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AIIT 2025

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Bitola, November 7, 2025

University “St. Kliment Ohridski” Bitola
Faculty of Information and Communication Technology - Bitola
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Introduction

As organizing partners of 15th International Conference on Applied Internet and Information Technologies AIIT 2025, we warmly welcome all participants, researchers, and colleagues joining us from various countries and universities, united by our shared commitment to advancing knowledge in the fields of computer science, applied Internet, and information technologies.

The AIIT conference has become a long-standing tradition of excellence and collaboration, co-organized by the Faculty of Information and Communication Technologies – Bitola, University "St. Kliment Ohridski," and the Technical Faculty "Mihajlo Pupin" – Zrenjanin, University of Novi Sad, Serbia. Over the past fifteen years, this partnership has fostered not only strong academic cooperation but also genuine friendship among our institutions and scholars.

This year's conference proudly continues that tradition, bringing together innovative research, diverse perspectives, and new insights into technologies that are shaping our digital future. The Scientific Program Committee once again faced the demanding task of selecting the highest-quality papers from more than sixty submissions spanning a wide range of topics—including Artificial Intelligence, Immersive Technologies, Mathematical Simulations, Data Science and Big Data Analytics, Knowledge and IT Management, Cybersecurity, Software Engineering, Data Mining, Digital Transformation, Behavioral Economics and Business, Social Engineering, Digital Humanities, Augmented Humanity, and Hybrid Intelligence. This ensures that the program reflects both scientific rigor and creative originality.

We would like to express our sincere gratitude to all reviewers for their dedicated work, as well as to the members of the Organizing Committee for their professionalism, commitment, and enthusiasm in preparing this event.

We are confident that these proceedings will provide an enriching and thought-provoking reading experience.

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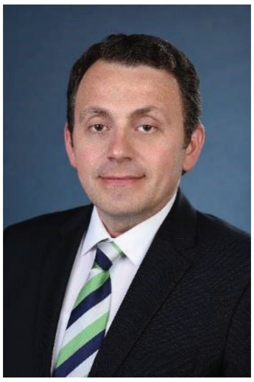

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CONTENT

Optimizing Real-Time Data Processing with Kafka and Databricks Integration for Scalable Machine Learning Solutions

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Abstract:
Integrating Apache Kafka with Databricks enables seamless streaming, analytics, and model deployment, bridging the gap between raw data and actionable insights. Recent trends focus on optimizing performance, reducing latency, and enhancing scalability, allowing organizations to build intelligent, responsive systems. Advances such as event-driven architectures, real-time feature engineering, and automated model orchestration are driving new levels of efficiency in data processing pipelines. Moreover, cloud-native deployments and containerized environments are making these integrations more flexible and resilient, supporting diverse workloads across industries. This paper examines these advancements and their implications for efficient, large-scale machine learning solutions, highlighting both current best practices and emerging innovations that can transform how organizations leverage their data assets.

Keywords:
Scalable machine learning, Apache Kafka, Azure Databricks, real-time data processing.

1. Introduction

Leveraging powerful tools like Apache Kafka and Databricks allows enterprises not only to handle high-volume data efficiently but also to derive actionable insights through advanced analytics and machine learning. The integration of these platforms is reshaping how data pipelines are designed, enabling greater flexibility, scalability, and responsiveness. As data volumes continue to grow, real-time processing and scalable machine learning have become critical for modern organizations.

Data processing is rapidly evolving to meet the demands of real-time analytics and large-scale machine learning [1]. Key trends include the adoption of streaming architectures, which allow continuous ingestion and analysis of data as it is generated, and the integration of artificial intelligence and machine learning for automated insights and anomaly detection. Cloud-native and serverless technologies are increasing scalability and flexibility, while distributed computing frameworks are optimizing performance and resource utilization. Additionally, organizations are focusing on end-to-end pipeline automation, data governance, and low-latency processing to ensure reliable, actionable insights across diverse business applications [2], [3].

The remainder of this paper is structured as follows: Section 2 discusses enhancements in Kafka and Databricks integration. The trends utilized for data processing in real-time are described in Section 3. Section 4 describes optimizing system architecture, while Section 5 presents the implementation of various machine learning solutions. Section 6 provides analytical results and performance evaluation. Finally, Section 7 concludes the paper and provides aspects for future research and development.

2. Kafka and Databricks integration

Optimizing the integration between Apache Kafka and Databricks is critical for building scalable and efficient data processing pipelines capable of supporting real-time analytics and machine learning workloads. Kafka, with its distributed streaming architecture, provides a reliable mechanism for ingesting high-throughput data streams, while Databricks offers a unified analytics platform for processing, analyzing, and operationalizing this data, as shown in Figure 1. Effective integration requires careful consideration of data serialization, partitioning strategies, and throughput optimization to minimize latency and ensure consistent data flow [4], [5]. Additionally, leveraging features such as structured streaming, delta lake storage, and parallelized processing within Databricks can enhance performance and fault tolerance [6]. Recent research and industry practices emphasize the importance of automated pipeline orchestration, real-time monitoring, and scalable infrastructure to fully exploit the capabilities of both platforms. By optimizing this integration, organizations can accelerate the deployment of machine learning models, improve predictive accuracy, and enable more responsive, data-driven decision-making [7].

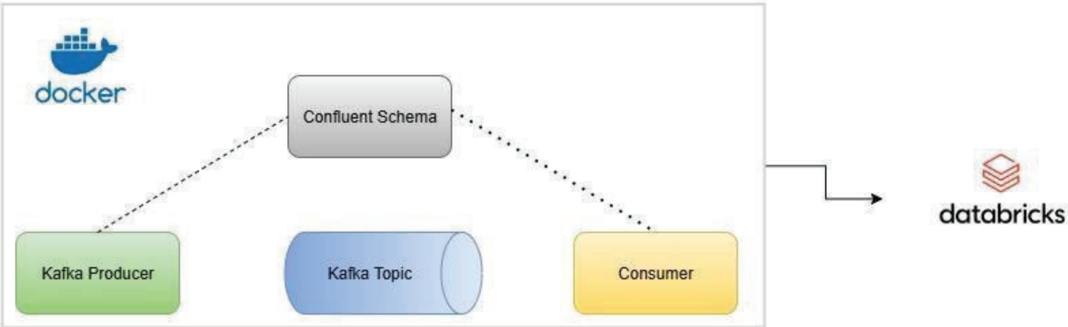

Figure 1: High-level integration of Kafka with the Databricks platform

3. Trends in Real-Time Data Processing

The field of real-time data processing has experienced significant advancements in recent years, driven by the growing demand for instantaneous insights from large-scale and continuously generated datasets. Modern architectures emphasize low-latency streaming, enabling organizations to process and analyze data as it is produced, rather than relying solely on batch processing. Key trends include the adoption of distributed streaming platforms such as Apache Kafka, which provide fault-tolerant and scalable mechanisms for data ingestion, and the integration of cloud-native and serverless technologies that enhance flexibility and resource efficiency. Additionally, real-time feature engineering, automated data pipelines, and machine learning model deployment are increasingly incorporated directly into streaming workflows, allowing for immediate predictive analytics and anomaly detection. These developments not only improve the responsiveness and intelligence of data-driven systems but also enable organizations to handle complex workloads with greater reliability, scalability, and operational efficiency [8]. Real-time data analytics processes involve continuous ingestion, processing, and analysis of data as it is generated, enabling organizations to make instant, data-driven decisions, as shown in Figure 2.

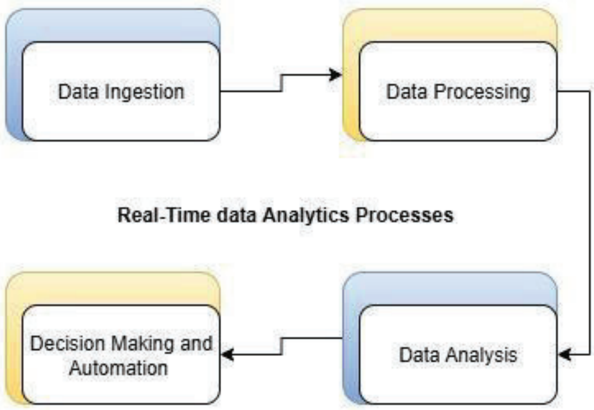

Figure 2: Cycle of the Real-Time analytics process

4. Optimizing System Architecture

The system architecture designed for this study leverages a combination of distributed streaming, cloud-based analytics, and scalable machine learning frameworks to ensure efficient data processing and analysis, which is an extension of our previous work [9]. At its core, Apache Kafka serves as the primary data ingestion and streaming platform, enabling reliable, high-throughput handling of real-time data streams. Databricks is employed as the unified analytics and processing environment, supporting both batch and streaming workloads through its integration with Apache Spark and Delta Lake for optimized storage and query performance [10]. The architecture is further enhanced with containerized deployment strategies and cloud-native orchestration tools to provide flexibility, fault tolerance, and scalability across diverse workloads. The infrastructure as code is deployed as shown in Figure 3. Additional technologies, such as structured streaming, automated pipeline scheduling, and monitoring frameworks, are incorporated to ensure seamless data flow, low latency, and efficient resource utilization. By combining these components, the system architecture provides a robust foundation for implementing scalable machine learning solutions and performing real-time analytics on large and heterogeneous datasets.

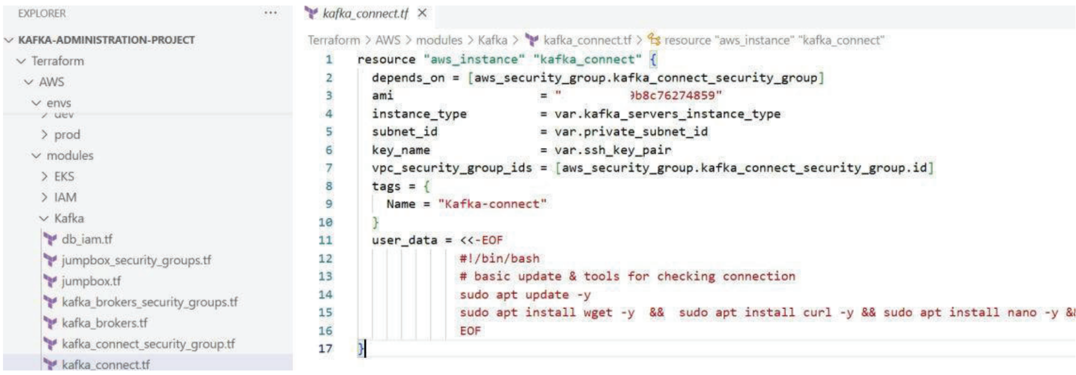

Figure 3. Infrastructure scripts for deploying resources

The solution is highly scalable, providing flexibility to easily add new resources or remove existing ones as requirements evolve. This adaptability ensures that the system can efficiently handle growth, changes in workload, or shifts business priorities without significant rework or downtime. Furthermore, it introduces a clear and well-structured approach to managing the codebase, which simplifies future maintenance and enhancements.

5. Implementation of Machine Learning Solutions in Databricks

The implementation of machine learning solutions within Databricks leverages its unified analytics platform to streamline the entire data-to-insight workflow. Databricks provides an environment that integrates data engineering, feature engineering, model development, training, and deployment, enabling scalable and collaborative machine learning pipelines [11]. By utilizing Apache Spark's distributed computing capabilities, large volumes of structured and unstructured data can be processed efficiently, facilitating both batch and real-time analytics. The platform supports a wide range of machine learning frameworks and libraries, such as MLlib, TensorFlow, and PyTorch, allowing the development of predictive models tailored to specific business needs. Additionally, features like Delta Lake ensure data consistency and reliability, while MLflow provides robust experiment tracking, model versioning, and deployment management. This integration of tools and frameworks within Databricks not only accelerates the development of machine learning models but also ensures reproducibility, scalability, and seamless operationalization in production environments, making it a comprehensive solution for advanced analytics.

We utilized a dataset originating from the automotive domain, encompassing features such as car_name, company_name, car_price, discount, and various customer and company location attributes [14]. Prior to implementing any machine learning techniques, the dataset underwent a comprehensive validation process to ensure data quality, consistency, and completeness. This included verifying the accuracy of numerical variables, examining categorical attributes for missing or inconsistent values, and performing initial exploratory analysis to detect potential outliers or anomalies. Only after this rigorous validation step was completed did we proceed with the development and application of machine learning models, ensuring the reliability and robustness of subsequent analytical results.

Firstly, a linear regression model was employed to analyze the relationship between the selected predictor variables and the target variable. Linear regression, as a widely used statistical method, estimates the dependent variable as a linear combination of independent variables, allowing for the quantification of the influence of each predictor [12].

```
Model Coefficients: [ 9.94489579e-01 -1.06947871e+02 -1.16760661e-01 -8.22234880e-01
 -1.17586645e+00 -4.79181110e-02]
Model Intercept: 183.7967266474443
```

Figure 4. Linear regression model results

These results indicate that, holding all other variables constant, the target variable increases by approximately 0.995 units for each one-unit increase in the first predictor, while the remaining predictors contribute negative adjustments of varying magnitude, as shown in Figure 4. The intercept represents the expected value of the target variable when all predictors are equal to zero.

The visualization of the linear regression coefficients provides a clear representation of the relative impact of each feature on the prediction of discounted car prices, as shown in Figure 5. The results reveal that discount and car price are the most dominant factors influencing the target variable. The negative coefficient of discount -106.94 suggests that higher discounts lead to a substantial reduction in the final price, which aligns with business expectations. On the other hand, the car price exhibits a strong positive coefficient of 0.99, indicating a nearly direct proportional relationship with the discounted price. From a methodological perspective, these findings highlight the need for improved feature engineering techniques to better represent categorical data. Additionally, the dominance of numerical features suggests that future research should explore non-linear models (e.g., Random Forest or Gradient Boosted Trees) to capture potential complex interactions between features.

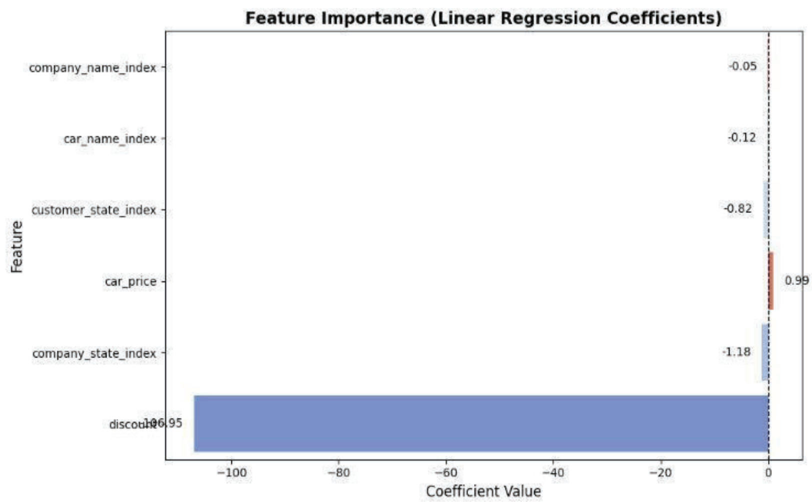

Figure 5. Visualization of feature importance based on the coefficients

To evaluate the linear relationships among variables relevant to car pricing, a correlation heatmap was constructed. This visualization illustrates the correlation coefficients between key features, including car price, discount, company, and customer identifiers, and the discounted price. The heatmap serves as a diagnostic tool to inform feature selection and assess multicollinearity in the context of a linear regression model, as shown in Figure 6. The variable car_price exhibits a strong positive correlation with discounted_price r = 0.73, indicating that the discounted price is largely dependent on the original car price. This relationship is expected, given that the discounted price is typically derived by subtracting the discount from the base price. Conversely, discount shows a weak negative correlation with discounted_price r = –0.14, suggesting that the magnitude of the discount does not linearly scale with the final price, potentially due to pricing strategies or categorical discounting mechanisms. Among categorical indices, company_name_index and company_state_index demonstrate a moderate positive correlation (r = 0.45), implying a non-negligible association between company identity and geographic location. However, other categorical variables, such as car_name_index, customer_state_index, and company_name_index, show weak or negligible correlations with pricing variables, indicating limited predictive value in a linear framework.

The diagonal of the heatmap, representing self-correlations r = 1.0, confirms the integrity of the matrix. Overall, the heatmap highlights that while some variables are strongly linearly related and suitable for inclusion in a regression model, others may contribute noise or redundancy. These insights are critical for optimizing model performance and ensuring interpretability in predictive analytics.

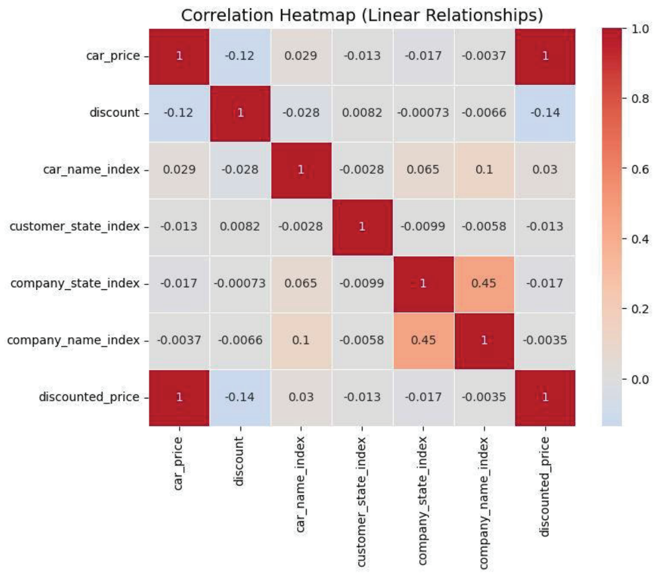

Figure 6. Correlation Heatmap while using linear regression

The Random Forest regression model was implemented to predict the discounted_price of vehicles using features such as car_price, discount, car_name_index, etc [13]. After training the model, feature importance was computed to understand the contribution of each variable to the predictive task. The model identified car_price as the most influential predictor, which aligns with domain expectations since the base price directly impacts the discounted price. Other features, such as company_name_index and customer_state_index, exhibited significantly lower importance, indicating their comparatively smaller role in determining pricing outcomes.

To evaluate the model's performance, metrics such as Root Mean Square Error (RMSE) and R-squared (R^2) were calculated. A low RMSE value suggests that the model can predict discounted prices with reasonable accuracy. The R^2 score indicated that a substantial proportion of variance in the target variable (discounted price) was explained by the model, validating its predictive effectiveness.

The scatter plot indicates that the model performs adequately in predicting lower car prices but exhibits reduced accuracy for high-value cases, presented in Figure 7. Most of the data points are concentrated near the origin, whereas outliers with actual prices reaching up to 800,000 are systematically underpredicted, with predictions plateauing around 600,000. This pattern suggests that the model may be underfitting extreme values, potentially due to their scarcity in the dataset or insufficient representation in the feature set. Enhancing feature engineering or applying a logarithmic transformation to the target variable could mitigate this issue and improve predictive performance for high-priced vehicles.

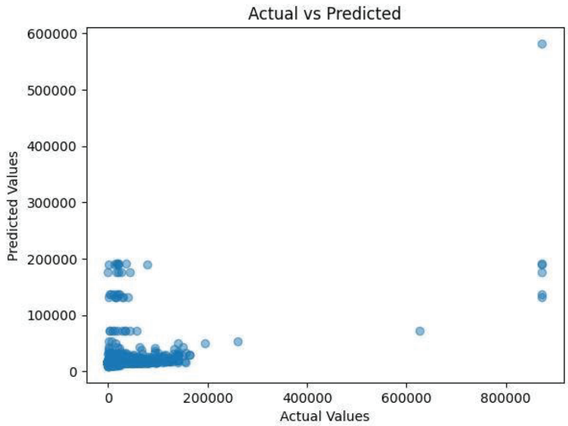

Figure 7. Model evaluation through an actual or predicted scatter plot

6. Performance Evaluation

Performance evaluation is essential for assessing the efficiency and effectiveness of integrated data processing and machine learning systems [13]. Key metrics include throughput, latency, scalability, and model accuracy, which provide insights into system responsiveness and reliability. In Kafka- Databricks pipelines, evaluating data ingestion rates, processing times, and machine learning outcomes helps identify bottlenecks and optimization opportunities. Rigorous performance assessment ensures that the system can deliver real-time, actionable insights while supporting scalable and robust analytics workflows. Below is explained how the performances were improved after the implementation of the solution:

Reduced latency: real-time data ingestion and processing through the optimized Kafka–Databricks pipeline significantly decreases end-to-end latency, enabling faster availability of actionable insights.

Improved throughput: the integrated solution efficiently handles higher data volumes, ensuring consistent processing rates and preventing bottlenecks even under peak load conditions.

Enhanced model accuracy: By providing timely and clean streaming data to machine learning models, predictions are more accurate and reflect the latest trends in the data.

Scalability: the architecture supports horizontal scaling, allowing the system to accommodate growing data streams and expanding computational requirements without degradation in performance.

Robust fault tolerance: Kafka’s distributed messaging combined with Databricks’ resilient processing framework improves system reliability, minimizing data loss and ensuring continuous operation.

Comprehensive monitoring and evaluation: integration enables end-to-end observability of data flow and model performance, allowing precise performance evaluations and informed decision-making for further optimization, as shown in Figure 8.

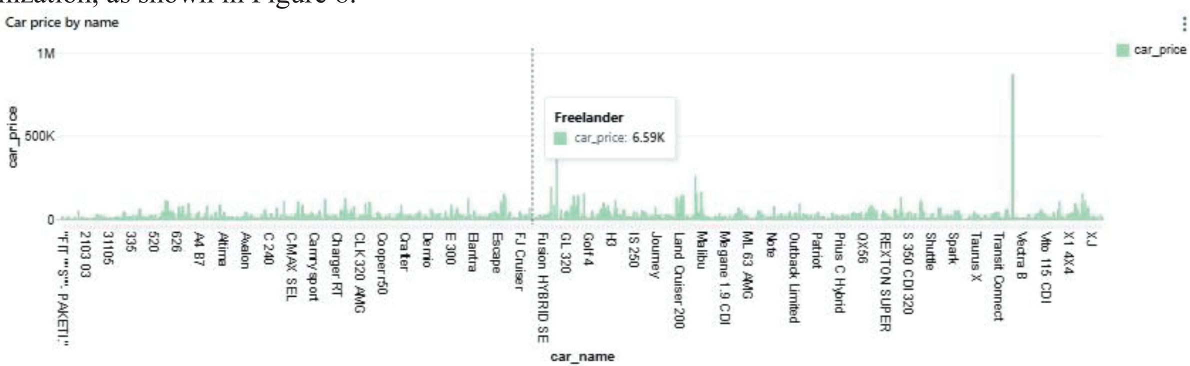

Figure 8. Visualization of the data on Databricks dashboard

7. Conclusions

In conclusion, this paper synthesizes the key findings regarding the integration of Kafka and Databricks for scalable machine learning solutions, highlighting the performance improvements, architectural considerations, and practical implementation strategies identified throughout the study. Furthermore, it outlines several directions for future research and development, including the exploration of advanced optimization techniques, real-time feature engineering, automated model orchestration, and the integration of emerging cloud-native and edge computing technologies. By addressing these areas, future work can further enhance the efficiency, scalability, and robustness of data processing and machine learning systems, supporting more intelligent, responsive, and data-driven decision-making across diverse applications and industries. Moreover, continuous experimentation with emerging stream processing technologies can further amplify performance, scalability, and model accuracy.

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