Exploring Human Usability Challenges in Dataspaces

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Abstract

Dataspaces are a key pillar of the European Union's digital strategy, designed to facilitate secure, interoperable, and sovereign data sharing across various sectors while ensuring regulatory compliance. These ecosystems enable seamless data exchange among businesses, governments, and individuals, fostering advancements in artificial intelligence, big data analytics, and digital services. However, despite their potential, it remains unclear whether they provide the necessary tools to fully support efficient and user-friendly exploitation. This paper presents a preliminary vision aimed at identifying usability challenges within dataspaces and exploring how human users can better interact with them. In particular, we investigate whether Large Language Models (LLMs) can bridge the gap between raw, machine-oriented datasets and intuitive, human-centered data interaction.

Keywords

Dataspaces, Large Language Models (LLMs), Human-Data Interaction

This paper integrates with the W3C Dataspaces Community Group by addressing the generic dataspaces issue https://github.com/w3c-cg/dataspaces/issues/11.

1. Introduction

The concept of dataspaces is a cornerstone of the European Union's digital strategy, designed to enable secure, trusted, and sovereign data sharing across various sectors while ensuring compliance with regulations. By facilitating seamless data exchange among businesses, governments, and individuals, dataspaces drive innovation in fields such as artificial intelligence, big data analytics, and digital services. Additionally, they promote interoperability and sector-specific advancements in areas like healthcare, energy, and agriculture, enhancing efficiency, competitiveness, and sustainability. Dataspaces aim to establish a fair and open data economy, balancing economic growth with ethical and legal safeguards.

The Internet is often referred to as the "network of networks" because it serves as a global infrastructure that connects multiple computer networks worldwide. Building on this foundation, the World Wide Web (WWW) emerged as a global information system designed to provide access to documents, or web pages. To interact with this information, users rely on web browsers, which interpret HTML code and present the data in a human-readable format.

In the context of dataspaces, the ultimate goal is to achieve seamless interoperability between different spaces, creating a "single market for data" or a "space of spaces," a concept akin to the Internet's "network of networks." Within a dataspace, data is typically organized into catalogs, accessible via web browsers, allowing users to explore available datasets, their formats, metadata, and other relevant details. However, this data is often presented as large, complex collections of numbers, labels, and other elements in formats such as CSV and JSON. While these formats are useful for machine processing, they may not always be intuitive, easily interpretable, or manageable for human users.

This raises several important questions: Are machines the primary users of dataspaces? How can humans effectively interact with and extract value from these vast datasets? What is the equivalent of an Internet web browser for seamless interaction within dataspaces? This paper explores these questions and others related to the practical exploitation of dataspaces, examining whether recent advancements in Large Language Models (LLMs) can improve usability, accessibility, and overall human-data interaction within these ecosystems.

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2. Examining Dataspace Projects: Usability and Accessibility

In this section, we analyze several dataspace projects that are currently being developed with support from EU and national funding. By examining these initiatives, we aim to identify common patterns and challenges related to usability, data accessibility, and practical exploitation. Understanding these key aspects will provide valuable insights into how dataspaces are being implemented, the obstacles they face, and the potential strategies to enhance their effectiveness and adoption across different sectors.

2.1. Overview of the Selected Projects

Next, we present six ongoing projects in which Libelium is actively involved, each focused on implementing dataspaces to enhance data sharing, interoperability, and digital transformation across various sectors. The selected projects are DEPLOYTOUR, BeatTheHeat, SENSE, Geo4Water, LDT-DS, and SC-DIXAE.

2.1.1. DEPLOYTOUR

DEPLOYTOUR [1] is a project aimed at developing the European Tourism Dataspace (ETDS) to enhance the competitiveness, sustainability, and resilience of the tourism sector. It focuses on improving access to fragmented tourism data, empowering Small and Medium-sized Enterprises and Destination Management Organizations in their digital and green transitions, and fostering innovative practices. The project involves five pilot use cases across different EU regions, demonstrating the benefits of the ETDS for the tourism industry. It is co-funded by the European Union and seeks to create synergies with other initiatives, initiatives such as DATES [2], Gaia-X [3] and SIMPL [4], ensuring interoperability and enhancing data sharing in tourism.

2.1.2. BeatTheHeat

The BeatTheHeat project [5] addresses the growing concern of Urban Heat Islands (UHIs) exacerbated by climate change, particularly in Mediterranean cities. It focuses on enhancing urban health and resilience by providing data-driven solutions for urban managers. This collaborative project will involve three cities: Cartagena (Spain), Naples, and Taranto (Italy), all impacted by rising temperatures and frequent heatwaves. The project aims to integrate diverse data sources like weather forecasts, satellite data, IoT sensors, and urban maps into a shared data ecosystem. The BeatTheHeat dataspace will create high-value datasets, including shadow maps, thermal comfort maps, UHI maps, and pollution maps, to inform decisions on urban planning, mobility, and climate change mitigation efforts. By leveraging these insights, cities will be able to improve sustainability and health outcomes, aligning with the EU Green Deal goals for urban resilience and climate change adaptation.

2.1.3. SENSE

The SENSE (Strengthening Cities and Enhancing Neighbourhood Sense of Belonging) project [6] aims to create a network of interconnected virtual environments that replicate real cities, supporting the EU Smart Communities initiative. By leveraging European data infrastructure and adhering to interoperability standards, SENSE will develop practical Citiverse applications that benefit local authorities and citizens alike.

The project fosters collaboration with the EU Citiverse industry, including SMEs, to integrate Virtual Reality, and metaverse technologies, enabling citizens to navigate and engage with digital urban spaces. However, SENSE goes beyond technological advancements—it seeks to enhance the social, architectural, environmental, and cultural dimensions of urban living. By creating immersive and interconnected virtual spaces, the project strengthens citizens' sense of belonging, ultimately enriching urban life across Europe.

2.1.4. Geo4Water

The `Geo4Water` project [7] focuses on enhancing urban resilience to water-related climate events such as heavy rainfall, storms, and flooding, which have become more frequent and intense due to climate change. The project aims to create a dataspace that integrates diverse geospatial, environmental, and infrastructure data to improve urban management and disaster response. The Geo4Water dataspace will bring together data from multiple sources, including satellite imagery, weather data, IoT sensors, and aerial footage, to monitor flooding events, water pollution, and infrastructure damage. It will support four pilot cities: Valencia and San Javier in Spain, Oslo in Norway, and Donegal in Ireland, all of which are frequently affected by extreme water-related events. The dataspace will enable better decision-making, resource allocation, and the development of local digital twins for future resilience. By providing high-value datasets and services such as infrastructure monitoring, water pollution mapping, damage assessment, and urban resilience evaluation, Geo4Water will help cities improve their preparedness and response to water-related disasters, ultimately fostering more sustainable and resilient urban environments.

2.1.5. LDT-DS

The `Local Digital Twins Dataspace (LDT-DS)` project [8] aims to create a unified infrastructure that enables individuals, businesses, local governments, and researchers to access high-quality, interoperable data and related services. It addresses fragmentation and inconsistency by supporting the exchange of data within and between local silos, ensuring flexible processing while respecting data owners' rights and European values. The project envisions a common dataspace for key datasets, applications, and algorithms across sectors, designed to be FAIR (Findable, Accessible, Interoperable, Reusable). This dataspace will allow stakeholders—from policymakers to citizens—to collaboratively tackle pressing challenges such as climate change, circular economy, zero pollution, biodiversity protection, deforestation, and meeting EU objectives. The LDT-DS facilitates the development of Digital Twins, which can monitor, understand, predict, and respond to environmental and climate-related challenges, including disasters. For example, see Figure 1. This will improve urban life quality by enabling smarter city planning, energy consumption, mobility, and resource use. The project will focus on environmental management, sustainability, resilience, and promoting data-driven innovation and the data economy. Implemented across five cities (Valencia, Las Rozas, Cartagena, Granada, and Málaga), the LDT-DS will leverage a collaborative ecosystem involving organizations such as FIWARE [9], GAIA-X, and SIMPL.

2.1.6. SC-DIXAE

Combining the paradigms of cybersecurity, smart cities and dataspaces, the `SC-DIXAE` project [10] aims to create an ecosystem supported by a digital infrastructure for sharing and analyzing information on cyber threats that may target a city. It utilizes a dataspace that ensures control over the use and sovereignty of such data. The results of this initiative will improve the sharing and accessibility of large amounts of high-quality data, facilitating efforts to combat the digital vulnerabilities that affect organizations and individuals both within and outside the smart city.

2.2. On Usability and Data Accessibility

Table 1 provides an overview of the key aspects of the selected projects. Specifically, it highlights four elements: (1) the domain in which the dataspace is implemented, (2) the real-world environments demonstrating its application, (3) the types of datasets that can be shared within the dataspace, and (4) the primary use cases it enables.

According to the projects we have presented, dataspaces are mainly being valued with a series of data and AI services. These services offer users an experience tailored to the application domain and the profile of the individuals who use them. For example, in the `BeatTheHeat` project, city managers will be able to identify Urban Heat Islands (UHI), quantify heat retention, and assess their effects on

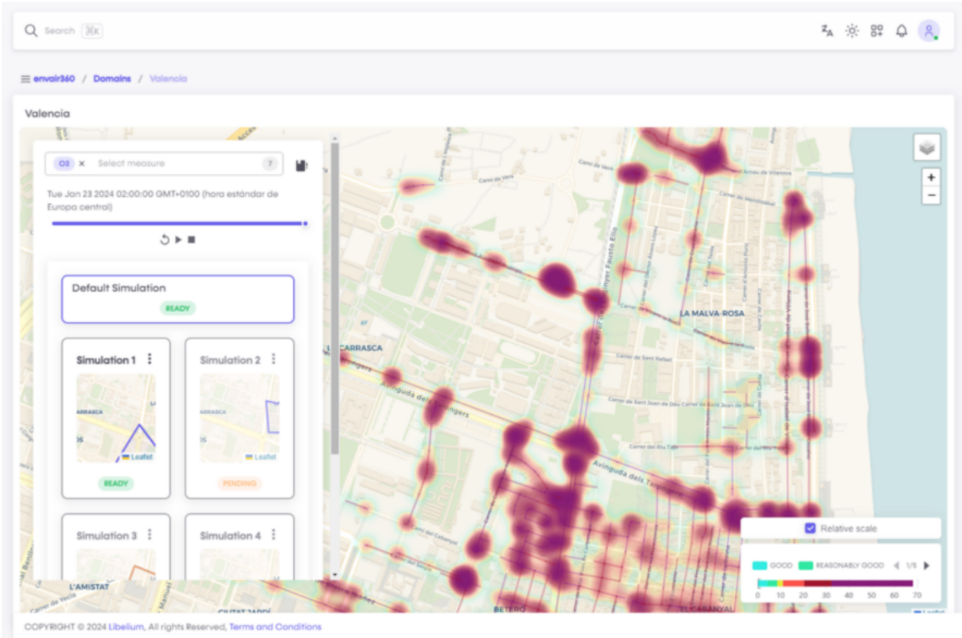

Figure 1: Example of a service that can leverage LDT-DS data: Libelium's Envair360 solution, which simulates low-emission zones in cities by integrating pollution, meteorological, mobility, and other relevant datasets

night-time temperatures. This data will guide decisions on urban planning, such as selecting pavement types, building materials, and implementing infrastructure improvements like green roofs and other heat mitigation strategies.

Additionally, the `Geo4Water` project will enable city managers to assess urban resilience to extreme rainfall events, helping them make informed decisions on nature-based solutions like rain gardens and Sustainable Urban Drainage Systems (SUDs). These specific use cases provide user interfaces tailored for city managers, offering functionalities for: (1) configuration of settings, (2) customized visualization of results, and (3) generation of detailed reports, ensuring transparency and easy interaction with the underlying dataspaces.

On the other hand, SENSE will offer citizens immersive 3D experiences, enabling them to explore their cities and interact with data such as public transport systems, points of interest, and more. The interfaces provided by these services will be designed for the general public, ensuring that users of all backgrounds can engage with the data and derive meaningful insights from their surroundings.

Therefore, usability and data accessibility are integral aspects considered in the development of services, and are typically addressed using the same principles applied in any software development project. These principles are rooted in human-centered design, which aims to ensure that the final product is intuitive, effective, and user-friendly. To achieve these goals, developers usually adopt well-established guidelines such as the Web Content Accessibility Guidelines (WCAG) and implement best practices.

In general, direct user interaction with dataspaces primarily involves data catalogs, which allow users to discover and access datasets from various sources. However, this approach presents several challenges. First, data catalogs often lack uniformity, making it difficult to assess the quality, relevance, and usability of datasets quickly. Second, interoperability issues arise when data is stored in different formats or systems, complicating seamless integration across platforms. Additionally, the sheer volume of data can overwhelm users, especially if there are no effective tools to filter or prioritize information based on specific needs. Finally, ensuring the accessibility and usability of these catalogs for a wide range of users, including non-technical stakeholders, remains a significant hurdle, requiring interfaces that are both intuitive and flexible.

This issue stems from Open Data portals, which promote the free distribution of data for public consumption and republishing [11]. Governmental organizations are among the major sources of

Table 1
Dataspace Projects

Project	Main Domain	Real-World Pilots	Datasets	Use cases
DEPLOYTOUR	Tourism	5 pilots in different EU regions, including Andalusia and Canary Islands (SP), Paris (FR), Syros Island (GR), Lapland (FI), Alpine regions (SL, AT)	Data on visitor behavior, preferences, transportation, accommodations, cultural attractions, events, infrastructure, environmental impacts, and more	Decision support services for public and private tourism managers, focusing on sustainable tourism, resilience, competitiveness in mature destinations, management of the cultural heritage sector, and the MICE industry
BeatTheHeat	UHI and extreme weather	3 cities: Cartagena (SP), Naples (IT) and Taranto (IT)	Weather forecasts, Earth observation data, IoT devices, building database, urban tree catalogs, traffic mobility data	Decision-support services for city managers, providing high-value datasets like shadow maps, thermal comfort maps, UHI maps, pollution maps, and Health Impact metrics
SENSE	Citiverse	2 cities: Cartagena (SP) and Kiel (DE)	3D Models, IoT devices, urban plans, public transport, city infrastructure and other city data	City virtualization for managers and citizens, focusing on culture, environmental awareness, infrastructure resilience, city planning, and smart mobility
Geo4Water	Extreme water-related weather	4 cities: Valencia (SP), San Javier (SP), Donegal (IE) and Oslo (NO)	Weather forecasts, Earth observation data, IoT devices, building database, city infrastructure, geophysical data	Decision-support services for city managers, including infrastructure monitoring, water pollution maps, damage assessment, urban resilience, and event history
LDT-DS	Local Digital Twins	5 cities: Granada (SP), Las Rozas (SP), Málaga (SP), Valencia (SP) and Cartagena (SP)	Data on water and energy consumption, transportation, waste management, parking, IoT devices, and more	Environmental management to aid decision-making for city officials in urban planning and mobility
SC-DIXAE	Cybersecurity in smart cities	City of Avilés (SP)	Inventory of IT equipment and networks, access and authentication logs, system vulnerabilities, security incidents, IoT sensor network data, network traffic monitoring, security policies and protocols, software update and patch status and more	Services for city managers, including risk assessments, vulnerability evaluations, and disaster recovery and resilience planning

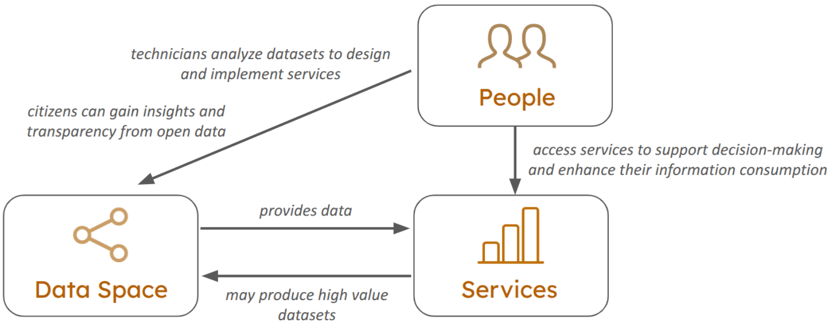

Figure 2: Collaboration diagram depicting interactions and relationships between dataspaces, services, and people

Open Data, making their datasets available online to enhance transparency and empower the public to monitor and hold government actions accountable. However, despite the abundance of available data, few individuals have the technical expertise to fully leverage it. For those who do, the process can still be daunting. Finding relevant datasets, understanding their formats, and validating their usefulness through basic tests or visualizations requires significant time and effort.

As a result, based on all the above, the answer to the question posed in the introduction—"Are machines the primary users of dataspaces?"—is no. Dataspaces have the potential to benefit all types of users, regardless of their technical expertise. Enhancing human-centered interaction not only makes data more accessible to the general public but also empowers technical users to develop data-driven services more efficiently and rapidly, ultimately strengthening the capabilities of dataspaces. Figure 2 presents a collaboration diagram that broadly illustrates the interactions and relationships between users and dataspaces.

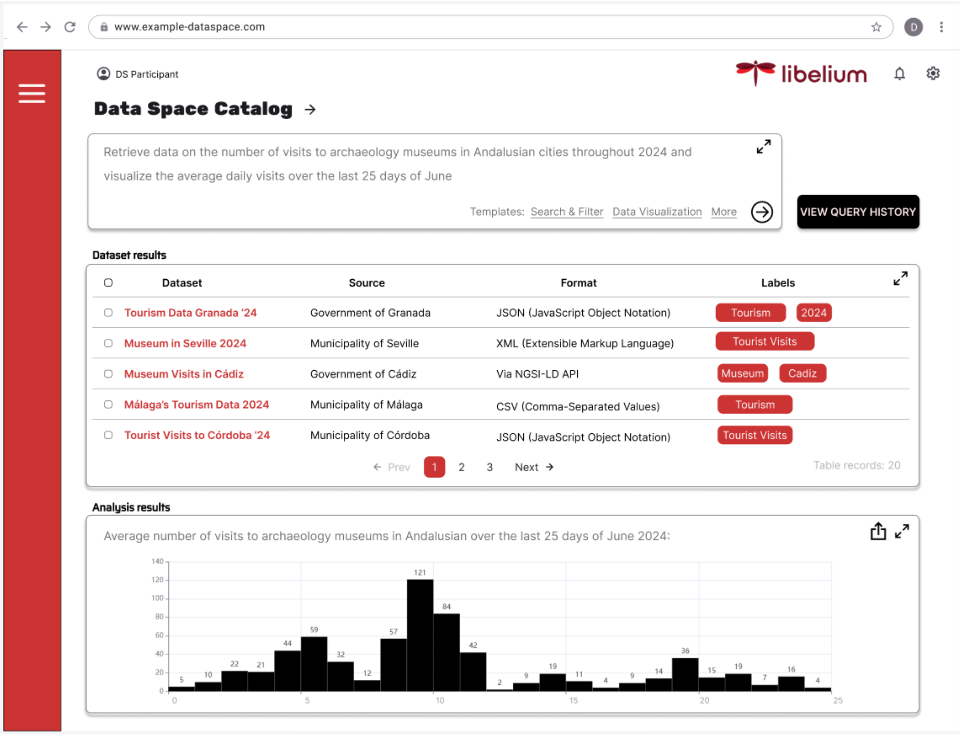

Figure 3: Conceptual illustration of a dataspace catalog improved with LLMs

3. Leveraging LLMs to Enhance User Interaction with Data Catalogs

Large Language Models (LLMs) are advanced AI systems trained on extensive text data to understand, generate, and process human-like language. Models such as OpenAI's GPT series, Google's Gemini, and Meta's LLaMA leverage deep learning techniques, particularly transformer architectures, to deliver context-aware and coherent responses. Through conversational interactions, LLMs can assist users with a wide range of tasks, improving accessibility, efficiency, and automation. These capabilities make LLMs invaluable for applications in digital ecosystems, including chatbots, virtual assistants, and knowledge management systems, ultimately improving user experiences across sectors.

3.1. Incorporating LLMs into the User Experience

Figure 3 presents a conceptual illustration of how the catalog interface could be structured with new capabilities powered by LLMs. This is merely an example, so the specific details displayed, such as the query, the datasets or the resulting graph, are not intended to be relevant.

The interface would be primarily organized into three panels, from top to bottom:

- **Query Input Panel**: Users can enter natural language queries to search for data, apply filters, and request basic processing or visualizations. For example, "Retrieve data on the number of visits to archaeology museums in Andalusian cities throughout 2024 and visualize the average daily visits over the last 25 days of June". Additionally, predefined query templates for common tasks such as "Search & Filter" or "Data Visualization" can be provided, following the template structures proposed by [12]. This conversational interface functions similarly to OpenAI's GPT series or Google's Gemini, allowing users to provide context and chain queries together, applying new queries to previously generated results. A query history feature would also be available, enabling users to track their interactions and maintain a clear line of reasoning throughout their data exploration.
- **Dataset Results Panel**: This panel presents a list of datasets that match the query and are considered for generating analysis results. Users can browse the datasets, click to view detailed

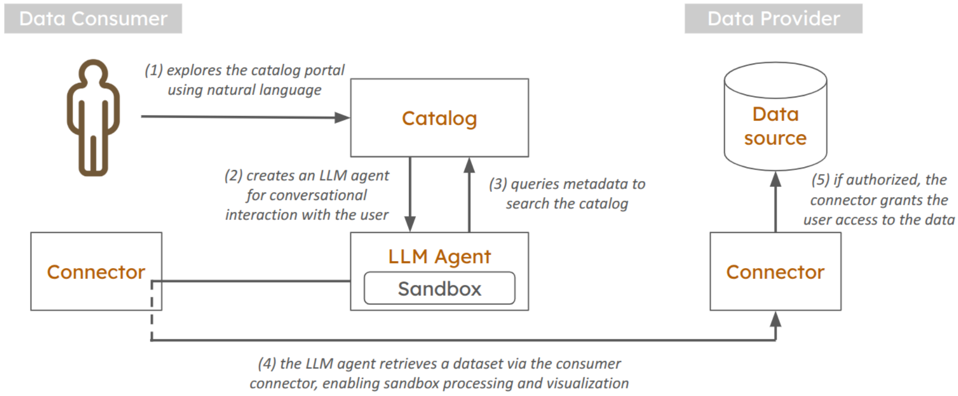

Figure 4: Proposed approach for integrating LLMs into the dataspace architecture

metadata, and access the data if needed, just as they would in a standard catalog.

- **Analysis Results Panel**: This panel presents the generated visualizations and basic data processing outputs, such as graphs, statistical summaries, or tables with a limited set of transformed data samples. It provides users with an intuitive way to interpret the results derived from the selected datasets.

Regarding the functionalities that the conversational interface could offer, they may align with the features suggested by Distefano et al. in [12]:

1. **Searching and filtering data**: Users can define queries to retrieve relevant datasets.
2. **Integrating data from multiple sources**: LLMs can assist in merging datasets within the dataspace, identifying inconsistencies such as format mismatches, and suggesting necessary transformations to ensure data coherence.
3. **Ensuring data accuracy and consistency**: LLMs can detect issues such as missing values, formatting errors, and inconsistencies, helping users enhance dataset reliability.
4. **Enriching data for deeper insights**: LLMs can suggest data augmentation techniques, including generating synthetic data while ensuring compliance with predefined rules and constraints.
5. **Visualizing and summarizing data for better understanding**: LLMs can recommend appropriate visualization techniques and generate concise summaries to help users interpret key findings effectively.

3.2. Towards Integrating LLMs into the Dataspace Architecture

Figure 4 presents the proposed approach for integrating LLMs into the dataspace architecture. When a user accesses the catalog, an LLM agent is instantiated to manage the conversational interaction. As the user engages with the agent, the LLM may need to interact with the catalog API to retrieve metadata about datasets and perform searches. In alignment with the IDS-RAM [13], a widely recognized reference architecture model for dataspaces, the catalog can serve as or be connected to a metadata broker, enabling the registration, publication, maintenance, and querying of Self-Descriptions provided by dataspace connectors.

When a query requires accessing data for processing or visualization, this operation must be executed via the user connector. This ensures that, firstly, the user has the necessary authorization to access the data, and secondly, that the traceability of transactions is preserved. Furthermore, if it is necessary to download data for processing or temporarily store intermediate data or results, this will be carried out in a sandbox environment within the LLM agent. This approach optimizes integration with the LLM while also enabling the implementation of secure processing environments in compliance with the European Data Governance Act [14]. In this context, the sandbox environment could be distributed across the data provider connectors that the LLM agent interacts with. As outlined in the IDS-RAM, these connectors can deploy specific data processing applications, ensuring that the handling of data remains both secure and flexible.

3.3. The Role of LLMs in Enhancing Semantics within Dataspaces

Recent research has highlighted the potential of LLMs for semantic labeling tasks. For instance, studies like [15] have explored the use of LLMs for semantic type detection through arbitrary domain ontologies, as well as the creation of semantic models for datasets. These studies have demonstrated promising results, indicating that LLMs could effectively assist in the organization and interpretation of data, although further work is needed to improve their accuracy.

The IDS-RAM introduces the Vocabulary Hub as a component for managing domain-specific vocabularies based on RDF schemas. This functionality enables the assignment of meaningful attributes to datasets, ensuring that the data can be properly categorized and interpreted in relation to its context. By using well-defined vocabularies, the component improves the semantics of the data, facilitating more accurate and relevant searches. However, when LLMs are employed, their interpretation of user queries depends on the general-language semantics embedded during their training. A few key points arise in this context:

1. LLMs could directly process natural language descriptions of datasets, reducing the need to create complex ontologies or annotate datasets manually. This approach would not only save efforts but also enable non-technical users to contribute to the process of describing semantics. Moreover, providing LLMs with contextual information can enhance their understanding of domain-specific descriptions, improving their ability to interpret and interact with the data.
2. Despite advancements in Ethics and Explainable AI, LLMs remain black-box models that lack transparency. For instance, the assumptions they make to interpret user queries may not be traceable. This lack of transparency can introduce biases and inaccuracies, which may affect data searches. The potential risks of this are similar to those posed by internet search engines, where results are influenced by opaque algorithms and may favor certain perspectives over others. In dataspaces, this could lead to some datasets being more visible than others, depending on the LLM interpretation.
3. The Vocabulary Hub could play a relevant role in addressing the previous issue. We could extract semantic terms from user queries automatically according to a specific ontology. Then, the consistency of these terms could be validated against the datasets resulting from the search performed by the LLM, ensuring alignment between the query and the selected data. This process could help mitigate potential biases and enhance the relevance of search results.

4. Conclusions

This paper has explored the usability challenges that human users face in interacting with dataspaces, particularly in the context of accessing and leveraging data effectively. Through the analysis of multiple projects, we identified that while dataspaces provide a robust framework for secure and interoperable data sharing, they often fall short in offering intuitive, human-centered access mechanisms, making it difficult for non-technical users to extract value from available datasets.

To address this gap, we examined the potential of Large Language Models (LLMs) as a bridge between complex, raw data and more accessible, human-friendly interfaces. Our analysis suggests that LLMs can enhance usability in several ways, including facilitating natural language search queries, improving data discovery, enabling contextual visualizations, and assisting with semantic interpretation. By integrating LLMs into dataspace architectures, we can lower the technical barriers for users, making data-driven decision-making more inclusive and effective.

However, challenges remain. Issues such as data quality, bias in AI-generated responses, and the need for secure and transparent interactions with dataspaces must be carefully managed. Additionally, integrating LLMs requires adherence to ethical and regulatory guidelines to ensure fair and unbiased data access. Future research should focus on refining LLM capabilities within dataspaces, optimizing human-data interaction models, and developing approaches to improve accessibility while maintaining data sovereignty and security.

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Declaration on Generative AI

During the writing of this paper, the authors used GPT-4o in order to: Grammar, translation and spelling check. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the publication's content.

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