A Cloud-Enabled Platform for Dynamic Simulation of Inflammation-Driven Astrocyte-Neuron Interactions

# Abstract

Neuroinflammation profoundly alters astrocyte-neuron communication, yet computational frameworks to model this process remain limited. We present an open-source, cloud-deployable platform that simulates inflammation-driven astrocytic calcium dynamics and neuronal excitability using ordinary differential equations (ODEs) coupled with realistic cytokine profiles. Our system incorporates dynamic feedback loops, data upload capabilities, and real-time visualization. Model outputs align with key neurophysiological metrics such as peak firing and firing duration. Future expansions will integrate multi-scale modeling, stochasticity, and ML-based surrogate models.

# Introduction

Neuroinflammatory processes, mediated by cytokines such as tumor necrosis factor-alpha (TNF-α), play a critical role in modifying astrocyte and neuron function. Understanding these interactions requires simulation tools that are biologically realistic, dynamic, and accessible to researchers. This project introduces a modular platform that models calcium signaling in astrocytes, glutamate release, and neuronal excitability with tunable feedback dynamics. Realistic TNF-α inputs (double-exponential for acute, logistic for chronic) enhance biological plausibility.

# Methods

Model Equations:  
- Calcium dynamics:  
 dCa\_astro/dt = α ⋅ TNF(t) + η ⋅ F\_neuron(t) - β ⋅ Ca\_astro(t)  
- Neuronal firing dynamics:  
 dF\_neuron/dt = (δ ⋅ Glu(Ca\_astro) - ε - F\_neuron) / τ  
where Glu(Ca) = γ ⋅ Ca.  
  
TNF-α Profiles:  
- Acute: Double-exponential  
- Chronic: Logistic saturation  
  
Simulation Setup:  
- 0–50 seconds (user adjustable)  
- Solved via odeint with caching enabled  
- Metrics: Peak firing, AUC, time to peak, firing duration >1 Hz  
  
Streamlit App Features:  
- Parameter sliders for α–η  
- Time-grid adjustability  
- Upload and visualization of user data  
- Simulation log CSV recording

# Results

- Realistic astrocyte calcium and neuronal firing dynamics  
- Acute TNF triggers transient firing bursts; chronic TNF maintains sustained low-level excitation  
- Feedback strength η modulates reverberatory vs damped responses  
- Output metrics dynamically change with parameter tuning

# Discussion

The platform lays groundwork for integrating stochastic models, bifurcation analysis, and experimental validation datasets. Future updates will implement voltage-gated neuron models, spatial diffusion of TNF, and predictive ML surrogates. This open tool enables educational, experimental, and translational research into neuroimmune dynamics.

# Code and App Availability

All source code, app files, and deployment instructions are available in the bundled download.