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Ontology-Driven Analytic Models for Pension Management and Decision Support System

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Abstract

Ontology-Driven Analytic Models for Pension Management are sophisticated approaches that integrate the principles of ontology and analytics to optimize the management and decision-making processes within pension systems. While Ontology-Driven Analytic Models offer significant benefits for pension management, there are also challenges associated with implementing and utilizing the models. Developing a comprehensive and accurate ontology for pension management requires a deep understanding of the domain, including regulatory frameworks, investment strategies, retirement planning, and integration of data from heterogenous sources. Integrating these data into a cohesive ontology can be challenging. This research work leverages on semantic ontology as an approach for structured representation of knowledge about concepts and their relationships, and applies it to analyze and optimize decision support for pension management. The proposed ontology presents a formal and explicit specification of concepts (classes), their attributes, and the relationships between them and provides a shared and standardized understanding of the domain; enabling precise communication and knowledge representation for decision-support. The ontology deploys computational frameworks and analytic models to assess and evaluate data, generate insights, predict future pension fund performance as well as assess risk exposure. The research adopts the Reasoner, SPARQL query and OWL Visualizer executed over Java IDE for modelling the ontology-driven analytics. The approach encapsulated and integrated semantic ontologies with analytical models to enhance the accuracy, contextuality, and comprehensiveness of analyses and decisions within pension systems.

Keywords

Data Analytic, Web Ontologies, Data Visualization, Resource Description Framework, Reasoner, SPARQL

1. Introduction

Pension management is an essential component of financial planning, especially for individuals and organizations seeking to ensure retirement financial security [1]. As individuals live longer and confront changing economic conditions, the importance of effective pension management grows. Pension management entails the administration, investment, and distribution of funds set aside to provide retirement income or benefits to individuals. Pension Management and Decision Support Systems (DSS) have become valuable instruments for navigating the complexities of pension management and making informed decisions. These systems utilize technology and data analysis to help pension fund managers, financial advisors, and individuals optimize their pension-related decisions and strategies. Pension Management and Decision Support Systems provide a number of essential features. Analyzing risk tolerance, market trends, and investment performance, Decision Support Systems assist in the selection and management of investment portfolios [2]. Pension Management and Decision Support Systems play a crucial role in modern financial planning by providing the tools and insights necessary for effective pension fund management. These systems enable individuals and organizations to navigate the complexities of pension planning, investment, and distribution, resulting in more secure and well-informed retirement strategies [3].

1.1. Extending Ontologies for Analytics

Ontology-Driven Analytic Models (ODAM) is an approach that combines the power of ontologies, which provide formal representations of knowledge and semantics, with analytical models, which involve data processing, pattern recognition, and predictive modeling. This integration aims to enhance the interpretation, analysis, and utilization of data in various domains. By infusing analytical processes with semantic context, ODAM offers a more comprehensive and informed approach to understanding complex data [4]. ODAM deploys a structured representation of knowledge about concepts and their relationships, to analyze and optimize various facets of pension management. The ontology-driven method integrates domain-specific taxonomies with analytical models. This improves the models' ability to comprehend the semantics of data, relationships, and concepts within the domain of pension management. This integration enables for more accurate and contextually pertinent analysis. Benefits of Ontology-Driven Models for Pension Management include a shared comprehension of pension management's concepts and relationships [3]. This clarity improves communication between stakeholders, including pension fund administrators, beneficiaries, and regulators. By integrating domain knowledge from ontologies, analytic models can effectively manage the complexities and interdependencies of pension-related factors, resulting in more precise and thorough analyses. The flexibility and adaptability of the ontology-driven analytics model to changing regulations, market conditions, and individual preferences is one of its primary advantages. This adaptability is essential in the ever-changing pension management landscape. The combination of ontologies and analytics enables stakeholders to make well-informed pension-related data and concept-based decisions.

1.2. Complexity in Semantic Heterogeneity

While Ontology-Driven Analytic Models provide substantial benefits for pension management, implementing and utilizing such models does not come without challenges. Developing and maintaining ontologies necessitates both domain-specific and ontology engineering expertise [4]. Finding individuals with the necessary skills to design, develop, and refine ontologies can be difficult. Given the substantial amount of data involved in pension management, it is essential to implement scalable ontology-driven models in order to effectively manage large datasets. A significant challenge in modelling is ensuring efficient data processing and analysis without sacrificing performance. Particularly in the context of ontology-driven modelling, interoperability plays a crucial role in addressing this difficulty. This method involves the creation of structured representations of knowledge and data using ontologies and seeks to improve the overall model [5]. Achieving interoperability across diverse systems and data sources requires the alignment of ontologies and data formats in an extensive manner. Nevertheless, the significance of interoperability in ontology-driven modelling cannot be overemphasized for a number of reasons. These include semantic coherence, the facilitation of information dissemination, integration across diverse domains, the establishment of standards, machine learning application, and the facilitation of querying processes [6]. Interoperability ensures that diverse systems, domains, and applications can incorporate and share ontologies seamlessly. Consolidating ontologies facilitates semantic consistency, in which concepts and relationships have the same meaning in all contexts. Additionally, ontologies serve the purpose of encapsulating domain-specific information. Interoperability enables diverse consumers, organizations, and applications to share information. This promotes a culture of cooperation and facilitates the active participation of experts in a shared information repository. Cross-Domain Integration enables the consolidation of multiple domains' ontologies, thereby facilitating a thorough comprehension of multidisciplinary complex systems. Interoperable ontologies allow for the efficient deployment of reasoners and SPARQL queries for search and retrieval capabilities. Utilizing a shared ontology across multiple systems improves the precision and efficacy of information searches. This is due to the ability to align queries with a unified understanding of concepts and relationships. Utilizing interoperable ontologies facilitates the improvement of machine learning and reasoning. Common ontologies can be utilized by artificial intelligence (AI) systems for data interpretation, deriving logical inferences, and facilitating decision-making processes [7]. Interoperability is essential to ontology-driven modelling because it facilitates the interchange of information, improves integration across domains, and enables the effective integration and analysis of data. This framework provides the foundation for the development of consistent, reusable, and scalable ontologies.

This study deploys OWL (Web Ontology Language) and RDF (Resource Description Framework) [8] to construct and query Ontology-Driven Analytic Models for Pension Management. Using inheritance and specialization to represent hierarchies, the classes (concepts) that represent the domain's primary entities are designed, and their relationships and properties are established. The object semantics and data properties that characterize the relationships and attributes between classes are specified, as well as the cardinality and domain/range restrictions for each property. The ontology is expressed formally using OWL syntax and constructs. Finally, Reasoners and ontology validation tools such as SPARQL are used to ensure the validity of the ontology as it is tested against multiple scenarios to ensure effectiveness.

2. Related Works

Ontologies are conceptual frameworks that illustrate concepts, their attributes, and their relationships within a given domain [9]. In addition, ontologies serve as contextual frameworks that provide depth and context to the data under analysis and play a crucial role in augmenting the understanding of data elements through the use of homogeneous semantics. Numerous authors have made efforts to differentiate between ontologies and analytical models for data processing [4] [10]. They contend that while analytical models encompass various techniques such as statistical analysis, machine learning, data mining, and predictive modelling, ontologies primarily serve as structured representations of knowledge within a particular domain. Though ontologies provide a formal and shared understanding of the semantics of the domain, analytical models refer to algorithms or methods that process that data to uncover patterns, relationships, trends, and insights [7]. As a result, ODAM effectively combines analytical techniques with ontologies to ensure that the analysis is both data-driven and contextually aware. Ontology plays a crucial role in addressing the semantic gap that arises from the diverse sources and structures of ODAM data. By offering a shared vocabulary, ontologies facilitate the mapping of data to a unified framework [10]. It has been suggested that ODAM integration is especially beneficial when dealing with diverse data that require harmonization and joint analysis [8]. Though many authors agree that this integration is particularly valuable when working with heterogeneous data that needs to be harmonized and analyzed together [9] [11], there is need to carry out more investigation and explore how ontologies are used to integrate and harmonize heterogeneous pension-related data sources. This integration would ensure that pension data from diverse sources can be analyzed cohesively

Within the ODAM framework, the interpretation of results is conducted within the specific context of the ontology associated with the domain. This implies that the insights produced are not solely numerical results, but also meaningful interpretations that align with the underlying concepts and relationships established in the ontology, thereby improving decision-making [10]. It has been suggested that analytical models, guided by ontological context, can provide more informed insights for pension fund administrators and individuals planning their retirement. In favor of this notion is the assertion that by leveraging both ontological context and analytical insights, ODAM can empower decision-makers to make informed choices. Furthermore, the rich contextual information from ontologies ensures that decisions are made based on a holistic understanding of the data and its implications. In spite of the fact that ODAM has continued to promote collaboration between experts from different fields, there still exist gaps in accurate representation of the nuances of the domain. Analytical models sometimes are seen as "black boxes" that produce results without clear explanations [12]. However, with integration of ontologies, results interpretability can be enhanced such that users can understand not only the outcome but also the reasons behind it, making the results more transparent and actionable. Thus, ontology-Driven Analytic Models go beyond traditional data analysis by infusing it with semantic context [10]. This approach leads to deeper insights, more informed decision-making, and enhanced collaboration across domains. To a large extent, while challenges such as ontology maintenance and integration complexities exist, the benefits of aligning data analytics with ontological semantics hold great potential for various applications, including healthcare, finance, scientific research, and more [11]. Ontologies provide the semantic foundation for data analysis, ensuring that insights are contextually relevant, while analytical models process data to extract valuable insights [12]. Both aspects are essential in achieving a comprehensive understanding of data and informed decision-making.

The use of Ontology-Driven Analytic Models brings together the strengths of ontologies and analytical models to enhance the process of data analytics [13]. Analytical models, such as machine learning algorithms or statistical methods, have been designed to leverage the ontology-defined concepts and relationships based on its enriched with semantic context. A significant benefit of the Ontology-Driven Analytics Methodology is that, during the analysis phase, the analytical models effectively handle the annotated data within the framework of the ontology. The process of contextual analysis guarantees that insights are obtained in accordance with the semantics of the specific domain. [9]. In particular, the use of ontologies allows the analytical models to adapt and scale as the domain evolves. Changes in the domain can be seamlessly integrated into the ontology, ensuring that the analytics remain relevant over time. It is often agreed that ODAM aligns with the principles of interoperability and reusability and provide a common semantic framework that enables data and analytics to be shared and reused across different systems and applications.

The authors [12] in their research suggested that the use of Ontology-Driven Analytic Models in pension management involves leveraging ontologies and analytical models to enhance the understanding, analysis, and decision-making processes within the context of pension systems and retirement planning. The authors explained that integrating data from various sources, such as financial records, retirement plans, investment portfolios, and demographic information into a unified representation can enhance the analytical models for identifying irregularities or potential fraud in pension fund transactions by combining ontological context with analytical insights. The analytical models driven by ontological semantics can contribute to risk assessment in pension fund investment and protection of fund growth under different investment scenarios. Additionally, the semantic integration has been affirmed to provide a cohesive view of pension-related data. Analytical models specific to pension management include predictive models for retirement fund growth, risk assessment models for investment decisions, and scenarios for pension fund sustainability [11]. Utilizing the results of the analysis to provide personalized retirement planning recommendations, predictive models can project future pension fund growth based on various investment scenarios, helping individuals plan for retirement. Kumar, D. [13] investigated the collaborative potentials of ODAM to reflect domain-specific knowledge accurately and the ability to provide insights into the probable impact of different investment strategies on pension fund sustainability. The contextual analysis of their results and interpretation indicated that ODAM can help pension managers, financial advisors, and retirees to understand the implications of analysis outcomes and make informed decisions. The analytical models were used to identify irregularities or potential fraud in pension fund transactions. The linkage between data, ontological context, and analysis results allowed for clear explanations of how conclusions were reached, promoting trust and understanding. In pension management, ODAM helps improve the accuracy of retirement planning, investment decisions, and risk assessment by integrating semantic context with quantitative analysis. The approach ensures that pension-related data are not only processed numerically but also understood within the broader context of pension regulations and individual retirement goals. Though Ontology-Driven Analytic Models can offer substantial benefits in pension management, researchers have observed some with limitations and potential drawbacks that need to be considered. For instance, integrating diverse data sources into the ontology-driven framework can be challenging, especially when dealing with legacy systems and various data formats [10]. Also ensuring seamless data integration while maintaining data quality and the computational overhead introduced by ontology-driven analysis might impact the scalability of the system, especially when dealing with large datasets.

3. Method

Ontology-based analytic models harness structured and organized knowledge representations to aid in a wide range of data analytics tasks. There are several methods commonly used in ontology-driven analytic models [14]. This study incorporates five methods; specifically, Ontology-Driven Data Classification, Semantic Annotation, Semantic Querying, Ontology-Based Reasoning, and Ontology-Driven Visualization methods. Ontology-Driven Data Classification improved data segments and classification by using predetermined categories and concepts [15]. This approach was further supported by Semantic annotation, which allowed for the linking of data with concepts or phrases created from the ontology (**Figure 1**). The proposed methodology facilitated the establishment of relationships between the data and the relevant concepts, classes, and attributes present in the ontology. This approach aimed to enhance data integration and ensure semantic enrichment, ultimately enabling more insightful analysis and interpretation. The incorporation of data enrichment, together with its semantic composition facilitates a more profound analysis and interpretation [9]. Semantic Querying was implemented to enhance query capabilities for the purpose of data retrieval. Semantic Querying provided a structured and semantically rich query language, facilitating the retrieval of relevant information from heterogeneous data sources. This also enhanced information retrieval by leveraging the semantic relationships encoded within the ontology. It has been suggested [15] that utilizing ontologies to conduct reasoning and inference over data from structured representations of knowledge can facilitate a variety of data analytics tasks. By defining rules and relationships within the ontology, new knowledge can be inferred, implicit relationships in the data discovered and inconsistencies identified. This approach is particularly valuable for advanced analytics and knowledge discovery. It has been demonstrated that Ontology-Driven Visualization facilitates the visual representation of data, thereby enhancing the comprehension and interpretation of complex datasets [10]. A combination of these methods facilitates understanding of complex and diverse data as it incorporates domain knowledge and semantics. Ontology-driven analytic models offer significant advantages when working with data that necessitates an in-depth understanding of the fundamental concepts and relationships. Consequently, they have proven to be a valuable approach in diverse domains such as healthcare, finance, and scientific research [6]. The methodologies adopted for implementing the ontology-driven analytic models provided a powerful framework for enhancing pension management and decision support systems. By deploying a systematic methodology to construct and evaluate the ontology, the scope of the ontology-based decision support system (DSS) for pension management was explicitly delineated, elucidating the precise aims, objectives, and problematic domains that need to be addressed. In carrying out this work, domain understanding was achieved by collaboration with domain experts, pension fund managers, financial analysts, and regulatory authorities to gather insights. Data collection and analysis was obtained through relevant data sources including financial data, member records, investment information, regulatory documents, and historical performance data. Ontology development was implemented by creating a taxonomy that represents the key class hierarchy (**Figure 1**), relationships and object property hierarchy (**Figure 2**), Annotation Property Hierarchy (**Figure 3**), Arc Annotations (Figure 4) within the pension management domain using Protégé and OWL to build the ontology (Figure 5). The ontology has been carefully designed to precisely capture the semantic aspects of the domain [15]. This is achieved through the definition of classes, properties, individuals, and axioms.

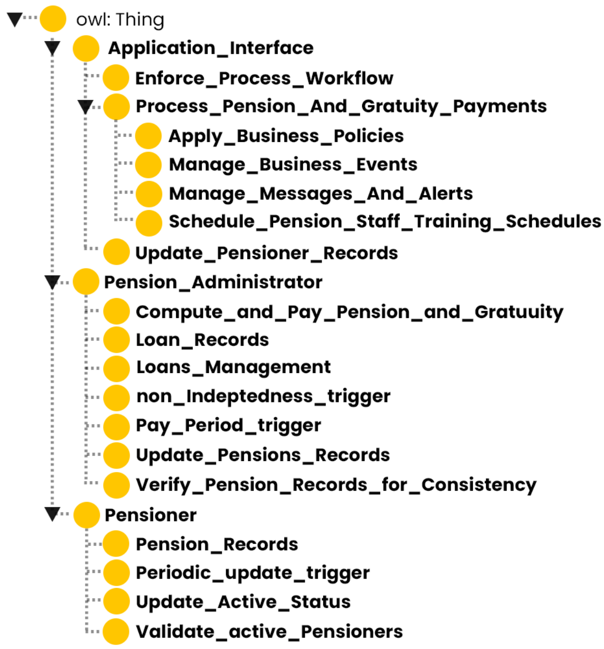

Figure 1. Class hierarchy presentation in protégé.

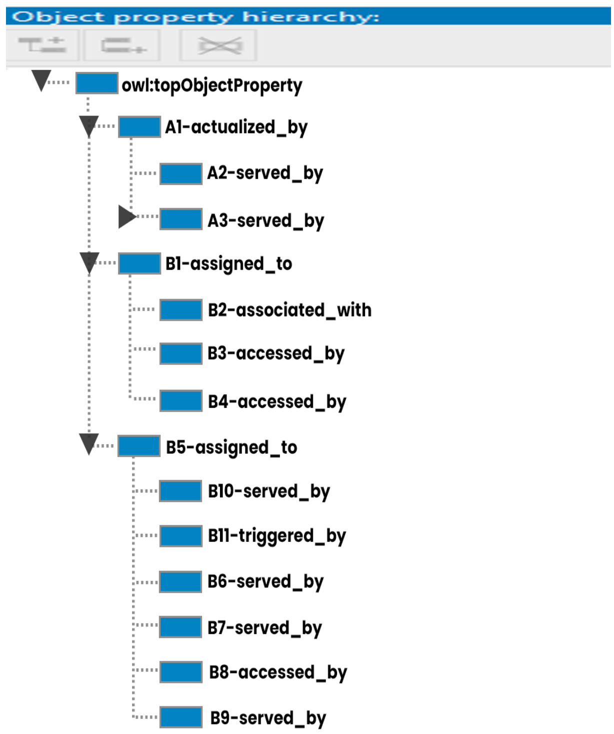

Figure 2. Object property hierarchy.

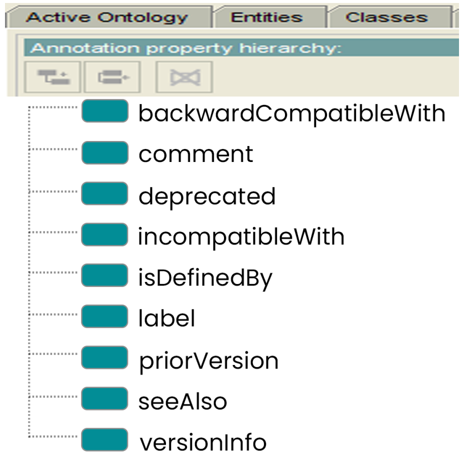

Figure 3. Annotation property hierarchy.

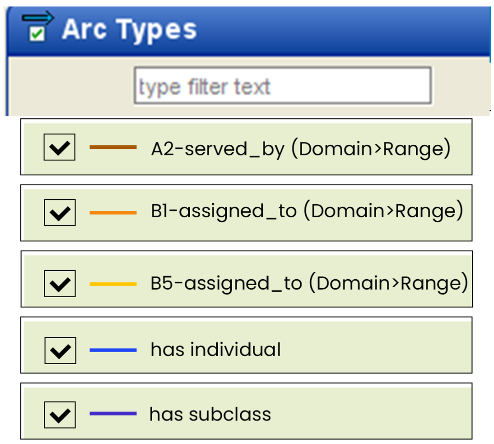

Figure 4. Arc annotation.

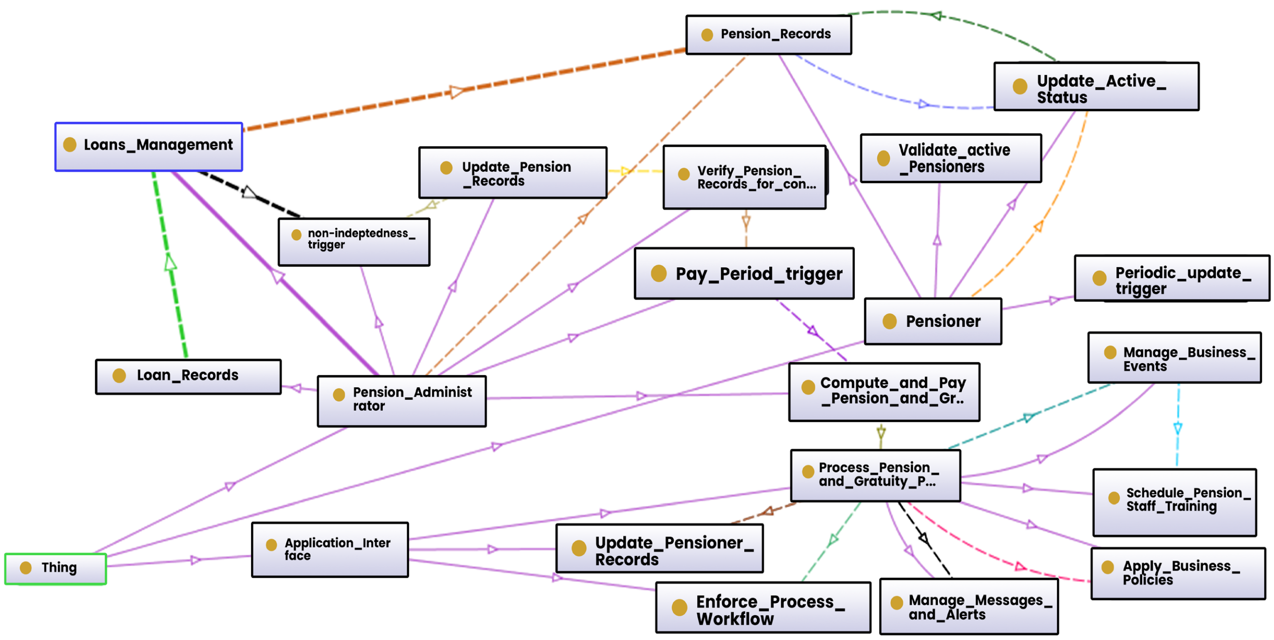

Figure 5. ODAM for pension management.

Data from different sources are mapped and integrate to the ontology and semantic links between the ontology's concepts and the corresponding data elements established. Data is also annotated with semantic metadata to enrich its meaning and context by tagging data elements with ontology concepts and properties. The query mechanisms that leverage the ontology's structure for semantic querying deployed is SPARQL for RDF data, annotated in the ontology of **Figure 7**. The analytics algorithms and models are used to query the ontology to perform tasks like risk assessment, portfolio optimization, and compliance checks. For decision support, decision rules and logic are encoded into the ontology. These rules include regulatory compliance checks, risk tolerance assessments, and investment strategies based on individual profiles. The ontology-driven DSS was simulated with varying scenarios to validate its performance, accuracy, and compliance with domain requirements. The computational model for an Ontology-Driven Analytic system in pension management leverages the ontology's semantic power to provide accurate, efficient, and context-aware data analysis and decision support. It also enhanced data integration, knowledge representation, and the overall effectiveness of pension management processes while facilitating compliance with regulatory requirements.

4. Results and Simulations

The design of the Ontology-Driven Analytic system for pension management involves delineating the system's high-level structure, components, and guiding principles. This design phase assists in defining the fundamental concepts, functionalities, and interactions of the system. The structure of the ontology comprises classes, properties, individuals, and their relationships. The created taxonomy represents key facets of pension administration, including pension funds, beneficiaries, investments, and regulations. The Object Property Hierarchy defined in **Figure 2** specifies the relationships and hierarchy among object properties. The Object Properties describe relationships between individuals or instances and organizes the object properties into a hierarchical structure. In the hierarchy, sub-properties that inherit the characteristics of their parent properties are specified with additional constraints and logical rules that regulate ontology. In essence, the Object Property Hierarchy in the ontology helps to structure and organize the knowledge represented within the ontology, making it more semantically rich and allowing for more accurate querying and reasoning about relationships between individuals or instances in the domain. Integrating semantics with ontology improves the meaning and comprehension of the data and relationships represented in an ontology. This integration is essential for knowledge representation, semantic web technologies, and knowledge-based systems. This work integrates semantics and ontology via semantic annotations, reasoning and inference, and semantic ontology (**Figure 5**). To provide more context and meaning, semantic annotations were added to ontology elements such as classes, properties, and individuals as descriptive information. This annotation includes labels, definitions, synonyms, and remarks. By annotating ontology elements with rich semantics, the intended meanings and relationships within the ontology are simpler to understand. Integration of semantics enables advanced reasoning and inference capabilities [11]. The ODAM for Pension Management defines logical rules and axioms that define the relationships and constraints among data elements. The Reasoning engine uses these principles to infer new knowledge or validate existing data based on the ontology's semantics.

In this implementation, data from multiple sources is integrated to create the three main components Pension Administration, Pensioner, and Application Interface. To establish connections between distinct ontologies or data schemas, semantic mappings are defined. This permits the translation of data and queries across various semantic structures. SPARQL-based deductive reasoning is used as the inference mechanism to derive new knowledge and insights from the ontology. Deductive inference is a type of reasoning that draws specific conclusions from general principles, premises, or assumptions [14]. Deductive reasoning is characterized by certainty and necessity, in contrast to inductive reasoning, which involves drawing probabilistic conclusions from specific observations. In other words, the conclusion must be true if the premises are true and the deductive argument is valid. Visualization is performed using OWLViz and OntoGraf to effectively interpret complex data and analytical results. The ontology defines three key actors involved in pension systems. These are the Application Interface, Pension Administrator, Pensioner shown on ontologies in **Figures 6-8** respectively.

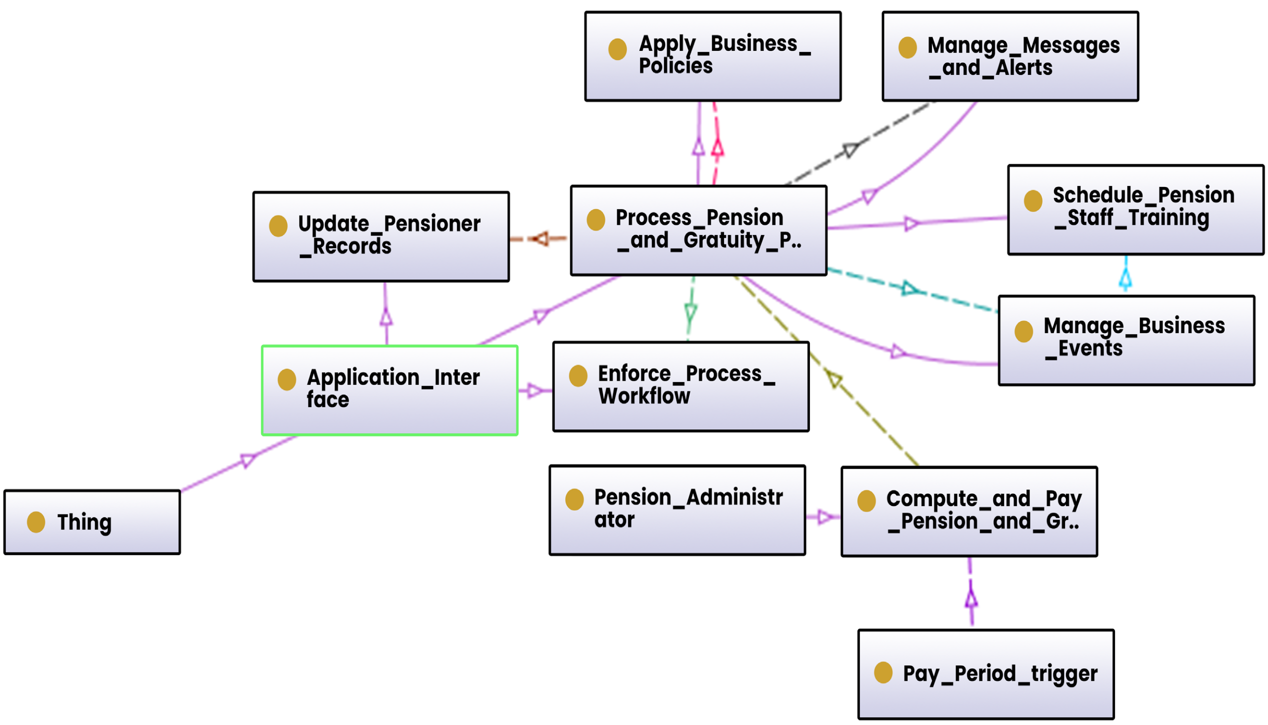

Figure 6. OWL visualization of application interface ontology.

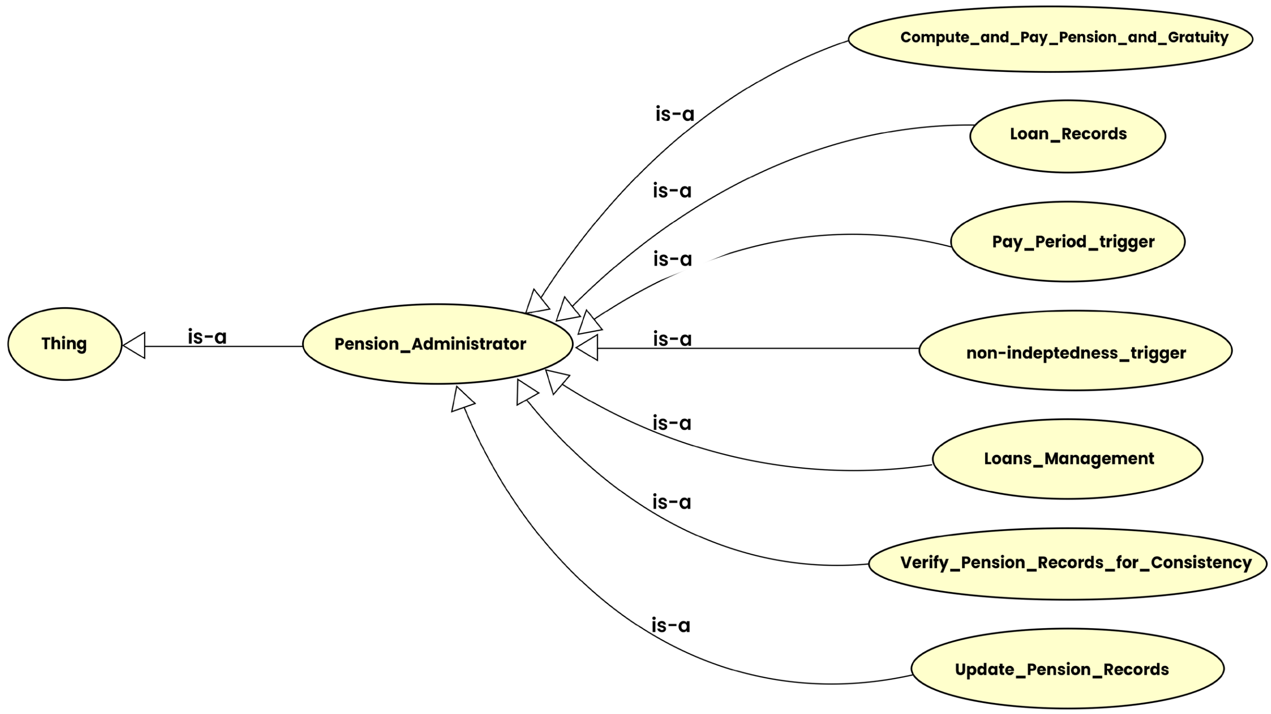

Figure 7. OWL visualization of administrator ontology.

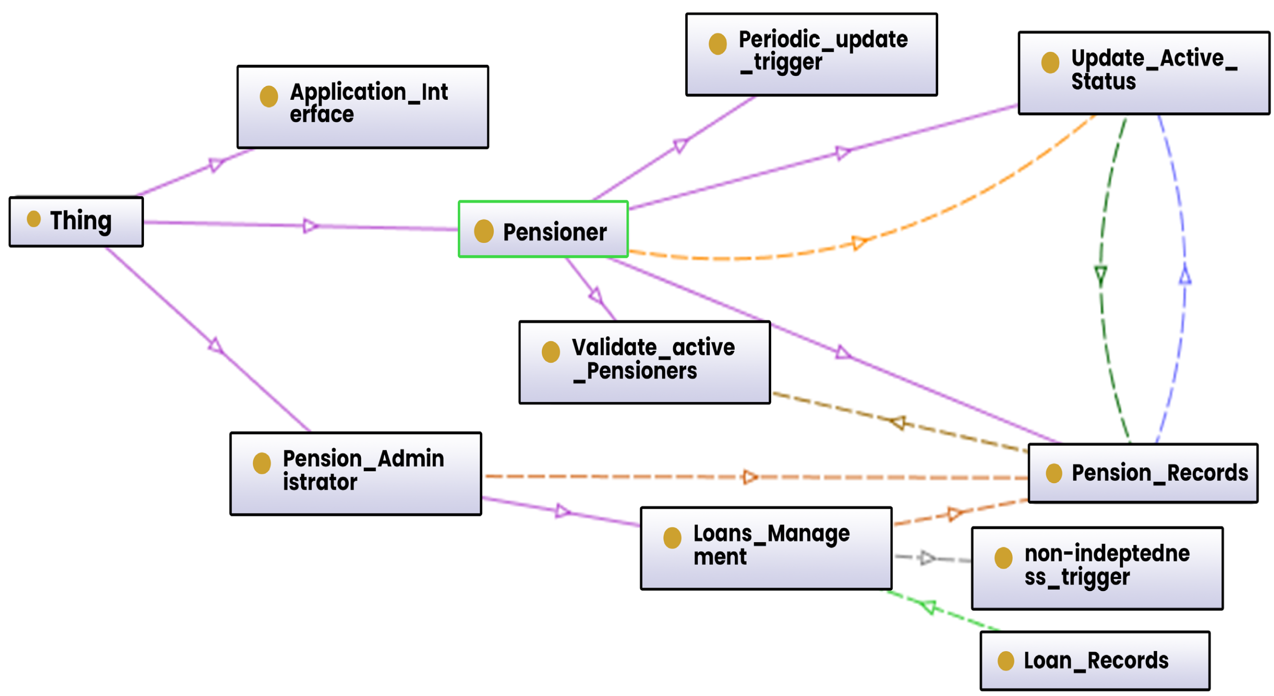

Figure 8. OWL visualization of pensioner ontology.

The Application Interface of a pension ontology specifies the way in which the ontology is used and interacted with by various applications, systems and users. It serves as the bridge between the ontology's structured knowledge representation and practical applications in the context of pension-related tasks, services, or information retrieval. This simulation approach facilitates better understanding, analysis, and prediction of the outcomes of various changes or scenarios within a pension system.

The Pension Administrator is the entity responsible for managing and overseeing various aspects of a pension plan. This includes tasks related to plan administration, participant management, compliance with regulatory requirements, investment management, and communication with Pensioners. The ontology outlines each stakeholder's roles, responsibilities, and interactions within the system. The subclasses of the ontology describe the different types of pension plans and their characteristics, such as defined benefit, defined contribution, or hybrid plans. It outlines the rules governing contributions, investment strategies, and benefit calculations. This aspect helps policymakers and analysts evaluate the sustainability and effectiveness of different pension plans in providing retirement income security. In summary, pensions systems ontology is a valuable tool for comprehensively understanding the intricate web of factors that make up pension systems. By breaking down these systems into key elements and their relationships, it aids in the analysis, design, and assessment of pension schemes, ultimately contributing to the development of more effective and sustainable retirement income solutions.

The SPARQL Protocol and RDF Query Language, commonly known as SPARQL, are utilized in this project to query the ODAM for Pension Management. SPARQL is a query language specifically designed for retrieving information from RDF (Resource Description Framework) data sources. It is particularly well-suited for querying Ontology-Driven Analytic Models for Pension Management, as these models commonly rely on RDF-based ontologies. RDF uses a simple and flexible syntax for representing structured data on the web. RDF data consists of statements called "triples", consisting of three components: subject, predicate, and object [11]. The subject refers to the resource or entity that is being depicted, as indicated by **Figure 7**. The predicate serves to denote the attribute or connection between the subject and object, while the object refers to the specific value or entity that is linked to the subject and predicate. In this specific context, SPARQL plays a crucial role in enabling complex queries on the structured data represented by the ontology. The versatility of SPARQL empowers users to create queries that are customized to their precise analytical needs, allowing them to extract valuable insights from the data guided by the ontology.

Applying the SPARQL protocol, a query is issued as presented **Figure 9(a)** to seek for data in RDF (Resource Description Framework) databases used in representing and storing the semantic data. The variable specified as "?subject" is a placeholder for the resources in the RDF data of interest. rdfs: subClassOf is a relationship predicate in RDF that represents subclass relationships between classes or types. The query essentially seeks to retrieve all subjects (represented by the "?subject" variable) that are subclasses of the class "Application_Interface". The result of this SPARQL is shown in **Figure 9(b)**.

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
SELECT ?subject
        WHERE {?subject rdfs:subClassOf?Application_Interface}
```

(a)

subject
Update_Pensioner_Records
Manage_Messages_and_Alerts
Compute_and_Pay_Pension_and_Gratuity
Enforce_Process_Workflow
Update_Active_Status
Loan_Records
Periodic_update_trigger
non-indeptedness_trigger
Manage_Business_Events

(b)

Figure 9. SPARQL query (a) and executed result (b).

The code in **Figure 10** presents code snippet of direct graph (digraph) visual representations of the ODAM for Pension Management Ontology. The snippet represents nodes and edges with each node representing a concept or entity, while the edges represent relationships between these entities. The nodes in the graph represent different entities or concepts.

The code snippet depicted in **Figure 10** serves as a semantic representation of the underlying logic of the ontology. The artifact "Process_Pension_and_Gratuity_Payments" with snippet semantics "Process_Pension_and_Gratuity_Payments" → "Manage_Business_Events" [label = "A5-served_by (Domain > Range)"] represents a relationship between the entity "Process_Pension_and_Gratuity_Payments" and "Manage_Business_Events." The label "A5-served_by (Domain > Range)" provides additional information about this relationship, signifying that "Process_Pension_and_Gratuity_Payments" is associated with "Manage_Business_Events".

Similarly, "Process_Pension_and_Gratuity_Payments" → "Apply_Business_Policies" [label = "A4-served_by (Domain > Range)"] represents a relationship between two entities: "Process_Pension_and_Gratuity_Payments" and "Apply_Business_Policies." "Process_Pension_and_Gratuity_Payments" is "served by" or "associated with" the concept "Apply_Business_Policies." The ontology explicates that the process of handling pension and gratuity payments (such as calculations, disbursements, or other related tasks) is "served by", dependent on the application of business policies.

As part of ontology query, the OWL supports filtering. Ontology filtering, in the context of knowledge representation and management, refers to the process of selecting or extracting specific information or concepts from a larger ontology or knowledge graph based on predefined criteria or filters [15]. It allows users or applications to focus on relevant subsets of knowledge within the ontology while excluding irrelevant or unnecessary information.

Ontology filtering is deployed to filter the knowledge contained in an ontology to specific needs or requirements. Filtering is often used to extract relevant

```
digraph g {
	"Process_Pension_and_Gratuity_Payments" -> "Manage_Business_Events" [label="A5-served_by (Domain>Range)"]
	"Process_Pension_and_Gratuity_Payments" -> "Manage_Messages_and_Alerts" [label="has subclass"]
	"Application_Interface" -> "Process_Pension_and_Gratuity_Payments" [label="has subclass"]
	"Process_Pension_and_Gratuity_Payments" -> "Update_Pensioner_Records" [label="A6-served_by (Domain>Range)"]
	"Application_Interface" -> "Enforce_Process_Workflow" [label="has subclass"]
	"Process_Pension_and_Gratuity_Payments" -> "Apply_Business_Policies" [label="has subclass"]
	"Process_Pension_and_Gratuity_Payments" -> "Manage_Messages_and_Alerts" [label="A3-served_by (Domain>Range)"]
	"Compute_and_Pay_Pension_and_Gratuity"->"Process_Pension_and_Gratuity_Payments"[label="A1-actualized_by
	(Domain>Range)"]
	"Process_Pension_and_Gratuity_Payments" -> "Apply_Business_Policies" [label="A4-served_by (Domain>Range)"]
	"Process_Pension_and_Gratuity_Payments" -> "Manage_Business_Events" [label="has subclass"]
	"Process_Pension_and_Gratuity_Payments" -> "Enforce_Process_Workflow" [label="A2-served_by (Domain>Range)"]
	"owl:Thing" -> "Application_Interface" [label="has subclass"]
	"Application_Interface" -> "Update_Pensioner_Records" [label="has subclass"]
	"Process_Pension_and_Gratuity_Payments" -> "Schedule_Pension_Staff_Training_Schedules" [label="has subclass"]
}
```

Figure 10. Code snippet of direct graph (digraph) visual representations of ODAM.

information for tasks such as data retrieval, information extraction, semantic search, and data integration [15]. Filtering criteria are rules or conditions used to determine what information is retained or extracted from the ontology. These criteria can be based on various factors, such as specific concepts, relationships, properties, or metadata. In this work, Ontology filtering is achieved through SPARQL queries (to retrieve specific triples), ontology reasoning (to infer additional information). From the taxonomy in **Figure 5**, **Figure 11** represents a filtering of the ontology for entities related to Loans. Similarly, **Figure 12** represents a filtering of all Update processes within the ontology. Various other techniques for filtering exist, depending on the capabilities of the ontology management system and the filtering requirements.

5. Discussion

The transformative impact of Ontology-Driven Analytic Models for Pension Management is evident in the results and simulations obtained. These models possess the potential to greatly enhance the management of pension funds, decision-making procedures, and the overall retirement planning experience [16]. The implementation of these models has resulted in improved data quality and accuracy in pension management. By utilizing ontologies to organize and merge various data sources, pension administrators can obtain a consolidated perspective of pension-related information. Based on simulations conducted, it has been observed that this approach results in a decrease in calculation errors, mitigated data inconsistencies, and enhanced adherence to regulatory requirements. As a result, pension fund administrators are able to make well-informed decisions regarding investment strategies, asset allocation, and risk management. Simulations also suggest that the predictive analytics capabilities of these models empower pension managers to more effectively anticipate future pension liabilities, thereby aiding in the strategic planning for the long-term viability of pension funds.

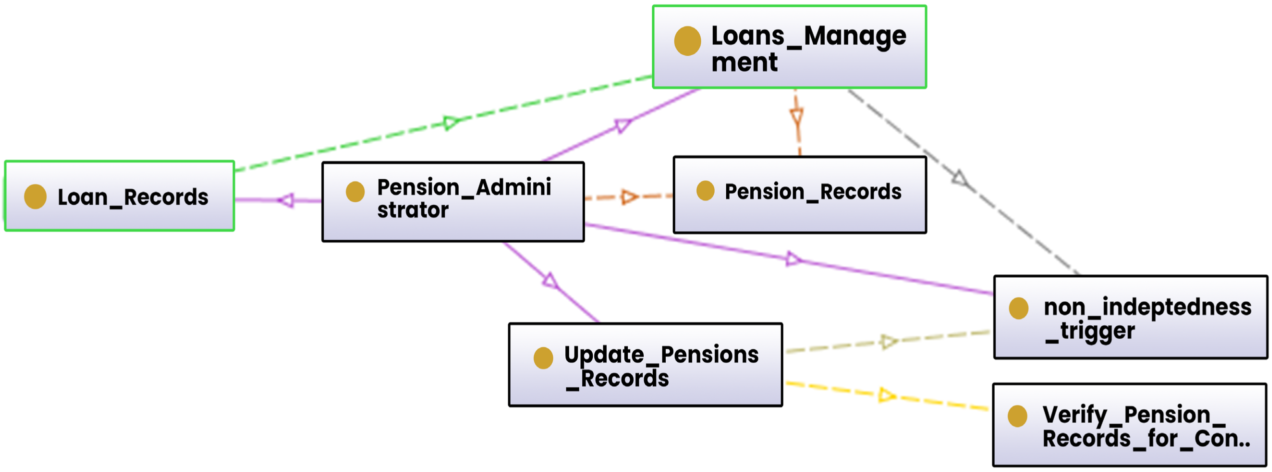

Figure 11. Filtering of loans management entities by searching the ontology.

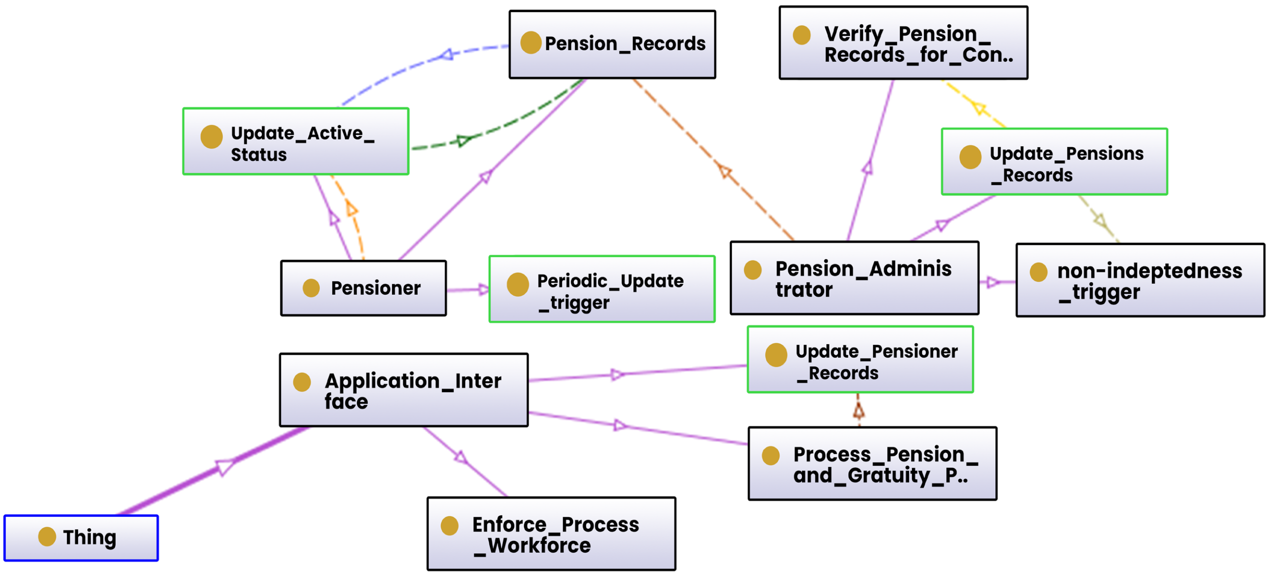

Figure 12. Filtering of all update processes by searching the ontology.

Additionally, the simulation results demonstrate the advantages of utilizing the Decision Support System (DSS) component. The Decision Support System (DSS), utilizing ontological knowledge, enables pension administrators to analyze different hypothetical situations and evaluate the potential consequences of policy modifications [15]. These simulations support proactive decision-making, allowing administrators to optimize pension plans, contribution rates, and investment portfolios. In addition, the DSS has the capability to offer personalized retirement planning guidance to individual plan members, enabling them to make well-informed decisions regarding their financial prospects. In general, the utilization of Ontology-Driven Analytic Models for Pension Management presents a favorable opportunity to enhance pension fund performance, ensure regulatory compliance, and increase member satisfaction by leveraging structured ontological knowledge and advanced analytics.

6. Conclusions

Ontology-Driven Analytic Models for Pension Management and Decision Support Systems are novel approaches that leverage structured ontologies to improve the efficacy and efficiency of managing pension funds and supporting decision-making processes. These models combine the power of ontology, data analytics, and decision support tools to create a robust, pension management-specific system. Ontologies provide a standardized and semantically rich representation of pension-related concepts, including pension schemes, contributions, beneficiaries, regulations, and investment options. These ontologies play a crucial role in facilitating data integration by ensuring seamless integration and querying of diverse data sources. Analytic models constructed upon these ontologies enable pension administrators to perform advanced data analytics, including trend analysis, risk assessment, and performance evaluation. This improves our understanding of the pension fund's financial health, investment strategies, and member demographics. In addition, these models support predictive analytics to forecast future pension liabilities, enabling administrators to effectively plan and allocate resources.

Second, the Decision Support System (DSS) component of these models leverages the ontology-driven data to provide pension administrators and planners with actionable insights and recommendations. By analyzing historical data, market trends, and member behavior, the DSS can aid in the formulation of well-informed investment strategies, contribution rates, and benefit distributions. It can also support regulatory compliance by automatically monitoring for violations and discrepancies and alerting administrators when they occur. In addition, these systems can provide pension plan participants with personalized retirement planning guidance, empowering them to make informed decisions regarding their financial destinies. In conclusion, Ontology-Driven Analytic Models for Pension Management and Decision Support Systems combine the semantic power of ontologies with advanced analytics and decision support capabilities, offering a comprehensive solution for pension administrators to effectively manage pension funds, ensure compliance, and provide valuable insights to plan members. Pension management ontology is an evolving field, and there are several areas for further research and development to enhance the effectiveness and utility of these ontologies. Some potential research directions include delving into advanced decision support and analytics capabilities within pension management ontologies to aid planning and informed decision-making as well as exploring the integration of machine learning and artificial intelligence techniques with pension ontologies to improve anomaly detection, fraud prevention, and personalized financial advice.

Conflicts of Interest

The authors whose names appear below certify that they have NO affiliations with, competing interests or involvement in any organisation or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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