Project 2020:
Develop a Graph Database using a NoSQL Cloud-Native Database

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Who should read this?

Those interested in designing a NoSQL database application, the performance capabilities of *Dynamodb* and CSP programming in Go.

Software Stack

Quick review of the technology stack that will be employed.

Component	Provider	Description
Public Cloud	*AWS*	
Databases	*Dynamodb*	Cloud-native datastore for graph data and type definitions. Full query support except full text search capability.
	ElasticSearch	Provides full text searching across all text attributes. Returns node UUID (universal unique identifier) which is passed into *Dynamodb* query. While ElasticSearch exists as a cloud-service from a number of cloud vendors including Elastic, AWS, Azure, for the purpose of this project a single server implementation was used sourced from a Bitnami AMI (Amazon Machine Image) running on a small EC2 instance.
Language	*Go*	A wonderfully pragmatic and productive C-styled language designed by a small team of software luminaries, some of which were responsible for C and Unix, and supported by none other than Google. With a CV like that why would you not use it. It is also one of a very languages that supports *Communicating Sequential Processors* (CSP) natively, which in the age of increasingly multi, multi-core CPUs is a must have capability.
Testing	*go test command*	All testing used Go's command line tool *go test*
Source Control	*Git*	

The Project Aims

This aims of the project are detailed in the table below:

Aim	Outcome
More Go programming makes a better Go programmer	*GoGraph*, a rudimentary graph database with GraphQL* like query language, node cache and concurrent RDF loader.
Is a NoSQL database a suitable Graph database?	Create a Graph Data model in Dynamodb
Incorporate a Type system	Graph schemas stored in the database
Create a concurrent RDF load program	Load the Movie RDF file containing 1.1 million triples
Incorporate full text search capability	Simultaneously load RDF data into Dynamodb and ElasticSearch. Define ElasticSearch query functions.
Non-blocking node cache	API to Fetch Nodes from cache.Locking AP ???? Disable for testing as we are testing Dynamodb fetch performance not the cache performance.
Create a functional test suite of GraphQL queries.	Publish results in this document
Quantify query performance	Run some demanding graph queries

* Syntax and some functions based on DGraph's GraphQL

Project Results

All the aims listed in the Project Aims have been achieved and are discussed at length in this document. However to highlight the most significant design aspects in *GoGraph*:

* **Cluster node data around the node's UUID** (Universal Unique Identifier): which becomes the table's partition key. However very large items, like edge data (aka UID edges) with millions of child nodes, will be offloaded to overflow blocks which will spread over multiple partitions for scalability purposes

* **Partition a node's data based on sort key:** a sort key design has been implemented, that enables queries to target individual parts of a node's data e.g. all or a subset of the scalar data, all edges or subset of edges, only reverse edge data etc to minimise *Dynamodb's* read costs.

* **Duplicate scalar data** (aka scalar propagation) from child to parent node and additionally, child to grandparent node, for the case of 1:1 edge cardinality between child and parent node. Scalar propagation adds to the clustering affect.

* **Incorporating two data stores:** *Dynamodb* for general graph queries and *ElasticSearch* for full text queries. *GoGraph* seamlessly integrates the two.

* **Overflow UID blocks:** that enables nodes with very large number of edges to scale across *Dynamodb* partitions and enable multiple concurrent read processes to query the data.

Onto the performance of GoGraph and the effectiveness of *Dynamodb*. Ideally it would be useful to directly compare GoGraph's performance to other graph databases by loading in the same data and execute the same queries in whatever language the alternate graph database used. However this would be a project in itself so I will simply rely on the performance metrics from each test using the Movie data to provide some level of judgement on performance. On this basis the performance is more than adequate I believe.

Note: there were no external or application level data caches employed in any of these tests. GoGraph disabled its internal node cache for all these tests. Queries therefore must source all node data from the databases, Dynamodb and/or ElasticSearch.

Examples:

* the **Dynamodb Query API** for a single node takes between **3.5ms and 4.5ms** for 90% of the queries. Because of scalar propagation a single node query can return scalar data from all child nodes across each edge predicate, so a 3.5ms query can return not only the node data but also all its child node's scalar data which will benefit any filter condition as the data is already present in memory.**?????**

* Test 11 demonstrates the power of duplicating data for edges with a 1:Many cardinality. It shows 90 nodes effectively returned from 6 Dynamodb read calls with an **average response of 55 us (microseconds) per node**

* Test 12 demonstrates the power of duplicating data from child to grandparent for edges with 1:1 cardinality between child and parent. It shows **1166 nodes can be effectively queried in 122 ms for an average of 104 us (microseconds) per node**.

* **ElasticSearch** queries took between **7ms and 8ms**.

What is a Cloud-Native Database?

At a high level a cloud-native NoSQL database must be **elastic, highly resilient and fully managed.** To achieve this it must implement the following:

Feature	Comment
Be Distributed	The database must run across multiple servers. An essential attribute for scaling and resilience

Feature	Comment
Scale horizontally on demand	The database must have the ability to automatically add (and remove) compute and storage servers in response to database load and distribute both the data (e.g. table partitions) and the load over the additional resources.*
Runs on elastic infrastructure	The underlying infrastructure must not pose any limits on the resource requirements of the database and its ability to scale on demand.
Replicates Data	For availability and resilience purposes the database must replicate across storage servers and availability zones.
Nothing to provision	A cloud native NoSQL database should always be on, available and accessible via an API with no requirement to provision resources on behalf of the user *
Charge by usage	Charge by usage for any services used. Services may include backup and restore, streaming, external caching, auto scaling. Storage costs are charged by amount by period.
Self-Healing	The database cluster should detect failed servers and replace them automatically. The database should also be able to detect table hot spots and automatically implement strategies to reduce its impact.
Detailed Monitoring	The underlying database infrastructure should be monitored with sufficient detail to drive any scaling design decisions or analysis of a failed operation.
Automatic Backups	The database should be backed up automatically without human intervention
Advanced Security	Data should be encrypted both at rest and in transit. There should be a thorough identity and access management system in place to define and control privileges.
Consistently achieve single-digit millisecond response at any scale	Ultimately most of the above is aimed at providing a foundation for achieving consistently fast query response.
Automatic patching and upgrades	The database software should apply patches automatically without any outages.

* This is in contrast to some cloud-native SQL databases that require the user to first provision a cluster of compute nodes. The storage nodes are a separate service that scale independently and automatically from the compute.

These features are not necessarily the sole domain of NoSQL databases as some of the latest SQL databases, e.g. Google's Spanner and AWS Aurora, exhibit many, if not all, of the attributes of a cloud-native database except the requirement the no-provision requirement.

Cloud-native NoSQL databases are available on all the big three public cloud providers, *Dynamodb* from AWS, *Cosmos DB* on Azure and *Google Cloud Datastore* on GCP (Google Cloud Platform). There are also a number of open-source cloud-native offerings, such as Datatax *Casandra and Mongodb* DB *Atlas*.

Why Dynamodb?

There is a daunting array of proprietary and open-source NoSQL databases available today with an equally daunting of capabilities. *Dynamodb* however, has the considerable advantage that it has been battle tested in what is possibly the worlds biggest shopping site amazon.com, and as a result has received a laser like focus on continual improvements to

scalability, raw performance and operational resilience like no other NoSQL database[1]. The focus on continual improvement ensures *Dynamodb* can cope with the next Black Friday sale.

Because *Dynamodb's* design is heavily biased towards scalability and raw performance it has had to judiciously sacrifice any feature that would get in the way of that goal[2]. Data consistency has however not been sacrificed and strong consistency can be specified for any query when required, otherwise eventual consistency is the default.

So as a cloud-native datastore for a Graph database, *Dynamodb* must be at or very near the top for raw performance. If GoGraph does not perform I cannot blame the datastore.

Finally, I have used *Dynamodb* in previous projects and can attest to its simplicity in development, it's always on availability and its ability to consistently respond to queries with single digit millisecond response times.

GoGraph Limitations

As this is a personal exercise and not an open-sourced project, I have restricted the features in GoGraph and GraphQL[3] to the bare minimum to provide a reasonable test for the effectiveness of *Dynamodb* as a datastore for Graph queries.

GoGraph Feature	Supports	Restrictions
Type System	Node and Edge Facets Nested types Syntax for edge cardinality ie. one to one and one-to-many edges. Multiple graphs supported	
Concurrent RDF Loader	Configurable degree of parallelism	File size limited to available memory on server. No support for edge facets.
Graphs	Multiple graphs Graphs consists of nodes and edges (node->child) Each node has a type Unlimited number of nodes supported All scalar attributes are indexed Each node has any number of scalar edges (attributes) Each node has any number of UID predicates (node-node edges) Each UID predicate connects unlimited child nodes Each child node maintains reverse edges	No support for Edge Facets No support for Graph Algorithms
Query Language	GraphQL based on DGraphs (DGraph.io) query language Query applies to a graph nominated at parse time. Root Query with Filter Filter Edge (on child node scalar data) Root & Filter functions: has,gt,lt,eq,le,ge Boolean Filter operators: AND, OR Full Text Search: via ElasticSearch	No support for querying Facets No support for Mutations No support for Transactions No support for NOT Boolean filter operator

GoGraph's Code Dependencies

The projects **go.mod** file, (https://github.com/rosshpayne/GoGraph/go.mod) also shown below, lists GoGraph's dependencies. The only dependency outside of AWS and ElasticSearch is a package, by satori, which is responsible for generating Version 4 UUIDs for GoGraph.

```
module github.com/DynamoGraph

go 1.13

require (
	github.com/aws/aws-sdk-go v1.34.9
```

---

[1] For example, the "adaptive capacity" features is a recent resilience improvement

[2] While SQL is supported it is part of its code base, rather it is supported via a PartiQL client driver that simply issues standard Dynamodb API calls.

[3] The GraphQL language developed for GoGraph is based on DGraph's (DGraph.io) GraphQL language

```
	github.com/elastic/go-elasticsearch/v7 v7.9.0
	github.com/satori/go.uuid v1.2.1-0.20180404165556-75cca531ea76
)
```

The Type System

Github: https://github.com/rosshpayne/GoGraph/types

Each node in a graph is an instance of a single type defined in the type system. The assignment of a node to a type is defined in the graph's RDF file, which is describe in detail in the next section. While a node can only have the attributes of its assigned type there is a work-around that enables a node to be effectively a composite of multiple types - more on that later.

A type can only belong to a single graph. The definition of each type is composed of ***Scalar attributes*** and/or ***Nested-type attributes***. A *Scalar attribute* is either a *number*, *string* or *binary* type or one of their *set* counterparts. The type of a *Nested-type attribute* matches an existing type in the type system. In the case of nested-types, if the type name is enclosed in [ ] it represents a 1:Many cardinality, if it is not enclosed in [ ], it represents a 1:1 cardinality, meaning the associated predicate will only ever have one edge (See RDF section below).

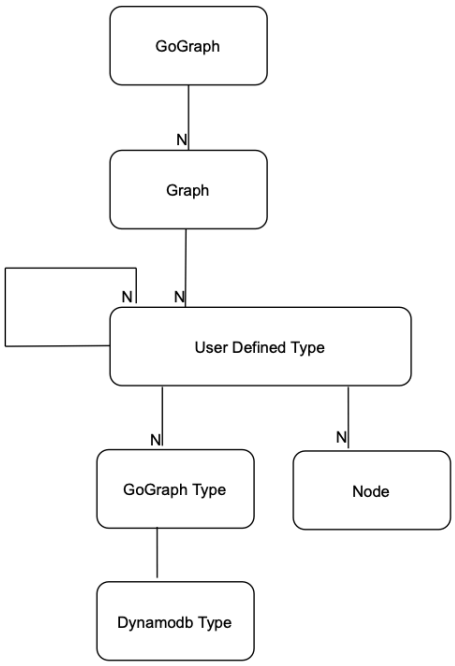
To expedite development there is no DDL language for types, rather each type is defined as a JSON entry in file and loaded into a single Dynamodb table using the AWS CLI:

```
aws dynamodb batch-write-item \
  --request-items file://<typeFile>.json \
  --return-consumed-capacity TOTAL
```

For an example of a JSON type definition file, see https://github.com/rosshpayne/GoGraph/json/Types.Movie.json . This file defines the type that are used in the Movie graph. The associated load script: https://github.com/rosshpayne/GoGraph/json/batchWrite.sh

The *Type* table is scanned into multiple caches (Go maps) as GoGraph's initialises during startup. Thereafter, all type data is sourced from the caches.

GoGraph supports multiple independent **graphs**, as depicted in the diagram below. Each graph in turn is defined with one or more **user-defined types**. Types cannot be shared between graphs (although that might be a good idea). A Person type in Graph A is different to a type Person in Graph B.



Each instance of a user-defined *type* is represented by a **node**, which like a *type,* can belong to only one graph. As mentioned previously, a node can only be defined as a single *type*, however, if the node type specification has a nested type with a cardinality of 1:1, then it is possible to emulate a node of composite types.

RDF to Type Mapping

When loading a RDF file of graph data, GoGraph verifies each predicate in a **subject-predicate-object (s-p-o)** triple, matches an attribute in the type definition of the type assigned to the subject (node). *If a predicate p has type T, then for all s-p-o triples with predicate p, the object o is of type T.*

If the name of the predicate matches a scalar attribute name it is referred to as a **Scalar-Predicate**. If the predicate matches a nested-type attribute it is referred to as a **UID-Predicate** (or Edge-Predicate) and represents a node-to-node edge. Internally GoGraph stores the object values of a UID-Predicate as an array of UUIDs, where each UUID represents a parent-child edge.

Schemas

A graph's schema is represented by all the types that have been assigned to the graph.

The *Type* Data Model

All type related data, such as, the *graph name*, the *types* that are associated with each graph and the *type definitions* themselves are stored in single *Dynamodb table*.

The primary key of the table is a composite key, composed of a *partition key* (attribute name: *PKey*) of type *string* and a *Sort Key* (attribute name: *SortK*) of type *string*. The *PKey* value identifies the category of the type data and the *SortK* and the non-key attributes provides the instance data. For example, the first entry in the table below represents an instance of Graph metadata consisting of a graph's short and long name, supplied in the **Sort Key** and **name** attributes. The second entry in the table gives an example of this data, where "m" is the short name of a graph called "Movies"

Category	***Partition Key* format** *Example*	***Sort Key* format** *Example*	**Other Attributes (description)** *Example*
Graph	**#Graph**	<graph short name>	Name (Graph Name)
	#Graph	*m*	*Movies*
Type *Defines the subject's **type** in RDF's "subject-predicate-object"*	**#<graph short name>.T**	<type short name>	Name (**type name**)
	#m.T	*P*	*Person*
Type Attributes *Attribute name must match predicate names in RDF's "subject-predicate-object"*	**<graph short name>.<type name>**	<attribute name>	See table below…
	m.Person *m.Person* *m.Person*	*name* *director.film* *performance.actor*	Ty: S,… Ty: [Film],… Ty: [Performance],…

The non-key attributes specific to **Type Attributes** are describe below. The actual data type for an attribute is defined in the *Ty* attribute.

Table Attribute	**Attribute**	**Dynamodb Data type**	**Nullable**	**Description**
PKey	ID	String	No	Type name e.g. "Person"
F	Facet	String Set	Yes	
C	Short Name	String	No	Keep as short as possible, ideally single character. Is used in SortK attribute in Dynamodb.
N	Nullable	Boolean	No	

Table Attribute	Attribute	Dynamodb Data type	Nullable	Description
Ty	Data type	String	No	***Scalar*** *type:* “S” String “I” Integer “F” Float “Bl” Boolean “DT” DateTime ***Set*** *type: an unordered collection* “SS” String Set “NS” Number Set “BlS” Boolean Set “BS” Binary Set ***List*** *type: an ordered collection* “LS” String List “LN” Number List “LBl” Boolean List “LB” Binary List ***UID*** *type: denotes a node-node edge* For cardinality 1:1 “Type ID” e.g. Person For cardinality 1:M “[Type ID]” e.g. [Person]
P	Partition ID	String	No	Partitions “A”. . “F” are reserved for scalar attributes. Default is “A”. It is good practice to partition the data when there are tens or hundreds of attributes that are not always queried together or an attribute contains a lot more data than others and is rarely queried. Partitions “G”. . ”K” are reserved for UID-Predicates. Default is “G”. This allows the designer to group UID-Predicates in queries and eliminate unnecessary data fetches
Pg	Propagate	Boolean	No	Should the attribute value be propagated to its parent. Default is True.
Ix	Index	String	Yes	Extend GoGraph’s default index behaviour which is to automatically add scalar data to a GSI ‘X’ - for Set types only. Will add entries in set to GSI ‘FT’ - add attribute data to ElasticSearch for full text searching ‘FTg’ - add attribute data to GSI and ElasticSearch

RDF Data

Github: https://github.com/rosshpayne/GoGraph/data

The *GoGraph's* data load program accepts RDF (Resource Description Framework) files only. As the entire file is loaded into memory its maximum size is approximately half the available memory on the server.

RDF Specification

The format for an RDF triple is as follows:

<subject> <predicate> <object> .

Comments may follow the dot (".") in the usual form of // or /* */

RDF Triple Component	Contents	
subject	A *blank node id* in the form: _:<*userDefinedString*> *userDefinedString* should match up with another triple with predicate *__type* defined.	
predicate	Matches an attribute name in a user defined type, or one of the system predicates describe below. A scalar-predicate matches a scalar attribute in a type definition. A UID-predicate matches a nested-type attribute in a type definition. A UID-predicates is internally represented by an array of UUIDs	
	System Predicates	**Description**
	__type "<*type name*>"	Specifies the Node's Type which must be defined in Type Table.
	__ID <*UUID*>	Explicitly defined node *UUID,* which is helpful for testing purposes. If not used *GoGraph* will generate a UUID during load.
object	Either a *blank node id* in the case of a UID-predicate, or a *literal scalar value,* when the predicate matches an attribute name from the node's type definition (from type system) that is a scalar type.	

Example of RDF Data: Relationship Graph

The RDF data that was used to populate the Relationship Graph is presented below. Note, there are only five *Person* nodes defined. The limited data set is intentional as its main objective is to validate the functional test cases which is best achieved when the data is simple and well understood.

```
_:abc __type "Person" . /* specify type for blank node */
_:abc __ID "66PNdV1TSKOpDRlO71+Aow==" .
_:abc Name "Ross H Fullerton" .
_:abc DOB "13 March 1958" .
_:abc Age "62" .
_:abc Siblings _:b  .
_:abc Friends _:d .
_:abc Friends _:c .
_:abc Siblings _:c  .
_:abc Cars "Fiat"  .
_:abc Cars "Honda"  .
_:abc Cars "Alfa"   .
_:abc Address "67/55 Fauxvoue St Lombardi, Cuffi, Italy"
_:abc Comment "Another fun  video. Loved it my Grandmother was from Passau. Dad was over in Germany but there was
something going on over there at the time we won't discuss right now. Thanks for posting it. Have a great weekend
everyone." .
_:abc SalaryLast3Year "112000" .
_:abc SalaryLast3Year "152000" .
_:abc SalaryLast3Year "218000" .

_:b __type "Person" . /* specify type for blank node */
_:b __ID "TsI2Qay8T2SxnOcuI3pPeg==" .
_:b Name "John Fullerton" .
_:b DOB "2 June 1960"  .
_:b Age "58"  .
_:b Siblings _:abc  .
_:b Siblings _:c  .
_:b Cars "Suzuki"  .  // specify type for blank node
_:b Cars "Honda"  .
_:b Cars "VW Golf"   .
_:b Friends _:abc .
_:b Friends _:c .
_:b Comment "A foggy snowy morning lit with sodium lamps is an absolute dream" .
```

```
_:b SalaryLast3Year "100000" .
_:b SalaryLast3Year "122000" .
_:b SalaryLast3Year "145000" .

_:c __type "Person" . /* specify type for blank node */
_:c __ID "6KIuWuyTRKSgDqwYAghl7A==" .
_:c Name "Ian Fullerton"  .
_:c DOB "29 Jan 1953"  .
_:c Age "67" .
_:c Siblings _:abc  .
_:c Siblings _:b    .
_:c Friends _:abc .
_:c Friends _:b .
_:c Friends _:d .
_:c Cars "VW Passat"  .
_:c Cars "Mitsubishi"  .
_:c Cars "Ford Laser"   .
_:c Cars "Honda"   .
_:c Comment "One of the best cab rides I have seen to date!?" .
_:c SalaryLast3Year "90000" .
_:c SalaryLast3Year "90000" .
_:c SalaryLast3Year "110000" .

_:d __type "Person" . /* specify type for blank Payne node */
_:d __ID "OlTBKXemTNWATwDDt6U5/A==" .
_:d Name "Phil Smith"  .
_:d Siblings _:e    .
_:d Friends _:abc .
_:d Friends _:b .
_:d Friends _:c .
_:d DOB "17 June 1976"  .
_:d Age "36" .
_:d Cars "Roll Roycet"  .
_:d Cars "Bentley"   .
_:d Cars "Honda"   .
_:d Cars "VW Golf"  .
_:d Comment "It seems to me the camera's Smith focus is better, clearer, thank you for sharing, I think Austria is
a beautiful country I'm not surprised that it produced so many great classical musicians." .

_:e __type "Person" . /* specify type for blank node */
_:e __ID "6nG/Cd+dSoyD48CrXQjrLQ==" .
_:e Name "Jenny Jones"  .
_:e Friends _:abc .
_:e Friends _:b .
_:e DOB "17 February 1963"  .
_:e Age "59" .
_:e Cars "Renault 302"  .
_:e Cars "Zonda"  .
_:e  Comment "A great video Payne which I have enjoyed watching. It is always very interesting to see such
beautiful scenery which I am unable to visit personally. Thank you." .
```

A Concurrent RDF Loader Design

Github: https://github.com/rosshpayne/GoGraph/rdf

Let's write a Go program to load a RDF file, like the Relationship RDF file displayed in the previous section, into the *Dynamodb* graph table. To make it more challenging, let's presume the RDF file is tens of MBs if not GBs in size[4]. To expedite the load we need the program to consume all of the available compute resources (think cores not servers) and database IO throughput (think distributed database at massive scale e.g. *Dynamodb*).

This leads us to Go's best feature, in the author's humble opinion, which is the adoption of *communicating sequential processors* (CSP) as a model for concurrency[5]. In Go CSP programming is native to the language and consequently is as accessible as any other other language construct providing the ability to scale an application across cores with relative ease. It enables the building of sophisticated infrastructure of communicating processors without undue distraction from the mechanics. There is however one gotcha that needs to be kept in mind - shared variables - which exists between concurrent routines and the potential they present for data corruption due to race conditions. Fortunately the language provides a feature rich API to manage this issue and a toolset to verify your code as "concurrency safe". Once this is understood CSP programming becomes a normal way to design and build your applications rather than as an exception.

At this point if you are unfamiliar or need a quick reminder of the Go CSP semantics and support packages please review Appendix A.

To achieve this scale out capability the program designer first deconstructs the problem into a number of tasks and decides which tasks can run concurrently, either as parallel routines (i.e. as multiple concurrent versions of itself) or as a single asynchronous routine that may be pipelined together with other concurrent tasks.

A quick list of potential candidate concurrent routines are:

Candidate Concurrent Routine
Read RDF file into batches of triples.
Validate RDF tuple
Accumulate Graph Edges
Convert internal IDs to Universal Unique Identifiers (UUIDs)
Error logging
Event and Stats logging
Save each valid RDF triple representation to the database.
Create a graph edge (attach a node to a node) and persist its representation to the database
Manage the instantiation of parallel concurrent routines

Not surprisingl, the concurrent Loader program makes extensive use of CSP. Run the Loader on a CPU with more cores and the Go runtime scheduler will dynamically allocate the concurrent routines to use as many cores possible resulting in a faster load.

The objective is to enable the program to scale so as to reach the limits of the database throughput, which in the case *Dynamodb* can be exceptionally high.

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[4] The limit on file size is approximately half the available memory on the server as the entire file is ingested into Go memory structures during the load and validated in memory

[5] The author can think of only two other languages that support CSP natively, namely, ES6 and Oracle's PL/SQL via the *dbms_alert* package. Python probably has a library that achieves some level of CSP programming but that is not native to the language.

Concurrent *goroutines* fall into two categories. One type provides a long running *service* to the main program (aka "*main goroutine"*) or to other *goroutines* and performs a relatively simple task, like serialising access to a resource with some data enhancement, and uses *channels* to asynchronously respond to and communicate with other *goroutines*. *Services* are typically started by the main program and are shutdown when the main program terminates. For example the *Error logging* and *UUID Generator* routines would each run as a *service.* A service goroutine typically provides serialised accesss to a shared resource

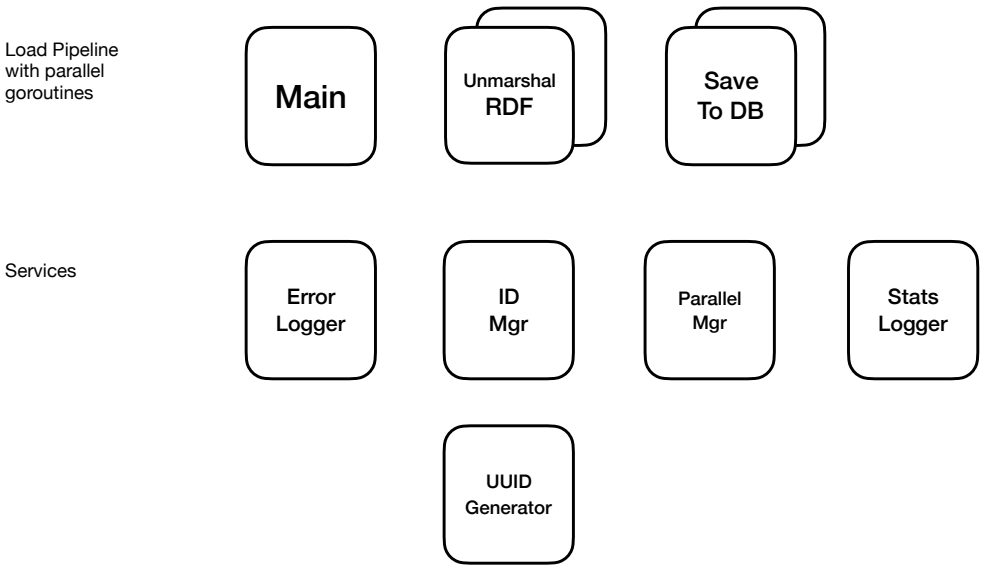
Other *goroutines* are designed to run in parallel, usually performing heavy workloads that require some scale out capability. Routines *Validate-RDF-triple* and *Save-RDF-triple* would be prime candidates to run as parallel goroutines. To support the instantiation of parallel routines the Loader makes use of a *service* that manages the instantiation of these parallel routines*,* called the *Parallel Manager Service*.

Finally, *goroutines* can be assembled into **pipelines**, where they are chained together and the output of one *goroutine* becomes the the input to the next *goroutine* in the chain. Channels are used to synchronise and pass information between the routines. The Loader program has chained the following *goroutines* together into a pipeline for end-to-end processing of RDF triples, from input file to database.

Main[6](read RDF input) | *UnmarshalRDF* | *Save-to-DB*

The Unix pipe symbol | represents Go *channels.*

From the list of candidate concurrent routines we can allocate them as follows:



Not shown in the above diagram are the associated *channels* that connect the *goroutines* together, either to exchange data and/or synchronise with one another.

The *Save-to-DB goroutine* first saves all the node data to the database and then runs the Attach-Node operation which logically attaches a child node to a parent node, for each edge defined in the RDF data. The attach-node is itself run as two concurrent *goroutines.* One routine reads the parent node data from the database (a multi-millisecond operation), concurrently with another *goroutine* that reads the child node data (another multi-millisecond operation) and then connects the child to the parent node by adding the associated "connect" items to the database under the parent node UUID. Information is exchanged via a single channel while the two *goroutines* are synchronised at various points using both a *channel* and the *sync package (ie. methods on type Waitgroup*).

Load Performance

To process 1.1 million triples in the Movie.rdf file took 1hr 18min for a concurrent setting of 16 on a *m5.large* EC2 instance (2 vCUPs, 8MB). This is much slower than expected. The cause was identified as a design oversight with a node's *Reverse Edge* attribute. The design uses a Binary Set datatype to store the reverse edge data for each edge, which consists of a parent node's UUID and its Edge Predicate's short name, to which the child node is attached. In the

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[6] The main *goroutine* has several responsibilities but as far as the pipeline is concerned it reads RDF tuples into batches, writes a reference to the batch to a channel which is then read by the next routine in the pipeline.

case of the genre node, which can be attached to thousands of parent nodes, this presents a couple of problems. The first problem is data size, as the 400KB item size limit will ultimately be reached on a large graph wth “type” nodes (like Genre). The other problem is adding a new reverse edge to a Binary Set progressively slows as the Binary Set grows in size, to the point where it is taking around 2 seconds to update a reverse edge for some Genres, like “Drama”, which is a very popular genre. While the solution exists in *GoGraph* to fix both problems it was not applied to Reverse Edge attributes, only to UID Predicates (to fix the million subscriber problem). This was a complete oversight. I expect that if it had been applied to the Reverse Edge attribute then the load time would be slashed by around 20% to 30%.

Why didn’t I fix the Reverse Edge issue and reload the data? GoGraph development had reached its “use by date”. It is a personal project, not a product that I expect people to use, although I built it with that in mind. I have identified the problem, I have a solution that is working on other attributes, that is sufficient. Time to move onto the next project.

Storage Hierarchy

An understanding of the storage components will help in understanding the constraints on the physical design imposed by *Dynamodb* and how they have influenced the design of the GoGraph *Block* component.

The top component is not surprisingly a *Dynamodb* **table**. All graph data is stored in a single table. The table's primary key is a composite of a binary type partition key and a string type sort key. A table is split into separate **storage partitions** (SP), each allocated to a different server as a way to spread the data and database load over multiple storage resources. The number of SPs is determined by the table's read and write capacity where each SP is constrained to a maximum of 3000 read capacity units (RCU) and 1000 write capacity units (WCU). RCU and WCU define the throughput of a Dynamodb table and determine its operating costs.

The partition key stores the UUID of either a node block or a overflow block. A **block**[7] is an ordered collection, based on a sort key value, of related Dynamodb **items,** which can be accessed in a single Dynamodb Query call. A node block can itself be further partitioned, which is advantageous when there is an appreciable amount of node data, enabling queries to target smaller and smaller subsets of the block data and thereby optimise database response and minimise AWS costs. See Section Sort Key Specification on Page 23 for details on how to partition a block. A block is only accessed using the Dynamodb Query API.

The table below summaries the storage hierarchy.

Table A single key-value store for all graph data *Max Size: unlimited*			
	Storage Partitions Internal to Dynamodb and a fundamental IO scaling component. Dynamodb partitions a table into one or more SPs the number of which is based on the table's IO capacity. Items are assigned to SP hashed on *partition key* value. Dynamodb replicates each SP across multiple Availability Zones for redundancy which can also aid in faster query response. *Max Size: 10GB* *Number: dynamic*		
		Blocks See Section: GoGraph Block Types Data is grouped in "blocks" based on its *partition key* value. Items in a block are stored in *sort key* order. The data for each node is stored in its own block. Optionally it may also use a number of UID Overflow blocks. A block is assigned to one SP, whereas any Overflow Blocks will be allocated to different partition to balance the load across partitions SPs. Access by API *Query.* *Max Size: 10GB* *Number: unlimited*	
			Items Each *node or overflow block* contains one or more Dynamodb items. Access by API *GetItem*. *Max Size: 400K* *Number: unlimited*

Block Types

A *GoGraph block* is a minor abstraction on the *Dynamodb's* **item**. A *block* represents a sorted collection of related *Dynamodb* items with the same UUID *partition key* value. A block represents the basic read unit of a GoGraph query and is the only storage component that the GoGraph designer can tune in any way. For example, the designer can partition the data within a block into small sorted groupings that can be read as a single unit rather than having to read the complete block or large portions of it each time. This may save considerable read capacity units and hasten the response when a query requires only a small subset of a block's data. By default GoGraph divides a block into three partitions, one partition for scalar data, another for all UID-Predicates (containing child node UUIDs) and another for Reverse edge data.

As detailed in the table below there are two types of blocks, Node and Overflow.

[7] a block is a term I borrowed from Oracle, which in some ways is not entirely appropriate since Oracle uses a fixed block size (4KB, 8KB etc) and the block in GoGraph is variable, however when Dynamodb is factored in, where it reads in units of 4KB, it makes more sense. Some may prefer the term "collection" instead.

<table>
<tr><th>Type</th><th colspan="2">Description</th></tr>
<tr><td>Node Block</td><td colspan="2">Contains the data related to a node. Every node contains the same data elements, albeit some may not be present in some nodes depending on its type, as describe in the list below;</td></tr>
<tr><td></td><td>Block Element</td><td>Description</td></tr>
<tr><td></td><td>Node Type</td><td>User-defined type</td></tr>
<tr><td></td><td>Scalar Data</td><td>(Optional) As defined in the user-defined type for the node type. Scalar data is represented by a user-defined types scalar predicates.</td></tr>
<tr><td></td><td>Edge Data</td><td>(Optional) Edge data denotes the collection of node-node edges for a particular UID Predicate. Each UID Predicate(1) has its own edge data which internally is represented by a Dynamodb List data type constrained to hold UUIDs only.</td></tr>
<tr><td></td><td>Propagated Child’s Scalar data</td><td>(Optional) For each UID type in the nodes user-defined type there will be data elements for the each child node’s scalar data (if defined).</td></tr>
<tr><td></td><td>Propagated Grandchild’s Scalar data</td><td>(Optional) For each UID type in the nodes user-defined type there will be data elements for the each grandchild node’s scalar data (if defined). This is only applicable when the grandchild has a 1:1 cardinality with its parent type.</td></tr>
<tr><td></td><td>Reverse edges</td><td>While a graph’s edge is unidirectional (parent->child) it is useful to store the reverse edge (child->parent).</td></tr>
<tr><td>Overflow Block</td><td colspan="2">After a configured number of child nodes for a parent node’s UID Type are attached, future attached nodes will have the child node’s UUID and scalar data no longer is written to the parent's node block, but instead will be written to separate Overflow blocks, one for the UID data and one for all the child’s scalar attributes. The purpose of overflow blocks is to spread node related data over multiple storage partitions to reduce IO contention.
See Section ? For further details.</td></tr>
</table>

NoSQL vs SQL Databases

NoSQL databases are perceived to be cheaper, faster and scale significantly better than their fancier feature rich SQL cousins. Some of the justification for this view is supported by AWS's NoSQL offering, *Dynamodb who's raison d'etre* was the failure of traditional SQL databases, notably Oracle, to scale to the extreme loads of amazon.com, one if worlds largest shopping sites, causing several unplanned outages. *Dynamodb* was created to specifically process the queries at huge scale, that Amazon claims, Oracle could not[8]. So in this section I attempt to explain why NoSQL databases have the edge on speed and scalability.

However it is not all upside for NoSQL databases as they are also perceived to have a narrower range of use cases compared to their SQL counterparts which offer a more familiar implementation of the relational model, ACID transaction, higher levels of data consistency and a SQL interface of course.

The genesis of NoSQL databases was also radically different to the ones that dictated traditional SQL database development of fifty years ago. Principal drivers for NoSQL is scalability to global scale, low cost, high availability and resilience, all of which were an impossible combination to satisfy in the early days of SQL development when large and expensive SMP servers were the only available option.

Over the intervening period, small commodity based servers where increasing in power sufficient to take on some enterprise workloads while universities where frantically publishing research papers describing how to cluster thousands of these commodity servers into large, powerful, highly available and resilient systems to build vast distributed storage systems, HPC and large batch processing systems. In response commercial and open source software designers either re-architected or architected their products from the ground up to be distributed while at the same time data centres started filling up with commodity servers attached to fast low latency networks and SSDs. This was a match made in heaven for the NoSQL database designer.

Software designers also knew each database feature, while useful, came at a measurable cost to scalability[9]. Why? Each feature adds to the number of "shared resources" (such as caches and locks) that need to be managed via a mutex and under extreme load mutex waits can start and dominant all other waits leading to potential scalability issues[10]. This was a clue to NoSQL database designers to be judicious with features to the point of eliminating all but the essentials. So the "No" in NoSQL not only means no SQL, it also means no Query Optimiser, no Node Cache (yes, every read is a physical read), no Schemas, no Data Relationships, no Sequencers, that is, no to almost anything that must be shared between database sessions. The result was a large reduction in the number of speed reducing "shared resources". For this reason NoSQL is synonymous with bare bone databases designed to be fast because of what they don't do.

In the case of Dynamodb, and I presume other NoSQL's databases, the faster response can also be attributed to the use of the ***index organised table*** (IOT) structure for tables. IOTs have the benefit that all key and non-key data is clustered together enabling all related data to be accessed in one read request. SQL databases on the other hand use a heap structure for table data with separate index structures for each lookup key. As a result fetching from a SQL table requires two read operations unless the index also includes all the required non-key data. Consequently what is performed in one physical read operation of a NoSQL database typically requires two physical reads in a SQL database[11]. Note: some SQL databases do offer an IOT as an alternative to the heap table, and in the authors opinion, are not used enough.

Finally, the ***schemaless*** nature of a NoSQL database means all related data, with different attributes, can be clustered together under the same partition key value in a single table. The immediate advantage is all

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[8] To quantity Dynamodb performance, it peaked at 45 million requests a second during Amazon Prime day in 2019.

[9] See Appendix C for a explanation and example

[10] See Appendix C for further explanation of why a mutex is required and mutex waits

[11] Of course some of those reads may be from the data cache that SQL databases use. Depending on the type of application (OLTP for example) the cache may be beneficial for other applications (batch processing, analytics) it may add little to no benefit and may in fact slow the overall response because of the mutexes associated with the data cache.

related non-key data can be loaded into application memory in a single database read request[12]. This compares to the “normalised” SQL database design which allocates a table for each data type, requiring one more more IO reads per table to orchestrate the data into program memory. Some SQL database’s offer a “clustered table” as a design option which attempts to emulate NoSQL’s schemaless design advantage by physically pre-joining table data at the storage block level. However, there are so many constraints on its implementation clustered tables are rarely used in my experience, at least with Oracle.

The clustering benefits of both *IOTs* and *schemaless* design combined with NoSQL shorter code paths and lack of mutex’s all combine to put it ahead of SQL databases in scalability and absolute speed of response.

Design Highlights

Research has found the most significant factor in determining a database’s query response is the degree to which data is clustered at the storage level. Documented below are the major design decisions that were made to maximise data clustering or more generally aid in faster query performance. Broadly these design decisions can be categorised into **data duplication**, **attribute compression, node data partitioning, table key design** and **GSI design.**

As previously mentioned, GoGraph makes use of a single table to store all the graph data. The table and its associated GSI’s are defined in this JSON script:

Table create JSON: https://github.com/rosshpayne/GoGraph/json/dgraph-table.7.json

Design Decision	Clustering Benefit
Single Table	All graph data is stored in a single table. There are separate tables for *type* data and logging.
Composite Primary Key	The single graph table has a composite primary key. This forces clustering of data around the *partition key* value and guarantees the data is sorted within the partition key based on the *sort key* value*.* The data can be further partitioned within a partition key using an appropriate sort key design. See *Sort Key Design*
Node’s UUID as the partition key	Using a node’s *UUID* as the *partition key* means a node's *scalar* data and other node related data (*UID predicates*, *propagated* data etc) is clustered under the one index entry and can therefore be accessed via a single *Dynamodb query*. The data indexed under a node’s *UUID* is referred to as a **node block**.
OverFlow blocks	Having all the node’s data stored under one *partition key* value means scalable read options are limited as it will ultimately lead to IO contention on the associated storage partition. To circumvent this it is possible to configure a node to have overflow blocks which extends the node data across multiple partition keys when a configured data size is reached. While the data is still clustered within each partition key, multiple partitions means the option of concurrent reads without risk of IO contention is now possible. See Section ?.
Sort Key Design	A thoughtful *sort key* design enables partitioning of a node’s data into commonly accessed items e.g. *scalar* data, *propagated scalar* for each *UID predicate or all the node data.* By specifying the appropriate *sort key* string a query has some control over just what is returned to the application potentially saving significant number of RCUs. See Section ?
Sort Key compression	To increase the clustering factor any attribute name referenced in the *sort key* uses the attribute’s short name. Note: *as part of a type definition each attribute is assigned a short name which is typically one character. An attribute’s short name must be unique to the type in which the attribute belongs.* Given some sort keys refer to multiple attribute names this can save considerable storage and reduce the amount of data returned to the application which may result in less database calls.

[12] depending on the amount of data returned their maybe multiple Read Capacity Units consumed.

Design Decision	Clustering Benefit
Partitioning node data for optimised reads	The Sort Key specification provides the data designer with up to three levels of nested partitioning of node data. Each level can be specifically targeted by a Dynamodb query using a leading portion of a Sort Key value. This flexibility to target reads to any partition level prevents unwanted node data from being read thereby minimising response times and saving AWS read costs. The benefits of partitioning increase as the quantity of data stored in a node increases and only subsets of node data are required to be returned to the app for a query. The top two levels of nested partitioning are system partitions. The first level divides the node data into two partitions, **node data** and **reverse edge data**. Within the node data partition the Sort Key specification further partitions it into **scalar**, and **propagated** data. The next nested level is determined by the data designer who can further divide the scalar partition into a further 6 sub-partitions and propagated data partition into another 5 sub-partitions, via the partition attribute ("P") in the type definition.
Duplicate data to improve data clustering	A vital part of the GoGraph design is duplicating node data to achieve higher levels of data clustering. Specifically each child node has its scalar data duplicated into its parent node. Duplicating the scalar data occurs as part of the attach-node operation. The act of duplicating the data is known as **scalar propagation**. The immediate benefit is a node's scalar data and all its child node's scalar data is clustered together in the node's data block, and is accessible through a single database read. This effectively reduces the depth of a graph from *n* to *n-1, which has huge benefits to query performance particularly for highly connected graphs.* For the particular edge case where a type's *UID predicate* has a 1:1 cardinality the scalar data can be duplicated into the grandparent node, effectively reducing the depth of a graph from n to n-2. *The cost to incorporate this design is handling updates to scalar data. This is conveniently out of scope for this exercise, however, it maybe a good use of Dynamodb streams to asynchronously update all instances of propagated data after a node scalar update.*
List Data Types for Columnar like querying	The propagated scalar data is stored in **List** datatypes in the parent or grandparent node. See the Data Model section for further details. Each newly attached node will have each one of its scalar data predicates appended to a List datatype appropriate for the predicate's type. The List type is very compact form of data storage that lends itself to fast in-memory scans. In essence it is quite similar benefits to Columnar tables in some SQL databases.
Gobal Secondary Indexes	The GraphQL root queries will make use of GSI's to retrieve the initial set of candidate node UUIDs. Each scalar attribute has its own sparsely populated GSI. There is also a GSI for the type of the node, to help resolve root queries based on type. The GSI json definitions is include in the table definition link at the top of this section.

The Million Subscribers Problem

Storing all the node data under one partition key value will present a read scalability issue when the node data increases in volume. The *million subscribers problem* demonstrates this issue. For a real world example of a million subscribers look no further than *YouTube*, where the popular content producers will have multiple millions of subscribers. Another example is any node that represents "type" data. For example, in the Movie database there is an predicate of a Movie called "genre" type, which can accept multiples genre values. A popular genre like "Drama" will be present in most movies. In such a circumstance the "Drama" genre node will have a **reverse edge attribute** containing thousands of movie UIDs. In a larger graph, a type node's reverse edge could easily have millions of nodes.

Why is there a problem?

As the volume of a node's data grows the ability for the application to scale the read is non-existent as all the data resides in a single **Node Block** in a single storage partition. Any attempt to parallelise the read will ultimately lead to IO contention on the storage partition which may cause *Dynamodb* to throttle reads, ultimately limiting its read performance and scalability.

What is the scale of the problem?

A *UUID* occupies 16 bytes internally, so a million subscribers will consume approximately 16MB of storage. This immediately presents an issue as the maximum size of a *Dynamodb* item is 400KB. Then there is the read performance. For this quantity of data *Dynamodb* will consume 4000 read capacity units (RCUs), presuming full consistency reads. Now we have issue number 2. As *Dynamodb* imposes a limit of 3000 RCUs on a partition, *it* will immediately start throttling read throughput. The result is the read time will be well in excess of 20 seconds.

Consequently the fix to the million subscriber problem needs to resolve two issues, the 400KB item limit and the lack of scalability in read performance.

How to fix it.

In the case of the subscriber example, each new subscriber is added to the parent node's "subscribers" UID-Predicate, which internally, is a binary list datatype with attribute name **Nd**. To provide the level of redirection required, a new block type is introduced, called a ***UUID Overflow Block*** *(UOB).* In the revised design, each new subscriber is added to the "subscribers" internal Nd attribute until a configured number is reached at which point a UOB is created. The UUID of the UOB is added to the Nd attribute, and the UUID of the new subscriber is added to the UOB. Thereafter all new subscribers are added to the UOB. The node data is now split over two UUIDs, the original **Node Block** and the **UOB**. The actual design is more involved than this description, involving multiple UOBs and Overflow Batches, but in essence that is it. A more detailed description is delayed until the GoGraph Data Model is discussed on Page 25.

Key Design

GoGraph stores all graph data, comprising a node's scalar and facet data[13], edge data plus all propagated node data in a single *Dynamodb* table. As a result the key design is critical as it needs to cope with all access paths.

Composite Primary Key

The graph table employees a composite primary key design, comprising a *partition key* and *sort key. DynamoDB* uses the *partition key* value as input to an internal hash function which determines the storage partition where the associated node data will be stored. All items with the same *partition key* value are stored together, in *sort key* order.

The graph table has the following composite key specification:

Key	GoGraph Type	Dynamodb Attribute	Dynamodb Type	Go Type	Size Bytes [Max DB Size]	Description
Partition Key	UUID (1)	**PKey**	Binary	[]byte	16 [1000]	Contains UUIDs assigned to node blocks or overflow blocks.
Sort Key	String	**SortK**	String	string	2-14 [2000]	Value determines what non-key attributes will be populated. See Sort Key Specification.

1. Universally Unique Identifier (UUID) version 4, is a 128-bit number used to identify information in computer systems.

Sort Key Specification

The *Sort Key* value follows a specification that enables a *GraphQL* query to address all the possible access paths as efficiently as possible.

Each access path will use a combination of:

* Dynamodb's **Query** API
* **BeginsWith** function
* *a* leading portion of a ***sort key*** **value**

By add more detail to the sort key value, GoGraph can target increasingly specific parts of a node's data, from all or parts of the scalar data or all or parts of the edge data or all or parts of the propagated child data. The ability to target how much data is read by *Dynamodb* in a single API read enables GoGraph to minimise the r*ead capacity units* consumed by a query and thereby save AWS monthly charges.

The following components comprise the elements that make up a query.

Component	Description
Query Statement	Defines the predicates that need to be fetched. Each predicate is matched against an identically named attribute in the type system.
Data Partition	Each type definition includes an attribute ("p") that defines the data partition in the Node Block where instances of the type reside. The default partition is "A" for scalar predicates and "G" for UID predicates.*
Sort Key Value	Based on the query predicates and their associated partition values, GoGraph will generate a sort key value that targets one or more of the node's data partitions, with the aim of minimising the consumption of Dynamodb's read capacity units.
Query() API	The Dynamodb *Query* API is used to fetch all or a subset of data within a Node Block using a leading portion of a sort key. The Query API accepts a *partition key* value and a comparison function, *BeginsWith(),* in the second argument into which is passed a leading portion of a *sort key* value.

[13] Facets have not been implemented in current version of GoGraph

* Internally, a *UID predicate* contains a list of UUIDs representing the child nodes.

The table below describes the three partition types in a Node Block. In total over 11 partitions can be defined. This may be very useful as a way to optimise the database read costs when nodes have considerable amounts of data.

Node Partitions	Permitted Value(s)*	Default Partition	Description
systemPartition	A	A	Internally GoGraph uses this value to separate node data from system generated data for a node.
scalarPartition	A..F	A	User defined value to separate scalar predicates into different partitions if it makes sense to do so. For example if there are tens of scalar predicates then it may make sense to group them into a few partitions based on predicates that are commonly queried together.
UIDPartition	G..K	G	The node's edge data (parent to child nodes for each edge predicate) can be separated into five partitions. (Currently only one partition, G, is supported)

* as specified in the associated attribute's type definition

The *sort key* specification is defined in the table below. To keep the sort key as short as possible only short names are used for all predicate names. A predicate's short name is defined in its associated attribute in the type definition (where predicate name matches a type's attribute name). The specification also references the data node partitions described in the table above.

Node Data	Sort Key Specification
Scalar predicates	*<systemPartition>#<ScalarPartition>#:<predicateShortName>*
UID predicates	*<systemPartition>#<UIDPartition>#:<UIDpredicateShortName>*
Promoted child node scalar predicates	*<systemPartition>#<UIDPartition>#:<UIDpredicateShortName>#:<predicateShortName>* *<systemPartition>#<UIDPartition>#:<UIDpredicateShortName>#:<predicateShortName>#<UOBbatchId>*
Promoted grandchild node edge data	*<systemPartition>#<UIDPartition>#:<UIDpredicateShortName>#<UIDPartition>#:<UIDpredicateShortName>*
UOB variant	*<systemPartition>#<UIDPartition>#:<UIDpredicateShortName>#<UIDPartition>#:<UIDpredicateShortName>#<UOBbatchID>*
Promoted grandchild node scalar predicates (for 1:1 cardinality only)	*<systemPartition>#<UIDPartition>#:<UIDpredicateShortName>#<UIDPartition>#:<grandchildUIDpredicateShortName>#:<childPredicateShortName>*
UOB variant	*<systemPartition>#<UIDPartition>#:<UIDpredicateShortName>#<UIDPartition>#:<grandchildUIDpredicateShortName>#:<childPredicateShortName>#<UOBbatchID>*

For an example of *sort key* usage see the graph data from the Movie database at the end of the next section.

The table below lists the system generated data for each node. show the system Sort Key values that are generated for each node.

Generated Node Data	Sort Key
Node Type	*A#A#T*
Reverse Edge	*R#*

GoGraph Data Model

Details of the GoGraph data model are presented for the Node Block and UOB in the two tables below. After you become familiar with the data model you should review the next section which demonstrates its usage with an example of node data for a Person type from the Movie Graph.

Both table lists by category of data in a Node Block or UOB (e.g scalar, UID-Predicate, Type etc), the available table attributes and their associated *GoGraph, Dynamodb* and *Go* types. While most *Dynamodb* types need no explanation the use of the **List** type for the *UID Predicates* (aka Edge Predicates) and corresponding *propagated scalar predicates* is critical to GoGraph's design and will require some further explanation.

Internally *GoGraph* makes extensive use of the *Dynamodb* **List** data type, because, unlike the **Set** data type, the order of the elements in a List type is always fixed. *This feature of a List type represents a critical component of GoGraphs design because it can safely presume the same index entry in a related set of List type attribute's in the same item or across different but related items, refers to the same node.*

For example, each *UID Predicate* exists as a *Dynamodb* item with three attributes, **Nd, XF** and **Id**, which are all List types, as shown in the table below. For the case where the number of child nodes attached to a parent node is below a configurable threshold, a new child node will have its UUID appended to the **Nd** attribute in the parent node block. It will also append to the **XF** attribute an integer which indicates the UUID is a node block not a UOB. Finally, it appends to the **Id** attribute a value of 0, again to indicate it is a node block. The List type guarantees that the same index entry in the **Nd, XF** and **Id** attributes represents the same child node.

For the case when the number of child nodes attached to a parent node is above the threshold, a new child node will have its UUID appended to the **Nd** attribute, not in the parent node, but to an overflow item in the associated UOB. A UOB will have been created as part of the process of attaching a node when the threshold is first exceeded. Each item in a UOB (called a Batch item) has the same **Nd, XF** and **Id** List type attributes. After the child UUID is appended to the Nd attribute GoGraph will append UOB related data to the **XF** and **Id** attributes. Again, the same index entry across all attributes represents the same child node.

Interestingly, if you are familiar with Columnar tables in most RDBMS, then List types exhibit similar advantages. In this case, GoGraph has taken three distinct pieces of meta data from a child node and appended the data to three distinct “columns”, represented by the List types, **Nd, XF** and **Id i**n the parent node. Like Columnar tables, it is far quicker to scan a List than it is to scan a lot of child node items to retrieve the same data.

In the case of scalar data propagation from child to parent node, each scalar attribute for a child node is appended to an associated List type attribute, either a **LS, LN, LB** or **LBl** depending on the scalar type (*string, number, binary* or *boolean* respectively*),* in an item in the parent’s node block. In addition the item will also have an **XBl** attribute, to indicate if the scalar attribute is defined on the child node. The XBl attribute has similar semantics to the NOT NULL or NULL values in a SQL database.

For example, if a parent node’s *UID Predicate* type has an attribute “Name”, of type string, then the propagation routine, which executes as part of the attach-node operation, will append the child node’s Name value (e.g. “Jack Smith”) to attribute **LS** and append the boolean value “false” to the **XBl** attribute as “Name” exists in the child node. If the Name attribute did not exit in the child node the value “true” would be appended to **XBl** and the value “_NULL_” to the **LS** attribute[14]. Note, the item containing **LS** and **XBl** attributes is identified with a sort key value of “A#G#:D#:N” (see Sort Key Design for details) in the parent node block where the short names for the *UID Predicate* and “Name" attribute are separated by “#:”. This allows GoGraph to address a specific propagated scalar attribute or as is the usual case, address all propagated scalar attribute for a particular UID Predicate, in a single API call by using the leading portion of the sort key , “A#G#:D”.

Finally, the **XF** attribute can also be used to represent a child node that has detached. Rather than remove all the child data that has been duplicated in the parent node and UOB, a soft delete approach is employed and the **XF** entry for the node will be changed to “deleted” ie. value 2. GoGraph will ignore all index entries in the associated attribute Lists for this node, as though it did not exist.

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[14] *A null value entry is required because the child node’s UUID has already been appended to the **Nd** attribute and so all propagated scalar attribute Lists must have an associated index entry to maintain the index entry relationship.*

Node Block	Dynamodb Table Attribute	GoGraph Type	Dynamodb Type	Go Type	Description
Composite Key	**PKey**	Binary	Binary	[]byte	Partition key - Node's UUID
	SortK	String	String	string	Sort Key - see section on Sort Key Design
Node Type	**Ty**	String	String	string	User defined type (short name)
Scalar Predicate	**S**	String	String	string	String data
	N	Int	Number	int64, float64	Integer or Float data depending on attribute in Type spec
	B	Binary	Binary	[]byte	Binary data
	Bl	Boolean	Boolean	bool	Boolean data
	DT	DateTime	String	string	DateTime data
	P	String	String	string	When populated with the predicate long name the associated scalar value (attribute, **S, N, B**) will be indexed into a GSI. The GSI is used for root queries.
Set Scalar Predicate	**NS**	Number Set	Number Set	[]float64	Set of numbers
	SS	String Set	String Set	[]string	set of strings
	BS	Binary Set	Binary Set	[][]byte	Set of binary
	*PBS**	*Binary Set*	*Binary Set*	*[][]byte*	*Set of binary*
List Scalar Predicate	**LN**	Number List	List	[]int	List constrained to number
	LS	String List	List	[]string	List constrained to string
	LB	Binary List	List	[][]byte	List constrained to binary
	LBl	Boolean List	List	[]bool	List constrained to boolean
UID Predicate **(node-to-node edge)**	**Nd**	UUID List	List	[][]byte	Ordered list of Binary (child node UUIDs)
	XF	Int List	List	[]int	UUID type flag: 1 - *child UUID* 2 - *Node Deleted* 3 - *UID Overflow* 4 - *Overflow Block Full*
	Id	Int List	List	[]int	
Propagated Scalar Data	**LN**	Number List	List	[]int	List constrained to number
	LS	String List	List	[]string	List constrained to string
	LB	Binary List	List	[][]byte	List constrained to binary
	XBl	Boolean List	List	[]bool	List constrained to boolean: TRUE means associated scalar list data is NULL ie. not defined
Reverse Edge	**BS**	Binary Set	Binary Set	[][]byte	Set of binary
	*PBS**	*Binary Set*	*Binary Set*	*[][]byte*	*Set of binary*

* internal to GoGraph - do not use

The UOB is the overflow edge data from a UID-Predicate. UOB's stores the UUID of the child nodes and their propagated data.

UID Overflow Block (UOB)	Dynamodb Table Attribute	GoGraph Type	Dynamodb Type	Go Type	Description
Composite Key	**PKey**	Binary	Binary	[]byte	Partition key - UOB's UUID
	SortK	String	String	string	Sort Key - see section on Sort Key Design for overflow sort key format
UID Predicate **(node-to-node edge)**	**Nd**	UUID List	List	[][]byte	Ordered list of Binary (child node UUIDs)
	XF	Int List	List	[]int	UUID type flag: 1 - *child UUID* 2 - *Node Deleted*
Propagated Scalar Data	**LN**	Number List	List	[]int	List constrained to number
	LS	String List	List	[]string	List constrained to string
	LB	Binary List	List	[][]byte	List constrained to binary
	XBl	Boolean List	List	[]bool	List constrained to boolean: TRUE means associated scalar list data is NULL ie. not defined

Reverse Edge Design

The reverse edge predicate stores all the parent nodes to which a node has been attached, for each UID-Predicate. The reverse edge data resides in a single item in the node block (Sort Key value is "R#"). It is allocated its own system partition separate from the main partition (Sort Key starting with "A#") containing the node scalar and propagated data.

Testing has show the reverse edge design is a little "under thought". While the data content is sufficient to define each reverse edge (UID of the parent plus the name of the UID-Predicate), the single item makes it both slow to append, affecting RDF load times, and expensive to query, particularly for nodes that have thousands of parents.

Refactoring the reverse edge design should include the following components:

Refactoring Component	Comment
Make it optional	Not all UID-Predicates require the reverse edge to be recorded
Create a reverse edge item per UID-Predicate	Currently all reverse edge data, across all UID Predicates, is saved in one Dynamodb item. For faster and less expensive reads, reverse edgedata for each UID-Predicate should be saved separately, in its own item. The Sort Key format would be: **R#<*UID-Predicate*>** This design still allows all reverse edge data across all UID-Predicates to be read with a single database read call using a leading sort key of "R#".

Refactoring Component	Comment
Introduce Reverse Edge Overflow Blocks (REOB)	A reverse edges may contain thousands of entries if not millions, which will be both slow to update and read. The million-subscriber-design needs to be applied to the reverse edge. This means each reverse edge item in the node will have an **XF** and **Id** attribute. REOBs will be created dynamically. The data model for an REOB will be the same as a UOB.

More Details about the UID Overflow Design

Now that the Data Model has been discussed in detail more details of the Overflow Design can be revealed.

As a reminder, UOB were introduced to spread the edge data for a UID-Predicate across multiple partition keys for cases where there are many hundreds to millions of edges (child nodes).

GoGraph will create a UOB when a configured number of child nodes have been attached to the parent node's UID-Predicate. In fact it will typically create a number of UOB blocks (configureable). Each UOB's UUID will be appended to the parent nodes **Nd** attribute associated with the UID-Predicate where the child node is being attached. In addition for each UOB added a value of 3 (id type for a UOB block) will be appended **XF** and an integer value of 0 to the **Id** attribute. The **Nd** attribute now contains UUIDs of child node blocks and UOBs. The same index entry in the **XF** attribute determines which block type it is. Once all the UOBs have been created, and they are all created in the one operation, and the data appended to the **Nd, XF** and **Id** attributes for each UOB, no more data will ever be added to these attributes. Instead newly attached child nodes will have their data added to one of the UOB's, selected at random, from the parent node's UID-Predicate **Nd** attribute.

However, the **Id** attribute will be updated from time to time as it tracks the current item id in the UOB. For UOB's the **Id** attribute values starts at 1 and increments for each new item added to the UOB. An item is added to the UOB after a configurable number of child nodes have been added to the UOB. While a Dynamodb item can be up to 400KB in size an item of this size will be very slow and expensive (in terms of read capacity units) to append values to in the associated List type attributes. An optimal size for an item is around 500 nodes which equates to about 20KB. Consequently when an item reaches this size in the UOB a new item is created and all new child nodes will have their UUID added to the new item. Each time this happens the **Id** attribute back in the parent node's UID-Predicate item will have to be updated to reflect this change. A virtually unlimited number of items can be added to the UOB.

The **XF** attribute can also be used to represent a child node that has detached, in the same way as the **XF** attribute is used in the node block to represent a soft delete of a detached node. GoGraph will update the entry in the XF attribute for the associated node to a value of 2, meaning "deleted", as in the node has been detached and the data is now soft deleted.

Data Example: Person Node from Movie Graph

Types

Review the following type definitions from the Movie database.

Type	Attribute (The predicate in S-P-O)	Attribute Short Name	GoGraph Type
Film	title	N	**String**
	init_release_date	R	**DT**
	film.performance	P	**[Performance]** Note: [ ] so cardinality 1:M
	film.director	D	**[Person]** Note: [ ] so cardinality 1:M
	film.genre	G	**[Genre]** Note: [ ] so cardinality 1:M
Genre	name	N	**String**
Person	name	N	**String**
	actor.performance	A	**[Performance]** Note: [ ] so cardinality 1:M
	director.film	D	**[Film]** Note: [ ] so cardinality 1:M
Character	name	N	**String**
Performance	performance.character	C	**Character** Note: no [ ] so cardinality 1:1
	performance.actor	A	**Person** Note: no [ ] so cardinality 1:1
	performance.film	F	**Film** Note: no [ ] so cardinality 1:1

Graph Data for a Person Node

Instance of **Person** scalar item. Please review the SortK Specification on page 17 for an explanation of the SortK values.

PKey	SortK	Non-Key Data: **Attribute -** Value
7kRfp8KyQ/erDWfM15ZnwA==	A#A#:N [*name*]	**P** - name **S** - “Stanley Kubrick”

Instances of Person ***UID Predicates*** (edges), *Actor.Performance* and *Director.Film*.

PKey	SortK	Non-Key Data: Attribute - Value
	A#G#:D [*director.film*]	**Nd** - [3WdQPRAiRG29iGuGHKuLMA== ymanEWWqSFSml9xvZK9tsA== . . . QZTfWCUWSr++82yW2QaoBQ== . . .] **XF** - [1 , 1, …, 1, …] **Id** - [0 , 0, …, 0, …]

Instances of Person, **propagated child scalar** Items for UID Predicate*, Director.Film*.

PKey	SortK	Non-Key Data: Attribute - Value
7kRfp8KyQ/erDWfM15ZnwA==	A#G#:D#:N [title]	**LS** - [“2001: A Space Odyssey” “Dr. Strangelove or: How I Learned to Stop Worrying and Love the Bomb” . . . “Eyes Wide Shut” . . .] **XBl** - [False, False, …, False,…]
	A#G#:D#:R [initial_release_date]	**LS** - [“1968-04-02T00:00:00Z” “1964-01-29T00:00:00Z” . . . “1999-07-13T00:00:00Z” . . .] **XBl** - [False, False, …, False,…]

Instances of Person, **propagated grandchild scalar** Items for UID Predicate, *Actor.Performance*

PKey	SortK	Non-Key Data: Attribute - Value
7kRfp8KyQ/erDWfM15ZnwA==	A#G#:A#G#:A [performance]	**Nd** - [7kRfp8KyQ/erDWfM15ZnwA== 7kRfp8KyQ/erDWfM15ZnwA==] **XF** - [1 , 1] **Id** - [0 , 0]
	A#G#:A#G#:A#:N [performance.actor]	**LS** - [“Stanley Kubrick” “Stanley Kubrick”] **XBl** - [False, False]
	A#G#:A#G#:C [performance.character]	**Nd** - [HmarwkocQkeBsMfQaAr5xg== tZJl2ecaTDOn0NYPhcudGA==] **XF** - [1 , 1] **Id** - [0 , 0]
	A#G#:A#G#:C#:N [name]	**LS** - [“Murphy” “Bearded Cafe Patron”] **XBl** - [False, False]
	A#G#:A#G#:F [performance.film]	**Nd** - [iTjsIAP3SimyDhKzQ4HZ0A== OL1MDBTnR3qltV5RCJCHuQ==] **XF** - [1 , 1] **Id** - [0 , 0]
	A#G#:A#G#:F#:N [name]	**LS** - ["Full Metal Jacket” “Eyes Wide Shut”] **XBl** - [False, False]
	A#G#:A#G#:F#:R [initial_release_date]	**LS** - [“1987-06-17T00:00:00Z” “1999-07-13T00:00:00Z”] **XBl** - [False, False] **Id** - [0 , 0]

Finally, the system generated items:

PKey	**SortK**	**Non-Key Data: Attribute -** Value
7kRfp8KyQ/erDWfM15ZnwA==	A#A#T	**Ty** - "P" (type short name) **Ix** - "Y"
	R#	**BS** - [AJchPqDKT+a+wfnqQI9eAACXIT6gyk/mvsH56kCPXgBEIzA= OL1MDBTnR3qltV5RCJCHuTi9TAwU50d6pbVeUQiQh7IEIzA= . . . 92A+y9KHS8ePq00cUfo/zvdgPsvSh0vHj6tNHFH6P85EIzA=] **PBS** - [AJchPqDKT+a+wfnqQI9eAEQ= OL1MDBTnR3qltV5RCJCHuUQ= . . . 92A+y9KHS8ePq00cUfo/zkQ=]

GoGraph Query Performance

The following performance test cases are taken from the GoGraph's test function suite. The first lot of tests demonstrate some of the implemented functions and the latter tests demonstrate query performance against the Movie database.

Non-Concurrent Query Engine

Git reference: https://github.com/rosshpayne/GoGraph/gql/ast/execute.go

Unlike the RDF Loader the query parse and execution are not concurrent designs. A concurrent design would enable each path in the graph to be executed independently in its own goroutine.

So the non-current design involves firstly executing the root query and for each node returned, walk the graph starting at the node while applying filters as necessary.

Node Cache

Github: https://github.com/rosshpayne/GoGraph/cache

There are no external caches used in testing. While a concurrent non-blocking node cache[15] was developed for GoGraph it was disabled for all tests as the point of the exercise is to quantify the performance of the underlying data stores not the performance of the cache. The query engine does cache nodes after they have been read from the database but unless the query revisits a node this will provide no benefit. This cache is cleared between queries.

A Word About The Data

Two graphs are used for testing. The *Relationship Graph* (https://github.com/rosshpayne/GoGraph/data/person.rdf) was handcrafted specifically for functional testing. It contains only a handful of nodes populated with familiar data and explicitly defined UUIDs to aid in the verification of the test results. *Note: because this graph is aimed at functional testing the query response times are unrealistic due to the limited number of nodes in the graph and internal caching in the query engine.*

The *Movie Graph,* on the other hand, is sourced from the internet (https://github.com/rosshpayne/GoGraph/data/million.rdf) and is large enough for performance testing. The internet file is however not in the appropriate format for the concurrent Loader and must be run through the migrate program to regenerate and reorder the RDF tuples it into an acceptable format for the Loader. The migration code is available here: https://github.com/rosshpayne/GoGraph/rdfm

The *Movie Graph* has the following stats.

RDF Triples: 1153863

947 director nodes

70780 actor nodes

283 genre nodes

6356 film nodes

119258 character nodes

119258 performance nodes

7389 film-director edges

119258 film-performance edges

119258 performance-actor edges

119258 performance-film edges

119258 performance-character edges

23679 film-genre edges

[15] Algorithm from the "The Go Programming Language" Alan Donovan, Brian Kernighan

Test 1: UID Predicate Filter with Boolean expression

Query Metrics

Metric	Value
Graph	Relationship
Nodes Queried	20
Nodes Displayed (after filtering)	15
Nodes at each depth	{ 3, 7, 10 }
Nodes Displayed at each Depth (after Filtering)	{ 3, 2, 10 }
Reduction in DB requests *	50%
Database requests	1 root request 4 node requests **
Query Elapsed Time (estimated) ***	52 ms
Average Node query time (estimated)	5.2 ms

* as a result of propagating scalar data from child to parent node
** limitation of test data. More realistic graph data would require 10 requests
*** based on 10 nodes queried, none cached.

Comment

This test highlights the use of a boolean expression inside an edge predicate filter.

See comments in red for further explanation.

Test Function

```
func TestUPredFilter4ab(t *testing.T) {                    <= Go Test function

input := `{                                                <= GraphQL statement
  directors(func: eq(count(Siblings), 2) ) {               <= Root expression. Find persons with 2 siblings.
    Age
    Name
    Friends @filter( (le(Age,40) or eq(Name,"Ian Payne")) and ge(Age,62)) { <= Boolean expression Filter
       Age
       Name
       Comment
       Friends   {
         Name
         Age
       }
       Siblings {
         Age
         Name
         Comment
       }
    }
  }
}`

       expectedTouchLvl = []int{3, 2, 10}         <= meta data to validate response. Nodes queried at each depth
       expectedTouchNodes = 15

       stmt := Execute("Relationship", input)     <= Graph to query. Parse and Execute.
       result := stmt.MarshalJSON()               <= Generate JSON output ofresponse
       t.Log(stmt.String())

       validate(t, result)
       Shutdown()

}
```

$ **go test -run=TestUPredFilter4ab -v**

```
Duration:  Parse  87.646126ms  Execute: 27.420353ms      <= Parse and Execute times
```

```
        {
        data: [
                {
                Age : 62,
                Name : "Ross Payne",
                Friends : [
                        {
                        Age: 67,
                        Name: "Ian Payne",
                             Comment: "One of the best cab rides I have Payne seen to date! Anyone know how fast the train was going
around 20 mins in?",
                        Friends : [
                                {
                                Name: "Phil Smith",
                                Age: 36,
                                },
                                {
                                Name: "Ross Payne",
                                Age: 62,
                                },
                                {
                                Name: "Paul Payne",
                                Age: 58,
                                },
                        ],
                        Siblings : [
                                {
                                Age: 58,
                                Name: "Paul Payne",
                                Comment: "A foggy snowy morning lit with Smith sodium lamps is an absolute dream",
                                },
                                {
                                Age: 62,
                                Name: "Ross Payne",
                                 Comment: "Another fun  video. Loved it my Payne Grandmother was from Passau. Dad was over in Germany
but there was something going on over there at the time we won't discuss right now. Thanks for posting it. Have a great weekend
everyone.",
                                },
                        ]
                        }
                ]
                },
                {
                Age : 67,
                Name : "Ian Payne",
                Friends : [
                ]
                },
                {
                Age : 58,
                Name : "Paul Payne",
                Friends : [
                        {
                        Age: 67,
                        Name: "Ian Payne",
                             Comment: "One of the best cab rides I have Payne seen to date! Anyone know how fast the train was going
around 20 mins in?",
                        Friends : [
                                {
                                Name: "Phil Smith",
                                Age: 36,
                                },
                                {
                                Name: "Ross Payne",
                                Age: 62,
                                },
                                {
                                Name: "Paul Payne",
                                Age: 58,
                                },
                        ],
                        Siblings : [
                                {
                                Age: 58,
                                Name: "Paul Payne",
                                Comment: "A foggy snowy morning lit with Smith sodium lamps is an absolute dream",
                                },
                                {
                                Age: 62,
                                Name: "Ross Payne",
                                 Comment: "Another fun  video. Loved it my Payne Grandmother was from Passau. Dad was over in Germany
but there was something going on over there at the time we won't discuss right now. Thanks for posting it. Have a great weekend
everyone.",
                                },
                        ]
                        }
                ]
                }
        ]
        }

in comparStat  [3 2 10]
--- PASS: TestUPredFilter4ab (2.13s)
PASS
ok      github.com/DynamoGraph/gql      2.170s
```

```
DB:2021/03/27 06:54:42 log.go:89: ================================== SetLogger ==========================================
gqlES: 2021/03/27 06:54:42.181911 Client: 7.9.0                                          <= Version: ElasticSearch client and server
gqlES: 2021/03/27 06:54:42.181938 Server: 7.8.1
gql: 2021/03/27 06:54:42.181951 Startup...
monitor: 2021/03/27 06:54:42.182082 Powering on...                                       <= Start required services: monitor, grmgr
grmgr: 2021/03/27 06:54:42.182099 Powering on...
gql: 2021/03/27 06:54:42.182110 services started
TypesDB: 2021/03/27 06:54:42.182467 db.getGraphId                                        <= Load GraphId, Type data into application
TypesDB: 2021/03/27 06:54:42.248367 getGraphId: consumed capacity for Query: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 1 Duration: 65.822007ms
TypesDB: 2021/03/27 06:54:42.248506 db.loadTypeShortNames
TypesDB: 2021/03/27 06:54:42.251117 loadTypeShortNames: consumed capacity for Query: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 1 Duration: 2.568258ms
TypesDB: 2021/03/27 06:54:42.254925 LoadDataDictionary: consumed capacity for Scan: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 10 Duration: 3.72274ms
gqlDB: 2021/03/27 06:54:42.276772 GSIS:consumed capacity for Query index P_S, {      <= Root query: GSI read
  CapacityUnits: 0.5,                                                                    <= eventually consistent read
  TableName: "DyGraphOD2"
}.  ItemCount 3  Duration: 6.638312ms                                                    <= 3 nodes satisfy root query
DB FetchNode: 2021/03/27 06:54:42.276875  node: TsI2Qay8T2SxnOcuI3pPeg== subKey: A#  <= Node Query: SortKey beginsWith “A#”
DB: 2021/03/27 06:54:42.282036 FetchNode:consumed capacity for Query  {              <= Query API
  CapacityUnits: 1,                                                                      <= strongly consistent read (configured)
  TableName: “DyGraphOD2"
}. ItemCount 19  Duration: 5.104856ms                                                    <= all node data fetched. 19 items
DB FetchNode: 2021/03/27 06:54:42.282643  node: 6KIuWuyTRKSgDqwYAghl7A== subKey: A#G#<= read propagated items only
DB: 2021/03/27 06:54:42.288979 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 12  Duration: 6.28986ms                                                     <= 12 items read into execution cache
DB FetchNode: 2021/03/27 06:54:42.289150  node: 66PNdV1TSKOpDRlO71+Aow== subKey: A#
grmgr: 2021/03/27 06:54:42.289192 EndCh received for execute. rCnt = 0
DB: 2021/03/27 06:54:42.293341 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 20  Duration: 4.14494ms
grmgr: 2021/03/27 06:54:42.293645 EndCh received for execute. rCnt = -1
DB FetchNode: 2021/03/27 06:54:42.293659  node: 6KIuWuyTRKSgDqwYAghl7A== subKey: A#  <= read scalar and propagated items
DB: 2021/03/27 06:54:42.297268 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 19  Duration: 3.570927ms
gql: 2021/03/27 06:54:42.297492 Duration: Parse  87.646126ms  Execute: 27.420353ms    <= Elapsed times: query parse, query execution
grmgr: 2021/03/27 06:54:42.297502 EndCh received for execute. rCnt = -2
monitor: 2021/03/27 07:00:57.929751 monitor: []interface {}{3, 3, 15, []int{3, 2, 10}, 4, (*monitor.Fetch)(0xc0004c14c0), interface
{}(nil), interface {}(nil)} monitor.Fetch{Fetches:4, CapacityUnits:4, Items:70, Duration:20530844}
gql: 2021/03/27 06:54:44.297627 Shutdown commenced...                                    <= Shutdown services: monitor, grmgr
grmgr: 2021/03/27 06:54:44.297682 Powering down...
monitor: 2021/03/27 06:54:44.297692 Powering down...
gql: 2021/03/27 06:54:44.297701 Shutdown Completed
```

Test 2: Full Text Searching and Root Filter Expression

Query Metrics

Metric	Value
Graph	Relationship
Nodes Queried	13
Nodes Displayed (after filtering)	12
Nodes at each depth	{ 2, 2, 3, 6 }
Nodes Displayed at each Depth (after Filtering)	{ 1, 2, 3, 6 }
Reduction in DB requests *	46%
Database requests	1 ElasticSearch request 7 Dynamodb requests
Query Elapsed Time	44.5 ms
Average Node query time	2.8 ms (44.5-7.79)/13

* as a result of propagating scalar data from child to parent node

Comment

This test demonstrates uses two data sources to resolve the query. The root query uses the full text search function, *anyofterms,* to query ***ElasticSearch***, which returns with the node UUIDs that satisfy the function. For each UUID GoGraph then searches ***Dynamodb*** to resolve the filter function. Those nodes that satisfy the filter are then passed through the rest of the GraphQL query.

Test Function

```
func TestRootQueryAnyPlusFilter2(t *testing.T) {

        input := `{
   directors(func: anyofterms(Comment,"sodium Germany Chris")) @filter(gt(Age,60)){ <= ElasticSearch query + filter
expression
    Age
    Name
    Comment
    Friends {
         Name
         Age
         Siblings {
                 Name
                  Friends {
                       Name
                       Age
                       Comment
                 }
         }
     }
  }
}`
        expectedTouchLvl = []int{1, 2, 3, 6}
        expectedTouchNodes = 12

        stmt := Execute("Relationship", input)
        result := stmt.MarshalJSON()
        t.Log(stmt.String())

        validate(t, result)
}
```

$ **go test -run=TestRootQueryAnyPlusFilter2 -v**

```
gql: 2021/03/30 03:29:55.220263 Duration: Parse  76.1568ms  Execute: 44.521291ms
```

```
monitor: 2021/03/30 03:29:57.220698 monitor: []interface {}{2, 1, 13, []int{2, 2, 3, 6}, 12, []int{1, 2, 3, 6}, 7, (*monitor.Fetch)(0xc0004b1140), interface {}(nil), interface {}(nil)} monitor.Fetch{Fetches:7, CapacityUnits:7, Items:94, Duration:32610743}

data: [
                {
                Age : 62,
                Name : "Ross Payne",
                    Comment : "Another fun  video. Loved it my Payne Grandmother was from Passau. Dad was over in Germany but there was something going on over there at the time we won't discuss right now. Thanks for posting it. Have a great weekend everyone.",
                Friends : [
                        {
                        Name: "Phil Smith",
                        Age: 36,
                        Siblings : [
                                {
                                Name: "Jenny Jones",
                                Friends : [
                                        {
                                        Name: "Ross Payne",
                                        Age: 62,
                                             Comment: "Another fun  video. Loved it my Payne Grandmother was from Passau. Dad was over in Germany but there was something going on over there at the time we won't discuss right now. Thanks for posting it. Have a great weekend everyone.",
                                        },
                                        {
                                        Name: "Paul Payne",
                                        Age: 58,
                                         Comment: "A foggy snowy morning lit with Smith sodium lamps is an absolute dream",
                                        },
                                ]
                                },
                        ]
                        },
                        {
                        Name: "Ian Payne",
                        Age: 67,
                        Siblings : [
                                {
                                Name: "Paul Payne",
                                Friends : [
                                        {
                                        Name: "Ross Payne",
                                        Age: 62,
                                             Comment: "Another fun  video. Loved it my Payne Grandmother was from Passau. Dad was over in Germany but there was something going on over there at the time we won't discuss right now. Thanks for posting it. Have a great weekend everyone.",
                                        },
                                        {
                                        Name: "Ian Payne",
                                        Age: 67,
                                         Comment: "One of the best cab rides I have Payne seen to date! Anyone know how fast the train was going around 20 mins in?",
                                        },
                                ]
                                },
                                {
                                Name: "Ross Payne",
                                Friends : [
                                        {
                                        Name: "Phil Smith",
                                        Age: 36,
                                             Comment: "It seems to me the camera's Smith focus is better, clearer, thank you for sharing, I think Austria is a beautiful country I'm not surprised that it produced so many great classical musicians.",
                                        },
                                        {
                                        Name: "Ian Payne",
                                        Age: 67,
                                         Comment: "One of the best cab rides I have Payne seen to date! Anyone know how fast the train was going around 20 mins in?",
                                        },
                                ]
                                },
                        ]
                        }
                ]
                }
        ]
        }
```

Log Output

```
DB:2021/03/30 03:29:55 log.go:89: ========================================= SetLogger
gqlES: 2021/03/30 03:29:55.098713 Client: 7.9.0
gqlES: 2021/03/30 03:29:55.098739 Server: 7.8.1
gql: 2021/03/30 03:29:55.098755 Startup...
monitor: 2021/03/30 03:29:55.098803 Powering on...
grmgr: 2021/03/30 03:29:55.098832 Powering on...
```

```
gql: 2021/03/30 03:29:55.098844 services started
TypesDB: 2021/03/30 03:29:55.099570 db.getGraphId
TypesDB: 2021/03/30 03:29:55.166821 getGraphId: consumed capacity for Query: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 1 Duration: 67.163807ms
TypesDB: 2021/03/30 03:29:55.166958 db.loadTypeShortNames
TypesDB: 2021/03/30 03:29:55.169869 loadTypeShortNames: consumed capacity for Query: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 1 Duration: 2.871743ms
TypesDB: 2021/03/30 03:29:55.173918 LoadDataDictionary: consumed capacity for Scan: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 10 Duration: 3.953619ms
gqlES: 2021/03/30 03:29:55.183507 ES Search duration: 7.79105ms                                <= ElasticSearch log
entry
DB FetchNode: 2021/03/30 03:29:55.185477  node: TsI2Qay8T2SxnOcuI3pPeg== subKey: A#
DB: 2021/03/30 03:29:55.192306 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 19  Duration: 6.682568ms
grmgr: 2021/03/30 03:29:55.192459 EndCh received for execute. rCnt = 0
DB FetchNode: 2021/03/30 03:29:55.192490  node: 66PNdV1TSKOpDRlO71+Aow== subKey: A#
DB: 2021/03/30 03:29:55.198446 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 20  Duration: 5.918953ms
DB FetchNode: 2021/03/30 03:29:55.198616  node: OlTBKXemTNWATwDDt6U5/A== subKey: A#G#
DB: 2021/03/30 03:29:55.203035 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 12  Duration: 4.378531ms
DB FetchNode: 2021/03/30 03:29:55.203210  node: 6nG/Cd+dSoyD48CrXQjrLQ== subKey: A#G#
DB: 2021/03/30 03:29:55.206455 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 7  Duration: 3.204773ms
DB FetchNode: 2021/03/30 03:29:55.206625  node: 6KIuWuyTRKSgDqwYAghl7A== subKey: A#G#
DB: 2021/03/30 03:29:55.211914 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 12  Duration: 5.249466ms
DB FetchNode: 2021/03/30 03:29:55.212071  node: TsI2Qay8T2SxnOcuI3pPeg== subKey: A#G#
DB: 2021/03/30 03:29:55.215904 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 12  Duration: 3.796902ms
DB FetchNode: 2021/03/30 03:29:55.216088  node: 66PNdV1TSKOpDRlO71+Aow== subKey: A#G#
DB: 2021/03/30 03:29:55.219507 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 12  Duration: 3.37955ms
grmgr: 2021/03/30 03:29:55.220246 EndCh received for execute. rCnt = -1
gql: 2021/03/30 03:29:55.220263 Duration: Parse  76.1568ms  Execute: 44.521291ms
monitor: 2021/03/30 03:29:57.220698 monitor: []interface {}{2, 1, 13, []int{2, 2, 3, 6}, 12, []int{1, 2, 3, 6}, 7,
(*monitor.Fetch)(0xc0004b1140), interface {}(nil), interface {}(nil)} monitor.Fetch{Fetches:7, CapacityUnits:7,
Items:94, Duration:32610743}
DB: 2021/03/30 03:29:57.228503 TestLog: consumed capacity for PutItem  {
  CapacityUnits: 4,
  TableName: "TestLog"
}. Duration: 7.498688ms
gql: 2021/03/30 03:29:57.228554 Shutdown commenced...
monitor: 2021/03/30 03:29:57.228570 Powering down...
monitor: 2021/03/30 03:29:57.228571 Powering down...
gql: 2021/03/30 03:29:57.228583 Shutdown Completed
```

Test 3: Generate a Graph of Depth 5

Query Metrics

Metric	Value
Graph	Relationship
Nodes Queried	145
Nodes Displayed (after filtering)	145
Nodes at each depth	{ 3, 7, 30, 32, 73}
Reduction in DB requests *	50%
Database requests	1 Root request 15 Node requests **
Query Elapsed Time	78 ms 340 ms ***
Average Node query time	4.7 ms

* as a result of propagating a child node's scalar data to the parent node
** Due to internal caches in the execution engine only 15 nodes are fetched from Dynamodb. For more realistic data 72 nodes would be fetched.
*** When extrapolated to 72 nodes.

Comment

This query demonstrates generating a graph of depth 5. The root query uses the equality function, *eq*, to find the nodes that have exactly two siblings.

Test Function

```
func TestRootQuery1f(t *testing.T) {

  input := `{
  directors(func: eq(count(Siblings), 2)) {
    Age
    Name
    Friends {
            Age
            Name
            Friends {
                    Name
                    Age
                    Siblings {
                            Name
                            Age
                            Friends {
                                    Name
                                    Age
                                    DOB
                            }
                    }
            }
            Siblings {
                    Name
            }
    }
  }
}`
        expectedTouchLvl = []int{3, 7, 30, 32, 73}
        expectedTouchNodes = 145

        stmt := Execute("Relationship", input)
        result := stmt.MarshalJSON()
        t.Log(stmt.String())

        validate(t, result)
        Shutdown()
}
```

$ **go test -run=TestRootQuery1f -v**

```
Duration: Parse  85.067525ms  Execute: 78.326803ms

monitor: []interface {}{3, 3, 145, []int{3, 7, 30, 32, 73}, 145, []int{3, 7, 30, 32, 73}, 15, (*monitor.Fetch)(0xc0000f4b20),
interface {}(nil), interface {}(nil)}

      {
        data: [
                {
                Age : 62,
                Name : "Ross Payne",
                Friends : [
                        {
                        Age: 36,
                        Name: "Phil Smith",
                        Friends : [
                                {
                                Name: "Paul Payne",
                                Age: 58,
                                Siblings : [
                                        {
                                        Name: "Ross Payne",
                                        Age: 62,
                                        Friends : [
                                                {
                                                Name: "Phil Smith",
                                                Age: 36,
                                                DOB: "17 June 1976",
                                                },
                                                {
                                                Name: "Ian Payne",
                                                Age: 67,
                                                DOB: "29 Jan 1953",
                                                },
                                        ]
                                        },
                                        {
                                        Name: "Ian Payne",
                                        Age: 67,
                                        Friends : [
                                                {
                                                Name: "Phil Smith",
                                                Age: 36,
                                                DOB: "17 June 1976",
                                                },
                                                {
                                                Name: "Ross Payne",
                                                Age: 62,
                                                DOB: "13 March 1958",
                                                },
                                                {
                                                Name: "Paul Payne",
                                                Age: 58,
                                                DOB: "2 June 1960",
                                                },
                                        ]
                                        },
                                ]


                        . . . .


                                       {
                                        Name: "Ian Payne",
                                        Age: 67,
                                        Friends : [
                                                {
                                                Name: "Phil Smith",
                                                Age: 36,
                                                DOB: "17 June 1976",
                                                },
                                                {
                                                Name: "Ross Payne",
                                                Age: 62,
                                                DOB: "13 March 1958",
                                                },
                                                {
                                                Name: "Paul Payne",
                                                Age: 58,
                                                DOB: "2 June 1960",
                                                },
                                        ]
                                        },
                                ]
                                },
                        ],
                        Siblings : [
                                {
                                Name: "Paul Payne",
                                },
                                {
                                Name: "Ross Payne",
                                },
                        ]
                        }
                ]
                }
        ]
        }
```

Log Output

```
DB:2021/03/31 09:03:18 log.go:89: ================================== SetLogger
```

```
gqlES: 2021/03/31 09:03:18.669729 Client: 7.9.0
gqlES: 2021/03/31 09:03:18.669749 Server: 7.8.1
gql: 2021/03/31 09:03:18.669760 Startup...
monitor: 2021/03/31 09:03:18.669800 Powering on...
monitor: 2021/03/31 09:03:18.669800 Powering on...
gql: 2021/03/31 09:03:18.669826 services started
TypesDB: 2021/03/31 09:03:18.669969 db.getGraphId
TypesDB: 2021/03/31 09:03:18.736810 getGraphId: consumed capacity for Query: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 1 Duration: 66.755535ms
TypesDB: 2021/03/31 09:03:18.736875 db.loadTypeShortNames
TypesDB: 2021/03/31 09:03:18.740159 loadTypeShortNames: consumed capacity for Query: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 1 Duration: 3.242505ms
TypesDB: 2021/03/31 09:03:18.744088 LoadDataDictionary: consumed capacity for Scan: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 10 Duration: 3.842719ms
gqlDB: 2021/03/31 09:03:18.762227 GSIS:consumed capacity for Query index P_S, {
  CapacityUnits: 0.5,
  TableName: "DyGraphOD2"
}.  ItemCount 3  Duration: 7.148268ms
DB FetchNode: 2021/03/31 09:03:18.762331  node: TsI2Qay8T2SxnOcuI3pPeg== subKey: A#
DB: 2021/03/31 09:03:18.769233 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 19  Duration: 6.848353ms
DB FetchNode: 2021/03/31 09:03:18.769934  node: 66PNdV1TSKOpDRlO71+Aow== subKey: A#G#
DB: 2021/03/31 09:03:18.773936 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 12  Duration: 3.954668ms
DB FetchNode: 2021/03/31 09:03:18.774061  node: OlTBKXemTNWATwDDt6U5/A== subKey: A#G#
DB: 2021/03/31 09:03:18.780447 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 12  Duration: 6.341387ms
DB FetchNode: 2021/03/31 09:03:18.780697  node: 6nG/Cd+dSoyD48CrXQjrLQ== subKey: A#G#
DB: 2021/03/31 09:03:18.788195 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 7  Duration: 7.428827ms
DB FetchNode: 2021/03/31 09:03:18.788311  node: 6KIuWuyTRKSgDqwYAghl7A== subKey: A#G#
DB: 2021/03/31 09:03:18.792966 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 12  Duration: 4.605103ms
DB FetchNode: 2021/03/31 09:03:18.793090  node: TsI2Qay8T2SxnOcuI3pPeg== subKey: A#G#
DB: 2021/03/31 09:03:18.796306 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 12  Duration: 3.174697ms
DB FetchNode: 2021/03/31 09:03:18.796415  node: 66PNdV1TSKOpDRlO71+Aow== subKey: A#G#
DB: 2021/03/31 09:03:18.799894 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 12  Duration: 3.437771ms
DB FetchNode: 2021/03/31 09:03:18.800165  node: 6KIuWuyTRKSgDqwYAghl7A== subKey: A#G#
DB: 2021/03/31 09:03:18.803994 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 12  Duration: 3.783304ms
DB FetchNode: 2021/03/31 09:03:18.804140  node: 66PNdV1TSKOpDRlO71+Aow== subKey: A#G#
DB: 2021/03/31 09:03:18.807903 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 12  Duration: 3.725294ms
DB FetchNode: 2021/03/31 09:03:18.808030  node: 6KIuWuyTRKSgDqwYAghl7A== subKey: A#G#
DB: 2021/03/31 09:03:18.811703 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 12  Duration: 3.633049ms
DB FetchNode: 2021/03/31 09:03:18.811831  node: TsI2Qay8T2SxnOcuI3pPeg== subKey: A#G#
DB: 2021/03/31 09:03:18.815188 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 12  Duration: 3.317495ms
grmgr: 2021/03/31 09:03:18.815325 EndCh received for execute. rCnt = 0
DB FetchNode: 2021/03/31 09:03:18.815352  node: 66PNdV1TSKOpDRlO71+Aow== subKey: A#
DB: 2021/03/31 09:03:18.819317 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 20  Duration: 3.91359ms
DB FetchNode: 2021/03/31 09:03:18.821221  node: OlTBKXemTNWATwDDt6U5/A== subKey: A#G#
DB: 2021/03/31 09:03:18.825456 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 12  Duration: 4.183986ms
grmgr: 2021/03/31 09:03:18.825589 EndCh received for execute. rCnt = -1
```

```
DB FetchNode: 2021/03/31 09:03:18.825700  node: 6KIuWuyTRKSgDqwYAghl7A== subKey: A#
DB: 2021/03/31 09:03:18.829595 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 19  Duration: 3.849564ms
DB FetchNode: 2021/03/31 09:03:18.829751  node: TsI2Qay8T2SxnOcuI3pPeg== subKey: A#G#
DB: 2021/03/31 09:03:18.833218 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 12  Duration: 3.428239ms
gql: 2021/03/31 09:03:18.833344 Duration: Parse  85.067525ms  Execute: 78.326803ms
grmgr: 2021/03/31 09:03:18.833353 EndCh received for execute. rCnt = -2
monitor: 2021/03/31 09:03:20.836150 monitor: []interface {}{3, 3, 145, []int{3, 7, 30, 32, 73}, 145, []int{3, 7,
30, 32, 73}, 15, (*monitor.Fetch)(0xc0000fe260), interface {}(nil), interface {}(nil)} monitor.Fetch{Fetches:15,
CapacityUnits:15, Items:197, Duration:65625327}
DB: 2021/03/31 09:03:20.853483 TestLog: consumed capacity for PutItem  {
  CapacityUnits: 12,
  TableName: "TestLog"
}. Duration: 17.1962ms
gql: 2021/03/31 09:03:20.853519 Shutdown commenced...
grmgr: 2021/03/31 09:03:20.853533 Powering down...
monitor: 2021/03/31 09:03:20.853542 Powering down...
gql: 2021/03/31 09:03:20.853547 Shutdown Completed
```

Test 4: Has Function in Filter

Query Metrics

Metric	Value
Graph	Relationship
Nodes Queried	5
Nodes Displayed (after filtering)	3
Nodes at each depth	{3, 2}
Nodes at each depthFiltered	{1, 2}
Reduction in DB requests *	40%
Database requests	1 Root request 3 Node requests
Query Elapsed Time	27.5 ms
Average Node query time for 5 nodes **	5.5 ms

* as a result of propagating a child node's scalar data to the parent node
** 3 nodes where fetched from database containing data for 5 nodes because of data propagation from child to parent

Comment

The *has* function checks each node for the existence of a particular attribute. In this example it filters any nodes returned from the root query that do not have an “Address" attribute.

Test Function

```
func TestRootFilterHas1(t *testing.T) {

        input := `{
          me(func: eq(count(Siblings),2)) @filter(has(Address)) { <= find all nodes with 2 siblings that have an address
            Name
            Address
            Age
            Siblings {
                Name
                Age
            }
          }
        }`

        expectedTouchLvl = []int{1, 2}
        expectedTouchNodes = 3

        stmt := Execute("Relationship", input)
        result := stmt.MarshalJSON()
        t.Log(stmt.String())

        validate(t, result)

}
```

$ **go test -run=TestRootFilterHas1 -v**

Duration: Parse 102.856088ms Execute: 27.534578ms

monitor: []interface {}{3, 1, 5, []int{3, 2}, 3, []int{1, 2}, 3, (*monitor.Fetch)(0xc00030a160), interface {}(nil), interface {}(nil)}

```
{
    data: [
        {
        Name : "Ross Payne",
```

```
        Address : "55 Fredrick St Helensville, QLD, Australia",
        Age : 62,
        Siblings : [
            {
            Name: "Paul Payne",
            Age: 58,
            },
            {
            Name: "Ian Payne",
            Age: 67,
            }
        ]
        }
    ]
}
```

Log Output

```
DB:2021/03/31 03:35:33 log.go:89: ================================== SetLogger
gqlES: 2021/03/31 03:35:33.692714 Client: 7.9.0
gqlES: 2021/03/31 03:35:33.692744 Server: 7.8.1
gql: 2021/03/31 03:35:33.692759 Startup...
monitor: 2021/03/31 03:35:33.692803 Powering on...
grmgr: 2021/03/31 03:35:33.692817 Powering on...
gql: 2021/03/31 03:35:33.692829 services started
TypesDB: 2021/03/31 03:35:33.693018 db.getGraphId
TypesDB: 2021/03/31 03:35:33.772950 getGraphId: consumed capacity for Query: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 1 Duration: 79.843545ms
TypesDB: 2021/03/31 03:35:33.773099 db.loadTypeShortNames
TypesDB: 2021/03/31 03:35:33.775855 loadTypeShortNames: consumed capacity for Query: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 1 Duration: 2.71016ms
TypesDB: 2021/03/31 03:35:33.785338 LoadDataDictionary: consumed capacity for Scan: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 10 Duration: 9.392268ms
gqlDB: 2021/03/31 03:35:33.802703 GSIS:consumed capacity for Query index P_S, {
  CapacityUnits: 0.5,
  TableName: "DyGraphOD2"
}.  ItemCount 3  Duration: 6.539166ms
DB FetchNode: 2021/03/31 03:35:33.802831  node: TsI2Qay8T2SxnOcuI3pPeg== subKey: A#
DB: 2021/03/31 03:35:33.811000 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 19  Duration: 8.10721ms
grmgr: 2021/03/31 03:35:33.811292 EndCh received for execute. rCnt = 0
DB FetchNode: 2021/03/31 03:35:33.811316  node: 66PNdV1TSKOpDRlO71+Aow== subKey: A#
DB: 2021/03/31 03:35:33.815989 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 20  Duration: 4.630716ms
DB FetchNode: 2021/03/31 03:35:33.816146  node: 6KIuWuyTRKSgDqwYAghl7A== subKey: A#
grmgr: 2021/03/31 03:35:33.816176 EndCh received for execute. rCnt = -1
DB: 2021/03/31 03:35:33.823228 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 19  Duration: 7.036968ms
gql: 2021/03/31 03:35:33.823396 Duration: Parse  102.856088ms  Execute: 27.534578ms
grmgr: 2021/03/31 03:35:33.823510 EndCh received for execute. rCnt = -2
monitor:  2021/03/31  03:35:35.823802  monitor:  []interface  {}{3,  1,  5,  []int{3,  2},  3,  []int{1,  2},  3,
(*monitor.Fetch)(0xc00030a160),  interface  {}(nil),  interface  {}(nil)}  monitor.Fetch{Fetches:3,  CapacityUnits:3,
Items:58, Duration:19774894}
DB: 2021/03/31 03:35:35.832098 TestLog: consumed capacity for PutItem  {
  CapacityUnits: 2,
  TableName: "TestLog"
}. Duration: 8.089336ms
```

Test 5: *Has* function in Root Filter and Edge Predicate

Query Metrics

Metric	Value
Graph	Relationship
Nodes Queried	9
Nodes Displayed (after filtering)	5
Nodes at each depth	{3, 6}
Nodes at each depthFiltered	{3, 2}
Reduction in DB requests *	66%
Database requests	1 Root request 3 Node requests
Query Elapsed Time	24.6 ms
Average Node query time for 9 nodes **	1.9 ms

* as a result of propagating a child node's scalar data to the parent node
** 3 nodes where fetched from database containing data for 9 nodes because of data propagation from child to parent

Comment

Test Function

```
func TestUidPredFilterHasScalar(t *testing.T) {

        input := `{
          me(func: eq(count(Siblings),2)) @filter(has(Friends)) {
                  Name
                 Address
                 Age
                 Siblings @filter(has(Address)) {
                         Name
                         Age
                 }
            }
        }`

        expectedTouchLvl = []int{3, 2}
        expectedTouchNodes = 5

        stmt := Execute("Relationship", input)
        result := stmt.MarshalJSON()
        t.Log(stmt.String())
        validate(t, result)
}
```

Test Function

```
$ go test -run=TestUidPredFilterHasScalar -v

Duration:  Parse  77.336338ms  Execute: 24.630652ms

monitor: []interface {}{3, 3, 9, []int{3, 6}, 5, []int{3, 2}, 3, (*monitor.Fetch)(0xc000562aa0), interface {}
(nil), interface {}(nil)}

      {
        data: [
                {
                Name : "Ross Payne",
                Address : "67/55 Burkitt St Page, ACT, Australia",
                Age : 62,
```

```
                Siblings : [
                ]
                },
                {
                Name : "Ian Payne",
                 Address : <nil>,
                Age : 67,
                Siblings : [
                        {
                        Name: "Ross Payne",
                        Age: 62,
                        }
                ]
                },
                {
                Name : "Paul Payne",
                 Address : <nil>,
                Age : 58,
                Siblings : [
                        {
                        Name: "Ross Payne",
                        Age: 62,
                        },
                ]
                }
        ]
        }


DB:2021/03/31 04:52:40 log.go:89: ==================================== SetLogger
gqlES: 2021/03/31 04:52:40.651728 Client: 7.9.0
gqlES: 2021/03/31 04:52:40.651748 Server: 7.8.1
gql: 2021/03/31 04:52:40.651759 Startup...
grmgr: 2021/03/31 04:52:40.651810 Powering on...
grmgr: 2021/03/31 04:52:40.651810 Powering on...
gql: 2021/03/31 04:52:40.651853 services started
TypesDB: 2021/03/31 04:52:40.652055 db.getGraphId
TypesDB: 2021/03/31 04:52:40.720110 getGraphId: consumed capacity for Query: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 1 Duration: 67.963248ms
TypesDB: 2021/03/31 04:52:40.720251 db.loadTypeShortNames
TypesDB: 2021/03/31 04:52:40.723177 loadTypeShortNames: consumed capacity for Query: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 1 Duration: 2.882168ms
TypesDB: 2021/03/31 04:52:40.727393 LoadDataDictionary: consumed capacity for Scan: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 10 Duration: 4.111155ms
gqlDB: 2021/03/31 04:52:40.736516 GSIS:consumed capacity for Query index P_S, {
  CapacityUnits: 0.5,
  TableName: "DyGraphOD2"
}.  ItemCount 3  Duration: 7.086526ms
DB FetchNode: 2021/03/31 04:52:40.736617  node: TsI2Qay8T2SxnOcuI3pPeg== subKey: A#
DB: 2021/03/31 04:52:40.742904 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 19  Duration: 6.240674ms
DB FetchNode: 2021/03/31 04:52:40.743327  node: 66PNdV1TSKOpDRlO71+Aow== subKey: A#
grmgr: 2021/03/31 04:52:40.743364 EndCh received for execute. rCnt = 0
DB: 2021/03/31 04:52:40.747538 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 20  Duration: 4.134888ms
grmgr: 2021/03/31 04:52:40.747704 EndCh received for execute. rCnt = -1
DB FetchNode: 2021/03/31 04:52:40.747713  node: 6KIuWuyTRKSgDqwYAghl7A== subKey: A#
DB: 2021/03/31 04:52:40.753837 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 19  Duration: 6.082396ms
gql: 2021/03/31 04:52:40.753992 Duration: Parse  77.336338ms  Execute: 24.630652ms
grmgr: 2021/03/31 04:52:40.754002 EndCh received for execute. rCnt = -2
monitor:  2021/03/31  04:52:42.754314  monitor:  []interface  {}{3,  3,  9,  []int{3,  6},  5,  []int{3,  2},  3,
(*monitor.Fetch)(0xc000562aa0),  interface  {}(nil),  interface  {}(nil)}  monitor.Fetch{Fetches:3,  CapacityUnits:3,
Items:58,  Duration:16958}
DB: 2021/03/31 04:52:42.762577 TestLog: consumed capacity for PutItem  {
  CapacityUnits: 2,
  TableName: "TestLog"
}. Duration: 8.036407ms
```

Test 6: *AnyOfTerms* function in Root Filter

Query Metrics

Metric	Value
Graph	Relationship
Nodes Queried	3
Nodes Displayed (after filtering)	2
Nodes at each depth	{ 3 }
Nodes at each depthFiltered	{ 2 }
Reduction in DB requests *	0%
Database requests	1 Root request 3 Node requests

* as a result of propagating a child node's scalar data to the parent node

Comment

Demonstrates the use of the *anyofterms* in a root filter. While the root query is resolved in Dynamodb the filter function is implemented in GoGraph.

Test Function

```
func TestRootFilteranyofterms1(t *testing.T) {

         input := `{
           me(func: eq(count(Siblings),2)) @filter( anyofterms(Comment,"sodium Germany Chris") ) {
                           Name
                 Comment
             }
           }`

         expectedTouchLvl = []int{2}
         expectedTouchNodes = 2

         stmt := Execute("Relationship", input)
         result := stmt.MarshalJSON()
         t.Log(stmt.String())

         validate(t, result)

}
```

$ **go test -run=TestRootFilteranyofterms1 -v**

Duration: Parse 75.978328ms Execute: 21.894101ms

monitor: []interface {}{3, 2, 3, []int{3}, 2, []int{2}, 3, (*monitor.Fetch)(0xc00020c2a0), interface {}(nil), interface {}(nil)}
in comparStat [2]


```
     {
     data: [
          {
          Name : "Ross Payne",
            Comment : "Another fun  video. Loved it my Payne Grandmother was from Passau. Dad was over in Germany but there was something going
on over there at the time we won't discuss right now. Thanks for posting it. Have a great weekend everyone.",
          },
          {
          Name : "Paul Payne",
          Comment : "A foggy snowy morning lit with Smith sodium lamps is an absolute dream",
          }
     ]
     }
```

```
DB:2021/03/31 05:43:33 log.go:89: ========================================== SetLogger
gqlES: 2021/03/31 05:43:33.319823 Client: 7.9.0
gqlES: 2021/03/31 05:43:33.319843 Server: 7.8.1
gql: 2021/03/31 05:43:33.319851 Startup...
monitor: 2021/03/31 05:43:33.319889 Powering on...
monitor: 2021/03/31 05:43:33.319889 Powering on...
gql: 2021/03/31 05:43:33.319918 services started
TypesDB: 2021/03/31 05:43:33.320116 db.getGraphId
TypesDB: 2021/03/31 05:43:33.387590 getGraphId: consumed capacity for Query: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 1 Duration: 67.398378ms
TypesDB: 2021/03/31 05:43:33.387852 db.loadTypeShortNames
TypesDB: 2021/03/31 05:43:33.391090 loadTypeShortNames: consumed capacity for Query: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 1 Duration: 3.195452ms
TypesDB: 2021/03/31 05:43:33.394467 LoadDataDictionary: consumed capacity for Scan: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 10 Duration: 3.282593ms
gqlDB: 2021/03/31 05:43:33.402388 GSIS:consumed capacity for Query index P_S, {
  CapacityUnits: 0.5,
  TableName: "DyGraphOD2"
}.  ItemCount 3  Duration: 6.281371ms
DB FetchNode: 2021/03/31 05:43:33.402457  node: TsI2Qay8T2SxnOcuI3pPeg== subKey: A#A
DB: 2021/03/31 05:43:33.408876 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 7  Duration: 6.384021ms
DB FetchNode: 2021/03/31 05:43:33.409059  node: 66PNdV1TSKOpDRlO71+Aow== subKey: A#A
grmgr: 2021/03/31 05:43:33.409302 EndCh received for execute. rCnt = 0
DB: 2021/03/31 05:43:33.413977 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 8  Duration: 4.858527ms
DB FetchNode: 2021/03/31 05:43:33.414086  node: 6KIuWuyTRKSgDqwYAghl7A== subKey: A#A
grmgr: 2021/03/31 05:43:33.414161 EndCh received for execute. rCnt = -1
DB: 2021/03/31 05:43:33.417852 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 7  Duration: 3.72264ms
gql: 2021/03/31 05:43:33.417945 Duration: Parse  75.978328ms  Execute: 21.894101ms
grmgr: 2021/03/31 05:43:33.417954 EndCh received for execute. rCnt = -2
monitor: 2021/03/31 05:43:35.418815 monitor: []interface {}{3, 2, 3, []int{3}, 2, []int{2}, 3, (*monitor.Fetch)
(0xc00020c2a0), interface {}(nil), interface {}(nil)} monitor.Fetch{Fetches:3, CapacityUnits:3, Items:22,
Duration:14965188}
DB: 2021/03/31 05:43:35.427508 TestLog: consumed capacity for PutItem  {
  CapacityUnits: 2,
  TableName: "TestLog"
}. Duration: 8.282496ms
```

Test 8: *AllOfTerms* function in Root Filter

Query Metrics

Metric	Value
Graph	Relationship
Nodes Queried	3
Nodes Displayed (after filtering)	1
Nodes at each depth	{ 3 }
Nodes at each depthFiltered	{ 1 }
Reduction in DB requests *	0%
Database requests	1 Root request 3 Node requests

* as a result of propagating a child node's scalar data to the parent node

Comment

Demonstrates the use of the *allofterms* in a root filter. While the root query is resolved in *Dynamodb* the filter function is implemented in GoGraph.

Test Function

```
func TestRootFilterallofterms1c(t *testing.T) {

input := `{
  me(func: eq(count(Siblings),2)) @filter( allofterms(Comment,"sodium Germany Chris") or eq(Name,"Ian Payne")) {
            Name
            }
          }`

         expectedTouchLvl = []int{1}
         expectedTouchNodes = 1

         stmt := Execute("Relationship", input)
         result := stmt.MarshalJSON()
         t.Log(stmt.String())

         validate(t, result)

}
```

$ **go test -run=TestRootFilterallofterms1c -v**

```
Duration:  Parse  96.683441ms  Execute: 24.462418ms

monitor: []interface {}{3, 1, 3, []int{3}, 1, []int{1}, 3, (*monitor.Fetch)(0xc00002c540), interface {}(nil),
interface {}(nil)}

        {
        data: [
                {
                Name : "Ian Payne",
                }
        ]
        }
```

Log Output

```
DB:2021/04/01 04:20:03 log.go:89: ================================== SetLogger
gqlES: 2021/04/01 04:20:03.427602 Client: 7.9.0
gqlES: 2021/04/01 04:20:03.427632 Server: 7.8.1
gql: 2021/04/01 04:20:03.427646 Startup...
monitor: 2021/04/01 04:20:03.427688 Powering on...
grmgr: 2021/04/01 04:20:03.427703 Powering on...
gql: 2021/04/01 04:20:03.427714 services started
TypesDB: 2021/04/01 04:20:03.428375 db.getGraphId
```

```
TypesDB: 2021/04/01 04:20:03.504709 getGraphId: consumed capacity for Query: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 1 Duration: 76.1864ms
TypesDB: 2021/04/01 04:20:03.504779 db.loadTypeShortNames
TypesDB: 2021/04/01 04:20:03.508742 loadTypeShortNames: consumed capacity for Query: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 1 Duration: 3.913565ms
TypesDB: 2021/04/01 04:20:03.514310 LoadDataDictionary: consumed capacity for Scan: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 10 Duration: 5.057964ms
gqlDB: 2021/04/01 04:20:03.530796 GSIS:consumed capacity for Query index P_S, {
  CapacityUnits: 0.5,
  TableName: "DyGraphOD2"
}.  ItemCount 3  Duration: 5.830418ms
DB FetchNode: 2021/04/01 04:20:03.530891  node: TsI2Qay8T2SxnOcuI3pPeg== subKey: A#A
DB: 2021/04/01 04:20:03.535560 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 7  Duration: 4.61992ms
DB FetchNode: 2021/04/01 04:20:03.536514  node: 66PNdV1TSKOpDRlO71+Aow== subKey: A#A
DB: 2021/04/01 04:20:03.543867 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 8  Duration: 7.227218ms
DB FetchNode: 2021/04/01 04:20:03.544370  node: 6KIuWuyTRKSgDqwYAghl7A== subKey: A#A
DB: 2021/04/01 04:20:03.549178 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 7  Duration: 4.748581ms
gql: 2021/04/01 04:20:03.549368 Duration: Parse  96.683441ms  Execute: 24.462418ms
monitor: 2021/04/01 04:20:05.549638 monitor: []interface {}{3, 1, 3, []int{3}, 1, []int{1}, 3, (*monitor.Fetch)
(0xc000292ba0), interface {}(nil), interface {}(nil)} monitor.Fetch{Fetches:3, CapacityUnits:3, Items:22,
Duration:16595719}
DB: 2021/04/01 04:20:05.561143 TestLog: consumed capacity for PutItem  {
  CapacityUnits: 2,
  TableName: "TestLog"
}. Duration: 11.347616ms
```

Test 9: Equality Expression in Root Query

Query Metrics

Metric	Value
Graph	Movies
Nodes Queried	8
Nodes at each depth	{1, 7}
Database requests	1 Root request 1 Node requests
Reduction in DB requests *	87.5%
Query Elapsed Time	12.5 ms
DB Average Request time for 1 node	5.2 ms
Average query time for 8 nodes	0.74 ms

* as a result of propagating a child node's scalar data to the parent node

Comment

The test demonstrates the use of the equality function *eq* in the root query.

It is also worthwhile mentioning the affect of data duplication (propagating child scalar data to parent) in this test. One node is returned from the root query but embedded in the response is the scalar data of the 7 child “genre” nodes, for a reduction in database query calls of 87.5%.

Test Function

```
func TestMovieEq(t *testing.T) {

input := `{
  me(func:eq(title, "Poison")) {
                               title
                               film.genre {
                                      name
                               }
  }
}`

        expectedTouchLvl = []int{1, 7}
        expectedTouchNodes = 8

        stmt := Execute("Movies", input)
        result := stmt.MarshalJSON()
        t.Log(stmt.String())

        validate(t, result)

}
```

$ **go test -run=TestMovieEq -v**

```
Duration:  Parse  85.993172ms  Execute: 17.19818ms
monitor: []interface {}{1, 1, 8, []int{1, 7}, 8, []int{1, 7}, 1, (*monitor.Fetch)(0xc0003364c0),
interface {}(nil), interface {}(nil)}

        {
       data: [
               {
               title : "Poison",
               film.genre : [
                       {
                       name: "Satire",
                       },
                       {
                       name: "LGBT",
                       },
```

```
                        {
                        name: "Indie film",
                        },
                        {
                        name: "Science Fiction",
                        },
                        {
                        name: "Drama",
                        },
                        {
                        name: "Experimental film",
                        },
                        {
                        name: "Horror",
                        }
                ]
                }
        ]
        }
```

Log Output

```
DB:2021/04/01 04:31:04 log.go:89: ==================================== SetLogger
gqlES: 2021/04/01 04:31:04.434237 Client: 7.9.0
gqlES: 2021/04/01 04:31:04.434267 Server: 7.8.1
gql: 2021/04/01 04:31:04.434281 Startup...
monitor: 2021/04/01 04:31:04.434330 Powering on...
grmgr: 2021/04/01 04:31:04.434344 Powering on...
gql: 2021/04/01 04:31:04.434354 services started
TypesDB: 2021/04/01 04:31:04.434971 db.getGraphId
TypesDB: 2021/04/01 04:31:04.504133 getGraphId: consumed capacity for Query: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 1 Duration: 69.074044ms
TypesDB: 2021/04/01 04:31:04.504277 db.loadTypeShortNames
TypesDB: 2021/04/01 04:31:04.508164 loadTypeShortNames: consumed capacity for Query: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 5 Duration: 3.832432ms
TypesDB: 2021/04/01 04:31:04.512256 LoadDataDictionary: consumed capacity for Scan: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 16 Duration: 3.508138ms
gqlDB: 2021/04/01 04:31:04.521130 GSIS:consumed capacity for Query index P_S, {
  CapacityUnits: 0.5,
  TableName: "DyGraphOD2"
}.  ItemCount 1  Duration: 6.969338ms
DB FetchNode: 2021/04/01 04:31:04.521205  node: sHoW3PRSQUuYvKC+FwcAHg== subKey: A#
DB: 2021/04/01 04:31:04.526427 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 15  Duration: 5.165045ms
gql: 2021/04/01 04:31:04.526621 Duration: Parse  79.214802ms  Execute: 12.498567ms
monitor:  2021/04/01  04:31:06.527012  monitor:  []interface  {}{1,  1,  8,  []int{1,  7},  8,  []int{1,  7},  1,
(*monitor.Fetch)(0xc0004e73e0),  interface  {}(nil),  interface  {}(nil)}  monitor.Fetch{Fetches:1,  CapacityUnits:1,
Items:15,  Duration:5165045}
DB: 2021/04/01 04:31:06.535189 TestLog: consumed capacity for PutItem  {
  CapacityUnits: 2,
  TableName: "TestLog"
}. Duration: 7.902135ms
```

Test 10: AnyOfTerms Function used in Edge Predicate Filter

Query Metrics

Metric	Value
Graph	Movies
Nodes Queried	31 (27 filtered out)
Nodes at each depth	{1, 30}
DB Requests	1 Root request 1 Node requests
Reduction in DB requests *	96.7%
Query Elapsed Time	15.9 ms
DB Request time for 1 node	8 ms
Average Node query time for 31 nodes	0.26 ms

* as a result of propagating a child node's scalar data to the parent node

Comment

Function *AnyOfTerms* is implemented in GoGraph not *Dynamodb*. In this example, all film titles are checked for the words “War” or “Minority”.

The test is also another example of the power of duplicating child scale data in its parent node. In this example 1 node is fetched from the database but embedded in the response is the scalar data of 30 child nodes, reducing database calls query calls by 96.7%.

Test Function

```
Query: show all films by Steven Spielberg with “War” or “Minority” in the title

func TestMovie1b(t *testing.T) {

        input := `{
  me(func: eq(name, "Steven Spielberg")) @filter(has(director.film)) {
    name
    director.film @filter(anyofterms(title,"War Minority") {
      title
    }
  }
}`

        expectedTouchLvl = []int{1, 3}
        expectedTouchNodes = 4

        stmt := Execute("Movies", input)
        result := stmt.MarshalJSON()
        t.Log(stmt.String())

        validate(t, result)

}
```

$ go test -run=TestMovie1b -v

```
Duration:  Parse  90.957263ms  Execute: 15.889374ms

monitor: []interface {}{1, 1, 31, []int{1, 30}, 4, []int{1, 3}, 1, (*monitor.Fetch)(0xc000205d40), interface {}(nil), interface {}
(nil)}

       {
       data: [
               {
               name : "Steven Spielberg",
               director.film : [
                       {
                       title: "War of the Worlds",
```

```
                    },
                    {
                    title: "Minority Report",
                    },
                    {
                    title: "War Horse",
                    },
                ]
                }
        ]
        }
```

Log Output

```
DB:2021/04/01 04:49:42 log.go:89: ================================== SetLogger
gqlES: 2021/04/01 04:49:42.748304 Client: 7.9.0
gqlES: 2021/04/01 04:49:42.748337 Server: 7.8.1
gql: 2021/04/01 04:49:42.748356 Startup...
grmgr: 2021/04/01 04:49:42.748400 Powering on...
monitor: 2021/04/01 04:49:42.748412 Powering on...
gql: 2021/04/01 04:49:42.748427 services started
TypesDB: 2021/04/01 04:49:42.749136 db.getGraphId
TypesDB: 2021/04/01 04:49:42.819382 getGraphId: consumed capacity for Query: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 1 Duration: 70.151441ms
TypesDB: 2021/04/01 04:49:42.819441 db.loadTypeShortNames
TypesDB: 2021/04/01 04:49:42.824586 loadTypeShortNames: consumed capacity for Query: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 5 Duration: 5.097431ms
TypesDB: 2021/04/01 04:49:42.829502 LoadDataDictionary: consumed capacity for Scan: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 16 Duration: 4.754526ms
gqlDB: 2021/04/01 04:49:42.847841 GSIS:consumed capacity for Query index P_S, {  <= index read for root query
  CapacityUnits: 0.5,                                                    <= <4KB read (eventual consistency)
  TableName: "DyGraphOD2"
}.  ItemCount 1  Duration: 7.73318ms                                          <= 1 item fetched
DB FetchNode: 2021/04/01 04:49:42.847917  node: Yw9EZVUiS6K4yCd+41frbQ== subKey: A#
DB: 2021/04/01 04:49:42.855442 FetchNode:consumed capacity for Query  {       <= node query
  CapacityUnits: 1,                                                      <= <8KB read (eventual consistency)
  TableName: "DyGraphOD2"
}. ItemCount 13  Duration: 7.481137ms                                         <= 13 items fetched
gql: 2021/04/01 04:49:42.856061 Duration: Parse  90.957263ms  Execute: 15.889374ms
monitor:  2021/04/01  04:49:44.856554  monitor:  []interface  {}{1,  1,  31,  []int{1,  30},  4,  []int{1,  3},  1,
(*monitor.Fetch)(0xc000205d40),  interface  {}(nil),  interface  {}(nil)}  monitor.Fetch{Fetches:1,  CapacityUnits:1,
Items:13, Duration:7481137}
DB: 2021/04/01 04:49:44.867515 TestLog: consumed capacity for PutItem  {
  CapacityUnits: 2,
  TableName: "TestLog"
}. Duration: 10.792321ms
```

Test 11: Propagating Child Scalar Data to Parent

Query Metrics

Metric	Value
Graph	Movies
Nodes Queried	90
Nodes at each depth	{ 6, 84 }
Reduction in DB requests *	93%
Database requests	1 Root request 6 Node requests
Query Elapsed Time	64.6 ms
Average Node request time for 6 nodes	7.9 ms
Average Node request time for 90 nodes	0.55 ms

* as a result of propagating a child node's scalar data to the parent node

Comment

This test demonstrates the power of duplicating data (propagating scalar data from child node to parent node). Retrieve 6 nodes from *Dynamodb* and 84 child nodes will be included in the result because of data duplication in the parent nodes. So, query 6 and get 90 nodes back which represents a 93% reduction in database requests.

Test Function

```
Query: show the directors name and genre names of any Movie  with 13 genre associated with it.

func TestMovie1e(t *testing.T) {

        input := `{
  me(func: eq(count(film.genre), 13)) {
    title
    film.director {
        name
    }
    film.genre {
        name
    }
  }
}`

        expectedTouchLvl = []int{6, 84}
        expectedTouchNodes = 90

        stmt := Execute("Movies", input)
        t.Log(stmt.String())
        result := stmt.MarshalJSON()
        t.Log(stmt.String())

        validate(t, result)

}
```

$ go test -run=TestMovie1e -v

```
Duration:  Parse  80.3016ms  Execute: 64.568085ms

monitor: []interface {}{6, 6, 90, []int{6, 84}, 90, []int{6, 84}, 6, (*monitor.Fetch)(0xc00025a000), interface {}(nil), interface {}
(nil)}

        {
        data: [
                {
                title : "South Park: Bigger, Longer & Uncut",
                film.director : [
                        {
                        name: "Trey Parker",
```

```
        }
film.genre : [
        {
        name: "War film",
        },
        {
        name: "Black comedy",
        },
        {
        name: "Musical comedy",
        },
        {
        name: "Animation",
        },
        {
        name: "Animated Musical",
        },
        {
        name: "Parody",
        },
        {
        name: "Gross out",
        },
        {
        name: "Satire",
        },
        {
        name: "Absurdism",
        },
        {
        name: "Comedy",
        },
        {
        name: "Political cinema",
        },
        {
        name: "Political satire",
        },
        {
        name: "Backstage Musical",
        }
]
},
{
title : "Stay Tuned",
film.director : [
        {
        name: "Chuck Jones",
        }
film.genre : [
        {
        name: "Black comedy",
        },
        {
        name: "Parody",
        },
        {
        name: "Musical comedy",
        },
        {
        name: "Satire",
        },
        {
        name: "Horror comedy",
        },
        {
        name: "Fantasy",
        },
        {
        name: "Family",
        },
        {
        name: "Adventure Film",
        },
        {
        name: "Science Fiction",
        },
        {
        name: "Horror",
        },
        {
        name: "Thriller",
        },
        {
        name: "Comedy",
        },
        {
        name: "Backstage Musical",
        }
]
},
{
title : "Even Cowgirls Get the Blues",
film.director : [
        {
        name: "Gus Van Sant",
        }
film.genre : [
        {
        name: "Feminist Film",
        },
        {
        name: "Romantic comedy",
        },
```

```
                    {
                    name: "Comedy Western",
                    },
                    {
                    name: "Absurdism",
                    },
                    {
                    name: "Comedy-drama",
                    },
                    {
                    name: "Fantasy",
                    },
                   . . . .
```

Log Output

```
DB:2021/04/01 05:22:33 log.go:89: ==================================== SetLogger
gqlES: 2021/04/01 05:22:33.463289 Client: 7.9.0
gqlES: 2021/04/01 05:22:33.463310 Server: 7.8.1
gql: 2021/04/01 05:22:33.463320 Startup...
monitor: 2021/04/01 05:22:33.463359 Powering on...
monitor: 2021/04/01 05:22:33.463362 Powering on...
gql: 2021/04/01 05:22:33.463389 services started
TypesDB: 2021/04/01 05:22:33.463571 db.getGraphId
TypesDB: 2021/04/01 05:22:33.532893 getGraphId: consumed capacity for Query: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 1 Duration: 69.197451ms
TypesDB: 2021/04/01 05:22:33.532958 db.loadTypeShortNames
TypesDB: 2021/04/01 05:22:33.536267 loadTypeShortNames: consumed capacity for Query: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 5 Duration: 3.272282ms
TypesDB: 2021/04/01 05:22:33.542444 LoadDataDictionary: consumed capacity for Scan: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 16 Duration: 6.056022ms
gqlDB: 2021/04/01 05:22:33.558967 GSIS:consumed capacity for Query index P_S, {
  CapacityUnits: 0.5,
  TableName: "DyGraphOD2"
}.  ItemCount 6  Duration: 15.073845ms
DB FetchNode: 2021/04/01 05:22:33.559058  node: S40/DoLkRWuqjvPnrlFNWw== subKey: A#
DB: 2021/04/01 05:22:33.565499 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 15  Duration: 6.394954ms
DB FetchNode: 2021/04/01 05:22:33.565718  node: u5vWespTQSigEJqIBwBUFA== subKey: A#
DB: 2021/04/01 05:22:33.575954 FetchNode:consumed capacity for Query  {
  CapacityUnits: 3,
  TableName: "DyGraphOD2"
}. ItemCount 15  Duration: 10.197994ms
DB FetchNode: 2021/04/01 05:22:33.576371  node: 98wbbFQmTcqXUzxOwvOVzg== subKey: A#
DB: 2021/04/01 05:22:33.588027 FetchNode:consumed capacity for Query  {
  CapacityUnits: 3,
  TableName: "DyGraphOD2"
}. ItemCount 15  Duration: 11.60112ms
DB FetchNode: 2021/04/01 05:22:33.588310  node: djTkRRQUS5Gfuz0vdSLXFQ== subKey: A#
DB: 2021/04/01 05:22:33.593769 FetchNode:consumed capacity for Query  {
  CapacityUnits: 2,
  TableName: "DyGraphOD2"
}. ItemCount 15  Duration: 5.415528ms
DB FetchNode: 2021/04/01 05:22:33.594029  node: MB70yljLTjOsh+tfQIxoNQ== subKey: A#
DB: 2021/04/01 05:22:33.598939 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 15  Duration: 4.868996ms
DB FetchNode: 2021/04/01 05:22:33.599091  node: axtdNL3WT3mshCK8EUAxzg== subKey: A#
DB: 2021/04/01 05:22:33.608154 FetchNode:consumed capacity for Query  {
  CapacityUnits: 2,
  TableName: "DyGraphOD2"
}. ItemCount 15  Duration: 9.028703ms
gql: 2021/04/01 05:22:33.608421 Duration: Parse  80.3016ms  Execute: 64.568085ms
monitor:  2021/04/01  05:22:35.611330  monitor:  []interface  {}{6,  6,  90,  []int{6,  84},  90,  []int{6,  84},  6,
(*monitor.Fetch)(0xc00025a000),  interface  {}(nil),  interface  {}(nil)}  monitor.Fetch{Fetches:6,  CapacityUnits:12,
Items:90,  Duration:47507295}
DB: 2021/04/01 05:22:35.619636 TestLog: consumed capacity for PutItem  {
  CapacityUnits: 5,
  TableName: "TestLog"
}. Duration: 8.156251ms
```

Test 12: Propagate scalar data to grandparent for 1:1 relationship

Query Metrics

Metric	Value
Graph	Movies
Nodes Touched	1166
Nodes at each depth	{ 1, 15, 15, 391, 744 }
Database requests	1 Root request 14 Node requests
Reduction in DB requests *	99.1%
Query Elapsed Time	122 ms
Average DB Request time	6.6 ms
Average Node Request time	0.10 ms
Read Capacity Units	23

* as a result of propagating scalar data from child to grandparent node
**

Comment

Examine the GraphQL query below and you will see the resulting graph output will have a depth of 5. The three paths in the output graph are shown below:

Depth 4: person->performance->film->director(name)
Depth 5: person->performance->film->performance->person(name)
Depth 5: person->performance->film->performance->character(name)

The following edges, *performance->film*, *performance->actor* and *performance->character* all have a 1:1 relationship (see type definition for Movie). For a 1:1 relationship GoGraph can propagate the child scale data all the way up to the grandparent node which in this case would be *film.* This means the execution algorithm does not need to follow the path from *film* nodes to its leaf nodes as all the intervening data has been duplicated in the *film* node. This will naturally benefit the response time as 391+744+14 nodes have had their scalar data duplicated into 14 film nodes and do not need to be queried. The result is that all 1166 nodes can be queried in around 122ms because 99.1% of nodes do not need to be queried from the database.

To help quantify the advantage of propagating to the grandparent in the case of 1:1 relationships, the next example performs the same query but has disabled child to grandparent propagation for 1:1 and instead implements the normal child to parent node propagation. In this case the query response took 1.61s which is over **13 times slower**. The other significant factor is a huge reduction in consumed *Dynamodb* read-capacity-units, 23 compared to 359 (see monitor output at end of log output in bold red), that is a **93.6% reduction in AWS costs**, when child-grandparent propagation is enabled for 1:1 relationships.

Test Function

```
Query: Find all the films Peter Sellers performed in along with the director's name and list all the actors and
their character they played in each film

func TestMoviePS3a(t *testing.T) {

        input := `{
  me(func: eq(name,"Peter Sellers") ) {
    name
    actor.performance {
        performance.film  {
                title
                film.director {
                        name
```

```
                }
                film.performance {
                        performance.actor {
                                name
                        }
                        performance.character {
                                name
                        }
                }
        }
   }
 }
}`

        expectedTouchLvl = []int{1, 15, 15, 391, 744}
        expectedTouchNodes = 1166

        stmt := Execute("Movies", input)
        result := stmt.MarshalJSON()
        t.Log(stmt.String())

        validate(t, result)

}
```

$ **go test -run=TestMoviePS3a -v**

```
       {
        data: [
                {
                name : "Peter Sellers",
                actor.performance : [
                        {
                        performance.film : [
                                {
                                title: "Where Does It Hurt?",
                                film.director : [
                                        {
                                        name: "Rod Amateau",
                                        },
                                ],
                                film.performance : [
                                        {
                                        performance.actor : [
                                                {
                                                name: "Harold Gould",
                                                },
                                        ],
                                        performance.character : [
                                                {
                                                name: "Dr. Zerny",
                                                },
                                        ]
                                        },
                                        {
                                        performance.actor : [
                                                {
                                                name: "Rick Lenz",
                                                },
                                        ],
                                        performance.character : [
                                                {
                                                name: "Lester Hammond",
                                                },
                                        ]
                                        },
                                        {
                                        performance.actor : [
                                                {
                                                name: "Keith Allison",
                                                },
                                        ],
                                        performance.character : [
                                                {
                                                name: "Hinkley",
                                                },
                                        ]
                                        },
                                        {
                                        performance.actor : [
                                                {
                                                name: "Hope Summers",
                                                },
                                        ],
                                        performance.character : [
                                                {
                                                name: "Nurse Throttle",
                                                },
                                        ]
                                        },
                                        {
                                        performance.actor : [
                                                {
                                                name: "Jo Ann Pflug",
                                                },
                                        ],
                                        performance.character : [
                                                {
                                                name: "Alice Gilligan",
                                                },
```

```
                        ]
                        },
                        {
                        performance.actor : [
                                {
                                name: "Paul Lambert",
                                },
                        ],
                        performance.character : [
                                {
                                name: "Dr. Pinikhes",
                                },
                        ]
                        },
                        {
                        performance.actor : [
                                {
                                name: "Peter Sellers",
                                },
                        ],
                        performance.character : [
                                {
                                name: "Dr. Albert T. Hopfnagel",
                                },
                        ]
                        },
                        {
                        performance.actor : [
                                {
                                name: "Pat Morita",
                                },
                        ],
                        performance.character : [
                                {
                                name: "Nishimoto",
                                },
                        ]
                        },
                        {
                        performance.actor : [
                                {
                                name: "Eve Bruce",
                                },
                        ],
                        performance.character : [
                                {
                                name: "Lamarr",
                                },
                        ]
                        },
                        {
                        performance.actor : [
                                {
                                name: "Norman Alden",
                                },
                        ],
                        performance.character : [
                                {
                                name: "Katzen",
                                },
                        ]
                        },
                ]
                },
        ]
        },
        {
        performance.film : [
                {
                title: "Revenge of the Pink Panther",
                film.director : [
                        {
                        name: "Blake Edwards",
                        },
                ],
                film.performance : [
                        {
                        performance.actor : [
                                {
                                name: "Keen Jing",
                                },
                        ],
                        performance.character : [
                                {
                                name: "Assistant Manager",
                                },
                        ]
                        },
                        {
                        performance.actor : [
                                {
                                name: "Tony Beckley",
                                },
                        ],
                        performance.character : [
                                {
                                name: "Guy Algo",
                                },
                        ]
                        },
          . . . . . .
        ]
        },
        {
```

```
performance.film : [
        {
        title: "Never Let Go",
        film.director : [
                {
                name: "John Guillermin",
                },
        ],
        film.performance : [
                {
                performance.actor : [
                        {
                        name: "Noel Willman",
                        },
                ],
                performance.character : [
                        {
                        name: "Inspector Thomas",
                        },
                ]
                },
                {
                performance.actor : [
                        {
                        name: "John Bailey",
                        },
                ],
                performance.character : [
                        {
                        name: "Mckinnon",
                        },
                ]
                },
                {
                performance.actor : [
                        {
                        name: "Mignon O'Doherty",
                        },
                ],
                performance.character : [
                        {
                        name: "Manageress",
                        },
                ]
                },
                {
                performance.actor : [
                        {
                        name: "Charles Houston",
                        },
                ],
                performance.character : [
                        {
                        name: "Cyril Spink",
                        },
                ]
                },
                {
                performance.actor : [
                        {
                        name: "Mervyn Johns",
                        },
                ],
                performance.character : [
                        {
                        name: "Alfie Barnes",
                        },
                ]
                },
                {
                performance.actor : [
                        {
                        name: "Adam Faith",
                        },
                ],
                performance.character : [
                        {
                        name: "Tommy Towers",
                        },
                ]
                },
                {
                performance.actor : [
                        {
                        name: "Nigel Stock",
                        },
                ],
                performance.character : [
                        {
                        name: "Regan",
                        },
                ]
                },
                {
                performance.actor : [
                        {
                        name: "Elizabeth Sellars",
                        },
                ],
                performance.character : [
                        {
                        name: "Anne Cummings",
                        },
                ]
```

```
                                        },
                                        {
                                        performance.actor : [
                                                {
                                                name: "John Le Mesurier",
                                                },
                                        ],
                                        performance.character : [
                                                {
                                                name: "Pennington",
                                                },
                                        ]
                                        },
                                        {
                                        performance.actor : [
                                                {
                                                name: "Peter Jones",
                                                },
                                        ],
                                        performance.character : [
                                                {
                                                name: "Alec Berger",
                                                },
                                        ]
                                        },
                                        {
                                        performance.actor : [
                                                {
                                                name: "Cyril Shaps",
                                                },
                                        ],
                                        performance.character : [
                                                {
                                                name: "Cypriot",
                                                },
                                        ]
                                        },
                                        {
                                        performance.actor : [
                                                {
                                                name: "David Lodge",
                                                },
                                        ],
                                        performance.character : [
                                                {
                                                name: "Cliff",
                                                },
                                        ]
                                        },
                                        {
                                        performance.actor : [
                                                {
                                                name: "Richard Todd",
                                                },
                                        ],
                                        performance.character : [
                                                {
                                                name: "John Cummings",
                                                },
                                        ]
                                        },
                                        {
                                        performance.actor : [
                                                {
                                                name: "Peter Sellers",
                                                },
                                        ],
                                        performance.character : [
                                                {
                                                name: "Lionel Meadows",
                                                },
                                        ]
                                        },
                                        {
                                        performance.actor : [
                                                {
                                                name: "Carol White",
                                                },
                                        ],
                                        performance.character : [
                                                {
                                                name: "Jackie",
                                                },
                                        ]
                                        },
                                        {
                                        performance.actor : [
                                                {
                                                name: "John Dunbar",
                                                },
                                        ],
                                        performance.character : [
                                                {
                                                name: "Station Sergeant",
                                                },
                                        ]
                                        },
                                ]
                                },
                        ]
                        }
                ]
                }
        ]
```

```
    }
```

Log Output

```
DB:2021/04/01 22:00:47 log.go:89: ================================== SetLogger
gqlES: 2021/04/01 22:00:47.490432 Client: 7.9.0
gqlES: 2021/04/01 22:00:47.490461 Server: 7.8.1
gql: 2021/04/01 22:00:47.490475 Startup...
grmgr: 2021/04/01 22:00:47.490578 Powering on...
monitor: 2021/04/01 22:00:47.490593 Powering on...
gql: 2021/04/01 22:00:47.490606 services started
TypesDB: 2021/04/01 22:00:47.491164 db.getGraphId
TypesDB: 2021/04/01 22:00:47.562158 getGraphId: consumed capacity for Query: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 1 Duration: 70.870534ms
TypesDB: 2021/04/01 22:00:47.562230 db.loadTypeShortNames
TypesDB: 2021/04/01 22:00:47.565497 loadTypeShortNames: consumed capacity for Query: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 5 Duration: 3.229603ms
TypesDB: 2021/04/01 22:00:47.569504 LoadDataDictionary: consumed capacity for Scan: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 16 Duration: 3.877985ms
gqlDB: 2021/04/01 22:00:47.587483 GSIS:consumed capacity for Query index P_S, {
  CapacityUnits: 0.5,
  TableName: "DyGraphOD2"
}.  ItemCount 1  Duration: 7.043006ms
DB FetchNode: 2021/04/01 22:00:47.587556  node: eneJBCenT1qrdnv4X//RLw== subKey: A#
DB: 2021/04/01 22:00:47.595070 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 11  Duration: 6.982168ms
DB FetchNode: 2021/04/01 22:00:47.595294  node: FZBl1d6RSuGcDFlf4khLZQ== subKey: A#G#
DB: 2021/04/01 22:00:47.602002 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 12  Duration: 6.357901ms
DB FetchNode: 2021/04/01 22:00:47.602358  node: k/4DFiGiQl21KIN++n5ApQ== subKey: A#G#
DB: 2021/04/01 22:00:47.612529 FetchNode:consumed capacity for Query  {
  CapacityUnits: 4,
  TableName: "DyGraphOD2"
}. ItemCount 12  Duration: 10.119915ms
DB FetchNode: 2021/04/01 22:00:47.616133  node: ymanEWWqSFSml9xvZK9tsA== subKey: A#G#
DB: 2021/04/01 22:00:47.623994 FetchNode:consumed capacity for Query  {
  CapacityUnits: 2,                                                          <= less than 8KB read
  TableName: "DyGraphOD2"
}. ItemCount 12  Duration: 7.79995ms
DB FetchNode: 2021/04/01 22:00:47.624582  node: 4+rG5lQbQKuoSF0sMLeQhQ== subKey: A#G#
DB: 2021/04/01 22:00:47.630979 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,                                                          <= less than 4KB read
  TableName: "DyGraphOD2"
}. ItemCount 12  Duration: 6.353675ms                                       <= 12 items read in 6.35 ms
DB FetchNode: 2021/04/01 22:00:47.631389  node: Nid9drj0Q/eCEHzR3aT1Yg== subKey: A#G#
DB: 2021/04/01 22:00:47.638431 FetchNode:consumed capacity for Query  {
  CapacityUnits: 2,
  TableName: "DyGraphOD2"
}. ItemCount 12  Duration: 6.993284ms
DB FetchNode: 2021/04/01 22:00:47.643496  node: 52APy4uhSpCp8DhmNt8jaA== subKey: A#G#
DB: 2021/04/01 22:00:47.652697 FetchNode:consumed capacity for Query  {
  CapacityUnits: 2,
  TableName: "DyGraphOD2"
}. ItemCount 12  Duration: 9.147216ms
DB FetchNode: 2021/04/01 22:00:47.656289  node: yDbaVHDsSgmDjvUaBGasCA== subKey: A#G#
DB: 2021/04/01 22:00:47.663093 FetchNode:consumed capacity for Query  {
  CapacityUnits: 2,
  TableName: "DyGraphOD2"
}. ItemCount 12  Duration: 6.721617ms
DB FetchNode: 2021/04/01 22:00:47.665111  node: ERxPeI++RNO1JXUksF0flQ== subKey: A#G#
DB: 2021/04/01 22:00:47.669605 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 12  Duration: 4.441593ms
DB FetchNode: 2021/04/01 22:00:47.670316  node: VUgeuT2YQbataNKytyUzww== subKey: A#G#
DB: 2021/04/01 22:00:47.677663 FetchNode:consumed capacity for Query  {
  CapacityUnits: 2,
  TableName: "DyGraphOD2"
}. ItemCount 12  Duration: 7.291921ms
DB FetchNode: 2021/04/01 22:00:47.678734  node: eZTcsNshQ7+/mBTKi7RH/w== subKey: A#G#
DB: 2021/04/01 22:00:47.685135 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 12  Duration: 6.353274ms
DB FetchNode: 2021/04/01 22:00:47.685742  node: uzlXBfnlSuWrhpE/ynkC5Q== subKey: A#G#
DB: 2021/04/01 22:00:47.691773 FetchNode:consumed capacity for Query  {
  CapacityUnits: 2,
  TableName: "DyGraphOD2"
```

```
}. ItemCount 12  Duration: 5.981037ms
DB FetchNode: 2021/04/01 22:00:47.692367  node: ocpPHhtCTZ2AMy/XBPe1tw== subKey: A#G#
DB: 2021/04/01 22:00:47.696371 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 12  Duration: 3.961547ms
DB FetchNode: 2021/04/01 22:00:47.696814  node: CS65MuW+RgqcOnqKWbWLfw== subKey: A#G#
DB: 2021/04/01 22:00:47.701538 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD2"
}. ItemCount 12  Duration: 4.686253ms
gql: 2021/04/01 22:00:47.702873 Duration: Parse  89.276114ms  Execute: 122.473852ms
monitor: 2021/04/01 22:00:50.372524 monitor: []interface {}{1, 1, 1166, []int{1, 15, 15, 391, 744}, 1166, []int{1,
15,  15,  391,  744},  14,  (*monitor.Fetch)(0xc0004cc400),  interface  {}(nil),  interface  {}(nil)}
monitor.Fetch{Fetches:14, CapacityUnits:23, Items:167, Duration:93191351}
DB: 2021/04/01 22:00:50.403159 TestLog: consumed capacity for PutItem  {
  CapacityUnits: 102,
  TableName: "TestLog"
}. Duration: 30.456313m
```

Test 13: Disabled child-to-grandparent propagation for 1:1 relationship.

Query Metrics

Metric	Value
Graph	Movies
Nodes Queried	1166
Nodes at each depth	{ 1, 15, 15, 391, 744 }
Database requests	1 Root request 359 Node requests
Reduction in DB requests *	65%
Query Elapsed Time	1.61 s
Average DB Request time	4.48 ms
Average Node Request time	1.38 ms
Read Capacity Units	359

* as a result of propagating scalar data from child to parent node

Comment

This example is used to quantity the performance advantage of child to grandparent propagation for 1:1 edge relationships when it is disabled and normal child to parent propagation is in effect. The previous test showed that when enabled the query response was 122ms compared with 1.61s in this test. Please review the previous test results on page 54.

Test Function

```
Query: Find all the films Peter Sellers performed in along with the director’s name and list all the actors and
the character they played in each film

func TestMoviePS3a(t *testing.T) {

        input := `{
  me(func: eq(name,"Peter Sellers") ) {
    name
    actor.performance {
         performance.film  {
                 title
                 film.director {
                         name
                 }
                 film.performance {
                         performance.actor {
                                 name
                         }
                         performance.character {
                                 name
                         }
                 }
         }
   }
 }
}`

        expectedTouchLvl = []int{1, 15, 15, 391, 744}
        expectedTouchNodes = 1166

        stmt := Execute("Movies", input)
        result := stmt.MarshalJSON()
        t.Log(stmt.String())

        validate(t, result)

}
```

$ go test -run=TestMoviePS3a -v

```
gql: 2021/04/05 22:31:47.368051 Duration: Parse  83.421952ms  Execute: 1.610042469s
```

See JSON output in previous test

Log Output

```
DB:2021/04/05 22:31:45 log.go:89: ================================== SetLogger
gqlES: 2021/04/05 22:31:45.673948 Client: 7.9.0
gqlES: 2021/04/05 22:31:45.673977 Server: 7.8.1
gql: 2021/04/05 22:31:45.673991 Startup...
monitor: 2021/04/05 22:31:45.674035 Powering on...
grmgr: 2021/04/05 22:31:45.674049 Powering on...
gql: 2021/04/05 22:31:45.674060 services started
TypesDB: 2021/04/05 22:31:45.674650 db.getGraphId
TypesDB: 2021/04/05 22:31:45.743634 getGraphId: consumed capacity for Query: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 1 Duration: 68.891098ms
TypesDB: 2021/04/05 22:31:45.743693 db.loadTypeShortNames
TypesDB: 2021/04/05 22:31:45.747590 loadTypeShortNames: consumed capacity for Query: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 5 Duration: 3.836628ms
TypesDB: 2021/04/05 22:31:45.752694 LoadDataDictionary: consumed capacity for Scan: {
  CapacityUnits: 0.5,
  TableName: "GoGraphSS"
},  Item Count: 15 Duration: 4.603517ms
gqlDB: 2021/04/05 22:31:45.766675 GSIS:consumed capacity for Query index P_S, {
  CapacityUnits: 0.5,
  TableName: "DyGraphOD"
}.  ItemCount 1  Duration: 8.619904ms
DB FetchNode: 2021/04/05 22:31:45.766771  node: eneJBCenT1qrdnv4X//RLw== subKey: A#
DB: 2021/04/05 22:31:45.772582 FetchNode:consumed capacity for Query  {  <= Node Query
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 4  Duration: 5.761901ms                                  <= 4 items fetched in 5.76 ms
DB FetchNode: 2021/04/05 22:31:45.772930  node: BnzFhcj1THeM1+qX3qUlrw== subKey: A#G# <= Propagated data only
DB: 2021/04/05 22:31:45.779757 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 6.777053ms                                  <= 7 propagated items fetched in 6.77 ms
DB FetchNode: 2021/04/05 22:31:45.779891  node: FZBl1d6RSuGcDFlf4khLZQ== subKey: A#G#
DB: 2021/04/05 22:31:45.785687 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 5  Duration: 5.749351ms
DB FetchNode: 2021/04/05 22:31:45.785795  node: imUjsX0TQza3kZAEnqn88g== subKey: A#G#
DB: 2021/04/05 22:31:45.792246 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 6.411359ms
DB FetchNode: 2021/04/05 22:31:45.792382  node: BhP8DIdtQROQp8euYg7eMw== subKey: A#G#
DB: 2021/04/05 22:31:45.796782 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 4.351894ms
DB FetchNode: 2021/04/05 22:31:45.796910  node: 76k8rK8WR2qiKxaKaXARrg== subKey: A#G#
DB: 2021/04/05 22:31:45.801587 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 4.60524ms
DB FetchNode: 2021/04/05 22:31:45.801772  node: Pdnun4yURwabuYON0emKCw== subKey: A#G#
DB: 2021/04/05 22:31:45.806297 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 4.45094ms
DB FetchNode: 2021/04/05 22:31:45.806520  node: 9VF0b6nIRsab6lRmgz5DEA== subKey: A#G#
DB: 2021/04/05 22:31:45.811010 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 4.438765ms
DB FetchNode: 2021/04/05 22:31:45.811269  node: fQ04rnM9TjmLVu+KUUrrow== subKey: A#G#
DB: 2021/04/05 22:31:45.815853 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 4.531328ms
DB FetchNode: 2021/04/05 22:31:45.815994  node: BnzFhcj1THeM1+qX3qUlrw== subKey: A#G#
DB: 2021/04/05 22:31:45.819420 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 3.380928ms
DB FetchNode: 2021/04/05 22:31:45.819565  node: dEXNfXIqQqCYjGAtbjYF/Q== subKey: A#G#
DB: 2021/04/05 22:31:45.824946 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
```

```
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 5.332675ms
DB FetchNode: 2021/04/05 22:31:45.825196  node: DPVhzClFReGftE5z/mY6Sw== subKey: A#G#
DB: 2021/04/05 22:31:45.831113 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 5.861799ms
DB FetchNode: 2021/04/05 22:31:45.831419  node: owlXqxNITf6PeDwNkmAi2A== subKey: A#G#
DB: 2021/04/05 22:31:45.837304 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 5.811945ms
DB FetchNode: 2021/04/05 22:31:45.837519  node: YWOEQhLoRlKWWTHARtqejQ== subKey: A#G#
DB: 2021/04/05 22:31:45.842090 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 4.49117ms
DB FetchNode: 2021/04/05 22:31:45.842227  node: k/4DFiGiQl21KIN++n5ApQ== subKey: A#G#
DB: 2021/04/05 22:31:45.847458 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 5  Duration: 5.175955ms
DB FetchNode: 2021/04/05 22:31:45.847655  node: q4ud/3POQBivuGKeVuvEXA== subKey: A#G#
DB: 2021/04/05 22:31:45.851123 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 3.420601ms
DB FetchNode: 2021/04/05 22:31:45.851248  node: LTGTzyBBSKin2KUPCGTRPQ== subKey: A#G#
DB: 2021/04/05 22:31:45.855850 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 4.558105ms
DB FetchNode: 2021/04/05 22:31:45.855984  node: e83avEkoQFiZo1fWVKUqTA== subKey: A#G#
DB: 2021/04/05 22:31:45.860046 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 4.011843ms
DB FetchNode: 2021/04/05 22:31:45.860489  node: AjOBJ9xlRRyDrBzRyMy+Xg== subKey: A#G#
DB: 2021/04/05 22:31:45.864930 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 4.394858ms
DB FetchNode: 2021/04/05 22:31:45.865036  node: 66sNzWLqQaCJkwO29mlqRQ== subKey: A#G#
DB: 2021/04/05 22:31:45.870679 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 5.600753ms
DB FetchNode: 2021/04/05 22:31:45.870784  node: BXFnHue0T/6UVY3DeBDMHA== subKey: A#G#
DB: 2021/04/05 22:31:45.874238 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 3.407276ms
DB FetchNode: 2021/04/05 22:31:45.874483  node: 0OiknU6VQfqAxqkUz+Y3vw== subKey: A#G#
DB: 2021/04/05 22:31:45.877697 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 3.162906ms
DB FetchNode: 2021/04/05 22:31:45.877824  node: Ul+IxXnHTsavwUKRH9PEvg== subKey: A#G#
DB: 2021/04/05 22:31:45.882406 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 4.536243ms
DB FetchNode: 2021/04/05 22:31:45.882539  node: nkDNMPYGSBSnRgsX0b2djA== subKey: A#G#
DB: 2021/04/05 22:31:45.886219 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 3.63708ms
DB FetchNode: 2021/04/05 22:31:45.886330  node: Bd9CVfTeR2+eSPTI/iaRmw== subKey: A#G#
DB: 2021/04/05 22:31:45.890296 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 3.919437ms
DB FetchNode: 2021/04/05 22:31:45.890421  node: APdVuKvIQAS/2KaXoMjhOA== subKey: A#G#
DB: 2021/04/05 22:31:45.893793 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 3.329915ms
DB FetchNode: 2021/04/05 22:31:45.893917  node: OB/DBDt3SlKhjlowjFxQQA== subKey: A#G#
DB: 2021/04/05 22:31:45.898262 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 4.303241ms

. . . .

DB FetchNode: 2021/04/05 22:31:46.187904  node: 02W0DG9TQ8iKKs4vV9m1bw== subKey: A#G#
DB: 2021/04/05 22:31:46.192385 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 4.431739ms
DB FetchNode: 2021/04/05 22:31:46.192623  node: 0l3jc2RfRUaIEHX85bmGpQ== subKey: A#G#
```

```
DB: 2021/04/05 22:31:46.196830 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 4.16039ms
DB FetchNode: 2021/04/05 22:31:46.197089  node: gG1g4BmVQA6dMmkQMhc5Ug== subKey: A#G#
DB: 2021/04/05 22:31:46.200507 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 3.358192ms
DB FetchNode: 2021/04/05 22:31:46.200670  node: tYQ19sZlTDW6lKYZCSQG7Q== subKey: A#G#
DB: 2021/04/05 22:31:46.204159 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 3.449152ms
DB FetchNode: 2021/04/05 22:31:46.204346  node: r78U68GPQLWpZF21IAqi5Q== subKey: A#G#
DB: 2021/04/05 22:31:46.208511 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 4.116352ms
DB FetchNode: 2021/04/05 22:31:46.208729  node: MWcKVKRYQ4WH7gP954orCw== subKey: A#G#
DB: 2021/04/05 22:31:46.212654 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 3.866351ms
DB FetchNode: 2021/04/05 22:31:46.213047  node: sOxHlO/ETj2JOVuGO7t+mg== subKey: A#G#
DB: 2021/04/05 22:31:46.216580 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 3.447009ms
DB FetchNode: 2021/04/05 22:31:46.216847  node: 4NlLo+tGT76nubRXnscZCw== subKey: A#G#
DB: 2021/04/05 22:31:46.220302 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 3.408951ms
DB FetchNode: 2021/04/05 22:31:47.326028  node: sii7dfM6TwGoFO3C8GxAvw== subKey: A#G#
DB: 2021/04/05 22:31:47.329682 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 3.58917ms
DB FetchNode: 2021/04/05 22:31:47.329846  node: VV2v0wrdQleKGcN1dlE8DQ== subKey: A#G#
DB: 2021/04/05 22:31:47.334625 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 4.735487ms
DB FetchNode: 2021/04/05 22:31:47.334768  node: fEhFAq5MTEmCGdvNA6h2dg== subKey: A#G#
DB: 2021/04/05 22:31:47.338794 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 3.976725ms
DB FetchNode: 2021/04/05 22:31:47.338959  node: yx7Ps+LcQ7WNKh6erqjn0Q== subKey: A#G#
DB: 2021/04/05 22:31:47.342810 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 3.766058ms
DB FetchNode: 2021/04/05 22:31:47.342952  node: SjqmklYPQseA64rf51EuNA== subKey: A#G#
DB: 2021/04/05 22:31:47.346280 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 3.286883ms
DB FetchNode: 2021/04/05 22:31:47.346397  node: kIS5FtuYTwKNPqInv/Fa5A== subKey: A#G#
DB: 2021/04/05 22:31:47.350928 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 4.491374ms
DB FetchNode: 2021/04/05 22:31:47.351115  node: FHQgpkSvTDCbEEPESKZbXg== subKey: A#G#
DB: 2021/04/05 22:31:47.354917 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 3.757904ms
DB FetchNode: 2021/04/05 22:31:47.355044  node: 3AkDImd+Qx+/B2mkdsL3ag== subKey: A#G#
DB: 2021/04/05 22:31:47.358707 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 3.55996ms
DB FetchNode: 2021/04/05 22:31:47.358866  node: dIPJwmoDRv6vTkYwsUQfCw== subKey: A#G#
DB: 2021/04/05 22:31:47.363957 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 5.041792ms
DB FetchNode: 2021/04/05 22:31:47.364091  node: JbRGSVEIR/u+ogbgSTx7Zg== subKey: A#G#
DB: 2021/04/05 22:31:47.367937 FetchNode:consumed capacity for Query  {
  CapacityUnits: 1,
  TableName: "DyGraphOD"
}. ItemCount 7  Duration: 3.7967ms
gql: 2021/04/05 22:31:47.368051 Duration: Parse  83.421952ms  Execute: 1.610042469s
monitor: 2021/04/05 22:31:49.373512 monitor: []interface {}{1, 1, 1166, []int{1, 15, 15, 391, 744}, 1166, []int{1,
15,  15,  391,  744},  359,  (*monitor.Fetch)(0xc0002faba0),  interface  {}(nil),  interface  {}(nil)}
monitor.Fetch{Fetches:359, CapacityUnits:359, Items:2484, Duration:1507493914}
DB: 2021/04/05 22:31:49.444505 TestLog: consumed capacity for PutItem  {
  CapacityUnits: 68,
  TableName: "TestLog"
```

}. Duration: 15.391477ms

Appendix A : CSP Programming in Go

To write a CSP (Communicating Sequential Process's) program in Go you need to be aware of these key concepts:

goroutines

Goroutines are normal functions that are made to run asynchronously to the calling routine be it the main program (aka the *main goroutine*) or another *goroutine,* by prefixing its instantiation with the “go” keyword. For example, to run function *foo(bar)* or a function literal*,* synchronously and asynchronously with the main routine:

```
func main() {
var x int
var y string
Var. c bool = true
…
// call foo synchronously

foo(bar)
…
// call foo asynchronously

go foo(bar)

// call a function literal asynchronously

go func() {….}()

// pass in arguments to a goroutine

go func(a int, b string) {….}( x, y )
```

The first instantiation of *foo* will run serially with the main program, whereas the second instantiation, prefixed with “go”, will run *foo* asynchronously with the main program. Both *foo* instantiations will have access to *boolean c* as they are closures (all Go functions are closures), however as c is a shared variable and if either *main* or *foo* modifies c, extra precautions will need to be made describe in the “shared variables” section below.

While *goroutines* provide a computing component they are useless unless they can communicate their output to other computing components. Channels are the mechanism *goroutines* use go pass data and synchronise events between other *goroutines*. Channels are the subject of the next section.

channels

While *goroutines* represent the SP (sequential processes) in CSP, channels represent the mechanism for the C (communicating). Channels are the way we link producers of data (SP) to consumers of the data. The producer writes some data onto the channel and the consumer reads that data from the channel using the syntax that is describe below. Channels are also used to synchronise events between produces and consumers. How do they do that? The write to a channel will always block if no consumer is listening on the channel. Similarly the consumer will always block when listening on the channel if no producer has written to the channel. Consequently when a producer writes to a channel without blocking we know that the produce and consumer are synchronised at that point in the code. Channels can also be defined with a buffer of any size, which will delay the synchronisation behaviour until the buffer has been filled.

To give you a feel for the elegant syntax that is Go channels, the following examples provide a basic overview, however there is more to Channels than presented here.

To define a channel called *myChan* that can accept integer data, declare the following:

```
var myChan int 5

// must make a channel before using it.
// second argument is the channel buffer value, yes a channel can b a queue
```

```
myChan = make(chan int, 0)
```

Channels can pass almost any data, *scalar* values, *slices*, *arrays*, *structs*, *pointers*, *channel* values, *function* values.

To write and read to a channel we use the symbol "<-" placed on the right or left of the channel variable respectively.

Lets write the value 5 to the channel:

```
a:=5

myChan <- a      // goroutine will wait here until the receiving goroutine reads from the channel
                 // alternatively, writing to the channel will unblock a waiting reading goroutine
```

Another *goroutine* can read from the channel using either of the following syntax:

```
for b := range myChan {…}     // often used in pipelined goroutines
```

or

```
b := <- myChan                // common way to synchronise and pass data
```

or

```
<- myChan                     // ignore data and synchronise goroutines instead
```

The myChan value, for the reading *goroutine*, might be passed in as an argument or passed via a channel.

Traditional system programming languages like *C* and *Java* use shared memory, provided by the OS, to facilitate data sharing and communication between concurrent programs. *Go* on the other hand, uses channels to pass data and synchronisation events between *goroutines*. This leads to one of Go's principal mantra's that I should mention at this point "*don't communicate by sharing memory, share memory by communicating*".

Don't be afraid to be generous with the use of channels. Channels are light weight components. Many applications require each instance of data in an array or slices to have its own channel for example.

shared variables

g*oroutines,* like all Go functions, are closures.

Variables created within a function are necessarily private to the function, variables declared outside the function represent *shared data* that can be accessed by other concurrent *goroutines* that have the same data scope. If the shared data is only ever read by the concurrent *goroutines* there will be no concurrency issues that can cause data corruption. However, if the shared data is modified by one or more concurrent *goroutine* special precautions need to be made, as concurrent read and update operations on the same data can lead to data corruption. If such precautions have been made the associated package that instantiates the concurrent *goroutines* is said to be *concurrency safe.*

Go provides two approaches to achieving *concurrency safe* programs*.*

One approach uses the *sync package API* (e.g. *Lock() & Unlock()*) to synchronise access to shared data provided all functions that access the data use the API.

Another approach encloses the shared data in its own *gofunction.* Any function requiring access to the data (both read or update) is forced to use a public accessibly channel to do so. In this way channels are used to serialise access.

To validate your *goroutines* are **concurrency safe** add the *-race* option when testing your code, e.g:

```
go test -run=parallelLoad -race -v
```

This will fail the test if an unsafe operation occurs on any shared data at runtime along with detailed diagnostic output. The *-race* option is not foolproof, however, as it will only fail a test if an actual race condition occurs, and by definition race conditions don't always occur. Consequently you need to run your tests multiple times if there is a chance it may experience a race condition, and even then unsafe code may not be caught during testing.

If you don't specify the *-race* option Go will PASS a test even if a race condition occurred. There's an overhead to using the option so only use it when your using concurrent routines that perform update and reads on the some shared data.s

Sync Package

I refer you to the WaitGroup type in the Go package documentation: https://golang.org/pkg/sync

Appendix B - How AWS Charges for Dynamodb?

For the best description of what factors affect the costs of using Dynamodb I cannot do better than the AWS documentation.

Read Consistency

https://docs.aws.amazon.com/amazondynamodb/latest/developerguide/HowItWorks.ReadConsistency.html

Read Write Capacity Units

https://docs.aws.amazon.com/amazondynamodb/latest/developerguide/HowItWorks.ReadWriteCapacityMode.html

Appendix C - Scalability and shared resources

Following on the from discussion on SQL vs NoSQL, ...

Any in-memory resource, be it a cache of any sort, a list structure of any sort, or just a single variable, that is accessible by two or more concurrent processors, must be protected against one process mutating the resource while another process reads it. Why does it need to be protected? Because a reading process is likely to get corrupted data while the resource is being mutated. To prevent the potential for corrupted reads all access to a shared resource must be serialised.

To serialise access to a shared resource there is an in-memory object called a **mutex** which acts as a kind of gatekeeper to the resource. Any process requesting to read or update a shared resource must first make a request to the mutex for access. The mutex will either grant access or block the requestor forcing it to wait (measured in microseconds) before it can try again, and therein lies a potential scalability issue. Increase the frequency of the requests and the waits on the requesting processes will increase.

So any **shared** resource that can be mutated has the potential to be a scalability issue. The factors that determine the potential are:

* how often is the resource accessed in the code
* is the access required in all, or often executed, code paths?
* the number of concurrent processors requesting access
* the frequency of that access from the database session

So to highlight this issue with a real world Oracle database scenario I will refer you to a Telco Billing product I was associated with many years ago. It was entirely written in Oracle's PL/SQL and at the time ran in a single Oracle instance on small to large SMP servers with 4 or more CPUs. The Rating Engines (RE) component would process hundreds of millions of Call Data Records (CDRs) a day and the server would usually be allocated a RE per CPU. However, as the number of REs increased beyond 4 there would be a measurable degradation in CDR throughput per RE. For the larger servers with up to 30 cpus, the degradation would continue to the point where adding an RE would make no difference to the overall CDR throughput.

Enter, Oracle's comprehensive and exquisitely detailed instrumentation of the database and the STATSPACK utility that aggregates this data by discrete time intervals (aka snapshots) and allows the user to generate a very detailed "stats report" between any two snapshots. One of the top level reports listed the top five "event waits" in database experienced for that interval. In a properly running database all the top five "events" would be related to some type of physical IO event, such as a "log sync", "sequential read", "scattered read" etc. However, when the REs were running one of the top five events was related to a mutex wait on the library cache. The "library cache" is a shared resource that maintains the parsed information of each SQL statement. So it was a surprise to see a mutex wait in the top five and even more of a surprise to find it consumed 24% of the overall event waits in the database. Why?

The problem was the REs. Each RE issued about 20 to 30 different SQL statements to the database on a continual basis. Each Oracle background process associated with an RE, would first generate a hash on the SQL statement and check if it existed in the library cache. So in answer to the four factors listed above to determine the potential for a scalability issue it it rates very high to extreme

* how often is the resource accessed in the code. **For every SQL statement issued to database.**
* is the access required in all, or often executed, code paths? **All**
* the number of concurrent processors requesting access. **Same as number of REs** (CPUs)
* the frequency of that access from the database session. **Extremely high - CPU speed**

The most significant of these is the last factor. REs generate SQL calls at CPU speed rather than the usual OLTP speeds of human operators. Consequently the pressure on the library cache mutex is extremely high to the point that each concurrent Oracle process is waiting hundreds of milliseconds to access the library cache rather than the usual tens to hundreds of microseconds of an OLTP application. As a result of these

mutex waits the REs where effectively throttled by 24% and the waits would only increase as more REs were added.

How did we resolve this disastrous scalability issue. There were two solutions. Either make the RE architecture distributed so there would be multiple Oracle instances with 2 to 4 REs per instance. This put less pressure on the mutex in each instance. The second solution relied upon the fact that the RE data was static when the REs was running. Updates to the data would only occur when the REs were shutdown. So instead of relying upon the Oracle data cache, each RE would load the static data (across perhaps 25 tables) into local memory (a PL/SQL table for each physical table) during startup. The downside of this solution was it took a long time to load some PL/SQL tables which seriously impacted startup times and PL/SQL tables are very very memory hungry. The final solutions was a merging of both. Make RE a distributed database application using commodity based servers and for heavily accessed tables cache them in application memory. Scalability issue resolved and performance was outstanding.