

# Developing an AI-Driven Framework for Real-Time Signal Processing and Data Exchange

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# Motivation

## Data Exchange: Definition

Data Exchange refers to the **efficient and secure** flow of data between different platforms and procedures [Zhang et al., 2021, Thakare and Kim, 2021].





# Motivation

## Data Exchange: Applications and Investments

It requires strong security and encryption, data quality and dependability, and industry-specific **compliance standards** [Attiogb   et al., 2021].

- Business intelligence and analytics [Kouper and Cook, 2021].
- Finance and banking [Elsaify and Hasan, 2021].
- Government and public services [Ball et al., 2020].
- Marketing and advertising [Mishra and Kaushik, 2023].
- Healthcare [Al-Kahtani et al., 2022].
- Research and academia [Qiu et al., 2021, Paltun et al., 2021, Adiga et al., 2022].





# Motivation

## The Growth of Data Centers in Colombia

Latin America's technological revolution plays a crucial role in promoting **regional economic growth**, closing the digital gap, creating a foundation for improved connectivity, innovation, and robust digital infrastructure [Global Services Location Index, 2021].



- Fourth largest data center market in Latin America.
- Significant investments in infrastructure.
- Attractive for international investments.
- Strategic location advantage.

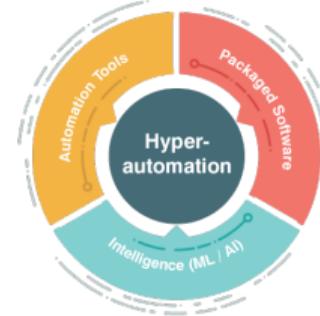


# Motivation

## AI-Driven Hyperautomation: The Future of Smart Workflows

**Hyperautomation** elevates traditional software automation, infusing it with AI to transform data ecosystems into adaptive, **self-optimizing entities**, reshaping the dynamics of data management and analysis.

- Data Process Automation
- Analysis and Decision-Making
- Workflow Optimization
- System Integration
- Data Governance
- Scalability and Maintenance



Integrating **AI** into software transforms data ecosystems into intelligent, self-evolving networks, revolutionizing the approach to data management and analysis. [Haleem et al., 2021].



# Motivation

SPRG: Signal Processing and Recognition Group

Our research group develops **transdisciplinary data exchange** since we know that it exposes novel approaches and supports collaborative discoveries **across academic areas** [Gomez Rivera, 2023, Aguirre-Arango et al., 2023].

- Data heterogeneity.
- Handling unstructured data.
- Real-Time Data Processing and Exchange.
- Privacy and security regulations.
- Interoperability and accessibility.
- Scalability and efficient management.





# Problem Statement

## Methodologies for Data Exchange

**APIs:** They are limited by request rate, security, and provider stability/changes

[Velepucha and Flores, 2023].

**ETL:** Performance and complexity concerns related to data quality and handling large amounts of diverse data.

[Abdelhafiz and Elhadef, 2021].

**Messaging:** Scalability, delivery assurance, state management, and security issues in distributed systems. [Fang et al., 2019].

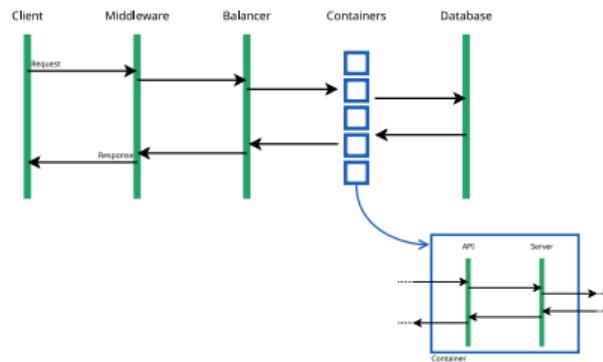
**File Transfer:** Security, file size, and bandwidth issues [Ordóñez et al., 2023, Yi et al., 2023].



# Problem Statement

## API Request Limits

API request **rate limits** may cause data transmission difficulties, especially in multimodal and real-time situations, and make API provider changes **harder to adapt and maintain** [Malki et al., 2022, Malki and Zdun, 2023].



*Manual configurations limit API effectiveness in multimodal and real-time environments.*

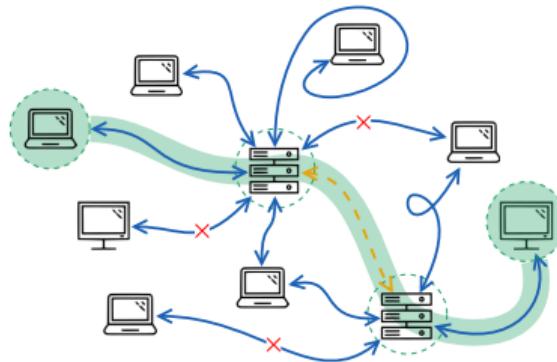


# Problem Statement

## Messaging Scalability

Scalability and delivery certainty problems in distributed messaging systems can lead to the **loss or delay of messages**, which can have a severe influence on the **efficiency and reliability** of communication in real-time and multimodal contexts

[Arellanes and Lau, 2020, Basin et al., 2020].



*Centralized server reliance in distributed messaging often results in inefficient routing.*

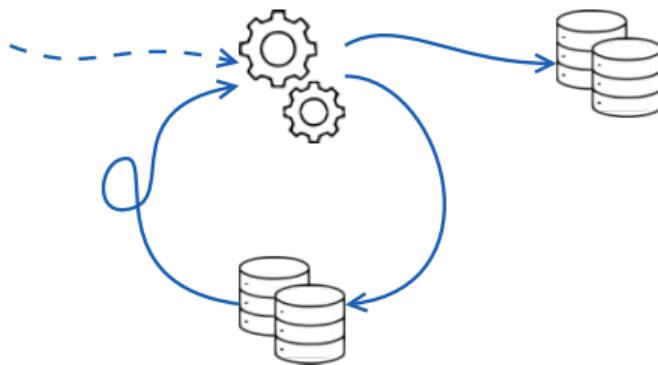


# Problem Statement

## Multimodal ETL & AI

Complex multimodal ETL processes can lead to **inaccurate data and disruptions** in AI analysis due to challenges with data integration and real-time data management

[Qaiser et al., 2023, Soussi, 2021].



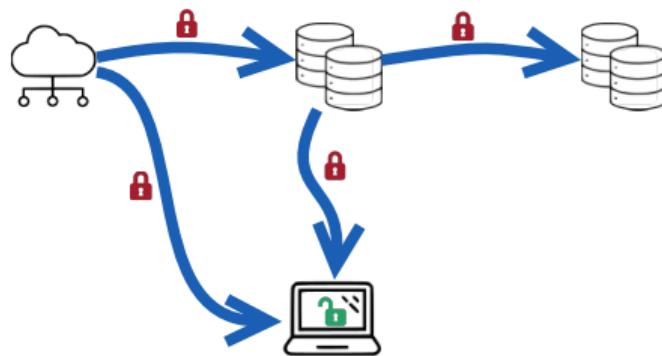
*Relying on rigid, sequential data handling poses challenges in data integration and real-time management .*



# Problem Statement

## Large-Scale File Transmission

Large-scale file transmission requires efficient and safe administration of continuous data flow, especially in integrating systems and platforms, while ensuring data **integrity** and **accessibility** in changing contexts [Zheng et al., 2020, Yin et al., 2023].

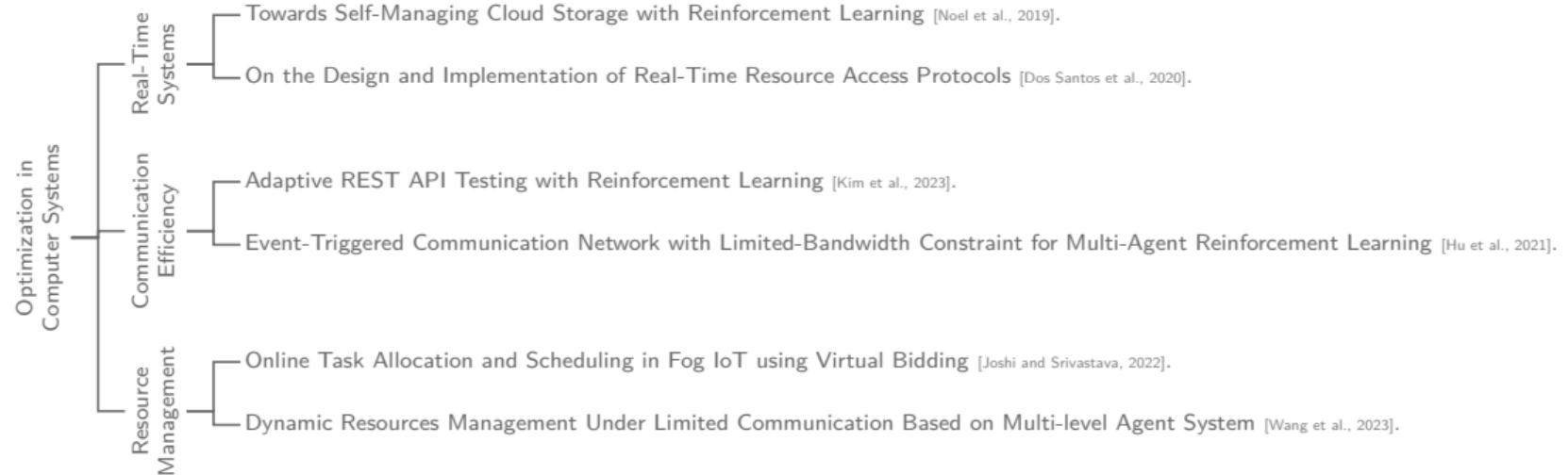


*Depends primarily on protocols that are static and universally applicable.*



# State-of-the-Art

## APIs: Infrastructure Improving

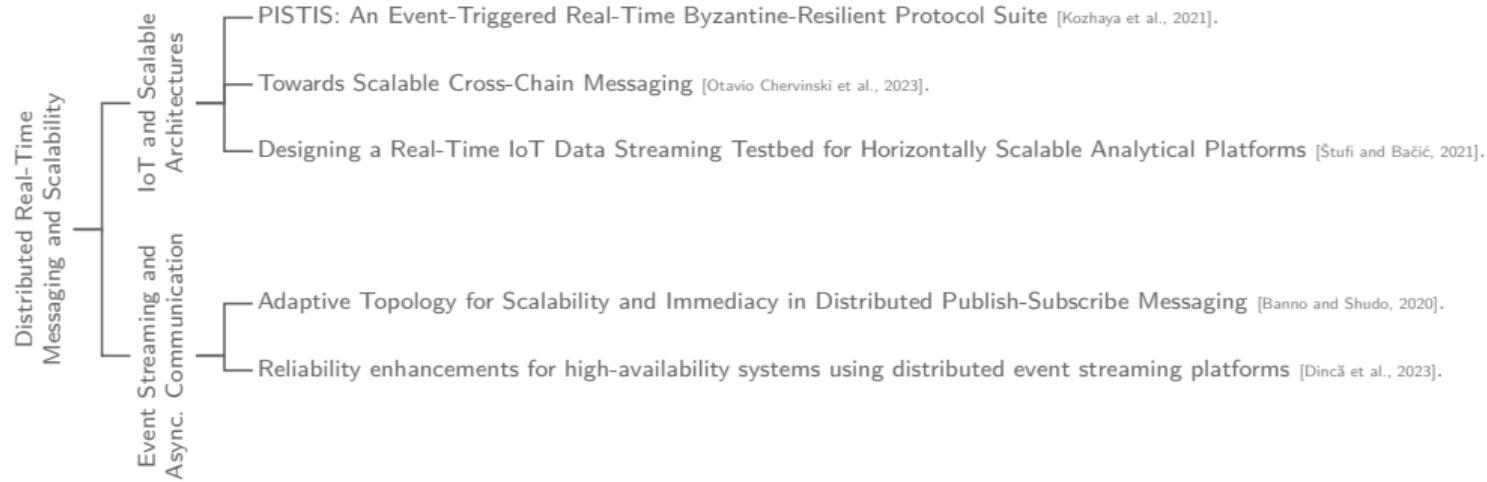


*Limitations in real-time API performance and adaptability due to static configuration settings.*



# State-of-the-Art

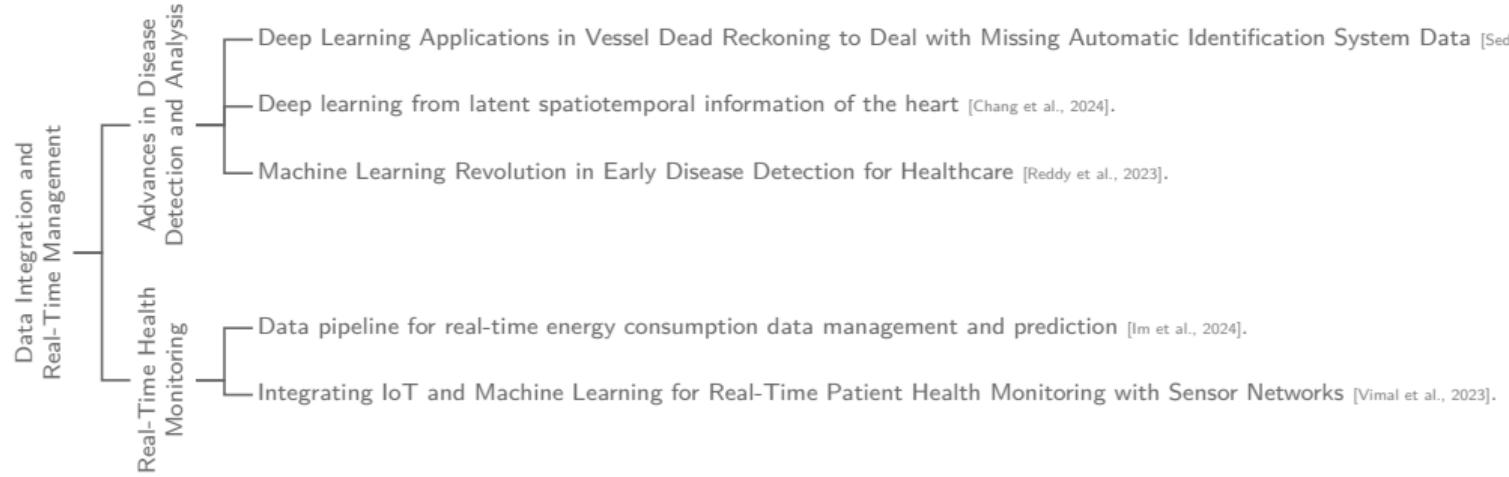
## Distributed Messaging: Scalability and Reliability



***Inefficiencies and scalability issues in distributed messaging systems affecting real-time communication.***



# State-of-the-Art AI-Enhanced ETL Processes

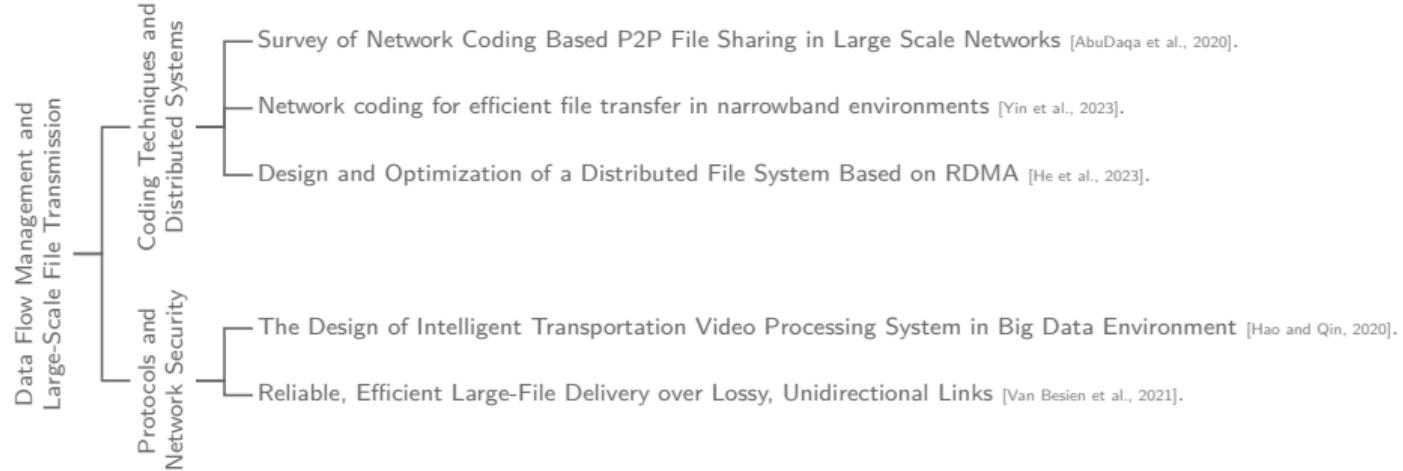


*Inefficiencies in processing **unstructured and temporal data** in AI-driven multimodal ETL systems.*



# State-of-the-Art

## Advancements in Large-Scale File Transmission



*Challenges in ensuring efficient and secure large-scale file transmission in varying network conditions.*



## How can advanced artificial intelligence and machine learning techniques enhance data management and communications in digital environments?

Specifically, in improving real-time *API* flexibility and effectiveness, boosting *distributed messaging* system efficiency and scalability, effectively processing unstructured and temporal data in multimodal *ETL* systems, and optimizing large-scale *file transmission* under varying network conditions?

# General Objectives



To develop an **AI-driven framework** for enhancing **real-time management of signals and data processing** across network protocols, focusing on **efficiency, security, scalability, and responsiveness** to improve research capabilities and data exchange.

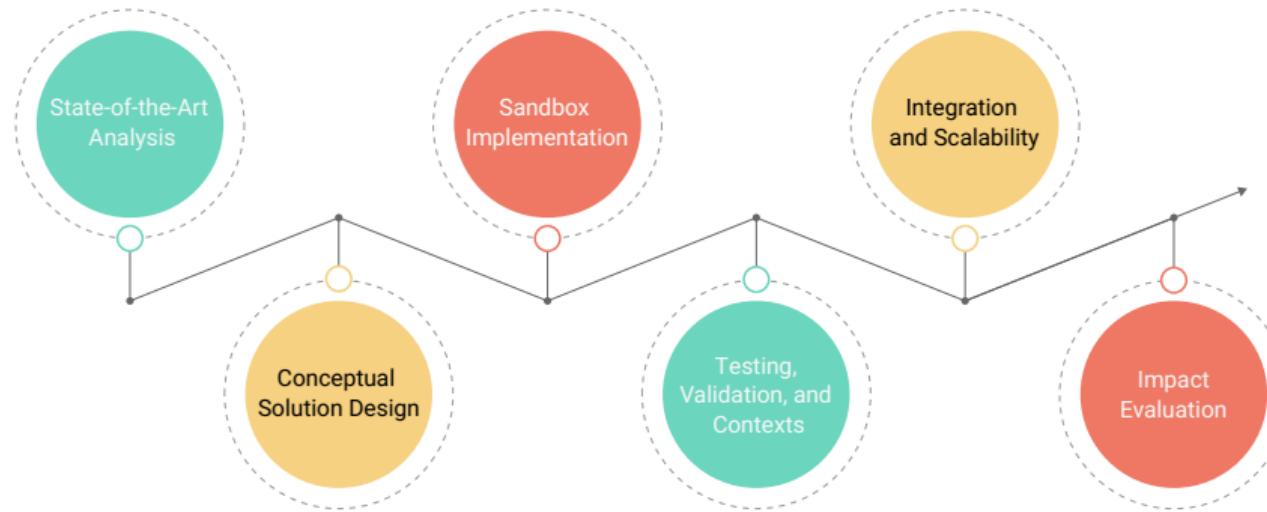


# Specific Objectives

- 1 To design a **multichannel time series processing strategy** to enhance and strengthen the structure for immediate collection and display of various types of signals, with a specific emphasis on **streamlining and parameterizing** the required infrastructure for experiments and **merging** different types of signals into a single interface.
- 2 To implement an **AI strategy** to improve the control of **real-time APIs** and **multimodal ETL processes** through the utilization of **advanced machine learning and deep learning methods** to enhance precision, effectiveness, and promptness in intricate data processing and analysis.
- 3 To create an **AI-based advanced platform** for transmitting **large files** and **distributing messages** on a large scale. This system will utilize artificial intelligence technologies to improve efficiency, security, and scalability, and will also be capable of **adjusting to changing network conditions** to boost communication and data transfer.



# General Methodology of Contributions



*A six-step approach to analyze, design, prototype, test, integrate, and evaluate real-time AI-driven solutions.*

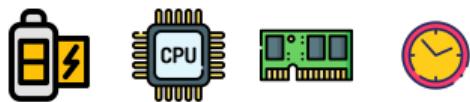
# AI-Based Hyperparameter Tuning and System-Level Optimization

## Enhancing Model Performance and System Efficiency through Dual Optimization Techniques



### Joint Optimization Approach

- Optimize both **model hyperparameters** and **system resources** (CPU, memory, latency, energy) to enhance overall performance.



### Reinforcement Learning (RL) for Adaptive Optimization

- RL** adjusts **system resources** (CPU/GPU, memory, network) in real-time to maintain efficiency under changing conditions.



### Synergy Between Techniques

- Bayesian Optimization** finds optimal initial configurations.
- RL** continuously adapts configurations to maintain **efficiency** under different operational conditions.



By integrating **Bayesian optimization** for initial setup with **reinforcement learning** for continuous adaptation, the goal is to achieve **robust performance** and **resource efficiency** under diverse system conditions.

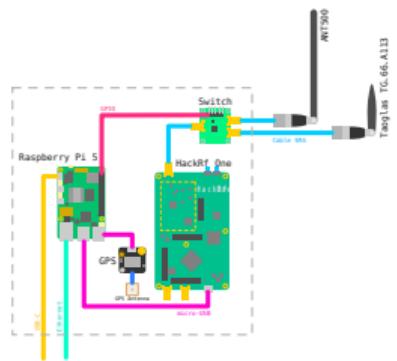


# Testing Contexts of Interest

## Scenarios for Testing

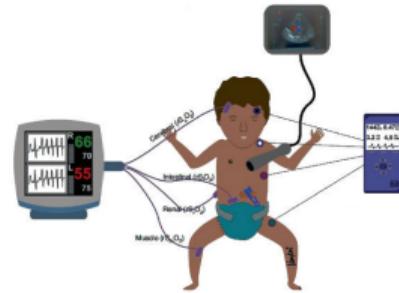
*Prototipo costo-eficiente y escalable para el monitoreo del espectro radioeléctrico en Colombia mediante radio definido por software y aprendizaje profundo.*

- Scalability
- Robustness
- Low Latency
- Reliability



*Sistema de integración de EEG, ECG y SpO2 para seguimiento de neonatos en unidad de cuidados intensivos del Hospital Universitario de Caldas - SES HUC.*

- Real-Time Monitoring
- Data Centralization
- Alarm Generation
- Accuracy in Critical Settings



*Two diverse research projects provide essential testing environments for validating scalability, robustness, and real-time data integration as part of the system development methodology.*

## Testing Contexts of Interest



## Scenarios for Testing

# *Prototipo Funcional de Lengua Electrónica para la Identificación de Sabores en Cacao Fino de Origen Colombiano.*

- Flavor Profile Identification
  - Portability and Real-Time Analysis
  - Quality Validation



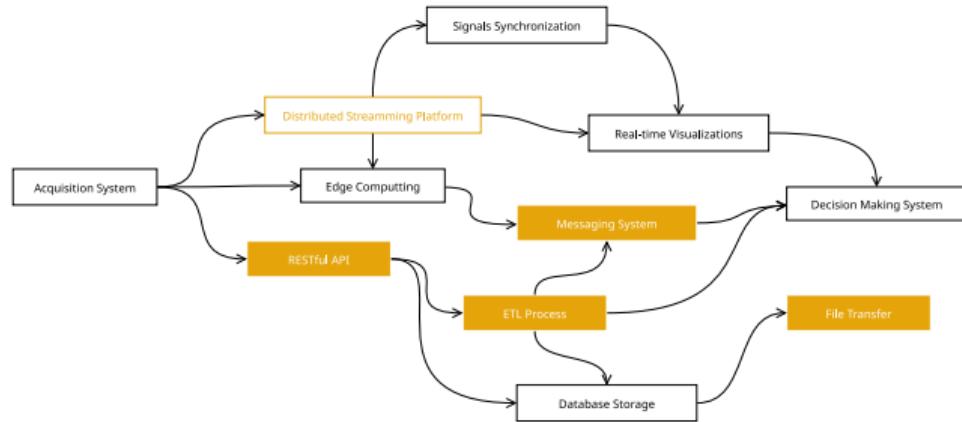
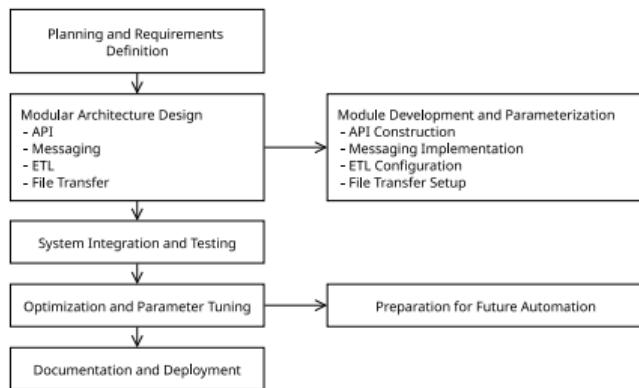
The electronic tongue prototype supports research by providing a practical testing environment for enhancing flavor analysis methodologies in cacao production.

Together, these three projects provide a **comprehensive validation of the AI-driven solution, enhancing robustness, adaptability, and practical applications across sectors from telecommunications to food quality.**

# Methodology [OBJ1]

## Streamlining Signal Integration:

### A Comprehensive Approach to Real-Time Data Management and Visualization

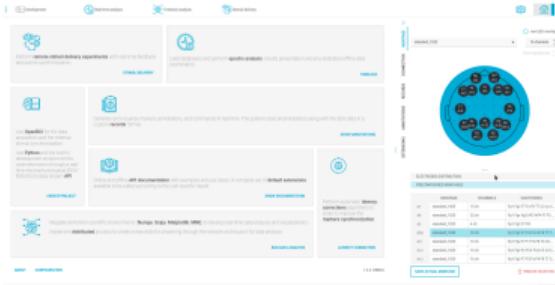
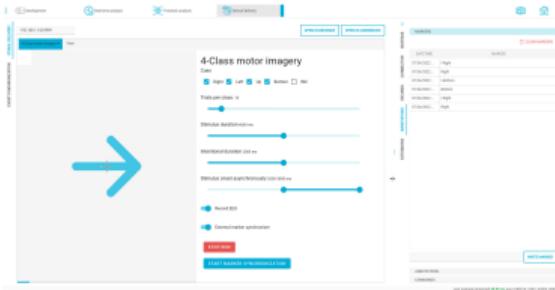
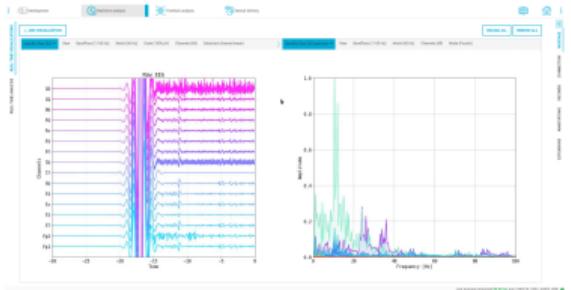


*Create a modular and parameterized system for real-time signal acquisition, processing, and integration.*



# Methodology [OBJ1]

BCI-Framework V1.0



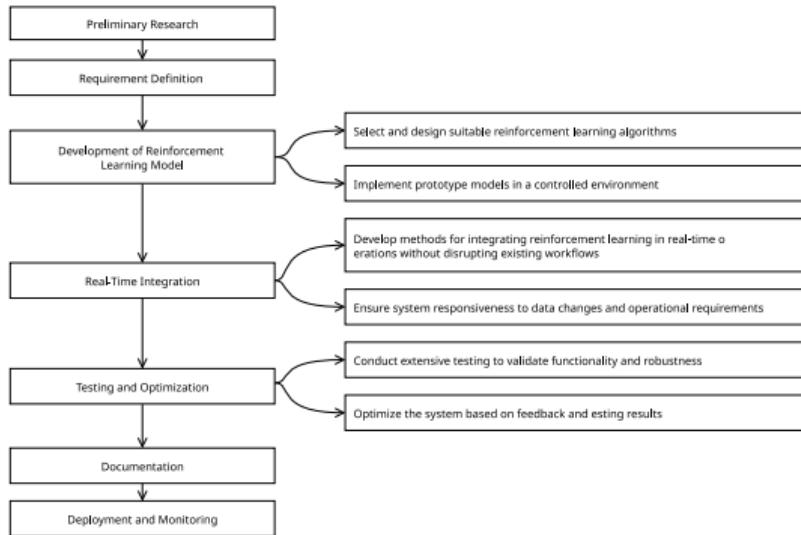
GitHub: <https://github.com/UN-GCPDS/bci-framework>

Documentation: <https://bci-framework.readthedocs.io/en/latest/>

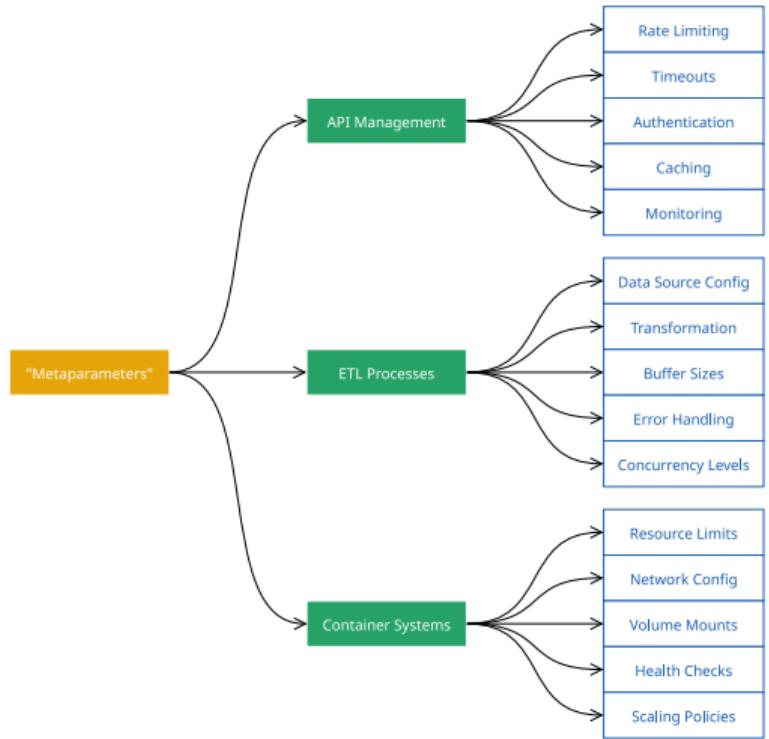
# Methodology [OBJ2]

Optimizing System Performance:

Configuring Key Parameters for Enhanced Efficiency and Security



*Implement AI-driven automation for optimizing real-time API and ETL configurations.*



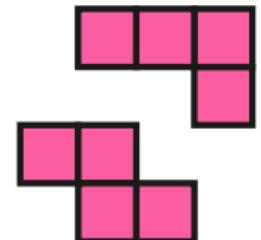
# Methodology [OBJ2]

## Scalable Service Management for AI Applications



**Foundation** is a scalable AI framework for managing distributed services and data processes, designed to optimize efficiency and flexibility in Docker Swarm environments.

- **Service Management:** Automates creation, deletion, and scaling of services in Docker Swarm.
- **Worker Lifecycle Control:** Manages Python, Django, and Brython services, ensuring efficient deployment and operation.
- **Distributed Logging:** Centralized log management via HTTP and Kafka for better monitoring.
- **Dynamic Resource Allocation:** Adaptive management of CPU, memory, and network resources to optimize performance.
- **Integration with AI Models:** Supports integration of machine learning models for automated decision-making and optimization.

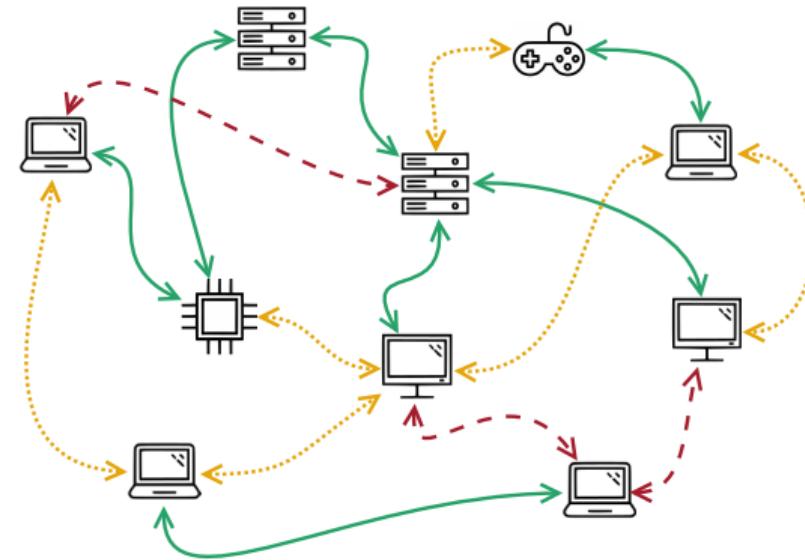
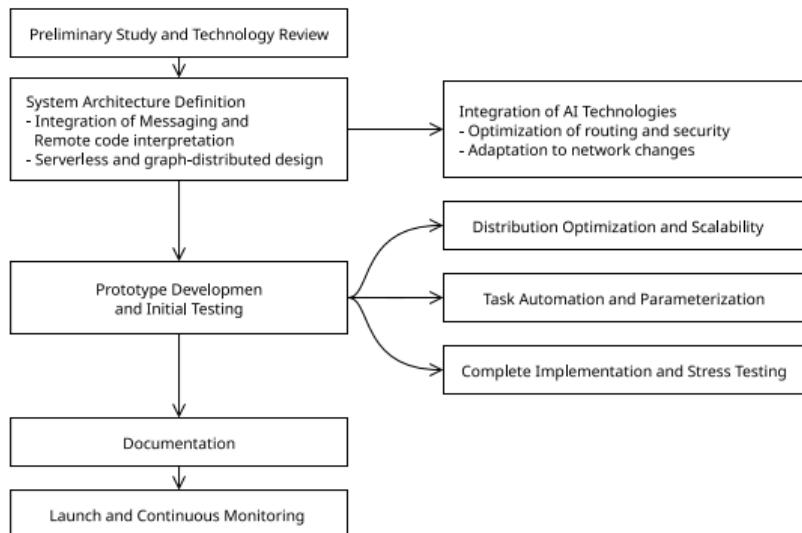


**GitHub:** <https://github.com/dunderlab/python-dunerlab.foundation>

**Documentation:** <https://dunderlab-foundation.readthedocs.io/en/latest/index.html> (Not yet)

# Methodology [OBJ3]

Building Advanced AI-based Network protocols:  
Enhancing Communication and Data Transfer Efficiency



*Build a scalable, AI-enhanced platform for efficient file transmission and distributed messaging.*



# Methodology [OBJ3]

## Dynamic Communication Framework for Distributed Networks

**Chaski-Confluent** is a distributed communication framework designed for scalable message handling and dynamic node pairing, tailored for TCP/IP networks and optimized for efficient data exchange.

- **Scalable Messaging:** Supports robust node discovery and efficient message routing in large-scale networks.
- **Dynamic Node Pairing:** Manages automatic pairing of nodes based on subscription topics, ensuring adaptive communication.
- **Remote Python Execution:** Facilitates remote Python script execution similar to RPyC, enhancing computational flexibility.
- **AI-Enhanced Data Transfer:** Integrates AI-based techniques for optimizing large file transfers and message distribution.
- **Real-Time Adaptability:** Adjusts to network changes for improved communication and resource utilization.



**GitHub:** <https://github.com/dunderlab/python-chaski>

**Documentation:** <https://chaski-confluent.readthedocs.io/en/latest/>



# Obtained Results

## Papers

- [2023] Published a research paper titled "**A Novel OpenBCI Framework for EEG-Based Neurophysiological Experiments**" in the journal Sensors. The paper discusses the development of an Open Brain-Computer Interface (OpenBCI) framework, utilizing open-source hardware and firmware to facilitate EEG-based neurophysiological experiments. The framework is designed to overcome the limitations of OpenBCI systems, particularly in communication and flexibility for various neurophysiological protocols. The research was published in Volume 23, Issue 7 of Sensors, 2023 (DOI: 10.3390/s23073763) (MDPI).
- [2023] At the "III Congreso Latinoamericano de Investigación, Innovación y Emprendimiento Educativo," presented "**Real-Time Processing for BCI-Based MI Paradigms Using Deep Learning Models**" This paper showcases advancements in BCI technology, highlighting the application of deep learning models for efficient, real-time processing in Motor Imagery (MI) paradigms. The study emphasizes improvements in processing speed and accuracy, addressing challenges in real-time applications and setting new standards for BCI system performance. The work has significant implications for both academic research and practical BCI applications in various fields.



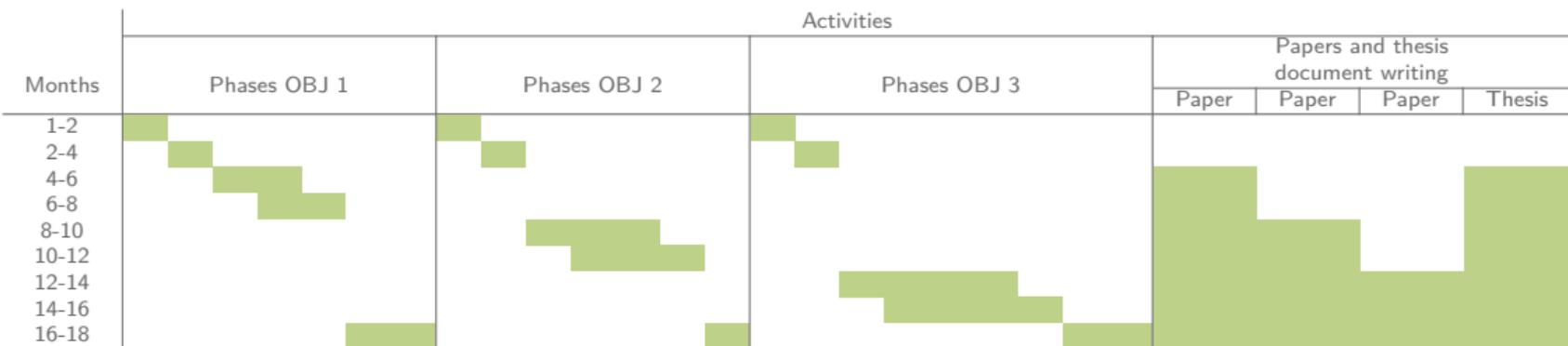
# Obtained Results

## Patents and software registers

- [2022] The systems were submitted to the Crearlo no es suficiente summons for a patentability search process with the Universidad Nacional de Colombia sede Manizales as main beneficiary with the title "**MÉTODO Y SISTEMA PARA LA SINCRONIZACIÓN DE MARCADORES ASOCIADOS A SISTEMAS DE INTERFAZ CEREBRO-COMPUTADOR**", postulation ID 343 and Application number NC2022/0007405 from May 28, 2022.
  
- [2022] A script developed with BCI-Framework for **Motor imagery paradigm with game-based stimulus (Pacman interface)** was submitted to the software register in the Universidad Nacional de Colombia sede Manizales.



# Implementation Schedule





# Acknowledgements

This research would not have been possible without the support provided by the project *Prototipo Funcional de Lengua Electrónica para la Identificación de Sabores en Cacao Fino de Origen Colombiano* (*código 202010039703*) funded by **Casa Luker**.



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