The most prominent knowledge bases do not support SPARQL time-traversal queries

Verifiability, not truth. We need provenance

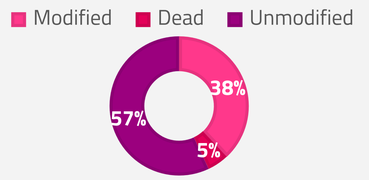
"The threshold for inclusion in Wikipedia is verifiability, not truth" (Garfinkel 2008)

- **Trustworthiness** must be evaluated by each application probing by the **context** of the statements
- **Provenance**: people, institutions, entities, and activities involved in producing, influencing, or delivering data

Data evolves. We need change-tracking

- Natural **evolution** of **concepts**, related to a change of place, jurisdiction, subjective perception of the receiver
- Correction of **mistakes**
- The latest version of knowledge may not be the most accurate

90,000 RDF DOCUMENTS MONITORED FOR 29 WEEKS (KÄFER ET AL. 2013)



We need provenance and change-tracking in RDF

- The **most extensive RDF datasets** – DBPedia, Wikidata, Yago, and the Dynamic Linked Data Observatory – do **not** use RDF to **track changes** and **provenance**. Some of them, such as YAGO 4, record provenance but not changes
- Therefore, such knowledge bases do not allow users to perform time-traversal SPARQL queries

Objective

- A methodology to perform **SPARQL time-traversal queries** on RDF datasets and **software** based on this procedure
- Enabling all the time-related **retrieval functionalities** defined by (Fernández et al., 2016) **live**

Time-related retrieval functionalities

- **Version materialization (VM)**: retrieves data using a query targeted at a single version
- **Delta materialization (DM)**: retrieves query's result change sets between two versions
- **Version query (VQ)**: annotates a query's results with the versions in which they are valid
- **Cross-version join (CV)**: joins the results of queries between different versions
- **Change materialization (CM)**: returns a list of versions in which a given query produces consecutively different results

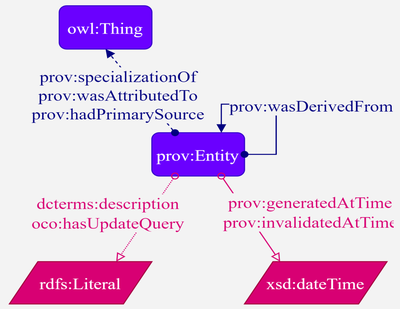
The OpenCitations provenance model was adopted to manage both provenance and change-tracking

Representing provenance in RDF

- Origin of the **first sin**: RDF 1.0 and **RDF Reification**
- Many alternatives have no concrete implementation and are only **theoretical models** (Sikos et al. 2020)
- **Named Graphs** and the **Provenance Ontology** are the most adopted approaches
- Recent promising solution: **RDF***

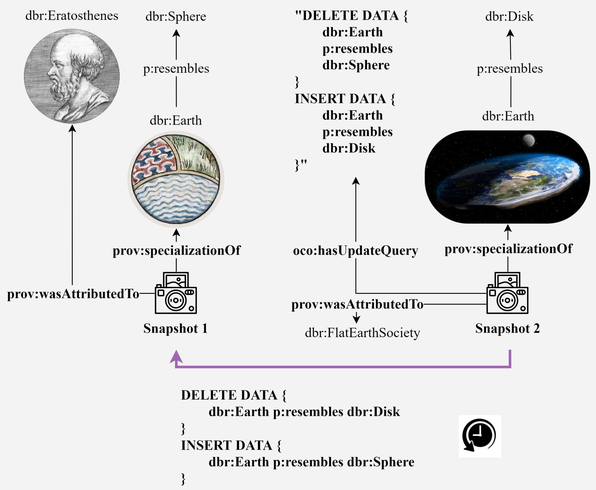
OpenCitations Data Model (OCDM)

- It combines **Named Graphs** and the **Provenance Ontology** (Daquino et al.)
- **Change-based** storage policy: it stores deltas using **SPARQL INSERT DATA** and **DELETE DATA** operations



How to rebuild past versions and achieve VM, VQ, and CV

- According to the OCDM, **only deltas** are **stored**; therefore, the dataset's **past conditions** must be **reconstructed** to query those states.
- However, restoring as many versions as snapshots would generate **massive** amounts of data, consuming time and storage. The adopted solution was to reconstruct only the past resources **significant** for the user's query
- To **recover** the status of an entity to a particular snapshot s_i, apply the **inverse update queries** from the most recent snapshot s_n to s_{i+1}



Time-Agnostic Library enables all the time-related retrieval functionalities via SPARQL live

Delta and change materializations are straightforward

- Delta queries can help understand which resources have **changed**, narrow the field, and achieve faster queries on versions if the subject is unknown
- The procedure is similar to the one for version queries, but with a crucial difference. Once the relevant entities have been found, there is no reason to rebuild their past conditions because **deltas** are **explicitly stored** according to the OpenCitations Data Model

Time-agnostic-library

- Such methodology was implemented in a **Python package**
  - It is available **open-source** on GitHub under ISC License
  - It can be installed with **pip**
  - **Test driven development**: 141 tests (98% coverage)

Evaluation of time-agnostic-library

- Two benchmarks: **execution times** and **memory**
  - **Ten queries** repeated **ten times** on **twenty random entities** having variable number of **provenance snapshots** (from **2** to **35**)
  - Benchmarks were performed on **Blazegraph**, **GraphDB Free Edition**, **Apache Jena Fuseki**, and **OpenLink Virtuoso**
  - The benchmarks are fully **reproducible** by simply running a bash script (Massari 2022)

Retrieval functionality	Time on Fuseki		RAM on Fuseki	
	Median	Stdev	Median	Stdev
VM, VQ	11.5s	6.57s	96.3MB	36.3MB
CV	15.6s	8.73s	156MB	78.9MB
CV where the subject is unknown	240s	28.3s	307MB	137MB
DM and CM	13.8s	7.74s	98.8MB	37.5MB
DM and CM where the subject is unknown	165s	26.9s	74.4MB	0.129MB

- **Compared** to **other software** to achieve time-agnostic SPARQL queries, time-agnostic-library support all retrieval functionalities **live** and **without** requiring **pre-indexing processes**

Software	Queries	Live
SemVersion	VM, DM	+
X-RDF-3X	VM, DM	+
RBDMS	All	-
R&Wbase	All	+
R43ples	All	+
TailR	VM, VQ, CV, CM	+
V-RDFCSA	VM, DM, V	+
Dydra	All	-
OSTRICH	All	-
QuitStore	All	?
Time-agnostic-library	**All**	**+**

Performing live time-traversal queries on RDF datasets

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