International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING
ISSN:2147-6799 www.ijisae.org Original Research Paper

Scalable Integration Architectures for Heterogeneous Multi-Source Data Extraction in Financial Services

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Abstract: Financial services applications frequently integrate with complex heterogeneous digital ecosystems. Integrating financial services sources with REST APIs, SFTP file downloads, web portals, and other services often leads to quadratic point-to-point integration complexity as the number of source systems increases, high engineering effort, and brittle integrations that break due to interface changes, API deprecations, or changing authentication schemes in third-party integrations. The solution consists of a scalable architecture that abstracts heterogeneous data extraction from heterogeneous data sources using an API-first integration approach, file-based extraction, and smart web navigation through headless browsers. The architecture's central contribution is the adapter pattern, using which new data sources can be connected without the need to modify the extraction logic, thus speeding up the integration process. The multi-strategy extraction framework uses standardized adapter interfaces for various source types. Centralized four-layer validation checks format, cross-reference statistical deviations, and user-defined business rules for all extracted data. The containerized microservices implementation allows horizontal scaling and high availability using auto-scaling parameters and deployment across availability zones. The web navigation domain-specific language allows users to write extraction scripts without needing to understand how browser automation works. Confidence scoring allows records to be routed along semantic processing pipelines based on the results of validation. The architectural patterns outlined above apply to any organization that needs to aggregate data or information from many external, heterogeneous sources subject to high-quality constraints.

Keywords: *Data Extraction; Heterogeneous Integration; Multi-Source Aggregation; Microservices Architecture; Adapter Pattern; Financial Services; Validation Engine*

I. Introduction

Modern financial services organizations operate within increasingly complex digital ecosystems characterized by data exchange requirements spanning dozens to hundreds of external partners. Insurance carriers, trading counterparties, regulatory bodies, and service providers expose operational data through fundamentally heterogeneous interfaces—ranging from contemporary RESTful APIs to legacy file-based transfer mechanisms and web portals rendering dynamic JavaScript content. This technological heterogeneity presents substantial engineering challenges, as organizations must construct and maintain extraction pipelines capable of reliably aggregating data from sources exhibiting fundamentally different technical characteristics, authentication mechanisms, and data format specifications.

The shortcomings of conventional database management systems (such as the ones in a relational database, which were designed for online transaction processing applications) have been demonstrated by their performance degradation under atypical workloads [1]. For example, specialized real-time stream processing engines can achieve 160,000 messages per second throughput, two orders of magnitude faster than 900 messages per second for an RDBMS. [1].

The performance gap traces to architectural distinctions between processing models. Inbound models store queries and pass incoming data through them. Outbound models store data before executing queries [1]. Market data applications processing feeds from multiple providers and detecting latency or quality anomalies within seconds illustrate workloads

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that conventional systems cannot adequately support [1].

But these issues extend not only to the technical sciences but also to organizational and planned management. Where there once were disparate functional information systems for manufacturing and service industries, integrated information systems have become operationally critical [2]. Recognition that integration complexity requires specialized approaches has driven evolution from general-purpose enterprise resource planning toward industry-oriented and service-oriented architectures [2]. Business process management, workflow management, and enterprise application integration now function as foundational enabling technologies. Current commercial solutions nevertheless lack the sophisticated integration capabilities that supply chain management and cross-organizational data coordination demand [2].

This article introduces a scalable architecture for heterogeneous multi-source data extraction. API-first integration, file-based processing, and intelligent web navigation through headless browser automation operate within a unified framework. The adapter pattern forms the central architectural contribution. New data sources connect rapidly without requiring modifications to core extraction logic. The following sections cover related work in data integration architectures, system architecture and design principles, the multi-strategy extraction framework, the validation engine, implementation results, lessons learned, and future research directions.

II. Related Work

Data integration has been studied in academic and industrial contexts. Many theoretical approaches to the problem aim to use data from multiple sources to produce an integrated representation of the data with a specific format. Lenzerini formalized this process using a global schema, source schemas, and semantic mappings between them [3]. Two primary mapping types may be used in this framework. In Local-as-View (LAV), each source is defined in terms of a view over the global schema. In Global-as-View (GAV), the global schema contains views over the source schemas [3]. Query answering is PTIME-complete, given sound view assumptions, for conjunctive queries. Exact view assumptions lead to coNP-complete algorithms [3]. LAV is extensible: the addition of sources requires the addition of assertions to the mappings and not modifications of the existing ones. GAV assumes that querying is evaluated over the source-to-global schema mappings [3]. However, in heterogeneous and extensible environments such as finance, these theoretical distinctions matter because of the wide variety of source schemas. Enterprise Integration Patterns is a seminal book in the field of reusable architecture design patterns for messaging systems. Barrett, Clarke, Tarr, and Wise designed the Event-Based Integration framework as a reference model to compare and contrast the integration patterns used by different software systems [4]. The system consists of four components: registrars, which manage participant registration; routers, which route messages from informers to listeners. Message-transforming functions affect message content and message route. Delivery constraints control the delivery semantics [4]. It covers point-to-point, multicast and broadcast delivery; the first two are considered special cases of multicast, sending to a single recipient, respectively to all recipients. While the static specification enables correctness checking, it may be less flexible. [4] Supporting dynamic specification, where the behavior of a module can be changed at runtime, is another aspect making it harder to reason about the process at design time [4]. A detailed analysis of the usage of enterprise integration patterns implemented in Open Source frameworks has led Thullner, Schatten and Schiefer to conclude that the frameworks provide full support for the routing and transformation patterns that fall into six categories: channel, construction, routing, transformation, endpoint and system management patterns [15]. They showed that domain-specific languages (DSLs), such as Apache Camel, exist for pattern implementations and that integration developers can express patterns as self-descriptive code [15]. The Content-Based Router, Message Translator and Channel Adapter patterns remain the basis for the majority of implementations of heterogeneous source aggregation architectures in practice. Headless browser technologies have enabled web scraping and other browser automation tasks that involve programmatically interacting with web applications using JavaScript. New frameworks for scraping web pages must be able to interface with applications that render over time, have stateful

URLs, and that change their front-end when executed. The Adapter Pattern from object-oriented design is the basis for the implementations, which adhere to existing design patterns, can be added onto systems without modification of any other part of the system, and are consistent with established principles of software design. Data mesh architectures are domain-oriented, with data products being first-class architectural entities with contracts, quality guarantees, discoverability, and federated data access even across remote systems.

III. System Architecture

A. Design Principles

There are five principles underlying an architecture of this kind, and each principle addresses a fundamental problem about extracting data from heterogeneous sources, based on operational experience with integrated financial data at scale.

Source agnosticism is the default mode, which allows the extraction engine to be indifferent to the source's protocols, formats and authentication. As with microservices, these are coherent units, communicating by means of messages, and are not tied to any particular technology solution [5]. The components of such a distributed application are autonomous components which can be built with arbitrary technology [5]. The use of adapter modules to encapsulate source-specific logic allows the extraction engine to achieve the modularity and reusability benefits of service-oriented computing [5].

Resilient operation is the second principle: external sources are intrinsically assumed unreliable. Examples include the circuit breaker pattern, exponential backoff retry strategies, and fallbacks. One of the most fundamental and effective techniques for achieving reliability despite component and system complexity is to keep components small and simple and give them simple, precise interfaces [5]. The integration domain poses the greatest threat to system reliability, especially if network communications are used for integration. One of the fundamental fallacies of distributed computing is the reliability of the underlying network [5]. Hence integration mechanisms have to ensure message delivery.

The third principle is horizontal scaling of components: containerized microservices can be scaled independently based on some properties of the workload. Container technology provides the isolation and multitenancy features distributed systems need and has become the infrastructure foundation of cloud computing [6]. Containers share the host OS, binaries, and libraries as necessary. In contrast to customary hypervisors, a large number of containers (in the hundreds) can run on a given physical host, compared to a small number of virtual machines. Kubernetes abstracts the application containers from the underlying system through scheduling and abstract resource requests [6]. Deploying an application in containers achieves a 5x speedup over hypervisor-based deployments in similar configurations [6].

The fourth principle is observable operation, which allows for health, data quality, and other performance metrics of all sources to be viewed in real-time.

The fifth principle, rapid extensibility, says that new sources can be added simply by implementing a source-specific adapter for the standardized interface. Adding and upgrading code can be done without restarting the system, which helps to provide for continuous integration and maintenance of the software [5].

B. Component Architecture

The five major components of the system are implemented as containerized microservices.

The Adapter Registry Service tracks source adapter catalogs and adapter configuration, health status, and extraction schedules. Dynamic adapter registration enables onboarding of new sources without service restarts.

The Extraction Orchestrator Service coordinates workflows using enterprise integration patterns.

The Extraction Engine enacts strategies inherited from the adapter type and is implemented in a functional style.

Validation Pipeline Service runs a multi-layer validation process on all extracted data.

The Monitoring and Alerting Service provides operational dashboards for extraction metrics.

Each service has a relatively small scope, resulting in smaller code bases and a smaller scope for bugs, enabling developers to test and debug them in isolation [5].

Metric	Container-Based Deployment	Hypervisor-Based Deployment	Performance Ratio
Deployment Speed	5x faster	1x (baseline)	5:1
Instances per Physical Host	Hundreds of containers	Small number of VMs	High-density advantage
Resource Sharing	Share host OS, binaries, libraries	Full OS per VM	Reduced overhead
Orchestration	Kubernetes scheduling and abstract resource requests	Traditional VM management	Enhanced abstraction

TABLE I. Virtualization Comparison for Distributed Extraction Systems [6]

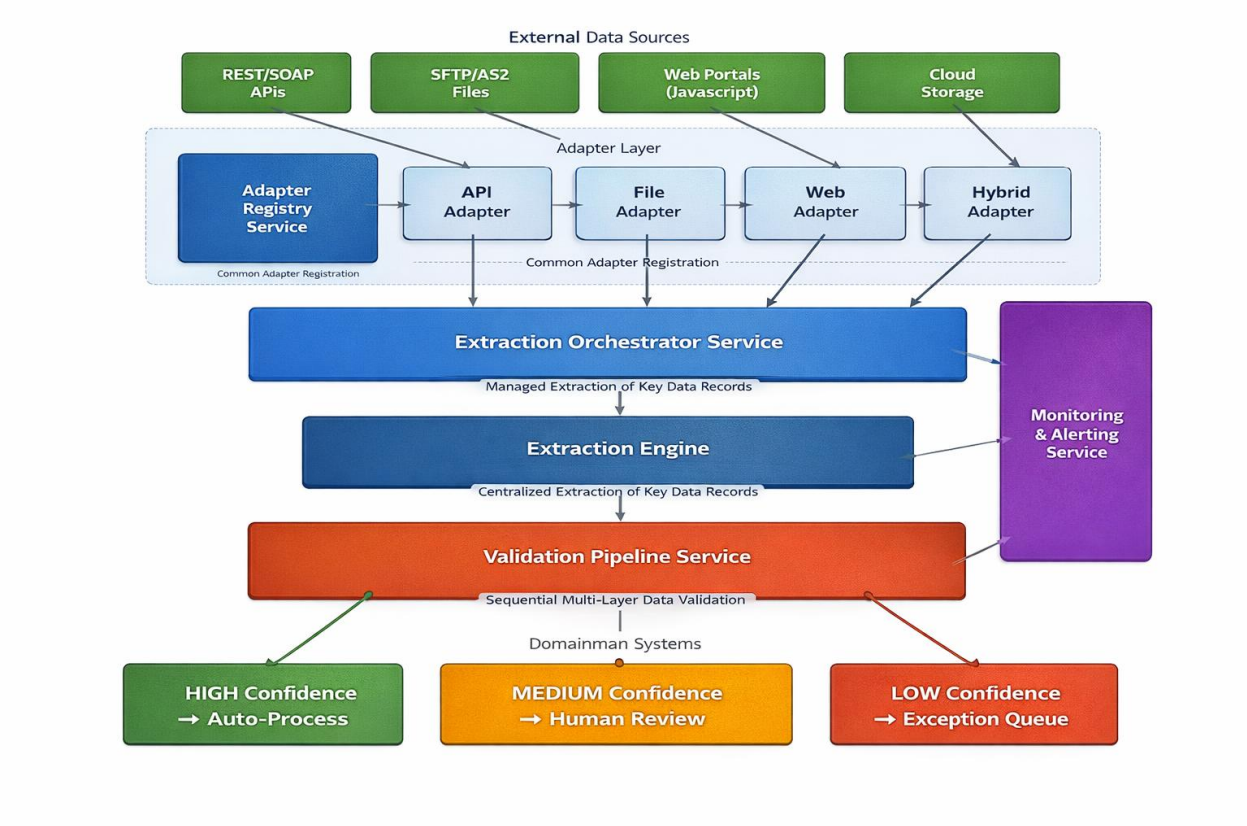

Fig. 1. High-level component architecture of the multi-source data extraction system showing adapter registry, extraction orchestrator, extraction engine, validation pipeline, and monitoring services.

IV. Multi-strategy extraction framework

A. API-First Integration Strategy

The API adapter provides out-of-the-box support for OAuth 2.0, API key authentication, rate limit management via token bucket algorithms, pagination management, and canonical data model responses from sources that expose a modern REST or SOAP API. As a result of both the structured nature of programmatic interfaces and the standardization of API responses, this is the most reliable of all extraction methods. A thorough set of architectural patterns has been defined within the web data extraction community to ease the automated extraction of heterogeneous data from the web. API-based solutions appear to have the advantage of more consistent rendering [7]. In addition to the standard functionality, client libraries provide capabilities such as connection management, respect for rate limits imposed by data source providers, and strong

pagination such as cursor-based or offset-based pagination typically used in financial services APIs.

B. File Based Integration Strategy

Where the sources feed streams of data at intervals via SFTP, AS2 or cloud-based file storage, the File Adapter implements idempotent consumers to ensure that exactly-once processing semantics are maintained. It also supports parsers with configurable delimiters, encodings and record layouts to accommodate heterogeneous financial data sources. The architecture tackles the technical problem of correlating the data collected from many sources that refer to the same entity [7]. In the case of cross-platform data extraction, automatic data correlation can be performed on hundreds of thousands of records. For instance, 667,141 user accounts were correlated across data sources by using string matching and attribute validation techniques [7]. The File Adapter applies similar correlation techniques to correlate records from multiple file-based sources, and applies configurable matching rules to correlate entities across extraction cycles.

C. Web portal extraction strategy

In the Web Adapter, headless browsers provide portal page access and fetch data from websites that use JavaScript to render pages. Engineers use a domain-specific language to write extraction scripts without having to understand how browser automation works. Smart agent-based web data extraction architectures can include multiple crawlers, typically with server-side components that run the extraction agents, cross-platform application services that implement agent behavior, and interface layers that mediate information transfer across web protocols [7]. The presence of privacy settings on a source portal, like the black hole problem in crawling social networks, can impede extraction. If users hide their personal information, the vertex and edge coverage is reduced by 7% to 9% compared to the configuration with no barrier to personal information disclosure [7]. The Web Adapter implements fallbacks and navigational paths to reduce coverage reduction from inaccessible portal sections.

D. Hybrid Extraction Strategy

Multiple different extraction methods may be chained together to achieve both higher reliability and better data coverage. For example, API calls may be backed up with web portal-based extraction of content that is not exposed in the API, or file-based feeds, used to reconcile real-time API data extractions. The Adapter Pattern provides a structural model for building these hybrid models through the use of interfaces to create a composition of extraction strategies [8]. Object-oriented design patterns for reuse enable systematic management of source-specific extraction algorithms as adapter modules implementing the shared interface [8].

Implementation of the extraction strategies follows standard integration patterns. Research on enterprise integration patterns has demonstrated strategies such as the Splitter, Aggregator and the Content-Based Router can be composed to route sub-sets of messages to different processing components based on the content of the messages, with each consuming only the content required to perform the processing task [15]. This allows the extraction architecture to correctly separate the incoming data streams, route their components through the appropriate validation paths, and recombine them to maintain data integrity. The architecture isolates extraction strategy selection from the core processing, allowing each source to provide a primary extraction strategy and an alternative strategy to apply in case the primary one fails persistently, and allows for the change of strategy at runtime without changing downstream validation and processing components.

Metric	Value	Extraction Strategy
User accounts correlated	667,141	File-Based Integration
Coverage reduction (minimum)	7%	Web Portal Extraction
Coverage reduction (maximum)	9%	Web Portal Extraction

TABLE II. Quantitative Performance Indicators for Multi-Source Data Extraction [7]

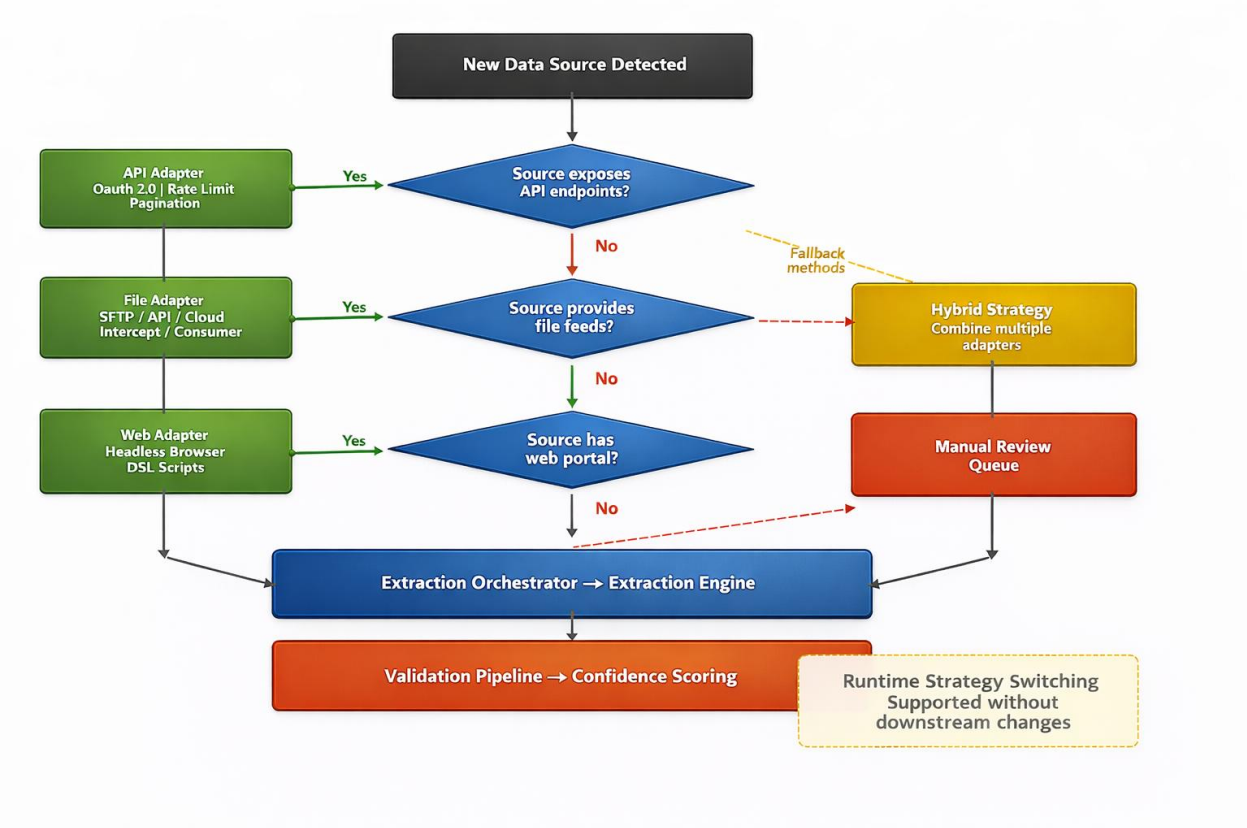

Fig. 2. Extraction strategy decision flow showing primary strategy selection (API, File, Web Portal) with hybrid fallback paths and runtime strategy switching.

V. Centralized Validation Engine

A. Multi-Layer Validation Architecture

The validation engine applies four successive layers over the data extracted from any source through any extraction strategy, ensuring that the same degree of quality assessment is done in every case, based on established data quality strategies, which are appropriate in situations of heterogeneous resource determination in organizations. The four-layer validation architecture aligns with ontologically grounded data quality dimensions. Wand and Wang derived four intrinsic data quality dimensions from representation theory: completeness (whether all real-world states can be represented), unambiguousness (whether information system states map to unique real-world states), meaningfulness (whether all information system states correspond to valid real-world states), and correctness (whether the mapping produces accurate representations) [16].

Format validation on the first layer considers techniques for checking requirements such as mandatory elements, field types, format validation, and schema validation. The information resource validation techniques on structured data are mostly the most mature in the organizations, as shown in the data quality literature [9]. This layer addresses meaningfulness by detecting states that violate canonical representation [16]. This layer detects issues that would make processed data unusable in later processing steps. An example is a truncated record. Another is the detection of a missing required field, which would violate canonical representation. This includes checking each data value against the value format and structure as expected in the canonical data model.

The second stage is cross-reference validation, which checks referential integrity between data instances and master data repositories. It further tests if representations of the same entity from different sources or extraction cycles are duplicates. The layer tests if the collected representations are complete and unambiguous by checking their referential integrity

and finding potentially duplicated representations of the same entity [16]. Based on previous studies, modeling the interdependence of the quality dimensions is an efficient and effective way of validating data quality.For example, accuracy and currency are often correlated. Roughly 70% of non-current data is not accurate [9]. The cross-reference validation layer uses these dimensional dependencies to detect quality issues in attribute relationships.

The third layer, statistical validation, uses statistical anomaly detection by comparing the distributions of extracted values to historical distributions and marking outlier ones for further human validation. This layer detects correctness issues through anomaly detection, identifying cases where the information system state may be mapped back into a meaningful state, but the wrong one [16]. Statistical, probabilistic, and functional relations among different data quality dimensions enable more accurate identification of data quality issues than approaches that analyze dimensions in isolation [9]. This layer detects subtle data quality issues that format validation may not catch, but may warrant investigation before entering downstream systems.

Business rule validation (validation of business rules in the domain) is implemented using a rule engine. It ensures that the extracted data is compliant with the business rules that describe the valid states for a particular real world domain [16].When business rules are separated from code, they can be modified by business analysts without code changes and are easier to adapt to changing business needs. As web archives discover, monitoring information quality is needed. In the first year, 40% of web pages disappear or change their content, while only 20% of web pages stay the same [9]. Because of this behavior, financial data sources require configurable rules to continuously monitor assumptions about source behavior.

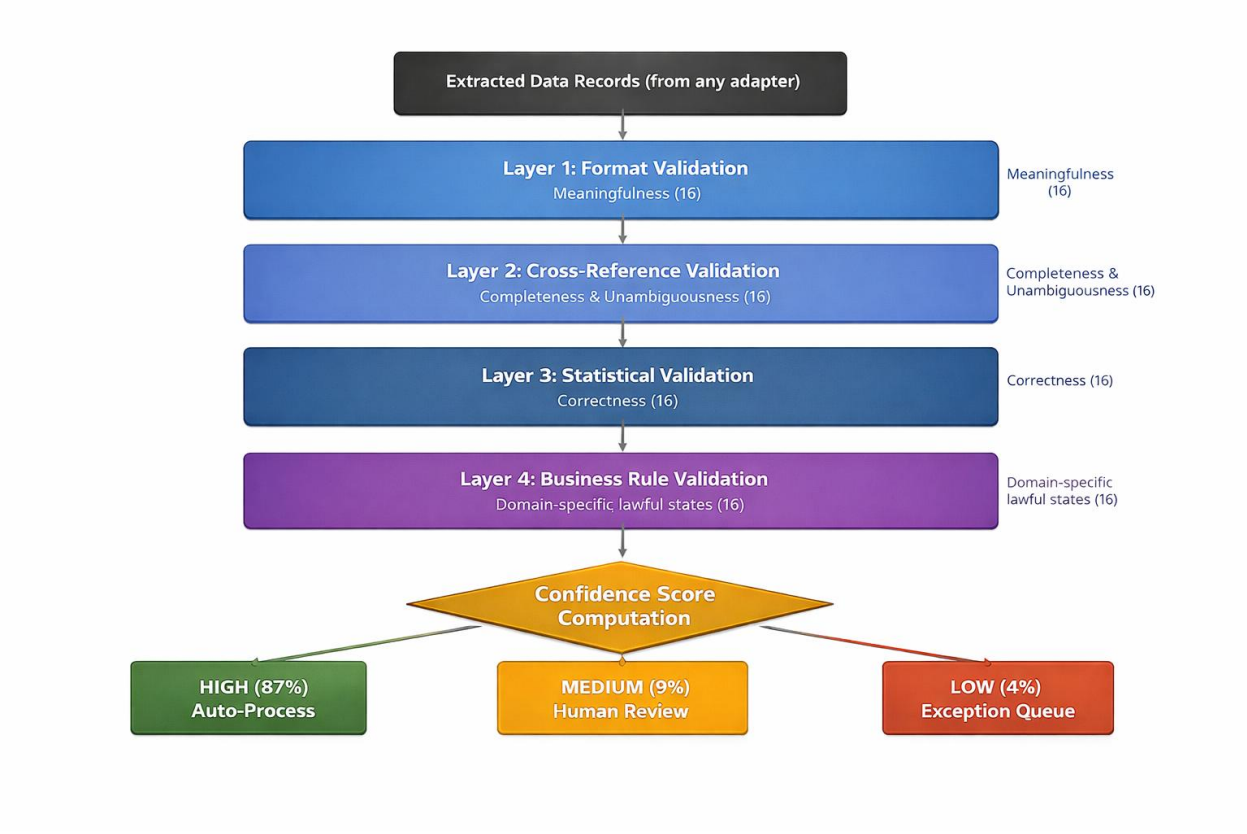

Fig. 3. Four-layer centralized validation pipeline showing format validation, cross-reference validation, statistical anomaly detection, and business rule validation with confidence scoring output.

B. Confidence Scoring

The outcome of the validation performed on each data record is a confidence score based on the four layers of validation. This is aligned to the principles of modern data processing architecture, where 100% accuracy is not always a requirement, but a largely complete view of data in reasonable time is critical to operations [10]. This aligns with the ontological view that data quality defects arise when the view of a real-world system inferred from the information system conflicts with the view of that system directly observed [16]. Whenever the confidence scores at all validation layers exceed a given threshold, the underlying record is correctly represented and unlikely to be deficient, while under-threshold scores may be seen as garbling, ambiguity, or incompleteness.

Confident records are sent downstream, while medium confidence records are sent to a separate accelerated human review queue, with metadata accompanying the record listing specific aspects to review and check. Low confidence records are sent to exception workflows if their confidence class requires acceptable validation. The amassing semantics are applied for each validation step [10]. Such multilevel validations reach a desirable tradeoff of thoroughness, as the manual review is focused only on the records where it would bring the highest value, and the remaining validations can be performed timely.

VI. Implementation Results and Analysis

A. Performance Analysis

The architecture was deployed in production at a Fortune 500 financial services organization managing healthcare benefit accounts for over 2.5 million participants. The organization required integration with over 50 external data sources including insurance carrier portals, claims processing APIs, file-based data feeds, and regulatory reporting systems. Prior to deployment, the organization relied on point-to-point integrations with processing cycles spanning 48 to 72 hours and significant manual intervention.

System administrators of such finely-tuned data sources may be reluctant to accept queries from external data sources unless these queries can be processed with guaranteed performance [11]. To address these issues, the service was designed to run parallelized extractions, to avoid any manual data collection steps, and to optimize job scheduling based on the availability of data sources. Convincing customers that a query processor that accesses sources in real time can provide sufficient throughput and predictable performance is paramount, given the tradeoff between cost of building a warehouse, running live queries and using stale data [11].

In this validation pipeline, quality thresholds could be configured to find a trade-off between precision and processing time. A general problem with database and data integration systems is the very high set-up time, since schemas have to be generated and semantic mappings defined before services can be offered or benefit gained. [11] This was eventually addressed in an implementation of the Adapter Pattern where the source-specific complexities were encapsulated in standard interfaces, allowing additional sources to be added without modifying the extraction engine.

B. Cost Impact

In addition, the architecture makes integration easier through the use of multiple extraction mechanisms. These integrated sources offer a variety of interfaces, including APIs, file-based feeds, and extraction from a web portal. Integration research has identified the generation and maintenance of mappings and source descriptions as the main bottleneck when setting up integration applications. In addition, knowledge of the databases is required to formalize the mappings, and knowledge of the business is needed to understand the schema semantics [11]. The new adapter interface separated source-specific logic from the core processing, enabling source engineers to onboard new sources without needing to have a meaningful understanding of how the extraction engine works.

Enterprise information integration products face several challenges, such as integration with other middleware products, horizontal growth vs. vertical growth, and competition with data warehousing products that stress real-time capabilities [11]. The architecture described in this paper addresses these challenges by providing an architecture for integrating several extraction methods and keeping validation and processing semantics consistent for all source types.

C. Scalability Validation

The containerized microservices architecture was horizontally scaled to handle peak loads. The production extraction architecture maintained 99.9% uptime across all extraction services, sustaining performance during enrollment periods with traffic spikes of up to 500% above baseline without performance degradation. The system served over 2.5 million participants across multiple plan sponsors while maintaining sub-second response times for extraction requests. Research on high-availability distributed systems states that the design of large-scale services is aimed towards service level objectives at the 99.9th percentile of the latency distribution, as end-user experience is better measured by the 99.9th percentile service response time rather than mean or median service response time [12]. These results align with high-availability design principles demonstrated in similar production systems, where services have achieved 99.9995% availability without event loss [12].

The overall extraction architecture is modeled on other high-availability designs in the literature, such as consistent hashing for load balancing, quorum-based reads and writes for high availability, and gossip protocols for membership information. The production system has shown that different decentralized concepts can be adopted as a highly available solution for server failure, data center failure, and network partition [12]. Building a service with that architecture has been positively reviewed. The service is available for 99.9995% of the requests and has not lost any events [12]. The typical configuration to meet performance, durability, consistency and availability SLAs uses replication factor and quorum settings to balance read and write latencies while satisfying durability requirements [12].

Performance Metric	Value	System Context
Data extraction accuracy	99.5%	From ~92% manual baseline
Processing time	4-6 hours	92% reduction (from 48-72 hrs)
Integration cost savings	~$1M	50+ point-to-point integrations eliminated
Manual intervention reduction	60%	~$500K annual operational savings
Claim resolution time	<24 hours	From up to 7 days (~$120K annual savings)
High-confidence auto-routing	87%	9% human review, 4% exceptions
System uptime	99.9%	Sustained during 500% traffic spikes
Participants served	2.5M+	Across multiple plan sponsors

TABLE III. Production Deployment Performance Metrics

VII. Lessons learned and discussion

A. Adapter Abstraction is Critical

The instantiation of the Adapter Pattern is the most important architectural decision in the extraction framework, since it allows the interface of each adapter module to be changed without the need to change either the extraction engine or the downstream processing components. It was also found that developers use an average of 3 architectural patterns per project to build system structure according to a study on architectural patterns in practice [14]. The commonest architectural patterns encountered in the software architectures were the Model-View-Controller pattern in 69%, the Client-Server pattern in 58% and the Layered Architecture and Service-Oriented Architectures in 30% [14]. The extraction architecture has benefited from the use of multiple architectural patterns in the combination of Adapter Pattern abstractions with layered validation and

service-oriented orchestration to achieve modular extensibility.

According to data mesh implementations, mesh principles of domain-oriented decentralized data ownership and treating data as a product, are the most valuable principles for organizations adopting distributed data architecture [13]. An empirical interview study with 15 semi-structured expert interviews across all sectors revealed that the top motivators for modernizing data architecture are: removing bottlenecks, leveraging domain knowledge, and dismantling silos [13]. The Adapter Pattern addresses this situation by allowing domain teams to implement source-specific extraction logic without having to go through centralized engineering bottlenecks.

B. Web Extraction Requires Continuous Investment

Of all the extraction types, web portal extraction was the most difficult to maintain, because of the dynamically rendered web pages, sessions, and constant redesigns of the target websites. The navigation domain specific language allowed the integration engineers to make changes to the extraction scripts without modifying core engine code. In architectural implementations, 63% require some modifications of the original pattern structure, 22% require a large degree of customization to satisfy the changing requirements [14]. The changing requirements and the environment is the problem that is most reported in the pattern implementation domain. It is reported in about half of the cases [14]. Web extraction is an example where an external portal interface is modified independently from the external extraction system.

C. Validation is Not Optional.

At early adoption stages, implementations relied on extraction accuracy; when data quality was poor, downstream business processes also suffered. Data quality became a faceted object with defined thresholds and confidence levels, rather than a chronic issue. Practitioners who consider quality requirements as part of their architectural decision-making are more likely to agree that the patterns they selected meet the goals of their project (62%) than practitioners who do not consider those requirements (43%) [14]. Performance is the most frequently considered quality attribute (56%), followed by modifiability and usability [14]. The validation engine can address the quality dimensions with a configurable rule-based assessment mechanism and support rapid adaptation.

D. Replicability

The described architectural styles apply to any domain that requires automated consumption of data from multiple external data sources. 717 distinct sub-codes for distributed data architecture of 15 expert semi-structured interviews and 48 hours of qualitative data-analysis were identified in industry literature reflecting a strong practitioner interest in implementation of distributed data architecture [13]. Of the 262 respondents, only three had completed these types of projects without using an architecture pattern, which indicates that pattern-oriented design is the industry standard [14]. Open-source software technology and a pattern-oriented architecture promote technology use in companies with a similar heterogeneous integration that the pattern addresses.

Conclusion

These three contributions of the scalable integration architecture for heterogeneous multi-source data extraction address the present key challenges of automated data aggregation. The multi-strategy extraction framework uses the platform agnostic Adapter Pattern interface for API, file-based and web portal data sources to decouple source-specific implementation details from the overall processing pipelines, allowing for rapid extension and scalability without negatively impacting the overall system. The four-layer centralized validation engine provides standardized validation for all extraction data sources by format, cross-reference, statistical anomaly detection and configurable business rules. Data quality is no longer an operational burden but a measurable dimension. The container-based microservices architecture provides horizontal scalability and operational high availability through the independent scaling of extraction, validation and storage components in accordance with the workload characteristics of the respective extraction sources. Production deployment at a Fortune 500 financial services institution demonstrated 99.5% data accuracy, 92% processing time reduction, and over $1.6 million in combined annual savings through elimination of redundant integrations, reduced manual intervention, and accelerated claim resolution. The architecture sustained 99.9% uptime

while serving over 2.5 million participants and handling 500% traffic spikes during peak enrollment periods. Possible future work includes extending the validation engine with predictive analytics for proactively managing data quality decline before downstream systems are impacted, for instance in an event-driven architecture with streaming extraction from real-time sources and a data mesh with domain ownership of data products and self-serve data infrastructure.

Declaration on Generative AI

Generative AI tools were used to assist in the preparation of this manuscript, including drafting, editing, and formatting assistance. The author critically reviewed and edited all AI-assisted content to ensure accuracy, originality, and alignment with the research findings. The author assumes full responsibility for the content of this publication.

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