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RDFPath
Path Query Processing on Large RDF Graphs with MapReduce

1st Workshop on High-Performance Computing for the Semantic Web (HPCSW 2011)

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Overview

Large RDF Graphs

- **Semantic Web**
  - Amount of Semantic Data increases steadily
  - RDF is W3C standard for representing Semantic Data
- **Social Networks**
  - > 500 million active users in Facebook
  - Interacting with >900 million objects (pages, groups, events)
  - Social Graphs can also be represented in RDF

- **How to explore, analyze such large RDF Graphs?**

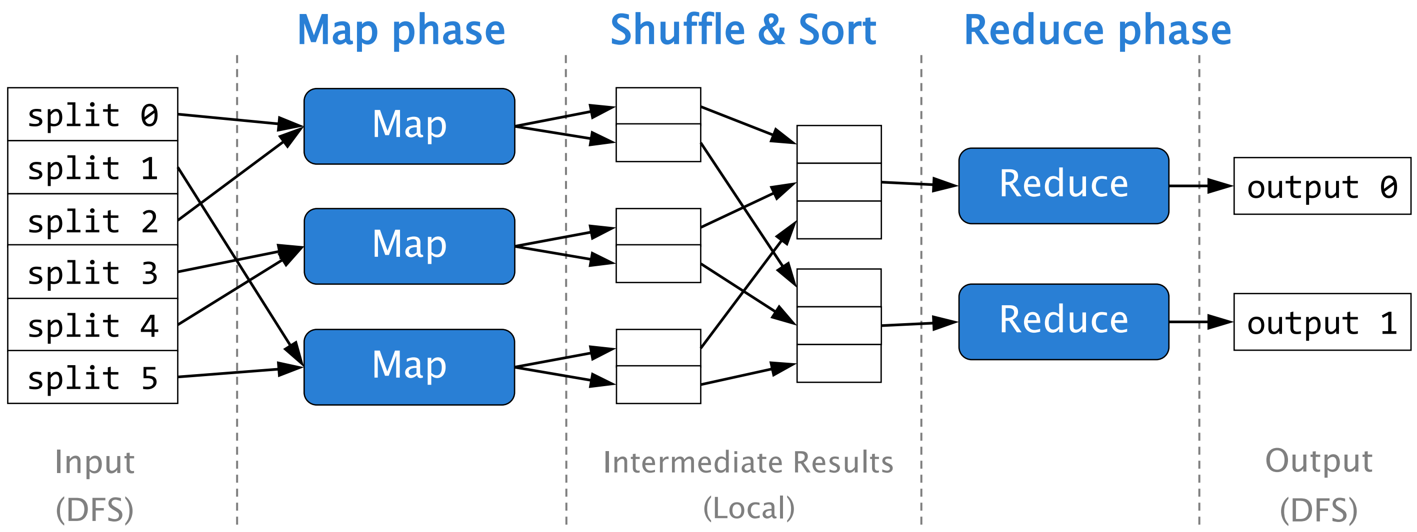
- **Our Approach:** **Distributed analysis of large RDF Graphs by mapping RDFPath to MapReduce**

MapReduce

- **MapReduce**
  - Popularized by Google & widely used
  - Automatic parallelization of computations
  - Fixed two-stage process: Map → Reduce → Map …
- **Distributed File System**
  - Clusters of commodity hardware
    → Fault tolerance by replication
  - Very large files / write-once, read-many pattern
- **Apache Hadoop**
  - Well-known Open-Source implementation
  - Used by Yahoo, Facebook, Amazon, IBM, Last.fm, …

MapReduce (2)

- Steps of a MapReduce execution



- Signatures
  - **Map:** (in_key, in_value) → *list* (out_key, intermediate_value)
  - **Reduce:** (out_key, *list* (intermediate_value)) → *list* (out_value)

3. RDFPath

Path queries on RDF Graphs

RDFPath

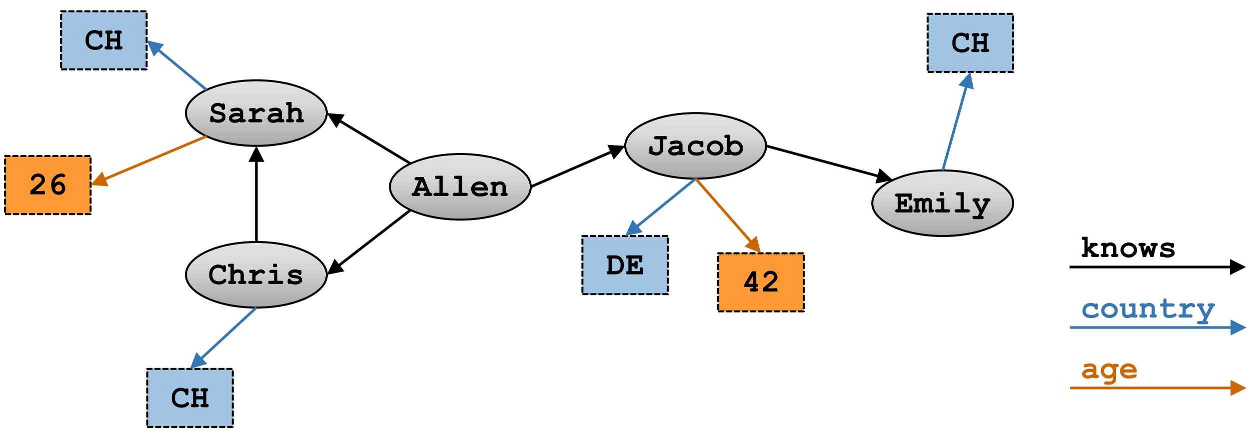
- **Idea**
  - Navigational queries on RDF Graphs
  - Declarative path specification inspired by XPath
  - Particularly designed with regard to MapReduce
    → Every location step is mapped to one MapReduce job
  - Extendibility

- **Features**
  - Fixed-length paths, shortest paths
  - Aggregate functions, degree of a node
  - Adjacent nodes and edges
  - …

Example (1)

- `Allen :: knows [country=equals("DE")] > age`

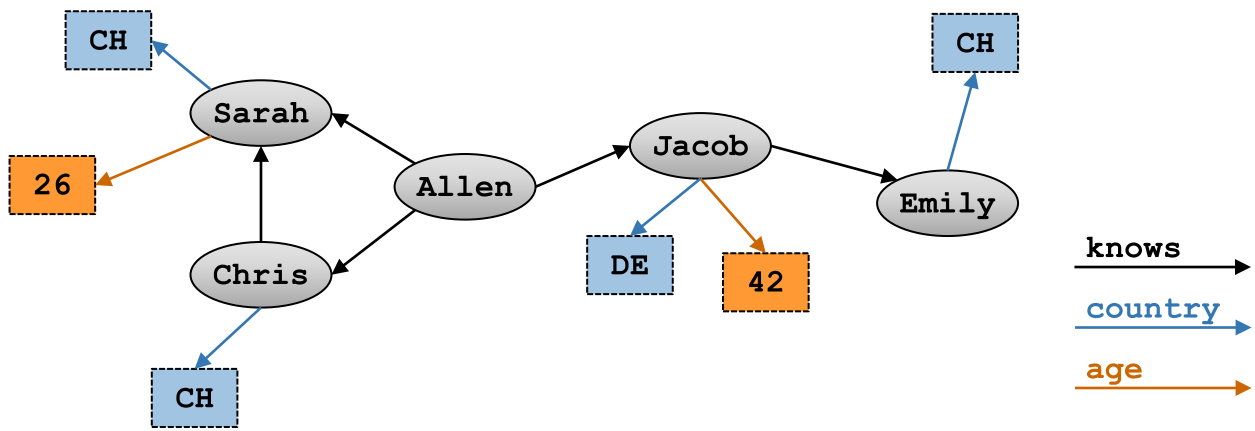
- Results
  - `Allen (knows) Jacob [country="DE"] (age) 42`
  - ~~`Allen (knows) Sarah [country="CH"]`~~
  - ~~`Allen (knows) Chris [country="CH"]`~~



Example (2)

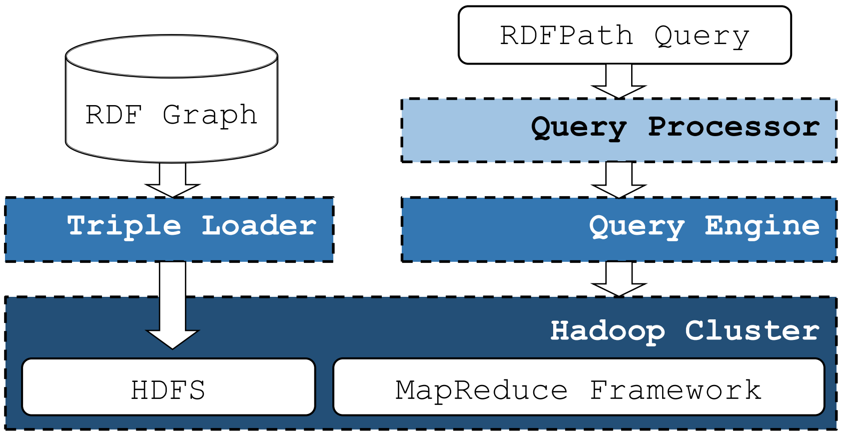
- Allen :: knows(*3)

- Results
  - Allen (knows) Jacob
  - Allen (knows) Jacob (knows) Emily
  - Allen (knows) Chris
  - Allen (knows) Sarah



Implementation

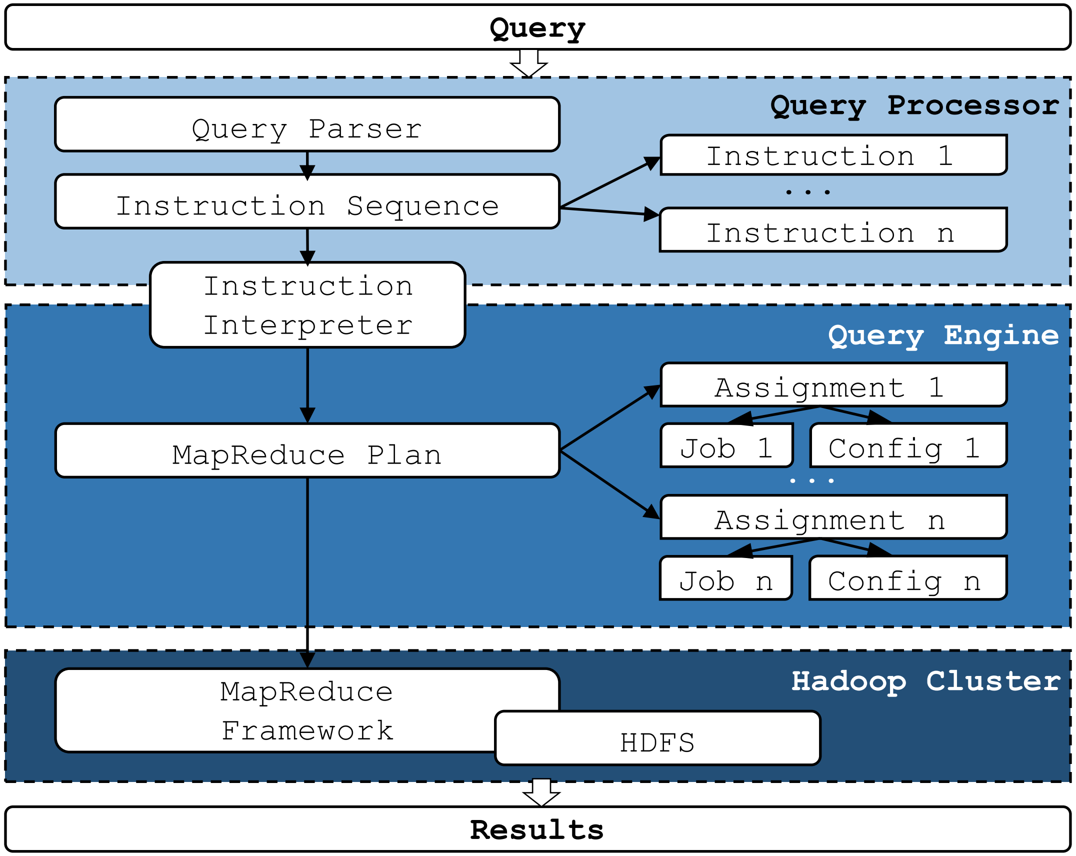
- System Architecture



- Storing RDF Graphs
  - RDF Graph is loaded in advance
  - Vertical Partitioning by predicate
  - Sequence Files stored in HDFS contain *PathObjects*

Implementation (2)

- Query Processing



Implementation (3)

- **Mapping to MapReduce Jobs**
  - $\underbrace{\texttt{Allen :: knows(*2)}}_{\text{intermediate paths}}$ > $\underbrace{\texttt{country [equals("DE")]}}_{\text{country}}$

intermediate paths

Allen	(knows)	Jacob	(knows)	Emily
Allen	(knows)	Jacob		
Allen	(knows)	Sarah		
…				

Join

country

Emily	CH
Jacob	DE
Sarah	CH
…	

- **Map task:**
  - Tagging `intermediate paths` and `country` partition for join
  - Applying filter condition
- **Reduce task:**
  - Perform join and store resulting paths back to HDFS

4. Experimental Results

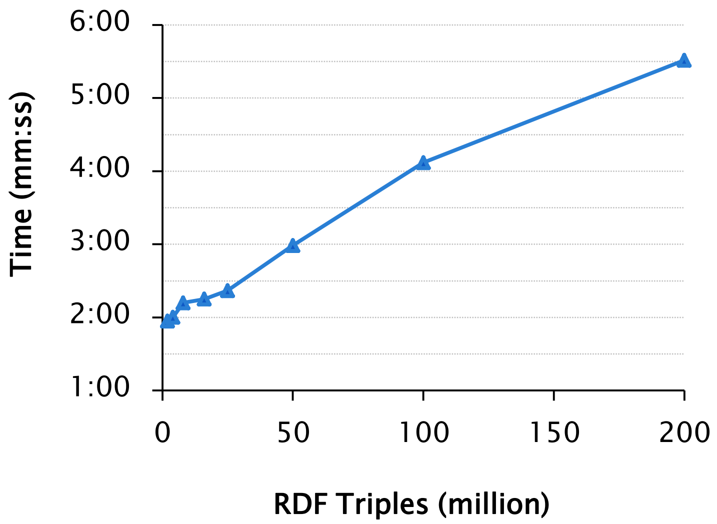
- Properties of RDFPath

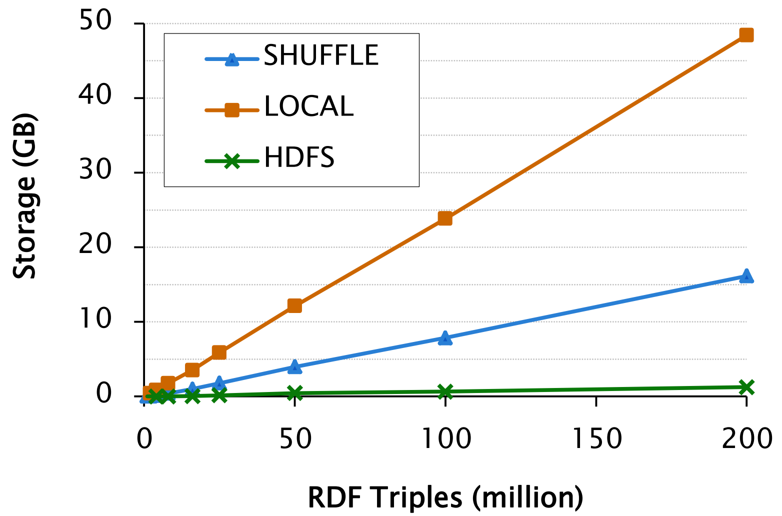
Experiments

- **Environment Setup**
  - Cluster of 10 machines (Dual Core CPU, 4GB RAM, 1GB HD)
  - Cloudera's Distribution for Hadoop 3 Beta 1
  - Default configuration with 9 reducers (one per HD)
- Real-World Last.fm dataset
  - 225 million RDF triples
- Different input-sizes instead of varying the number of machines

Query 1

- The Disco Boys - I Surrender :: trackSimilar(*4) > trackAlbum

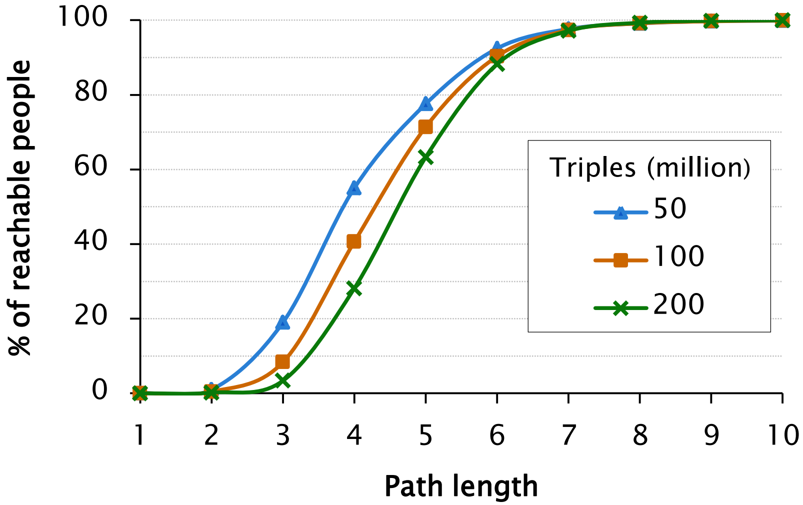


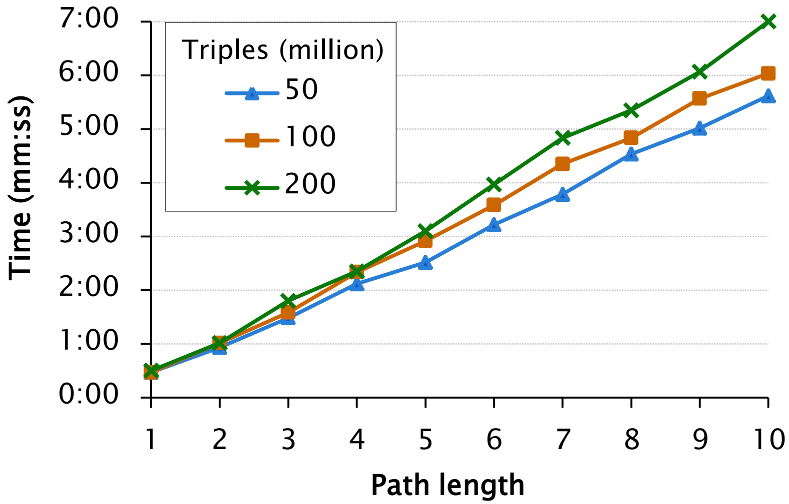


- Linear scaling behavior for execution times & amount of data
- Execution times mainly influenced by number of intermediate results stored locally as well as transferred data

Query 3

- Chris :: knows(*X) , 1 ≤ X ≤ 10

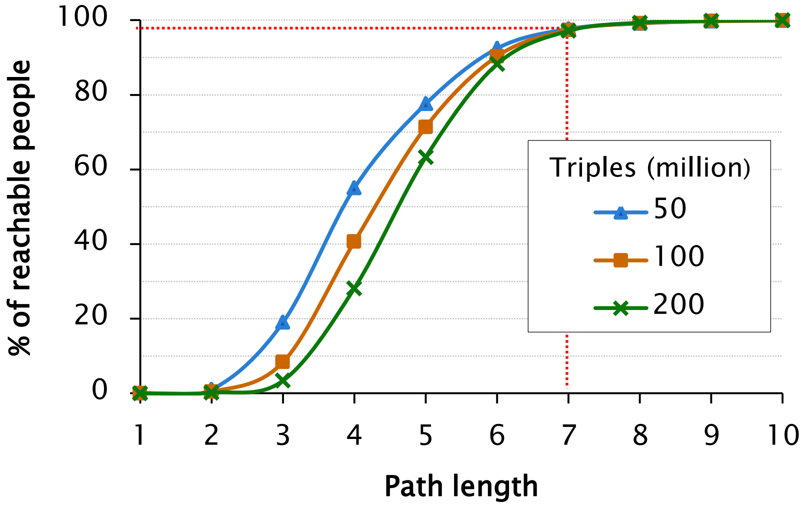


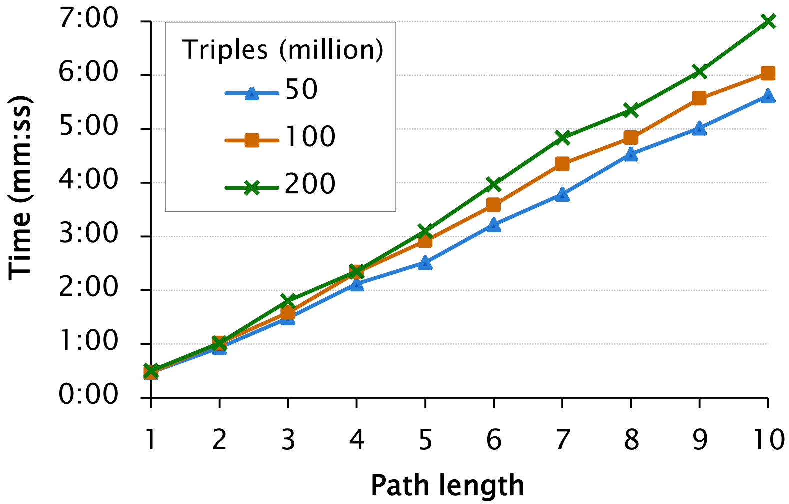


- 98% of all reachable persons can be reached by at most 7 edges
  → Corresponds to the well-known six degrees of separation paradigm
- Linear scaling behavior, mainly determined by number of joins

Query 3

- Chris :: knows(*X) , 1 ≤ X ≤ 10





- 98% of all reachable persons can be reached by at most 7 edges
  → Corresponds to the well-known six degrees of separation paradigm
- Linear scaling behavior, mainly determined by number of joins

Summary

- Amount of Semantic Web data is growing constantly!

- RDFPath
  - Intuitive syntax for path queries
  - Expression of interesting graph issues such as Friend of a Friend queries
  - Investigating small world properties like six degrees of separation
  - Designed with MapReduce in mind

- Execution
  - Direct mapping to MapReduce
  - Scaling properties of MapReduce enable analysis of large RDF Graphs

- Evaluation
  - Based on real-world data from Last.fm
  - Shows linear scaling behavior in the size of the graph
  - Confirms the effectiveness of our approach

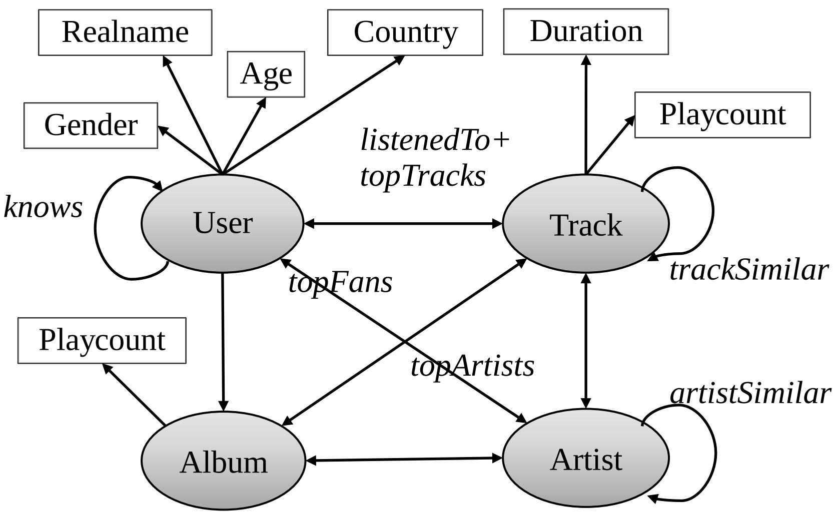
Thanks for your attention.

Backup Slides

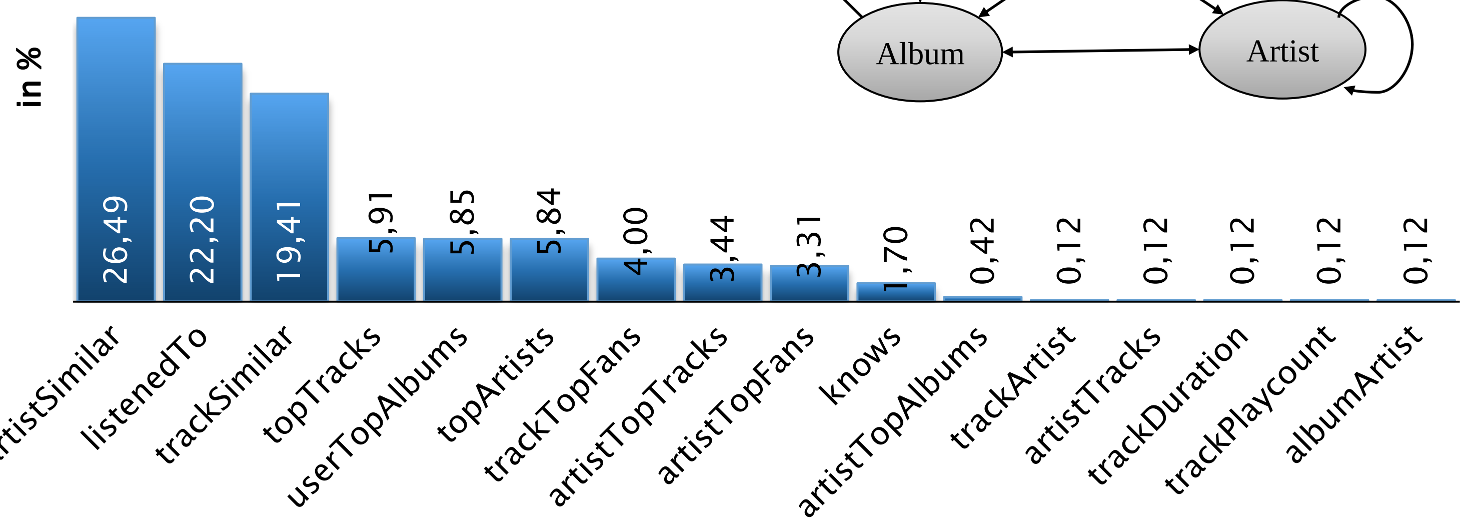
a) Last.fm
b) Examples cont.
c) Evaluation cont.
d) RDFPath Features
e) Mapping
f) Comparison
g) Reduce-Side-Join

Thanks

a) Last.fm



Realname
Age
Country
Duration
Gender
Playcount
listenedTo+
topTracks
knows
User
Track
trackSimilar
topFans
Playcount
topArtists
artistSimilar
Album
Artist

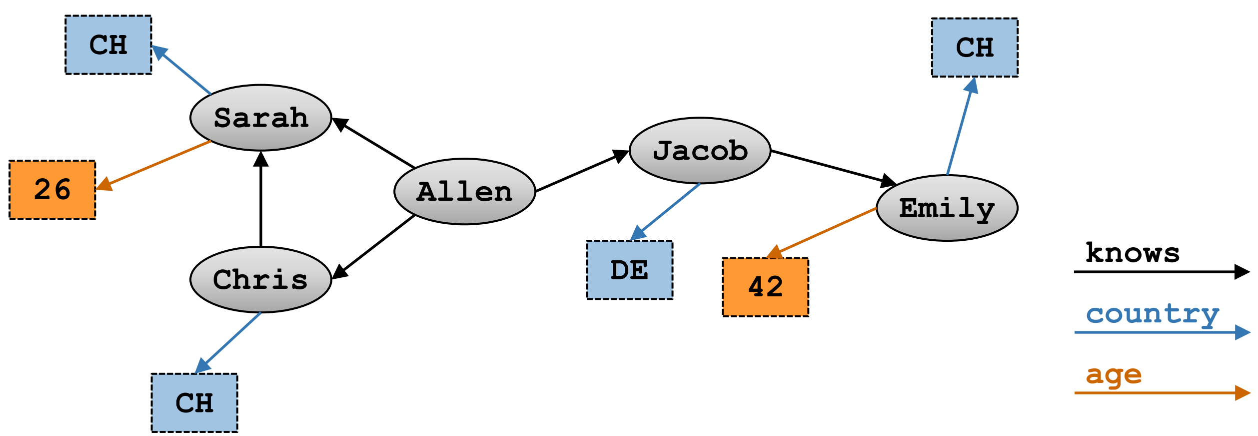


in %
26,49
22,20
19,41
5,91
5,85
5,84
4,00
3,44
3,31
1,70
0,42
0,12
0,12
0,12
0,12
0,12
artistSimilar
listenedTo
trackSimilar
topTracks
userTopAlbums
topArtists
trackTopFans
artistTopTracks
artistTopFans
knows
artistTopAlbums
trackArtist
artistTracks
trackDuration
trackPlaycount
albumArtist

b) Example (3)

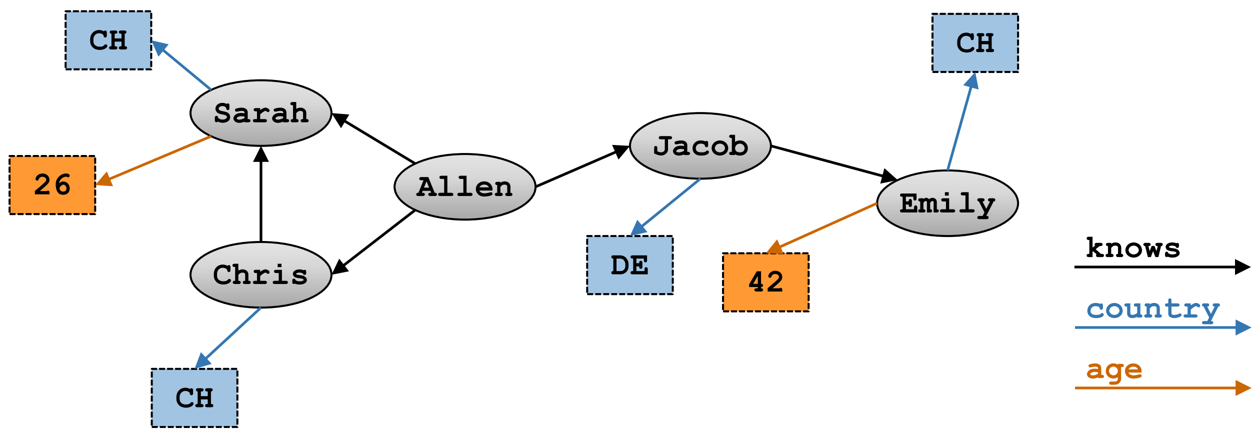
- `Allen :: knows > knows [country=prefix("C")] > age [min(18)][max(80)] .avg()`

- Result
  - 34



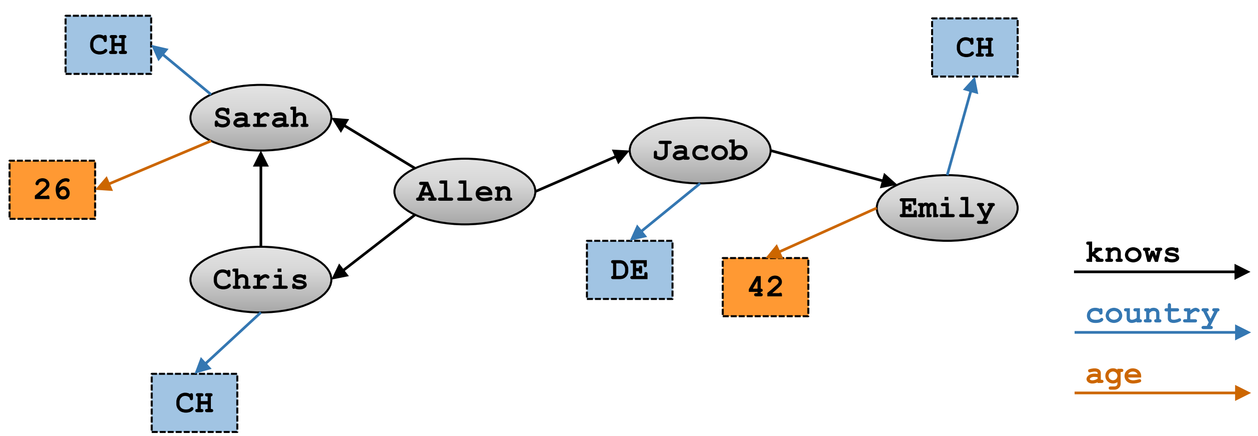
b) Example (4)

- `* :: knows [equals("Sarah")]`
- Results
  - Allen (knows) Sarah
  - Chris (knows) Sarah
  - ~~Jacob (knows) Emily~~
  - ~~Allen (knows) Jacob~~
  - ~~Allen (knows) Chris~~



b) Example (5)

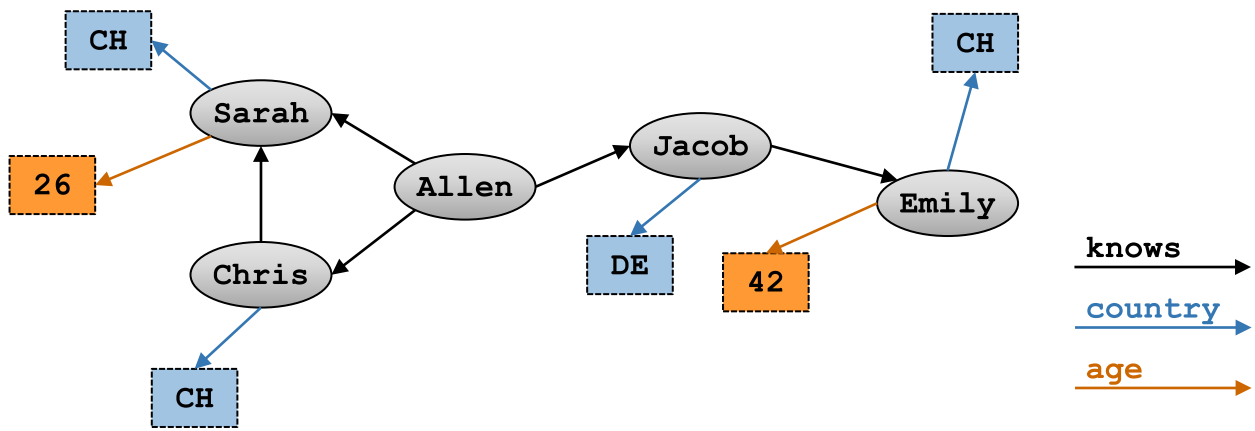
- `* :: knows > knows [equals("Sarah")]`
- Results
  - `Allen (knows) Chris (knows) Sarah`
  - ~~`Allen (knows) Jacob (knows) Emily`~~



b) Example (6)

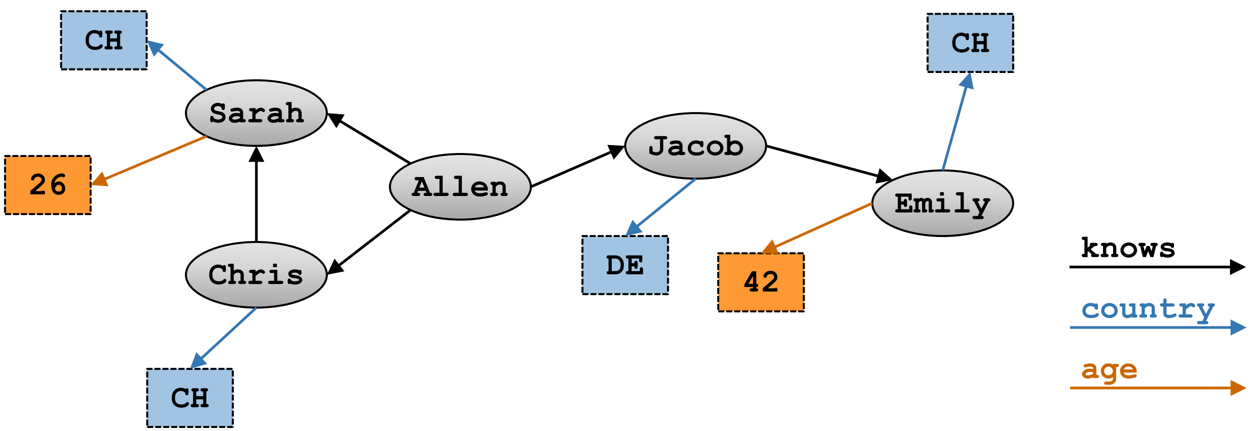
- `* :: * > * [equals("Sarah")]`

- Results
  - Allen (knows) Chris (knows) Sarah
  - ~~Allen (knows) Jacob (knows) Emily~~
  - ~~...~~



b) Example (7)

- `Allen :: * .count()`
- Result
  - 3



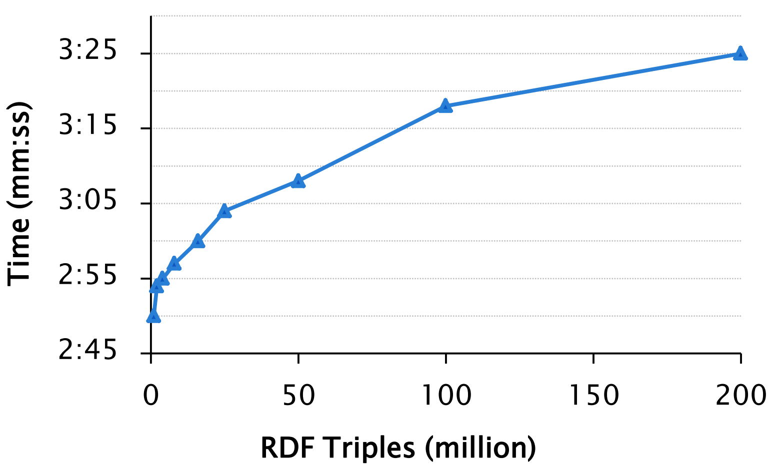
b) Example (Last.fm)

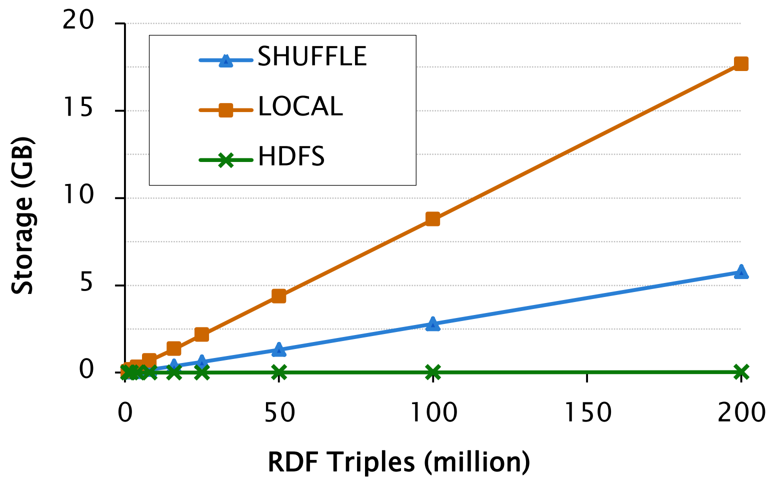
- ```
  Michael_Jackson :: artistTracks
        [trackAlbum = equals(Michael_Jackson_-_Thriller)]
          > trackSimilar [trackDuration = min(50000)]
          > trackTopFans [userCountry = equals(DE)].
  ```

- Results
  - Michael_Jackson (artistTracks)
    Michael_Jackson_-_Beat_It (trackSimilar)
    Michael_Jackson_-_Billie_Jean (trackTopFans) Mark
  - Michael_Jackson (artistTracks)
    Michael_Jackson_-_Someone_in_the_Dark (trackSimilar)
    Rihanna_-_Russian_Roulette (trackTopFans) Megan
  ```

c) Query 2 (Backup)

```
Michael_Jackson :: artistTracks
    [ trackAlbum = equals('Michael_Jackson_-_Thriller') ]
    > trackSimilar [ trackDuration = min(50000) ]
    > trackTopFans [ country = equals('DE') ]
```





d) RDFPath Features by Example

- **Startnode**
  - `Chris :: knows`
  - `* :: knows`
- **Location Step**
  - `Chris :: knows > knows > age`
  - `Chris :: knows (2) > age`
  - `Chris :: *`
- **Filters:** `equals(), prefix(), suffix(), min(), max()`
  - `Chris :: knows > age [min(18)] [max(67)] (6)`
  - `Chris :: * > * [equals('Peter')] (7)`
  - `Chris :: knows [age = min(30)] [country = prefix('D')] > name`
- **Bounded Search**
  - `Chris :: knows [country = equals('DE')] (*3)`
- **Bounded Shortest Path**
  - `Chris :: knows (*3).distance('Peter')`
- **Aggregation Functions:** `count(), sum(), avg(), min() and max()`
  - `Chris :: *.count()`
  - `Chris :: knows > age.avg()`

e) Mapping to MapReduce Jobs

- **Composition**
  - Queries in RDFPath are composed of location steps
  - One location step is mapped to a join in MapReduce
- **Map tasks:**
  - Tagging for RSJs
  - Applying filter conditions
- **Reduce tasks:**
  - Performing RSJs
  - Aggregating values
  - Computing Shortest paths
  - Checking for Cycles

f) RDF Query Languages

Property	RQL	SeRQL, RDQL[3], Triple	N3	Versa	RxPath	RPL	SPARQL (1.0)	RDFPath
Adjacent nodes	±	±	±	±	×	√	√	√
Adjacent edges	±	±	×	×	×	×	√	√
Degree of a node	±	×	×	×	×	×	×	√
Path	×	×	×	×	±	±	×	±
Fixed-length Path	±	±	±	×	±	±	√	√
Distance between 2 nodes	×	×	×	×	×	×	×	±
Diameter	×	×	×	×	×	×	×	×
Shortest Paths	×	×	×	×	×	×	×	±
Aggregate functions	±	×	×	×	±	×	×	±

(×: not supported, ±: partially supported, √: fully supported)

Table 1. Comparison of RDF Query Languages (adapted from [4, 5])

f) RDF Query Languages (2)

- **Adjacent nodes:**
  - All nodes adjacent to a `startnode`
- **Adjacent edges:**
  - All predicates of statements involving a given startnode
- **Degree of a node:**
  - Number of predicates involving a startnode
- **Path:**
  - Find paths between a fixed startnode and an endnote of arbitrary length
- **Fixed-length paths:**
  - Find all paths of length 2 between startnote and endnote
- **Distance between two resources:**
  - (length of shortest path without a max length!)
- **Diameter of a graph:**
  - Diameter of a given RDF Graph.

f) Comparison to SPARQL 1.0

- Fixed-length paths

```
SELECT  ?tmp1, ?tmp2, ?tmp3,
        ?tmp4, ?tmp5
WHERE {
  Allen knows ?tmp1 .
  ?tmp1 knows ?tmp2 .
  ?tmp2 knows ?tmp3 .
  ?tmp3 knows ?tmp4 .
  ?tmp5 knows ?tmp5
}
```

```
Allen :: knows(5)
```

SPARQL	RDFPath

f) Comparison to SPARQL 1.0

- Filters

```
SELECT  ?tmp1, ?tmp2, ?tmp3, ?tmp4
WHERE {
  Allen knows ?tmp1 .
  ?tmp1 age   ?age1 .
  Filter (?age1 >= 20)
  ?tmp1 knows ?tmp2 .
  ?tmp2 country “DE” .
}
```

```
Allen :: knows [age=min(20)]
        > knows [country=equals(“DE”)]
```

SPARQL

RDFPath

f) Comparison to SPARQL 1.0

- **Drawbacks of SPARQL**
  - Limited navigational capabilities
  - No Shortest Path Queries
  - No Aggregate functions (count, min, max , …)
  - No Abbreviations for following same edges

- **Advantages of SPARQL**
  - Expressive general purpose query language for RDF
  - Intuitive Syntax, related to SQL
  - SPARQL 1.1 adds support for some path queries

g) Reduce-Side Join

- Example:

$\underbrace{\texttt{* :: knows(*2)}}$ > $\underbrace{\texttt{knows}}$

intermediate paths

```
Peter (knows) Frank (knows) Chris
Peter (knows) Simon (knows) Johan
Klaus (knows) Simon (knows) Johan
Frank (knows) Chris
Peter (knows) Klaus
              …
```

Reduce-Side Join

knows

```
Chris   Peter
Johan   Frank
Johan   Lukas
Frank   Chris
     …
```

g) Reduce-Side Join (2)

Mapper Input

intermediate paths

```
Peter (knows) Frank (knows) Chris
Peter (knows) Simon (knows) Johan
Klaus (knows) Simon (knows) Johan
Frank (knows) Chris
Peter (knows) Klaus
…
```

knows

```
Chris   Peter
Johan   Frank
Johan   Lukas
Frank   Chris
…
```

...

Mapper Output

```
Key            Value
(Chris, 1)     Peter (knows) Frank (knows) Chris
(Johan, 1)     Peter (knows) Simon (knows) Johan
(Johan, 1)     Klaus (knows) Simon (knows) Johan
(Chris, 1)     Frank (knows) Chris
(Klaus, 1)     Peter (knows) Klaus
…

(Chris, 0)     Peter
(Johan, 0)     Frank
(Johan, 0)     Lukas
(Frank, 0)     Chris
…
```

g) Reduce-Side Join (3)

- **Sorting phase:**
  (1) Partition according to the first keypair % #reducer
  (2) Sort within a partition according to the whole keypair

- **Consequences**
  - A reducer gets all values with the same first keypair
  - The values within a partition contain at first all new nodes and thereafter all intermediate paths

g) Reduce-Side Join (4)

Reducer Input

```
                                     Chris
Peter
Manu
Peter (knows) Frank (knows) Chris
Frank (knows) Chris
                    …
```

```
                                     Johan
Frank
Lukas
Peter (knows) Simon (knows) Johan
Klaus (knows) Simon (knows) Johan
                    …
```

Reducer Output

~~Peter (knows) Frank (knows) Chris (knows) Peter~~

```
Peter (knows) Frank (knows) Chris (knows) Manu
Frank (knows) Chris (knows) Peter
Frank (knows) Chris (knows) Manu
                    …

Peter (knows) Simon (knows) Johan (knows) Frank
Peter (knows) Simon (knows) Johan (knows) Lukas
Klaus (knows) Simon (knows) Johan (knows) Frank
Klaus (knows) Simon (knows) Johan (knows) Lukas
```