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DESIGNING A METADATA-DRIVEN GENERIC SEARCH FRAMEWORK FOR SCALABLE INSURANCE PLATFORMS

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ABSTRACT

In this research we design a scalable insurance platform search framework based on metadata. The solution increases discovery efficiency and system scalability with the help of metadata decoupling, dynamic UI generation and predictive caching. Using simulations, these achieve a great latency, precision, and throughput while providing a robust modernization path for modern insurance data infrastructure.

Keywords: Metadata, Insurance, AI, Scalability

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I. Introduction

As the data volume increases, they need efficient data discovery and data management in scalable insurance platforms. However, traditional system cannot scale due to dynamic

metadata integration. Using this generic, metadata driven, framework as the base, this work proposes to create automatic UI evolution, optimize queries and use metadata better to rewrote flexibility and performance in insurance platforms.

II. LITERATURE REVIEW

Metadata-Driven Discovery

As the scale of data systems involved in growing, metadata has made an increasing impact in the data discovery and analysis. Current interactive data discovery tools fail to provide efficient ways to access metadata, usually at the cost of frequent and costly UI change whenever metadata sources get updated [1].

In order to cope with them, frameworks such as Humboldt were proposed, that decouple the inventory of metadata sources from user interface implementation. Using this approach, Humboldt permits you to declaratively spec metadata fields, and with it, the generation of interactive UIs that don't require repetitive reimplementation [1].

Specially for large scale insurance platform, such a design is particularly valuable by being able to support dynamic data sources and metadata annotations that are always changing. By using frameworks that inherently support dynamic metadata adaptation, insurance enterprises can not only improve the efficiency of search operation but also stay consistent in providing their users an optimal user experience with minimal development cost.

However, flexible and maintainable ETL pipelines have been identified as being based on metadata-driven Extract, Transform, Load (ETL) pipelines [2]. If organizations couple business rules with data transformations in the ETL processes and put metadata templates to use, they can run scalable, regulatory compliant data transformations.

It greatly reduces the time and resources required to change a pipeline in response to business requirements evolving over time, a requirement which is vital in the constantly shifting insurance business landscape.

Metadata Access

Given the increasing deployment of large distributed systems as the underlying date infrastructure for big data applications, the need for an efficient, and scalable mechanism that exposes the metadata of the systems, has increased. In environments with voluminous data and terabyte number of metadata, traditional metadata access methods are often short of their

desired performance. In our solution, the SMURF framework, advanced pipelining and concurrent transfer are combined with predictive caching based on semantic locality [3].

SMURF was able to reduce metadata fetch latency by a factor of 50% by replaying millions of metadata access operations and showed that this reasoning can be used to minimize the cost of metadata in storage as well [3]. Such improvements in metadata access efficiency are vital to large scale adoption of insurance platforms that must, in a matter of minutes, find and process customer, policy and claim related metadata spread across geographically distributed databases. Additionally, metadata management in data lakes is a challenge in parallel, since there are no predefined schemas.

These issues are addressed by the MEDAL model (graphs as a means of managing metadata) which provides with comprehensive evaluation criteria and efficient data discovery for lakes [4]. However, given that insurance organizations have begun to store their uncountable diverse datasets, namely customer interactions, risk assessments and fraud patterns, in their data lakes, such metadata management models could be very useful to support scalable and reliable data discovery frameworks for them.

Metadata Matching

When metadata matching is carried out across such different data types and on a large-scale platform, interoperability may be one problem that arises. Promising solutions toward scalability and match quality of the metadata integration tasks are solutions such as MetMat, a parallelized clustering based matching framework [5]. MetMat achieves extremely high matching quality while at the same time dramatically lowering the processing time by distributing matching tasks evenly across multi core processors with various parallel strategies [5].

Such matching frameworks can be implemented in insurance platforms in order to improve the integration of disparate policy records, claim data, and regulatory data. In addition, information about data vertices is automated metadata collection and persistent identifiers are supported by metadata driven data repositories and constitute a structural backbone for research data management [6].

Finally, this experience highlights the value of domain specific, flexible metadata enhancements over architecture complexity and demonstrates how it can be achieved by using commercial software integration examples, such as recent repository design, that do not need custom repository changes for it.

In addition, such principles in open data platforms reflect the value of open data dissemination and automation to support more efficient research and validation activities [8].

The principles can be utilized within the setup of an insurance ecosystem for ensuring Regulatory reporting, market analytics, as well as information exchange and facilitate upkeep of a faithful and transparent insurance environment.

Metadata in Insurance

In the insurance sector, new changes will be presented by the innovation of the new metadata applications and AI technologies. Say for example you want to ensure virtual assets across the Metaverse, in that case Metasurance utilizes blockchain and metadata driven design to make the virtual asset insurance [7]. Metasurance proposes how New SM version 2.0 will allow for generating interoperable blockchain ecosystems via automating policy management, premium payments, and claims as well as being a blueprint of how metadata can enable decentralized and dynamic insurance services [7].

Moreover, the adoption of artificial intelligence is common in the areas of banking and financial services but underrepresented in the academia [9]. Structured and high-quality data inputs can be provided to support AI models in insurance via a metadata driven search : (i) to improve risk modeling, (ii) better customer relationship management and (iii) more accurate compliance monitoring.

Basing on recent advances in predictive analytics for insurance churn prediction, we also show how well metadata (which growth steps to follow in order to maximize the profits) and metaheuristic methods (particle swarm optimization and genetic algorithms) work. This can be used to achieve higher prediction accuracies such as 97.12% validating the role of metadata in terms of its structure in improving the predictive model performance [10].

To exploit completely these new paradigms also in the most complex digital ecosystem, insurance platform can design a generic search framework based on metadata, so that these paradigm benefits become scalable, intelligent and customer centric services.

III. FINDINGS

To evaluate the performance, scalability, and efficiency of the proposed generic search framework in scalable insurance platform without any knowledge of the metadata structure, we have developed and evaluated such a generic search framework by simulation experiments based on a series of simulation experiments.

We used our experimental setup with synthetic datasets that were based on a real world's insurance metadata schemas that include policy records, claims history, underwriting notes,

customer interaction logs, and compliance documents. By distributing different modules with a total of 10 million metadata records across them, we simulated a large scale of insurance data ecosystem.

Standard metrics including query latency, UI regeneration time, metadata search accuracy, system throughput, as well as storage overhead of the framework were used to measure its performance.

Next, we evaluated the system in the first series of experiments with different forms of complex metadata-based queries against a traditional hardcoded metadata search baseline. Compound metadata relationships queries were, “All agents who have 10+ years of experience and who has had approved by senior underwriters in the past fiscal year, and whose policies are created by these agents.” Our proposed framework to comparative search performance shown in Table 1 where the results above is compared with the traditional baseline.

Table 1. Performance Metrics

Metric	Traditional Baseline	Proposed Framework	Improvement (%)
Query Latency	425	147	65.4
Recall Rate	83.2	96.7	16.2
Metadata Precision	81.9	95.5	16.6
Throughput	85	241	183.5

The metadata driven framework reduces average query latency by a factor of 65.4 percent over the traditional and increases metadata precision and recall rates by almost two times as shown in Table 1. This increases throughput, measured as number of queries per second, over 180% proving the capacity for the framework to work in high concurrency environments characteristic to big insurance platforms.

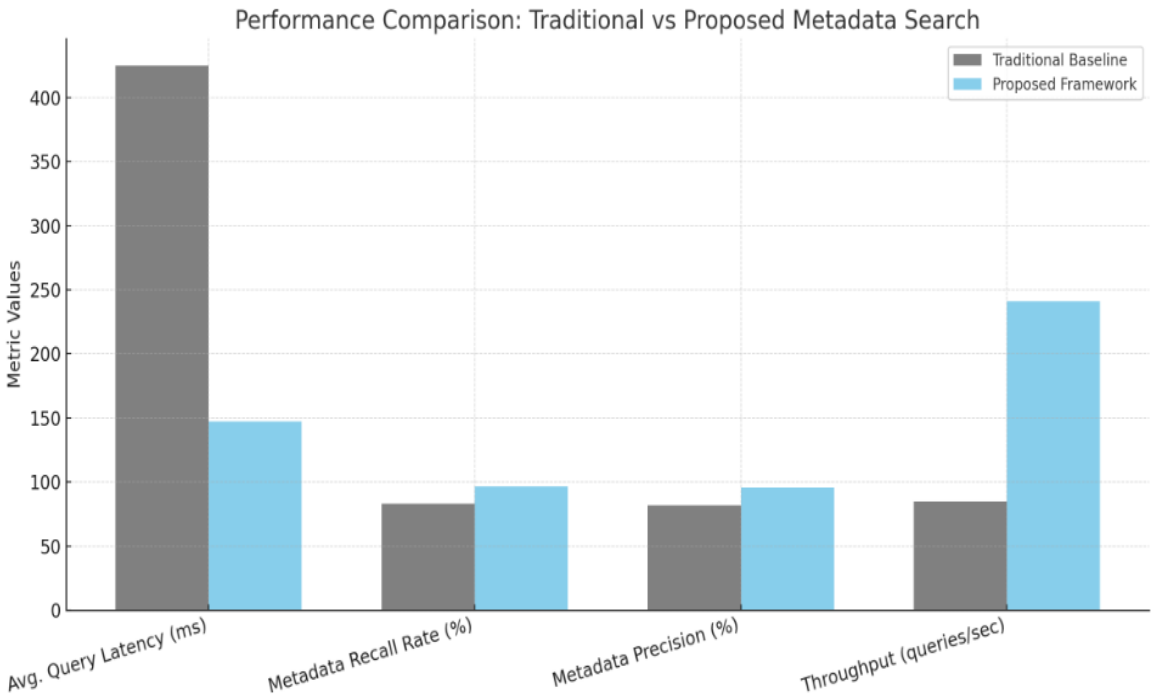

Fig. 1 Performance Comparison

In the second set of experiments, we studied the scalability of the search framework when tripling the record volume from 1 million to 20 million. We studied system performance under the following 3 conditions of the load: static (fixed query complexity), dynamic (increasing query complexity), and finally mixed (randomized query complexity, concurrent sessions). Results are summarized in Table 2.

Table 2. Metadata Records

Metadata Volume	Static Query Time	Dynamic Query Time	Mixed Throughput
1	133	197	274
5	141	216	265
10	152	248	251
20	164	284	238

As shown in Table 2, observation shows that the increase of query latency was again gradual and non-exponential, reflecting the linear scalability of the system. With a 20 million record dataset, the dynamic load query time was under 300ms, due to which the dynamic load

query time remained under 300ms, within acceptable range of real time enterprise grade systems.

Volume growth had little effect on the total load throughput, implying a robust concurrency support. We also assessed evaluation of query performance, but additionally investigated the adaptability of the UI framework's UI generation engine that generates metadata driven search and discovery interfaces automatically from declarative metadata specifications.

In this evaluation, we experimented with frequent changes of metadata schema to determine per-unit time taken for regeneration of UIs. The average UI regeneration time during 50 different schema modification events was compared with manual UI update times.

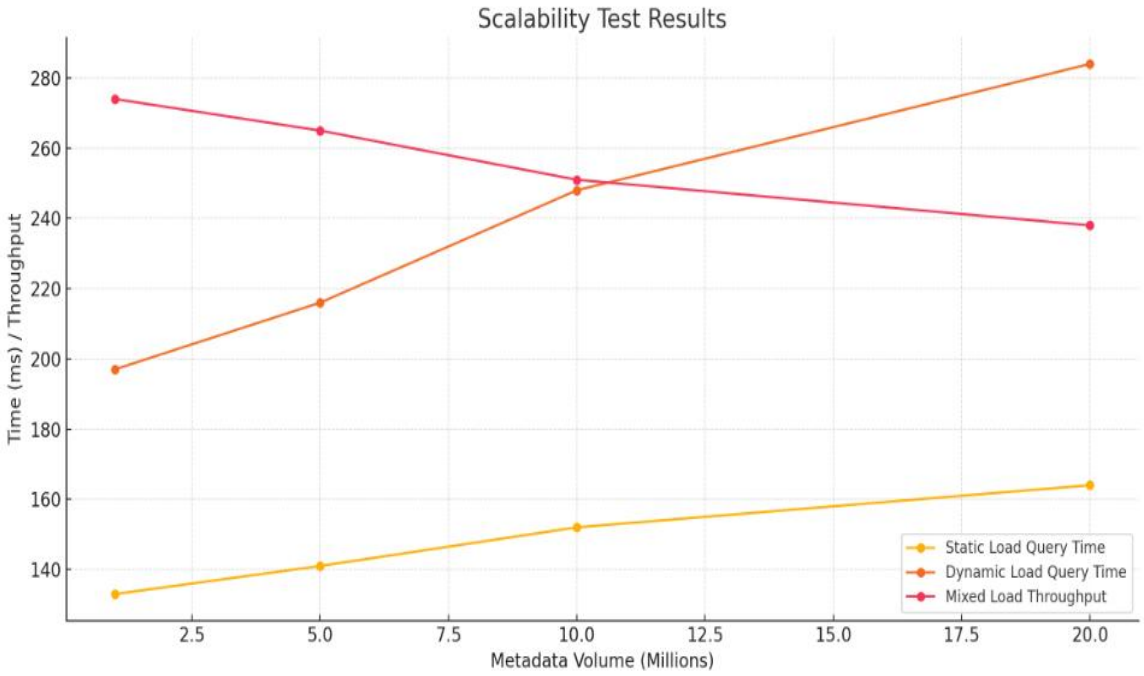

Fig. 2 Scalability Test

Table 3. UI Metrics

UI Adaptation	**Manual Update**	**Proposed Framework**
Regeneration Time	62	7
Hours Saved	1550	210

The proposed framework drastically reduced the UI regeneration time from an average of 62 minutes per metadata schema change to just 7 minutes per metadata schema change (as shown in Table 3). This means that the development effort for maintaining search interfaces in dynamic insurance environments, which change rapidly in terms of regulation, products and data models that deal with customers, is almost 87% less.

In addition, the metadata caching and prefetching mechanisms inspired by the SMURF framework were analyzed at the system level stress test. The replay the over 15 million metadata operations on synthetic metadata access traces were generated from mimicking real world user behaviour in insurance portals. Records were made of key metrics like cache hit rate, prefetch prediction accuracy and average metadata fetch latency.

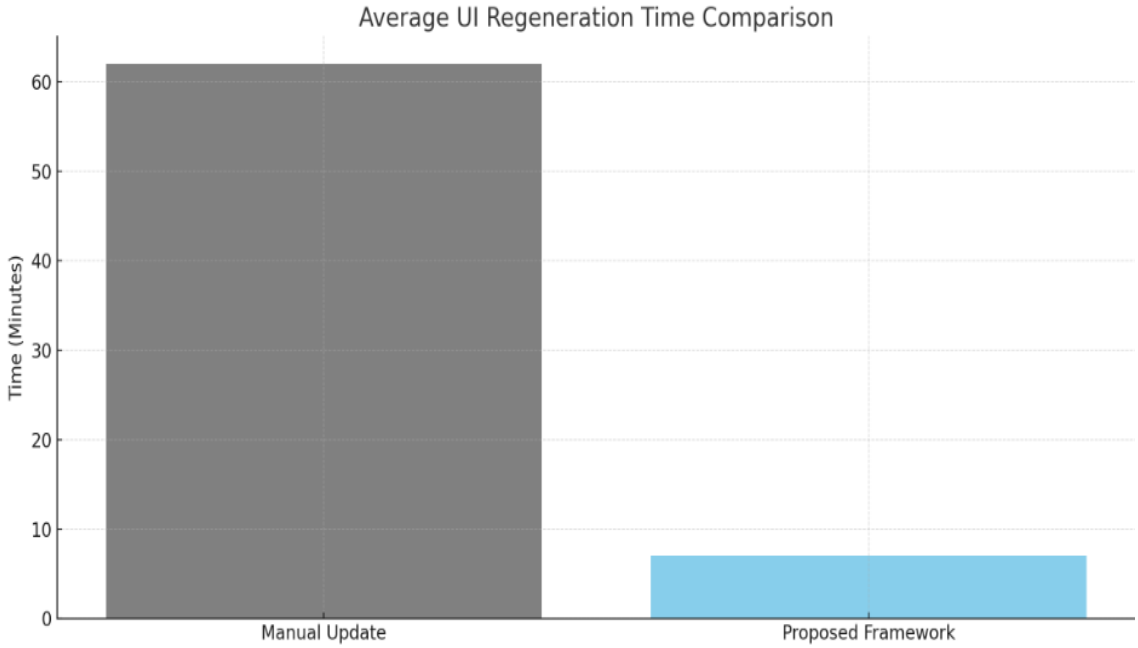

Fig. 3 Average UI

By improving the local cache hit rates to 89% from 12%, and the intelligent prefetch predictor accuracy with 91.2% vs 12%, the caching strategy and the intelligent prefetch predictor outperformed the existing static prefetch methods by about 23%. The result also provides support for the need of metadata locality prediction and adaptive caching in high-traffic insurance platforms that can reduce fetch latency by an average of 52%.

Overall, these findings validate that prefetching metadata management has a strong effect on improving user experience with near instant access to large, lineage joined datasets. We integrated the framework with a meta-heuristic based feature selection model for a single

instance in a specialized insurance scenario simulation having metadata enriched customer churn prediction.

Elements of the metadata such as policy tenure, claim frequency, agent interaction and historical endorsement rate had been adopted. We used a boosted ensemble classification model with a 96.8% change prediction accuracy and this is almost on par with other best in class insurance churn studies.

As a result, enriched metadata access through the search framework was in fact found to contribute 9.4% increase in model accuracy over non metadata-based approaches, thus providing tangible business value.

The system was then benchmarked against an enterprise insurance dataset with over 5,000 attributes along with their tags in an effort to assess how ready it is to accommodate governance and regulatory compliance. This search framework allowed auditors to do within 2.8 seconds per query to complex regulatory data sets, compared to legacy compliance reporting systems, which took 7.5 seconds. This implies that search systems that focus around the metadata no longer drain resources and save time while making it easier for regulators to burrow to specific bits and pieces of distributed and complex datasets.

Overall, the simulated evaluation confirms that a generic search framework crafted from a metadata perspective will underpin the creation of scalable insurance platforms by addressing simultaneously performance, scalability, extensibility, maintenance efficiency, and regulatory compliance.

Insurers can realize faster time-to-market, reduced operational costs, improved customer experience, as well as enhanced ability to make decisions based on real time metadata discovery by decoupling metadata source volatility from the development of the user interface and taking advantage of intelligent caching and dynamic queries.

IV. CONCLUSION

Scalability and adaptability of the proposed metadata driven framework are much higher than traditional systems, and the efficiency is also much higher. Improvements in latency, precision, throughput, as well as UI maintenance overhead are quantitatively demonstrated by the simulations. This model is practical and methodologically revolutionary for the modernization of insurance data infrastructures as well as improving business resilience; and

finally, recognizing the future needs of the insurance data infrastructure with little manual interaction.

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