The RDF* and SPARQL* Approach

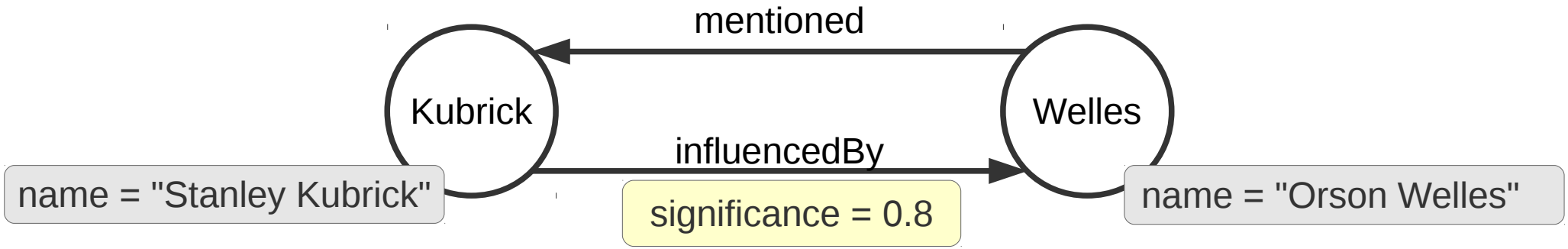
to Annotate Statements in RDF and to Reconcile RDF and Property Graphs

Olaf Hartig

@olafhartig

LINKÖPING UNIVERSITY

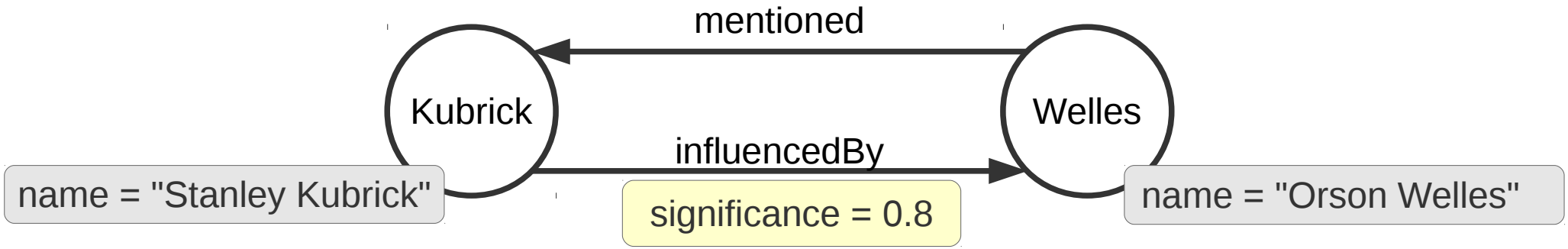
Not supported natively in the RDF data model



- RDF triples:

```
Welles   name        "Orson Welles" .
Welles   mentioned   Kubrick .
Kubrick  name        "Stanley Kubrick" .
Kubrick  influencedBy  Welles .
???  significance  0.8 .
```

Main Use Case: Statement-Level Metadata

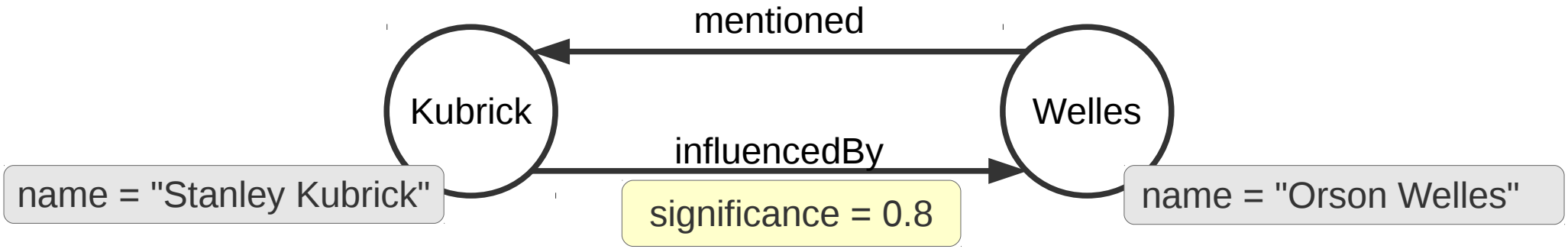


- RDF triples:

```
Welles   name        "Orson Welles" .
Welles   mentioned   Kubrick .
Kubrick  name        "Stanley Kubrick" .
Kubrick  influencedBy  Welles .
???  significance  0.8 .
```

- Certainty scores
- Weights
- Temporal restrictions
- Provenance information
- etc.

Standard RDF Reification




```
Welles   name          "Orson Welles" .
Welles   mentioned   Kubrick .
Kubrick   name     "Stanley Kubrick" .
Kubrick   influencedBy   Welles .
s     significance   0.8 .
s   rdf:type     rdf:Statement .
s   rdf:subject     Kubrick .
s   rdf:predicate   influencedBy .
s   rdf:object      Welles .
```

Queries?

Example 1:

List all people that Welles had a significant influence on.

```
SELECT ?x WHERE {
  ?x        influencedBy  Welles .
  ?t   significance  ?sig .
  ?t rdf:type    rdf:Statement .
  ?t rdf:subject    ?x .
  ?t rdf:predicate  influencedBy .
  ?t rdf:object     Welles .
  FILTER ( ?sig > 0.7 )       }
```

Queries?

Example 2:

```
SELECT ?x WHERE {
  ?x  influencedBy  Welles .
  Welles  influencedBy  ?x .
  ?t1  rdf:type     rdf:Statement .
  ?t1  rdf:subject     ?x .
  ?t1  rdf:predicate  influencedBy .
  ?t1  rdf:object     Welles .
  ?t1  significance  ?sig1 .
  ?t2  rdf:type     rdf:Statement .
  ?t2  rdf:subject     Welles .
  ?t2  rdf:predicate  influencedBy .
  ?t2  rdf:object     ?x .
  ?t2  significance  ?sig2 .
  FILTER (?sig1 > 0.7 && ?sig2 > 0.7)
}
```

Other Proposals: Single-Triple Named Graphs

- Example:

```
g1 { Kubrick  influencedBy  Welles }
g1  significance  0.8 .
```

  - Query:

```
SELECT ?x WHERE {
    GRAPH ?g {
      ?x  influencedBy  Welles
    }
    ?g  significance  ?sig .
    FILTER ( ?sig > 0.7 )
}
```

Other Proposals: Singleton Properties

- Example:

```
Kubrick  influencedBy  Welles .
Kubrick        p1      Welles .
p1  singletonPropertyOf influencedBy .
p1  significance  0.8 .
```

  - Query:

```
SELECT ?x WHERE {
 ?x  influencedBy  Welles .
 ?x        ?p      Welles .
 ?p  singletonPropertyOf influencedBy .
 ?p  significance  ?sig .
 FILTER ( ?sig > 0.7 )
}
```

Our Proposal: Nested Triples

```
Kubrick  influencedBy  Welles .
s  rdf:type  rdf:Statement .
s  rdf:subject  Kubrick .
s  rdf:predicate  influencedBy .
s  rdf:object  Welles .
s  significance  0.8 .
```

```
<<Kubrik influencedBy Welles>> significance 0.8
```

subject *predicate* *object*

… and Nested Triple Patterns

```
SELECT ?x WHERE {
  ?x influencedBy  Welles .
  ?t significance  ?sig .
  ?t rdf:type  rdf.Statement .
  ?t rdf:subject    ?x .
  ?t rdf:predicate  influencedBy .
  ?t rdf:object     Welles .
  FILTER ( ?sig > 0.7 )      }
```

```
SELECT ?x WHERE {
 <<?x influencedBy Welles>> significance ?sig
 FILTER (?sig > 0.7)
}
```

Grouping of Patterns with the Same Subject

- By the standard SPARQL syntax, we may write:

```
SELECT ?x WHERE {
  ?x influencedBy  Welles .
  ?t significance  ?sig ;
     rdf:type  rdf.Statement ;
     rdf:subject     ?x ;
     rdf:predicate  influencedBy ;
     rdf:object     Welles .
  FILTER ( ?sig > 0.7 )      }
```

- Hence, we may easily query for multiple metadata triples:

```
SELECT ?x ?sig ?src WHERE {
  <<?x influencedBy Welles>> significance ?sig ;
                             source    ?src . }
```

Extension of the BIND Clause

- Assign matching triples to variables:

```
SELECT ?x ?sig ?src WHERE {
  BIND(<<?x influencedBy Welles>> AS ?t)
  ?t  significance ?sig ;
      source    ?src .
}
```

```
SELECT ?x ?sig ?src WHERE {
  <<?x influencedBy Welles>> significance ?sig ;
                             source    ?src . }
```

Extension of the BIND Clause

- Assign matching triples to variables:

```
SELECT ?x ?sig ?src WHERE {
  BIND(<<?x influencedBy Welles>> AS ?t)
  ?t  significance ?sig ;
      source    ?src .
}
```

- Now, we may even output triples in query results:

```
SELECT ?t ?c WHERE {
  BIND(<<?x influencedBy Welles>> AS ?t)
  ?t  certainty  ?c .
}
```

Example Query 2 Revisited

```
SELECT ?x WHERE {
  ?x  influencedBy  Welles .
  Welles  influencedBy  ?x .
  ?t1  rdf:type    rdf:Statement .
  ?t1  rdf:subject    ?x .
  ?t1  rdf:predicate  influencedBy .
  ?t1  rdf:object     Welles .
  ?t1  significance  ?sig1 .
  ?t2  rdf:type    rdf:Statement .
  ?t2  rdf:subject    Welles .
  ?t2  rdf:predicate  influencedBy .
  ?t2  rdf:object     ?x .
  ?t2  significance  ?sig2 .
  FILTER (?sig1 > 0.7 && ?sig2 > 0.7)
}
```

Example Query 2 Revisited

```
SELECT ?x WHERE {
  ?x  influencedBy  Welles
  Welles  influencedBy  ?x .
  ?t1  rdf:type    rdf:Statement .
  ?t1  rdf:subject    ?x .
```

```
SELECT ?x WHERE {
 <<?x influencedBy Welles>>  significance  ?sig1 .
 <<Welles influencedBy ?x>>  significance  ?sig2 .

 FILTER (?sig1 > 0.7 && ?sig2 > 0.7)
}
```

```
  ?t2  rdf:predicate  influencedBy .
  ?t2  rdf:object     ?x .
  ?t2  significance  ?sig2 .
  FILTER (?sig1 > 0.7 && ?sig2 > 0.7)
}
```

Two Perspectives on RDF* and SPARQL*

1. Purely syntactic sugar on top of standard RDF and SPARQL
   - Can be parsed directly into standard RDF and SPARQL
   - Can be implemented easily by a small wrapper on top of any existing RDF DBMS

2. A logical model in its own right, with the possibility of a dedicated physical schema
   - Extension of the RDF data model and of SPARQL to capture the notion of nested triples
   - Supported by Blazegraph

Further Possible Applications of SPARQL*

1. Purely syntactic sugar on top of standard RDF and SPARQL

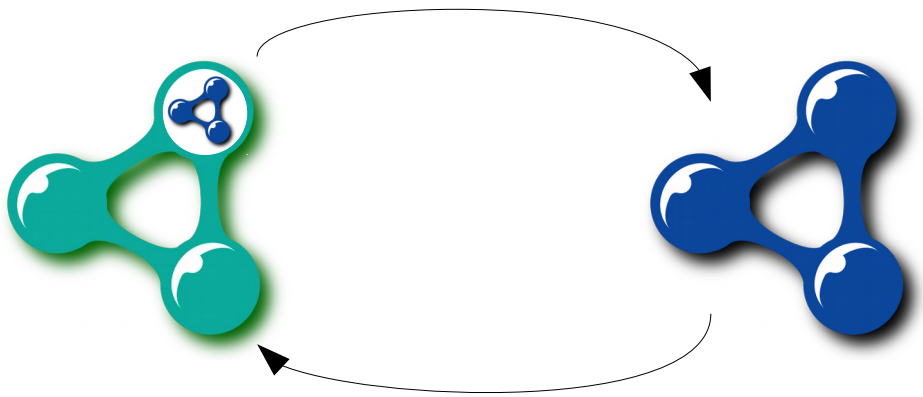
2. A logical model in its own right, with the possibility of a dedicated physical schema

- Query datasets that use RDF reification (or singleton properties, or single-triple named graphs)
  - By straightforward translation into ordinary SPARQL queries
- Query Property Graphs *including their edge properties*
  - By translation into Gremlin, Cypher, etc.

Contributions (Perspective 1)

1. Purely syntactic sugar on top of standard RDF and SPARQL

2. A logical model in its own right, with the possibility of a dedicated physical schema



- Definition of desirable properties of RDF*-to-RDF mappings
  - *Information preservation* and *query result preservation*
- Definition of RDF reification related mappings and proof that they possess the desirable properties

Contributions (Perspective 2)

1. Purely syntactic sugar on top of standard RDF and SPARQL

2. A logical model in its own right, with the possibility of a dedicated physical schema

- Formalization of the RDF* data model
  - Extends the RDF data model with the notions of an *RDF* triple* and an *RDF* graph*
- Definition of syntax and formal semantics of SPARQL*
  - Extends the semantics of SPARQL by defining the result of a SPARQL* query *Q* over an RDF* graph *G*

$$\text{eval}(Q,G) = \{ m_1, m_2, \ldots, m_n \}$$

Contributions (Perspective 2), cont'd

1. Purely syntactic sugar on top of standard RDF and SPARQL

2. A logical model in its own right, with the possibility of a dedicated physical schema

- Results regarding *redundancy* in RDF* graphs
  - Example:

```
<<Kubrik influencedBy Welles>> certainty 0.8 .
Kubrik  influencedBy  Welles
```

redundant

  - Query results are equivalent no matter whether there is redundancy in an RDF* graph or not

Contributions in Detail

1. Purely syntactic sugar on top of standard RDF and SPARQL

2. A logical model in its own right, with the possibility of a dedicated physical schema

- O Hartig: "**Foundations of RDF* and SPARQL* - An Alternative Approach to Statement-Level Metadata in RDF**." In Proc. of 11th Alberto Mendelzon Int. W. on Foundations of Data Mgmt (AMW), 2017.
- Olaf Hartig: "**Reconciliation of RDF* and Property Graphs.**" In CoRR abs/1409.3288, 2014
  - Formal definition of direct mappings b/w RDF* and Property Graphs
- O Hartig and Bryan Thompson: "**Foundations of an Alternative Approach to Reification in RDF**." CoRR abs/1406.3399, 2014
  - Specifies Turtle*
  - All relevant extensions of the SPARQL spec

Hold on!

… is this all theory only???

Implementations

- Full support in the Blazegraph triple store
  - “Reification done right” (RDR)
- Full support in Cambridge Semantics’ AnzoGraph
- RDF* Tools (https://github.com/RDFstar/RDFstarTools)
  - RDF* / SPARQL* extension of Apache Jena
  - Conversion tools (RDF* ↔ RDF, SPARQL* → SPARQL)
  - Simple query execution tool (SPARQL* over RDF*)
- RDF*-PG-Connection Tools (https://github.com/RDFstar/RDFstarPGConnectionTools)
  - Conversion tools (RDF* ↔ PGs)
- Other vendors have indicated interest in standardizing something along the lines of RDF* & SPARQL*

RDF* and SPARQL* in a Nutshell

```
<<Kubrik influencedBy Welles>> significance 0.8
```

subject *predicate* *object*

```
SELECT ?x WHERE {
 <<?x influencedBy Welles>> significance ?sig
 FILTER (?sig > 0.7)
}
```

1. Purely syntactic sugar on top of standard RDF and SPARQL
2. A logical model in its own right, with the possibility of a dedicated physical schema

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