A catalyst for European cloud services in the era of data spaces, high-performance and edge computing: NOUS

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Abstract

Europe's position in the current cloud market needs to be improved. This market is currently dominated by non-European players by 75%, shaping the way that Europe is deploying and using cloud services. Although these players are bound to laws and regulations of foreign powers, such as PR China and USA, generating legitimate concerns for the EU, its businesses and citizens. EU's digital future resides on having installed secure, high-quality data processing capacity. This can only be offered by cloud services both centrally and at the edge. In this context NOUS's ambition is completely

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in line with the European Strategy for data as aims to create the foundations for a European Cloud Service which exploits the HPC network and tackles specific-to-the-EU-economy requirements as well as leverages different data spaces (Mobility, Energy, Green Deal and Manufacturing).

CCS Concepts

• **Software and its engineering → Software Architectures**; *Software Infrastructure*; • **Computer systems organization → Cloud Computing**; *High-Performance Computing (HPC)*; Quantum Computing; • **Information systems → Data Management Systems**; *Data Privacy and Security*; Distributed Storage; • **Networks → Network Security**; *Network Protocols*; • **Security and privacy → Cryptography**; *Access Control*; • **Computing methodologies → Artificial Intelligence**; *Machine Learning*; • **Applied computing → Enterprise Computing**.

Keywords

Data spaces, cloud services, high-performance computing (HPC), quantum computing, data sovereignty, blockchain technology, edge computing, european cloud market, digital sovereignty, federated learning, data privacy, interoperability, data lifecycle management, EU digital strategy, cybersecurity, data standardization, Internet of Things (IoT), collaborative platforms, data exchange, data governance

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1 Introduction

The EuropeaN ClOUd Services in the era of data spaces, high-performance and edge computing (NOUS) project envisions to create a comprehensive blueprint for implementing a cloud service where each implementation is interconnected with other EU platforms, instead of creating a cloud service with all the infrastructure expected by a cloud service such as hyper-verticalized providers (Microsoft Azure, Amazon AWS, Google GCP). The project aspires to be the technological leg of Europe's Next Generation Cloud [2]. Data spaces are secure and controlled environments where organizations can share and utilize data while maintaining data sovereignty and privacy. These platforms facilitate collaboration and data exchange between different entities, enabling the creation of value from data. Key features of data spaces include:

- Interoperability: Data spaces enable seamless integration between different data sources and formats, removing technical barriers to collaboration. This is crucial for data exchange across diverse sectors and for fostering innovation.
- Access Control: Data spaces implement robust mechanisms to manage and control who can access data. This ensures that only authorized entities can access specific datasets, thereby maintaining security and privacy.
- Security and Privacy: Data spaces incorporate advanced security measures to protect data from unauthorized access and comply with data protection regulations, such as GDPR in Europe. This is vital for maintaining participant trust and ensuring responsible data handling.
- Data Sovereignty: Data providers retain ownership and control over their data, determining how and who can access it. This principle of data sovereignty is essential for allowing organizations to make informed decisions about the use and sharing of their data.
- Value Creation: Data spaces promote the creation of new insights and the development of innovative products and services. The federation of multiple actors within a data space enables value generation that would not be possible in isolation ensuring that data providers retain ownership and control over their data even when shared with others.

Distributed Ledger Technologies (DLT) provides a range of functionalities for enhancing data cataloging within data spaces, offering improvements in security, transparency, and efficiency. These features are particularly critical in environments where data integrity, provenance, and decentralized control are crucial [19]. The immutable ledger and smart contract capabilities of blockchain offer robust mechanisms for managing and verifying data catalogs, ensuring data sovereignty, and enabling secure data exchanges.

Connecting with Data Spaces and ensuring a seamless data flow within, to and from a European Cloud Service is a significant challenge. As from the point of view of the European economy, the goal is to creation a single data market facilitated by common Data Spaces [10]. A natural challenge is increasing the EU capacity to process vast amounts of data, while connecting and/or facilitating the creation of Data Spaces.

A catalyst for NOUS will serve as a catalyst for the establishment of a single data market. While Data Spaces are in their infancy and not well defined technologically, they are described as "an infrastructure that enables data transactions between different data ecosystem parties based on the governance framework of that data space. A data space should be generic enough to support the implementation of multiple use cases"[3]. The NOUS project will advance both the technological and business aspects, assisting in the convergence of data spaces. A key vision for the project is that NOUS will embody the technological framework of EU's vision for data spaces.

The connection with the Data Spaces will be achieved through a blockchain framework, which tracks the entire data´s lifecycle within a dataset. This framework will ensure transparency, adherence to legal requirements (GDPR), and interoperability with data spaces (DSSC), this could be possible using low-energy technologies such as Ethereum 2.0 or IOTA, applying smart contracts and oracles to manage interaction with data external to the ledger ensures a free and controlled flow of high-quality and secure data

The NOUS project integrates blockchain as a decentralized database to manage data spaces and enhance trust and security. It will develop services for data interconnection and governance, evaluate legal implications and sustainability, and use federated learning to

protect privacy.
The paper is organized as follows: in Section 2 NOUS project is deeply explained along with a brief presentation of the use cases. In Section 3 an overview of the architecture and the related methodology is presented. Section 4 shows how NOUS integrates and uses data spaces. Section 5 concludes the paper.

2 NOUS Concept

The concept of NOUS arises from the vision of providing technological infrastructure and services suitable for scientists and professionals running intensive and complex computing algorithms on a commercial cloud interface. This vision addresses the need to improve Europe's position in the cloud market, currently dominated by non-European players by 75%. Instead of limiting the use of foreign technologies, as suggested by some European initiatives, NOUS proposes a new paradigm for cloud infrastructure that promotes scientific excellence and the development of high-performance digital services within the European economy[17] [1]. NOUS's vision is based on three interrelated challenges that are crucial for advancing Europe's technological infrastructure and digital sovereignty. First, NOUS aims to fully leverage the existing high-performance computing (HPC) infrastructure and quantum computers provided by various vendors. This utilization will enable addressing and solving highly complex problems such as climate change prediction, the synthesis of new drugs, and the development of energy-efficient materials. By offering a cloud service that supports and enhances scientific excellence, NOUS positions itself as an essential pillar for technological and scientific advancement in Europe. Second, NOUS promotes the implementation and development of the next generation of Cloud-Edge-IoT technologies in Europe. This effort is aimed at strengthening the transition towards a continuum of computing and storage better distributed between central nodes (cloud) and peripheral nodes (edge). By doing so, it seeks to optimize the use of devices such as smartwatches, sensors, and connected cars, enhancing their capabilities to perform complex and computation-intensive tasks. This approach not only improves the operational efficiency of these devices but also ensures that user data and privacy are respected and protected. NOUS's edge computing infrastructure will allow for greater flexibility and responsiveness in various industrial and scientific applications, ensuring that data is processed and stored efficiently and securely. Finally, NOUS focuses on facilitating seamless data flow within, to, and from a European cloud service. This objective is essential for creating a single data market within the European Union, which is crucial for the region's competitiveness and digital sovereignty. By promoting technological and business convergence towards the European vision of interconnected data spaces, NOUS acts as a catalyst for the integration and efficient utilization of large volumes of data. This integration facilitates collaboration between different sectors and organizations, driving innovation and value creation from shared data.[12] Additionally, by fostering interoperability and compliance with common standards, NOUS ensures that data can be used effectively and securely in multiple contexts and applications. A vision that can be manifested during the project is that NOUS can become the technological scope of the EU vision on data spaces. Following this vision, NOUS's objectives are:

- Develop a technological connectivity framework between Europe's High-Performance Computing (HPC) network and NOUS, extending NOUS's computational capabilities through the seamless interaction of quantum computers with the HPC network. [#compute]
- Develop a data processing module for the fusion of data obtained from ubiquitous physical assets and digital models, addressing the distribution of computation among devices in the Edge-to-Fog-to-Cloud (E2F2C) continuum. [#edge]
- Implement Blockchain as a decentralized database connected to the edge, and compare it with classical storage models for standard applications and IoT-driven applications within the context of NOUS. [#data]
- Design an extensible translation-to-standards concept using a data lake and develop it as a software component for standards in the Mobility (NeTEx, GTFS), Energy (IEC, SAREF), and Green Deal (various CEN/CENELEC standards) Data Spaces. [#data]
- Develop the architecture for a suite of European cloud services that combines computing, edge, and data, increasing the EU's digital sovereignty.
- Create a collaboration platform based on the Living Labs concept, acting as a "Stack Overflow for data sharing," allowing users to ask questions and share data analysis results, especially using cross-domain data.
- Collaborate with other initiatives and organizations working on European Data Spaces to facilitate data sharing within NOUS, focusing on the convergence of ideas around a common (or set of common) European cloud services.

In the next subsection, the different use cases applications are presented.

2.1 NOUS Use Cases

The NOUS project includes a set of use cases that present specific challenges. These challenges will be addressed by NOUS through the development of new technologies within an industrially relevant environment.

2.1.1 *Use Case #1: Perception of Connected Vehicles using camera data.*

This use case aims to improve the perception of connected vehicles by using roadside and car cameras. By leveraging a network of IoT devices, connectivity infrastructure, and NOUS edge servers, the system will be able to precisely locate moving physical assets (with a special focus on pedestrians and vulnerable users) and provide real-time data to vehicles and road users, enhancing situational awareness. [6]

2.1.2 *Use Case #2: Energy Prediction and Energy Data Lifecycle Management.*

In this use case, NOUS wants to explore two data-intensive applications. The first is the energy prediction task, which processes historical energy and weather data, along with sensor data and future weather predictions, to forecast intra-day and day-ahead power consumption, generation, and optimal selling prices in the electricity markets. This application currently requires significant human involvement, leading to high costs, limited accuracy, and time consumption.

The second application involves managing the lifecycle of energy data. This encompasses reporting tasks that summarize customer, supplier, and production data at various levels of detail, providing valuable insights to the organization's executives for decision-making. The accuracy of these reports depends on the data lifecycle, as data initially generated in isolated auxiliary systems are regularly transferred to central information systems for retrieval by reporting systems. For this application, it is essential to ensure the confidentiality, integrity, and availability of customer, supplier, and production data throughout its lifecycle and during transit.

Within the NOUS framework, PPC aims to access the HPC network to identify and harness its potential for executing computationally intensive tasks. The objective is to enhance data management by implementing standardization and blockchain services for data handling. Additionally, PPC seeks to strengthen data confidentiality and integrity through cybersecurity services for computing operations. Furthermore, PPC will leverage the federated learning capabilities provided by edge computing.

2.1.3 Use Case #3: Crisis Management and Civil Protection Platform. This Use Case aims to enhance the capacities of a cloud-based crisis management platform by integrating NOUS for improved data lifecycle management. This will involve handling the access and traceability of vast amounts of data exchanged during major crises[5].

This NOUS Use Case is based on Crisis management using the Crimson application (C4 – Command, Control, Coordinate, Communicate) developed by CS Group - France. In this field, data are mostly composed by satellite images and geographical data for the static part. Then, for the dynamic part, we handle communications between the different instance of Crimson located in the command centers (the desktop version) or on the field with responders (the mobile application). These two types of data have their own particularities. The first one is most of the time quite heavy (up to 1To to handle online) while the second one is characterized by its criticality (orders, statements and alerts are transmitted).

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2.1.4 Use Case #4: Scientific Data HPC Storage and AI Analytics. This Use Case aims to apply NOUS tools for efficient data lifecycle management and AI analytics [4] to support scientific and technological excellence. The focus is on managing and analyzing complex datasets from various scientific fields, improving workflows, and reducing publication time. This involves the use of natural language processing and reinforcement learning for related work discovery, the development of predictive models to accelerate experiments or simulations and reduce costs, and the enhancement of process modeling and multiscale analysis. This use case addresses the challenge of conducting computationally expensive in silico experiments for researchers in engineering and environmental applications. The objective is to facilitate the migration of these workloads to High-Performance Computing (HPC) settings while minimizing the number of experimental calculations needed to sample large design spaces. This will be achieved by leveraging the NOUS resources navigator, a chatbot designed to assist inexperienced HPC users,along with AI-empowered algorithms such as active learning and Bayesian optimization.

3 NOUS Architecture

The NOUS architecture is an IaaS/PaaS/MLaaS architecture that incorporates the connection with HPC network and seamless computing between HPC Quantum computers in a (cyber) secure environment, provides a federated learning framework as a service with a proper load balancing based on AI (i.e., neural-evolutionary algorithms) and capability for parallel applications, utilises low-consumption DLT for ensuring data life cycle handling; while assisting in data standardisation using semantic data lakes and lakehouses, as well as recursive algorithms, and promoting self-sovereign data exchange through its connection with a Virtual Lab. The above should also incorporate connection with Data Spaces and address legal and ethical issues (e.g., following the EC's Ethics Guidelines for Trustworthy AI).

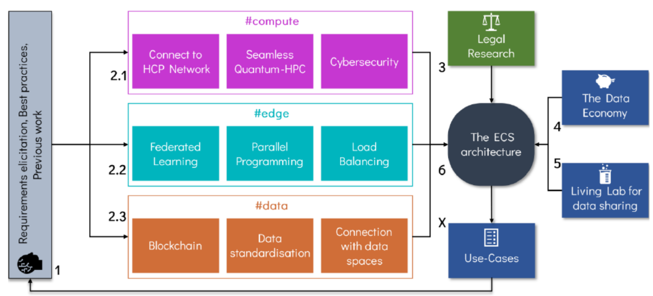

Figure 1: NOUS architecture

The methodology of the NOUS project is designed to meet specific requirements defined by its objectives and conceptual framework. It employs a two-layered approach: the upper layer consists of a generalizable methodology that can be easily adopted by other projects, while the lower layer is specific to the NOUS project and addresses all its objectives in detail. This dual approach ensures that the project's outcomes are both broadly applicable and specifically tailored to meet its unique goals.

On the upper layer, NOUS follows a modified Software Development Life Cycle (SDLC) approach, covering steps from concept to partial implementation and verification, aiming to reach Technology Readiness Level (TRL) 5. The lower layer delves deeper, employing a detailed methodology that aligns with the SDLC framework but is tailored to NOUS's needs. This involves meticulous requirements elicitation, architectural drafting, documentation and evaluation processes. The methodology is designed to ensure compliance with environmental objectives, leveraging a "Do no significant harm" principle to meet the EU Taxonomy Regulation standards.[11].

NOUS envisions a pipeline of three types of components:

- Compute components: The components that are responsible for executing computations. This is the standard cloud computation service and the sandbox environment for researchers to test their applications (as is the HPC network today).
- Edge components: The components that are responsible for communicating with edge devices such as smartphones and IoT sensors/actuators/devices.
- Data components: The components that are responsible for data storage, storage management, data sharing, standardisation and exchange.

In the next subsection these three components are described.

3.1 Compute component

The implementation of a methodology for an optimal implementation of High Performance Computing (HPC) will be considered not only in practice but also in theory. In addition, the aim is to provide an answer to issues such as possible solutions to crises in HPC and quantum computing systems. Finally, the computational component is based on two basic cybersecurity considerations. First, the project will investigate darknets, which can create a fully secure network that acts as a sub-network of the internet. Within this darknet, NOUS could offer digital services completely disconnected from the internet. Secondly, the project will investigate a zero trust security model that can work in addition to or separately from the darknet security model.

The computational aspect of the project focuses on optimizing the utilization of High-Performance Computing (HPC) resources within the envisioned NOUS cloud. This involves both practical considerations, such as authentication and data transfer protocols, and theoretical exploration of optimal methodologies for leveraging extisting European HPC networks. Identifying key technologies and configurations for this process is vital. This will include Kubernetes and VM-powered applications, as well as methods and processes specifically for applications with high demands for HPC resources, such as simulations or digital twins. Additionally, the architecture will enable the allocation of tasks between HPC and Quantum computers using multi-criteria evolutionary algorithms. These algorithms will optimize load scheduling based on factors like computational requirements, infrastructure costs, and energy consumption. Cybersecurity measures for the NOUS will also be addressed, including research the Zero Trust Security Model, to enhance trust and efficiency while securing the network from external threats.

3.2 Edge Component

The edge component of the project investigates aspects of edge computing within the NOUS framework. Services such as Federated Learning and Inference, parallel computation programming, and load balancing are designed to be user-manageable within the NOUS environment. The Federated Learning and Inference framework will comprise algorithms for decentralized Machine Learning, optimizing local learning processes to minimize resource consumption on devices. The developed architecture will use FastFlow [8] for parallel computation, enabling users to instantiate parallel applications with configurable parallel skeletons. Efficient mechanisms for thread cooperation and architectural optimization strategies will be implemented to address strict throughput and latency requirements. Load Balancing will involve hierarchical, algorithmic data and computation distribution for intelligent resource allocation between edge devices and cloud/fog data centers, considering privacy and data sovereignty.

3.3 Data Component

The data component emphasizes the implementation of blockchain technology, focusing on integrating DLTs like tangles or energy-efficient blockchains to facilitate transparency and lifecycle management in Data Spaces [19]. This architecture will enable the validation of ledgers across various applications, ensuring data integrity, provenance, and decentralized governance [13].

Standardization processes will be investigated for domains like mobility and energy, aiming to harmonize standards within data spaces and with existing frameworks. An auto-standardizer (AS) will be developed to assist organizations in standardizing their data, utilizing heuristic and recursive algorithms.

Blockchain's immutability and smart contracts will enable efficient data exchanges while addressing challenges of data tampering and unauthorized access [19]. The integration with Data Spaces will guarantee a secure and sovereign flow of data, with a particular emphasis on the management of the data lifecycle.

One of the fundamental challenges lies in data management and storage. Blockchain systems require a well-structured approach to efficiently manage data flow and storage [20]. Additionally, the storage limitations of blockchain necessitate innovative approaches, such as storing only metadata directories on the blockchain while keeping the actual data with the owners, thus balancing decentralization with practical storage needs [21]. A common technique involves using hashing for large datasets stored off-chain, while only the hash is maintained on the blockchain. This method ensures traceability and integrity of the data without the need for excessive on-chain storage. Hybrid architectures provide a solution for enhanced data management by combining blockchain with NoSQL databases to address scalability and throughput challenges. This approach facilitates efficient handling of both on-chain and off-chain data, c leveraging the advantages of each technology to enhance the overall performance of the system [16].

The integration of oracles within the framework of a data space architecture represents a crucial methodology for the verification of data integrity, particularly when the data is sourced from diverse origins. [7]. In some cases, redundancy mechanisms may be applied, where data from different sources is compared and checked to improve reliability. However, this approach consistently be requisite or effective, and its implementation depends on the specific requirements of the data space. In scenarios where high levels of trust are required or where critical data is involved, redundancy can add an extra layer of assurance by verifying consistency across multiple inputs [9].

In cases where data is continuously updated, oracles can dynamically feed new information into the blockchain. Through smart contracts, real-time comparisons of new data with previously stored entries can be automated, flagging any inconsistencies for review. This is particularly useful in data spaces where data integrity is critical but the frequency of updates necessitates continuous validation [15].

These technologies will support decentralized access control and permissions management, using blockchain to secure data access and ensure traceability contributing to the transparent and tamper-proof management of data spaces.

4 NOUS and Data Spaces

The NOUS project aims to design and develop an open architecture that integrates and interconnects Cloud and Edge Computing, HPC, Quantum Computing, IoT, Federated Learning, and DLT technologies. This approach will allow users to develop applications and services built for and operated largely with the use of edge computing devices while offering unprecedented computational power for backend services. This ambitious goal is centered around a cloud environment that allows fast, secure and trustworthy retrieval, processing and exchange of data. Therefore, the creation of the necessary data services will enable the efficient management and integration of existing and new Data Spaces supported by the exchange of data assets and applications.

Data Spaces as an umbrella term covering a wide range of data related ecosystems and interoperable hardware and software components faces a number of critical challenges for the implementation and adoption of federated and decentralized solutions. These challenges could be identified either as inter-organizational or intra-organizational [18], depending on the scope of the involved entities and their interactions with the data products or services. In both cases technical, organizational, business and legal compliance issues need to be tackled to allow and inspire large scale participation for both data consumers and producers. The NOUS project on one hand will adopt existing and established methodologies, frameworks and practises that promote sharing technologies and solutions, and on the other it will contribute by designing and developing innovative components.

For the provision of a highly collaborative environment that ensures data sovereignty, transparency and trust, the NOUS project will build upon Gaia-X's main principles. Gaia-X is a European initiative for building secure and federated data infrastructures that allows users to maintain control over their data and it is designed to ensure interoperability and portability. Instead of providing centralized cloud services similar to the ones offered by major companies such as Google, Microsoft and Amazon, Gaia-X provides the framework for a federated system that allows users to choose services from multiple providers while ensuring that these services are interoperable and compliant with GAIA-X standards. This approach encourages innovation and fosters synergies between organizations and the development of new business models, contributing to the creation of data economy ecosystems in different domains, such as healthcare, manufacturing, agriculture, and energy.[14]

By following a modular approach and by adopting the well established Gaia-X Reference Architecture Model, the Certification and Compliance process and the Data Sovereignty Framework the NOUS project will create the backbone for a federated system that will bridge the gap between Quantum Computing, HPC, IoT, AI and Edge Computing. This effort includes the development of a distributed architecture that will (co-)operate in an optimal and efficient manner with traditional cloud services, but also the necessary structured parallel programming environments that will enable participants to instantiate parallel applications and execute scenarios with strict throughput and latency requirements in services related to edge computing operations. Specialized modules will be designed and developed that will enable the seamless communication and data transfer between the NOUS ecosystem, HPC systems and the enormous capabilities of Quantum Computers.

On the other hand NOUS will create the AS component, as the dedicated tool for the translation of any relevant dataset to a data standard that is part of Mobility (NeTEx, GTFS), Energy (IEC, SAREF) and Green Deal (various CEN/CENELEC standards) Data Spaces. This will boost the semantic interoperability and allow for easier integration of data sources to the NOUS ecosystem. Data sharing and life-cycle management will be undertaken by a dedicated blockchain platform that will safeguard data ownership and ensure compliance through smart contract applications. The Data Space Agent will be based on the StreamHandler Platform a high-performance, low latency and high throughput distributed streaming platform for managing real-time data developed by Netcompany Intrasoft. It will be further developed to enable advanced stream handling service optimised and evaluated for the domains addressed by the NOUS projects. Mechanisms and services dedicated to data publication and discovery will be added alongside components that will facilitate identity and access management.

5 Conclusion

NOUS will allow users to develop applications and services built for and operated largely with the use of edge computing devices while offering unprecedented computational power for backend services. At the same time, the NOUS will exploit connection with Data Spaces to foster data sharing and provide data analytics related services especially focusing on knowledge sharing and collaboration. The NOUS results will be validated and demonstrated in four different use cases briefly presented in the paper. In this paper the concept and the potentiality of the NOUS project have been presented: initial results will come in the next years of the project.

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