Stakeholders

Researchers and Scientists

- **Description:** Individuals conducting biological or medical research focusing on microglia and mitochondrial function.
- **Interests:** High accuracy in establishing the relationship between microglial morphology and mitochondrial membrane potential, detailed quantitative results for scientific analysis, and reliable tools for visualizing complex data.

Software Development Team

- **Description:** The team responsible for building the machine learning model and the application that integrates it.
- **Interests:** Clear and minimal specifications for training and running the model, scalable architecture for handling diverse datasets, and seamless collaboration with research teams.

Academic Institutions and Funding Organizations

- **Description:** Entities funding the research and development of the project.
- **Interests:** Demonstration of scientific validity, potential for broader applications in related fields, and significant contributions to the understanding of neuroinflammation and microglial function.

Functional Requirements

Machine Learning Model

Data Input:

- Support for high-resolution fluorescence microscopy images of microglial cells.
- Accept three image types per cell: non-stained, red-stained (mitochondrial membrane potential), and green-stained (mitochondrial location).
- Validate image quality and format during input.

Morphological Analysis:

- Identify and categorize the shape of microglial cells into predefined categories (e.g., round, partially activated, fully activated).
- Quantify morphological features such as cell size, shape, and branching complexity.

Mitochondrial Membrane Potential Analysis:

- Analyze the intensity of red fluorescence to quantify mitochondrial membrane potential.
- Output numerical values representing the potential for each cell.

Mitochondrial Spatial Distribution Analysis:

- Analyze green fluorescence to determine the spatial distribution of mitochondria within the cell.
- Categorize distribution as “near the nucleus” or “spread throughout the cell.”

Correlation Analysis:

- Correlate microglial cell morphology with mitochondrial membrane potential and spatial distribution.
- Quantify the relationship and provide a detailed report of findings.

Visualization of Results:

- Generate graphical representations of analysis results, such as scatter plots, heatmaps, and bar charts.
- Present clear visual insights to facilitate interpretation by researchers.

Batch Processing:

- Support analysis of large datasets (e.g., thousands of images) in a single batch.
- Ensure seamless and efficient processing of multiple samples.

Output Reports:

- Produce detailed reports summarizing the analysis, including numerical data, visualizations, and insights.
- Provide exportable formats (e.g., CSV, PDF) for sharing and documentation.

Application

User Authentication:

- Registration and login functionality for researchers.
- Secure password recovery process.

Image Upload and Analysis:

- Allow users to upload new datasets of fluorescence microscopy images (non-stained, red-stained, and green-stained).
- Provide real-time feedback on the dataset format and compatibility.
- Analyze the uploaded images using the trained model and display results.

Visualization of Results:

- Display results in graphs and tables for both new and past datasets.
- Enable users to filter and compare results across different datasets.
- Allow export of analysis results in common formats (e.g., CSV, PDF).

Data Management:

- Store results of analyzed datasets for future reference.
- Allow users to view, organize, and search historical data within the application.
- Enable users to delete historical datasets they no longer need.

Non-Functional Requirements

Machine Learning Model

Performance:

- Efficiently process large datasets, supporting analysis of thousands of images within reasonable timeframes (e.g., under 5 minutes per 500 images).
- Optimize for scalability, ensuring smooth operation on datasets of varying sizes without performance bottlenecks.

Portability:

- Enable deployment across diverse environments, including local workstations with GPUs and cloud-based platforms.
- Support compatibility with multiple operating systems (e.g., Linux, Windows, macOS).
- Ensure adaptability to future datasets with minimal configuration adjustments.

Interpretability:

- Provide clear and detailed outputs that align with the research goals, such as visualizations of correlations and numerical insights.
- Include an intuitive explanation of the model's analyses to assist researchers in understanding the results.

Reproducibility:

- Allow seamless re-training of the model using new datasets without requiring significant changes to the architecture or codebase.
- Maintain detailed logging of model configurations and training parameters to facilitate reproducible experiments.

Flexibility:

- Ensure support for integration with future tools and workflows, allowing researchers to extend functionality as needed.
- Provide modularity in design, enabling updates or enhancements to specific components without affecting the overall system.

Application

Usability:

- Intuitive and user-friendly interface, accessible from desktop and mobile devices.
- Provide clear guidance for uploading and analyzing datasets.

Security:

- Use HTTPS for secure communication.
- Encrypt user passwords and sensitive data.
- Ensure role-based access to sensitive functionalities.

Reliability:

- Ensure 99.9% system uptime.
- Provide automated error handling and notifications for failures.
- Automatic backup of user data every 24 hours.

Compatibility:

- Support modern browsers (Chrome, Firefox, Edge).
- Ensure compatibility with both Windows and macOS operating systems.

Use Cases

Use Case 1: User Registration and Login

- **Goal:** Enable users to create accounts and log into the system securely.
- **Actors:** Researchers.
- **Preconditions:** User accesses the registration or login page.
- **Success End Condition:** User gains access to the system.
- **Main Flow:**
    1. User provides registration details (email, password, affiliation).
    2. System validates the input and creates an account.
    3. User logs in with their credentials.
- **Extensions:**
    1. If the email is already registered, the system prompts the user to log in or recover their password.
    2. If the password is incorrect, the system limits login attempts.

Use Case 2: Image Upload

- **Goal:** Allow users to upload fluorescence microscopy images for analysis.
- **Actors:** Researchers.
- **Preconditions:** User is logged into the system.
- **Success End Condition:** Uploaded images are processed and ready for analysis.
- **Main Flow:**
    1. User navigates to the "Upload Images" section.
    2. User selects one or more images for upload.
    3. System validates the image formats and provides feedback if there are issues.
    4. Images are stored and ready for analysis.
- **Extensions:**
    1. If the image format is unsupported, the system notifies the user and suggests acceptable formats.
    2. If the upload fails, the system retries or logs the error.

Use Case 3: Historical Data Access

- **Goal:** Allow users to view results of previously analyzed datasets.
- **Actors:** Researchers.
- **Preconditions:** User is logged into the system.
- **Success End Condition:** User views past results and optionally downloads them.
- **Main Flow:**
    1. User navigates to the "Historical Data" section.
    2. System displays a list of past datasets with key metrics.
    3. User selects a dataset to view detailed results.
- **Extensions:**
    1. If no past data exists, the system notifies the user.

Use Case 4: Deleting Historical Data

- **Goal:** Allow users to delete historical datasets that are no longer needed.
- **Actors:** Researchers.
- **Preconditions:** User is logged into the system.
- **Success End Condition:** The selected dataset is permanently deleted from the system.
- **Main Flow:**
    1. User navigates to the "Historical Data" section.
    2. User selects a dataset they wish to delete.
    3. System prompts for confirmation before deletion.
    4. Dataset is deleted, and the user is notified of successful removal.
- **Extensions:**
    1. If the dataset cannot be deleted (e.g., due to a system error), the user is notified with instructions to retry later.

Constraints

- The system will process only fluorescence microscopy images captured using predefined protocols (non-stained, red-stained, and green-stained).
- The initial training of the model requires sufficient GPU resources to handle the dataset efficiently.
-