

# Representing verifiable statistical index computations as linked data

Jose Emilio Labra Gayo  
University of Oviedo  
Dept. of Computer Science  
C/Calvo Sotelo, S/N  
labra@uniovi.es

Hania Farham  
The Web Foundation  
hania@webfoundation.org

Juan Castro Fernández  
WESO Research Group  
University of Oviedo  
C/Calvo Sotelo, S/N  
juan.castro@weso.es

## ABSTRACT

In this paper we describe the development of the Web Index linked data portal that represents statistical index data and computations.

The Web Index is a multi-dimensional measure of the World Wide Web's contribution to development and human rights globally. It covers 81 countries and incorporates indicators that assess several areas like universal access; freedom and openness; relevant content; and empowerment.

In order to empower the Web Index transparency, one internal requirement was that every published data could be externally verified. The verification could be that it was just raw data obtained from an external source, in which case, the system must provide a link to the data source or that the value has been internally computed, in which case, the system provides links to those values. The resulting portal contains data that can be tracked to its sources so an external agent can validate the whole index computation process.

We describe the different aspects on the development of the WebIndex data portal, which also offers new linked data visualization tools.

Although in this paper we concentrate on the Web Index development, we consider that this approach can be generalized to other projects which involve the publication of externally verifiable statistical computations.

## Categories and Subject Descriptors

H.2.8 [Database Applications]: Statistical databases; H.3.5 [Online Information Services]: Web-based services

## General Terms

Theory

## Keywords

Linked data, Statistics, Computations, RDF

## 1. INTRODUCTION

The creation and use of quantitative indexes is a widely accepted practice that has been applied to numerous domains like economics and Bibliometrics (Impact factor), research and academic performance (H-Index or Shanghai rankings), cloud computing (Global Cloud Index, by CISCO), etc.

We consider that those indexes could benefit from a Linked Data approach where the rankings could be seen, tracked and verified by their users.

We participated in the Web Index project (<http://thewebindex.org>), which created an index to measure the Web impact in different countries.

The 2012 version offered a data portal<sup>1</sup> whose data was obtained by transforming raw observations and precomputed values from Excel sheets to RDF [3].

In the 2013 version of that data portal, we are working on both validating and computing observations to automatically generate the index from raw data.

We have defined a generic vocabulary of computational index structures which could be applied to compute and validate any other kind of index and can be seen as an instance of the RDF Data Cube vocabulary [2]. The validation process employs SPARQL [4] queries to model the different integrity constraints and computation steps in a declarative way.

Along the paper we will use Turtle and SPARQL notation and assume that the namespaces have been declared using the most common prefixes found in <http://prefix.cc>.

## 2. WEBINDEX WORKFLOW

## 3. WEBINDEX COMPUTATION MODEL

Our data model consists of a list of observations which can be raw observations obtained from an external source or computed observations derived from other observations. An example observation can be:

```
obs:obsM23 a qb:Observation ;
  cex:computation [ a cex:Z-Score ;
    cex:observation obs:obsA23 ; cex:slice
      slice:sliceA09 ; ] ;
  cex:value 0.56 ;
  cex:md5-checksum "2917835203..." ;
  cex:indicator indicator:A ;
```

<sup>1</sup><http://data.webfoundation.org>

```

cex:concept country:ESP ;
qb:dataset dataset:A-Normalized ;
# ... other declarations omitted for
  brevity

```

Where we declare that `obs:obsM23` is an observation whose value is 0.56 that has been obtained as the Z-Score of the observation `obs:A23` using the slice `slice:sliceA09`. The observations refers to indicator `indicator:A`, to the concept `country:ESP` and to the dataset `dataset:A-Normalized`.

For each observation, we also add a value for `cex:md5-checksum` which is obtained as a combination of the different values of the observation and allows a user to verify the values asserted to that observation.

## 4. COMPUTEX VOCABULARY

The *Computex* vocabulary is available at <http://purl.org/weso/computex>. It defines terms related to the computation of statistical index data and is compatible with RDF Data Cube vocabulary. Some terms defined in the vocabulary are:

- **cex:Concept** represents the entities that we are indexing. In the case of the Web Index project, the concepts are the different countries. In other applications it could be Universities, journals, services, etc.
- **cex:Indicator**. A dimension whose values add information to the Index. Indicators can be simple dimensions, for example: the mobile phone suscriptions per 100 population, or can be composed from other indicators.
- **qb:Observation**. This is the same term as in the RDF Data Cube vocabulary. It contains values for the properties: `cex:value`, `cex:indicator` and `cex:concept`, etc. The value of a `qb:Observation` can be a Raw value obtained from an external source or a computed value obtained from other observations.
- **cex:Computation**. We have declared the main computation types that we needed for the WebIndex project, which have been summarized in Table 4. That list of computation types is non-exhaustive and can be further extended in the future.
- **cex:WeightSchema** a weight schema for a list of indicators. It consists of a weight associated for each indicator which can be used to compute an aggregated observation.

## 5. VALIDATION APPROACH

The validation approach employed in the 2012 WebIndex project was based on resource templates similar to the OSLC resource shapes<sup>2</sup> and the MD5 checksum field. Apart from that, we did not verify that the precomputed values imported from the Excel sheets really match the value that could be obtained by following the declared computation process.

The new validation approach proposed in the paper goes a step forward. The goal is not only to check that a resource contains a given set of fields and values, but also that those values really match the values that can be obtained by following the declared computations.

<sup>2</sup><http://www.w3.org/2012/12/rdf-val/SOTA>

The proposed approach has been inspired by the integrity constraint specification proposed by the RDF Data Cube vocabulary which employs a set of SPARQL ASK queries to check the integrity of RDF Data Cube data. Although ASK queries provide a good means to check integrity, in practice their boolean nature does not offer too much help when a dataset does not accomplish with the data model.

We decided to use CONSTRUCT queries which, in case of error, contain an error message and a list of error parameters that can help to spot the problematic data.

We transformed the ASK queries defined in the RDF Data Cube specification to CONSTRUCT queries. For example, the query to validate the RDF Data Cube integrity constraint 4 (IC-4) is:

```

CONSTRUCT {
  [ a cex:Error ; cex:errorParam [cex:name
    "dim"; cex:value ?dim ] ;
    cex:msg "Every Dimension must have a
      declared range" . ]
} WHERE { ?dim a qb:DimensionProperty .
  FILTER NOT EXISTS { ?dim rdfs:range [] }
}

```

In order to make our error messages compatible with EARL [1], we have defined `cex:Error` as a subclass of `earl:TestResult` and declared it to have the value `earl:failed` for the property `earl:outcome`.

We have also created our own set of SPARQL CONSTRUCT queries to validate the *Computex* vocabulary terms, specially the computation of index data. For example, the following query validates that every observation has at most one value.

```

CONSTRUCT {
  [ a cex:Error ; cex:errorParam # ...
    omitted
    cex:msg "Observation has two different
      values" . ]
} WHERE { ?obs a qb:Observation .
  ?obs cex:value ?value1 . ?obs cex:value
    ?value2 .
  FILTER ( ?value1 != ?value2 )
}

```

Using this approach, it is possible to define more expressive validations. For example, we are able to validate that an observation has been obtained as the mean of other observations.

```

CONSTRUCT {
  [ a cex:Error ; cex:errorParam # ...omitted
    cex:msg "Mean value does not match" ] .
} WHERE {
  ?obs a qb:Observation ;
    cex:computation ?comp ;
    cex:value ?val .
  ?comp a cex:Mean .
  { SELECT (AVG(?value) as ?mean) ?comp
    WHERE {
      ?comp cex:observation ?obs1 .
      ?obs1 cex:value ?value ;
    } GROUP BY ?comp }
  FILTER( abs(?mean - ?val) > 0.0001)
}

```

Computation	Description	Properties
Raw	No computation. Raw value obtained from external source.	
Mean	Mean of a set of observations	cex:observation cex:slice
Increment	Increment an observation by a given amount	cex:observation cex:amount
Copy	A copy of another observation	cex:observation
Z-score	A normalization of an observation using the values from a Slice.	cex:observation cex:slice
Ranking	Position in the ranking of a slice of observations.	cex:observation cex:slice
AverageGrowth	Expected average growth of N observations	cex:observations
WeightedMean	Weighted mean of an observation	cex:observation cex:slice cex:weightSchema

Table 1: Some types of statistical computations

## 6. EXPRESSIVITY LIMITS OF SPARQL QUERIES

Validating statistical computations using SPARQL queries offered a good exercise to check SPARQL expressivity. Although we were able to express most of the computation types, some of them had to employ functions that are not part of SPARQL 1.1 or had to be defined in a limited way. In this section we review some of the challenges that we found.

- The Z-score of a value  $x_i$  is defined as  $\frac{x_i - \bar{x}}{\sigma}$  where  $\bar{x}$  is the mean and  $\sigma = \sqrt{\frac{\sum_{i=1}^N (\bar{x} - x_i)^2}{N-1}}$  is the standard deviation. To validate that computation using SPARQL queries, it is necessary to employ the `sqrt` function. This function is not available in SPARQL 1.1 although some implementations like Jena ARQ<sup>3</sup> provide it.
- In order to validate the ranking of an observation (in which position it appears in a list of observations), we have found two approaches. One is to check all the observations that are below the value of that observation. This approach requires checking the value of each observation against all the other values. The other approach is to use a subquery that groups all the observations ordered by their value using the `GROUP_CONCAT`. However, SPARQL does not offer a function to calculate the position of a substring in a string<sup>4</sup>, so we divided the length of the substring before the concept's name by the length of the concept's name. This approach is more efficient but only works when all the names have the same length.
- Given a list of values  $x_1, x_2 \dots x_n$  the expected value  $x_{n+1}$  can be extrapolated using the forward average growth formula:  $x_n \times \frac{\frac{x_n}{x_{n-1}} + \dots + \frac{x_2}{x_1}}{n-1}$ . Accessing RDF collections in SPARQL 1.1 requires property paths and offers limited expressivity. In this particular case the query can be expressed as<sup>5</sup>:

```
CONSTRUCT {
  # ... omitted for brevity
} WHERE {
  ?obs cex:computation [a
    cex:AverageGrowth;
    cex:observations ?ls] ;
  cex:value ?val .
  ?ls rdf:first [cex:value ?v1] .
  { SELECT ( SUM(?v_n / ?v_n1)/COUNT(*)
    as ?meanGrowth) WHERE {
    ?ls rdf:rest* [ rdf:first [
      cex:value ?v_n ] ;
      rdf:rest [ rdf:first [
        cex:value ?v_n1 ]]]
    }
  }
  FILTER (abs(?meanGrowth * ?v1 - ?val)
    > 0.001) }
```

## 7. VISUALIZING THE WEB INDEX

## 8. RELATED WORK

**TODO: Validating RDF** **TODO: Statistical vocabularies**  
**TODO: Vocabularies to represent computations**

## 9. CONCLUSIONS

Using SPARQL queries to validate and compute index data seems a promising use case for linked data applications. Although we have successfully employed this approach to validate most of the statistical computations we needed for the WebIndex project, we have found some limitations in current SPARQL 1.1 expressivity with regards to built-in functions on maths, strings and RDF Collections.

We consider that our approach may be of interest to the RDF Validation workshop in 2 ways: firstly as a practical approach to validate RDF data which poses some expressivity challenges, and secondly, as a use case with real data than can act as a benchmark to compare different validation strategies.

Our future work is to automate the declarative computation of index data from the raw observations and to check the performance using the Web Index data. We are also studying the feasibility of this approach for online calculation of index scores and rankings.

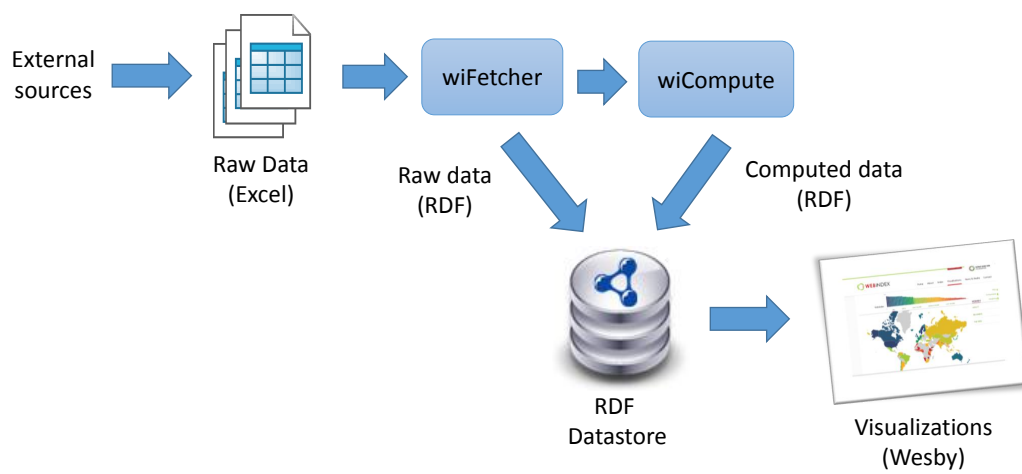
<sup>3</sup><http://jena.apache.org/documentation/query/library-function.html>

<sup>4</sup>This function is called `strpos` in PHP or `indexOf` in Java

<sup>5</sup>This query was suggested by Joshua Taylor.

## References

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**Figure 1: Web Index data portal WorkFlow**