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Informational Paper

The Cypher Language 2017

Presentation to the **LDBC Query Language Task Force**
Neo Technology Cypher Language Group

Date of original presentation	3 July 2017
Submitted to DM32.2	13 July 2018

Neo4j Query Languages Standards and Research Team

The Cypher Language 2017

Pre-existing, agreed and planned features

Neo Technology Cypher Language Group LDBC Query Language Task Force 3 July 2017

The problem space ...

How to concisely express in an “SQL-niche” declarative query language

- Which graphs and (nested) tables are inputs to a query
- The graphs and (nested) tables output by a query
- The operations over graphs
- The (optional, partial) schema of graphs
- The storage of graphs (representations)
- References to graphs (location, name) and their containers (stores)

... and its relationship to, or expression in, SQL

Does graph querying justify a special-purpose query language, distinct from SQL?

Or should SQL be extended to address the whole problem space?

If SQL is not extended to address the whole problem space then:

How do we address the whole space?

Our view is that a “native” graph query language is necessary ...

and that it is also important to interoperate between the native language and SQL.

The most complete and widely used native graph query language is Cypher

The features of Cypher today

Property graph data model Nodes and relationships have properties, and labels (types)

Single, implicit global graph ("context graph"), in which paths can be processed

Ubiquitous visual pattern syntax "Whiteboard friendly"

Matching (identifying) subgraphs, creating/updating subgraphs, constraints/indices

Fully-featured query language Reads, Updates, Schema definition

Application-oriented type system — Scalars, Lists, Maps

Result processing: Filtering, Ordering, Aggregation

By default, Cypher assumes heterogeneous data

Returns results as nested data (stored data limited to Scalar, List<Scalar>)

Use pipelining (“query parts”) for query composition

Visual pattern syntax is not just for MATCHing

```
MATCH path=(a:Person)-[:KNOWS*2]->(b:Person) RETURN path

MATCH (a)-[r:LIKES]->(b) WHERE abs(a.age - b.age) < 5
    WHERE NOT EXISTS (b)-[:MARRIED]-()

CREATE/MERGE (joe)-[:FRIEND]->(sue)

CREATE CONSTRAINT FOR (p:Person)-[:BORN_IN]->(c:City)
```

Visual pattern syntax is a pervasive feature of the graph query language

Enabling whiteboard-friendly, graph-oriented DML, DDL, and ultimately DCL, syntax

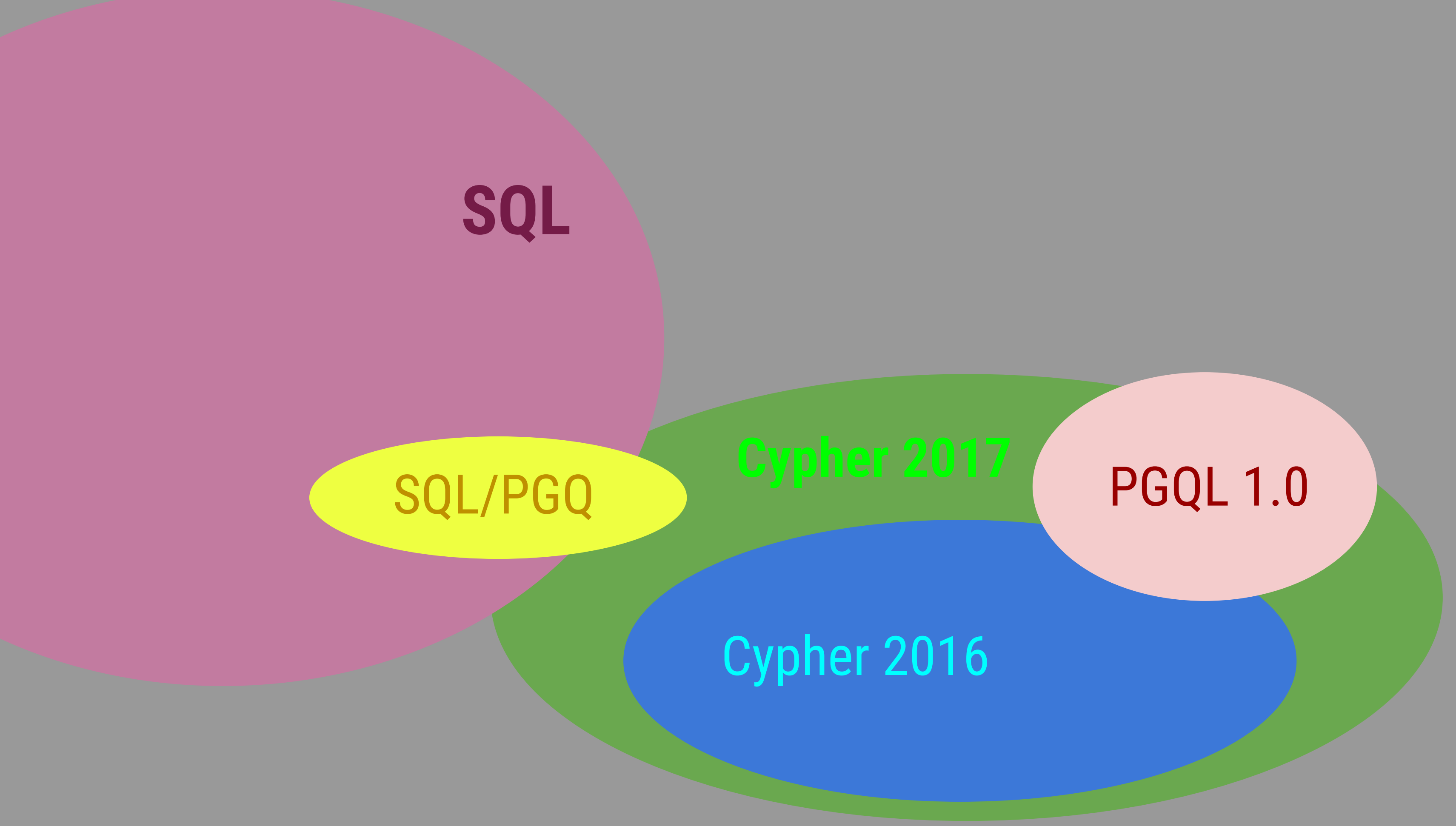
Composition with matching, aggregation, and sorting

```
// Top-down dataflow leads to natural query composition/chaining
// -- without introducing aliases and is similar to UNIX pipes

MATCH (p:Person)-[:KNOWS]->(friend:Person)
WITH p, count(friend) AS num_friends ORDER BY num_friends LIMIT 10
MATCH (p)-[:LIVES_IN]->(city:City)
RETURN p.name AS name, city.name AS city, num_friends
```

Top-down data flow enables visual query composition

Light-weight nested, correlated multi-row subqueries (like **LATERAL** in SQL)


SQL
SQL/PGQ
Cypher 2017
PGQL 1.0
Cypher 2016

The openCypher community: towards an open standard

In late 2015 Neo announced the openCypher initiative

- Apache-licensed grammar, ANTLR parser, TCK
- Open Cypher Improvements process based on Github issues/discussions
- Work has started on a formal specification of Cypher (denotational semantics) by University of Edinburgh

Governed by the openCypher Implementers Group

In 2017 two face-to-face openCypher Implementers Meetings have taken place

Regular openCypher Implementers Group virtual meetings scheduled through to October

Consensus-based governance:
open to all, but implementers
“at the heart of the consensus”

Cypher implementations

Cypher is used as the graph query language of four commercial/OSS databases

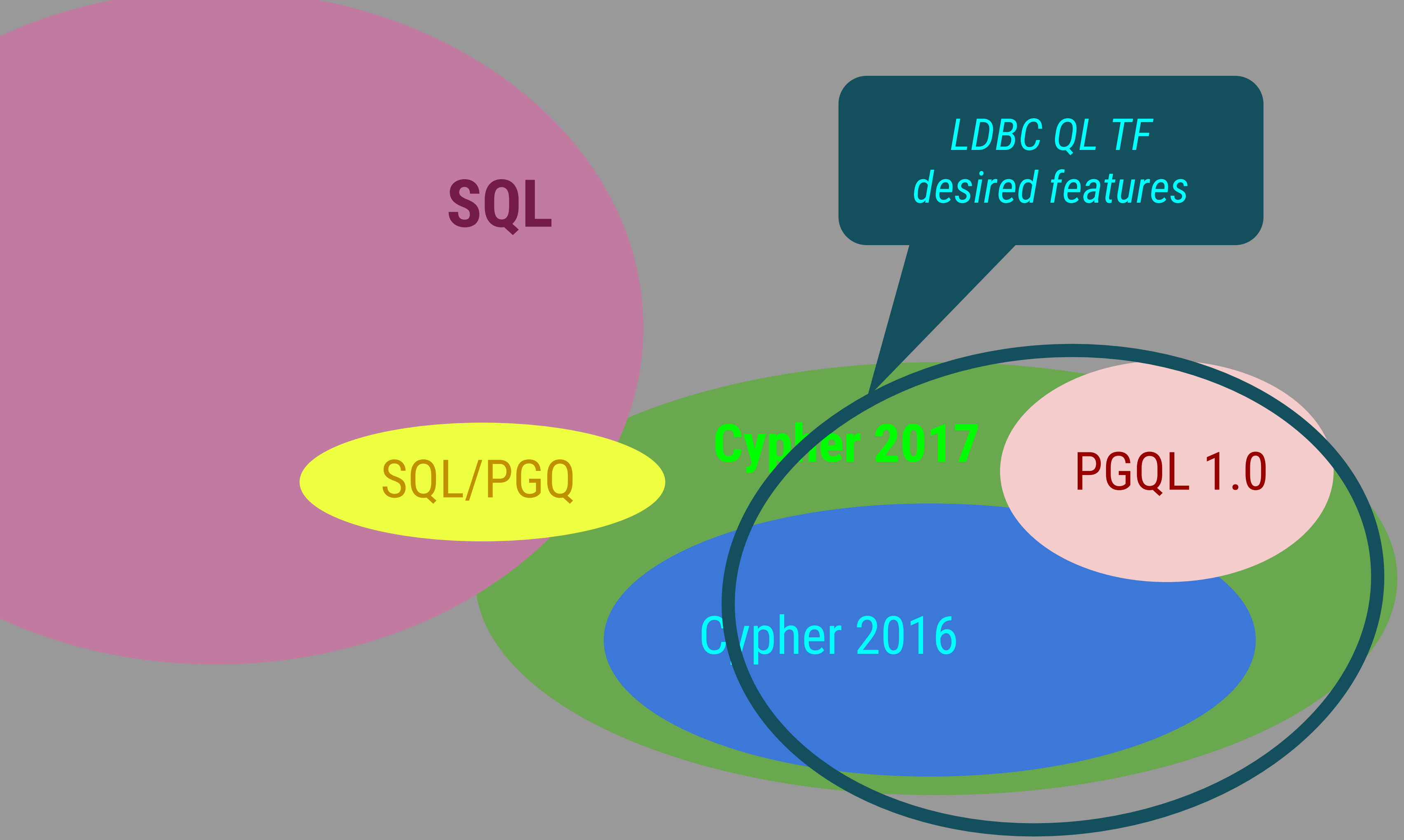
Neo4j Enterprise Server, SAP HANA Graph, AgensGraph/Postgres, and RedisGraph

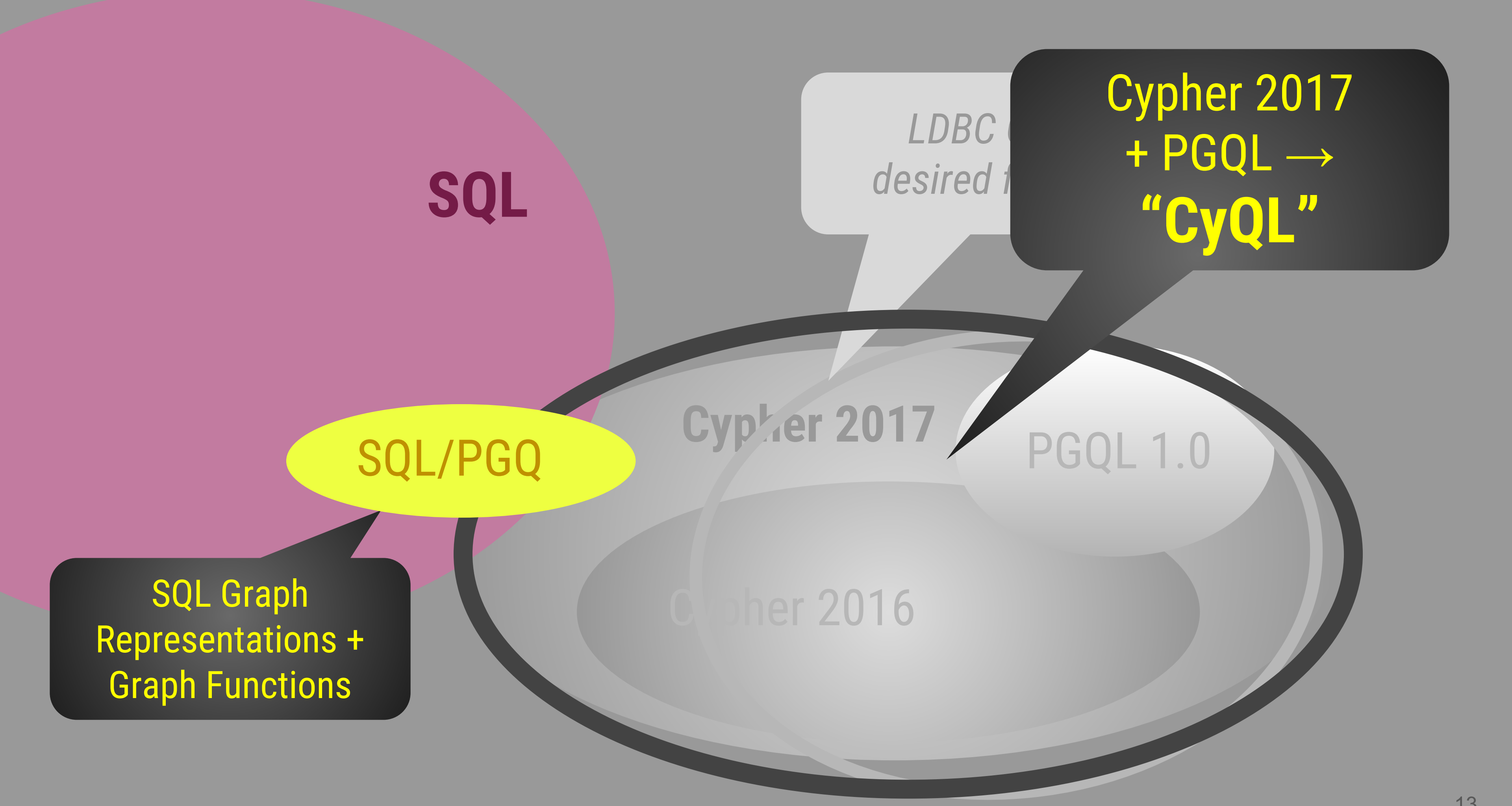
There are other databases/query engines in gestation or in the research community

Memgraph, Ingraph, Scott Tiger, Cypher for Apache Spark, Graphflow ...

There are several other projects or tools that use Cypher

IDEA plugin from Neueda, language parsers, editors, GraphQL Cypher directives, ...


SQL
LDBC QL TF
desired features
Cypher 2017
SQL/PGQ
PGQL 1.0
Cypher 2016


SQL
SQL/PGQ
SQL Graph Representations + Graph Functions
LDBC
desired
Cypher 2017 + PGQL → "CyQL"
PGQL 1.0
Cypher 2016

Features in active design or in adoption

Query Composition and Set Operations
Nested Subqueries (Scalar, Existential, Correlated, Updating, ...)

Map Comprehensions for working with nested data

Additional Constraints

Configurable *morphism

Path expressions and path patterns

Support for Multiple Graphs (graph-returning query composition)

Path Expressions and Path Patterns

CIP 2017-02-06 Path Patterns

```
PATH PATTERN unreciprocated_love = (a)-[:LOVES]->(b)
    WHERE NOT EXISTS { (b)-[:LOVES]->(a) }

MATCH (you)-/~unreciprocated_love*/->(someone)
```

Compared to GXPath

Compared to Regular Expressions With Memory (REMs)

Use-cases for multiple-graph support

Data integration Combining multiple data sources

Security Graph views

Visualization Returning graphs to the client

Time-based comparison Snapshots/Versioned Graphs, Deltas

Fraud-ring detection Graphlet results (multiple matching subgraphs)

Composition Function chains of queries and other graph functions

Summarization Show an abstracted (aggregated and/or simplified) graph

Cypher support for working with multiple graphs

Introduce globally addressable graphs with a graph URI scheme: `graph://...`

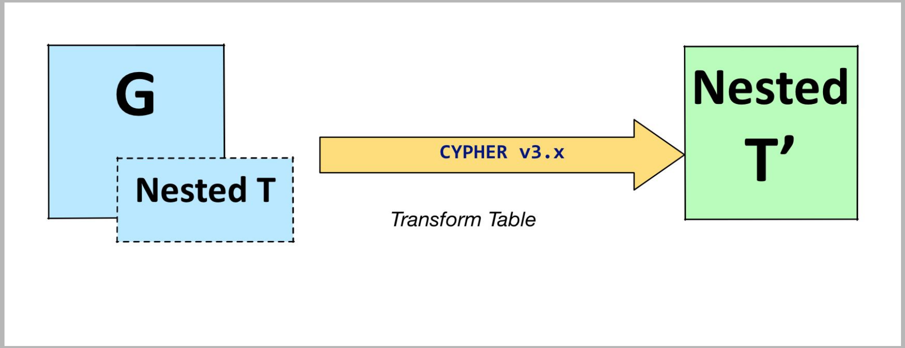
Enable naming and referring to graphs produced by earlier stages of a query/session

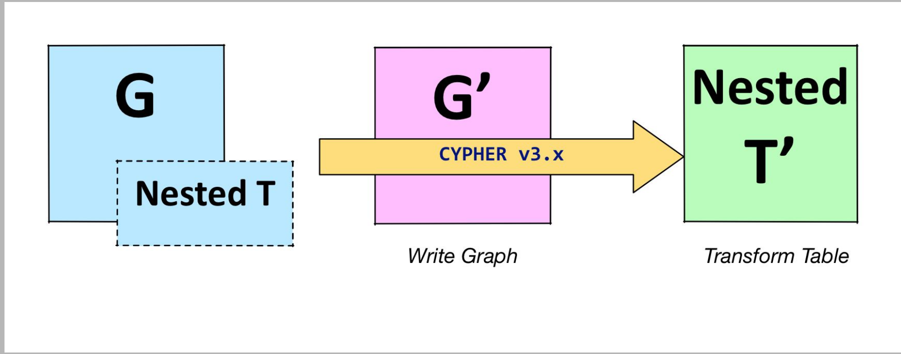
Introduce query context read and write graphs for ease of use and composition.

Create and amend graphs by emitting commutative updates into a target graph.

Define graph query composition via pipelining inside the language or outside the language (e.g. composing queries with other functions over graphs using an API).

Cypher Today: Queries (not yet) closed over graphs





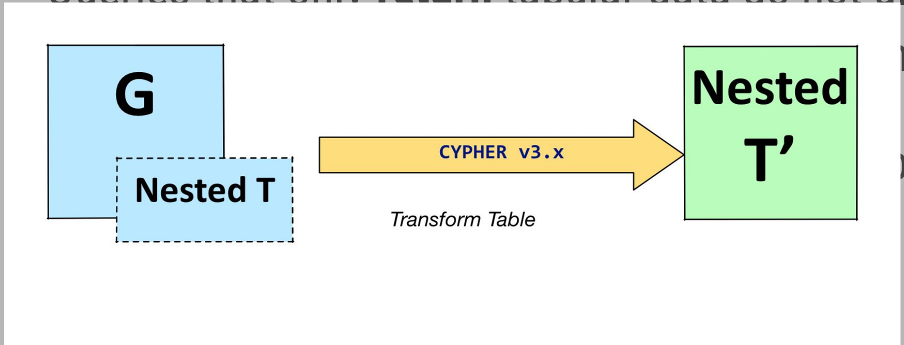
Read queries take a graph G, yielding a nested tabular result (relational sub-graph view)

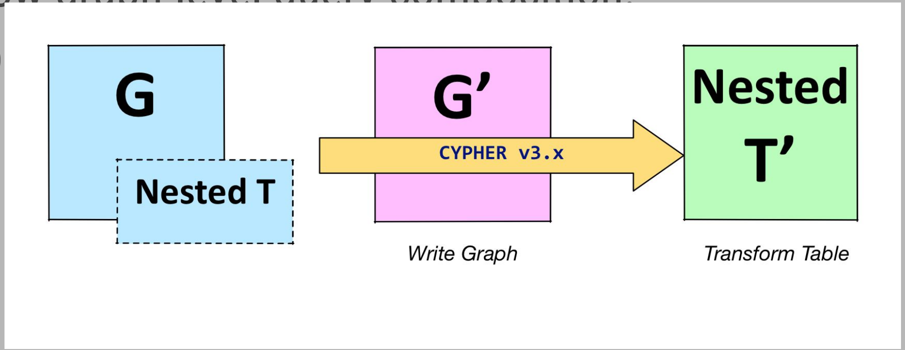
Lists and maps for parameters and results
Cypher transforms graphs to nested tables
G + (Nested) T → (Nested) T'

Write queries take a graph G, and modify it (implicitly resulting in G'), but can only return a nested tabular result

Cypher Today: Queries (not yet) closed over graphs

Queries that only **return** tabular data do not allow graph-level query composition:



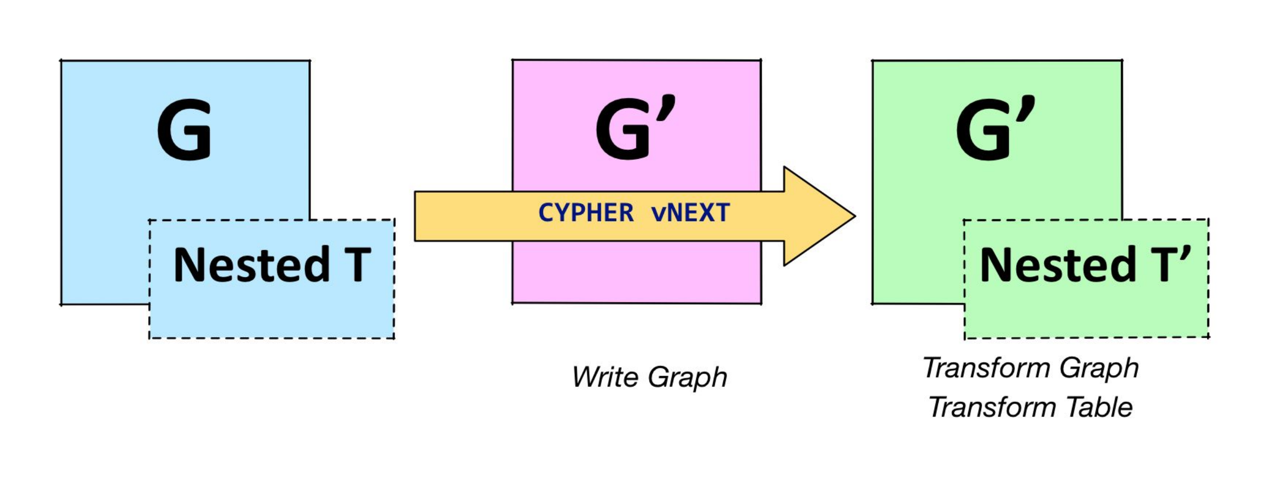


Cypher this summer: Queries closed over graphs

Natively handling multiple graphs requires adding **graph references**

Needed to refer to existing graphs or those produced as intermediary results

Enables seamless query composition / functional chaining.



Compositional queries

Accept the same type as they return

That type at its most general could be

- a tuple of graph references plus
- a tuple of table references

Cypher 2017 is focussed on **a tuple of graphs and one (nested) table**

This adds graphs in, graphs out to Cypher 2017

Cypher pipelining (WITH) is an existing compositional mechanism that is extended

Multiple Graphs Syntax and Pipeline Composition

```
WITH a, b GRAPHS g1, g2          // Normal Cypher composition and selection
FROM GRAPH <name>                // Sets source and target graph for the following statements
     AT 'graph://...'            // Resolves physical address
INTO NEW GRAPH <name>            // Sets target graph for the following statements
     AT 'graph://...'            // Resolves physical address
RETURN a, b GRAPHS g1, g2             // Returns table and graphs

WITH a, b GRAPHS g1, g2 ...      // first query
WITH GRAPHS g3, g4 ...           // second query over first query
RETURN c, d GRAPHS g5            // third query over seoond query over first query
```

Example 1

```
FROM GRAPH foo AT 'graph://my-graph'

MATCH (a:Person)-[r:KNOWS]->(b:Person)

MATCH (a)-[:LIVES_IN->(c:City)<-[:LIVES_IN]-(b)

INTO NEW GRAPH berlin

CREATE (a)-[:FRIEND]->(b) WHERE c.name = "Berlin"

INTO NEW GRAPH santiago

CREATE (a)-[:FRIEND]->(b) WHERE c.name = "Santiago"

RETURN c.name AS city, count(r) AS num_friends GRAPHS berlin, santiago
```

LDBC Example 1

```
FROM GRAPH AT “graph://social-network”                 // Set scope to whole social network
MATCH (a:Person)-[:KNOWS]->(b:Person)-[:KNOWS]->(c:Person)
    WHERE NOT (a)--(c)
INTO NEW GRAPH recommendations                              // Create a temporary named graph
CREATE (a)-[:POSSIBLE_FRIEND]->(c)                     // Containing existing nodes and new rels
FROM GRAPH recommendations                             // Switch context to named graph
MATCH (a:Person)-[e:POSSIBLE_FRIEND]->(b:Person)
RETURN a.name, b.name, count(e) AS cnt                 // Tabular output, and ...
    ORDER BY cnt DESC
    GRAPHS recommendation                                   // ... graph output!
```

LDBC Example 2

```
FROM GRAPH AT "graph://social-network"                   // Set scope to whole social network

MATCH (a:Person)-[:IS_LOCATED_IN]->(c:City),
              (c)->[:IS_LOCATED_IN]->(co:Country),
              (a)-[e:KNOWS]-(b)

INTO NEW GRAPH sn_updated                                    // Create a new temporary named
graph

CREATE (a)-[e]-(b)                                       // Add previous matches to new graph
    SET a.country = cn.name                              // Update existing nodes

FROM GRAPH sn_updated

MATCH (a:Person)-[e:KNOWS]->(b:Person)

WITH      a.country AS a_country, b.country AS b_country, count(a) AS a_cnt, count(b) AS
b_cnt,
     count(e) AS e_cnt

INTO NEW GRAPH rollup

MERGE (:Persons {country: a_country, cnt: a_cnt})-[:KNOW {cnt: e_cnt}]->(:Persons {country:
b_country, cnt: b_cnt})

RETURN GRAPH
```

LDBC Example 3

```
FROM GRAPH AT 'graph://social-network'                    // Set scope to whole social network

MATCH (a:Person)-[e]->(b:Person),
      (a)-[:LIVES_IN]->()->[:IS_LOCATED_IN]-(c:Country {name: ‘Sweden’}),
      (b)-[:LIVES_IN]->()->[:IS_LOCATED_IN]-(c)

INTO GRAPH sweden_people AT './swe'                       // Create a persistent graph “sn/swe”

CREATE (a)-[e]->(b)                                       // Containing persons and knows rels

MATCH (a:Person)-[e]->(b:Person),
     (a)-[:LIVES_IN]->()->[:IS_LOCATED_IN]-(c:Country {name: ‘Germany’}),
     (b)-[:LIVES_IN]->()->[:IS_LOCATED_IN]-(c)
INTO GRAPH german_people AT './ger'                       // Create a persistent graph “sn/ger”

CREATE (a)-[e]->(b)                                       // Containing :Person nodes and :KNOWS rels

RETURN *                                                  // Graph output (no tabular)

FROM GRAPH sweden_people                                  // Start query on Sweden people graph

MATCH p=(a)--(b)--(c)--(a) WHERE NOT (a)--(c)

INTO GRAPH swedish_triangles                              // Create a temporary graph

RETURN count(p) GRAPH swedish_triangles                   // Tabular and graph output
```

Many possible syntactical transformations

```
FROM GRAPH foo
MATCH ()-->()-->(n)
MATCH (n)-->()-->()
INTO GRAPH bar
CREATE *
     <==>
FROM GRAPH foo
MATCH (a)-[r1]->(b)-[r2]->(c)
MATCH (c)-[r3]->(d)-[r4]->(e)
INTO GRAPH bar
CREATE (a)-[r1]->(b)-[r2]->(c)
CREATE (c)-[r3]->(d)-[r4]->(e)
```

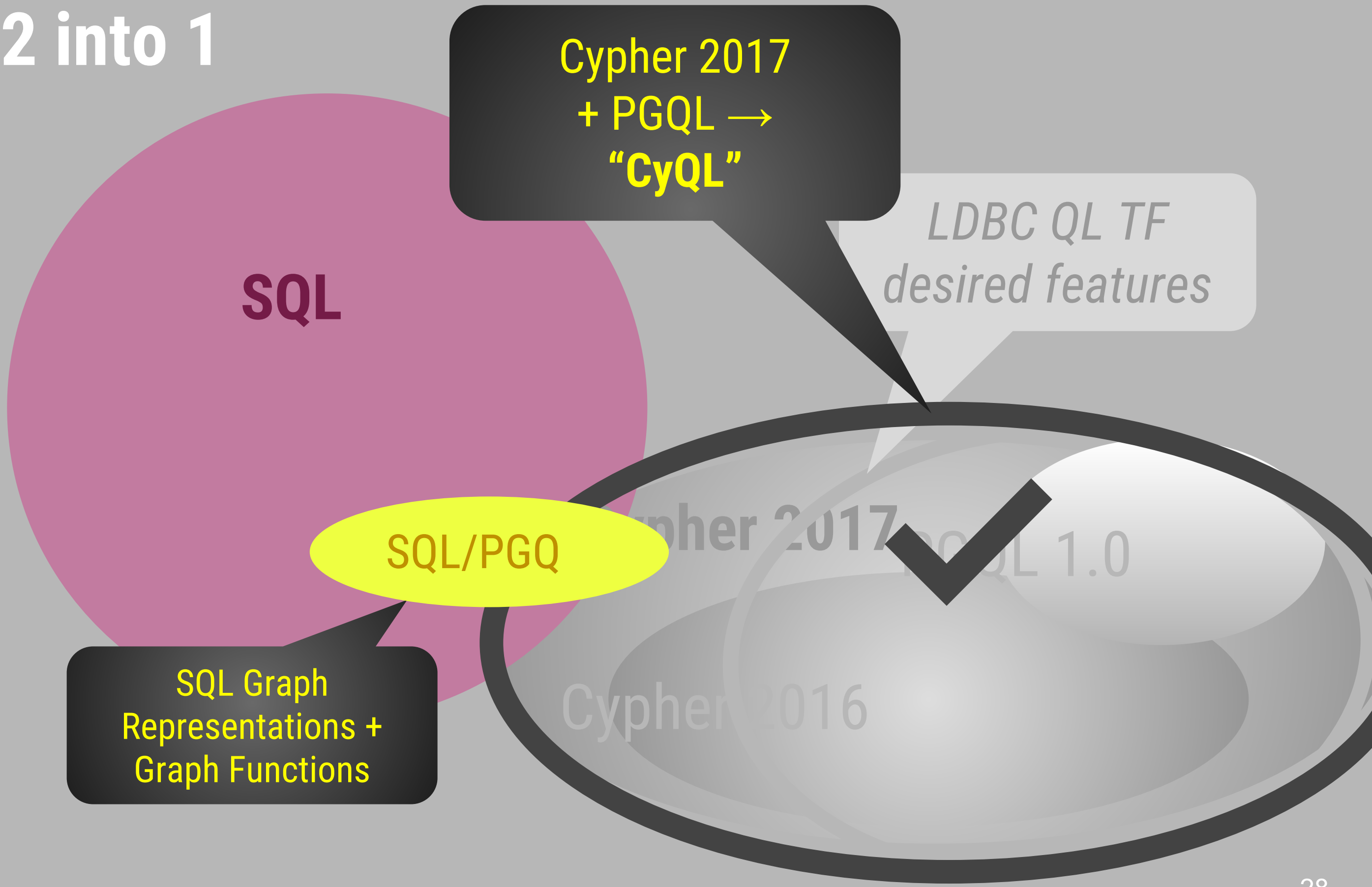
Not 2 to 3, but 2 into 1

openCypher

PGQL

QL TF GQL

...



Appendix **History and survey of Cypher**

The inception of property graphs

Real-world use cases Content management, recommendations, IAM, life sciences

- Graph first, transactional online processing (not just static analysis)
- Heterogenous data
- Quickly evolving (sometimes no) schema
- High traversal performance
- Results consumable by existing applications and libraries

Approaches

- Relational systems did not fit well at the time: Expressivity and performance
- Similarly with RDF at that time: Complexity and performance
- Initial prototype: Fast graph traversal engine

Initial Motivation for Cypher “The SQL of property graphs”

Declarative query language Use patterns to retrieve nodes, relationships, paths

- Read and write/update queries

Heterogenous data language using optional schema

- Static and dynamic typing should be possible

Visual language

- Graph patterns (ASCII-art) `(startNode)-[relationship:TYPE]->(endNode)`

Applications language

- From nothing to something: "top-down dataflow" (or "reverse SQL") order
- Returns (nested) tabular data for integrating with existing applications
- Covers majority of use-cases for manually implemented traversals

The features of Cypher today

Property graph data model Nodes and relationships have properties, and labels (types)

Single, implicit global graph ("context graph"), in which paths can be processed

Ubiquitous visual pattern syntax "Whiteboard friendly"

Matching (identifying) subgraphs, creating/updating subgraphs, constraints/indices

Fully-featured query language Reads, Updates, Schema definition

Application-oriented type system – Scalars, Lists, Maps

Result processing: Filtering, Ordering, Aggregation

By default, Cypher assumes heterogeneous data

Returns results as nested data (stored data limited to Scalar, List<Scalar>)

Use pipelining (“query parts”) for query composition

Property Graph Data Model openCypher, Neo4j > 2.0

Nodes with multiple labels ("roles") and multiple properties

Relationships with single type (label) and multiple properties

Grounded in >10 years experience with real world use cases from large enterprises

Next big step: Support for multiple graphs

Meta-properties (mainly for per-property auth)

Multi-properties (mainly covered by list properties)

Visual Pattern Matching: Reads

```
MATCH (a)-[r:FRIEND]->(b)
RETURN * // RETURN a, r, b

// Paths variables

MATCH p=(a:Person)-[:FRIEND*..3]->(b:Person),
        (a)-[:LIVES_IN]->(c:City)<-[:LIVES_IN]-(b)
WHERE abs(a.born - b.born) < 5
RETURN p
```

Visual Pattern Matching: Updates

```
CREATE (joe:Person {name: 'Joe'})
CREATE (joe)-[:FRIEND]->(sue)

MERGE (jack:Employee {name: 'Joe'})
  ON CREATE SET jack.created = timestamp()
  ON MATCH SET jack.updated = timestamp()
SET jack.salary = $newSalary

SET node:Label              REMOVE node:Label
SET node.prop = 42          REMOVE node.prop

DELETE node, rel
```

Fully-featured language: Postprocessing & Constraints

```
// Post-processing
MATCH (a)-[r:LIKES]->(b) WHERE abs(a.age - b.age) < 5
WHERE NOT EXISTS (b)-[:MARRIED]-()
RETURN b ORDER BY r.how_much

// Schema constraints and Index creation
// CIP2016-12-14-Constraint-syntax: an earlier syntax in Neo4j
ADD CONSTRAINT person_detail
FOR (p:Person)-[:BORN_IN]->(c:City)
REQUIRE exists(p.name)
    AND p.born >= c.founded
```

Visual pattern syntax is not just for MATCHing

```
MATCH (a)-[r:LIKES]->(b) WHERE abs(a.age - b.age) < 5

NOT EXISTS (b)-[:MARRIED]-()

PATH PATTERN co_author =
    (a)-[:AUTHORED]->(:Book)<-[:AUTHORED]-(b)

CREATE/MERGE (joe)-[:FRIEND]->(sue)

FOR (p:Person)-[:BORN_IN]->(c:City)
```

Visual pattern syntax is a pervasive feature of the graph query language

Enabling whiteboard-friendly, graph-oriented DML, DDL, and ultimately DCL, syntax

Query syntax order and composition

```
// From nothing to something: top-down dataflow
MATCH (n) RETURN *

// Leads to natural query composition/chaining
// -- without introducing aliases and similar to UNIX pipes
MATCH (p:Person)-[:KNOWS]->(friend:Person)

WITH p, count(friend) AS num_friends ORDER BY num_friends LIMIT 10

MATCH (p)-[:LIVES_IN]->(city:City)
RETURN p.name AS name, city.name AS city, num_friends
```

Top-down data flow enables visual query composition

Light-weight nested, correlated multi-row subqueries (like **LATERAL** in SQL)

“SQL-alien” features

```
// Querying heterogeneous data
// - This arises during early exploration/integration of
//   disparate data sets
// - Facilitates fast-paced microservice architectures
MATCH (a:Document)-[:FROM]-(s:Source)
RETURN a.id, a.score, properties(s)

MATCH (anything)-[:FROM]-(:Source)
RETURN properties(anything)

// Returning nested data is common requirement for web apps
MATCH (person:Person {userId: $user})-[:ADDRESS]->(address)
RETURN person {.firstName, .lastName, id: $user,
               address {.streetAddress, .city, .postalCode} }
```