Revisiting Link Prioritization for Efficient Traversal in Structured Decentralized Environments

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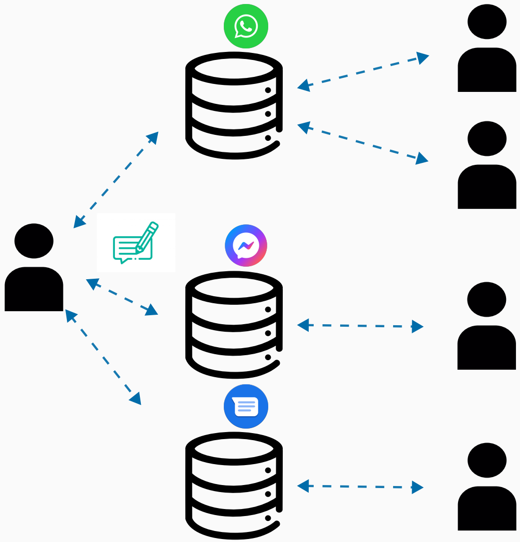
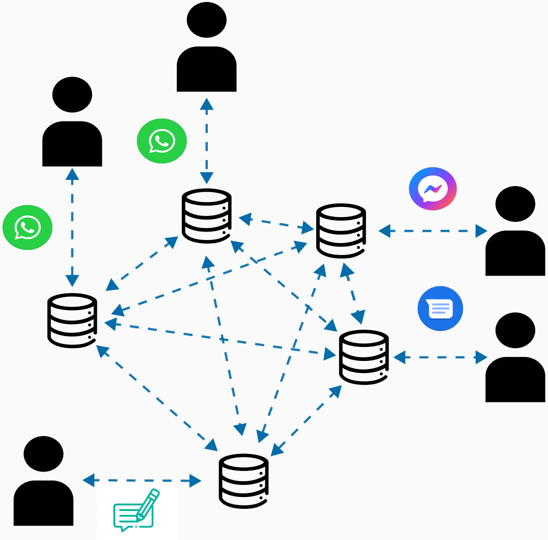
The Need for Decentralized Personal Data Storage



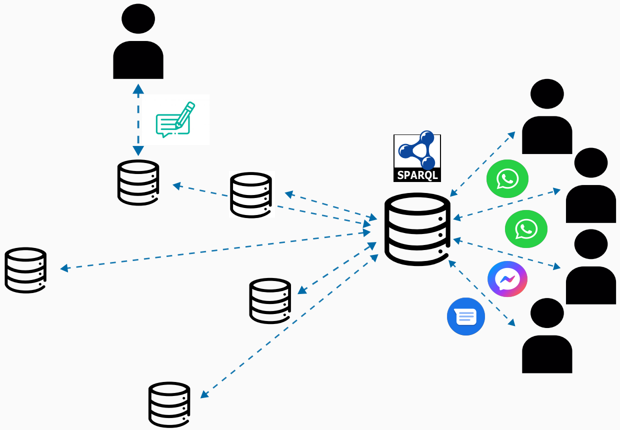
- Each application has its own data
- Stifles innovation
- Causes vendor lock-in

The Need for Decentralized Personal Data Storage



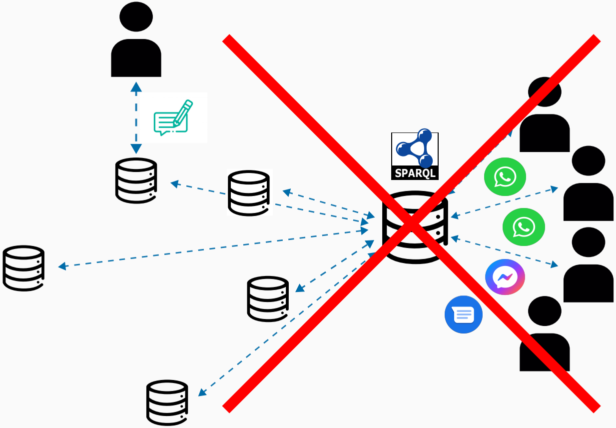
- Each application uses common data storage
- Easy to switch vendors
- Promotes innovation

The Problem with Centrally Aggregating and Querying



- Why not aggregate data and query it?
- Difficult in case of personal data due to privacy concerns

The Problem with Centrally Aggregating and Querying



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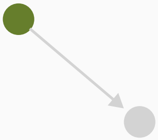
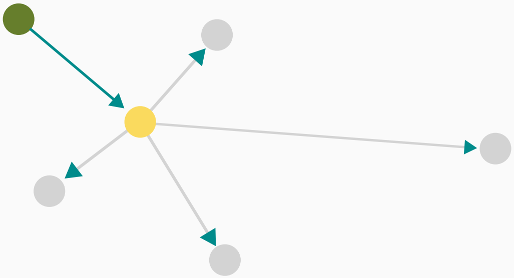
Link Traversal: Seed Document



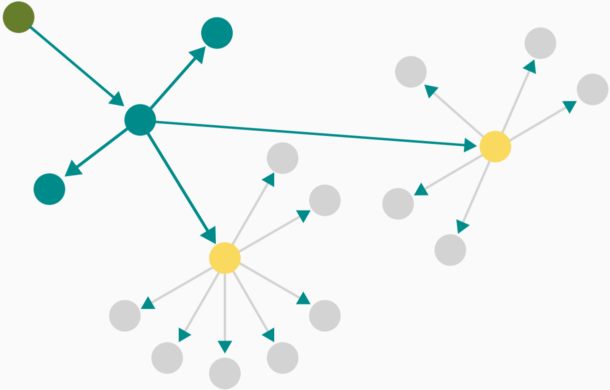
- Link Traversal starts from seed documents (URIs)
- These are provided by the user or in the query.

Link Traversal: Traversal



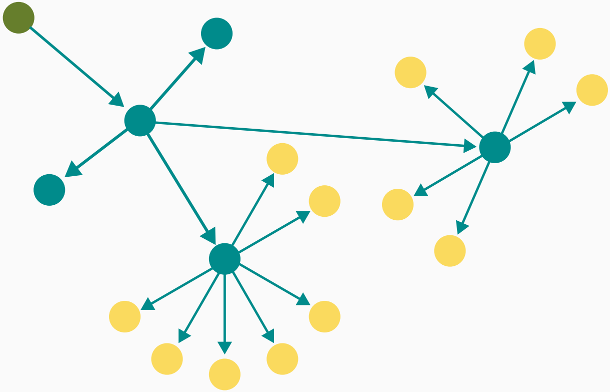
- New URIs are extracted from the seed document
- URIs are extracted in accordance with reachability criterions

Link Traversal: Traversal



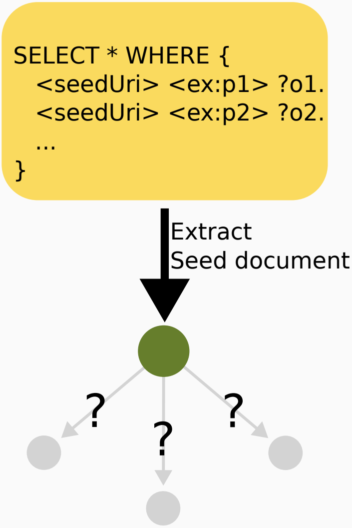
- New URIs are dereferenced and the process is repeated

Link Traversal: Termination



- This continues until all links are dereferenced
- Continuously produces results
- Can enforce fine-grained (document-level) access-control

Query Optimization for Link Traversal

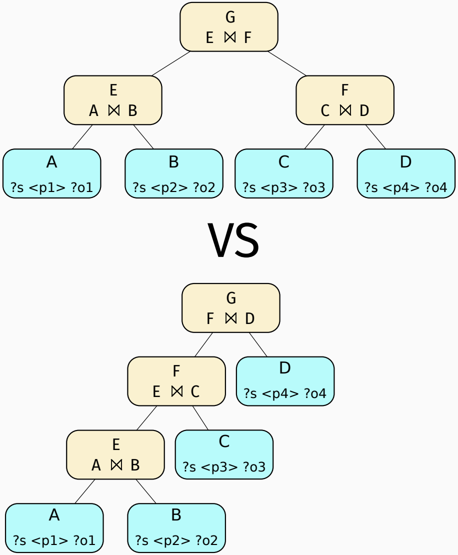


The query (partly) determines:

- The queried data
- The topology of the queried data
- The query-relevant documents

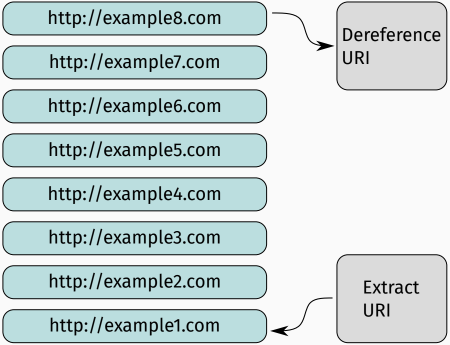
Result: limited prior knowledge for query optimization

Query Optimization for Link Traversal: Traditional Query Planning



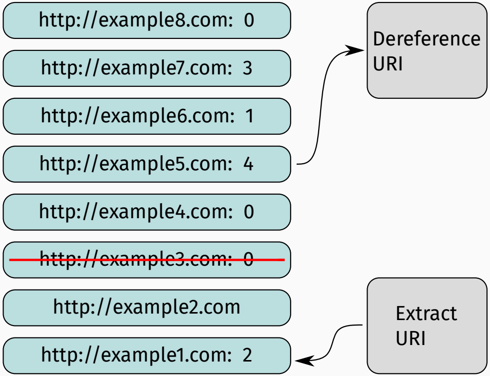
- Query optimization for link traversal involves traditional (zero knowledge) query planning
- Assume an optimize-then-execute

Query Optimization for Link Traversal: Traversal optimization



- URIs are put into a link queue
- Link traversal uses a FiFo queue by default

Query Optimization for Link Traversal: Traversal optimization



Optimizations:

- Prioritize query-relevant URIs
- Prune irrelevant URIs
- Pruning can lead to missing results without prior knowledge

Problem Statement

Investigate the performance of link prioritization algorithms in literature in new structured decentralized environments

Problem Statement

- These algorithms are implemented in an engine that is no longer maintained
- The baseline performance depends on design choices orthogonal to the prioritization algorithm
- The baseline should measure marginal prioritization performance

R^3 Metric: Introduction

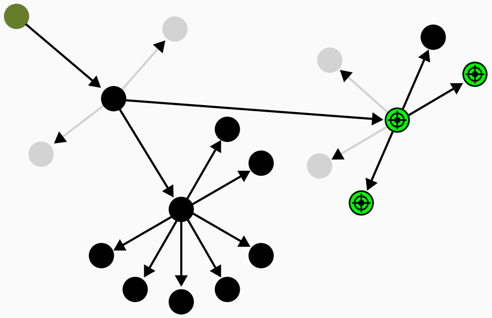


Figure 1: Actual traversal

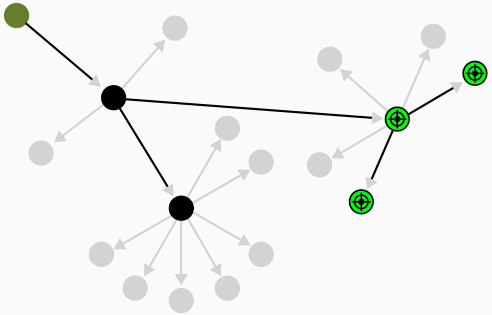


Figure 2: Optimal traversal: minimal cost path

$$R^3 = \frac{5}{13} = 0.38$$

R^3 metric: Definition

Definition

$$R^3 = \frac{C(X)}{C(O_\mathcal{T})}$$

- X: the **optimal traversal order** (minimal-cost path)
- $O_\mathcal{T}$: traversal order produced by the link prioritization algorithm
- $C(\cdot)$: The total cost of all arcs in the traversal path

Interpretation

- $R^3 = 1$ perfect match with the optimal traversal
- $R^3 < 1$ deviation from optimal performance
- **Higher values indicate better prioritization quality.**

R^3 metric: Steiner Trees

- Directed graph steiner tree over traversed directed graph $G = (V, A)$ with root r
- Query-relevant documents D_T serve as terminals $T \subseteq V$
- Find minimum cost sub-graph $X = (V', A')$ starting at root r and spanning all vertexes T.
- With cost: $C(X) = \sum_{a \in A'} c(a)$,, with $c(a)$ the cost of an edge in the topology

Investigated Structured Decentralized Environment

Simulated Solid Environment: SolidBench (Taelman and Verborgh 2023)

- Data is stored in vaults
- Vaults use document-centric structure
- Vaults simulate a social media application

Data attributes

- Generates 158,233 RDF files
- Across 1,531 data vaults
- containing a total of 3,556,159 triples.

Analysed queries

- Use discover queries

Prioritization algorithms (Hartig and Özsu 2016)

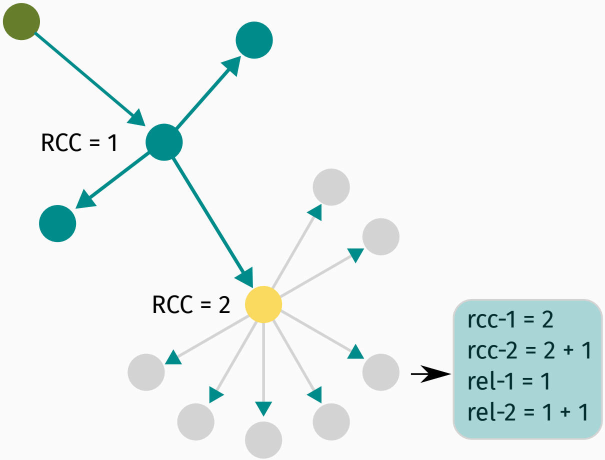
Non-adaptive

- Breadth-first (default), depth-first, random prioritization

Graph-based

- In-degree, PageRank score

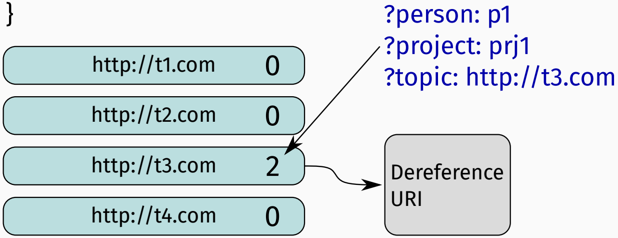
Prioritization algorithms: Result Contribution-Based (RCC)



- Nodes adaptively scored according to the number of results they contribute to
- Called *rcc-1*, *rcc-2*, *rel-1*, *rel-2*.

Prioritization algorithms: Intermediate Results-based

```
SELECT ?person ?project ?topic
WHERE {
  ?person ex:worksFor ?company .
  ?person ex:worksOn ?project .
  ?project ex:hasTopic ?topic .
}
```



- Nodes adaptively scored according to their contribution to intermediate results
- *IS* with initial priorities of 0, while *ISdcr* sets priority to the priority of the parent node - 1

Prioritization algorithms

Hybrid

- Multiply intermediate result and RCC-based scoring functions
- *is-rcc1*, *is-rcc2*, *is-rel1*, *is-rel2*

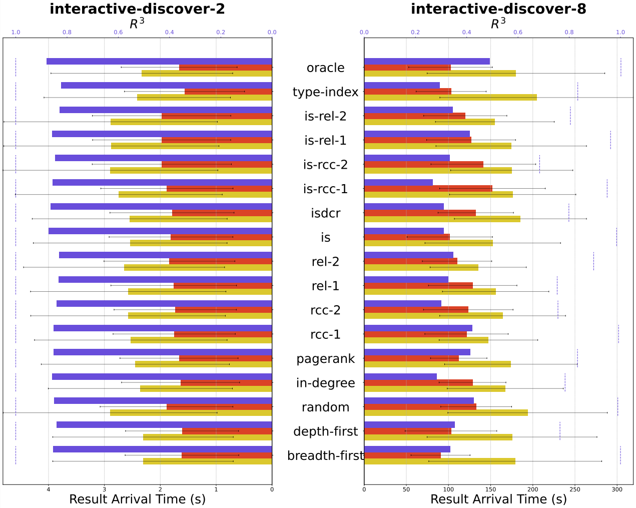
TypeIndex

- TypeIndex points to location for resource of specific type
- Prioritize TypeIndex

Oracle

- Compute RCC in hindsight
- Scores are propegated through the shortest path
- Serves as optimal performance oracle

Prioritization Has Limited Impact on Result Arrival Time



- Breadth-first outperforms most algorithms
- Oracle has significantly better R^3, but not execution time

Prioritization Has Limited Impact on Result Arrival Time

	1st		*Cmpl*		R^3	
	better	worse	better	worse	better	worse
depth-first	15.7	17.1	14.3	17.1	7.5	12.5
random	4.3	68.6	5.7	74.3	15.0	15.0
is-rcc-1	4.3	57.1	5.7	60.0	7.5	5.0
type-index	15.7	18.6	10.0	15.7	12.5	20.0
oracle	**18.6**	**11.4**	**18.6**	**12.9**	**25.0**	**2.5**

Table 1: Percentage of queries for which an algorithm performs at least 10% better or worse than the breadth-first baseline.

- No algorithm improves performance, and the oracle only marginally improves performance

Link Prioritization in Structured Decentralized Environments

- Link prioritization in Solid environment will not significantly improve query performance
- Research should instead focus on query planning Hanski et al. (2025) or traversal pruning Tam et al. (2024)

- Hanski, J. et al. (2025). **"Link Traversal over Decentralised Environments using Restart-Based Query Planning".** In: *International Conference on Web Engineering*.
- Hartig, O. and M. T. Özsu (2016). **"Walking without a map: Ranking-based traversal for querying linked data".** In: *International Semantic Web Conference*. Springer, pp. 305–324.
- Taelman, R. and R. Verborgh (2023). **"Link traversal query processing over decentralized environments with structural assumptions".** In: *International Semantic Web Conference*. Springer, pp. 3–22.
- Tam, B.-E. et al. (2024). **"Opportunities for Shape-based Optimization of Link Traversal Queries".** In: *arXiv preprint arXiv:2407.00998*.