LDBC

The LDBC Social Network Benchmark

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(with contributions from former members of the SNB Task Force)

Overview

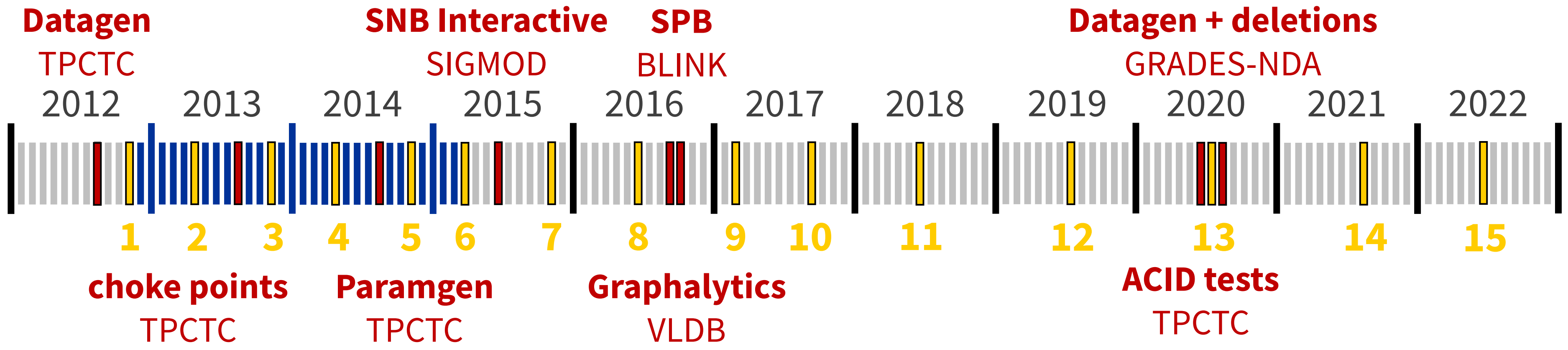
The LDBC Social Network Benchmark is a state-of-the-art benchmark suite for modern HTAP and OLAP database management systems.

- The Interactive workload focuses on HTAP systems with continuous updates
- The BI workload target OLAP systems with batched updates

The workloads operate a social graph which is highly connected and has correlations on attribute values (e.g. names) and structure (e.g. friendship).

They include graph features, e.g. traversing Message trees, finding the k-hop neighbourhoods of Persons, and computing unweighted/weighted shortest paths between Persons.

LDBC project, benchmark papers & meetings



EU FP7 project | **TUC meetings** | **Benchmark papers**

The LDBC Social Network Benchmark

- Initial mission during the EU project (2012-2015): develop a benchmark suite
  - Continued after the project, now in the making for almost 10 years
  - Influential in both academia and industry
- From 2015: new LDBC groups around query languages
  - Graph Query Language Task Force (G-CORE)
  - GQL Formal Semantics Working Group
  - Existing Languages Working Group
  - Property Graph Schema Working Group
- LDBC has a growing membership of individuals and organizations

This presentation is a summary of the LDBC Social Network Benchmark. We provide an overview of the benchmark and codify some lessons learnt.

For an overview of the LDBC, see the talk titled “The Linked Data Benchmark Council”

Data sets

- Graph schema
- Correlated data
- Deletions
- The Datagen project

Social network domain

Disclaimer: It is now established that serving as the primary database for a social network is *not the primary use case* of graph databases.

That said: It is a widely understood domain with interesting graph data structures. Additionally, it makes it easy to argue about correlations in the graph such as:

- "People are *Germany* are more likely to be called *Joachim* than in *Italy*"
- "People in the *France* make more trips to *Belgium* than people in *Mexico* to *Japan*"

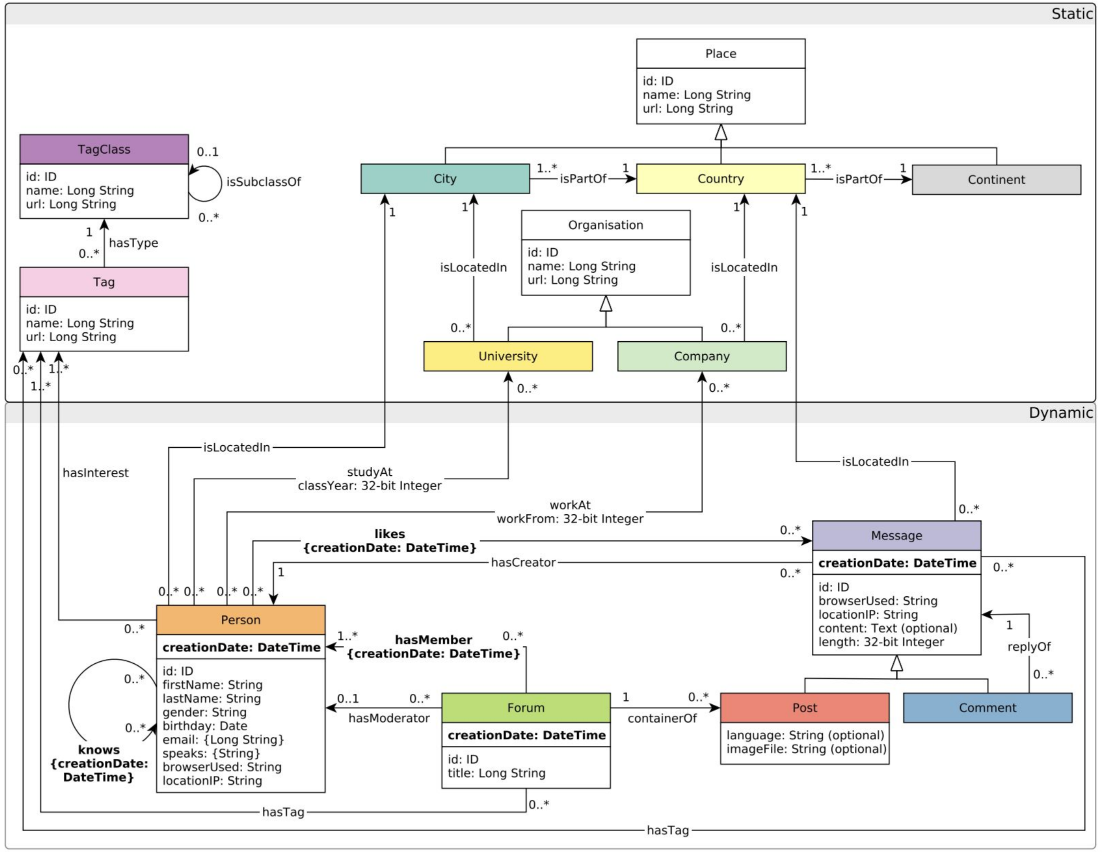
The generated graphs are realistic *to some extent* but not fully. The goal is to add some realistic correlations which query engines can exploit when optimizing the queries.

Statistics

Network of Person nodes, trees of Messages/TagClasses/Places

Statistics for scale factor 1:

- 3M nodes, 17M edges
- 11k Persons, avg. degree of knows edges: 39.4
- Branching factors
  - Message tree: 3.2
  - TagClass tree: 3.7
  - Place tree: 12.4



Graph schema

The graph is a **labelled property graph**. All edges are directed except the Person-knows-Person edges, which are *undirected*.

Edge types (between node types) can be categorized as follows:

- Bipartite: most edge types form a bipartite subgraph, e.g. Forum-hasMember-Person
- Network: Person nodes form network along the knows edges
- Hierarchies:
    - TagClasses: a rooted tree of TagClass nodes (root: “Thing”)
    - Places: a non-rooted tree of 3 levels (Continent, Country, City)
    - Messages: each thread is a rooted tree with a Post root node and Comment nodes

Data generator (Datagen)

The Datagen produces a **property graph** data set

The graph is fully dynamic: **inserts** and **deletes** with realistic distributions

Distributed generation for scalability:

- The Hadoop-based Datagen was used for the Interactive workload
- It was migrated to Spark in 2020, which is now used for the BI workload

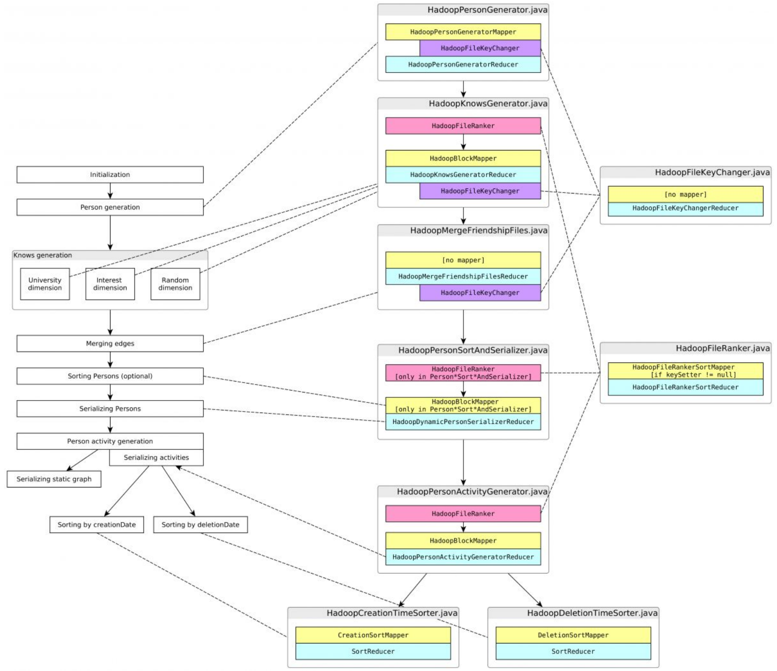
📃 S3G2: a Scalable Structure-correlated Social Graph Generator, TPCTC 2012
📺 LDBC SNB Datagen: Under the hood by Arnau Prat, 9th LDBC TUC meeting, 2017
📃 *Supporting dynamic graphs in SNB Datagen* by J. Waudby et al., GRADES-NDA 2020
📃 *Speeding up LDBC SNB Datagen*, blogpost, 2020

Data generator (Datagen)

Graphs are produced using a distributed data processing framework

- Earlier versions used Hadoop
- Migrated to Spark in 2020

Capable of producing output with different serializers (CSV variants, Turtle).



Initialization
Person generation
Knows generation
University dimension
Interest dimension
Random dimension
Merging edges
Sorting Persons (optional)
Serializing Persons
Person activity generation
Serializing activities
Serializing static graph
Sorting by creationDate
Sorting by deletionDate
HadoopPersonGenerator.java
HadoopPersonGeneratorMapper
HadoopFileKeyChanger
HadoopPersonGeneratorReducer
HadoopKnowsGenerator.java
HadoopFileRanker
HadoopBlockMapper
HadoopKnowsGeneratorReducer
HadoopFileKeyChanger
HadoopMergeFriendshipFiles.java
[no mapper]
HadoopMergeFriendshipFilesReducer
HadoopFileKeyChanger
HadoopPersonSortAndSerializer.java
HadoopFileRanker [only in Person*Sort*AndSerializer]
HadoopBlockMapper [only in Person*Sort*AndSerializer]
HadoopDynamicPersonSerializerReducer
HadoopPersonActivityGenerator.java
HadoopFileRanker
HadoopBlockMapper
HadoopPersonActivityGeneratorReducer
HadoopFileKeyChanger.java
[no mapper]
HadoopFileKeyChangerReducer
HadoopFileRanker.java
HadoopFileRankerSortMapper [if keySetter != null]
HadoopFileRankerSortReducer
HadoopCreationTimeSorter.java
CreationSortMapper
SortReducer
HadoopDeletionTimeSorter.java
DeletionSortMapper
SortReducer

📃 *Speeding up LDBC SNB Datagen*, blogpost, 2020

Refresh operations

The “dynamic” part of the graph is changing throughout the benchmark. This puts systems using static data structures (such as plain CSR) at a disadvantage.

Depending on the workload of SNB, the refresh operations are different:

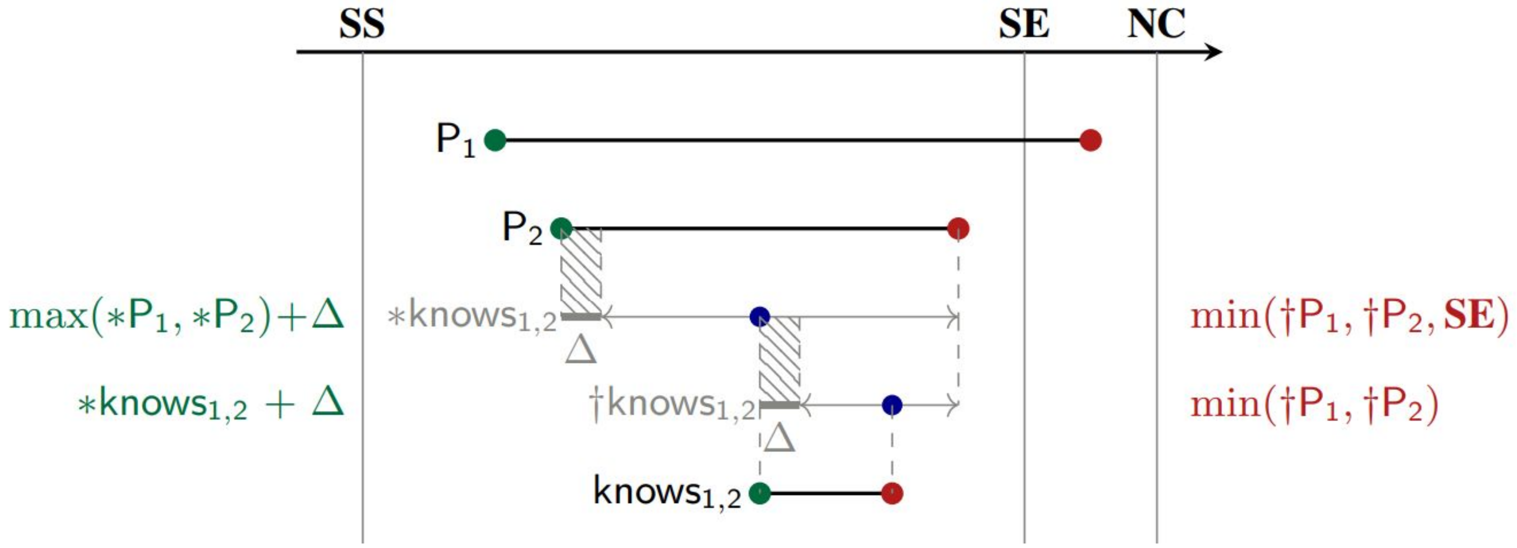
Interactive: New Persons/Forums/Messages are *inserted* along with their edges

BI: Same *inserts* plus the same type of entities are also subject to *deletes*

Generating deletions is challenging as it necessitates assigning a lifespan to each entity during generating, which takes into account how certain deletions are cascading (e.g. deleting an entire Forum or a Message thread) which has a significant impact on the distribution of the data.

Lifespan management, example 1

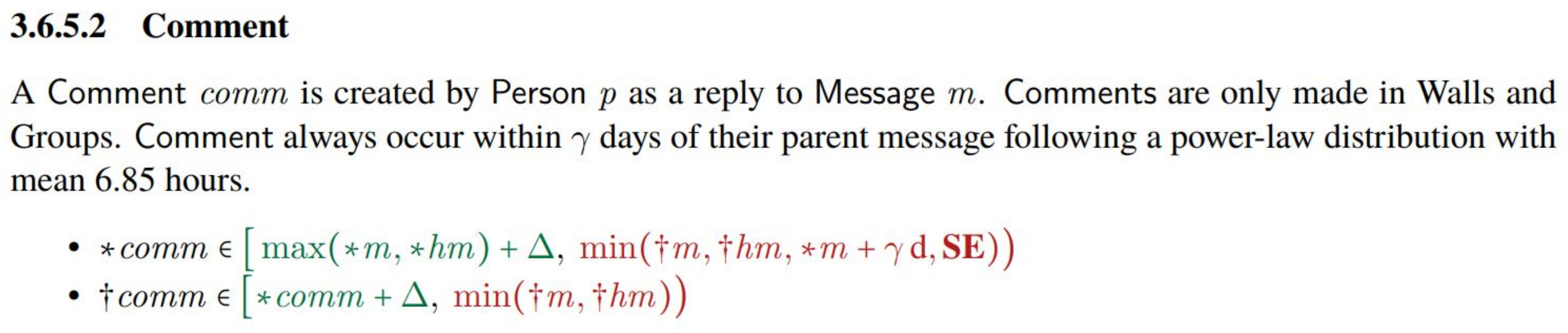
When can a Person-knows-Person edge exist? Its ∗*creation date* and †*deletion date* values are selected from intervals constrained by those of its Person endpoints.


SS
SE
NC
P_1
P_2
$\max(*P_1, *P_2) + \Delta$
$*\text{knows}_{1,2}$
Δ
$\min(\dagger P_1, \dagger P_2, \mathbf{SE})$
$*\text{knows}_{1,2} + \Delta$
$\dagger\text{knows}_{1,2}$
Δ
$\min(\dagger P_1, \dagger P_2)$
$\text{knows}_{1,2}$

📃 *Supporting fully dynamic graphs in LDBC SNB* [GRADES-NDA’20]

Lifespan management, example 2

To create a Comment, its parent Message and its creator Person has to exist and the person has to be a member (hm) of the Forum where the Message's root Post is located.

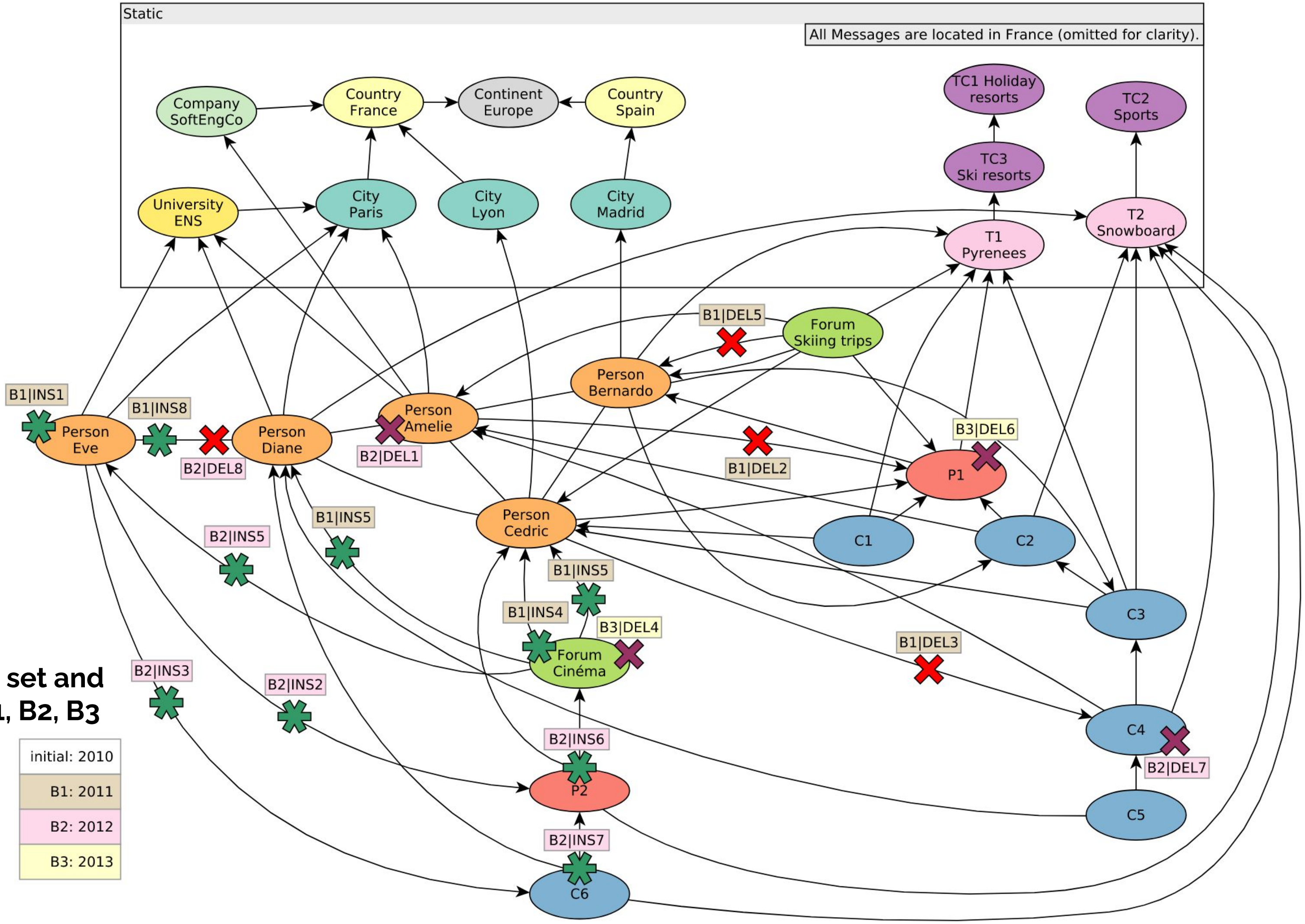


3.6.5.2 Comment

A Comment $comm$ is created by Person p as a reply to Message m. Comments are only made in Walls and Groups. Comment always occur within γ days of their parent message following a power-law distribution with mean 6.85 hours.

- $\ast comm \in \big[\max(\ast m, \ast hm) + \Delta,\ \min(\dagger m, \dagger hm, \ast m + \gamma\,\mathrm{d}, \mathbf{SE})\big)$
- $\dagger comm \in \big[\ast comm + \Delta,\ \min(\dagger m, \dagger hm)\big)$

📃 *Supporting fully dynamic graphs in LDBC SNB* [GRADES-NDA'20]



Initial data set and batches B1, B2, B3

initial: 2010
B1: 2011
B2: 2012
B3: 2013

Data sets

SNB Interactive data sets of SF0.1 to SF1000 are published at the SURF/CWI repository.

These data sets were generated using different serializers and partition numbers:

- Serializers:
  - csv_basic, csv_basic-longdateformatter
  - csv_composite, csv_composite-longdateformatter
  - csv_composite_merge_foreign, csv_composite_merge_foreign-longdateformatter
  - csv_merge_foreign, csv_merge_foreign-longdateformatter
  - ttl
- Partition numbers:
  - 2^k (1, 2, 4, 8, 16, 32, 64, 128, 256, 512, 1024)
  - 6×2^k (24, 48, 96, 192, 384, 768)

⚠️ The data sets are stored on tape and have to be staged to disks before downloading.

Workloads

- Interactive workload
- Business Intelligence workload

Comparison of workloads

	Business Intelligence v1.0	Interactive v1.0	Interactive v2.0
focus	OLAP	OLTP	OLTP
typical queries	multi-hop / path / subgraph queries with filtering & aggregation	2-3 hop top-k queries with filtering	2-3 hop top-k queries with filtering
data generator	Spark Datagen	Hadoop Datagen	Spark Datagen
refresh operations	inserts and deletes	inserts	inserts and deletes
target metric	throughput score power score	throughput (ops/s)	throughput (ops/s)
largest SF	10 000+	1 000	10 000+

Interactive workload

🔗 Specification

Interactive workload

Scenario: Users browsing a social network and producing content (Forums, Messages)

Queries: 14 complex reads, 7 short reads, 8 insert operations

Audit rules:

- Implementations using imperative code are allowed
- Defining materialized views is allowed if they are constantly maintained

✅ First audited benchmark in 2020, TuGraph by FMA Technologies (report)

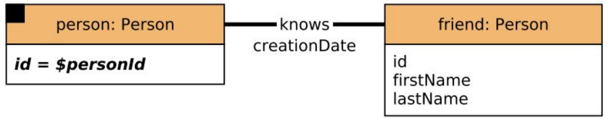
📃 SIGMOD’15 paper, slides

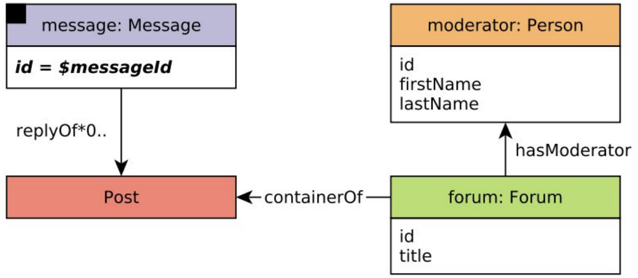
🔗 Benchmark page

Interactive workload: Queries

Complex queries: Always start from one or two Person nodes, and discover their neighbourhoods (1..2 nodes) or paths between Person nodes.

Short queries: Discover the neighbourhood of a Person or a Message node.

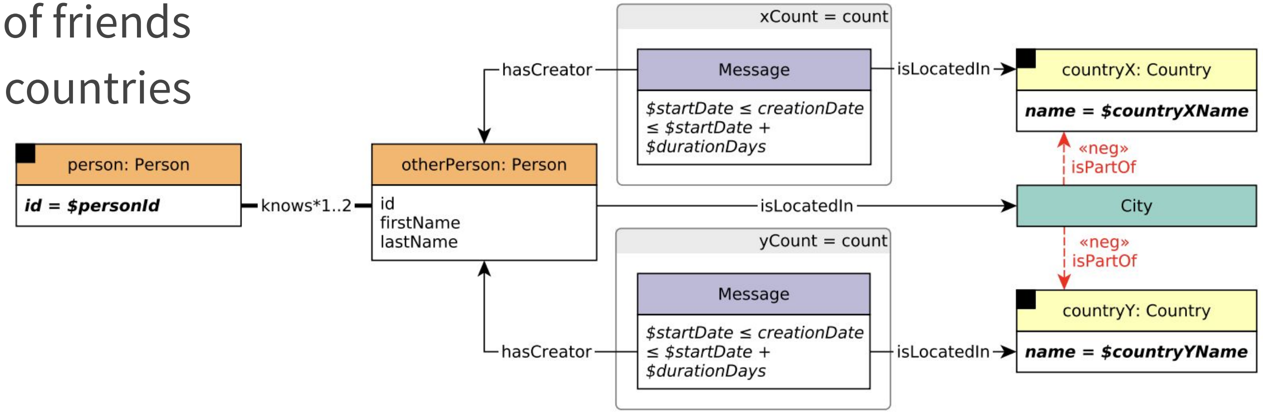




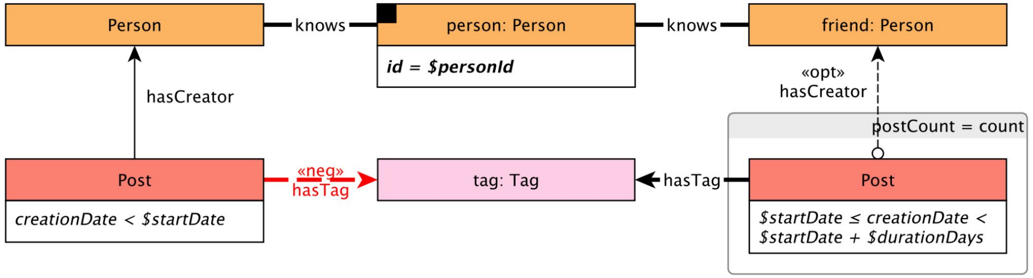
Insert operations: Each operation inserts a node (an connects it to its neighbourhood) or an edge between existing nodes.

Interactive workload: Complex queries

Q3: Friends and friends of friends that have been to given countries

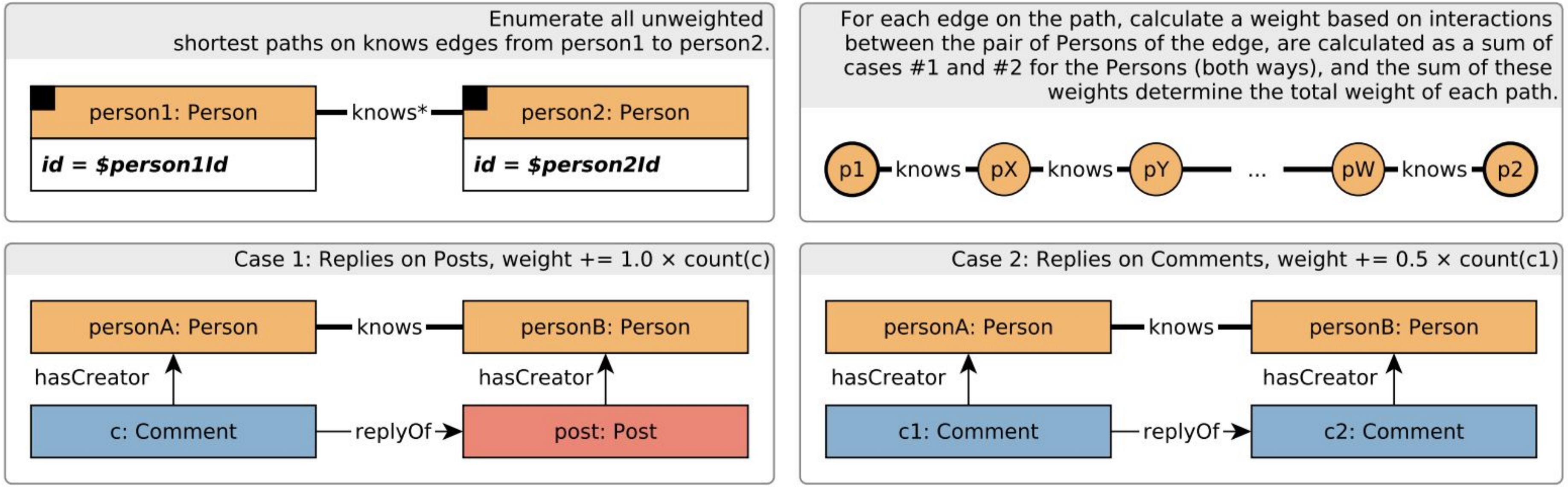


Q4: New topics



Interactive workload: Complex queries

Q14: Trusted connection paths


Enumerate all unweighted shortest paths on knows edges from person1 to person2.
person1: Person
id = $person1Id
knows*
person2: Person
id = $person2Id
For each edge on the path, calculate a weight based on interactions between the pair of Persons of the edge, are calculated as a sum of cases #1 and #2 for the Persons (both ways), and the sum of these weights determine the total weight of each path.
p1
knows
pX
knows
pY
...
pW
knows
p2
Case 1: Replies on Posts, weight += 1.0 × count(c)
personA: Person
knows
personB: Person
hasCreator
hasCreator
c: Comment
replyOf
post: Post
Case 2: Replies on Comments, weight += 0.5 × count(c1)
personA: Person
knows
personB: Person
hasCreator
hasCreator
c1: Comment
replyOf
c2: Comment

Interactive workload: Execution of queries

- **Insert operations' issue times are taken from the update streams generated by the data generator.** These are the times where the actual event happened during the simulation of the social network.
- **Complex reads' frequencies are expressed in terms of update operations.** For each complex read query type, a frequency value is assigned which specifies the relation between the number of updates performed per complex read.
- **For each complex read instance, a sequence of short reads is planned.** [...] The substitution parameters for short reads are taken from the results of previously executed complex reads and short reads. Once a short read sequence is issued (and provided that sufficient substitution parameters exist), there is a probability that another short read sequence is issued. This probability decreases for each new sequence issued. Since the same random number generator seed is used across executions, the workload is deterministic.

(See the specification for more details.)

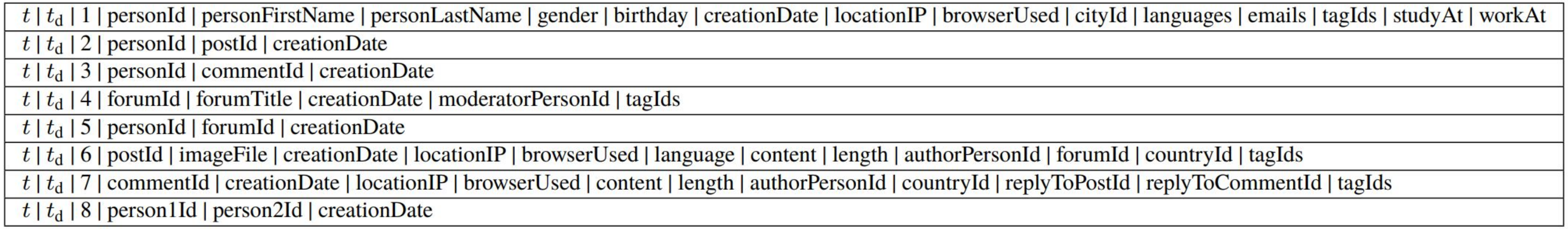
Interactive workload: Data set

The Datagen produces 3 years worth of data. From this data

- 90% is used the initial data set (separated into static/dynamic directories), and
- 10% is added later in the form of inserts (updates).

These inserts affect the entities in the “dynamic” category (e.g. Person/Message nodes, knows/likes edges). There are 8 insert operations, encoded in a variable-width CSV format:

- insert node: Person, Forum, Comment, Post
- insert edge: knows, hasMember, Comment-hasCreator-Person, Post-hasCreator-Person



t	t_d	1	personId	personFirstName	personLastName	gender	birthday	creationDate	locationIP	browserUsed	cityId	languages	emails	tagIds	studyAt	workAt
t	t_d	2	personId	postId	creationDate											
t	t_d	3	personId	commentId	creationDate											
t	t_d	4	forumId	forumTitle	creationDate	moderatorPersonId	tagIds									
t	t_d	5	personId	forumId	creationDate											
t	t_d	6	postId	imageFile	creationDate	locationIP	browserUsed	language	content	length	authorPersonId	forumId	countryId	tagIds		
t	t_d	7	commentId	creationDate	locationIP	browserUsed	content	length	authorPersonId	countryId	replyToPostId	replyToCommentId	tagIds			
t	t_d	8	person1Id	person2Id	creationDate											

Interactive workload: driver #1

The driver has 3 modes of operation, all starting with a database containing the initial data set.

1. Generate validation data set

- single-threaded, sequential execution
- input:
  - query parameters: `substitution_parameters/` dir
  - update streams: update streams directory with the `updateStream_0_0_{forum,person}.csv` files
- output:
  - `validation_params.csv` file

2. Validate implementation

- single-threaded, sequential execution
- input:
  - `validation_params.csv` file
- output:
  - passed/failed validation
  - if failed: expected vs. actual results

Interactive workload: driver #2

3. Execute benchmark

- multi-threaded, concurrent execution
  - some non-deterministic behaviour is possible due to concurrent execution
  - make sure your database client's connection pool support concurrent connections
- input:
  - **execution configuration values:** `warmup`, `operation_count`, and `time_compression_ratio`
  - **query frequencies:** e.g. `ldbc.snb.interactive.LdbcQuery1_freq` (need to be in sync with the SF)
  - **number of read threads:** `thread_count` value
  - **number of write threads:** based on the number of update streams. For 2*n* write threads, the framework requires *n* `updateStream_*_forum.csv` and *n* `updateStream_*_person.csv` files
  - **query parameters:** `substitution_parameters/` directory
- output:
  - passed/failed schedule audit
  - throughput (operations per second)
  - per-query performance results

Parameter selection

For each generated data set, the Datagen component creates *substitution parameters* (also known as “query parameters” and “query seeds”). Parameters are selected so that the *variance* of the expected execution times is limited. This is a non-trivial task as graph queries are prone to high-variance due to their skewed, power-law degree distribution (exhibited by e.g. the Person-knows-Person subgraph).

Path queries are especially tricky as the execution time has huge variance based on whether the path exist (usually quick to find) or does not exist (usually slow to prove).

There is a `txt` file for each query and each line them corresponds to a query execution.

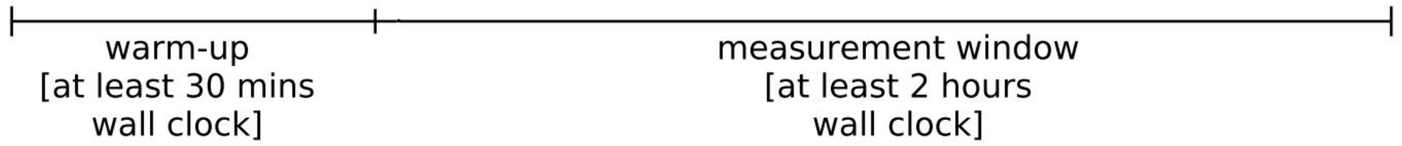
The datetime values in the `txt` files are represented as UNIX epoch values. The driver converts them into GMT-based timestamps.

📃 Parameter Curation for Benchmark Queries, TPCTC 2014

TCR and valid benchmark runs #1

Implementations compete on the throughput (operation/second), i.e. how quickly they can replay a sequence of operations. In the driver, the speed of the replay is defined by the total compression ratio (TCR) value. A TCR of 0.1 means the operations are played at 10x speed. A lower TCR is better as it indicates a higher throughput.

For a run to pass the audit, the implementation has to sustain its throughput for 2 hours (after a 30-minute initial warmup whose performance results are discarded).



TCR and valid benchmark runs #2

For a given SF/TCR, implementations have to satisfy the 95% on-time requirement:

In order to pass an audit, 95% of the executed queries must meet the following condition:

$$\mathit{actual\_start\_time} - \mathit{scheduled\_start\_time} < 1\ \mathit{second}$$

That is, 95% of the executed queries have to start in less than 1 second of their originally intended start time. If the system falls behind too much and less than 95% of the queries start on time, the run fails the audit.

In these cases, the test executor is advised to reduce the TCR and start another run.

⚠️ Due to potentially noisy execution environments and slight differences in individual runs (due to multi-threaded execution), it is recommended to leave a bit ‘in reserve’ when calibrating the TCR value.

Example graph

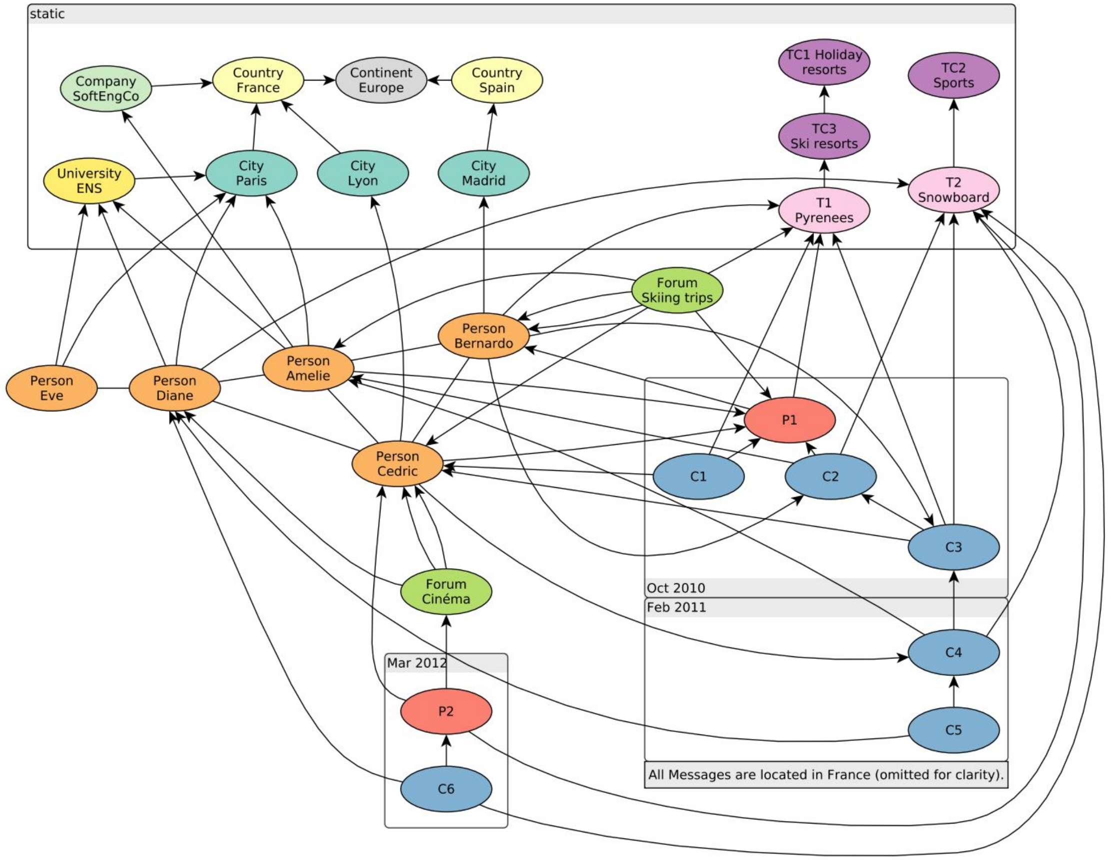
Example graph

Persons network

Forums

Message threads:

- root = Post
- other nodes = Comment



BI workload

🔗 Specification

- Analytical queries
- Cyclic subgraphs
- Shortest paths
- Inserts/deletes

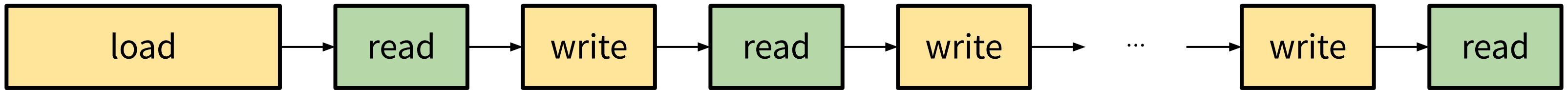
Business Intelligence workload

Scenario: Ad-hoc graph OLAP queries with daily updates

Workload:

- 20 complex read queries (some queries have a/b variants: 28 in total)
- Write operations: apply one day’s worth of updates

Reads and writes are run separately:



Benchmark workflow

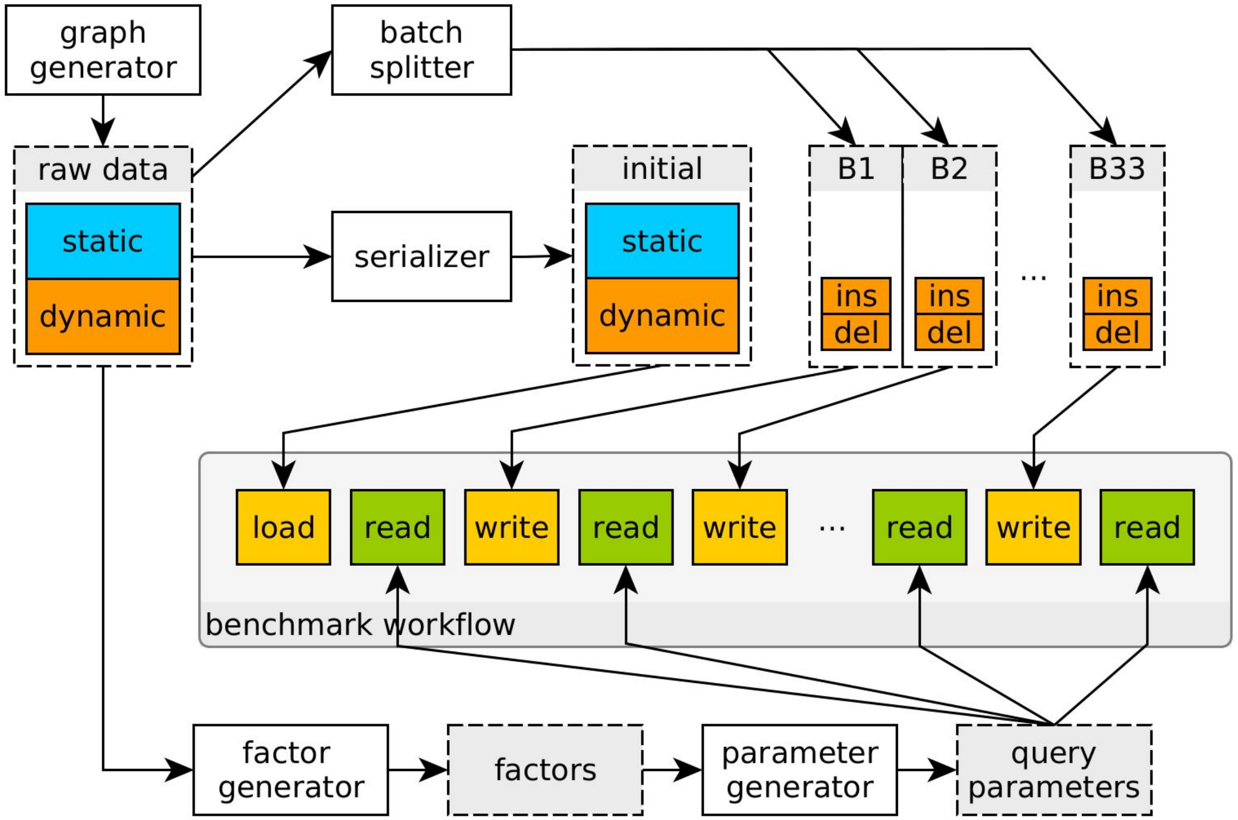
Load phase

Read phase

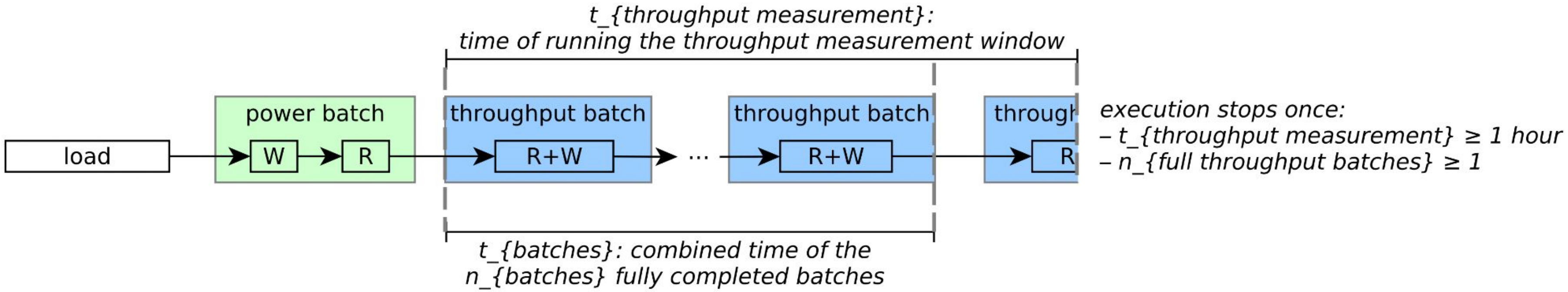
- Run 28 query variants
- 10 parameterized instances/variant
- Total 280 query instances

Write phase

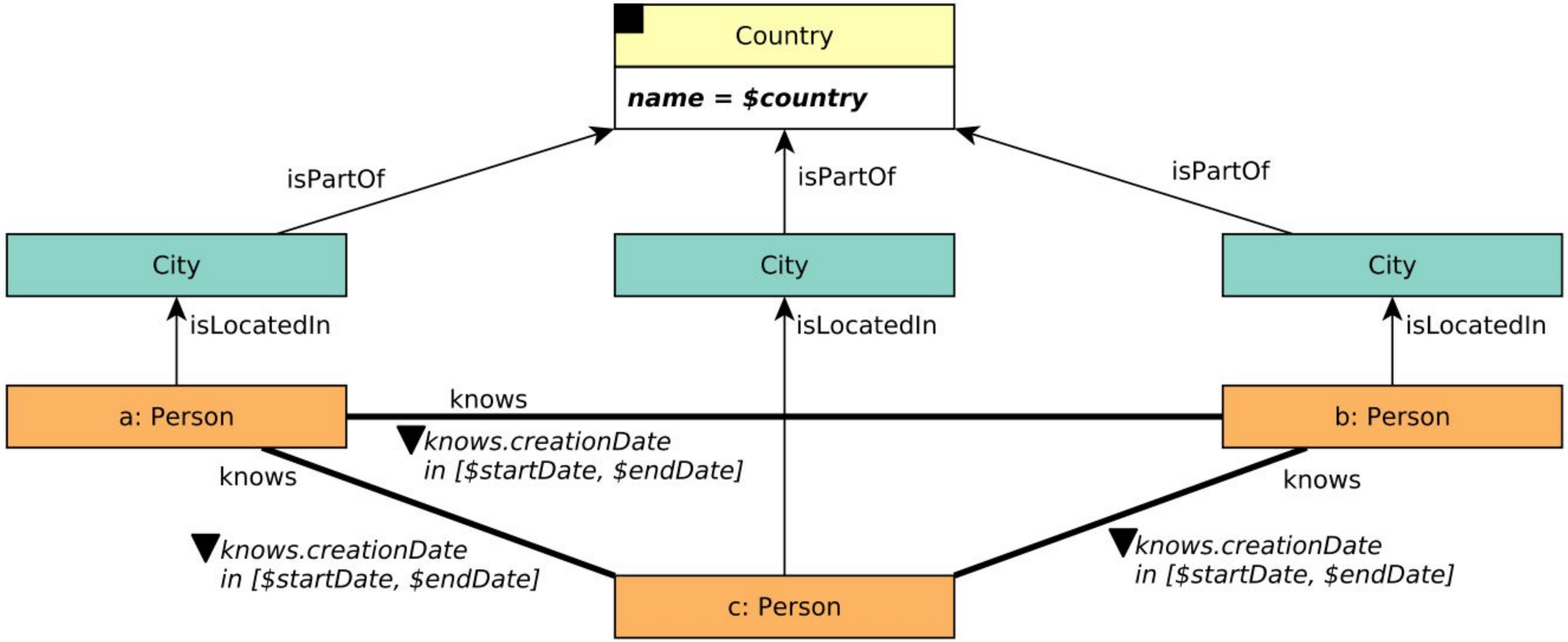
- 33 batches
- One batch = one day of inserts/deletes



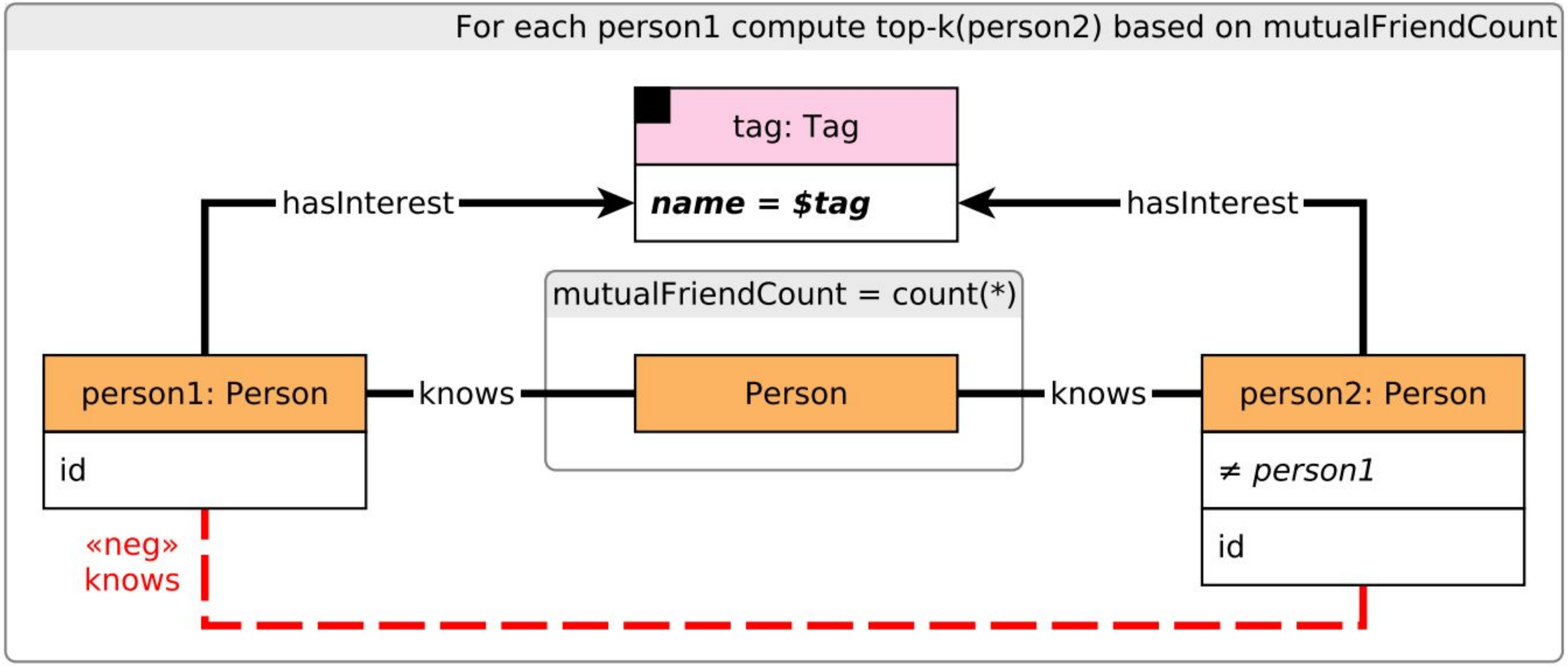
Test workflow


t_{throughput measurement}:
time of running the throughput measurement window
load
power batch
W
R
throughput batch
R+W
...
throughput batch
R+W
through
R
execution stops once:
– t_{throughput measurement} ≥ 1 hour
– n_{full throughput batches} ≥ 1
t_{batches}: combined time of the
n_{batches} fully completed batches

Q11: Triangle query (WCOJs are beneficial)



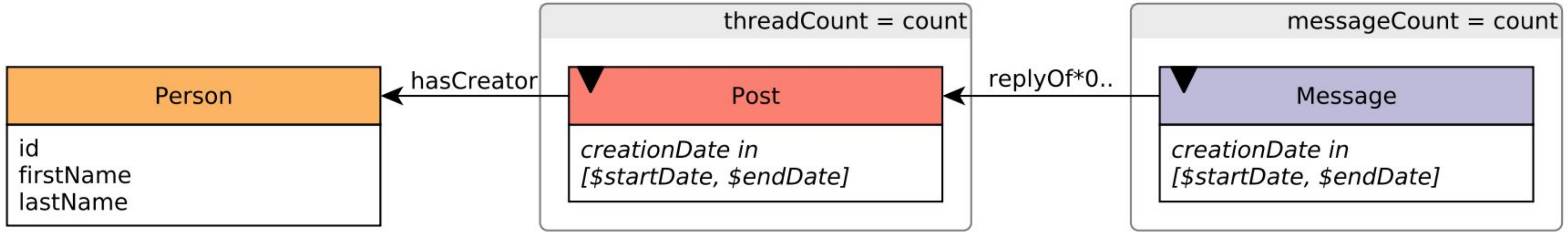
Q18: Diamond query (WCOJs are beneficial)



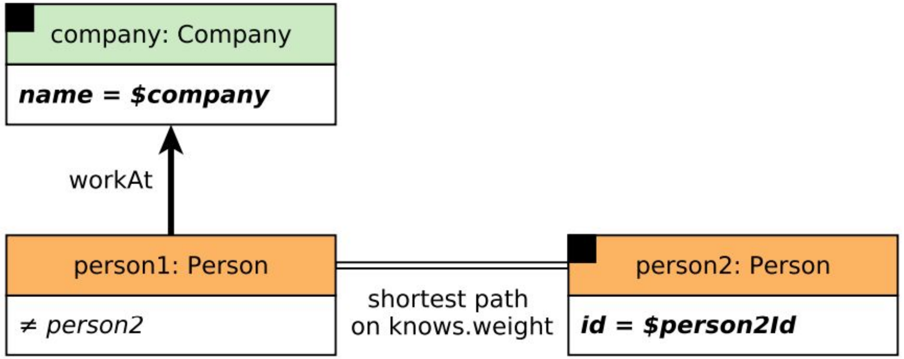
Q9: Message threads

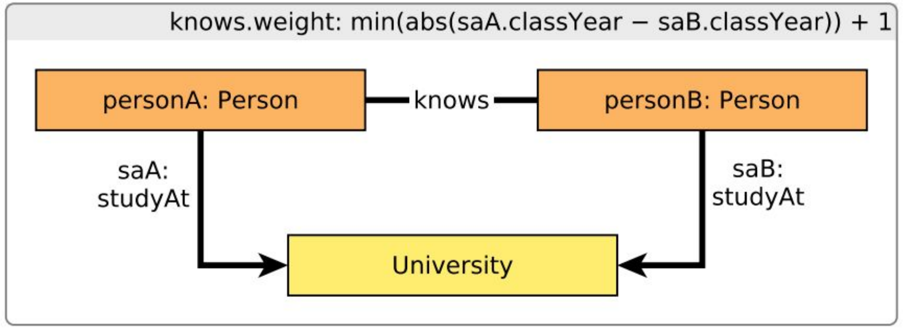
Traversing a message thread up/down is an important kernel in other queries.

Materializing the "root Post" of a Message thread seems useful.

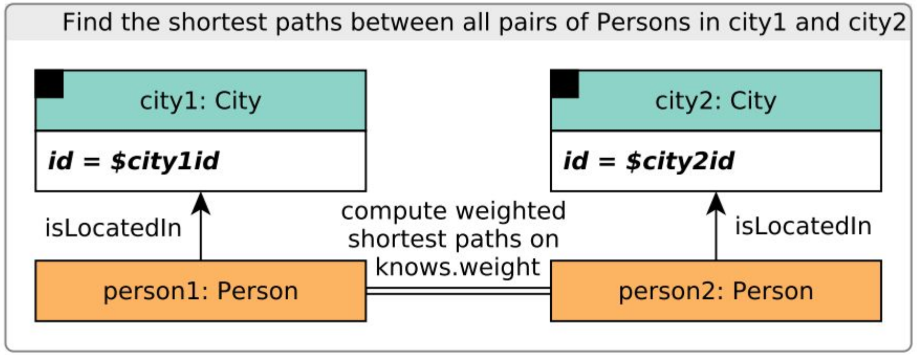


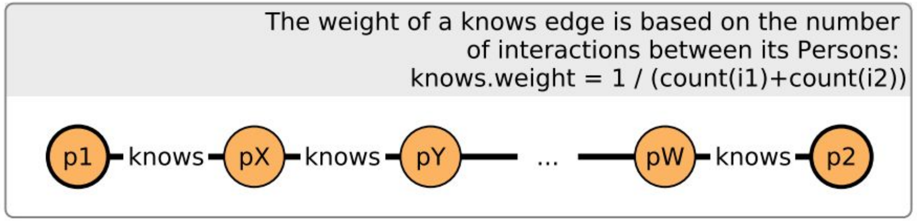
Q20: Single-source multi-destination shortest p.

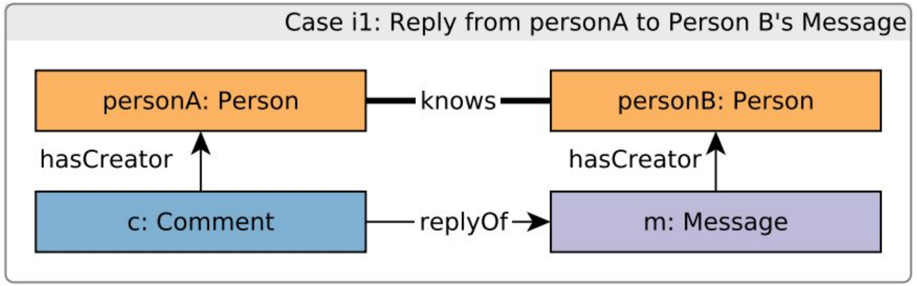


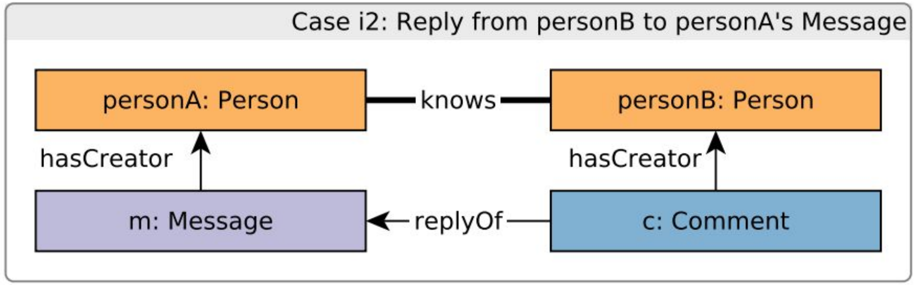


Q19: Multi-source multi-destination shortest p.


Find the shortest paths between all pairs of Persons in city1 and city2
city1: City
id = $city1id
city2: City
id = $city2id
isLocatedIn
compute weighted shortest paths on knows.weight
isLocatedIn
person1: Person
person2: Person


The weight of a knows edge is based on the number of interactions between its Persons: knows.weight = 1 / (count(i1)+count(i2))
p1
knows
pX
knows
pY
...
pW
knows
p2





Parameter generator

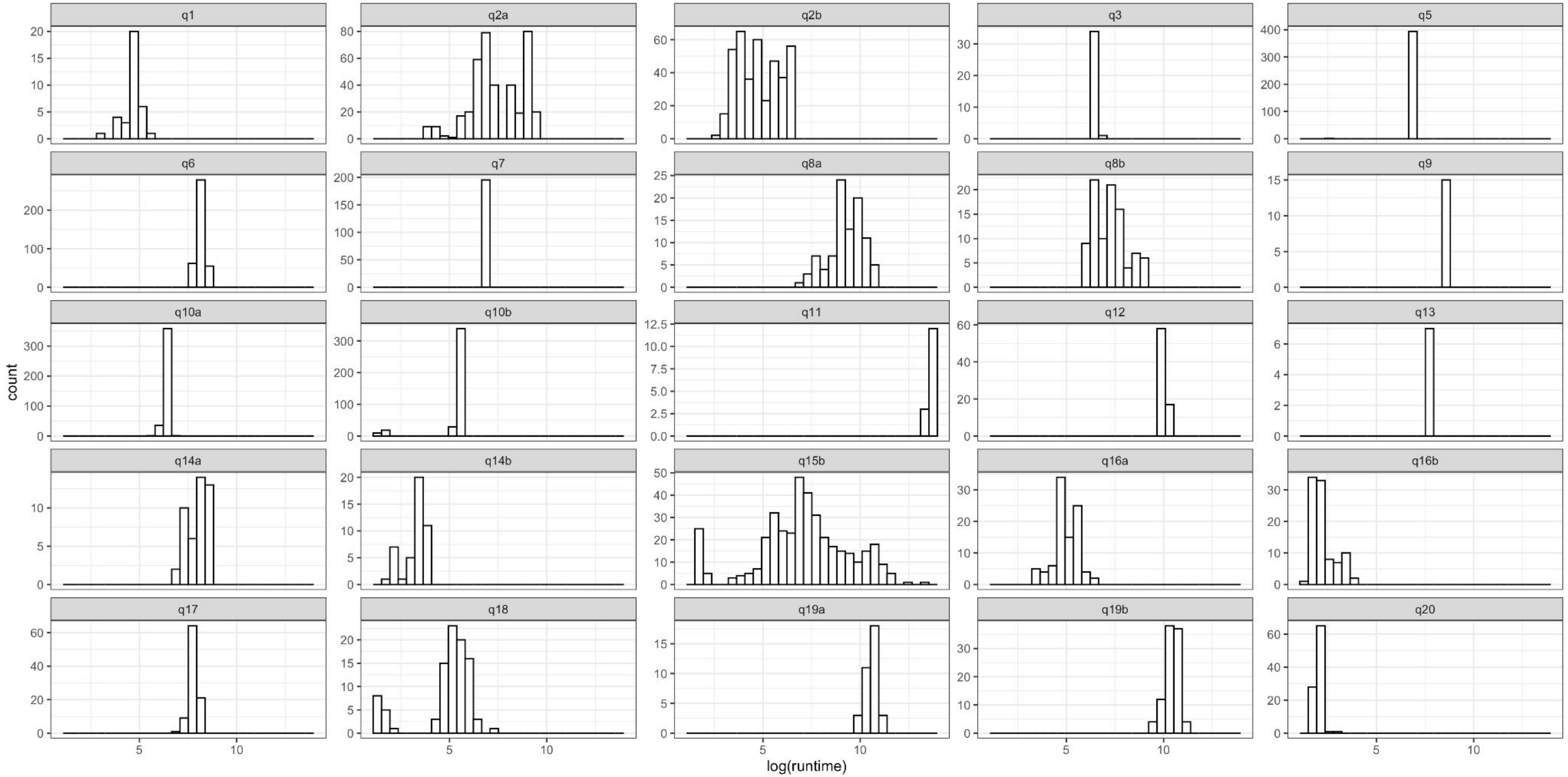
Goal: Ensure that runtimes for a given query variant follow a *unimodal normal distribution*.

(raw data)

—[Spark DataFrames API]—>(factor tables)

—[parameter queries]—>(parameters)

Parameter generation: 25 query variants tuned



BI implementations

● Neo4j	Cypher
● TigerGraph	GSQL
● PostgreSQL (partial)	SQL
● Umbra (partial)	SQL

SQL implementations lack support for the path queries

Ongoing developments for BI

Completed tasks:

- factor table generation ✅
- loading from compressed CSVs ✅
- script to create validation parameters (for cross-validating implementations) ✅
- parameter generation (based on the factors) ✅
- add instrumentation to save runtimes and result to a file ✅

Ongoing tasks:

- Umbra implementation (ported from Postgres) ✅
- visualize results (PR) (initial distribution ✅)
- decide exact workflow(s): **power test**/~~throughput test~~, metrics
- allow the driver to distinguish between “warm-up” and “measurement window” phases
- define metrics for performance (e.g. geometric mean for reads and for updates)

SNB BI publications

Papers:

🔗 Specification

📃 GRADES-NDA’18 paper, slides

BI auditing rules

Audit rules:

- Precise auditing rules are yet to be defined

What is already clear:

- Must use a domain-specific query language
  unlike Interactive where imperative languages can be used
- Views are allowed iff they are maintained
  same as Interactive but maintenance is easier due to daily batch updates

Query design

Choke points and parameters

- Intended query plan
- Choke point analysis
- Parameter curation

Query templates and parameters

Queries are given using a **query template** which can have multiple **input parameters**.

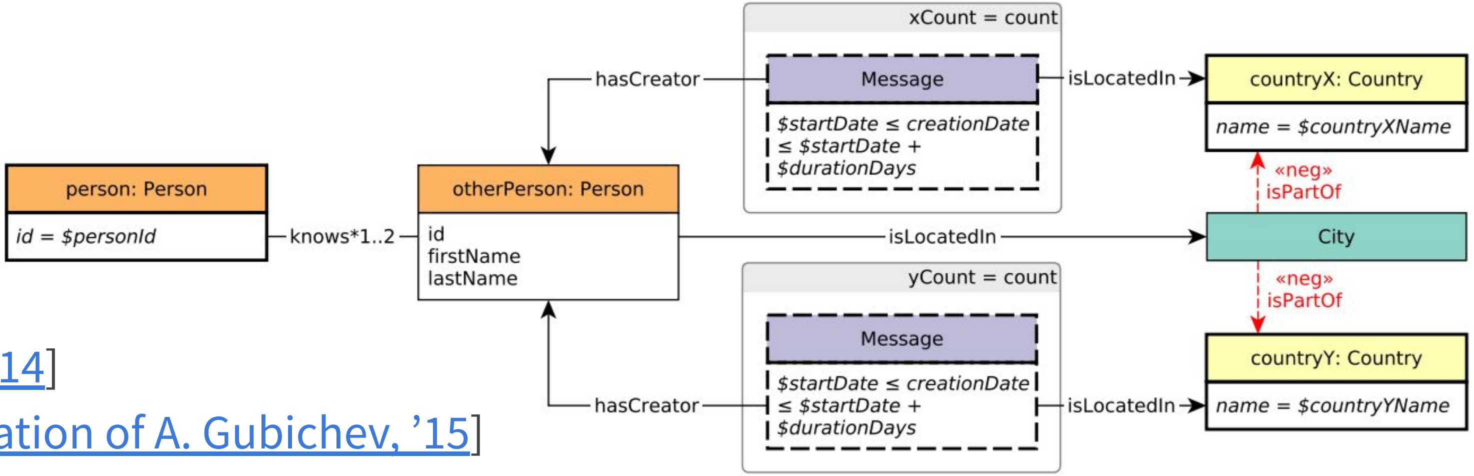
These are **substituted for with different parameters** during execution.

The parameters are produced by the **Paramgen** component of Datagen.

Intended query plan

The **intended query plan** of a query is the ideal execution plan to evaluate that query. E.g. in Interactive Q3 params can be chosen to produce a large or a small result:

● Neighbouring countries	X = Belgium	Y = France
● Far away countries	X = Mexico	Y = Japan



[TPCTC’14]

[Dissertation of A. Gubichev, ’15]

Choke points

A choke point is a **difficult aspect of query processing** that has a significant impact on the performance of the query *when evaluated using the intended query plan*.

The TPCTC'12 paper analyzed TPC-H based on the lessons learnt when implementing the benchmark on Vectorwise, Virtuoso, and HyPer.

Examples:

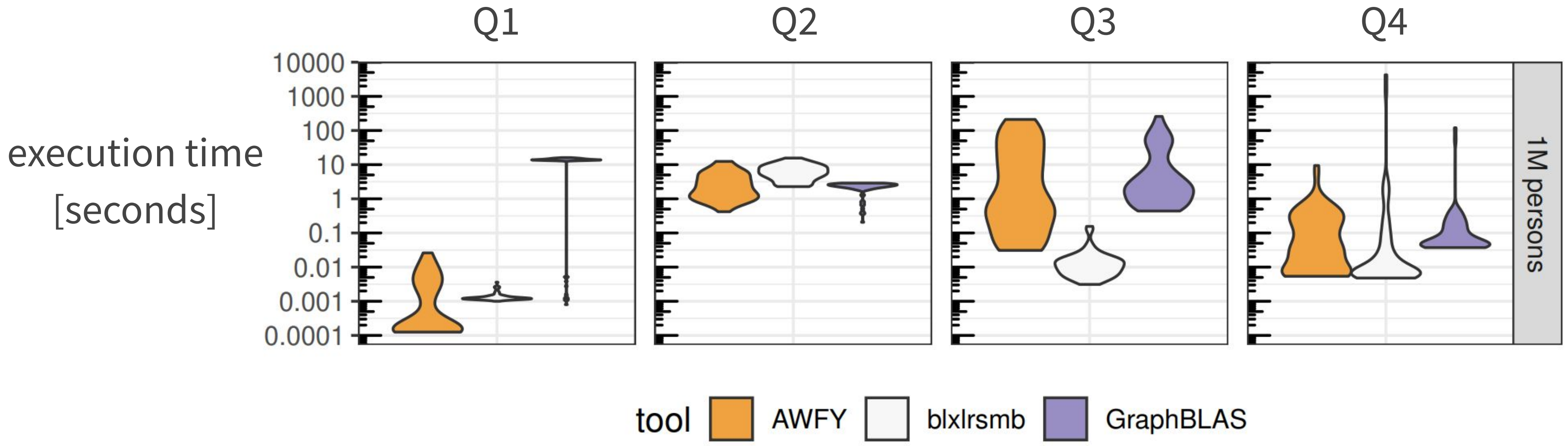
- Join ordering
- Efficient antijoins and outer joins
- Handling paths

📃 TPC-H choke points [TPCTC'12], Quantitative analysis of TPC-H CPs [VLDB'20]

Parameter curation

Goal: Reduce variance of query execution times, make results easier to interpret.

A negative example: Q1-Q4 of the SIGMOD 2014 Contest *without parameter curation*



📃 *A GraphBLAS solution to the SIGMOD 2014 Programming Contest* [HPEC'20]

Selecting entities for deletes

One can think of this as a special case of parameter curation: based on whether we select a Person

- with many friends and a lot of content or
- with little activity

The cost of performing the delete operation varies significantly.

⏳ This is currently being worked out as part of tuning the distribution of the deletes.

Some of the guiding principles

Both the choke point analysis and the parameter curation process are based on the **intended query plan**.

The **substitution parameters must specify existing entities**.

- Read query parameters must specify existing entities
- Insertions must connect to existing nodes
- Deletions must target existing entities

The Ecosystem of the LDBC SNB

- Specification
- Datagen
- Driver
- Implementations

Specification

Challenges:

- Coming up with a representative workload which has the “optimum” difficulty
- Establishing auditing rules (inspired by TPC)
- Specifying queries in an unambiguous way
- Creating a graphical notation (inspired by the graph transformation community)

We believe to have successfully tackled these in the latest specification.

📃 [specification]

Driver

Lots of challenges regarding concurrent execution: tracking dependencies between refresh operations while maintaining a high throughput.

The driver implements these features in Java and is by far the largest project in SNB:

- main project: 38k LOC
- tests: 22k LOC

The new BI queries and deletes are already supported by the driver.

⏳ Adding support for batched refresh operations is ongoing work.

📃 EU Deliverable “Benchmarking transactions” [D2.2.3]

Implementations

Reference implementations:

- PostgreSQL [SQL]: a row-oriented RDBMS
- Neo4j [Cypher]: a graph database management system
- DuckDB [SQL]: a column-oriented OLAP RDBMS with a vectorized runtime
- Umbra [SQL]: a column-oriented HTAP RDBMS with a compiled runtime, WIP

Audited systems:

- Sparksee (2015)
- Virtuoso (2015)
- FMA TuGraph (2020)
- More coming…

Auditing process

- Ensure objective comparison
- Drive competition among vendors

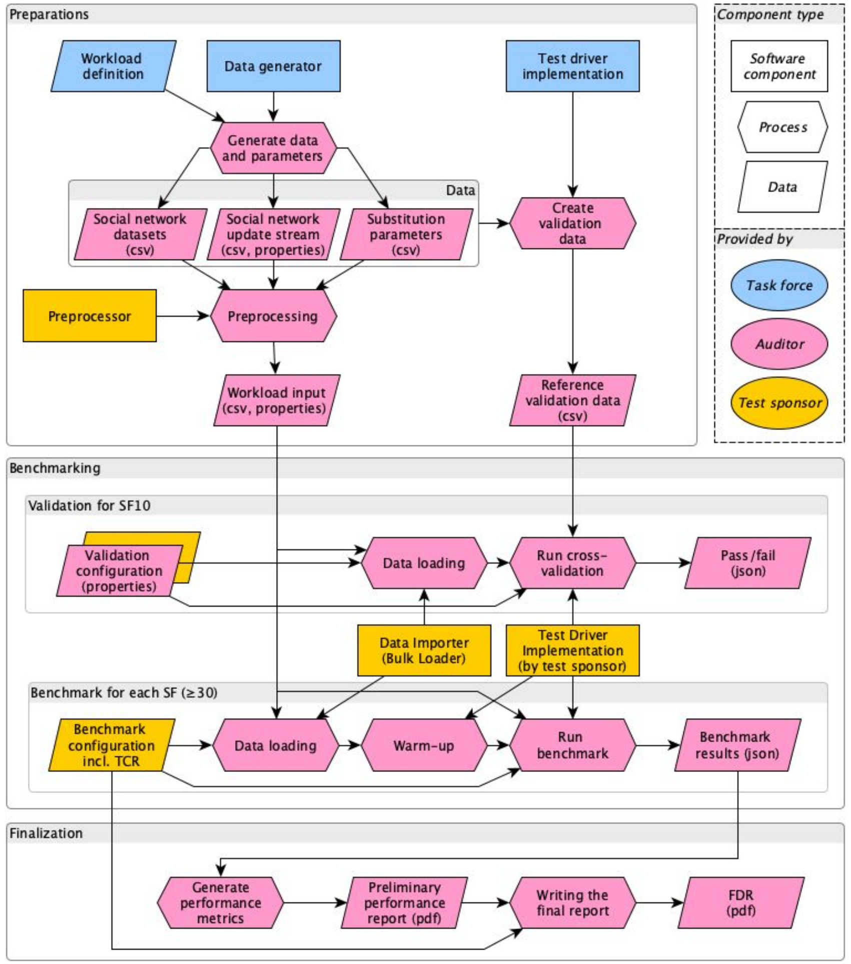
Auditing guidelines

Complex workflow to ensure fair comparison.

TPC has lots of rules to prevent cheating (including the use of “benchmark specials”), sometimes going as far as deprecating entire benchmarks such as TPC-D.

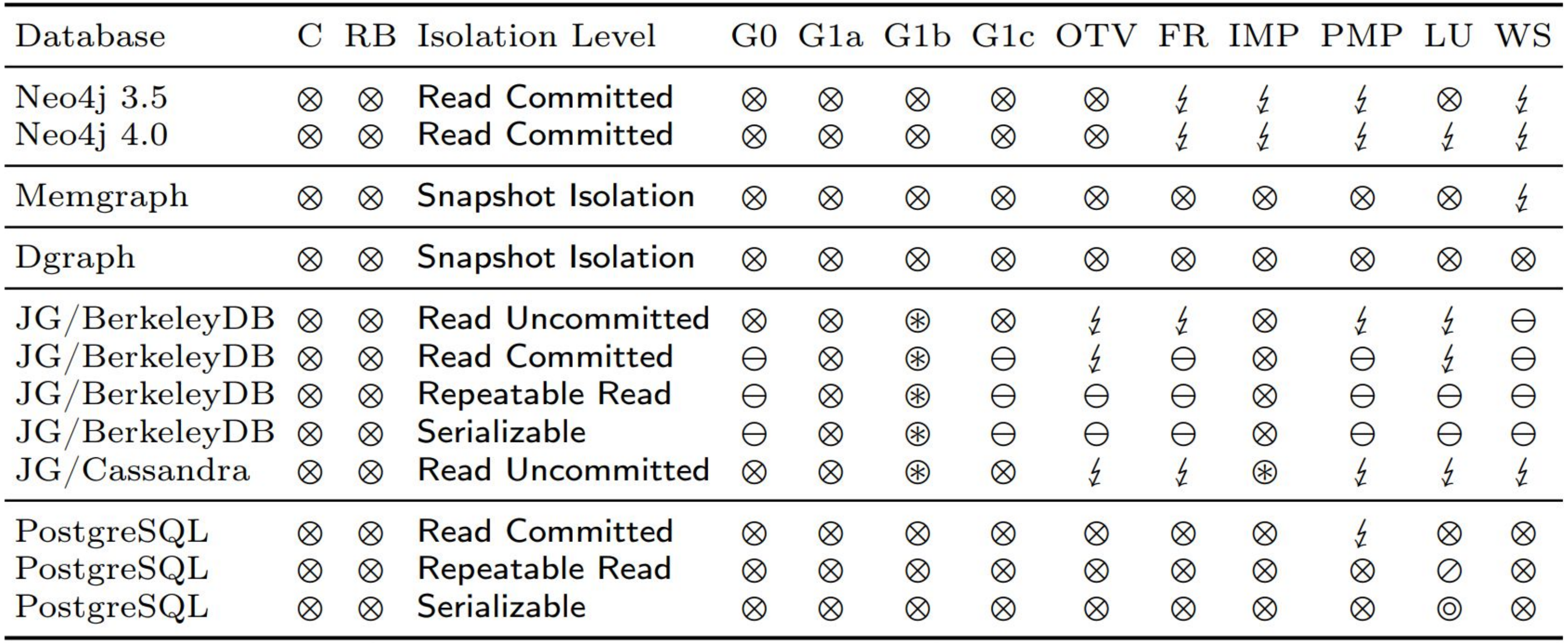
For **LDBC**, audited benchmark results:

- Are produced by an independent auditor
- Can be published as “LDBC benchmark results”


Preparations
Workload definition
Data generator
Test driver implementation
Generate data and parameters
Data
Social network datasets (csv)
Social network update stream (csv, properties)
Substitution parameters (csv)
Create validation data
Preprocessor
Preprocessing
Workload input (csv, properties)
Reference validation data (csv)
Component type
Software component
Process
Data
Provided by
Task force
Auditor
Test sponsor
Benchmarking
Validation for SF10
Validation configuration (properties)
Data loading
Run cross-validation
Pass/fail (json)
Data Importer (Bulk Loader)
Test Driver Implementation (by test sponsor)
Benchmark for each SF (≥30)
Benchmark configuration incl. TCR
Data loading
Warm-up
Run benchmark
Benchmark results (json)
Finalization
Generate performance metrics
Preliminary performance report (pdf)
Writing the final report
FDR (pdf)

ACID tests

Ensure that the isolation level claimed by the DBMS is enforced. 📃 [TPCTC’20]



Database	C	RB	Isolation Level	G0	G1a	G1b	G1c	OTV	FR	IMP	PMP	LU	WS
Neo4j 3.5	⊗	⊗	Read Committed	⊗	⊗	⊗	⊗	⊗	↯	↯	↯	⊗	↯
Neo4j 4.0	⊗	⊗	Read Committed	⊗	⊗	⊗	⊗	⊗	↯	↯	↯	↯	↯
Memgraph	⊗	⊗	Snapshot Isolation	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	↯
Dgraph	⊗	⊗	Snapshot Isolation	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗
JG/BerkeleyDB	⊗	⊗	Read Uncommitted	⊗	⊗	⊛	⊗	↯	↯	⊗	↯	↯	⊖
JG/BerkeleyDB	⊗	⊗	Read Committed	⊖	⊗	⊛	⊖	↯	⊖	⊗	⊖	↯	⊖
JG/BerkeleyDB	⊗	⊗	Repeatable Read	⊖	⊗	⊛	⊖	⊖	⊖	⊗	⊖	⊖	⊖
JG/BerkeleyDB	⊗	⊗	Serializable	⊖	⊗	⊛	⊖	⊖	⊖	⊗	⊖	⊖	⊖
JG/Cassandra	⊗	⊗	Read Uncommitted	⊗	⊗	⊛	⊗	↯	↯	⊛	↯	↯	↯
PostgreSQL	⊗	⊗	Read Committed	⊗	⊗	⊗	⊗	⊗	⊗	⊗	↯	⊗	⊗
PostgreSQL	⊗	⊗	Repeatable Read	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊘	⊗
PostgreSQL	⊗	⊗	Serializable	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	◎	⊗

The essential complexity of graph DB benchmarks

Why are the SNB Interactive/BI workloads so complex?

- Real graph data is correlated [TPCTC'12]
  - Graph data generator with correlations
  - Scalability is important -> distributed generator
  - Need to support multiple layouts (merged FK/projected FK)
- A mature database system has dozens of intertwined optimizations [TPCTC'13]
  - Characterized by choke points in the context of TPC-H
  - ~30 choke points (aggregation, join, data access locality, expressions, correlation, parallelism)
- Benchmark needs parameterized queries [TPCTC'14]
  - Some warmup is required but many systems cache results -> queries need to be parameterized
  - Parameter selection needs to be done carefully to make query times predictable
- Issuing updates needs a sophisticated driver [SIGMOD'15]
  - Update streams need to be able to run concurrently without cross-stream dependencies
- Updates are required to discourage read-only data structures [GRADES-NDA'20]
  - Without updates, materialization of partial results could give an unfair advantage
  - Introducing deletions needs lifespan management
- ACID compliance is required [TPCTC'20]
  - It is difficult to test within the full benchmark, needs a separate benchmark suite

LSQB

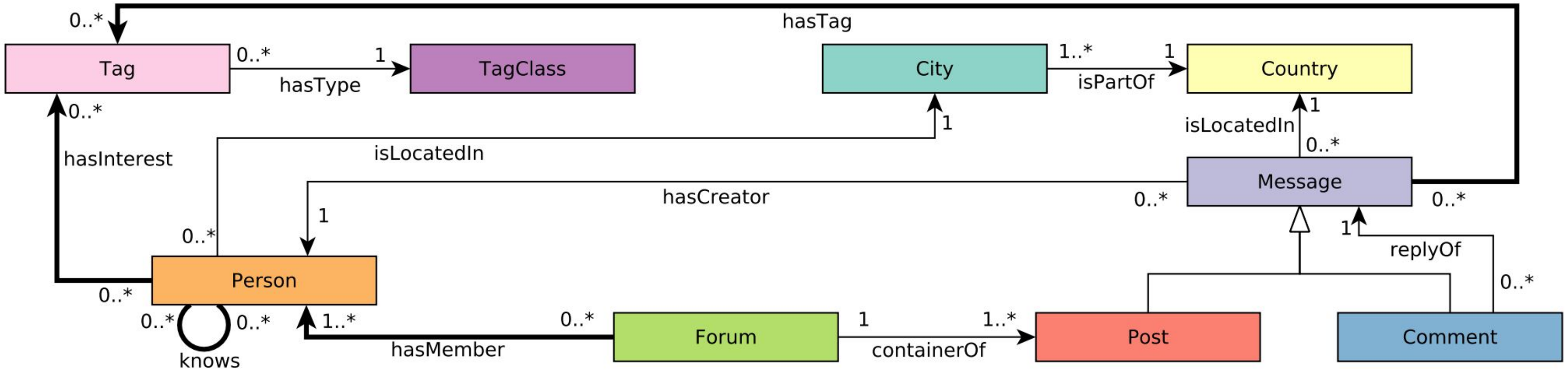
Labelled Subgraph Query Benchmark

LSQB: Labelled Subgraph Query Benchmark

Note: This in not an official LDBC benchmark but a microbenchmark for developers

Reuse Datagen from the LDBC SNB:

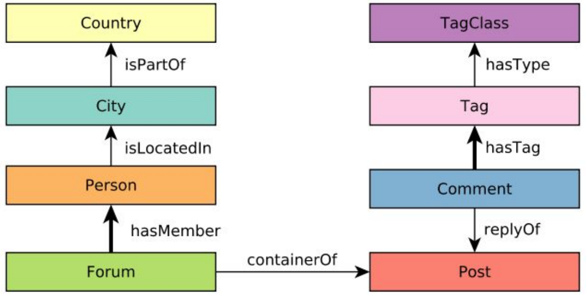
- Same scale factors, same vertex and edges labels
- Lots of many-to-many cardinality edges with interesting distributions
- No updates, no properties, just INT64 identifiers



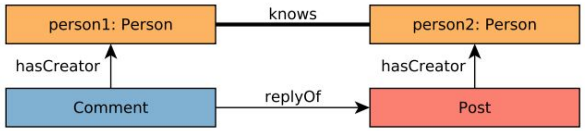
Basic graph patterns

Simplified the queries from the BI workload

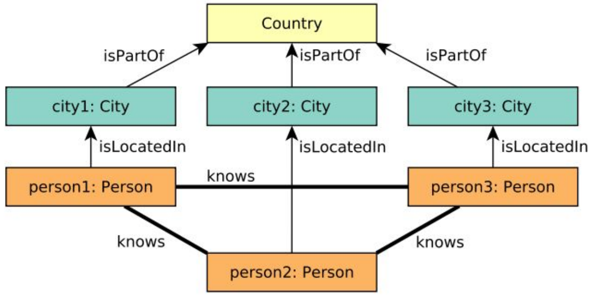
All queries are global and use `count(*)` aggregation



Q1: long path

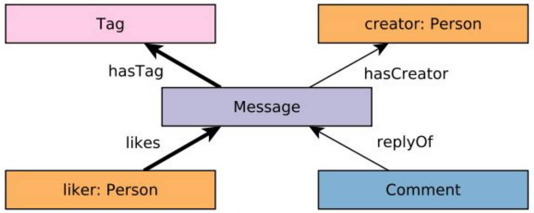


Q2: simple cycle

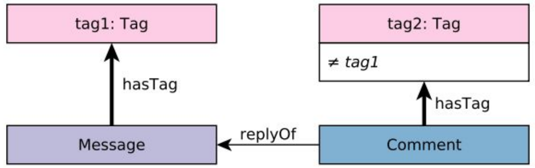


Q3: triangle

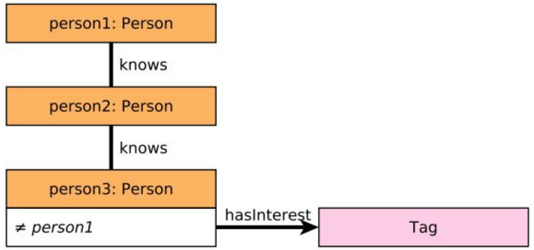
Basic and complex graph patterns



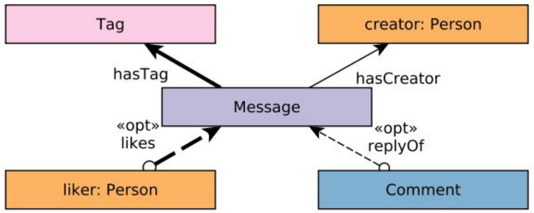
Q4: star



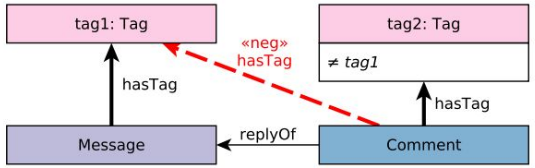
Q5: low-cardinality path



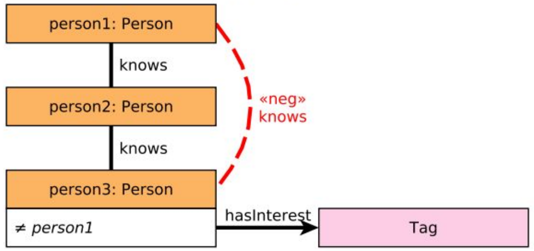
Q6: high-cardinality path



Q7: star
with optional edges



Q8: low-cardinality path
with negative condition



Q9: high-cardinality path
with negative condition

Future work

Future work

⚙️ **Continuous:** We support the adoption of this benchmark and help audits

💡 **New benchmarks:** There are many possibilities to discover, including

- a benchmark with “financial fraud detection”-like queries
- streaming/temporal graph queries
- machine learning (embeddings, GNNs)

We are happy to discuss proposed new graph benchmarks. Feel free to reach out at info@ldbcouncil.org

LDBC

The graph & RDF benchmark reference

Implementing the SNB

Implementation guidelines

- For best performance, using multiple read and write threads is a must. These are configurable separately (see the Interactive repository's README).
- For the Interactive workload, using imperative code is allowed for all queries, including complex, short, update, and ACID test queries.
- For BI, all queries and insert/delete operations must use a domain-specific language.

Creating a new SNB Interactive implementation

Steps to create an auditable SNB Interactive implementation

Creating a new SNB Interactive implementation #1

It is recommended to base a new implementation on an existing one:

- Graph DBMSs: use the Neo4j/Cypher or the TigerGraph/GSQL implementation
- Relational DBMSs: use the PostgreSQL or the Microsoft SQL Server implementation

Pick a data set serializer. In general:

- Graph DBMSs: use data sets produced by the CsvComposite serializer
- Relational DBMSs: use data sets produced by the CsvMergeForeign serializer

Creating a new SNB Interactive implementation #2

1. Generate or download the required data sets and query substitution parameters.
   a. Use SF10 for cross-validation.
   b. For benchmarks, SF30+ is required.
2. Fork the SNB Interactive repository and create a new Maven subproject.
3. Add a **Java client** to the DBMS as a Maven dependency (e.g. `org.postgresql:postgresql`)
4. Implement a **bulk loader** which loads the initial data set. Test it with a small data set (available in the `cypher/test-data/` and `postgres/test-data/` directories), then proceed to larger data sets.
5. Implement the **complex read queries**:
   a. Create the query implementations and their glue code in the `*Db` and `*QueryStore` classes.
   b. Turn the update and short operations off, then use the ***create-validation-parameters*** **mode** to generate the validation data set with an existing implementation.
   c. Use the ***validation*** **mode** to check the correctness of the queries on the SF10 data set.

Creating a new SNB Interactive implementation #3

6. Implement the **short read queries** and the **insert operations**:
   a. Implement the 7 short queries and 8 insert operations and their glue code.
   b. Create a full validation data set and cross-validate the new implementation against it on SF1 and SF10. Note that the database has to be reset to its initial state between runs: use the `scripts/snapshot-database.sh` and `scripts/restore-database.sh` scripts.
7. Use the ***benchmark* mode** to perform a benchmark run.
8. Determine the **best `total_compression_ratio` value** for benchmarks.
   a. The `driver/determine-best-tcr.sh` script can help find this value.
   b. Ensure that the warmup plus benchmark runs execute for 2.5h+ in total.
9. Implement the **ACID test suite** and ensure that the system passes it.
10. Perform a **recovery test** by killing the system during a benchmark run (e.g. `kill -9`, `reboot`) and checking whether the inserted entities are in the database after restarting.

Creating a new SNB Business Intelligence implementation

Steps to create an auditable SNB BI implementation

Creating a new SNB BI implementation #1

It is recommended to base a new implementation on an existing one:

- Graph DBMSs: use the Neo4j/Cypher or the TigerGraph/GSQL implementation
- Relational DBMSs: use the Umbra implementation

Pick a data set serializer. As a general rule of thumb:

- Graph DBMSs: use the `csv-composite-projected-fk` data sets
- Relational DBMSs: use the `csv-composite-merged-fk` data sets

Creating a new SNB BI implementation #2

1. Generate or download the required data sets and query substitution parameters.
    a. Use SF10 for validation
    b. For benchmarks, SF30+ is required.
2. Fork the SNB BI repository and create a new directory with the required Python and shell scripts.
3. Implement a **bulk loader** which loads the initial data set.
4. Implement the **20 read query templates.**
5. Cross-validate the read queries using the `--queries` flag of the benchmark script. It is recommended to start with a small scale factor, e.g. the SF0.003 sample data set and proceed gradually towards the SF10 data set.
6. Implement **the update operations (inserts and deletes).**
7. Cross-validate the read queries and updates using the `--validate` flag of the benchmark script.

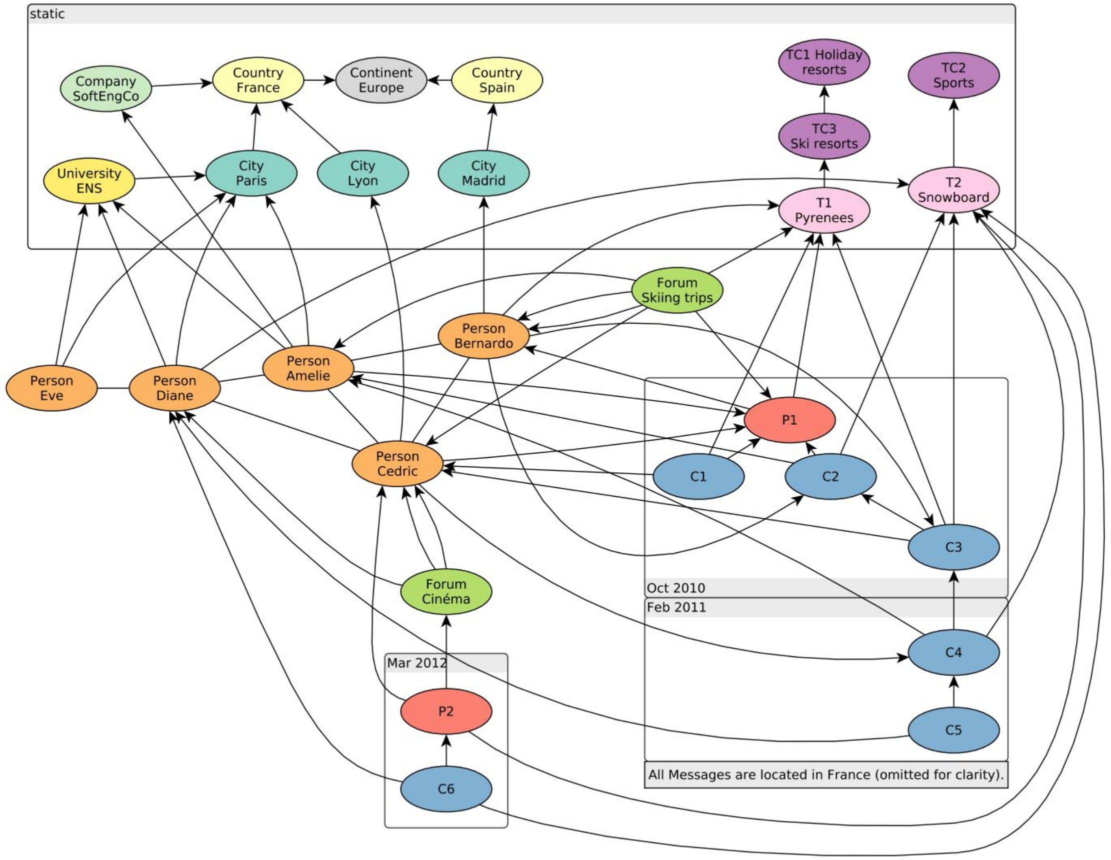
Creating a new SNB BI implementation #3

8. Decide on whether to use concurrent read and write operations. If so:
    a. Adjust the benchmark script such that the throughput batches use concurrent RWs.
    b. Implement the **ACID test suite** and ensure that the system passes it.
    c. Perform a **recovery test** by killing the system during a benchmark run (e.g. `kill -9`, `reboot`) and checking whether the inserted entities are in the database after restarting.
9. Use the **benchmark mode** (`run-benchmark.sh` script) to perform a benchmark run on small data sets.
10. Test the implementation on the scale factor(s) used for the benchmark (e.g. SF3,000 and SF10,000).

Example graph

Example graph

~30 nodes and ~60 edges



LDBC

The graph & RDF
benchmark reference