A microservice-based framework for integrating IoT management platforms,
semantic and AI services for supply chain management

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Introduction

This journal discusses the impact of the Internet of Things (IoT) on supply chain management, emphasizing the emergence of new opportunities and capabilities. Highlighting key trends, such as Artificial Intelligence (AI), IoT, and predictive/prescriptive analytics, the text underscores their importance in real-time monitoring, management, and optimization of goods distribution and supply chains. The integration of cloud-based services, software as a service (SaaS) product management systems, and smart sensors on products enables monitoring of factors like temperature, humidity, and location. The combination of technologies, including smart sensing and cloud-based analysis, addresses distribution challenges and facilitates monitoring of sensitive goods. The paper emphasizes data centricity as a crucial feature, enabling companies to optimize risk assessment and sustainable supply chain management. However, it acknowledges practical challenges in integrating diverse IT systems and reasoning on data effectively. The paper proposes a microservice-based system architecture called the AffectUs framework to address these challenges, aiming for seamless integration and deployment of critical elements in supply chain management. These elements include external IoT management platforms, semantic services with specialized ontologies for annotating data, and AI mechanisms for detecting abnormal conditions. The paper concludes with measurements on the framework's operation, emphasizing the importance of agility achieved through integration, adaptation to new technologies, and meeting the needs of the global supply chain.

Literature Overview

1. **Field Data and Supply Chain Tracking**: The text highlights the rationale of using field data to populate data stores for information gathering and processing in the supply chain and product tracking context. It emphasizes the need for relevant alerts to stakeholders concerning specific products. A distinction is made between static registration and dynamic identification based on semantics, as demonstrated in the AffectUs framework.
2. **Reference Architecture for Food Supply Chain Management**: A reference architecture for food supply chain management is presented in a specific study. This architecture incorporates event intelligence, manual rule insertion, and predictive analytics for supply chain and object automation. The distributed nature of the approach is acknowledged, using Electronic Product Code Information Services (EPCIS) for critical information sharing among supply chain participants.
3. **Labview Prototype for Supply Chain Modeling**: A Labview prototype for modeling stages of the supply chain, especially in the food domain, is introduced in another work. The prototype aims to simulate similar stages defined in the discussed paper.
4. **Big Data Architectural Solutions in SCM**: The value of using enhanced Big Data-related architectural solutions in the context of SCM is argued. This includes the use of NoSQL data stores, parallel computation through MongoDB queries, visualization components, and Extract, Transform, Load (ETL) processes for linking supply chain data.

Methodologies and Approach

1. **Containerization with Docker:**
   - The system has been implemented using containerization, specifically Docker. All system elements are encapsulated as Docker images.

- Docker deployment allows for easy management, updating, and deployment processes. It provides flexibility in deploying individual containers or grouping them together for an overall service.

2. **Docker Compose for Deployment:**
    - Docker Compose is utilized for deployment, and a relevant Docker Compose file describes various aspects such as virtual networks, virtual IPs, ports, startup sequence, and dependencies.
    - A one-click deployment process is facilitated through the Docker Compose file, streamlining the deployment of the entire service.
3. **Docker Swarm for Cluster Management:**
    - Docker Swarm, a cluster management system, is employed for load balancing between nodes during service deployment.
    - The use of Docker Swarm enhances the scalability and reliability of the system, ensuring effective load distribution.
4. **User Interface Implementation with Node-RED:**
    - Node-RED is used for implementing user interfaces, specifically for linking with external platforms like EVRYTHNG and selecting products to be incorporated.
    - The logic behind the UI is designed to transform user-friendly declarations into triples for inclusion in the Ontological Knowledge Base (KB).
5. **Semantic Communication:**
    - A connector subflow is created in Node-RED to establish semantic communication between various flows (e.g., UI captured and generated ones) and the Semantic web service.
    - SPARQL queries are used for querying and processing the KB. Dynamic query formulation is achieved through passing a query template and dynamic parameters.
6. **Healthcheck Feature for Monitoring:**
    - Docker's "Healthcheck" feature is utilized for monitoring the status of the system chain. This involves validating that the application inside the container is running through methods like an HTTP GET request at the respective endpoint.

- Relevant UIs have been created for monitoring the status of the chain, providing insights into the health and responsiveness of the deployed services.

7. **System Deployment and Testing:**
    - System deployment is streamlined with a single command to launch the Docker Compose file, initiating containerized service elements.
    - Measurement of the time delay in spinning up the service cluster includes considerations for container start time, application launch time, and endpoint responsiveness.
    - UIs are created for monitoring and assessing the status of the deployed services.

Overall, the approach involves leveraging containerization for efficient deployment, utilizing Docker Compose and Swarm for orchestration and scaling, implementing user interfaces with Node-RED, and ensuring semantic communication between different components of the system. The use of health checks and monitoring UIs reflects a focus on system reliability and performance.

Finding and Trends

Findings:

1. **Challenges in IoT and AI Integration:** The text highlights challenges in integrating IoT and AI technologies into supply chain management. Practical difficulties arise due to the diversity of IT systems and technical limitations in merging and reasoning over provided data in a semantically meaningful manner.
2. **Importance of Data Centricity:** Emphasis is placed on data centricity as a key feature. The lack of sufficient information in complex supply chains can be mitigated through solutions that provide real-time monitoring, analysis, and optimization, reducing risks and facilitating sustainable supply chain management.
3. **Globalization Impact:** While globalization increases competition and potentially improves supply conditions, it also introduces complexities, adaptation needs, and risks in managing a global supply chain. The paper suggests that these challenges may offset the benefits of increased competition.

4. **Agility through Integration:** Agility in supply chain management is identified as a significant contributor to optimization. Process and information integration, along with the incorporation of new technologies, are highlighted as essential for adapting to factory needs and processes.

Trends:

1. **Microservice-Based Architecture:** The AffectUs framework adopts a microservice-based system architecture, reflecting a trend in system design. Microservices allow for modularity and scalability, making it easier to integrate and deploy various critical elements of a supply chain management system.
2. **Semantic Technologies:** The use of semantic services enriched with specialized ontologies suggests a trend toward leveraging semantic technologies for annotating and understanding incoming data in the supply chain. This approach contributes to more structured and meaningful data representation.
3. **AI for Anomaly Detection:** The inclusion of an Artificial Intelligence block, using Tensorflow, indicates a trend in using AI for anomaly detection in supply chain processes. The AI framework aims to infer key metrics of each stage and detect anomalies based on annotated historical data.
4. **Containerization and Docker Technology:** The system implementation involves encapsulating all elements as Docker images, reflecting a trend toward using containerization and Docker technology for easy management, updates, and deployment processes.
5. **User-Friendly UIs for Supply Chain Interaction:** The emphasis on Node-RED as a tool for creating user interfaces indicates a trend toward developing user-friendly interfaces for supply chain stakeholders. This allows stakeholders to interact with the system intuitively.
6. **Integration of External IoT Management Platforms:** The framework integrates external IoT management platforms for baseline data feeds, reflecting a trend in leveraging third-party services for enhanced functionality and data collection in supply chain management.
7. **Incorporation of Predictive Analytics:** Predictive/prescriptive analytics is highlighted as an important trend. This involves using AI and analytics to predict

future events, optimize processes, and prescribe actions for better supply chain management.

Challenge and Gaps

1. **Integration Challenges:**
    - **Diversity of IT Systems:** The text mentions challenges arising from the diversity of involved IT systems. Integrating the AffectUs framework with various existing systems may prove challenging due to differences in technologies, protocols, and data formats.
2. **Semantic Data Integration:**
    - **Technical Inability to Merge Data:** There is a mention of the technical inability to merge and reason on the provided data in a semantically meaningful manner. This highlights a potential gap in how well semantic data integration is achieved within the system.
3. **Global Supply Chain Complexity:**
    - **Increased Complexity in Global Supply Chains:** Managing a global supply chain introduces complexities and risks. The text suggests that the increased complexity may pose challenges that negate the benefits of globalization. The specific challenges and strategies for addressing them are not explicitly detailed.
4. **Adaptation Needs:**
    - **Adaptation Challenges:** The text refers to adaptation needs and challenges associated with managing a global supply chain. However, the specific nature of these adaptation challenges and how the AffectUs framework addresses them is not clearly outlined.
5. **Dynamic User Identification:**
    - **Dynamic User Identification:** The related work section mentions that the identification of notified users in some systems is performed through static registration to a common publish/subscribe system. A potential gap is the absence of dynamic user identification based on identified dependencies using semantics within the AffectUs framework.

6. **Predictive Analytics Limitations:**
    - **Limitations in Predictive Analytics:** While the text mentions the use of predictive analytics for anomaly detection, it does not delve into potential limitations or challenges associated with predictive modeling, such as accuracy, data quality, or adaptability to changing conditions.
7. **Complexity in IoT and AI Integration:**
    - **Practical Integration Challenges:** The text highlights practical challenges in integrating IoT and AI technologies. The specific difficulties, complexities, and potential pitfalls in achieving seamless integration are not explicitly detailed.
8. **Scalability and Performance:**
    - **Scalability Concerns:** While Docker and microservices are mentioned for ease of management, there might be challenges related to the scalability of the AffectUs framework, especially when dealing with large-scale supply chain systems.
9. **Security and Privacy:**
    - **Security and Privacy Concerns:** The text does not explicitly address security and privacy considerations. Given the sensitive nature of supply chain data, potential challenges related to securing data and ensuring privacy should be considered.
10. **External Platform Dependencies:**
    - **Dependency on External IoT Platforms:** The integration of external IoT management platforms introduces dependencies. Potential challenges may arise in ensuring seamless communication, data compatibility, and reliability with these external platforms.

Future Research Direction

1. **Enhanced Semantic Integration:**
    - Research could focus on improving the technical capabilities for merging and reasoning on semantically meaningful data. This includes addressing the

challenges associated with diverse IT systems and enhancing the integration of semantic technologies for more effective data processing.

2. **Dynamic User Identification and Notification:**
    - Future research could explore dynamic user identification mechanisms based on identified dependencies using semantics. Investigating ways to dynamically notify users based on real-time changes and relationships within the supply chain could enhance the responsiveness of the system.
3. **Adaptation Strategies for Global Supply Chains:**
    - Given the challenges and risks associated with managing global supply chains, research could delve into specific adaptation strategies. This might involve exploring technologies and methodologies that facilitate agile responses to changing conditions in a global context.
4. **Predictive Analytics Advancements:**
    - Future research could focus on advancing predictive analytics within the AffectUs framework. This might involve addressing limitations, improving accuracy, and exploring new approaches to predictive modeling for anomaly detection in supply chain management.
5. **Practical Integration of IoT and AI:**
    - Research efforts could be directed towards practical integration challenges of IoT and AI technologies. This includes exploring ways to streamline the integration process, enhance compatibility, and address complexities associated with real-world deployment.
6. **Scalability and Performance Optimization:**
    - Future research could investigate scalability concerns related to the AffectUs framework, especially as it interacts with large-scale supply chain systems. Optimization techniques and technologies for improving system performance could be explored.
7. **Security and Privacy Considerations:**
    - Given the sensitivity of supply chain data, future research could delve into security and privacy considerations within the AffectUs framework. This might

involve exploring robust security measures and privacy-preserving techniques to safeguard sensitive information.

8. **Reducing External Platform Dependencies:**
    - Research could explore ways to reduce dependencies on external IoT management platforms. This might involve developing more self-sufficient components within the AffectUs framework, reducing reliance on external services, and ensuring greater autonomy in supply chain monitoring and management.
9. **Human-Machine Collaboration and Interaction:**
    - Investigate how human-machine collaboration can be improved within the supply chain context. This could include designing more user-friendly interfaces, enhancing the interaction between stakeholders and the AffectUs system, and exploring ways to facilitate decision-making.
10. **Sustainability and Ethical Considerations:**
    - Future research might explore the integration of sustainability principles and ethical considerations within the AffectUs framework. This could involve investigating ways to optimize supply chains for sustainability, reduce environmental impact, and ensure ethical practices throughout the system.

Conclusion

As a conclusion, combining a multitude of technologies spanning across different domains such as semantics, AI, integration approaches and IoT management platforms can prove both challenging and beneficial in order to increase the level of situational awareness around the status of a supply chain and its dependencies. The usage of Node-RED has enabled the integration between diverse and complex systems, enabling information adaptation and workflow creation in order to implement the sequences of actions needed. Finally, dockerization of the service enabled the quick and seamless deployment of all the elements and their automated connection, discovery and configuration, while the extended focus on enabling inputs to be performed through UIs may enable the easier usage and needed declarations of the framework, fully decoupling the end user from the underlying semantic definitions.

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