Modern Graph Analytic Support in GSQL, TigerGraphs's GQL

Alin Deutsch

TigerGraph Chief Scientist

Professor, UC San Diego

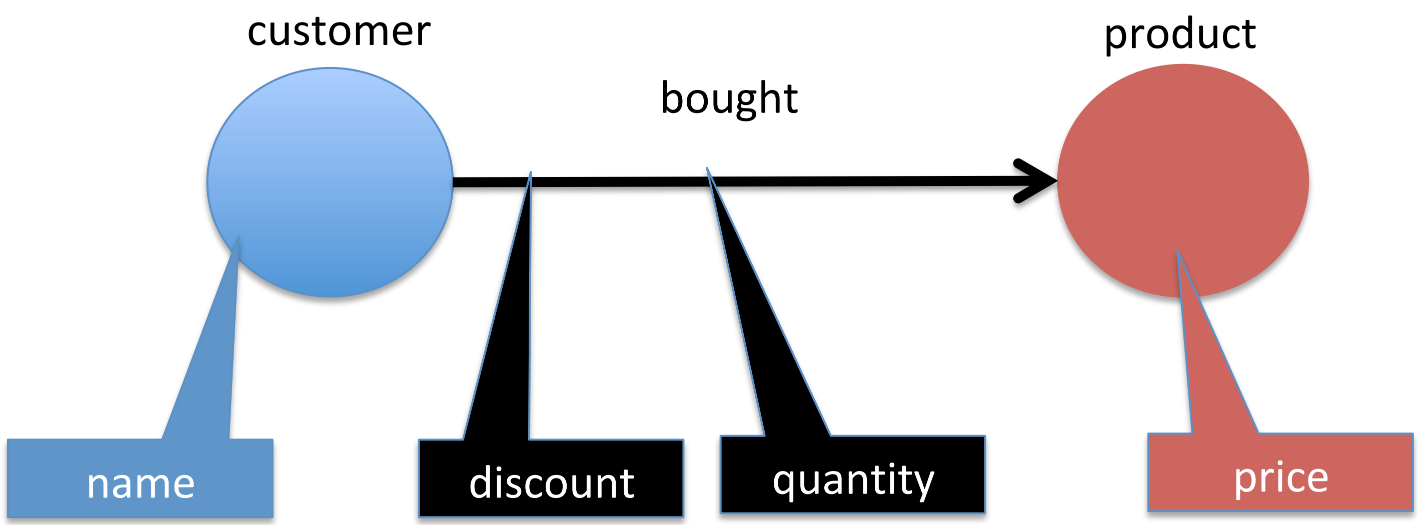
The Age of the Graph Is Upon Us (Again)

- Early-mid-90s: semi- or un-structured data research was all the rage
  - data logically viewed as graph
  - initially motivated by modeling WWW (page=vertex, link=edge)
  - query languages expressing constrained reachability in graph
- Late 90s-late 2000s: special case XML (graph restricted to tree shape)
  - Mature: W3C standard ecosystem for modeling and querying (XQuery, XPath, XLink, XSLT, XML Schema, …)
- Since mid 2000s: JSON and friends (also restricted to tree shape)
  - Mongodb, Couchbase, SparkSQL, GraphQL, AsterixDB, …
- Present: back to unrestricted graphs
  - Initially motivated by analytic tasks in social networks
  - Now universal use (most interesting data is linked, after all)

The Traditional Graph Data Model

- Nodes correspond to entities
- Edges correspond to binary relationships
- Edges may be directed or undirected (asymmetric, resp. symmetric relationships)
- Nodes and edges may be labeled/typed
- Nodes and edges annotated with data
  – both have sets of attributes (key-value pairs)

Example: Customers Buy Products



Key Traditional Language Ingredients

- Pioneered by academic work on relational query extensions for graphs (since ‘87)
  - Path expressions (PEs) for navigation
  - Variables for referring to and manipulating data found during navigation
  - Stitching multiple PEs into complex navigation patterns → conjunctive path queries
  - Constructors for new nodes and edges

Path Expressions

- Express reachability via constrained paths
- Early graph-specific extension over conjunctive queries
- Introduced initially in academic prototypes in early 90s
  - StruQL (AT&T Research - Fernandez, Halevy, Suciu)
  - WebSQL (U Toronto - Mendelzon, Mihaila, Milo)
  - Lorel (Stanford - Widom et al)
- Supported by modern languages
  - SparQL, Cypher, Gremlin, GSQL

Path Expression Examples (1)

- Pairs of customer and product they bought:

  -Bought->

- Pairs of customer and product they were involved with (bought or reviewed)

  -***Bought|Reviewed->***

- Pairs of customers who bought same product
  (lists customers with themselves)

  -***Bought->.<-Bought-***

Path Expression Examples (2)

- Pairs of customers involved with same product (like-minded)

  -Bought|Reviewed->.<-Bought|Reviewed-

- Pairs of customers connected via a chain of like-minded customer pairs

  (-Bought|Reviewed->.<-Bought|Reviewed-)*

Conjunctive Regular Path Queries

- Path expressions as atomic building blocks
- Explicitly introduce variables binding to source and target nodes of path expressions.
- Variables can be used to stitch multiple path expression atoms into complex patterns.

CRPQ Examples

- Pairs of customers who have bought same product (do not list a customer with herself):

Q1(c1,c2) :- c1 –Bought->.<-Bought- c2, c1 != c2

- Customers who have bought a product and also reviewed it:

Q2(c) :- c –Bought-> p, c –Reviewed-> p

Key Language Ingredients Needed in Modern Applications

– All primitives inherited from past
  - path expressions + variables + conjunctive patterns + node/edge construction

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– Support for large-scale graph analytics
  - Aggregation of data encountered during navigation

    → requires bag semantics for pattern matches
  - Control flow support for class of iterative algorithms that converge in multiple steps
    – (e.g. PageRank-class, recommender systems, shortest paths, etc.)

Aggregation

Aggregation in Modern Graph QLs

- PGQL, Gremlin and SparQL use an SQL-style GROUP BY clause
- Cypher's RETURN clause uses similar syntax as aggregation-extended CQs
- GSQL uses aggregating containers called "accumulators"
  - (soon to add above solutions as syntactic sugar, but accumulators remain strictly more versatile)

GSQL Accumulators

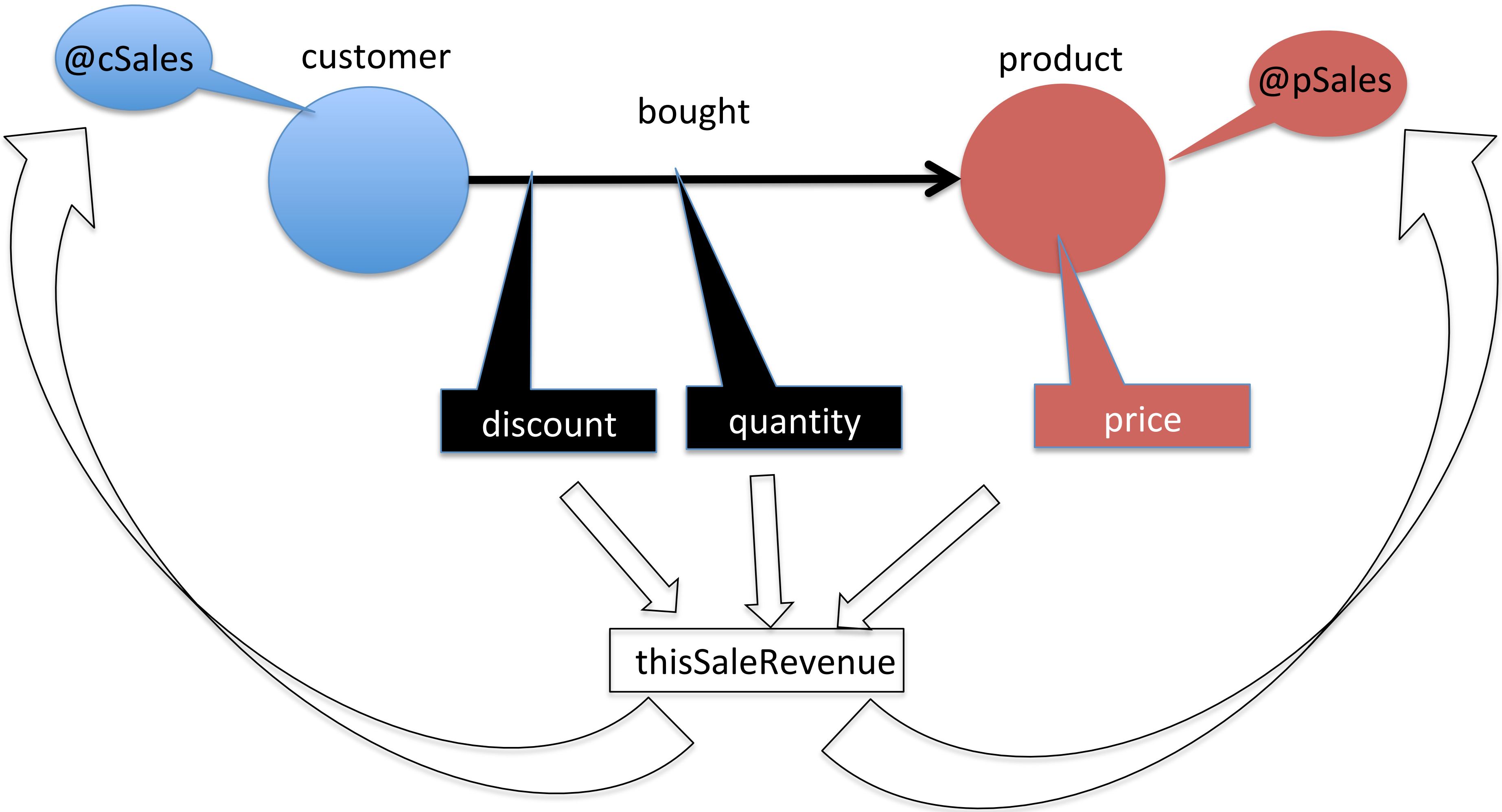
- GSQL traversals collect and aggregate data by writing it into *accumulators*

- Accumulators are containers (data types) that
  - hold a data value
  - accept inputs
  - aggregate inputs into the data value using a binary operator

- May be built-in (sum, max, min, etc.) or user-defined

- May be
  - global (a single container)
  - Vertex-attached (one container per vertex)

Vertex-Attached Accumulator Example: Revenue per Customer and per Product



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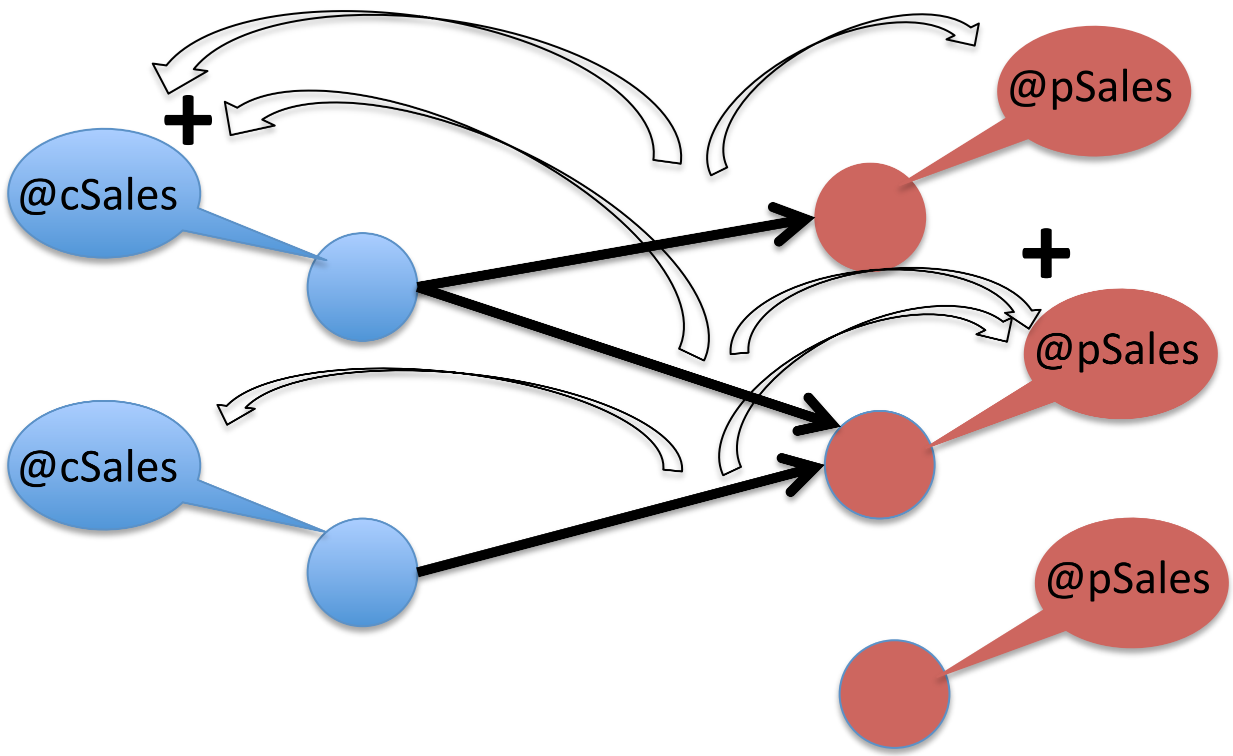

Vertex-Attached Accumulator Example: Revenue per Customer and per Product

```
SumAccum<float> @cSales, @pSales;

SELECT   c
FROM     Customer :c −(Bought :b)-> Product :p
ACCUM    thisSaleRevenue = b.quantity*(1-b.discount)*p.price,
         c.@cSales += thisSaleRevenue,
         p.@pSales += thisSaleRevenue;
```

accumulator declaration

groups are distributed, each node accumulates its own group

same sale revenue contributes to two aggregations, each by distinct grouping criteria

Recommended Toys Ranked by Log-Cosine Similarity

```
SumAccum<float> @rank, @lc;
SumAccum<int>    @inCommon;

Me = {Customer.1};
     SELECT        p INTO ToysILike, o INTO OthersWhoLikeThem
     FROM          Me:c -(Likes)-> Product:p <-(Likes)- Customer:o
     WHERE         p.category == "Toys" and o != c
     ACCUM         o.@inCommon += 1
     POST-ACCUM    o.@lc = log (1 + o.@inCommon);

ToysTheyLike =   SELECT   t
                 FROM     OthersWhoLikeThem:o –(Likes)-> Product:t
                 WHERE    t.category == "toy"
                 ACCUM    t.@rank += o.@lc;

RecommendedToys = ToysTheyLike – ToysILike;
```

Control Flow Primitives

Loops Are Essential

- Loops (until condition is satisfied)
  - Necessary to program iterative algorithms, e.g. PageRank, recommender systems, shortest-path, etc.
  - They synergize with accumulators. This GSQL-unique combination concisely expresses sophisticated graph analytics
  - Can be used to program unbounded-length path traversal under various semantics

PageRank in GSQL

```
CREATE QUERY pageRank (float maxChange, int maxIteration, float dampingFactor) {

  MaxAccum<float> @@maxDifference = 9999;  // max score change in an iteration
  SumAccum<float> @received_score = 0;     // sum of scores received from neighbors
  SumAccum<float> @score = 1;              // initial score for every vertex is 1.

  AllV = {Page.*};                         // start with all vertices of type Page
  WHILE @@maxDifference > maxChange LIMIT maxIteration DO
   @@maxDifference = 0;

    S= SELECT         s
       FROM           AllV:s -(Linkto)-> :t
       ACCUM          t.@received_score += s.@score/s.outdegree()
       POST-ACCUM     s.@score = 1-dampingFactor + dampingFactor * s.@received_score,
                      s.@received_score = 0,
                      @@maxDifference +=   abs(s.@score - s.@score');
  END;
}
```

Takeaway

Serendipitous synergy of

flexible aggregation + loops

from point of view of both

expressive power (conciseness, naturalness)
performance