Graphing Your Way Through the Cosmos

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CodeMash
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Who is Chad Green

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ScholarRx

Microsoft® MVP Most Valuable Professional

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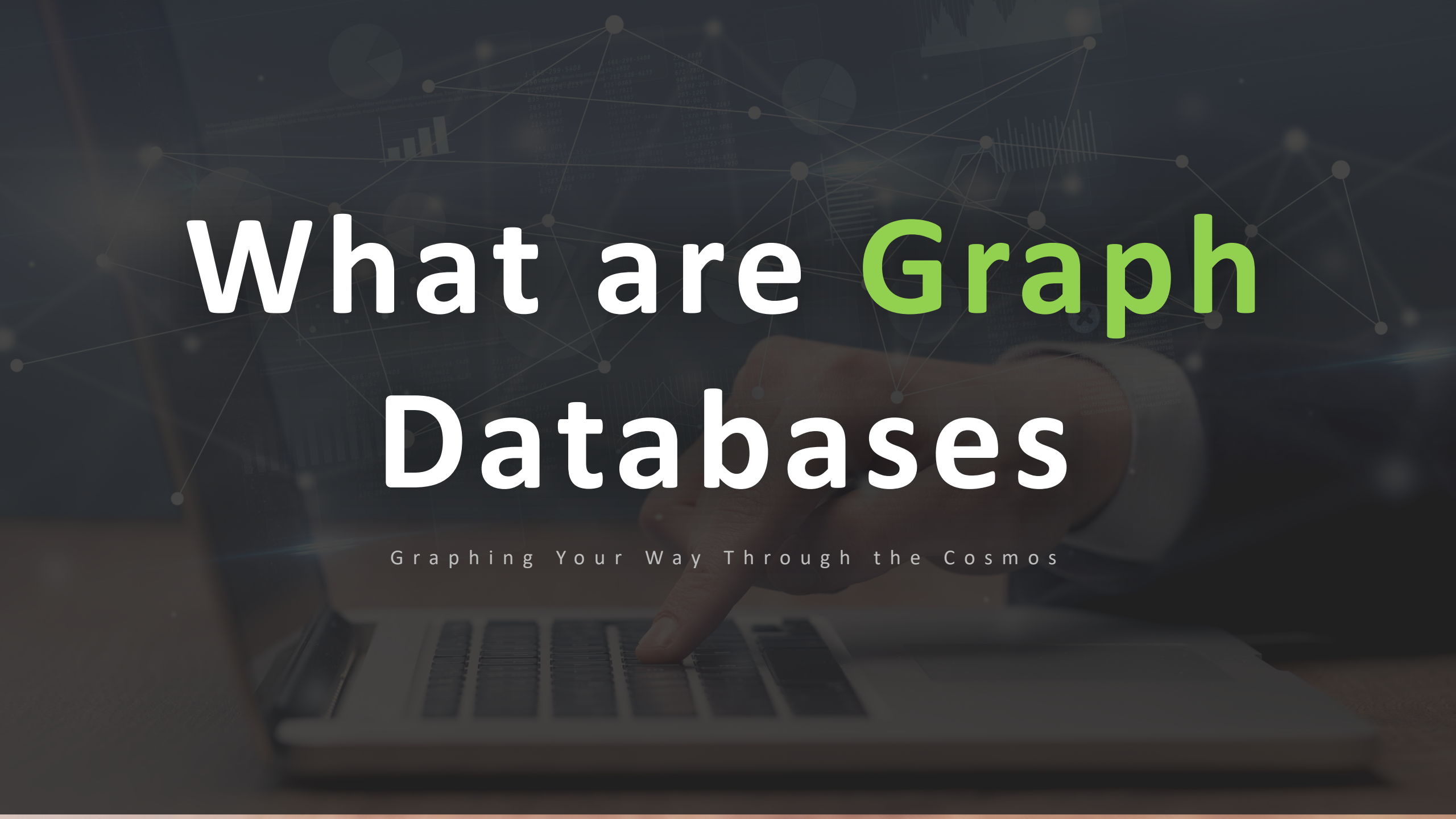
ChadGreen

ChadwickEGreen



What are Graph Databases

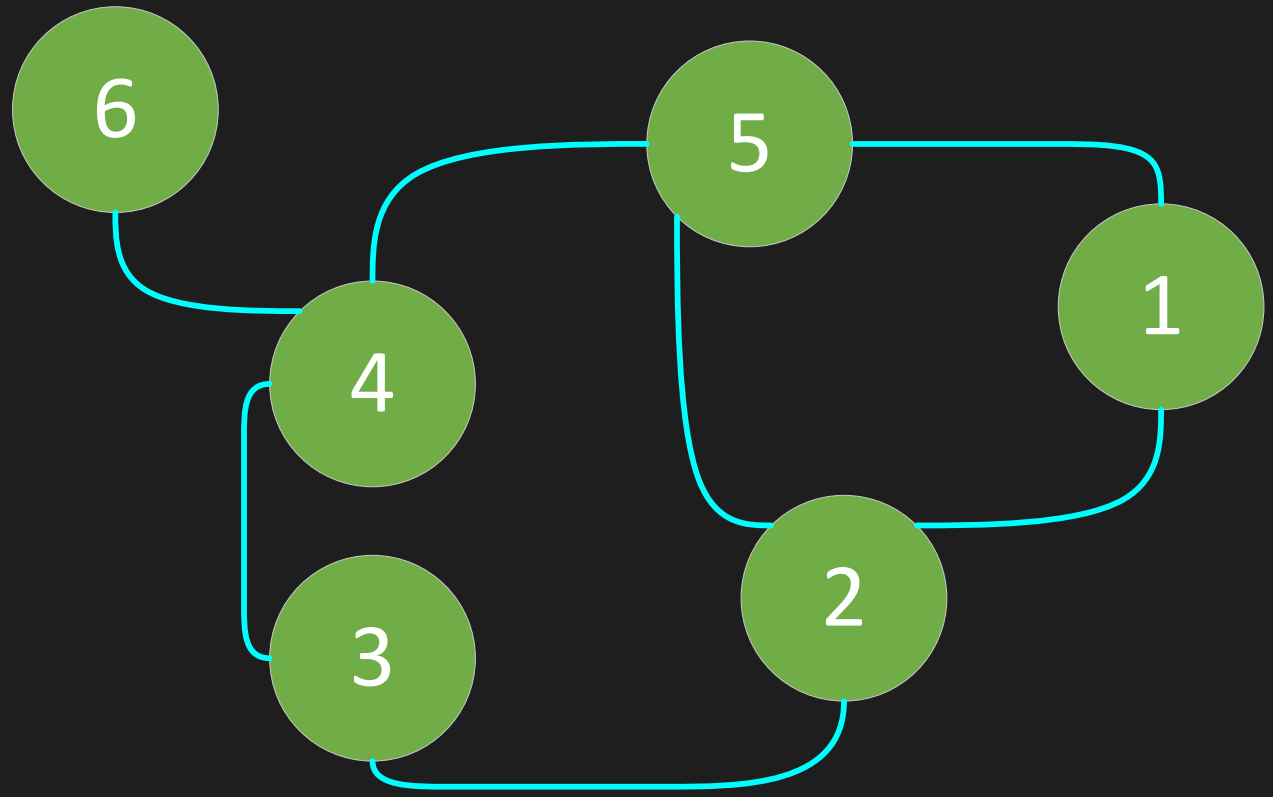
Graphing Your Way Through the Cosmos

What is a Graph

- Discrete mathematics
- Structure amounting to a set of objects in which some pairs of the objects are in some sense related
- Objects correspond to mathematical abstractions called vertices and each of the related pairs of vertices is called an edge
- Graph Theory is the study of graphs

What is a Graph

- Depicted in diagrammatic form as a set of dots or circles for the vertices, joined by lines or curves for the edges

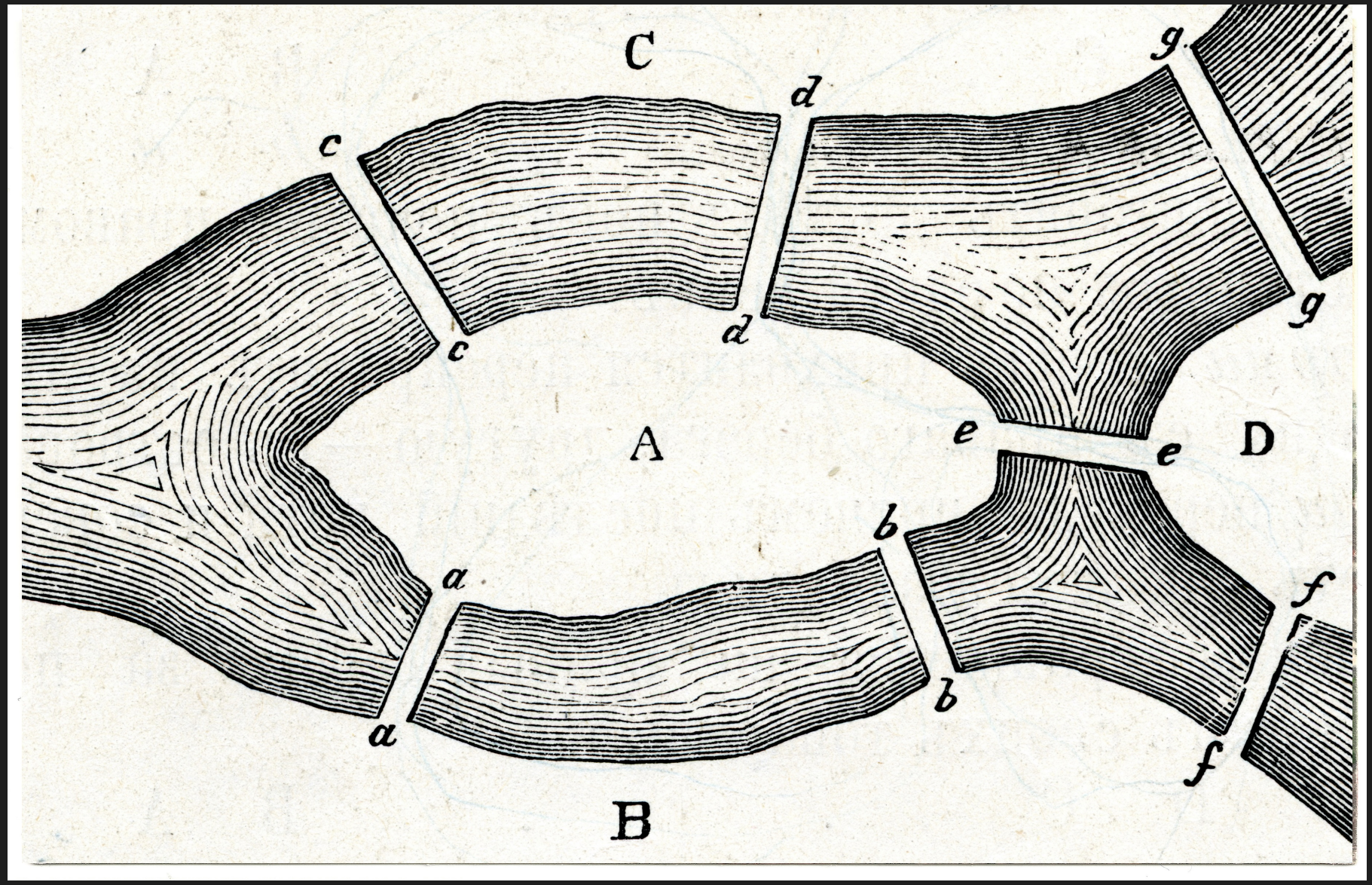


What is a Graph

$$G = (V, E)$$

History of Graph Theory

History of Graph Theory

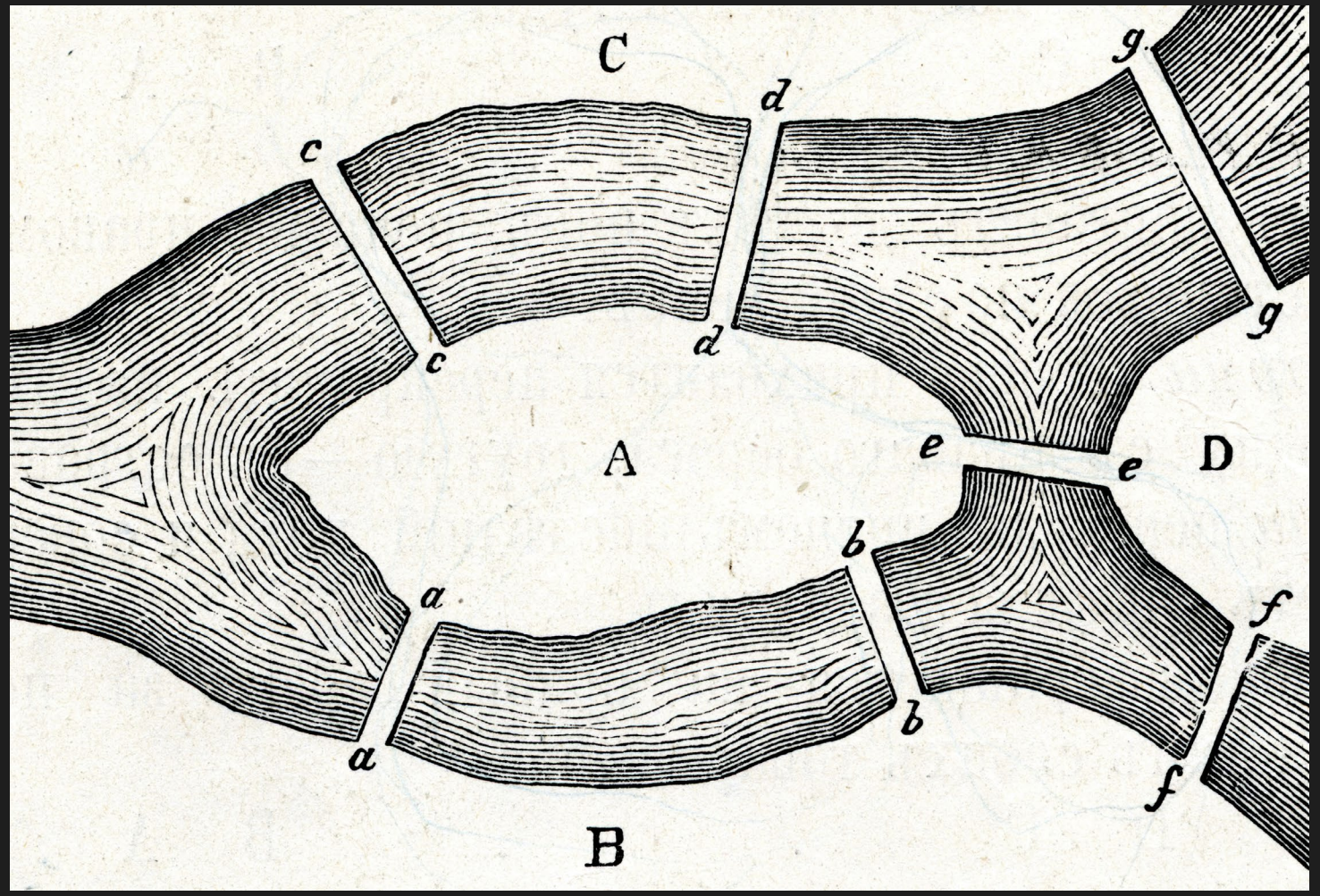


History of Graph Theory

Leonard Euler

@chadgreen

History of Graph Theory

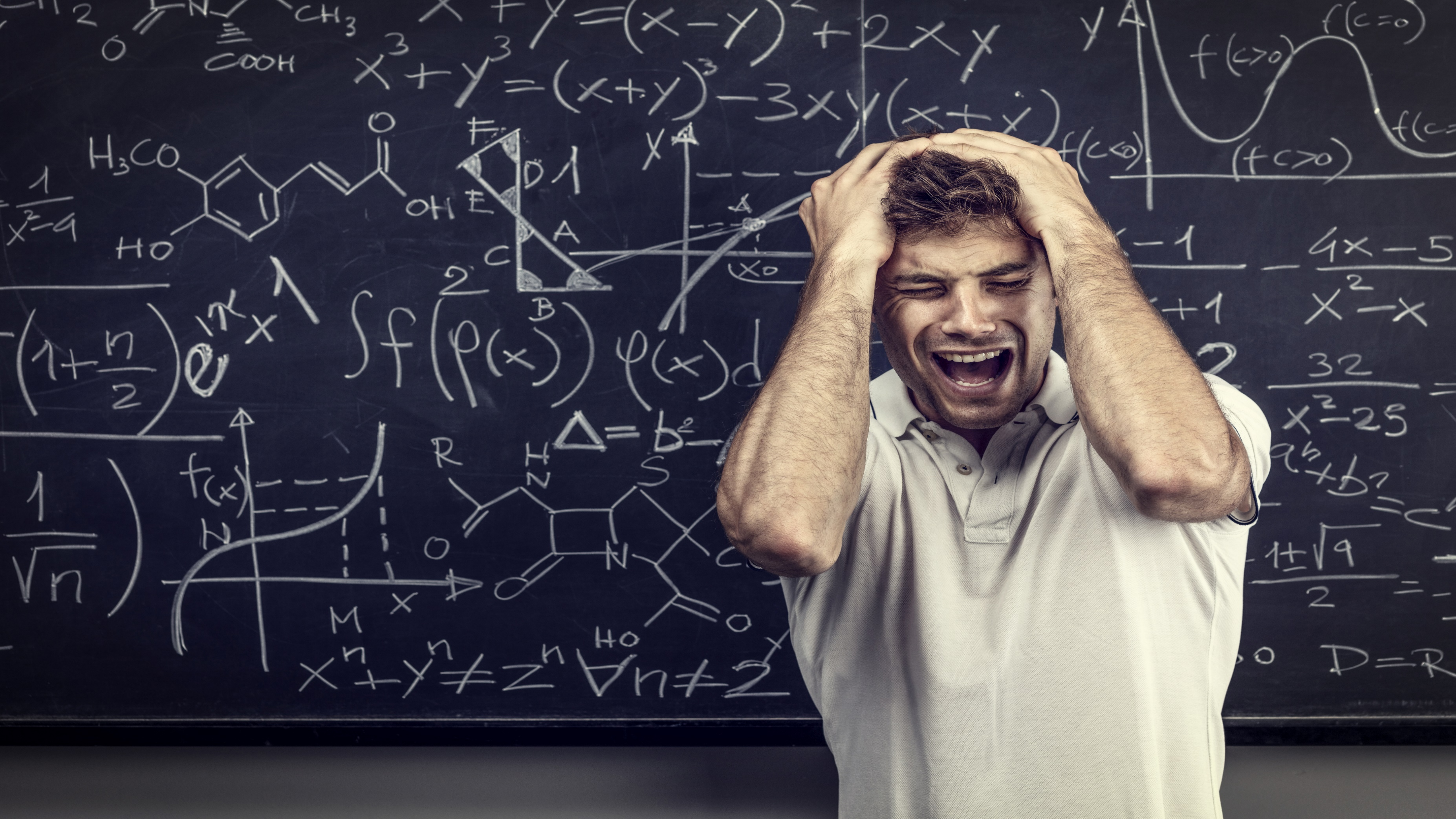


Solutio problematis ad geometriam situs pertinentis

The solution of a problem relating to the geometry of position

Applications of Graph Theory

- Linguistics
- Physics and Chemistry
- Social Sciences
- Biology
- Computer Science

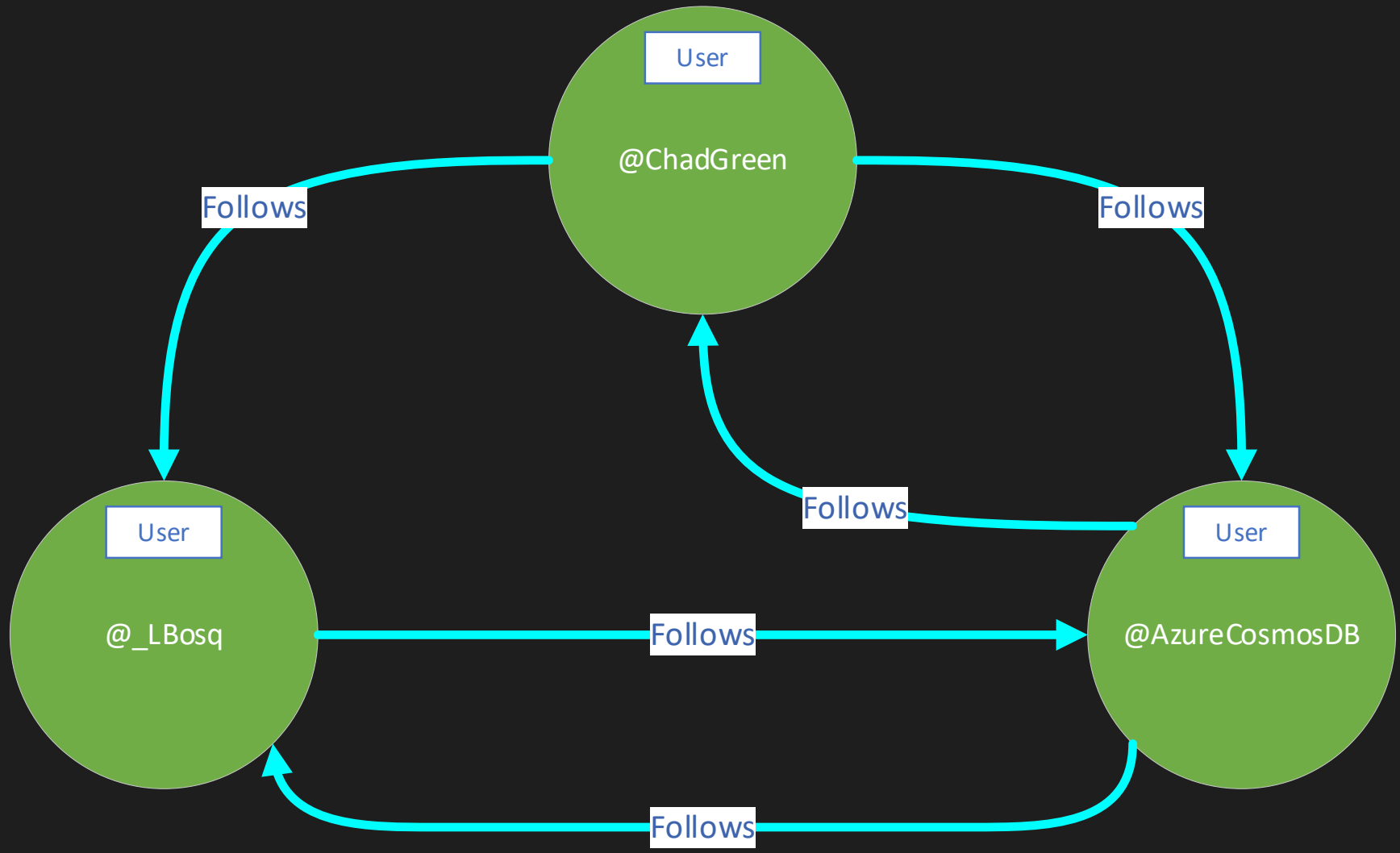


COOH
x³+y³=(x+y)³−3xy(x+y)
H₃CO
OH
HO
Δ=b²
f(x)
xⁿ+yⁿ≠zⁿ ∀n≠2
1±√9
2

What is a Graph

- Collection of *vertices* and *edges*
- Represent entities as vertices and the ways in which those entities relate to the world as relationships
- Allow us to model all kinds of scenarios

What is a Graph



What is a Graph Database

A graph database is a database that uses graph structures to represent and store data.

What is a Graph Database

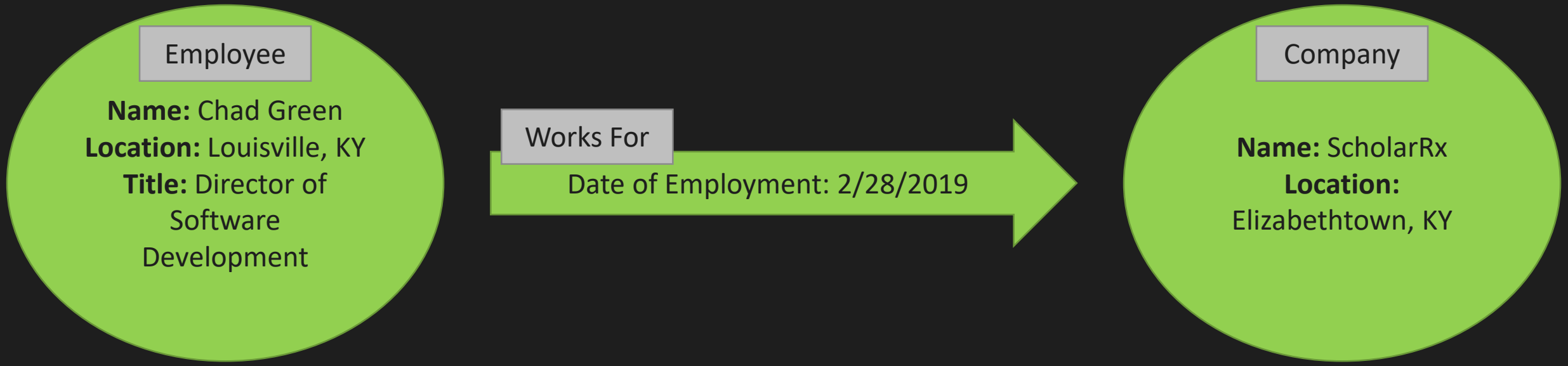
- Represents data as it exists in the real world that are naturally connected
- Does not try to change them in any way to define them as entities
- Graphs are composed of *vertices* and *edges*
- Vertices represent specific objects
- Edge is a relation between vertices
- Both vertices and edges can have any number of properties

Property Graph Model

Contains **nodes** (vertices) and **relationships** (edges)

Nodes and relationships contain **properties**

Relationships are **named** and **directed** with a **start** and **end** node

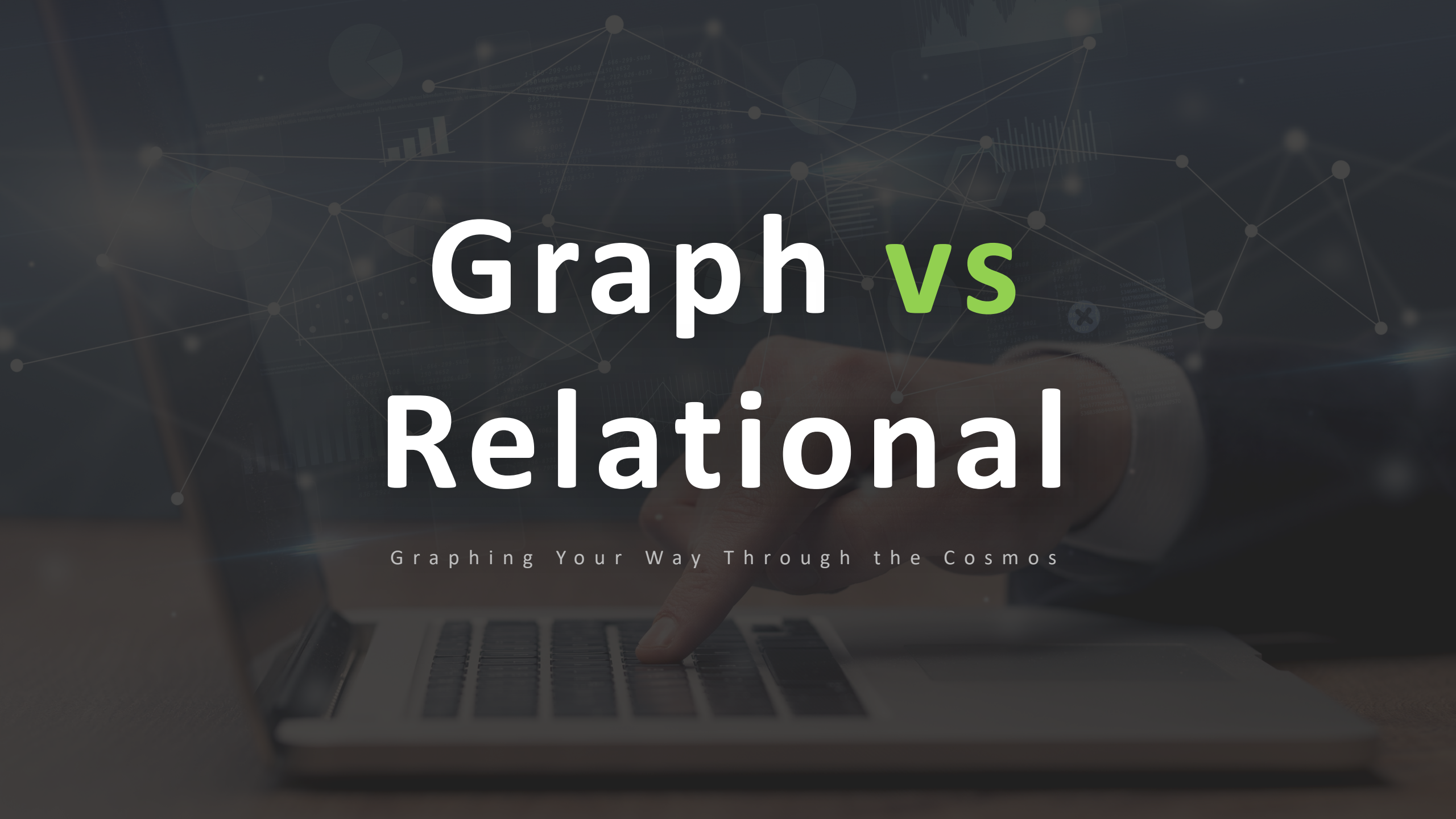


The Power of Graph Databases

- Performance
  - Graph database performance tends to remain relatively constant, even as the dataset grows
- Flexibility
  - Graph data model better accommodates changing business needs
- Agility
  - Equip us to perform frictionless development and graceful system maintenance
  - Governance is typically applied in a programmatic fashion

Common Graph Use Cases

- Internet of Things
- Customer 360
- Asset management
- Recommendations
- Fraud detection
- Data Integration
- Identity and access management
- Social networks
- Communication networks
- Genomics
- Epidemiology
- Semantic Web
- Search


Graph vs
Relational
Graphing Your Way Through the Cosmos

Graph Databases vs Relational Databases

Relational	Graph
Tables	Vertices (Nodes)
Schema with nullables	No schema
Relations with foreign keys	Relation is first class citizen
Related data fetched with joins	Related data fetched with a pattern

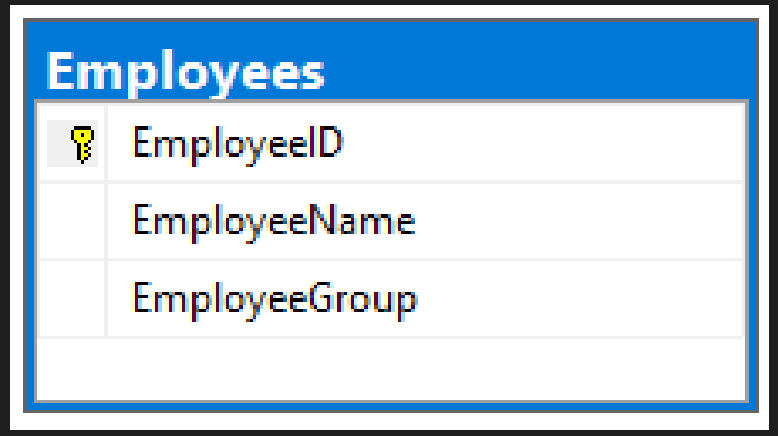
Human Resource Data

Graph Databases vs Relational Databases

Human Resource Data

Graph Databases vs Relational Databases

EmployeeId	EmployeeName	EmployeeGroup
1	Willis B. Hawkins	Sales
2	Neil S. Vega	Sales
3	Ada C. Lavigne	Engineering



Human Resource Data

Graph Databases vs Relational Databases

```
-- Create the Employee Table
CREATE TABLE Employees
(
    EmployeeID    INT           IDENTITY(1,1),
    EmployeeName  VARCHAR(64),
    EmployeeGroup VARCHAR(32),
    CONSTRAINT pkcEmployees PRIMARY KEY CLUSTERED (EmployeeId)
)
GO

-- Populate the Employee Table
INSERT INTO Employees (EmployeeName, EmployeeGroup)
               VALUES ('Willis B. Hawkins', 'Sales'),
                      ('Neil S. Vega',      'Sales'),
                      ('Ada C. Lavigne',    'Engineering');
GO
```

Human Resource Data

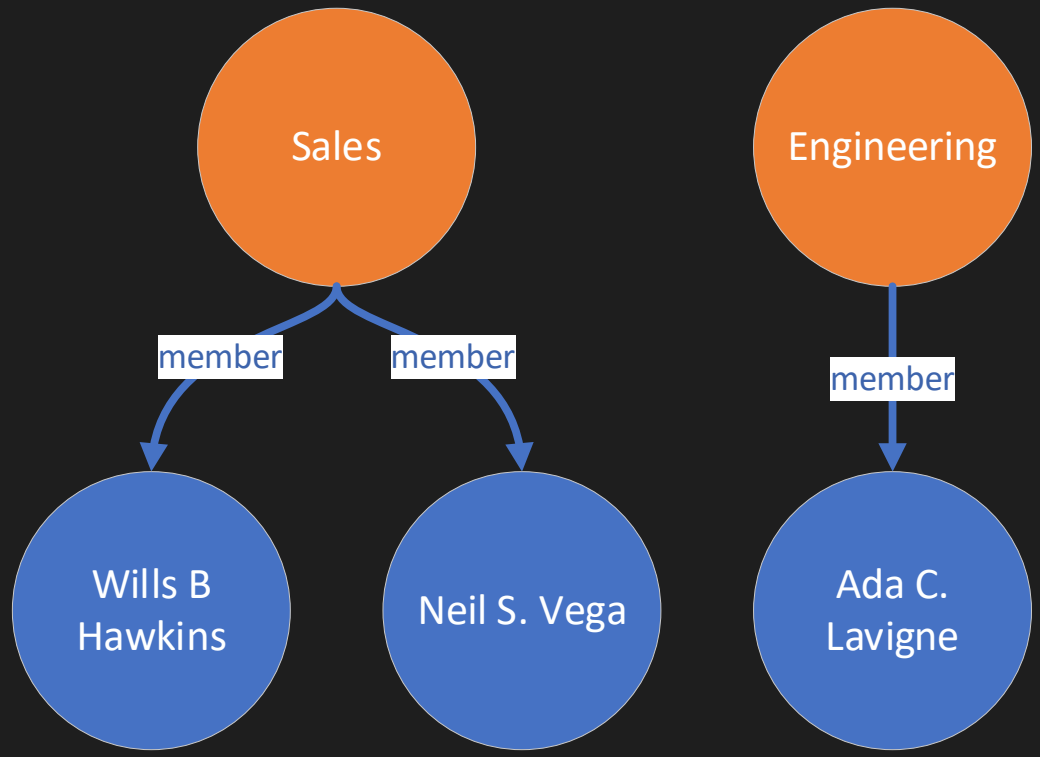
Graph Databases vs Relational Databases

```
// Create group nodes
g.addV('group').property('id', 'Sales’)
g.addV('group').property('id', 'Engineering’)

// Create employee nodes
g.addV('employee').property('id', 'Willis B. Hawkins’)
g.addV('employee').property('id', 'Neil S. Vega’)
g.addV('employee').property('id', 'Ada C. Lavigne’)

// Create relationships between groups and employees
g.V('Sales').addE('member').to(g.V('Willis B. Hawkins’))
g.V('Sales').addE('member').to(g.V('Neil S. Vega’))
g.V('Engineering').addE('member').to(g.V('Ada C. Lavignee'))
```

Human Resource Data

Graph Databases vs Relational Databases

EmployeeId	EmployeeName	EmployeeGroup
1	Willis B. Hawkins	Sales
2	Neil S. Vega	Sales
3	Ada C. Lavigne	Engineering



3 rows, 3 columns

8 documents (vertices and edges)

Human Resource Data

Graph Databases vs Relational Databases

EmployeeId	EmployeeName	EmployeeGroup
1	Willis B. Hawkins	Sales
2	Neil S. Vega	Sales
3	Ada C. Lavigne	Engineering


```
SELECT * FROM Employees;
```

```
g.V().hasLabel('employee')
```

Company Reorganization

Employees can now belong to multiple groups

Graph Databases vs Relational Databases

```
-- Create the Groups table
CREATE TABLE Groups
(
  GroupId   INT          IDENTITY(1,1),
  GroupName VARCHAR(64),
  CONSTRAINT pkcGroups PRIMARY KEY CLUSTERED (GroupId)
)
```

Employees can now belong to multiple groups

Graph Databases vs Relational Databases

```
-- Create the Employee_Group join table
CREATE TABLE Employee_Group
(
  GroupId INT,
  EmployeeId INT,
  CONSTRAINT pkcEmployeeGroup PRIMARY KEY CLUSTERED (GroupId, EmployeeId),
  CONSTRAINT fkEmployeeGroup_Groups    FOREIGN KEY (GroupId)    REFERENCES Groups(GroupId),
  CONSTRAINT fkEmployeeGroup_Employees FOREIGN KEY (EmployeeId) REFERENCES Employees(EmployeeId)
)
```

Employees can now belong to multiple groups

Graph Databases vs Relational Databases

```
-- Populate the Employee_Group table from Employees and Groups
INSERT INTO Employee_Group (GroupId, EmployeeId)
SELECT Groups.GroupId,
       Employees.EmployeeId
  FROM Employees,
       Groups
 WHERE Groups.GroupName = Employees.EmployeeGroup
```

Employees can now belong to multiple groups

Graph Databases vs Relational Databases

```
-- Drop the Employees.EmployeeGroup column that is no longer valid
ALTER TABLE Employees DROP COLUMN EmployeeGroup
```

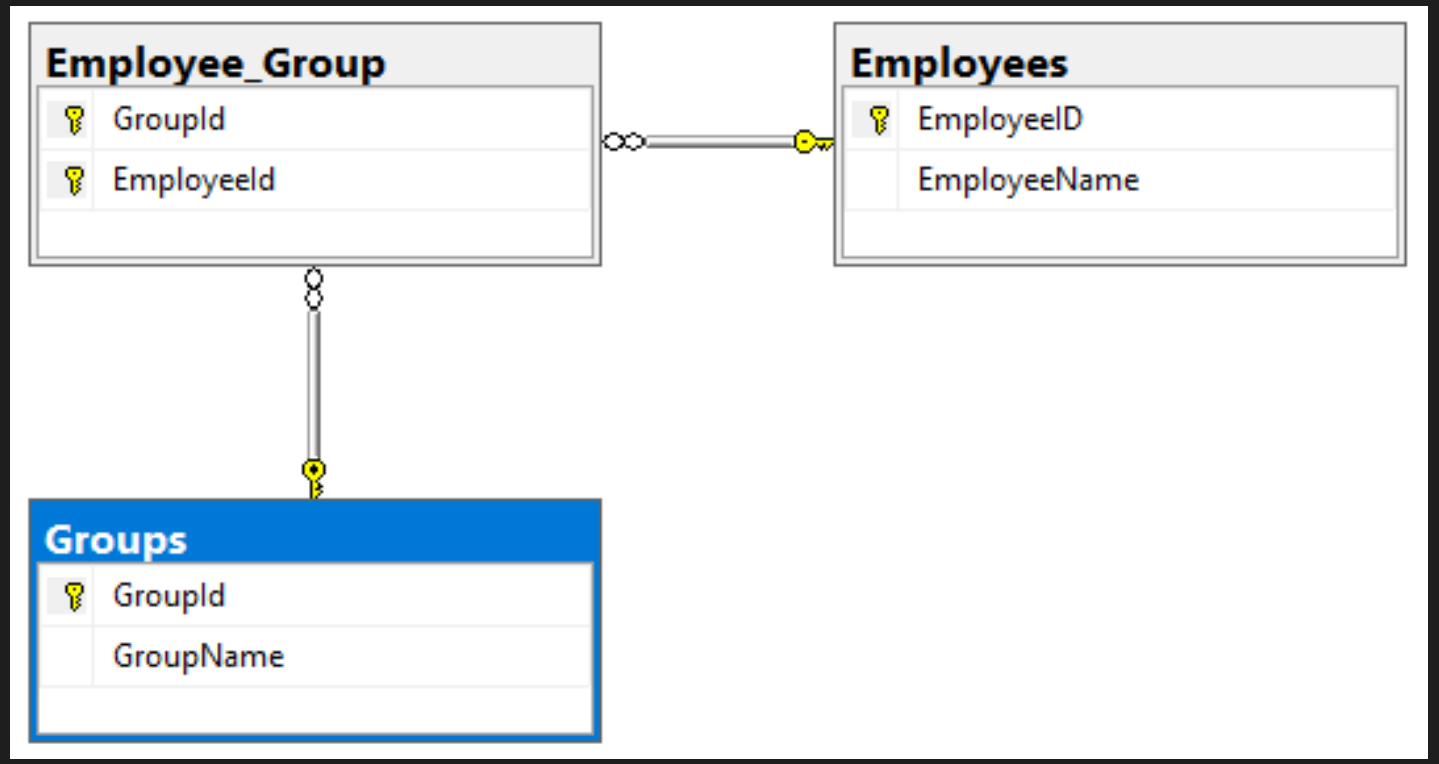
Employees can now belong to multiple groups

Graph Databases vs Relational Databases

EmployeeId	EmployeeName
1	Willis B. Hawkins
2	Neil S. Vega
3	Ada C. Lavigne

GroupId	GroupName
1	Engineering
2	Sales

GroupId	EmployeeId
1	3
2	1
2	2



Employees can now belong to multiple groups

Graph Databases vs Relational Databases

```
// Add link to existing node
g.V('Sales').addE('member').to(g.V('Ada C. Lavigne’))
```

Employees can now belong to multiple groups

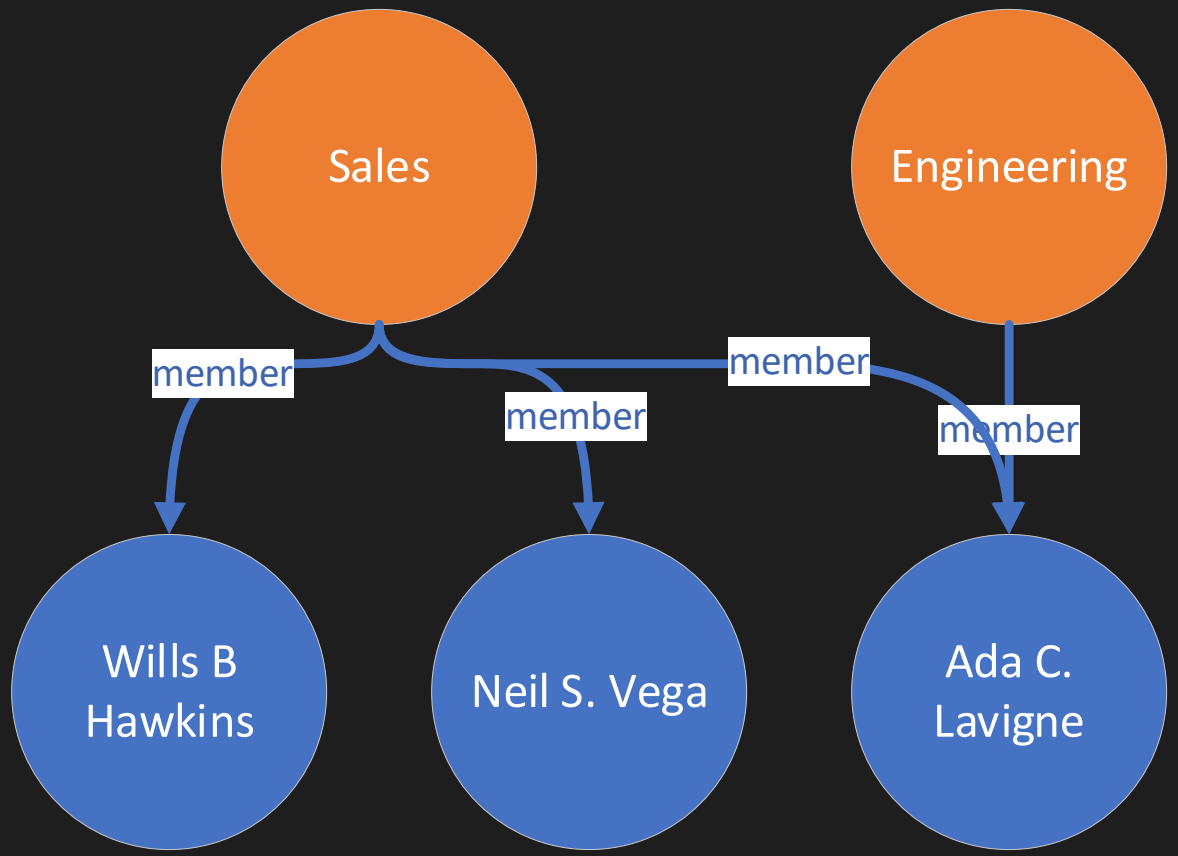
Graph Databases vs Relational Databases

EmployeeId	EmployeeName
1	Willis B. Hawkins
2	Neil S. Vega
3	Ada C. Lavigne

GroupId	GroupName
1	Engineering
2	Sales

GroupId	EmployeeId
1	3
2	1
2	2

Added 2 tables; 6 rows; 4 new columns
Removed a column



+1 document

Employees can now belong to multiple groups

Graph Databases vs Relational Databases

EmployeeId	EmployeeName
1	Willis B. Hawkins
2	Neil S. Vega
3	Ada C. Lavigne


```
SELECT Employees.EmployeeId,
       Employees.EmployeeName
  FROM Employees
 INNER JOIN Employee_Group
         ON Employee_Group.EmployeeId = Employees.EmployeeId
 INNER JOIN Groups
         ON Groups.GroupId = Employee_Group.GroupId
 WHERE Groups.GroupName = 'Sales'
```

```
g.V('Sales').outE('member').inV()
```


Corporate Merger

Nested Groups

Graph Databases vs Relational Databases

```
-- Create the new Product Group
INSERT INTO Groups (GroupName) VALUES ('Product Group')
```

Nested Groups

Graph Databases vs Relational Databases

```
-- Associate everyone to the new Product Group
INSERT INTO Employee_Group (GroupId, EmployeeId)
SELECT Groups.GroupId,
       Employees.EmployeeId
  FROM Groups,
       Employees
 WHERE Groups.GroupName = 'Product Group
```

Nested Groups

Graph Databases vs Relational Databases

```
-- Create the Group/Group union table
CREATE TABLE Group_Group
(
  ParentGroupId INT,
  ChildGroupId  INT,
  CONSTRAINT pkcGroup_Group PRIMARY KEY CLUSTERED (ParentGroupId, ParentGroupId),
  CONSTRAINT fkGroupGroup_Groups_Parent FOREIGN KEY (ParentGroupId) REFERNCES Groups(GroupId),
  CONSTRAINT fkGroupGroup_Groups_Child  FOREIGN KEY (ChildGroupId)  REFERNCES Groups(GroupId)
)
```

Nested Groups

Graph Databases vs Relational Databases

```
-- Relate the child groups to the parent group
INSERT INTO Group_Group (ParentGroupId, ChildGroupId)
SELECT (SELECT GroupId FROM Groups WHERE GroupName = 'Product Group’),
       Groups.GroupId
  FROM Groups
 WHERE Groups.GroupName <> 'Product Group’
```

Nested Groups

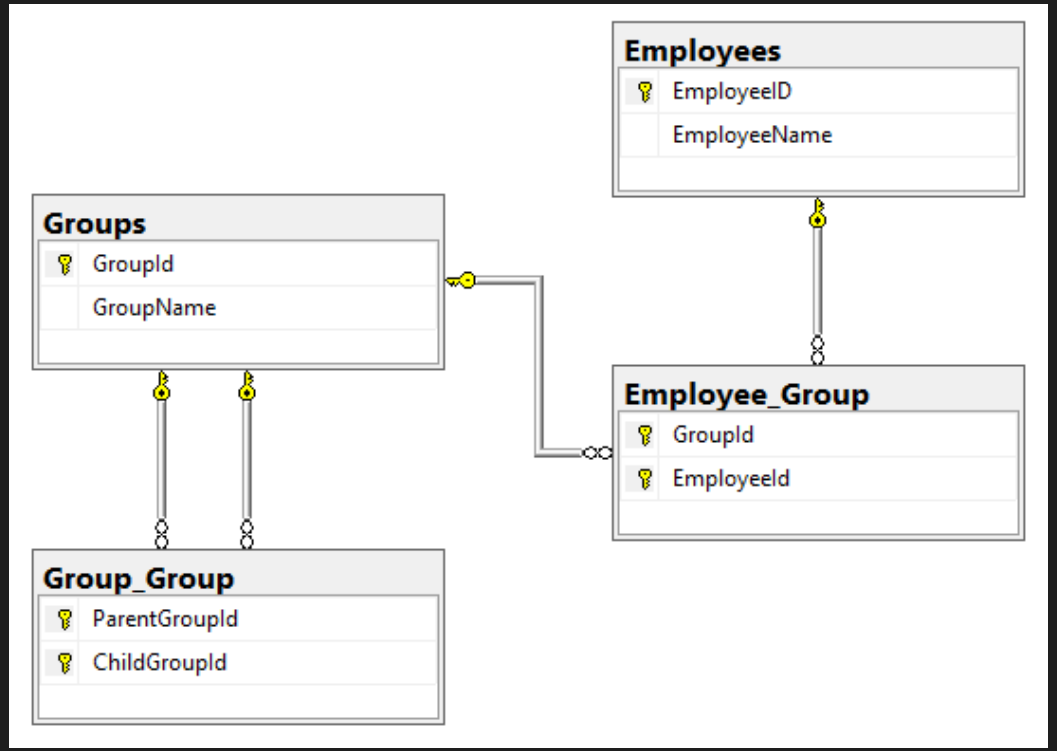
Graph Databases vs Relational Databases

EmployeeId	EmployeeName
1	Willis B. Hawkins
2	Neil S. Vega
3	Ada C. Lavigne

GroupId	GroupName
1	Engineering
2	Sales
3	Product Group

ParentGroupId	ChildGroupId
3	1
3	2

GroupId	EmployeeId
1	3
2	1
2	2
2	3
3	1
3	2
3	3



Nested Groups

Graph Databases vs Relational Databases

```
// Add supergroup node
g.addV('group').property('id', 'Product Group')

// Link to adjacent nodes
g.V('Product Group').addE('contains_subgroup').to(g.V('Engineering’))
g.V('Product Group').addE('contains_subgroup').to(g.V('Sales'))
```

Nested Groups

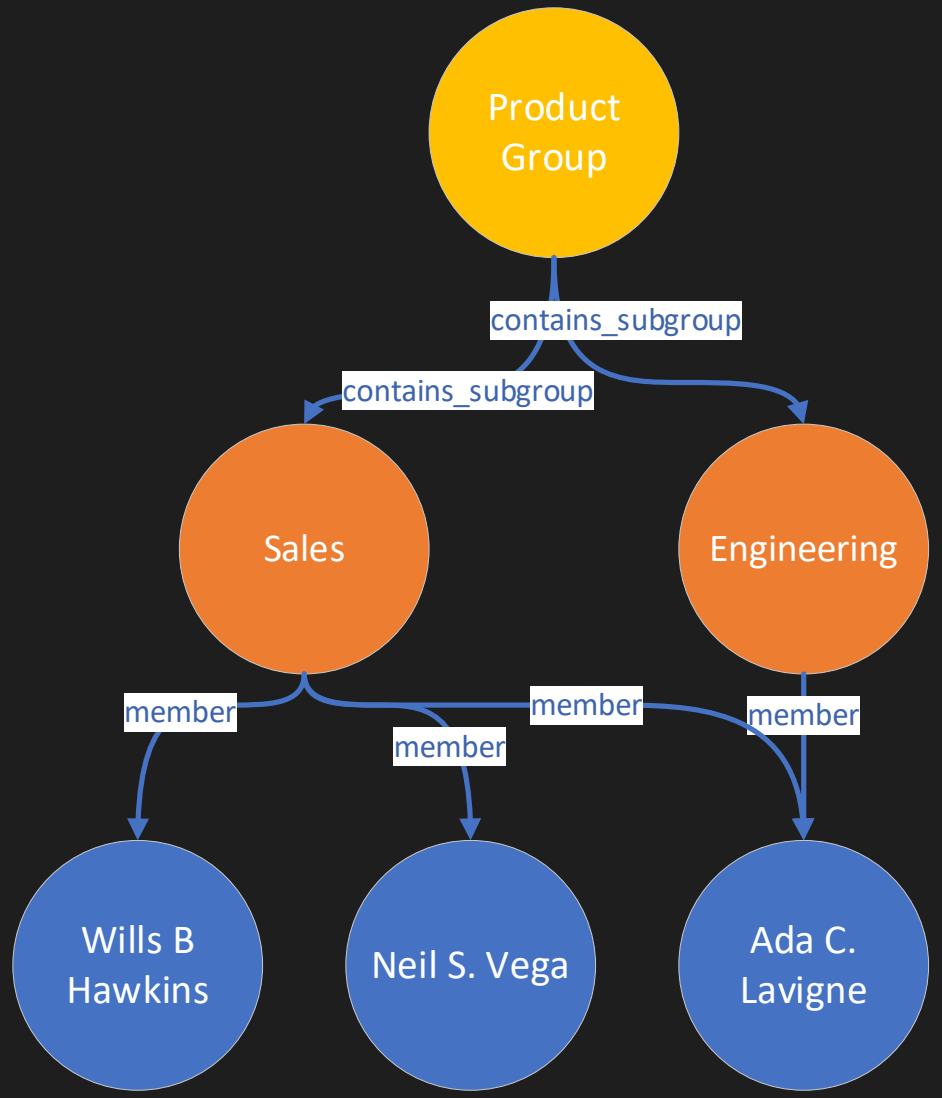
Graph Databases vs Relational Databases

EmployeeId	EmployeeName
1	Willis B. Hawkins
2	Neil S. Vega
3	Ada C. Lavigne

GroupId	GroupName
1	Engineering
2	Sales
3	Product Group

ParentGroupId	ChildGroupId
3	1
3	2

GroupId	EmployeeId
1	3
2	1
2	2
2	3
3	1
3	2
3	3



Added 1 table; 6 rows; 2 new columns

+3 documents

Nested Groups

Graph Databases vs Relational Databases

GroupId	GroupName
1	Engineering
2	Sales


```
SELECT Groups.GroupId,
       Groups.GroupName
  FROM Groups
 INNER JOIN Group_Group ON Group_Group.ChildGroupId = Groups.GroupId
 WHERE Group_Group.ParentGroupId = (SELECT GroupId
                                      FROM Groups
                                     WHERE GroupName = 'Product Group')
```

```
g.V('Product Group’)
.outE('contains_subgroup’)
.inV()
```

Management

Additional Hierarchies

Graph Databases vs Relational Databases

```
-- Create the Employee/Employee join table
CREATE TABLE Employee_Employee
(
  ParentEmployeeId INT,
  ChildEmployeeId  INT,
  CONSTRAINT pkcEmployeeEmployee PRIMARY KEY CLUSTERED (ParentEmployeeId, ChildEmployeeId),
  CONSTRAINT fkEmployeeEmployee_Employee_Parent FOREIGN KEY (ParentEmployeeId) REFERENCES Employees(EmployeeId),
  CONSTRAINT fkEmployeeEmployee_Employee_Child  FOREIGN KEY (ChildEmployeeId)  REFERENCES Employees(EmployeeId)
)
```

Additional Hierarchies

Graph Databases vs Relational Databases

```
-- Make Ada the boss
INSERT INTO Employee_Employee (ParentEmployeeId, ChildEmployeeId)
SELECT (SELECT EmployeeId FROM Employees WHERE EmployeeName = 'Ada C. Lavigne'),
       EmployeeId
  FROM Employees
 WHERE EmployeeId IN (SELECT EmployeeId
                        FROM Employee_Group
                       WHERE Employee_Group.GroupId = (SELECT GroupId
                                                         FROM Groups
                                                        WHERE GroupName = 'Sales'))
```

Additional Hierarchies

Graph Databases vs Relational Databases

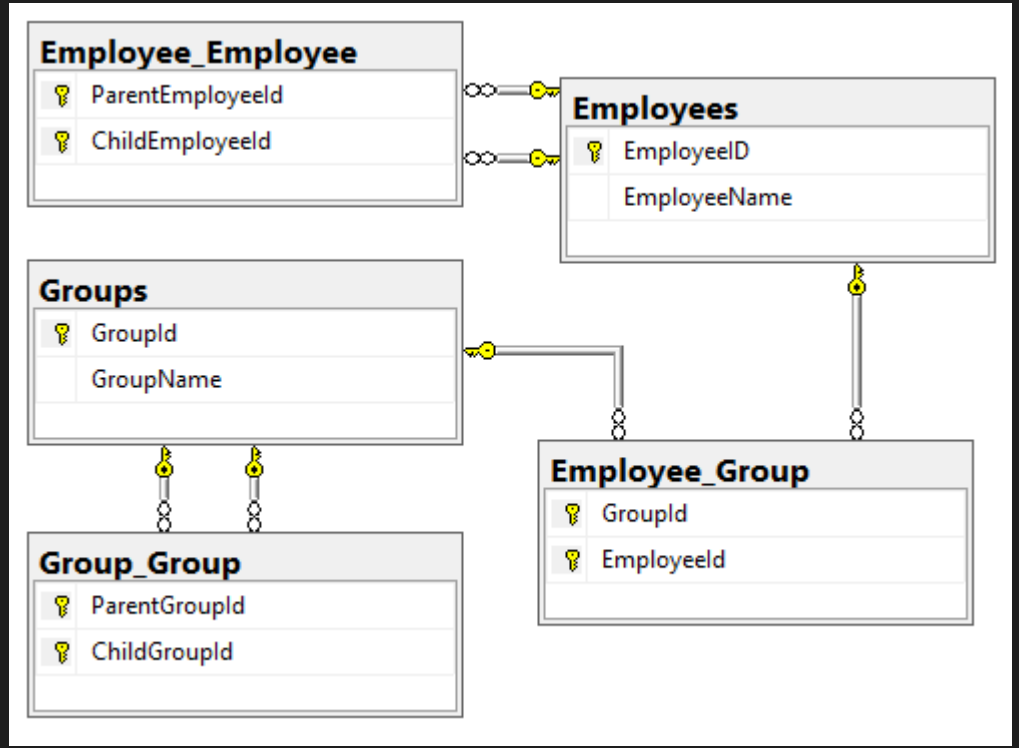
EmployeeId	EmployeeName
1	Willis B. Hawkins
2	Neil S. Vega
3	Ada C. Lavigne

GroupId	GroupName
1	Engineering
2	Sales
3	Product Group

ParentGroupId	ChildGroupId
3	1
3	2

GroupId	EmployeeId
1	3
2	1
2	2
2	3
3	1
3	2
3	3

ParentEmployeeId	ChildEmployeeId
3	1
3	2
3	3



Additional Hierarchies

Graph Databases vs Relational Databases

```
// Add relationships
g.V('Ada C. Lavigne').addE('has_report').to(g.V('Willis B. Hawkins'))
g.V('Ada C. Lavigne').addE('has_report').to(g.V('Neil S. Vega'))
```

Additional Hierarchies

Graph Databases vs Relational Databases

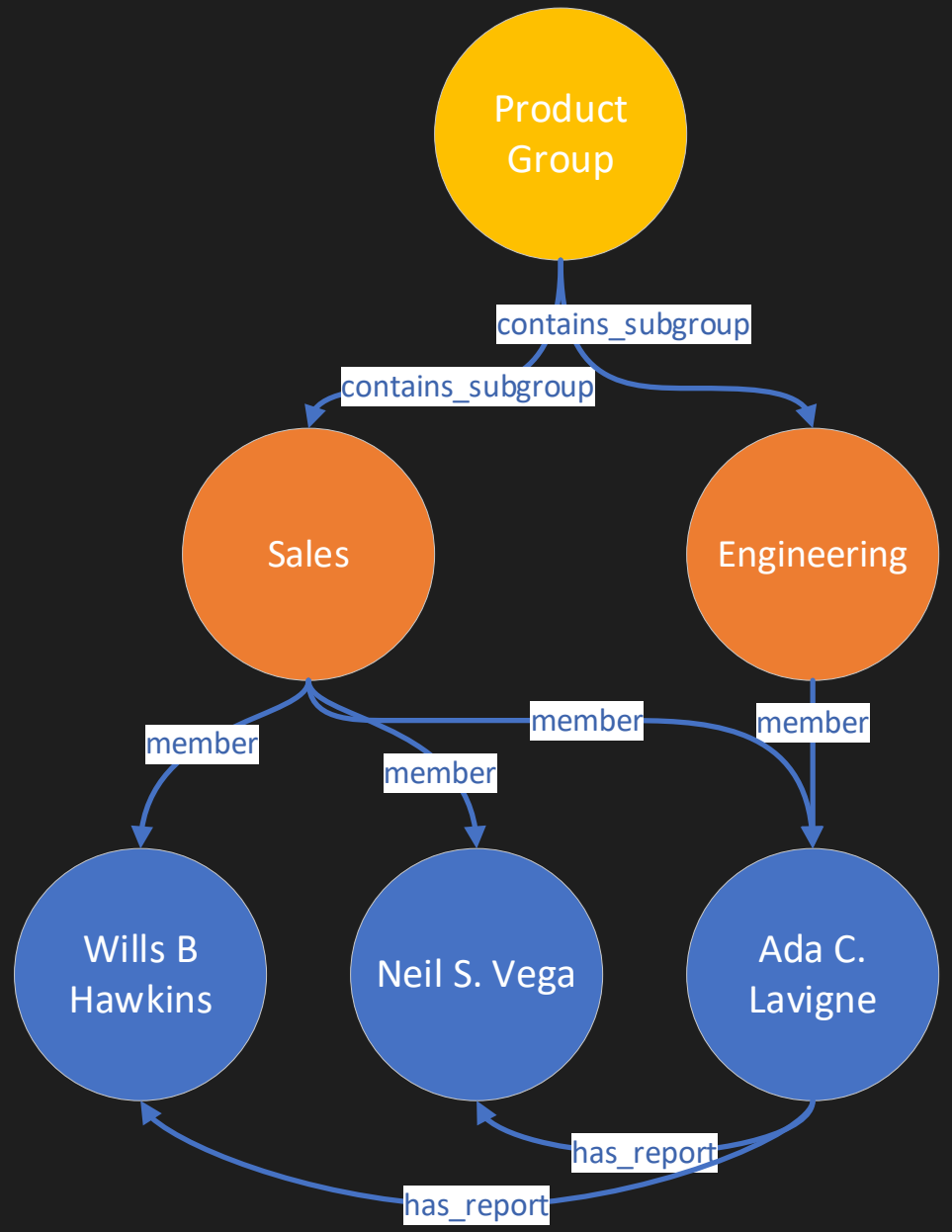
EmployeeId	EmployeeName
1	Willis B. Hawkins
2	Neil S. Vega
3	Ada C. Lavigne

GroupId	GroupName
1	Engineering
2	Sales
3	Product Group

ParentGroupId	ChildGroupId
3	1
3	2

GroupId	EmployeeId
1	3
2	1
2	2
2	3
3	1
3	2
3	3

ParentEmployeeId	ChildEmployeeId
3	1
3	2
3	3



Added 1 table; 2 rows; 2 new columns

+2 documents

Additional Hierarchies

Graph Databases vs Relational Databases

EmployeeName
Ada C. Lavigne

Ada C. Lavigne

```
SELECT DISTINCT EmployeeName
  FROM Employees
 INNER JOIN Employee_Group
    ON Employee_Group_EmployeeId = Employes.EmployeeId
 INNER JOIN Employee_Employee
    ON Employee_Employee.ParentEmployeeId = Employees.EmployeeId
 WHERE Employee_Group.GroupId = (SELECT GroupId
                                   FROM Groups
                                  WHERE GroupName = ‘Engineering')
```

```
g.V('Engineering’)
.outE('member’)
.inV()
.outE('has_report’)
.values('id')
```

Challenges of Relational Databases

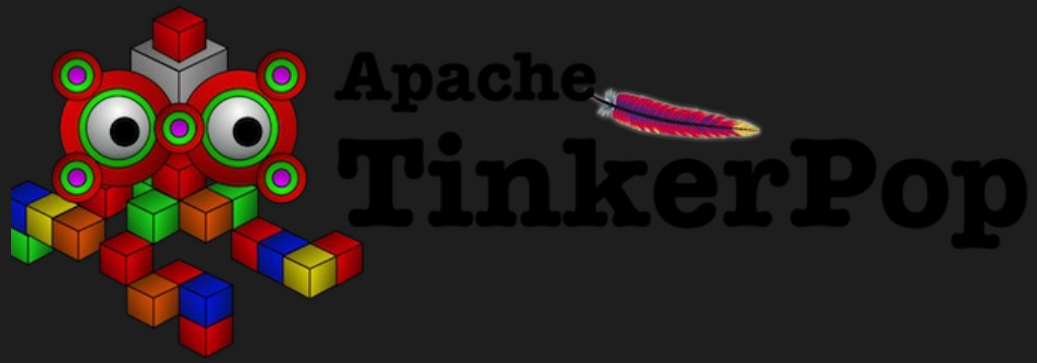
Graph Databases vs Relational Databases

- Schema management
- Table alterations
- Costly writes against multiple tables
- Multiple JOIN operations
- Complex read queries


What is Gremlin
Graphing Your Way Through the Cosmos

What is a TinkerPop

- Open source, vendor-agnostic, graph computing framework
- Apace2 license
- Allows users to model their domain as graph and analyze using Gremlin
- TinkerPop-enable systems integrate with one another



What is a TinkerPop

- Gremlin
- Gremlin Console
- Gremlin Server
- TinkerGraph
- Programming Interfaces
- Documentation
- Useful Recipes

What is a Gremlin

- Graph traversal language and virtual machine
- Supports OLTP and OLAP
- Supports imperative and declarative querying
- Supports user-defined domain specified languages


What is Cosmos DB
Graphing Your Way Through the Cosmos

Azure Cosmos DB

A globally distributed, massively scalable, multi-model database service

Turnkey global distribution

Azure Cosmos DB

A globally distributed, massively scalable, multi-model database service

Turnkey global distribution

Azure Cosmos DB

A globally distributed, massively scalable, multi-model database service

Elastic scale out of storage & throughput

Azure Cosmos DB

A globally distributed, massively scalable, multi-model database service

Guaranteed low latency at the 99th percentile

Elastic scale out of storage & throughput

Turnkey global distribution

Comprehensive SLAs

Azure Cosmos DB

A globally distributed, massively scalable, multi-model database service

Guaranteed low latency at the 99th percentile

Elastic scale out of storage & throughput

Guaranteed low latency at the 99th percentile

Turnkey global distribution

Comprehensive SLAs

Azure Cosmos DB

A globally distributed, massively scalable, multi-model database service

No schema or index management

Five well-defined
consistency models

Elastic scale out
of storage & throughput

Guaranteed low latency
at the 99th percentile

Turnkey global
distribution

Comprehensive
SLAs

Azure Cosmos DB

A globally distributed, massively scalable, multi-model database service

Battle tested database service

Five well-defined consistency models

Elastic scale out of storage & throughput

Guaranteed low latency at the 99th percentile

Turnkey global distribution

Comprehensive SLAs

@chadgreen

Azure Cosmos DB

A globally distributed, massively scalable, multi-model database service

Battle tested database service

Coca-Cola · AVEVA Schneider Electric · Albertsons SAFEWAY · Johnson Controls · SIEMENS Healthineers · BMT

Liberty Mutual INSURANCE · jet · Rolls-Royce · ExxonMobil · Cincinnati Children's · scholar

Five well-defined consistency models

Elastic scale out of storage & throughput

Guaranteed low latency at the 99th percentile

Turnkey global distribution

Comprehensive SLAs

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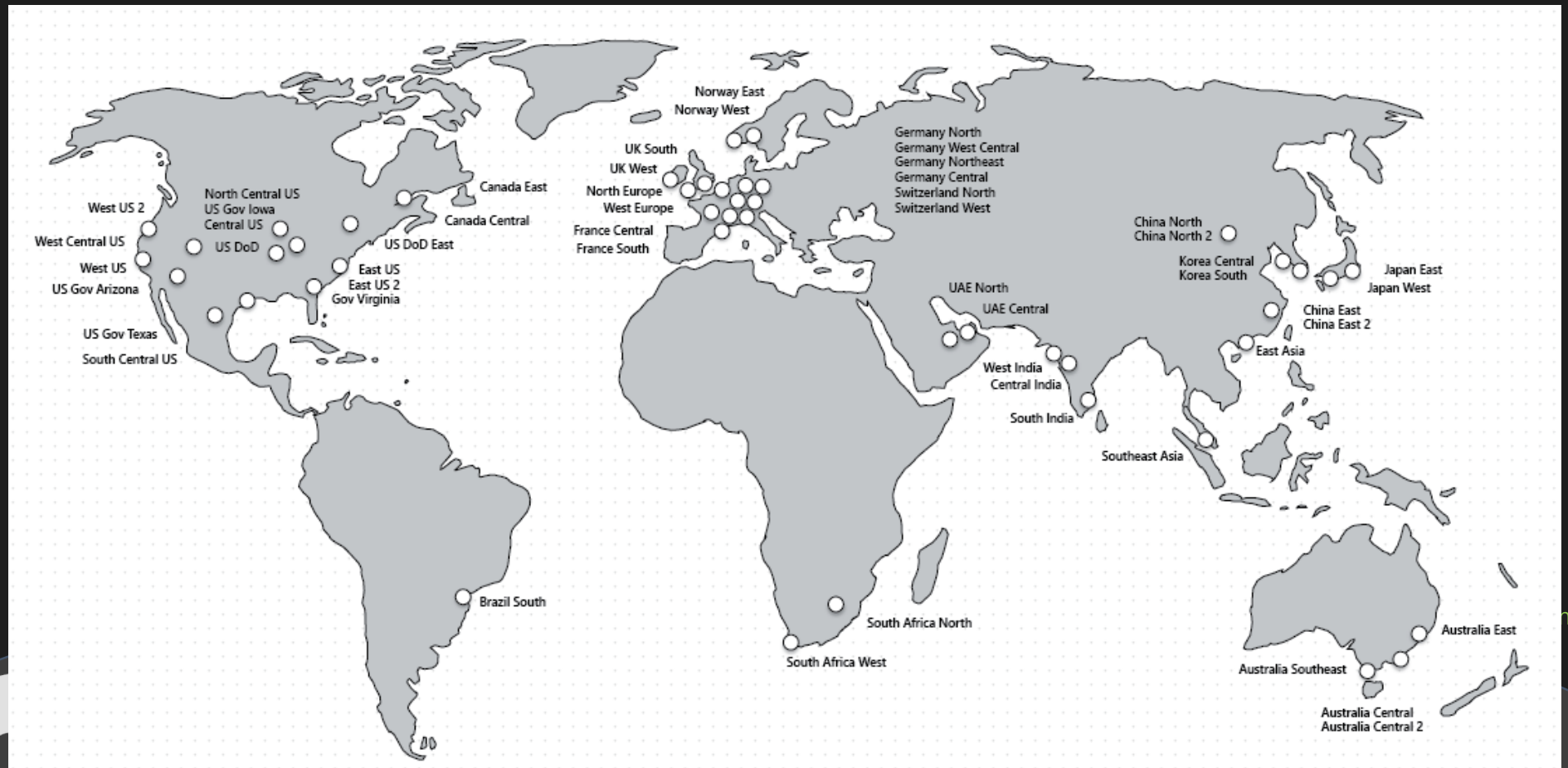
Azure Cosmos DB

A globally distributed, massively scalable, multi-model database service

Ubiquitous regional presence



Regions where Azure Cosmos DB is available

Turnkey global distribution

nprehensive SLAs

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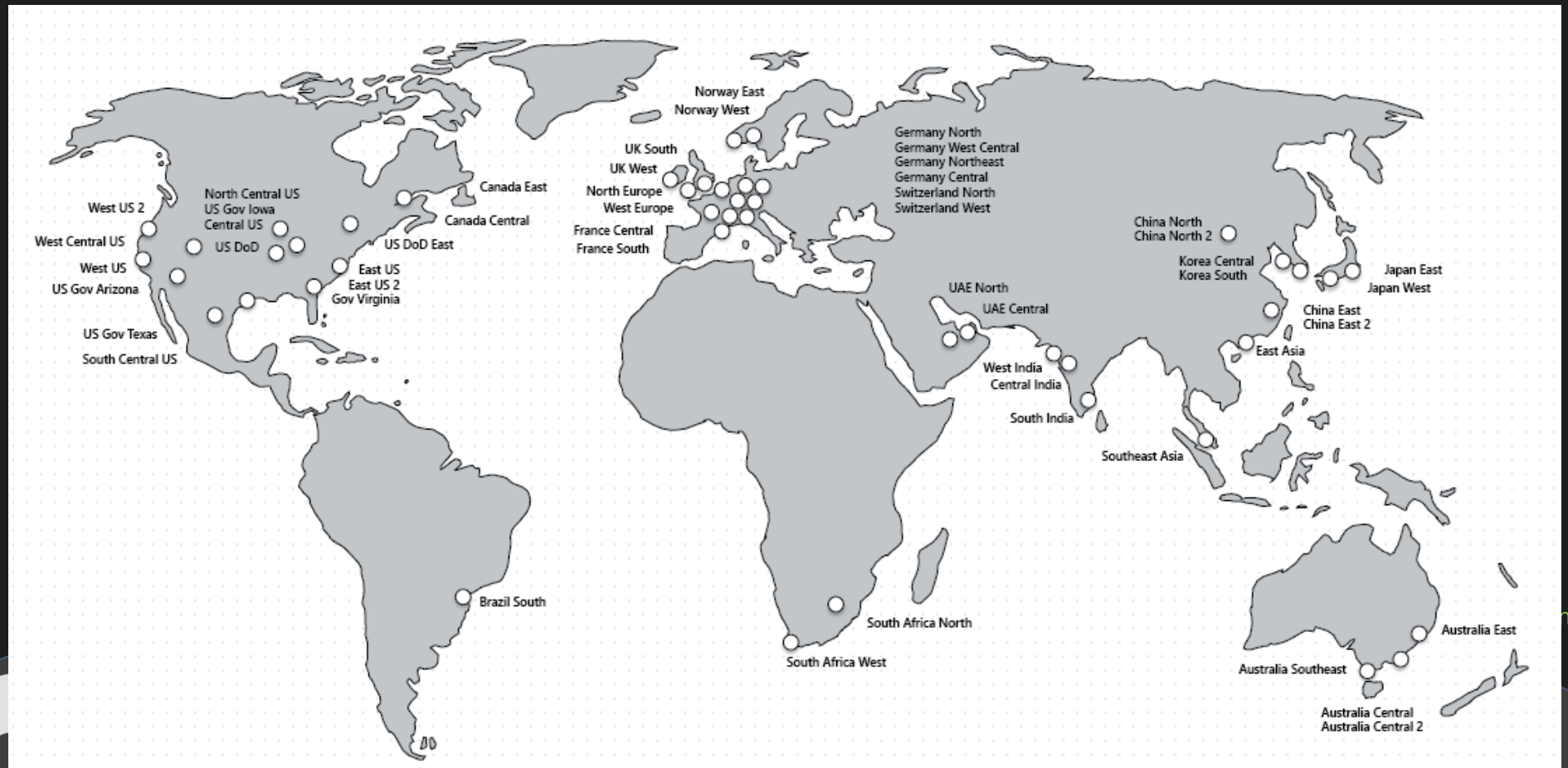
Azure Cosmos DB

A globally distributed, massively scalable, multi-model database service

Secure by default and enterprise ready



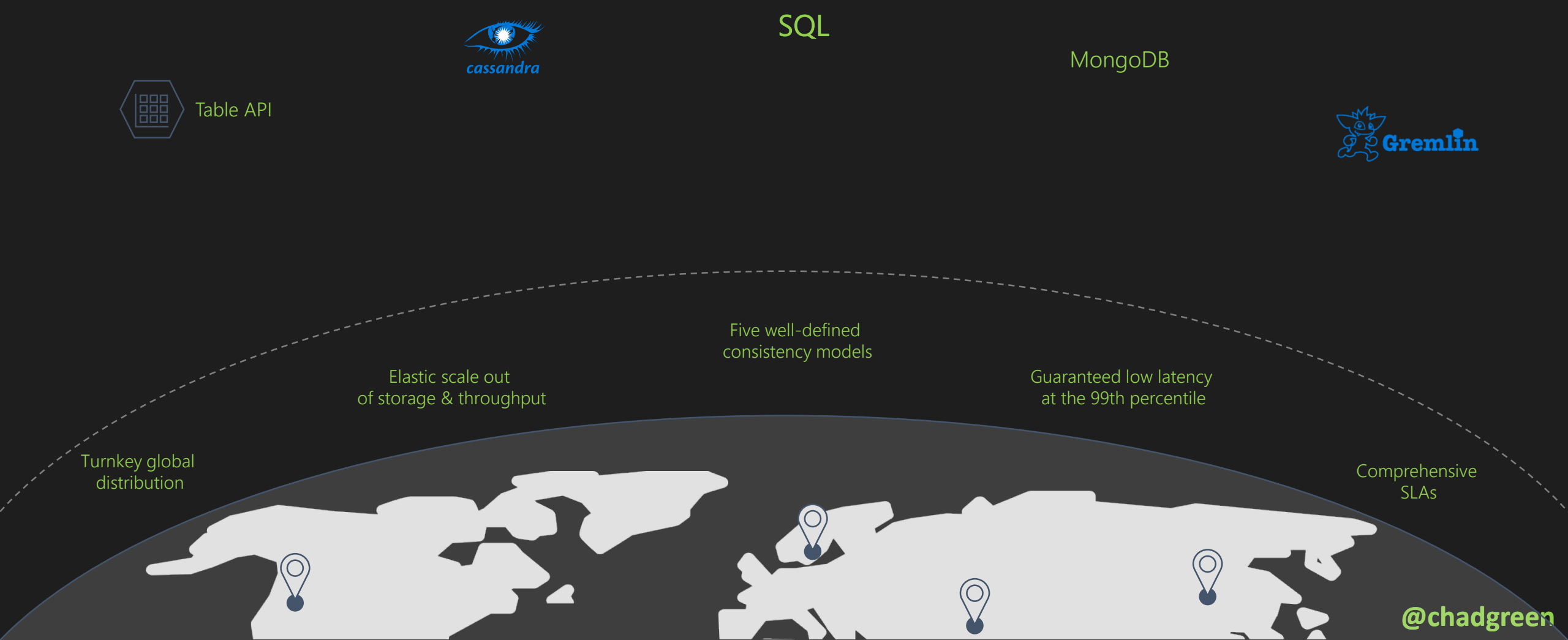
Regions where Azure Cosmos DB is available

Turnkey global distribution

nprehensive SLAs

Azure Cosmos DB

A globally distributed, massively scalable, multi-model database service



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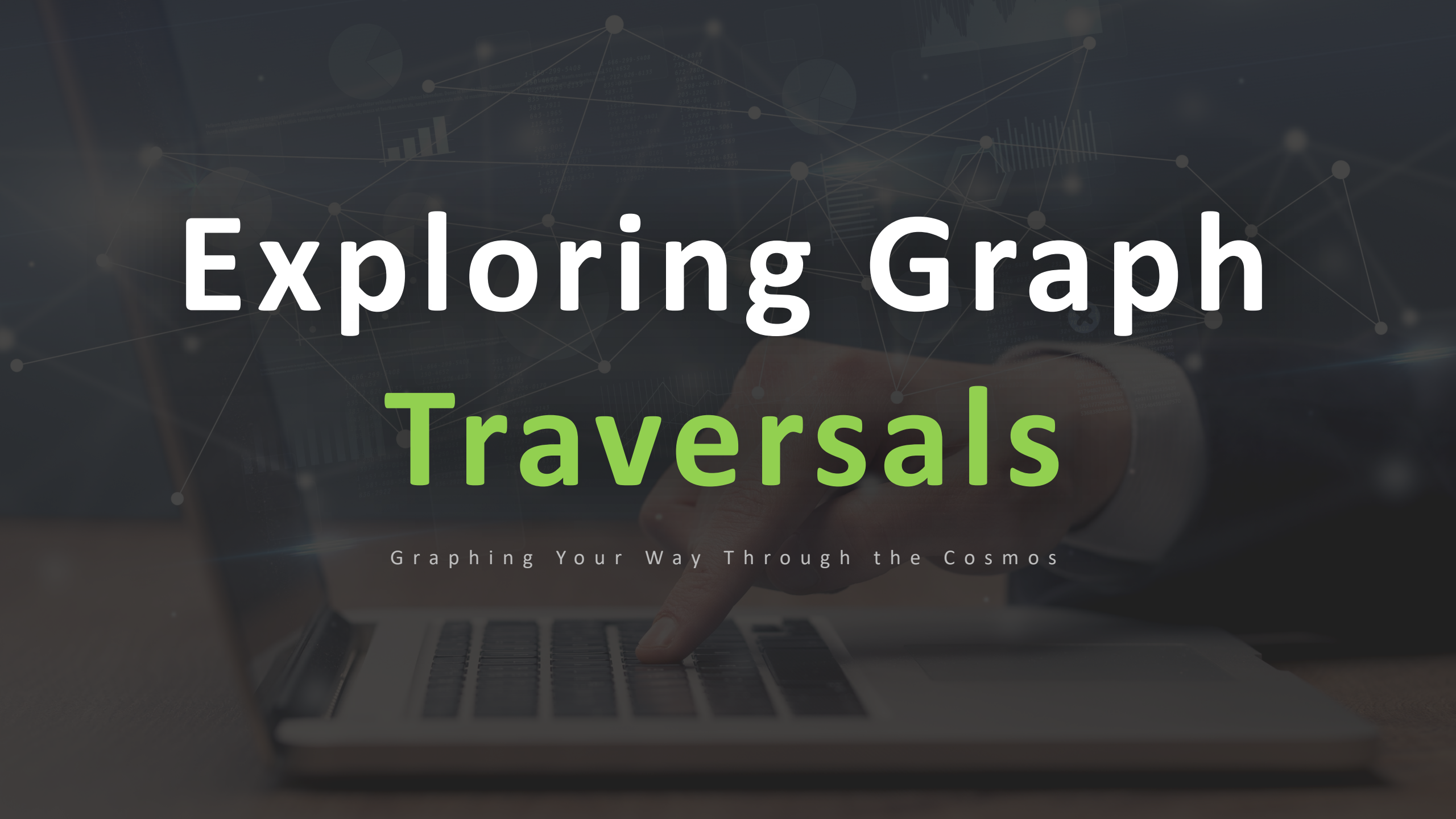


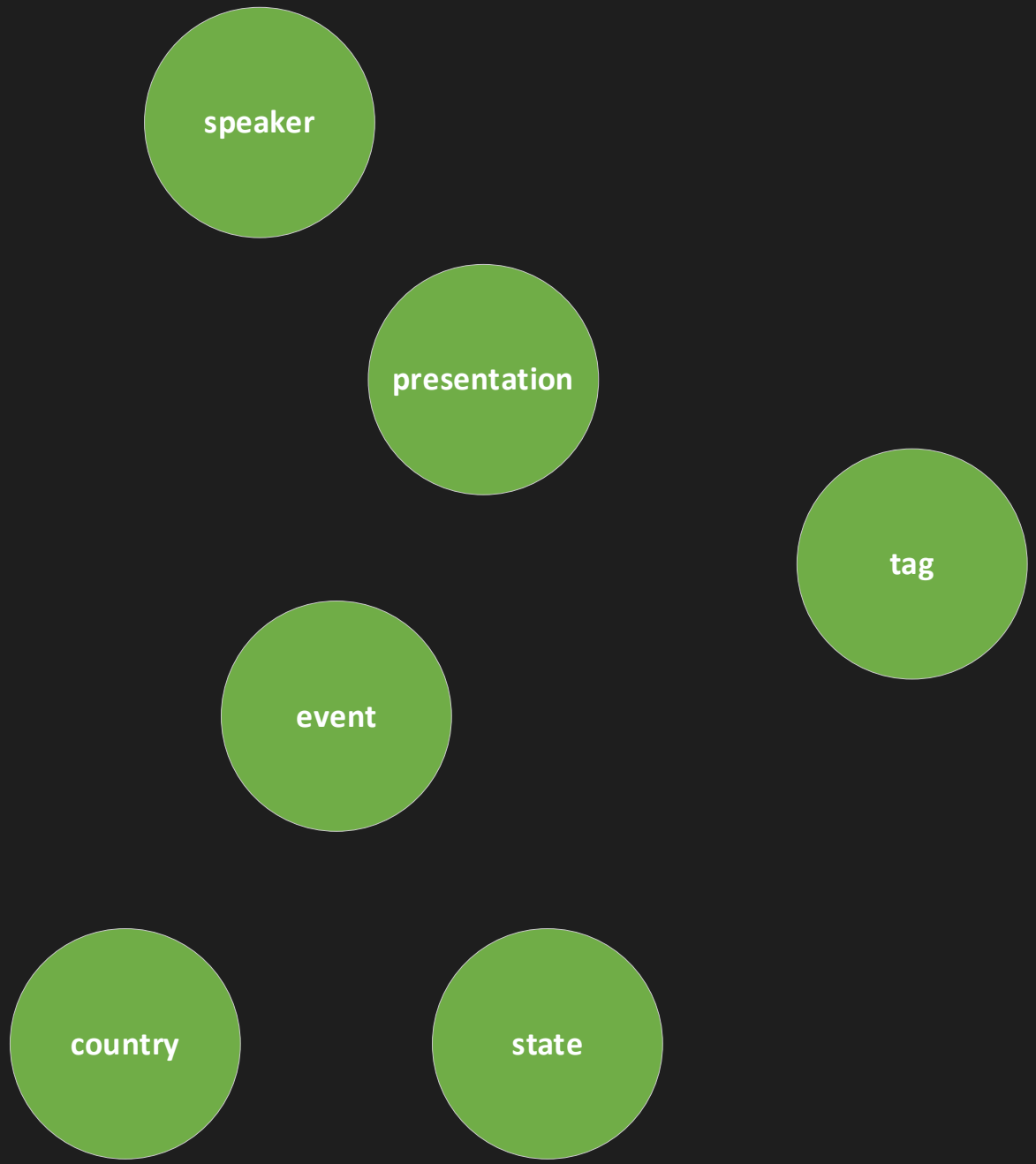
Exploring Graph Traversals

Graphing Your Way Through the Cosmos

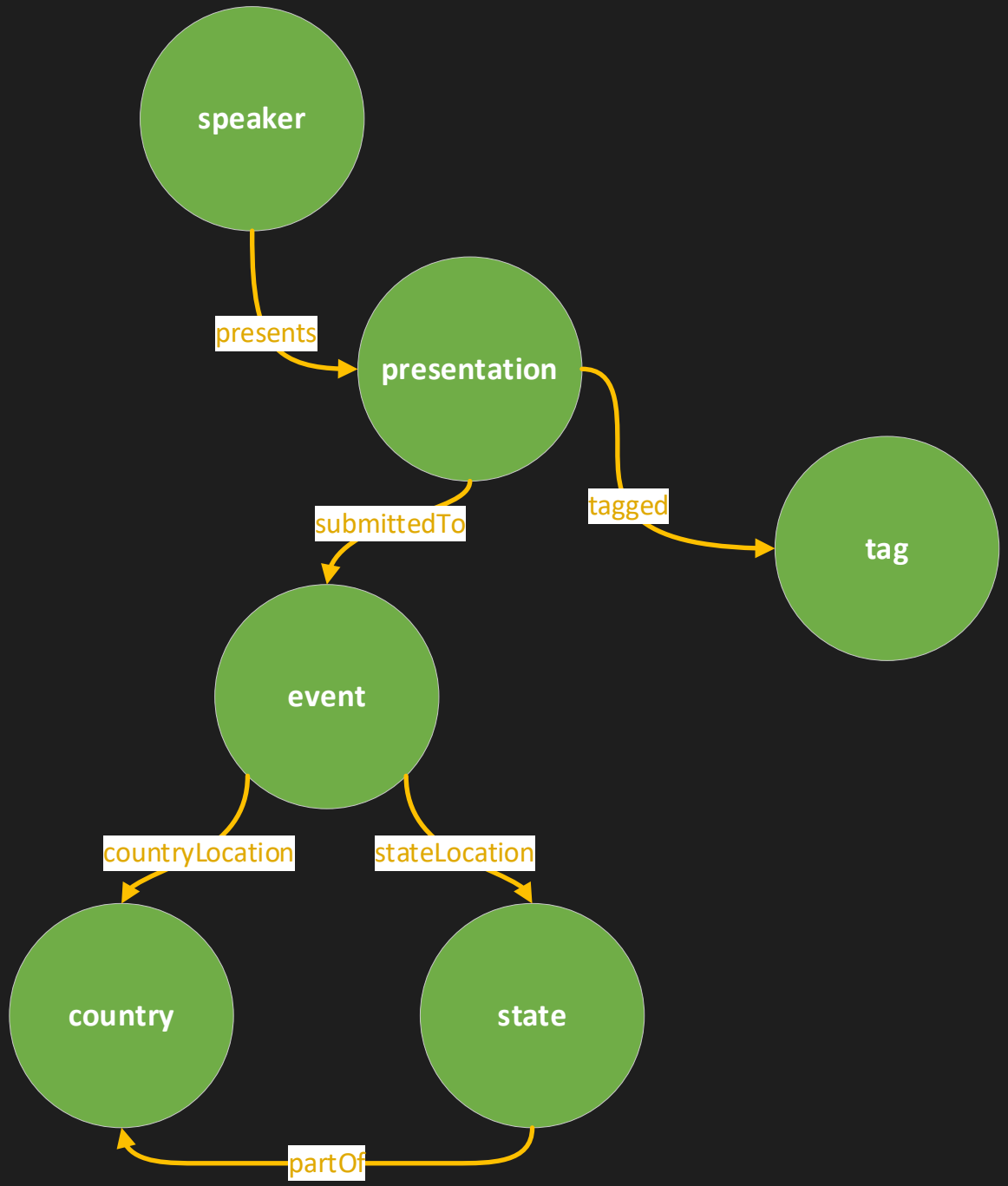
Requirements for Speaking Engagement Management

- Where has a presentation been submitted?
- What presentations are tagged with a particular tag?
- Where have presentations tagged with a particular tag been accepted?
- What events has a speaker been accepted at?
- Where were the events a speaker has been accepted to?

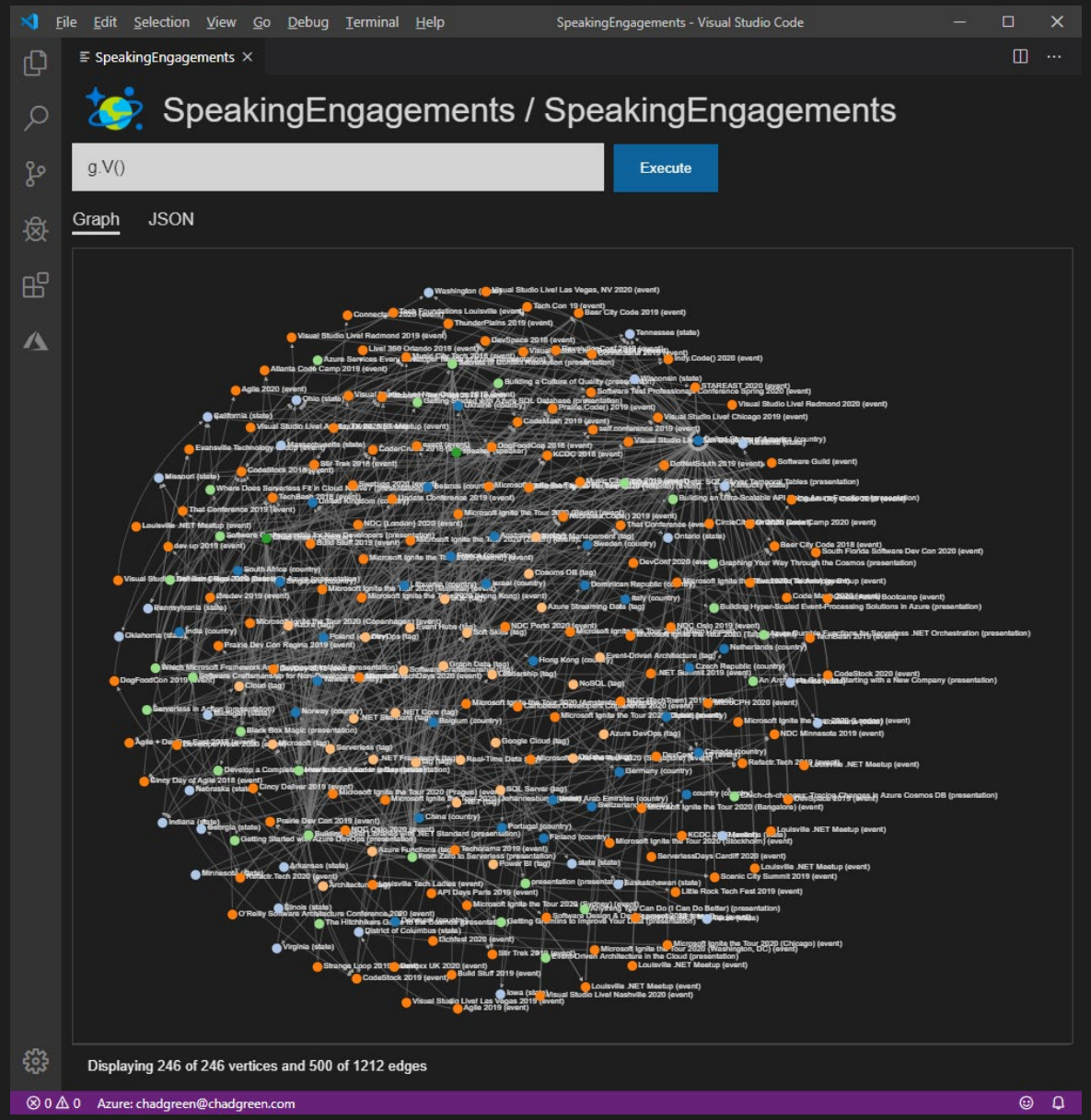
“Schema”



“Schema”


speaker
presents
presentation
tagged
tag
submittedTo
event
countryLocation
stateLocation
country
state
partOf

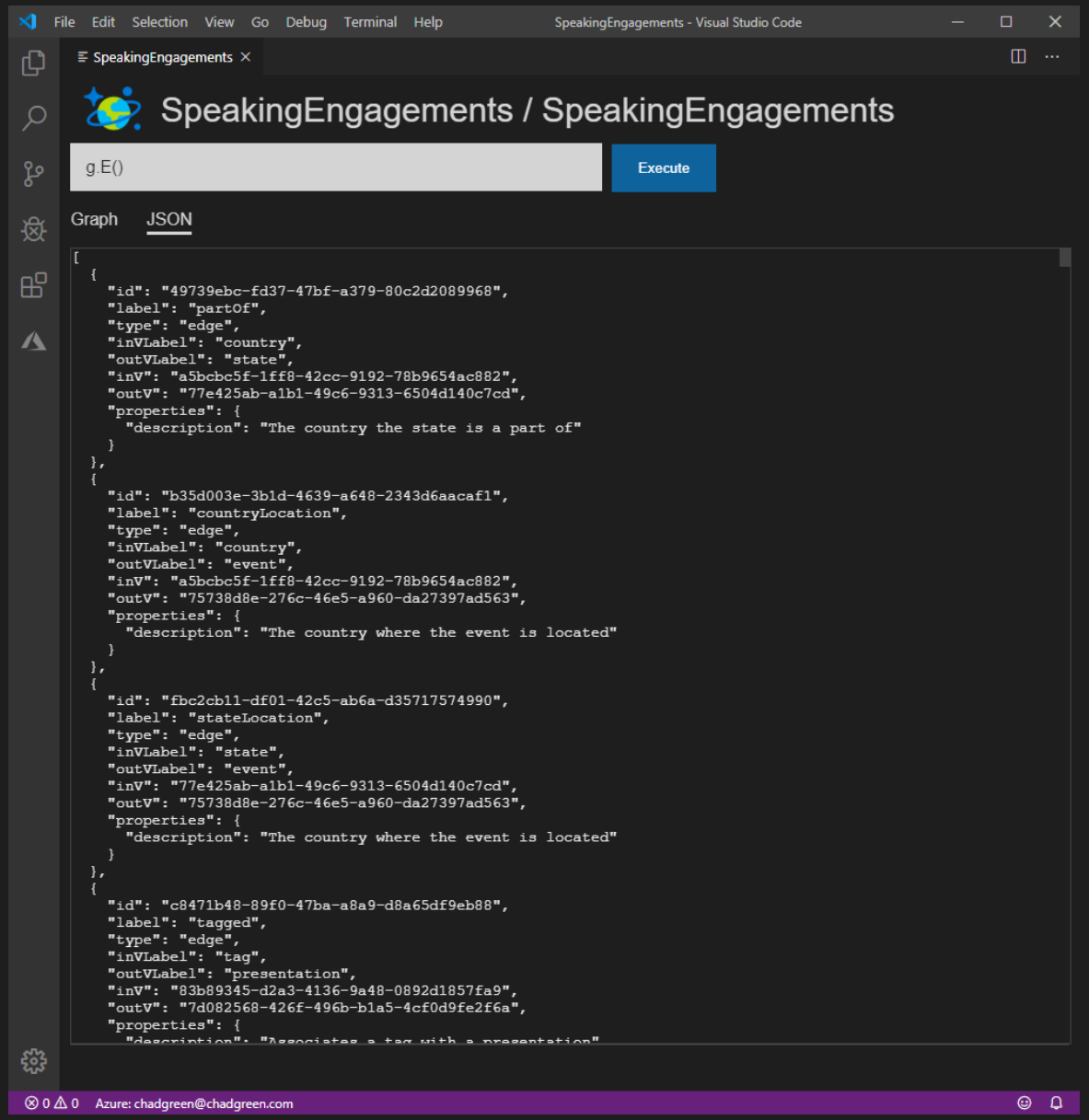
View the whole graph



g.V()

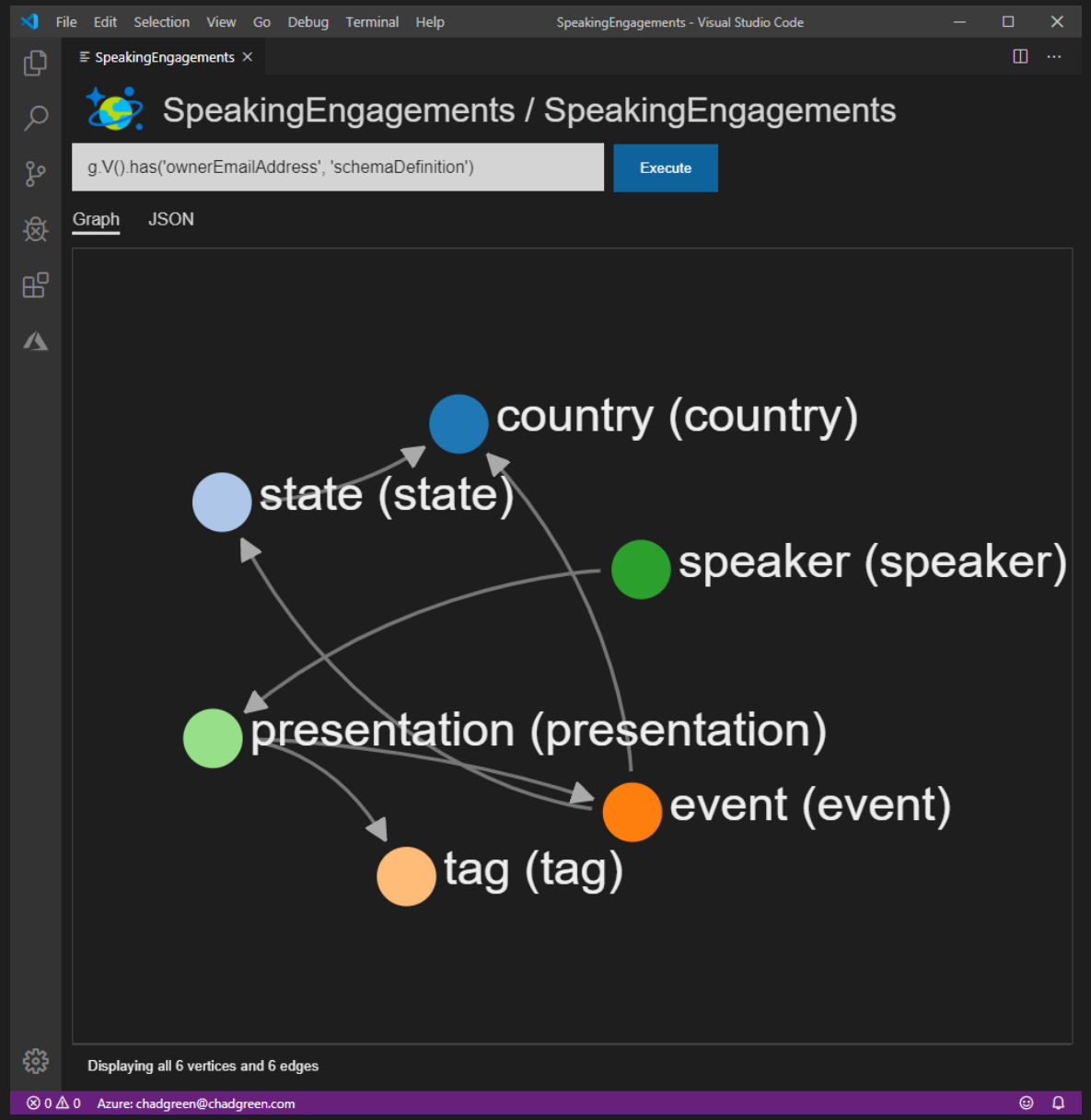
@chadgreen

View all of the edges



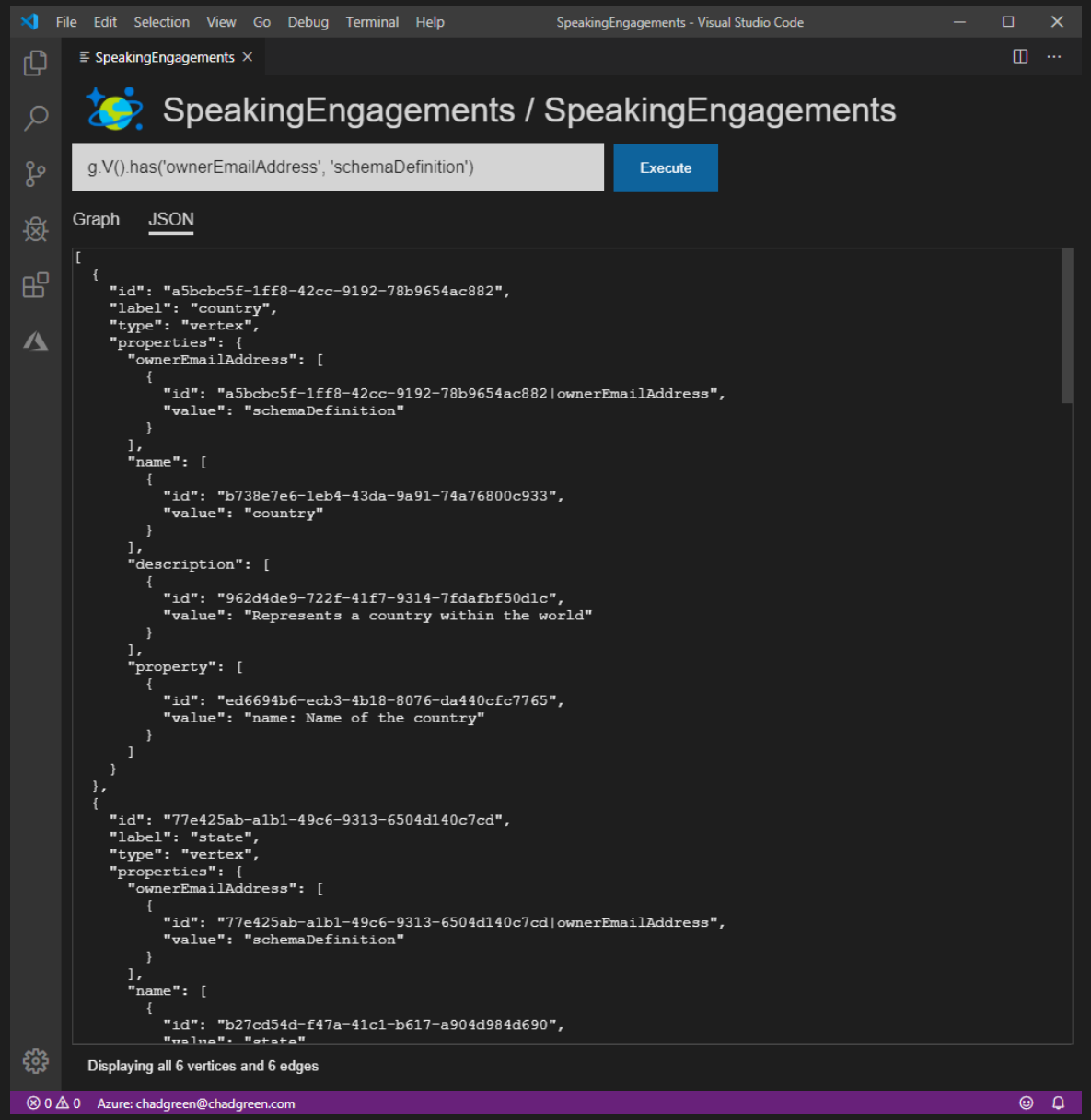
g.E()

View the schema definition



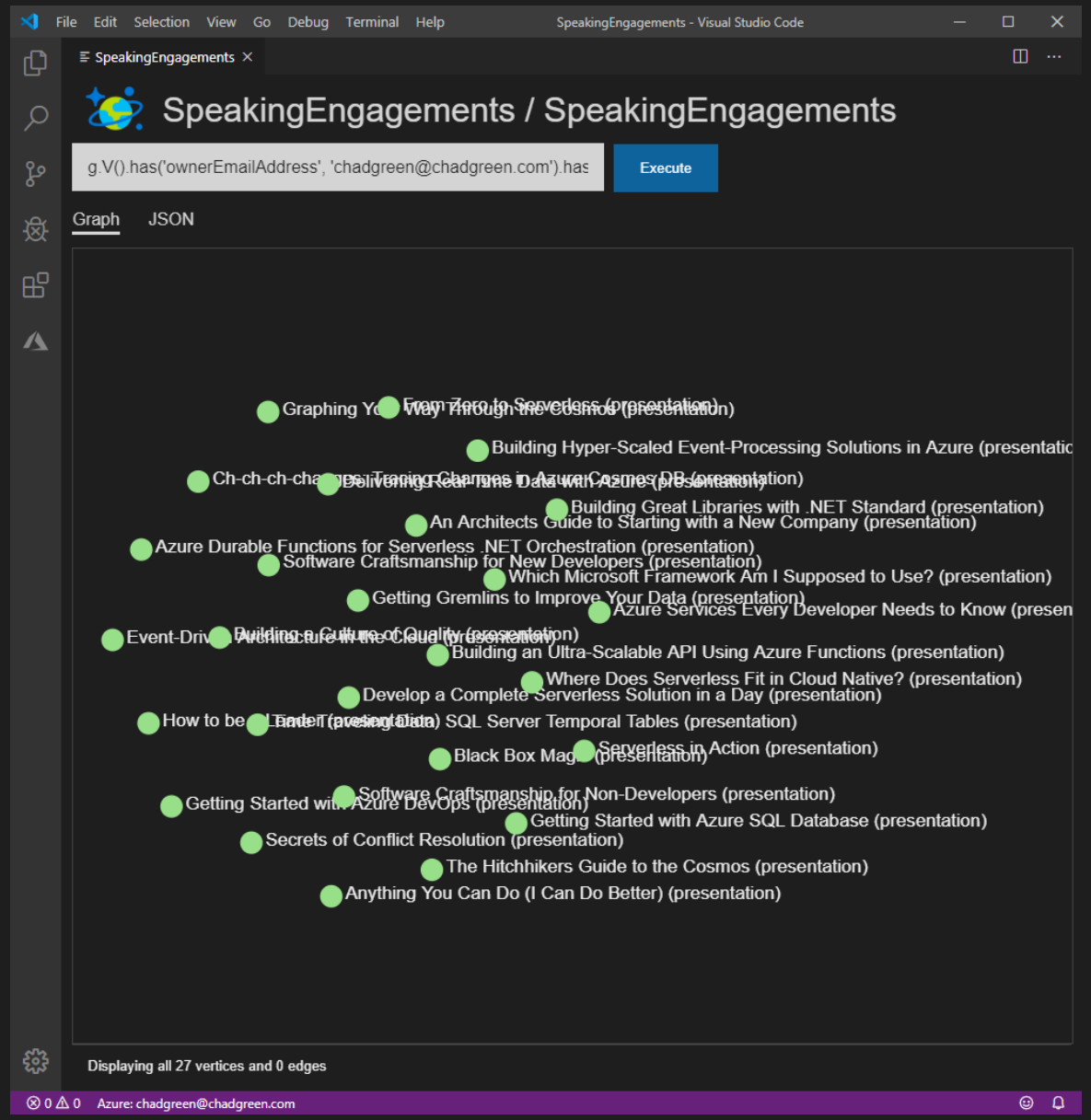

```
g.V()
.has('ownerEmailAddress',
'schemaDefinition')
```

View the schema definition




```
g.V()
.has('ownerEmailAddress',
'schemaDefinition')
```

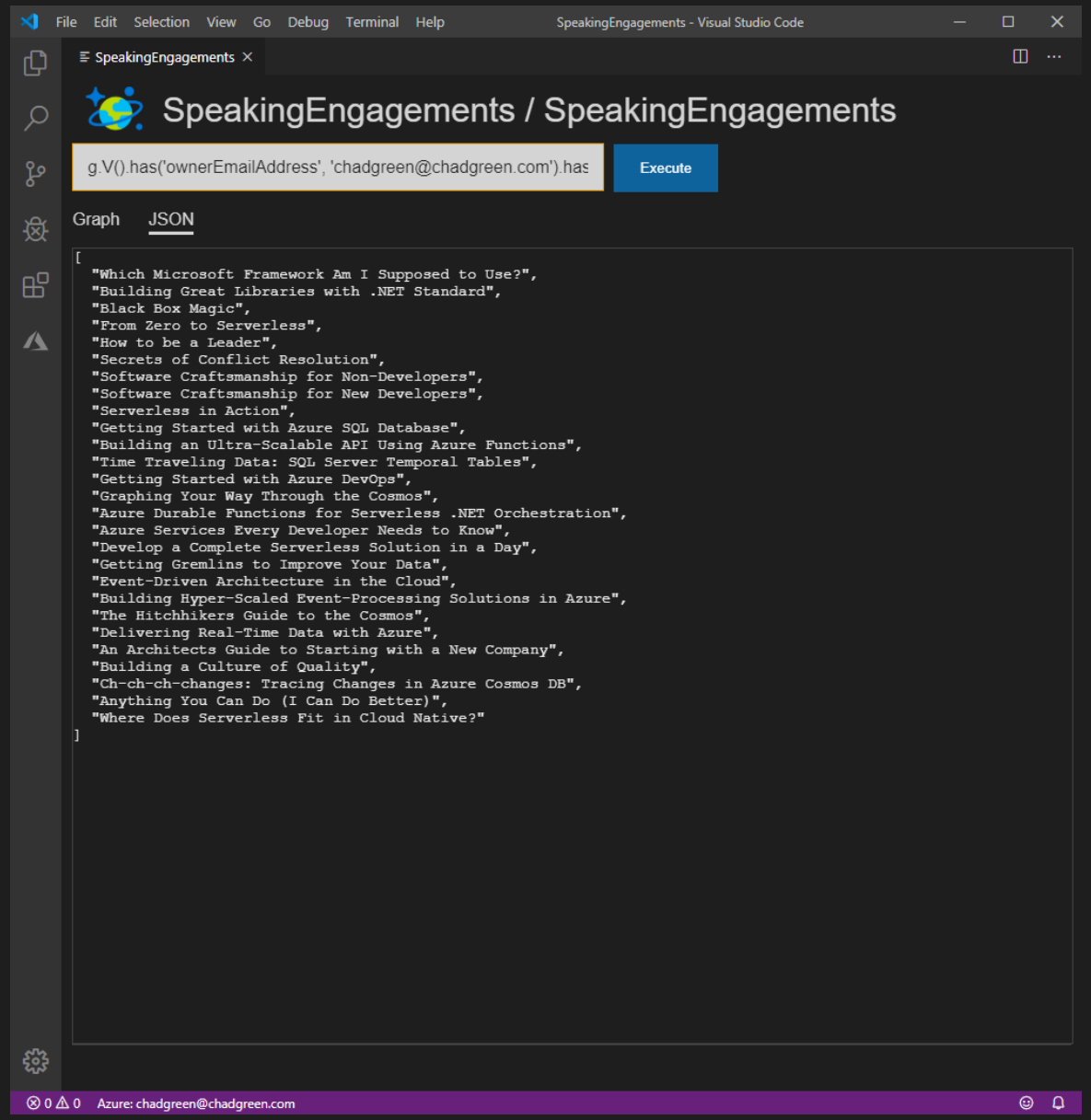
What presentations are in my repertoire?




```
g.V()
.has('ownerEmailAddress',
'chadgreen@chadgreen.com')
.hasLabel('presentation')
```

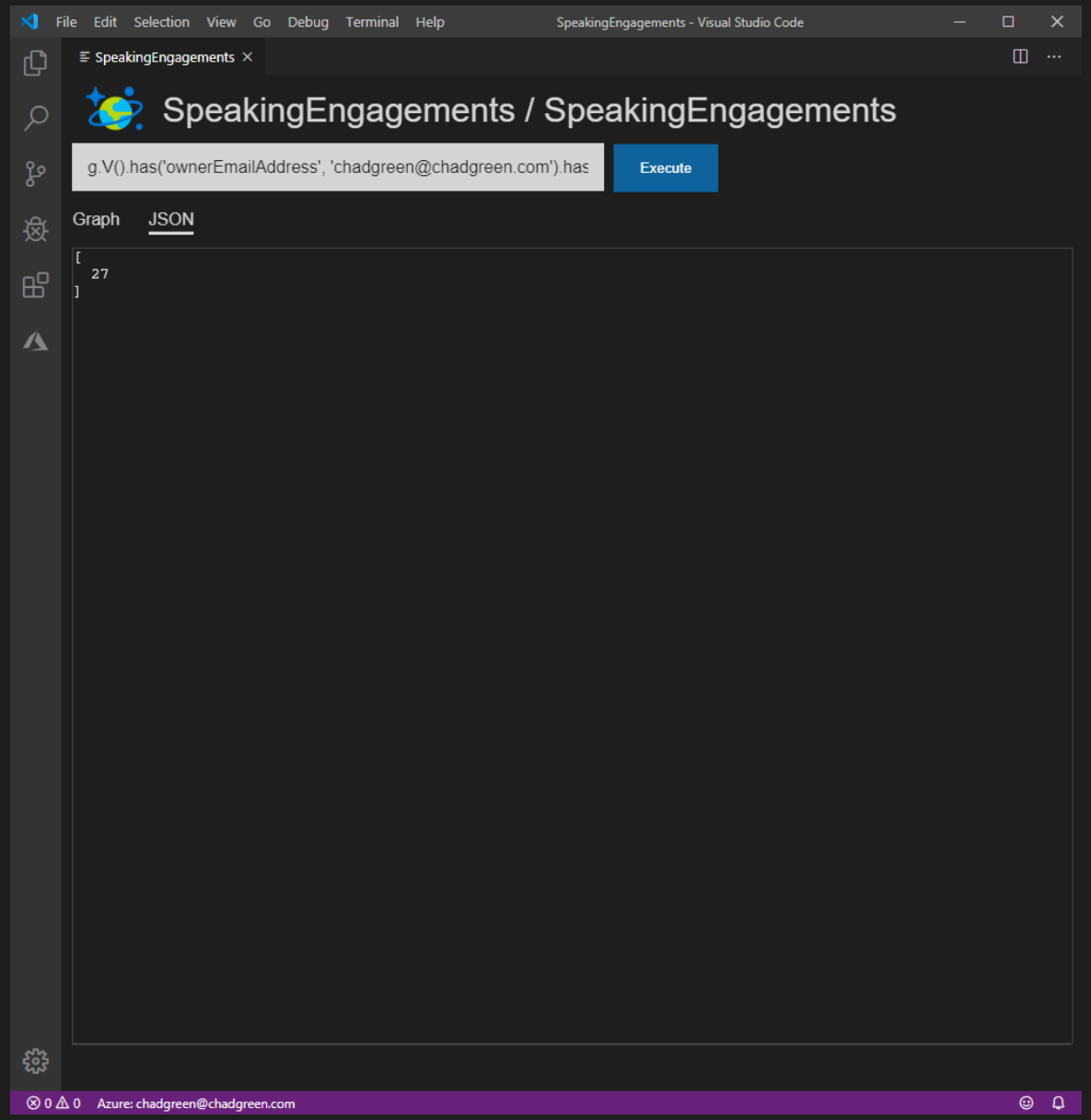
@chadgreen

What presentations are in my repertoire?



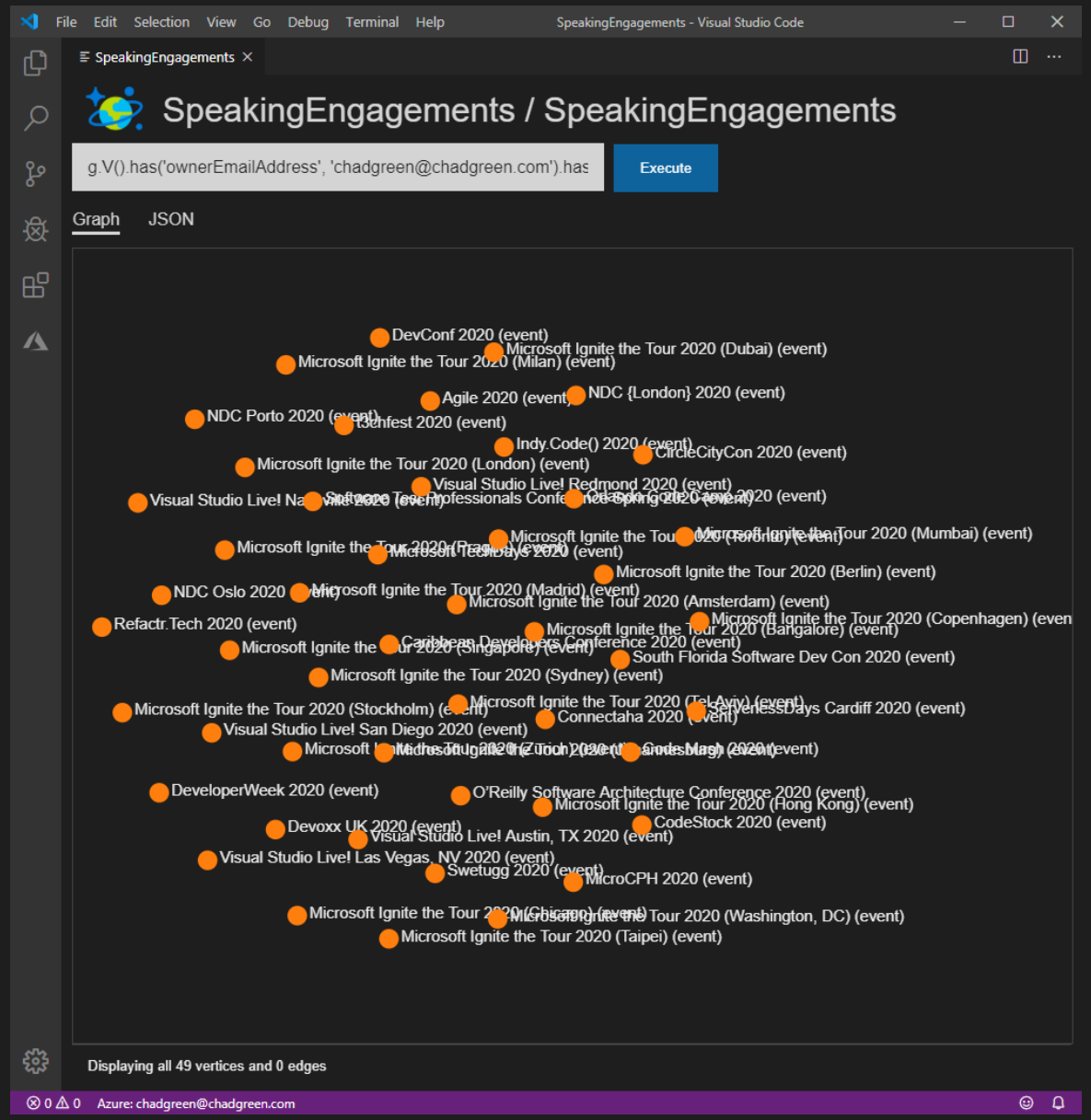

```
g.V()
.hasLabel('presentation')
.values('name')
```

How many presentations are in my repertoire?



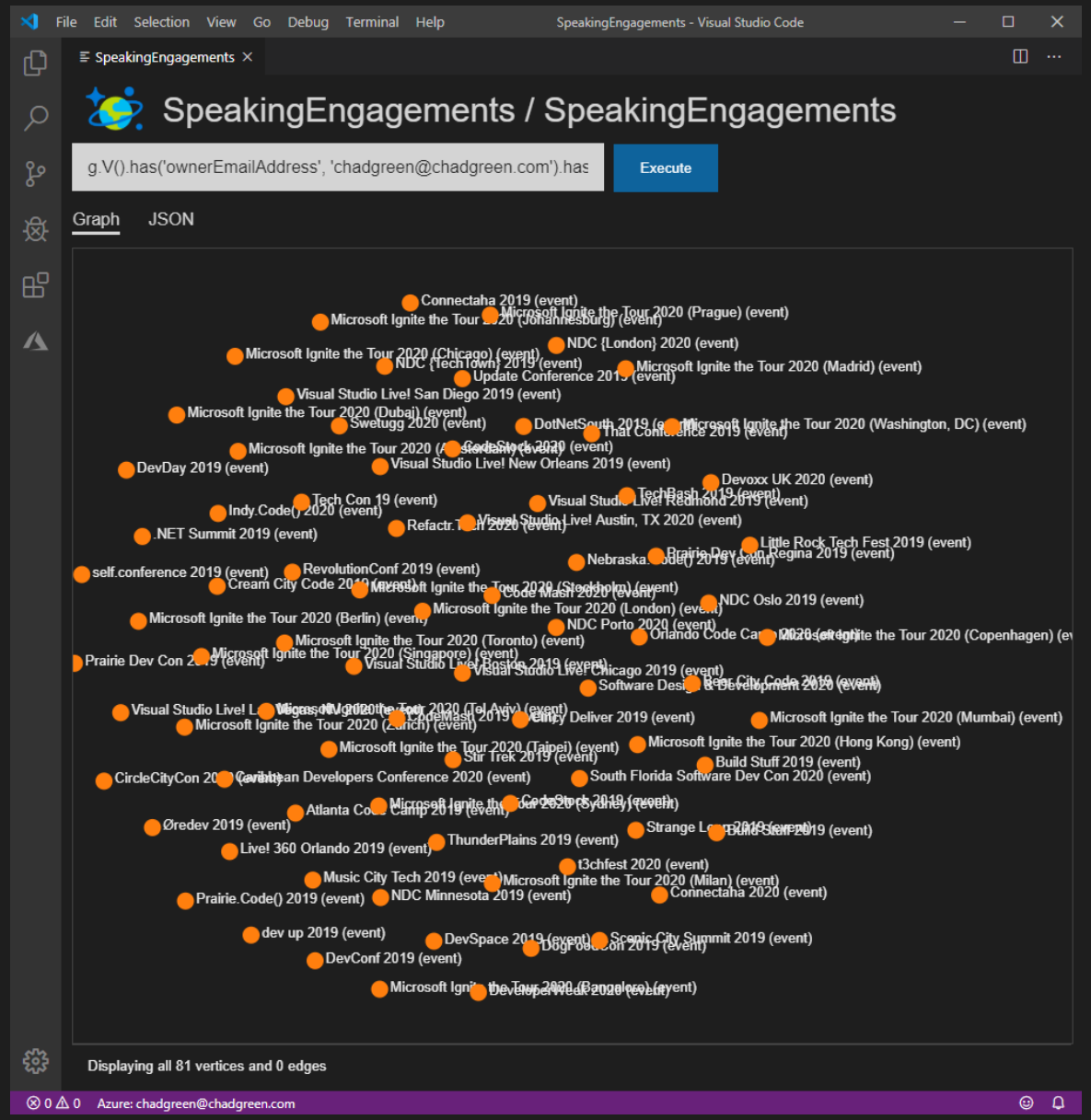

```
g.V()
.hasLabel('presentation')
.count()
```

What are the events that I have submitted to?




```
g.V()
.hasLabel('event')
.has('year', '2020')
```

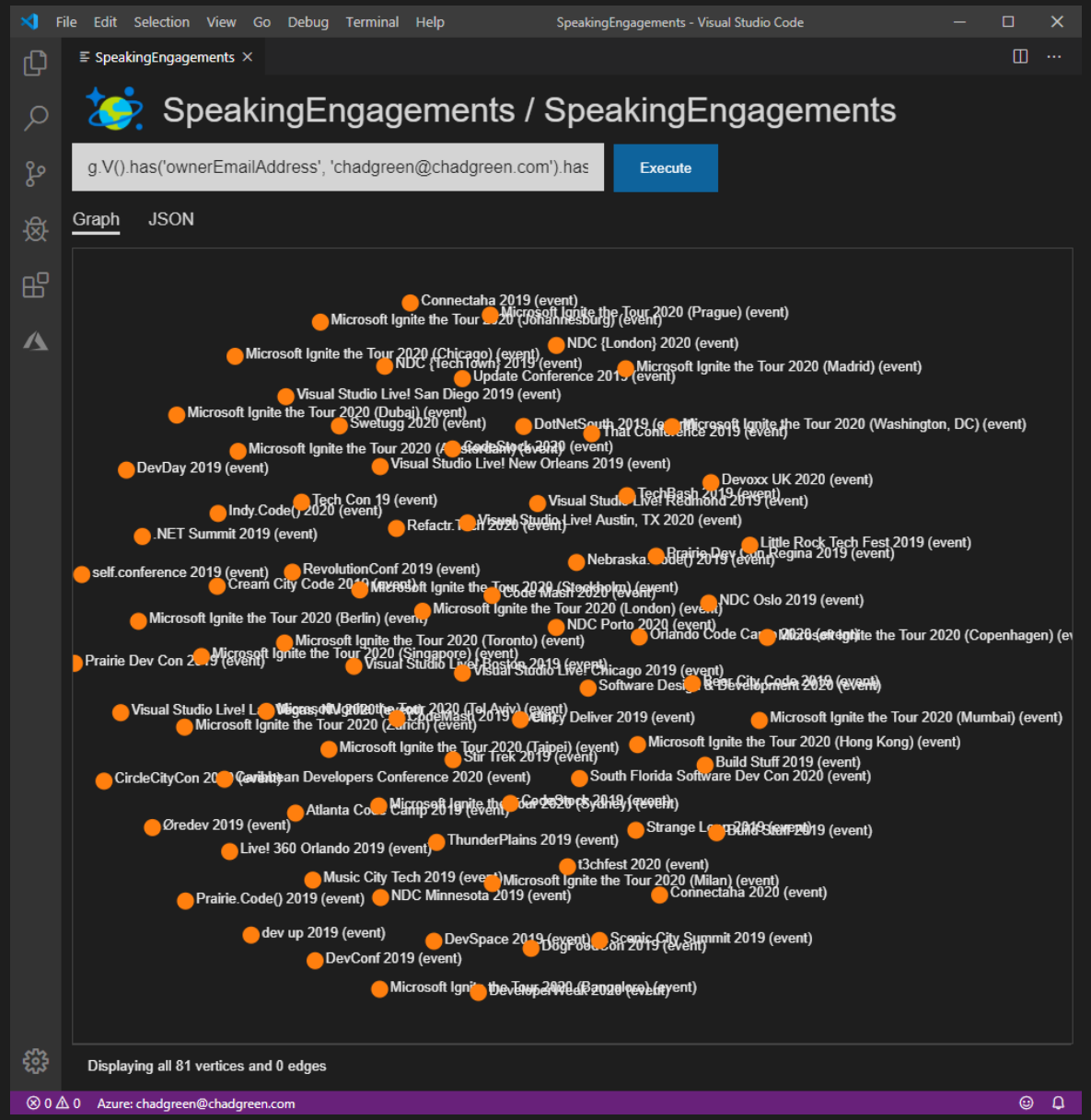
Where has *Graphing Your Way Through the Cosmos* been submitted to?




```
g.V()
.hasLabel('presentation')
.has('name', 'Graphing Your Way Through the Cosmos')
.outE('submittedTo')
.inV()
```

@chadgreen

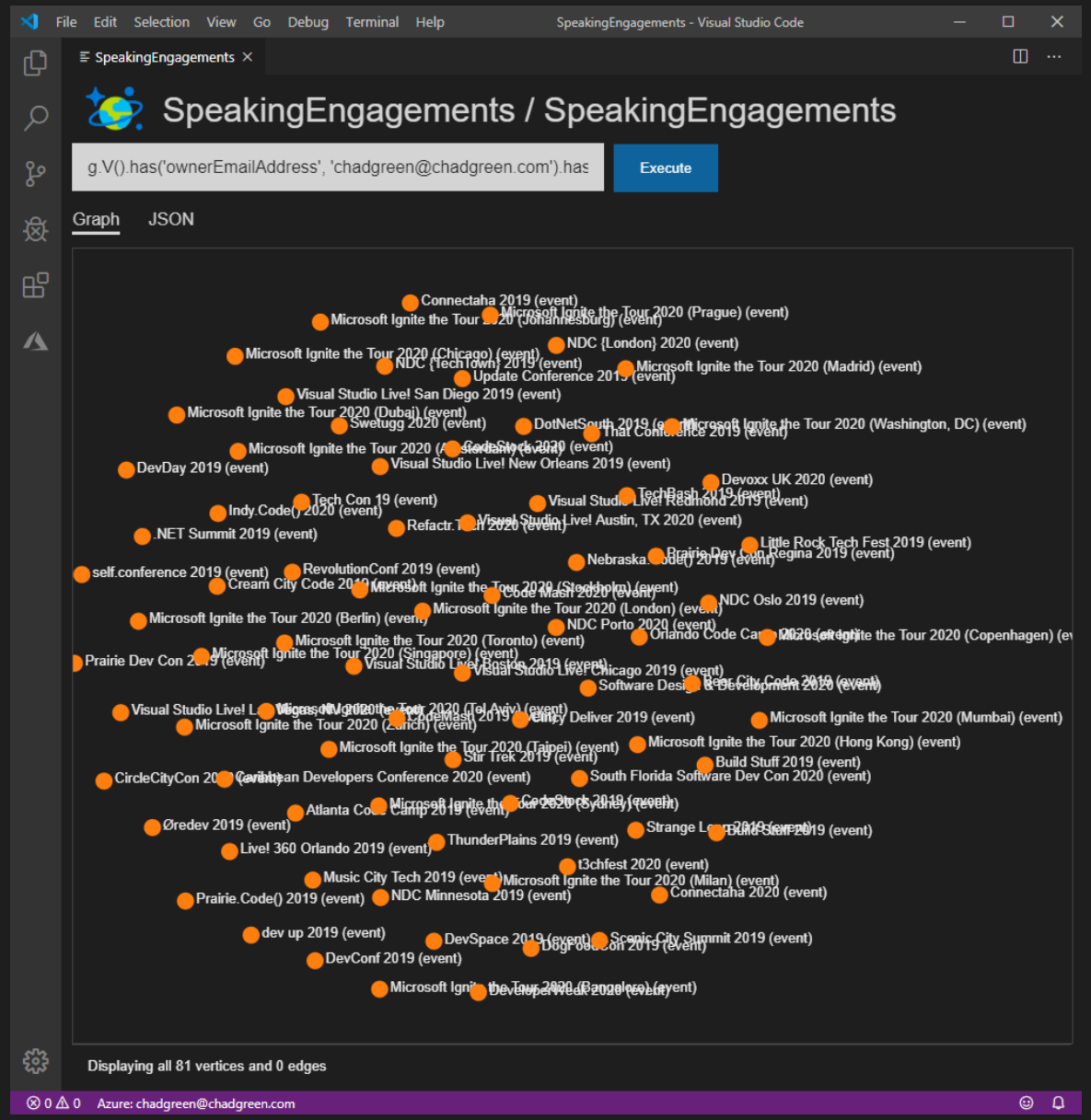
Where has *Graphing Your Way Through the Cosmos* been submitted to?




```
g.V()
.hasLabel('presentation')
.has('name', 'Graphing Your
Way Through the Cosmos')
.outE('submittedTo')
.inV()
.has('year', '2020')
```

@chadgreen

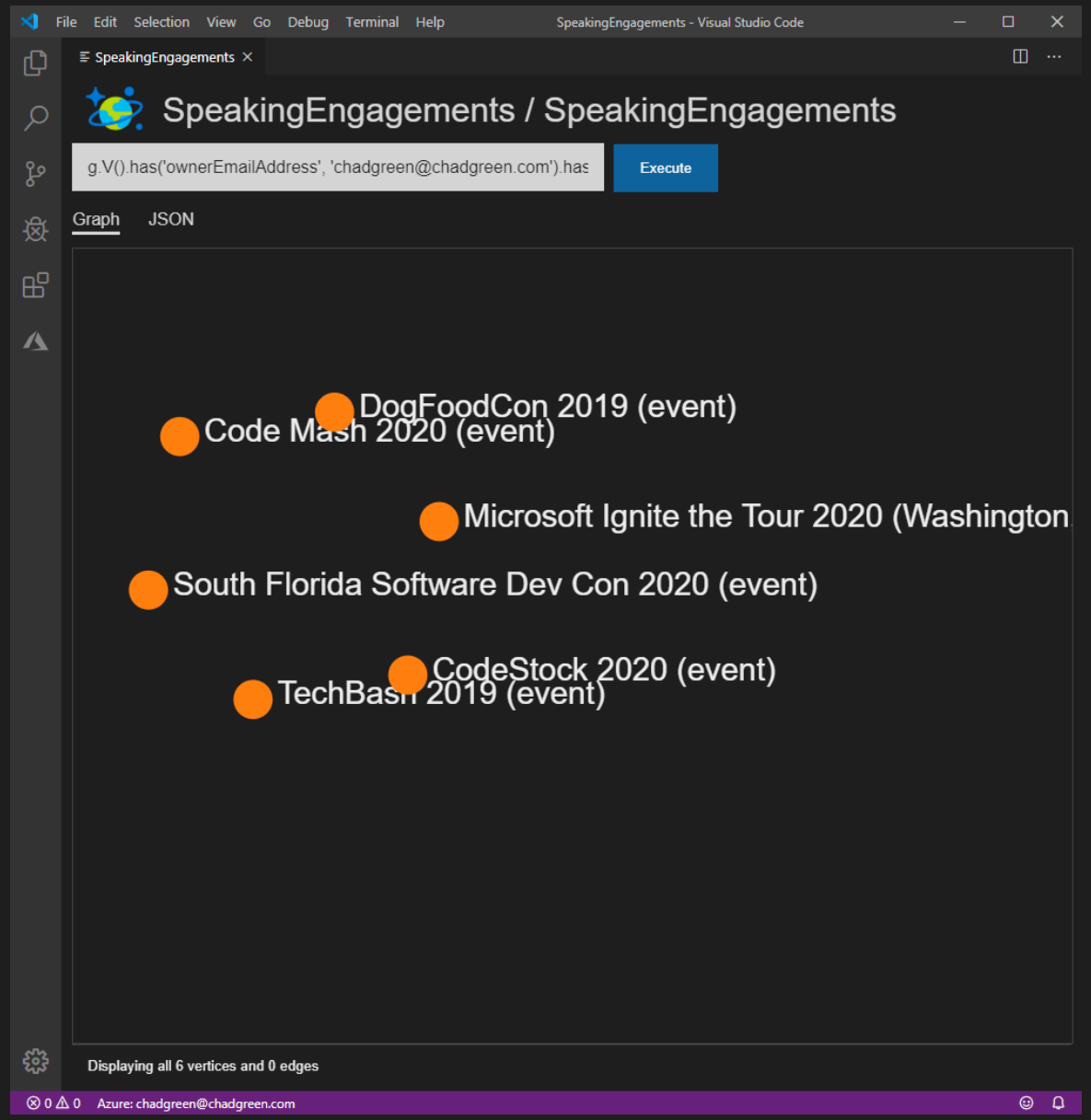
Where has *Graphing Your Way Through the Cosmos* been submitted to?




```
g.V()
.hasLabel('presentation')
.has('name', 'Graphing Your Way Through the Cosmos')
.outE('submittedTo')
.inV()
```

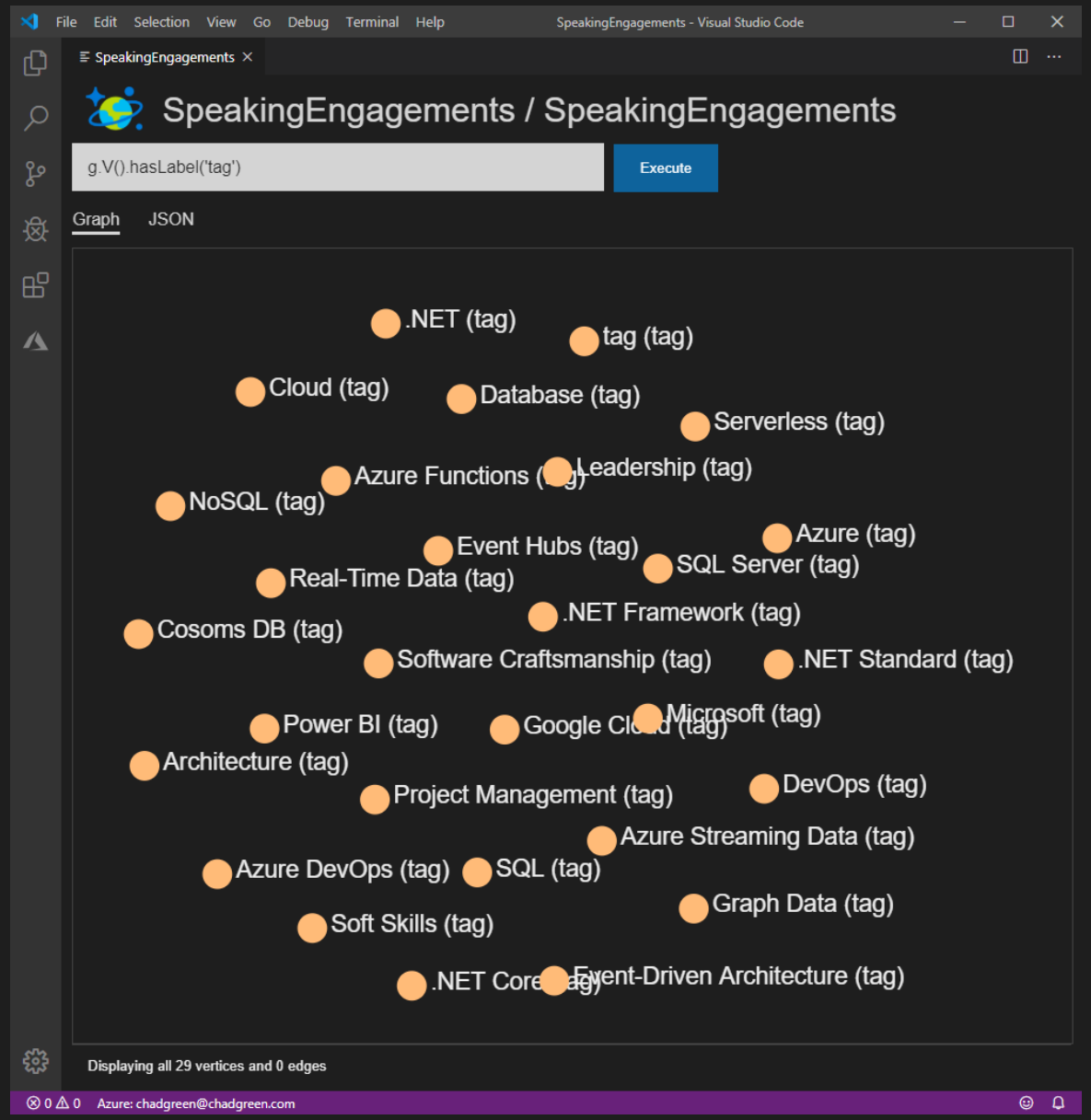
@chadgreen

Where has *Graphing Your Way Through the Cosmos* been scheduled?



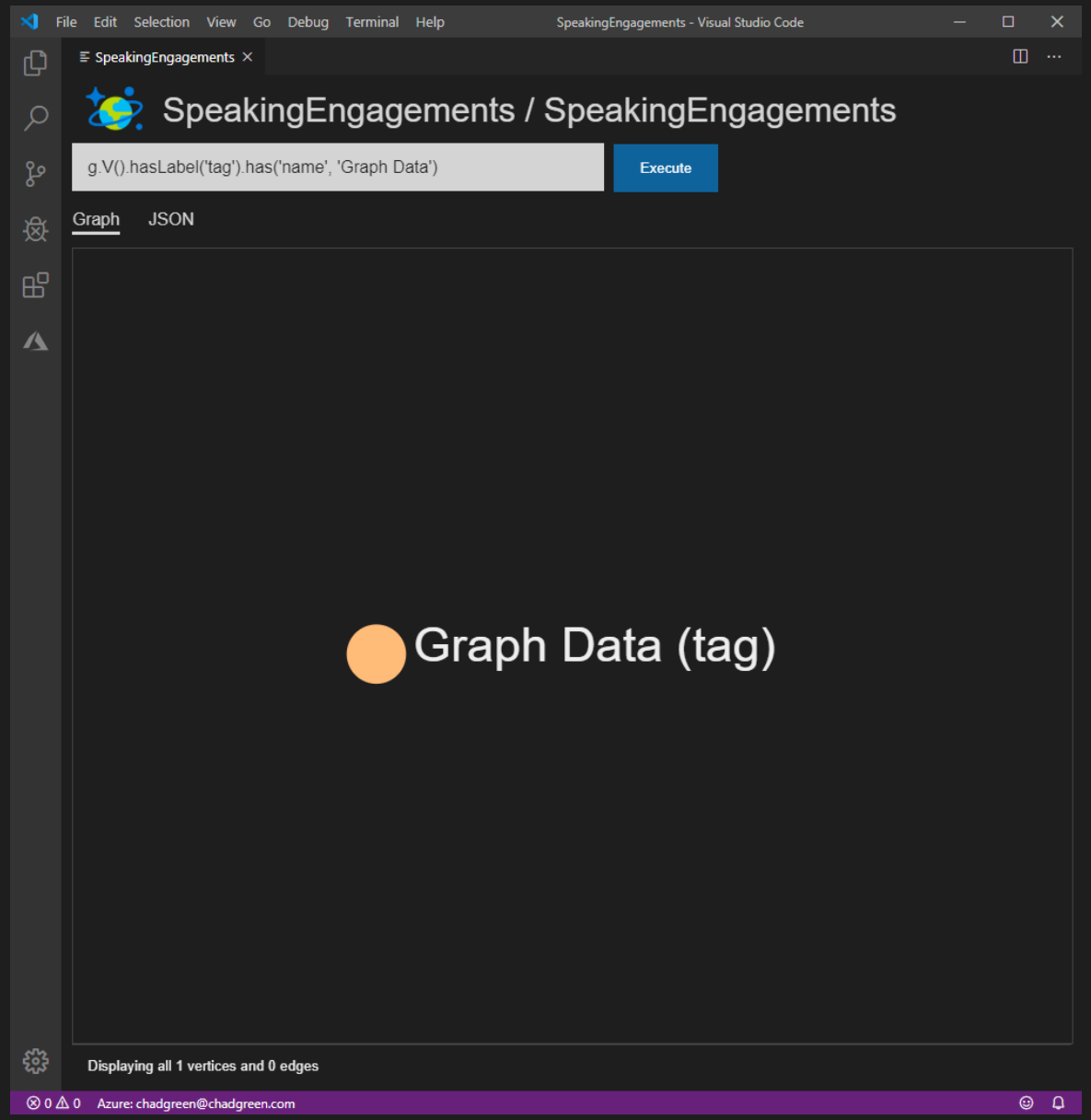

```
g.V()
.hasLabel('presentation')
.has('name', 'Graphing Your
Way Through the Cosmos')
.outE('submittedTo')
.has('status', 'Confirmed')
.inV()
```

View all of the tags



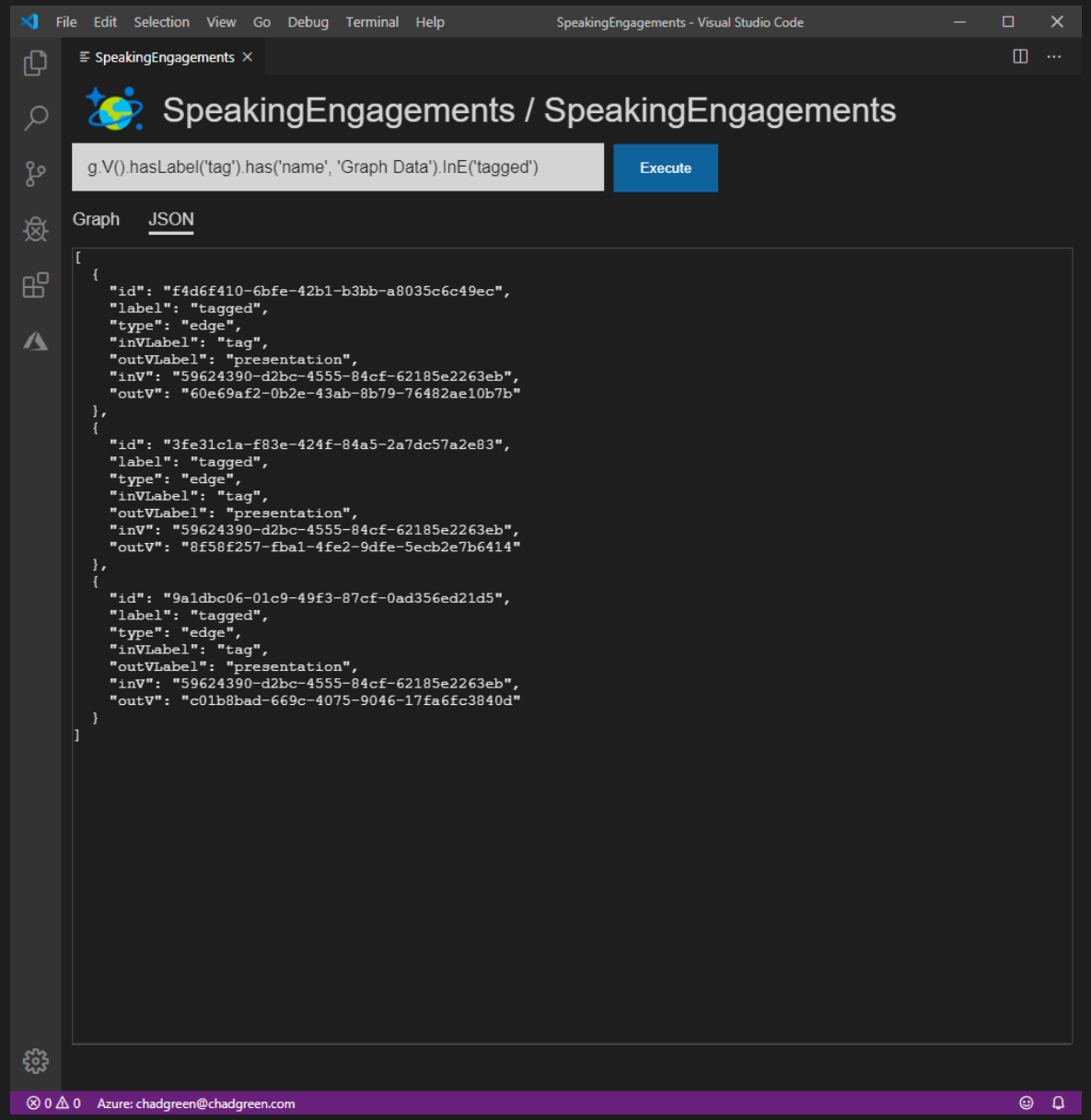

```
g.V()
.hasLabel('tag')
```

Focus on the *Graph Data* tag



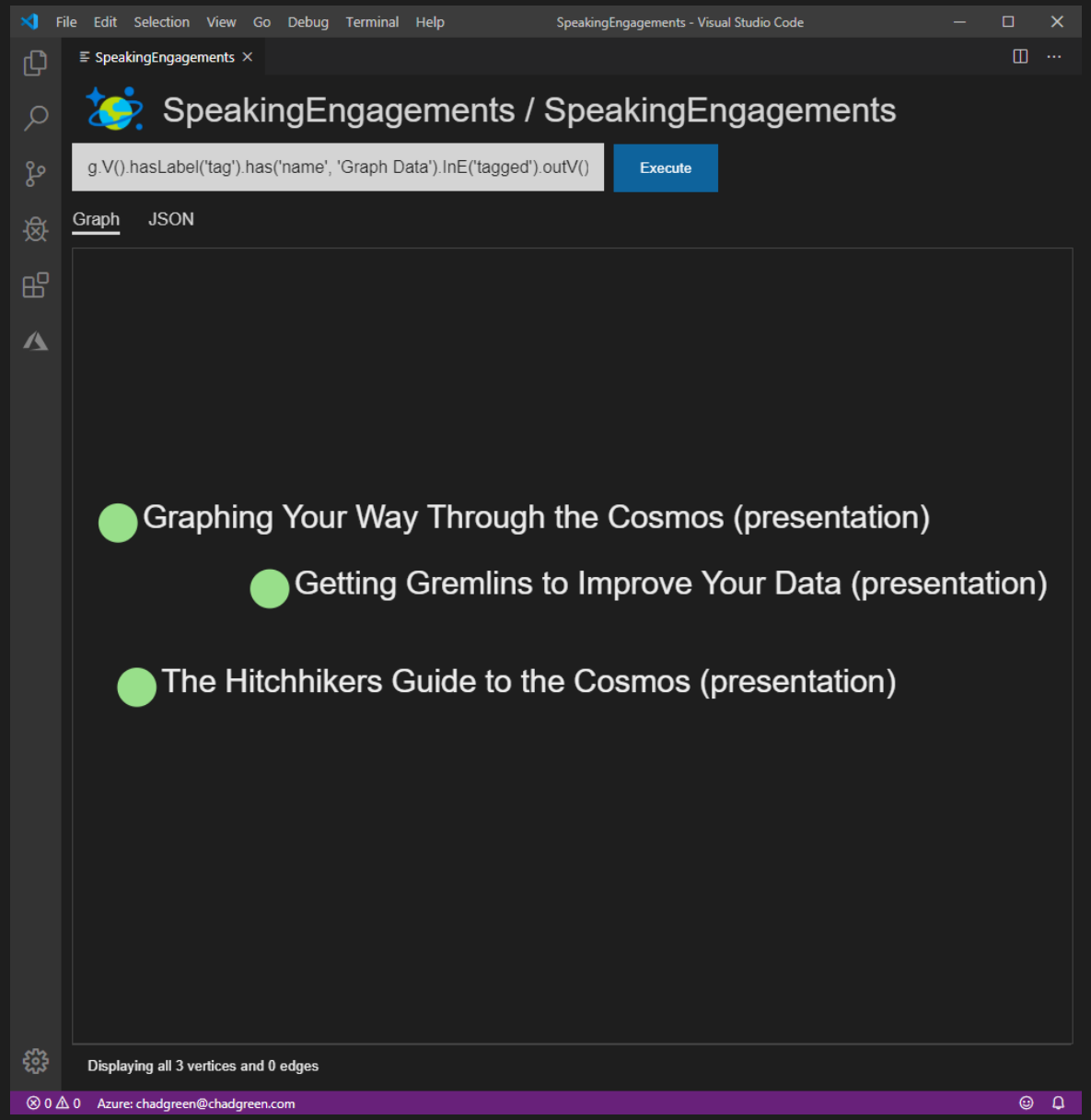

```
g.V()
.hasLabel('tag’)
.has('name', 'Graph Data')
```

What presentations are tagged with *Graph Data?*



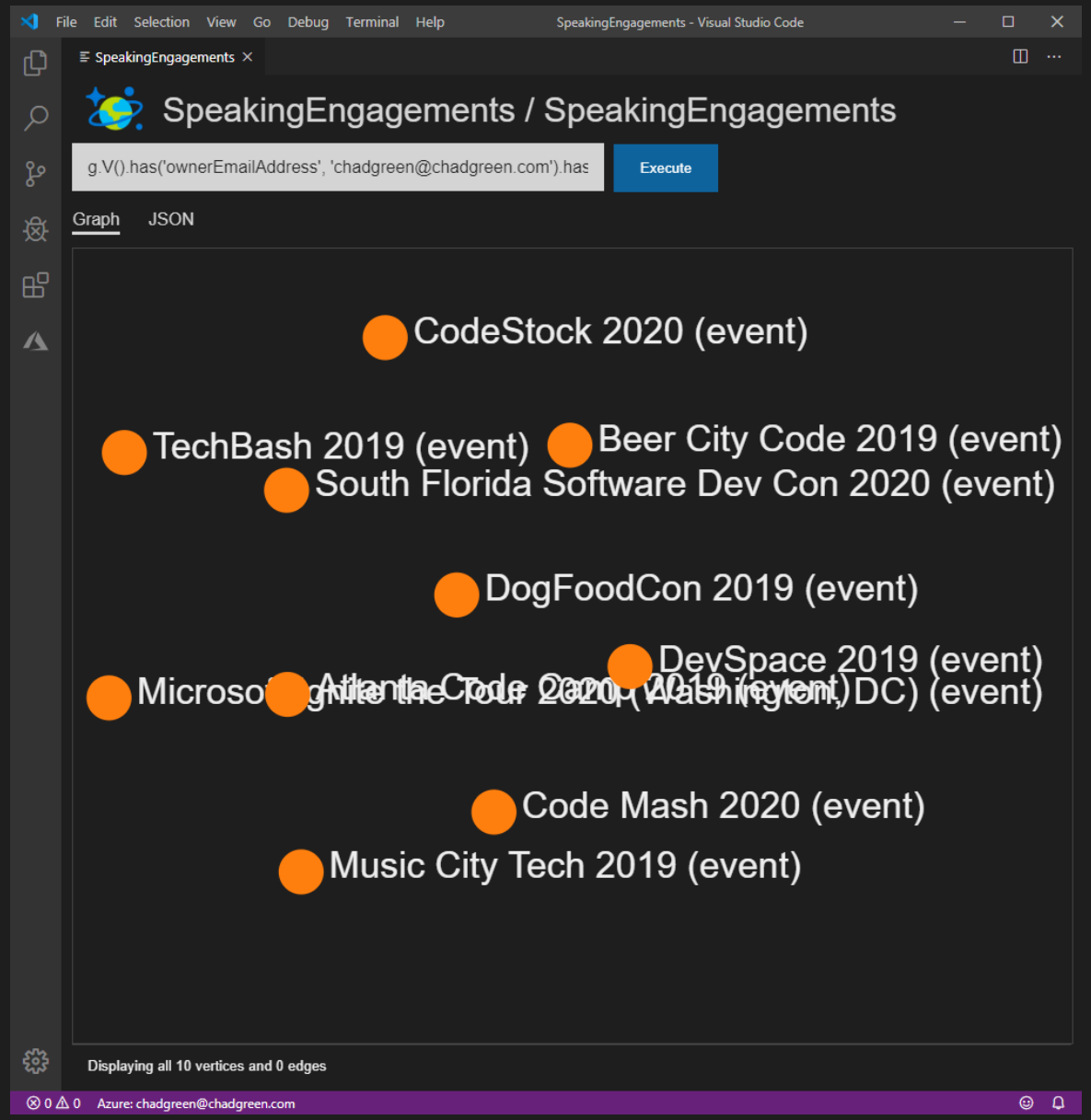

```
g.V()
.hasLabel('tag')
.has('name', 'Graph Data')
.inE('tagged')
```

What presentations are tagged with *Graph Data?*




```
g.V()
.hasLabel('tag')
.has('name', 'Graph Data')
.inE('tagged')
.outV()
```

Where have the presentations tagged *Graph Data* been scheduled?




```
g.V()
.hasLabel('tag')
.has('name', 'Graph Data')
.inE('tagged')
.outV()
.outE('submittedTo')
.has('status', 'Confirmed')
.inV()
```

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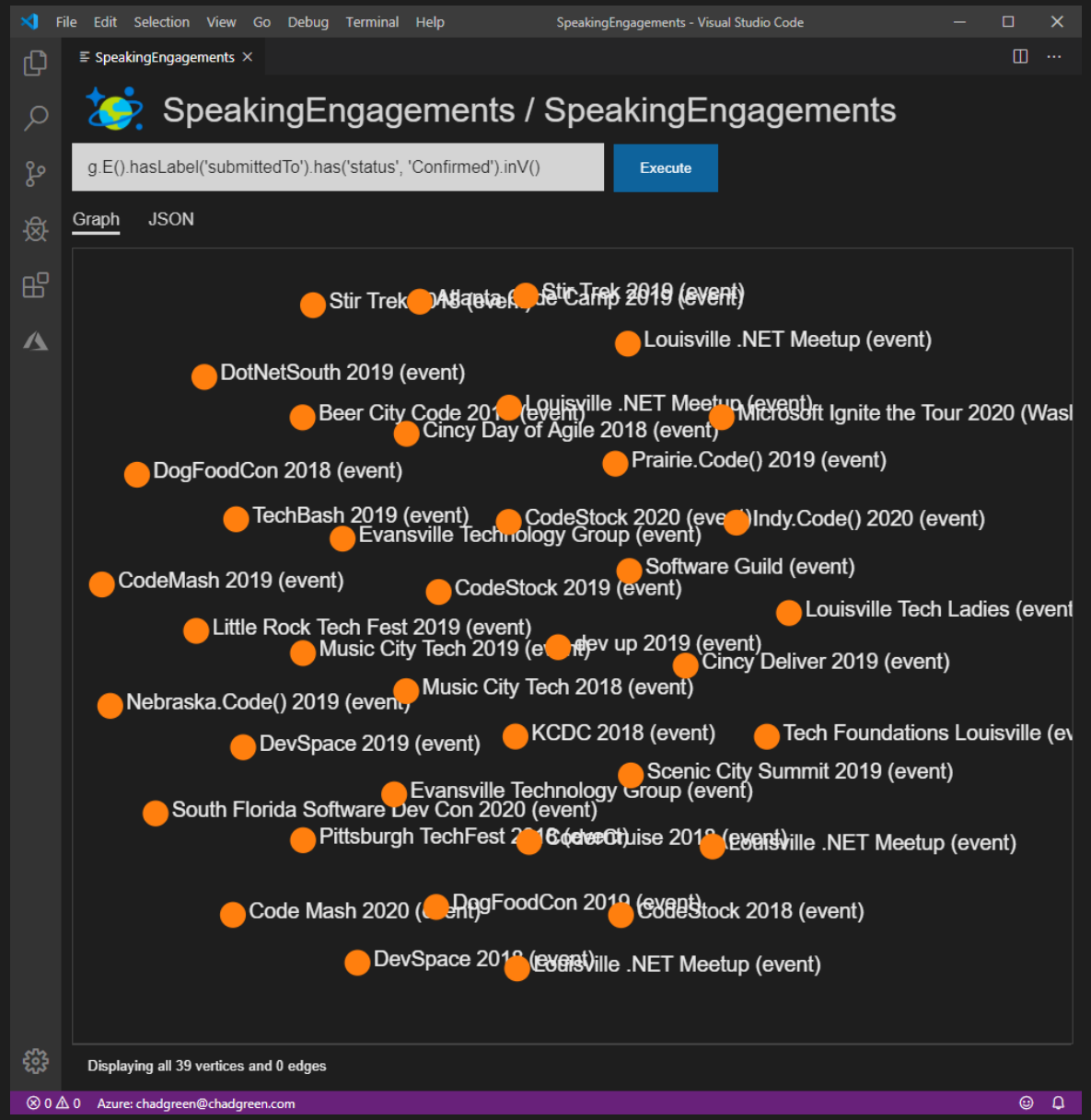
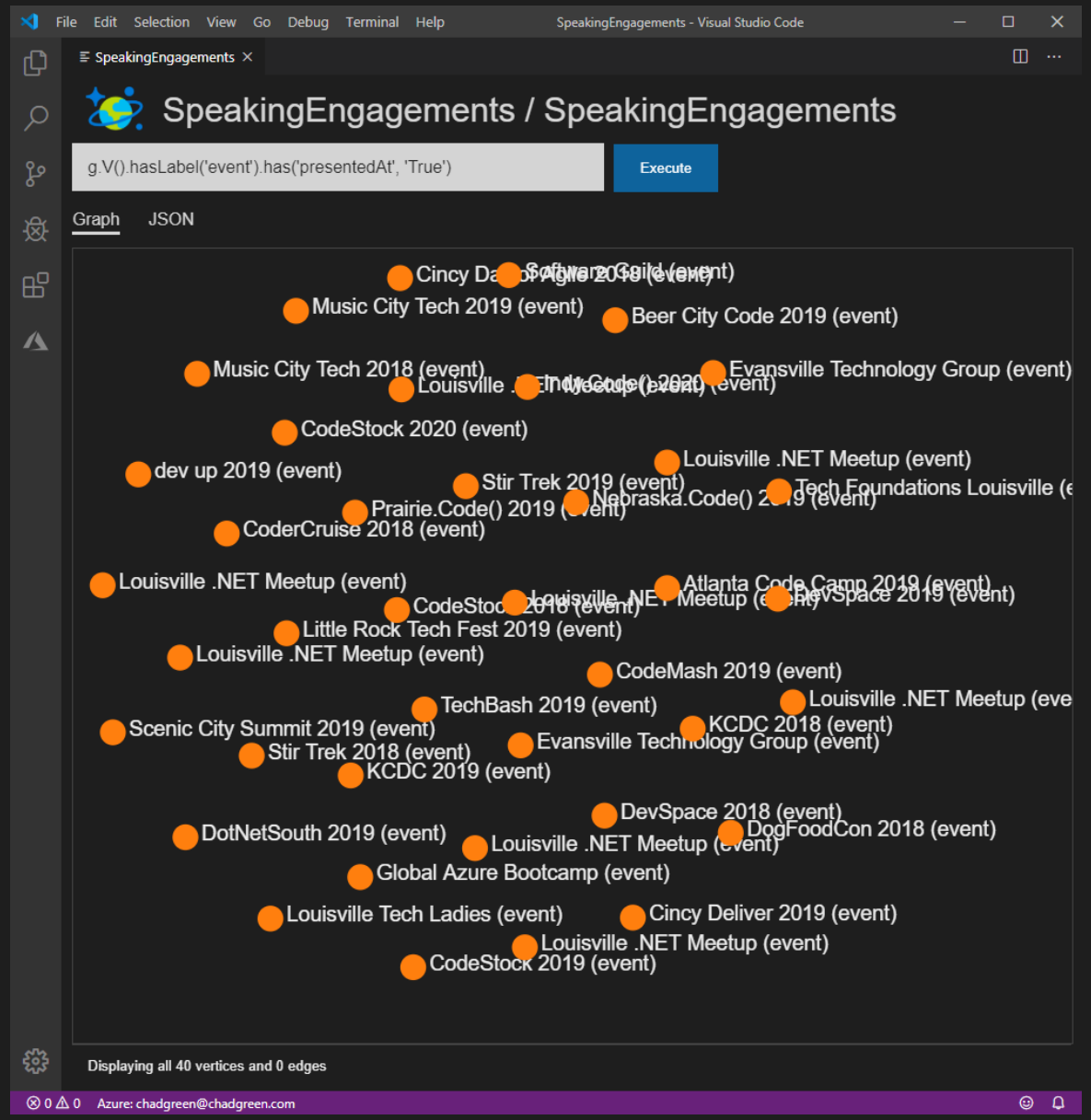
What events have I been scheduled for?




```
g.E()
.hasLabel('submittedTo')
.has('status', 'Confirmed')
.inV()
```

What events have I been scheduled for?

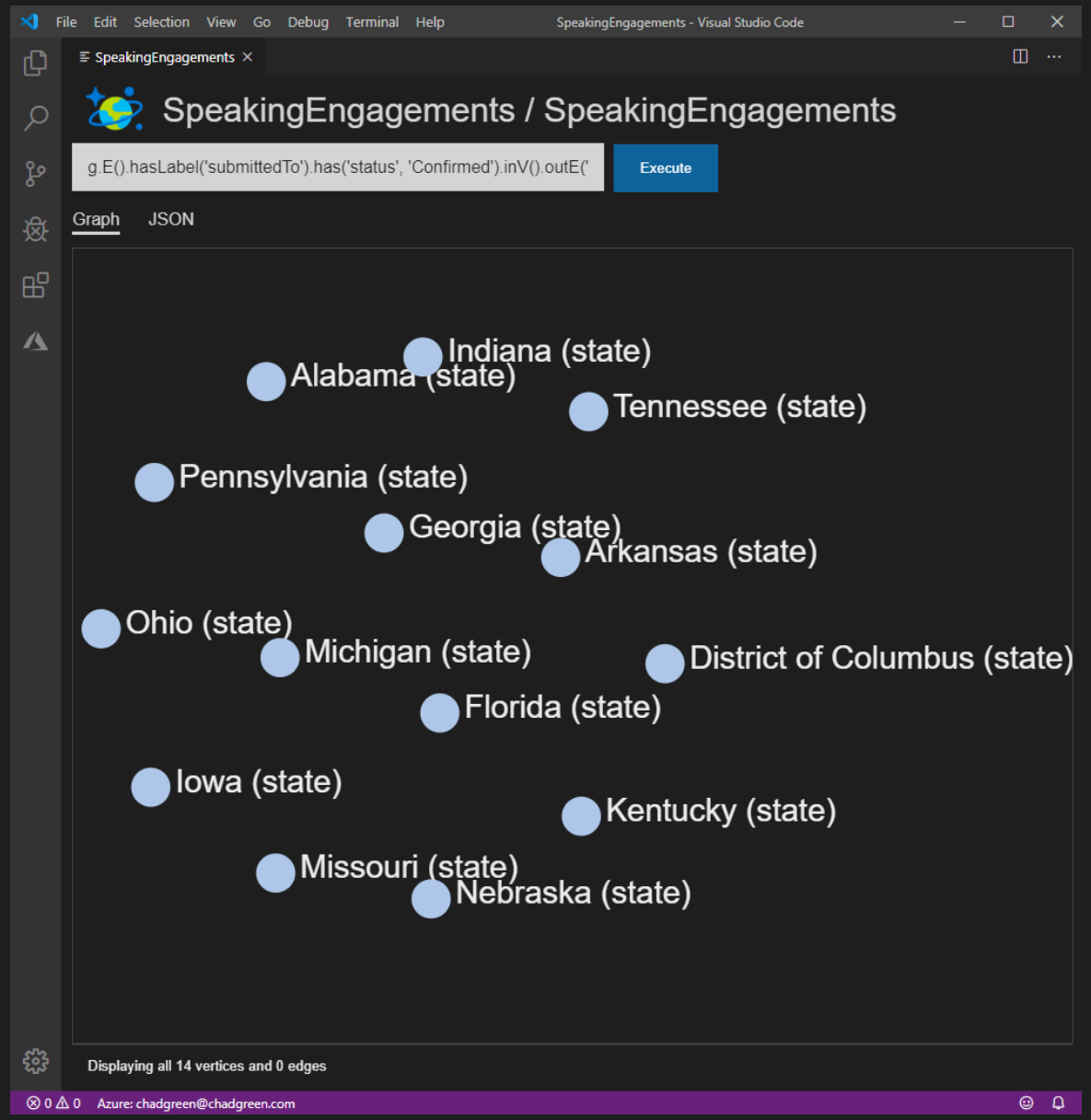



```
g.E()
.hasLabel('submittedTo')
.has('status', 'Confirmed')
.inV()
```

```
g.V()
.hasLabel('event')
.has('presentedAt', 'True')
```

@chadgreen

What states have I been scheduled to speak in?




```
g.E()
.hasLabel('submittedTo’)
.has('status', 'Confirmed’)
.inV()
.outE('stateLocation’)
.inV()
```

@chadgreen

Wrapping Up

- Graphs – set of objects in which pairs are in some sense related
- Graph Theory – Starts with the 7 bridges of Königsberg
- Graph databases – use graph structure to represent and store data
- Azure Cosmos DB – globally distributed, multi-model database service
- Graph vs Relational – lots of benefits that make graph database worth a look
- Graph Traversal – Navigating graph data using patterns

Thank You

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ChadGreen
ChadwickEGreen