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Open-source numerical simulation tool for two-dimensional neural fields involving finite axonal transmission speed

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Motivation

This work aims to provide an open source and cross-platform simulation tool that integrates numerically integral-differential equations of the type

$$\left(\eta \frac{\partial^2}{\partial t^2} + \gamma \frac{\partial}{\partial t} + 1\right) V(x, t) = I(x, t) + \int_{\Omega} d^2y K(\|x - y\|) S \left[V \left(y, t - \frac{\|x - y\|}{c} \right) \right] \quad (1)$$

with mean neuron potential V in a two-dimensional quadratic spatial domain Ω with periodic boundary conditions. The term I denotes the external stimulus, K is the synaptic connectivity kernel and S is the firing rate. Finite axonal transmission speed c induces space-dependent delays.

To this end, we present the *Neural Field Simulator* [1].

Features

► Great usability

- Parametrization can be as simple or complex as field model
- Visualization is easily modified by a keypress

► Complete control over Eq. (1) variables

- Free choice of values provided by text-based Python interface

► Spatio-temporal kernel

- Integral renders into a spatial integral and an integral over delays [2]

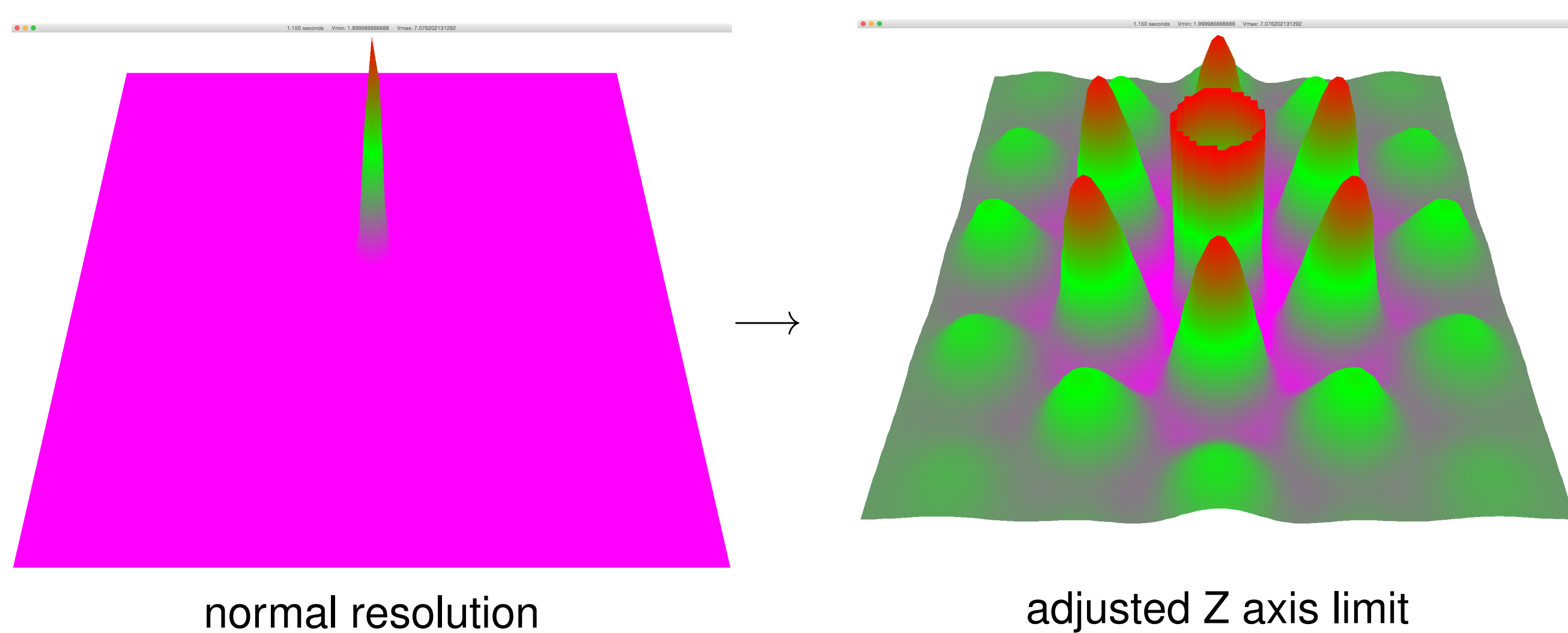
► Optimal acceleration

1. Fast Fourier transform in space
2. Self-writing code based on interface selections
3. Utilization of graphics processing unit for hardware acceleration
4. Reduced rate of GPU uploads optimised for visual perception

► Output in rich detail

- 2D matrices output in 3D whereby $[x, y] \rightarrow [z]$

This allows features normally hidden in neural fields to be magnified and examined



- Matrices can be moved, rotated, zoomed and colors and axis limits are easily changed
- Movies and images of simulations can be saved

Breather

A breather (Fig. 1) is simulated with a spatial grid of $n=512$ squared elements and parameters $dt=0.001$, $\gamma=1$, $\eta=0$, length $l=30$, $V(t=0)=0$, $V_{noise}(t>0)=\frac{e^{(a^2+b^2)\sqrt{dt}}}{320\pi}$ where a and b are a meshgrid of $[-l/2, \dots, l/2]$, $l=\frac{20e^{-x^2/32}}{32\pi}$, $K=\frac{-e^{-x/3}}{4.5\pi}$, $S=\frac{1}{1+e^{-10000(V-0.005)}}$ and $c=500$.

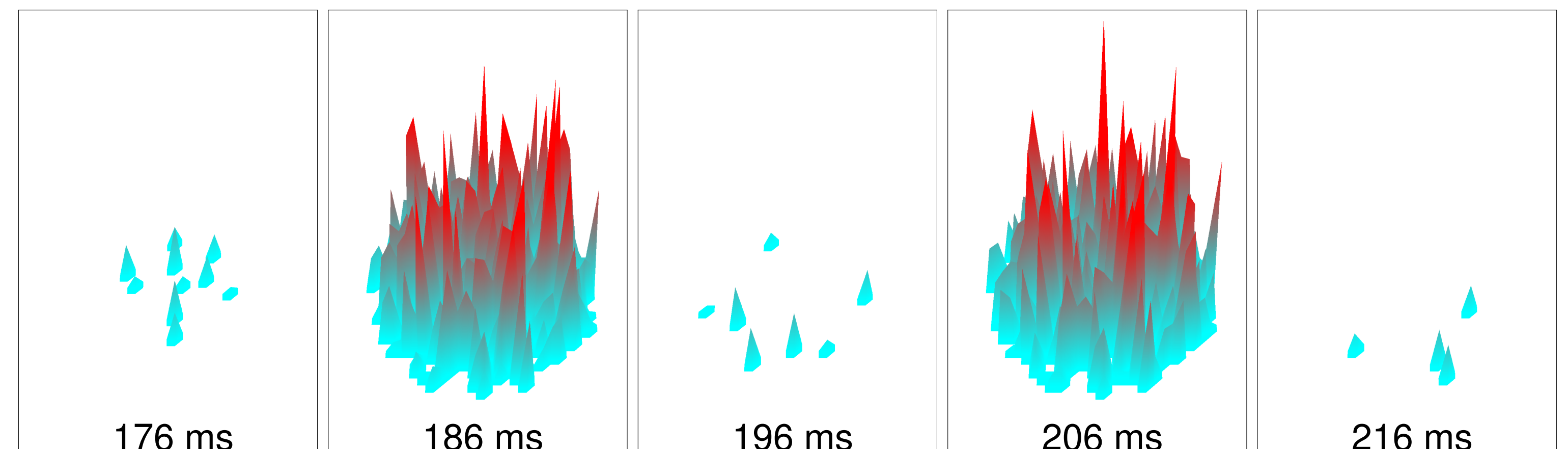


Figure 1: A breather at 10 millisecond intervals with manually set minimum Z axis (=0.0048).

Turing Pattern

Turing patterns emerge from noisy field voltage (Fig. 2) with terms $dt=0.01$, $\gamma=1$, $\eta=0$, $l=90$, $n=512$, $V(t=0)=5.4+\frac{e^{-x^2/0.02}}{\sqrt{0.02\pi}}$, $l=0$, $K=K_0 - \sin(\vec{v})/200$ with $K_0 = \sin(\vec{v})/150$ and $\vec{v}=[-9\pi, \dots, 0]$, $S=\frac{2}{1+e^{-1.24(V-3)}}$ and $c \geq l\sqrt{2}\Delta t$ is infinite (=6364).

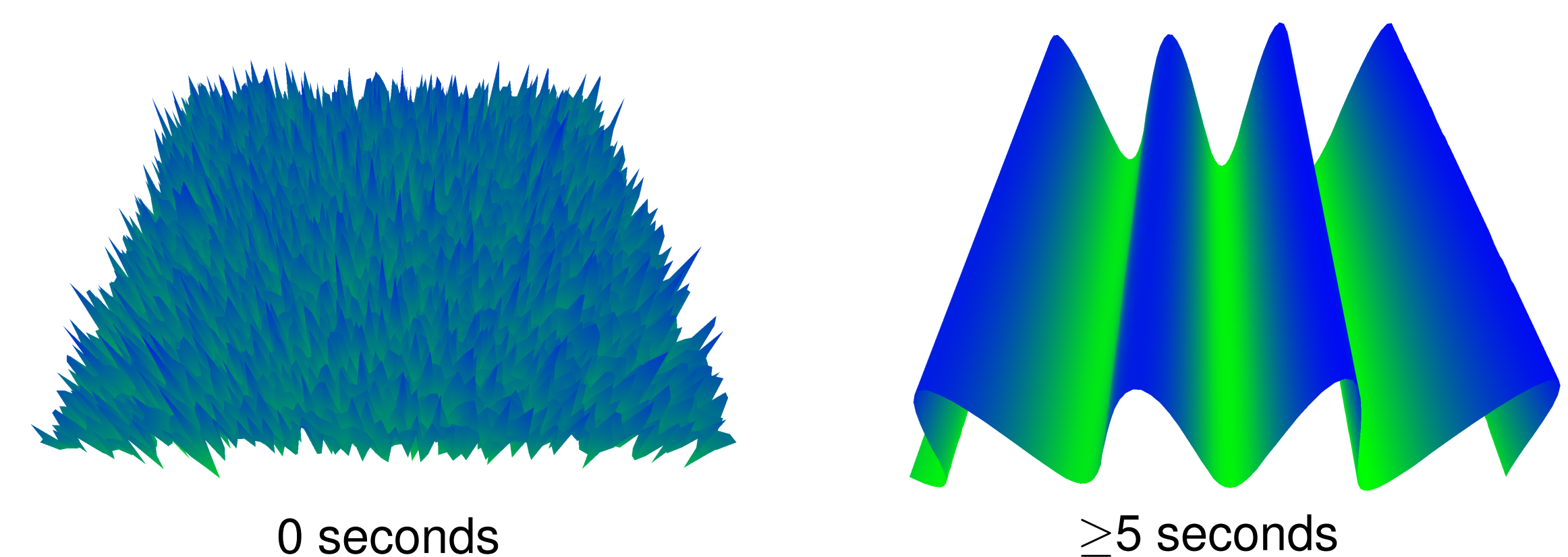


Figure 2: A smooth constant Turing pattern exists from noise after 5 seconds.

Alternating Roll

Reference [1] presents an alternating roll solution (Fig. 3) with descriptions of the following values: $dt=0.02$, $\gamma=2$, $\eta=1$, $l=40.3805226$, $n=512$, $k_c=1.0891958379832$, $\omega_c=3.4003003526352$, $V(t=0)=3+0.4 \sin(k_c a)$, $U_{excite}=0.4\omega_c \cos(k_c b)$, $l=2.5$, $K=\frac{121e^{-x}-235.2e^{-1.4x}}{2\pi}$, $S=\frac{1}{1+e^{-2.856(V-3)}}$ and finite $c=6$.

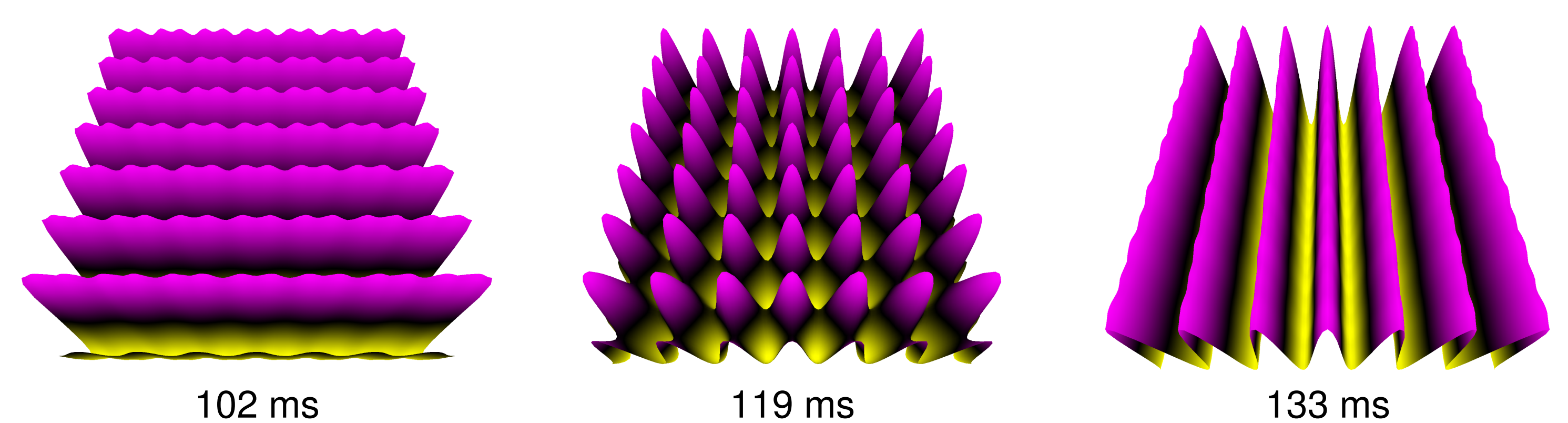


Figure 3: A stable alternating roll continuously transforms between horizontal and vertical line patterns every ≈ 31 milliseconds.

Acknowledgments

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References

- [1] <http://nfsimulator.gforge.inria.fr>
- [2] A. Hutt and N. Rougier. Activity spread and breathers induced by finite transmission speeds in two-dimensional neural fields, *Physical Review E* 82 (5):055701 (2010).
- [3] K.R. Green and A. Hutt. Dynamic square patterns in a two-dimensional neural field with finite transmission speed. *Society for Industrial and Applied Mathematics* (2015), Submitted for publication.