The LDBC Graph Query Language Proposal

LDBC GraphQL Task Force:

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What, How and Where

• Goal:
  – Recommend a query language core that could be incorporated in future (versions) of industrial graph query languages.
  – Perform deep academic analysis of the functional and complexity space to ensure a powerful and practical language.
• 2 years of work in the GraphQL task force
• 3-day workshop in Santiago de Chile (Aug 8-10)
  – Lots of progress, this proposal.
• Writing workshop for SIGMOD industrial paper (Dagstuhl Nov 26- Dec 1)
Principles & Goals

- Closed Query Language
  - to allow subqueries, views
  - Define PG property graphs as
    - “directed, labeled graphs with paths, and properties on all of these”
PG Data Model

- Property Graph data model has never been formally defined
- We define it here:
  - \( L \) is an infinite set of label names for nodes, edges and paths;
  - \( K \) is an infinite set of property names;
  - \( V \) is an infinite set of literals (actual values).

Moreover, given a set \( X \), we assume that \( \text{SET}(X) \) is the set of all finite subsets of \( X \) (including the empty set), and \( \text{LIST}(X) \) is the set of all finite lists of elements from \( X \).

Then a property graph is a tuple \( G = (N, E, P, \rho, \delta, \lambda, \sigma) \), where:
  - \( N \) is a finite set of nodes.
  - \( E \) is a finite set of edges.
  - \( P \) is a finite set of paths. We assume that \( N, E \) and \( P \) are pairwise disjoint.
  - \( \rho : E \to (N \times N) \) is a total function.
  - \( \delta : P \to \text{LIST}(N \cup E) \) is a total function. We assume that for every path \( p \in P \), it holds that either \( \delta(p) = [a] \) with \( a \in N \) or \( \delta(p) = [a_1, e_1, a_2, \ldots, a_n, e_n, a_{n+1}] \),
    1. \( n \geq 1 \),
    2. \( a_j \in N \) for every \( 1 \leq j \leq n+1 \),
    3. \( e_j \in E \) for every \( 1 \leq j \leq n \), and (iv) \( \rho(e_j) = (a_j, a_{j+1}) \) or \( \rho(e_j) = (a_{j+1}, a_j) \) for every \( 1 \leq j \leq n \)
  - \( \lambda : (N \cup E \cup P) \to \text{SET}(L) \) is a total function.
  - \( \sigma : (N \cup E \cup P) \times K \to \text{SET}(V) \) is a total function. We assume that there is a finite set of tuples \( (a,b) \) in \( (N \cup E \cup P) \times K \) such that \( \sigma(a,b) \) is not the empty set.
Principles & Goals

• Closed Query Language
  – to allow subqueries, views
  – Define PG property graphs as
    • “directed, labeled graphs with paths, and properties on all of these”

• Powerful Language Features
  – PATH ... \rightarrow \text{specifies path patterns, (weighted) shortest path finding types}
    • Also ALLPATHS, using PROJECT GRAPH to return all matching edges as a graph
  – MATCH ... \rightarrow \text{graph matching resulting in bindings}
  – WHERE ... \rightarrow \text{specifies filtering}
  – CONSTRUCT GRAPH ... \rightarrow \text{project bindings into a graph (incl grouping)}
  – Full query: e.g. UNION of multiple CONSTRUCT GRAPH returning one graph
Notation

- $x$ variable
- $(x)$ node
- $[y]$ edge
- $/p/$ path

Given a variable $x$, we use notation

- $x:L$ $L$ is a label of a node, edge or path $x$
- $x:L \{ p = v \}$ the value of property $p$ is $v$ for $x$

In regular expressions:

- $(r)^*$ Kleene star,
- $(r_1 + r_2)$ union
- $(r_1 r_2)$ concatenation
MATCH

binds variables using homomorphic pattern matching, it results in an (imaginary) binding table where the columns are the variables and the rows the bindings.

- MATCH (a:Person {age=21})-[[:knows]->(b)-[:knows]->(c)
- MATCH (a:Person {age=21})-[/<knows*>/-](b)-[/<knows*>/-](c)
- MATCH (a:Person {age = 21})-[/p<friend*>/-](b:Person {age = 21})
- MATCH (a)-[/p<knows*> {confidence = 0.9}/-(b)

distinguish between an edge label and a regular expressions composed by a single edge label:

- MATCH (a)-[/p<knows*>/-](b) // p binds to a path object
- MATCH (a)-[/p:knows]-/(b) // p binds to an edge object

checking multiple labels by using notations (x:L1:L2), [y:L3:L4:L5] and /z:L6:L7/. The semantics of these expressions is conjunctive;

Variables are typed depending to which kind of object (node, edge, or path) they are assigned. Invalid: (x)-[x]-(y)
MATCH ...OPTIONAL ... ON

- **Optional match.** Inside the sequence conjunctive. Variables are NULL if not matchable.

  \[ \text{MATCH } p_1, p_2, ..., p_k \text{ OPTIONAL } q_1, q_2, ..., q_l \text{ OPTIONAL } r_1, r_2, ..., r_m \ldots \]

  where each \( p_i, q_i, \) and \( r_i \) is a basic graph pattern. Example

  \[
  \text{MATCH } (x)-[:name]->(y) \text{ OPTIONAL } (x)-[:phone]->(z)
  \]

  There is only one level of nesting for the \texttt{OPTIONAL} operator.

- **Graph source.** The graph the matching operates on can be specified by \texttt{ON} after a basic match pattern. The specification is optional. If no graph is specified the matching will operate on the base graph. If a graph is specified, the matching will operate on that graph. Graphs can be specified by an identifier for named graphs or by a subquery.

  \[
  \text{MATCH } (x)-[:name]->(y) \texttt{ ON Employees}
  \]
Expressions

- Local connectives: **AND, OR, NOT**
- Grouping: parenthesis
- Standard Functions: \( \text{abs}(x), \sin(x), \ldots \)
- Graph Functions: \( \text{labels}(n), \text{nodes}(p), \text{rels}(p), \text{startNode}(r), \text{endNode}(r), \text{length}(p) \)
  \( \text{size}(l), \text{bound}(n) \)
- Label-Test:
  - \( n: \text{Person}\ \text{true} \) iff \( n \) has the Person label
  - \( n: \_\ \text{true} \) iff \( n \) has any label
- Collections:
  - Membership test \( \text{elem IN} \) collection
  - Indexing collection[elem]
  - Slicing collection[slice]
  - List comprehension \([x \ \text{IN} \ \text{list WHERE} \ \text{predicate | expr}] \)
WHERE

Filters bindings resulting from MATCH.

Operators with boolean result:
- =, <>,
- <, <=, >, >=
- +, -, *, /, %, ...
- v.prop (where v is a node/edge/path variable)
- CASE

Subqueries:
- EXISTS { <full-query> }
- Can refer to variables from outer scope

Shorthand for dealing with expressions on set-valued properties?
- Startswith((person.phone), “+1”)
- If c.phone is multi-valued: ERROR (or EXISTS/ALL semantics?)
Existential WHERE match

Examples.

MATCH (x)-[:friend]->(y)-[:friend]->(z) WHERE (x)-[:friend]->(z)
is equivalent to:
MATCH (x)-[:friend]->(y)-[:friend]->(z) WHERE EXISTS { MATCH (x)-[:friend]->(z) }

Negation:

MATCH (x)-[:friend]->(y)-[:friend]->(z) WHERE NOT (x)-[:friend]->(z) is equivalent to:
is equivalent to:
MATCH (x)-[:friend]->(y)-[:friend]->(z) WHERE NOT EXISTS { MATCH (x)-[:friend]->(z) }

WHERE clause does not introduce new bindings in the outer scope. It just filters MATCH bindings.
PATH

- syntactically starts on the left with a vertex, ends at its rightmost vertex
  - PATH abc AS ()-[a:A]-()-[b:B]-()

- the pattern can be augmented to be nonlinear, by comma
  - PATH abc AS (src)-[a:A]-()-[b:B]-[dst), (dst)-[c:C]-()

- can have a COST clause:
  - PATH abc AS ()-[a:A]-()-[b:B]-()-[c:C]-()
    COST a.x + b.y + c.z

- can have a WHERE clause:
  - PATH unreciprocated_love AS (a) -[:LOVES]->(b)
    WHERE NOT (b)-[:LOVES]->(a)

which is equivalent to:
  - PATH unreciprocated_love AS (a) -[:LOVES]->(b)
    WHERE NOT EXISTS { MATCH (b)-[:LOVES]->(a) }
PATH usage in MATCH

Existence of paths (no path variable binding)
- **MATCH** (x)-/^friend*/-(y)

Shortest path queries - a fixed number of shortest paths
- **MATCH** ()-/^SHORTEST p:^friend*/-(() (single shortest path)
- **MATCH** ()-^5 SHORTEST p:^friend*/-(() (5 shortest path2)

Weighted shortest path:
- **MATCH** ()-/^SHORTEST p:^friend* COST x/-(()

Disjunct shortest path queries
- **MATCH** ()-^5 DISJUNCT SHORTEST p:^friend*/-(() (5 disjunct shortest path)

All paths : should only end in PATH PROJECT which returns the induced graph:
- **MATCH** ()-/^ALLPATHS p:^friend* COST x/-(()

PATH PROJECT p
CONSTRUCT GRAPH  ($a)-[:knows]->($b)

CONSTRUCT <fullGraphPattern> SET ... REMOVE
introduce copy patterns like (=n) or ()-[=e]->()
  – This copies all labels and properties
  – Additionally given literal labels and properties in copy patterns are always additive
• Further before the in-line patterns:
  – SET n.prop = value
  – SET labels(n) = labels(m)
  – SET properties(n) = properties(m)
  – SET n:Label
  – REMOVE n.prop
  – REMOVE n:Label
Can only describe changes on unbound variables
Full Query: Union/Intersection

consistency condition.

- Two property graphs $G_1 = (N_1, E_1, P_1, \rho_1, \delta_1, \lambda_1, \sigma_1)$ and $G_2 = (N_2, E_2, P_2, \rho_2, \delta_2, \lambda_2, \sigma_2)$ are said to be consistent if:
  - For every $e \in E_1 \cap E_2$, it holds that $\rho_1(e) = \rho_2(e)$
  - For every $p \in P_1 \cap P_2$, it holds that $\delta_1(p) = \delta_2(p)$
  - For every $o \in ((N_1 \cap N_2) \cup (E_1 \cap E_2) \cup (P_1 \cap P_2))$, it holds that $\lambda_1(o) = \lambda_2(o)$
  - For every $o \in ((N_1 \cap N_2) \cup (E_1 \cap E_2) \cup (P_1 \cap P_2))$ and $p \in K$, it holds that $\sigma_1(o, p) = \sigma_2(o, p)$

Set operations.

- Let $G_1 = (N_1, E_1, P_1, \rho_1, \delta_1, \lambda_1, \sigma_1)$ and $G_2 = (N_2, E_2, P_2, \rho_2, \delta_2, \lambda_2, \sigma_2)$ be consistent property graphs. Then, for $* \in \{\cup, \cap\}$, $G_1 * G_2$ is defined to be the property graph $G = (N, E, P, \rho, \delta, \lambda, \sigma)$ where
  - $N = N_1 * N_2$, $E = E_1 * E_2$ $P = P_1 * P_2$, $\rho = \rho_1 * \rho_2$, $\delta = \delta_1 * \delta_2$, $\lambda = \lambda_1 * \lambda_2$, $\sigma = \sigma_1 * \sigma_2$
  - and $*$ is the standard set-theoretic operation.
## Full Query: Union/Intersection

**consistency condition.**

- Two property graphs $G_1 = (N_1, E_1, P_1, \rho_1, \delta_1, \lambda_1, \sigma_1)$ and $G_2 = (N_2, E_2, P_2, \rho_2, \delta_2, \lambda_2, \sigma_2)$ are said to be consistent if:
  - For every $e \in E_1 \cap E_2$, it holds that $\rho_1(e) = \rho_2(e)$
  - For every $p \in P_1 \cap P_2$, it holds that $\delta_1(p) = \delta_2(p)$
  - For every $o \in ((N_1 \cap N_2) \cup (E_1 \cap E_2) \cup (P_1 \cap P_2))$, it holds that $\lambda_1(o) = \lambda_2(o)$
  - For every $o \in ((N_1 \cap N_2) \cup (E_1 \cap E_2) \cup (P_1 \cap P_2))$ and $p \in K$, it holds that $\sigma_1(o,p) = \sigma_2(o,p)$
CONSTRUCT GRAPH \((\$a)-[:\text{knows}]\rightarrow(\$b)\)

- **Anonymous variables.** Object patterns with no variable assigned by the user get an anonymous variable assigned.
- **Bound and unbound patterns.** All variables that occur as columns in the binding table are bound variables. All others are unbound variables. Their respective object patterns are called unbound patterns.
  - Edge patterns are only allowed to have a bound variable if they link node patterns with the same variables as in the match pattern that bound them.

**Projection result.** The pattern is instantiated on every tuple of binding table. Each instantiation forms a small graph isomorphic to the projection pattern. The result of the projection is the union of all pattern instantiations.

- **Pattern instantiation.**
  - for each bound object pattern: the object bound to that variable in the binding tuple.
  - for each unbound object pattern the instantiation contains a newly created object of the respective kind.
Aggregating Graph Projection

Example: ($a \text{ GROUP } \$x\text{-}[\text{GROUP } \$w, \$y\text{-}>(\text{GROUP } \$z$)

Node pattern ($a \text{ GROUP } \$x$) has grouping variable $\$x$ assigned,
Edge pattern -[\text{GROUP } \$y\text{-} has grouping variable $\$w$ and $\$y$ assigned
Node pattern (\text{GROUP } \$z$) has grouping variable $\$z$ assigned.

- All grouping variable have to be bound variables in the binding tables.
- Bound object patterns are implicitly grouped by their own bound variable.
- Unbound node patterns not specifying grouping variables are implicitly grouped by all variables bound in the binding tables.
- Unbound edge patterns are implicitly grouped by the grouping variables of their adjacent nodes.
  - Additionally to these, unbound edge patterns may specify more grouping variables.
G-Core Examples

Co-publications weighted by venue

GRAPH CONSTRUCT (a)-[:COAUTHOR{weight:cost(copath)}]-(b)
PATH coauthor AS ()<-[:AUTHOR]-(paper)-[:AUTHOR]->(),
(paper)-[p:PUBLISHED_IN]->(venue)
WHERE venue.name IN [ "VLDB", "SIGMOD", "ICDE" ]
COST min( case venue.type
    when "conference" then 2
    when "journal" then 1
    else infinity
end *
  case p.type
    when "proceedings" then 4 else 1 end )
MATCH (a{name:"Claudio Gutierrez"}), (b{name:"Kevin Bacon"}),
SHORTEST (a)-/copath:~coauthor*/-(b)
G-Core Examples

PATH conf_publ AS ()-[p:PUBLISHED_IN]->(:conference)
WHERE NOT p.type = "proceedings"
PATH conf_coauthor = ()<-[:AUTHOR]-(p)-[:AUTHOR]->()
WHERE (p)-/~conf_publ/-()
MATCH (a{name:"Marcelo Arenas"}), (b{name:"Paul Erdös"}),
   DISJOINT 10 SHORTEST (a)-/x:~conf_coauthor*/-(b)
CONSTRUCT GRAPH (a)-[:COAUTHOR{length:length(x)}]->(b)
Summary

- Closed Query Language, that allow subqueries, views
- Property graphs = “directed, labeled graphs with paths, and properties on all of these”
- Powerful Language Features
  - PATH ... → specifies path patterns, (weighted) shortest path finding types
    - Also ALLPATHS, using PROJECT GRAPH to return all matching edges as a graph
  - MATCH ... → graph matching resulting in bindings
  - WHERE ... → specifies filtering
  - CONSTRUCT GRAPH ... → project bindings into a graph (incl grouping)
  - Full query: e.g. UNION of multiple CONSTRUCT GRAPH returning one graph
  - Extension: CONSTRUCT TABLE ... → project bindings into a table
Construct Table

**CONSTRUCT TABLE** `returnItems`

where `returnItems` is

- a comma-separated list of variables bound to graph objects (nodes, edges, or paths), or
- expression followed by the keyword AS and the name of an unbound variable

Example:

- **CONSTRUCT TABLE** `a, r.weight, r.weight*2 AS doubleWeight, b.name AS name`

**MATCH** `(a)-[r]->(b)`

multi-valued properties are dealt with by cartesian product (or by inline aggregation, reducing them to single values)