Integrating the Property Graph and RDF Data Models

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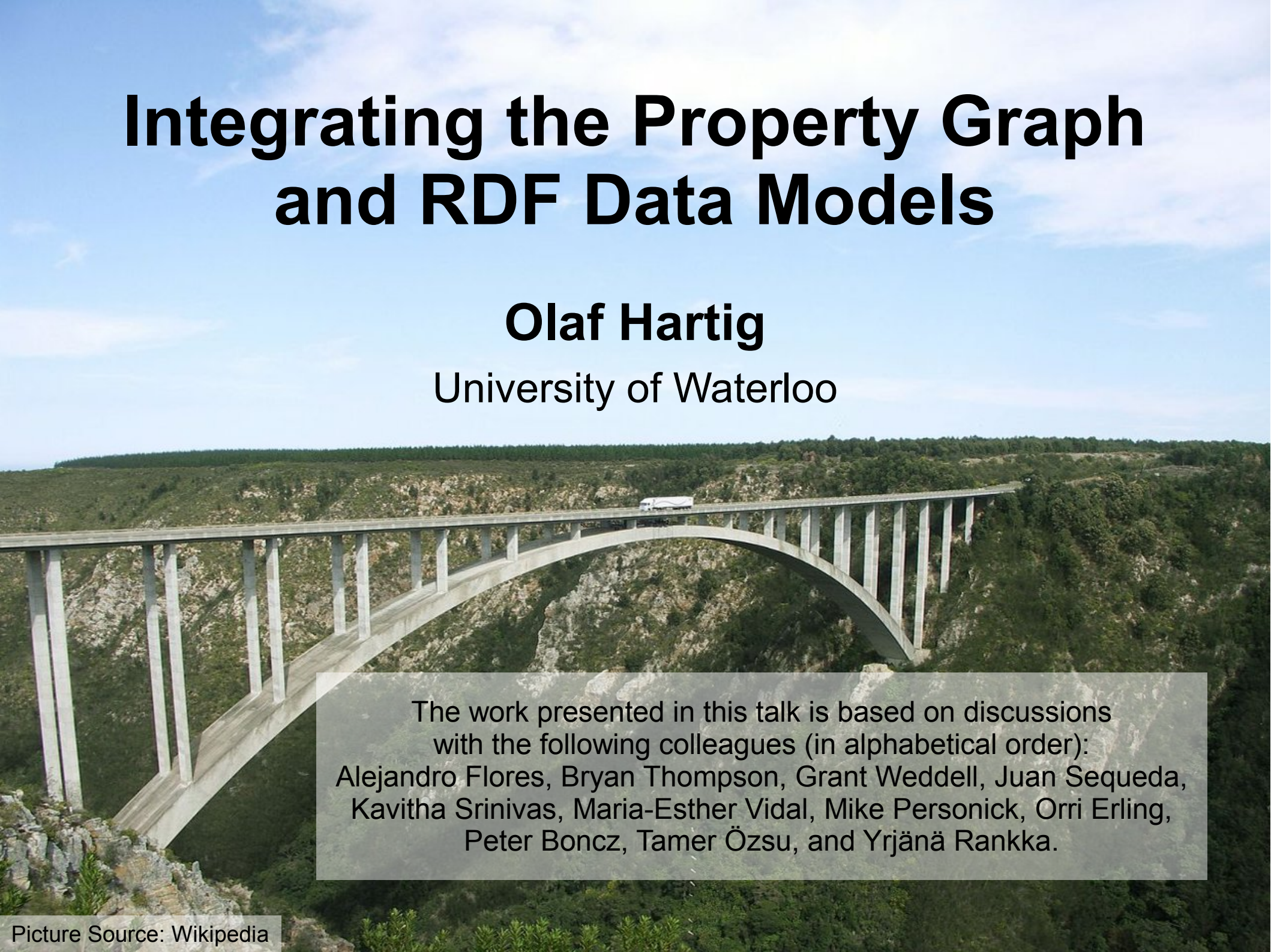


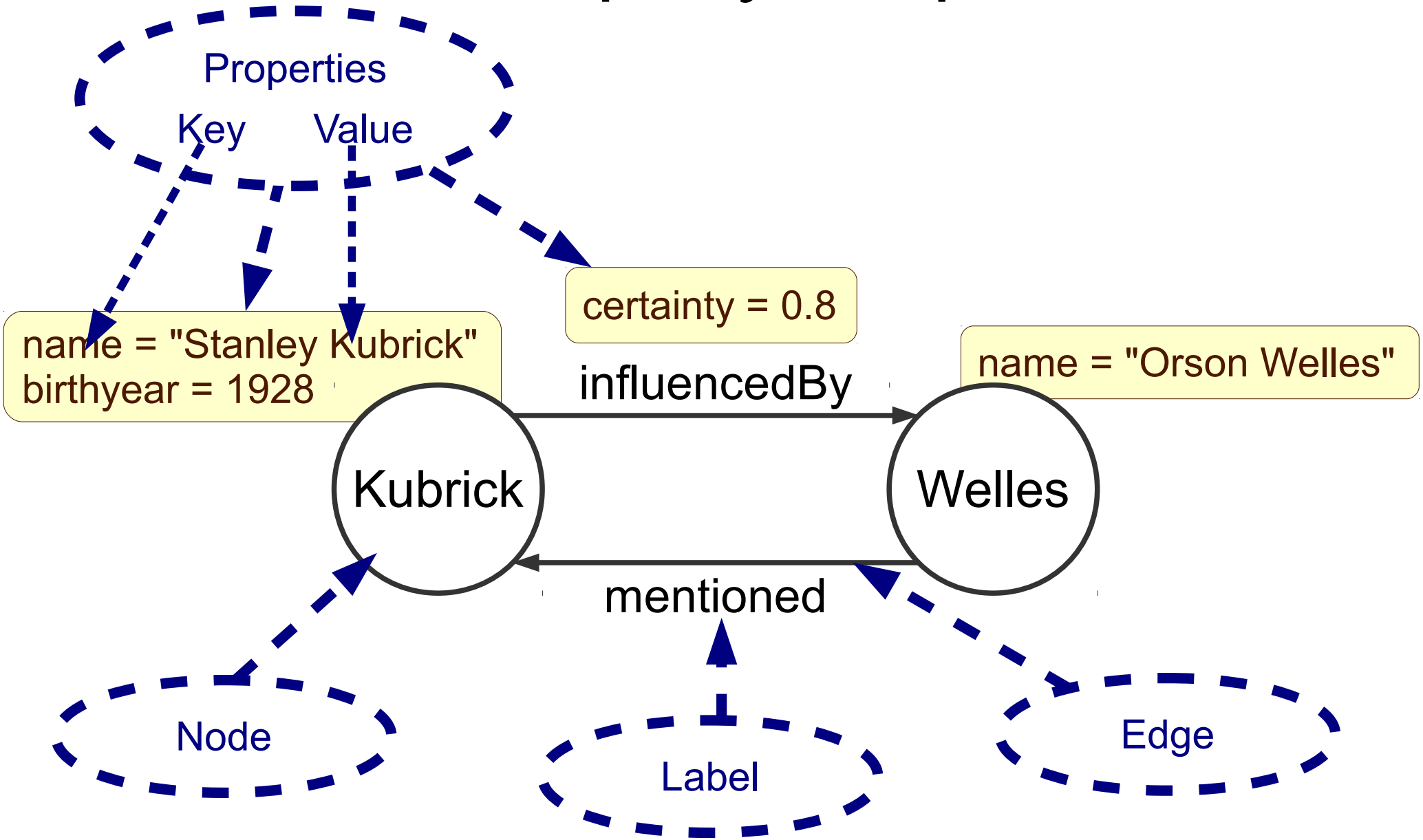
The work presented in this talk is based on discussions with the following colleagues (in alphabetical order): Alejandro Flores, Bryan Thompson, Grant Weddell, Juan Sequeda, Kavitha Srinivas, Maria-Esther Vidal, Mike Personick, Orri Erling, Peter Boncz, Tamer Özsu, and Yrjänä Rankka.

Picture Source: Wikipedia

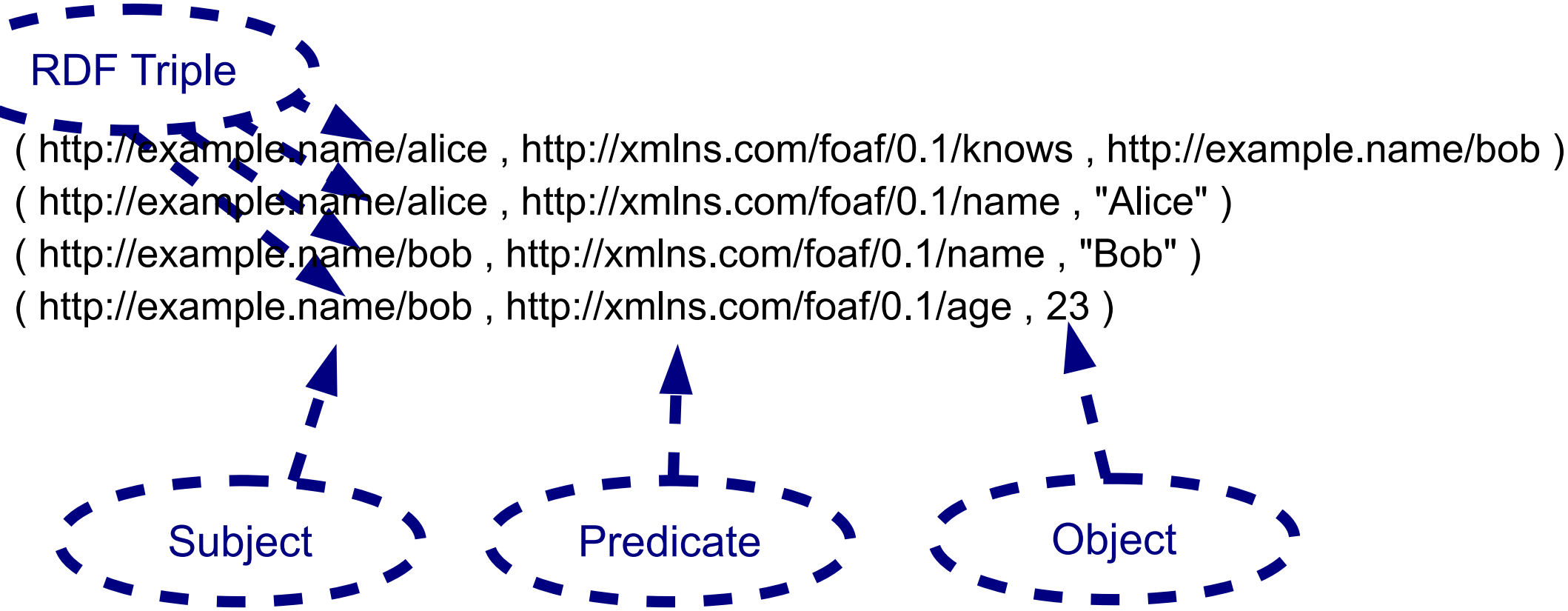
Outline

1. The Data Models
2. Property Graphs to RDF
3. RDF to Property Graphs

A Property Graph



An RDF “Graph”


RDF Triple
(http://example.name/alice , http://xmlns.com/foaf/0.1/knows , http://example.name/bob)
(http://example.name/alice , http://xmlns.com/foaf/0.1/name , "Alice")
(http://example.name/bob , http://xmlns.com/foaf/0.1/name , "Bob")
(http://example.name/bob , http://xmlns.com/foaf/0.1/age , 23)
Subject
Predicate
Object

An RDF “Graph”

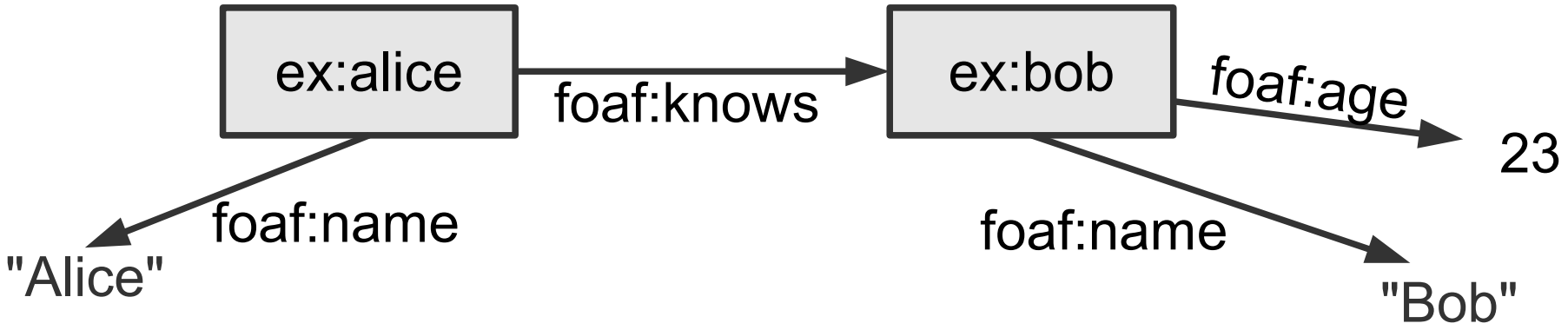
prefix foaf: http://xmlns.com/foaf/0.1/
prefix ex: http://example.name/

(ex:alice , foaf:knows , ex:bob)
(ex:alice , foaf:name , "Alice")
(ex:bob , foaf:name , "Bob")
(ex:bob , foaf:age , 23)

An RDF “Graph”

prefix foaf: http://xmlns.com/foaf/0.1/
prefix ex: http://example.name/

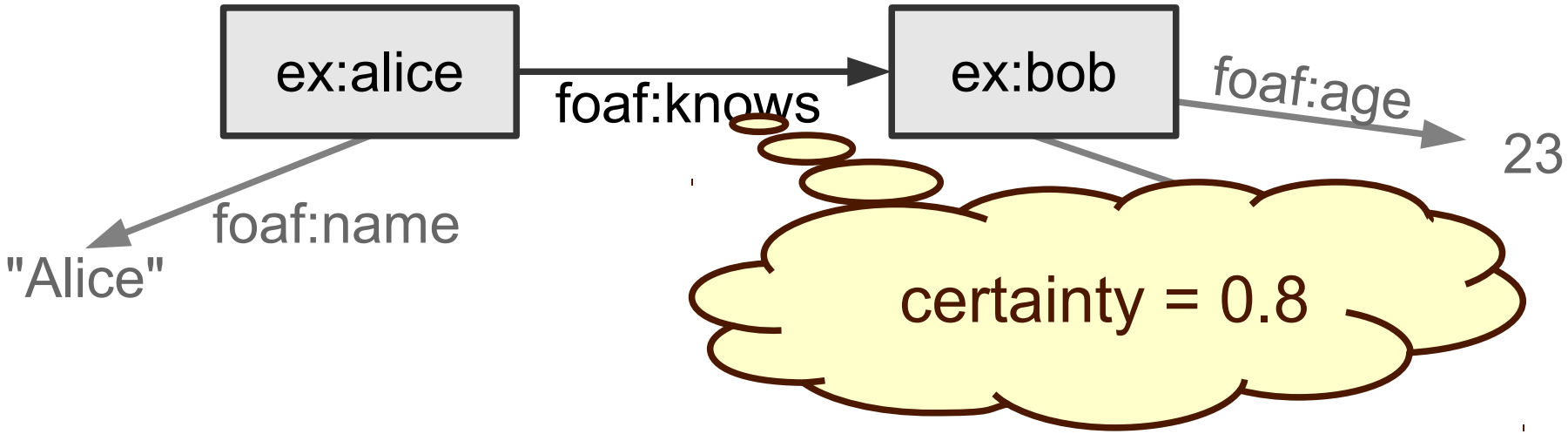
(ex:alice , foaf:knows , ex:bob)
(ex:alice , foaf:name , "Alice")
(ex:bob , foaf:name , "Bob")
(ex:bob , foaf:age , 23)



Statement-level Metadata?

prefix foaf: http://xmlns.com/foaf/0.1/
prefix ex: http://example.name/

(ex:alice , foaf:knows , ex:bob)
(ex:alice , foaf:name , "Alice")
(ex:bob , foaf:name , "Bob")
(ex:bob , foaf:age , 23)



RDF Reification

prefix foaf: http://xmlns.com/foaf/0.1/
prefix ex: http://example.name/

(ex:alice , foaf:knows , ex:bob)
(ex:alice , foaf:name , "Alice")
(ex:bob , foaf:name , "Bob")
(ex:bob , foaf:age , 23)
(_:b1 , rdf:type , rdf:Statement)
(_:b1 , rdf:subject , ex:alice)
(_:b1 , rdf:predicate , foaf:knows)
(_:b1 , rdf:object , ex:bob)
(_:b1 , ex:certainty , 0.8)

Querying with SPARQL

```
SELECT ?c
WHERE {
   ?s   rdf:type   rdf:Statement .
   ?s   rdf:subject   ex:alice .
   ?s   rdf:predicate   foaf:knows .
   ?s   rdf:object   ex:bob .
   ?s   ex:certainty   ?c
}
```

Querying with SPARQL

```
SELECT ?c
WHERE {
   ?s   rdf:type   rdf:Statement .
   ?s   rdf:subject   ex:alice .
   ?s   rdf:predicate   foaf:knows .
   ?s   rdf:object   ex:bob .
   ?s   ex:certainty   ?c .
   ex:alice   foaf:known   ex:bob
}
```

RDF*

```
prefix foaf:    http://xmlns.com/foaf/0.1/
prefix ex:      http://example.name/

(( ex:alice , foaf:knows , ex:bob ) , ex:certainty , 0.8 )
 ( ex:alice , foaf:name , "Alice" )
 ( ex:bob , foaf:name , "Bob" )
 ( ex:bob , foaf:age , 23 )
```

RDF*


```
prefix foaf:    http://xmlns.com/foaf/0.1/
prefix ex:      http://example.name/

(( ex:alice , foaf:knows , ex:bob ) , ex:certainty , 0.8 )
( ex:alice , foaf:name , "Alice" )
( ex:bob , foaf:name , "Bob" )
( ex:bob , foaf:age , 23 )
```

SPARQL*

```
SELECT ?c
WHERE {
        << ex:alice  foaf:knows  ex:bob >> ex:certainty  ?c
}
```

SPARQL*

```
SELECT ?c
WHERE {
        << ex:alice  foaf:knows  ex:bob >>  ex:certainty  ?c
}
```

```
SELECT ?c
WHERE {
   ?s   rdf:type   rdf:Statement .
   ?s   rdf:subject   ex:alice .
   ?s   rdf:predicate   foaf:knows .
   ?s   rdf:object   ex:bob .
   ?s   ex:certainty   ?c .
   ex:alice   foaf:known   ex:bob
}
```

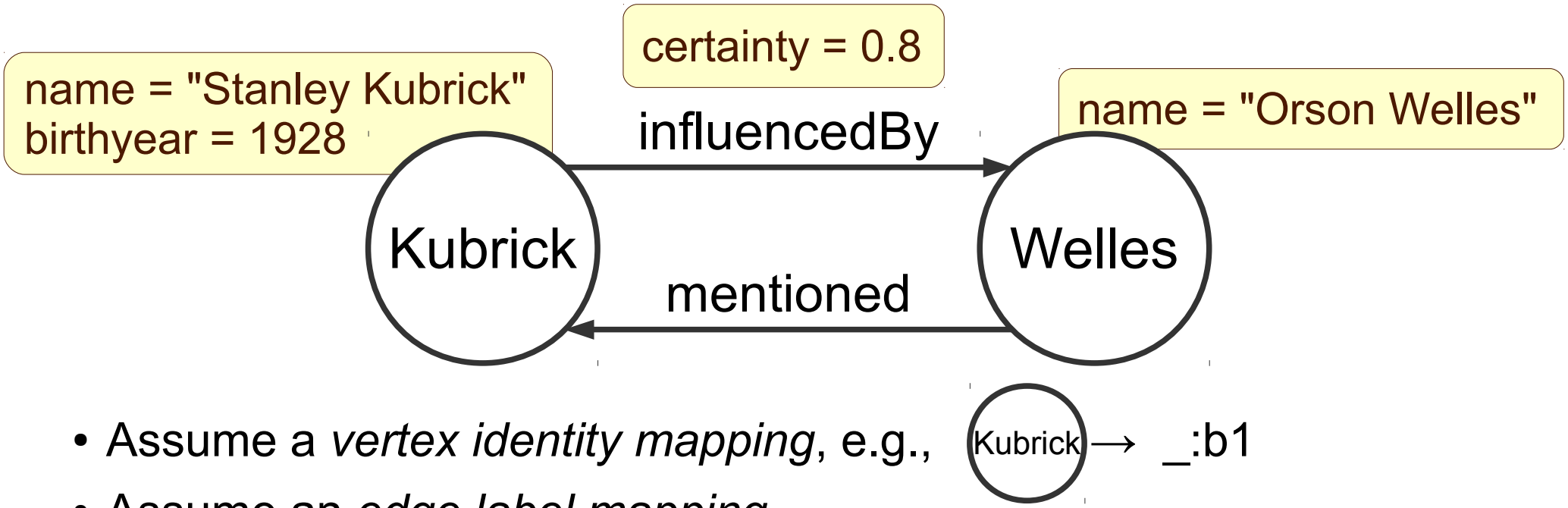
Outline

1. The Data Models √
2. Property Graphs to RDF
3. RDF to Property Graphs

Outline

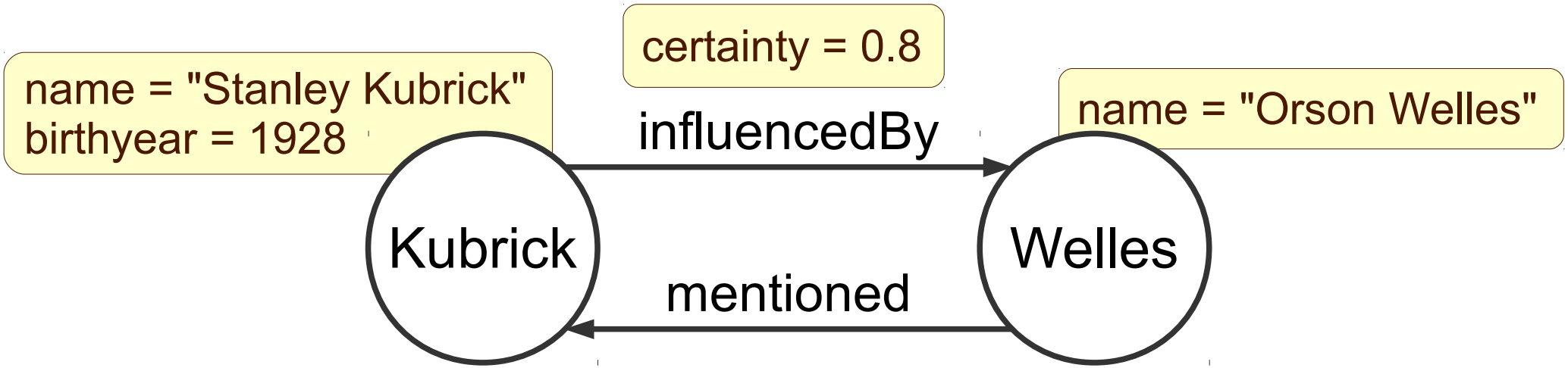
1. The Data Models √
2. Property Graphs to RDF*
3. RDF* to Property Graphs

PGs to RDF* Preliminaries



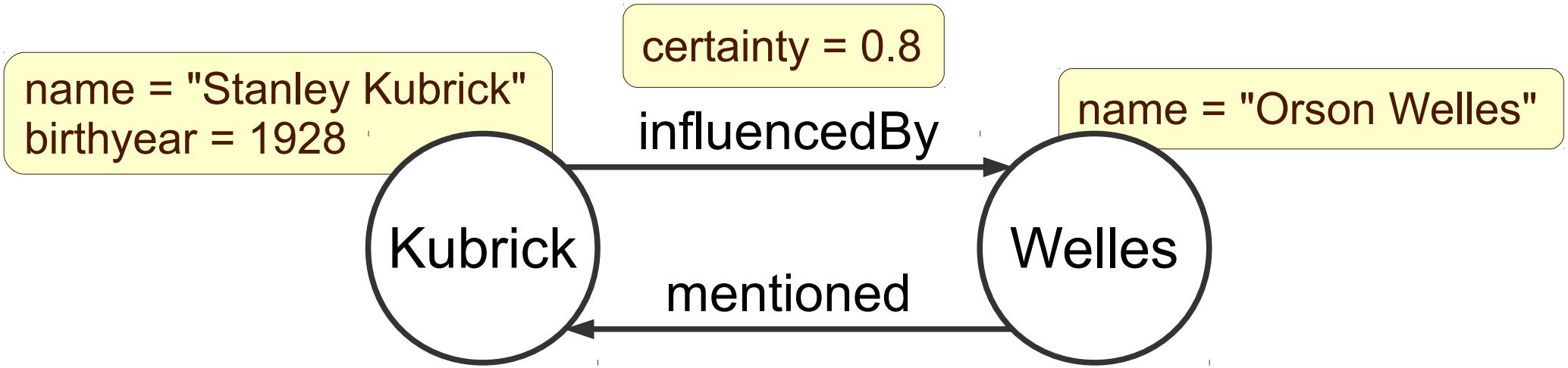
- Assume a *vertex identity mapping*, e.g., Kubrick → _:b1
- Assume an *edge label mapping*,
  e.g., mentioned → http://example.org/relationship/mentioned
- Assume a *property key mapping*,
  e.g., name → http://example.org/property/name
- Assume a *value to literal mapping*

PGs to RDF* Idea



- Transform each edge (+ its label) to an ordinary triple
- Transform each node property into an ordinary triple
- Transform each edge property to a metadata triple

PGs to RDF* Example



prefix p: http://example.org/property/

prefix r: http://example.org/relationship/

(_:b1 , p:name , "Stanley Kubrick")

(_:b1 , p:birthyear , 1928)

(_:b2 , p:name , "Orson Welles")

(_:b2 , r:mentioned , _:b1)

((_:b1, r:influencedBy, _:b2) , p:certainty , 0.8)

Querying the Resulting RDF*

```
SELECT ?n WHERE {
   ?p  p:name  ?n .
   <<?p  r:influencedBy  ?w>>  p:certainty  ?c .
   ?w   p:name  "Orson Welles" .
}
ORDER BY ?c
```

```
( _:b1 , p:name , "Stanley Kubrick" )
( _:b1 , p:birthyear , 1928 )
( _:b2 , p:name , "Orson Welles" )
( _:b2 , r:mentioned , _:b1 )
(  ( _:b1, r:influencedBy, _:b2 ) , p:certainty , 0.8 )
```

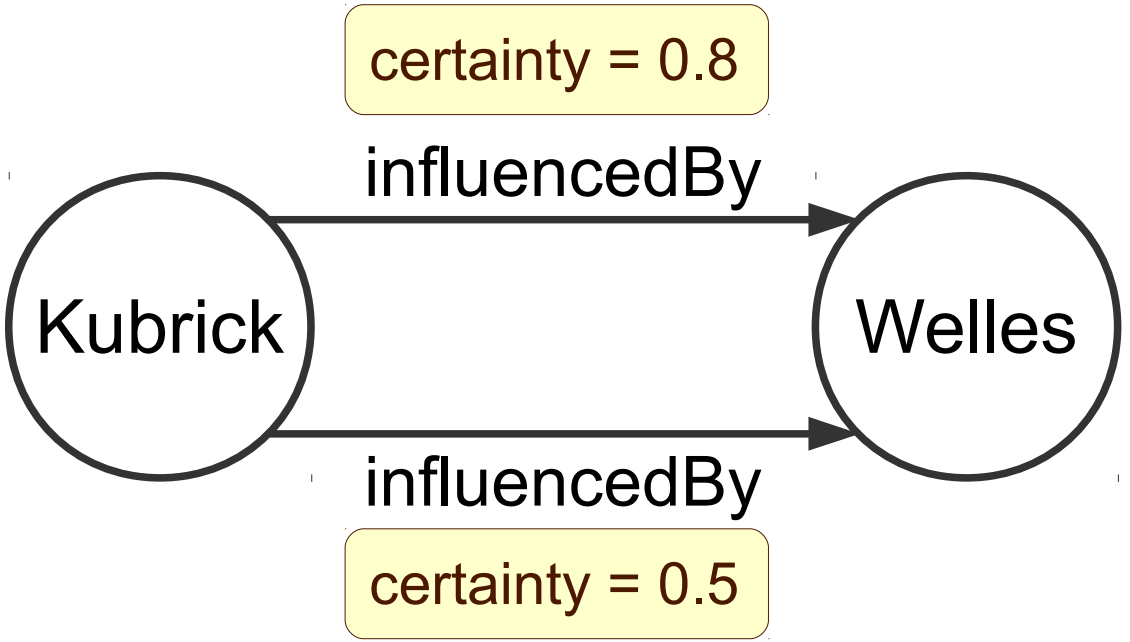
“Equivalent” Cypher Query

```
SELECT ?n WHERE {
   ?p  p:name  ?n .
   <<?p  r:influencedBy  ?w>>  p:certainty  ?c .
   ?w   p:name  "Orson Welles" .
}
ORDER BY ?c
```

```
START p=node(*)
MATCH (p)-[x:influencedBy]->( w { name="Orson Welles" } )
RETURN p.name
ORDER BY x.certainty
```

Limitation

- Distinct edges with the same source node, the same target node, and the same label would be mapped to a single RDF triple
  - RDF graphs / RDF* graphs are sets



Limitation

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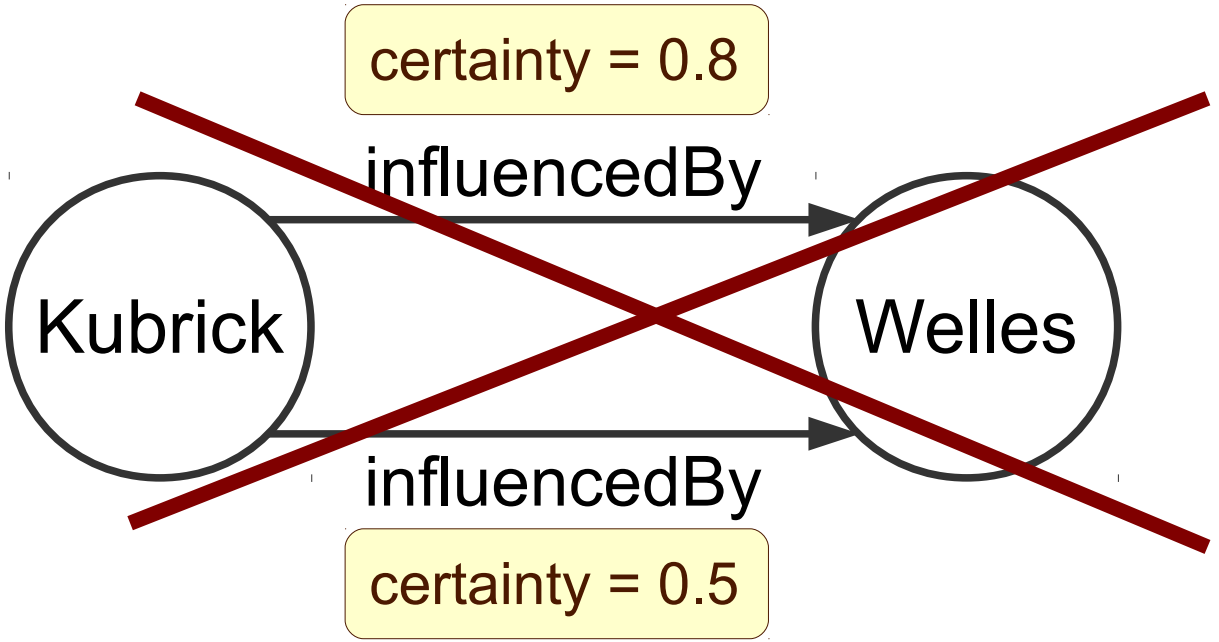


Outline

1. The Data Models √
2. Property Graphs to RDF* √
3. RDF* to Property Graphs

RDF* to PGs Idea

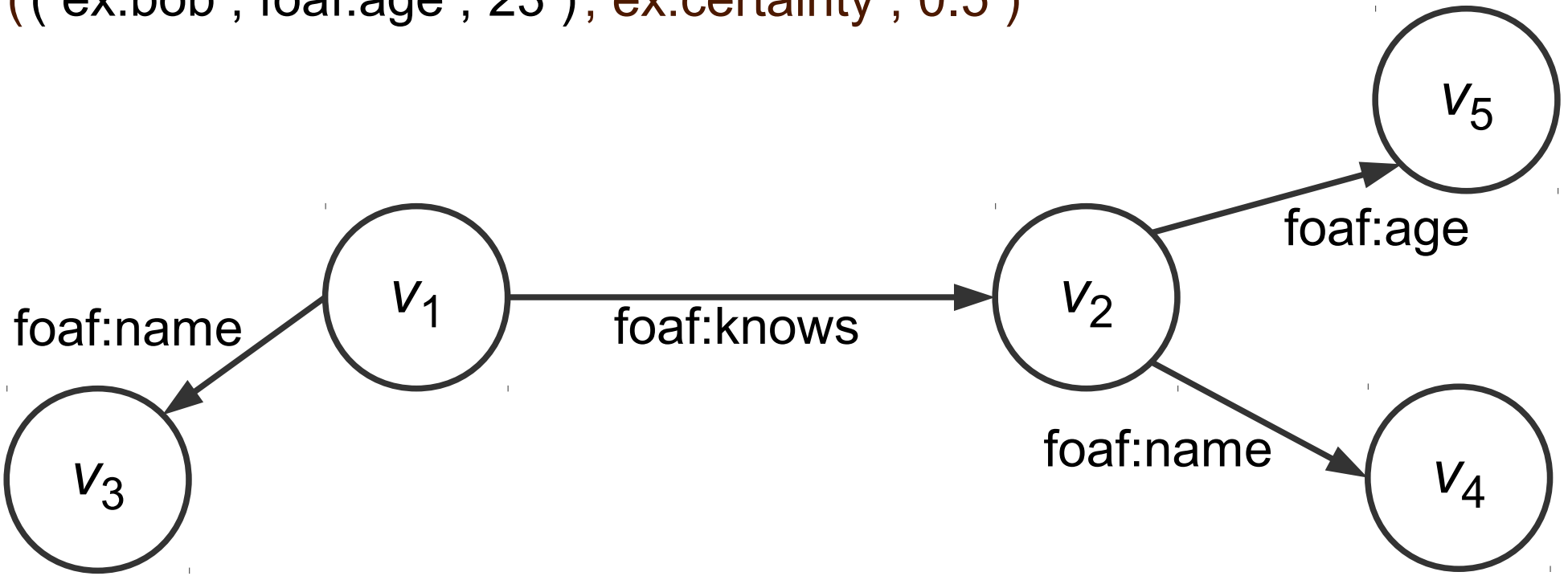
- Transform each ordinary triple to an edge
- Transform each metadata triple to an edge property

RDF* to PGs Example

((ex:alice , foaf:knows , ex:bob) , ex:certainty , 0.8)
(ex:alice , foaf:name , "Alice")
(ex:bob , foaf:name , "Bob")
((ex:bob , foaf:age , 23), ex:certainty , 0.5)

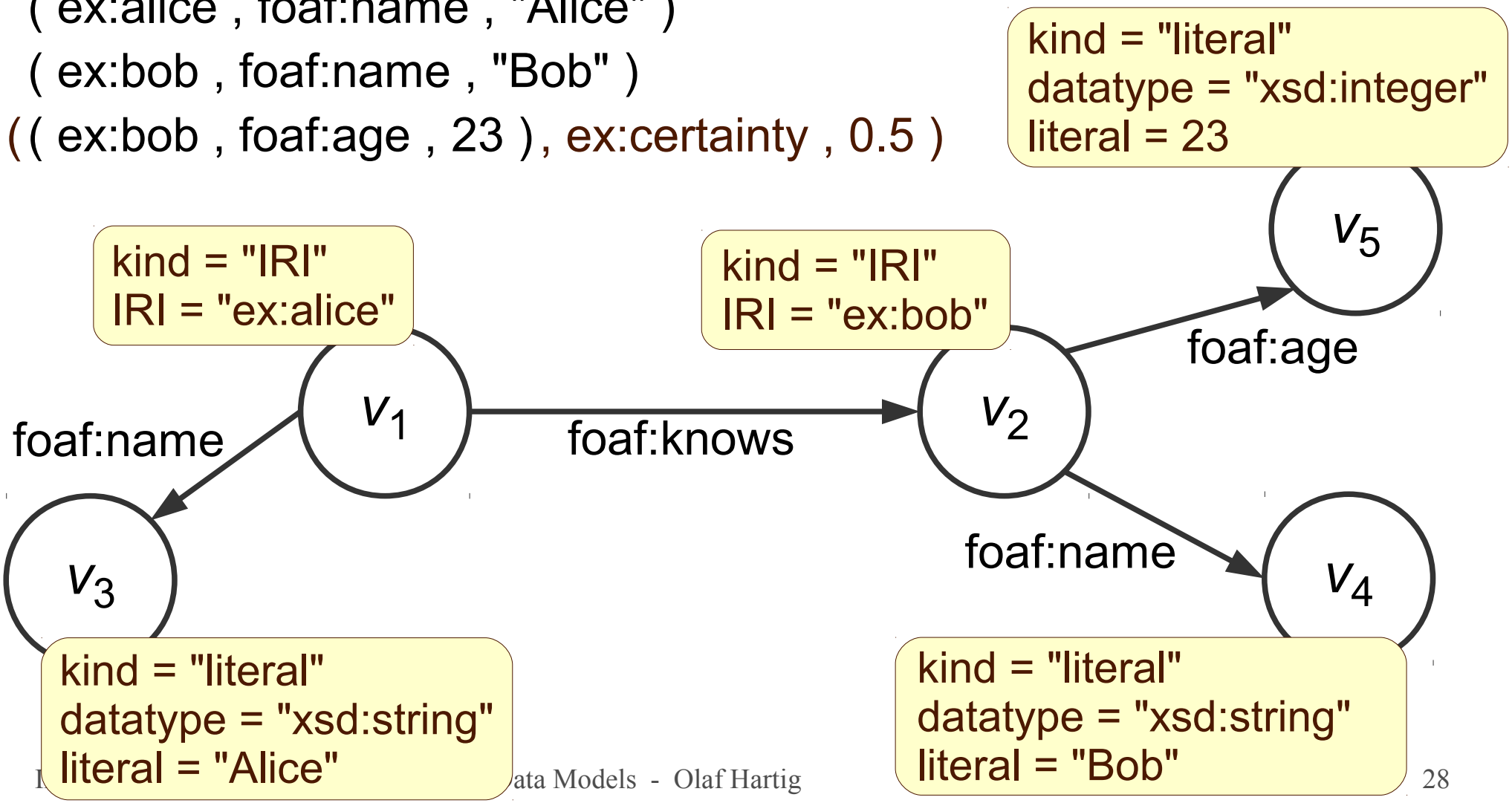
RDF* to PGs Example

((ex:alice , foaf:knows , ex:bob) , ex:certainty , 0.8)
(ex:alice , foaf:name , "Alice")
(ex:bob , foaf:name , "Bob")
((ex:bob , foaf:age , 23), ex:certainty , 0.5)



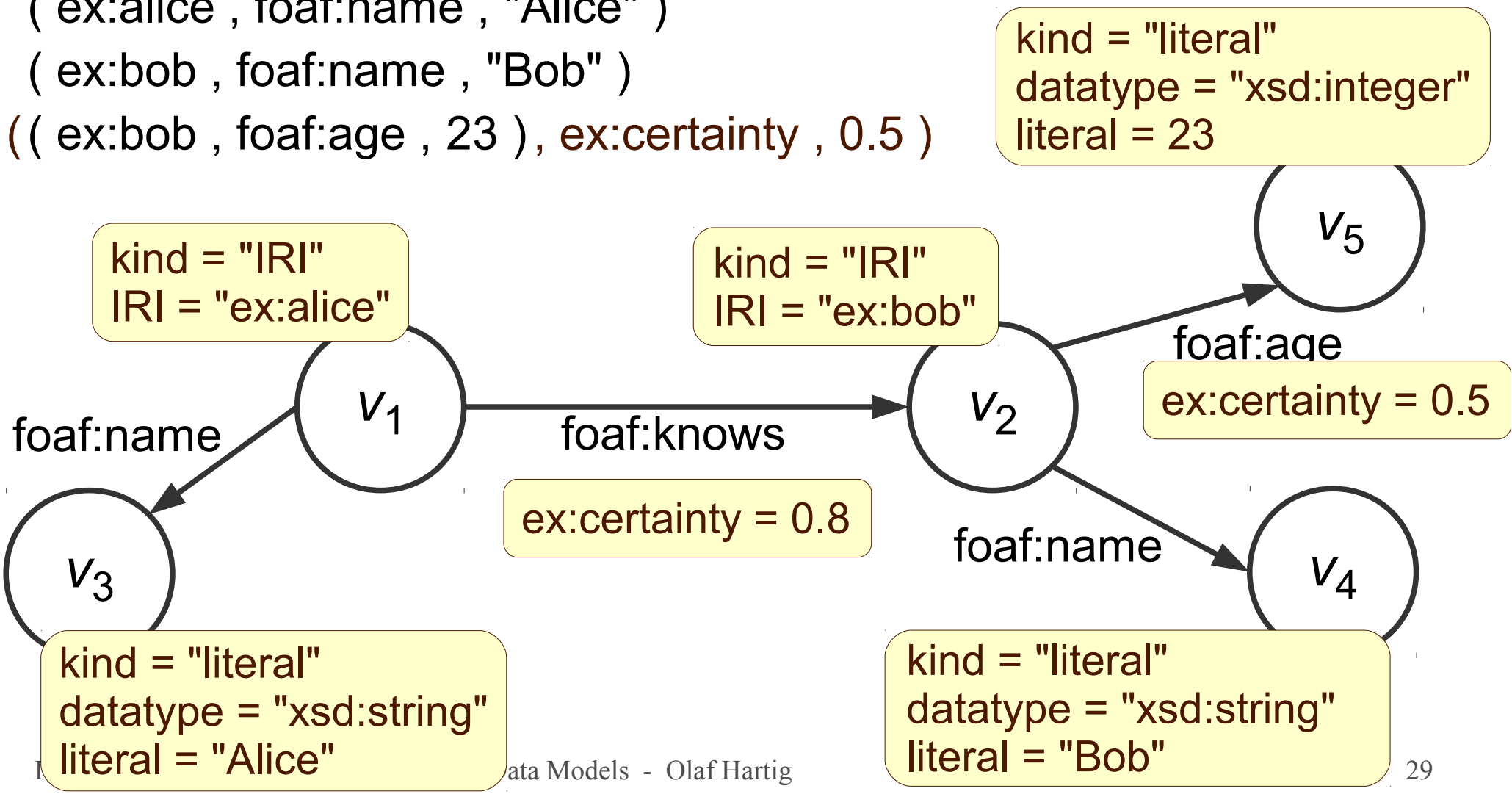
RDF* to PGs Example

((ex:alice , foaf:knows , ex:bob) , ex:certainty , 0.8)
(ex:alice , foaf:name , "Alice")
(ex:bob , foaf:name , "Bob")
((ex:bob , foaf:age , 23), ex:certainty , 0.5)



RDF* to PGs Example

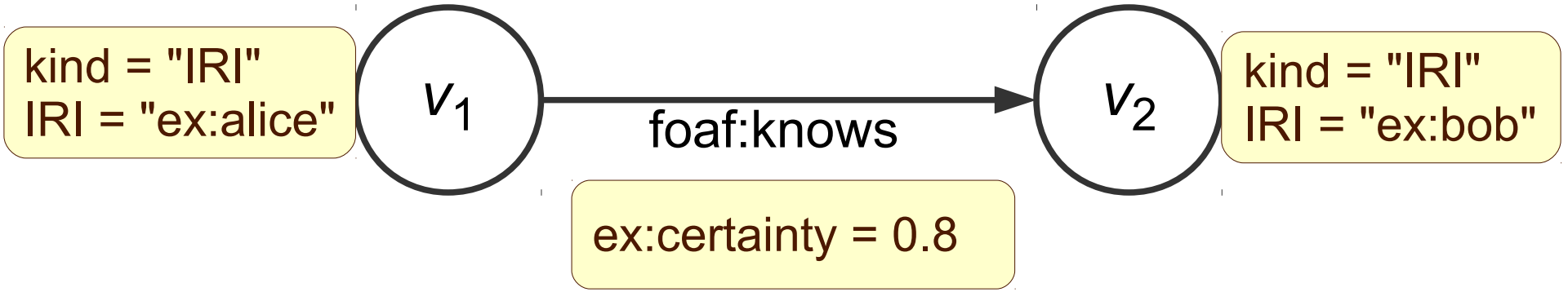
((ex:alice , foaf:knows , ex:bob) , ex:certainty , 0.8)
(ex:alice , foaf:name , "Alice")
(ex:bob , foaf:name , "Bob")
((ex:bob , foaf:age , 23), ex:certainty , 0.5)



PG-Convertible RDF* Graphs

Condition 1: Metadata triples are not nested

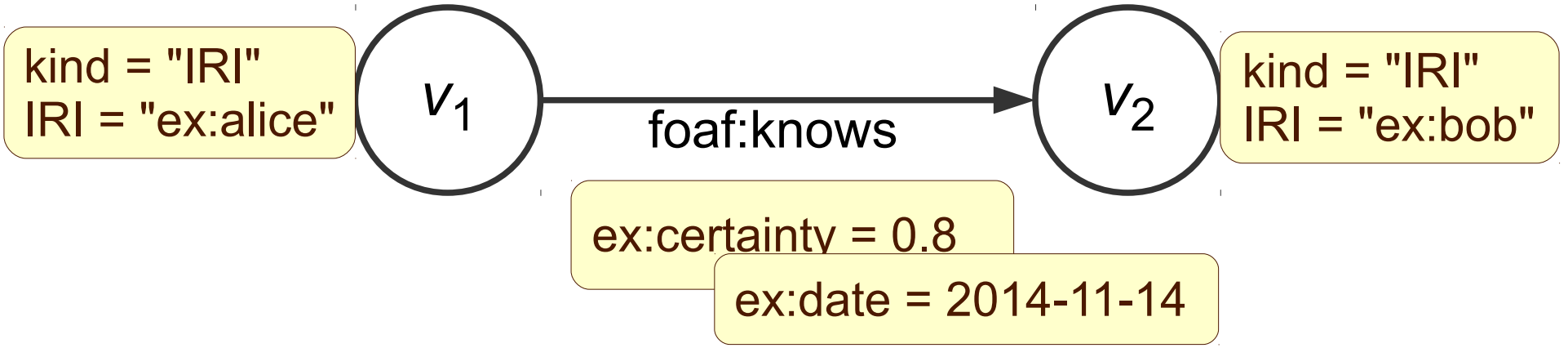
((ex:alice,foaf:knows,ex:bob) , ex:certainty, 0.8)



PG-Convertible RDF* Graphs

Condition 1: Metadata triples are not nested

(((ex:alice,foaf:knows,ex:bob) , ex:certainty, 0.8) ,
ex:date, 2014-11-14)

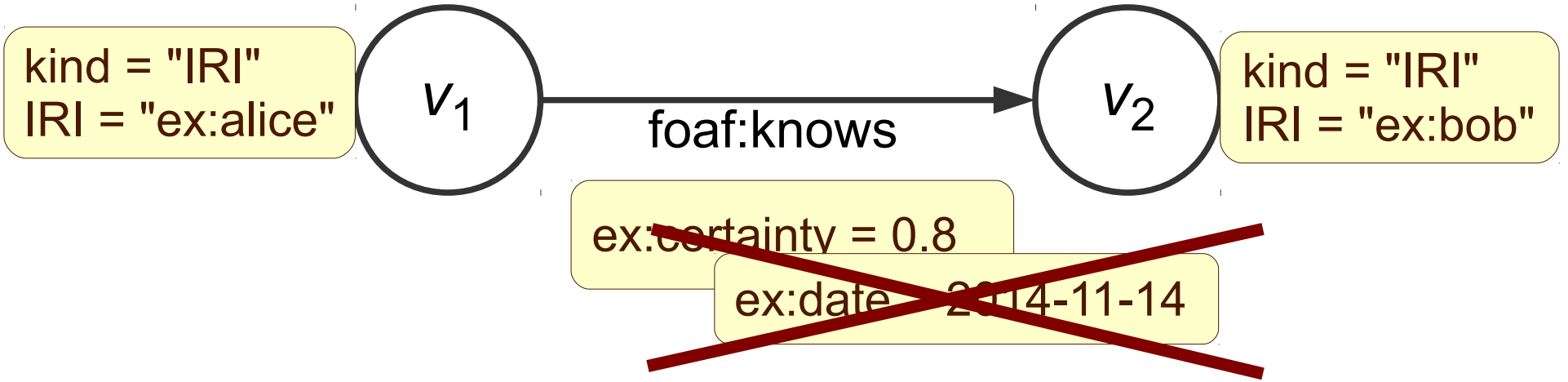


PG-Convertible RDF* Graphs

Condition 1: Metadata triples are not nested

(((ex:alice,foaf:knows,ex:bob) , ex:certainty, 0.8) ,

ex:date, 2014-11-14)

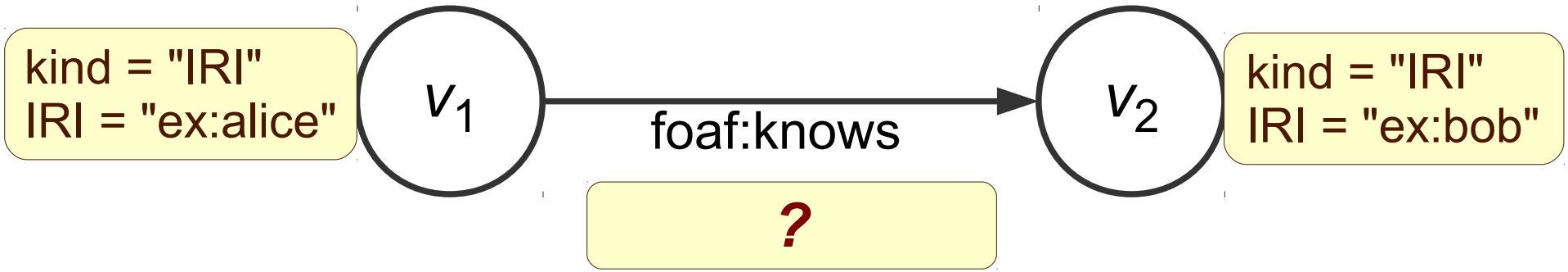


PG-Convertible RDF* Graphs

Condition 1: Metadata triples are not nested

Condition 2: Triples embedded as subject only

(ex:olaf , ex:believes , (ex:alice,foaf:knows,ex:bob))

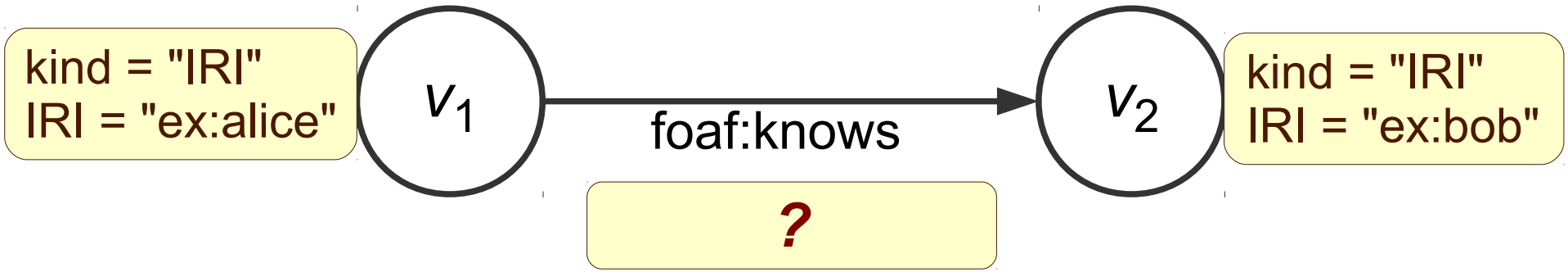


PG-Convertible RDF* Graphs

Condition 1: Metadata triples are not nested

Condition 2: Triples embedded as subject only

~~(ex:olaf , ex:believes , (ex:alice,foaf:knows,ex:bob))~~



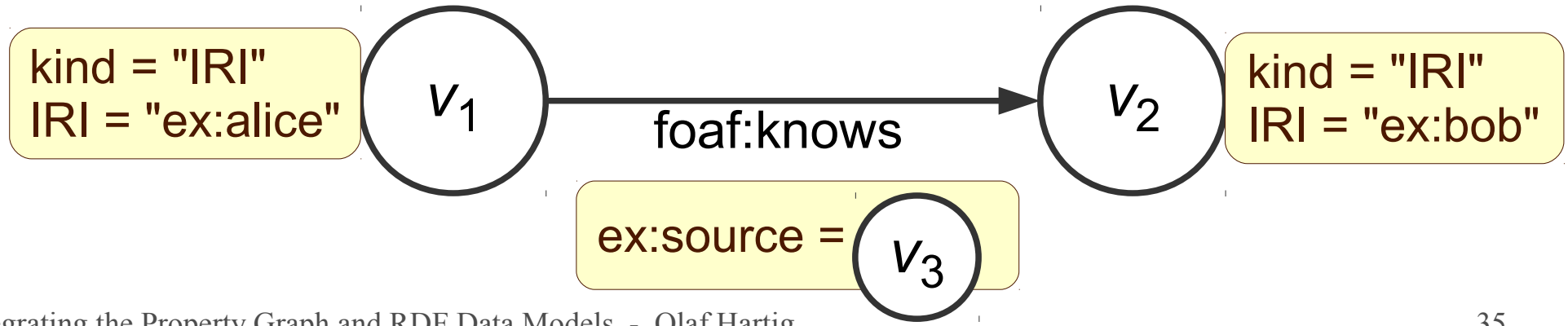
PG-Convertible RDF* Graphs

Condition 1: Metadata triples are not nested

Condition 2: Triples embedded as subject only

Condition 3: Object of any metadata triple must be a literal

((ex:alice,foaf:knows,ex:bob) , ex:source , ex:olaf)



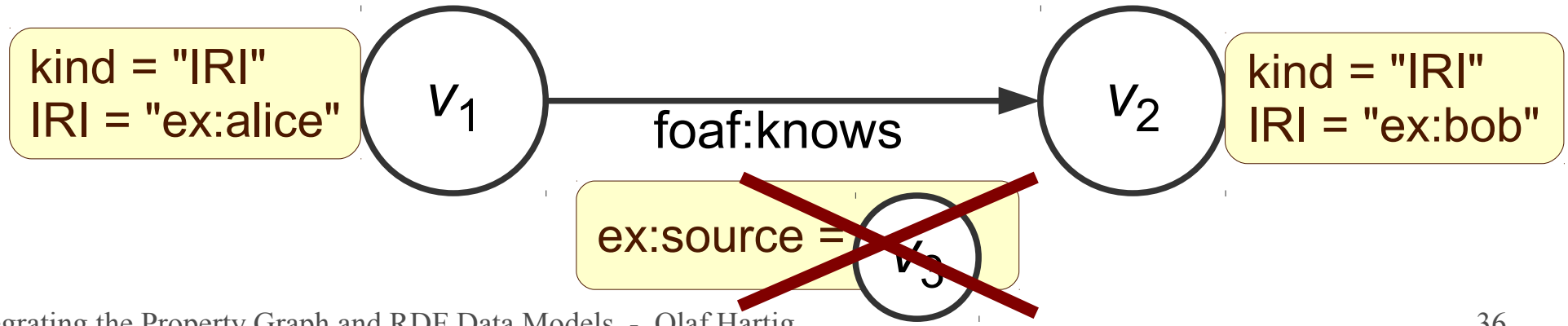
PG-Convertible RDF* Graphs

Condition 1: Metadata triples are not nested

Condition 2: Triples embedded as subject only

Condition 3: Object of any metadata triple must be a literal

~~((ex:alice,foaf:knows,ex:bob) , ex:source , ex:olaf)~~



PG-Convertible RDF* Graphs

Condition 1: Metadata triples are not nested

Condition 2: Triples embedded as subject only

Condition 3: Object of any metadata triple must be a literal

Condition 4: Any literal must be convertible to a value of some (programming language specific) data type

Properties of the Mapping

- **Lossless:** any Property Graph produced by the mapping contains all information present in the original RDF* graph
  - Resulting Property Graphs are “RDF-like”
- For PG users, such Property Graphs may be “unnatural” and too complex
  - Nodes for literals
  - Queries become quite verbose

Example Queries

```
SELECT ?pn WHERE {
    ?a  foaf:name  "Alice" .
    ?a  foaf:knows  ?p .
    ?p  foaf:name  ?pn    }

START a=node(*)
MATCH   (a)-[:foaf:name]->( bn { literal="Alice" } ) ,
            (a)-[:foaf:knows]->(p)-[:foaf:name]->(pn)
RETURN pn.literal
```

Example Queries

```
SELECT ?pn WHERE {
    ?a  foaf:name  "Alice" .
    ?a  foaf:knows  ?p .
    ?p  foaf:name  ?pn    }

START a=node(*)
MATCH   (a)-[:foaf:name]->( bn { literal="Alice" } ) ,
            (a)-[:foaf:knows]->(p)-[:foaf:name]->(pn)
RETURN pn.literal

START a=node(*)
MATCH   (a {foaf:name="Alice"} )-[:foaf:knows]->(p)
RETURN p.foaf:name
```

Outline

1. The Data Models √
2. Property Graphs to RDF* √
3. RDF* to
   - … “RDF like” Property Graphs √
   - … “Simple” Property Graphs

RDF* to “Simple” PGs

((ex:alice , foaf:knows , ex:bob) , ex:certainty , 0.8)
(ex:alice , foaf:name , "Alice")
(ex:bob , foaf:name , "Bob")
(ex:bob , foaf:age , 23)

1. Transform each *relationship triple* to an edge
   - i.e., ordinary triples with an IRI or bnode object

RDF* to “Simple” PGs

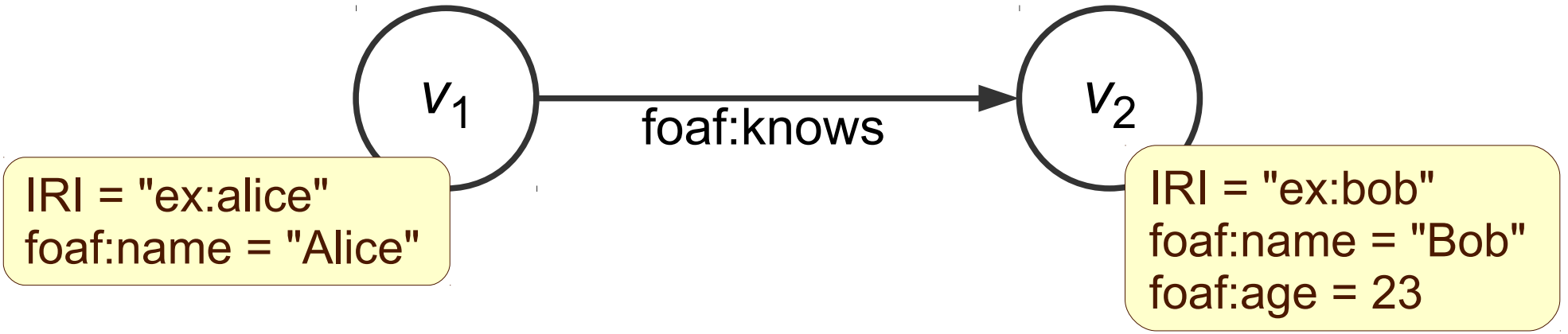
((ex:alice , foaf:knows , ex:bob) , ex:certainty , 0.8)
(ex:alice , foaf:name , "Alice")
(ex:bob , foaf:name , "Bob")
(ex:bob , foaf:age , 23)

1. Transform each *relationship triple* to an edge
   - i.e., ordinary triples with an IRI or bnode object

RDF* to “Simple” PGs

((ex:alice , foaf:knows , ex:bob) , ex:certainty , 0.8)
(ex:alice , foaf:name , "Alice")
(ex:bob , foaf:name , "Bob")
(ex:bob , foaf:age , 23)

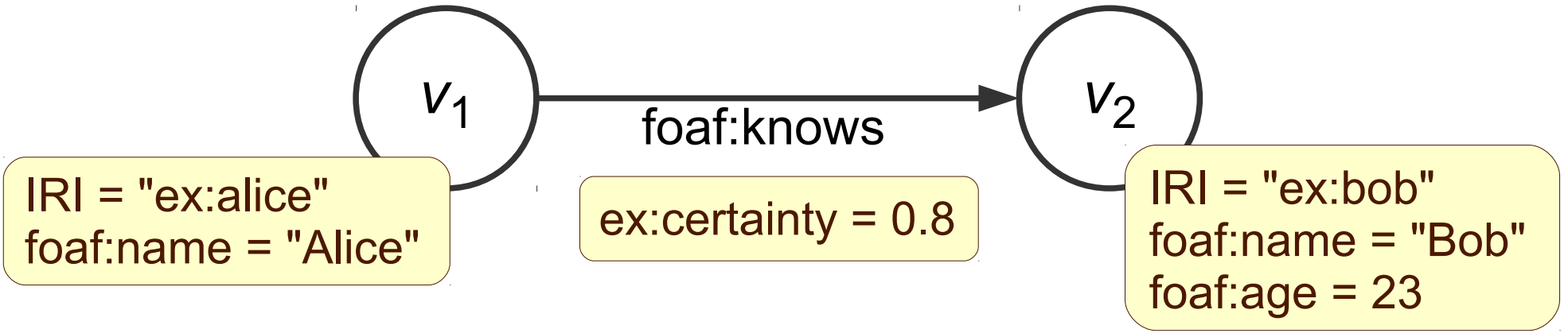
2. Transform *attribute triples* to node properties
   - i.e., ordinary triples with a literal as object



RDF* to “Simple” PGs

((ex:alice , foaf:knows , ex:bob) , ex:certainty , 0.8)
(ex:alice , foaf:name , "Alice")
(ex:bob , foaf:name , "Bob")
(ex:bob , foaf:age , 23)

3. Transform each metadata triple about a relationship triple to an edge property

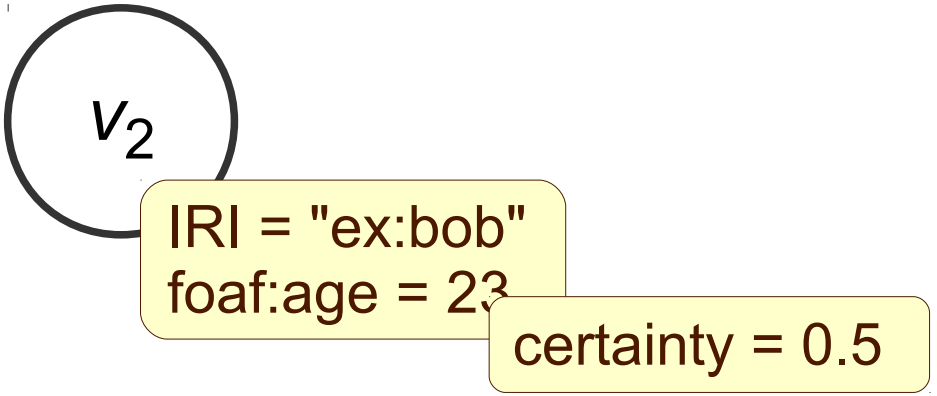


Strong PG-Convertibility

Condition 1: PG-convertibility

Condition 2: No metadata triple about an attribute triple

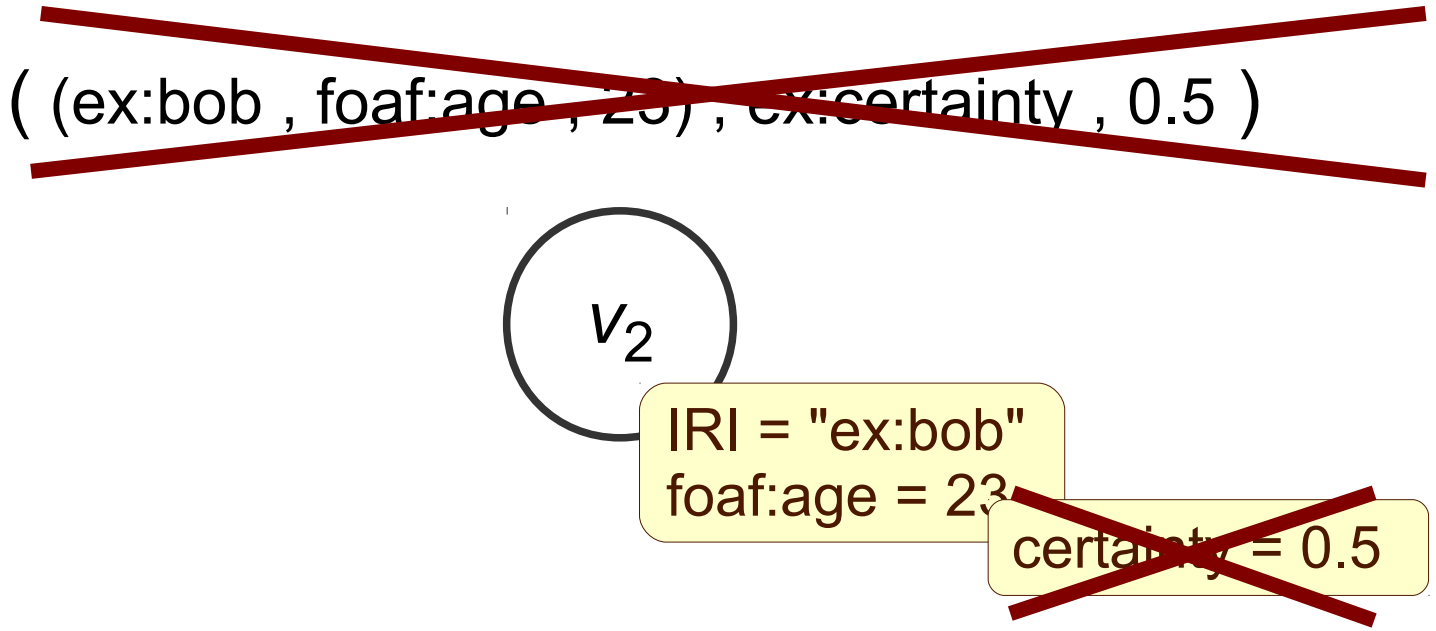
((ex:bob , foaf:age , 23) , ex:certainty , 0.5)



Strong PG-Convertibility

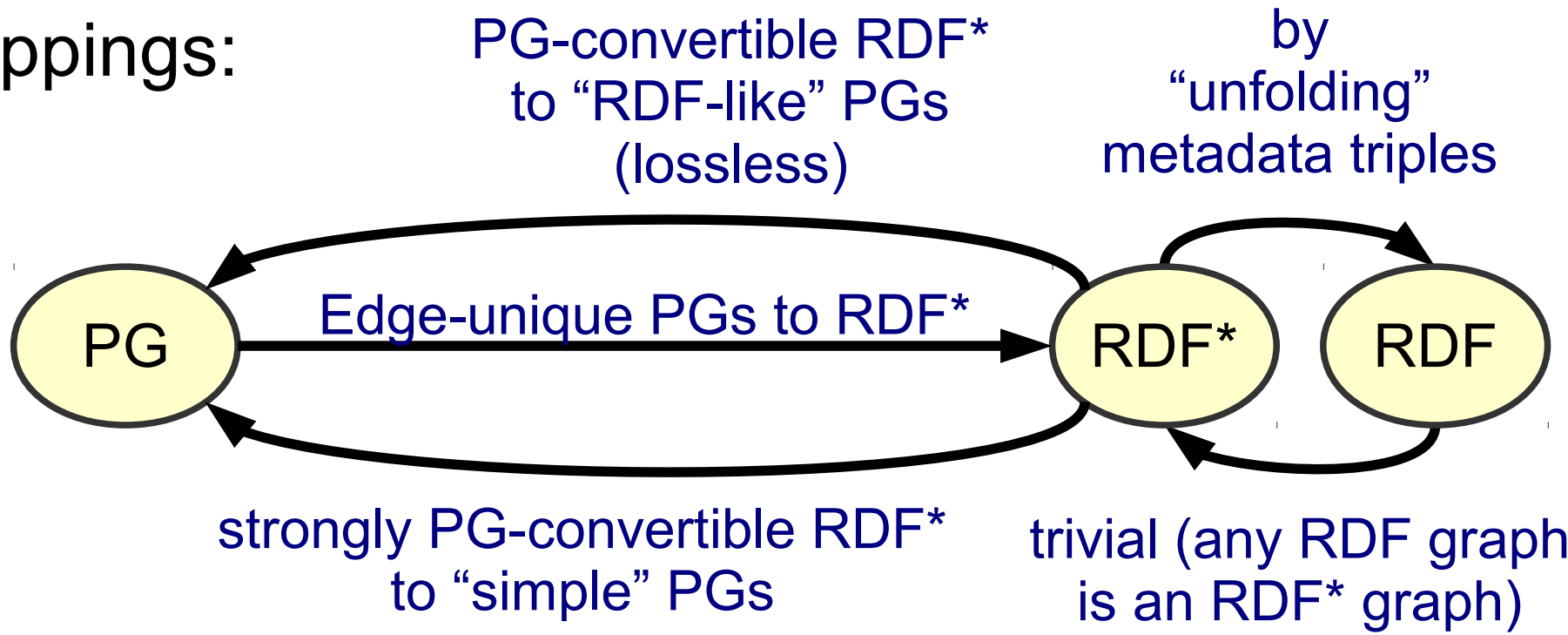
Condition 1: PG-convertibility

Condition 2: No metadata triple about an attribute triple



Summary

- RDF* – an compact form of RDF reification
  - Turtle*, SPARQL*
- Mappings:



- Documents: arxiv/1409.3288 (arxiv/1406.3399)

Thanks!

Questions?

Backup Slides

Named Graphs

```
                prefix foaf:    http://xmlns.com/foaf/0.1/
                prefix ex:  http://example.name/
ex:mygraph {    ( ex:alice , foaf:knows , ex:bob )   }
                ( ex:alice , foaf:name , "Alice" )
                ( ex:bob , foaf:name , "Bob" )
                ( ex:bob , foaf:age , 23 )

                ( ex:mygraph , ex:certainty , 0.8 )
```

Querying Named Graphs

```
SELECT ?c
WHERE {
  GRAPH ?g  {    ex:alice   foaf:knows   ex:bob    }

                                  ?g   ex:certainty   ?c
}
```

Querying Named Graphs

```
SELECT ?c
WHERE {
  GRAPH ?g  {     ex:alice   foaf:knows   ex:bob
                  { SELECT ( COUNT(*) AS ?cnt )
                    WHERE { ?s ?p ?o } }
              }
    FILTER ( ?cnt = 1 )
}                                  ?g   ex:certainty   ?c
```

SPARQL*

```
SELECT ?c
WHERE {
        << ex:alice  foaf:knows  ex:bob >>  ex:certainty  ?c
}
```

```
SELECT ?c
WHERE {
  BIND ( << ex:alice  foaf:knows  ex:bob >> AS ?s )
  ?s  ex:certainty  ?c
}
```

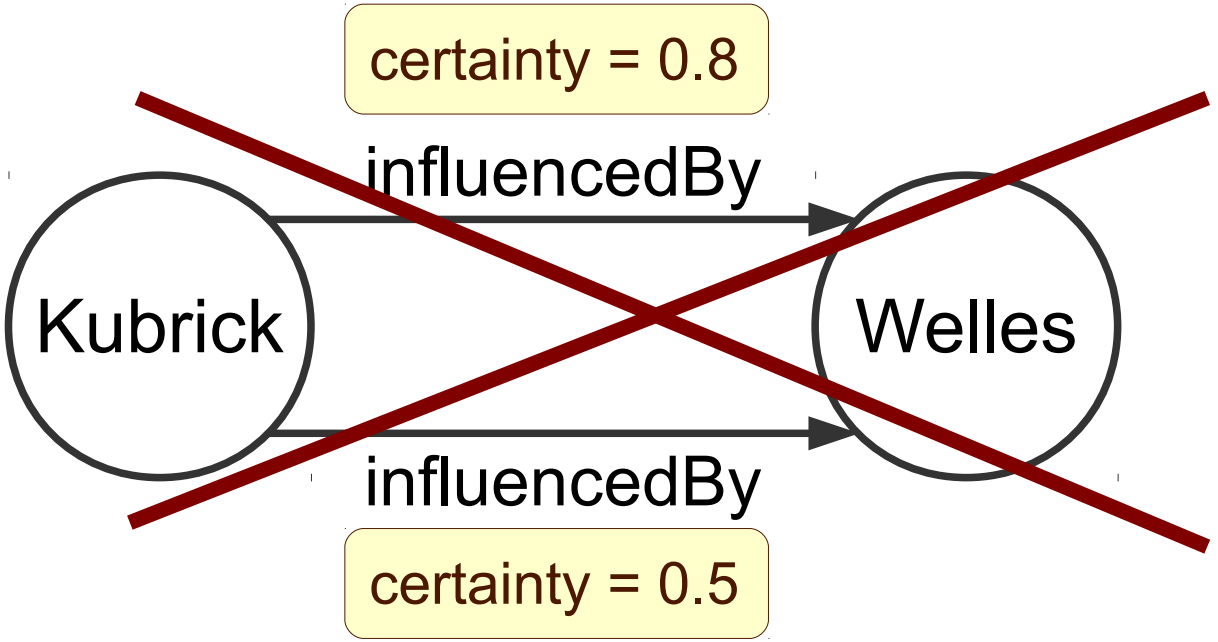
Definition: Property Graph

A *Property Graph* is a tuple $G=(V,E,src,tgt,lbl,\Phi)$ s.t.

- (V,E,src,tgt,lbl) is a labeled multigraph, i.e.,
  - V and E are vertices and edges, respectively,
  - $src: E \rightarrow V$, $tgt: E \rightarrow V$, and $tgt: E \rightarrow S$; and
- Φ is a function that maps every vertex and edge to a finite set of pairs $p = (k,v)$ such that k is a string and v is a value from the domain of some (programming language specific) datatype.

Definition: Edge Uniqueness

A Property Graph $G = (V,E,src,tgt,lbl,\Phi)$ is *edge-unique* if it does not contain a pair of distinct edges e and e' such that $src(e) = src(e')$, $tgt(e) = tgt(e')$, and $lbl(e) = lbl(e')$.



Definition: Property Uniqueness

Property Graph $G = (V,E,src,tgt,lbl,\Phi)$ is *property-unique* if, for each vertex or edge x, $k \neq k'$ for all pairs of distinct properties (k,v) and (k',v') in $\Phi(x)$.

- Implementations usually assume (resp. enforce) property uniqueness
- For some RDF* graphs, the transformations result in a Property Graph that is *not* property-unique.