

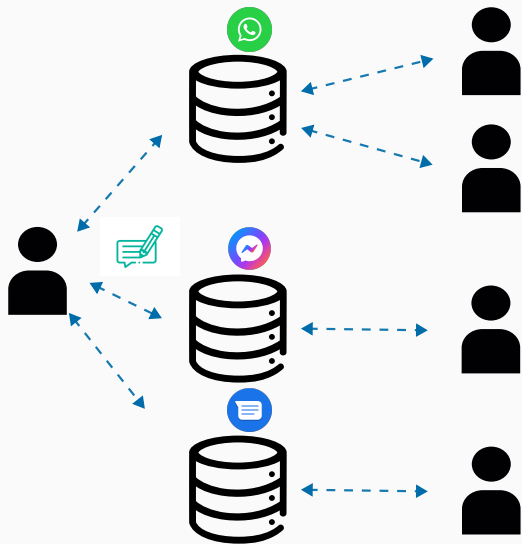
Revisiting Link Prioritization for Efficient Traversal in Structured Decentralized Environments

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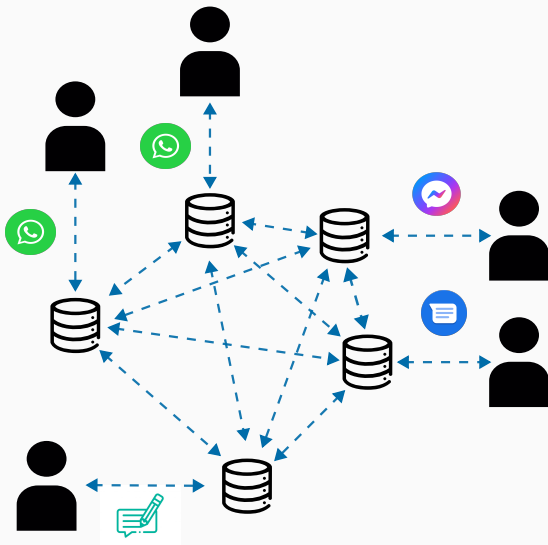
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The Need for Decentralized Personal Data Storage



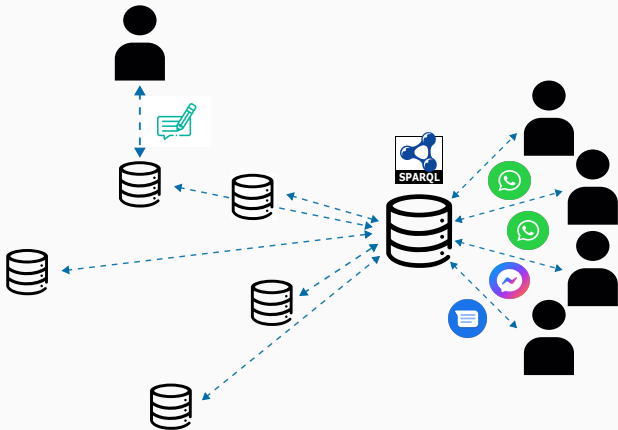
- Each application has its own data
- Stifles innovation
- Causes vendor lock-in

The Need for Decentralized Personal Data Storage



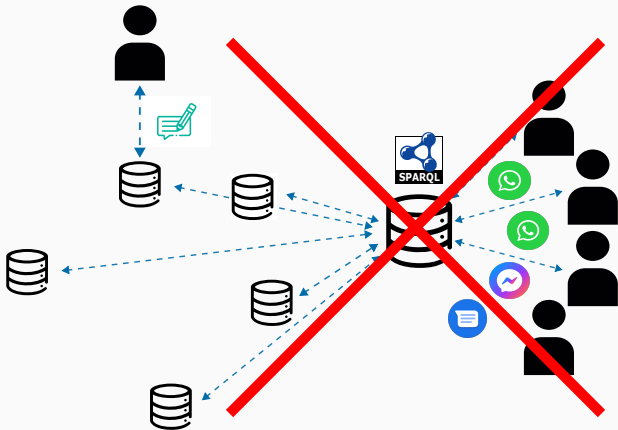
- Each application uses common data storage
- Easy to switch vendors
- Promotes innovation

The Problem with Centrally Aggregating and Querying



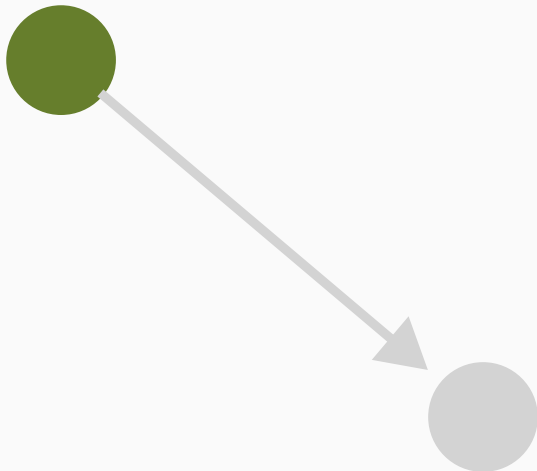
- Why not aggregate data and query it?
- Difficult in case of personal data due to privacy concerns

The Problem with Centrally Aggregating and Querying



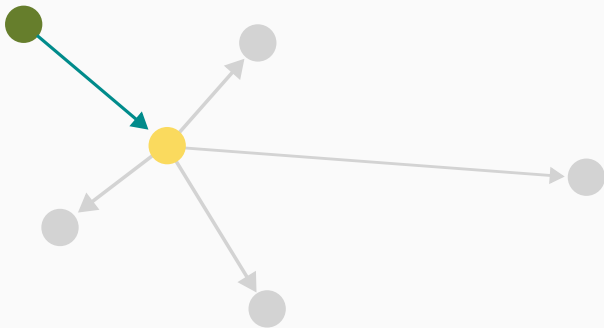
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Link Traversal: Seed Document



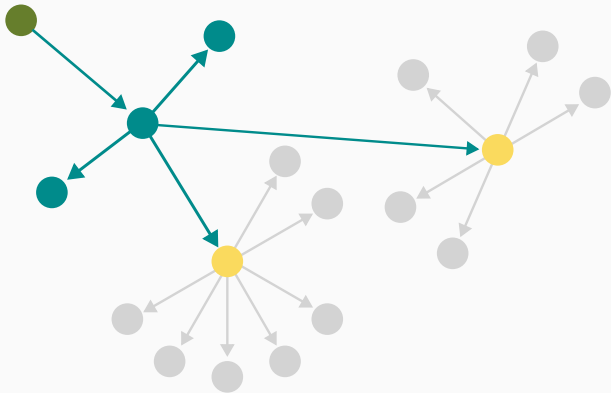
- Link Traversal starts from seed documents (URIs)
- These are provided by the user or in the query.

Link Traversal: Traversal



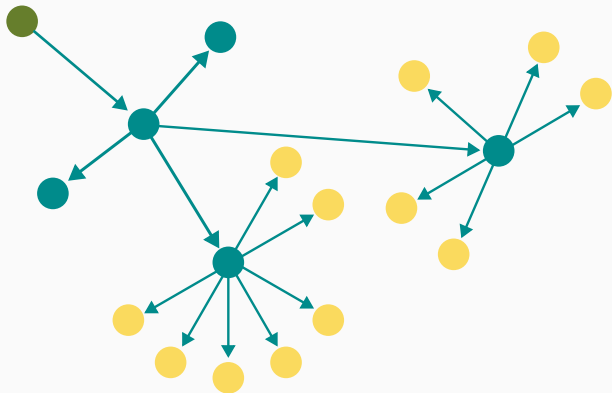
- New URIs are extracted from the seed document
- URIs are extracted in accordance with reachability criteria

Link Traversal: Traversal



- New URIs are dereferenced and the process is repeated

Link Traversal: Termination

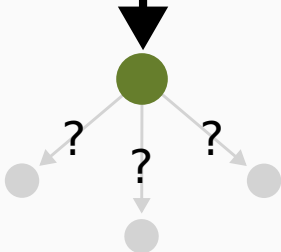


- This continues until all links are dereferenced
- Continuously produces results
- Can enforce fine-grained (document-level) access-control

Query Optimization for Link Traversal

```
SELECT * WHERE {  
  <seedUri> <ex:p1> ?o1.  
  <seedUri> <ex:p2> ?o2.  
  ...  
}
```

Extract
Seed document

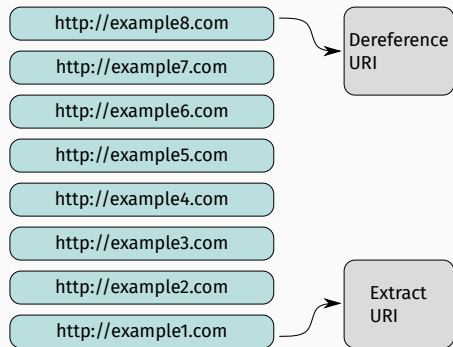


The query (partly) determines:

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

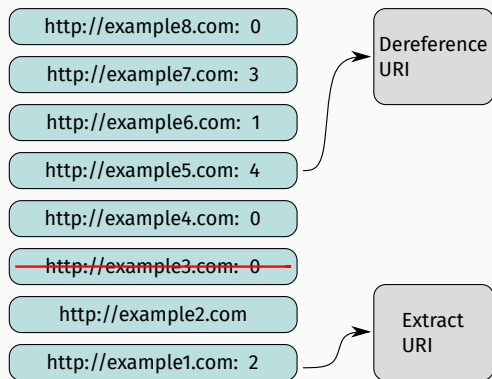
Result: limited prior knowledge for query optimization

Query Optimization for Link Traversal: 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
- We introduce the R^3 metric

- 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

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: Illustration

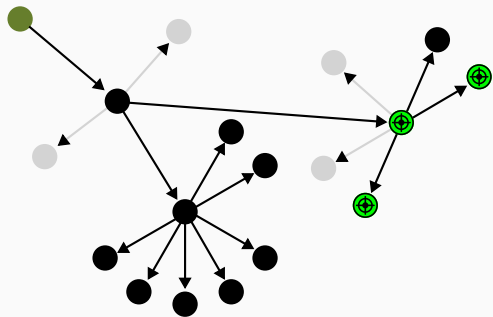


Figure 1: Actual traversal

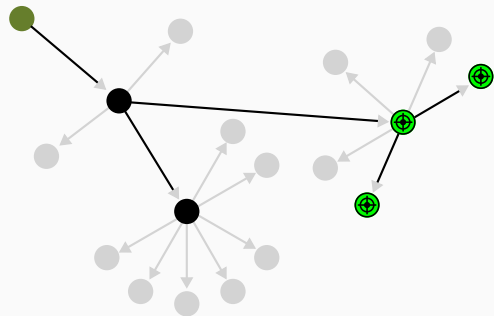


Figure 2: Optimal traversal: minimal cost path

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

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

Result-based

- Uses result contribution count (RCC) of each node (URI)
- Priority equal to the sum / count of non-zero RCC of the 1 or 2-hop in-neighbours of a node
- Called *rcc-1*, *rcc-2*, *rel-1*, *rel-2* respectively.

Prioritization algorithms

Intermediate-results

- Uses intermediate solutions in the engine
- Priority of URI equal to the largest intermediate result with that URI bound
- *IS* sets initial priorities to 0, while *ISdcr* sets priority to the priority of the parent node - 1

Hybrid

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

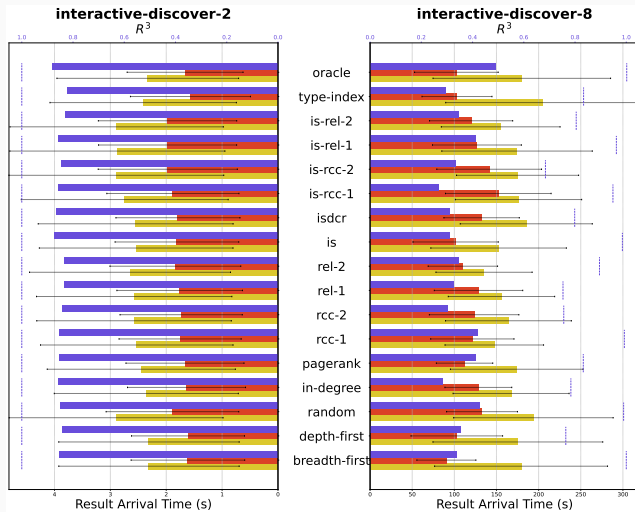
TypeIndex

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

Oracle

- Compute RCC in hindsight
- Scores are propagated 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





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

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*.