

KNOWLEDGE GRAPHS

Lecture 12: Knowledge Graph Quality

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Knowledge-Based Systems

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Review: The Cypher Query Language

Example: Find pairs of siblings:

MATCH

```
(parent)-[:HAS_CHILD]->(child1),  
(parent)-[:HAS_CHILD]->(child2)
```

WHERE id(child1) <> id(child2)

RETURN child1, child2

Cypher features

- Graph patterns that can be matched to (sets of) paths in graphs
- Querying for and counting of paths
- Various filter conditions (**WHERE**)
- Expressions for accessing aspects of the Property Graph model
- Grouping and aggregates, subqueries, unions, optional matches

Knowledge Graph Quality

Motivation

The quality of KGs is an aspect of utmost importance:

- Almost any data can be turned into a graph format and called “knowledge graph”
- When switching to graphs, we need to know if it was a success or failure
- As time passes, the quality of the KG must be monitored

What does quality mean in this context?

How can it be measured?

How can it be monitored automatically?

Can quality be measured?

A project manager's dream: capture the objective quality as a single numeric value

- easy to communicate; fits into business culture
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However, the world is not that simple:

- Quality is multi-dimensional and non-linear
- Usually not metric (“We improved by 12.6%”) but merely ordinal (“We improved a lot”)
- Relationship to (metric) cost/revenue numbers all but clear

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Functional and non-functional requirements are rarely independent

Example: TimBL's Open Data Quality proposal

Tim Berners-Lee in 2006 proposed a **5-star quality metric** for open data:

- ★ make your stuff available on the Web (whatever format) under an open license
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Notes:

- ★ is not about data quality
- All other criteria are non-functional
- The criteria are ordinal, not metric, and no means of estimating partial progress is given (esp. for ★ ★ ★ ★ ★)
- The term **Linked Open Data** refers to 5-★ RDF data with resolvable URIs

KGs as software?

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But there are important differences:

- development process (many editors, often weakly coordinated; data imports; unclear development life cycle)
- lack of modularisation/interfaces/separation of concerns (integration vs. separation of knowledge)
- KGs have no fully self-contained function: they need to be used by some software
- KGs may be intended for multiple or yet unknown functions

And measuring software quality is already a difficult issue . . .

Checking instead of measuring

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Way forward:

- We will focus on methods of checking specific quality criteria
- The outcomes of many checks can be quantified to obtain measures
- One can aggregate measures by (subjective) weighting functions, or analyse them as multi-dimensional aspects of the KG's status

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 - Operational: Ad hoc implementation of quality checks

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- Declarative: Specification of quality criteria in some formal language that can be interpreted by (standard) tools

Example: Schema document that constrains syntactic form of KG.

Declarative quality checks for KGs

The distinction between “operational” and “declarative” is often fuzzy

- A testing script is operational: implementation-specific meaning; not portable
- A schema document in a standard language (e.g., XML Schema) is declarative: meaning standardised and understood by many tools
- Many other approaches are in between:
 - Graph database constraints: possibly proprietary language; may or may not be portable
 - Wikidata property constraints: community-developed approach for expressing schema information in data
 - SPARQL test queries: declarative queries used in some operational wrapper that validates results
 - Business rules: rule-based programs interpreted by proprietary software
 - ...

↪ declarativity is not a rigorously defined feature, but an ideal to strive for

Competency questions

A classical approach of knowledge model evaluation are so-called **competency questions**

Definition 12.1: A **competency question** is a (usually application-related) question towards the KG that is formalised in a query language, together with a formal specification of how an acceptable answer may look.

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Definition 12.1: A **competency question** is a (usually application-related) question towards the KG that is formalised in a query language, together with a formal specification of how an acceptable answer may look.

A competency question does not need to pre-determine the KG data in all detail.

Example 12.2: We can specify that Wikidata should “know” that humans (Q5) are mammals (Q7377) by requiring that the query `SELECT * WHERE { wd:Q5 wdt:P171* wd:Q7377 }` returns a non-empty result (“true”). This query leaves empty how the taxonomic hierarchy is modelled.

Competency questions

Competency questions focus on functional metrics:

- coverage/completeness (but cannot check all cases)
- correctness
- accessibility (using query answering software)

They can be used in several situations:

- To define the initial scope (requirements) of a new KG project
- To formalise data modelling decisions (how should knowledge be encoded to be accessible)
- For regression testing (ensure that KG does not break in the future)

However, there are also costs: modelling effort, maintenance, ...

Unit testing

Competency questions take a content-oriented view (application- and domain-specific), but the approach can be generalised to set up unit testing:

- Define a test suite of queries + (constraints on) expected answers
- Automatically run queries to detect problems

Unit tests can also validate non-functional criteria.

Schema languages

The most formal way of defining quality criteria is by specifying structural requirements in a formal [schema language](#)

Example 12.3: XML Schema is a classical schema language to constrain the syntactic form of XML documents (DTD is another, older, approach with similar goals).

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For RDF, there are mainly two schema languages today:

- [SHACL](#), a W3C standard (since 2017)
- [ShEx](#), a W3C member submission and community group effort

Note: [RDF Schema](#), despite its name, is a lightweight ontology language rather than a schema language.

SHACL

SHACL is the W3C Shapes Constraint Language

Basic principles:

- Overall approach similar to query-based unit testing
- SHACL **shapes** specify constraints by defining two aspects:
 - (1) a pattern that RDF graph nodes may match (akin to simple queries),
 - (2) and the set of target nodes that should match the pattern
- **SHACL-SPARQL** extension allows using SPARQL for pattern specification
- Shapes can have **meta-data** to define, e.g., error messages and severity levels
- Shapes and sets of shapes are encoded in RDF as **shape graphs**

Further reading:

- W3C SHACL Recommendation at <https://www.w3.org/TR/shacl/>
- Labra Gayo, Prud'hommeaux, Boneva, Kontokostas: Validating RDF Data (Morgan Claypool 2018); see <https://book.validatingrdf.com/>

SHACL by Example

The following RDF graph (in Turtle, without prefixes) defines a shape `ex:PersonShape`:

```
ex:PersonShape rdf:type sh:NodeShape ;
  sh:targetClass ex:Person ; # Applies to all persons
  sh:property [ # Declare a constraint on property usage
    sh:path ex:ssn ; # ... for property ex:ssn
    sh:maxCount 1 ; # ... at most one value
    sh:datatype xsd:string ; # ... having type string
    sh:pattern "\\d{3}-\\d{2}-\\d{4}$" # ... matching this regexp
  ] ;
  sh:property [ # Declare another property constraint
    sh:path ex:worksFor ; # ... for property ex:worksFor
    sh:nodeKind sh:IRI ; # ... values are IRIs
    sh:class ex:Company # ... of rdf:type ex:Company (or a subclass)
  ] ;
  sh:closed true ; # No other properties are allowed
  sh:ignoredProperties ( rdf:type ) . # ... except for rdf:type
```

Shapes in SHACL

... are identified by IRIs and may optionally include:

- a specification of **target** nodes they apply to (`sh:targetClass`, `sh:targetSubjectsOf`, `sh:targetObjectsOf`, or `sh:targetNode`)
- a set of **property shapes** that define constraints on values reached through (paths of) properties
- constraints on whether the shape is **closed**
- **non-validating constraints**, e.g., `sh:description`

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There is a rich vocabulary for specifying property constraints, including:

- (SPARQL-like) property paths instead of single properties
- minimal and maximal cardinalities
- resource types, datatypes, or RDF classes for values
- lists of admissible values
- ways to say that one property's values are disjoint or equal to another's
- (possibly recursive) reference to the `NodeType` of property values
- Boolean combinations of constraints (and, or, not)

ShEx

ShEx is the [Shape Expressions Language](#) as proposed by a W3C Community Group

Basic principles:

- Overall approach similar matching a grammar description to a graph
- ShEx [shapes](#) specify constraints by defining a pattern that refers to
 - (1) required features of the RDF graph
 - (2) required patterns matched by adjacent nodes (recursively)
- Validation tries to consistently map nodes in an RDF graphs to types as required (based on some initial map)
- Sets of shapes form a [schema](#), encoded in an RDF-inspired own syntax

Further reading:

- ShEx community homepage at <http://shex.io/>
- Labra Gayo, Prud'hommeaux, Boneva, Kontokostas: Validating RDF Data (Morgan Claypool 2018); see <https://book.validatingrdf.com/>

ShEx by Example

The following defines a shape `a:PersonShape` (without prefix declarations), which is functionally equivalent to the previous SHACL example:

```
a:PersonShape CLOSED EXTRA rdf:type {  
  ex:ssn xsd:string /^\\d{3}-\\d{2}-\\d{4}$/? ;  
  ex:worksFor IRI @a:CompanyShape * ;  
}  
a:CompanyShape [ ex:Company ] OR { rdfs:subClassOf @:CompanyShape }
```

Notes:

- **CLOSED** and **EXTRA** play the role of `sh:closed` and `sh:ignoredProperties`
- “property shapes” are compactly expressed in single lines
- taking indirect typing (instances of subclasses) into account requires the use of recursive shape definitions

As for SHACL, there are many further features. For example, shape expressions can be combined with boolean operators AND, OR, and NOT.

Validating SHACL and ShEx

Both approaches support recursive constraints and disjunctions:

- Node types are not part of the data: their recursive use means that validation has to extend shapes to new target nodes
- Disjunction means that this assignment might be non-deterministic

~> worst-case NP-complete complexity **in the size of the graph** (data complexity!)

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However:

- In SHACL, recursive assignments are a minor feature, and the specification does not define their semantics. Selection of target nodes mostly governed by conditions on RDF.
- In ShEx, type maps are the only mechanism for selecting targets, and recursive assignments are necessary to check indirect class membership

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Since SHACL is mostly deterministic, it can also provide detailed error reports in case of **failing constraints** (this is hard if many assignments need to be considered which may all fail, but for different reasons)

Summary

Defining and measuring **knowledge graph quality** is difficult; there are many criteria

Competency questions and **unit tests** are basic approaches for automatic quality checks

RDF constraint languages like **SHACL** and **ShEx** can declaratively specify constraints

What's next?

- Graph analysis
- Examinations