descending order (DESC), as well as offset and LIMIT the number of results. Note: The order of such high-level operations influences the output!

```
FOR a IN airports
  FILTER a.vip
  SORT a.state, a.name DESC
  LIMIT 5
  RETURN a
```

- You don't have to RETURN full documents, you can also return just parts of them (see the KEEP() and UNSET() functions for instance) or construct the query result as you desire:

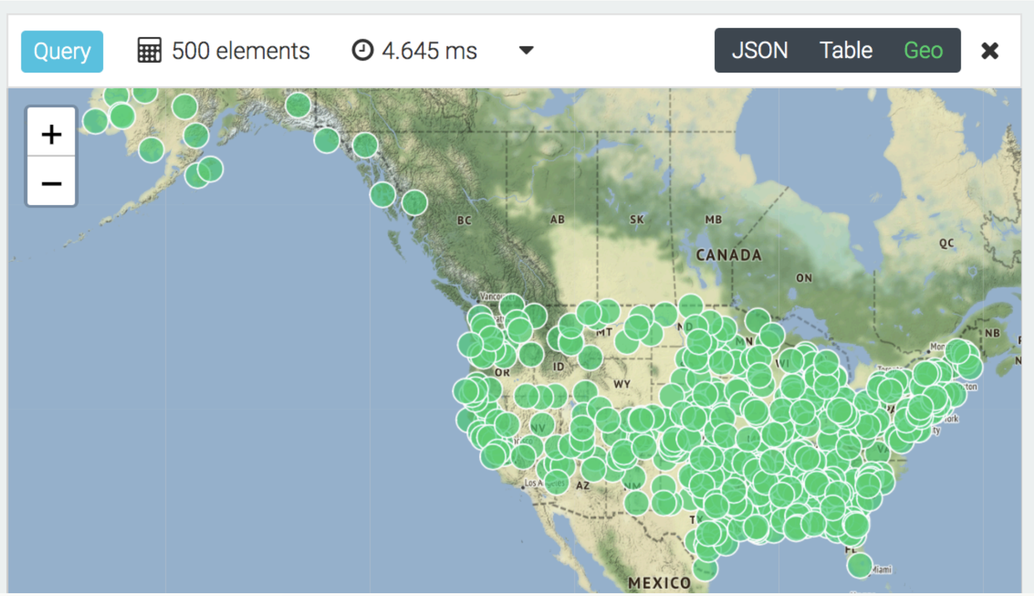
```
FOR a IN airports
  FILTER a._key IN ["JFK", "LAX"]
  RETURN { fullName: a.name }
```

First AQL Queries – Hands on

- Make a GeoJSON object with GEO_POINT() from the *long* and *lat* attributes for 500 airports:

```
FOR a IN airports
  LIMIT 500
  RETURN GEO_POINT(a.long, a.lat)
```

The web interface detects that the result is an array of GeoJSON features and displays a map:



- Count all documents in the collection:

```
RETURN COUNT(airports)
```

- Count how many V.I.P. airports there are. Below we use COLLECT to group the intermediate results without condition, which means all filtered documents are grouped together. COLLECT has a syntax variation which allows us to count the number of documents efficiently. We return this number as result:

```
FOR airport IN airports
  FILTER airport.vip
  COLLECT WITH COUNT INTO count
  RETURN count
```

Feel free to experiment further. You can do a lot more with AQL, but that is beyond the scope of this course. Find the full AQL documentation online and also see the Training Center on our website!

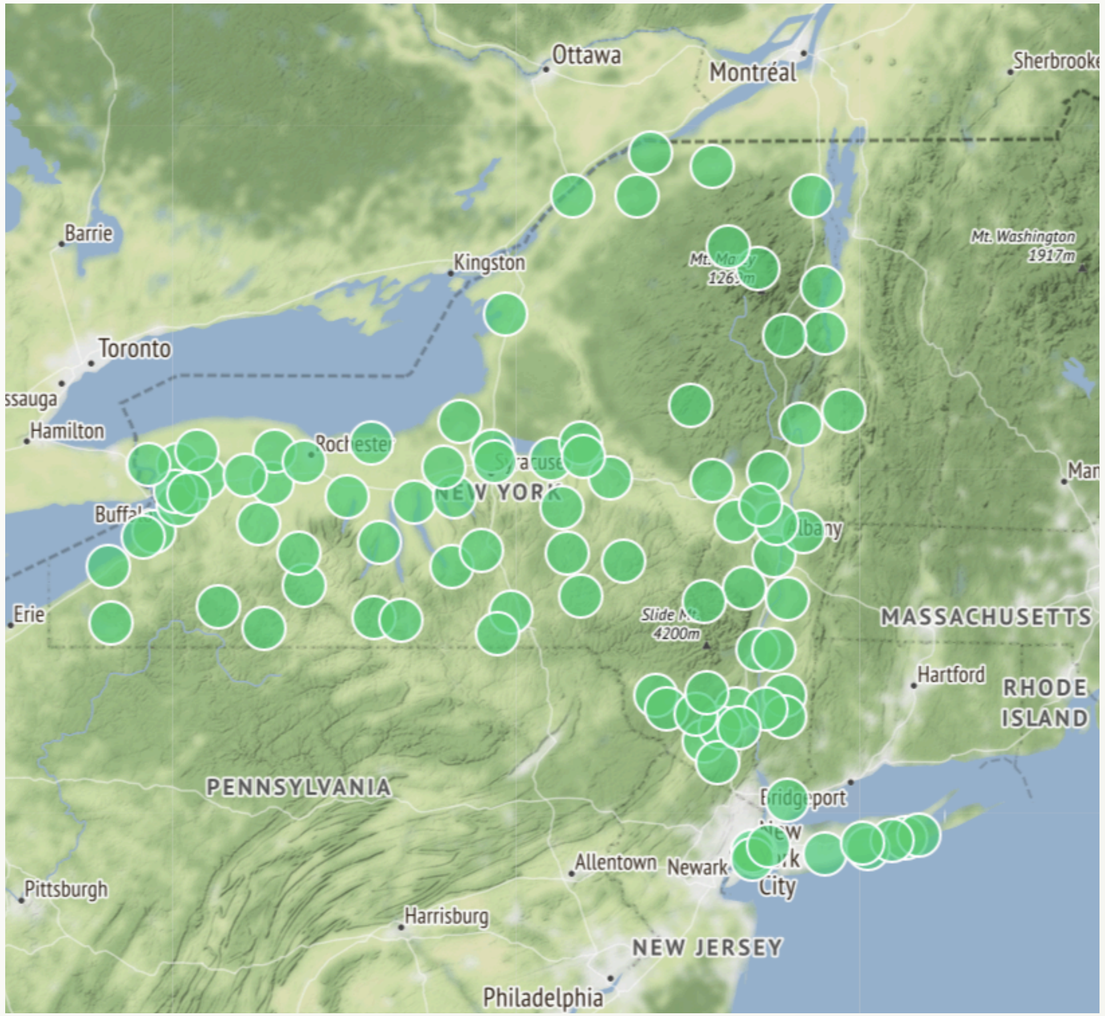
First AQL Queries – Knowledge Check

ArangoDB

Exercises A: Document Queries

Here are some challenges if you want to practice your AQL skills. Example solutions can be found at the end of this course.

1. Retrieve the airport document of Los Angeles International (LAX).
2. Retrieve all airport documents of the city Los Angeles.
3. Find all airports of the state North Dakota (ND) and return the name attribute only.
4. Retrieve multiple airports via their primary key (_key), for example BIS, DEN and JFK. Return an object for each match: `RETURN {airport: a.name}`
5. Count the airports in the state New York (NY) which are **not** vip.



Graph Traversals

Traversals explained

&

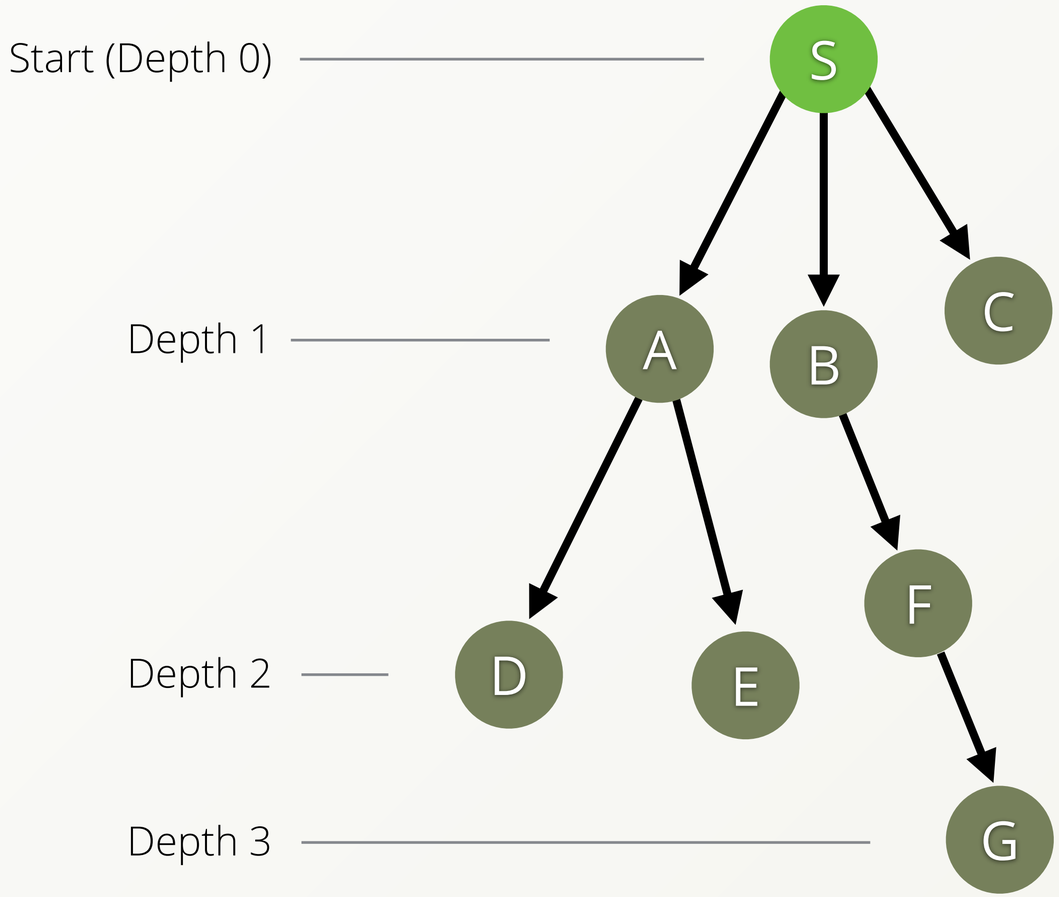
Graph Traversal Syntax

Traversals explained

Traversal means to walk along edges of a graph in certain ways, optionally with some filters. Traversing is very efficient in graph databases. In ArangoDB, this is achieved by a hybrid index type which you already heard of: the edge index.

How many steps to go in a traversal is known as traversal **depth**:

- The starting vertex in a traversal (S) has a traversal depth of zero.
- At depth = 1 are the direct neighbors of S (A, B and C).
- Their neighbor vertices in turn are at depth = 2 (D, E and F).



Graph Traversal Syntax

ArangoDB

Before we do more graph queries we should spend some time on the underlying concepts of the query options. We will go through the keywords and basic options step-by-step:

Query Syntax

```
FOR vertex[, edge[, path]]
  IN [min[..max]]
  OUTBOUND|INBOUND|ANY startVertex
  edgeCollection[, more…]
```

By the way: Keywords like **FOR**, **IN** and **ANY** are written all upper case in the code examples, but it is merely a convention. You may also write them all lower case or in mixed case. Names of variables, attributes and collections are case-sensitive however!

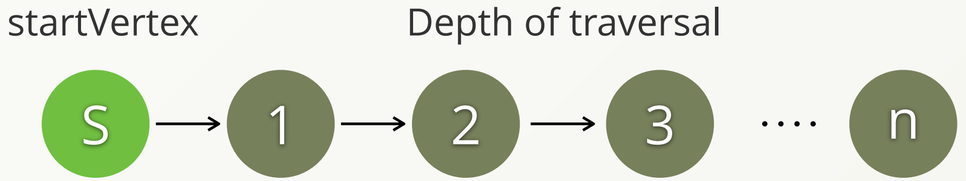
Traversal in AQL documentation

Explanation

FOR emits up to three variables

- vertex (object): the current vertex in a traversal
- edge (object, optional): the current edge in a traversal
- path (object, optional): representation of the current path with two members:
  - vertices: an array of all vertices on this path
  - edges: an array of all edges on this path

IN min..max: defines the minimal and maximal depth for the traversal. If not specified **min** defaults to **1** and **max** defaults to **min**



Graph Traversal Syntax

ArangoDB

Before we do more graph queries we should spend some time on the underlying concepts of the query options. We will go through the keywords and basic options step-by-step:

Query Syntax

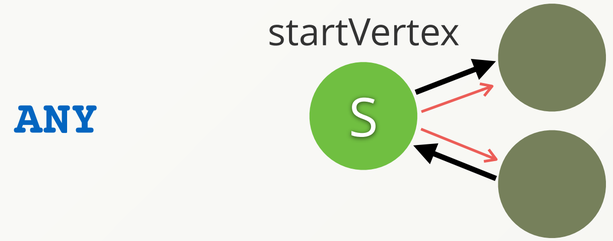
```
FOR vertex[, edge[, path]]
  IN [min[..max]]
  OUTBOUND|INBOUND|ANY startVertex
  edgeCollection[, more…]
```

Explanation

`OUTBOUND/INBOUND/ANY` defines the direction of your search

Traversal follows **outgoing** edges

Traversal follows **incoming** edges



Traversal follows edges pointing in **any direction**

Traversal in AQL documentation

`edgeCollection`: one or more names of collections holding the edges that we want to consider in the traversal (anonymous graph)

First Graph Queries – Hands on

ArangoDB

Take a look at the following graph queries to get a better understanding for the traversal syntax, try them out and inspect the results:

- Return the names of all airports one can reach directly (1 step) from Los Angeles International (LAX) following the flights edges:

```
FOR airport IN 1..1 OUTBOUND
'airports/LAX' flights
  RETURN DISTINCT airport.name
```

- Return any 10 flight documents with the flight **departing** at LAX and the destination airport documents like `{"airport":{…},"flight":{…}}`

```
FOR airport, flight IN OUTBOUND
'airports/LAX' flights
  LIMIT 10
  RETURN {airport, flight}
```

- Return 10 flight numbers with the plane **landing** in Bismarck Municipal airport (BIS):

```
FOR airport, flight IN INBOUND
'airports/BIS' flights
  LIMIT 10
  RETURN flight.FlightNum
```

- Find all connections which **depart from or land at** BIS on January 5th and 7th and return the destination city and the arrival time in universal time (UTC):

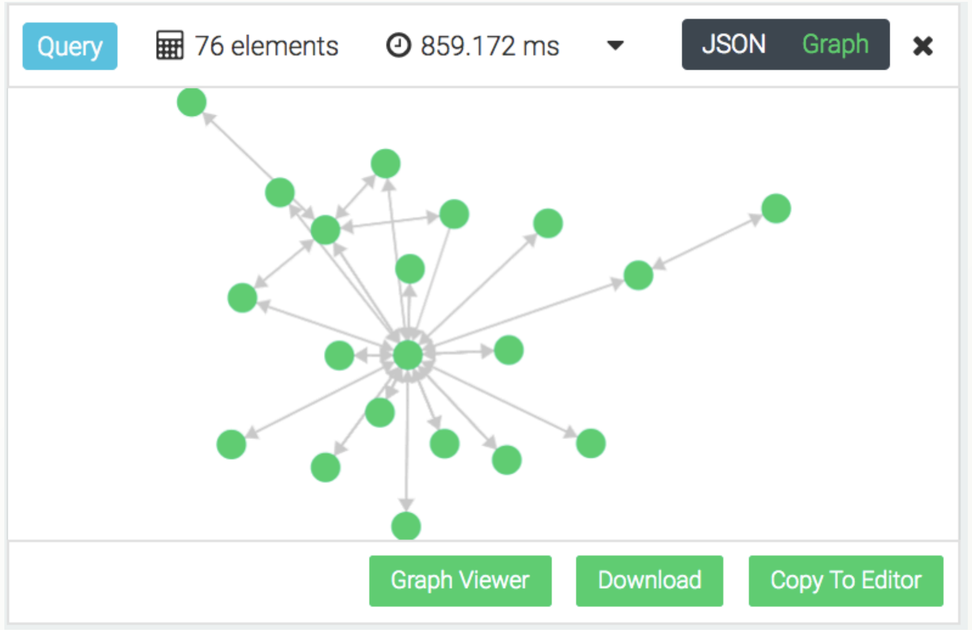
```
FOR airport, flight IN ANY
'airports/BIS' flights
  FILTER flight.Month == 1
     AND flight.Day >= 5
     AND flight.Day <= 7
  RETURN { city: airport.city,
           time: flight.ArrTimeUTC }
```

First Graph Queries – Knowledge Check

- Edges can also be accessed without using graph traversals – they are just documents:

```
FOR flight IN flights
  FILTER flight.TailNum == "N238JB"
  RETURN flight
```

If there are *_from*, *_to* and *_id* attributes in the response, the WebUI will try to display the result in *Graph* view mode:



Exercises B: Graph Queries

1. Find all flights with FlightNum 860 (number) on January 5th and return the *_from* and *_to* attributes only (you may use KEEP() for this).
2. Find all flights departing or arriving at JFK with FlightNum 859 or 860 and return objects with flight numbers and airport names where the flights go to or come from respectively.
3. Combine a **FOR** loop and a traversal like:

```
FOR orig IN airports
 FILTER orig._key IN ["JFK", "PBI"]
 FOR dest,flight IN ANY orig flights
   …
```

to do multiple traversals with different starting points. Filter by flight numbers 859 and 860. Return `orig.name`, `dest.name`, FlightNum and Day. Name the attributes appropriately.

Traversal Options

Depth vs. Breadth First Search

&

Uniqueness Options

Depth vs. Breadth First Search

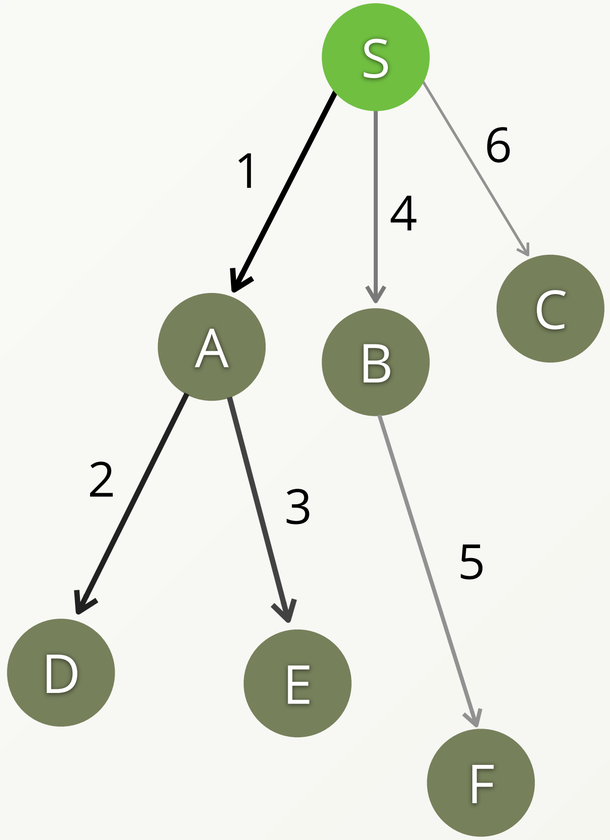
Everybody who already took a closer look into the documentation about traversals, saw that there are also **OPTIONS** to control the traversal behavior.

For traversals with a minimum depth greater than or equal to 2, you have two options how to traverse the graph:

- **Depth-first** (default): Continue down the edges from the start vertex to the last vertex on that path or until the maximum traversal depth is reached, then walk down the other paths.

- **Breadth-first** (optional): Follow all edges from the start vertex to the next level, then follow all edges of their neighbors by another level and continue this pattern until there are no more edges to follow or the maximum traversal depth is reached.

Depth-first search



Depth vs. Breadth First Search

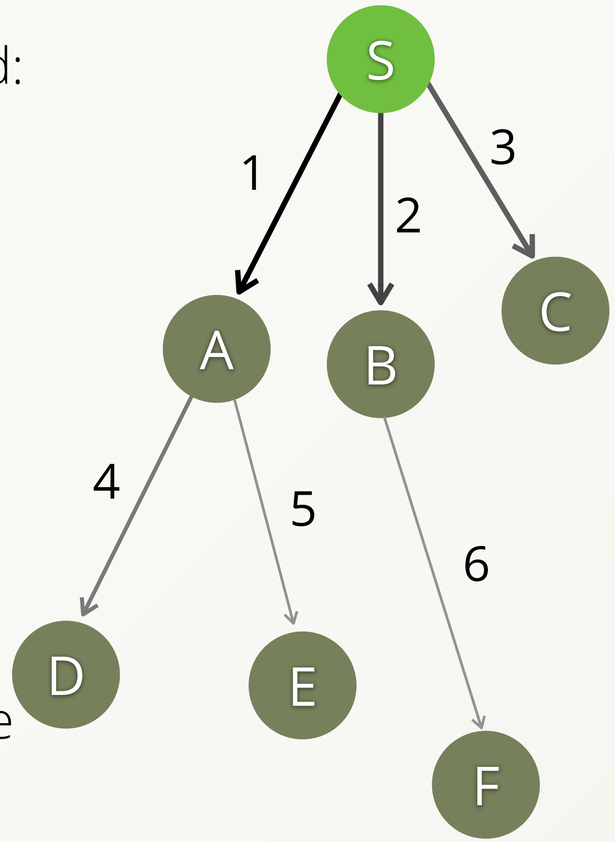
Both algorithms return the same amount of paths if all other traversal options are the same, but the order in which edges are followed and vertices are visited is different.

With a variable traversal depth of 1..2, the following paths would be found:

Depth-first	**Breadth-first**
S → A	S → A
S → A → D	S → B
S → A → E	S → C
S → B	S → A → D
S → B → F	S → A → E
S → C	S → B → F

Note that there is no particular order in which edges of a single vertex are followed. Hence, S→C may be returned before S→A and S→B. Shorter paths are returned before longer paths using breadth-first search still.

Breadth-first search



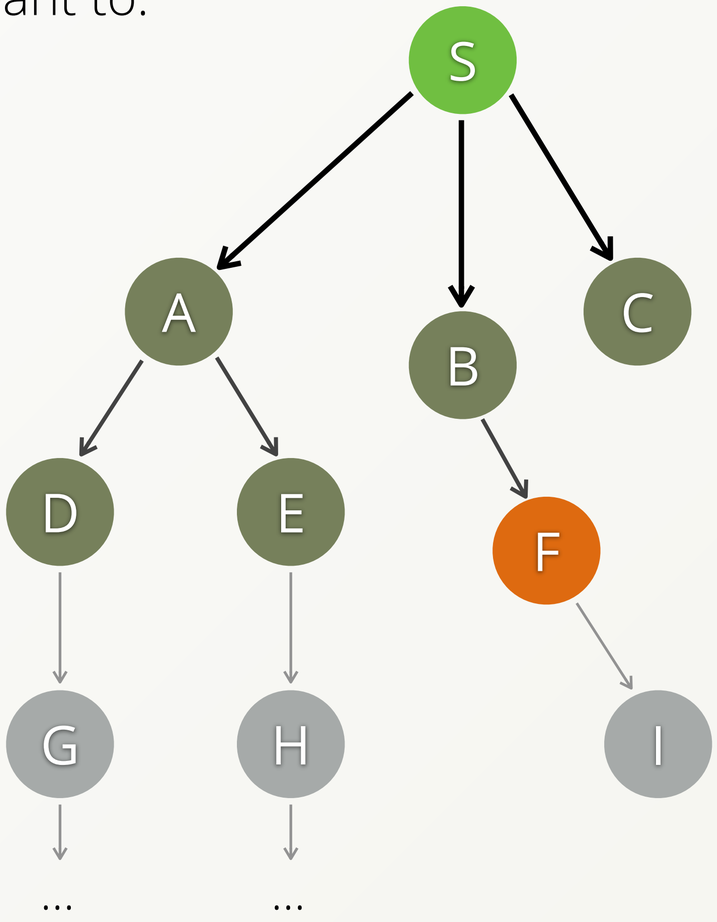
Depth vs. Breadth First Search

Breadth-first search can significantly improve performance if used together with filters and limits by stopping before the maximal depth is reached.

Whether it is applicable depends on the use case. For example, you want to:

- Traverse a graph from vertex S with depth 1..10
- Find 1 vertex that fulfills your criteria,
  lets assume vertex F meets your conditions
- Depth-first might follow the edge to A first, then all the way down up to 10 hops to D, G, E, H and more
- Breadth-first however finds F at depth 2 and never visits vertices past that level if you limit the query to a single match:

```
FOR v IN 1..10 OUTBOUND 'verts/S' edges
  OPTIONS {bfs: true}
  FILTER v._key == 'F'
  LIMIT 1
  RETURN v
```

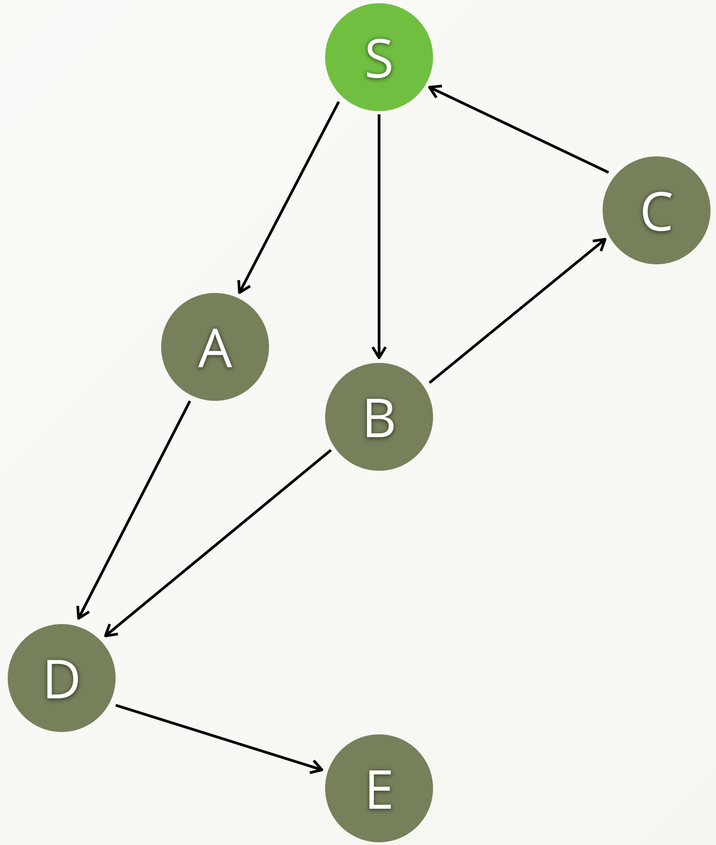


Uniqueness Options

Not every graph has just a single path from a chosen start vertex to its connected vertices. There may even be cycles in a graph.

- By default, the traversal along any of the paths is stopped if an edge is encountered again, that has already been visited. It keeps your traversals from running around in circles until the maximum traversal depth is reached. It is a safe guard to not produce a plethora of unwanted paths.
- Duplicate vertices on a path are allowed unless the traversal is configured otherwise.

Graph with cycle S→B→C→S and multiple paths from S to E



Uniqueness Options

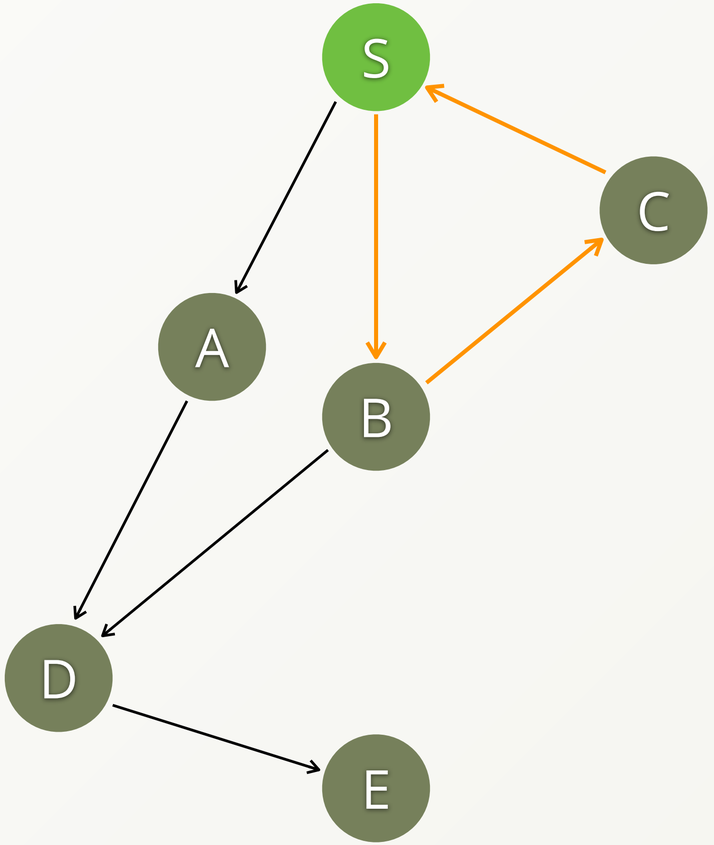
The following query specifies the uniqueness options explicitly, although the ones shown are used by default anyway:

```
FOR v, e, p IN 1..5 OUTBOUND 'verts/S' edges
  OPTIONS {
    uniqueVertices: 'none',
    uniqueEdges: 'path'
  }
  RETURN CONCAT_SEPARATOR('->', p.vertices[*]._key)
```

We use the path variable *p*, which is emitted by the traversal, and concatenate all vertex keys of the paths neatly as single string per path, like `"S->A->D->E"`. The array expansion operator `[*]` is used for convenience.

Array expansion in AQL documentation

Graph with cycle S→B→C→S and multiple paths from S to E



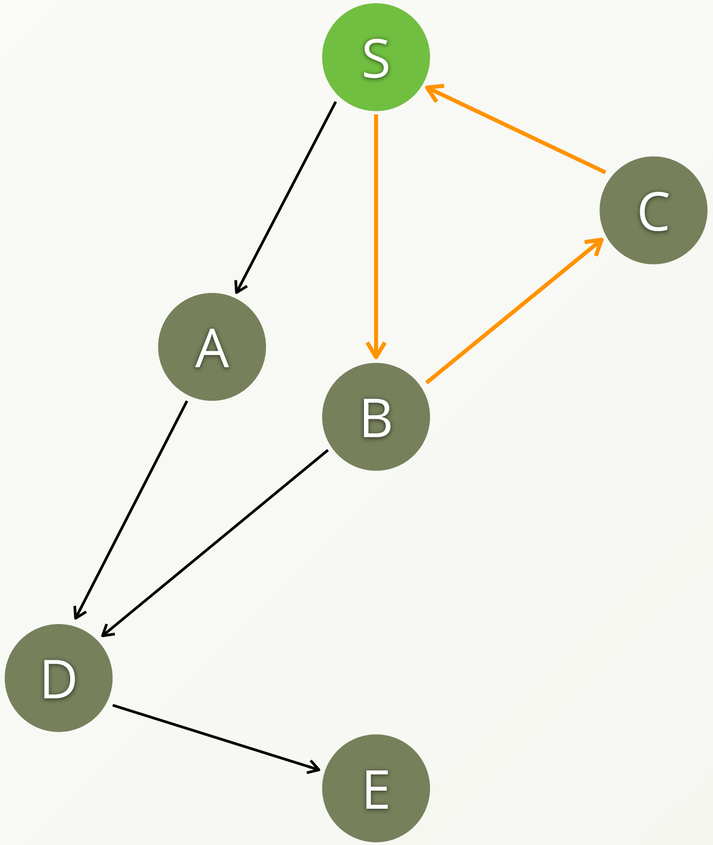
Uniqueness Options

The query finds a total of 10 paths. One of them is S→B→C→S. The start vertex is also the last vertex on that path, which is possible because uniqueness of vertices is not ensured.

A path such as S→B→C→S→B→C is not present in the result, because uniqueness of edges for paths avoids following the same edge twice.

- **`uniqueEdges:`** `'none'` would make the traverser follow the edge from S to B to C to S, and from S to B to C again. It would only stop there, because the maximum depth of 5 is reached at that point. If the maximum depth of the query was higher, then the traversal would run very long, producing a high amount of paths because of the loop.

Graph with cycle S→B→C→S and multiple paths from S to E



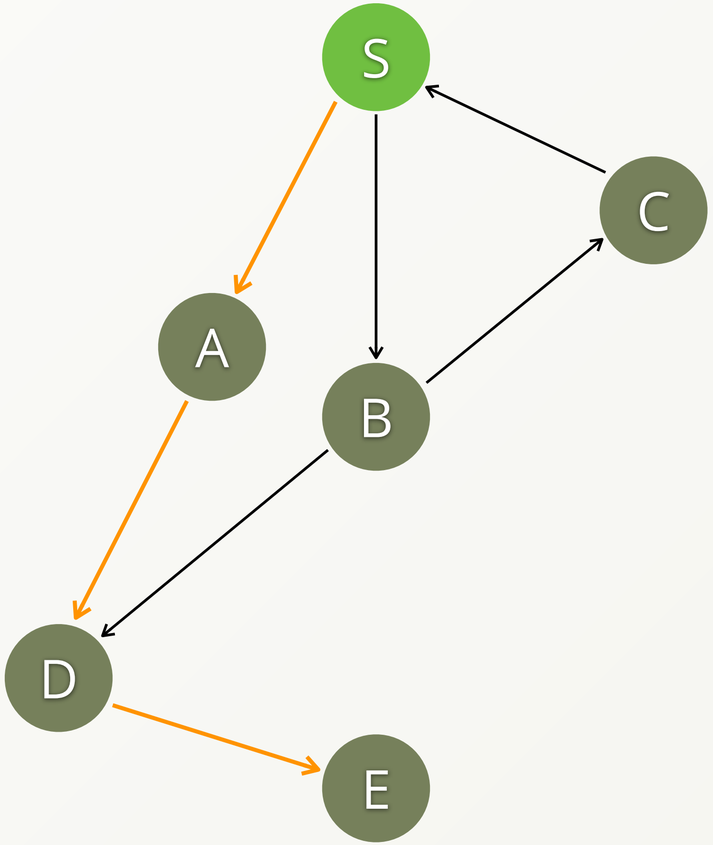
Uniqueness Options

To stop the start vertex (or other vertices) from being visited more than once, we can enable uniqueness for vertices in two ways:

- `uniqueVertices: 'path'` ensures no duplicate vertices on each individual path.
- `uniqueVertices: 'global'` ensures every reachable vertex to be visited once for the entire traversal.

  It requires `bfs: true` (breadth-first search). It is not supported for depth-first search, because the results would be completely non-deterministic (varying between query runs), as there is no rule in which order the traverser follows the edges of a vertex. The uniqueness rule would lead to randomly excluded paths whenever there are multiple paths to chose from, of which it would take one.

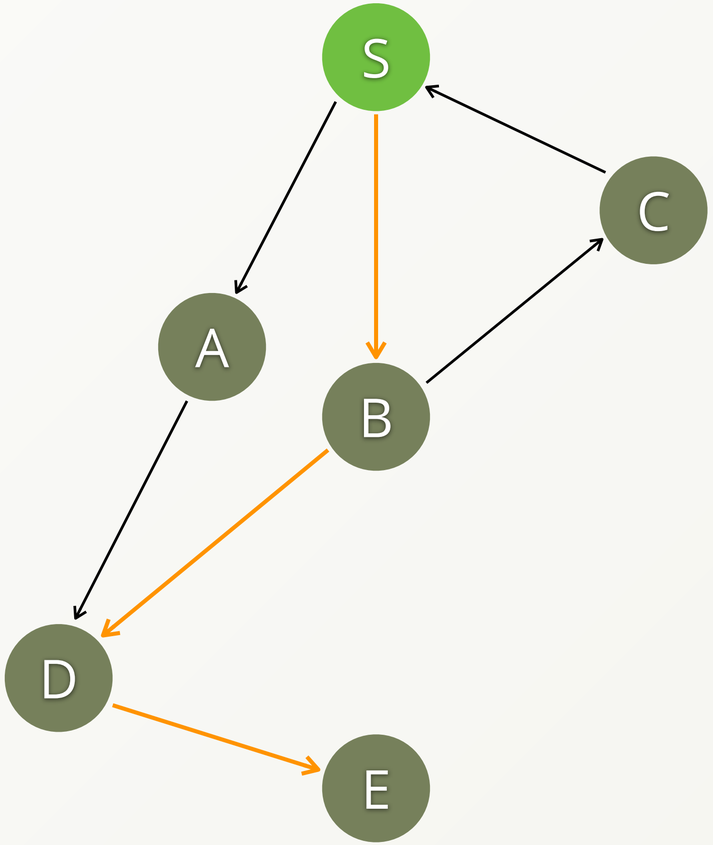
Graph with cycle S→B→C→S and multiple paths from S to E



Uniqueness Options

```
FOR v IN 0..5 OUTBOUND 'verts/S' edges
  OPTIONS {
    bfs: true,
    uniqueVertices: 'global'
  }
  RETURN v._key
```

Graph with cycle S→B→C→S and multiple paths from S to E



The query gives us all vertex keys of this example graph exactly once. Path or or uniqueness of vertices would give us a lot of duplicates instead, 14 in total.

Which edges are actually followed in this traversal is not deterministic, but since it is breadth-first search, every reachable vertex is guaranteed to be visited one way or another.

Note: A depth of zero makes the traversal include the start vertex, which would otherwise only be accessible via the emitted path variable like `p.vertices[0]`.

Traversal Options – Hands on

ArangoDB

For our domestic flights example we might want to have all airports directly reachable from a given airport. Let's see which airports we can reach from Los Angeles

- Return all airports directly reachable from LAX:

```
FOR airport IN OUTBOUND 'airports/LAX' flights
  OPTIONS { bfs: true, uniqueVertices: 'global' }
  RETURN airport
```

- Compare the execution times to this earlier shown query, which returns the same airports:

```
FOR airport IN OUTBOUND 'airports/LAX' flights
  RETURN DISTINCT airport
```

You will see a significant performance improvement.

What happens is that `RETURN DISTINCT` de-duplicates airports only after the traversal has returned all vertices (huge intermediate result), whereas `uniqueVertices: 'global'` is a traversal option that instructs the traverser to ignore duplicates right away.

Advanced Graph Queries

Shortest Path

&

Pattern Matching

Shortest Path – Hands on

A shortest path query finds a connection between two given vertices with the fewest amount of edges. With our domestic flights dataset we could search for a connection between two airports with the fewest stops for example.

- Find a shortest path between Bismarck Municipal airport and John F. Kennedy airport and return the airport names on the route:

```
FOR v IN OUTBOUND
  SHORTEST_PATH 'airports/BIS'
  TO 'airports/JFK' flights
  RETURN v.name
```

We defined BIS as our start vertex and JFK as our target vertex.

Shortest Path in AQL documentation

Shortest Path

Bismarck Municipal

John F Kenny Intl

Source: Google Maps

We found a route via Denver International airport:

Query 3 elements 22.669 ms

```
1 [
2   "Bismarck Municipal",
3   "Denver Intl",
4   "John F Kennedy Intl"
5 ]
```

Shortest Path

Denver Intl

Source: Google Maps

The result of the previous shortest path query shows that you have to change in Denver (DEN) for example to get to JFK. There is apparently no direct flight.

Note: A Shortest_Path query can return different results. It just finds and returns one of possibly multiple shortest paths. In this case it found: BIS→DEN→JFK

Shortest Path – Hands on

ArangoDB

Sometimes you just want the length of the shortest path. To achieve this you can use LET.

- Return the minimum number of flights from BIS to JFK

```
LET airports = (
  FOR v IN OUTBOUND
    SHORTEST_PATH 'airports/BIS'
    TO 'airports/JFK' flights
    RETURN v
)
RETURN LENGTH(airports) - 1
```

Your result should be 2.

Note:

- We placed a `-1` at the end of the query to not count the end vertex as a step!
- **Using the shortest path algorithm one can not apply filters.**
  We need to resort to *pattern matching* instead to do so.

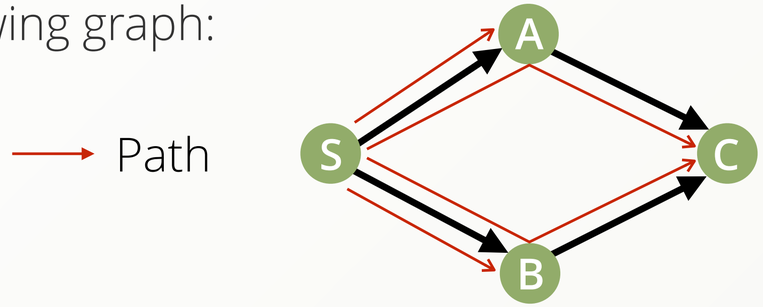
Pattern Matching

We adventured pretty deep into the graph jungle already. Exploring pattern matching in detail is beyond the scope of this course, but let us take a quick look at it nonetheless.

We can easily add filter conditions for the end vertex and/or the edge which leads to it. Both are emitted by the traversal as we know:

```
FOR endVertex, edgeToVertex IN ...
```

With a variable traversal depth of 1..2 and the default traversal options, there are 4 paths in the following graph:



If we return the emitted end vertex, then the result will contain the vertices A, B, C and C again.

We could also return the edges and would end up with four edges in total. However, for the paths S→A→C and S→B→C we may want to to choose one over the other based on certain criteria. Full paths can be optionally emitted as third variable:

```
FOR vertex, edge, path IN ...
```

The path variable can then be used to apply filter conditions on intermediate or all vertices and/or edges on the path. This allows for queries like:

What are the best connections between the airports A and B determined by the lowest total travel time?

It can be used to apply complex filter conditions in traversals taking the entire path into account. In other words, it lets you discover specific patterns – combinations of vertices and edges in graphs – and is therefore called *pattern matching*.

Landing

Survey and Support

&

Exercise Solutions

Survey and Support

What would you like to learn next?

Tell us with 3 clicks:

Survey

Support ArangoDB :)

Feedback to the course

Star us on GitHub

Feeling stuck? Not for long.

Join the ArangoDB community to get help, challenge ideas or discuss new features!

Slack Community

StackOverflow

Exercises A – Solutions

ArangoDB

There are often multiple ways in AQL to retrieve the same result. If your solution is different to below queries but produces the correct result then you did very well :)

1. Retrieve the airport document of Los Angeles International (LAX).

```
RETURN DOCUMENT("airports/LAX")
```

2. Retrieve all airport documents of the city Los Angeles.

```
FOR a IN airports
  FILTER a.city == "Los Angeles"
  RETURN a
```

3. Find all airports of the state North Dakota (ND) and return the name attribute only.

```
FOR airport IN airports
  FILTER airport.state == "ND"
  RETURN airport.name
```

4. Retrieve multiple airports via their primary key (_key), for example BIS, DEN and JFK. Return an object for each match: `RETURN {airport: a.name}`

```
FOR a IN airports
  FILTER a._key IN ["BIS","DEN","JFK"]
  RETURN { airport: a.name }
```

5. Count the airports in the state New York (NY) which are **not** vip.

```
FOR airport IN airports
  FILTER airport.state == "NY"
  AND NOT airport.vip
  COLLECT WITH COUNT INTO count
  RETURN count
```

Exercises B – Solutions

1. Find all flights with FlightNum 860 (number) on January 5th and return the *_from* and *_to* attributes only (you may use KEEP() for this).

```
FOR f IN flights
  FILTER f.FlightNum == 860
     AND f.Month == 1
     AND f.Day == 5
  RETURN KEEP(f, "_from", "_to")
```

2. Find all flights departing or arriving at JFK with FlightNum 859 or 860 and return objects with flight numbers and airport names where the flights go to or come from respectively.

```
FOR a, f IN ANY
"airports/JFK" flights
  FILTER f.FlightNum IN [859,860]
  RETURN { airport: a.name,
           flight: f.FlightNum }
```

3. Combine a **FOR** loop and a traversal like:

```
FOR orig IN airports
 FILTER orig._key IN ["JFK", "PBI"]
 FOR dest, flight IN ANY orig flights
    …
```

to do multiple traversals with different starting points. Filter by flight numbers 859 and 860. Return `orig.name`, `dest.name`, FlightNum and Day. Name the attributes appropriately.

```
FOR orig IN airports
  FILTER orig._key IN ["JFK", "PBI"]
  FOR dest, flight IN
    ANY orig flights
  FILTER flight.FlightNum IN [859,860]
    RETURN { from: orig.name,
                to: dest.name,
            number: flight.FlightNum,
               day: flight.Day }
```

ArangoDB

We hope you enjoyed the course and it helped you to get started!

Simran

Documentation Manager

AQL and data modeling enthusiast with a passion for technical writing

Jan

Head of Communications

Makes complex things easier to digest. Big fan of community support