



WHITEPAPER

DATA FEDERATION

Unifying Data for Enhanced Decision-Making & Operational Efficiency.

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ABSTRACT

This whitepaper provides a comprehensive overview of Data Federation, exploring its definition, significance, and the necessity of implementing this approach in today's data-driven organizations. As businesses increasingly grapple with fragmented data across various systems, data federation emerges as a vital solution for achieving a unified view of information, thereby enhancing decision-making and operational efficiency. The document will outline the key reasons for adopting data federation, including improved accessibility, reduced storage costs, and better data governance. Additionally, it will examine the tools and technologies available for effective implementation, offering insights into best practices and real-world applications.

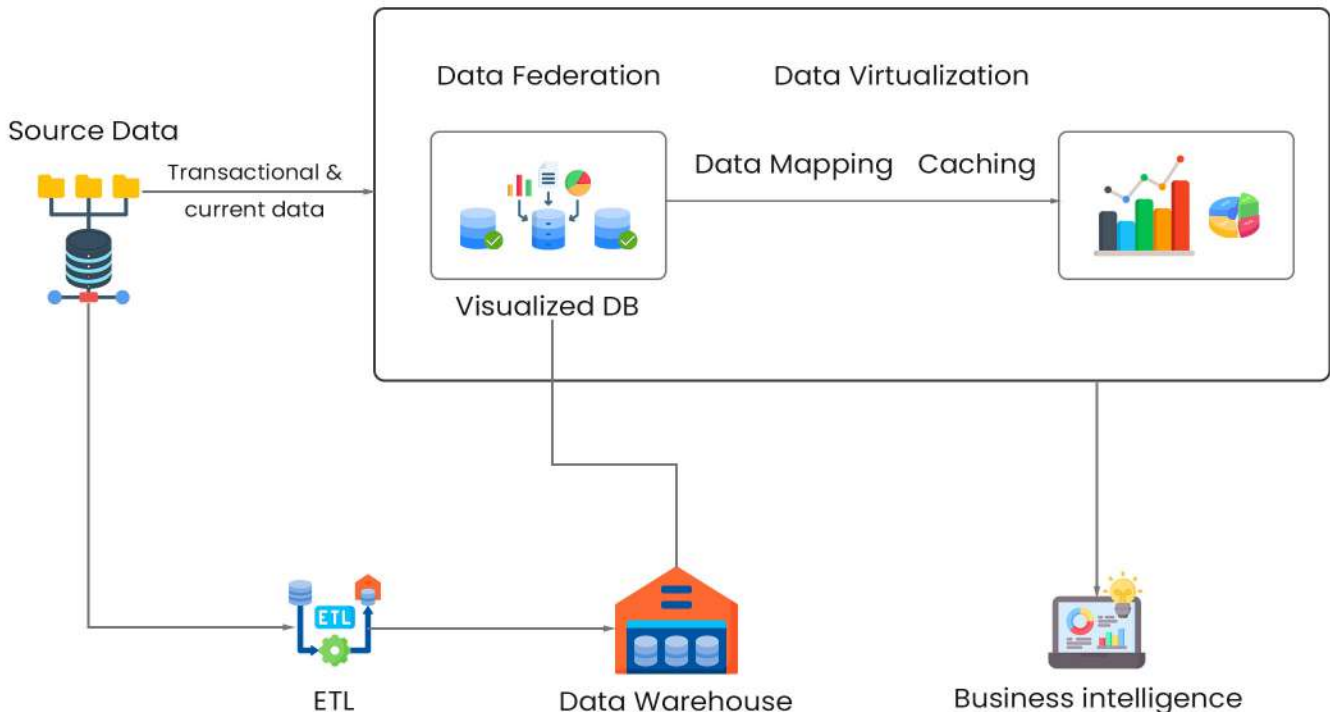
1. INTRODUCTION

In today's fast-evolving data landscape, organizations face the growing challenge of data fragmentation across multiple systems, cloud environments, and storage silos. With global data volumes projected to reach 394 zettabytes by 2028 (Statista, 2024), the need for robust data management practices to ensure accessibility, governance, and cost efficiency has never been more urgent. Traditional data integration mechanisms, such as Extract, Transform, Load (ETL) processes and centralized data warehouses, are increasingly proving to be resource-intensive and ineffective in maintaining real-time data freshness. As a result, organizations are shifting towards federated data integration architectures, which provide unified access to distributed datasets without the need for extensive data replication or movement.

Data Federation has emerged as a critical solution to address these challenges, enabling organizations to seamlessly integrate multiple disparate data sources into a single interface while maintaining the independence of each system. Unlike traditional data consolidation methods, data federation leverages virtualization to provide real-time access to data and analytics without requiring physical data migration. This approach enhances agility, reduces costs, and accelerates insights, a crucial advantage for businesses seeking to harness AI-driven analytics. Given the diversity of data formats—ranging from structured relational databases to unstructured flat files—organizations increasingly recognize the value of unifying and augmenting data to drive growth, improve decision-making, and enhance customer satisfaction.

However, the growing complexity of data, characterized by the 3Vs of Big Data—Volume, Variety, and Velocity, has exposed the limitations of traditional data integration processes. Data warehousing, while widely used, is costly and often fails to meet real-time data needs, driving demand for more scalable, efficient, and real-time integration solutions. According to DataCore Research, 88% of businesses report significant inadequacies in their storage infrastructure, citing gaps in high availability, scalability, tamper-resistant data protection, and AI-enabled storage operations. As organizations strive to reduce storage costs, enhance performance, future-proof their infrastructure, and ensure seamless remote access, the adoption of modern data integration strategies such as data federation becomes increasingly critical.

2. STRATEGIC EVOLUTION OF DATA INTEGRATION ARCHITECTURES: ETL TO DATA FEDERATION TO DATA VIRTUALIZATION



The integration of disparate data sources remains one of the most critical challenges in enterprise technology strategy. Over the past four decades, organizations have progressed from batch-oriented ETL pipelines to real-time federation and virtualization architectures, each addressing distinct operational requirements. This evolution reflects not a replacement of prior technologies but a strategic layering of capabilities to meet evolving business needs. ETL continues to serve as the backbone for structured historical analysis, while data federation enables real-time operational visibility, and virtualization introduces performance optimization across hybrid environments.

2.1 ETL: THE FOUNDATION OF STRUCTURED DATA INTEGRATION

ETL (Extract, Transform, Load) systems emerged in the 1990s to integrate data from diverse sources, enabling enterprise-wide business intelligence. They effectively supported rigorous data quality needs through batch processing, ideal for financial reporting and compliance. Modern ETL pipelines have evolved to incorporate cloud-native parallel processing and machine learning-driven data quality checks, enhancing efficiency and scalability.

2.2 SHIFT TOWARDS DATA FEDERATION

Data federation emerged as a strategic complement to ETL, addressing the critical need for real-time data access without physical consolidation. By creating virtualized views across distributed databases, applications, and APIs, federation layers allow queries to execute directly against source systems. This architecture proves particularly valuable in several key scenarios:

Operational Dashboards: Retail chains like Walmart employ federation to combine real-time POS transactions with inventory databases, enabling minute-by-minute restocking decisions

Regulatory Compliance: Financial institutions federate transaction records across 30+ legacy systems to meet Basel III liquidity reporting requirements without data replication

M&A Integration: Companies merging IT systems federate HR and ERP data during transition periods, avoiding disruptive data migration projects

Technical advances in query optimization and schema mapping have mitigated early performance concerns. The latest federation engines from IBM and Denodo achieve sub-100ms response times for complex joins across 10+ data sources through intelligent caching and parallel query routing. However, practitioners note federation works best when:

- Source systems maintain high availability and low latency
- Transformation requirements remain minimal (<15% of query logic)
- Security policies permit direct source system access

2.3 EVOLUTION TO DATA VIRTUALIZATION

Data virtualization builds upon data federation by enhancing real-time data integration with features such as caching, optimized query execution, and hybrid environment support across on-premises and cloud systems. By reducing latency, improving query performance, and enabling scalability, data virtualization is well-suited for modern data integration needs.

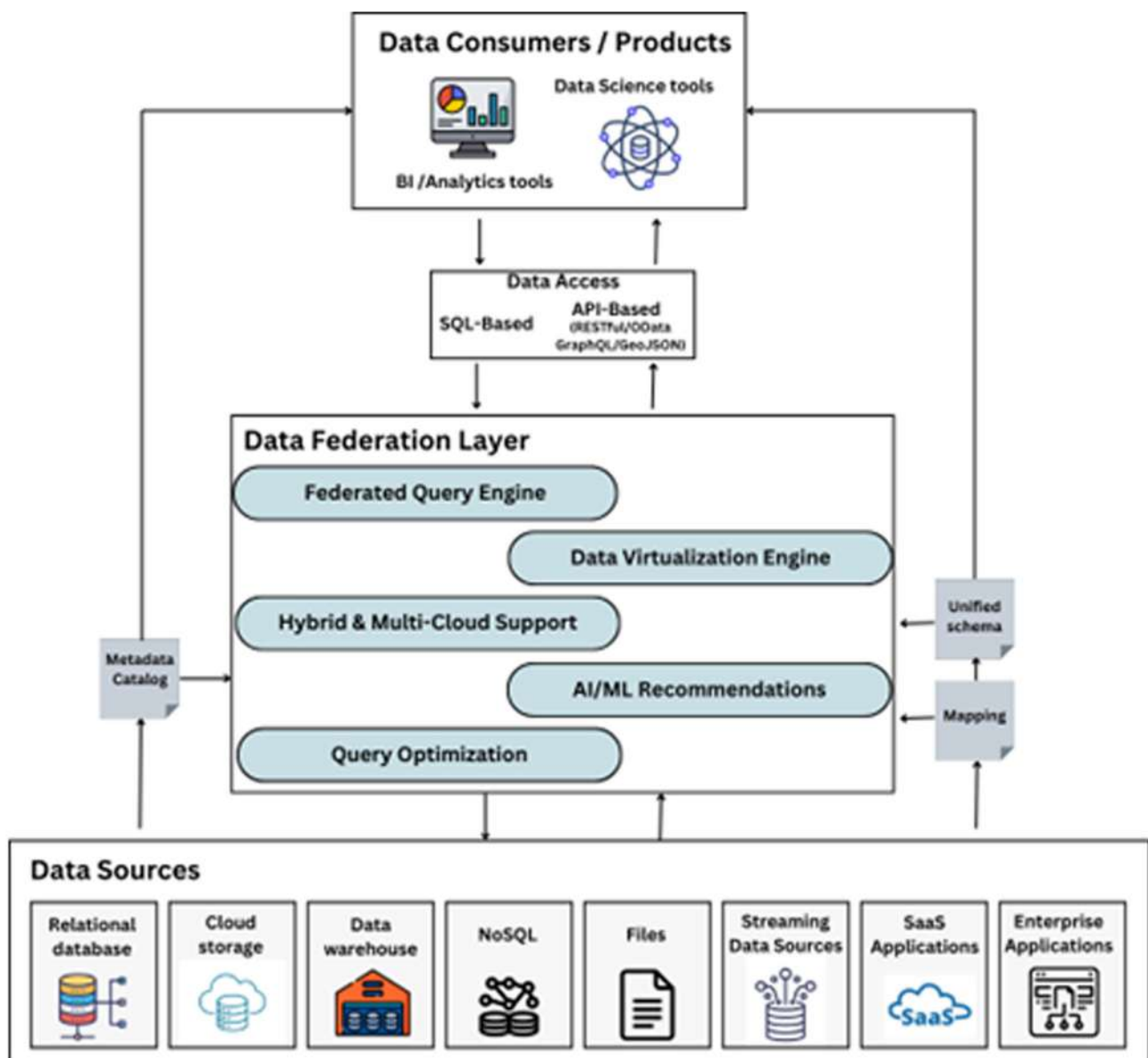
Strategic Implementation Guidelines

Enterprises should evaluate integration approaches through four dimensions:

Factor	ETL	Federation	Virtualization
Data Freshness	Hours-Days	Seconds-Minutes	Sub-second
Transformation	Complex Business Logic	Light Transformations	On-demand ML Models
Latency Tolerance	High	Moderate	Low
Use Case	Regulatory Reporting	Operational BI	Real-time Analytics

3. UNDERSTANDING DATA FEDERATION

Data federation is a critical data management technique that provides a unified view of data residing in multiple, autonomous, and potentially heterogeneous data sources. Unlike traditional data warehousing approaches, data federation allows data access in situ, negating the need to copy or centralize data into a single repository.



Architecture Overview

Data Sources

Data federation integrates diverse data sources, including structured databases (SQL-based systems like MySQL and PostgreSQL), unstructured cloud storage (AWS S3, Google Cloud Storage), and analytical data warehouses (Snowflake, BigQuery). NoSQL databases (MongoDB, Cassandra) offer flexible schema storage, while file-based sources (CSV, JSON, XML) provide static data. Real-time streaming platforms (Kafka, Pulsar) ensure continuous data processing, and SaaS applications (Salesforce, Workday) deliver business-critical data. Enterprise applications like ERP and CRM store transactional and operational data essential for business processes.

Metadata Catalog & Schema Integration

- The **Metadata Catalog** centralizes schema management, data lineage tracking, and governance, ensuring consistency, security, and compliance across multiple sources. It standardizes data definitions and access controls while maintaining regulatory adherence.
- A **Unified Schema** provides a standardized data representation, enabling seamless integration across sources. It abstracts data complexity using relational schemas or RDF(S) ontologies, ensuring interoperability and efficient querying.
- **Mappings** define relationships between disparate datasets and the unified schema, ensuring data consistency and seamless integration within the Data Federation Layer for optimized querying and analysis.

DATA FEDERATION LAYER

This core component enables seamless integration and efficient querying of data from multiple sources.



Federated Query Engine

Executes queries across different sources without data replication.



Data Virtualization Engine

Provides a unified view of data, eliminating physical data movement.



Hybrid & Multi-Cloud Support

Ensures compatibility across on-premise and cloud environments.



AI/ML Recommendations

Enhances performance with automated query optimization & anomaly detection.



Query Optimization

Improves efficiency using caching, indexing, and distributed query execution.

Data Access Layer

Standardized access mechanisms allow seamless interaction with federated data. SQL-based queries enable compatibility with traditional databases, while API-based access (REST, OData, GraphQL) ensures interoperability with web applications and external platforms.

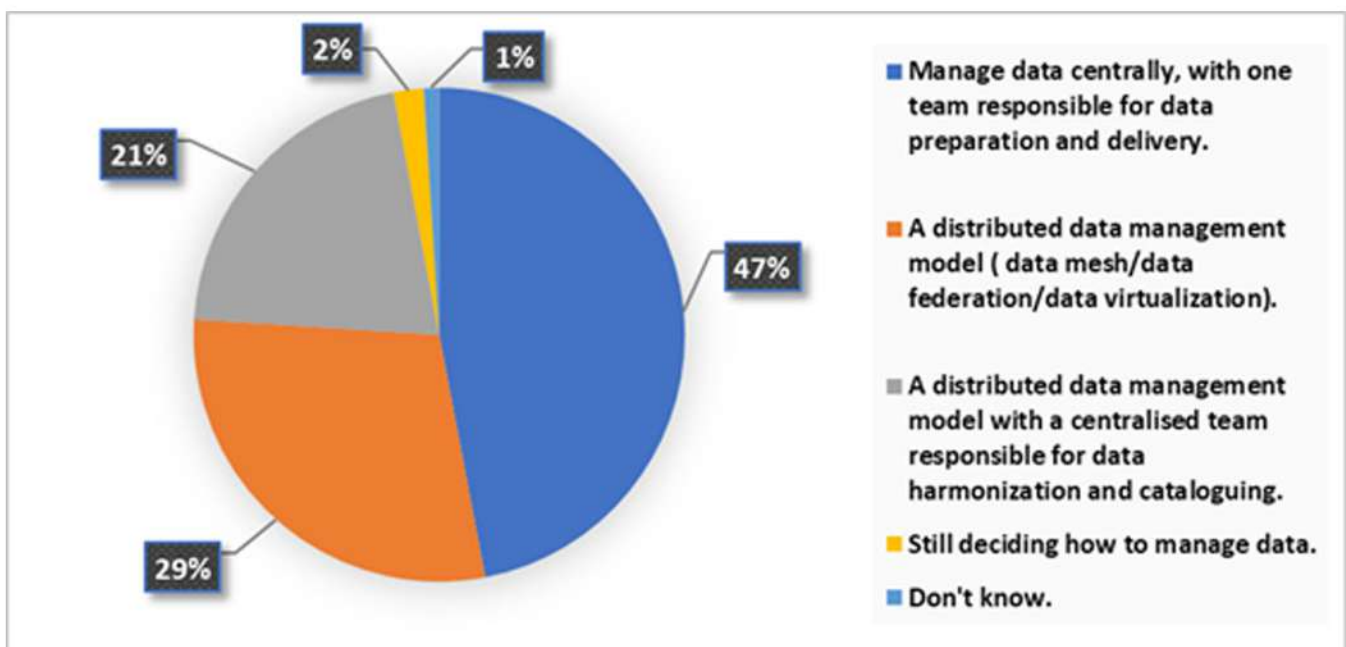
Data Consumers / Products

Federated data is consumed by various tools and applications. Business Intelligence (BI) and analytics tools (Tableau, Power BI) generate reports and dashboards. Data science platforms (Jupyter, TensorFlow) leverage AI/ML models, while enterprise applications (ERP, CRM) rely on real-time insights for operational efficiency.

4. Why & When Data Federation?

The need for agility, simplicity, and efficiency in handling data has never been more immense. Companies today need to revamp their method of handling data to address the fast-changing demands of data users.

According to the Denodo Data Gap Report, a significant number of organizations are struggling with data management challenges. The report highlights critical issues such as data silos, inefficient data integration processes, and the inability to access real-time data. Many organizations find themselves overwhelmed by the sheer volume and variety of data sources, leading to delays in decision-making and missed opportunities. The report emphasizes the growing need for solutions that provide seamless access to data across diverse systems while maintaining governance and security. These insights underline why a data federation strategy is essential for modern enterprises looking to stay competitive and data-driven.



Nearly half of organizations rely on a central data team for data preparation and delivery, while 30% adopt a fully distributed model, and 21% implement a hybrid approach with central oversight. AI/ML adoption remains limited, with only 18% of organizations extensively utilizing these technologies, although 43% plan to increase their use. Furthermore, 68% acknowledge a pressing need to improve their data and analytics platforms or enhance their workforce's ability to leverage company data effectively.

Formal data management policies provide multiple advantages, including improved data integration (50%), regulatory compliance (41%), and enhanced collaboration across teams (38%). Organizations adopt varied data storage strategies, with 46% using a hybrid setup, 31% relying on private cloud, 25% following a multi-cloud approach, and 22% either storing data locally or utilizing public cloud solutions. While 77% recognize the benefits of distributed data management, 75% still favor a centralized approach, highlighting the disparity between strategic preferences and implementation feasibility. Leadership responsibilities in data management are primarily held by Chief Data Officers (59%), followed by CIOs (17%) and Chief IT Architects (8%). Additionally, 69% of organizations acknowledge that traditional architectures are increasingly inadequate for managing the growing velocity and volume of data, underscoring the need for modern, scalable data management solutions. Data federation should be considered when organizations need to unify access to diverse, distributed data sources without the complexity & cost of traditional integration methods.

As organizations face the growing complexity of managing multiple, dispersed data sources, data federation becomes an invaluable solution, particularly when:



Dealing with Multiple, Dispersed Data Repositories

If your organization relies on various data sources (e.g., data warehouses, data lakes, SQL/NoSQL systems), data federation provides unified access without physically moving the data.



Avoiding High Costs and Long Timelines of Traditional Integration

Instead of building costly and time-consuming ETL/ELT pipelines, data federation offers a quicker and more cost-effective alternative by providing direct access to data without extensive processing.



Real-Time Data Access is Required

Data federation allows access to the latest data from multiple sources without delays, making it ideal for scenarios needing timely insights, such as in marketing, sales, or finance.



Faster Decision-Making is a Priority

By streamlining data access, data federation helps business users focus on analytics rather than data preparation, leading to quicker insights and faster time-to-market.



Migrating to the Cloud

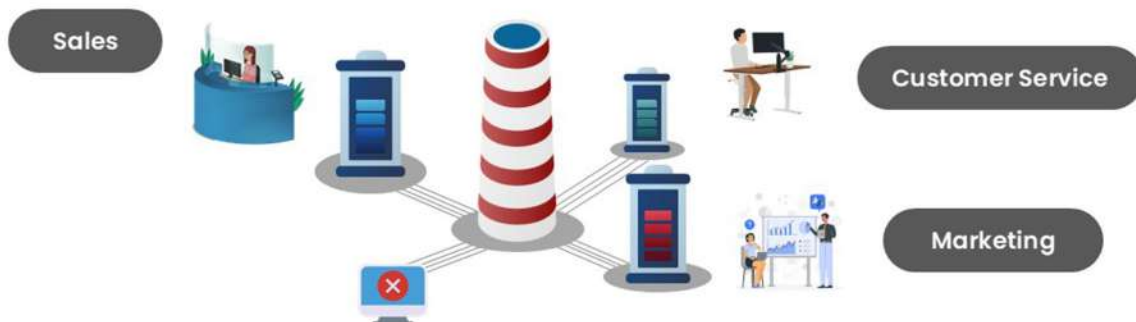
During cloud migrations, data federation simplifies the process by enabling fast access to data across cloud and on-premise environments without extensive data movement.



Improved Governance and Security are Needed

Many data federation platforms offer robust governance, security features, and metadata management, ensuring data is accessed securely and in a compliant manner.

5. Leveraging Data Federation to Overcome Data Silos



Companies are increasingly using artificial intelligence (AI) and analytics to improve decision-making and gain a competitive advantage. Yet, data silos—disconnected repositories in various departments, legacy systems, and cloud environments—can undermine the effectiveness of AI and restrict operational efficiency. Data federation provides a solution by providing real-time access to heterogeneous data sources without physical consolidation.

Though data federation gives shape to a cohesive integration of data, success would largely rely on having a good strategy in place. Effective regulation, regulatory adherence, security for the data, and support to higher-level business initiatives are key to avoiding unguided fragmentation. If not accounted for, data federation could create new silos instead of dispelling existing silos.

5.1 When Data Federation Fends off Silos?

If used properly, data federation offers a connected data ecosystem. Success is brought about under the following conditions:



Strong Data Governance – A centralized approach to governance mandates uniform data quality, security, and accessibility for all departments.



Successful Schema Mapping – Converging data structures from varied sources avoids differing interpretations and guarantees consistency



Agile and Scalable Analytics – Removing time-consuming extraction, transformation, and loading (ETL) makes possible real-time insights and rapid decision-making



Cost and Storage Optimization – Virtualized access minimizes redundant data replication and storage expenses



Cross-Departmental Collaboration – A single data management approach promotes increased adoption and operational consistency



In-Depth Training and Adoption – Educating teams on the utilization of federation tools effectively eliminates fragmentation and suboptimization

5.1.1 Real-World Example: Salesforce & Amazon Redshift – Zero Copy Data Federation

Modern enterprises deal with disconnected data across multiple platforms. For example, teams in Sales, Service, and Marketing often struggle to access key data trapped within analytics and machine learning systems. This results in delays, inefficiencies, and missed opportunities for business growth.

To solve this, Salesforce and Amazon Redshift have introduced Zero Copy Data Federation, enabling businesses to access Redshift data in real-time within Salesforce Data Cloud—without the need for data replication.

This integration provides a seamless, data-driven experience, unlocking better personalization, operational efficiency, and cost savings.

Key Benefits of Zero Copy Data Federation

- **Real-Time Data Access** – Instantly access Redshift data within Salesforce Data Cloud for immediate decision-making.
- **Eliminates Data Silos** – Unifies customer data across platforms, providing a 360-degree customer view.
- **Personalized Customer Engagement** – Leverage enriched data to deliver more relevant marketing, sales, and service experiences.
- **Enhanced Efficiency & Reduced Costs** – No need for redundant data storage or manual data transfers.

Use Case Scenarios



Targeted Marketing – Combine Redshift customer profiles with Salesforce data for highly personalized campaigns.



Personalized Promotions – Merge purchase history with feedback data to offer tailored discounts and recommendations.



Enhanced Customer Service – Integrate customer support case data with behavioural insights to improve service quality.



Optimized Business Offers – Use billing and order history data to suggest next-best actions for customers.



Advanced Customer Segmentation – Enrich Salesforce profiles with detailed purchase behavior insights for better targeting.



360-Degree Customer View – Provide Sales, Service, & Marketing teams with a unified, enriched customer profile for better engagement.

Conclusion: Breaking Silos, Powering Real-Time Insights

Zero Copy Data Federation marks a significant breakthrough in enterprise data management. By eliminating silos and enabling real-time insights, businesses can enhance collaboration, improve efficiency, and deliver superior customer experiences.

5.2 When Data Federation Can Form New Silos?

Incorrect usage or insufficient management may result in unanticipated silos. The most important risks are:

Absence of Governance – In the absence of standardized data management methods, departments can establish isolated federated systems with inconsistent rules.

Inadequate Schema Mapping – Inadequately designed mappings result in inconsistent interpretations of data, lowering the level of trust in federated platforms

Over-Reliance on Technology Without Cultural Adoption – Technology cannot fill organizational gaps if teams fail to actively share and integrate data.

Low-Quality Data Integration – Federating low-quality or incomplete data leads to unreliable insights, compelling users to use localized sources.

Limited Training and Awareness – Employees will not effectively use or not use federation tools, perpetuating existing silos, if they are not trained.

6. Top Leaders in the Data Federation Landscape

While a dedicated Gartner Magic Quadrant for data federation tools does not exist, the Gartner Magic Quadrant for Data Integration Tools offers valuable insights into vendors providing data integration solutions, including data federation capabilities. To identify key players in the data federation landscape, we analyzed the vendors featured in the November 2024 Gartner Magic Quadrant for Data Integration Tools and evaluated their offerings based on data federation functionalities.



The following vendors are identified as Leaders in this category:

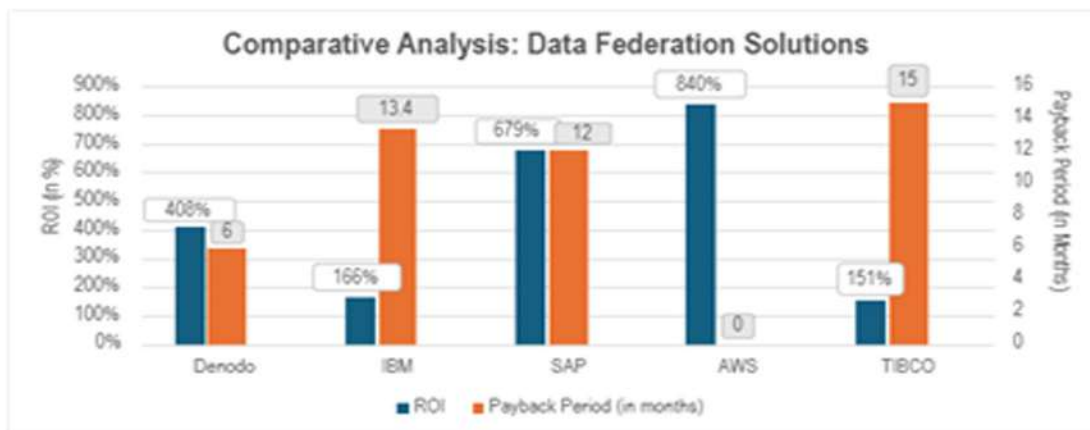
Denodo: The data virtualization technology offered by Denodo enables seamless data federation, allowing organizations to integrate disparate data sources without physical consolidation. This approach accelerates data access and reduces reliance on traditional extract, transform, and load (ETL) processes. The TEI study reported a 65% faster access to data compared to ETL methods, contributing to improved business user productivity and efficiency for data scientists, who spend 67% less time on data preparation. These efficiencies contribute to a three-year benefit of \$6.8 million and a return on investment (ROI) of 408%, with payback in less than six months.

InfoSphere Federation server (IBM): IBM's InfoSphere Federation Server, part of its Information Integration and Governance (IIG) suite, provides powerful data federation capabilities, enabling efficient data integration and governance. The TEI study found a 15% to 25% improvement in data governance team efficiency, a 28% cost reduction in data integration and governance, and a 34% faster return on big data initiatives. These efficiencies contributed to a three-year benefit of \$13.9 million, delivering a return on investment (ROI) of 166% with a payback period of 13.4 months.

TIBCO Data Virtualization: With its robust data federation capabilities, TIBCO's data virtualization platform enables organizations to connect and unify data from diverse sources without the need for data replication. The TEI study highlighted that TIBCO's Connected Intelligence Platform delivers a 151% Return on Investment (ROI) over three years, generating a Net Value of \$5.63 million and delivering benefits with a Value of \$9.36 million. The solution achieves a payback period of 15 months.

AWS Athena (AWS): Benchmark testing of AWS Athena using TPC-DS benchmark queries at a 3 TB scale revealed a 3x improvement in query performance and a 70% reduction in costs due to decreased scanned data size compared to the previous engine. Considering that the average data scanned per query is 2 TB, the annual query cost dropped to \$540,000 after the optimization. This improvement led to an ROI of 840% per annum

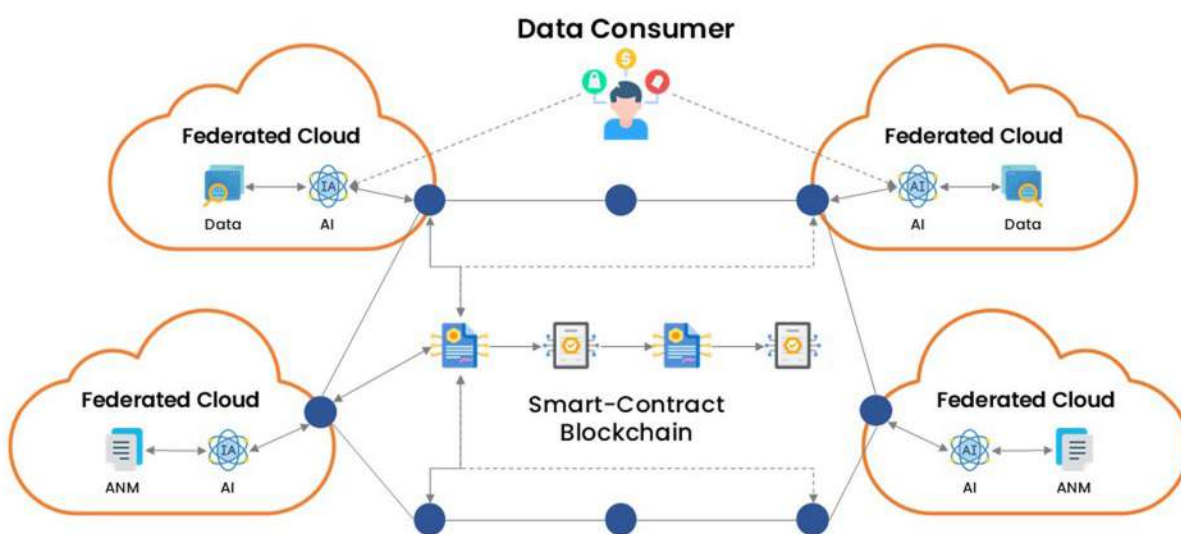
SAP HANA (SAP): With its Smart Data Access (SDA) feature, SAP HANA delivers robust data federation capabilities, allowing organizations to integrate diverse data sources seamlessly. An IDC study reported that organizations leveraging SAP HANA achieved a 679% return on investment (ROI) over five years, generating average revenue gains of \$34.1 million per organization. Additionally, SAP HANA improved business productivity by 21% and enhanced IT team efficiency, contributing to reduced operational costs and faster innovation. These efficiencies support substantial business growth, with a payback period of less than one year.



7. Future Directions

As data ecosystems continue to evolve, emerging technologies are set to redefine the future of data federation. Among these advancements, blockchain integration and AI-driven automation stand out for their potential to significantly enhance security, efficiency, and intelligence in federated data management. Blockchain ensures tamper-proof, transparent data exchanges, while AI-driven automation streamlines data processing, governance, and decision-making. These innovations are just the beginning as technology advances, we anticipate even more groundbreaking developments that will revolutionize how organizations manage and leverage federated data.

7.1 Blockchain Integration in Data Federation



One of the primary challenges of data federation today is ensuring data security, provenance, and trust in a distributed environment. Blockchain, with its decentralized ledger and cryptographic security, offers a transformative approach to addressing these concerns. By integrating blockchain with data federation, organizations can:

- **Ensure Data Integrity:** Each data transaction can be recorded on an immutable blockchain ledger, reducing the risks of data tampering or unauthorized modifications.
- **Decentralized Access Control:** Smart contracts can enforce role-based data access policies, ensuring compliance and preventing unauthorized access.
- **Auditability and Transparency:** Blockchain-powered audit trails can help organizations track data lineage, proving the authenticity and source of data for regulatory and operational purposes.

As blockchain matures, its integration with data federation frameworks will enable trustworthy and decentralized data access across multiple organizations and industries, from finance and healthcare to supply chain management.

7.2 AI and Automation in Data Federation

AI and automation are playing an increasingly significant role in shaping the future of data federation, with several features already making their way into the market at various stages of adoption. Some of these advancements include:

- **AI-Driven Schema Alignment:** While partially available in metadata management and ETL tools, this technology is still in its early stages and is emerging as AI models improve their ability to automate schema mapping across heterogeneous data sources.
- **Smart Query Optimization:** Already present in federated query engines, this feature is growing, with AI-driven optimizations improving query execution speeds, cost efficiency, and adaptive indexing.
- **Automated Governance:** Early AI-based implementations in metadata management and compliance systems are in their early adoption phase, helping organizations enforce data access controls, privacy policies, & regulatory compliance with minimal manual intervention.

As these technologies continue to mature, we can expect even more self-optimizing, intelligent federated data architectures that require minimal human intervention while ensuring efficiency, security, and seamless interoperability across diverse data sources.

While blockchain integration and AI-driven automation are two promising directions for data federation, they are by no means the only ones. The future of data federation will likely be influenced by many more emerging technologies, including edge computing, quantum computing, and advanced data virtualization techniques. As technology continues to evolve, new innovations will redefine how organizations integrate, access, and manage federated data in increasingly complex and distributed environments.

8. CONCLUSION

The strategic alignment of ETL, data federation, and virtualization underscores their complementary roles in modern data architectures, with each approach addressing specific operational demands. ETL retains dominance in scenarios requiring robust transformation and historical analysis, particularly for regulatory compliance and batch processing, where structured workflows ensure auditability and accuracy. Meanwhile, data federation emerges as a critical enabler for real-time operational intelligence, particularly in distributed environments where minimizing data replication and latency is paramount. Organizations adopting hybrid architectures—combining nightly ETL batches with federated access layers—report measurable improvements in decision velocity and cost efficiency, with industry analyses indicating a 40–65% reduction in time-to-insight compared to siloed approaches¹. This paradigm shift reflects a maturation in enterprise data strategy, where architectural choices are driven by nuanced evaluations of data velocity, governance requirements, and source-system constraints rather than one-size-fits-all solutions.

Future advancements in blockchain-integrated federation and AI-driven schema alignment promise to address persistent challenges in security and interoperability. Industry studies project that intelligent query optimization and decentralized access controls could reduce manual governance efforts by 55% while accelerating cross-source analytics by orders of magnitude¹. However, success hinges on implementing robust metadata frameworks, with organizations prioritizing centralized governance catalogs observing 30–50% fewer integration errors compared to ad-hoc implementations. As enterprises navigate evolving compliance mandates and hybrid cloud environments, decision matrices balancing transformation complexity, latency thresholds, and infrastructure stability will remain critical. Gartner's projection of 327% ROI for context-aware integration strategies reinforces the urgency of adopting adaptive architectures that harmonize ETL's rigor with federation's agility and virtualization's performance optimizations.

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