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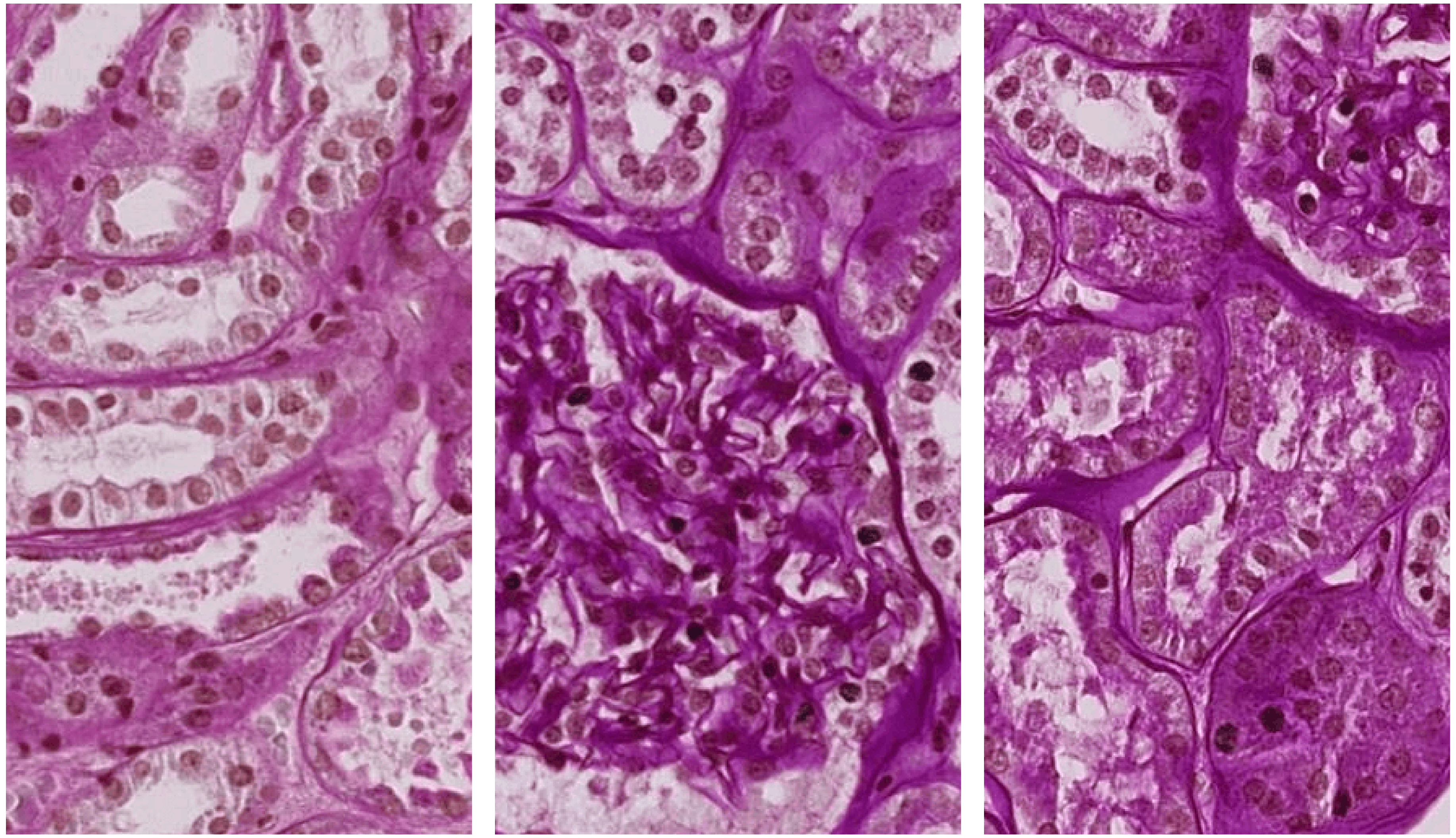


CELLULAR AUTOMATON MODELING FOR KIDNEY BLOOD VESSEL DYNAMICS

A Systems Engineering Approach to Microvascular Simulation

INDEX

INTRODUCTION

CHALLENGES

Capturing **emergent vascular behavior is difficult** using traditional mathematical models.

MOTIVATION

Understanding **microvascular dynamics** in kidney tissue, especially under pathological conditions.

PROPOSED APPROACH

Use of **Cellular Automata (CA)** to simulate vascular behavior based on local interaction rules.

BACKGROUND

Extends previous work based on histological image classification by incorporating dynamic simulation.

WHY IT'S IMPORTANT?

Allows the exploration of phenomena like aneurysm formation, vessel propagation, and tissue regeneration — critical for understanding renal pathology.

SYSTEMIC PROBLEM ANALYSIS

KIDNEY MICROVASCULAR SYSTEM AS A COMPLEX SYSTEM

High interdependence between arterial sources, glomeruli, and surrounding tissue.

KEY SYSTEMIC CHALLENGES

NONLINEARITY

STRUCTURAL SENSITIVITY

DYNAMIC BEHAVIOR

SYSTEMIC PROBLEM ANALYSIS

Pathological Scenarios

SPARSE OR OBSTRUCTED VASCULATURE → *tissue hypoxia, aneurysm formation.*

ANEURYSM CLUSTERING → *systemic destabilization and collapse of local filtration units.*

INABILITY TO REGENERATE → *accumulation of dead zones, organ dysfunction.*

SYSTEMIC PROBLEM ANALYSIS

WHY SIMULATION IS NEEDED?

Real renal tissue can't be manipulated in real time.

Simulation allows controlled testing of:

Arterial configurations.
Vessel failure propagation.
Regeneration under different constraints.

SYSTEM DESIGN

SIMULATION MODEL

Cellular Automaton (CA) on a 60×60 grid.
Each cell represents a unit of kidney tissue.
Discrete time steps simulate dynamic evolution.

RULE-BASED BEHAVIOR

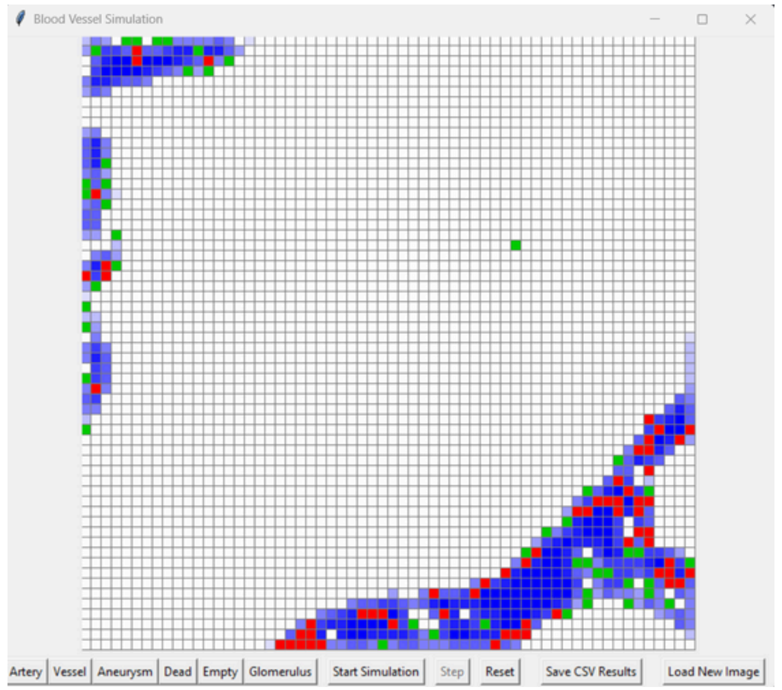
Local interactions define:

- Propagation of vessels from arteries.
- Formation and explosion of aneurysms.
- Death and regeneration of tissue.
- Degradation of glomeruli without vascular support.

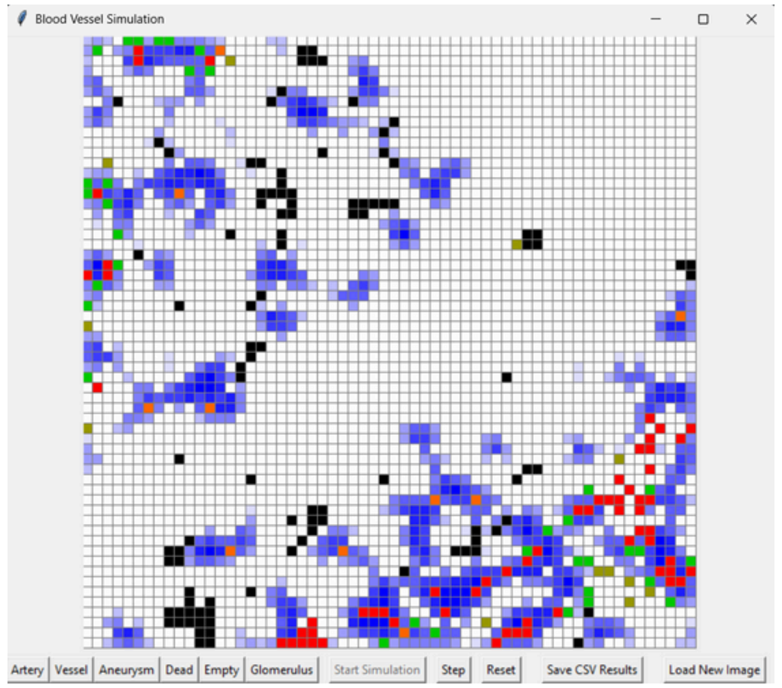
Artery (A)	- Constantly generates vessels in cardinal directions (↑ ↓ ← →) - Maintains adjacent vessels
Vessel (V)	- Propagates to adjacent empty cells with 30% probability - Becomes aneurysm if ⩾ 5 neighboring vessels/arteries - Dies if isolated
Aneurysm (X)	- Explodes if ⩾ 2 neighboring aneurysms in cardinal directions - Destroys nearby vessels within radius 2 - Cures if < 4 neighboring vessels
Dead Cell (D)	- Revives into vessel if ⩾ 1 neighboring vessel or artery
Empty Tissue (T)	- Can be colonized by arteries or propagating vessels
Glomerulus (G)	- Static filter unit - Remains healthy if vascularized
Failing Glomerulus (GF)	- Degrades from G if insufficient support from nearby vessels or arteries

SIMULATION

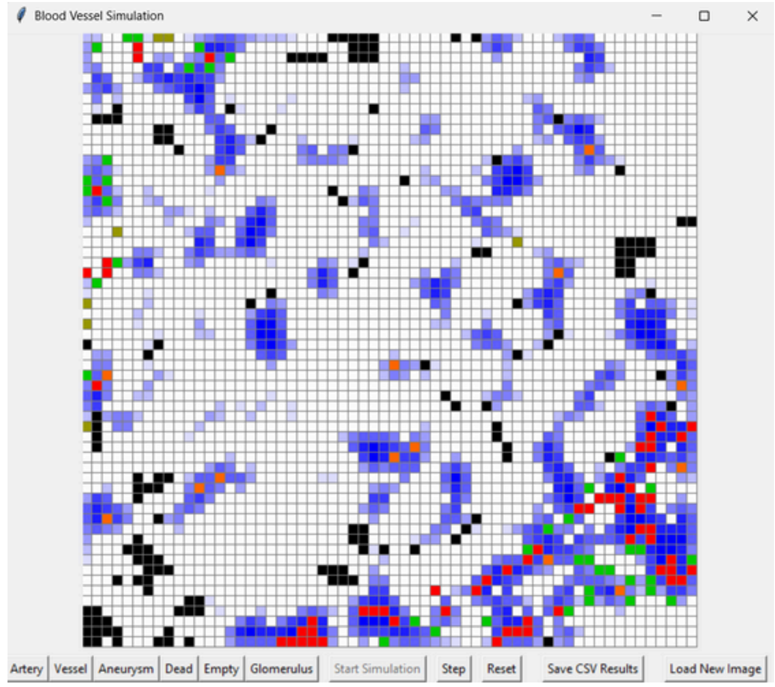
Case #1



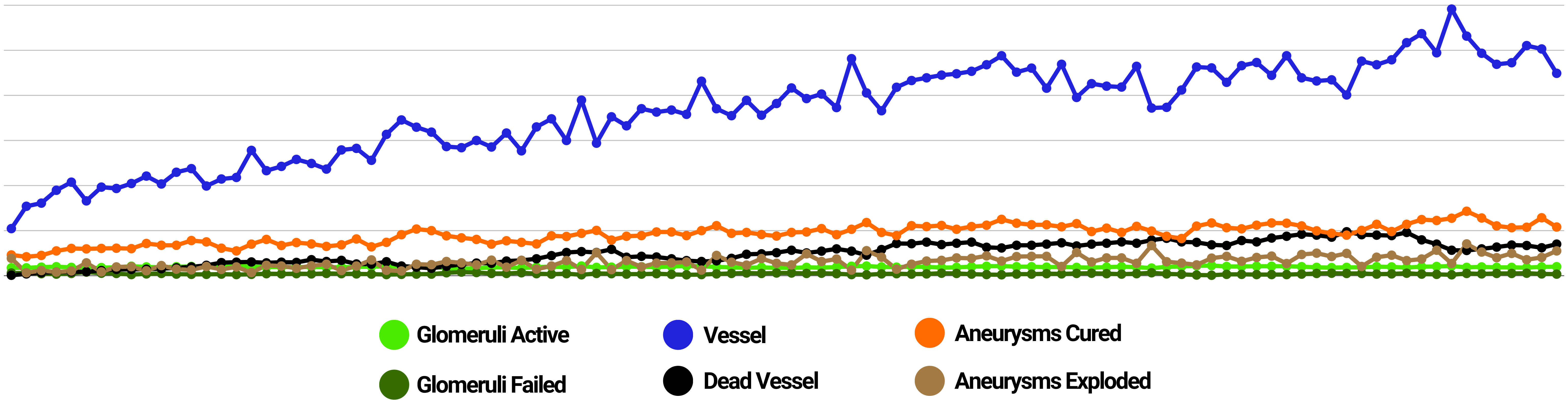
Iteration #1



Iteration #50

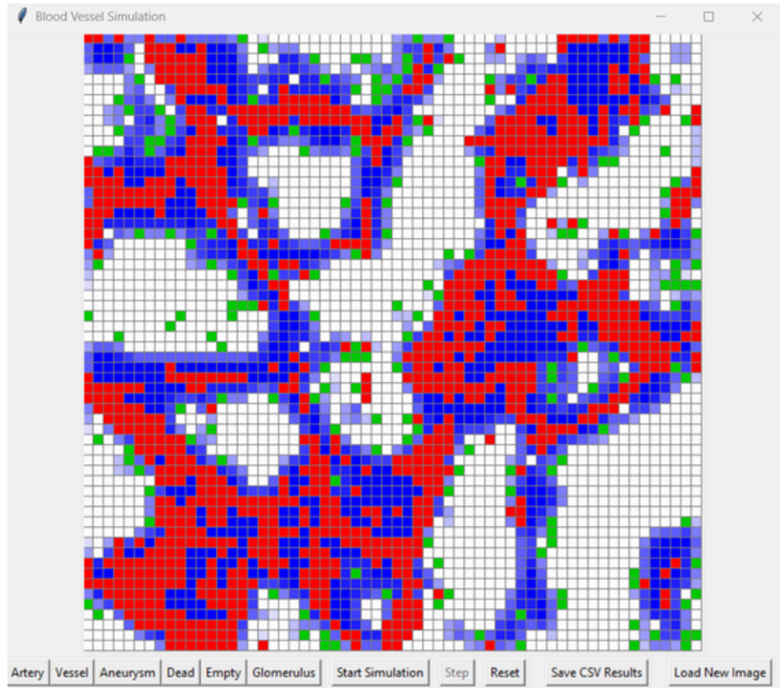


Iteration #100



SIMULATION

Case #2



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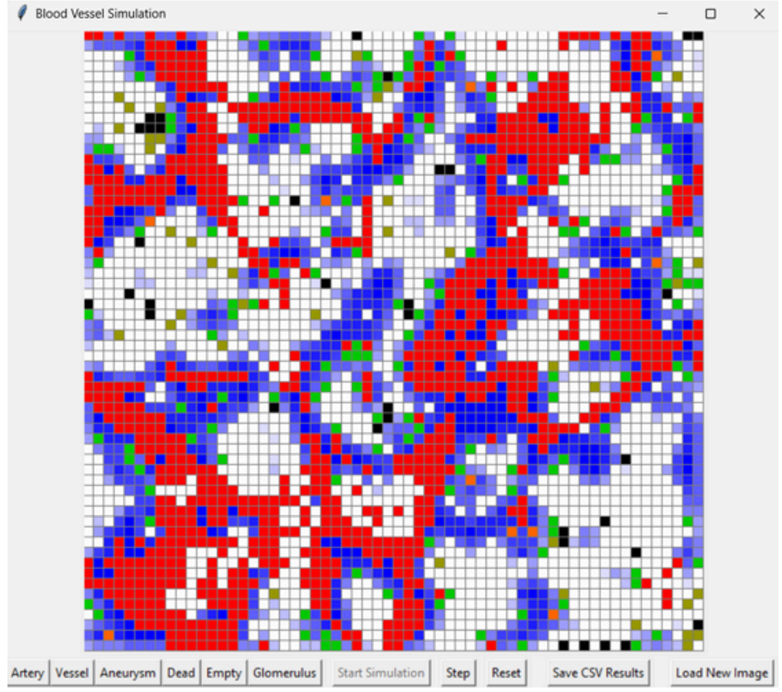

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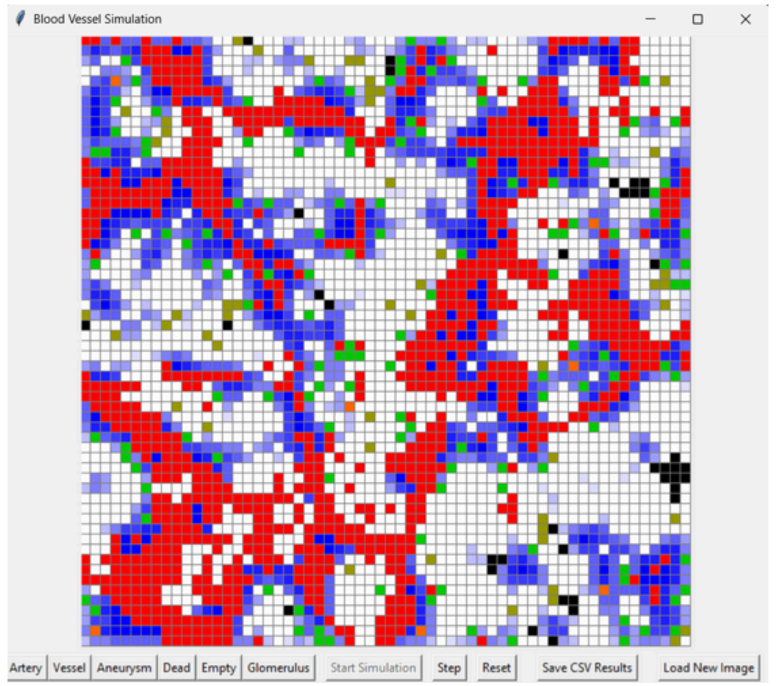

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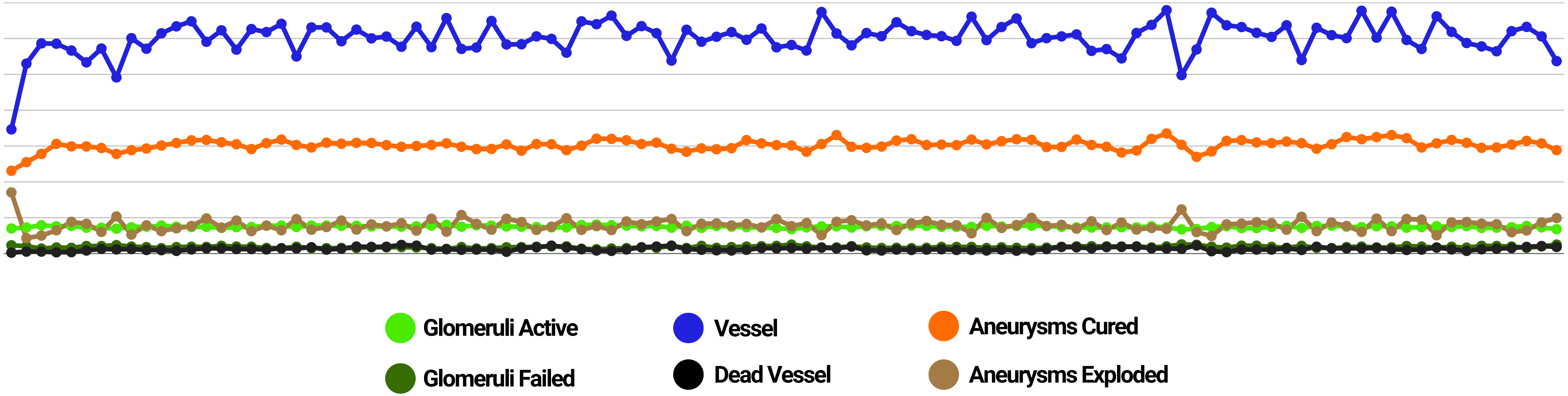

CONCLUSIONS

The simulation demonstrates that **renal vascular systems behave as chaotic systems**: small changes in initial arterial placement lead to dramatically different outcomes.

The model reveals that **kidney vasculature behaves as a complex adaptive system**, where **simple local rules generate unpredictable global outcomes**.

This reinforces the idea that **biological systems can be understood through computational abstraction** and systemic modeling.

THANK YOU!