

Interesting muscle pathway knockouts, perturbations and potentiations on the C. elegans worm model

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1 Introduction

Openworm is the first large scale computational model which aims to mimic the *Caenorhabditis elegans* (*C. elegans*), a microscopic roundworm's neural structure. With only an approximately 1000 cells, this creature can solve obstacle detection, predator avoidance, feeding and mating. My goal is to apply knock-outs, perturbations and potentiations to the model and look for "mutated" offsprings which are in some form more interesting than the original model.

I will also showcase my facade script system which allows the testing and analyzing of the perturbations, knockouts and potentiations. The system also contains a movement analysis module which can determine the characteristics of the mutated variant based on movement.

I also propose a ranking system for the mutated variants of the *C. elegans* worm which can also be applied in different species of worms and even insects.

2 Terminology and Neural Network Interpretation

This section defines the terminology used throughout the OpenWorm movement analysis and provides a neural-network interpretation of locomotion phenotypes. In this framework, locomotion is treated as the emergent output of a distributed sensorimotor network in which sensory neurons, interneurons, motor neurons, neuromuscular junctions, muscles, and the mechanical body interact dynamically. Consequently, a behavioral phenotype such as backward crawling or hyperkinetic movement is an observable consequence of changes somewhere within this network rather than necessarily identifying a single defective connection.

2.1 General Interpretation Framework

The locomotor nervous system can be represented abstractly as a directed weighted network,

$$\mathbf{x} * t + 1 = F(\mathbf{W}\mathbf{x} * t + \mathbf{I}_t, \boldsymbol{\theta}), \quad (1)$$

where $\mathbf{x} * t$ represents neuronal activity at time t , $\mathbf{W}$ represents effective synaptic connectivity, $\mathbf{I} * t$ represents sensory and other external inputs, and $\boldsymbol{\theta}$ represents neuronal parameters such as thresholds, gains, time constants, and adaptation parameters. Motor output is subsequently transformed through neuromuscular coupling and body mechanics into the measured trajectory.

Within this interpretation, three classes of neural manipulation are particularly useful:

- **Knockout:** Removal or functional silencing of a neuron, connection, synapse, receptor, or other network component. In a connectivity model, this can be represented by setting an affected connection weight to zero,

$$W_{ij}^{\text{KO}} = 0. \quad (2)$$

A neuronal knockout may alternatively be represented by suppressing the neuron’s output entirely.

- **Perturbation:** A partial or otherwise non-baseline modification of network structure or neuronal dynamics. For a synaptic connection, this may be represented as

$$W_{ij}^{\text{perturbed}} = W_{ij}^0 + \Delta W_{ij}, \quad (3)$$

where W_{ij}^0 is the baseline connection strength and ΔW_{ij} is the imposed change. Perturbations may also modify thresholds, delays, membrane properties, sensory gain, or neuromuscular coupling.

- **Potentiation:** An increase in the effective influence of a neuronal connection or population. For a multiplicative potentiation,

$$W_{ij}^{\text{potentiated}} = \alpha W_{ij}^0, \quad \alpha > 1. \quad (4)$$

Potential can therefore increase the influence of excitatory drive, inhibitory drive, sensory feedback, or motor commands depending on the identity and sign of the affected connection.

These manipulations should not be interpreted as synonymous with behavioral outcomes. The same behavioral phenotype can arise from multiple network mechanisms, while a single neural manipulation can produce multiple behavioral changes through downstream propagation across the network. In the following section, I will propose a ranking system which can help ranking the mutants of the *C. elegans* into 4 distinct categories.

2.2 Locomotion State Terminology

2.2.1 Forward Crawling

Forward crawling describes sustained movement in the animal’s anatomically defined forward direction (Which by default is the openworm simulation’s left facing direction from the camera). At the neural-network level, forward locomotion generally corresponds to coordinated activation of motor pathways that generate a propagating body bend in the appropriate direction. In a simplified network representation, forward command interneurons provide descending or distributed drive to motor neurons, while proprioceptive feedback helps maintain the phase relationship between neighboring body segments.

A reduction in forward-crawling fraction can therefore result from weakened forward command connections, excessive competing backward drive, impaired sensory feedback, or disruption of motor-neuron coordination.

2.2.2 Backward Crawling

Backward crawling describes sustained locomotion opposite to the normal forward direction. In a neural-network interpretation, backward crawling indicates that the network is preferentially producing the motor pattern associated with reverse locomotion.

A simplified interpretation is

$$D_{\text{backward}} > D_{\text{forward}}, \quad (5)$$

where D denotes the effective network drive toward the corresponding locomotor state.

2.2.3 Stationary State

Stationary denotes periods in which translational movement falls below the analyzer’s movement threshold. Neurally, this can correspond to low motor output, balanced opposing motor commands, insufficient command drive, or a mechanical state in which neural activity does not produce appreciable translation.

A stationary phenotype may therefore arise either from reduced network activation or from excessive cancellation between opposing pathways.

2.2.4 Reversal

A **reversal** is a transition between forward and backward locomotor states. Reversals require coordinated reconfiguration of the locomotor network rather than merely changing the sign of instantaneous velocity.

In network terms, a reversal can be represented as a transition between competing motor-state attractors,

$$\mathcal{A} * \text{forward} \longleftrightarrow \mathcal{A} * \text{backward}. \quad (6)$$

The reversal frequency is therefore informative about the stability of these states and the threshold for switching between them. Excessive reversal can indicate unstable command-state competition, altered inhibitory gating, or abnormally strong sensory feedback.

2.2.5 Omega Turns

Omega turns are large-amplitude turning events in which the body adopts an approximately Ω -shaped configuration. They require coordinated modulation of body-wall motor neurons and substantial dorsoventral asymmetry.

A reduction in omega turns may indicate impaired turning command pathways, insufficient asymmetric motor drive, or disrupted propagation of the motor pattern along the body.

2.2.6 Shallow Turns

Shallow turns are lower-amplitude changes in trajectory that do not constitute a full omega turn. They can arise from smaller imbalances between dorsal and ventral motor activity or from modulation of the undulatory wave.

2.2.7 Irregular / Abnormal Locomotion

Irregular / abnormal locomotion describes trajectories that do not satisfy the expected criteria for normal forward, backward, stationary, or turning states. At the network level, this category is particularly relevant to manipulations that disrupt temporal coordination, phase relationships, or sensory-motor feedback.

2.3 Kinematic and Velocity Terminology

2.3.1 Net Displacement

Net displacement is the magnitude of the overall change in position between the beginning and end of the analyzed trajectory. It measures the resulting translational progress rather than the total amount of movement.

A low net displacement can occur despite substantial internal motor activity if the animal repeatedly changes direction or if opposing movements cancel.

2.3.2 Gross Distance

Gross distance is the total distance traveled along the measured trajectory. Unlike net displacement, it captures movement regardless of whether that movement ultimately contributes to progress toward a final position.

The relationship

$$\text{Path Efficiency} = \frac{\text{Net Displacement}}{\text{Gross Distance}} \quad (7)$$

provides a measure of how directly movement is translated into net progress.

2.3.3 Path Efficiency

Path efficiency ranges from approximately 0 to 1. A value near 1 indicates that most movement contributes directly to net displacement, whereas a low value indicates inefficient movement, such as excessive reversals, turning, or lateral wandering. (Note that a near 1 value is very unlikely because of the undulatory wave movement.)

From a neural-network perspective, reduced efficiency can reflect poor coordination between command pathways and the distributed motor program. (Compared to the real movement of a *C. elegans*)

2.3.4 Mean Speed

Mean speed is the average magnitude of translational velocity over the analyzed interval. It measures how rapidly the animal moves without inherently specifying the direction of movement.

2.3.5 Forward and Backward Velocity

Forward velocity and **backward velocity** describe the signed translational velocity relative to the animal’s anatomical orientation. The sign convention must be preserved when interpreting these values: a negative “maximum forward velocity” does not necessarily mean that the animal possesses a negative physical speed but it may indicate that the reported forward-axis velocity was directed backward.

For this reason, signed velocity metrics should always be interpreted together with the analyzer’s state classification.

2.3.6 Median Velocity

The **median velocity** is the midpoint of the velocity distribution and is less sensitive to extreme values than the mean. A substantial difference between mean and median velocity can indicate skewed or intermittent movement dynamics.

2.3.7 Velocity Standard Deviation

Velocity standard deviation measures temporal variability in velocity. High values indicate that the locomotor output is fluctuating strongly rather than remaining at a stable speed.

In a neural network, such fluctuations can emerge from unstable recurrent dynamics, rapid state transitions, abnormal sensory feedback, or excessive modulation of motor output.

2.3.8 Velocity RMS

Velocity root-mean-square measures the overall magnitude of velocity while emphasizing larger deviations. It is useful when comparing locomotor activity even when the signed mean velocity is close to zero.

2.3.9 Fraction of Time Moving

The **fraction of time moving forward**, **fraction of time moving backward**, and **fraction of time stationary** describe the proportion of analyzed frames or time intervals assigned to each locomotor direction.

These measurements provide a direct behavioral readout of the relative occupancy of competing network states.

2.3.10 Acceleration

Mean acceleration measures the average temporal rate of change in velocity. **Maximum acceleration** captures the strongest instantaneous acceleration, while **acceleration RMS** summarizes the overall magnitude of acceleration fluctuations.

Extremely high acceleration values can indicate rapid changes in inferred body position or velocity. They should therefore be interpreted in conjunction with the temporal resolution and numerical filtering of the trajectory data.

2.3.11 Velocity Autocorrelation

Velocity autocorrelation measures how strongly velocity at one point in time predicts velocity at later time points. A high value indicates temporally persistent locomotor dynamics.

In network terms, high autocorrelation is consistent with a relatively stable dynamical regime, whereas low autocorrelation can indicate rapid state transitions, noisy motor output, or disrupted recurrent coordination. A high autocorrelation can also occur if the network’s locomotor system is immobilized.

2.3.12 Reversal Frequency

Reversal frequency measures the rate at which the locomotor direction changes. A high value may indicate unstable competition between forward and backward

command states. A slightly high value may appear because the simulations take only approximately 1 seconds.

2.3.13 Mean Curvature

Mean curvature quantifies the degree to which the animal’s trajectory or body centerline bends. Higher curvature indicates stronger bending.

At the neural level, curvature is closely related to differential activation of dorsal and ventral motor pathways. If the effective drive to one side of the body exceeds the other,

$$A_{\text{dorsal}} \neq A_{\text{ventral}}, \quad (8)$$

the resulting torque produces body bending.

2.3.14 Omega Turn Count

Omega turn count is the number of detected omega-shaped turning events. A value of zero indicates that no trajectory satisfied the analyzer’s omega-turn criteria during the analyzed interval.

2.4 Undulation Wave Mechanics

2.4.1 Crawl Amplitude

Crawl amplitude describes the magnitude of rhythmic body bending during locomotion. In a neural-network interpretation, amplitude depends on the magnitude of motor-neuron activation, muscle responsiveness, and mechanical coupling between adjacent body segments.

Reduced amplitude can result from weakened motor drive, reduced muscle activation, impaired neuromuscular transmission, or excessive inhibitory influence.

2.4.2 Dominant Frequency

The **dominant frequency** is the strongest periodic component detected in the locomotor signal. It represents the characteristic temporal rhythm of the measured undulatory behavior.

A change in dominant frequency can result from altered oscillatory dynamics within the locomotor network, including changes in synaptic delays, recurrent excitation/inhibition, neuronal time constants, or sensory-feedback gain.

2.4.3 Wavelength

Wavelength is the spatial distance associated with one complete cycle of the propagating body-bending wave.

A simplified traveling-wave representation is

$$\theta(s, t) = A \sin \left(\frac{2\pi s}{\lambda} - 2\pi f t + \phi \right) \quad (9)$$

where A is amplitude, λ is wavelength, f is frequency, and ϕ is phase.

2.4.4 Wave Velocity

Wave velocity is the propagation speed of the undulatory wave along the body. In an idealized traveling-wave system,

$$v_{\text{wave}} = f\lambda. \quad (10)$$

Thus, changes in either dominant frequency or wavelength can alter the propagation velocity of the motor pattern.

2.4.5 Phase Coherence

Phase coherence measures how consistently different portions of the body maintain their expected phase relationship during undulation. High coherence indicates an organized propagating motor wave.

Reduced coherence can therefore be interpreted as a breakdown in network synchronization.

2.4.6 Mean Muscle Activation

Mean muscle activation represents the average inferred activation of the musculature. It is a downstream quantity and should not automatically be equated with neural activity.

A useful conceptual relationship is

$$M(t) = G_{\text{NMJ}}(A_{\text{motor}}(t)), \quad (11)$$

where A_{motor} is motor-neuron output and G_{NMJ} represents neuromuscular transmission and muscle response.

2.4.7 Mean Hydrodynamic Pressure

Mean hydrodynamic pressure represents the average fluid-pressure contribution associated with the simulated environment. In a fluid-coupled simulation, pressure and drag provide mechanical feedback to the body and therefore indirectly influence the neural-to-behavioral mapping.

Note that a zero value should not automatically be interpreted as evidence that the animal experiences no mechanical resistance.

2.5 Phenotype Severity Terminology

2.5.1 Phenotype Severity

Phenotype severity is an aggregate score intended to quantify deviation from a defined baseline phenotype. The score should be understood as the analyzer-specific metric rather than a universal biological scale.

A useful conceptual formulation is

$$S_{\text{overall}} = \sum_{k=1}^N w_k S_k \quad (12)$$

where S_k is the severity of phenotype domain k and w_k is its weighting factor.

2.5.2 Locomotion Severity

Locomotion severity quantifies abnormality in translational movement, including failure to move, incorrect direction, abnormal speed, or inefficient progression.

2.5.3 Turning Severity

Turning severity measures abnormalities in the ability to initiate, execute, or terminate turning behaviors.

2.5.4 Undulation Severity

Undulation severity represents deviations in wave amplitude, frequency, wavelength, propagation, or phase organization.

2.5.5 Muscle Output Severity

Muscle output severity measures abnormalities in the magnitude or temporal organization of inferred muscle activation. High severity may result from altered motor-neuron drive, neuromuscular transmission, or muscle responsiveness.

2.5.6 Symmetry Severity

Symmetry severity measures deviation from expected bilateral or dorsoventral symmetry. A high value can indicate strongly unbalanced activation between opposing motor pathways.

For example,

$$S_{\text{symmetry}} \propto |A_{\text{dorsal}} - A_{\text{ventral}}|. \quad (13)$$

The exact relationship depends on the implementation of the analyzer.

2.6 Diagnostic Classification

The labels below describe the full spectrum of phenotypic classifications evaluated by the movement analysis engine:

- **PARALYTIC:** Characterized by near-zero movement speed and minimal muscle activity output (<0.001 relative units).
- **NEAR-PARALYTIC:** Exhibits extremely suppressed mobility and speed thresholds consistently below the minimal baseline.
- **HYPOKINETIC:** Phenotype marked by sluggish, reduced overall movement speed and restricted kinematic range.
- **HYPERKINETIC:** Characterized by excessive, abnormally variable, or poorly regulated movement dynamics (distinguished from simply having a high mean speed).
- **BACKWARD-BIASED:** Dominated by persistent reverse locomotion patterns where the backward crawl time fraction exceeds 50%.
- **TURNING-BIASED:** Exhibits excessive steering behavior, frequent omega turns (> 5 counts), or high shallow-turn distribution percentages ($> 40\%$).
- **OSCILLATORY/UNSTABLE:** Marked by low wave phase coherence (< 0.4) or velocity standard deviation exceeding twice the mean speed.
- **NORMAL:** Standard wildtype-like locomotion patterns without significant kinematic defects.

$$\text{Motor Output} \approx f(E - I + \text{Feedback}), \quad (14)$$

where E represents effective excitatory drive and I represents effective inhibitory drive.

Thus, increasing excitation and decreasing inhibition can produce superficially similar behavioral phenotypes even though the underlying neural manipulations are different.

2.7 Knockouts in a Neural Connectivity Model

A **knockout** represents the removal or functional silencing of a network component.

For a connection from neuron i to neuron j ,

$$W_{ji}^0 \rightarrow W_{ji}^{\text{KO}} = 0. \quad (15)$$

For a neuronal knockout, the activity of neuron i can instead be constrained as

$$x_i(t) = 0. \quad (16)$$

The behavioral consequence depends on the network position of the removed component.

- **Sensory-neuron knockout:** Removes or reduces a source of environmental or proprioceptive information. Expected consequences include impaired feedback, altered state transitions, or reduced behavioral responsiveness.
- **Interneuron knockout:** Removes an intermediate computation or command pathway. This can disrupt gating between forward, backward, turning, and other behavioral states.
- **Motor-neuron knockout:** Removes part of the motor command distributed to the body. This can produce localized weakness, altered curvature, or asymmetry.
- **Synaptic knockout:** Removes a particular directed influence while leaving both neurons otherwise intact. This is especially useful for identifying causal connections within the locomotor circuit.
- **Neuromuscular knockout:** Removes the effective transmission from motor neurons to muscle. Neural activity may remain present while mechanical output is strongly reduced.

Importantly, knockout effects may be nonlinear. Removing one connection can cause a small phenotype if redundant pathways compensate, while removal of a highly central connection can produce a large behavioral change.

2.8 Perturbations in a Neural Connectivity Model

A **perturbation** represents a controlled departure from the baseline network. Unlike a knockout, a perturbation does not necessarily eliminate the affected component.

Examples include

$$W_{ij} \rightarrow W_{ij} + \Delta W_{ij}, \quad (17)$$

or modification of neuronal parameters,

$$\tau_i \rightarrow \tau_i + \Delta\tau_i, \quad \theta_i \rightarrow \theta_i + \Delta\theta_i, \quad (18)$$

where τ_i is a neuronal time constant and θ_i is an activation threshold. Perturbations may therefore represent changes in:

- synaptic strength;
- synaptic sign or effective balance;

- neuronal excitability;
- firing threshold;
- adaptation;
- synaptic delay;
- sensory gain;
- inhibitory or excitatory feedback;
- neuromuscular transmission;
- muscle responsiveness; or
- environmental coupling.

Perturbation experiments are particularly useful for identifying whether a phenotype is sensitive to the magnitude of a connection rather than simply its presence or absence.

2.9 Potentiation in a Neural Connectivity Model

Potentiation is a directional increase in the effective influence of a network component. For a connection $i \rightarrow j$,

$$W_{ji}^{\text{pot}} = \alpha W_{ji}^0, \quad \alpha > 1 \quad (19)$$

For an excitatory connection, potentiation generally increases downstream excitation. For an inhibitory connection, potentiation increases inhibition and can therefore decrease the activity of the target neuron.

This distinction is critical:

$$\text{Potentiated excitatory connection leads to increased target drive,} \quad (20)$$

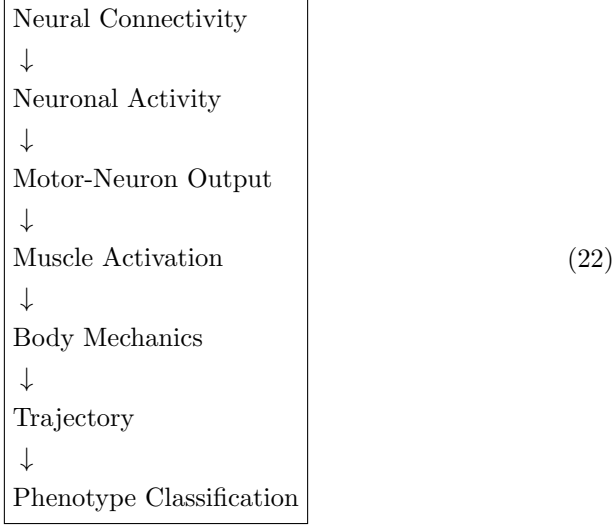
whereas

$$\text{Potentiated inhibitory connection leads to decreased target drive.} \quad (21)$$

Therefore, ‘potentiation’ should never be interpreted universally as ‘more movement.’ Its effect depends on the identity, sign, timing, and network context of the connection being potentiated.

2.10 Recommended Interpretation of Analyzer Outputs

The analyzer’s measurements can be organized into a causal hierarchy:



Accordingly, a behavioral metric should not automatically be interpreted as a direct measurement of a neural connection. For example, a high backward-crawling fraction is an observable behavioral consequence; it is not itself a measurement of the strength of a backward-command synapse.

The strongest causal interpretation is obtained by comparing a manipulated run with a matched baseline and examining how the manipulation changes multiple levels of the hierarchy. A useful experimental comparison is therefore:

$$\Delta M = \frac{M_{\text{KO/perturbed/potentiated}}}{M_{\text{baseline}}} \quad (23)$$

where M represents any analyzer metric.

Large, coherent changes across locomotion state, velocity, curvature, undulation, muscle output, and symmetry provide stronger evidence for a systematic network effect than a change in a single metric alone.

2.11 Summary of Terminology

Table 1: Summary of Behavioral Metrics and Their Neural-Network Interpretation

Term	Interpretation
Forward Crawling	Occupancy of the forward locomotor network state.
Backward Crawling	Occupancy of the reverse locomotor network state.
Stationary	Low translational motor output or balanced opposing drives.
Reversal	Transition between competing locomotor states.
Omega Turn	Large-amplitude coordinated turning motor program.
Shallow Turn	Lower-amplitude asymmetric motor output producing trajectory curvature.
Net Displacement	Overall translational consequence of the motor program.
Gross Distance	Total trajectory length generated by movement.
Path Efficiency	Fraction of movement contributing to net progress.
Velocity	Instantaneous translational output of the locomotor system.
Acceleration	Rate of change of translational motor output.
Velocity Autocorrelation	Temporal persistence of locomotor dynamics.
Curvature	Degree of body/trajectory bending resulting from asymmetric motor activity.
Amplitude	Magnitude of the body-bending motor pattern.
Frequency	Temporal rate of the repeating locomotor rhythm.
Wavelength	Spatial scale of one undulatory cycle.
Wave Velocity	Propagation rate of the locomotor wave.
Phase Coherence	Consistency of timing between distributed body segments.
Muscle Activation	Downstream mechanical output of motor-neuron activity.
Phenotype Severity	Aggregate deviation from the defined baseline phenotype.
Knockout	Functional removal of a neuron, connection, or network component.
Perturbation	Partial modification of connectivity or neuronal parameters.
Potentiation	Increase in effective influence of a network component.

3 Proposal for classifying mutations

I propose a system which ranks the mutated offsprings in 4 quartiles of the final ranking between 0 to 10, where X is the final ranking number:

1. ($0.0 \leq X < 2.5$) **Infantile mutant**: The mutations classified here perform way worse than the baseline model. Most commonly they are immobilized by the mutation or have very low net displacement value.
2. ($2.5 \leq X < 5.0$) **Slightly degenerate**: The mutations classified here perform only a little worse than the baseline model. Mutations which reach slightly smaller score in the defined categories will be assigned in this ranking category.
3. ($5.0 \leq X < 7.5$) **Suitable offspring**: The mutations classified here perform a little better than the baseline model. Mutations which reach slightly higher score in the defined categories will be assigned in this ranking category.
4. ($7.5 \leq X \leq 10.0$) **Suitable, but infeasible offspring**: The mutations classified here perform a lot better than the baseline model but in order for them to occur in nature, they would first need to have degenerate traits which nature generally does not allow. Mutations which reach the highest scores in the defined categories and overall scores will be assigned in this ranking category.

This ranking is weighted around the fact, that the baseline model achieves a near $X = 5.0$ value.

You may notice that the higher the value in the code, the more it means an anomaly yet the distribution of the offspring lurk near 5.0. This is due to the fact that some anomalies are cancelling out. For example the Body Mechanics and Motor-Neuron Output cancel out. But furthermore this is based on empirical measurement and there is no way of me proving it as this is trivial.

4 Simulation environment

I have set up a custom simulation environment which allows the ease of trying multiple combinations of knockoffs, perturbations or potentiations. Note, that this framework is merely a facade which communicates with the Openworm instance preset docker container. It can be used to extract and override the siberetic file. The framework will also generate a movement analysis and based on the analysis script configuration, it will spit out the rating from 0 to 10 in the prespecified standard. It uses modified master and running batch scripts from the Openworm installation 0.9.8 version. <https://github.com/openworm/OpenWorm/releases/tag/0.9.8>

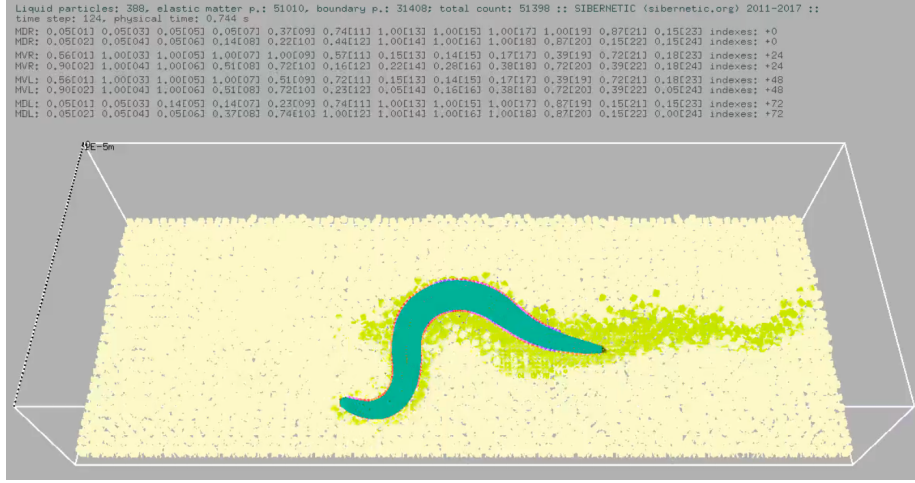


Figure 2: An example media generated by the simulation and display program about the *C. elegans* worm.

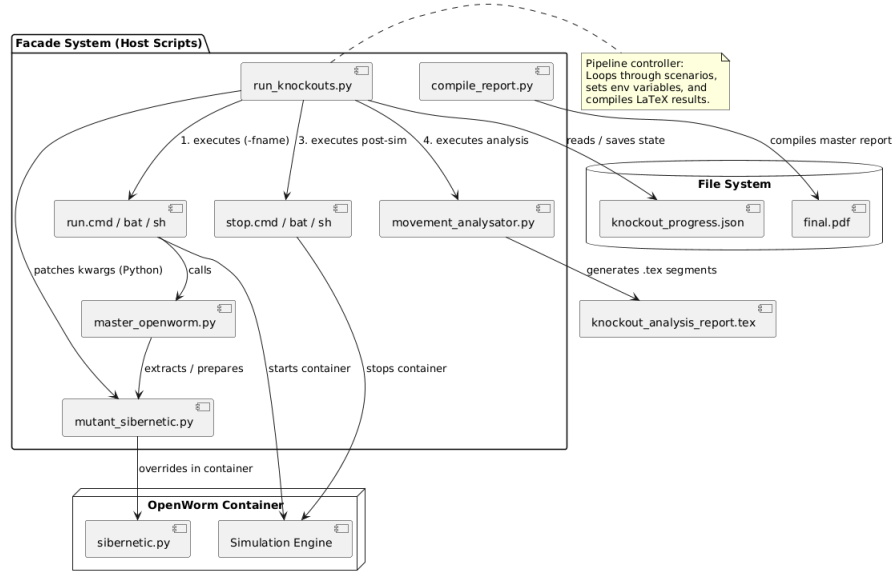


Figure 1: A basic connection and purpose can be seen for each module here.

5 Simulation Parameters and Experimental Setup

To investigate the effects of neural knockout and perturbation experiments on *Caenorhabditis elegans* using the OpenWorm framework, specific numerical and

simulation parameters were established. The core configuration parameters utilized in the simulation runs are summarized in Table 2.

Table 2: Simulation parameters used for the OpenWorm knockout/perturbation experiments.

Parameter	Value / Setting	Description
duration	sim_duration (1.0 s)	Total simulation duration per run
dt	0.015 s (Range: 0.01–0.015 s)	Integration time step
dtNrn	0.08 s	Neuron simulation time step
logstep	400	Data logging interval
reference	"FW"	Muscle/movement reference
c302params	"C2"	Network parameter set
verbose	False	Verbose output flag
device	"GPU"	Computational execution device
configuration	configuration	System configuration profile
noc302	noc302	Custom network flag
datareader	UpdatedSpreadsheetDataReader2	Data reader backend
outDir	OW_OUT_DIR	Output directory for simulation logs

Table 3: c302 network reference configurations

Reference string	File	What it contains (summary)	Notes
FW	c302_FW.py	Forward locomotion circuit (AVB, DB, VB, DD, VD + muscles)	Small, focused on crawling. Does not contain AVA or RME.
Muscles	c302_Muscles.py	Large set of motor/interneurons that connect to body-wall muscles + AVAL / AVAR / AVBL / AVBR / AVDL / AVDR / PVCL / PVCR + muscles	Contains AVAL, AVAR, RMEL, RMER (and many others). This is what the simulation will use.

Continued on next page

Table 3 – continued from previous page

Reference string	File	What it contains (summary)	Notes
Full	c302_Full.py	Essentially the whole hermaphrodite nervous system (≈ 302 neurons) + muscles	Largest / most complete.
Pharyngeal	c302_Pharyngeal.py	Pharyngeal nervous system only (M1–M5, I1–I6, etc.)	Feeding circuit.
Social	c302_Social.py	Social behaviour related neurons	Smaller specialised circuit.
Oscillator	c302_Oscillator.py	Oscillator / rhythmic circuit	Used for testing rhythmic activity.
OscillatorM	c302_OscillatorM.py	Oscillator + muscles variant	—
Syns	c302_Syns.py	Focused on synaptic connections (test/example)	—
IClamp	c302_IClamp.py	Simple current-clamp examples (few cells)	Not a behavioural circuit.
IClampMuscle	c302_IClampMuscle.py	Current-clamp + muscle	—
TargetMuscle	c302_TargetMuscle.py	Targets specific muscles	—
TapWithdrawal	c302_TapWithdrawal.py	Tap-withdrawal circuit	—
RIA	c302_RIA.py	RIA-related circuit	—
MultiSyns	c302_MultiSyns.py	Multi-synapse examples	—
MuscleTest	c302_MuscleTest.py	Muscle testing	—
MusclesSine	c302_MusclesSine.py	Muscles network driven by sine-wave current (example)	Variant of Muscles.

5.1 Duration and Time-Step Justification

Each simulation was configured to run for a duration of 1.0 s. This duration was selected because a complete undulation cycle (body wave loop) of the worm is reliably visible across almost all experimental instances within this timeframe, capturing the full dynamic range of locomotion without unnecessary computational overhead.

The integration time step (dt) was set within the range of 0.01 s to 0.015 s (with a default specific setting of 0.015 s), balancing numerical stability and precision for the biomechanical and neural update cycles. Similarly, the neural network time step (dtNrn) was set to 0.08 s, ensuring accurate propagation of electrical activity across the c302 network architecture.

6 Simulated scenarios

I’ve split the scenarios to these main groups:

- important reciprocal command connections
- A-type motor neurons (core reversal pathway)
- B-type motor neurons
- Cross-talk between command interneurons
- AS motor neurons (also part of reversal output)
- Strength perturbations
- command system lesions

There are more groups which I will also denote.

I denote these groups in my `run_knockouts.py` file. The facade project can be downloaded here: https://afghangoat.hu/imports/src/mutator_facade/mutator_facade.zip

6.1 Movement Analysis: AVAL-DA1

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run `C2_Muscles_2026-08-10_16-33-32-AVAL-DA1`.

6.1.1 Locomotion State Classification

Table 4: Behavioral State Breakdown for AVAL-DA1

Locomotion State	Time Fraction (%)
Forward Crawling	17.6%
Backward Crawling	26.1%
Stationary	0.0%
Reversal	12.1%
Omega Turns	26.7%
Shallow Turns	17.6%
Irregular / Abnormal	0.0%

6.1.2 Kinematic & Velocity Dynamics

Table 5: Kinematic and Velocity Metrics for AVAL-DA1

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.033	mm
Gross Distance	0.1598	mm
Path Efficiency (Net/Gross)	0.2062	[0.0 – 1.0]
Mean Speed	0.1605	mm/s
Maximum Forward Velocity	0.741	mm/s
Maximum Backward Velocity	0.7642	mm/s
Median Velocity	0.0878	mm/s
Velocity Std Deviation	0.206	mm/s
Velocity RMS	0.2611	mm/s
Fraction Time Moving Forward	50.0%	ratio
Fraction Time Moving Backward	50.0%	ratio
Fraction Time Stationary	0.0%	ratio
Acceleration (Mean)	-0.4553	mm/s ²
Maximum Acceleration	168.7895	mm/s ²
Acceleration RMS	24.2722	mm/s ²
Velocity Autocorrelation	0.8273	correlation
Reversal Frequency	20.0803	s ⁻¹
Mean Curvature	3774.8456	rad/mm
Omega Turn Count	44	count

6.1.3 Undulation Wave Mechanics

Table 6: Undulation Wave Parameters for AVAL-DA1

Undulation Parameter	Value	Unit
Crawl Amplitude	0.0071	rad (bending)
Dominant Frequency	0.0	Hz
Wavelength	0.82	mm
Wave Velocity	0.0	mm/s
Phase Coherence	0.81	[0.0 – 1.0]
Mean Muscle Activation	0.789854	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.1.4 Worm Motion and Activity Figures

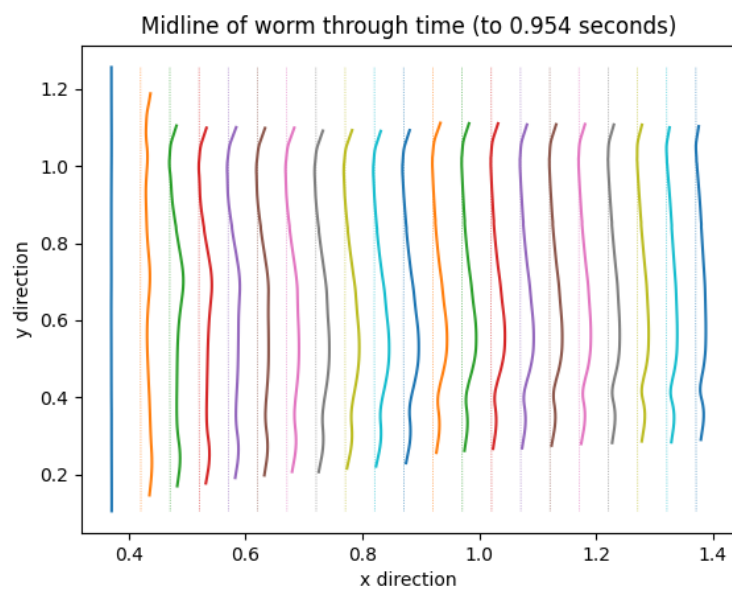


Figure 3: Midline of worm through time.

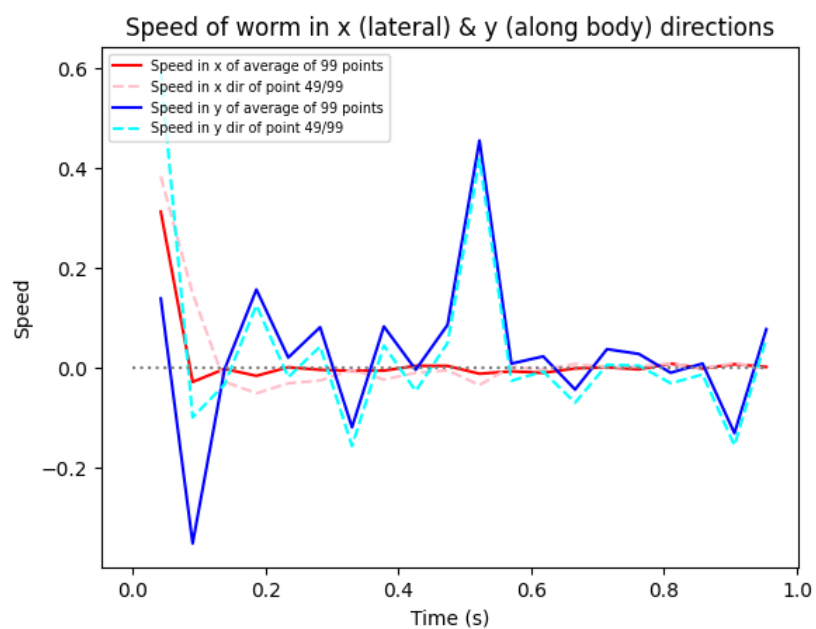


Figure 4: Speed of worm along body directions.

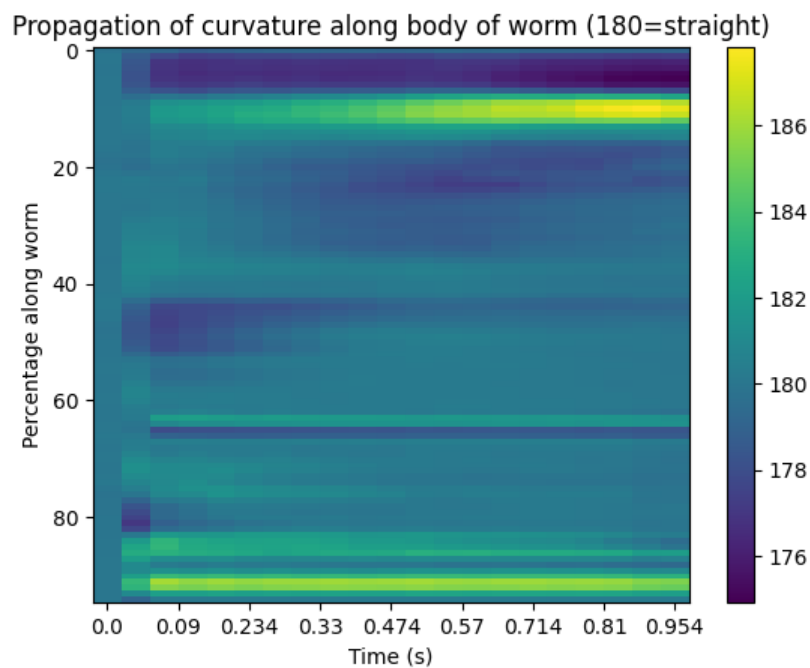


Figure 5: Propagation of curvature along body of worm.

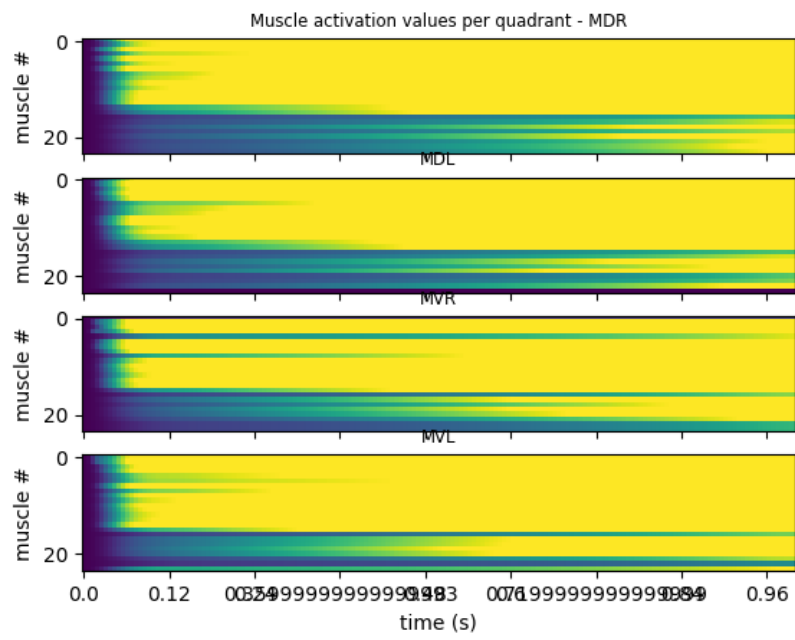


Figure 6: Muscle activities per quadrant.

6.1.5 Trace Figures

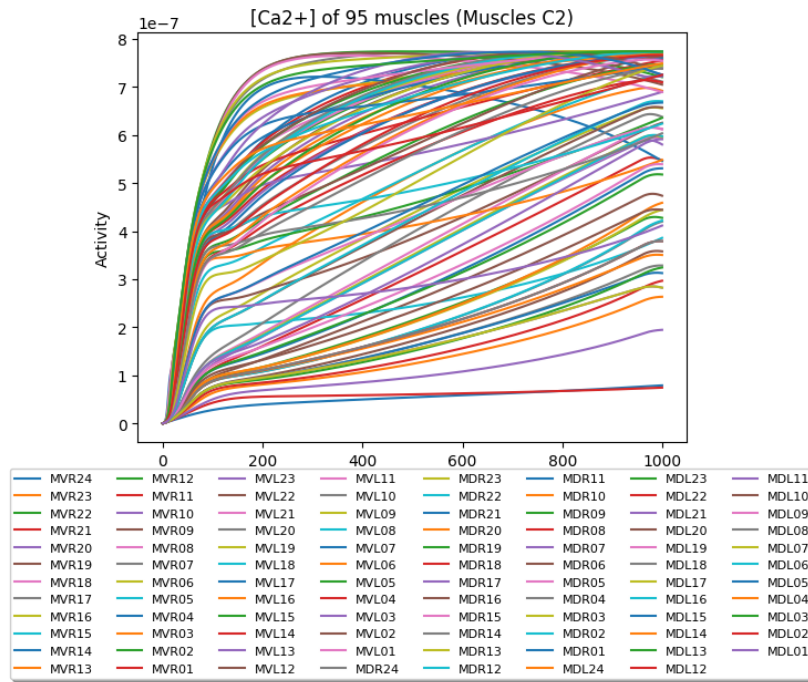


Figure 7: Traces of muscle activity and potentials.

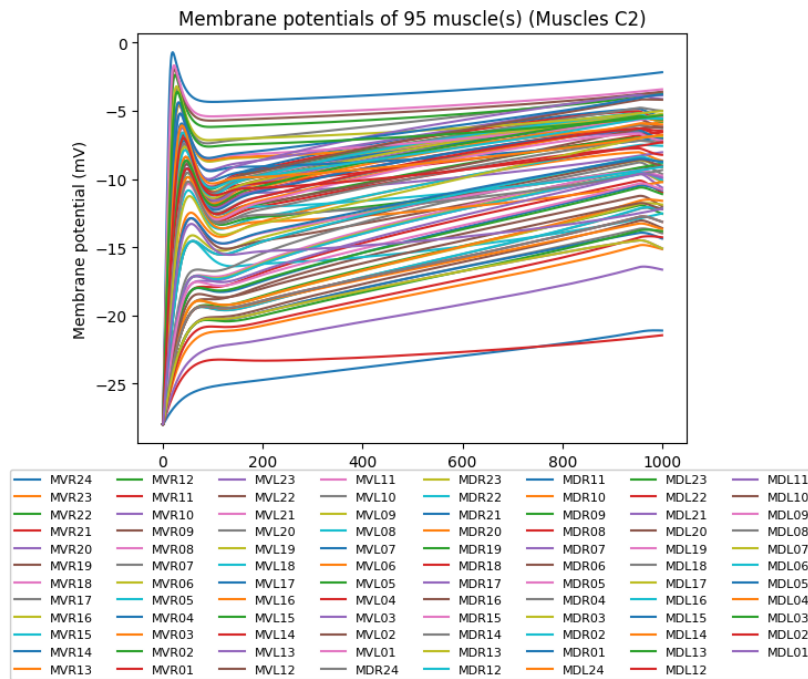


Figure 8: Traces of muscle activity.

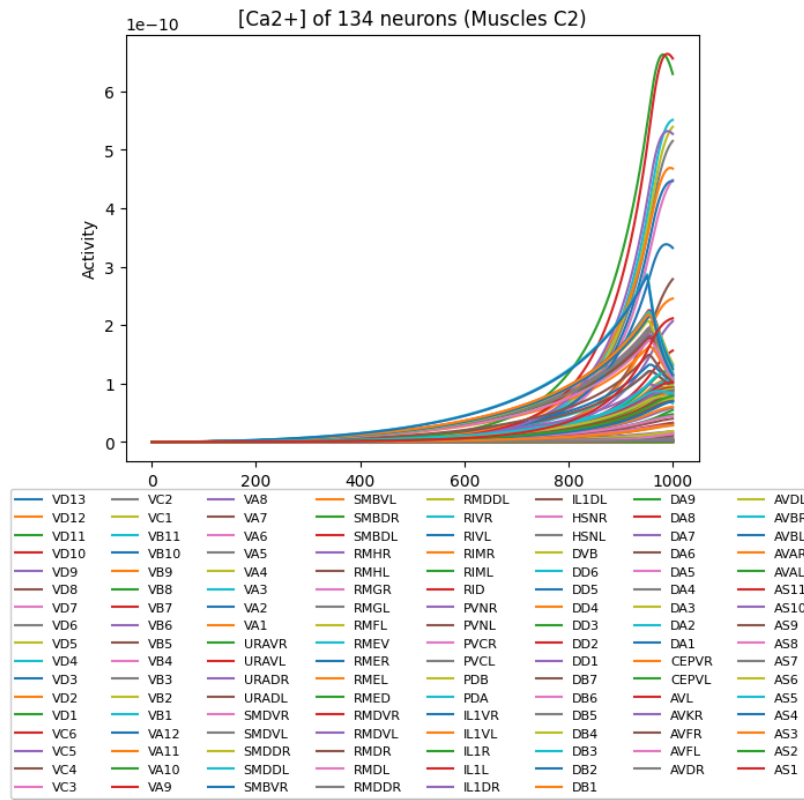
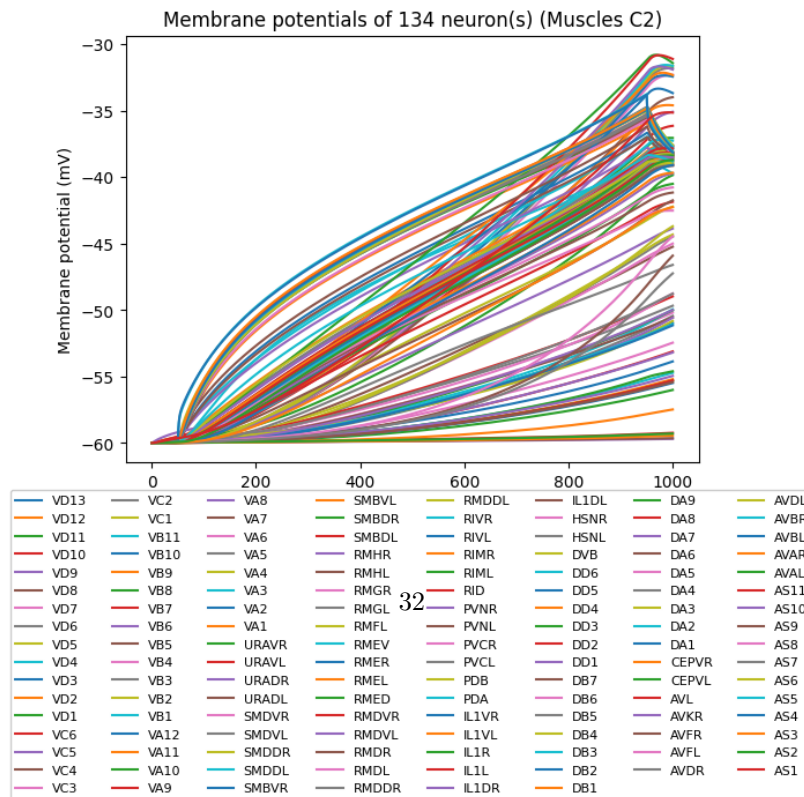


Figure 9: Traces of neuron activity and potentials.



6.1.6 Compact Morphology Grid

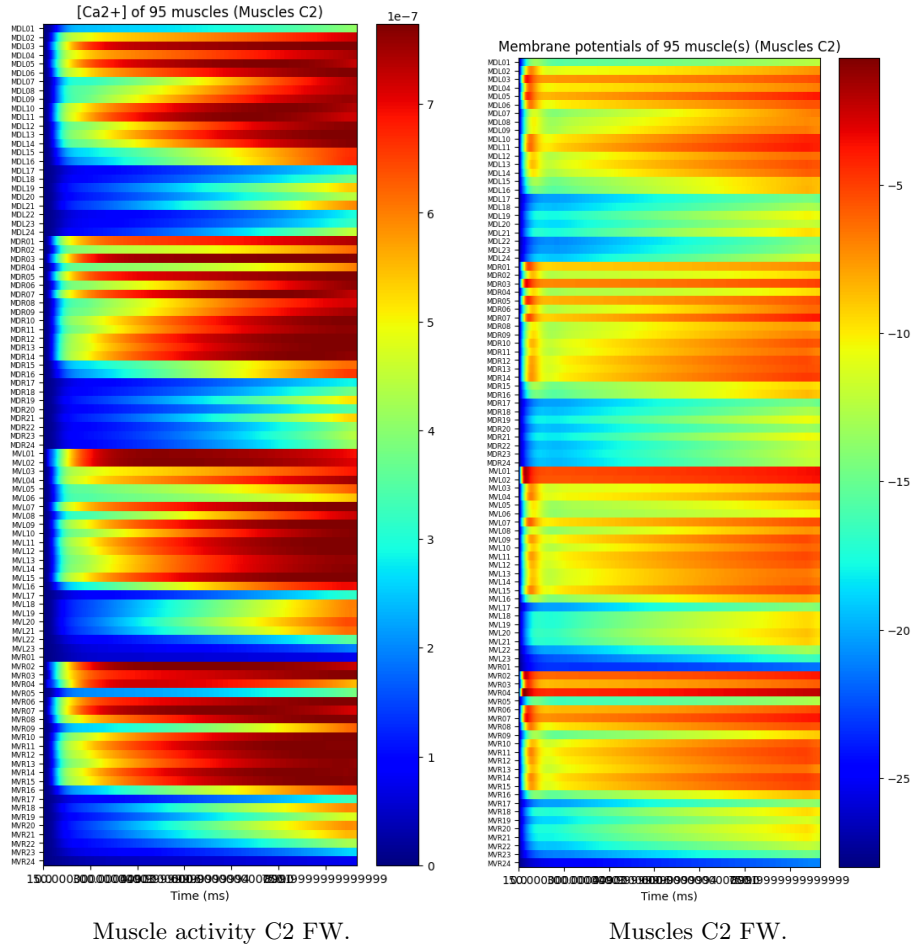


Figure 11: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).

6.1.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.4 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 7: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	1.9 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[-----]	0.0 / 10
Overall Severity	[====-----]	4.4 / 10

6.2 Movement Analysis: AVAR-DA1

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run C2_Muscles_2026-08-10_18-12-16-AVAR-DA1.

6.2.1 Locomotion State Classification

Table 8: Behavioral State Breakdown for AVAR-DA1

Locomotion State	Time Fraction (%)
Forward Crawling	9.1%
Backward Crawling	30.3%
Stationary	0.0%
Reversal	12.1%
Omega Turns	24.2%
Shallow Turns	24.2%
Irregular / Abnormal	0.0%

6.2.2 Kinematic & Velocity Dynamics

Table 9: Kinematic and Velocity Metrics for AVAR-DA1

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.0446	mm
Gross Distance	0.149	mm
Path Efficiency (Net/Gross)	0.2994	[0.0 – 1.0]
Mean Speed	0.1496	mm/s
Maximum Forward Velocity	0.6	mm/s
Maximum Backward Velocity	0.8391	mm/s
Median Velocity	0.0901	mm/s
Velocity Std Deviation	0.1876	mm/s
Velocity RMS	0.24	mm/s
Fraction Time Moving Forward	46.4%	ratio
Fraction Time Moving Backward	53.6%	ratio
Fraction Time Stationary	0.0%	ratio
Acceleration (Mean)	-0.326	mm/s ²
Maximum Acceleration	168.7897	mm/s ²
Acceleration RMS	22.11	mm/s ²
Velocity Autocorrelation	0.8317	correlation
Reversal Frequency	20.0803	s ⁻¹
Mean Curvature	3739.8273	rad/mm
Omega Turn Count	40	count

6.2.3 Undulation Wave Mechanics

Table 10: Undulation Wave Parameters for AVAR-DA1

Undulation Parameter	Value	Unit
Crawl Amplitude	0.0067	rad (bending)
Dominant Frequency	0.0	Hz
Wavelength	0.82	mm
Wave Velocity	0.0	mm/s
Phase Coherence	0.77	[0.0 – 1.0]
Mean Muscle Activation	0.789911	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.2.4 Worm Motion and Activity Figures

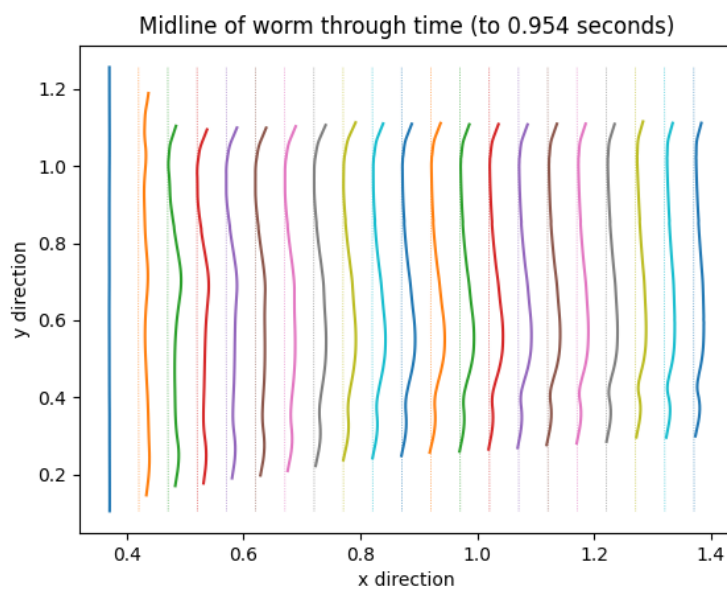


Figure 13: Midline of worm through time.

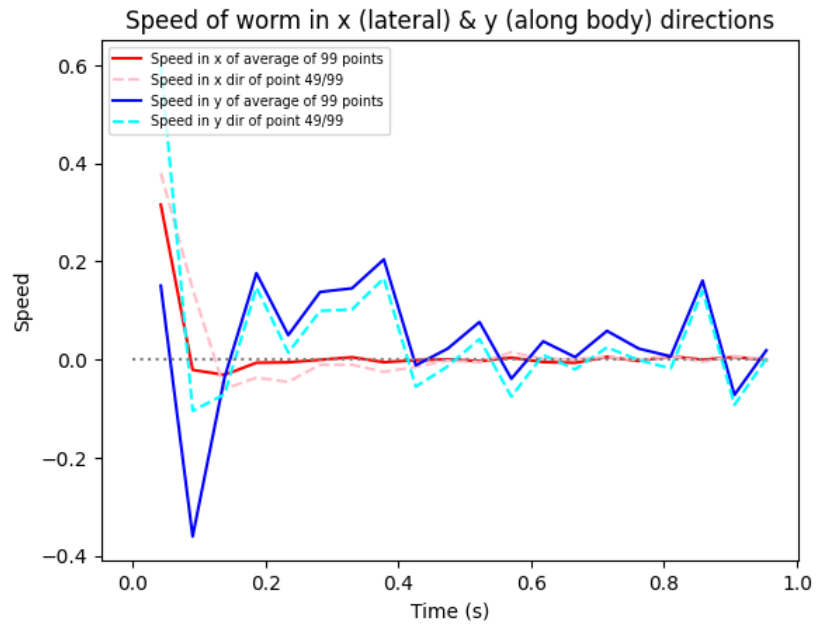


Figure 14: Speed of worm along body directions.

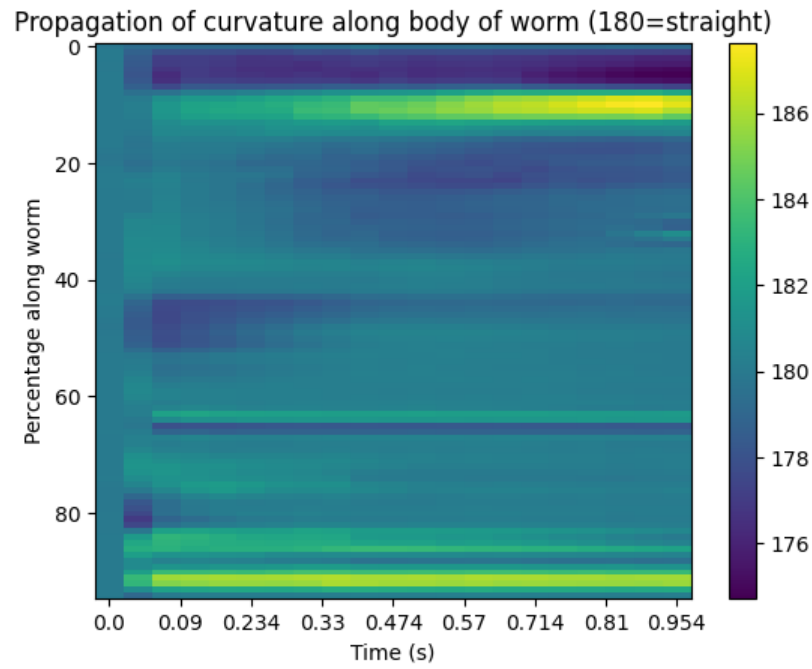


Figure 15: Propagation of curvature along body of worm.

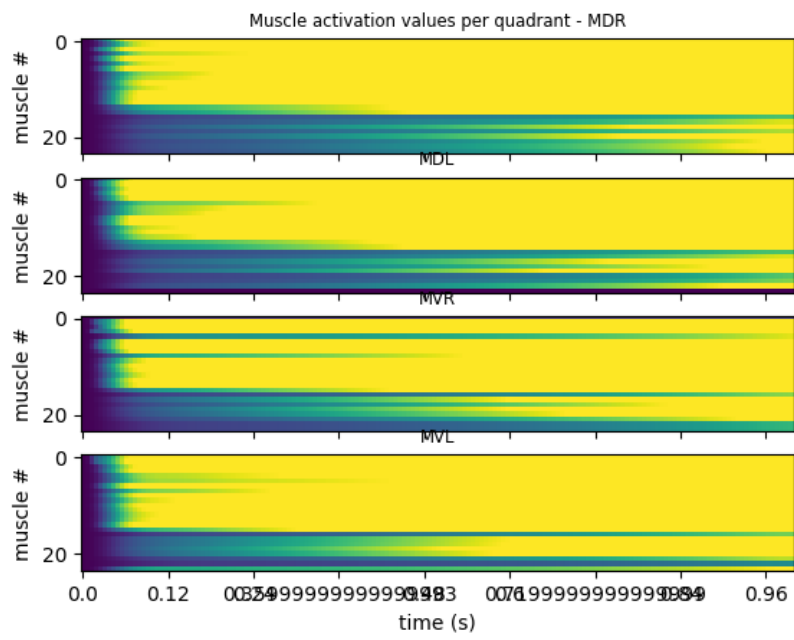


Figure 16: Muscle activities per quadrant.

6.2.5 Trace Figures

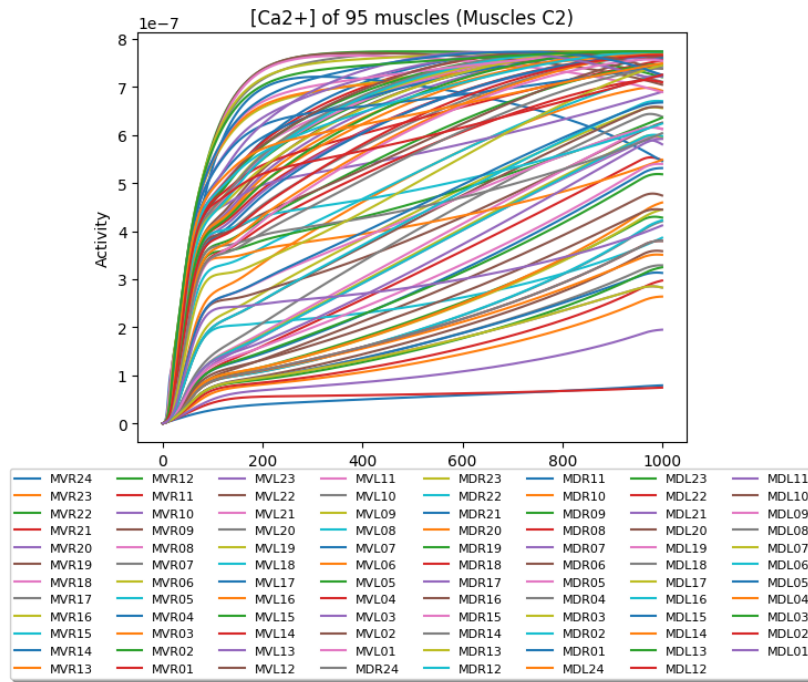


Figure 17: Traces of muscle activity and potentials.

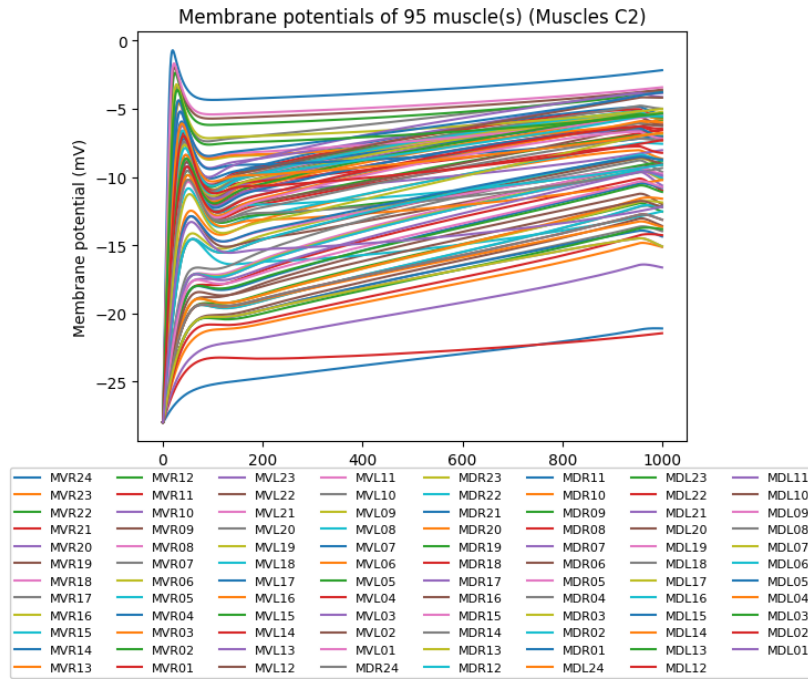


Figure 18: Traces of muscle activity.

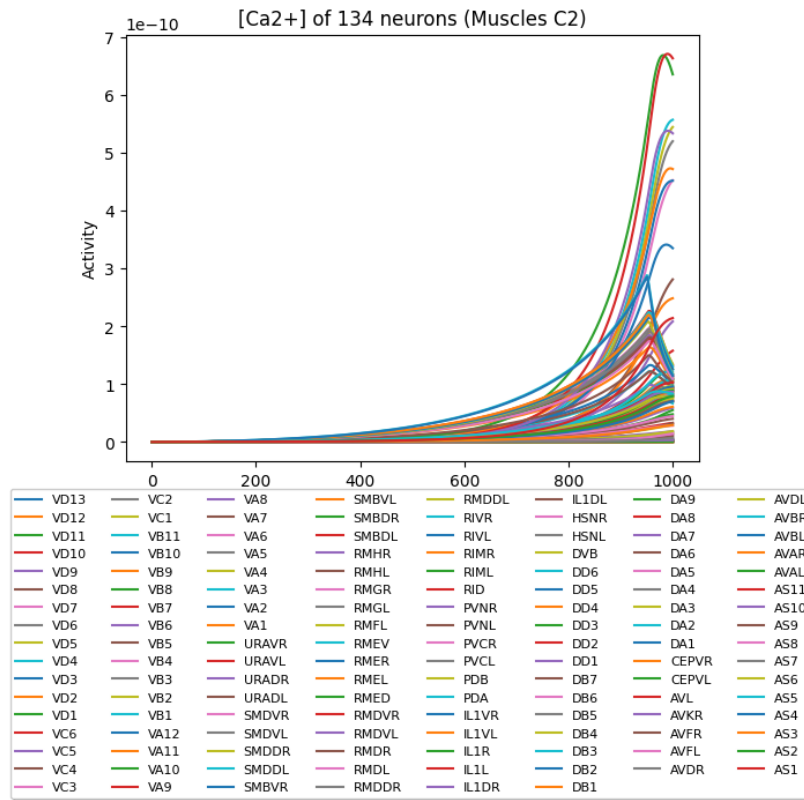
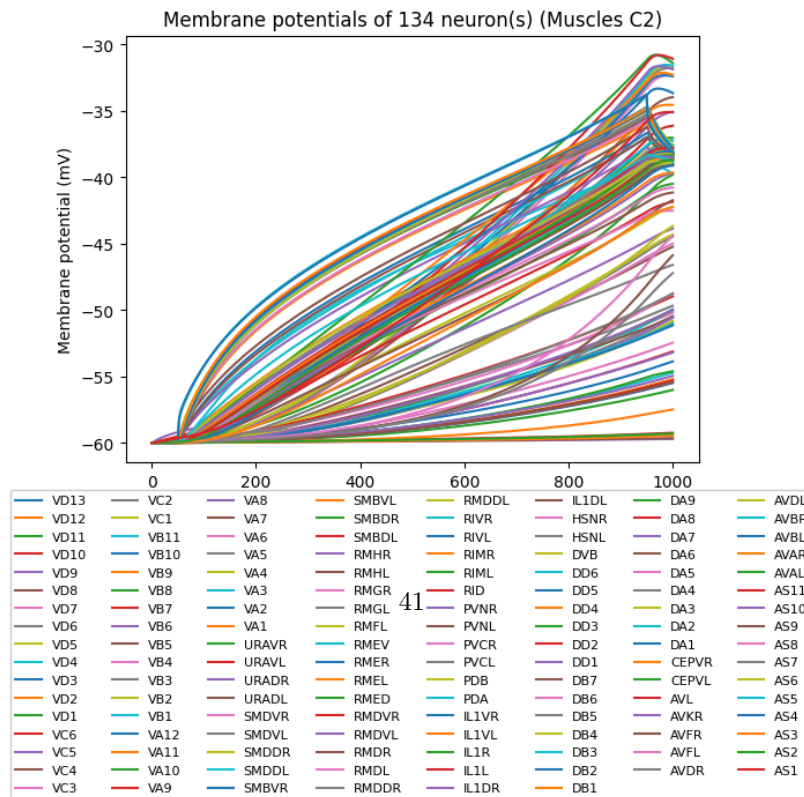


Figure 19: Traces of neuron activity and potentials.



6.2.6 Compact Morphology Grid

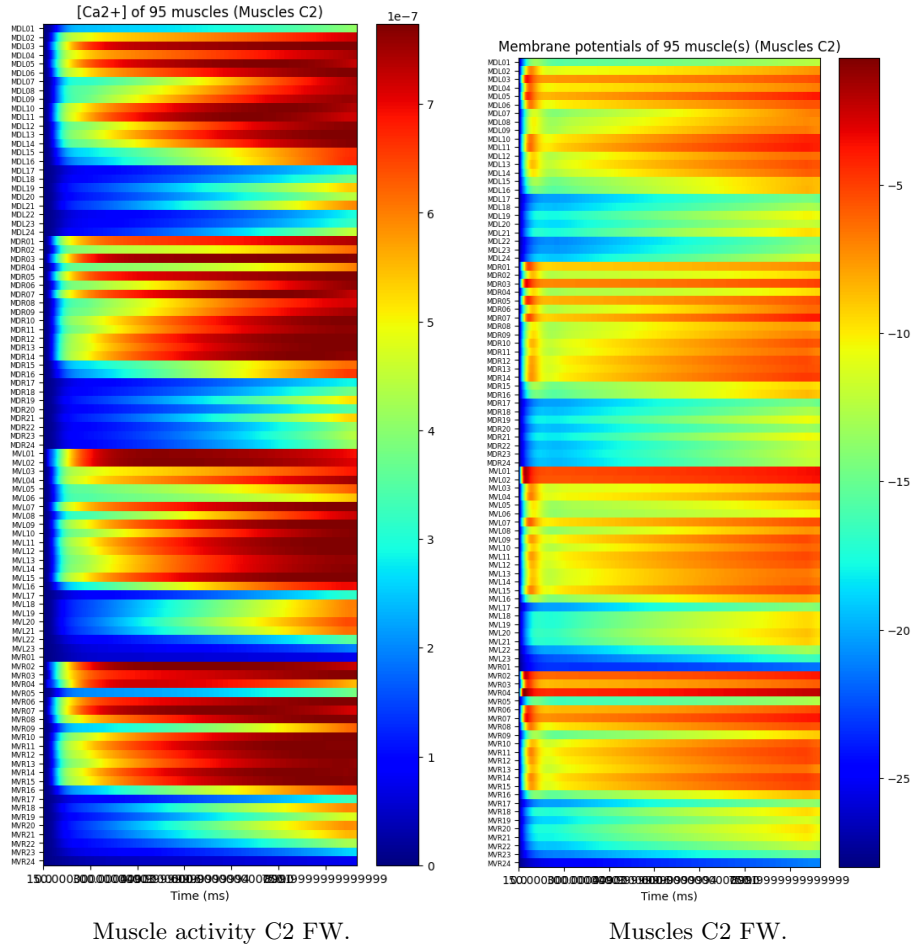


Figure 21: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).

6.2.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.6 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 11: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	2.3 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[=-----]	0.7 / 10
Overall Severity	[=====]	4.6 / 10

6.3 Movement Analysis: AVAL-DA3

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run C2_Muscles_2026-08-11_10-04-56-AVAL-DA3.

6.3.1 Locomotion State Classification

Table 12: Behavioral State Breakdown for AVAL-DA3

Locomotion State	Time Fraction (%)
Forward Crawling	14.6%
Backward Crawling	34.5%
Stationary	0.0%
Reversal	8.5%
Omega Turns	20.0%
Shallow Turns	22.4%
Irregular / Abnormal	0.0%

6.3.2 Kinematic & Velocity Dynamics

Table 13: Kinematic and Velocity Metrics for AVAL-DA3

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.0365	mm
Gross Distance	0.151	mm
Path Efficiency (Net/Gross)	0.2417	[0.0 – 1.0]
Mean Speed	0.1516	mm/s
Maximum Forward Velocity	0.8695	mm/s
Maximum Backward Velocity	0.8126	mm/s
Median Velocity	0.0859	mm/s
Velocity Std Deviation	0.2009	mm/s
Velocity RMS	0.2517	mm/s
Fraction Time Moving Forward	47.6%	ratio
Fraction Time Moving Backward	52.4%	ratio
Fraction Time Stationary	0.0%	ratio
Acceleration (Mean)	-0.4728	mm/s ²
Maximum Acceleration	168.7738	mm/s ²
Acceleration RMS	23.2192	mm/s ²
Velocity Autocorrelation	0.8484	correlation
Reversal Frequency	14.0562	s ⁻¹
Mean Curvature	2648.8306	rad/mm
Omega Turn Count	33	count

6.3.3 Undulation Wave Mechanics

Table 14: Undulation Wave Parameters for AVAL-DA3

Undulation Parameter	Value	Unit
Crawl Amplitude	0.0067	rad (bending)
Dominant Frequency	0.0	Hz
Wavelength	0.82	mm
Wave Velocity	0.0	mm/s
Phase Coherence	0.79	[0.0 – 1.0]
Mean Muscle Activation	0.789825	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.3.4 Worm Motion and Activity Figures

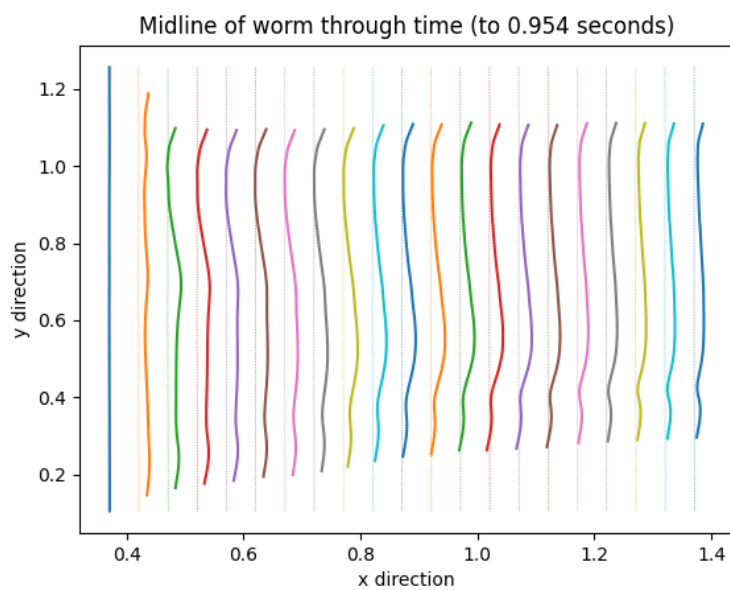


Figure 23: Midline of worm through time.

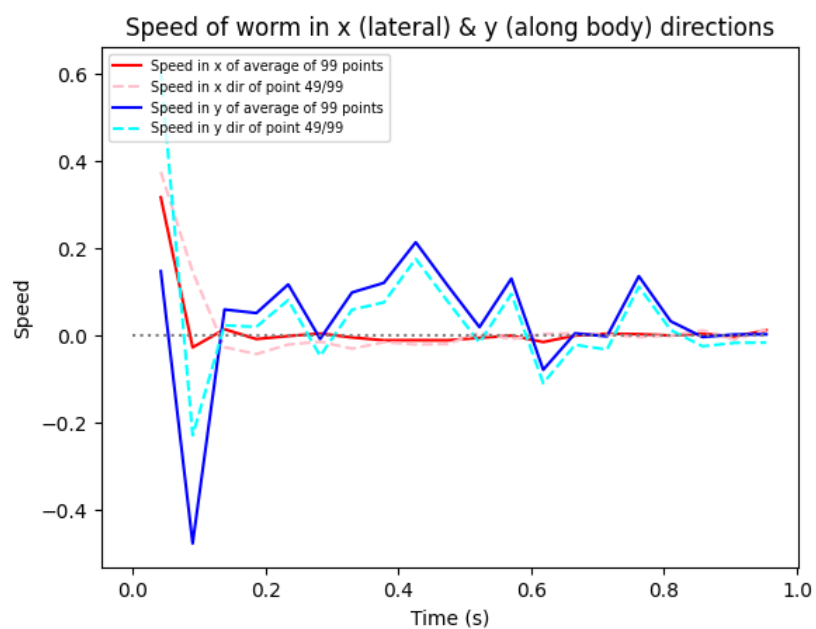


Figure 24: Speed of worm along body directions.

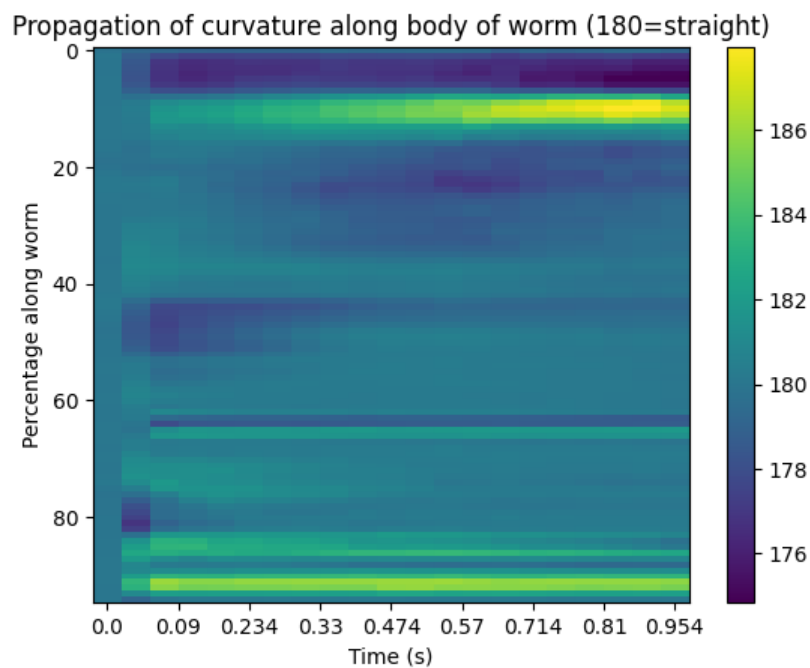


Figure 25: Propagation of curvature along body of worm.

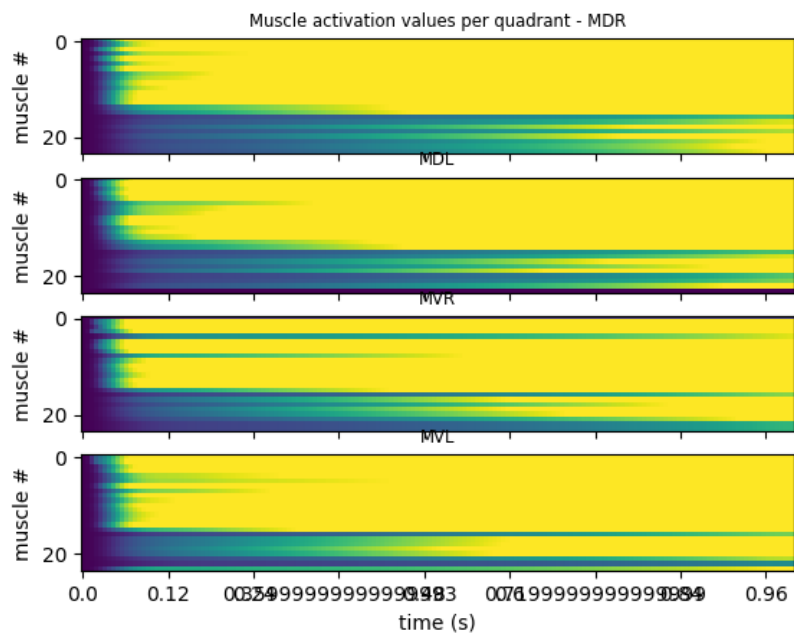


Figure 26: Muscle activities per quadrant.

6.3.5 Trace Figures

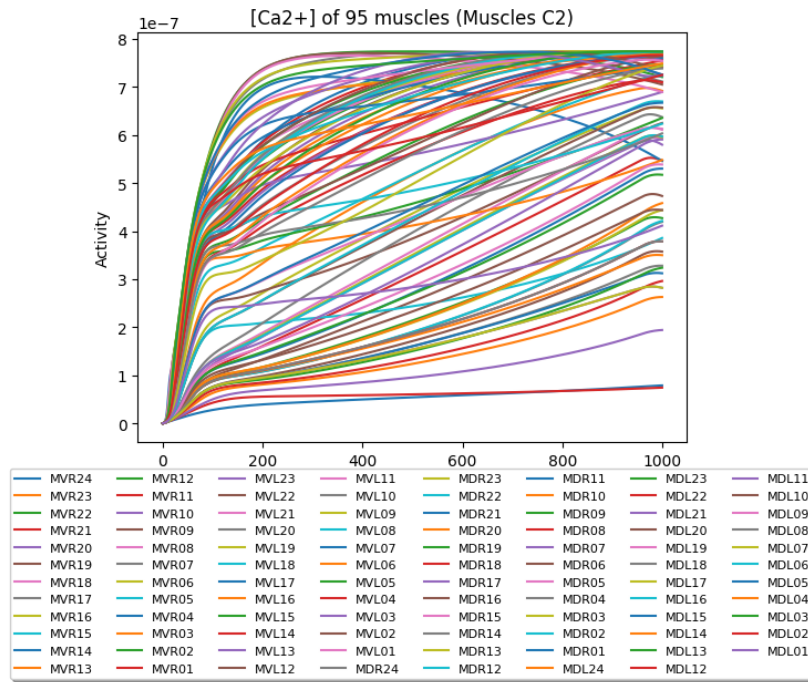


Figure 27: Traces of muscle activity and potentials.

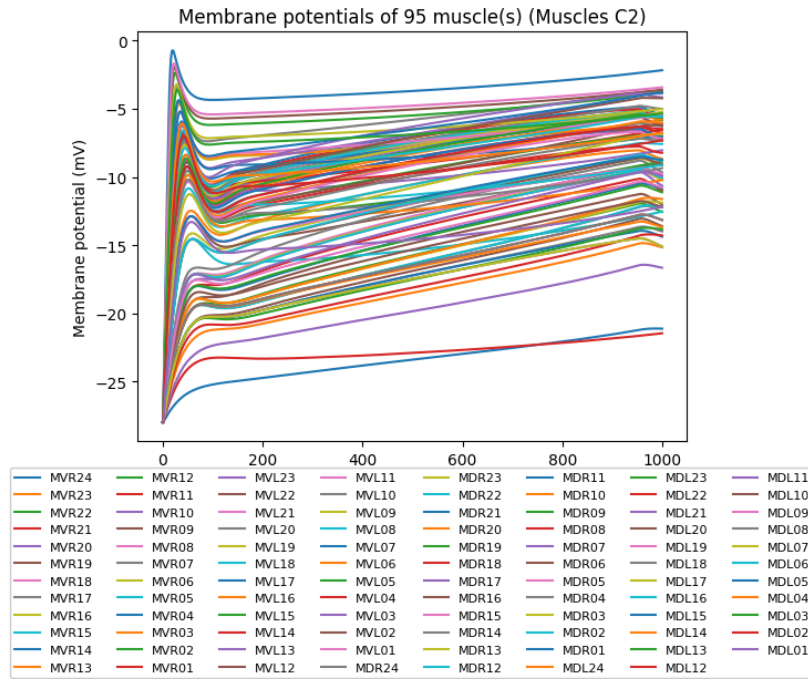


Figure 28: Traces of muscle activity.

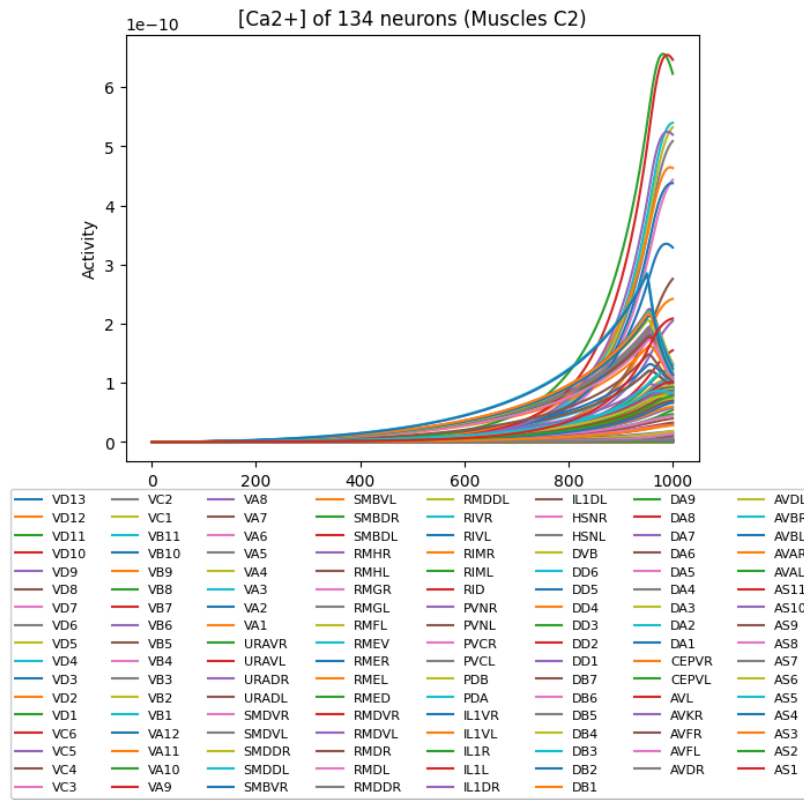
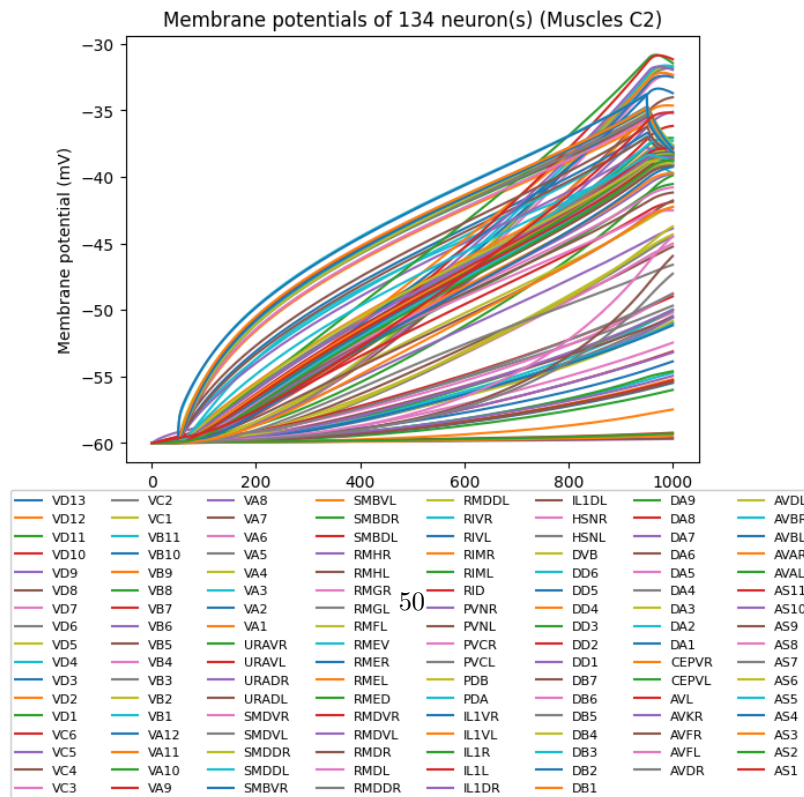


Figure 29: Traces of neuron activity and potentials.



6.3.6 Compact Morphology Grid

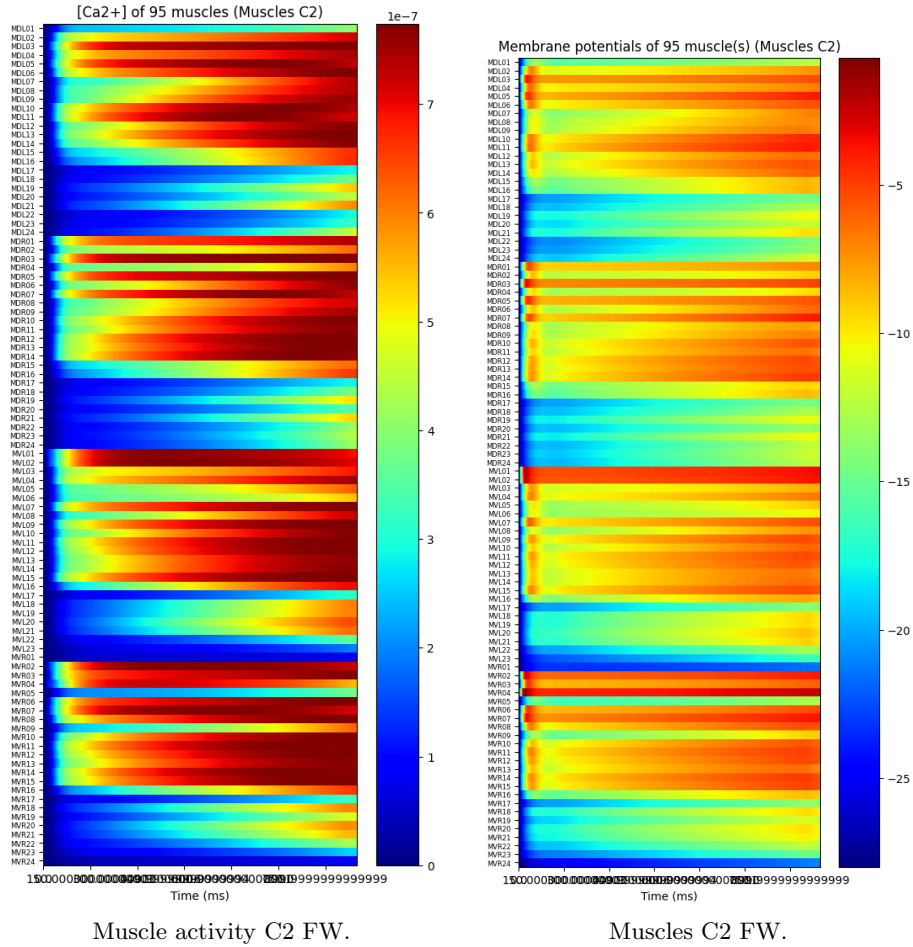


Figure 31: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).

6.3.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.5 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 15: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	2.1 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[-----]	0.5 / 10
Overall Severity	[====-----]	4.5 / 10

6.4 Movement Analysis: AVAR-DA3

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run C2_Muscles_2026-08-11_12-57-13-AVAR-DA3.

6.4.1 Locomotion State Classification

Table 16: Behavioral State Breakdown for AVAR-DA3

Locomotion State	Time Fraction (%)
Forward Crawling	11.5%
Backward Crawling	34.5%
Stationary	0.0%
Reversal	10.3%
Omega Turns	23.0%
Shallow Turns	20.6%
Irregular / Abnormal	0.0%

6.4.2 Kinematic & Velocity Dynamics

Table 17: Kinematic and Velocity Metrics for AVAR-DA3

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.0366	mm
Gross Distance	0.1405	mm
Path Efficiency (Net/Gross)	0.2607	[0.0 – 1.0]
Mean Speed	0.141	mm/s
Maximum Forward Velocity	0.9613	mm/s
Maximum Backward Velocity	0.8233	mm/s
Median Velocity	0.0816	mm/s
Velocity Std Deviation	0.2037	mm/s
Velocity RMS	0.2478	mm/s
Fraction Time Moving Forward	42.2%	ratio
Fraction Time Moving Backward	57.8%	ratio
Fraction Time Stationary	0.0%	ratio
Acceleration (Mean)	-0.4727	mm/s ²
Maximum Acceleration	168.7928	mm/s ²
Acceleration RMS	24.4651	mm/s ²
Velocity Autocorrelation	0.8352	correlation
Reversal Frequency	17.0683	s ⁻¹
Mean Curvature	5305.6943	rad/mm
Omega Turn Count	38	count

6.4.3 Undulation Wave Mechanics

Table 18: Undulation Wave Parameters for AVAR-DA3

Undulation Parameter	Value	Unit
Crawl Amplitude	0.0067	rad (bending)
Dominant Frequency	0.0	Hz
Wavelength	0.82	mm
Wave Velocity	0.0	mm/s
Phase Coherence	0.8	[0.0 – 1.0]
Mean Muscle Activation	0.789879	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.4.4 Worm Motion and Activity Figures

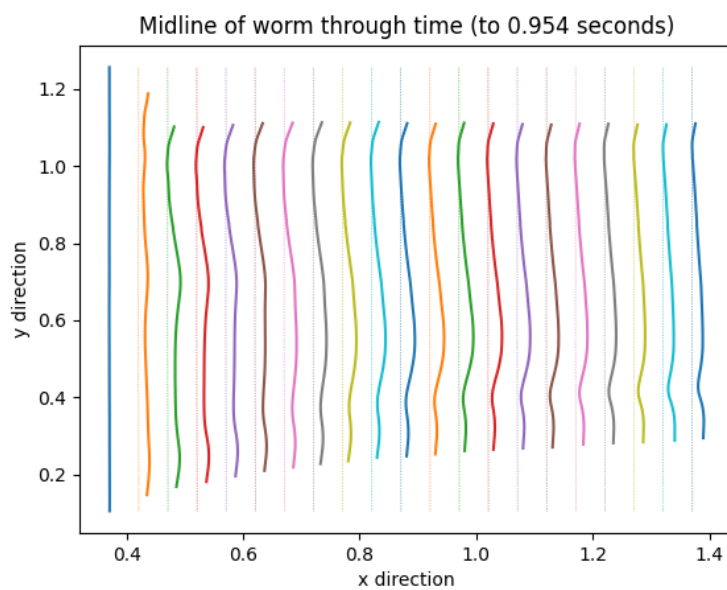


Figure 33: Midline of worm through time.

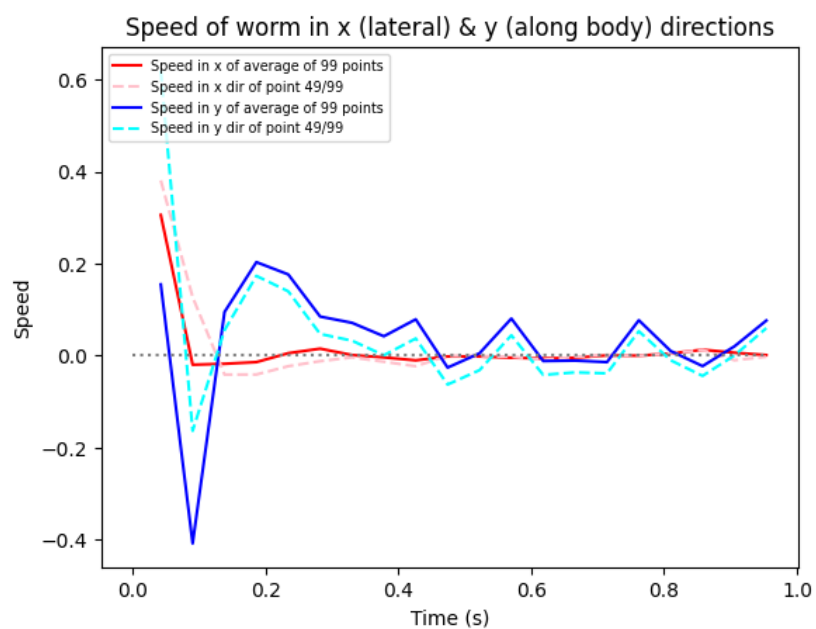


Figure 34: Speed of worm along body directions.

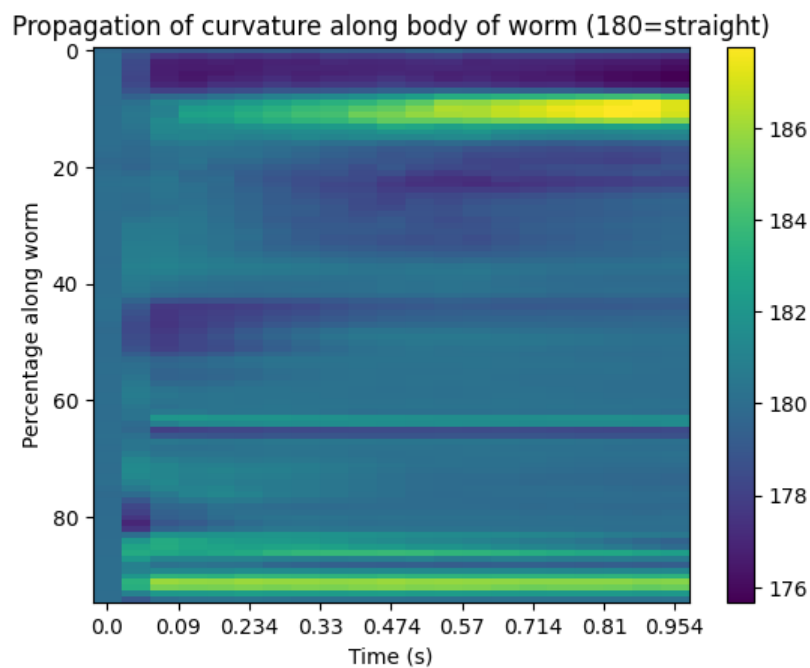


Figure 35: Propagation of curvature along body of worm.

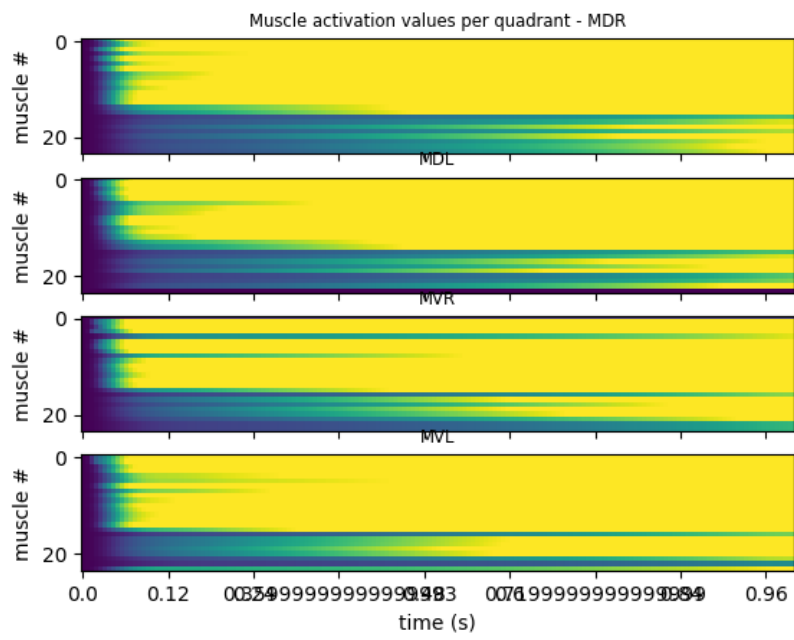


Figure 36: Muscle activities per quadrant.

6.4.5 Trace Figures

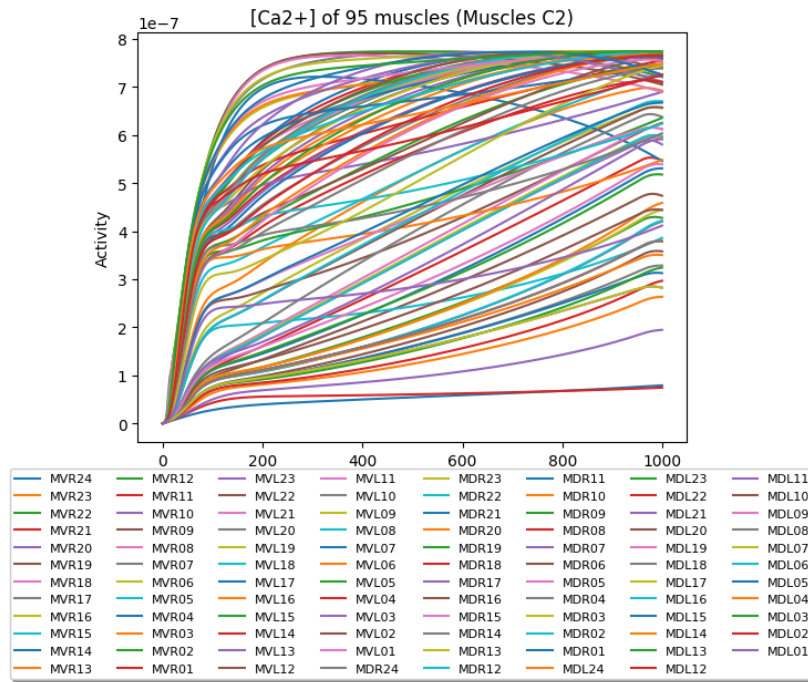


Figure 37: Traces of muscle activity and potentials.

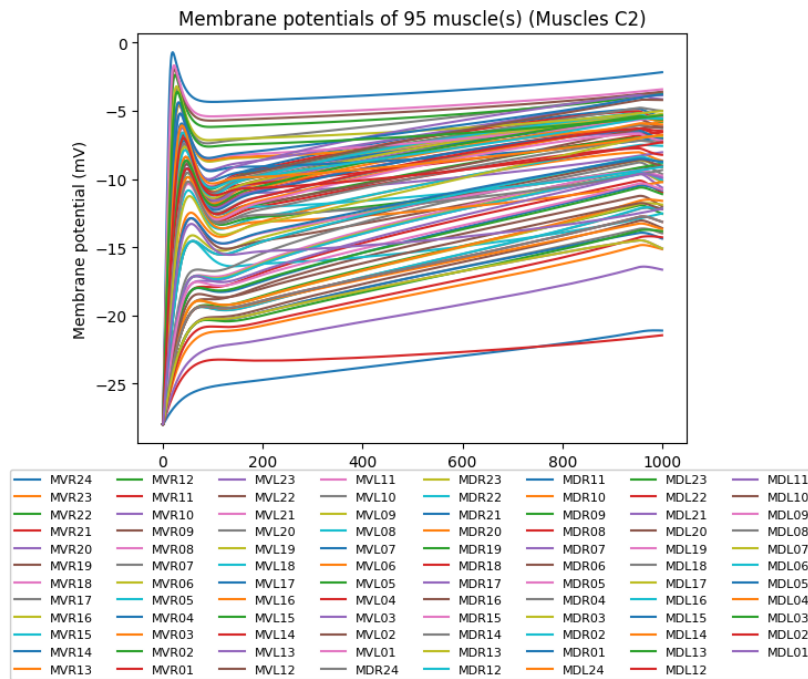


Figure 38: Traces of muscle activity.

6.4.6 Compact Morphology Grid

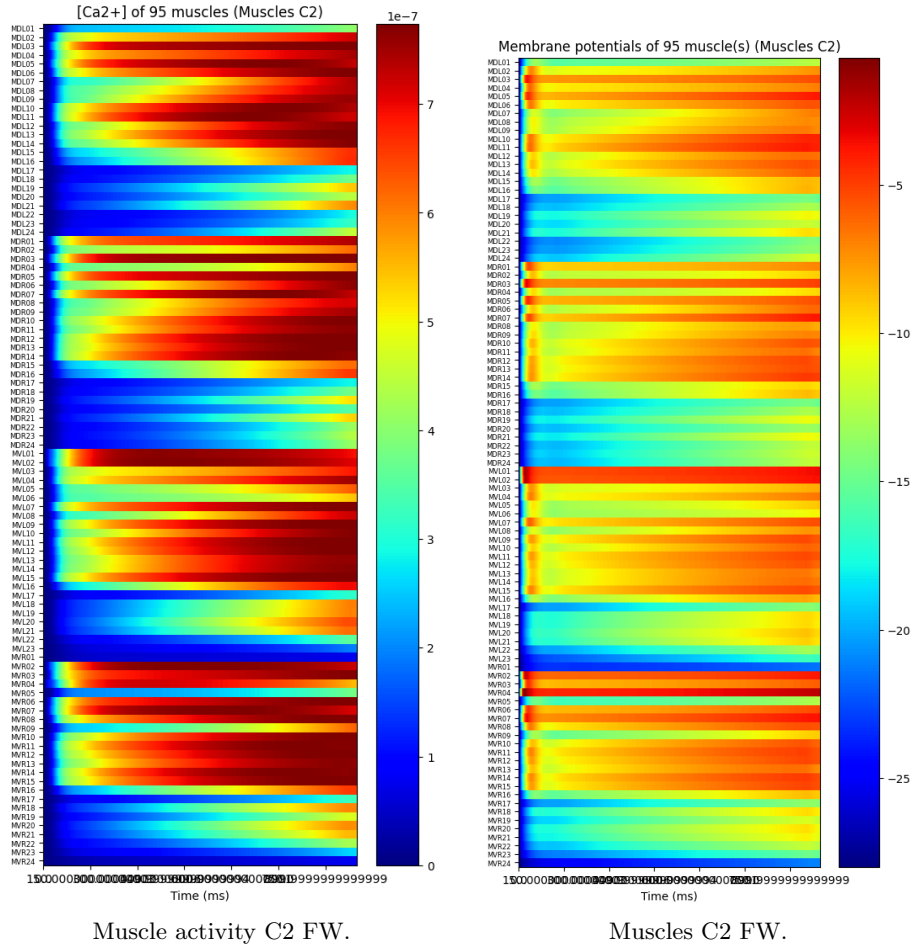


Figure 41: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).

6.4.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.7 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 19: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	2.0 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[=-----]	1.6 / 10
Overall Severity	[=====]	4.7 / 10

6.5 Movement Analysis: AVAL-VA5

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run C2_Muscles_2026-08-15_13-46-57-AVAL-VA5.

6.5.1 Locomotion State Classification

Table 20: Behavioral State Breakdown for AVAL-VA5

Locomotion State	Time Fraction (%)
Forward Crawling	7.9%
Backward Crawling	30.3%
Stationary	0.0%
Reversal	12.7%
Omega Turns	26.7%
Shallow Turns	22.4%
Irregular / Abnormal	0.0%

6.5.2 Kinematic & Velocity Dynamics

Table 21: Kinematic and Velocity Metrics for AVAL-VA5

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.0458	mm
Gross Distance	0.1672	mm
Path Efficiency (Net/Gross)	0.2738	[0.0 – 1.0]
Mean Speed	0.1679	mm/s
Maximum Forward Velocity	0.6965	mm/s
Maximum Backward Velocity	0.9217	mm/s
Median Velocity	0.0926	mm/s
Velocity Std Deviation	0.2084	mm/s
Velocity RMS	0.2676	mm/s
Fraction Time Moving Forward	44.6%	ratio
Fraction Time Moving Backward	54.8%	ratio
Fraction Time Stationary	0.0%	ratio
Acceleration (Mean)	-0.3289	mm/s ²
Maximum Acceleration	168.7925	mm/s ²
Acceleration RMS	23.8987	mm/s ²
Velocity Autocorrelation	0.8316	correlation
Reversal Frequency	21.0843	s ⁻¹
Mean Curvature	3737.1681	rad/mm
Omega Turn Count	44	count

6.5.3 Undulation Wave Mechanics

Table 22: Undulation Wave Parameters for AVAL-VA5

Undulation Parameter	Value	Unit
Crawl Amplitude	0.0066	rad (bending)
Dominant Frequency	0.0	Hz
Wavelength	0.82	mm
Wave Velocity	0.0	mm/s
Phase Coherence	0.78	[0.0 – 1.0]
Mean Muscle Activation	0.789866	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.5.4 Worm Motion and Activity Figures

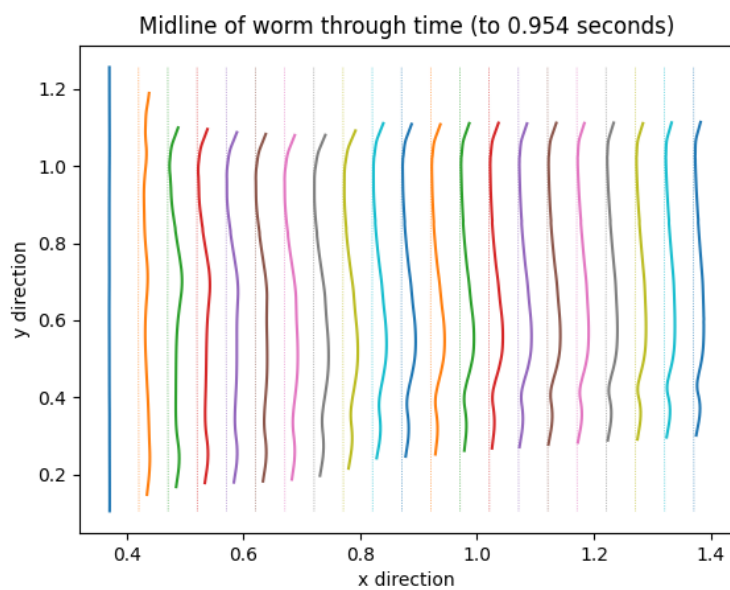


Figure 43: Midline of worm through time.

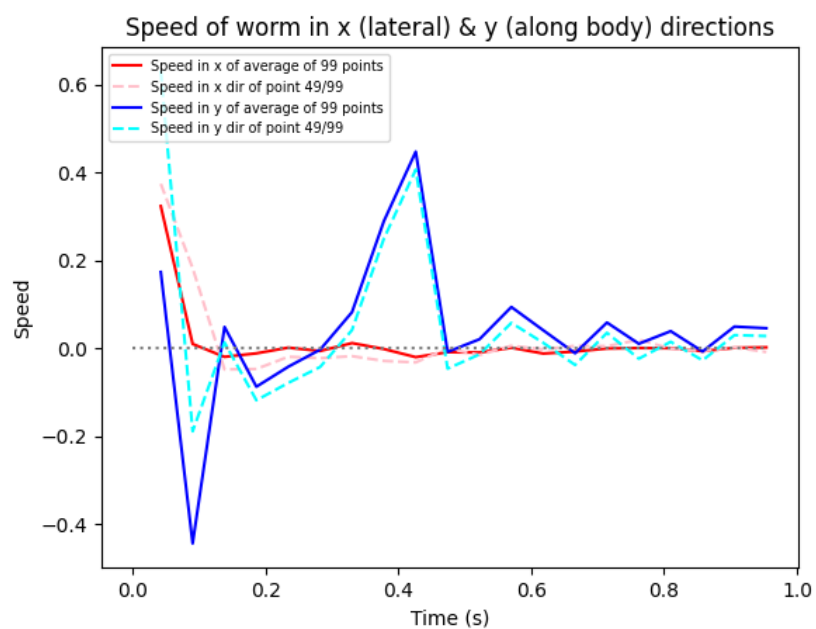


Figure 44: Speed of worm along body directions.

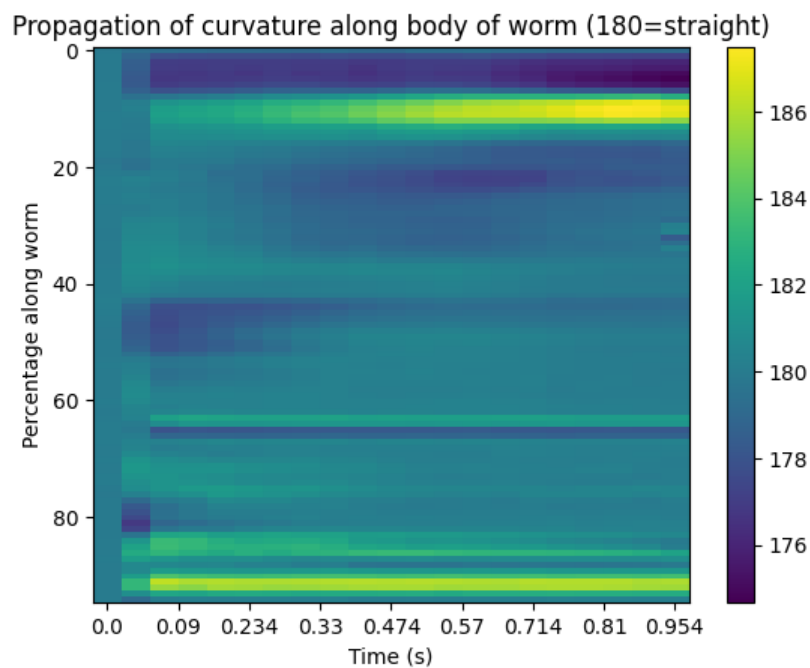


Figure 45: Propagation of curvature along body of worm.

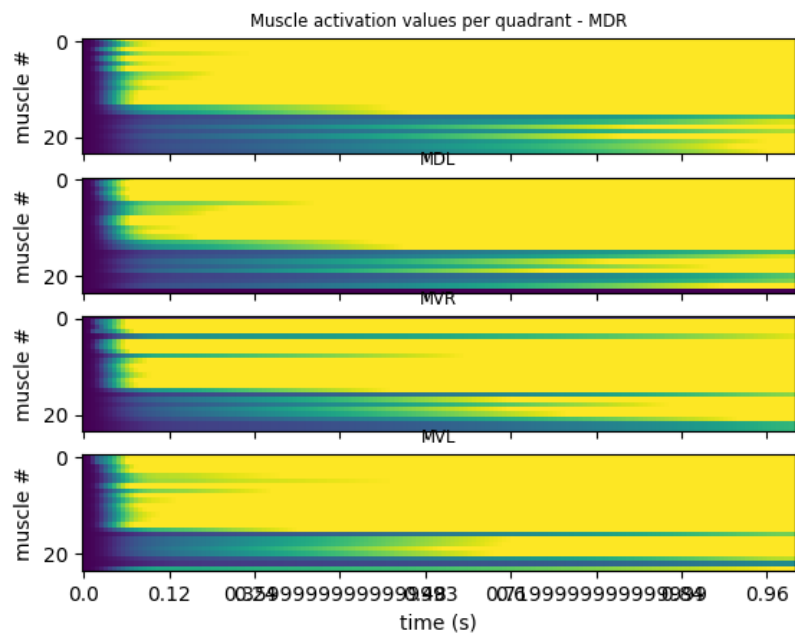


Figure 46: Muscle activities per quadrant.

6.5.5 Trace Figures

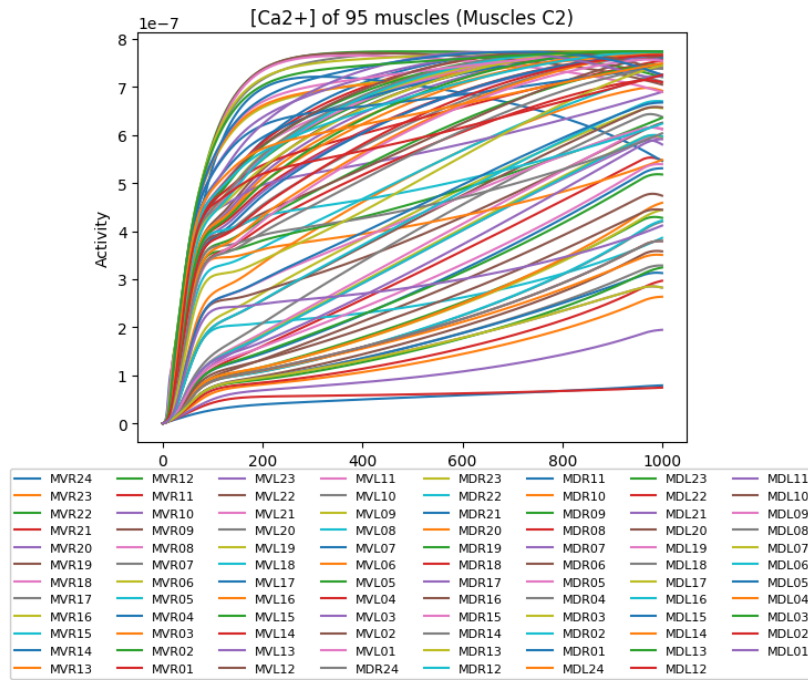


Figure 47: Traces of muscle activity and potentials.

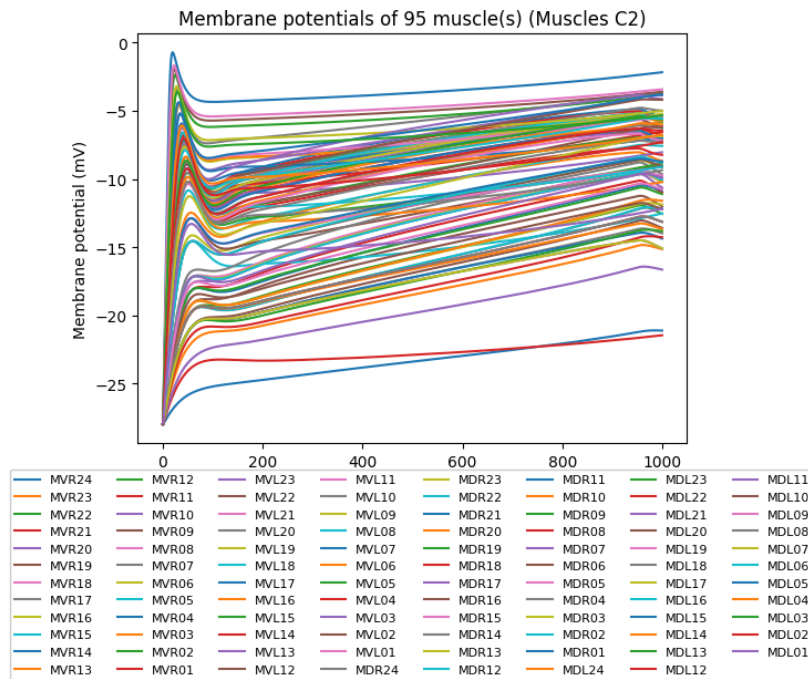


Figure 48: Traces of muscle activity.

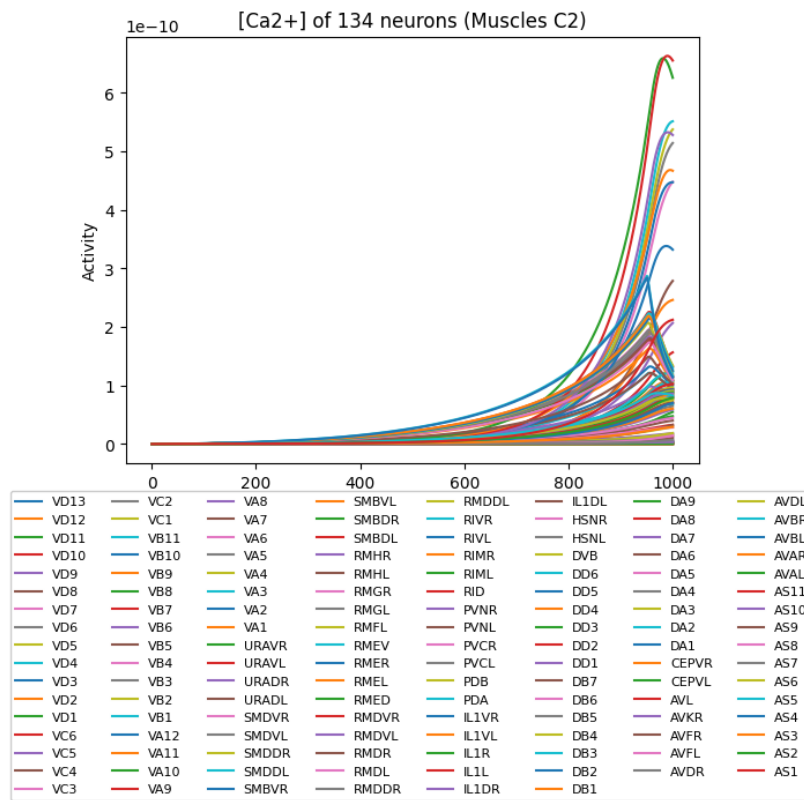
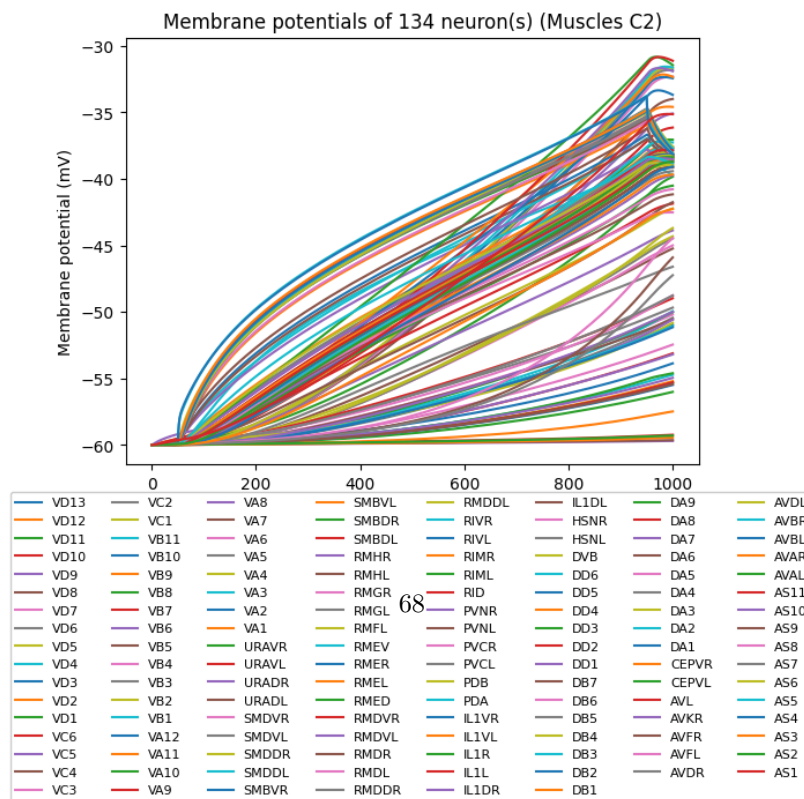


Figure 49: Traces of neuron activity and potentials.



6.5.6 Compact Morphology Grid

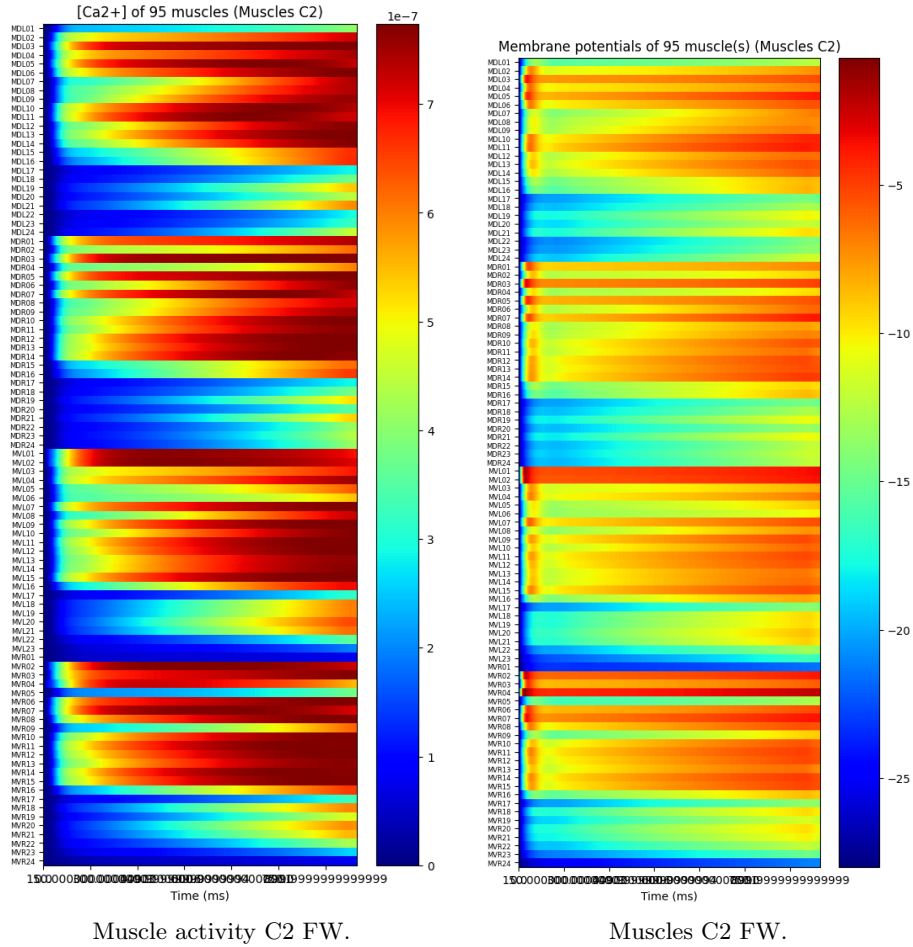
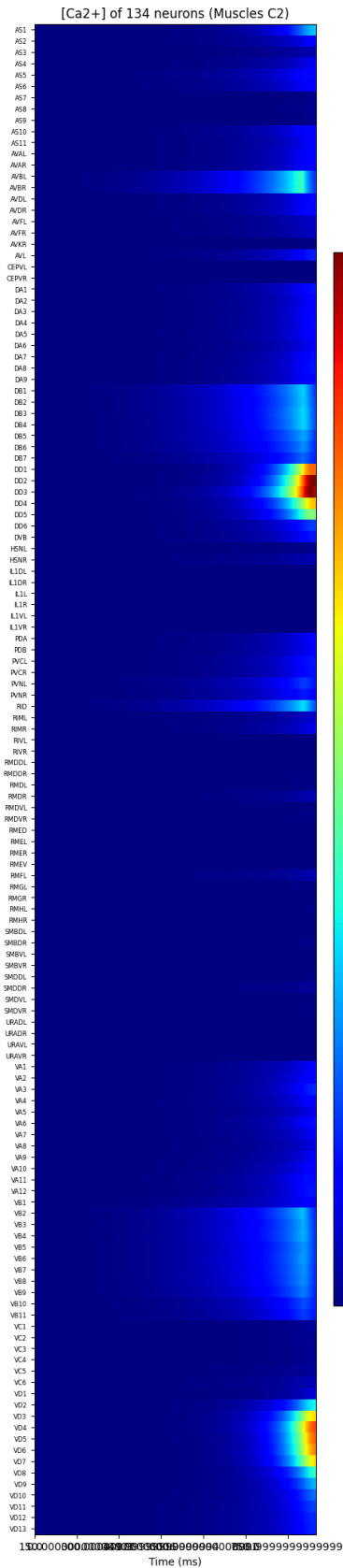


Figure 51: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).



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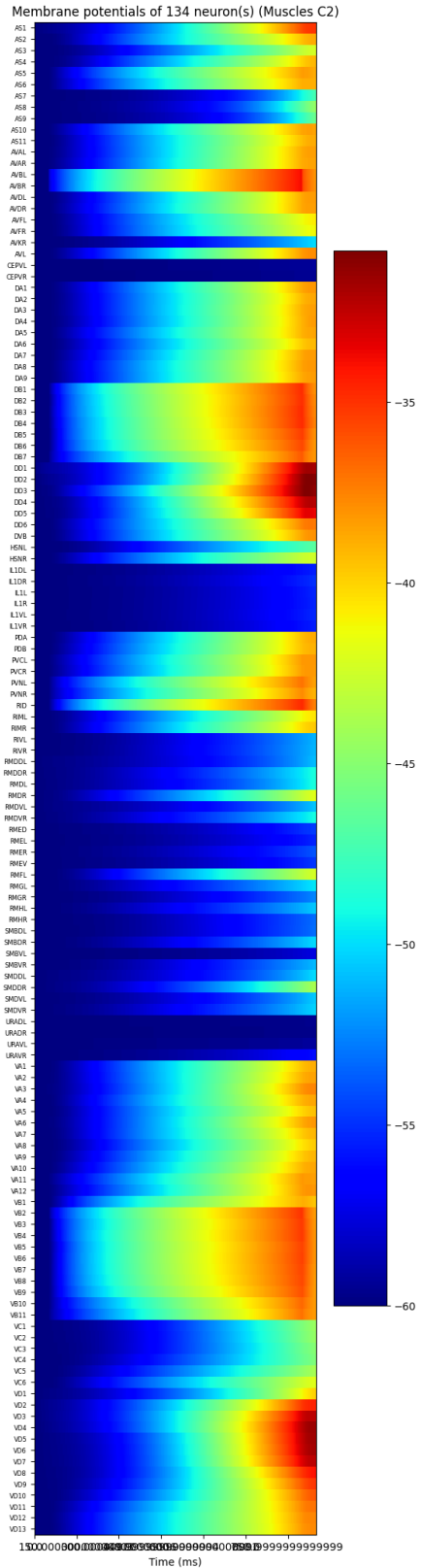


Figure 52: Neuron activity and morphology, shown as a 2x1 grid for compact

6.5.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.6 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 23: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	2.2 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[=-----]	1.0 / 10
Overall Severity	[=====]	4.6 / 10

6.6 Movement Analysis: AVAR-VA5

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run C2_Muscles_2026-08-15_15-44-05-AVAR-VA5.

6.6.1 Locomotion State Classification

Table 24: Behavioral State Breakdown for AVAR-VA5

Locomotion State	Time Fraction (%)
Forward Crawling	10.3%
Backward Crawling	35.1%
Stationary	0.0%
Reversal	12.7%
Omega Turns	27.9%
Shallow Turns	13.9%
Irregular / Abnormal	0.0%

6.6.2 Kinematic & Velocity Dynamics

Table 25: Kinematic and Velocity Metrics for AVAR-VA5

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.0528	mm
Gross Distance	0.1375	mm
Path Efficiency (Net/Gross)	0.3844	[0.0 – 1.0]
Mean Speed	0.138	mm/s
Maximum Forward Velocity	0.8556	mm/s
Maximum Backward Velocity	0.8404	mm/s
Median Velocity	0.071	mm/s
Velocity Std Deviation	0.199	mm/s
Velocity RMS	0.2422	mm/s
Fraction Time Moving Forward	37.4%	ratio
Fraction Time Moving Backward	62.6%	ratio
Fraction Time Stationary	0.0%	ratio
Acceleration (Mean)	-0.4603	mm/s ²
Maximum Acceleration	168.7669	mm/s ²
Acceleration RMS	23.6072	mm/s ²
Velocity Autocorrelation	0.8017	correlation
Reversal Frequency	21.0843	s ⁻¹
Mean Curvature	4043.3923	rad/mm
Omega Turn Count	46	count

6.6.3 Undulation Wave Mechanics

Table 26: Undulation Wave Parameters for AVAR-VA5

Undulation Parameter	Value	Unit
Crawl Amplitude	0.0069	rad (bending)
Dominant Frequency	0.0	Hz
Wavelength	0.82	mm
Wave Velocity	0.0	mm/s
Phase Coherence	0.78	[0.0 – 1.0]
Mean Muscle Activation	0.789929	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.6.4 Worm Motion and Activity Figures

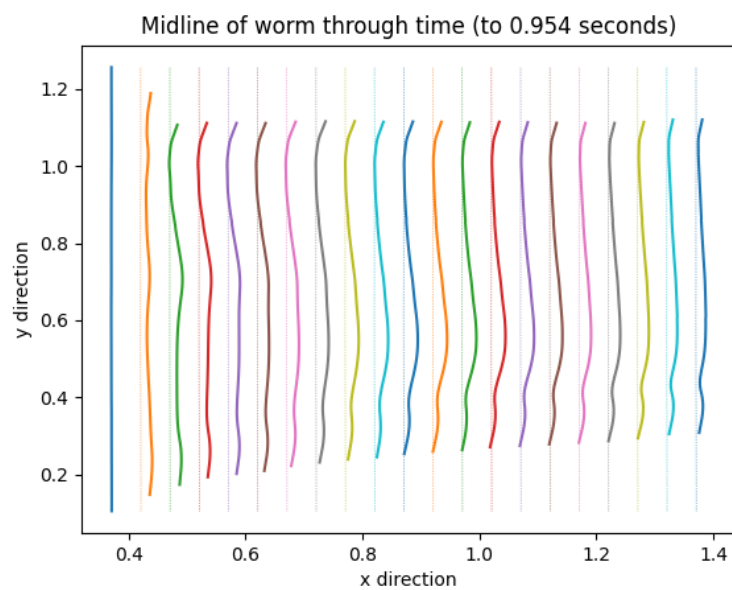


Figure 53: Midline of worm through time.

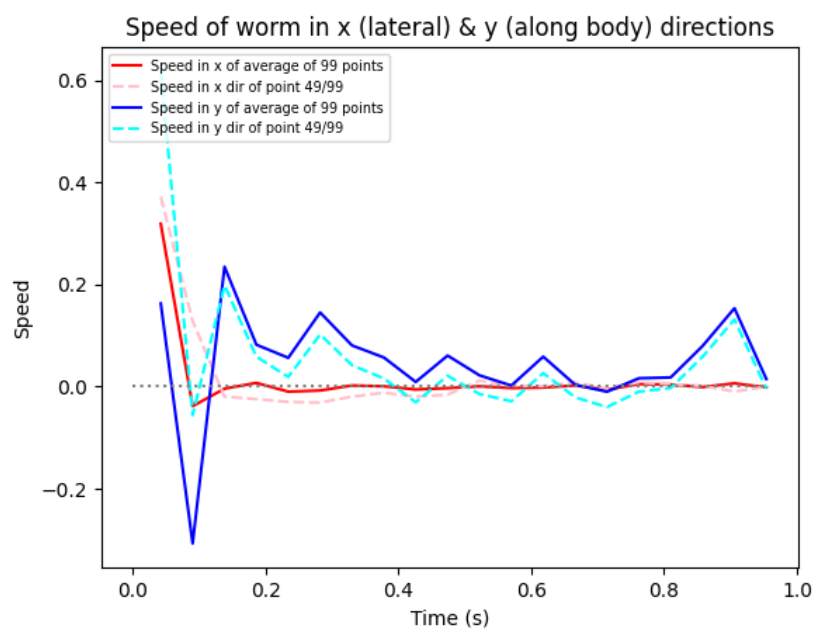


Figure 54: Speed of worm along body directions.

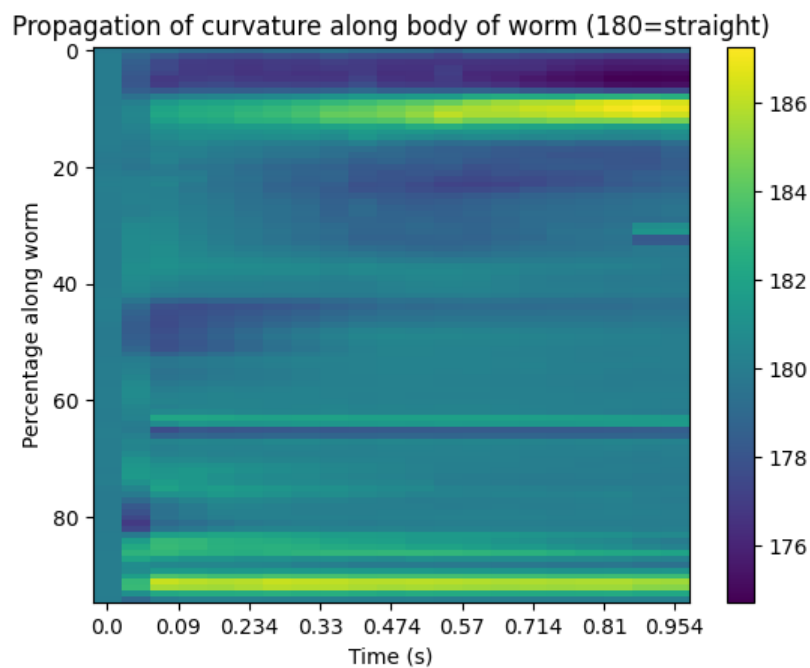


Figure 55: Propagation of curvature along body of worm.

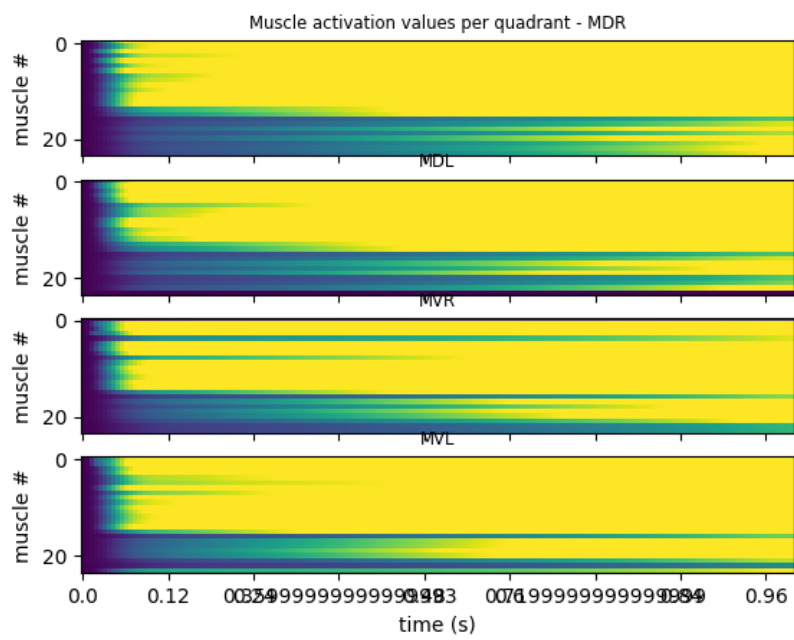


Figure 56: Muscle activities per quadrant.

6.6.5 Trace Figures

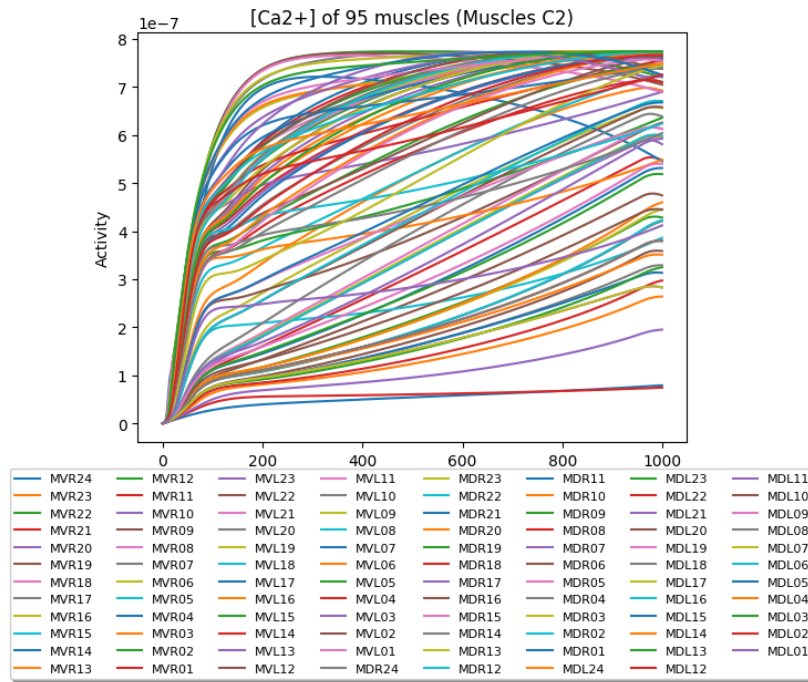


Figure 57: Traces of muscle activity and potentials.

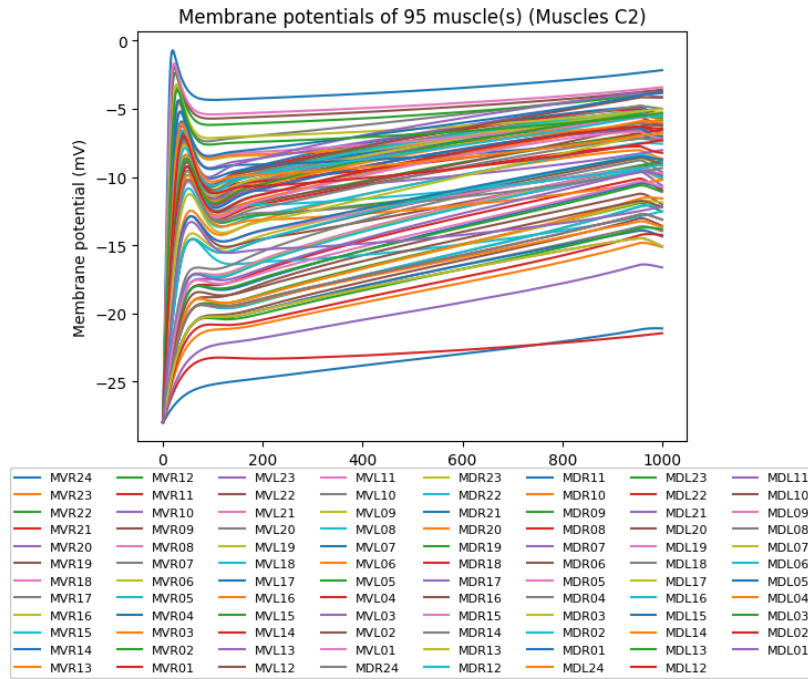


Figure 58: Traces of muscle activity.

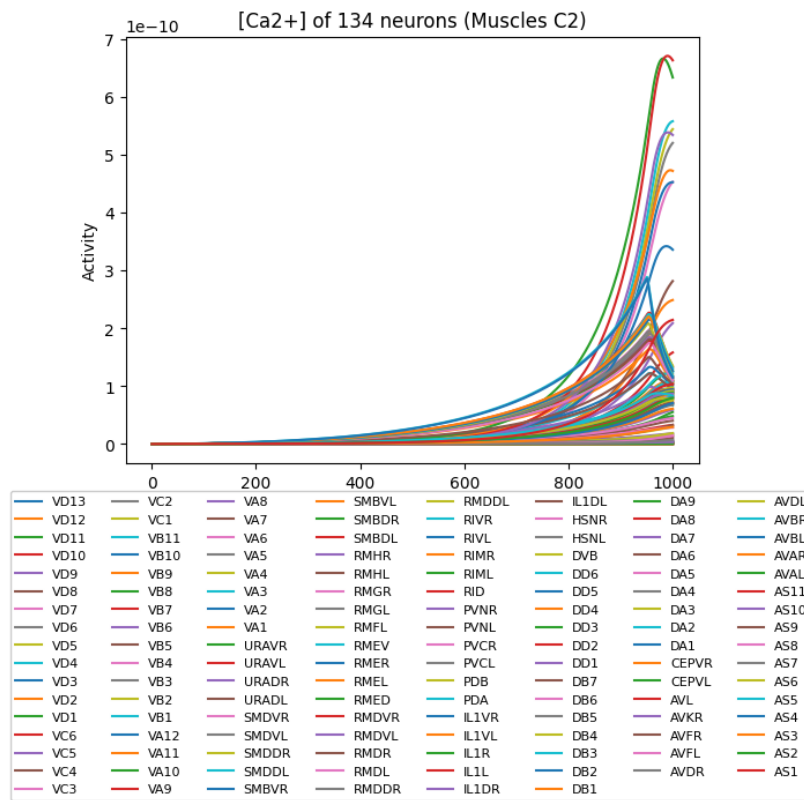
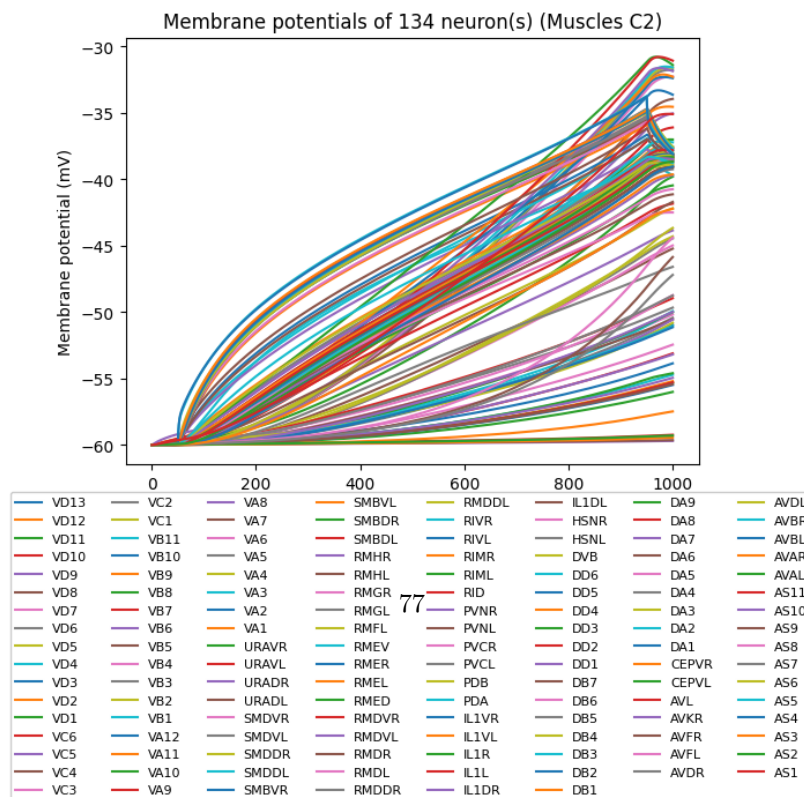


Figure 59: Traces of neuron activity and potentials.



6.6.6 Compact Morphology Grid

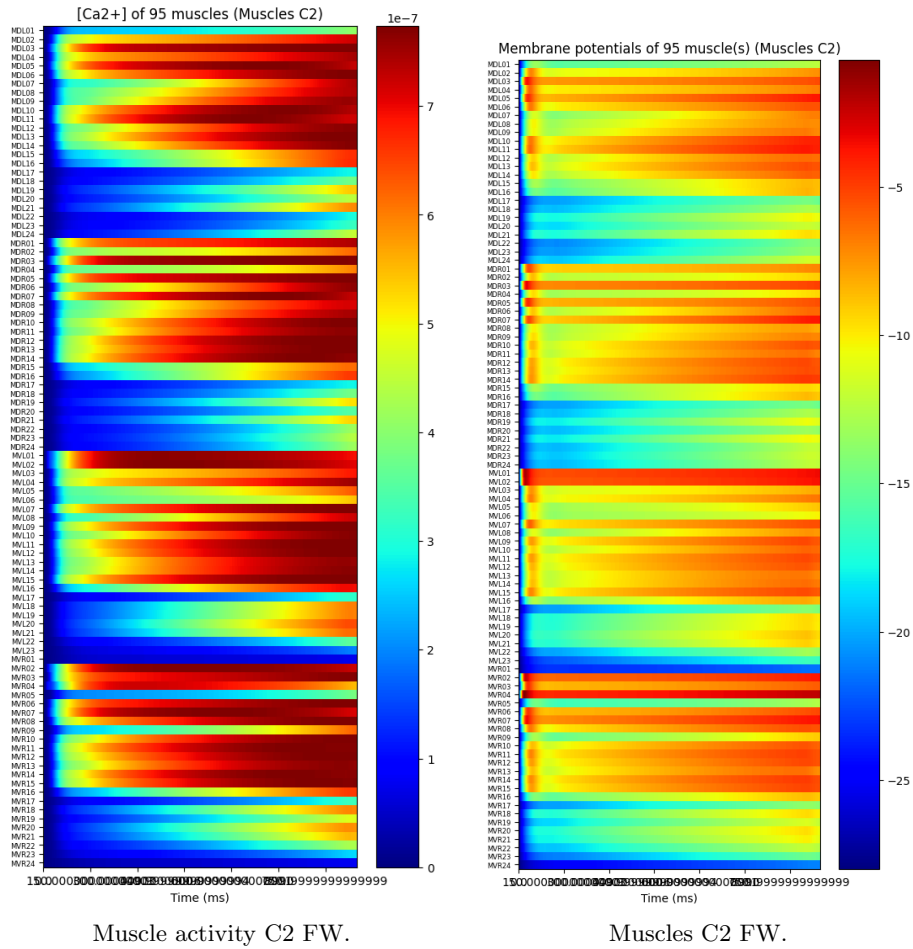


Figure 61: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).

6.6.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.9 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 27: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	2.2 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[=-----]	2.5 / 10
Overall Severity	[=====]	4.9 / 10

6.7 Movement Analysis: AVAL-VA8

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run C2_Muscles_2026-08-15_17-32-25-AVAL-VA8.

6.7.1 Locomotion State Classification

Table 28: Behavioral State Breakdown for AVAL-VA8

Locomotion State	Time Fraction (%)
Forward Crawling	15.8%
Backward Crawling	22.4%
Stationary	0.0%
Reversal	13.3%
Omega Turns	32.1%
Shallow Turns	15.8%
Irregular / Abnormal	0.6%

6.7.2 Kinematic & Velocity Dynamics

Table 29: Kinematic and Velocity Metrics for AVAL-VA8

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.0382	mm
Gross Distance	0.1482	mm
Path Efficiency (Net/Gross)	0.2577	[0.0 – 1.0]
Mean Speed	0.1488	mm/s
Maximum Forward Velocity	0.8347	mm/s
Maximum Backward Velocity	0.801	mm/s
Median Velocity	0.0846	mm/s
Velocity Std Deviation	0.1995	mm/s
Velocity RMS	0.2488	mm/s
Fraction Time Moving Forward	48.8%	ratio
Fraction Time Moving Backward	50.0%	ratio
Fraction Time Stationary	0.0%	ratio
Acceleration (Mean)	-0.4441	mm/s ²
Maximum Acceleration	168.7912	mm/s ²
Acceleration RMS	23.4832	mm/s ²
Velocity Autocorrelation	0.8135	correlation
Reversal Frequency	22.0884	s ⁻¹
Mean Curvature	4702.9887	rad/mm
Omega Turn Count	53	count

6.7.3 Undulation Wave Mechanics

Table 30: Undulation Wave Parameters for AVAL-VA8

Undulation Parameter	Value	Unit
Crawl Amplitude	0.0068	rad (bending)
Dominant Frequency	0.0	Hz
Wavelength	0.82	mm
Wave Velocity	0.0	mm/s
Phase Coherence	0.77	[0.0 – 1.0]
Mean Muscle Activation	0.789766	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.7.4 Worm Motion and Activity Figures

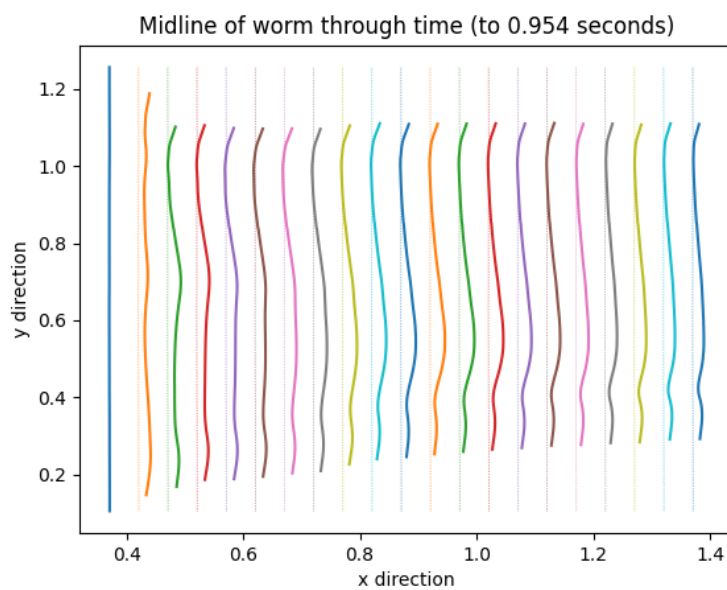


Figure 63: Midline of worm through time.

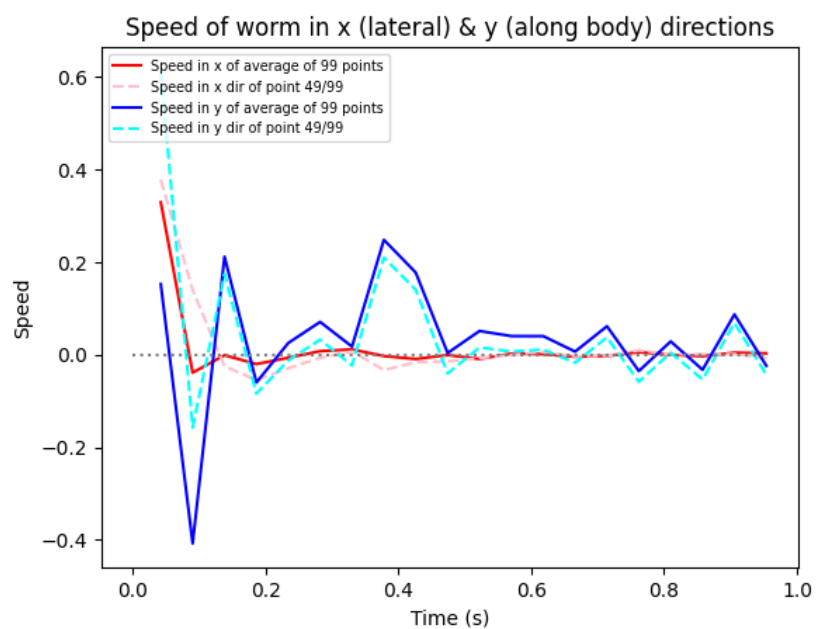


Figure 64: Speed of worm along body directions.

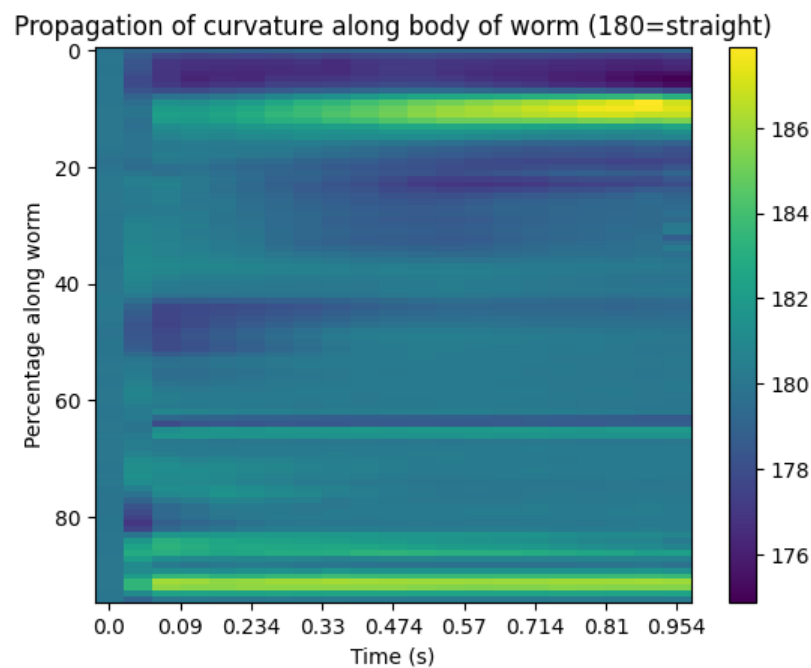


Figure 65: Propagation of curvature along body of worm.

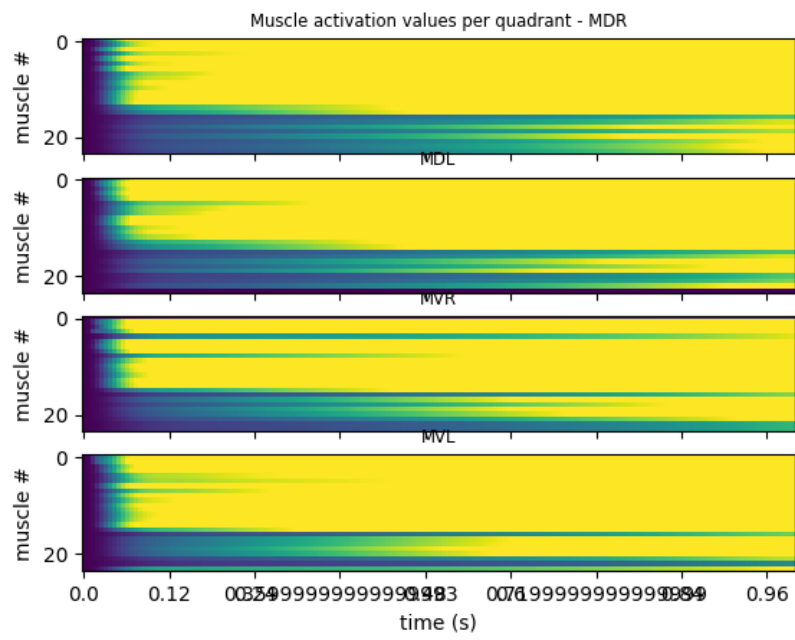


Figure 66: Muscle activities per quadrant.

6.7.5 Trace Figures

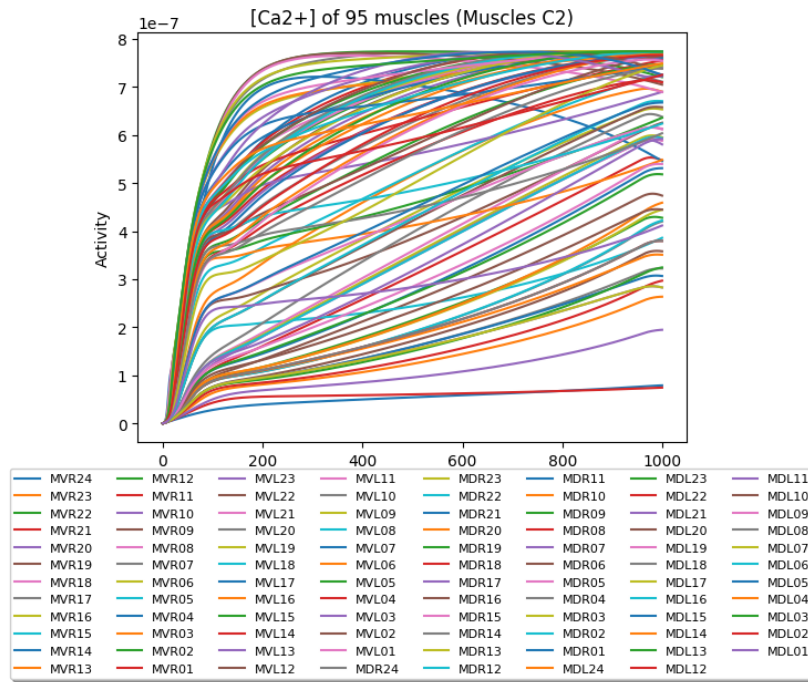
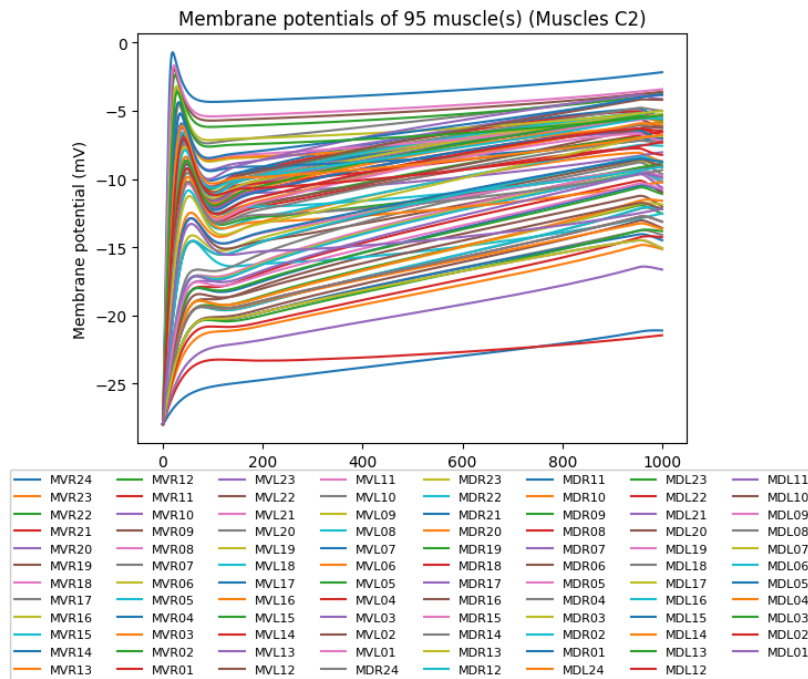


Figure 67: Traces of muscle activity and potentials.



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Figure 68: Traces of muscle activity.

6.7.6 Compact Morphology Grid

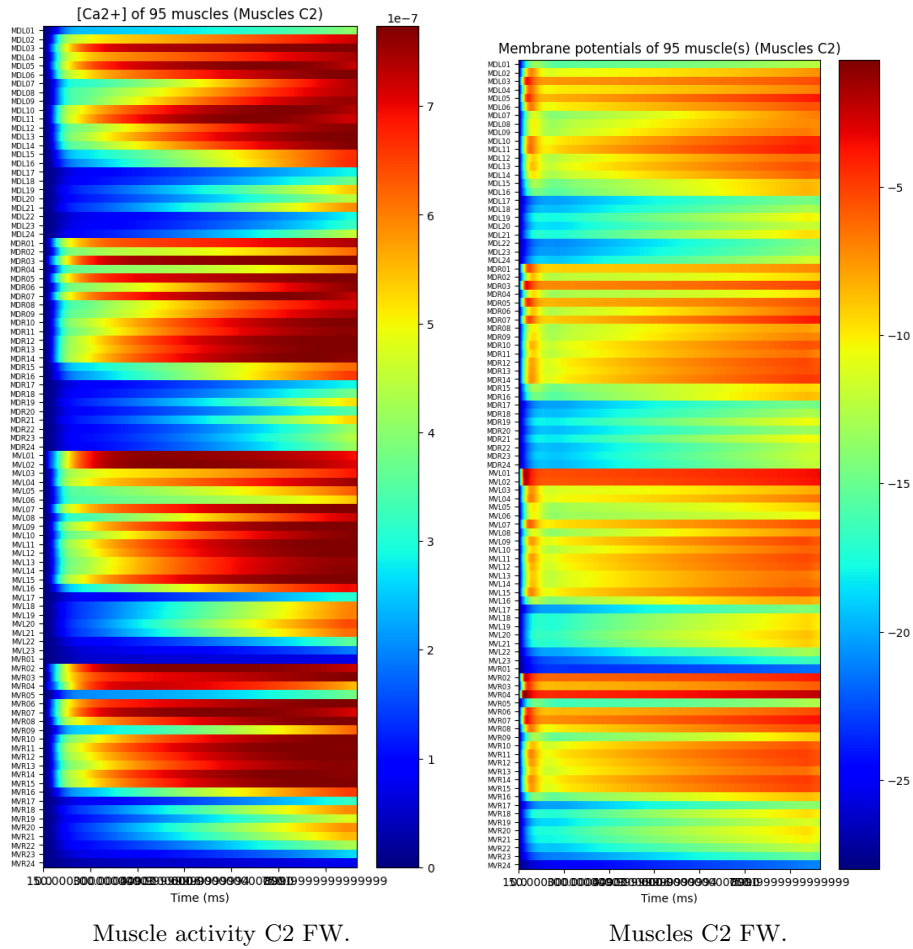


Figure 71: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).

6.7.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.5 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 31: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	2.3 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[-----]	0.1 / 10
Overall Severity	[====-----]	4.5 / 10

6.8 Movement Analysis: AVAR-VA8

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run C2_Muscles_2026-08-15_19-25-10-AVAR-VA8.

6.8.1 Locomotion State Classification

Table 32: Behavioral State Breakdown for AVAR-VA8

Locomotion State	Time Fraction (%)
Forward Crawling	15.8%
Backward Crawling	23.6%
Stationary	0.0%
Reversal	15.2%
Omega Turns	26.1%
Shallow Turns	19.4%
Irregular / Abnormal	0.0%

6.8.2 Kinematic & Velocity Dynamics

Table 33: Kinematic and Velocity Metrics for AVAR-VA8

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.0221	mm
Gross Distance	0.1449	mm
Path Efficiency (Net/Gross)	0.1528	[0.0 – 1.0]
Mean Speed	0.1455	mm/s
Maximum Forward Velocity	0.801	mm/s
Maximum Backward Velocity	0.7948	mm/s
Median Velocity	0.08	mm/s
Velocity Std Deviation	0.1984	mm/s
Velocity RMS	0.246	mm/s
Fraction Time Moving Forward	48.8%	ratio
Fraction Time Moving Backward	51.2%	ratio
Fraction Time Stationary	0.0%	ratio
Acceleration (Mean)	-0.4414	mm/s ²
Maximum Acceleration	168.8079	mm/s ²
Acceleration RMS	23.4686	mm/s ²
Velocity Autocorrelation	0.7991	correlation
Reversal Frequency	25.1004	s ⁻¹
Mean Curvature	5050.7093	rad/mm
Omega Turn Count	43	count

6.8.3 Undulation Wave Mechanics

Table 34: Undulation Wave Parameters for AVAR-VA8

Undulation Parameter	Value	Unit
Crawl Amplitude	0.0069	rad (bending)
Dominant Frequency	0.0	Hz
Wavelength	0.82	mm
Wave Velocity	0.0	mm/s
Phase Coherence	0.78	[0.0 – 1.0]
Mean Muscle Activation	0.789758	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.8.4 Worm Motion and Activity Figures

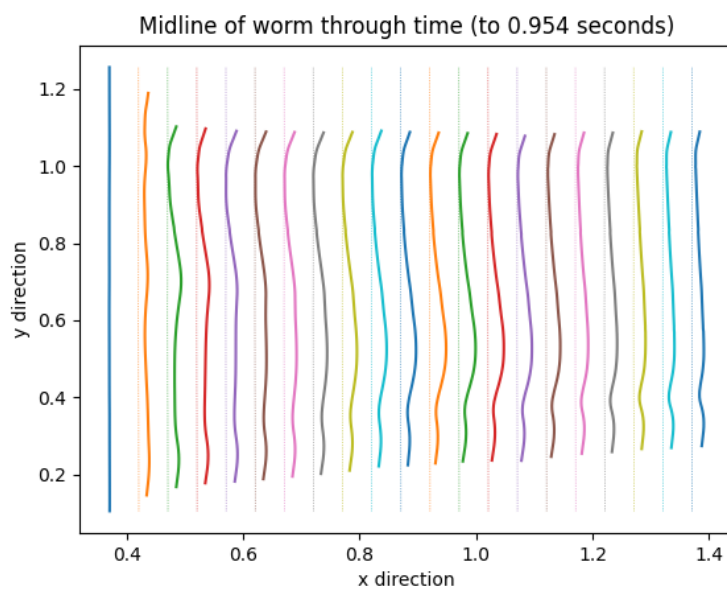


Figure 73: Midline of worm through time.

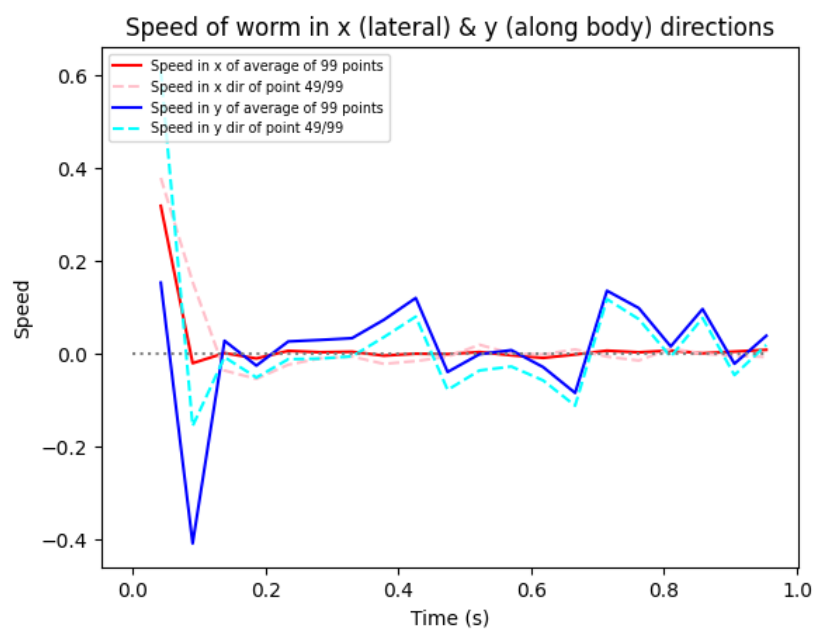


Figure 74: Speed of worm along body directions.

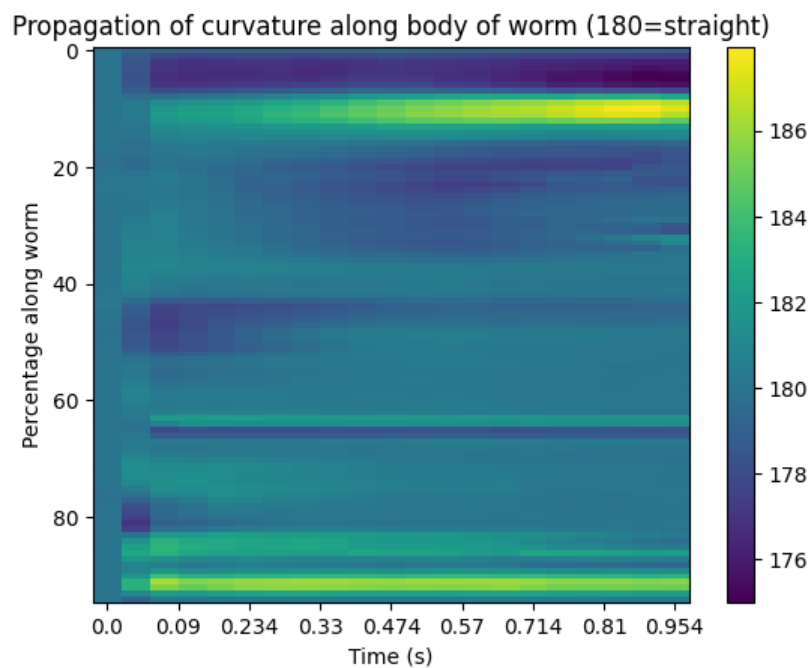


Figure 75: Propagation of curvature along body of worm.

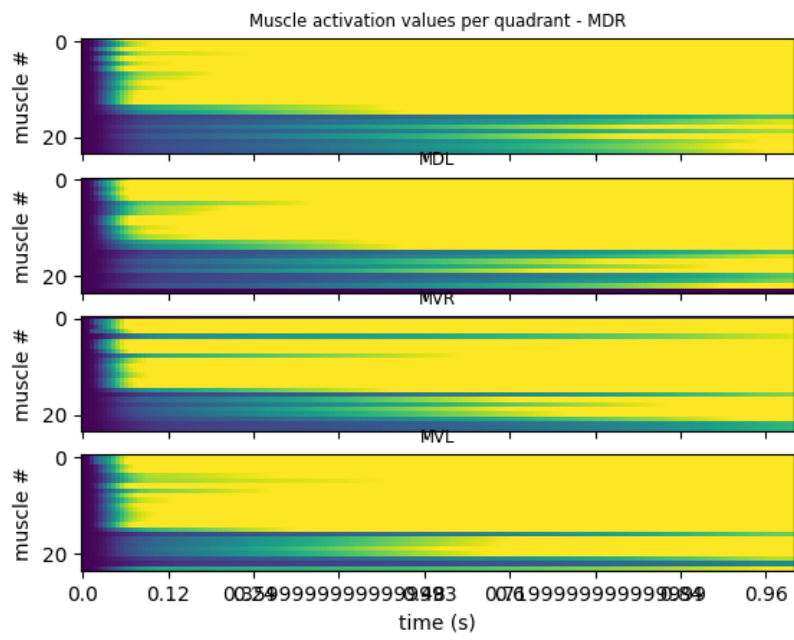


Figure 76: Muscle activities per quadrant.

6.8.5 Trace Figures

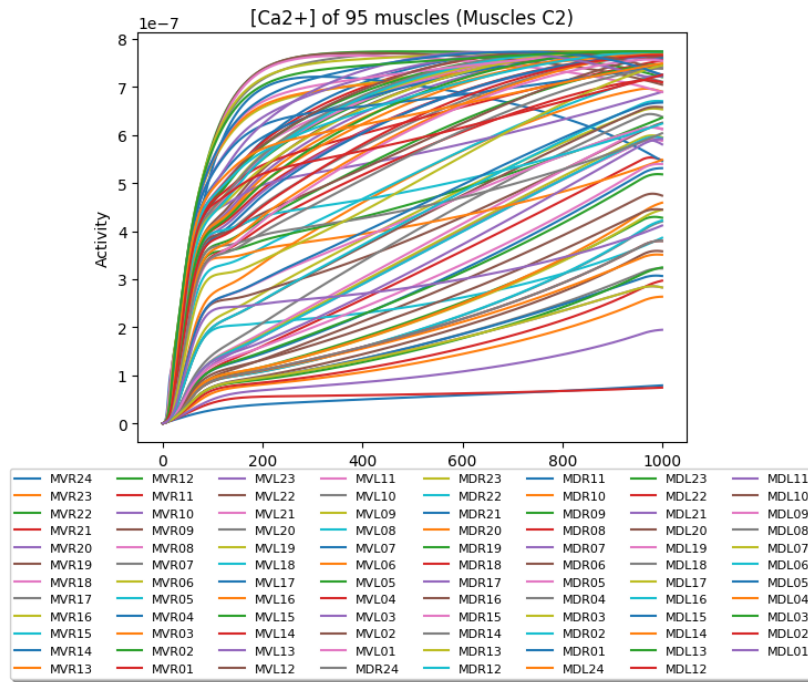


Figure 77: Traces of muscle activity and potentials.

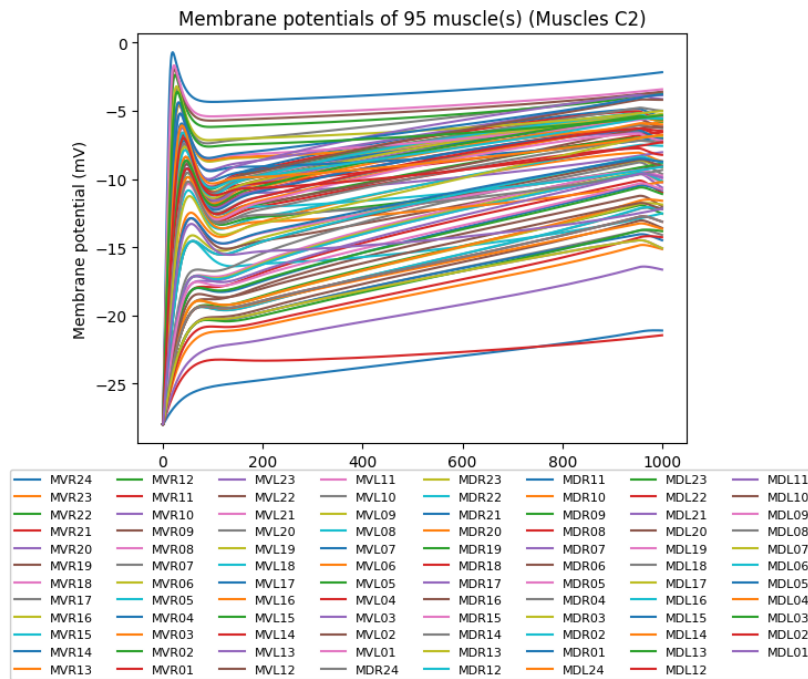


Figure 78: Traces of muscle activity.

6.8.6 Compact Morphology Grid

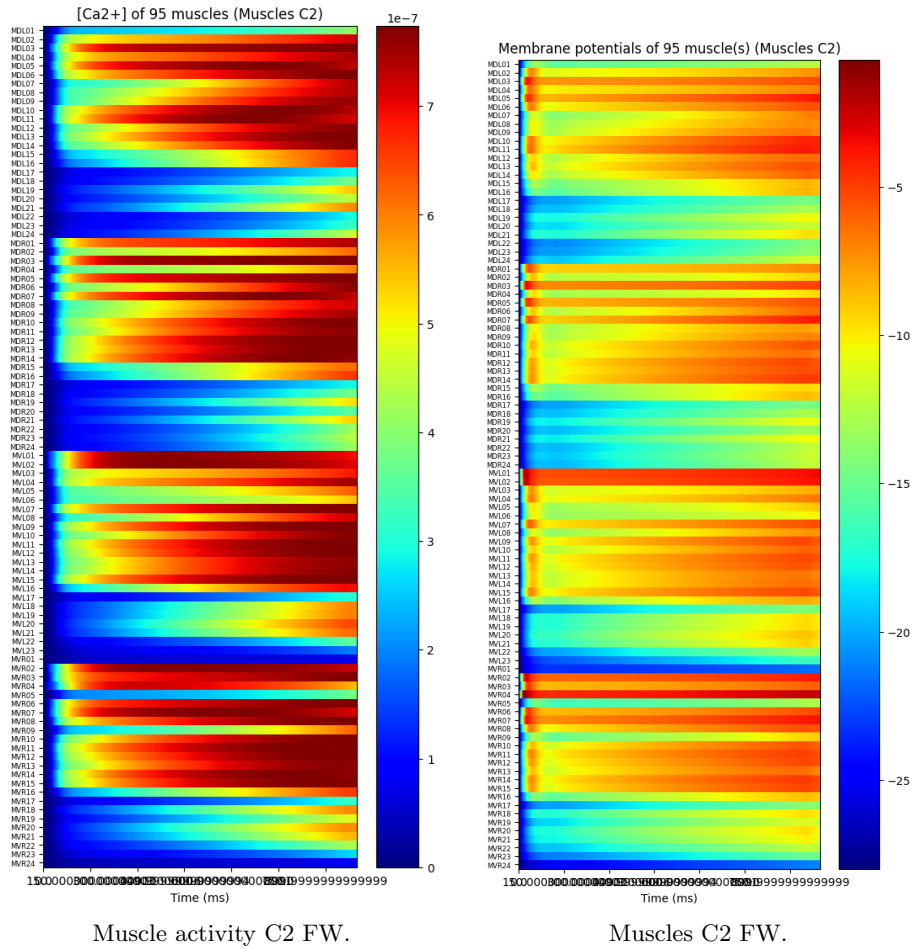
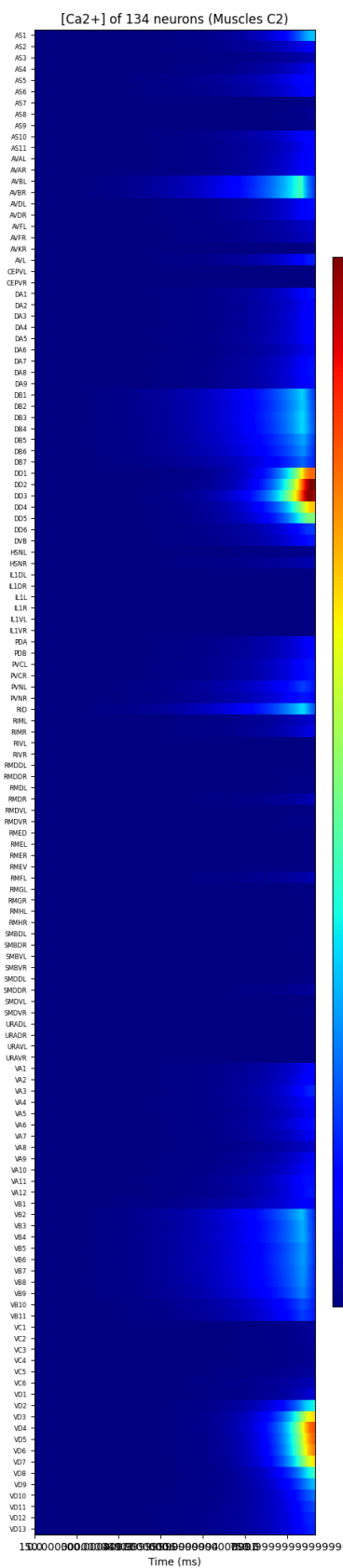


Figure 81: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).



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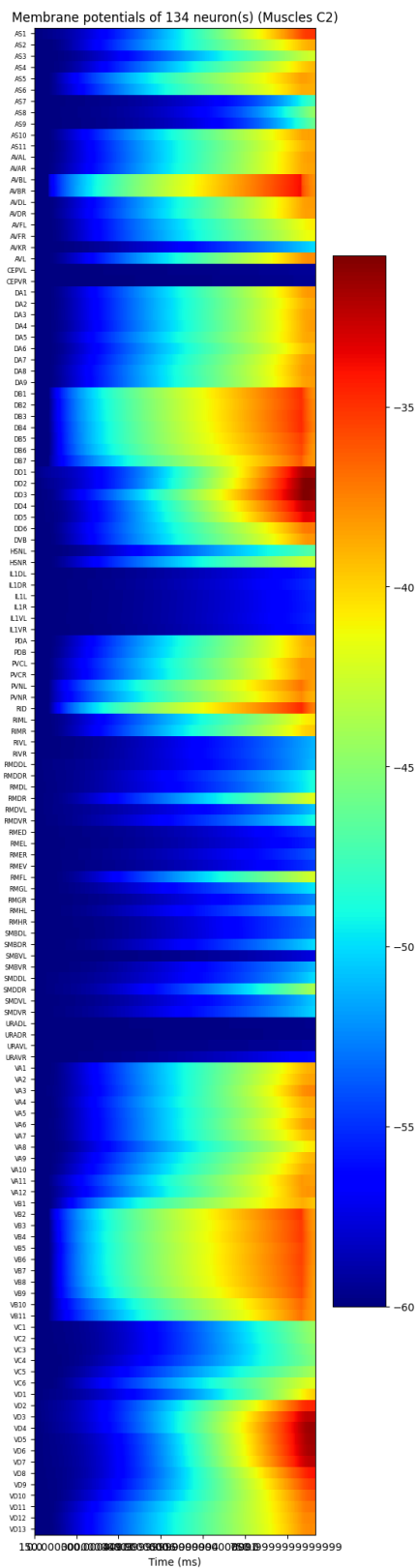


Figure 82: Neuron activity and morphology, shown as a 2x1 grid for compact

6.8.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.5 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 35: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	2.2 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[-----]	0.2 / 10
Overall Severity	[==-----]	4.5 / 10

6.9 Movement Analysis: AVA-DA_bilateral

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run C2_Muscles_2026-08-16_10-33-55-AVA-DA_bilateral.

6.9.1 Locomotion State Classification

Table 36: Behavioral State Breakdown for AVA-DA_bilateral

Locomotion State	Time Fraction (%)
Forward Crawling	17.0%
Backward Crawling	21.8%
Stationary	0.0%
Reversal	10.3%
Omega Turns	27.3%
Shallow Turns	23.6%
Irregular / Abnormal	0.0%

6.9.2 Kinematic & Velocity Dynamics

Table 37: Kinematic and Velocity Metrics for AVA-DA_bilateral

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.018	mm
Gross Distance	0.1617	mm
Path Efficiency (Net/Gross)	0.1114	[0.0 – 1.0]
Mean Speed	0.1623	mm/s
Maximum Forward Velocity	1.113	mm/s
Maximum Backward Velocity	0.8744	mm/s
Median Velocity	0.1011	mm/s
Velocity Std Deviation	0.2106	mm/s
Velocity RMS	0.2659	mm/s
Fraction Time Moving Forward	54.8%	ratio
Fraction Time Moving Backward	44.6%	ratio
Fraction Time Stationary	0.0%	ratio
Acceleration (Mean)	-0.3912	mm/s ²
Maximum Acceleration	168.7928	mm/s ²
Acceleration RMS	25.3843	mm/s ²
Velocity Autocorrelation	0.8359	correlation
Reversal Frequency	17.0683	s ⁻¹
Mean Curvature	3802.4853	rad/mm
Omega Turn Count	45	count

6.9.3 Undulation Wave Mechanics

Table 38: Undulation Wave Parameters for AVA-DA_bilateral

Undulation Parameter	Value	Unit
Crawl Amplitude	0.0071	rad (bending)
Dominant Frequency	0.0	Hz
Wavelength	0.82	mm
Wave Velocity	0.0	mm/s
Phase Coherence	0.78	[0.0 – 1.0]
Mean Muscle Activation	0.789778	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.9.4 Worm Motion and Activity Figures

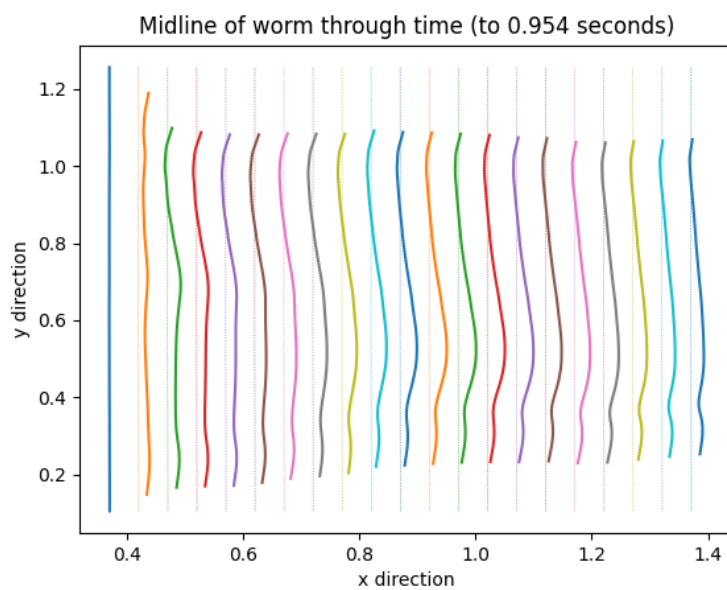


Figure 83: Midline of worm through time.

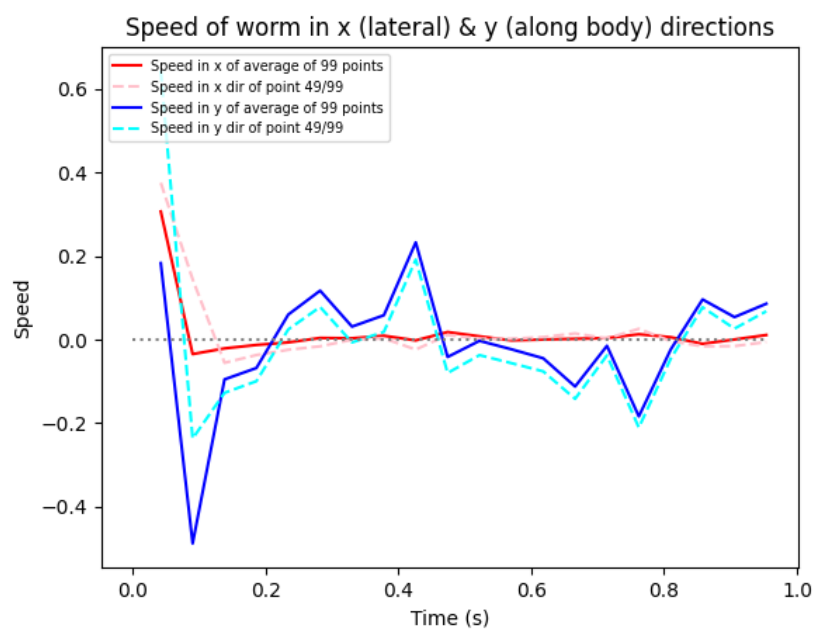


Figure 84: Speed of worm along body directions.

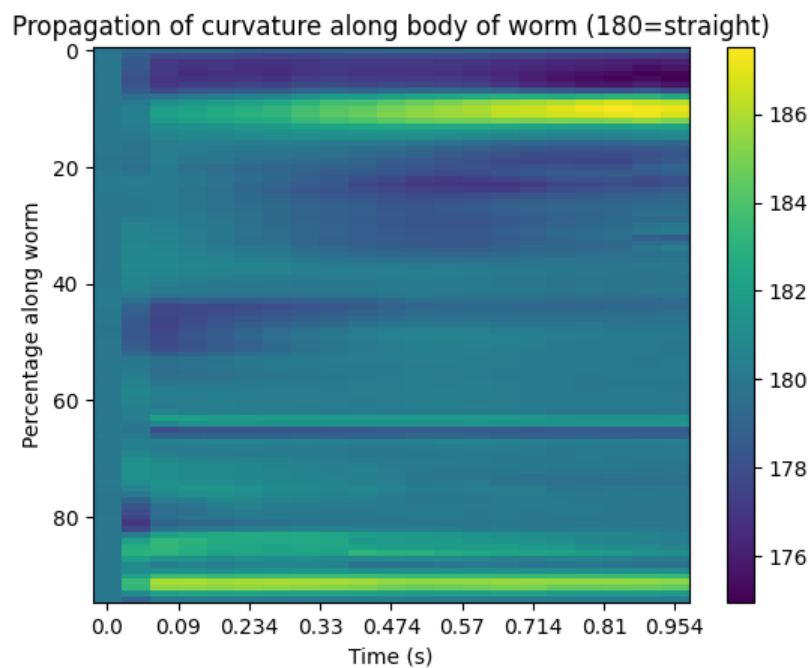


Figure 85: Propagation of curvature along body of worm.

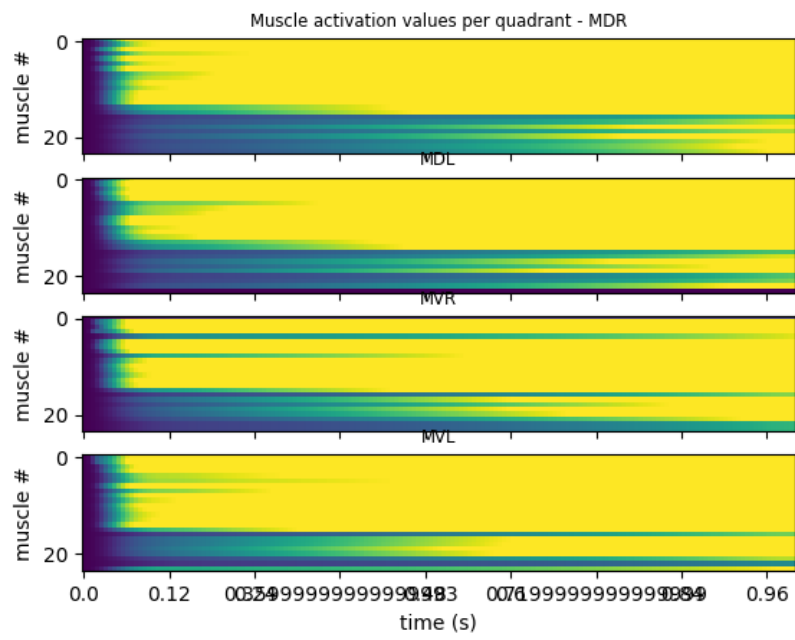


Figure 86: Muscle activities per quadrant.

6.9.5 Trace Figures

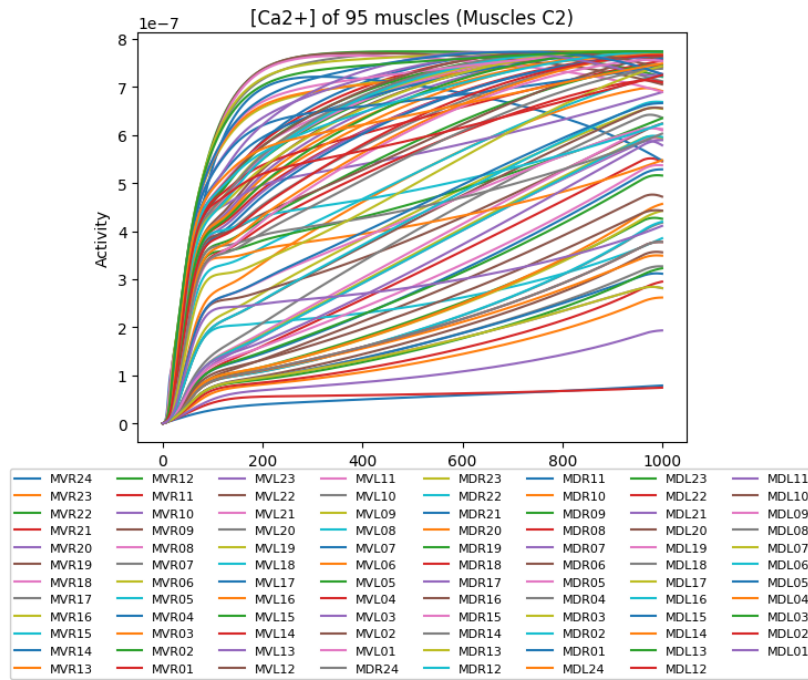
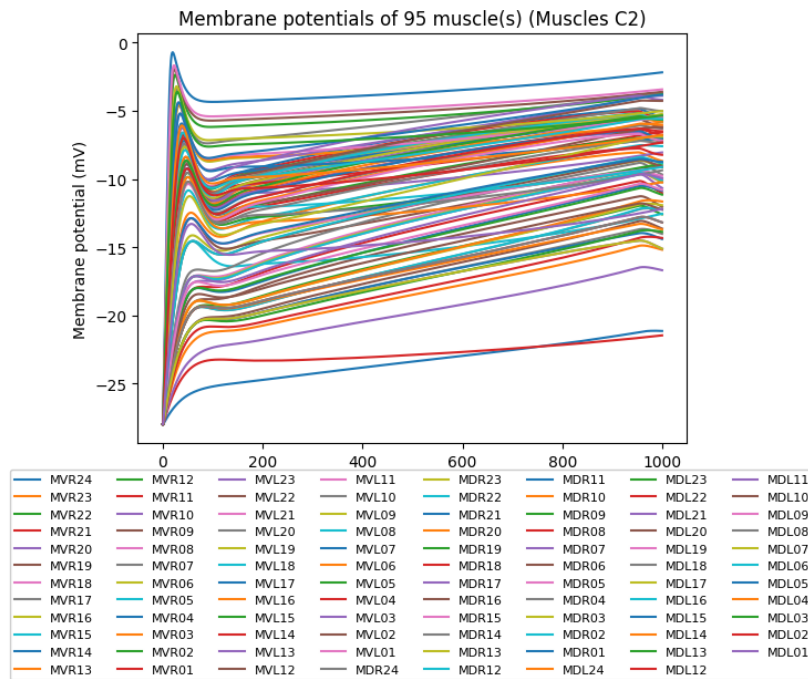


Figure 87: Traces of muscle activity and potentials.



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Figure 88: Traces of muscle activity.

6.9.6 Compact Morphology Grid

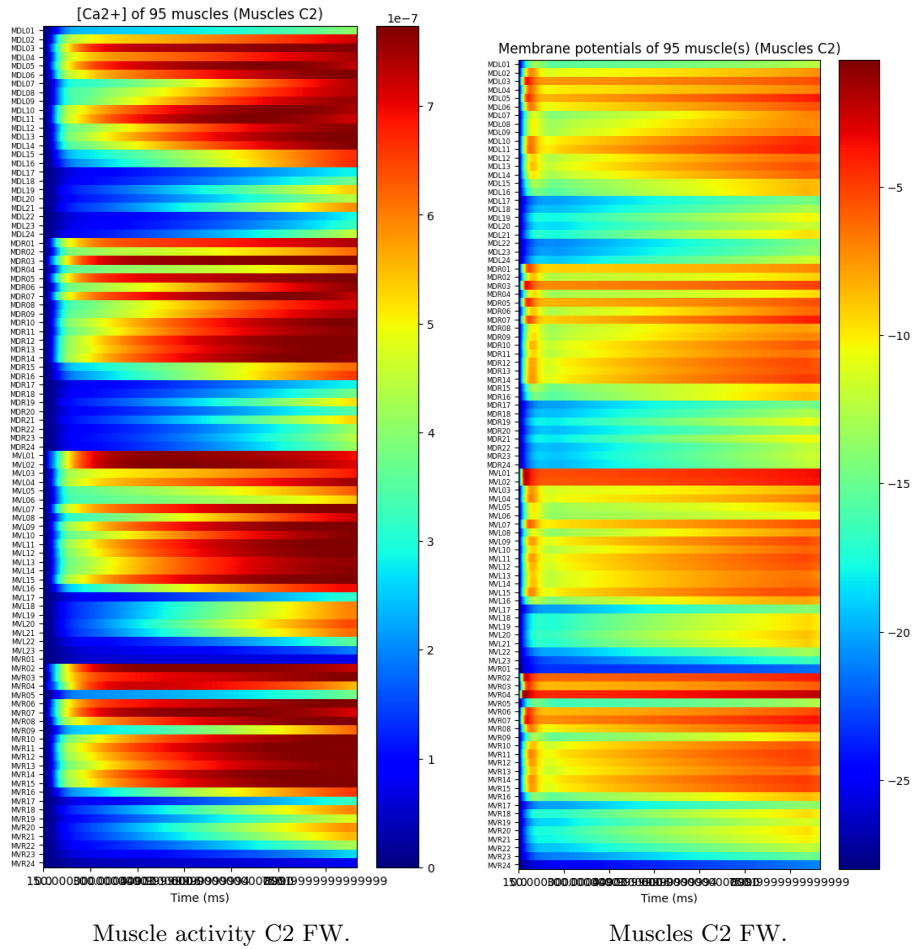


Figure 91: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).

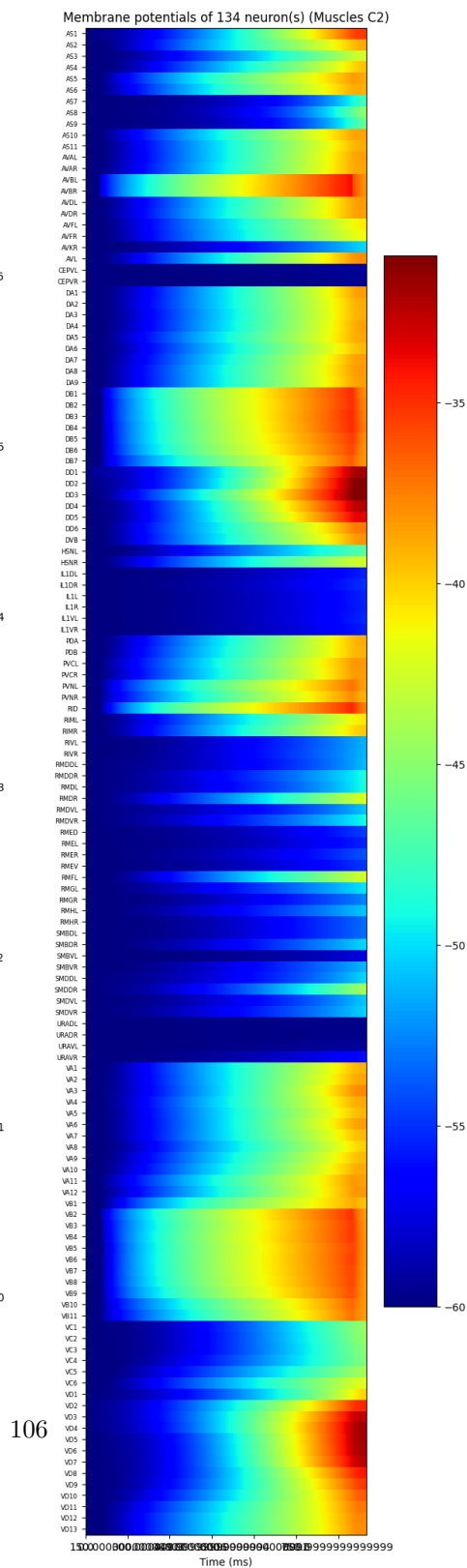
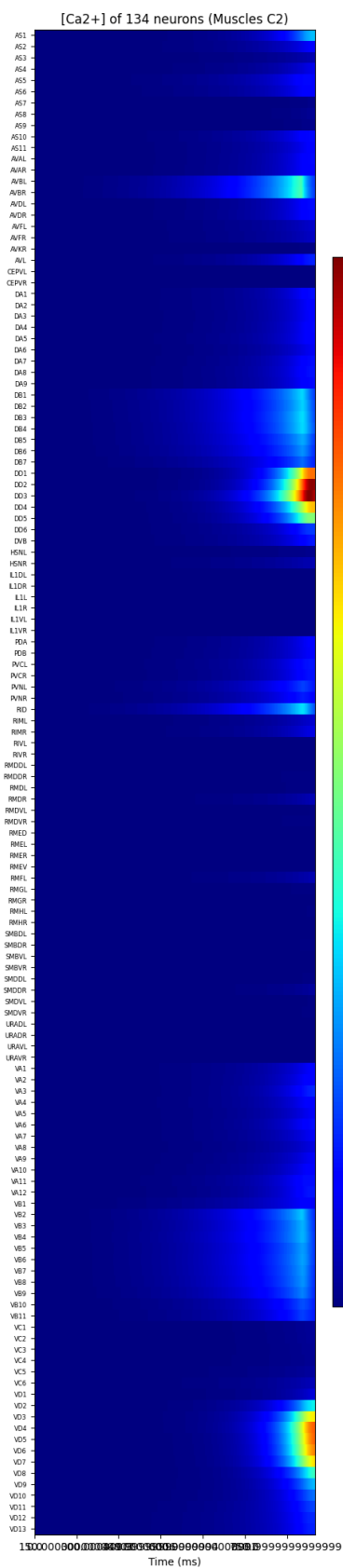


Figure 92: Neuron activity and morphology, shown as a 2x1 grid for compact

6.9.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.7 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 39: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	2.2 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[=-----]	1.0 / 10
Overall Severity	[=====]	4.7 / 10

6.10 Movement Analysis: AVA-VA_bilateral

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run C2_Muscles_2026-08-16_14-41-41-AVA-VA_bilateral.

6.10.1 Locomotion State Classification

Table 40: Behavioral State Breakdown for AVA-VA_bilateral

Locomotion State	Time Fraction (%)
Forward Crawling	12.7%
Backward Crawling	24.9%
Stationary	0.0%
Reversal	13.3%
Omega Turns	26.1%
Shallow Turns	23.0%
Irregular / Abnormal	0.0%

6.10.2 Kinematic & Velocity Dynamics

Table 41: Kinematic and Velocity Metrics for AVA-VA_bilateral

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.0392	mm
Gross Distance	0.1418	mm
Path Efficiency (Net/Gross)	0.2766	[0.0 – 1.0]
Mean Speed	0.1424	mm/s
Maximum Forward Velocity	0.628	mm/s
Maximum Backward Velocity	0.8177	mm/s
Median Velocity	0.0787	mm/s
Velocity Std Deviation	0.1902	mm/s
Velocity RMS	0.2376	mm/s
Fraction Time Moving Forward	49.4%	ratio
Fraction Time Moving Backward	50.6%	ratio
Fraction Time Stationary	0.0%	ratio
Acceleration (Mean)	-0.3288	mm/s ²
Maximum Acceleration	168.7979	mm/s ²
Acceleration RMS	24.1378	mm/s ²
Velocity Autocorrelation	0.794	correlation
Reversal Frequency	22.0884	s ⁻¹
Mean Curvature	4492.0114	rad/mm
Omega Turn Count	43	count

6.10.3 Undulation Wave Mechanics

Table 42: Undulation Wave Parameters for AVA-VA_bilateral

Undulation Parameter	Value	Unit
Crawl Amplitude	0.0069	rad (bending)
Dominant Frequency	0.0	Hz
Wavelength	0.82	mm
Wave Velocity	0.0	mm/s
Phase Coherence	0.81	[0.0 – 1.0]
Mean Muscle Activation	0.789577	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.10.4 Worm Motion and Activity Figures

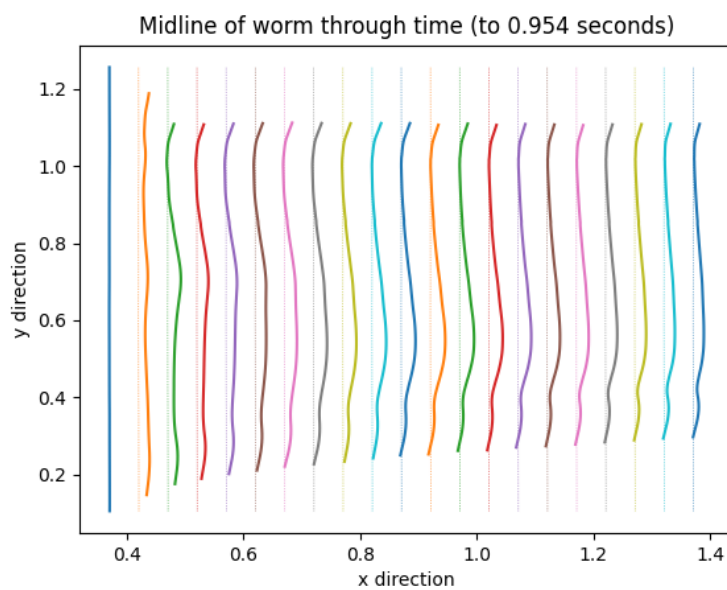


Figure 93: Midline of worm through time.

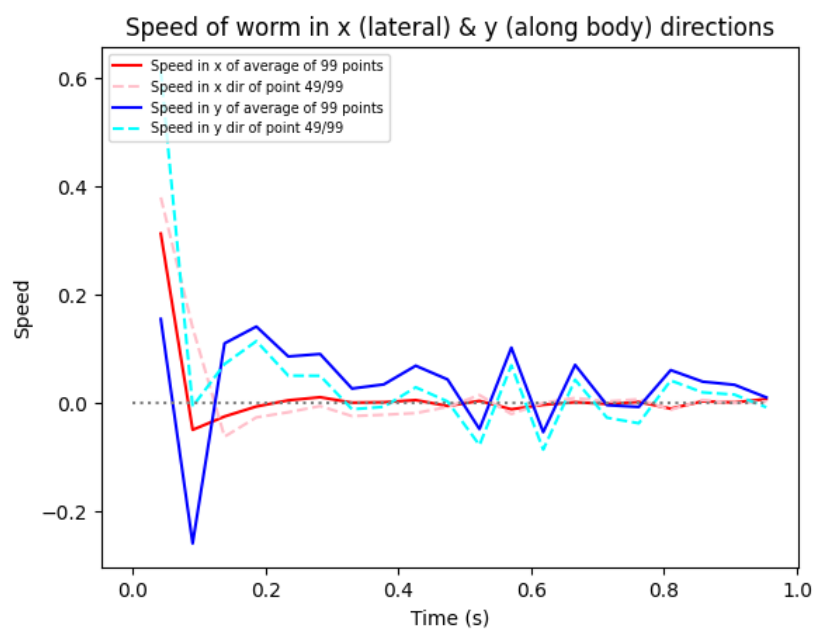


Figure 94: Speed of worm along body directions.

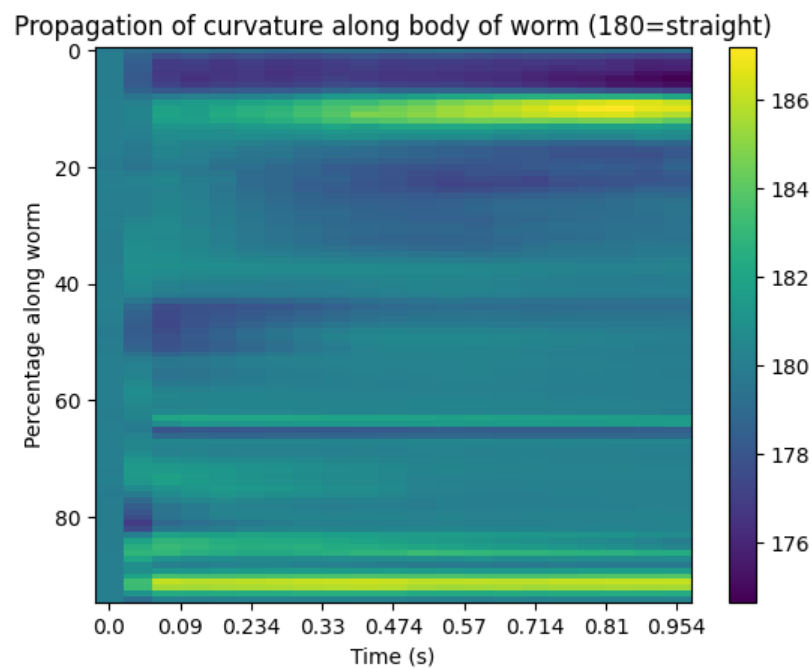


Figure 95: Propagation of curvature along body of worm.

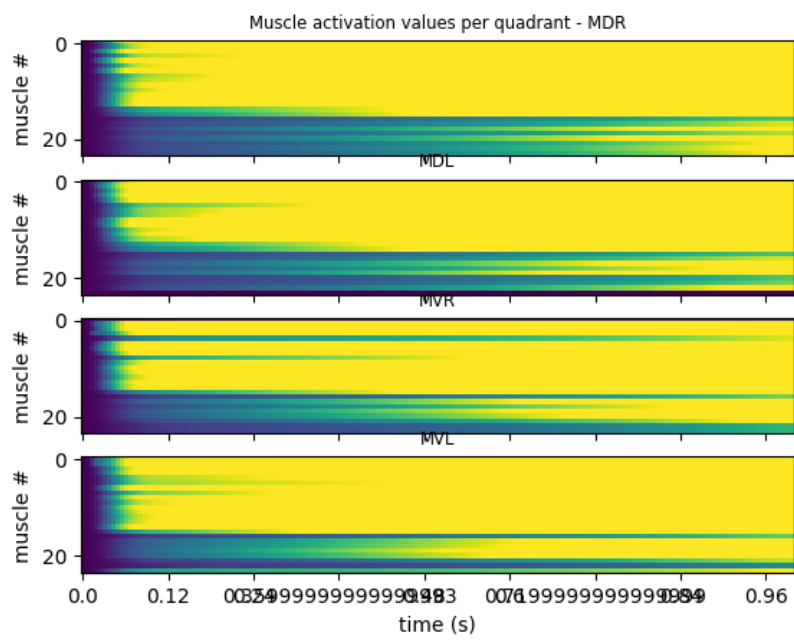


Figure 96: Muscle activities per quadrant.

6.10.5 Trace Figures

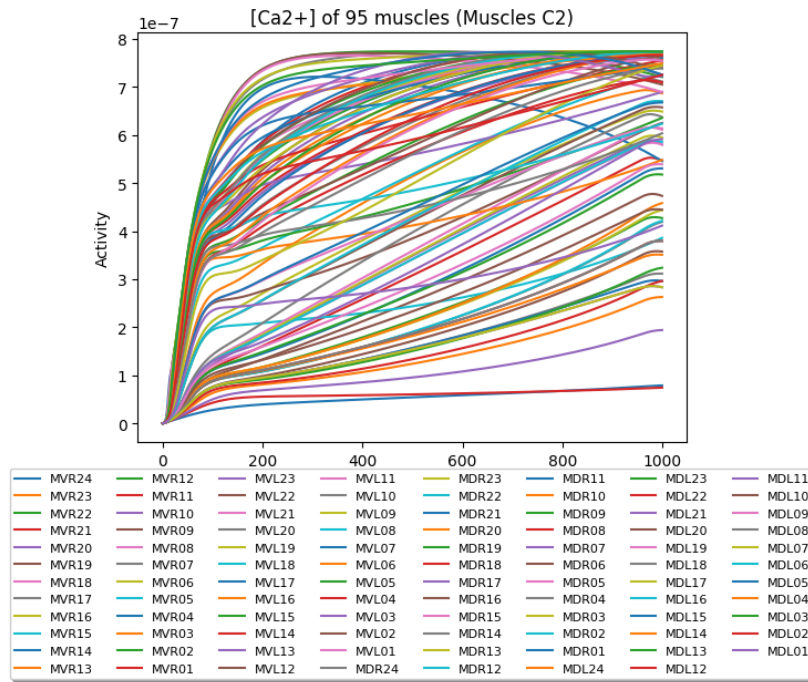
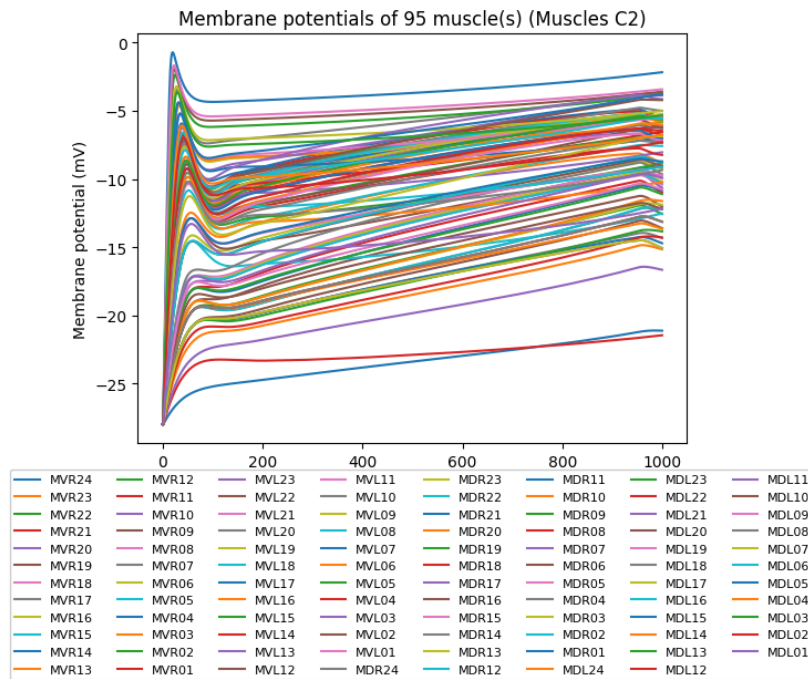


Figure 97: Traces of muscle activity and potentials.



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Figure 98: Traces of muscle activity.

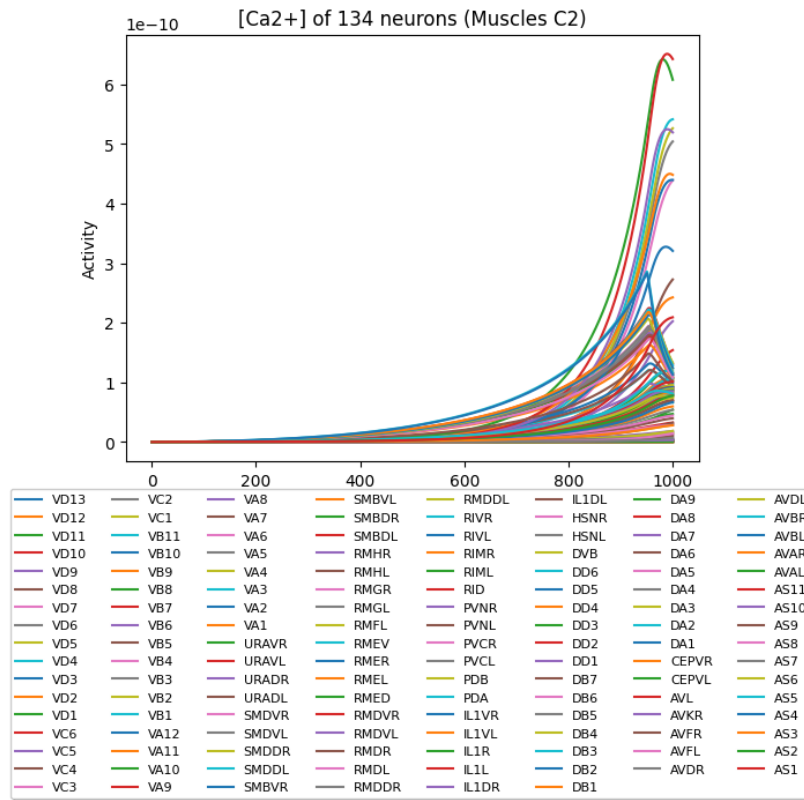
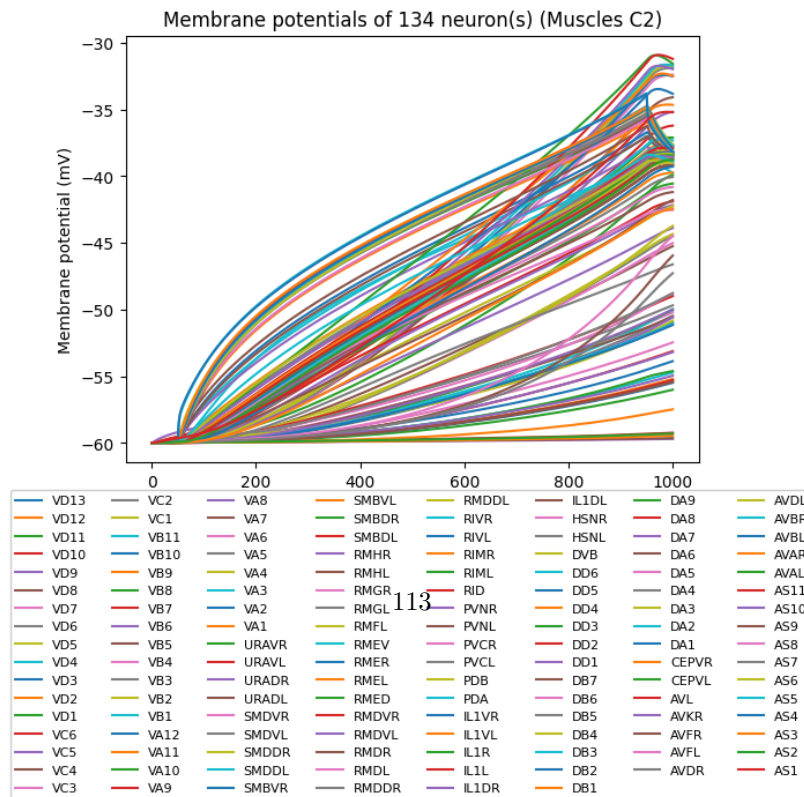


Figure 99: Traces of neuron activity and potentials.



6.10.6 Compact Morphology Grid

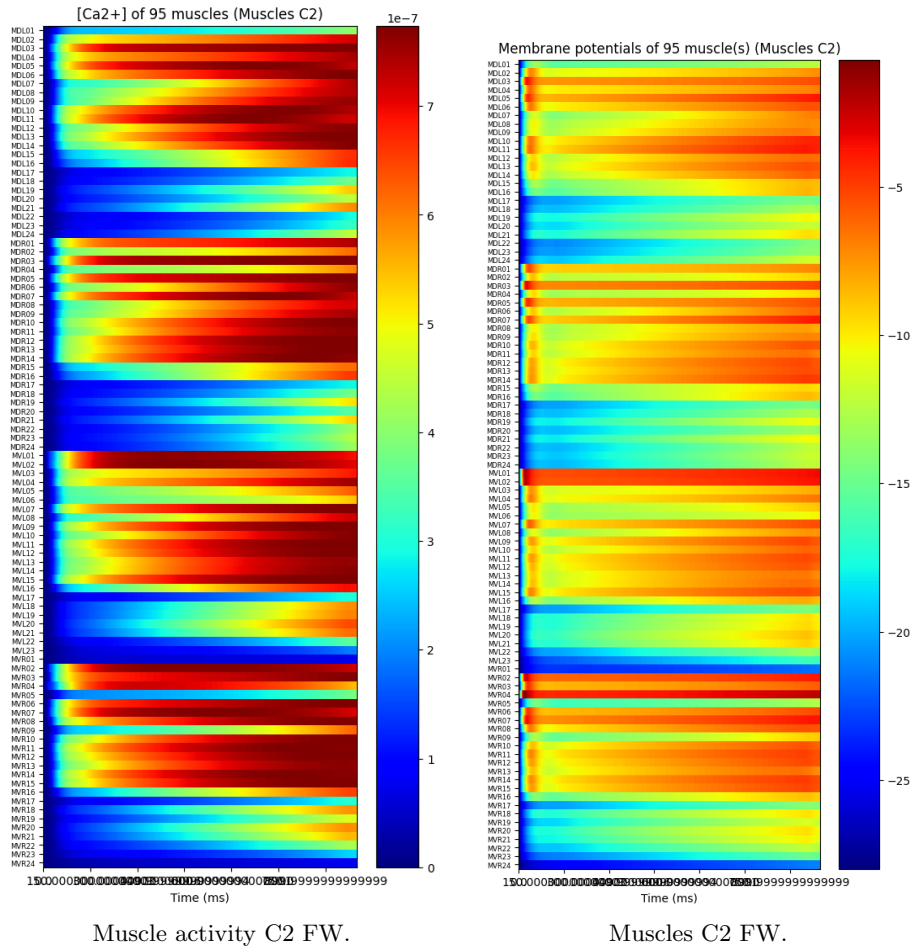


Figure 101: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).

6.10.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.4 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 43: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	1.9 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[-----]	0.1 / 10
Overall Severity	[====-----]	4.4 / 10

6.11 Movement Analysis: AVAR-PVCL_chem

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run C2_Muscles_2026-08-16_19-12-52-AVAR-PVCL_chem.

6.11.1 Locomotion State Classification

Table 44: Behavioral State Breakdown for AVAR-PVCL_chem

Locomotion State	Time Fraction (%)
Forward Crawling	12.1%
Backward Crawling	25.4%
Stationary	0.0%
Reversal	10.9%
Omega Turns	27.3%
Shallow Turns	24.2%
Irregular / Abnormal	0.0%

6.11.2 Kinematic & Velocity Dynamics

Table 45: Kinematic and Velocity Metrics for `AVAR-PVCL_chem`

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.0376	mm
Gross Distance	0.1436	mm
Path Efficiency (Net/Gross)	0.2615	[0.0 – 1.0]
Mean Speed	0.1442	mm/s
Maximum Forward Velocity	0.5715	mm/s
Maximum Backward Velocity	0.8616	mm/s
Median Velocity	0.0776	mm/s
Velocity Std Deviation	0.194	mm/s
Velocity RMS	0.2417	mm/s
Fraction Time Moving Forward	50.6%	ratio
Fraction Time Moving Backward	48.8%	ratio
Fraction Time Stationary	0.0%	ratio
Acceleration (Mean)	-0.397	mm/s ²
Maximum Acceleration	168.5681	mm/s ²
Acceleration RMS	23.1361	mm/s ²
Velocity Autocorrelation	0.805	correlation
Reversal Frequency	18.0723	s ⁻¹
Mean Curvature	3467.7248	rad/mm
Omega Turn Count	45	count

6.11.3 Undulation Wave Mechanics

Table 46: Undulation Wave Parameters for `AVAR-PVCL_chem`

Undulation Parameter	Value	Unit
Crawl Amplitude	0.0069	rad (bending)
Dominant Frequency	0.0	Hz
Wavelength	0.82	mm
Wave Velocity	0.0	mm/s
Phase Coherence	0.78	[0.0 – 1.0]
Mean Muscle Activation	0.789687	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.11.4 Worm Motion and Activity Figures

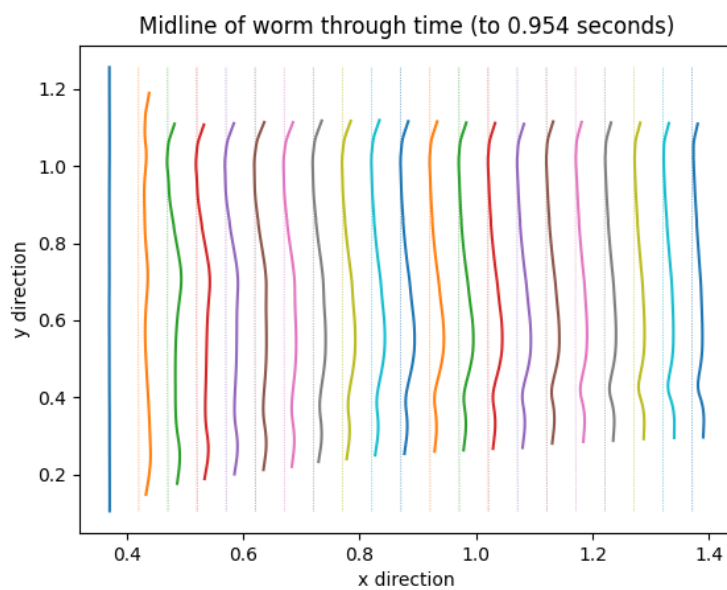


Figure 103: Midline of worm through time.

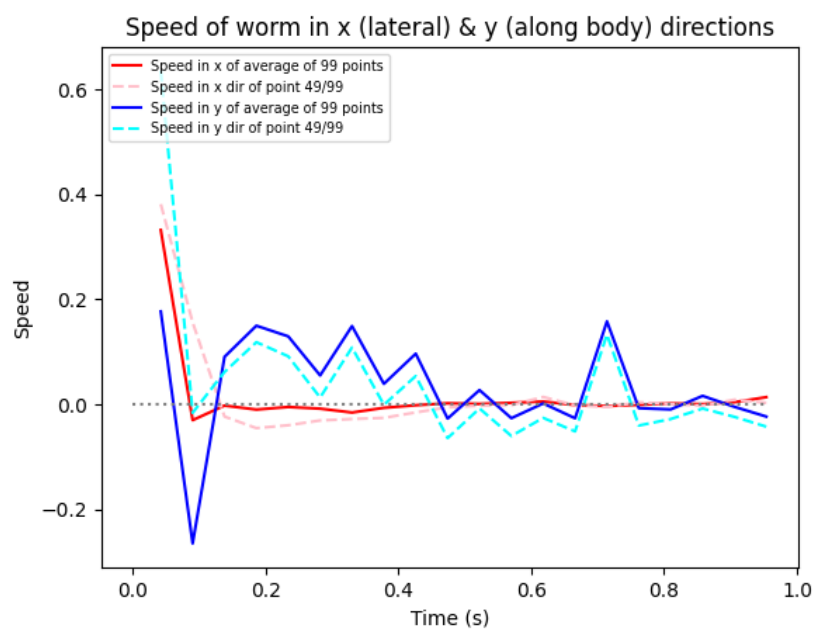


Figure 104: Speed of worm along body directions.

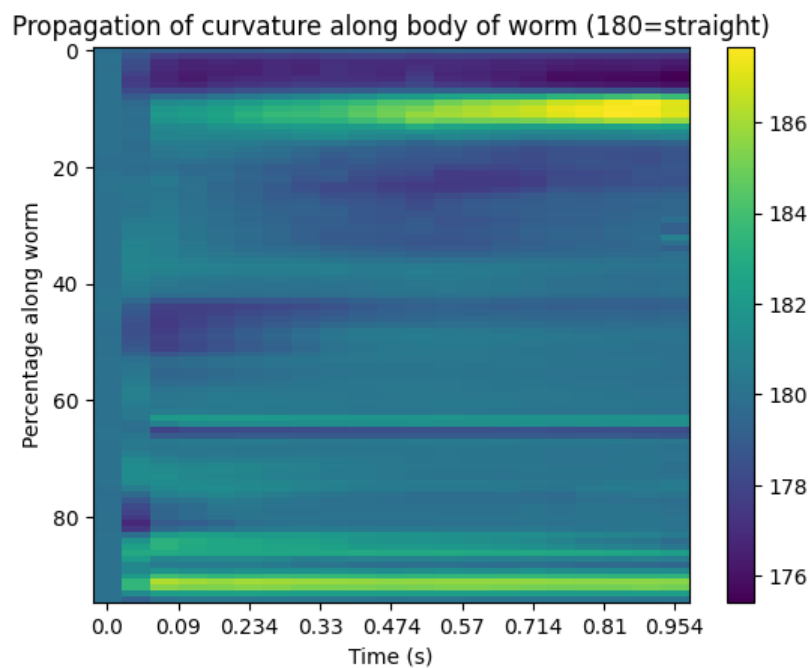


Figure 105: Propagation of curvature along body of worm.

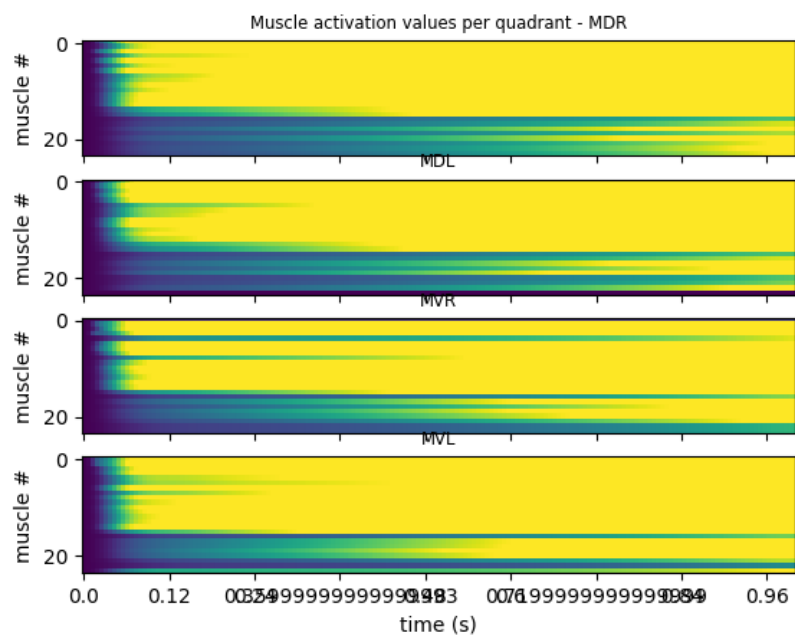


Figure 106: Muscle activities per quadrant.

6.11.5 Trace Figures

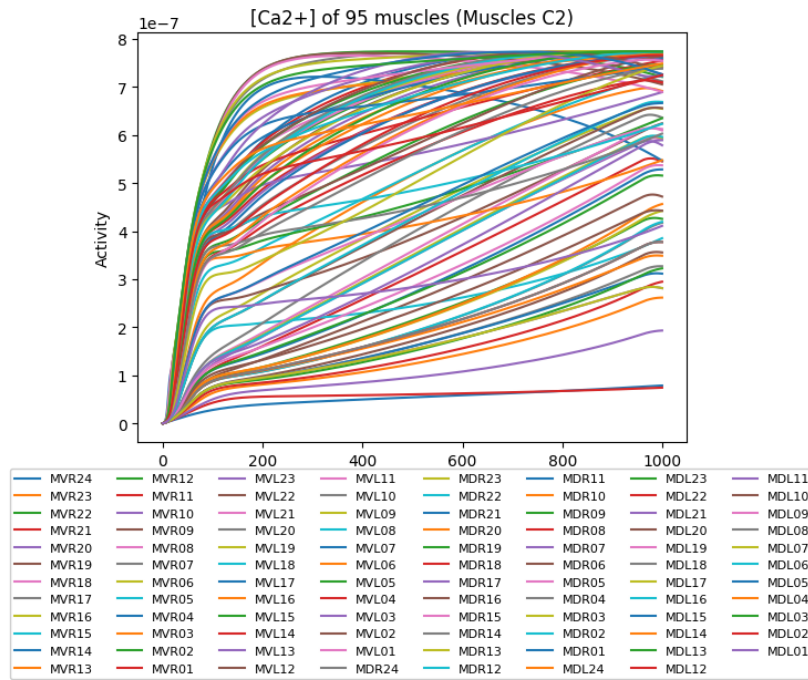


Figure 107: Traces of muscle activity and potentials.

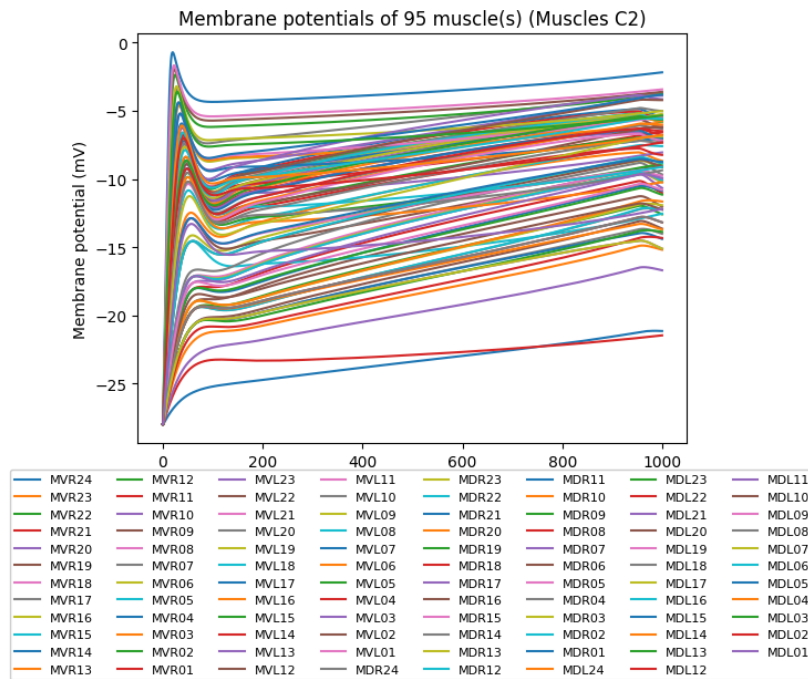


Figure 108: Traces of muscle activity.

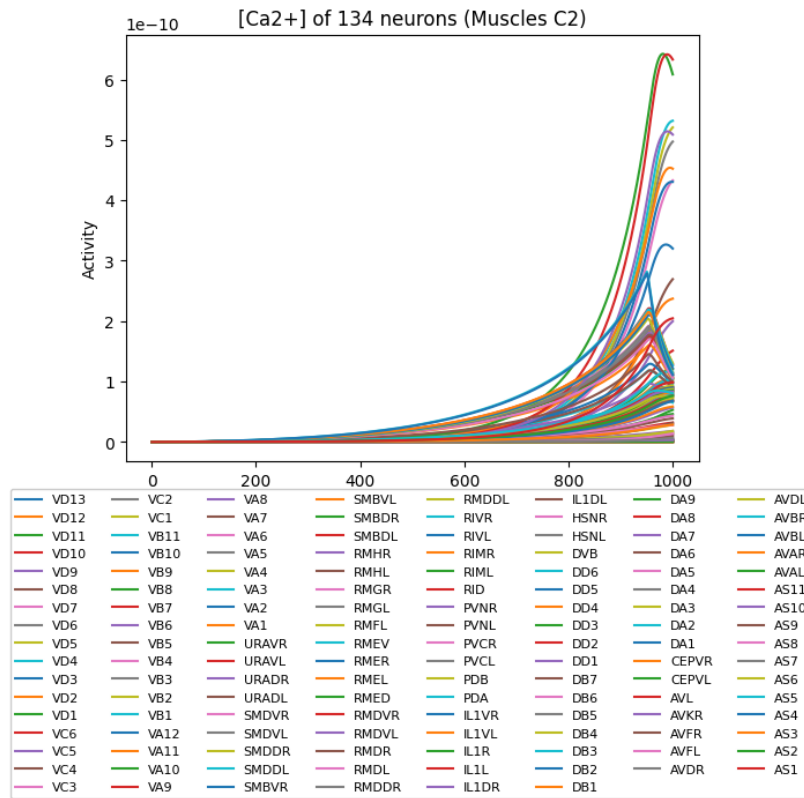
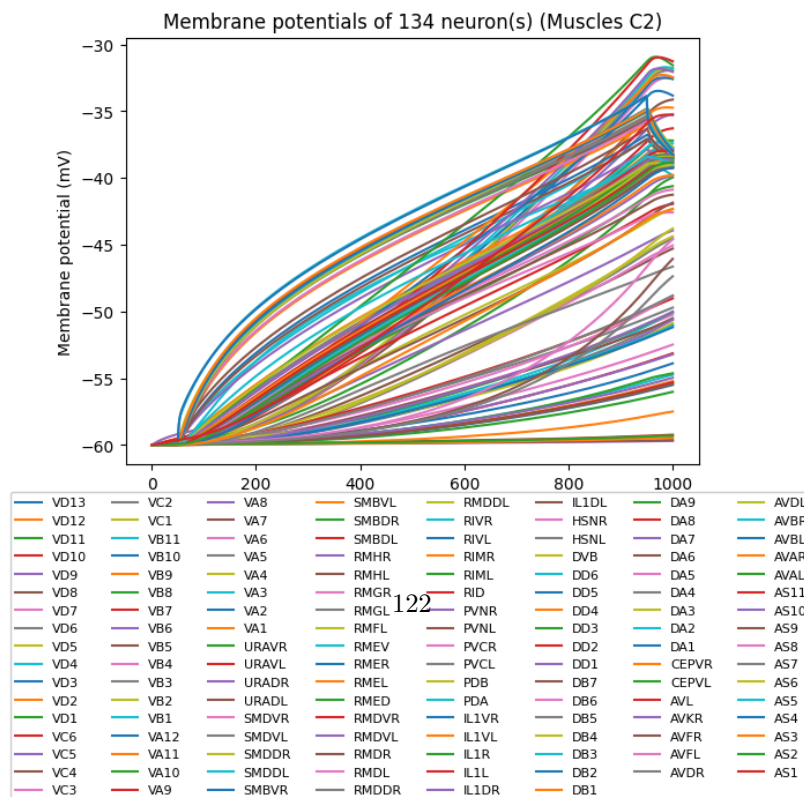


Figure 109: Traces of neuron activity and potentials.



6.11.6 Compact Morphology Grid

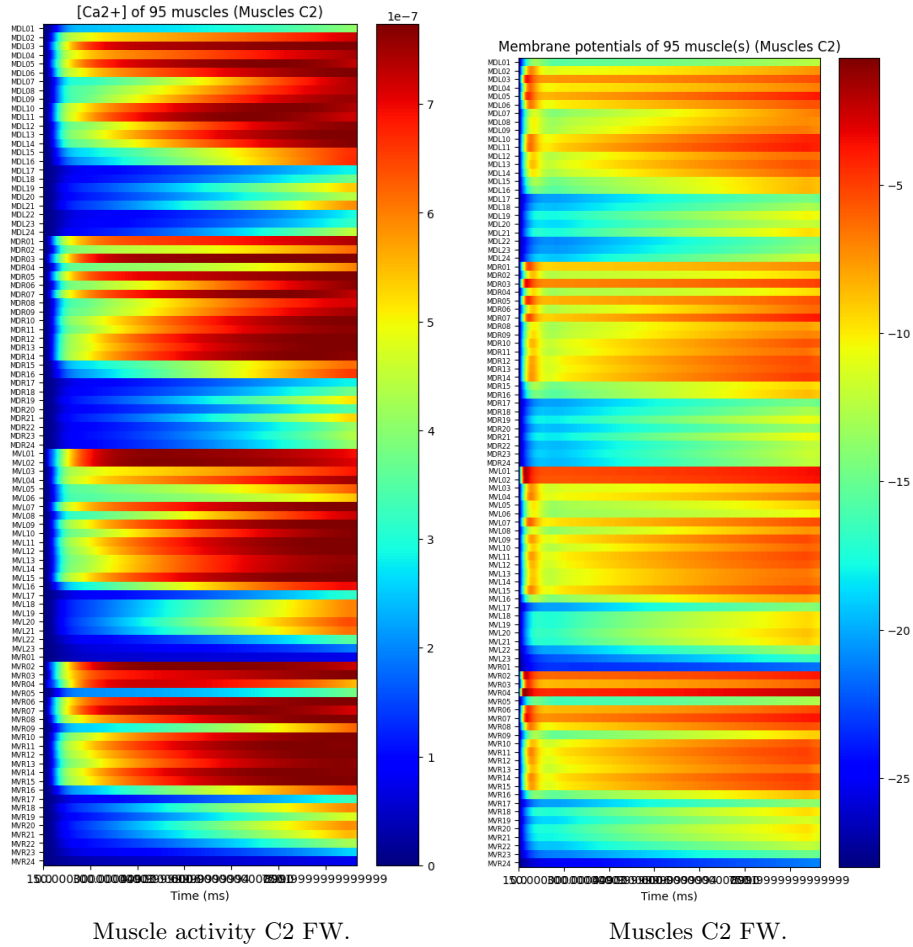


Figure 111: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).

6.11.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.5 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 47: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	2.2 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[-----]	0.2 / 10
Overall Severity	[====-----]	4.5 / 10

6.12 Movement Analysis: AVAR-PVCL_GJ

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run C2_Muscles_2026-08-17_08-39-22-AVAR-PVCL_GJ.

6.12.1 Locomotion State Classification

Table 48: Behavioral State Breakdown for AVAR-PVCL_GJ

Locomotion State	Time Fraction (%)
Forward Crawling	13.3%
Backward Crawling	29.7%
Stationary	0.0%
Reversal	13.3%
Omega Turns	27.3%
Shallow Turns	16.4%
Irregular / Abnormal	0.0%

6.12.2 Kinematic & Velocity Dynamics

Table 49: Kinematic and Velocity Metrics for `AVAR-PVCL_GJ`

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.0397	mm
Gross Distance	0.1422	mm
Path Efficiency (Net/Gross)	0.2791	[0.0 – 1.0]
Mean Speed	0.1428	mm/s
Maximum Forward Velocity	1.0113	mm/s
Maximum Backward Velocity	0.7735	mm/s
Median Velocity	0.0786	mm/s
Velocity Std Deviation	0.2006	mm/s
Velocity RMS	0.2462	mm/s
Fraction Time Moving Forward	42.2%	ratio
Fraction Time Moving Backward	57.8%	ratio
Fraction Time Stationary	0.0%	ratio
Acceleration (Mean)	-0.4351	mm/s ²
Maximum Acceleration	168.7679	mm/s ²
Acceleration RMS	25.0487	mm/s ²
Velocity Autocorrelation	0.7836	correlation
Reversal Frequency	22.0884	s ⁻¹
Mean Curvature	4088.0379	rad/mm
Omega Turn Count	45	count

6.12.3 Undulation Wave Mechanics

Table 50: Undulation Wave Parameters for `AVAR-PVCL_GJ`

Undulation Parameter	Value	Unit
Crawl Amplitude	0.0069	rad (bending)
Dominant Frequency	0.0	Hz
Wavelength	0.82	mm
Wave Velocity	0.0	mm/s
Phase Coherence	0.79	[0.0 – 1.0]
Mean Muscle Activation	0.789967	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.12.4 Worm Motion and Activity Figures

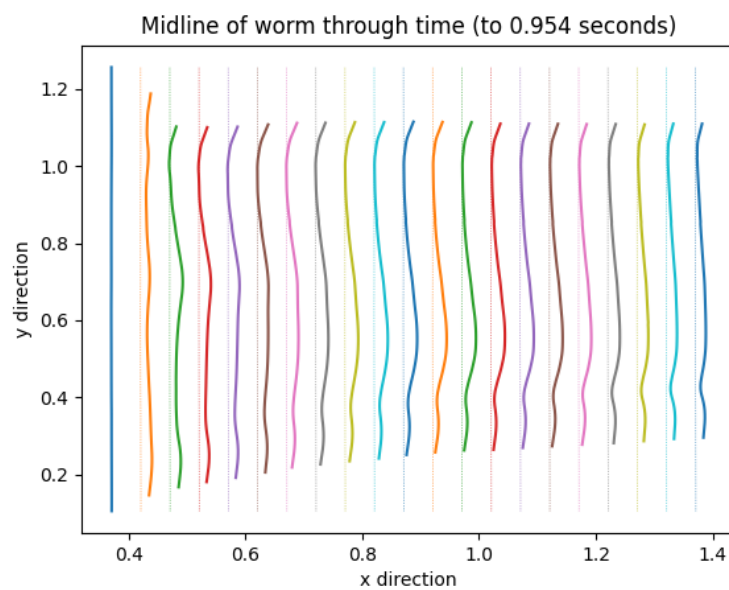


Figure 113: Midline of worm through time.

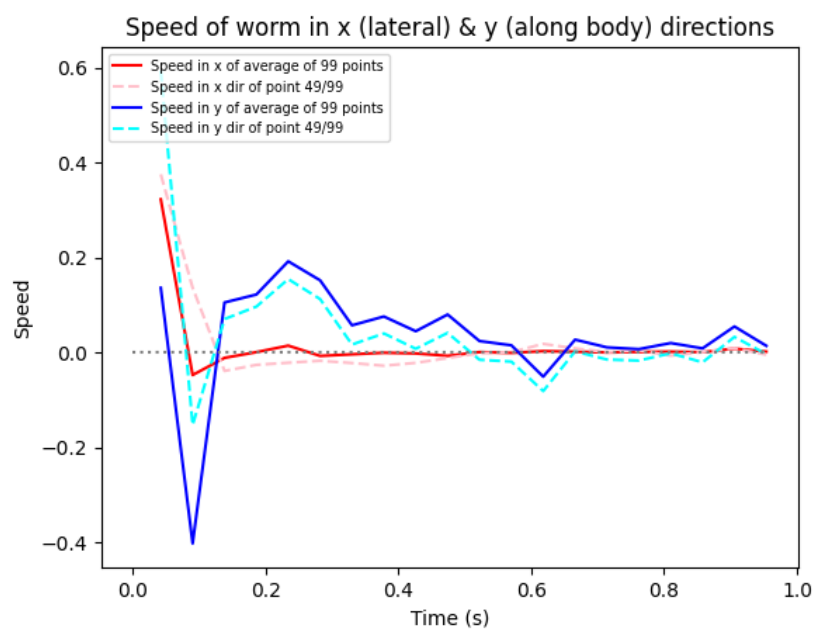


Figure 114: Speed of worm along body directions.

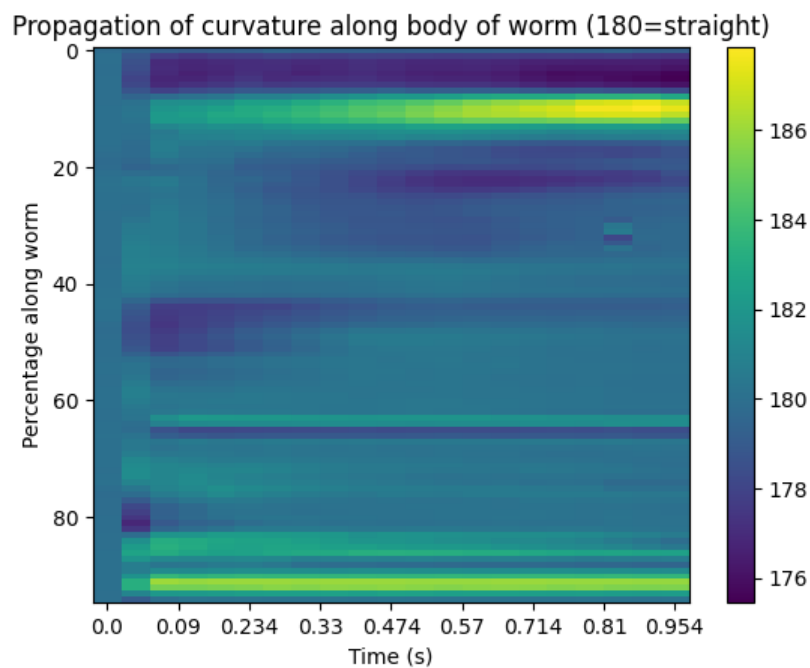


Figure 115: Propagation of curvature along body of worm.

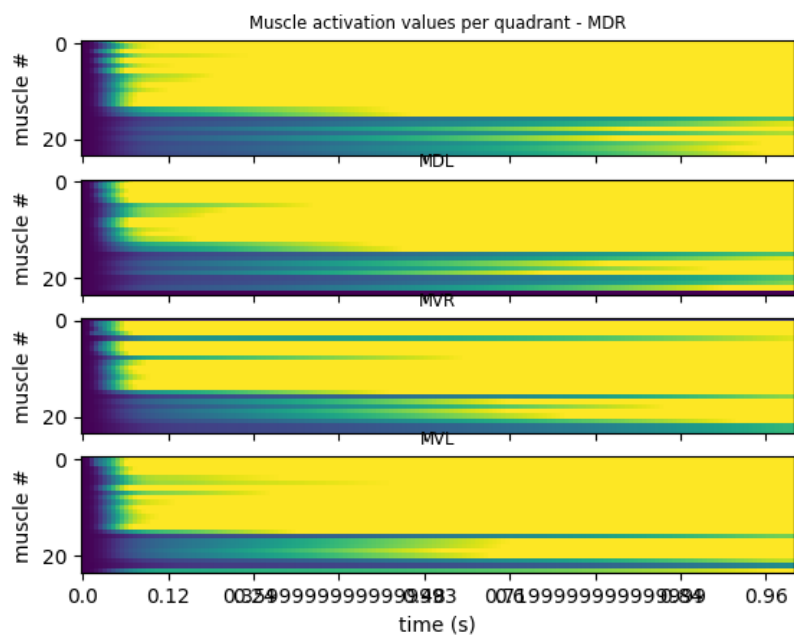


Figure 116: Muscle activities per quadrant.

6.12.5 Trace Figures

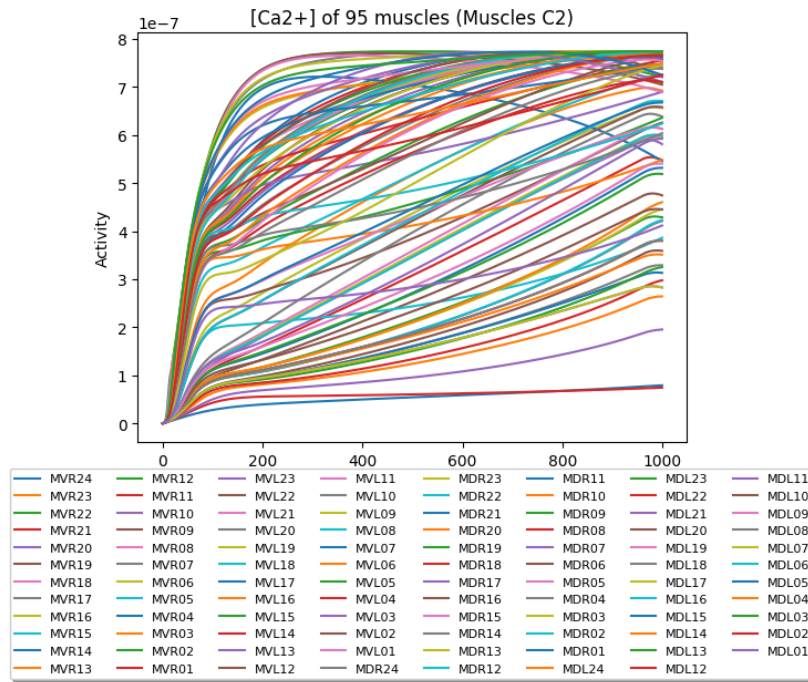
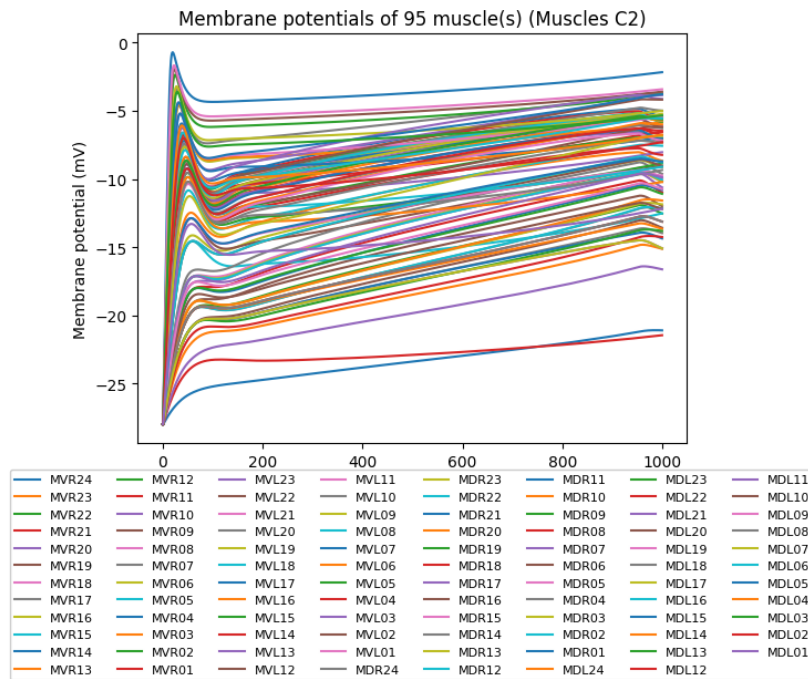


Figure 117: Traces of muscle activity and potentials.



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Figure 118: Traces of muscle activity.

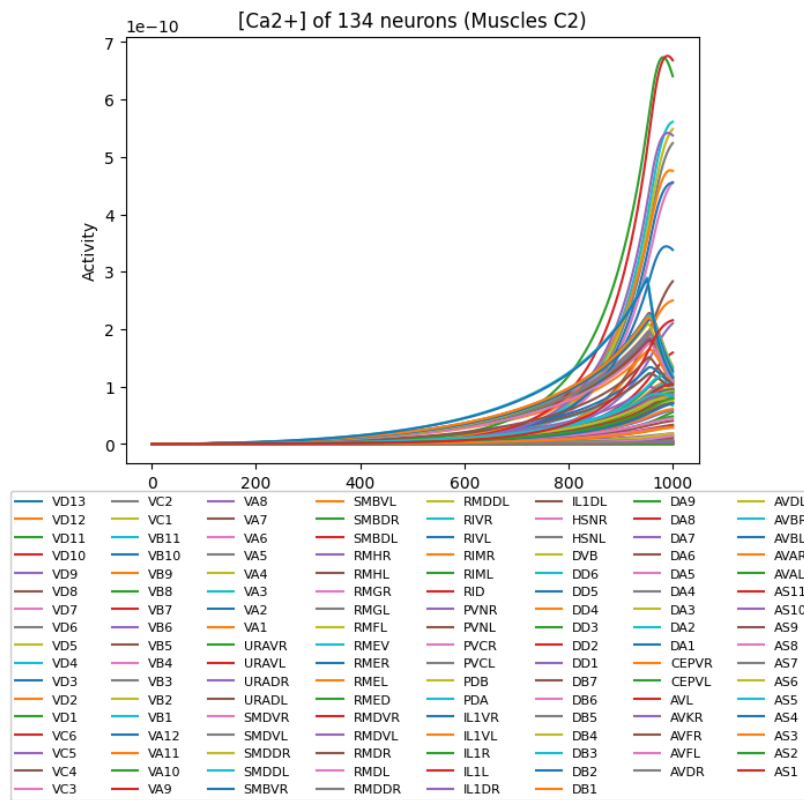
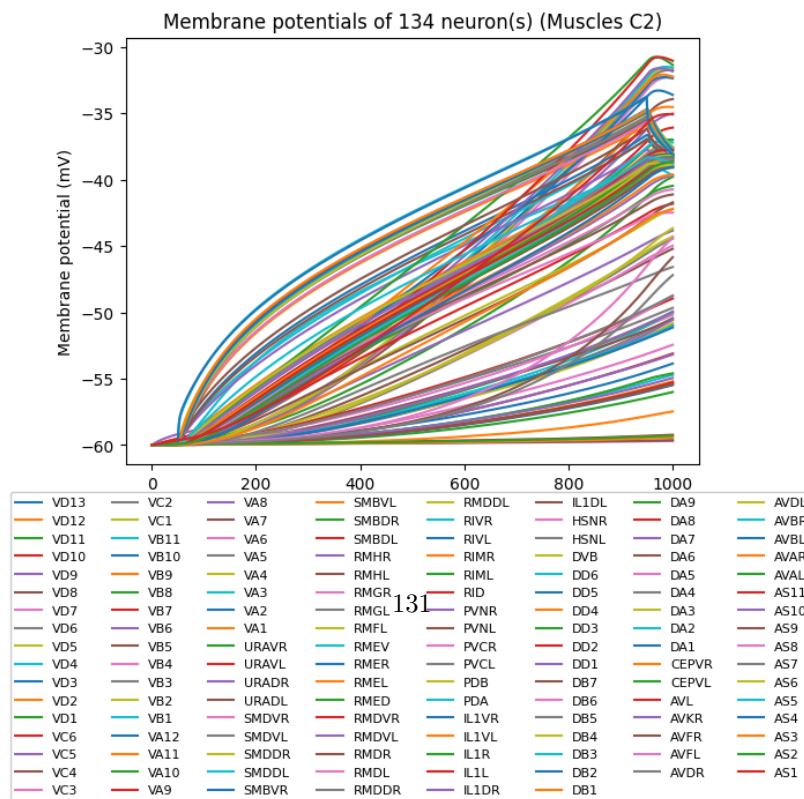


Figure 119: Traces of neuron activity and potentials.



6.12.6 Compact Morphology Grid

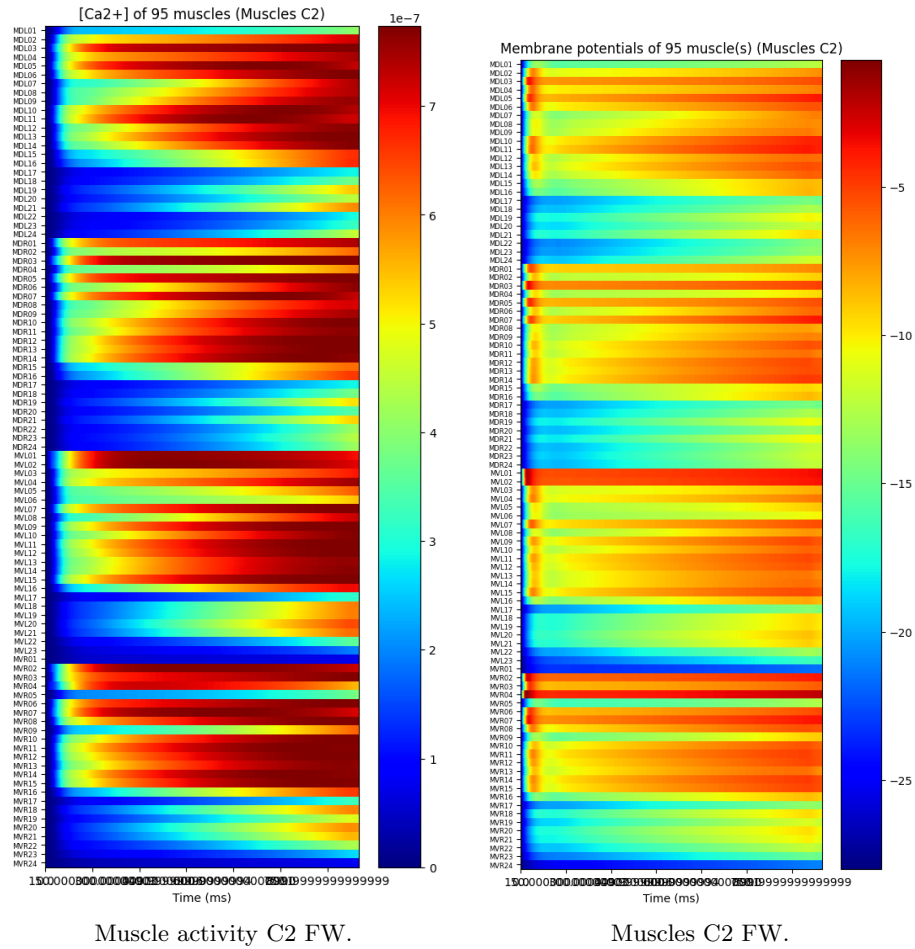


Figure 121: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).

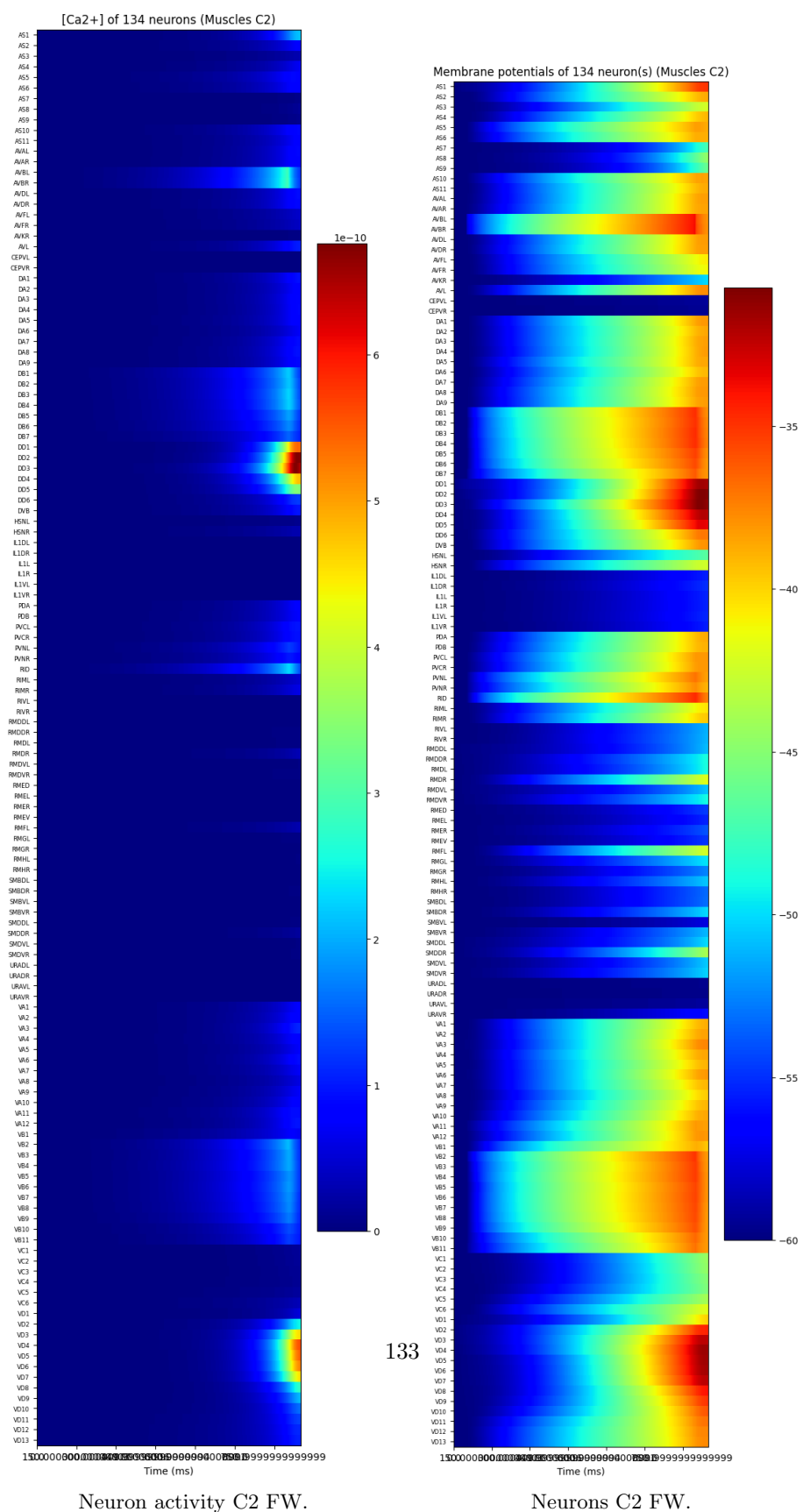


Figure 122: Neuron activity and morphology, shown as a 2x1 grid for compact

6.12.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.7 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 51: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	2.1 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[=-----]	1.6 / 10
Overall Severity	[=====]	4.7 / 10

6.13 Movement Analysis: AVAR-PVCL_both

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run C2_Muscles_2026-08-17_15-15-20-AVAR-PVCL_both.

6.13.1 Locomotion State Classification

Table 52: Behavioral State Breakdown for AVAR-PVCL_both

Locomotion State	Time Fraction (%)
Forward Crawling	14.6%
Backward Crawling	26.1%
Stationary	0.0%
Reversal	11.5%
Omega Turns	21.2%
Shallow Turns	26.7%
Irregular / Abnormal	0.0%

6.13.2 Kinematic & Velocity Dynamics

Table 53: Kinematic and Velocity Metrics for AVAR-PVCL_both

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.0274	mm
Gross Distance	0.1657	mm
Path Efficiency (Net/Gross)	0.1656	[0.0 – 1.0]
Mean Speed	0.1664	mm/s
Maximum Forward Velocity	0.6941	mm/s
Maximum Backward Velocity	0.8846	mm/s
Median Velocity	0.1062	mm/s
Velocity Std Deviation	0.1949	mm/s
Velocity RMS	0.2563	mm/s
Fraction Time Moving Forward	51.8%	ratio
Fraction Time Moving Backward	48.2%	ratio
Fraction Time Stationary	0.0%	ratio
Acceleration (Mean)	-0.4719	mm/s ²
Maximum Acceleration	168.5698	mm/s ²
Acceleration RMS	22.8415	mm/s ²
Velocity Autocorrelation	0.8591	correlation
Reversal Frequency	19.0763	s ⁻¹
Mean Curvature	2922.1599	rad/mm
Omega Turn Count	35	count

6.13.3 Undulation Wave Mechanics

Table 54: Undulation Wave Parameters for AVAR-PVCL_both

Undulation Parameter	Value	Unit
Crawl Amplitude	0.0069	rad (bending)
Dominant Frequency	0.0	Hz
Wavelength	0.82	mm
Wave Velocity	0.0	mm/s
Phase Coherence	0.76	[0.0 – 1.0]
Mean Muscle Activation	0.789747	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.13.4 Worm Motion and Activity Figures

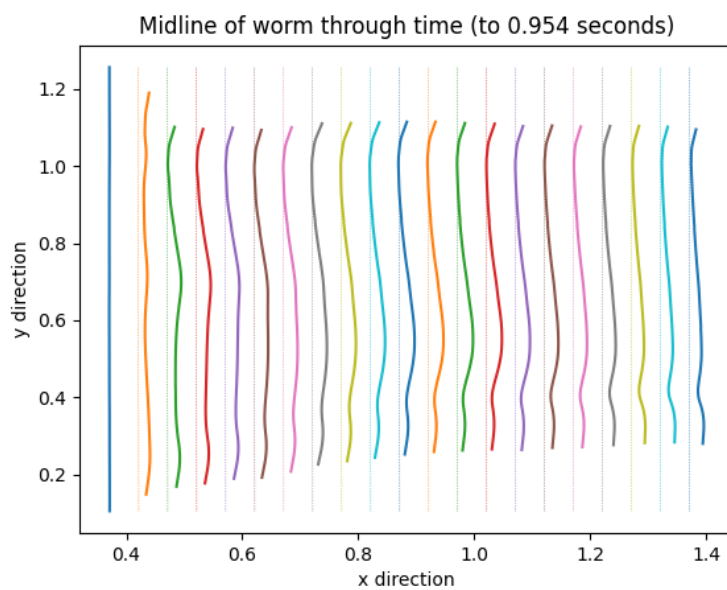


Figure 123: Midline of worm through time.

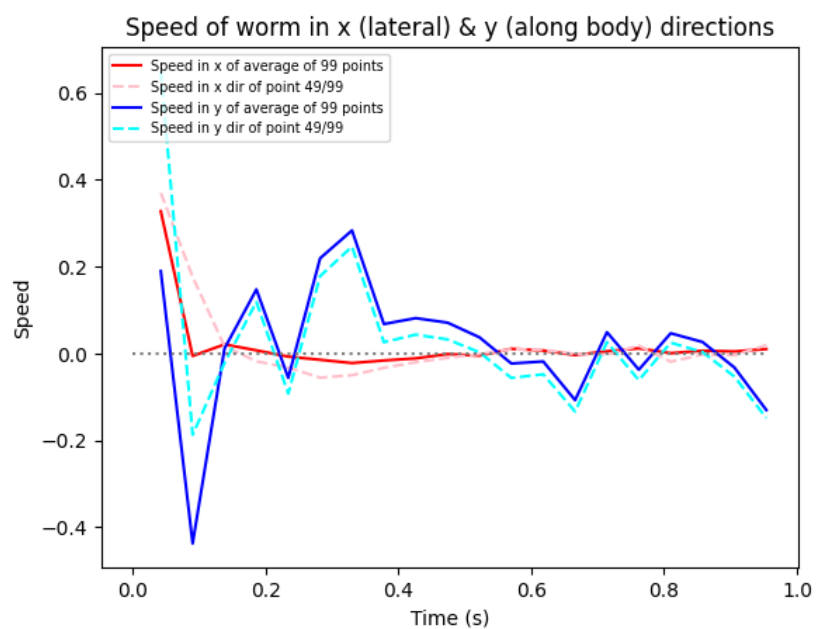


Figure 124: Speed of worm along body directions.

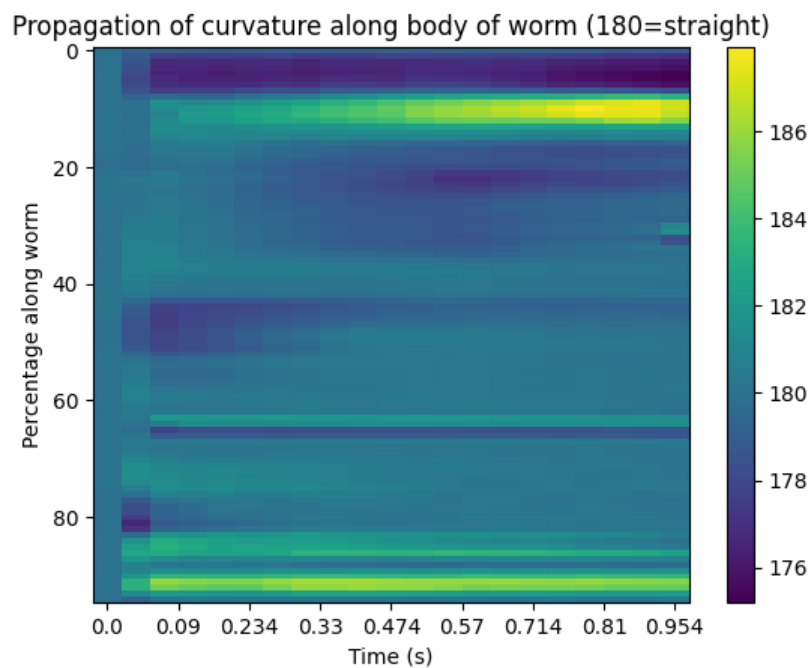


Figure 125: Propagation of curvature along body of worm.

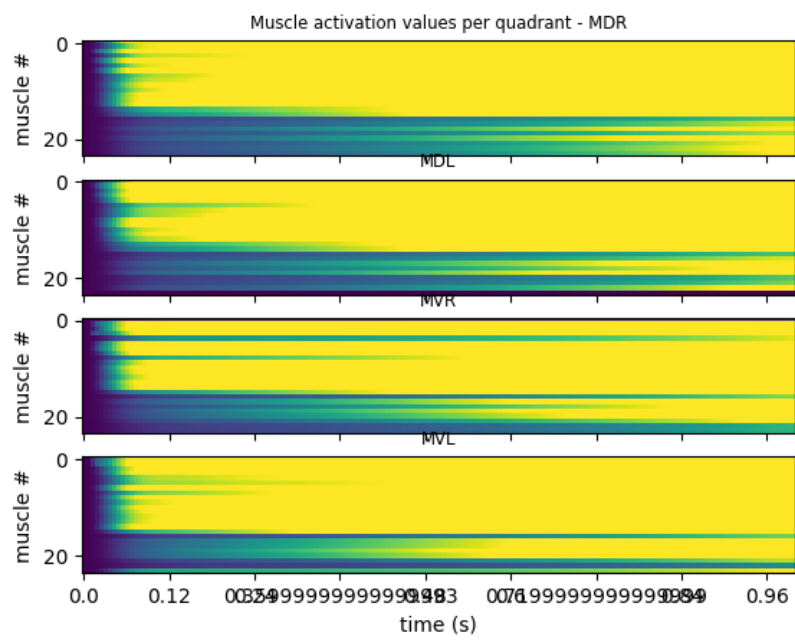


Figure 126: Muscle activities per quadrant.

6.13.5 Trace Figures

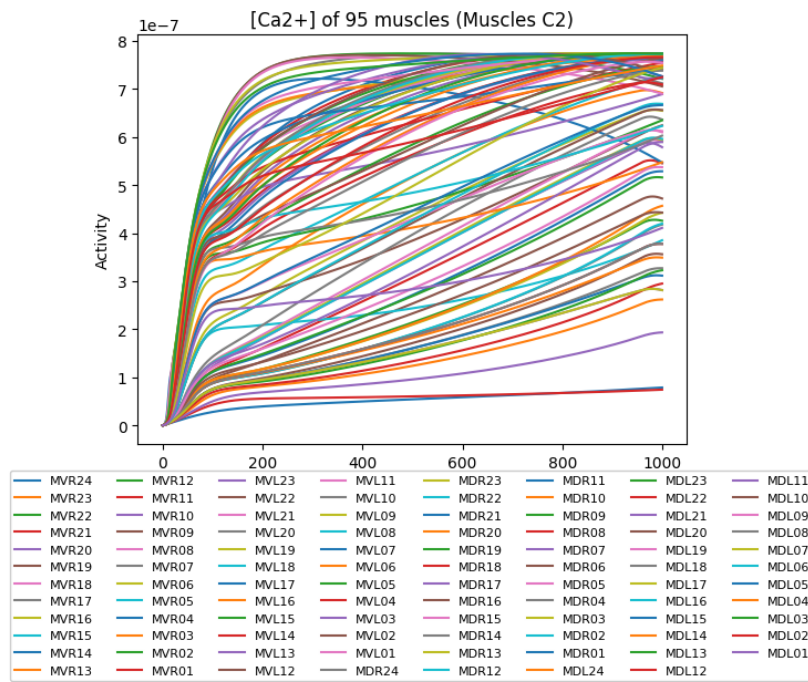
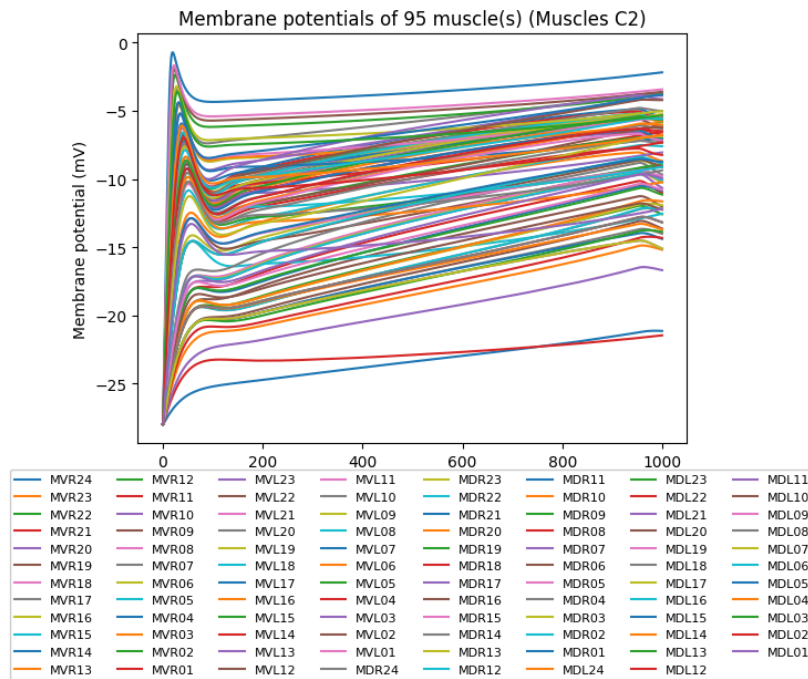


Figure 127: Traces of muscle activity and potentials.



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Figure 128: Traces of muscle activity.

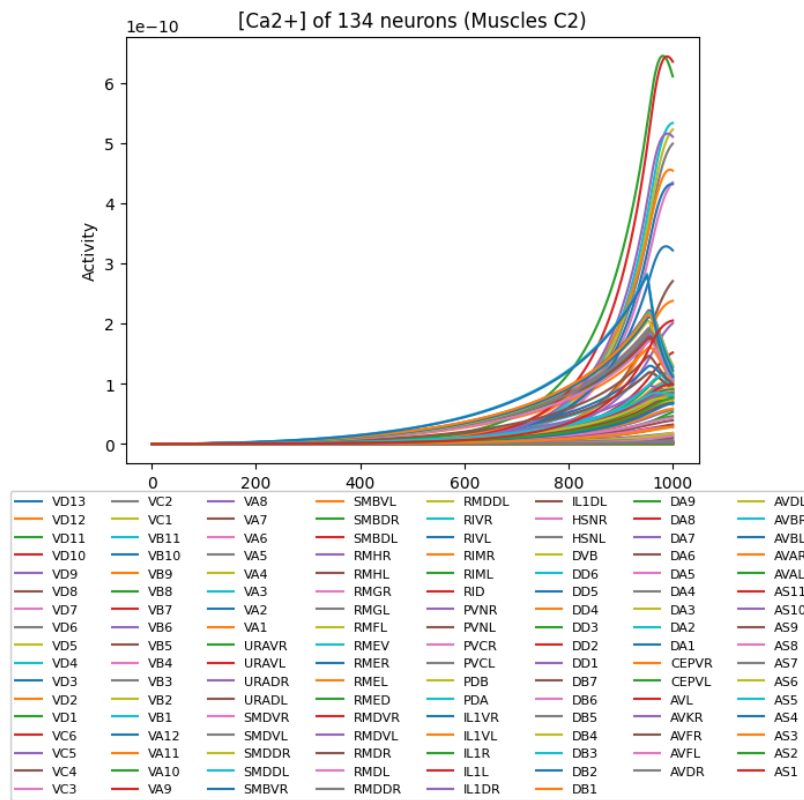
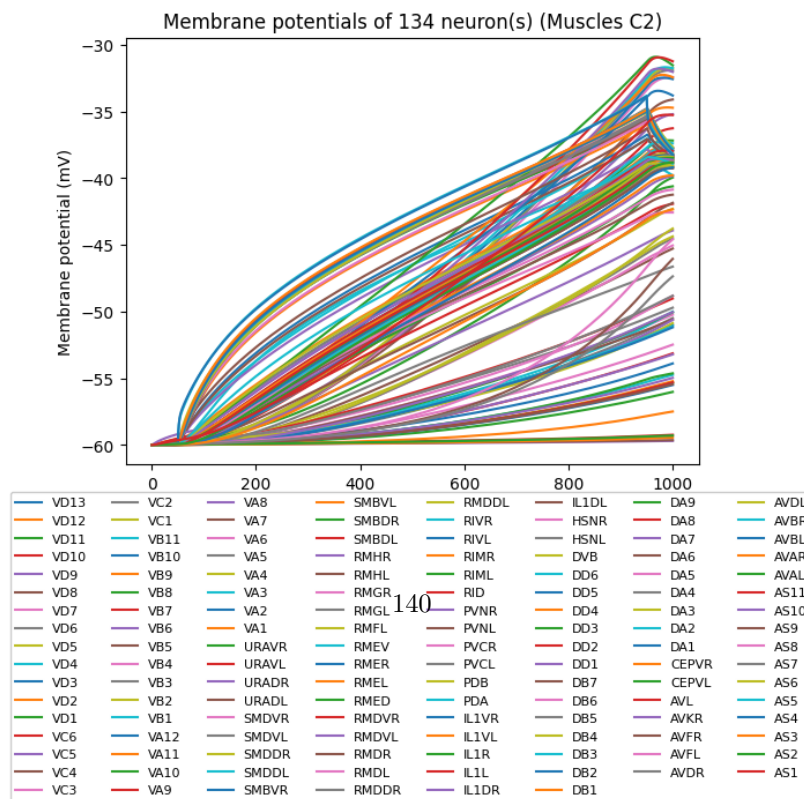


Figure 129: Traces of neuron activity and potentials.



6.13.6 Compact Morphology Grid

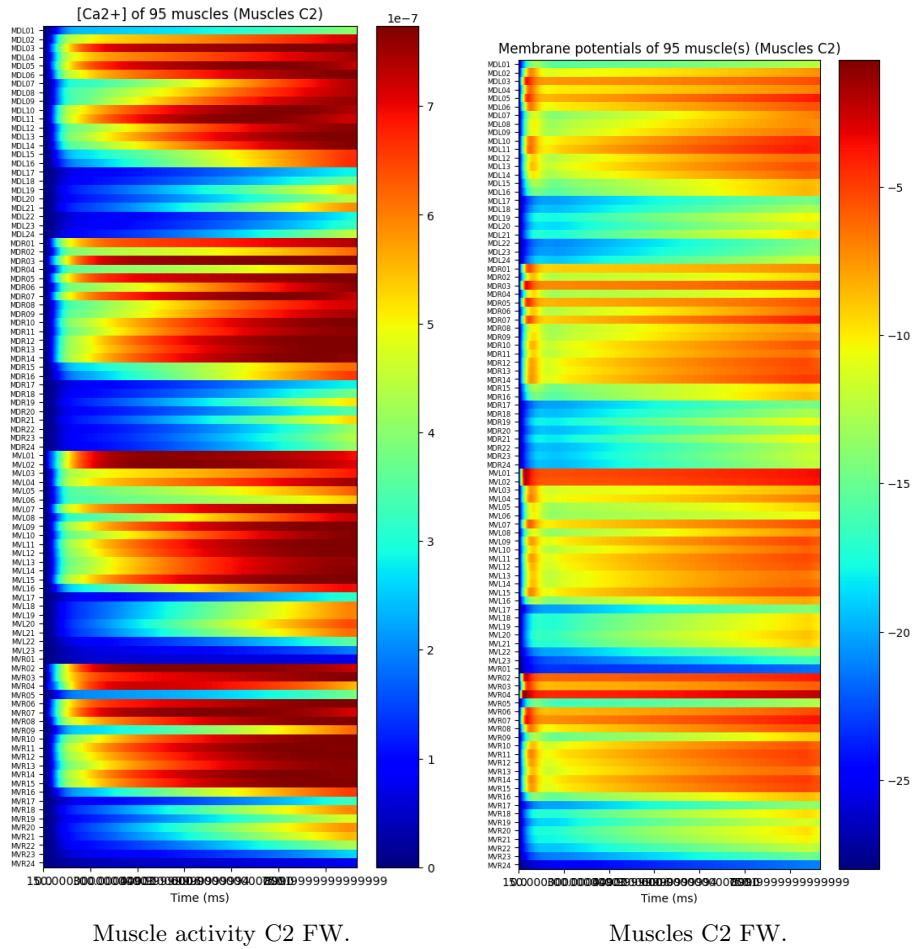


Figure 131: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).

6.13.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.5 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 55: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	2.4 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[-----]	0.4 / 10
Overall Severity	[====-----]	4.5 / 10

6.14 Movement Analysis: AVA-PVC_bilateral

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run C2_Muscles_2026-08-17_16-49-54-AVA-PVC_bilateral.

6.14.1 Locomotion State Classification

Table 56: Behavioral State Breakdown for AVA-PVC_bilateral

Locomotion State	Time Fraction (%)
Forward Crawling	14.6%
Backward Crawling	27.9%
Stationary	0.0%
Reversal	10.9%
Omega Turns	27.9%
Shallow Turns	18.8%
Irregular / Abnormal	0.0%

6.14.2 Kinematic & Velocity Dynamics

Table 57: Kinematic and Velocity Metrics for AVA-PVC.bilateral

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.0236	mm
Gross Distance	0.1465	mm
Path Efficiency (Net/Gross)	0.1614	[0.0 – 1.0]
Mean Speed	0.1471	mm/s
Maximum Forward Velocity	0.733	mm/s
Maximum Backward Velocity	0.7593	mm/s
Median Velocity	0.0847	mm/s
Velocity Std Deviation	0.1883	mm/s
Velocity RMS	0.239	mm/s
Fraction Time Moving Forward	47.0%	ratio
Fraction Time Moving Backward	53.0%	ratio
Fraction Time Stationary	0.0%	ratio
Acceleration (Mean)	-0.4934	mm/s ²
Maximum Acceleration	168.7694	mm/s ²
Acceleration RMS	22.6017	mm/s ²
Velocity Autocorrelation	0.8105	correlation
Reversal Frequency	18.0723	s ⁻¹
Mean Curvature	3966.7257	rad/mm
Omega Turn Count	46	count

6.14.3 Undulation Wave Mechanics

Table 58: Undulation Wave Parameters for AVA-PVC.bilateral

Undulation Parameter	Value	Unit
Crawl Amplitude	0.007	rad (bending)
Dominant Frequency	1.0	Hz
Wavelength	1.66	mm
Wave Velocity	1.67	mm/s
Phase Coherence	0.78	[0.0 – 1.0]
Mean Muscle Activation	0.789408	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.14.4 Worm Motion and Activity Figures

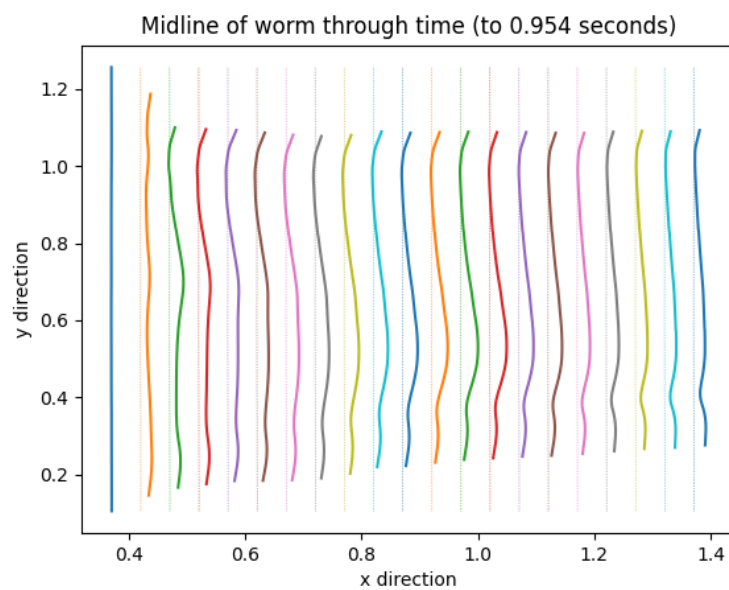


Figure 133: Midline of worm through time.

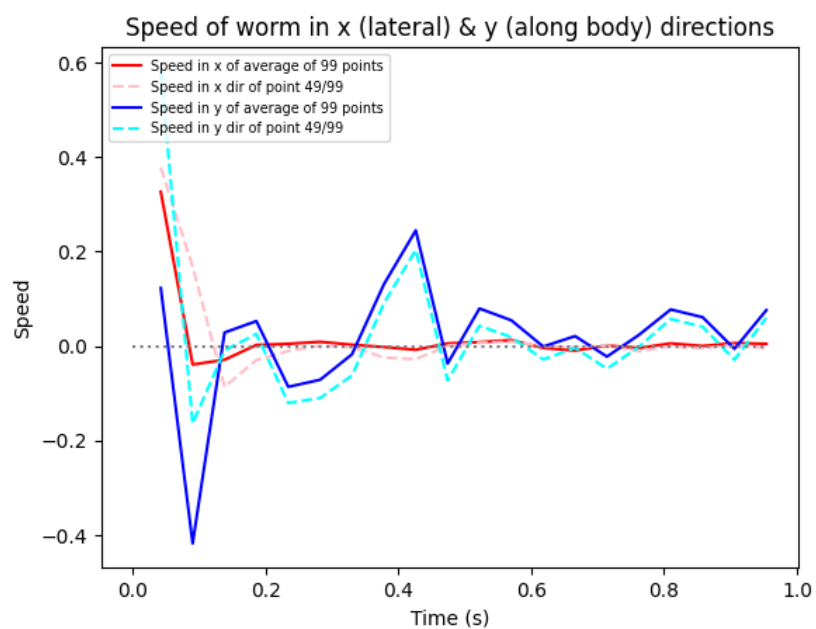


Figure 134: Speed of worm along body directions.

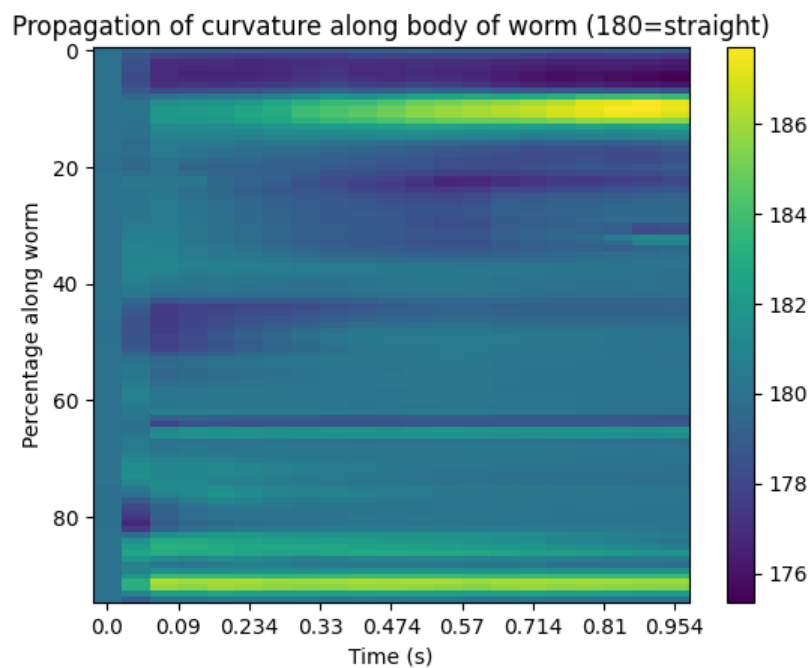


Figure 135: Propagation of curvature along body of worm.

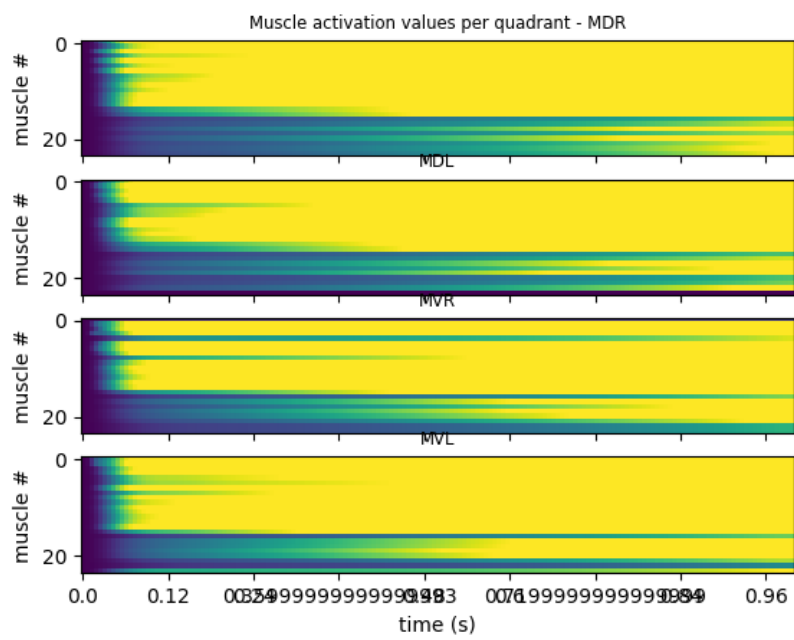


Figure 136: Muscle activities per quadrant.

6.14.5 Trace Figures

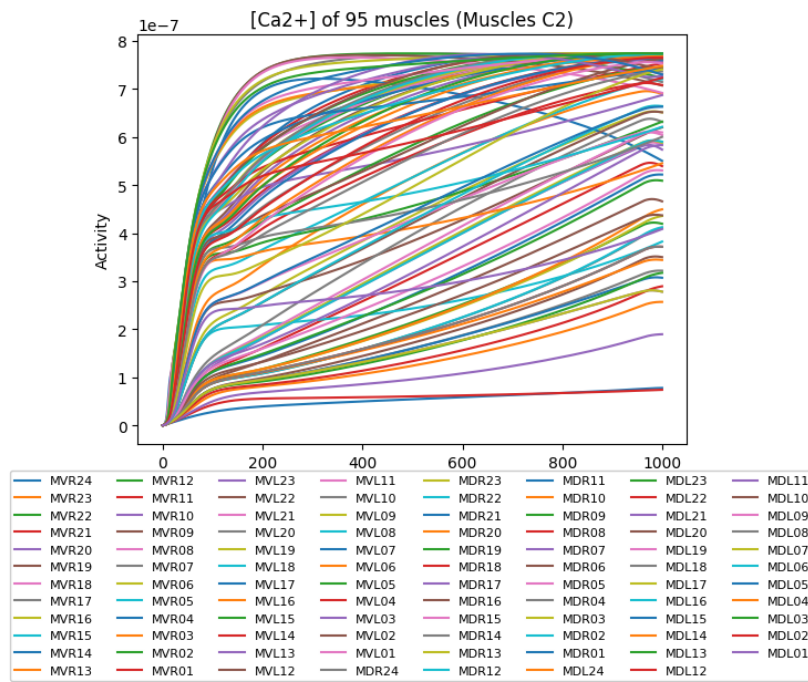
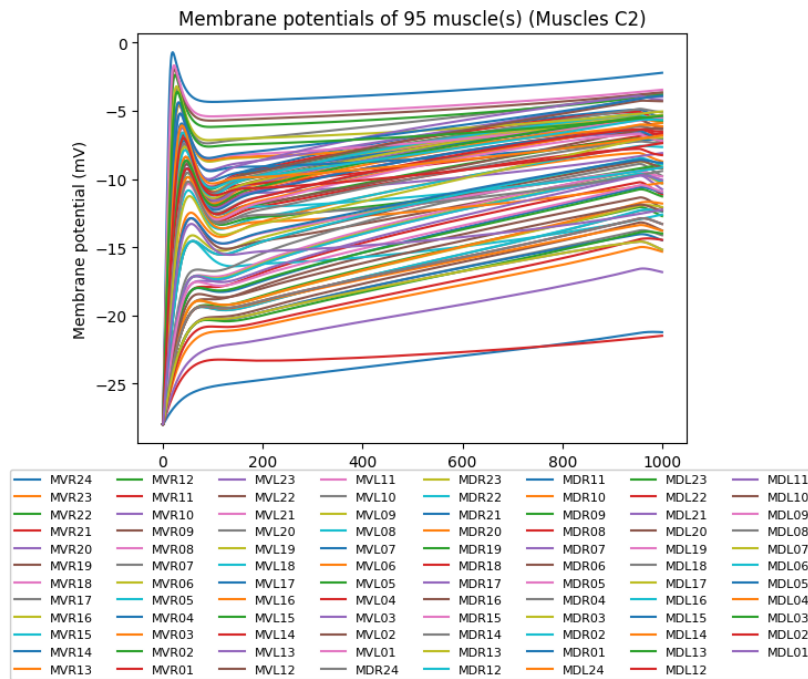


Figure 137: Traces of muscle activity and potentials.



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Figure 138: Traces of muscle activity.

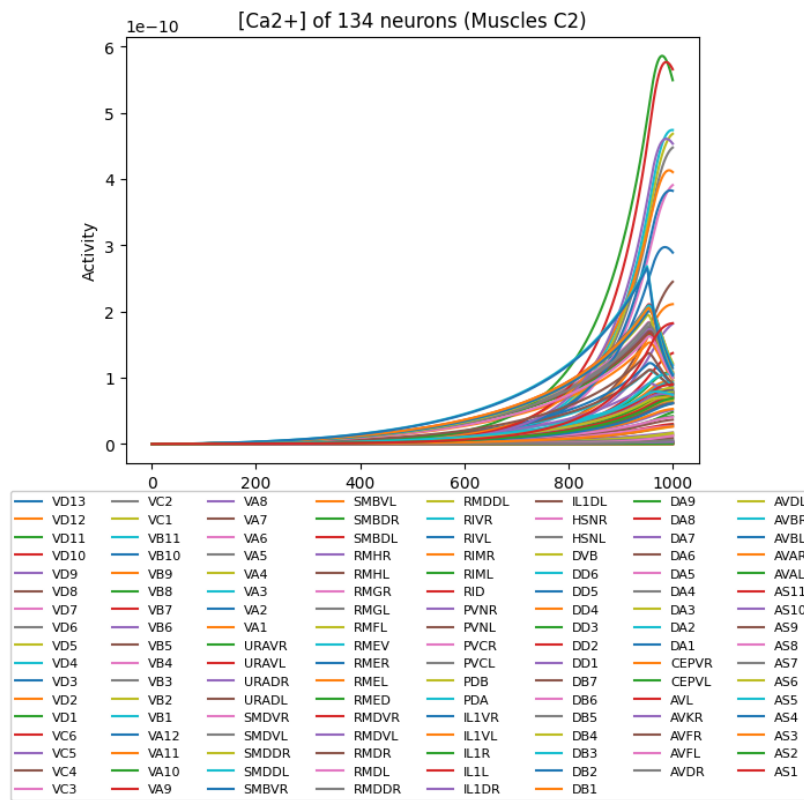
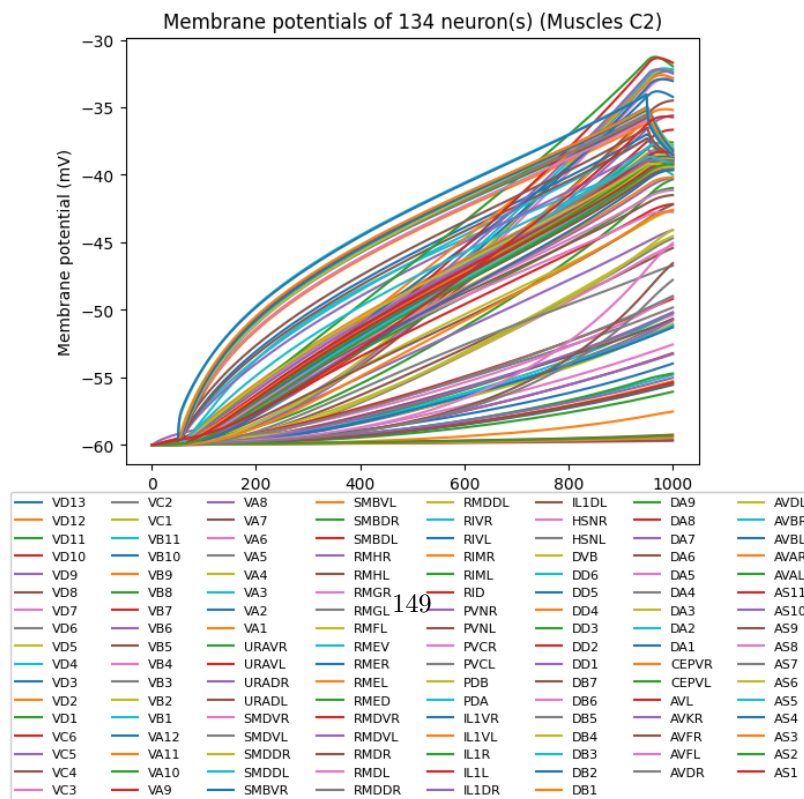


Figure 139: Traces of neuron activity and potentials.



6.14.6 Compact Morphology Grid

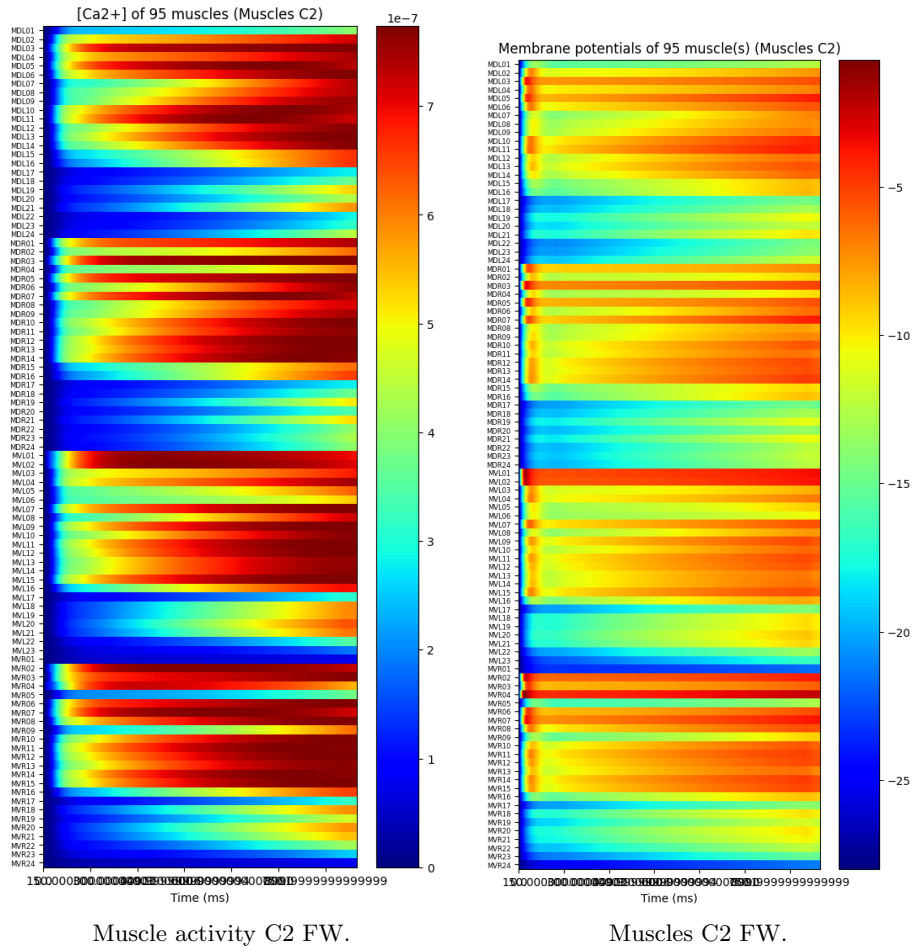


Figure 141: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).

6.14.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.6 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 59: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	2.2 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[=-----]	0.6 / 10
Overall Severity	[=====]	4.6 / 10

6.15 Movement Analysis: AVAL-PVCR_both

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run C2_Muscles_2026-08-18_08-04-13-AVAL-PVCR_both.

6.15.1 Locomotion State Classification

Table 60: Behavioral State Breakdown for AVAL-PVCR_both

Locomotion State	Time Fraction (%)
Forward Crawling	12.7%
Backward Crawling	38.2%
Stationary	0.0%
Reversal	11.5%
Omega Turns	24.2%
Shallow Turns	13.3%
Irregular / Abnormal	0.0%

6.15.2 Kinematic & Velocity Dynamics

Table 61: Kinematic and Velocity Metrics for AVAL-PVCR_both

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.0406	mm
Gross Distance	0.1524	mm
Path Efficiency (Net/Gross)	0.2663	[0.0 – 1.0]
Mean Speed	0.153	mm/s
Maximum Forward Velocity	0.7893	mm/s
Maximum Backward Velocity	0.7932	mm/s
Median Velocity	0.0961	mm/s
Velocity Std Deviation	0.1938	mm/s
Velocity RMS	0.247	mm/s
Fraction Time Moving Forward	38.0%	ratio
Fraction Time Moving Backward	61.5%	ratio
Fraction Time Stationary	0.0%	ratio
Acceleration (Mean)	-0.4843	mm/s ²
Maximum Acceleration	168.6062	mm/s ²
Acceleration RMS	23.852	mm/s ²
Velocity Autocorrelation	0.8343	correlation
Reversal Frequency	19.0763	s ⁻¹
Mean Curvature	4423.3797	rad/mm
Omega Turn Count	40	count

6.15.3 Undulation Wave Mechanics

Table 62: Undulation Wave Parameters for AVAL-PVCR_both

Undulation Parameter	Value	Unit
Crawl Amplitude	0.0066	rad (bending)
Dominant Frequency	0.0	Hz
Wavelength	0.82	mm
Wave Velocity	0.0	mm/s
Phase Coherence	0.78	[0.0 – 1.0]
Mean Muscle Activation	0.789819	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.15.4 Worm Motion and Activity Figures

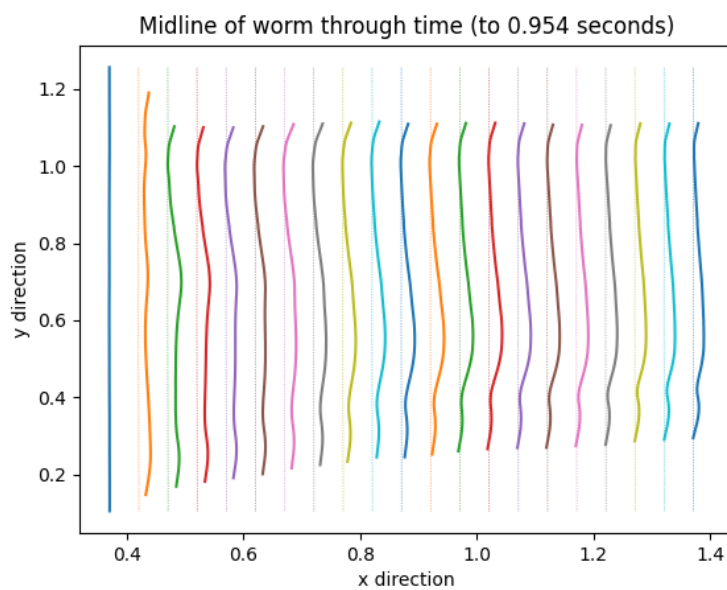


Figure 143: Midline of worm through time.

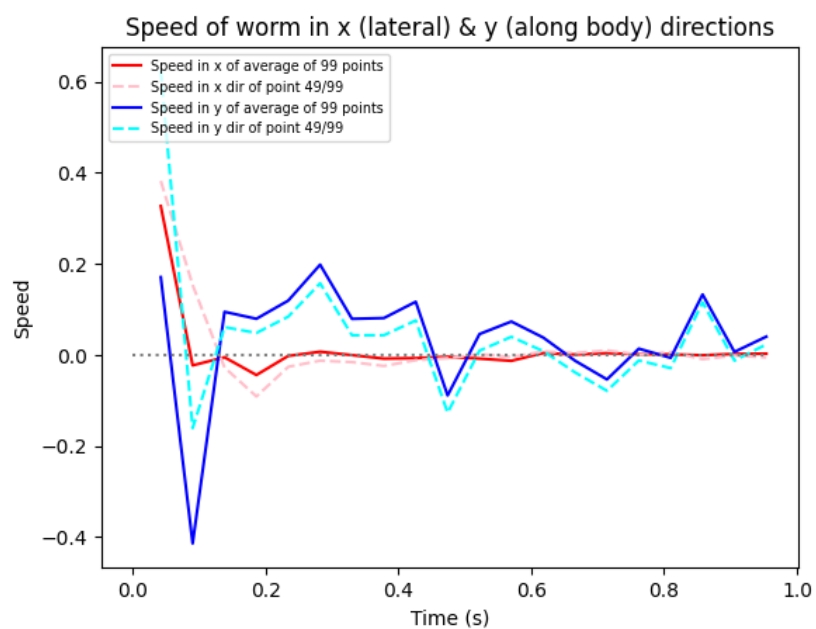


Figure 144: Speed of worm along body directions.

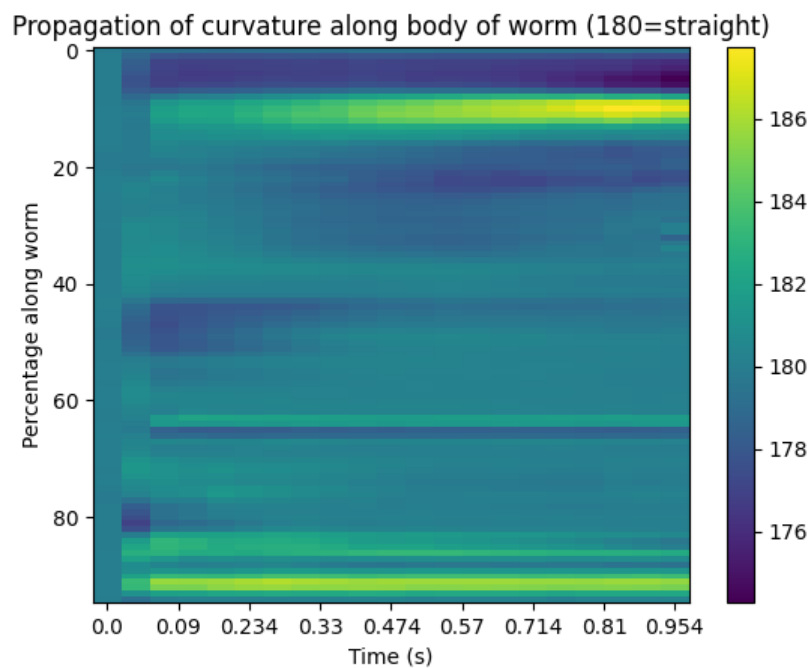


Figure 145: Propagation of curvature along body of worm.

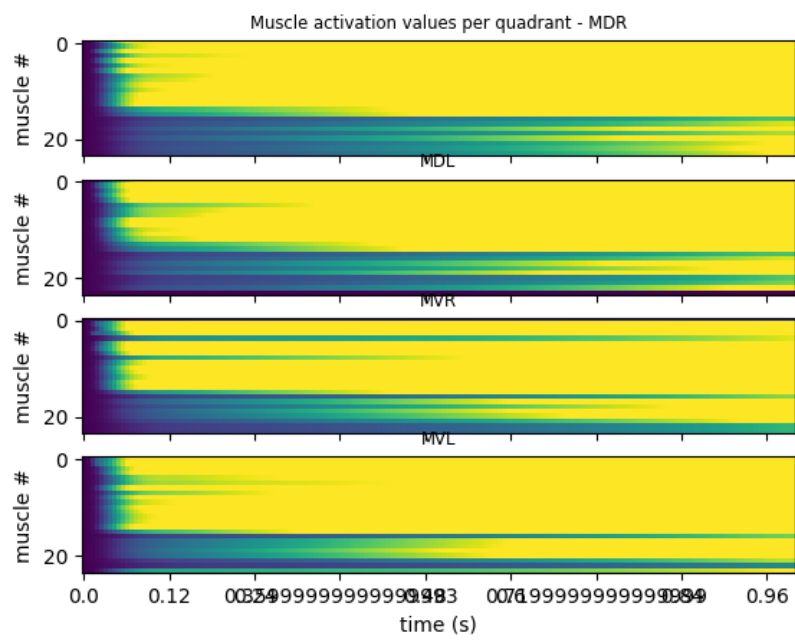


Figure 146: Muscle activities per quadrant.

6.15.5 Trace Figures

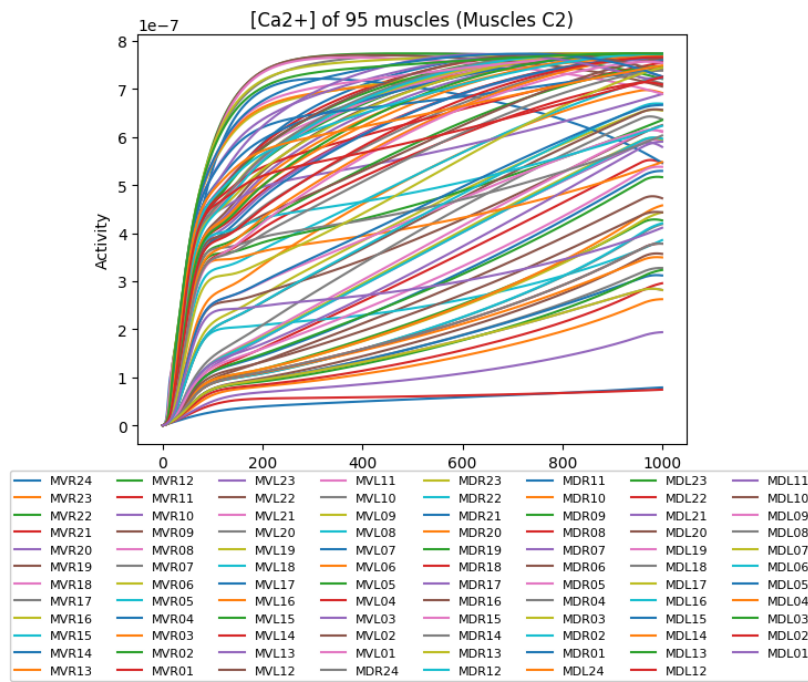
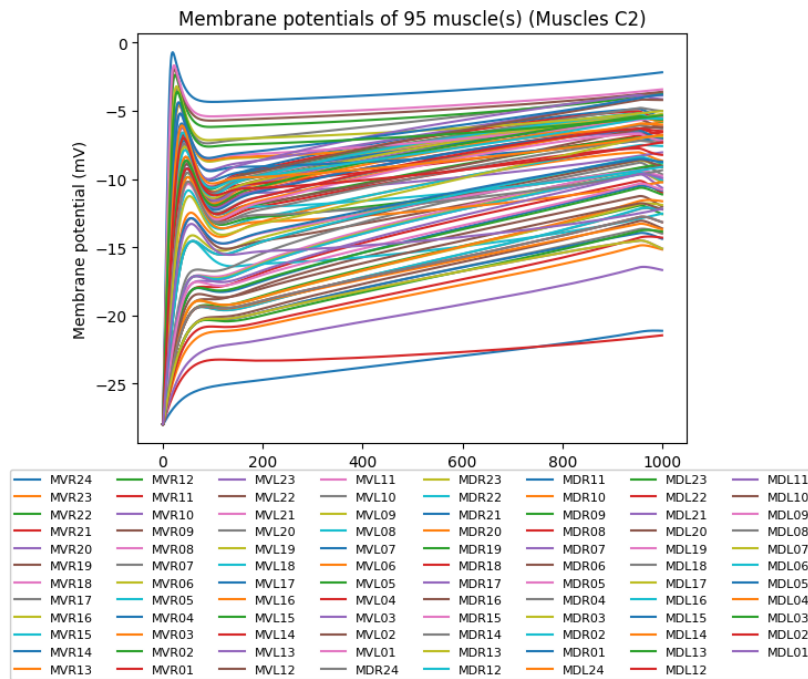


Figure 147: Traces of muscle activity and potentials.



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Figure 148: Traces of muscle activity.

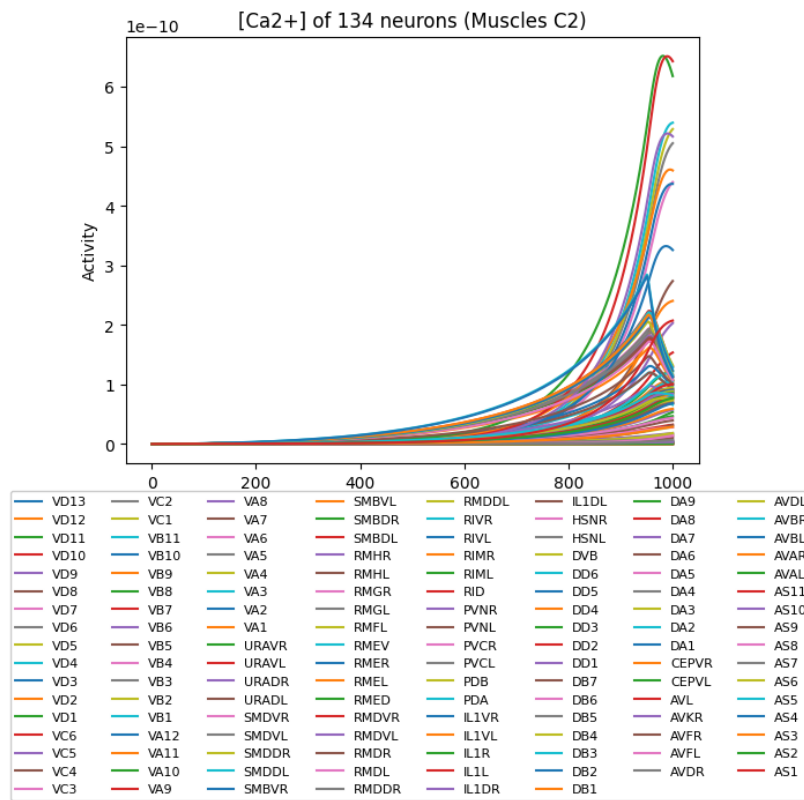
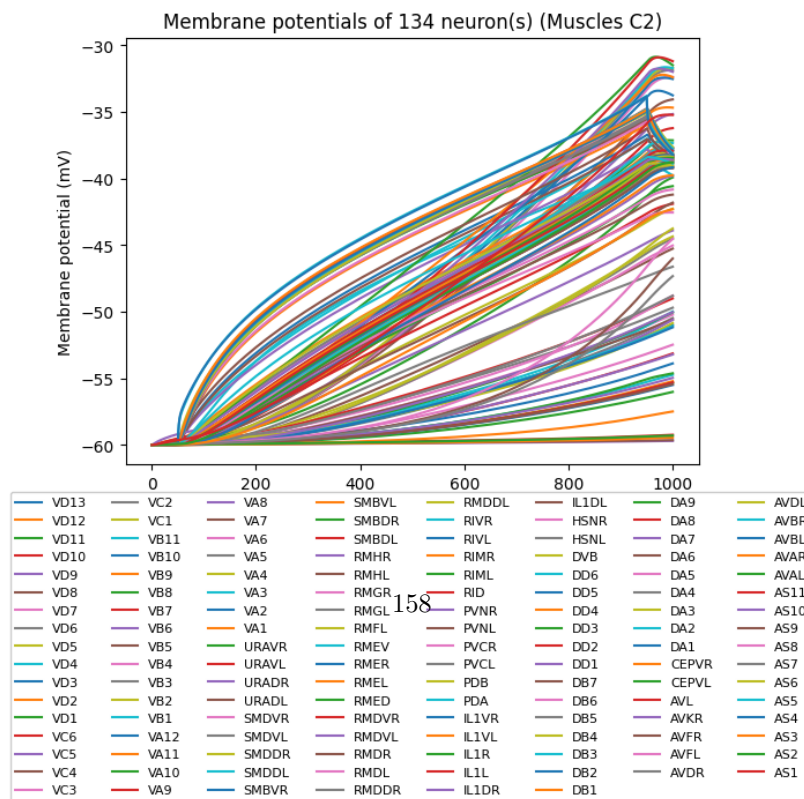


Figure 149: Traces of neuron activity and potentials.



6.15.6 Compact Morphology Grid

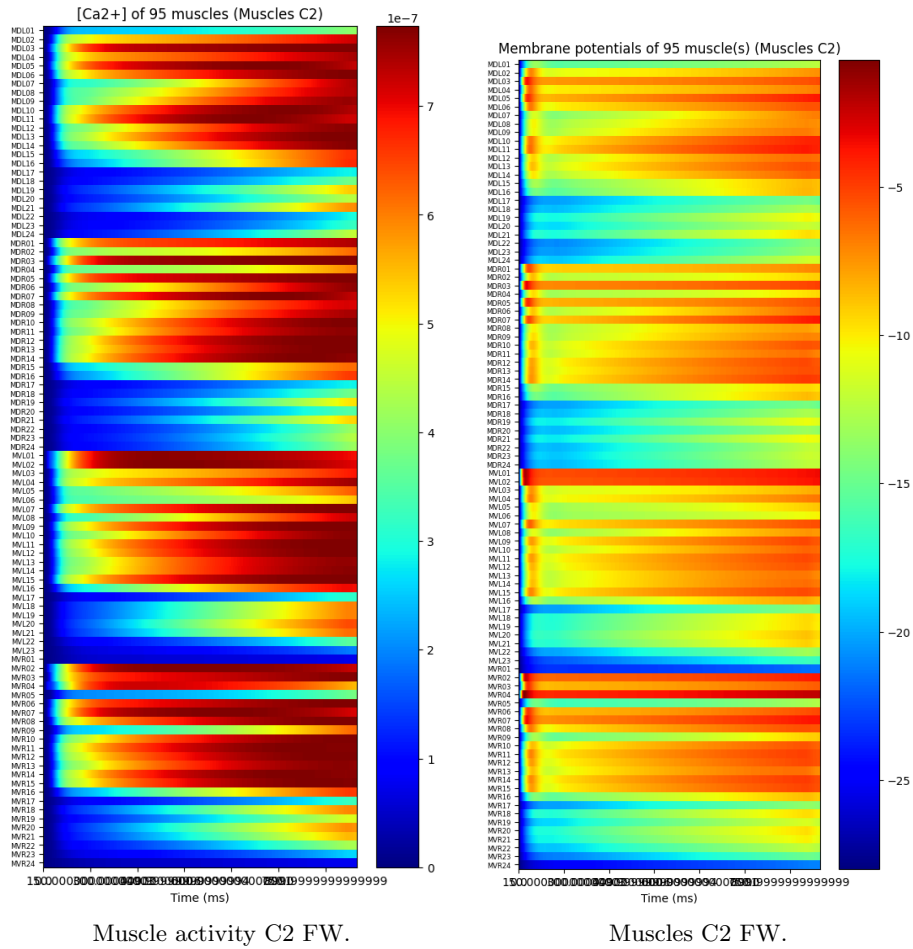


Figure 151: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).

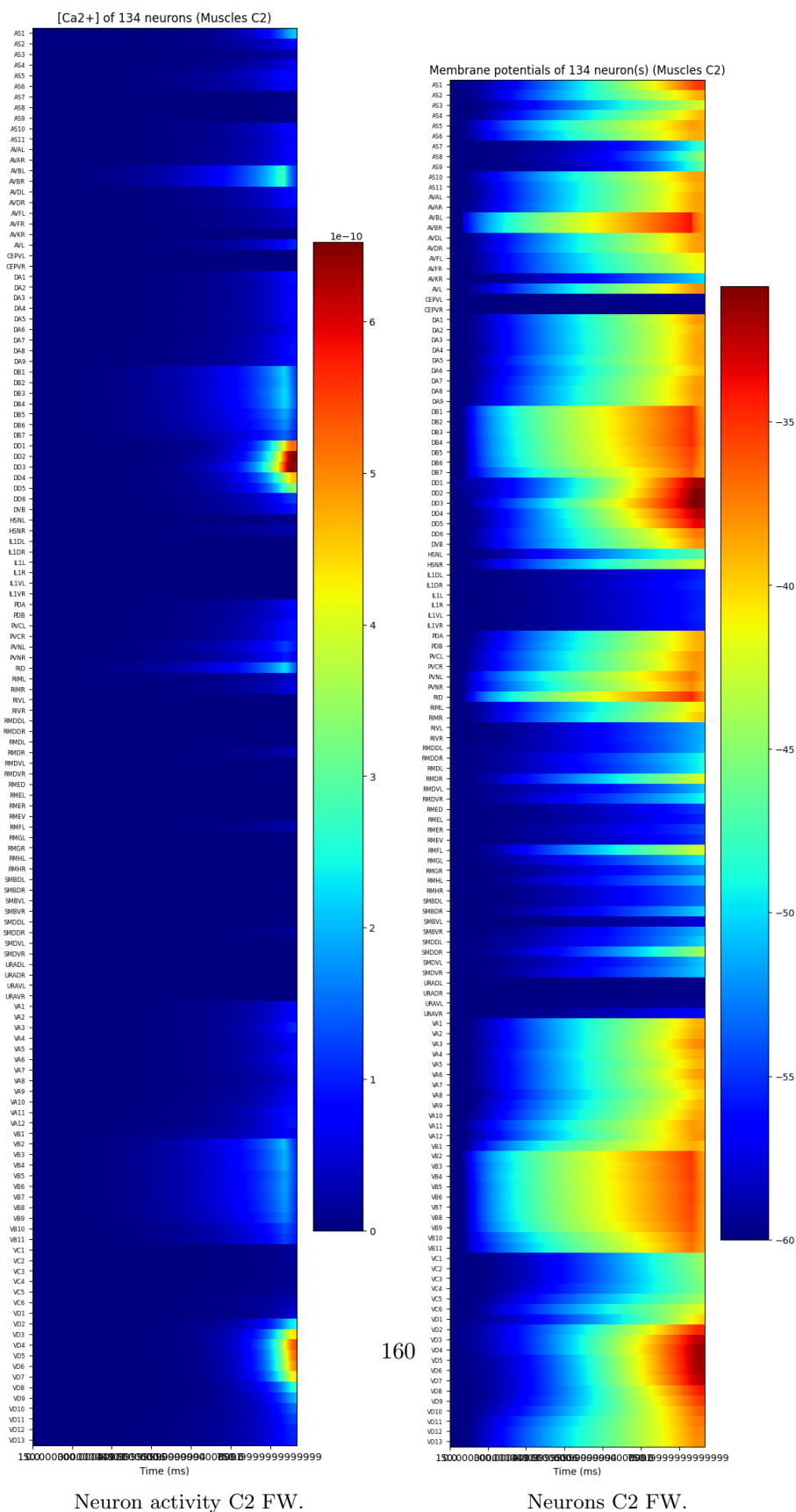


Figure 152: Neuron activity and morphology, shown as a 2x1 grid for compact

6.15.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.9 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 63: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	2.2 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[=-----]	2.3 / 10
Overall Severity	[=====]	4.9 / 10

6.16 Movement Analysis: AVAL-AVAR_both

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run C2_Muscles_2026-08-18_09-47-25-AVAL-AVAR_both.

6.16.1 Locomotion State Classification

Table 64: Behavioral State Breakdown for AVAL-AVAR_both

Locomotion State	Time Fraction (%)
Forward Crawling	17.0%
Backward Crawling	19.4%
Stationary	0.0%
Reversal	10.9%
Omega Turns	30.9%
Shallow Turns	21.8%
Irregular / Abnormal	0.0%

6.16.2 Kinematic & Velocity Dynamics

Table 65: Kinematic and Velocity Metrics for AVAL-AVAR_both

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.0165	mm
Gross Distance	0.1392	mm
Path Efficiency (Net/Gross)	0.1182	[0.0 – 1.0]
Mean Speed	0.1397	mm/s
Maximum Forward Velocity	0.6542	mm/s
Maximum Backward Velocity	0.895	mm/s
Median Velocity	0.0787	mm/s
Velocity Std Deviation	0.1958	mm/s
Velocity RMS	0.2405	mm/s
Fraction Time Moving Forward	50.6%	ratio
Fraction Time Moving Backward	48.8%	ratio
Fraction Time Stationary	0.0%	ratio
Acceleration (Mean)	-0.4685	mm/s ²
Maximum Acceleration	168.8009	mm/s ²
Acceleration RMS	21.7904	mm/s ²
Velocity Autocorrelation	0.8642	correlation
Reversal Frequency	18.0723	s ⁻¹
Mean Curvature	4688.8245	rad/mm
Omega Turn Count	51	count

6.16.3 Undulation Wave Mechanics

Table 66: Undulation Wave Parameters for AVAL-AVAR_both

Undulation Parameter	Value	Unit
Crawl Amplitude	0.0068	rad (bending)
Dominant Frequency	0.0	Hz
Wavelength	0.82	mm
Wave Velocity	0.0	mm/s
Phase Coherence	0.79	[0.0 – 1.0]
Mean Muscle Activation	0.789792	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.16.4 Worm Motion and Activity Figures

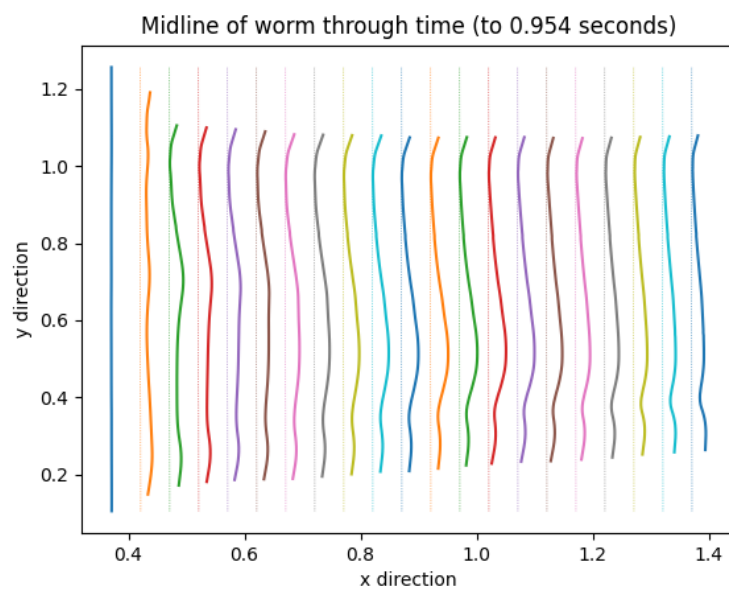


Figure 153: Midline of worm through time.

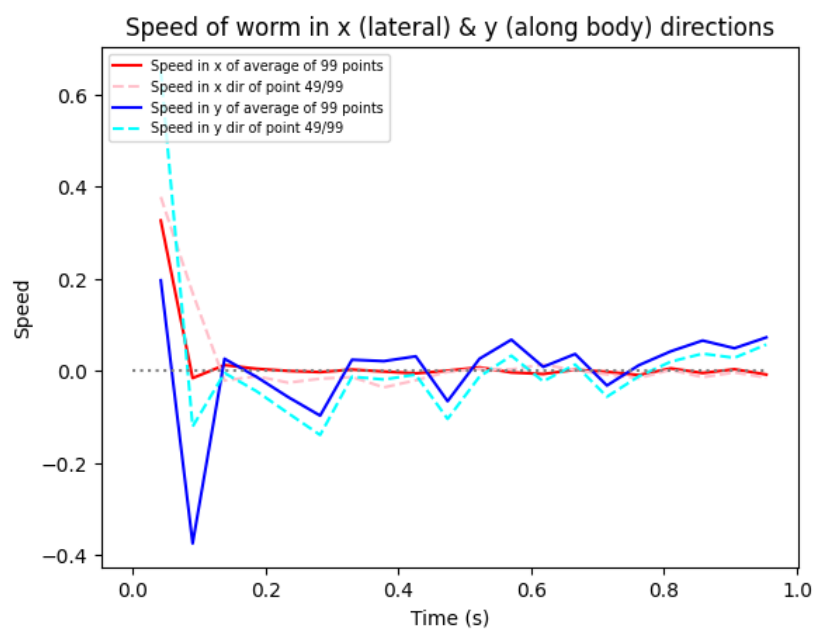


Figure 154: Speed of worm along body directions.

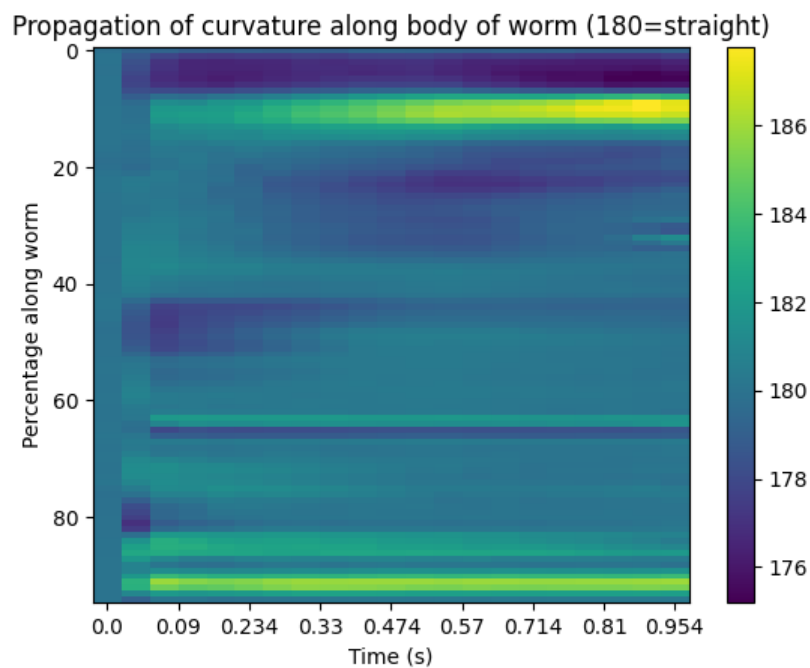


Figure 155: Propagation of curvature along body of worm.

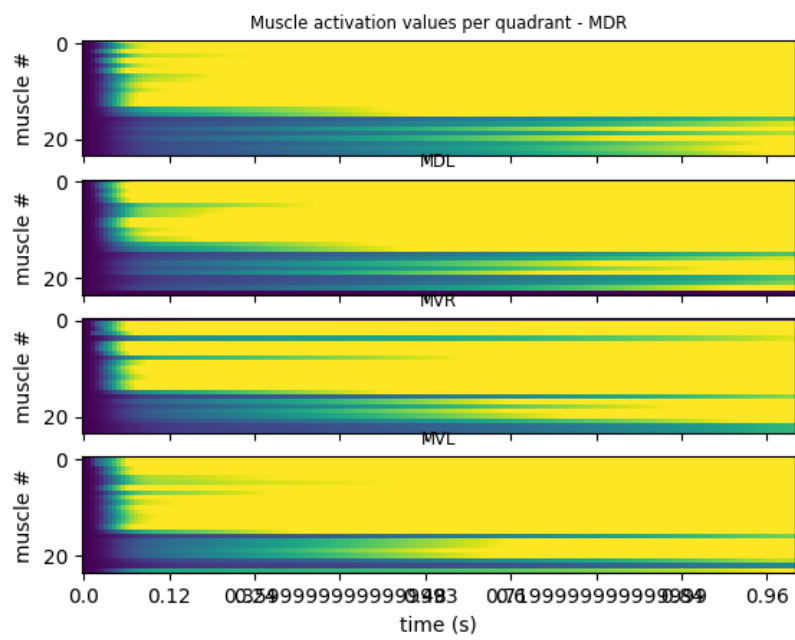


Figure 156: Muscle activities per quadrant.

6.16.5 Trace Figures

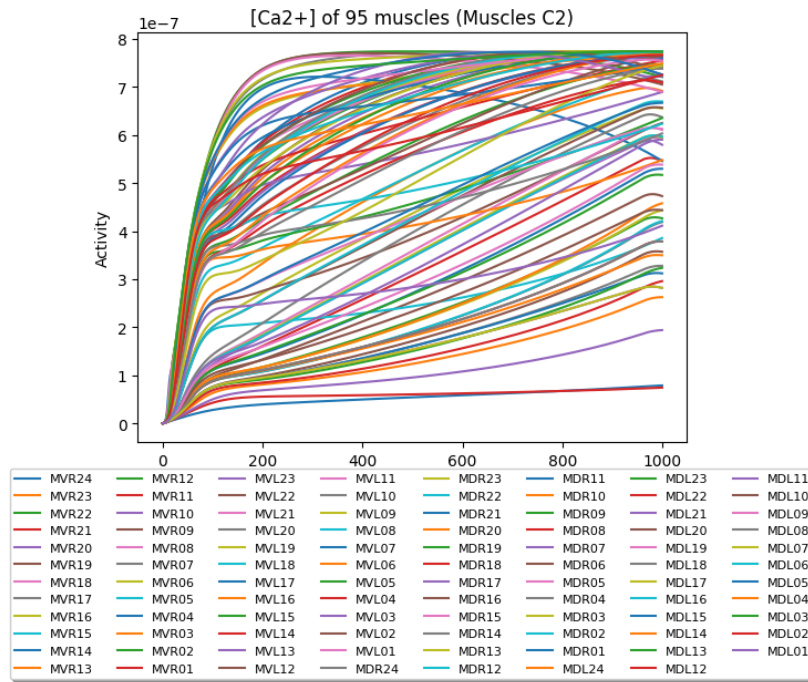


Figure 157: Traces of muscle activity and potentials.

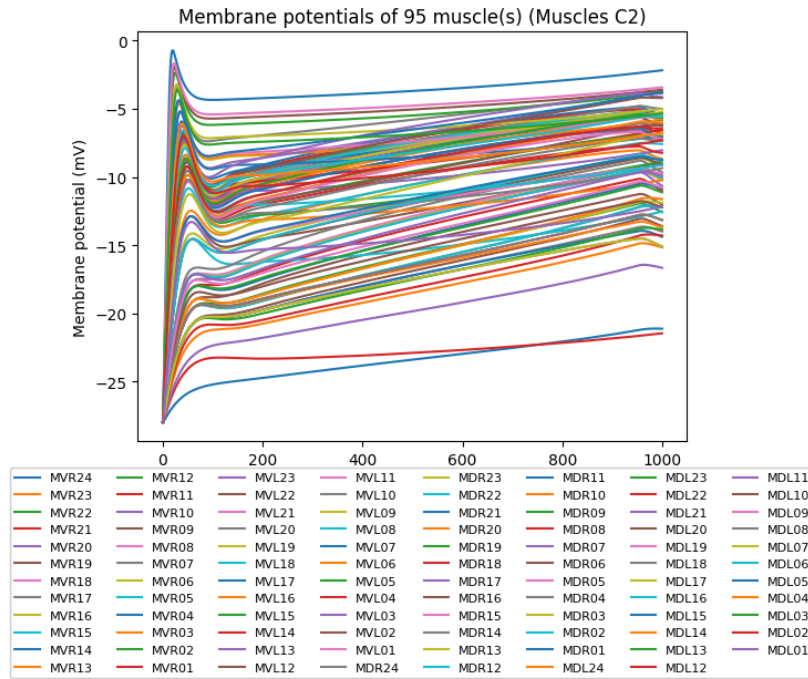


Figure 158: Traces of muscle activity.

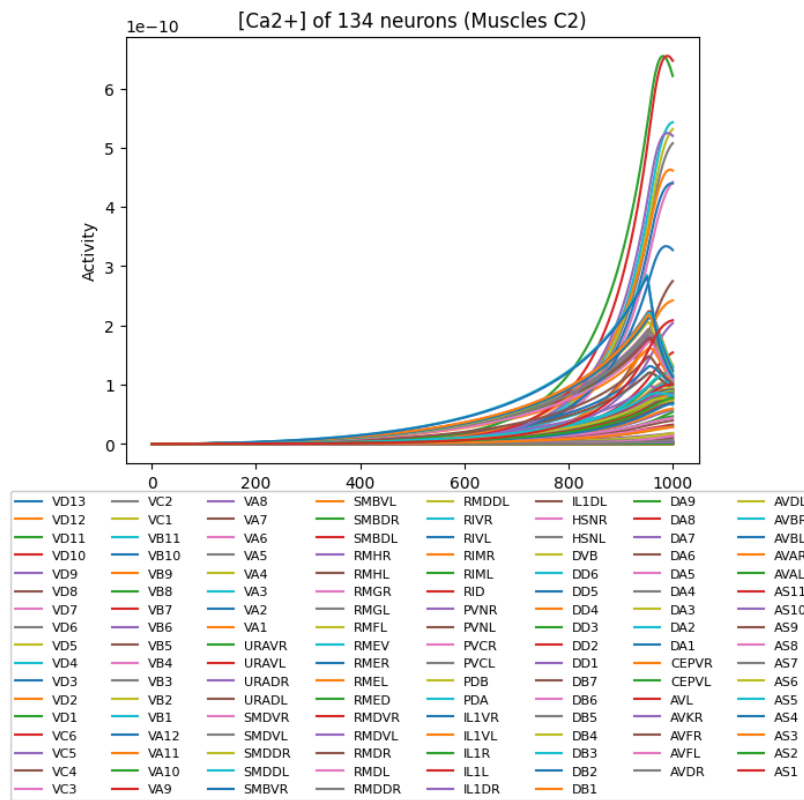
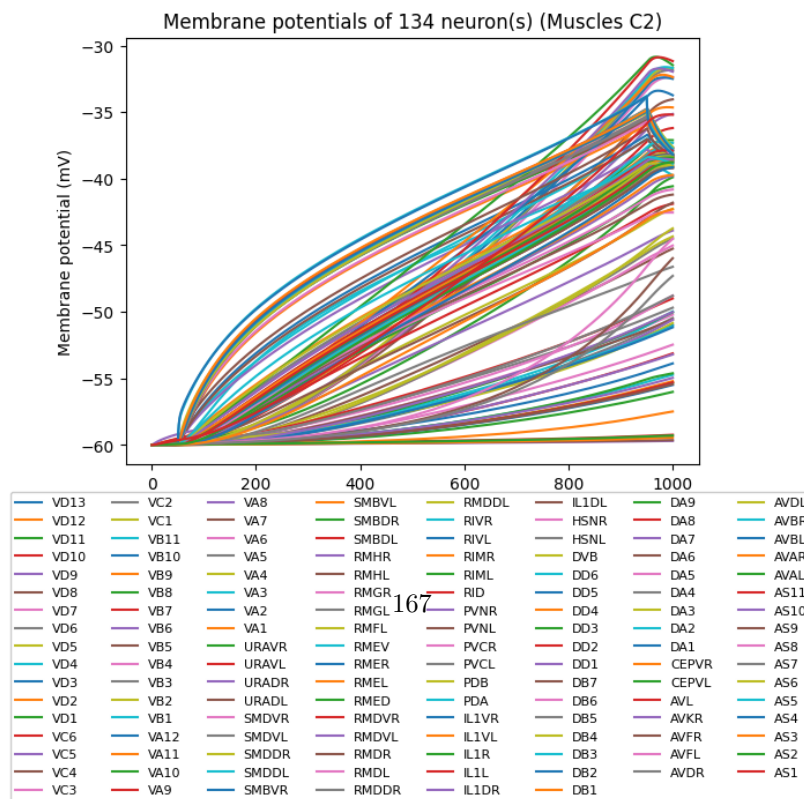


Figure 159: Traces of neuron activity and potentials.



6.16.6 Compact Morphology Grid

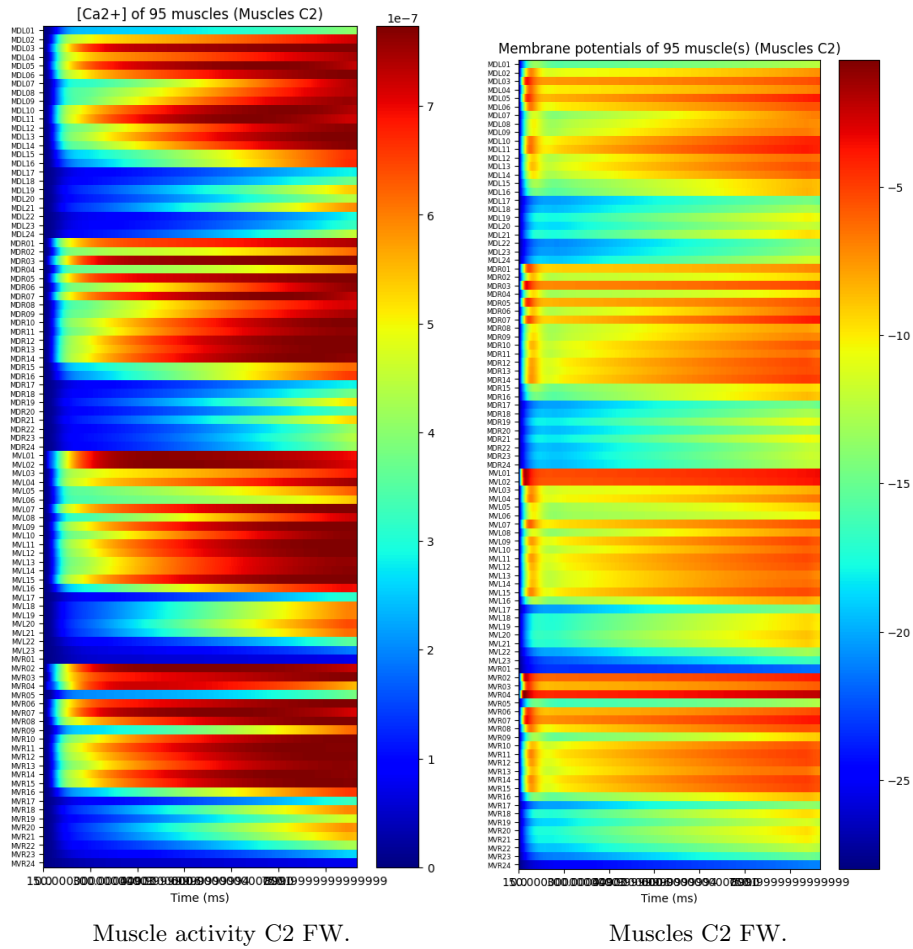


Figure 161: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).

6.16.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.5 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 67: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	2.1 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[-----]	0.2 / 10
Overall Severity	[====-----]	4.5 / 10

6.17 Movement Analysis: AVBL-VB1_GJ

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run C2_Muscles_2026-08-18_12-51-52-AVBL-VB1_GJ.

6.17.1 Locomotion State Classification

Table 68: Behavioral State Breakdown for AVBL-VB1_GJ

Locomotion State	Time Fraction (%)
Forward Crawling	10.9%
Backward Crawling	33.3%
Stationary	0.0%
Reversal	10.9%
Omega Turns	26.7%
Shallow Turns	18.2%
Irregular / Abnormal	0.0%

6.17.2 Kinematic & Velocity Dynamics

Table 69: Kinematic and Velocity Metrics for AVBL-VB1_GJ

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.0494	mm
Gross Distance	0.1508	mm
Path Efficiency (Net/Gross)	0.3278	[0.0 – 1.0]
Mean Speed	0.1514	mm/s
Maximum Forward Velocity	0.7547	mm/s
Maximum Backward Velocity	0.9115	mm/s
Median Velocity	0.0887	mm/s
Velocity Std Deviation	0.2025	mm/s
Velocity RMS	0.2528	mm/s
Fraction Time Moving Forward	43.4%	ratio
Fraction Time Moving Backward	56.6%	ratio
Fraction Time Stationary	0.0%	ratio
Acceleration (Mean)	-0.2126	mm/s ²
Maximum Acceleration	168.7816	mm/s ²
Acceleration RMS	23.5169	mm/s ²
Velocity Autocorrelation	0.821	correlation
Reversal Frequency	18.0723	s ⁻¹
Mean Curvature	3901.8403	rad/mm
Omega Turn Count	44	count

6.17.3 Undulation Wave Mechanics

Table 70: Undulation Wave Parameters for AVBL-VB1_GJ

Undulation Parameter	Value	Unit
Crawl Amplitude	0.0067	rad (bending)
Dominant Frequency	0.0	Hz
Wavelength	0.82	mm
Wave Velocity	0.0	mm/s
Phase Coherence	0.78	[0.0 – 1.0]
Mean Muscle Activation	0.79001	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.17.4 Worm Motion and Activity Figures

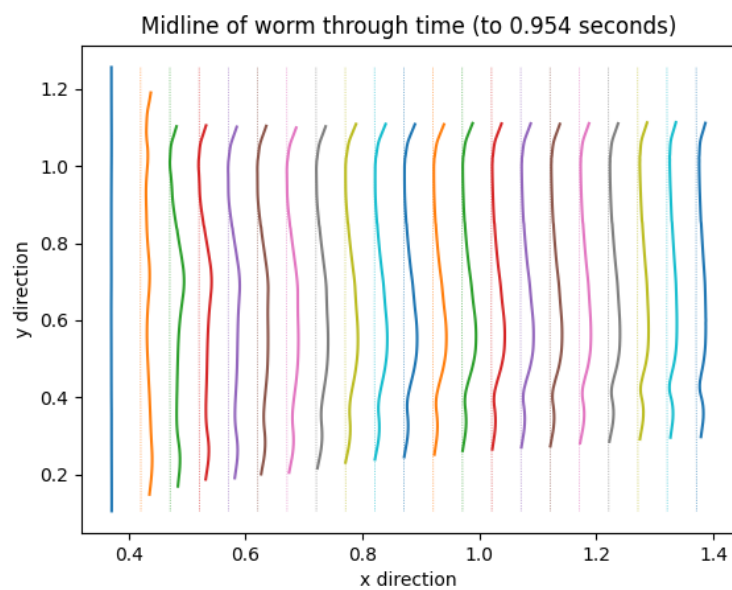


Figure 163: Midline of worm through time.

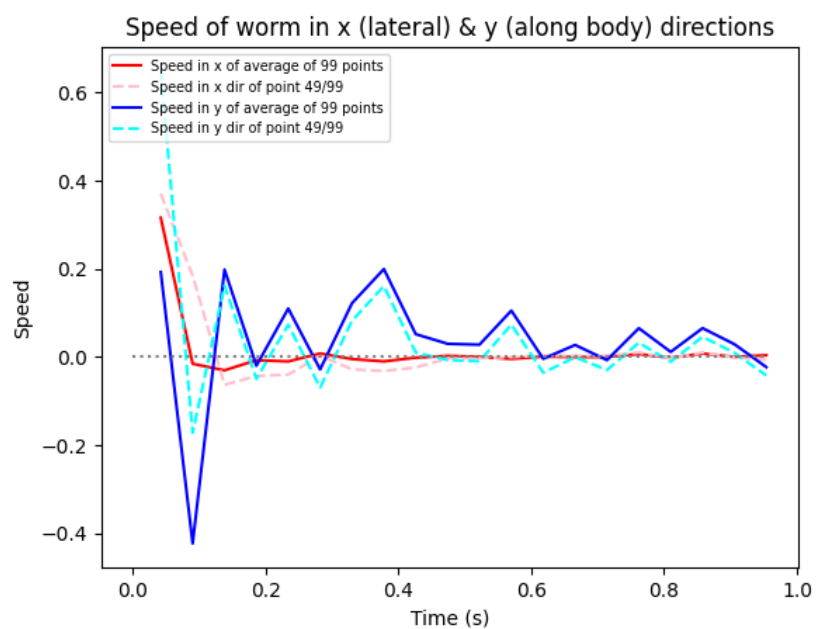


Figure 164: Speed of worm along body directions.

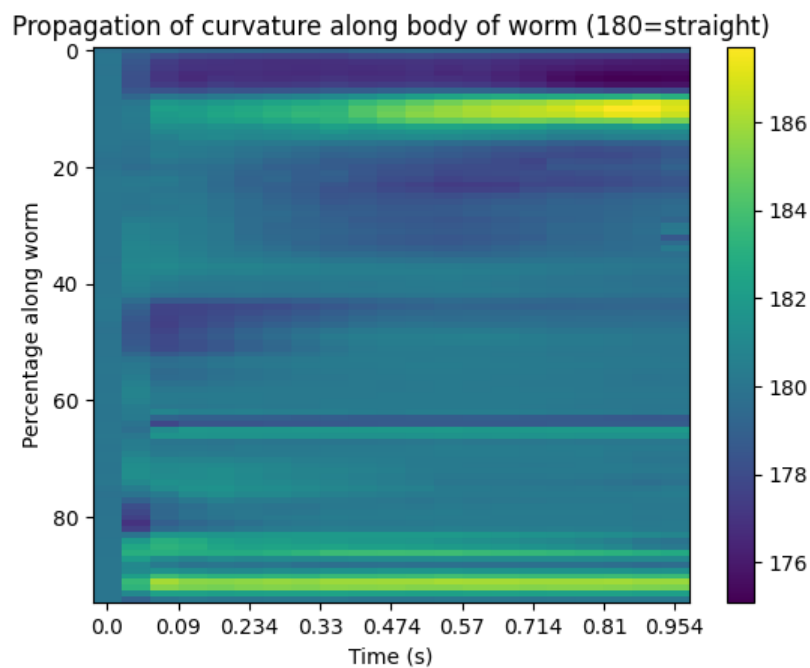


Figure 165: Propagation of curvature along body of worm.

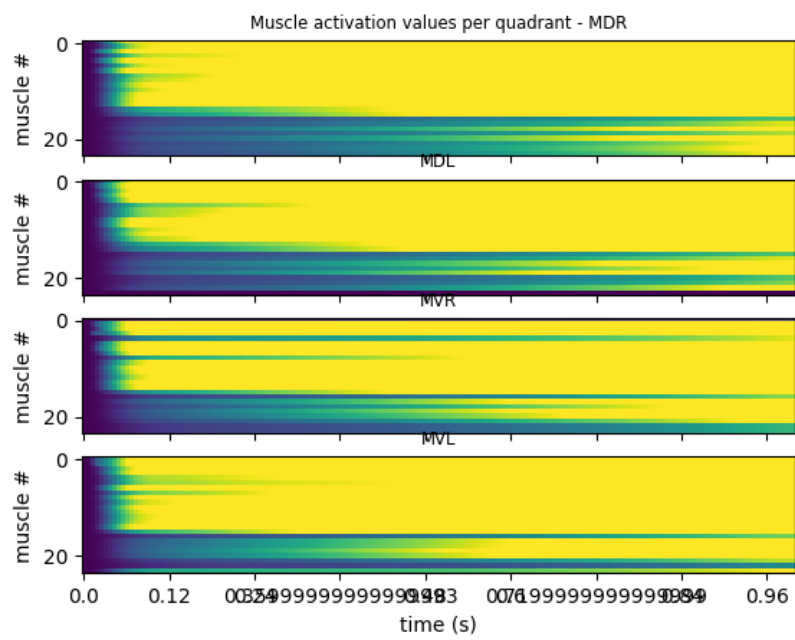


Figure 166: Muscle activities per quadrant.

6.17.5 Trace Figures

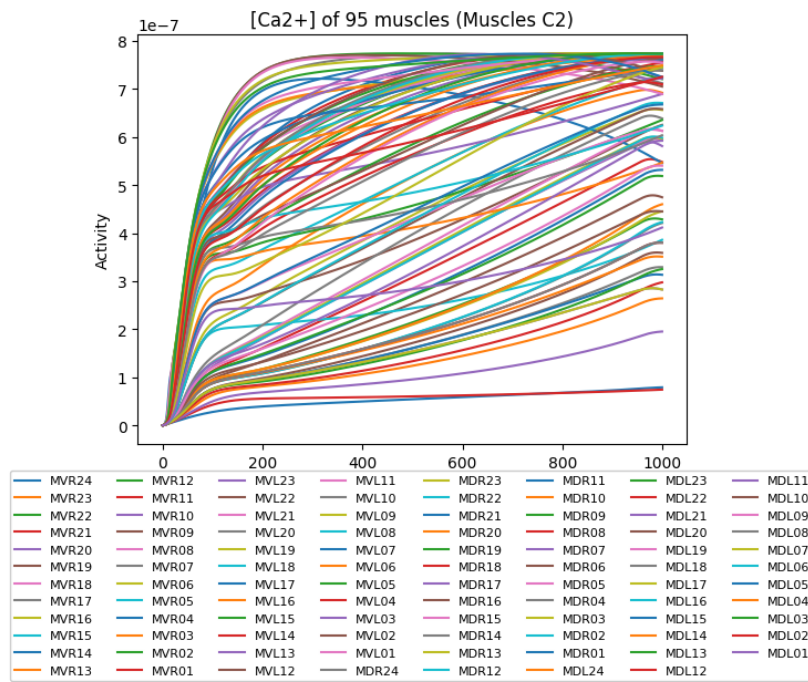
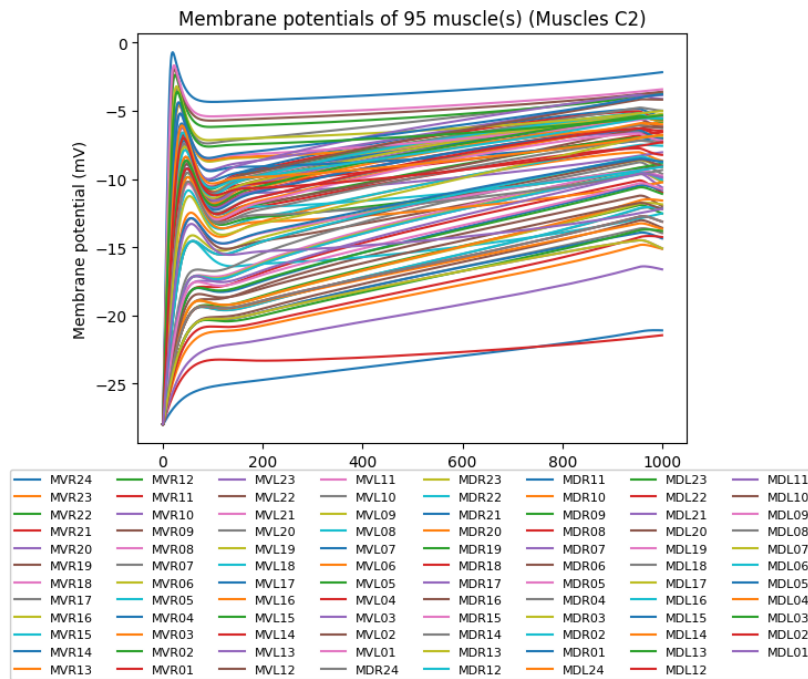


Figure 167: Traces of muscle activity and potentials.



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Figure 168: Traces of muscle activity.

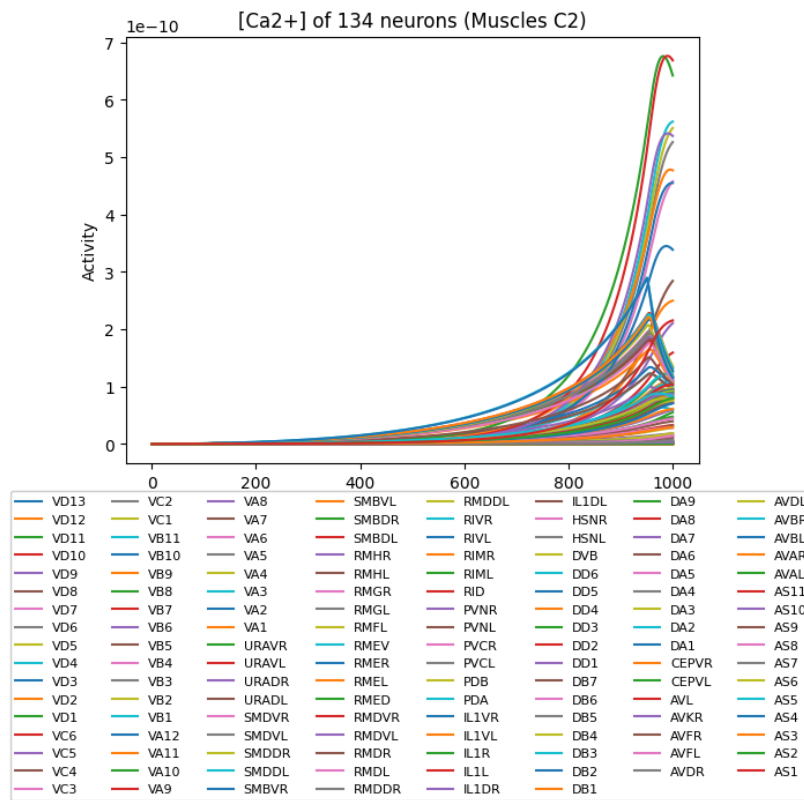
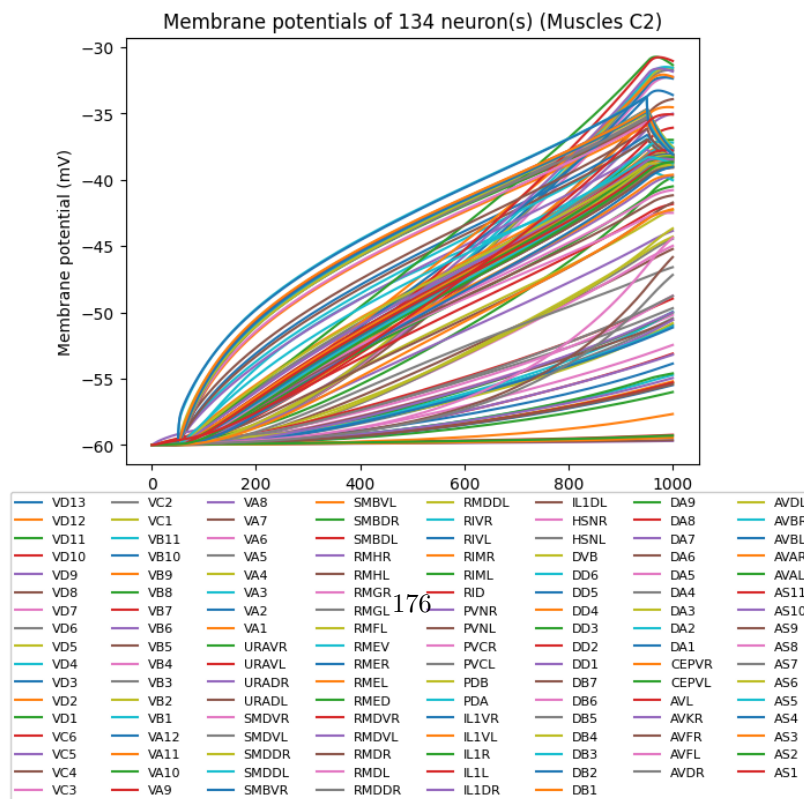


Figure 169: Traces of neuron activity and potentials.



6.17.6 Compact Morphology Grid

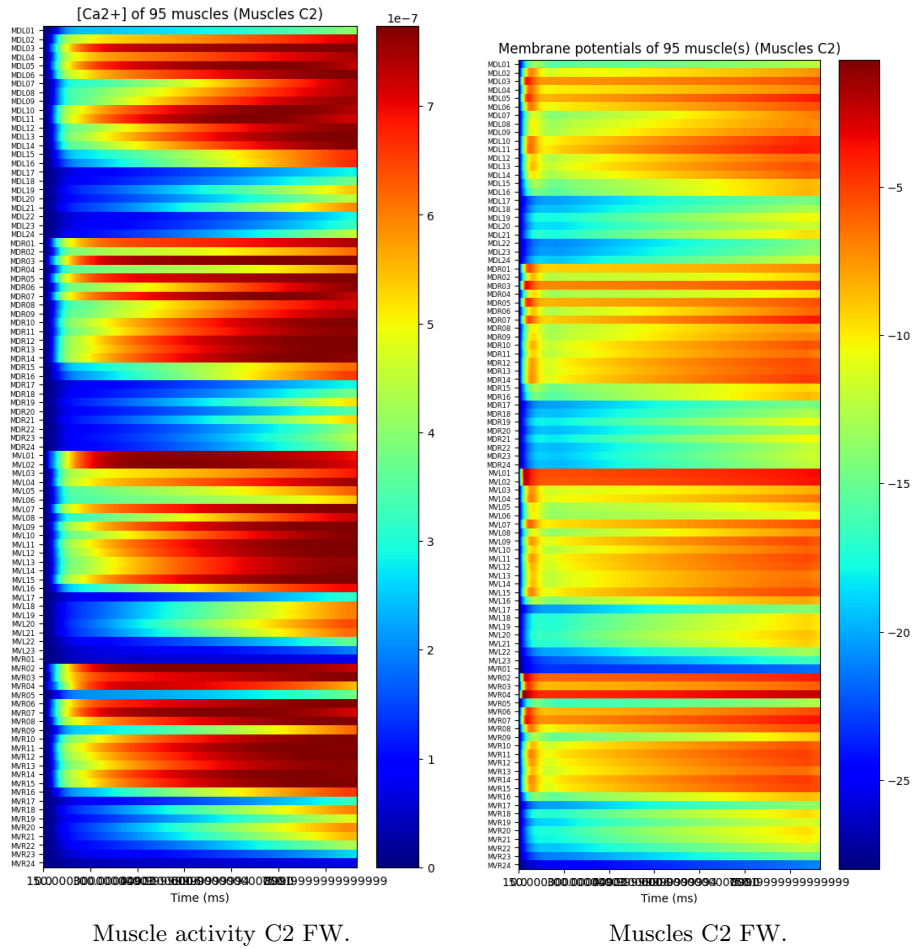
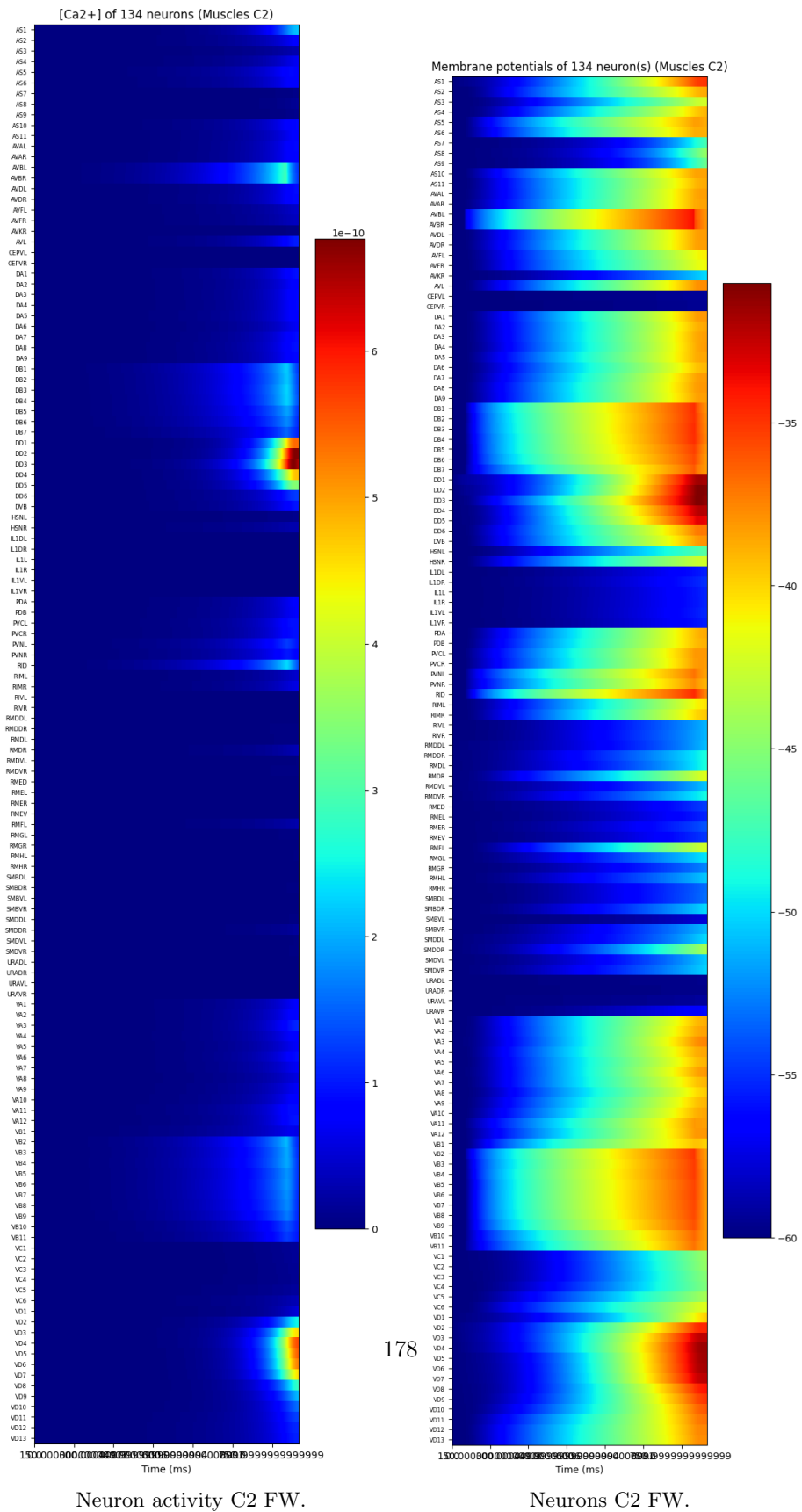


Figure 171: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).



6.17.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.7 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 71: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	2.2 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[=-----]	1.3 / 10
Overall Severity	[=====]	4.7 / 10

6.18 Movement Analysis: AVBR-VB1_GJ

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run C2_Muscles_2026-08-18_14-46-16-AVBR-VB1_GJ.

6.18.1 Locomotion State Classification

Table 72: Behavioral State Breakdown for AVBR-VB1_GJ

Locomotion State	Time Fraction (%)
Forward Crawling	17.6%
Backward Crawling	27.9%
Stationary	0.0%
Reversal	11.5%
Omega Turns	23.0%
Shallow Turns	20.0%
Irregular / Abnormal	0.0%

6.18.2 Kinematic & Velocity Dynamics

Table 73: Kinematic and Velocity Metrics for AVBR-VB1_GJ

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.02	mm
Gross Distance	0.1482	mm
Path Efficiency (Net/Gross)	0.1352	[0.0 – 1.0]
Mean Speed	0.1488	mm/s
Maximum Forward Velocity	0.7835	mm/s
Maximum Backward Velocity	0.7273	mm/s
Median Velocity	0.0988	mm/s
Velocity Std Deviation	0.183	mm/s
Velocity RMS	0.2359	mm/s
Fraction Time Moving Forward	49.4%	ratio
Fraction Time Moving Backward	50.6%	ratio
Fraction Time Stationary	0.0%	ratio
Acceleration (Mean)	-0.3988	mm/s ²
Maximum Acceleration	168.7648	mm/s ²
Acceleration RMS	22.8884	mm/s ²
Velocity Autocorrelation	0.8198	correlation
Reversal Frequency	19.0763	s ⁻¹
Mean Curvature	4170.9753	rad/mm
Omega Turn Count	38	count

6.18.3 Undulation Wave Mechanics

Table 74: Undulation Wave Parameters for AVBR-VB1_GJ

Undulation Parameter	Value	Unit
Crawl Amplitude	0.007	rad (bending)
Dominant Frequency	1.0	Hz
Wavelength	1.66	mm
Wave Velocity	1.67	mm/s
Phase Coherence	0.78	[0.0 – 1.0]
Mean Muscle Activation	0.789907	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.18.4 Worm Motion and Activity Figures

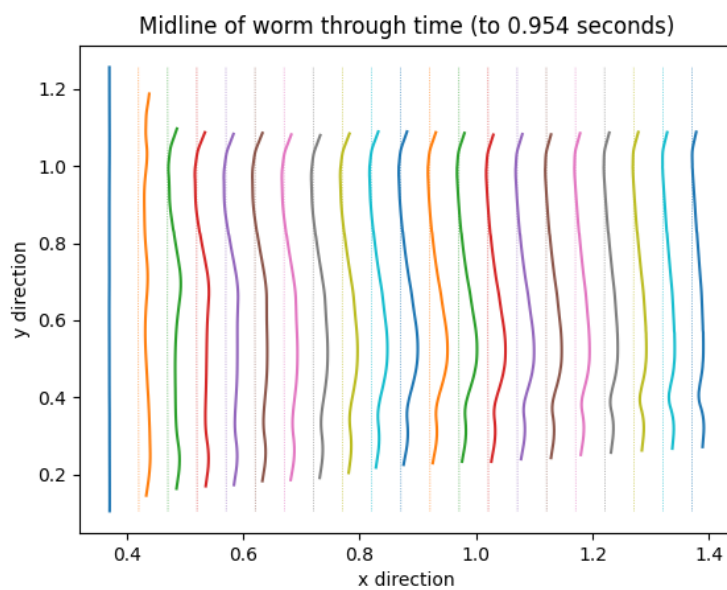


Figure 173: Midline of worm through time.

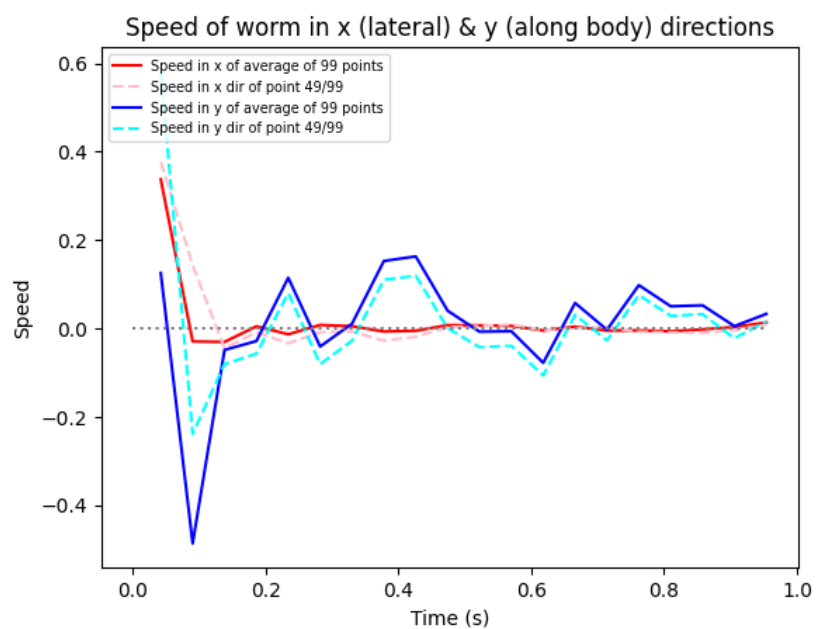


Figure 174: Speed of worm along body directions.

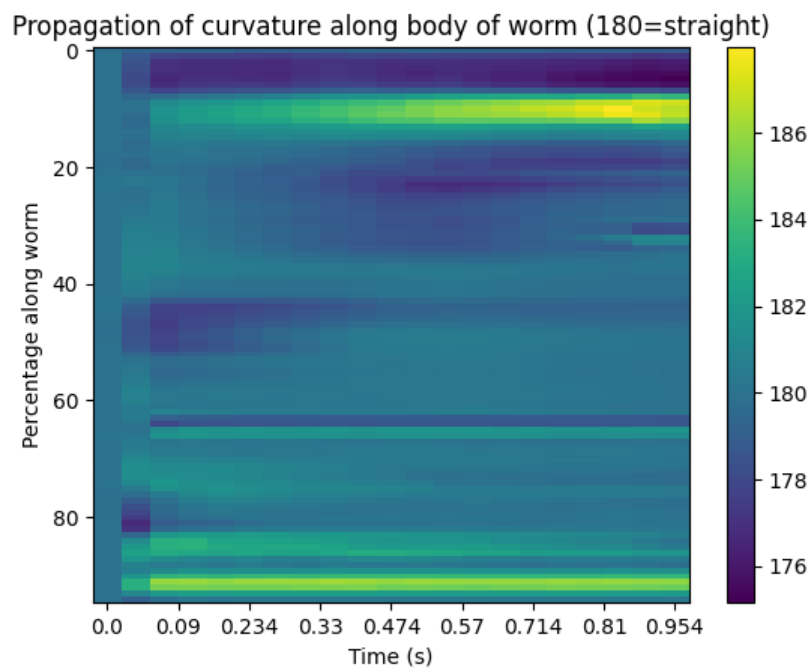


Figure 175: Propagation of curvature along body of worm.

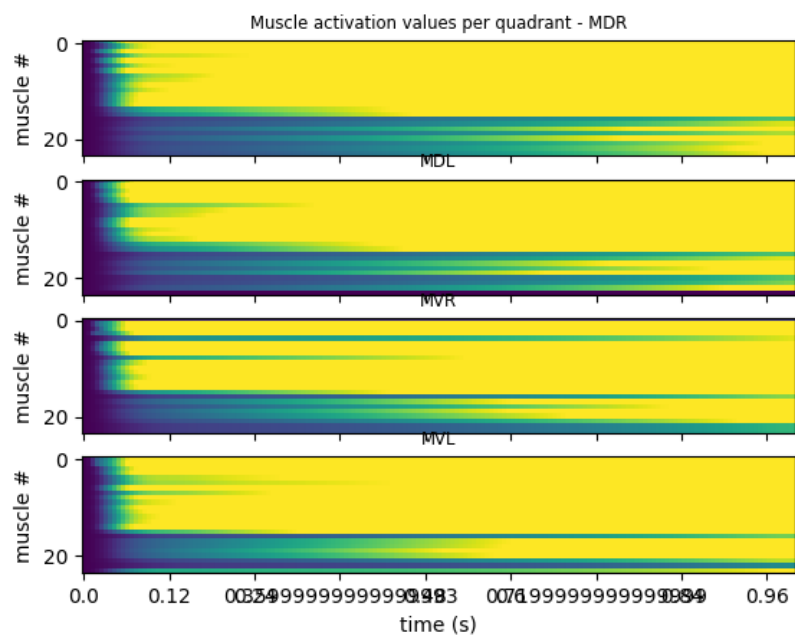


Figure 176: Muscle activities per quadrant.

6.18.5 Trace Figures

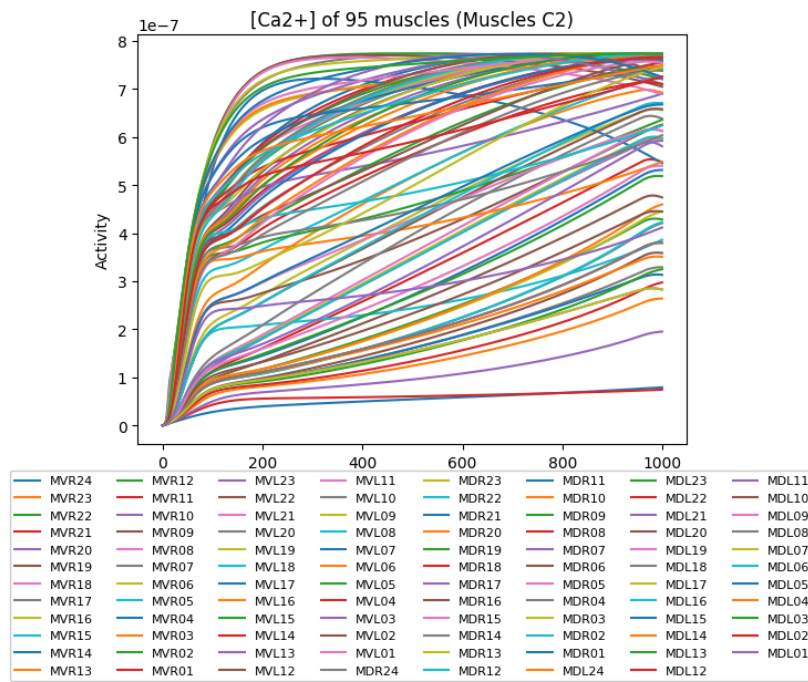
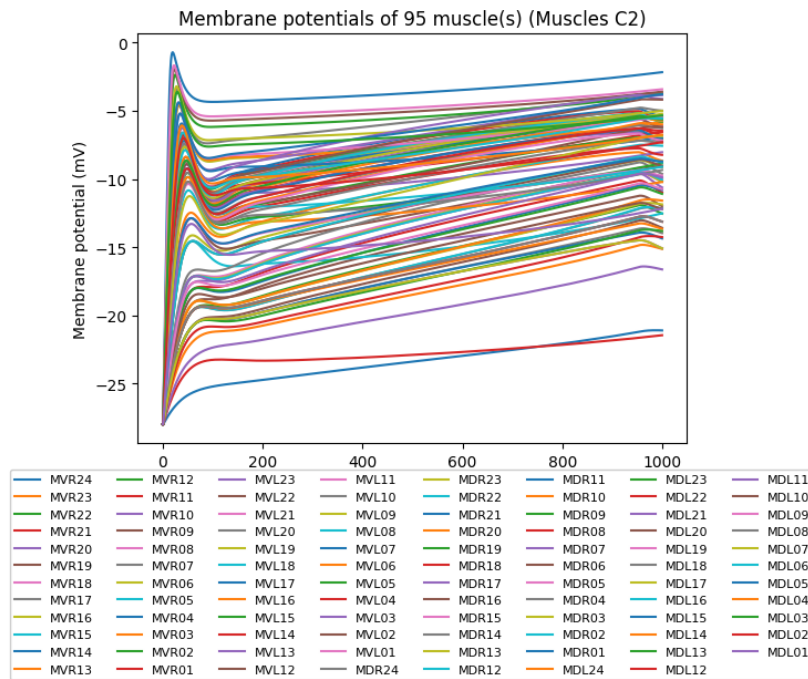


Figure 177: Traces of muscle activity and potentials.



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Figure 178: Traces of muscle activity.

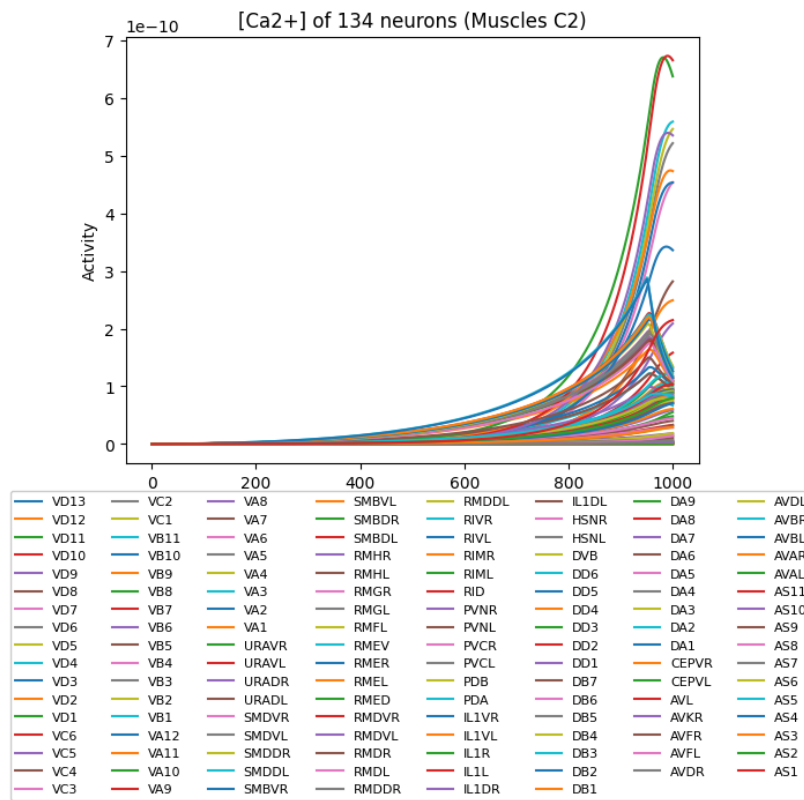
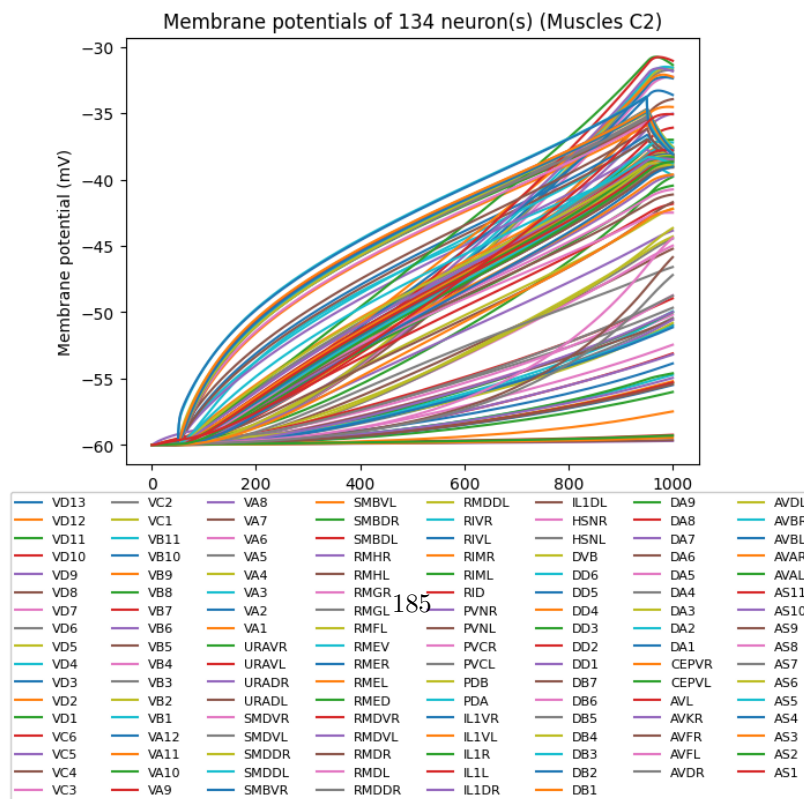


Figure 179: Traces of neuron activity and potentials.



6.18.6 Compact Morphology Grid

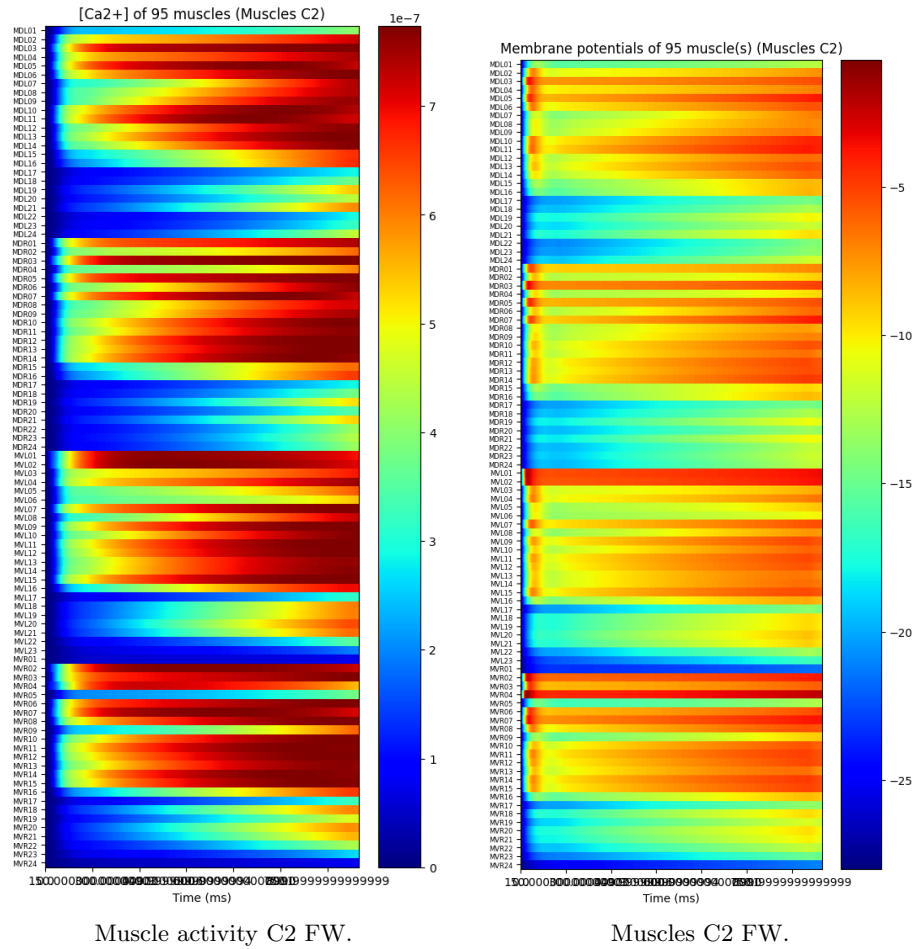


Figure 181: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).

6.18.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.5 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 75: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	2.2 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[-----]	0.1 / 10
Overall Severity	[====-----]	4.5 / 10

6.19 Movement Analysis: AVBL-VB2.GJ

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run C2_Muscles_2026-08-18_16-28-02-AVBL-VB2.GJ.

6.19.1 Locomotion State Classification

Table 76: Behavioral State Breakdown for AVBL-VB2.GJ

Locomotion State	Time Fraction (%)
Forward Crawling	13.9%
Backward Crawling	29.1%
Stationary	0.0%
Reversal	12.1%
Omega Turns	24.9%
Shallow Turns	20.0%
Irregular / Abnormal	0.0%

6.19.2 Kinematic & Velocity Dynamics

Table 77: Kinematic and Velocity Metrics for AVBL-VB2_GJ

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.0208	mm
Gross Distance	0.1507	mm
Path Efficiency (Net/Gross)	0.1377	[0.0 – 1.0]
Mean Speed	0.1513	mm/s
Maximum Forward Velocity	0.9235	mm/s
Maximum Backward Velocity	0.7152	mm/s
Median Velocity	0.0852	mm/s
Velocity Std Deviation	0.1969	mm/s
Velocity RMS	0.2483	mm/s
Fraction Time Moving Forward	46.4%	ratio
Fraction Time Moving Backward	53.6%	ratio
Fraction Time Stationary	0.0%	ratio
Acceleration (Mean)	-0.4619	mm/s ²
Maximum Acceleration	168.7748	mm/s ²
Acceleration RMS	23.1613	mm/s ²
Velocity Autocorrelation	0.8169	correlation
Reversal Frequency	20.0803	s ⁻¹
Mean Curvature	3480.7488	rad/mm
Omega Turn Count	41	count

6.19.3 Undulation Wave Mechanics

Table 78: Undulation Wave Parameters for AVBL-VB2_GJ

Undulation Parameter	Value	Unit
Crawl Amplitude	0.007	rad (bending)
Dominant Frequency	0.0	Hz
Wavelength	0.82	mm
Wave Velocity	0.0	mm/s
Phase Coherence	0.78	[0.0 – 1.0]
Mean Muscle Activation	0.78998	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.19.4 Worm Motion and Activity Figures

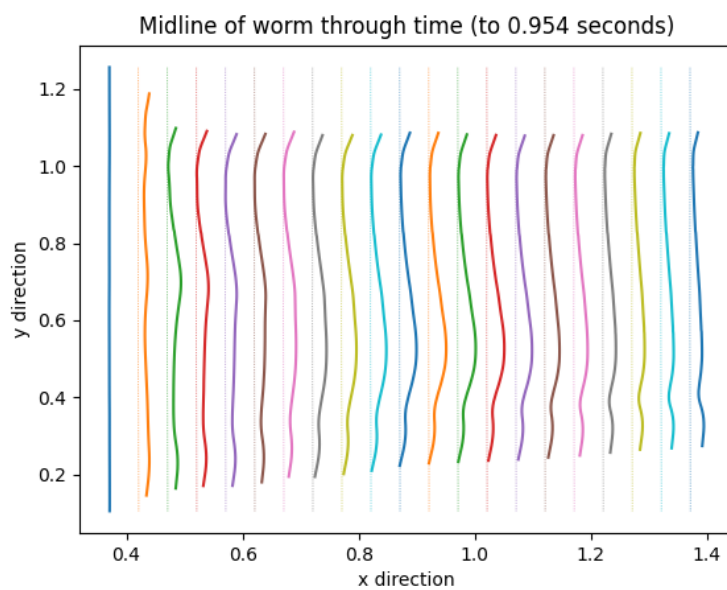


Figure 183: Midline of worm through time.

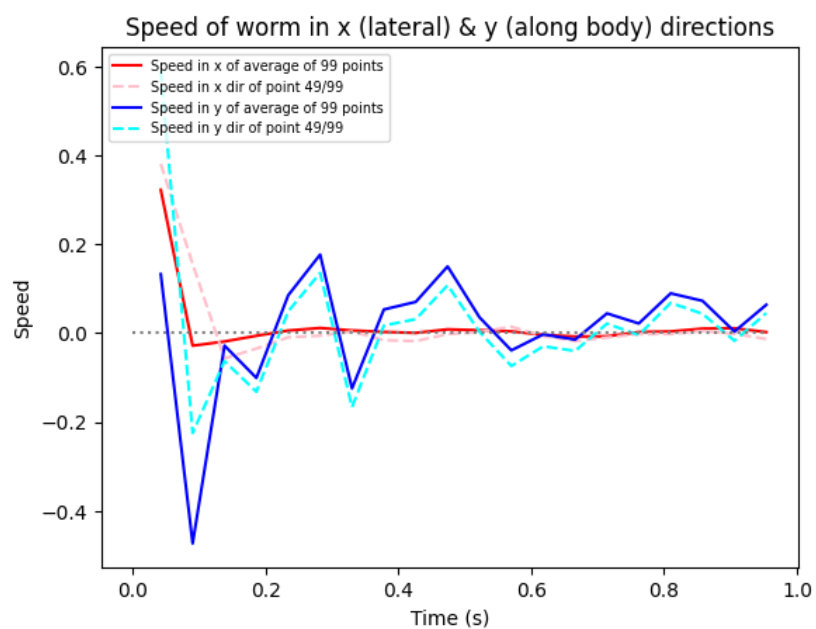


Figure 184: Speed of worm along body directions.

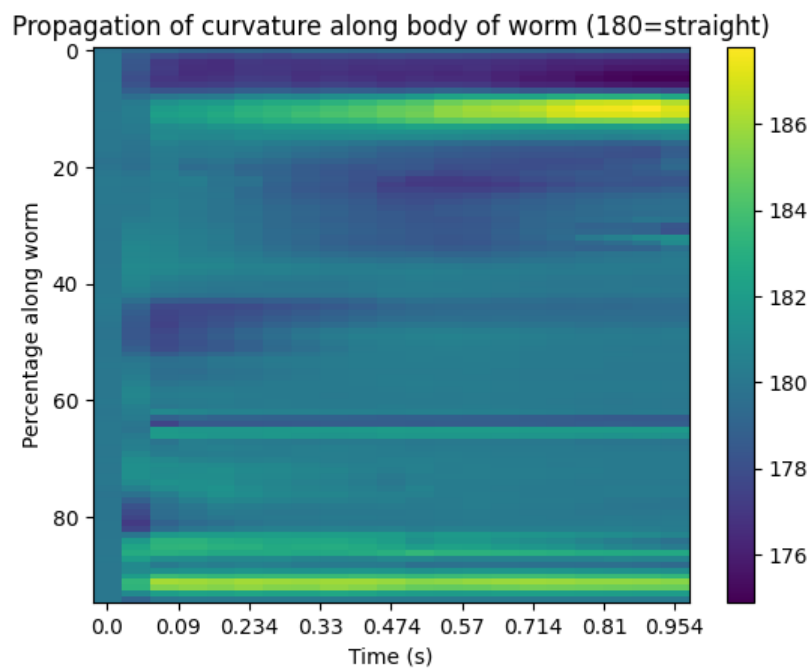


Figure 185: Propagation of curvature along body of worm.

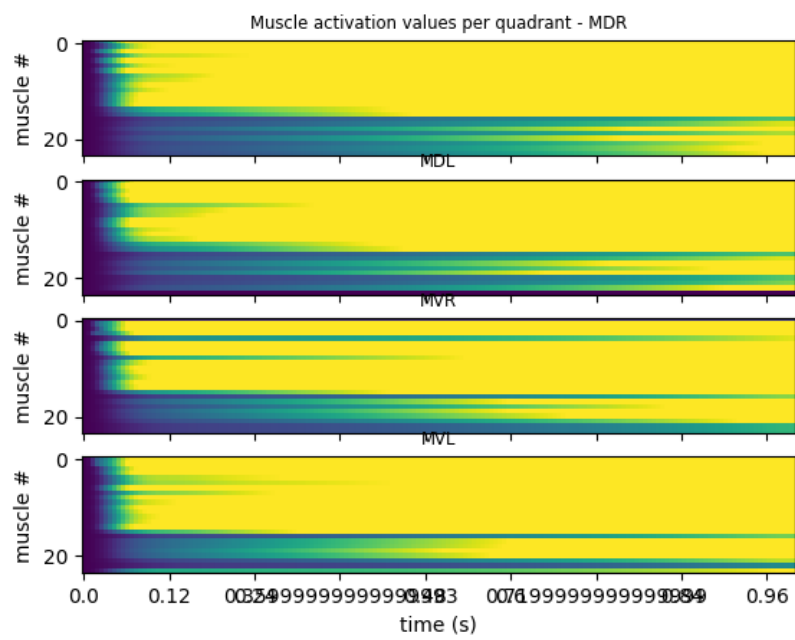


Figure 186: Muscle activities per quadrant.

6.19.5 Trace Figures

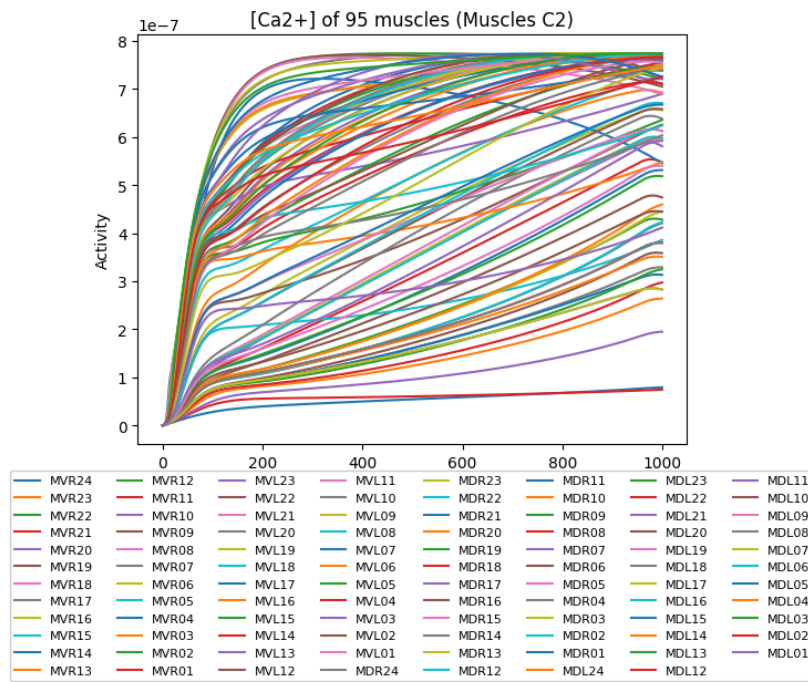
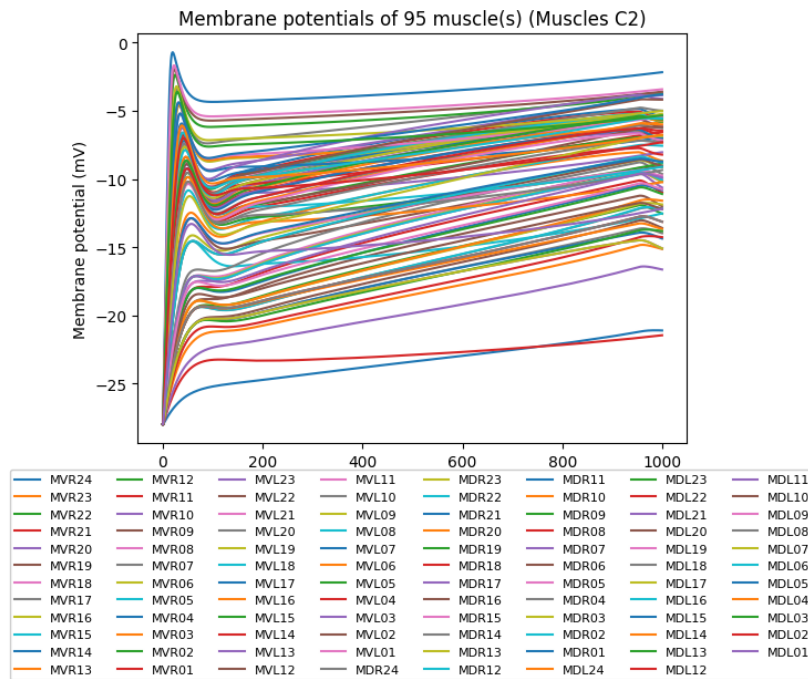


Figure 187: Traces of muscle activity and potentials.



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Figure 188: Traces of muscle activity.

6.19.6 Compact Morphology Grid

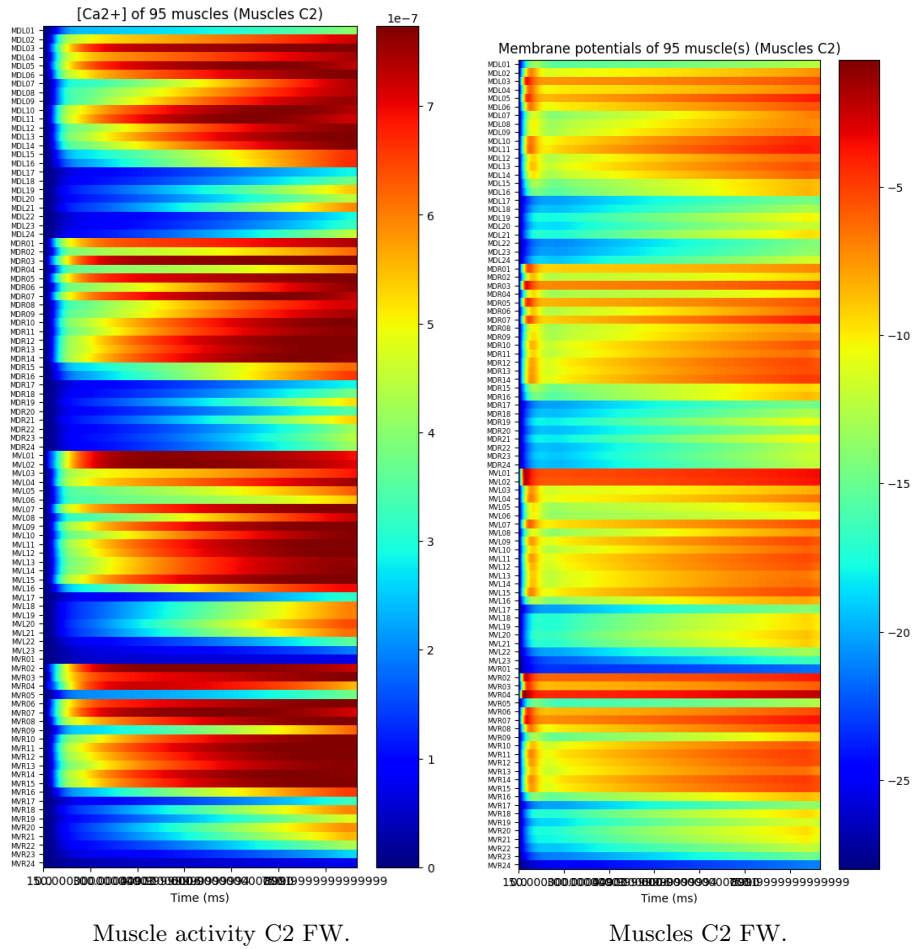


Figure 191: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).

6.19.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.6 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 79: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	2.2 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[=-----]	0.7 / 10
Overall Severity	[=====]	4.6 / 10

6.20 Movement Analysis: AVBR-VB2.GJ

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run C2_Muscles_2026-08-18_19-24-29-AVBR-VB2.GJ.

6.20.1 Locomotion State Classification

Table 80: Behavioral State Breakdown for AVBR-VB2.GJ

Locomotion State	Time Fraction (%)
Forward Crawling	17.6%
Backward Crawling	24.9%
Stationary	0.0%
Reversal	10.3%
Omega Turns	23.0%
Shallow Turns	24.2%
Irregular / Abnormal	0.0%

6.20.2 Kinematic & Velocity Dynamics

Table 81: Kinematic and Velocity Metrics for AVBR-VB2_GJ

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.0176	mm
Gross Distance	0.152	mm
Path Efficiency (Net/Gross)	0.1155	[0.0 – 1.0]
Mean Speed	0.1526	mm/s
Maximum Forward Velocity	0.8491	mm/s
Maximum Backward Velocity	0.779	mm/s
Median Velocity	0.1023	mm/s
Velocity Std Deviation	0.1942	mm/s
Velocity RMS	0.247	mm/s
Fraction Time Moving Forward	53.0%	ratio
Fraction Time Moving Backward	47.0%	ratio
Fraction Time Stationary	0.0%	ratio
Acceleration (Mean)	-0.4889	mm/s ²
Maximum Acceleration	168.7875	mm/s ²
Acceleration RMS	23.2082	mm/s ²
Velocity Autocorrelation	0.8242	correlation
Reversal Frequency	17.0683	s ⁻¹
Mean Curvature	3345.2634	rad/mm
Omega Turn Count	38	count

6.20.3 Undulation Wave Mechanics

Table 82: Undulation Wave Parameters for AVBR-VB2_GJ

Undulation Parameter	Value	Unit
Crawl Amplitude	0.0069	rad (bending)
Dominant Frequency	0.0	Hz
Wavelength	0.82	mm
Wave Velocity	0.0	mm/s
Phase Coherence	0.77	[0.0 – 1.0]
Mean Muscle Activation	0.789929	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.20.4 Worm Motion and Activity Figures

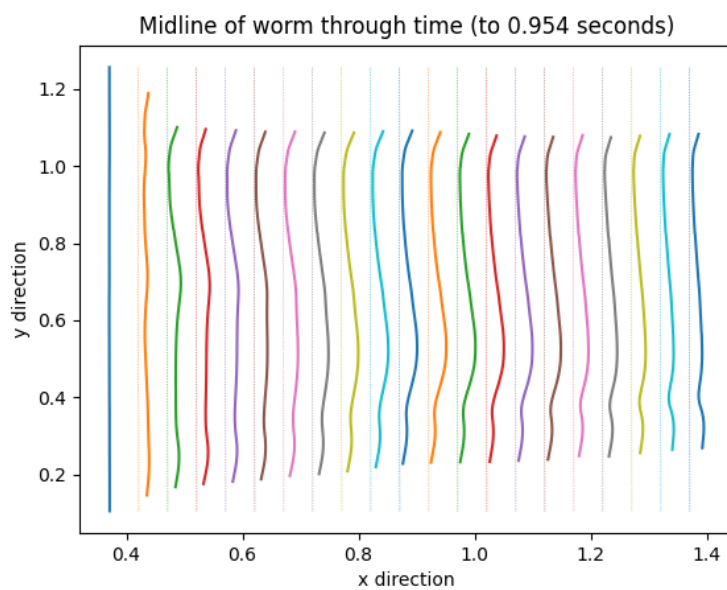


Figure 193: Midline of worm through time.

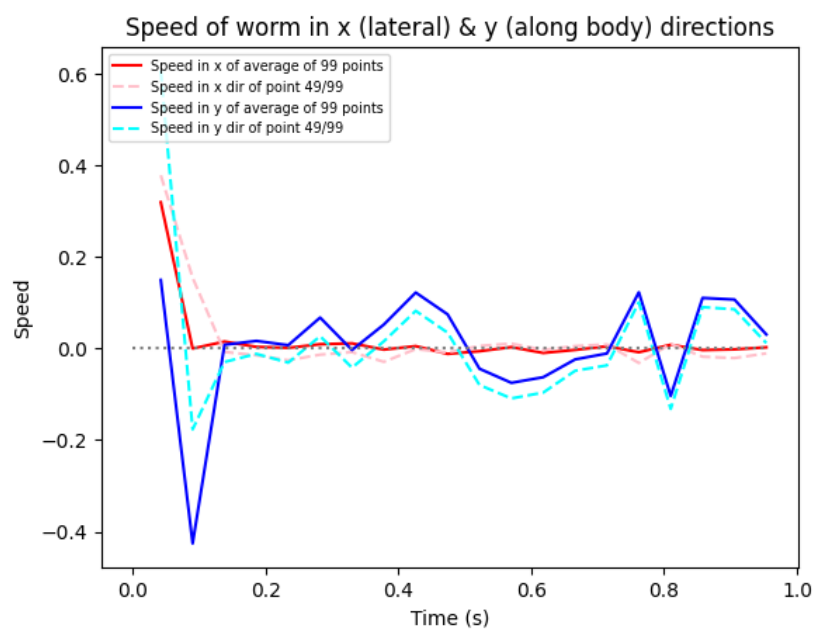


Figure 194: Speed of worm along body directions.

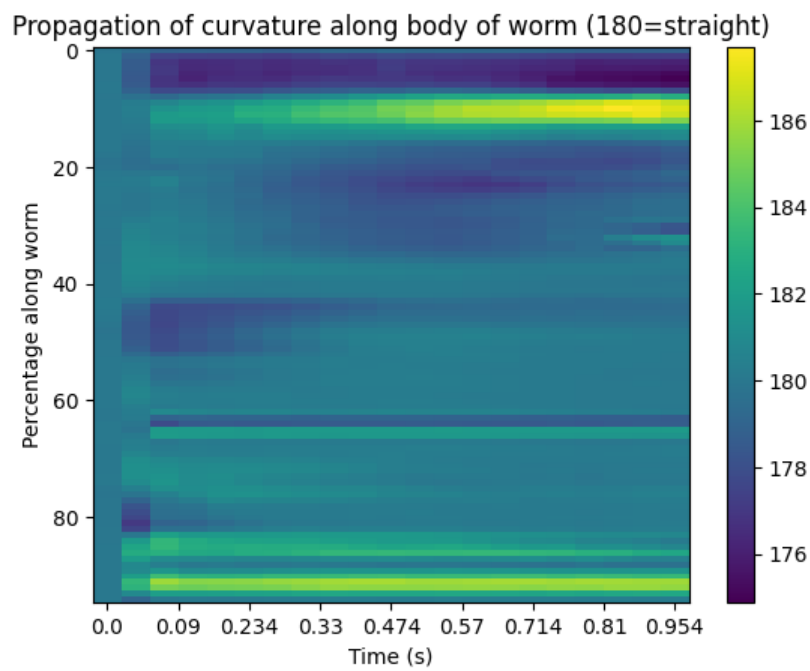


Figure 195: Propagation of curvature along body of worm.

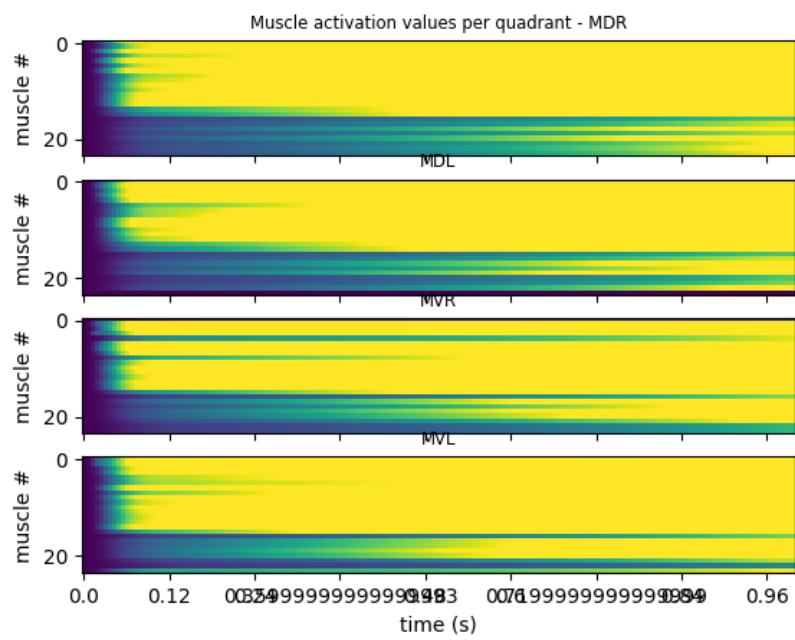


Figure 196: Muscle activities per quadrant.

6.20.5 Trace Figures

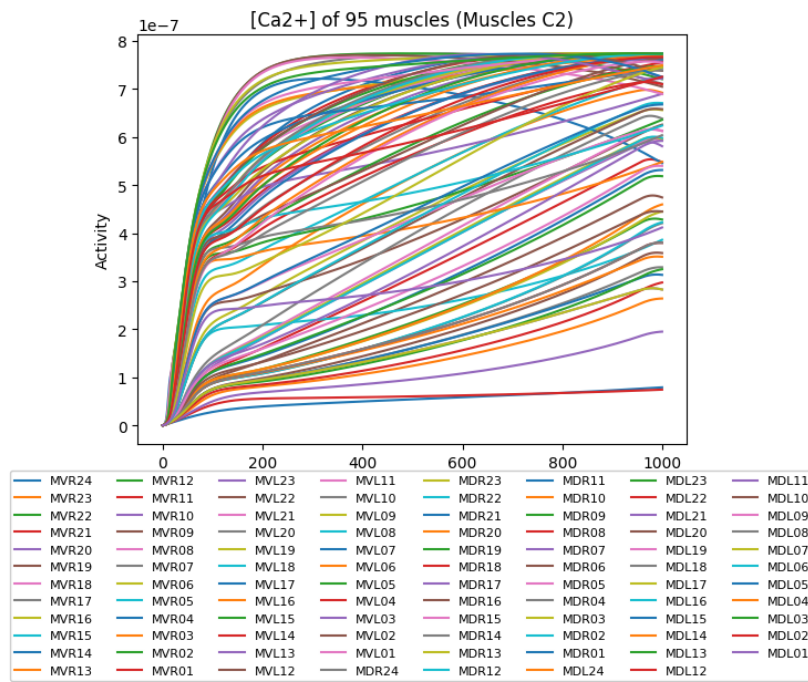
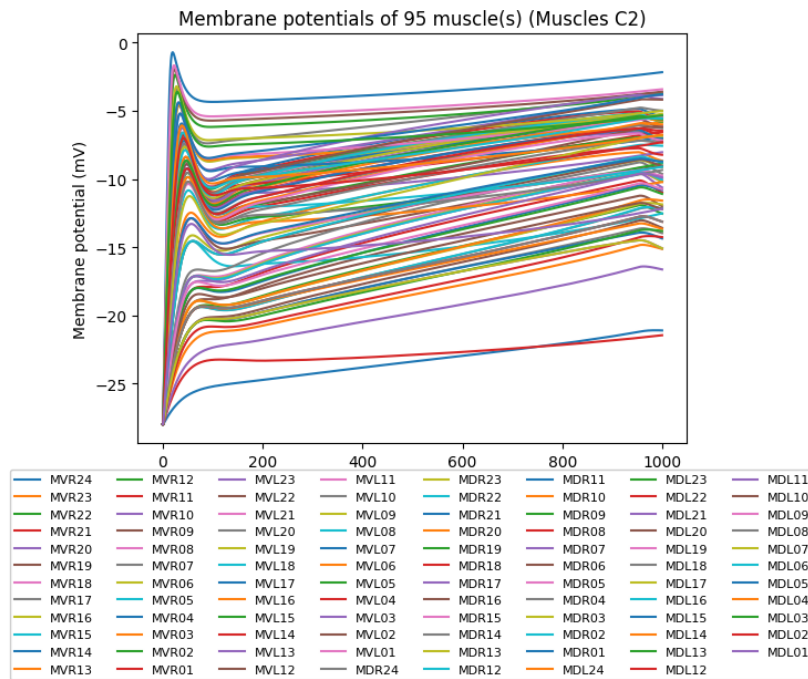


Figure 197: Traces of muscle activity and potentials.



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Figure 198: Traces of muscle activity.

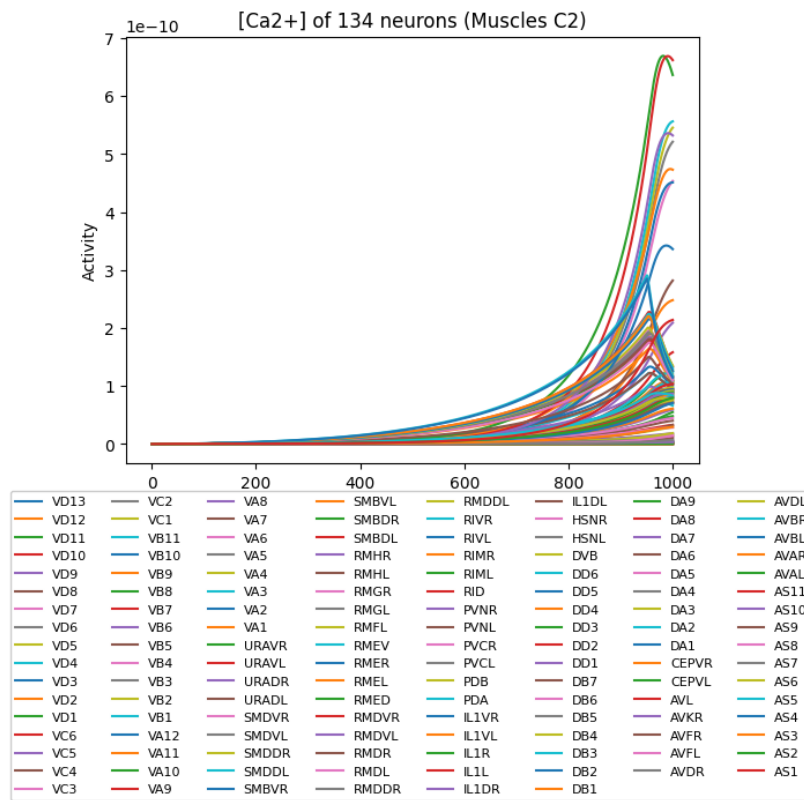
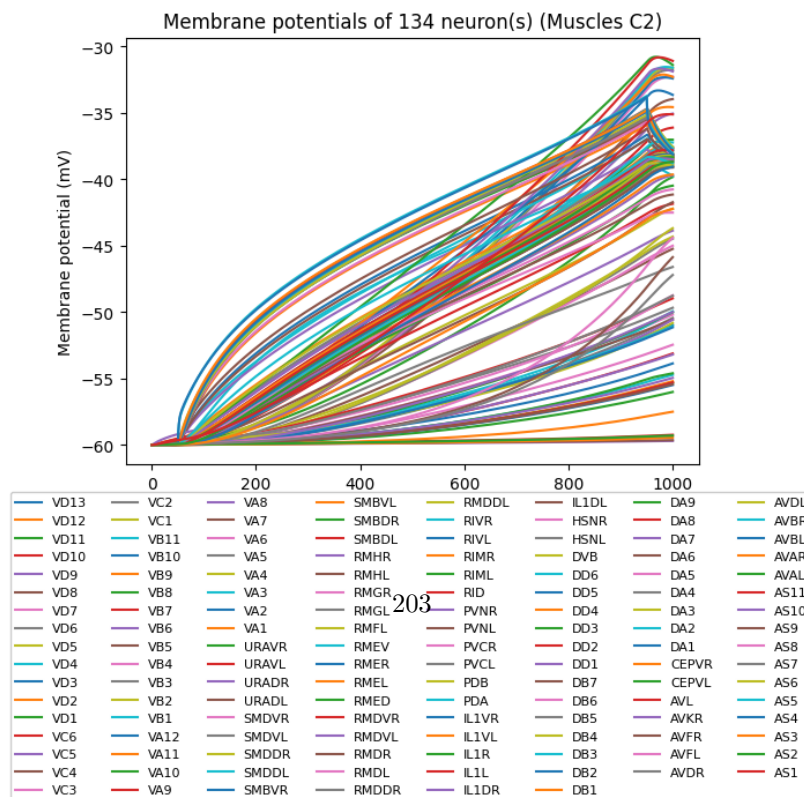


Figure 199: Traces of neuron activity and potentials.



6.20.6 Compact Morphology Grid

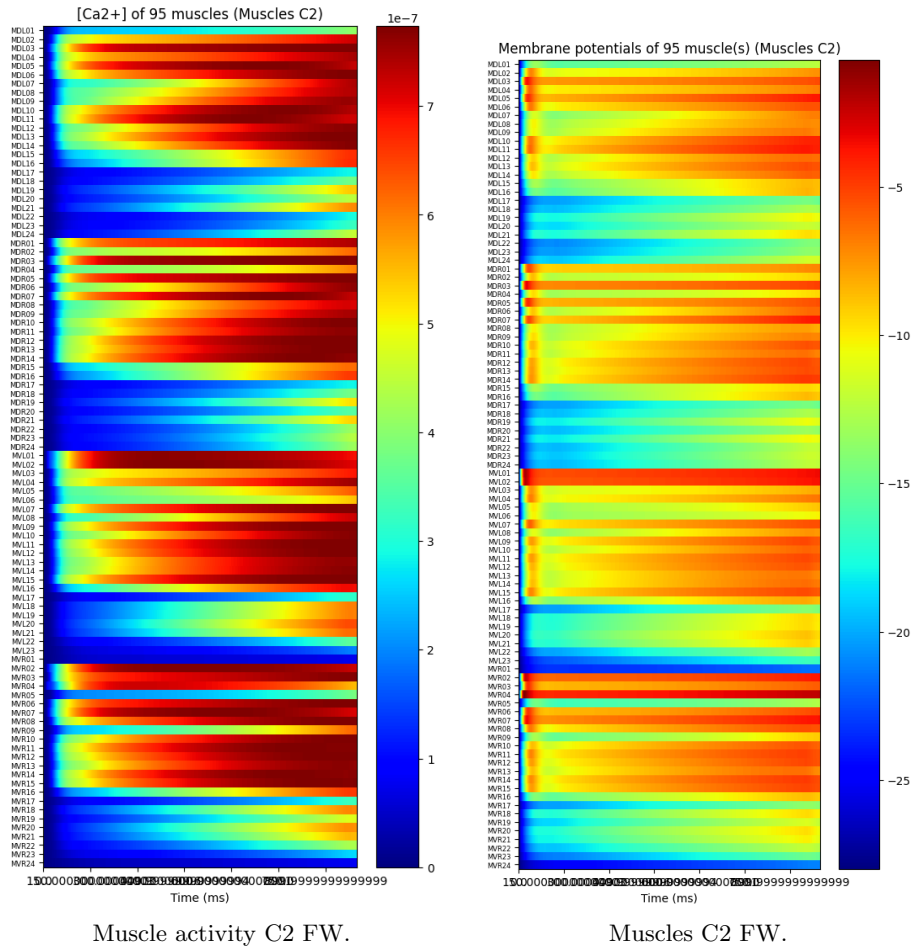


Figure 201: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).

6.20.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.6 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 83: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	2.3 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[=-----]	0.6 / 10
Overall Severity	[=====]	4.6 / 10

6.21 Movement Analysis: AVB-VB_bilateral_GJ

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run C2_Muscles_2026-08-19_08-50-02-AVB-VB_bilateral_GJ.

6.21.1 Locomotion State Classification

Table 84: Behavioral State Breakdown for AVB-VB_bilateral_GJ

Locomotion State	Time Fraction (%)
Forward Crawling	12.1%
Backward Crawling	26.7%
Stationary	0.0%
Reversal	14.6%
Omega Turns	29.1%
Shallow Turns	17.6%
Irregular / Abnormal	0.0%

6.21.2 Kinematic & Velocity Dynamics

Table 85: Kinematic and Velocity Metrics for AVB-VB_bilateral_GJ

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.0403	mm
Gross Distance	0.1426	mm
Path Efficiency (Net/Gross)	0.2824	[0.0 – 1.0]
Mean Speed	0.1431	mm/s
Maximum Forward Velocity	0.7181	mm/s
Maximum Backward Velocity	0.6649	mm/s
Median Velocity	0.0869	mm/s
Velocity Std Deviation	0.1852	mm/s
Velocity RMS	0.2341	mm/s
Fraction Time Moving Forward	43.4%	ratio
Fraction Time Moving Backward	55.4%	ratio
Fraction Time Stationary	0.0%	ratio
Acceleration (Mean)	-0.4871	mm/s ²
Maximum Acceleration	168.7893	mm/s ²
Acceleration RMS	22.4432	mm/s ²
Velocity Autocorrelation	0.7753	correlation
Reversal Frequency	24.0964	s ⁻¹
Mean Curvature	3901.942	rad/mm
Omega Turn Count	48	count

6.21.3 Undulation Wave Mechanics

Table 86: Undulation Wave Parameters for AVB-VB_bilateral_GJ

Undulation Parameter	Value	Unit
Crawl Amplitude	0.0068	rad (bending)
Dominant Frequency	0.0	Hz
Wavelength	0.82	mm
Wave Velocity	0.0	mm/s
Phase Coherence	0.79	[0.0 – 1.0]
Mean Muscle Activation	0.790137	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.21.4 Worm Motion and Activity Figures

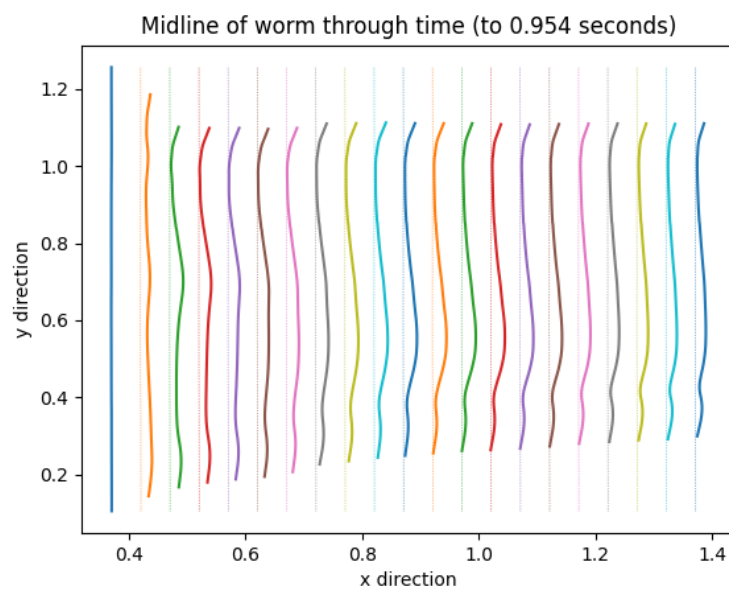


Figure 203: Midline of worm through time.

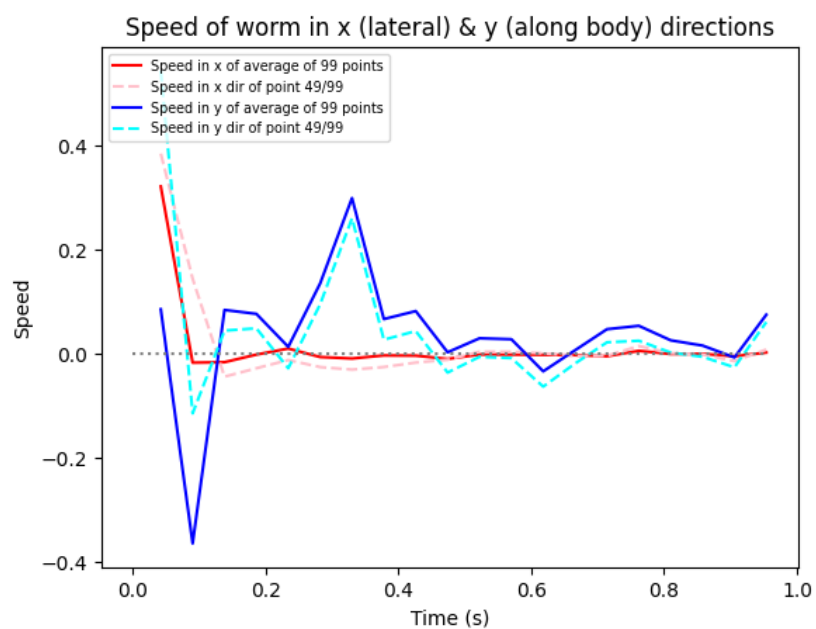


Figure 204: Speed of worm along body directions.

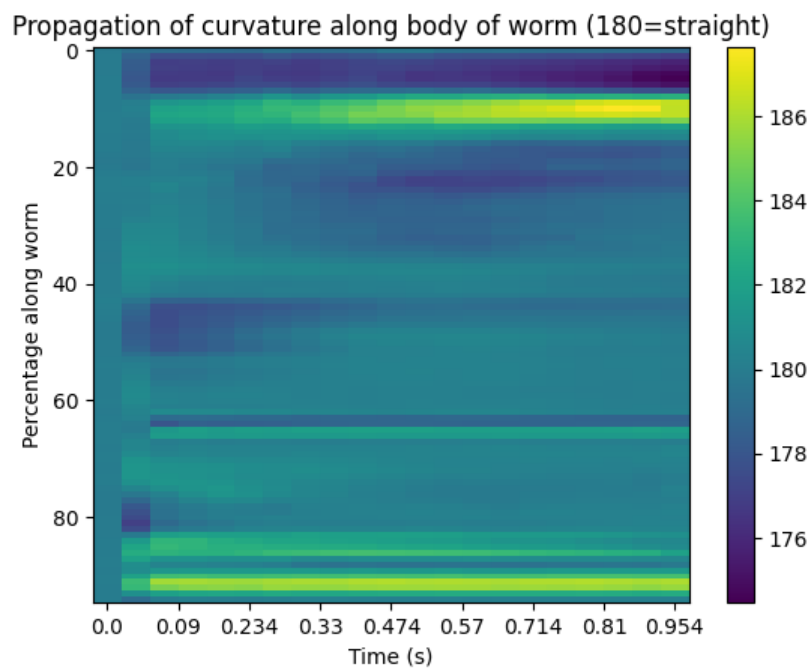


Figure 205: Propagation of curvature along body of worm.

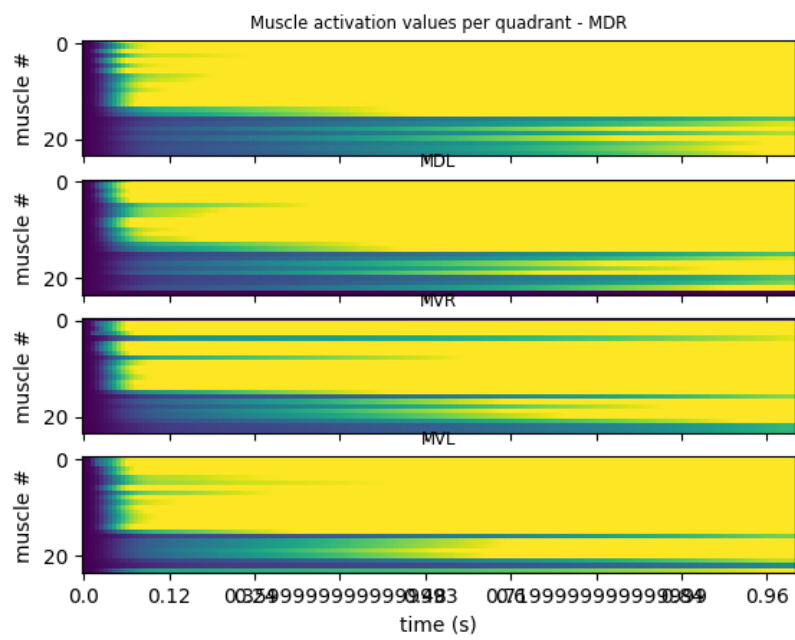


Figure 206: Muscle activities per quadrant.

6.21.5 Trace Figures

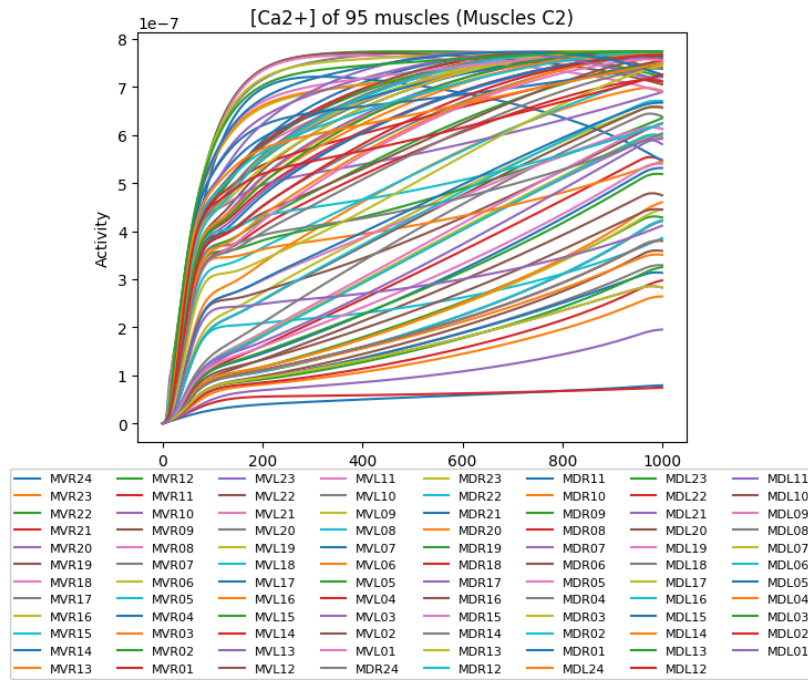
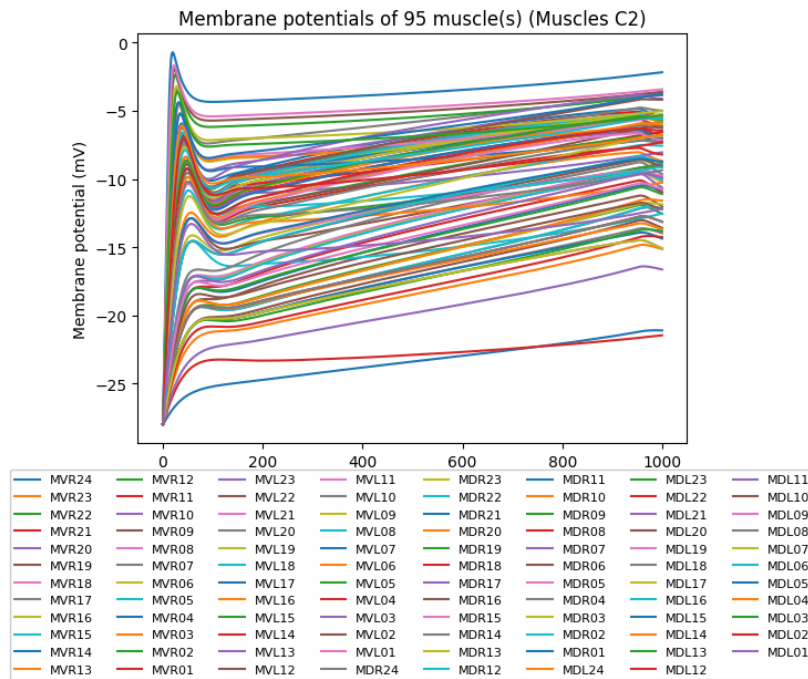


Figure 207: Traces of muscle activity and potentials.



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Figure 208: Traces of muscle activity.

6.21.6 Compact Morphology Grid

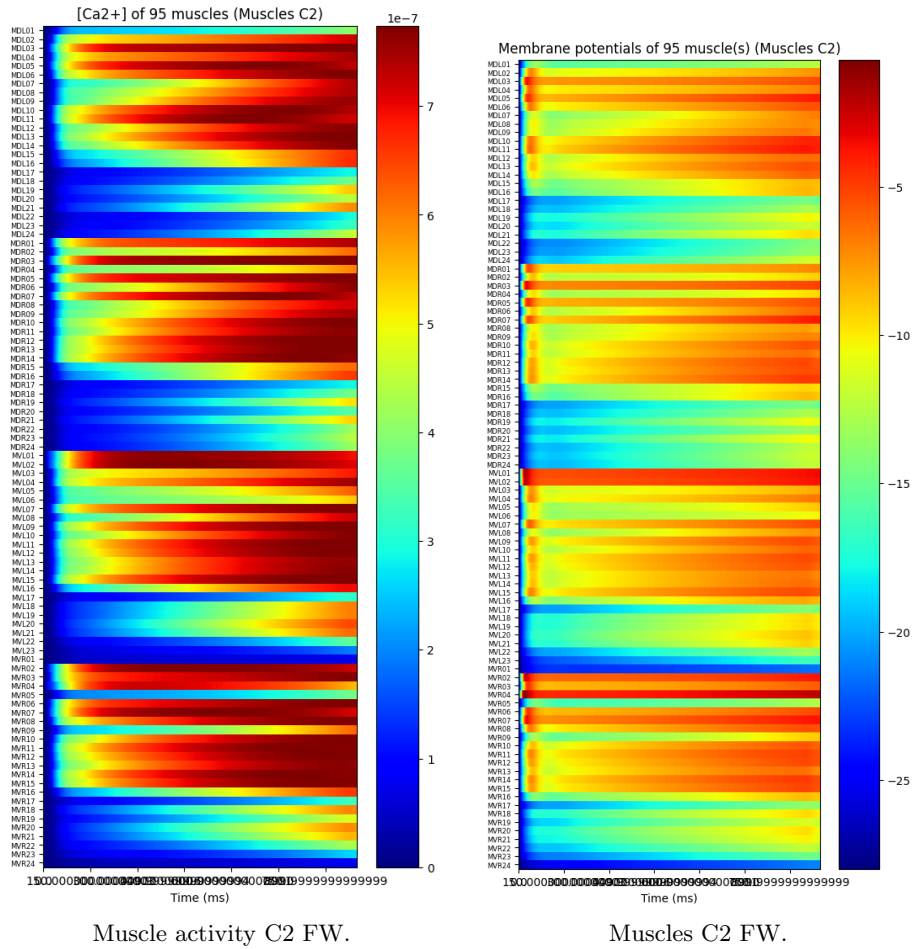


Figure 211: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).

6.21.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.7 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 87: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	2.1 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[=-----]	1.2 / 10
Overall Severity	[=====]	4.7 / 10

6.22 Movement Analysis: AVAL-AVBL

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run C2_Muscles_2026-08-19_10-23-22-AVAL-AVBL.

6.22.1 Locomotion State Classification

Table 88: Behavioral State Breakdown for AVAL-AVBL

Locomotion State	Time Fraction (%)
Forward Crawling	14.6%
Backward Crawling	24.9%
Stationary	0.0%
Reversal	11.5%
Omega Turns	27.3%
Shallow Turns	21.8%
Irregular / Abnormal	0.0%

6.22.2 Kinematic & Velocity Dynamics

Table 89: Kinematic and Velocity Metrics for AVAL-AVBL

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.0271	mm
Gross Distance	0.1418	mm
Path Efficiency (Net/Gross)	0.1913	[0.0 – 1.0]
Mean Speed	0.1423	mm/s
Maximum Forward Velocity	0.9191	mm/s
Maximum Backward Velocity	0.8249	mm/s
Median Velocity	0.09	mm/s
Velocity Std Deviation	0.1964	mm/s
Velocity RMS	0.2426	mm/s
Fraction Time Moving Forward	50.0%	ratio
Fraction Time Moving Backward	49.4%	ratio
Fraction Time Stationary	0.0%	ratio
Acceleration (Mean)	-0.3169	mm/s ²
Maximum Acceleration	168.7871	mm/s ²
Acceleration RMS	23.6106	mm/s ²
Velocity Autocorrelation	0.8096	correlation
Reversal Frequency	19.0763	s ⁻¹
Mean Curvature	3767.1856	rad/mm
Omega Turn Count	45	count

6.22.3 Undulation Wave Mechanics

Table 90: Undulation Wave Parameters for AVAL-AVBL

Undulation Parameter	Value	Unit
Crawl Amplitude	0.0071	rad (bending)
Dominant Frequency	2.01	Hz
Wavelength	0.91	mm
Wave Velocity	1.83	mm/s
Phase Coherence	0.79	[0.0 – 1.0]
Mean Muscle Activation	0.789889	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.22.4 Worm Motion and Activity Figures

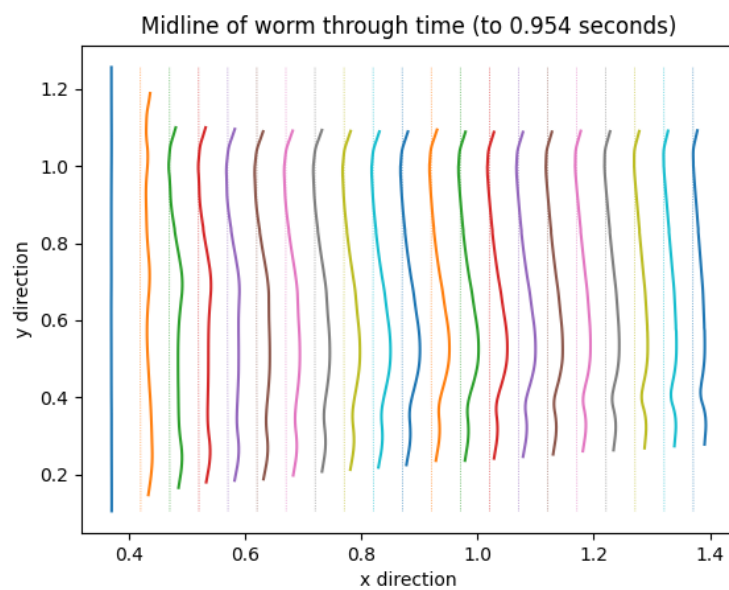


Figure 213: Midline of worm through time.

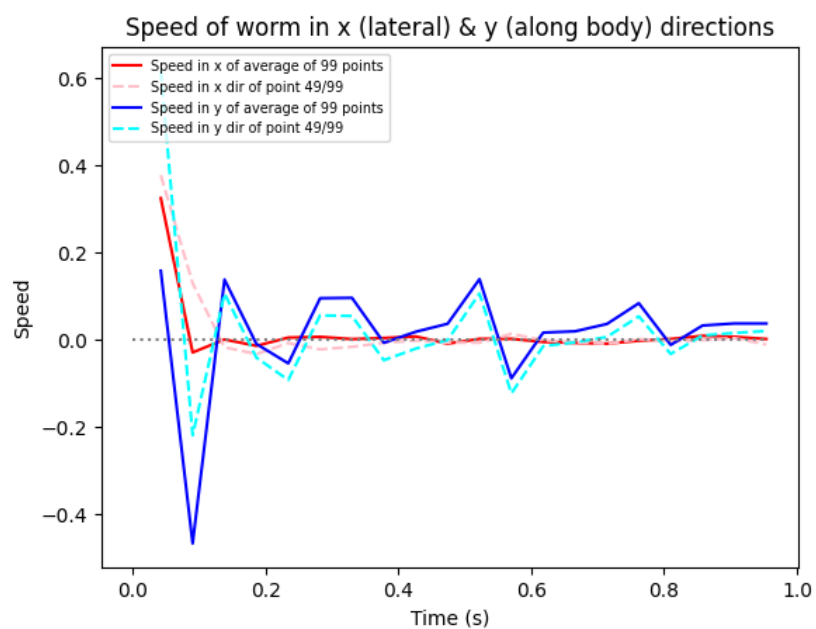


Figure 214: Speed of worm along body directions.

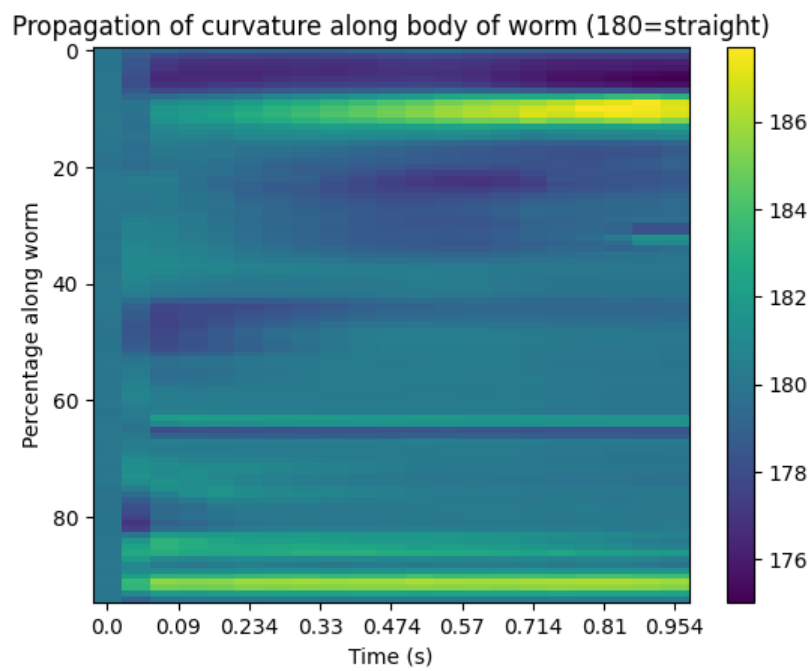


Figure 215: Propagation of curvature along body of worm.

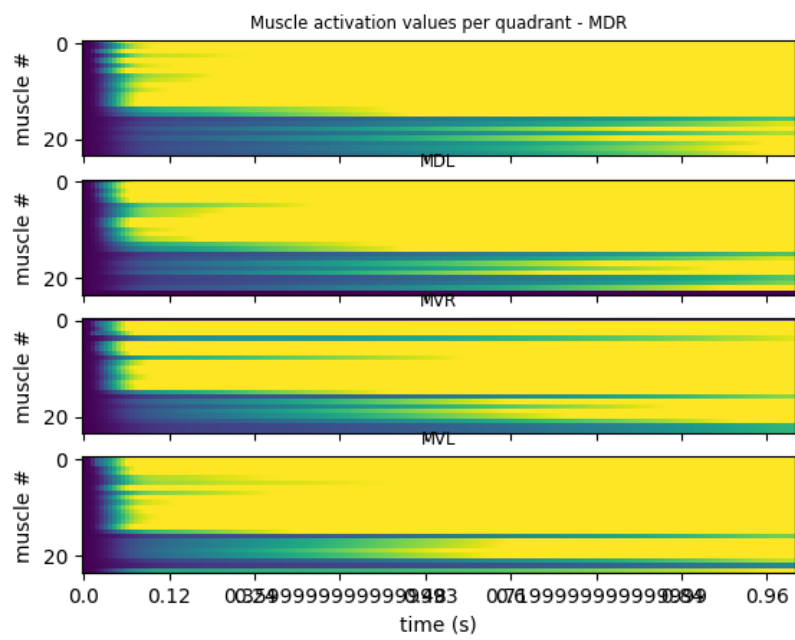


Figure 216: Muscle activities per quadrant.

6.22.5 Trace Figures

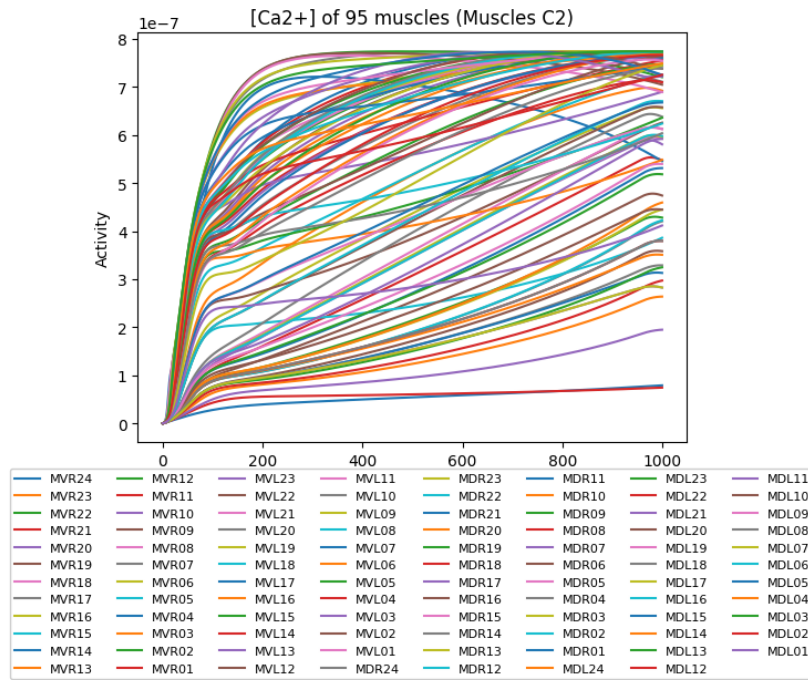
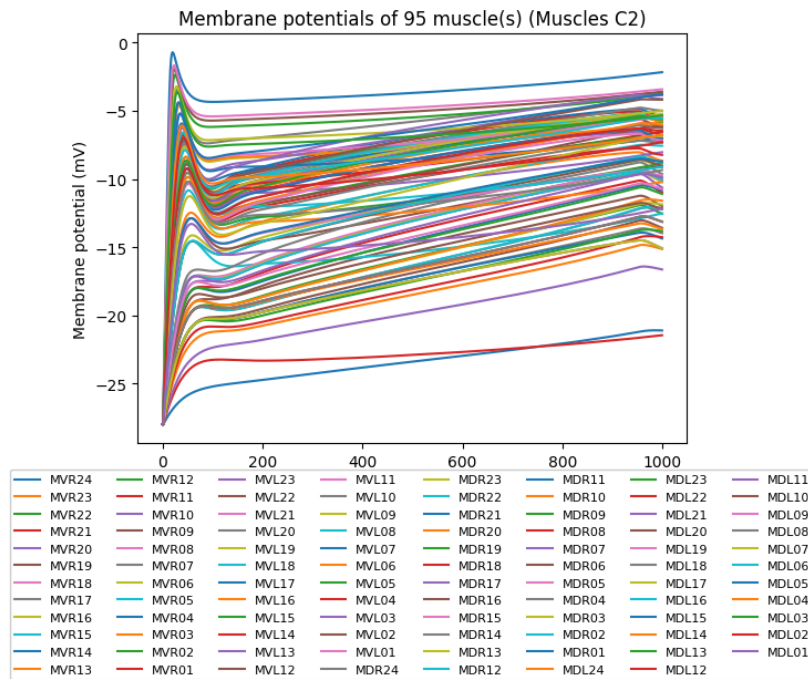


Figure 217: Traces of muscle activity and potentials.



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Figure 218: Traces of muscle activity.

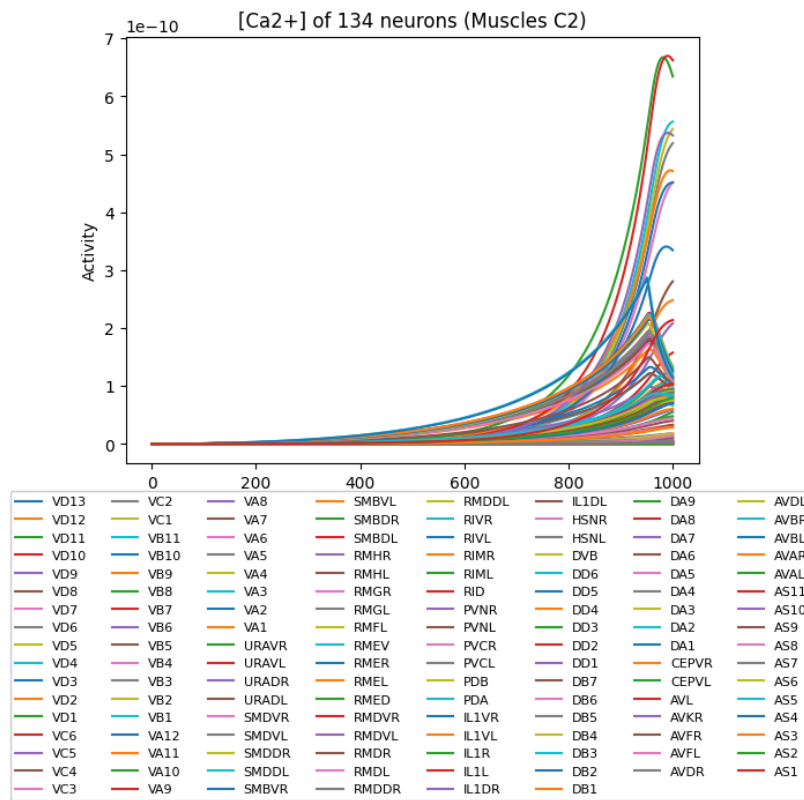
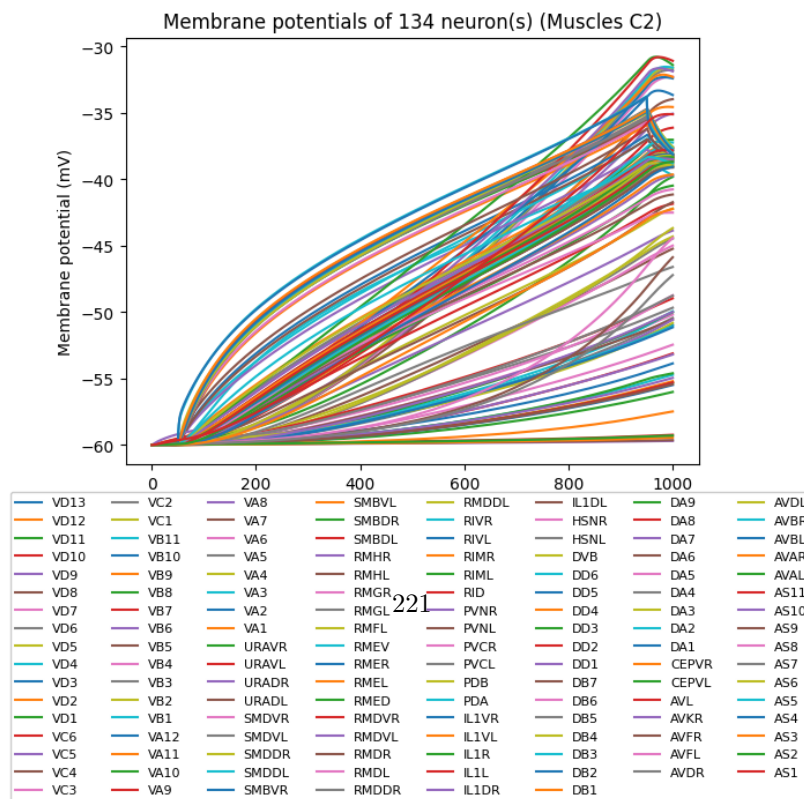


Figure 219: Traces of neuron activity and potentials.



6.22.6 Compact Morphology Grid

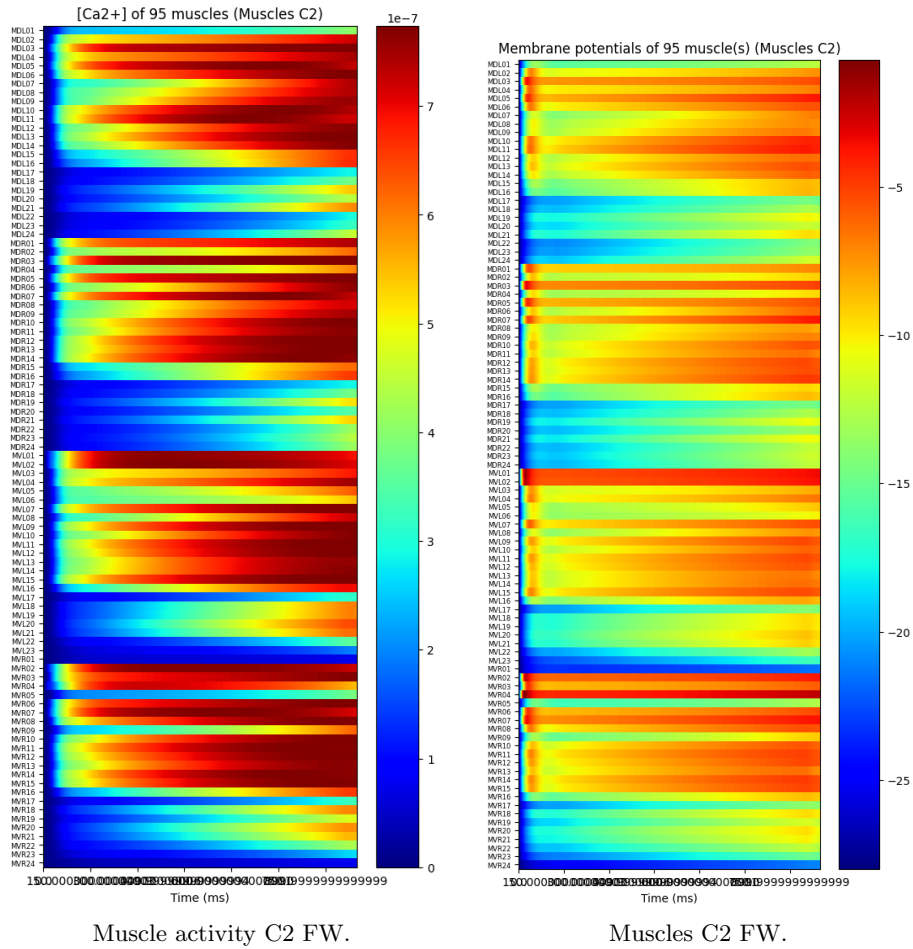


Figure 221: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).

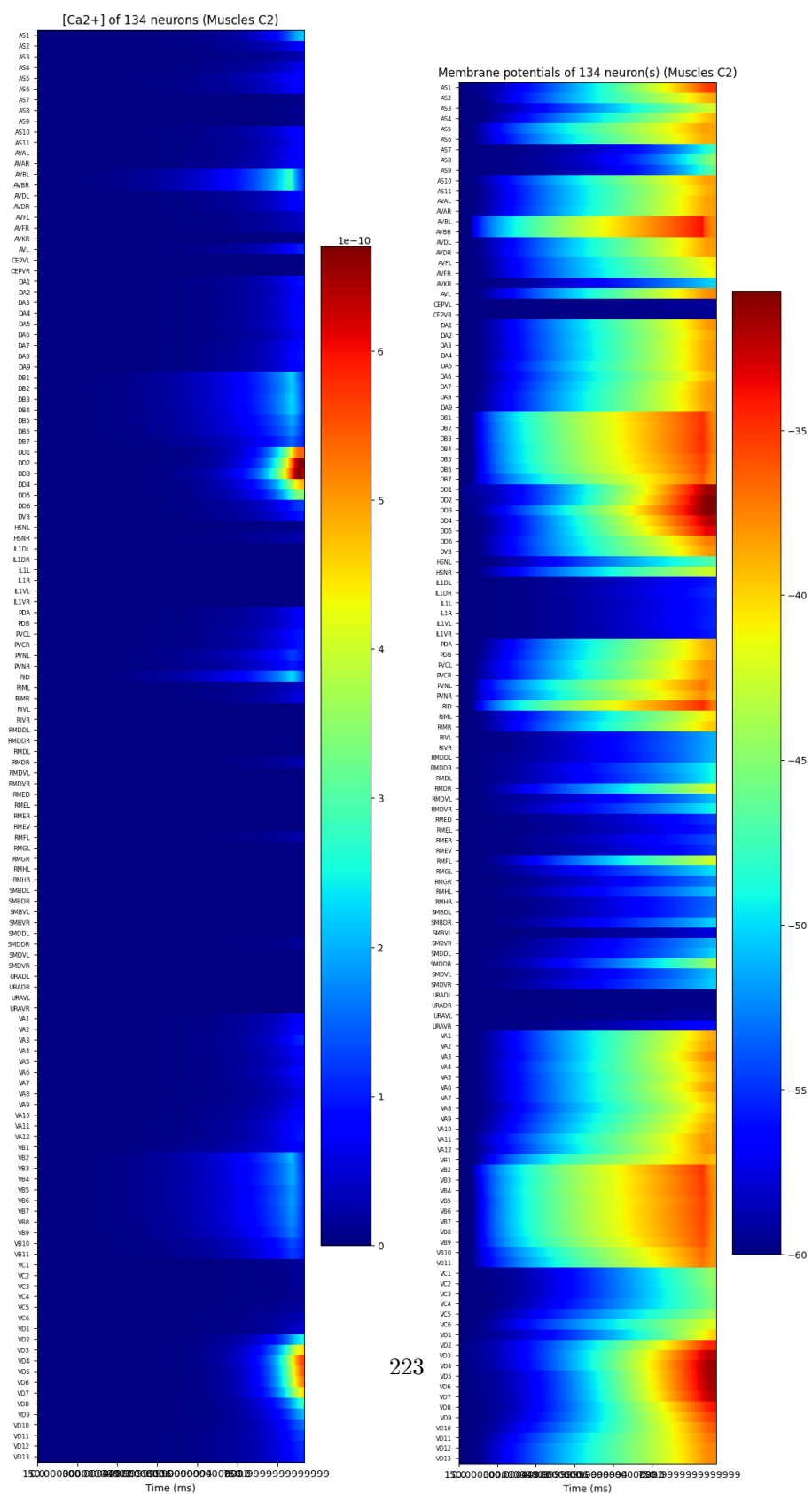


Figure 222: Neuron activity and morphology, shown as a 2x1 grid for compact

6.22.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.4 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 91: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	2.1 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[-----]	0.1 / 10
Overall Severity	[====-----]	4.4 / 10

6.23 Movement Analysis: AVAR-AVBL_both

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run C2_Muscles_2026-08-19_14-05-37-AVAR-AVBL_both.

6.23.1 Locomotion State Classification

Table 92: Behavioral State Breakdown for AVAR-AVBL_both

Locomotion State	Time Fraction (%)
Forward Crawling	11.5%
Backward Crawling	25.4%
Stationary	0.6%
Reversal	13.3%
Omega Turns	28.5%
Shallow Turns	20.6%
Irregular / Abnormal	0.0%

6.23.2 Kinematic & Velocity Dynamics

Table 93: Kinematic and Velocity Metrics for AVAR-AVBL_both

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.0387	mm
Gross Distance	0.1416	mm
Path Efficiency (Net/Gross)	0.2734	[0.0 – 1.0]
Mean Speed	0.1421	mm/s
Maximum Forward Velocity	0.7519	mm/s
Maximum Backward Velocity	0.8256	mm/s
Median Velocity	0.0789	mm/s
Velocity Std Deviation	0.1913	mm/s
Velocity RMS	0.2383	mm/s
Fraction Time Moving Forward	45.8%	ratio
Fraction Time Moving Backward	53.0%	ratio
Fraction Time Stationary	0.6%	ratio
Acceleration (Mean)	-0.4885	mm/s ²
Maximum Acceleration	168.7795	mm/s ²
Acceleration RMS	24.3684	mm/s ²
Velocity Autocorrelation	0.7825	correlation
Reversal Frequency	22.0884	s ⁻¹
Mean Curvature	10811.9682	rad/mm
Omega Turn Count	47	count

6.23.3 Undulation Wave Mechanics

Table 94: Undulation Wave Parameters for AVAR-AVBL_both

Undulation Parameter	Value	Unit
Crawl Amplitude	0.0067	rad (bending)
Dominant Frequency	0.0	Hz
Wavelength	0.82	mm
Wave Velocity	0.0	mm/s
Phase Coherence	0.78	[0.0 – 1.0]
Mean Muscle Activation	0.790241	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.23.4 Worm Motion and Activity Figures

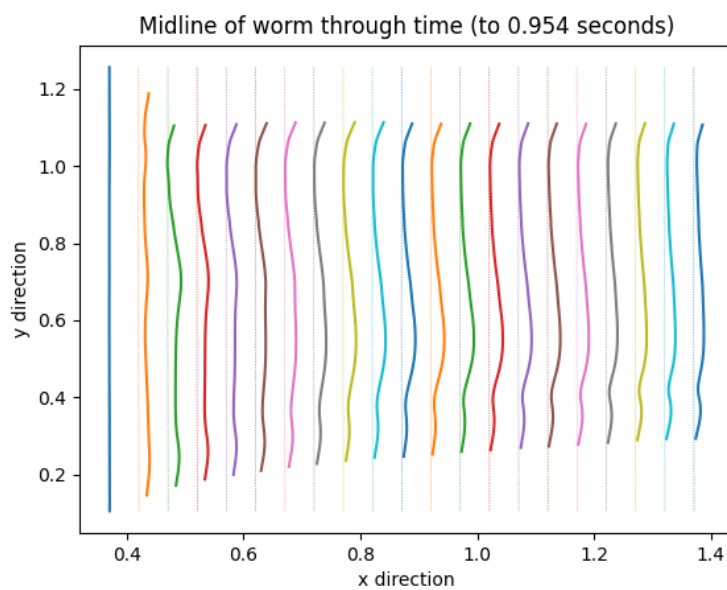


Figure 223: Midline of worm through time.

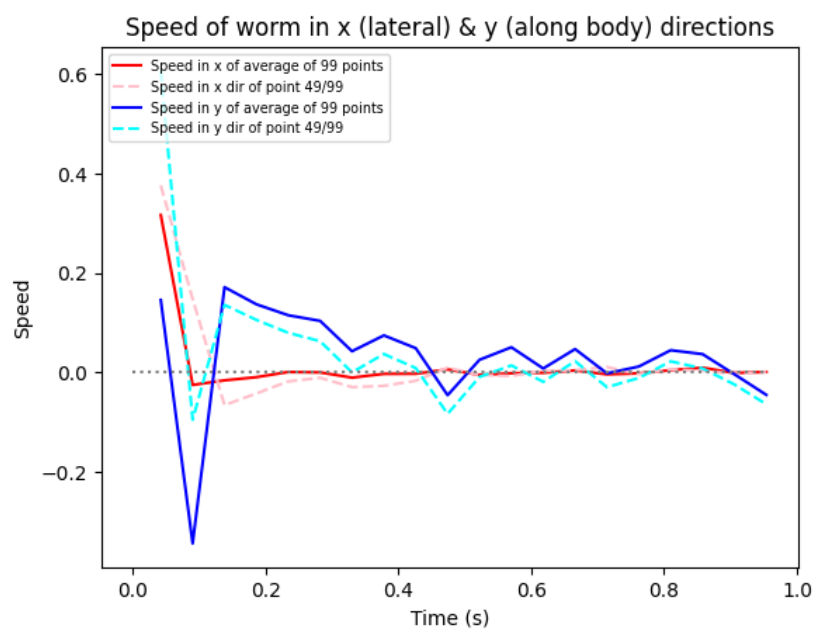


Figure 224: Speed of worm along body directions.

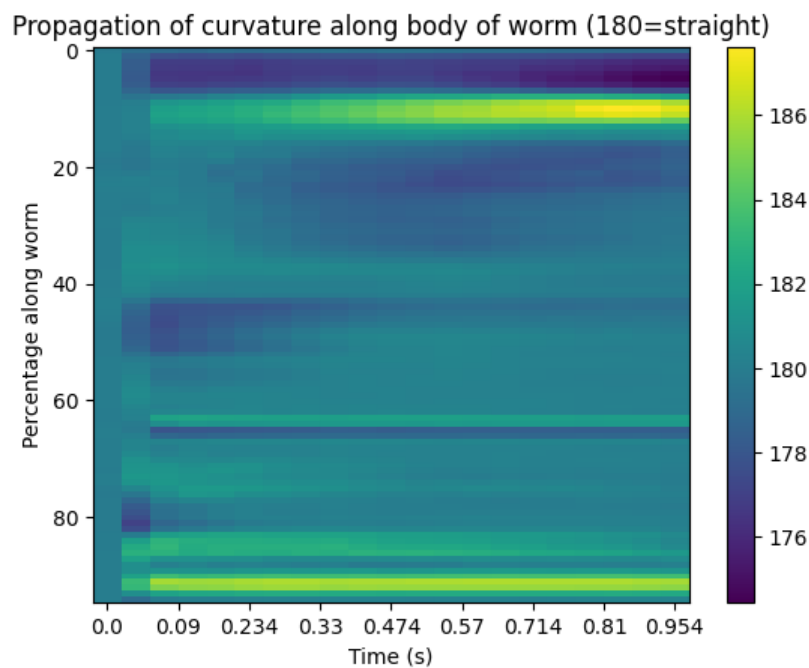


Figure 225: Propagation of curvature along body of worm.

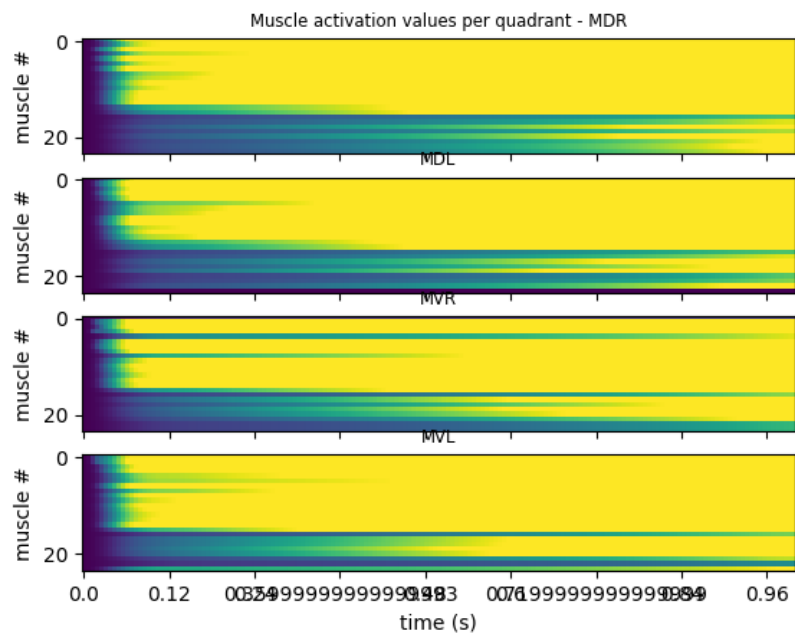


Figure 226: Muscle activities per quadrant.

6.23.5 Trace Figures

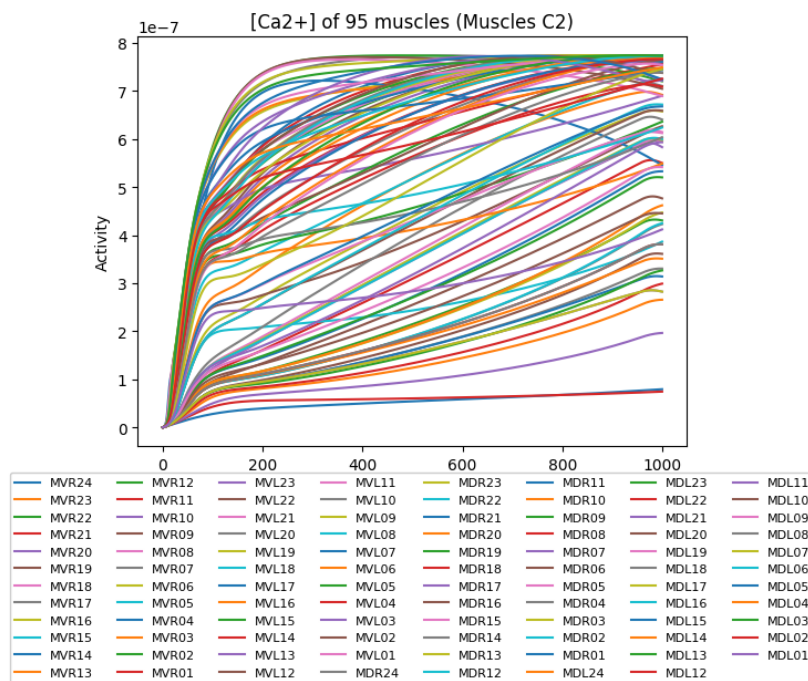
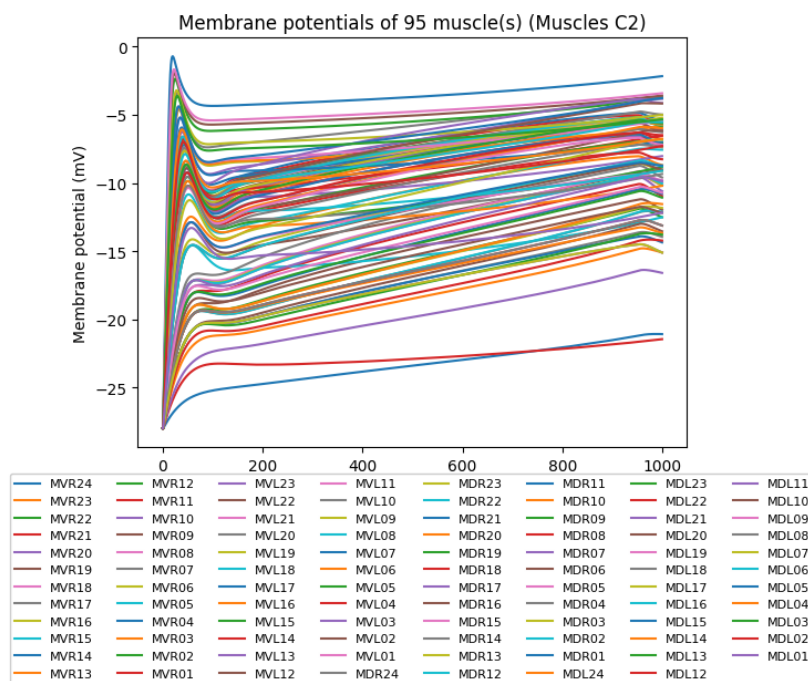


Figure 227: Traces of muscle activity and potentials.



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Figure 228: Traces of muscle activity.

6.23.6 Compact Morphology Grid

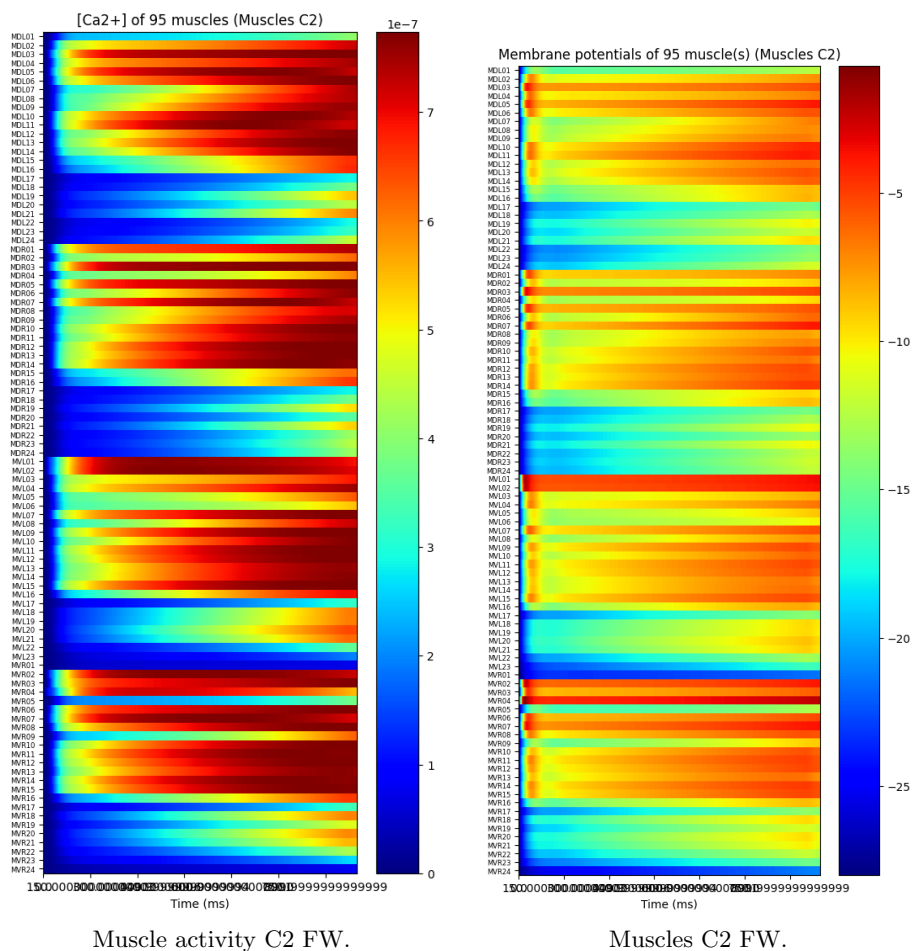


Figure 231: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).

6.23.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.6 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 95: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	2.2 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[=-----]	0.7 / 10
Overall Severity	[=====]	4.6 / 10

6.24 Movement Analysis: AVAL-AVDL_both

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run C2_Muscles_2026-08-19_17-32-25-AVAL-AVDL_both.

6.24.1 Locomotion State Classification

Table 96: Behavioral State Breakdown for AVAL-AVDL_both

Locomotion State	Time Fraction (%)
Forward Crawling	10.3%
Backward Crawling	31.5%
Stationary	0.0%
Reversal	11.5%
Omega Turns	26.7%
Shallow Turns	20.0%
Irregular / Abnormal	0.0%

6.24.2 Kinematic & Velocity Dynamics

Table 97: Kinematic and Velocity Metrics for AVAL-AVDL_both

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.0386	mm
Gross Distance	0.1446	mm
Path Efficiency (Net/Gross)	0.2671	[0.0 – 1.0]
Mean Speed	0.1452	mm/s
Maximum Forward Velocity	0.8641	mm/s
Maximum Backward Velocity	0.7662	mm/s
Median Velocity	0.0851	mm/s
Velocity Std Deviation	0.1996	mm/s
Velocity RMS	0.2468	mm/s
Fraction Time Moving Forward	43.4%	ratio
Fraction Time Moving Backward	56.6%	ratio
Fraction Time Stationary	0.0%	ratio
Acceleration (Mean)	-0.4186	mm/s ²
Maximum Acceleration	168.7895	mm/s ²
Acceleration RMS	23.329	mm/s ²
Velocity Autocorrelation	0.803	correlation
Reversal Frequency	19.0763	s ⁻¹
Mean Curvature	3807.855	rad/mm
Omega Turn Count	44	count

6.24.3 Undulation Wave Mechanics

Table 98: Undulation Wave Parameters for AVAL-AVDL_both

Undulation Parameter	Value	Unit
Crawl Amplitude	0.007	rad (bending)
Dominant Frequency	0.0	Hz
Wavelength	0.82	mm
Wave Velocity	0.0	mm/s
Phase Coherence	0.78	[0.0 – 1.0]
Mean Muscle Activation	0.789878	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.24.4 Worm Motion and Activity Figures

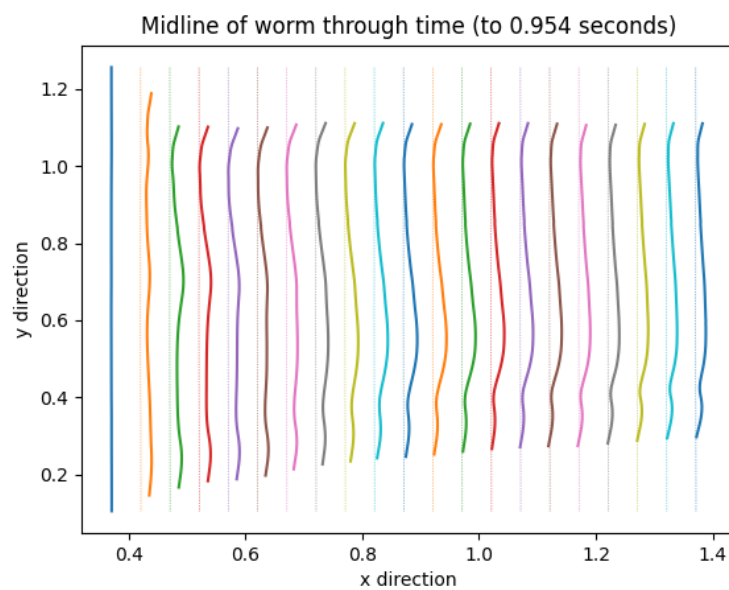


Figure 233: Midline of worm through time.

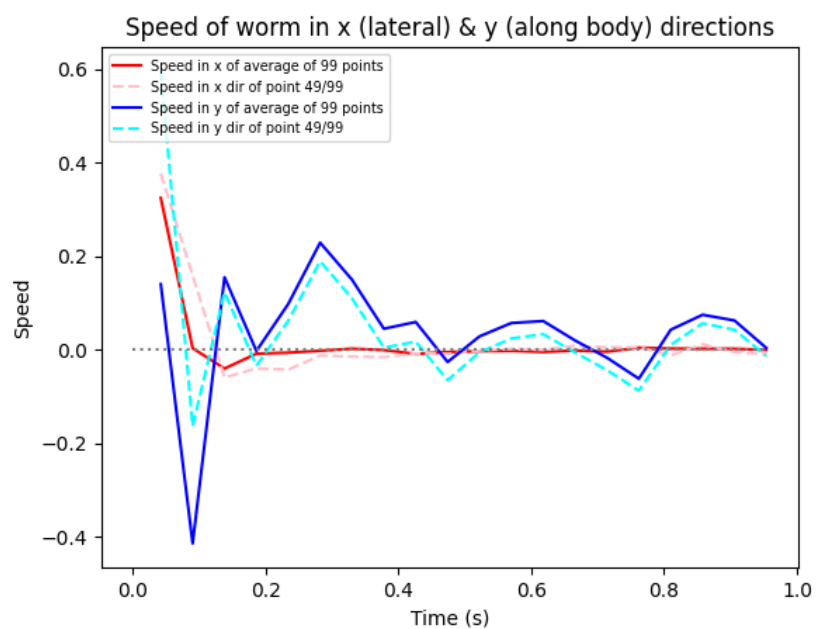


Figure 234: Speed of worm along body directions.

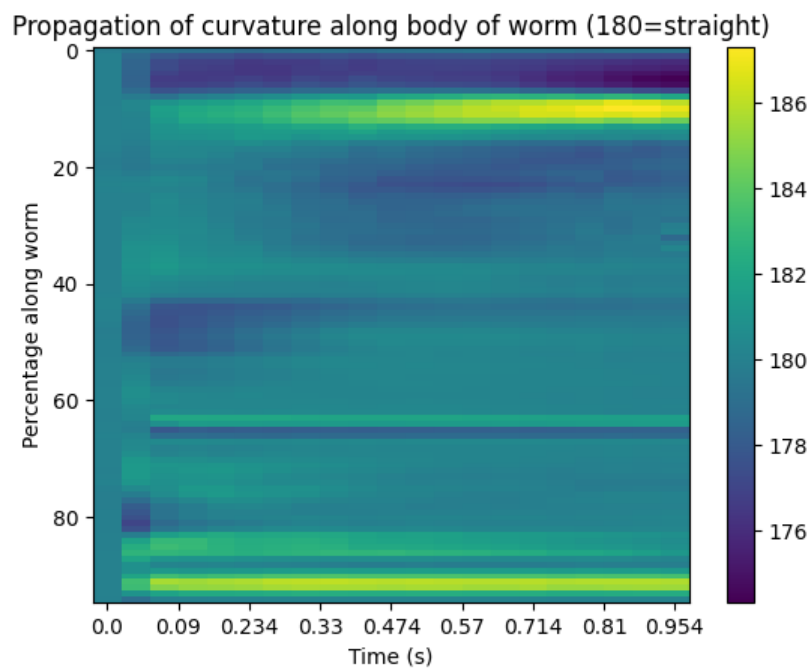


Figure 235: Propagation of curvature along body of worm.

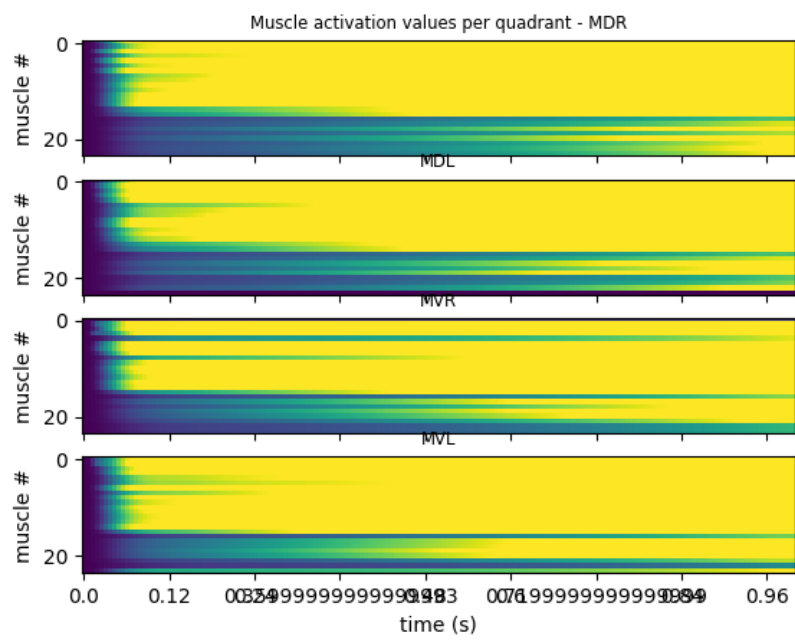


Figure 236: Muscle activities per quadrant.

6.24.5 Trace Figures

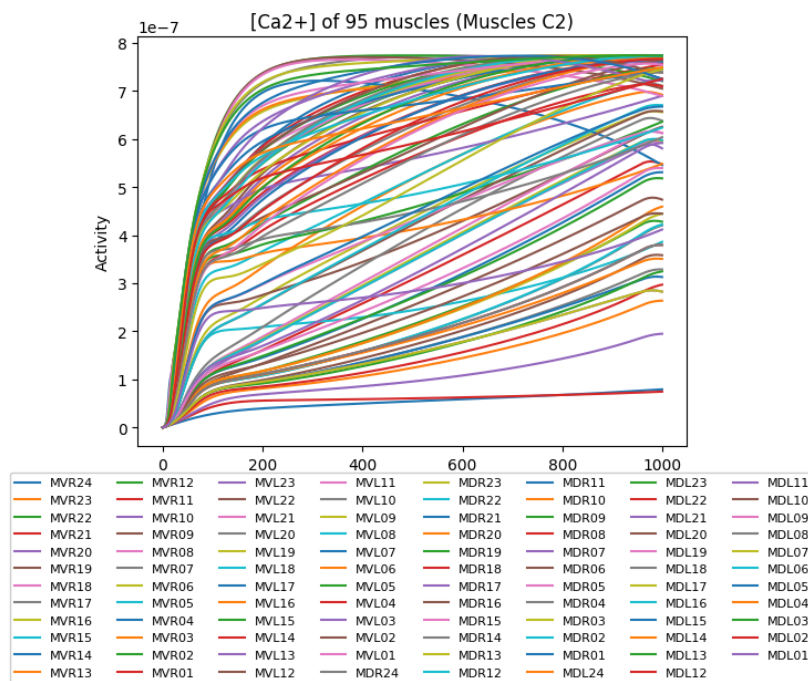
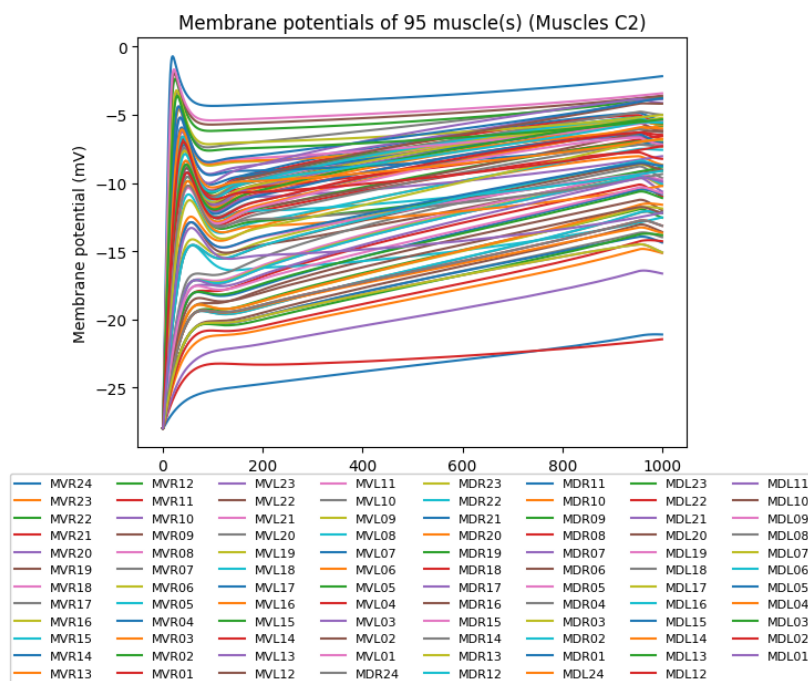


Figure 237: Traces of muscle activity and potentials.



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Figure 238: Traces of muscle activity.

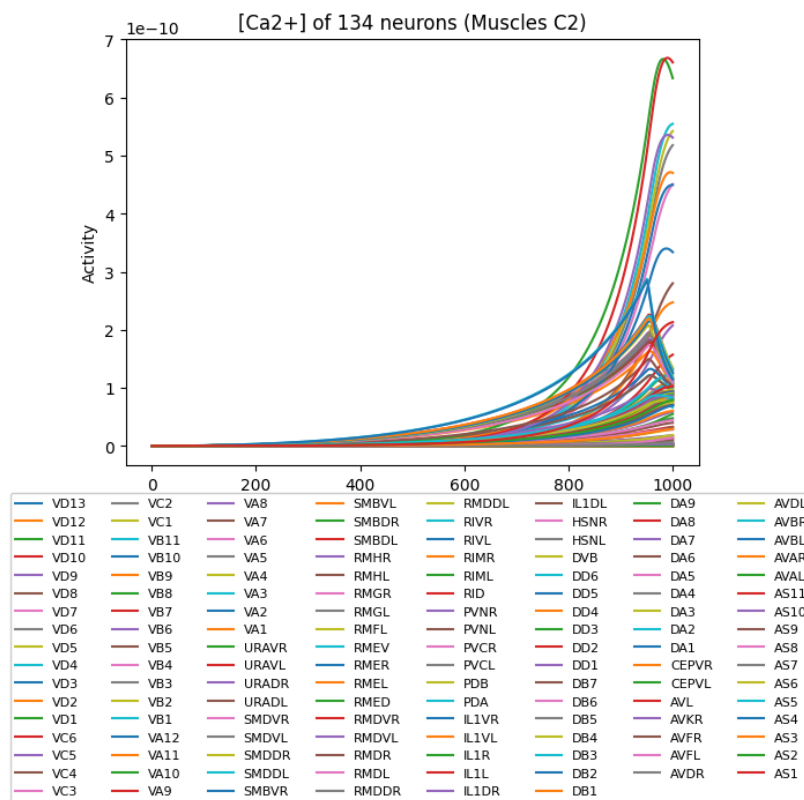
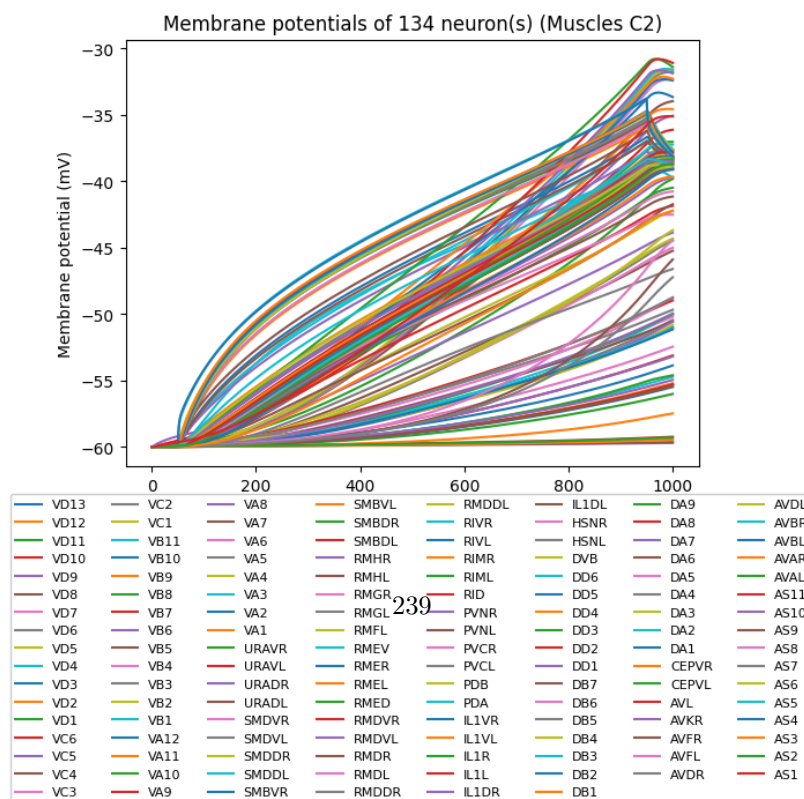


Figure 239: Traces of neuron activity and potentials.



6.24.6 Compact Morphology Grid

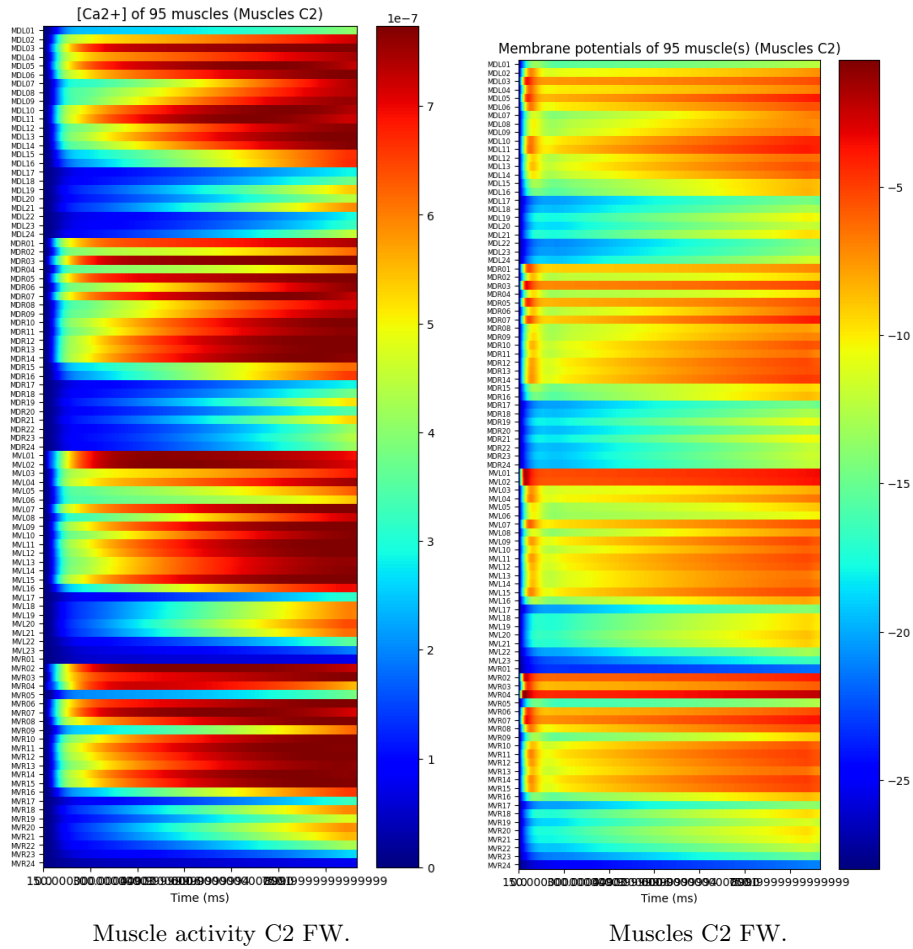
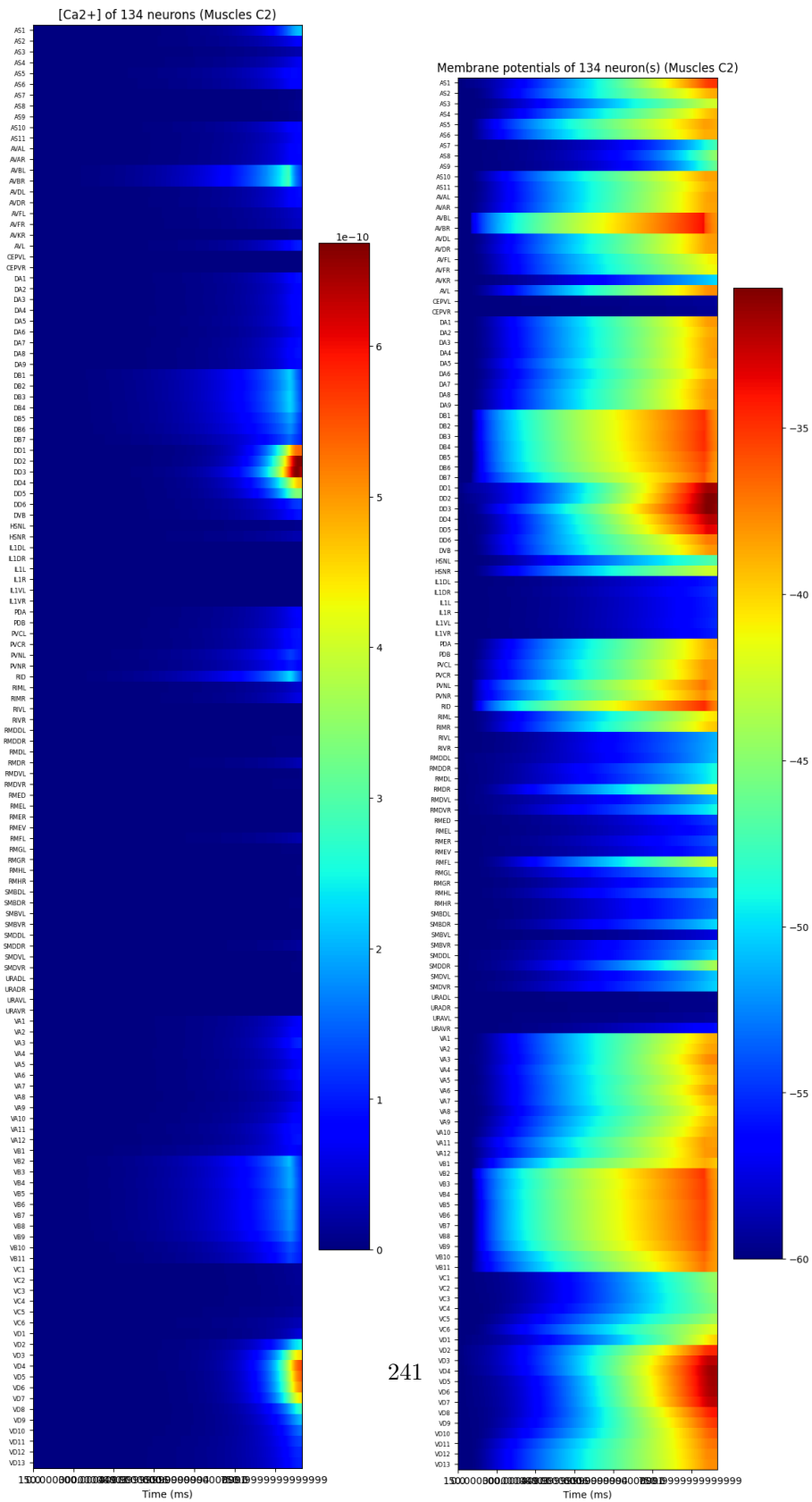


Figure 241: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).



Neuron activity C2 FW.

Neurons C2 FW.

Figure 242: Neuron activity and morphology, shown as a 2x1 grid for compact

6.24.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.7 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 99: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	2.2 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[=-----]	1.3 / 10
Overall Severity	[=====]	4.7 / 10

6.25 Movement Analysis: AVAR-AVDR_both

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run C2_Muscles_2026-08-19_19-12-00-AVAR-AVDR_both.

6.25.1 Locomotion State Classification

Table 100: Behavioral State Breakdown for AVAR-AVDR_both

Locomotion State	Time Fraction (%)
Forward Crawling	10.3%
Backward Crawling	28.5%
Stationary	0.0%
Reversal	13.3%
Omega Turns	31.5%
Shallow Turns	16.4%
Irregular / Abnormal	0.0%

6.25.2 Kinematic & Velocity Dynamics

Table 101: Kinematic and Velocity Metrics for AVAR-AVDR_both

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.0413	mm
Gross Distance	0.1363	mm
Path Efficiency (Net/Gross)	0.3029	[0.0 – 1.0]
Mean Speed	0.1369	mm/s
Maximum Forward Velocity	0.7071	mm/s
Maximum Backward Velocity	0.7374	mm/s
Median Velocity	0.0765	mm/s
Velocity Std Deviation	0.1898	mm/s
Velocity RMS	0.234	mm/s
Fraction Time Moving Forward	42.2%	ratio
Fraction Time Moving Backward	57.2%	ratio
Fraction Time Stationary	0.0%	ratio
Acceleration (Mean)	-0.3798	mm/s ²
Maximum Acceleration	168.7867	mm/s ²
Acceleration RMS	23.3327	mm/s ²
Velocity Autocorrelation	0.8188	correlation
Reversal Frequency	22.0884	s ⁻¹
Mean Curvature	5006.643	rad/mm
Omega Turn Count	52	count

6.25.3 Undulation Wave Mechanics

Table 102: Undulation Wave Parameters for AVAR-AVDR_both

Undulation Parameter	Value	Unit
Crawl Amplitude	0.007	rad (bending)
Dominant Frequency	0.0	Hz
Wavelength	0.82	mm
Wave Velocity	0.0	mm/s
Phase Coherence	0.78	[0.0 – 1.0]
Mean Muscle Activation	0.789847	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.25.4 Worm Motion and Activity Figures

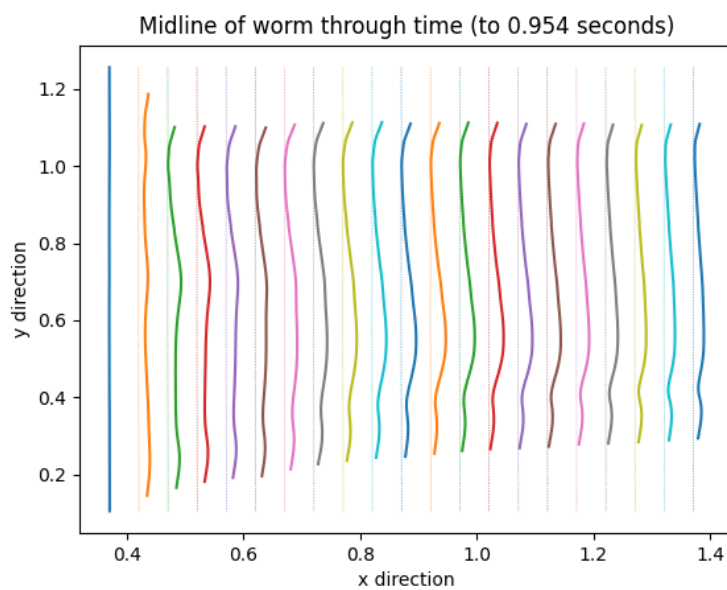


Figure 243: Midline of worm through time.

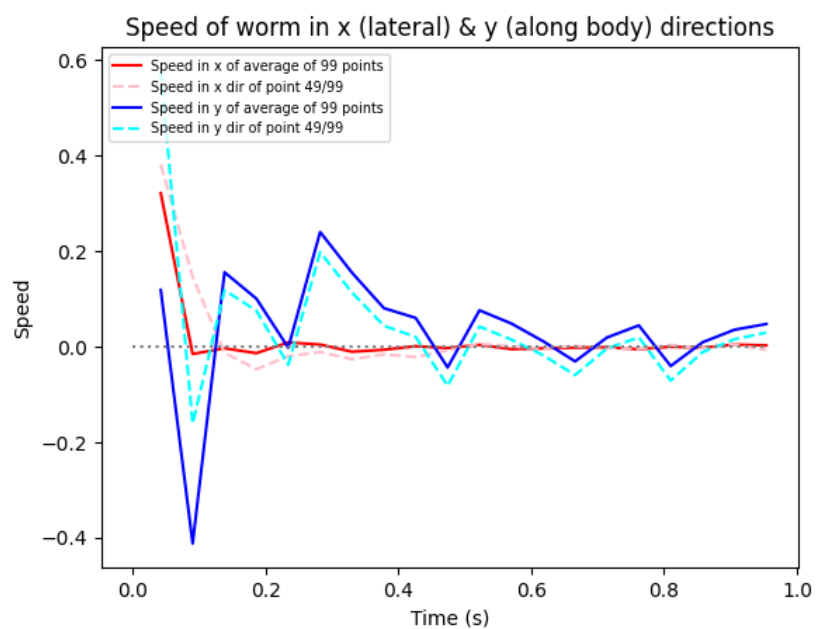


Figure 244: Speed of worm along body directions.

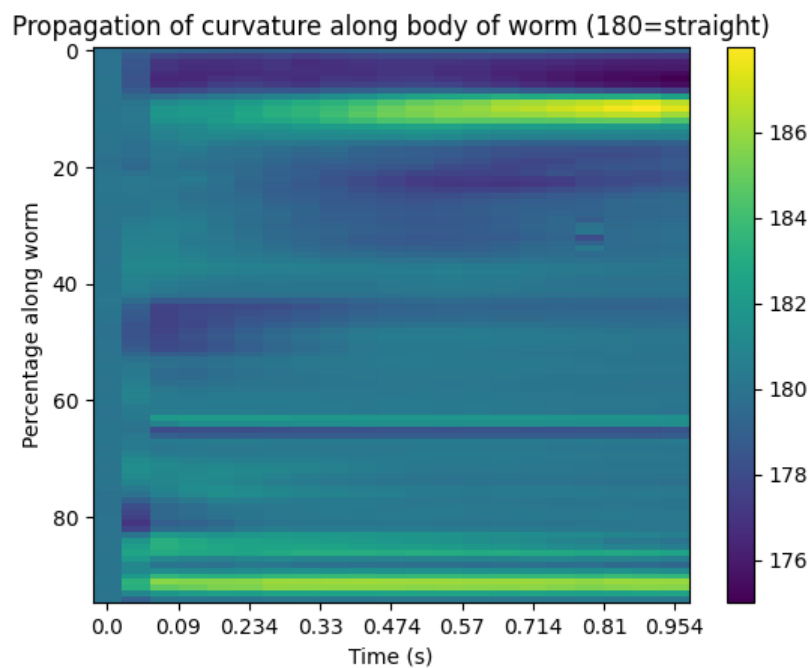


Figure 245: Propagation of curvature along body of worm.

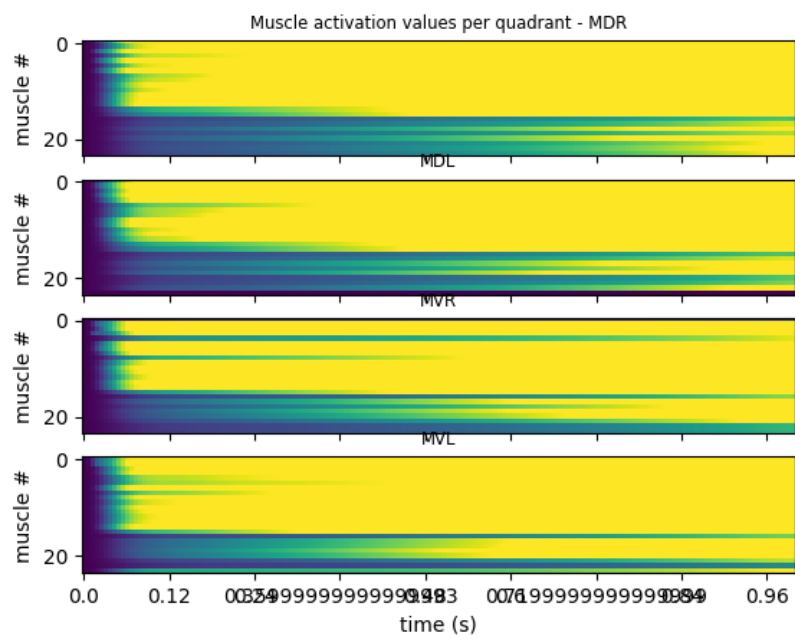


Figure 246: Muscle activities per quadrant.

6.25.5 Trace Figures

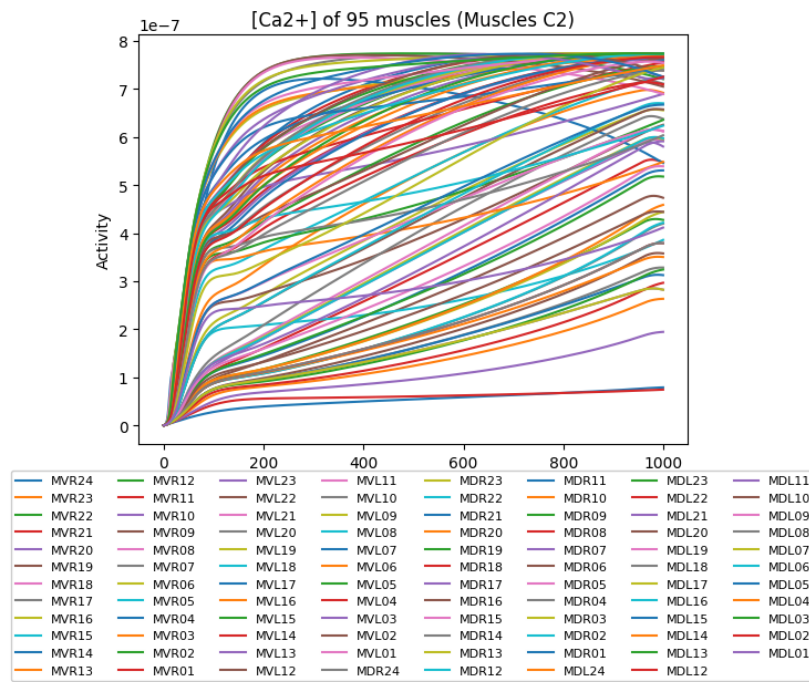
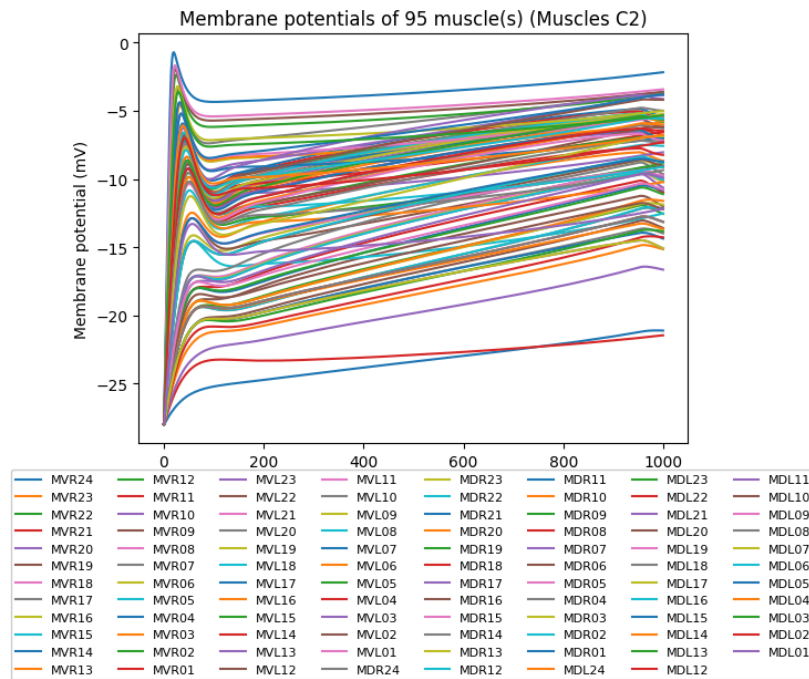


Figure 247: Traces of muscle activity and potentials.



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Figure 248: Traces of muscle activity.

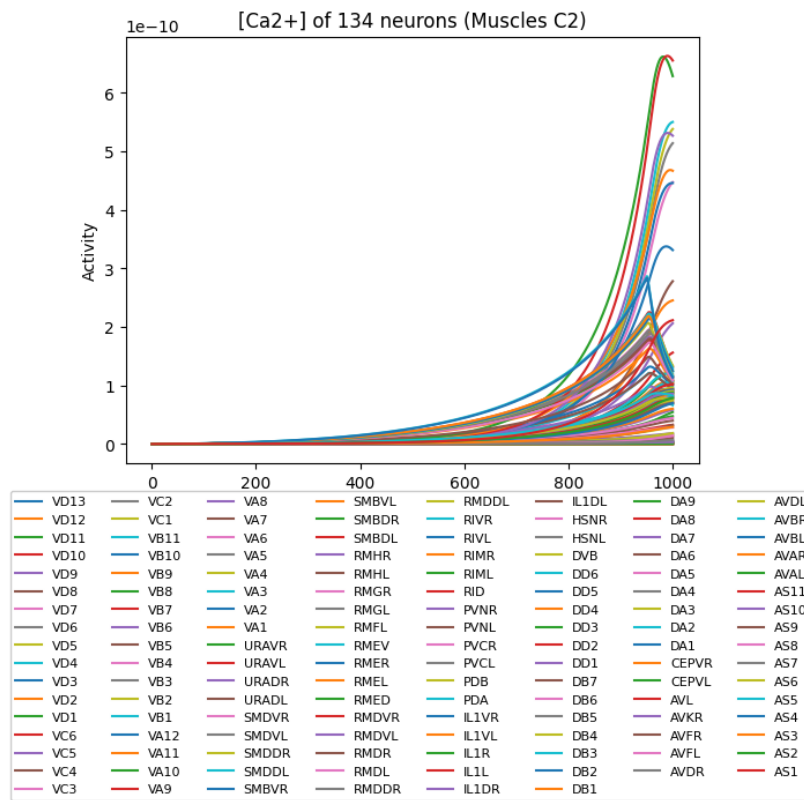
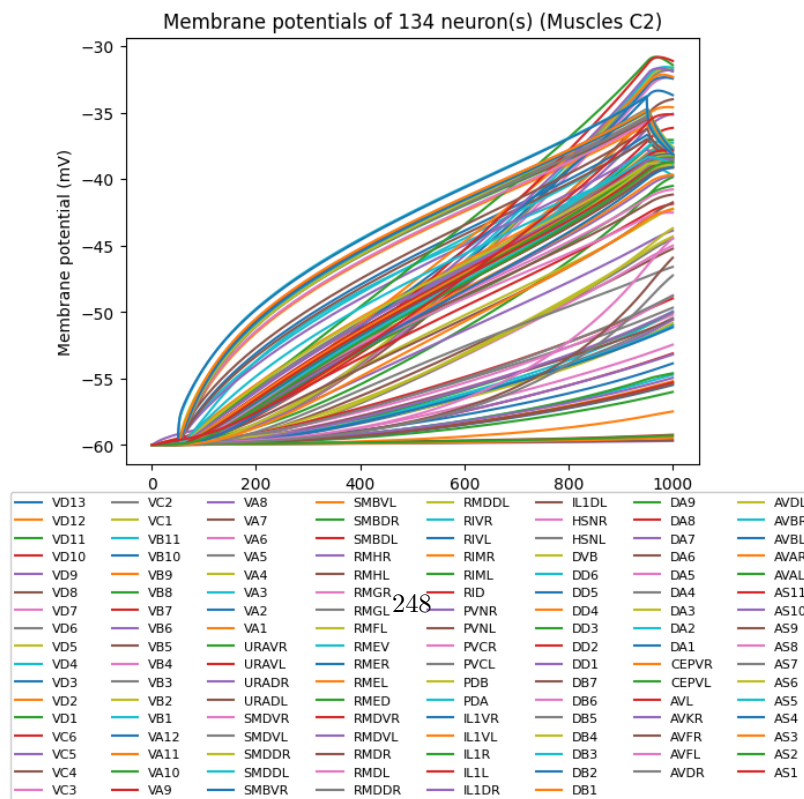


Figure 249: Traces of neuron activity and potentials.



6.25.6 Compact Morphology Grid

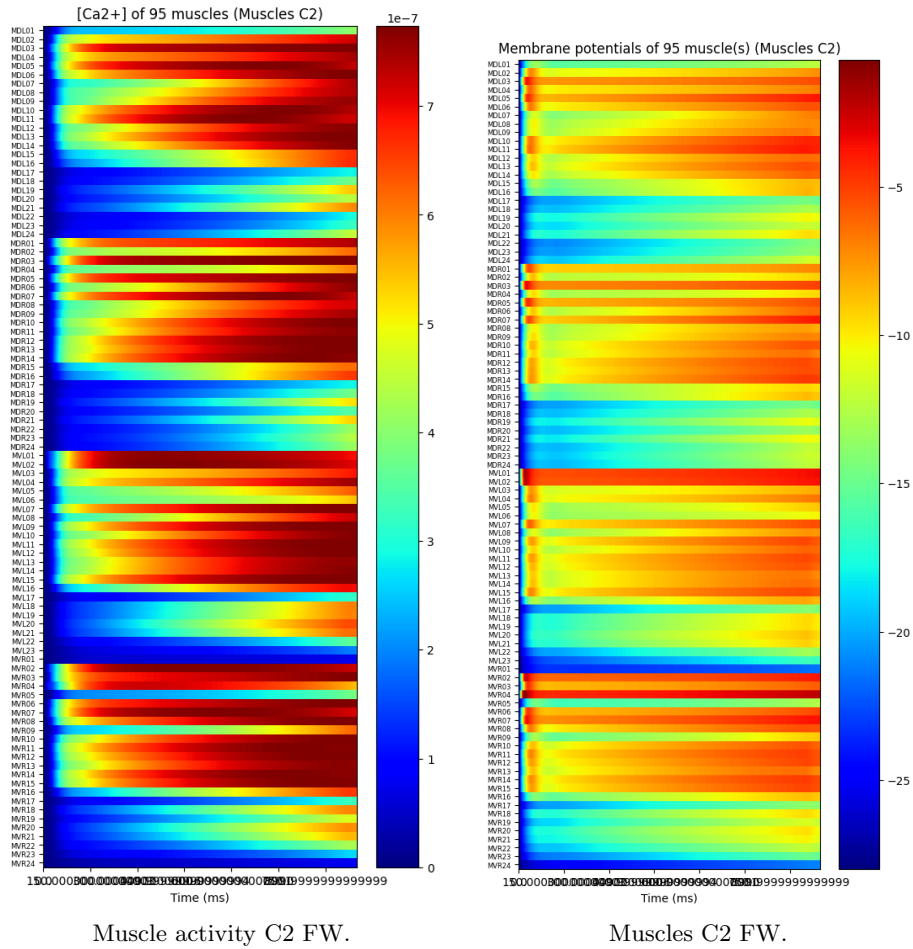


Figure 251: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).

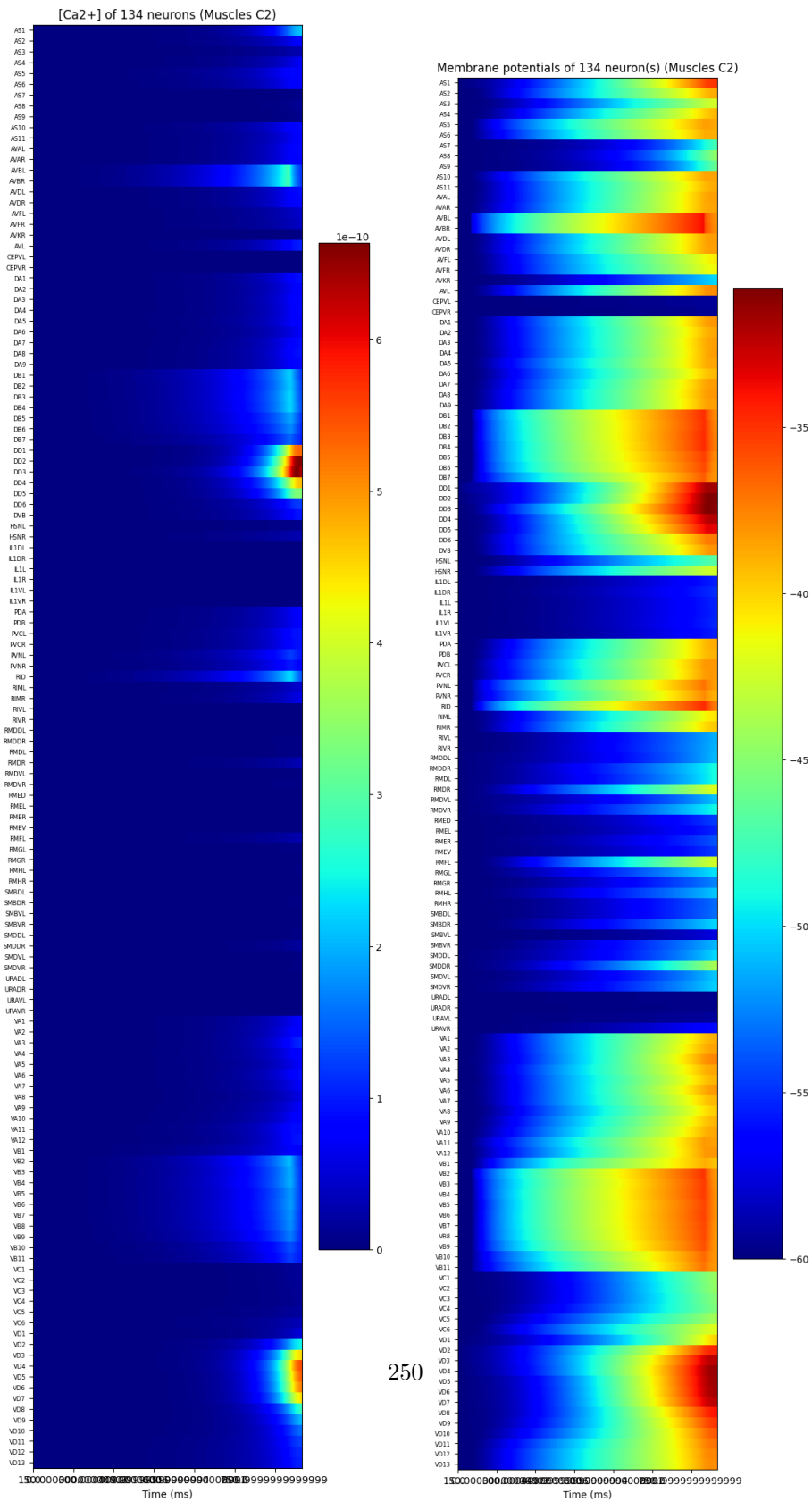


Figure 252: Neuron activity and morphology, shown as a 2x1 grid for compact

6.25.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.7 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 103: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	2.2 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[=-----]	1.5 / 10
Overall Severity	[=====]	4.7 / 10

6.26 Movement Analysis: AVAL-AS10_both

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run C2_Muscles_2026-08-20_09-32-42-AVAL-AS10_both.

6.26.1 Locomotion State Classification

Table 104: Behavioral State Breakdown for AVAL-AS10_both

Locomotion State	Time Fraction (%)
Forward Crawling	15.2%
Backward Crawling	30.3%
Stationary	0.0%
Reversal	9.7%
Omega Turns	26.1%
Shallow Turns	18.8%
Irregular / Abnormal	0.0%

6.26.2 Kinematic & Velocity Dynamics

Table 105: Kinematic and Velocity Metrics for AVAL-AS10_both

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.034	mm
Gross Distance	0.1482	mm
Path Efficiency (Net/Gross)	0.2294	[0.0 – 1.0]
Mean Speed	0.1488	mm/s
Maximum Forward Velocity	0.7495	mm/s
Maximum Backward Velocity	0.767	mm/s
Median Velocity	0.0982	mm/s
Velocity Std Deviation	0.1872	mm/s
Velocity RMS	0.2391	mm/s
Fraction Time Moving Forward	47.6%	ratio
Fraction Time Moving Backward	52.4%	ratio
Fraction Time Stationary	0.0%	ratio
Acceleration (Mean)	-0.4536	mm/s ²
Maximum Acceleration	168.6328	mm/s ²
Acceleration RMS	22.2858	mm/s ²
Velocity Autocorrelation	0.8181	correlation
Reversal Frequency	16.0643	s ⁻¹
Mean Curvature	3817.7009	rad/mm
Omega Turn Count	43	count

6.26.3 Undulation Wave Mechanics

Table 106: Undulation Wave Parameters for AVAL-AS10_both

Undulation Parameter	Value	Unit
Crawl Amplitude	0.0071	rad (bending)
Dominant Frequency	1.0	Hz
Wavelength	1.66	mm
Wave Velocity	1.67	mm/s
Phase Coherence	0.8	[0.0 – 1.0]
Mean Muscle Activation	0.789884	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.26.4 Worm Motion and Activity Figures

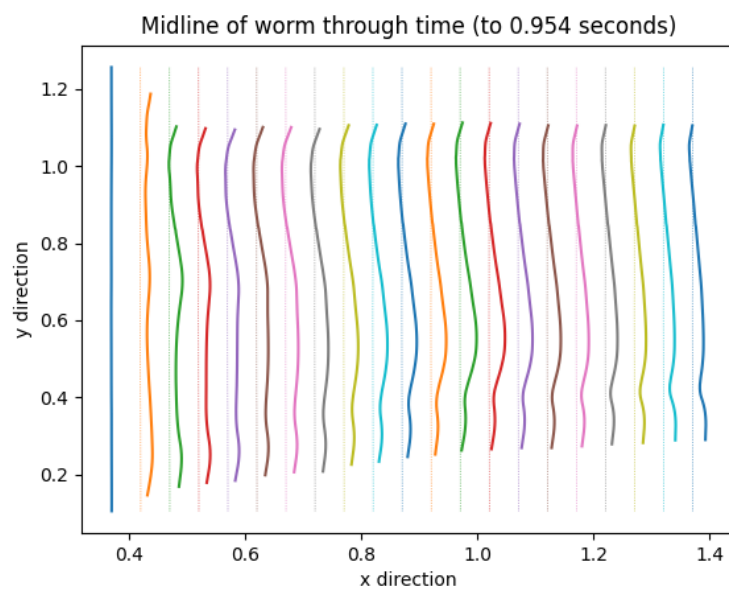


Figure 253: Midline of worm through time.

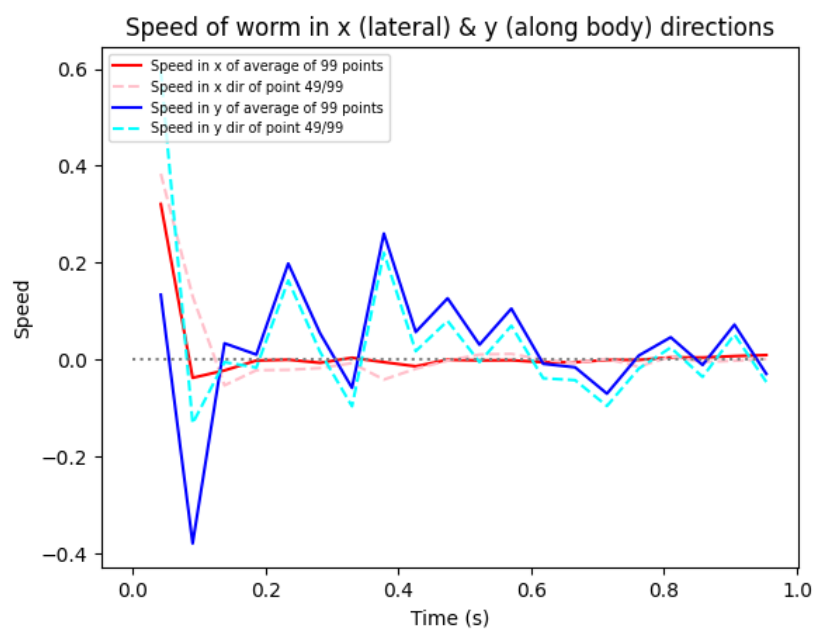


Figure 254: Speed of worm along body directions.

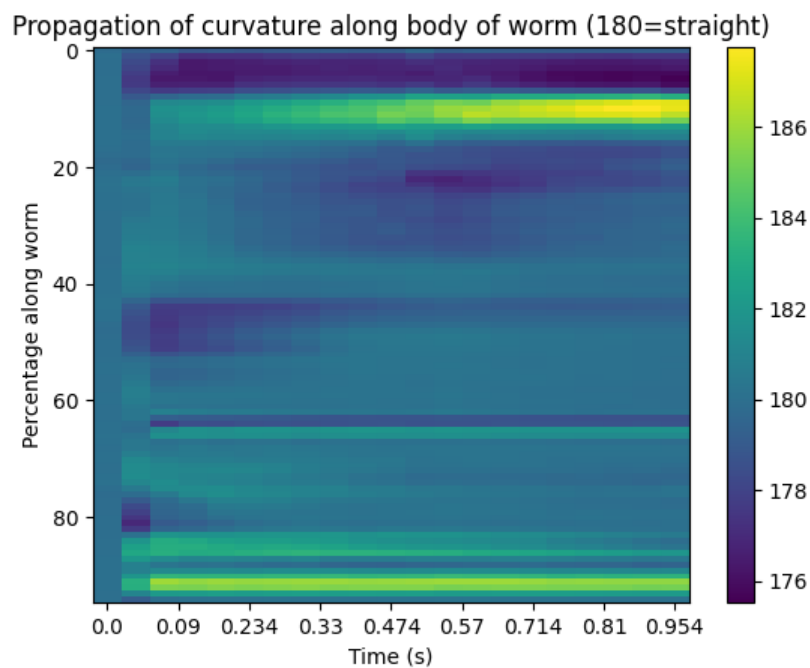


Figure 255: Propagation of curvature along body of worm.

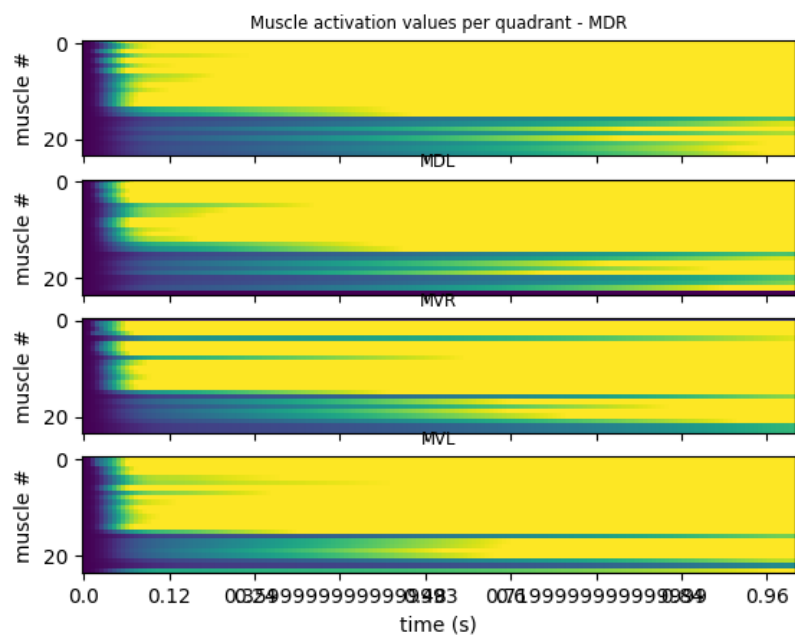


Figure 256: Muscle activities per quadrant.

6.26.5 Trace Figures

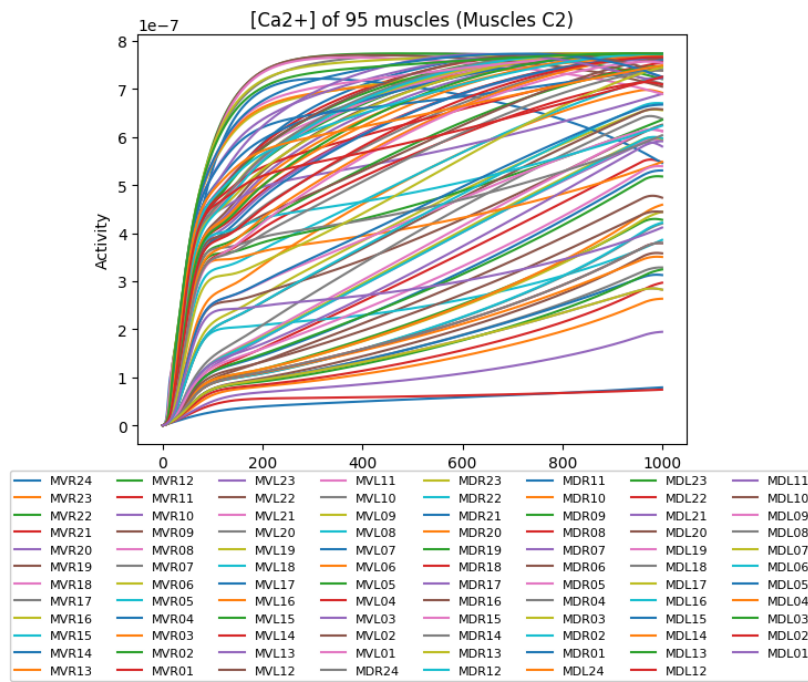
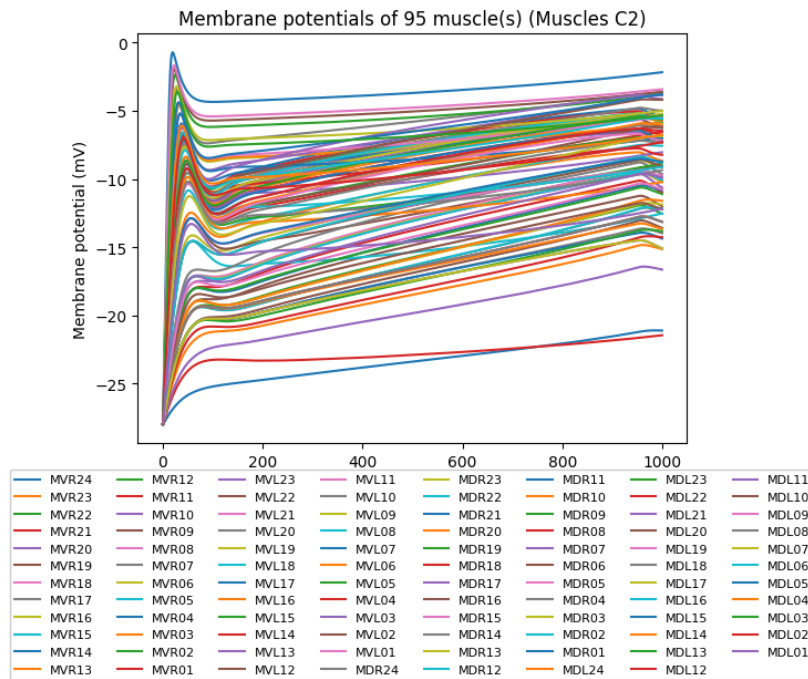


Figure 257: Traces of muscle activity and potentials.



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Figure 258: Traces of muscle activity.

6.26.6 Compact Morphology Grid

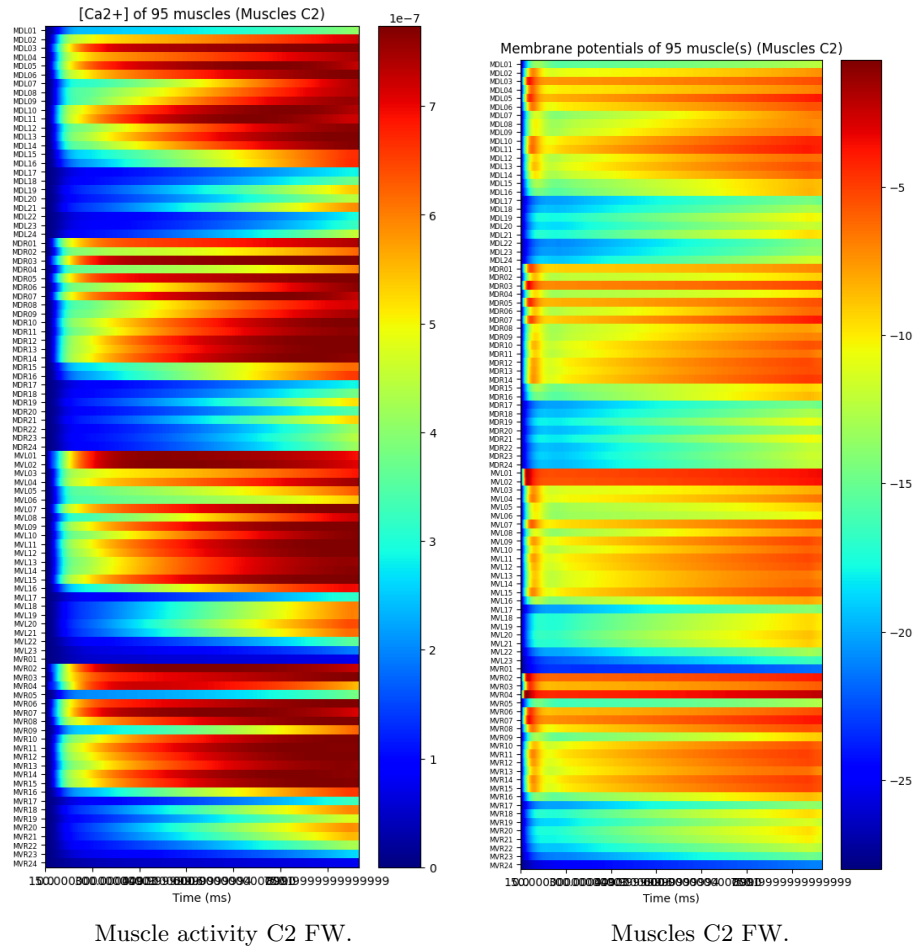


Figure 261: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).

6.26.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.5 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 107: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	2.0 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[-----]	0.5 / 10
Overall Severity	[====-----]	4.5 / 10

6.27 Movement Analysis: AVAR-AS11_both

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run C2_Muscles_2026-08-20_11-19-41-AVAR-AS11_both.

6.27.1 Locomotion State Classification

Table 108: Behavioral State Breakdown for AVAR-AS11_both

Locomotion State	Time Fraction (%)
Forward Crawling	10.3%
Backward Crawling	28.5%
Stationary	0.0%
Reversal	12.1%
Omega Turns	28.5%
Shallow Turns	20.6%
Irregular / Abnormal	0.0%

6.27.2 Kinematic & Velocity Dynamics

Table 109: Kinematic and Velocity Metrics for AVAR-AS11_both

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.0392	mm
Gross Distance	0.1239	mm
Path Efficiency (Net/Gross)	0.3162	[0.0 – 1.0]
Mean Speed	0.1244	mm/s
Maximum Forward Velocity	0.7592	mm/s
Maximum Backward Velocity	0.6951	mm/s
Median Velocity	0.0627	mm/s
Velocity Std Deviation	0.1899	mm/s
Velocity RMS	0.2271	mm/s
Fraction Time Moving Forward	43.4%	ratio
Fraction Time Moving Backward	56.6%	ratio
Fraction Time Stationary	0.0%	ratio
Acceleration (Mean)	-0.4731	mm/s ²
Maximum Acceleration	168.7868	mm/s ²
Acceleration RMS	22.6306	mm/s ²
Velocity Autocorrelation	0.7977	correlation
Reversal Frequency	20.0803	s ⁻¹
Mean Curvature	5350.5948	rad/mm
Omega Turn Count	47	count

6.27.3 Undulation Wave Mechanics

Table 110: Undulation Wave Parameters for AVAR-AS11_both

Undulation Parameter	Value	Unit
Crawl Amplitude	0.0068	rad (bending)
Dominant Frequency	0.0	Hz
Wavelength	0.82	mm
Wave Velocity	0.0	mm/s
Phase Coherence	0.79	[0.0 – 1.0]
Mean Muscle Activation	0.789792	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.27.4 Worm Motion and Activity Figures

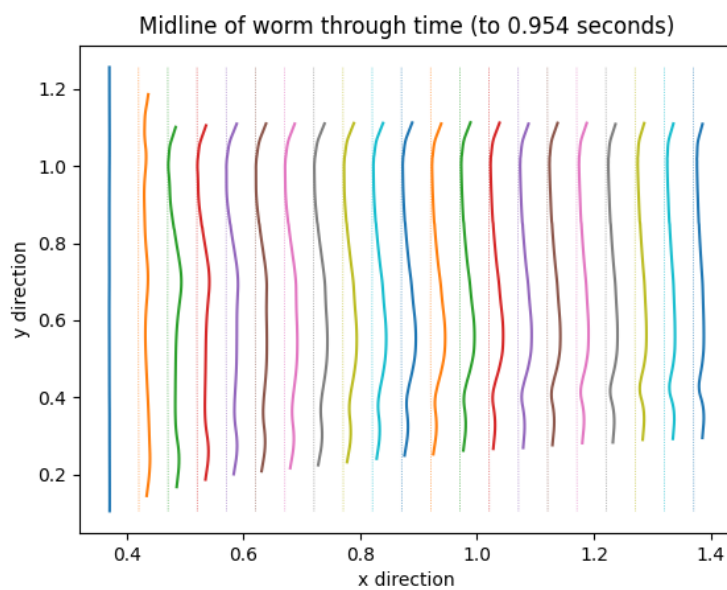


Figure 263: Midline of worm through time.

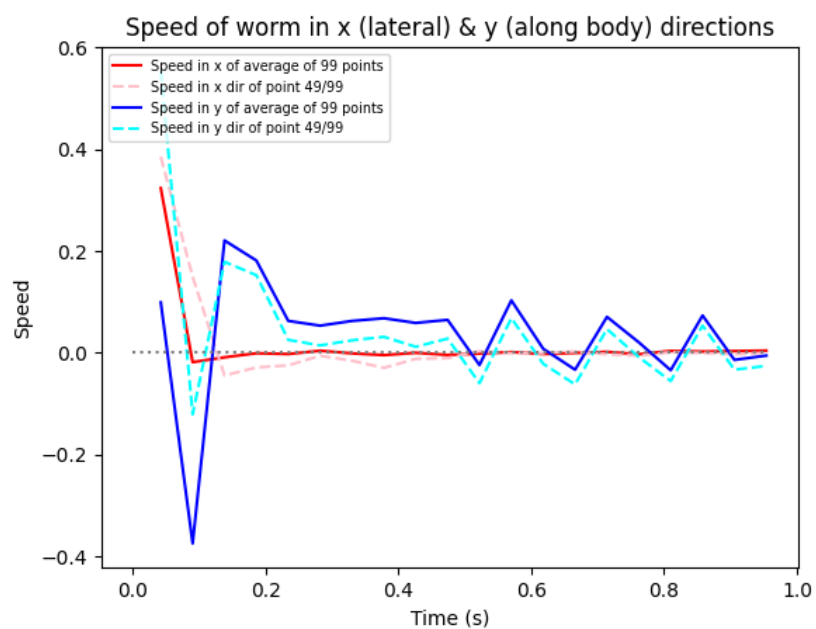


Figure 264: Speed of worm along body directions.

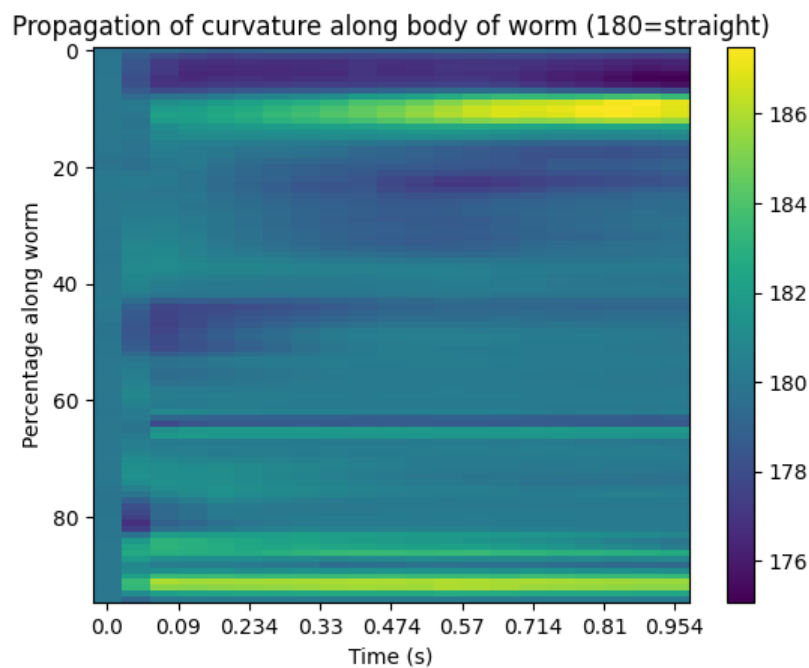


Figure 265: Propagation of curvature along body of worm.

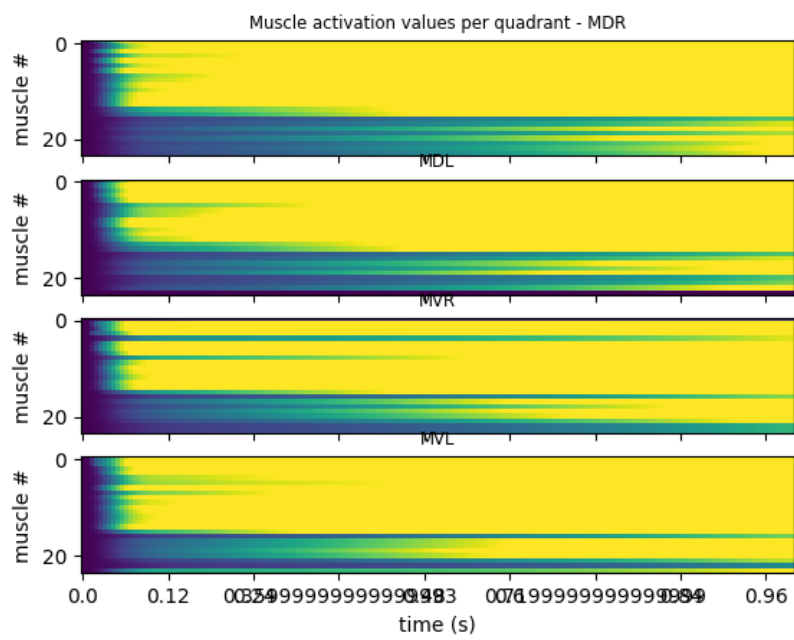


Figure 266: Muscle activities per quadrant.

6.27.5 Trace Figures

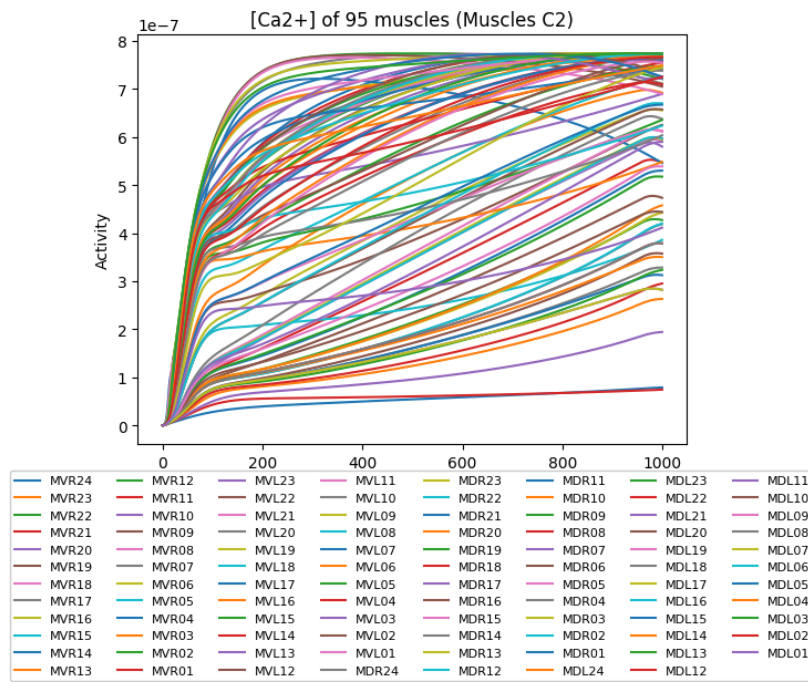
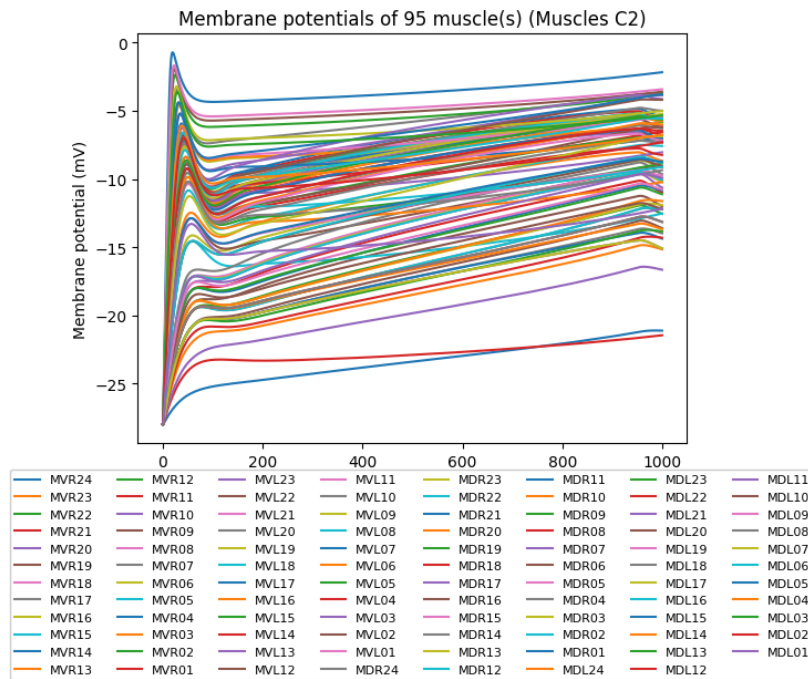


Figure 267: Traces of muscle activity and potentials.



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Figure 268: Traces of muscle activity.

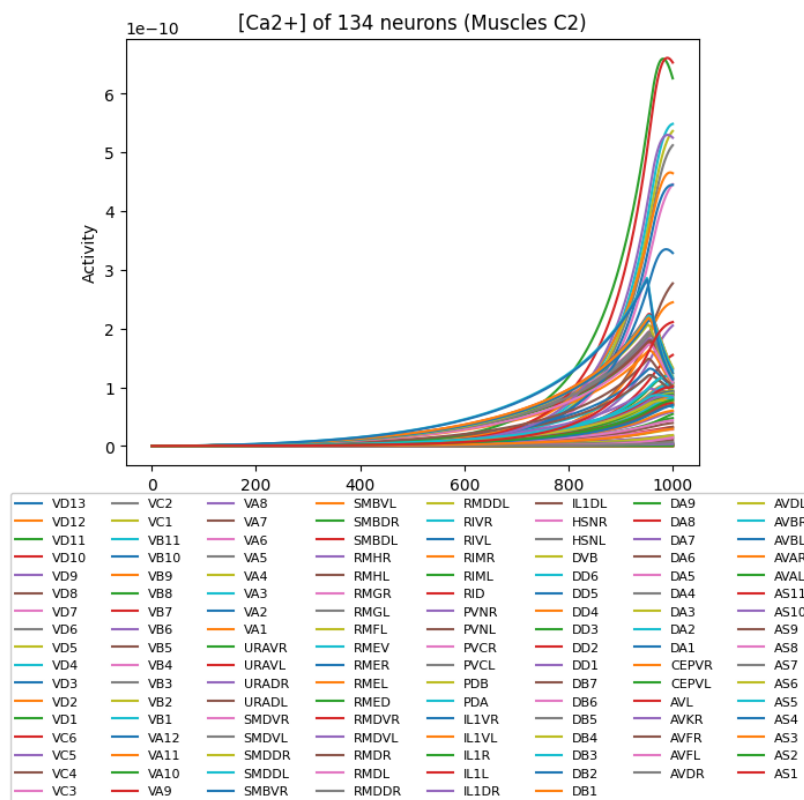
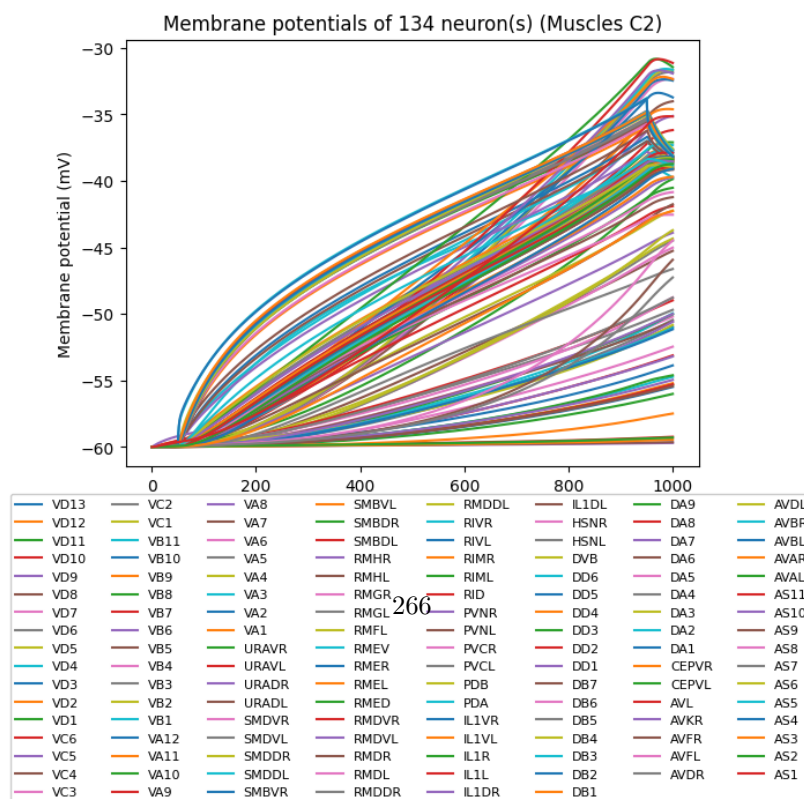


Figure 269: Traces of neuron activity and potentials.



6.27.6 Compact Morphology Grid

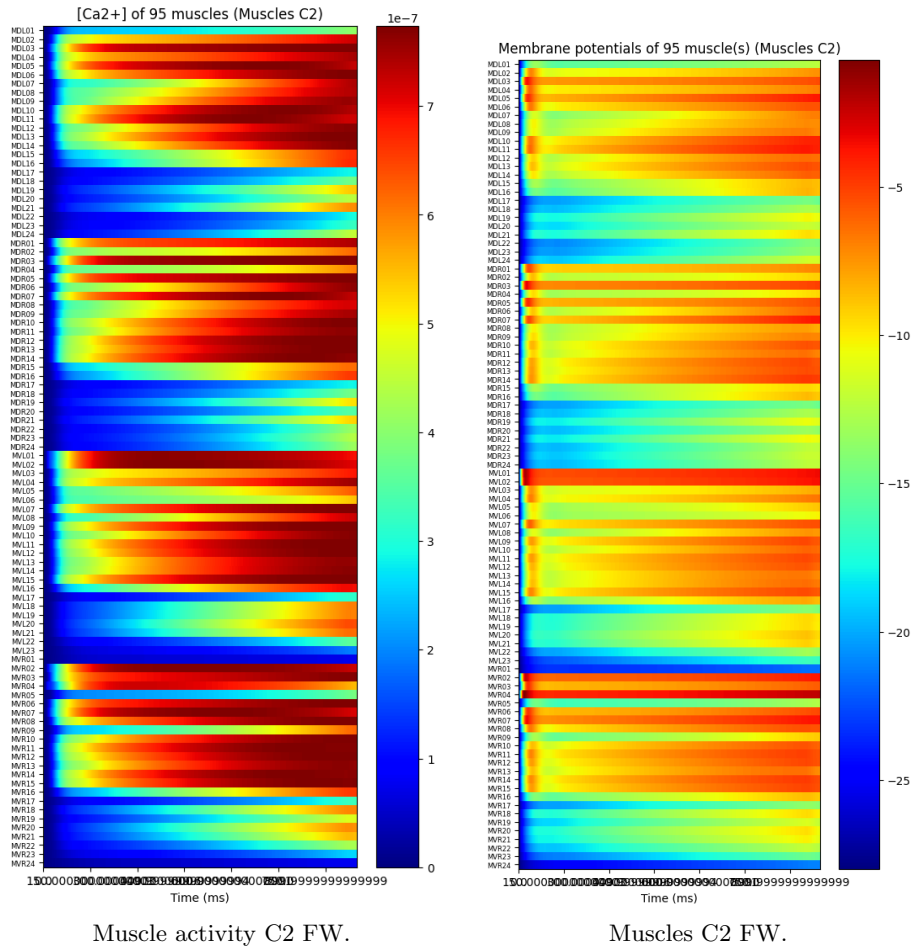


Figure 271: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).

6.27.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.7 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 111: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	2.1 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[=-----]	1.3 / 10
Overall Severity	[=====]	4.7 / 10

6.28 Movement Analysis: AVA-AS_selected

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run C2_Muscles_2026-08-20_16-49-07-AVA-AS_selected.

6.28.1 Locomotion State Classification

Table 112: Behavioral State Breakdown for AVA-AS_selected

Locomotion State	Time Fraction (%)
Forward Crawling	7.9%
Backward Crawling	32.7%
Stationary	0.0%
Reversal	11.5%
Omega Turns	29.7%
Shallow Turns	18.2%
Irregular / Abnormal	0.0%

6.28.2 Kinematic & Velocity Dynamics

Table 113: Kinematic and Velocity Metrics for AVA-AS_selected

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.0433	mm
Gross Distance	0.136	mm
Path Efficiency (Net/Gross)	0.3182	[0.0 – 1.0]
Mean Speed	0.1366	mm/s
Maximum Forward Velocity	0.6039	mm/s
Maximum Backward Velocity	0.7218	mm/s
Median Velocity	0.0835	mm/s
Velocity Std Deviation	0.1755	mm/s
Velocity RMS	0.2224	mm/s
Fraction Time Moving Forward	41.6%	ratio
Fraction Time Moving Backward	58.4%	ratio
Fraction Time Stationary	0.0%	ratio
Acceleration (Mean)	-0.4992	mm/s ²
Maximum Acceleration	168.5813	mm/s ²
Acceleration RMS	21.8582	mm/s ²
Velocity Autocorrelation	0.8007	correlation
Reversal Frequency	19.0763	s ⁻¹
Mean Curvature	4343.6962	rad/mm
Omega Turn Count	49	count

6.28.3 Undulation Wave Mechanics

Table 114: Undulation Wave Parameters for AVA-AS_selected

Undulation Parameter	Value	Unit
Crawl Amplitude	0.0069	rad (bending)
Dominant Frequency	0.0	Hz
Wavelength	0.82	mm
Wave Velocity	0.0	mm/s
Phase Coherence	0.81	[0.0 – 1.0]
Mean Muscle Activation	0.789656	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.28.4 Worm Motion and Activity Figures

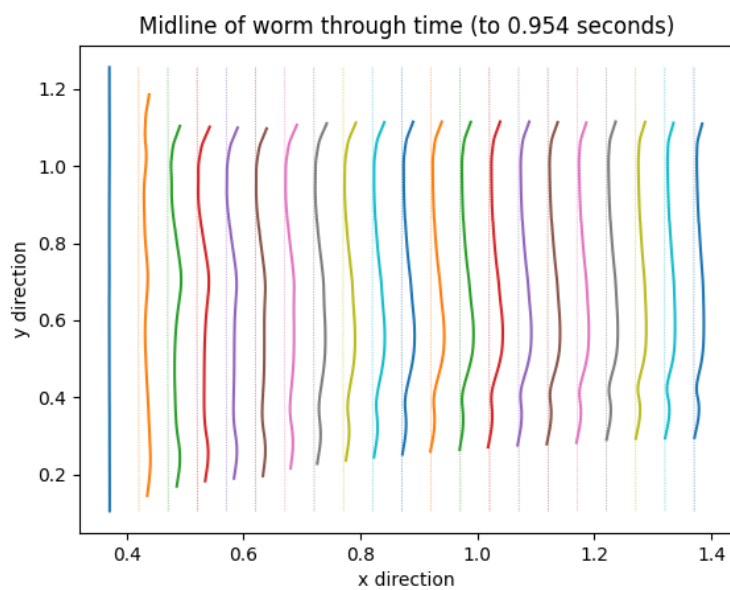


Figure 273: Midline of worm through time.

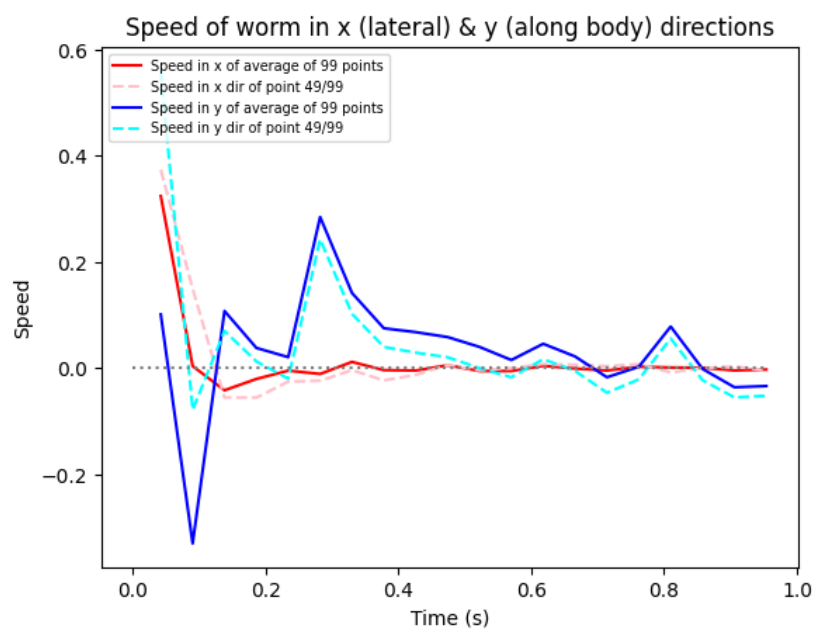


Figure 274: Speed of worm along body directions.

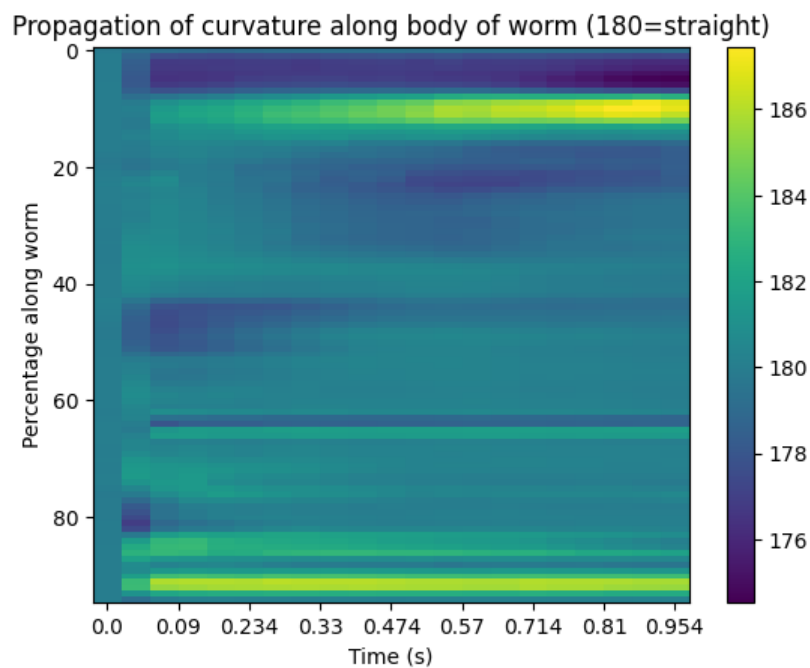


Figure 275: Propagation of curvature along body of worm.

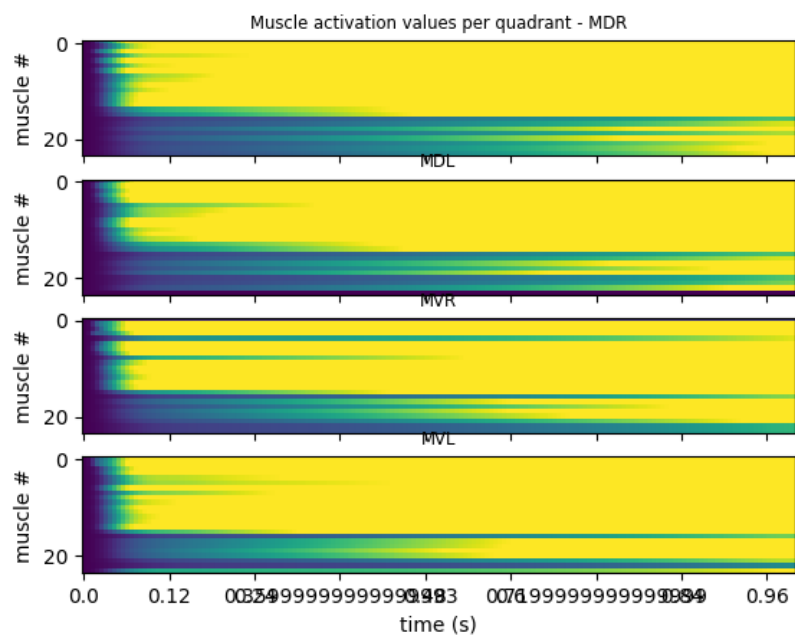


Figure 276: Muscle activities per quadrant.

6.28.5 Trace Figures

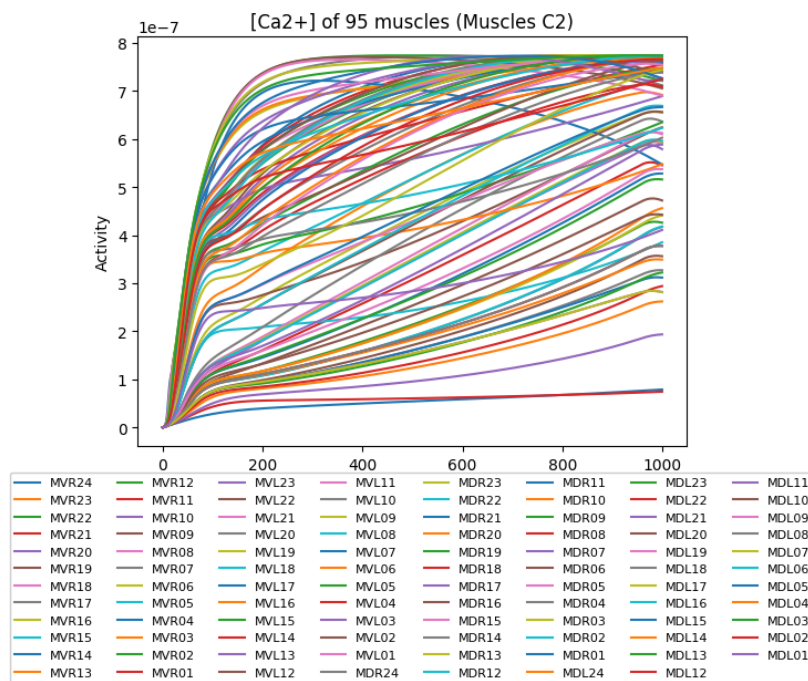
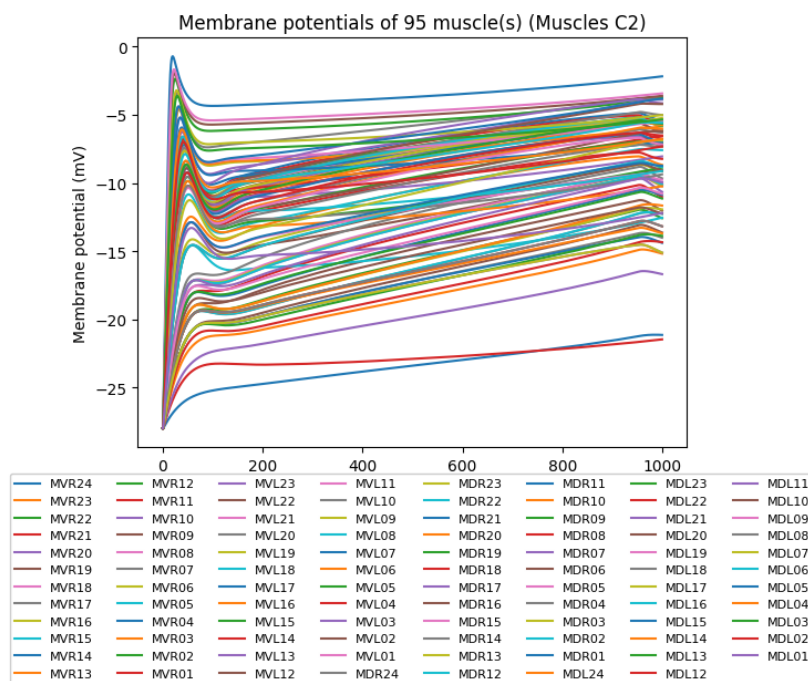


Figure 277: Traces of muscle activity and potentials.



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Figure 278: Traces of muscle activity.

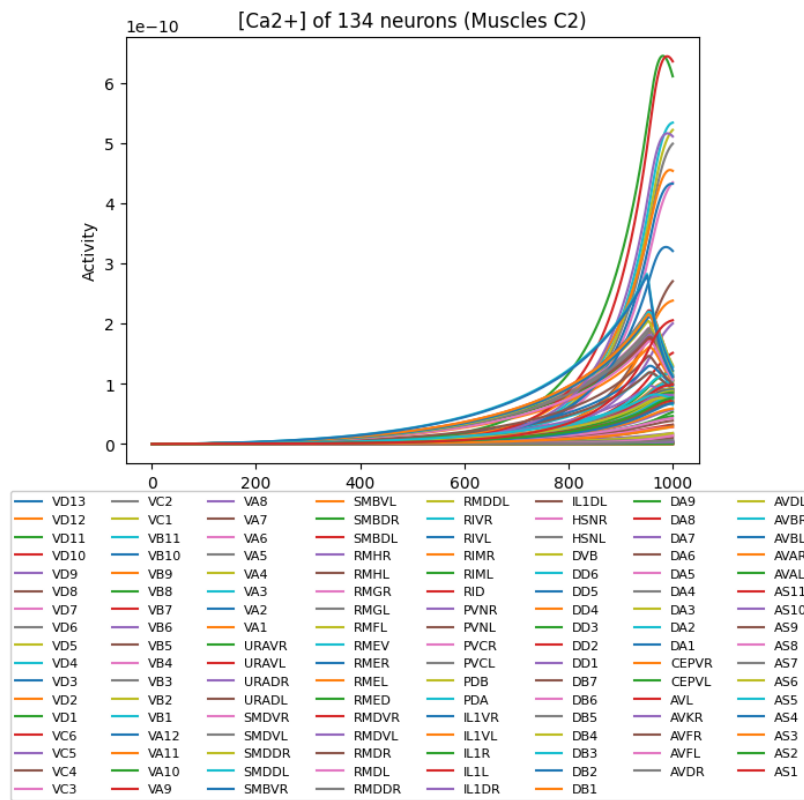
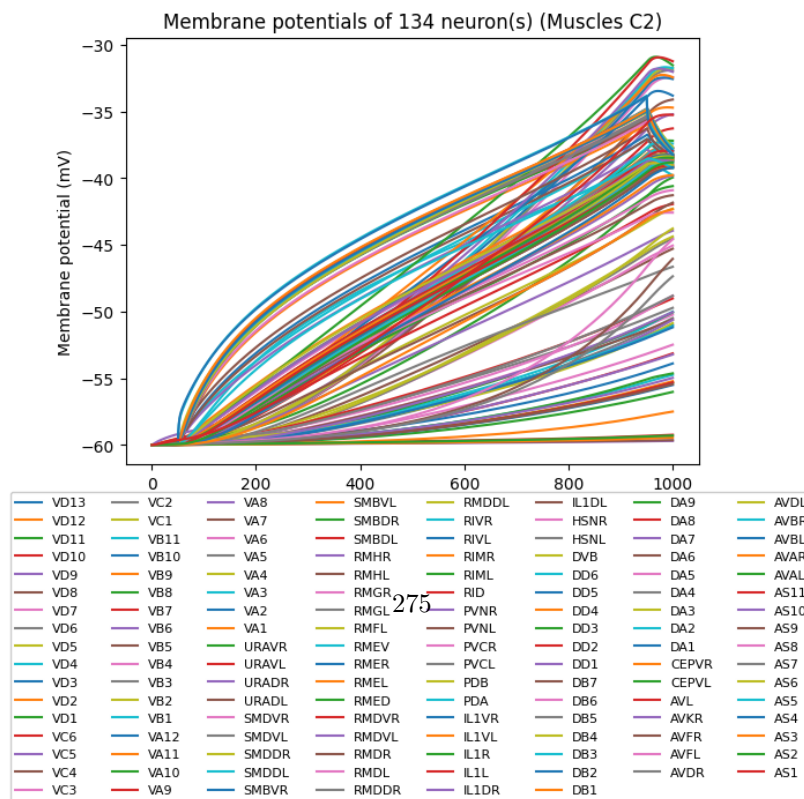


Figure 279: Traces of neuron activity and potentials.



6.28.6 Compact Morphology Grid

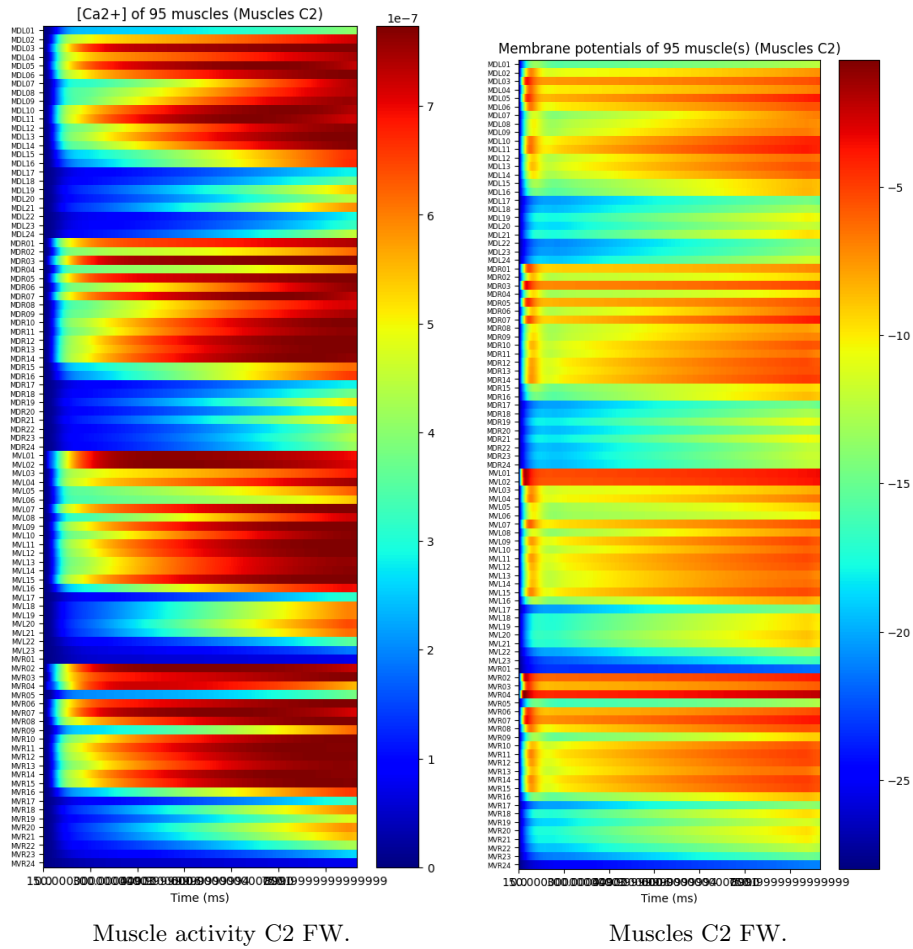


Figure 281: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).

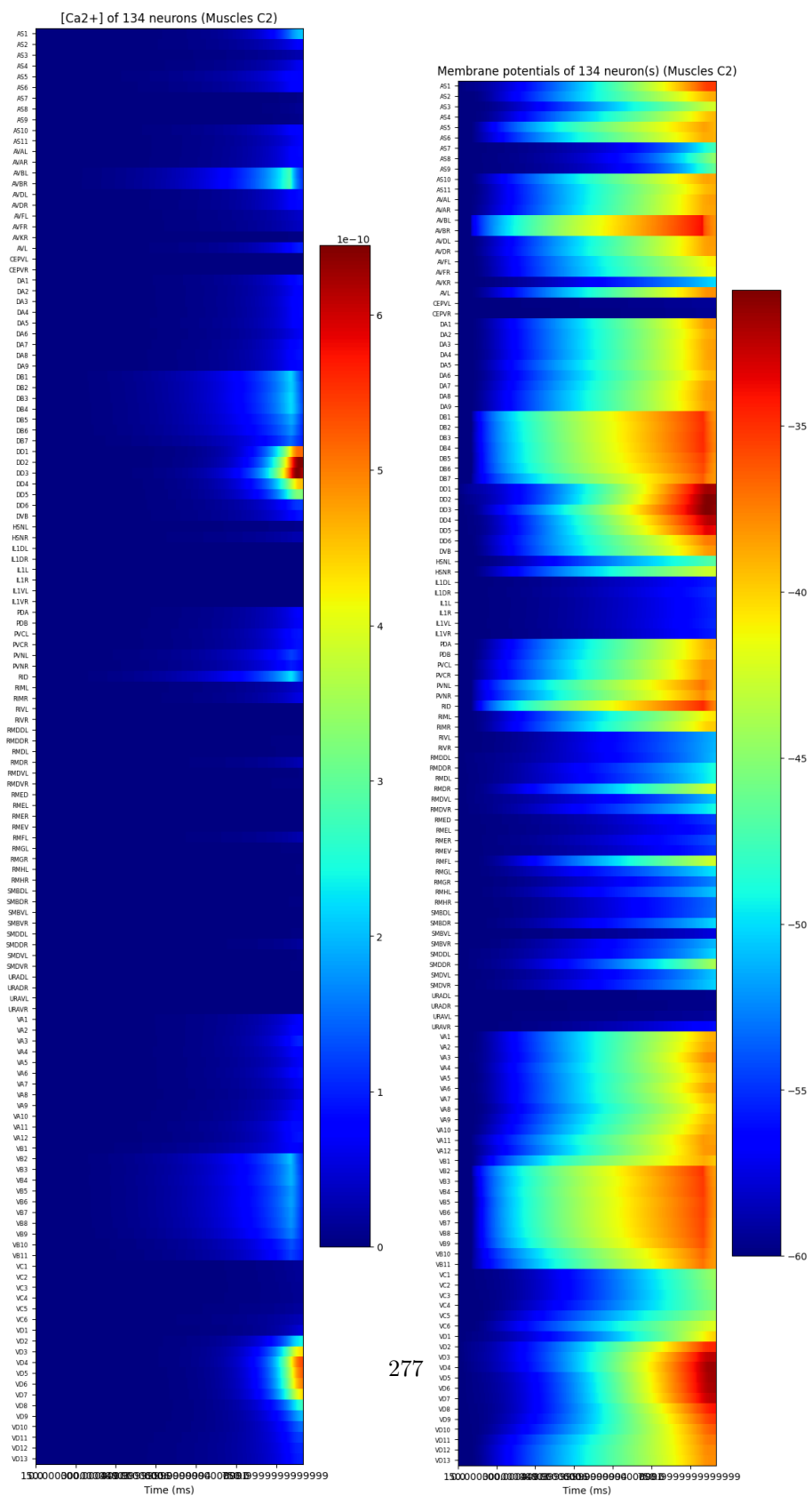


Figure 282: Neuron activity and morphology, shown as a 2x1 grid for compact

6.28.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.7 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 115: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	1.9 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[=-----]	1.7 / 10
Overall Severity	[=====]	4.7 / 10

6.29 Movement Analysis: AVAR-PVCL_STRONG

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run C2_Muscles_2026-08-20_18-33-52-AVAR-PVCL_STRONG.

6.29.1 Locomotion State Classification

Table 116: Behavioral State Breakdown for AVAR-PVCL_STRONG

Locomotion State	Time Fraction (%)
Forward Crawling	19.4%
Backward Crawling	28.5%
Stationary	0.0%
Reversal	10.3%
Omega Turns	20.6%
Shallow Turns	21.2%
Irregular / Abnormal	0.0%

6.29.2 Kinematic & Velocity Dynamics

Table 117: Kinematic and Velocity Metrics for AVAR-PVCL_STRONG

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.0377	mm
Gross Distance	0.1847	mm
Path Efficiency (Net/Gross)	0.2039	[0.0 – 1.0]
Mean Speed	0.1854	mm/s
Maximum Forward Velocity	0.9387	mm/s
Maximum Backward Velocity	0.908	mm/s
Median Velocity	0.1081	mm/s
Velocity Std Deviation	0.2145	mm/s
Velocity RMS	0.2836	mm/s
Fraction Time Moving Forward	51.2%	ratio
Fraction Time Moving Backward	48.8%	ratio
Fraction Time Stationary	0.0%	ratio
Acceleration (Mean)	-0.4712	mm/s ²
Maximum Acceleration	168.7864	mm/s ²
Acceleration RMS	25.6805	mm/s ²
Velocity Autocorrelation	0.8487	correlation
Reversal Frequency	17.0683	s ⁻¹
Mean Curvature	3095.7805	rad/mm
Omega Turn Count	34	count

6.29.3 Undulation Wave Mechanics

Table 118: Undulation Wave Parameters for AVAR-PVCL_STRONG

Undulation Parameter	Value	Unit
Crawl Amplitude	0.0067	rad (bending)
Dominant Frequency	0.0	Hz
Wavelength	0.82	mm
Wave Velocity	0.0	mm/s
Phase Coherence	0.78	[0.0 – 1.0]
Mean Muscle Activation	0.789852	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.29.4 Worm Motion and Activity Figures

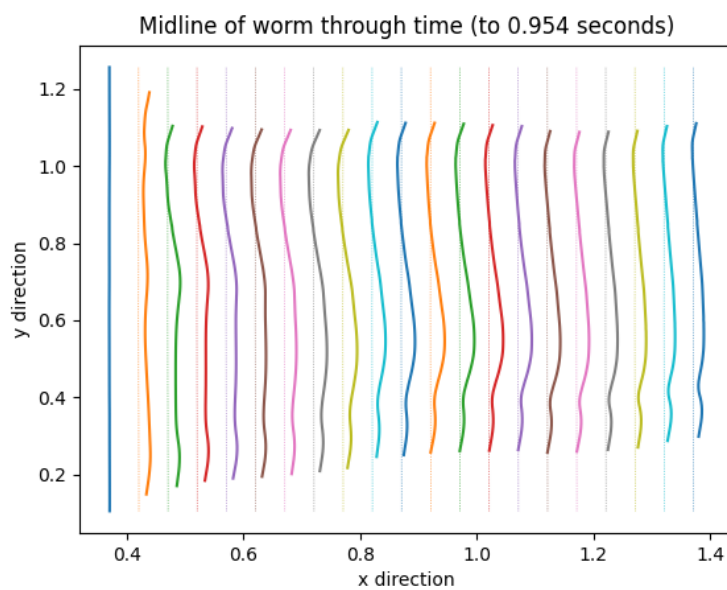


Figure 283: Midline of worm through time.

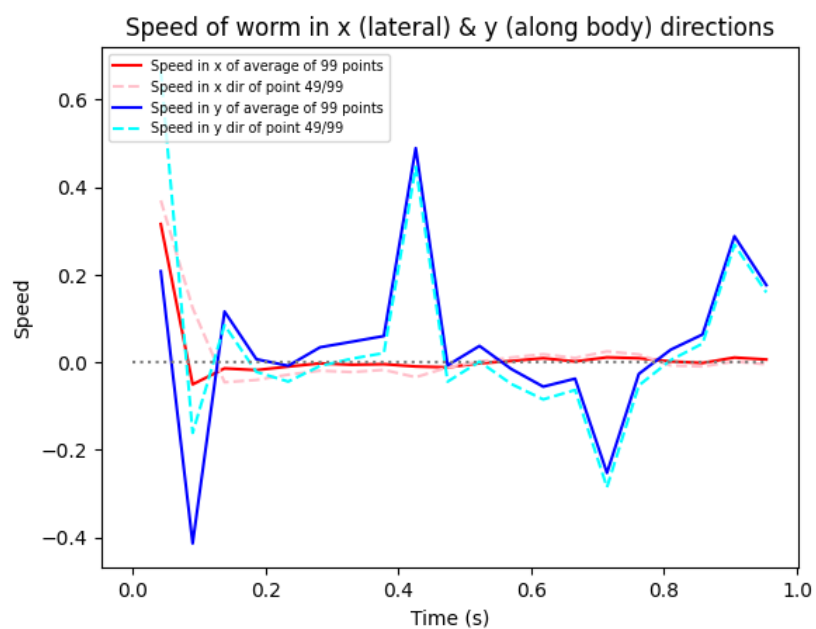


Figure 284: Speed of worm along body directions.

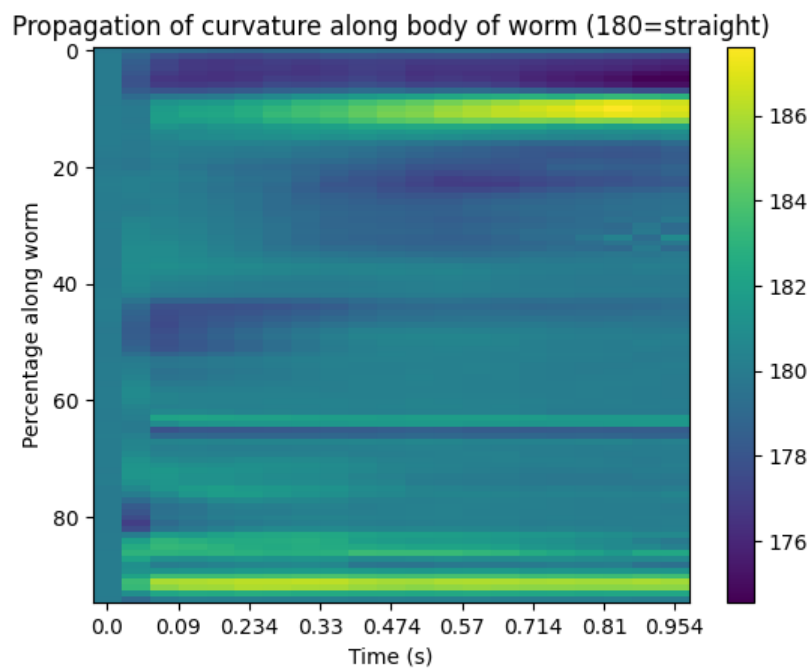


Figure 285: Propagation of curvature along body of worm.

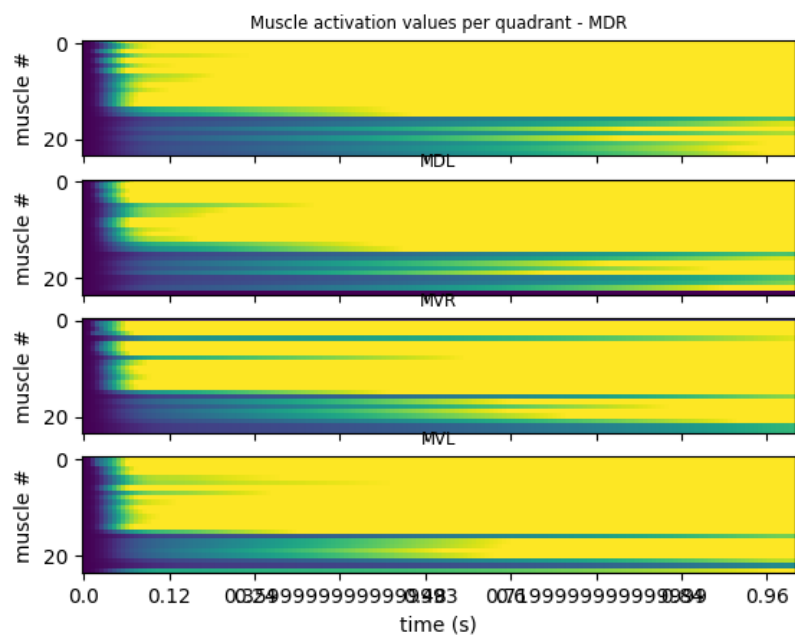


Figure 286: Muscle activities per quadrant.

6.29.5 Trace Figures

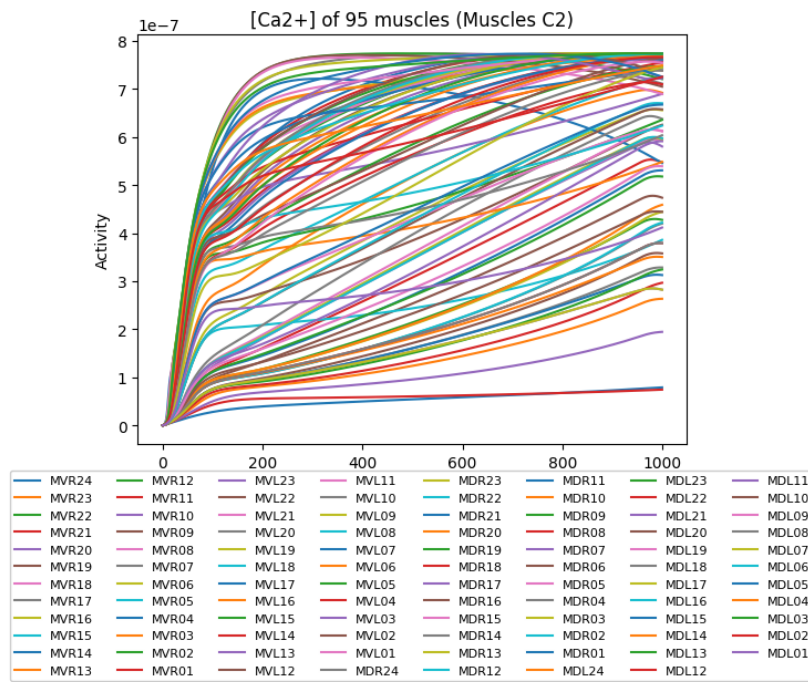
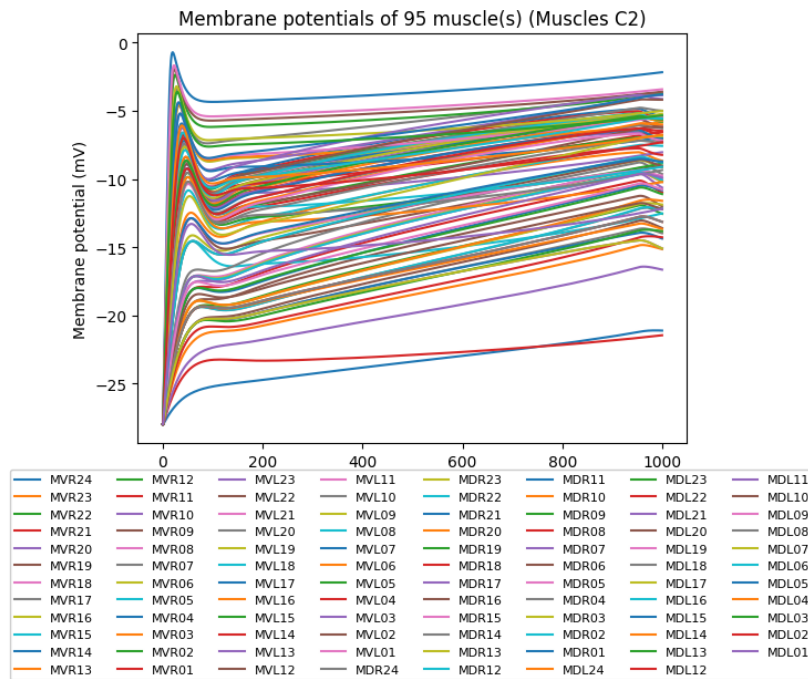


Figure 287: Traces of muscle activity and potentials.



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Figure 288: Traces of muscle activity.

6.29.6 Compact Morphology Grid

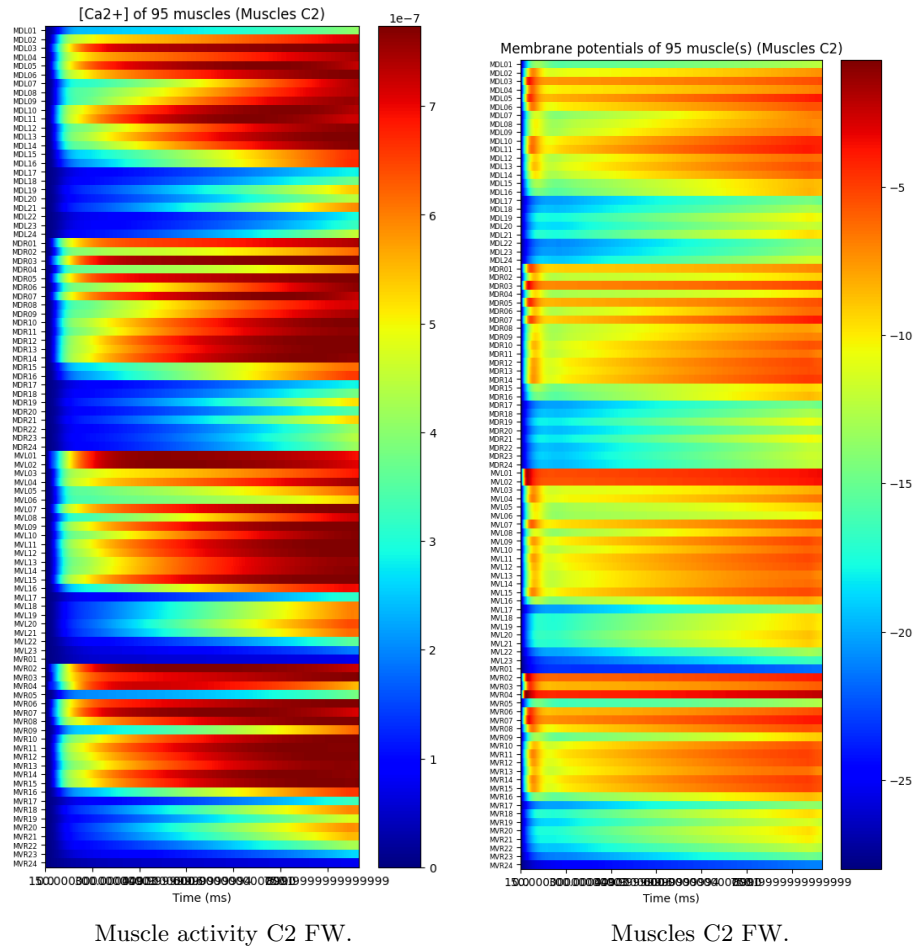


Figure 291: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).

6.29.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.5 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 119: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	2.2 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[-----]	0.2 / 10
Overall Severity	[====-----]	4.5 / 10

6.30 Movement Analysis: AVAL-DA3_HALF

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run C2_Muscles_2026-08-21_09-00-03-AVAL-DA3_HALF.

6.30.1 Locomotion State Classification

Table 120: Behavioral State Breakdown for AVAL-DA3_HALF

Locomotion State	Time Fraction (%)
Forward Crawling	10.3%
Backward Crawling	31.5%
Stationary	0.0%
Reversal	10.9%
Omega Turns	24.9%
Shallow Turns	22.4%
Irregular / Abnormal	0.0%

6.30.2 Kinematic & Velocity Dynamics

Table 121: Kinematic and Velocity Metrics for AVAL-DA3_HALF

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.0417	mm
Gross Distance	0.1451	mm
Path Efficiency (Net/Gross)	0.2877	[0.0 – 1.0]
Mean Speed	0.1456	mm/s
Maximum Forward Velocity	0.4963	mm/s
Maximum Backward Velocity	0.6958	mm/s
Median Velocity	0.0932	mm/s
Velocity Std Deviation	0.1775	mm/s
Velocity RMS	0.2296	mm/s
Fraction Time Moving Forward	45.8%	ratio
Fraction Time Moving Backward	54.2%	ratio
Fraction Time Stationary	0.0%	ratio
Acceleration (Mean)	-0.4555	mm/s ²
Maximum Acceleration	168.779	mm/s ²
Acceleration RMS	22.0002	mm/s ²
Velocity Autocorrelation	0.8088	correlation
Reversal Frequency	18.0723	s ⁻¹
Mean Curvature	4494.6012	rad/mm
Omega Turn Count	41	count

6.30.3 Undulation Wave Mechanics

Table 122: Undulation Wave Parameters for AVAL-DA3_HALF

Undulation Parameter	Value	Unit
Crawl Amplitude	0.0068	rad (bending)
Dominant Frequency	0.0	Hz
Wavelength	0.82	mm
Wave Velocity	0.0	mm/s
Phase Coherence	0.76	[0.0 – 1.0]
Mean Muscle Activation	0.789827	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.30.4 Worm Motion and Activity Figures

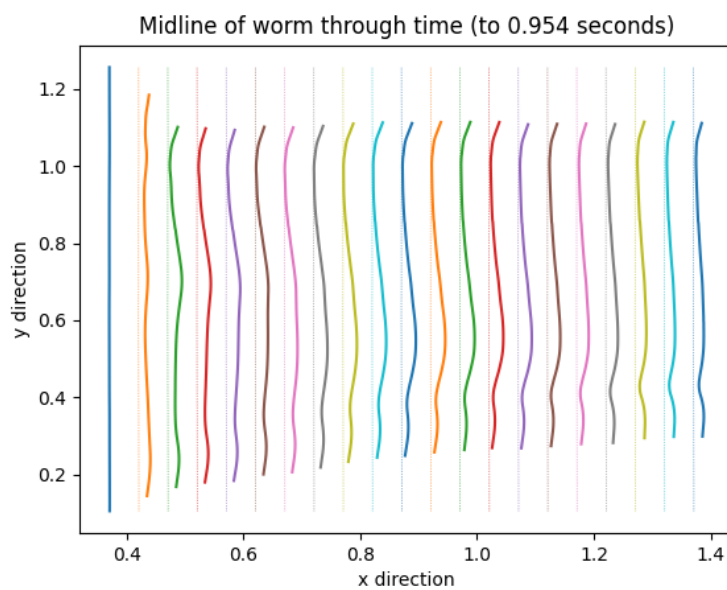


Figure 293: Midline of worm through time.

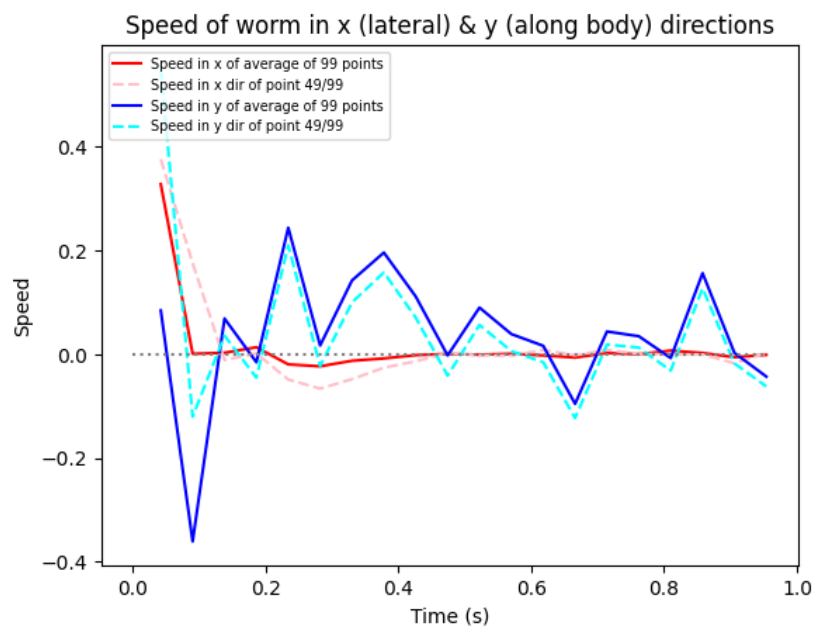


Figure 294: Speed of worm along body directions.

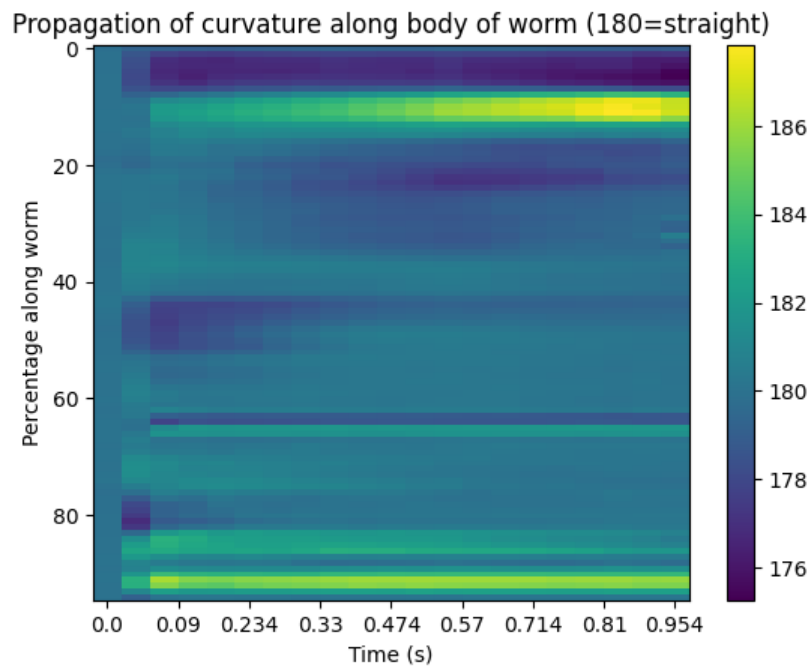


Figure 295: Propagation of curvature along body of worm.

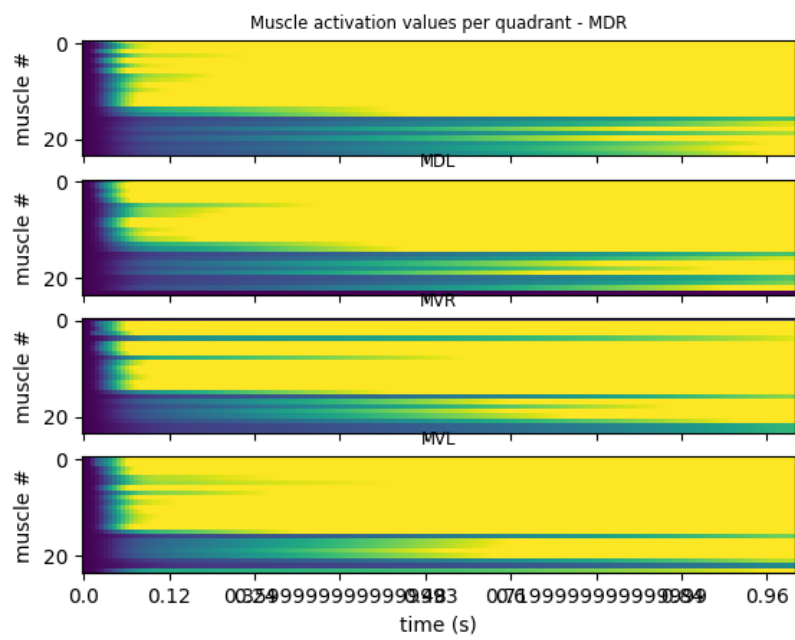


Figure 296: Muscle activities per quadrant.

6.30.5 Trace Figures

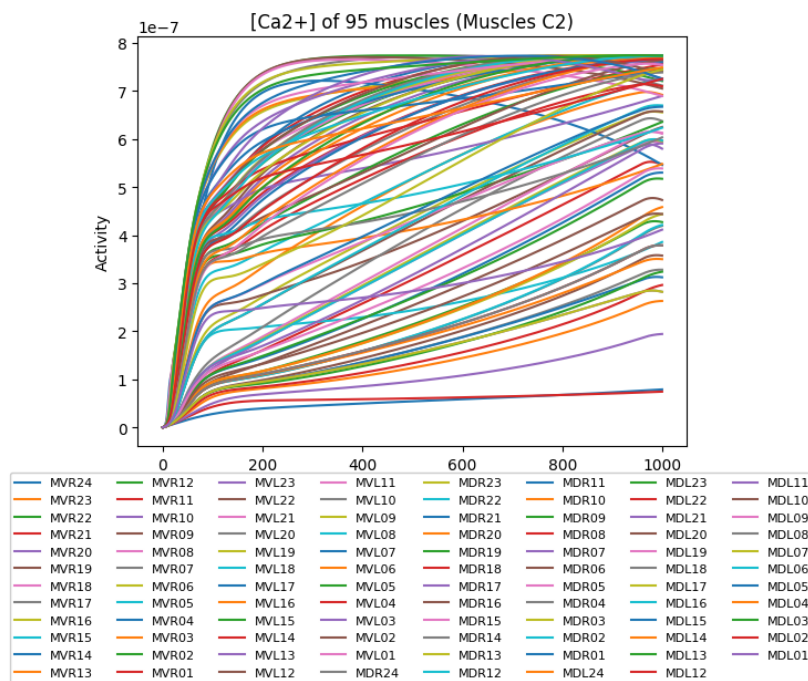
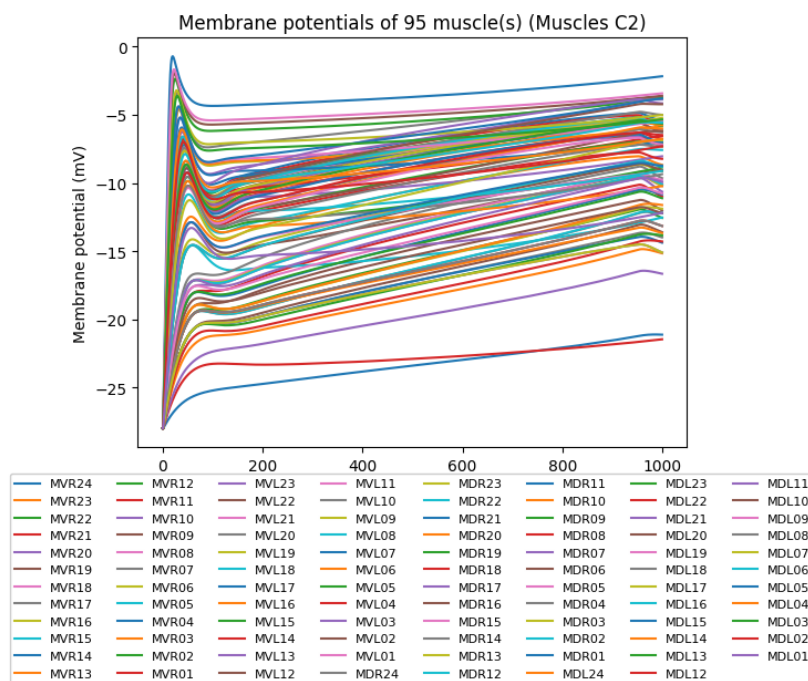


Figure 297: Traces of muscle activity and potentials.



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Figure 298: Traces of muscle activity.

6.30.6 Compact Morphology Grid

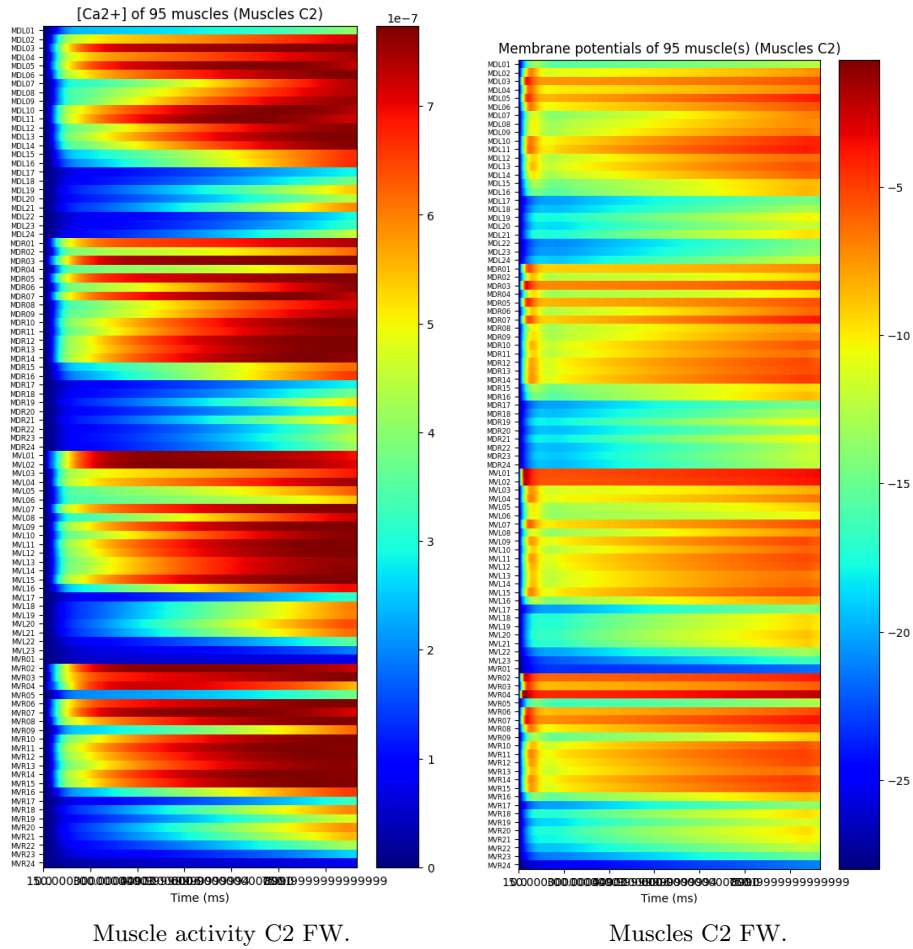


Figure 301: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).

6.30.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.6 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 123: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	2.4 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[=-----]	0.8 / 10
Overall Severity	[=====]	4.6 / 10

6.31 Movement Analysis: AVAR-PVCL_GJ_STRONG

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run C2_Muscles_2026-08-21_10-37-01-AVAR-PVCL_GJ_STRONG.

6.31.1 Locomotion State Classification

Table 124: Behavioral State Breakdown for AVAR-PVCL_GJ_STRONG

Locomotion State	Time Fraction (%)
Forward Crawling	11.5%
Backward Crawling	27.9%
Stationary	0.0%
Reversal	11.5%
Omega Turns	23.0%
Shallow Turns	26.1%
Irregular / Abnormal	0.0%

6.31.2 Kinematic & Velocity Dynamics

Table 125: Kinematic and Velocity Metrics for AVAR-PVCL_GJ_STRONG

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.0275	mm
Gross Distance	0.15	mm
Path Efficiency (Net/Gross)	0.1831	[0.0 – 1.0]
Mean Speed	0.1506	mm/s
Maximum Forward Velocity	0.5856	mm/s
Maximum Backward Velocity	0.7237	mm/s
Median Velocity	0.1013	mm/s
Velocity Std Deviation	0.1812	mm/s
Velocity RMS	0.2356	mm/s
Fraction Time Moving Forward	49.4%	ratio
Fraction Time Moving Backward	50.6%	ratio
Fraction Time Stationary	0.0%	ratio
Acceleration (Mean)	-0.3642	mm/s ²
Maximum Acceleration	168.7655	mm/s ²
Acceleration RMS	23.0163	mm/s ²
Velocity Autocorrelation	0.8277	correlation
Reversal Frequency	19.0763	s ⁻¹
Mean Curvature	3989.8244	rad/mm
Omega Turn Count	38	count

6.31.3 Undulation Wave Mechanics

Table 126: Undulation Wave Parameters for AVAR-PVCL_GJ_STRONG

Undulation Parameter	Value	Unit
Crawl Amplitude	0.007	rad (bending)
Dominant Frequency	1.0	Hz
Wavelength	1.66	mm
Wave Velocity	1.67	mm/s
Phase Coherence	0.78	[0.0 – 1.0]
Mean Muscle Activation	0.789881	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.31.4 Worm Motion and Activity Figures

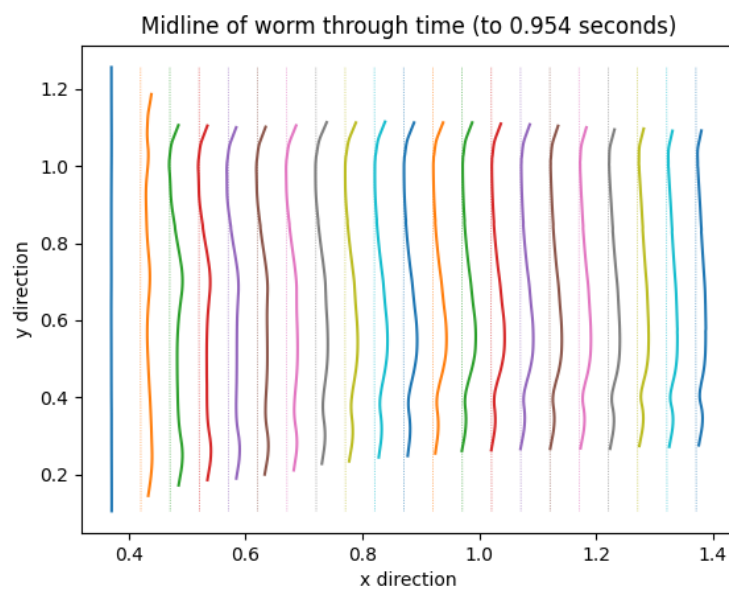


Figure 303: Midline of worm through time.

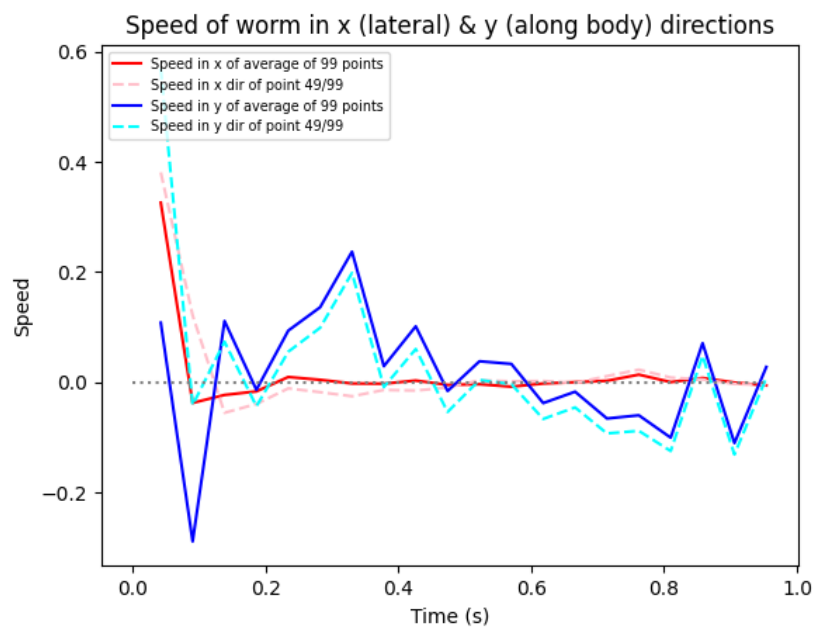


Figure 304: Speed of worm along body directions.

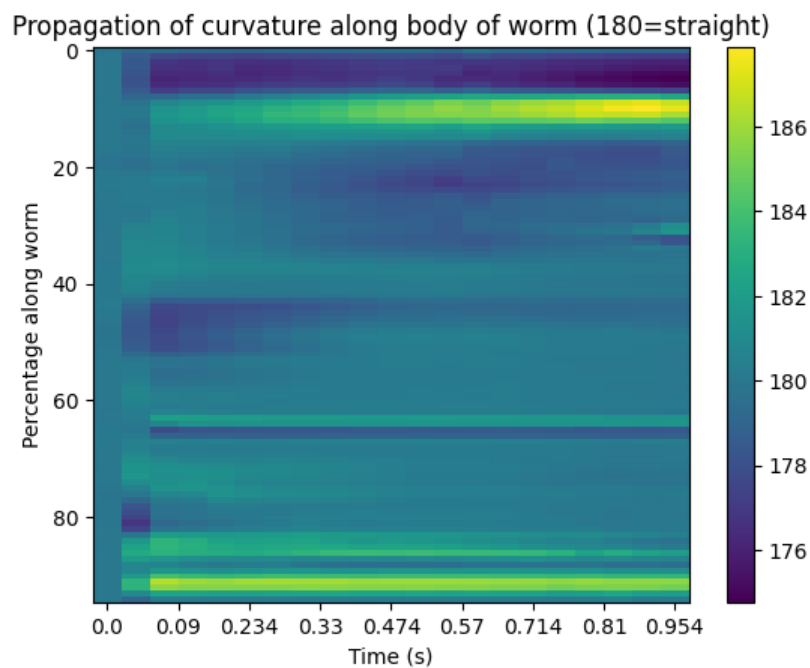


Figure 305: Propagation of curvature along body of worm.

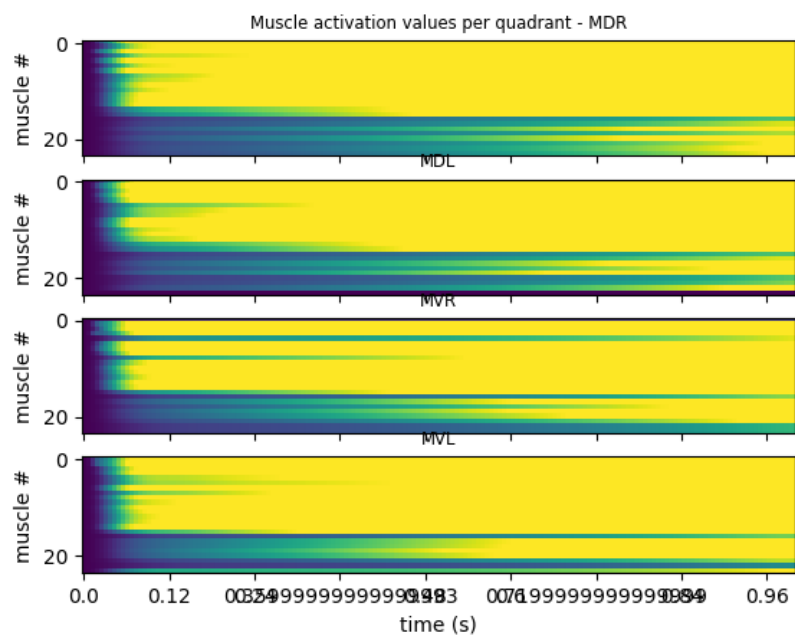


Figure 306: Muscle activities per quadrant.

6.31.5 Trace Figures

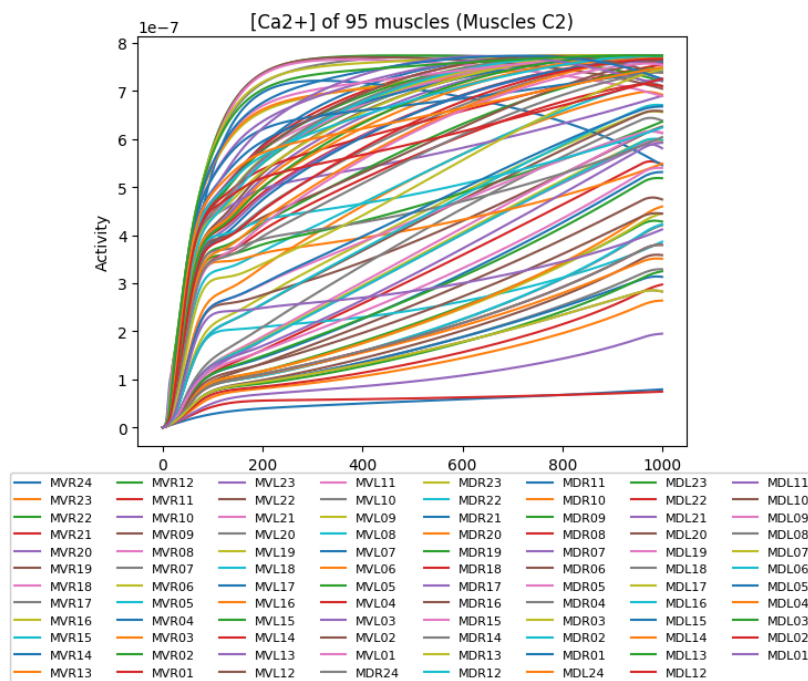
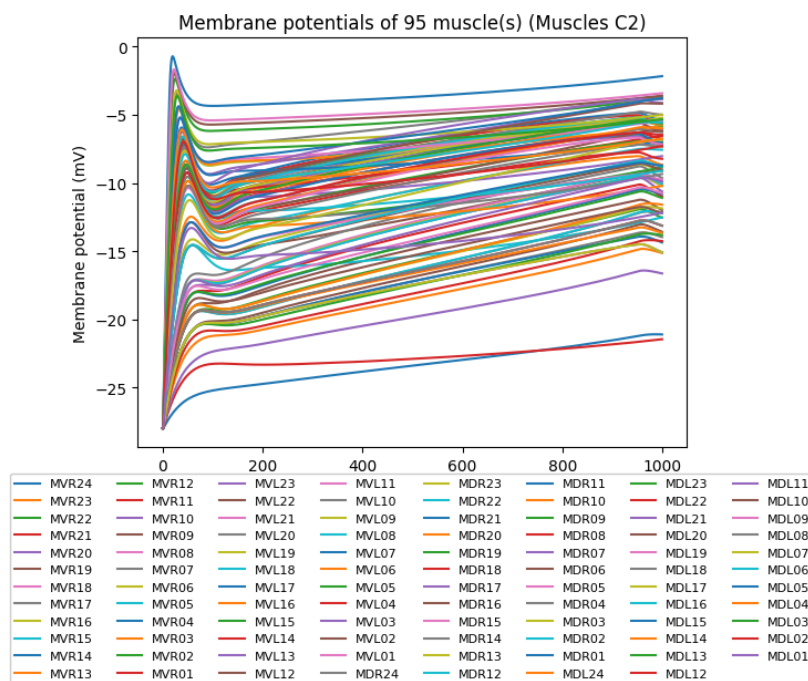


Figure 307: Traces of muscle activity and potentials.



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Figure 308: Traces of muscle activity.

6.31.6 Compact Morphology Grid

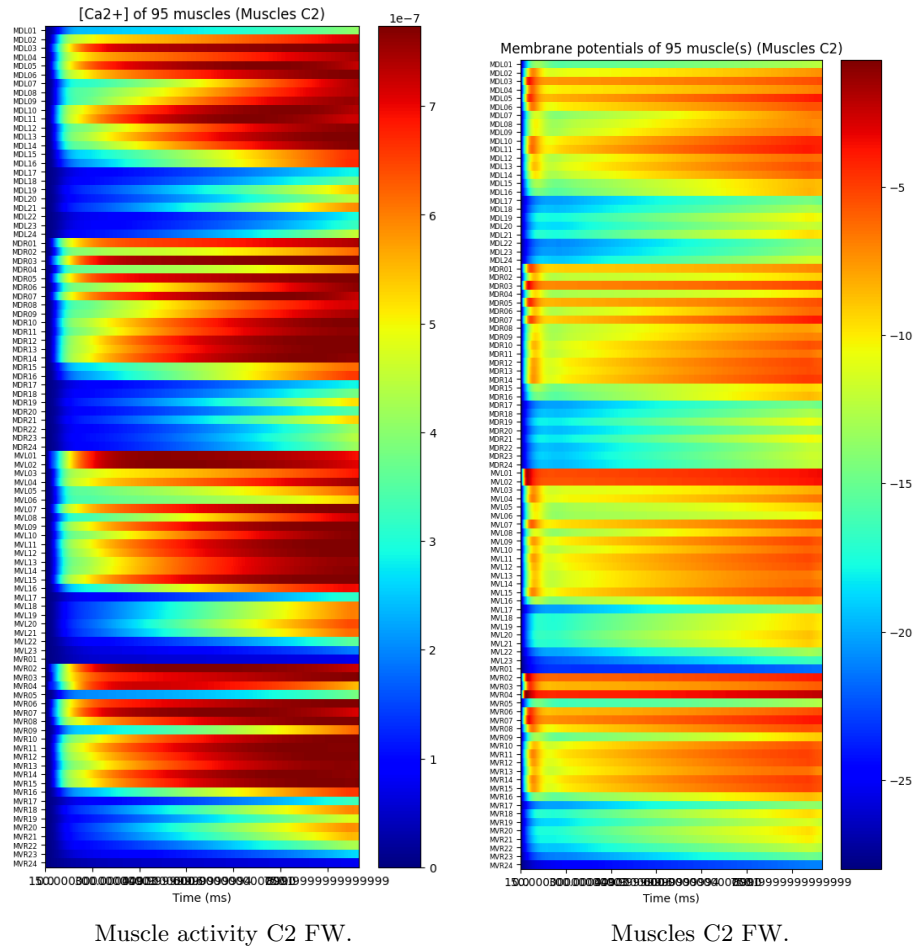


Figure 311: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).

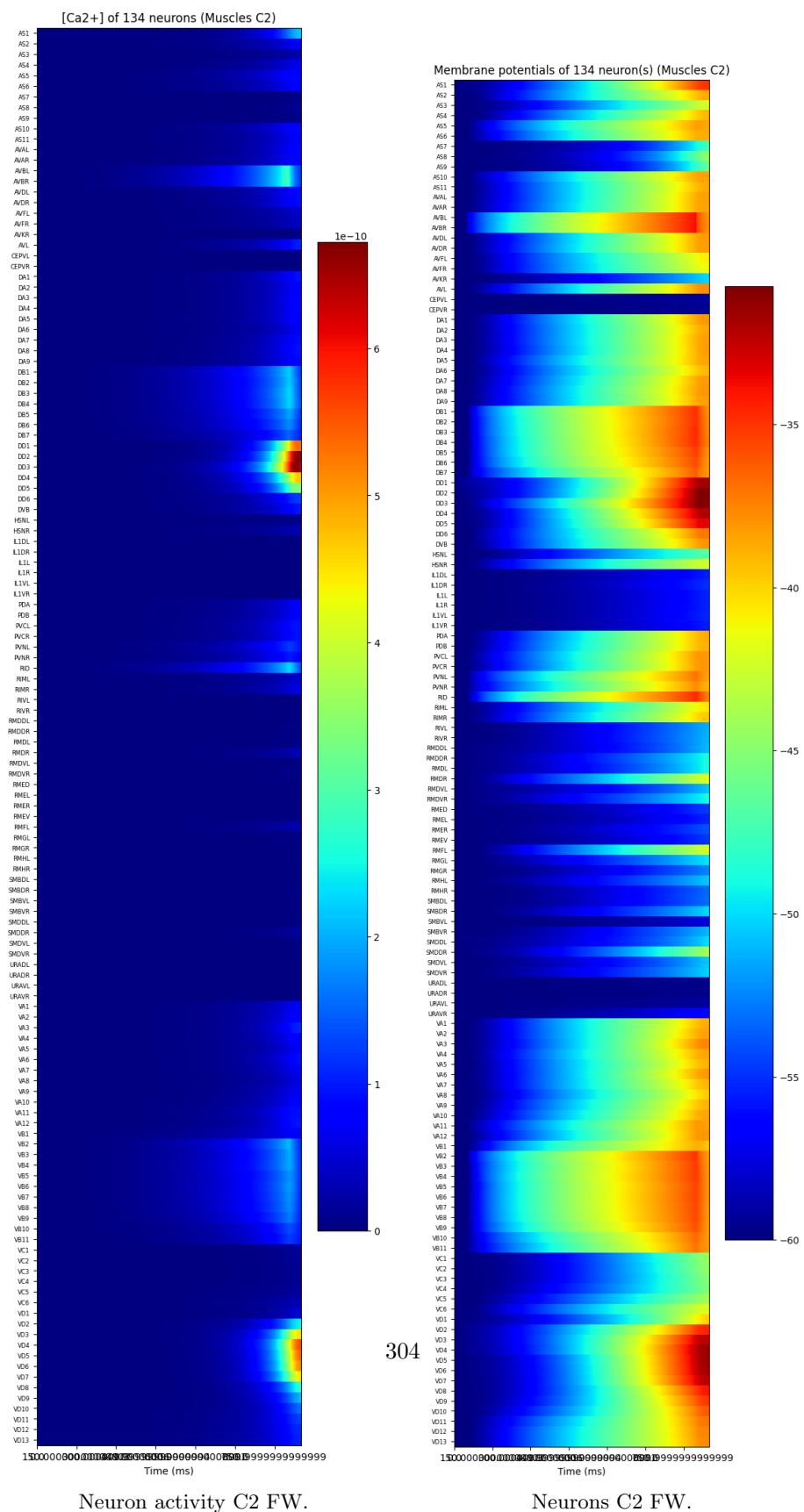


Figure 312: Neuron activity and morphology, shown as a 2x1 grid for compact

6.31.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.5 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 127: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	2.2 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[-----]	0.1 / 10
Overall Severity	[====-----]	4.5 / 10

6.32 Movement Analysis: AVAL-VA5_HYPER

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run C2_Muscles_2026-08-21_12-48-32-AVAL-VA5_HYPER.

6.32.1 Locomotion State Classification

Table 128: Behavioral State Breakdown for AVAL-VA5_HYPER

Locomotion State	Time Fraction (%)
Forward Crawling	12.7%
Backward Crawling	32.1%
Stationary	0.0%
Reversal	11.5%
Omega Turns	22.4%
Shallow Turns	21.2%
Irregular / Abnormal	0.0%

6.32.2 Kinematic & Velocity Dynamics

Table 129: Kinematic and Velocity Metrics for AVAL-VA5_HYPER

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.0344	mm
Gross Distance	0.1497	mm
Path Efficiency (Net/Gross)	0.2296	[0.0 – 1.0]
Mean Speed	0.1503	mm/s
Maximum Forward Velocity	0.6905	mm/s
Maximum Backward Velocity	0.8032	mm/s
Median Velocity	0.0939	mm/s
Velocity Std Deviation	0.184	mm/s
Velocity RMS	0.2376	mm/s
Fraction Time Moving Forward	45.2%	ratio
Fraction Time Moving Backward	54.2%	ratio
Fraction Time Stationary	0.0%	ratio
Acceleration (Mean)	-0.3495	mm/s ²
Maximum Acceleration	168.8	mm/s ²
Acceleration RMS	22.8276	mm/s ²
Velocity Autocorrelation	0.8174	correlation
Reversal Frequency	19.0763	s ⁻¹
Mean Curvature	2704.7174	rad/mm
Omega Turn Count	37	count

6.32.3 Undulation Wave Mechanics

Table 130: Undulation Wave Parameters for AVAL-VA5_HYPER

Undulation Parameter	Value	Unit
Crawl Amplitude	0.0071	rad (bending)
Dominant Frequency	0.0	Hz
Wavelength	0.82	mm
Wave Velocity	0.0	mm/s
Phase Coherence	0.78	[0.0 – 1.0]
Mean Muscle Activation	0.79008	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.32.4 Worm Motion and Activity Figures

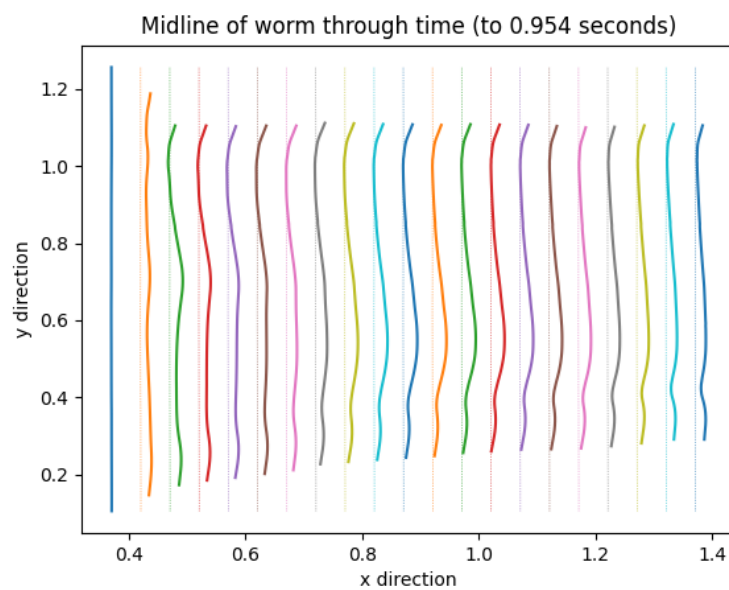


Figure 313: Midline of worm through time.

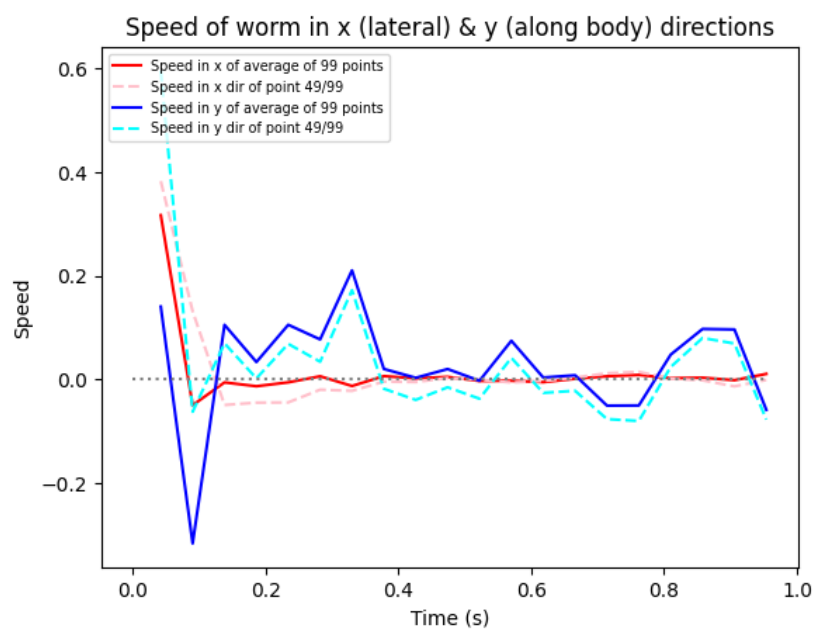


Figure 314: Speed of worm along body directions.

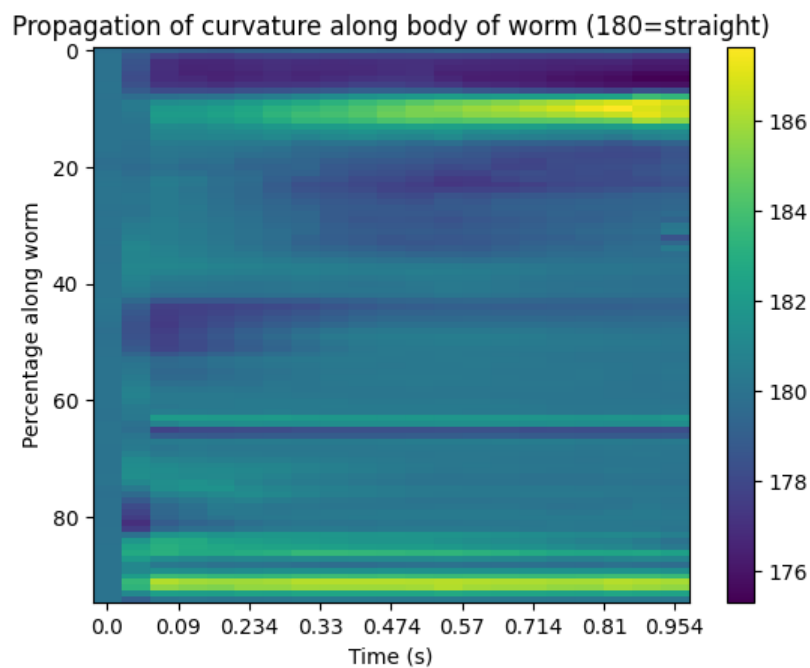


Figure 315: Propagation of curvature along body of worm.

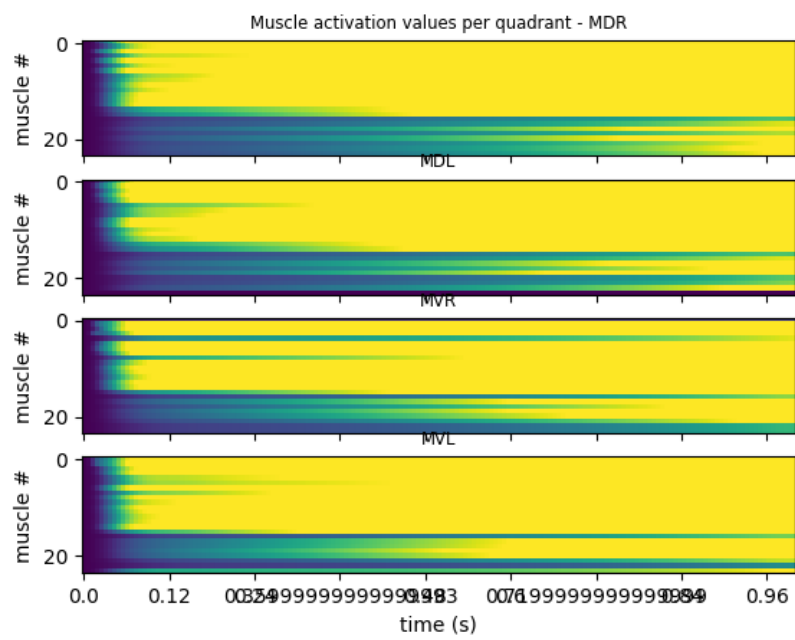


Figure 316: Muscle activities per quadrant.

6.32.5 Trace Figures

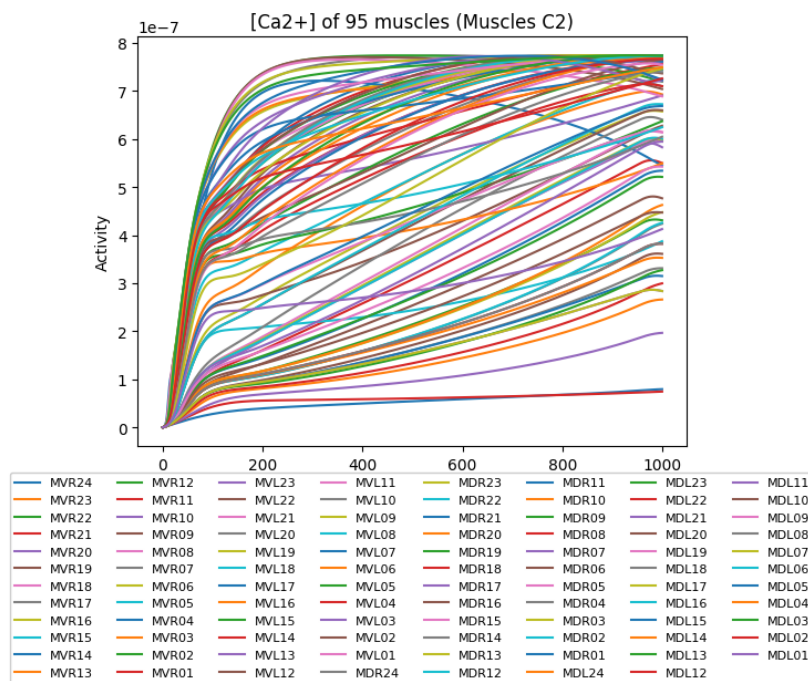
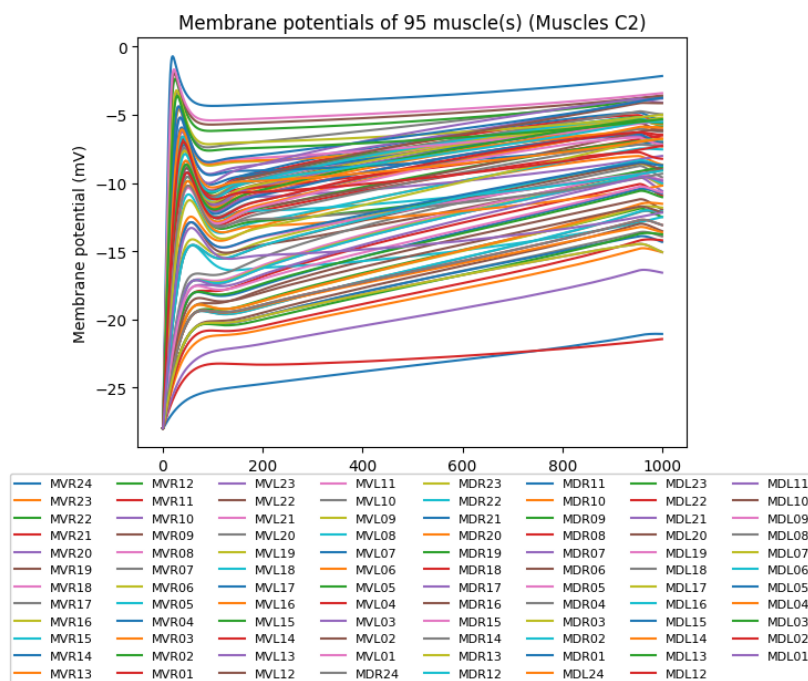


Figure 317: Traces of muscle activity and potentials.



310
Figure 318: Traces of muscle activity.

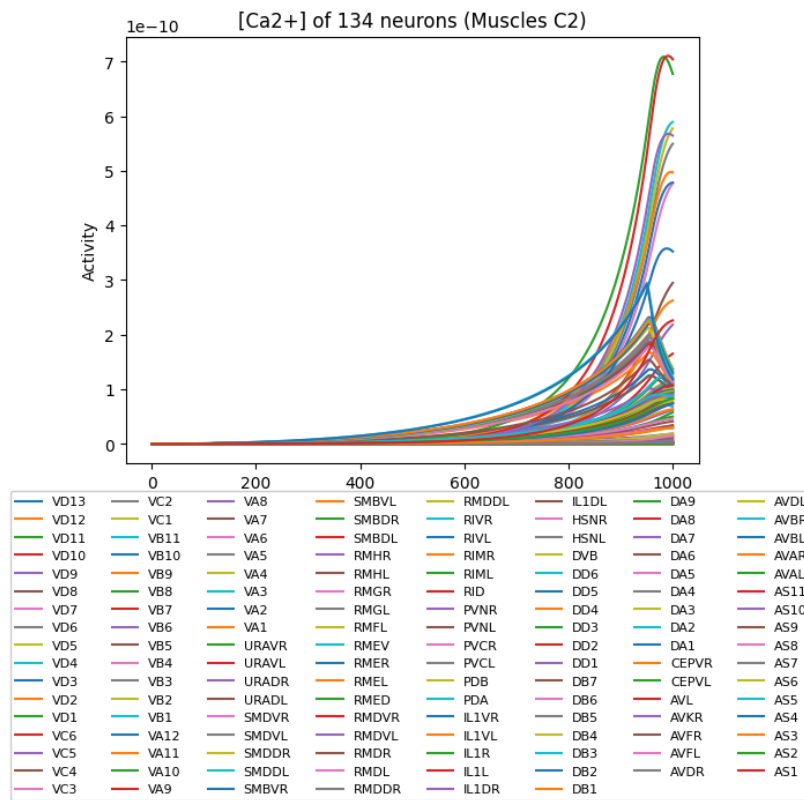
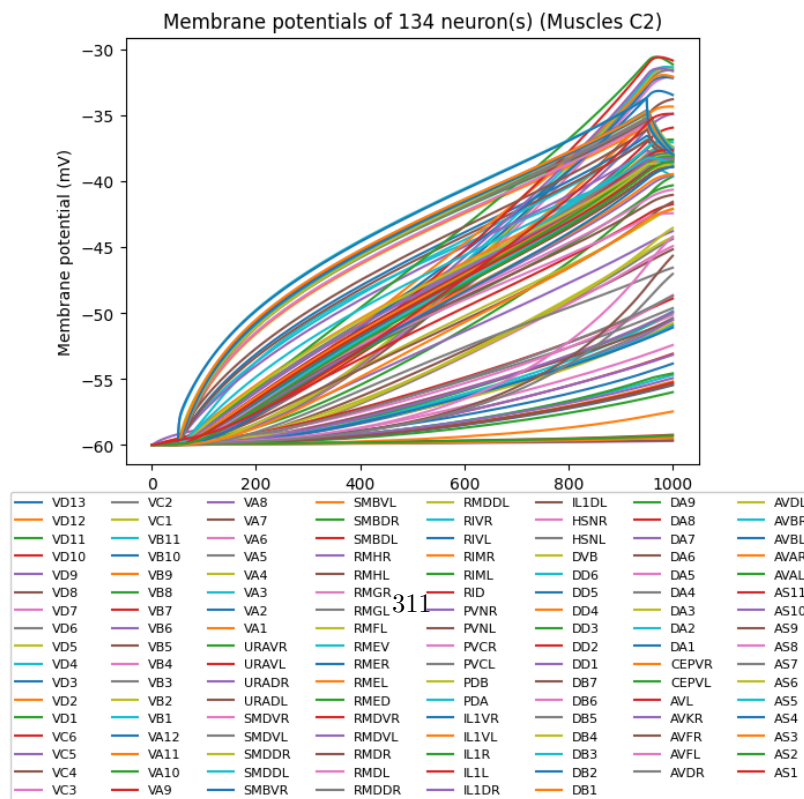


Figure 319: Traces of neuron activity and potentials.



6.32.6 Compact Morphology Grid

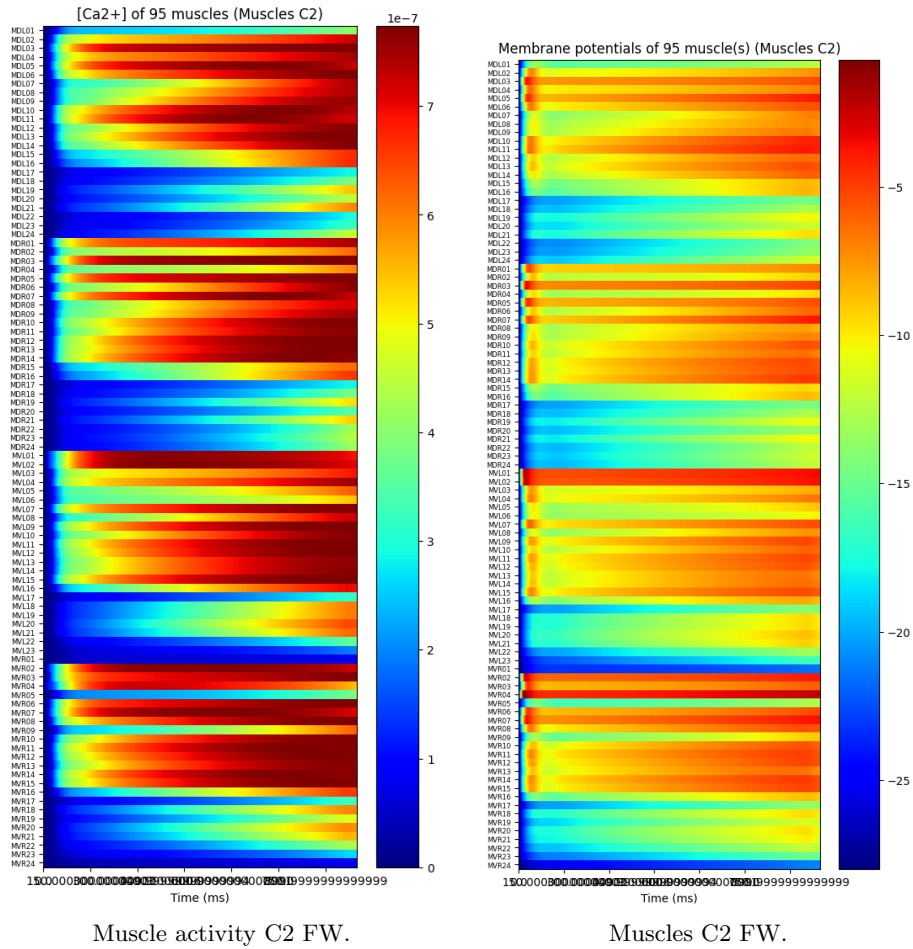


Figure 321: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).

6.32.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.6 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 131: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	2.2 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[=-----]	0.9 / 10
Overall Severity	[=====]	4.6 / 10

6.33 Movement Analysis: AVA_full_output_light

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run C2_Muscles_2026-08-21_14-19-18-AVA_full_output_light.

6.33.1 Locomotion State Classification

Table 132: Behavioral State Breakdown for AVA_full_output_light

Locomotion State	Time Fraction (%)
Forward Crawling	8.5%
Backward Crawling	27.3%
Stationary	0.0%
Reversal	11.5%
Omega Turns	30.9%
Shallow Turns	21.8%
Irregular / Abnormal	0.0%

6.33.2 Kinematic & Velocity Dynamics

Table 133: Kinematic and Velocity Metrics for AVA_full_output_light

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.0378	mm
Gross Distance	0.1378	mm
Path Efficiency (Net/Gross)	0.2746	[0.0 – 1.0]
Mean Speed	0.1383	mm/s
Maximum Forward Velocity	0.6638	mm/s
Maximum Backward Velocity	0.9951	mm/s
Median Velocity	0.072	mm/s
Velocity Std Deviation	0.2009	mm/s
Velocity RMS	0.2439	mm/s
Fraction Time Moving Forward	44.6%	ratio
Fraction Time Moving Backward	54.8%	ratio
Fraction Time Stationary	0.0%	ratio
Acceleration (Mean)	-0.4784	mm/s ²
Maximum Acceleration	168.8289	mm/s ²
Acceleration RMS	22.0923	mm/s ²
Velocity Autocorrelation	0.8286	correlation
Reversal Frequency	19.0763	s ⁻¹
Mean Curvature	6442.7362	rad/mm
Omega Turn Count	51	count

6.33.3 Undulation Wave Mechanics

Table 134: Undulation Wave Parameters for AVA_full_output_light

Undulation Parameter	Value	Unit
Crawl Amplitude	0.0068	rad (bending)
Dominant Frequency	0.0	Hz
Wavelength	0.82	mm
Wave Velocity	0.0	mm/s
Phase Coherence	0.81	[0.0 – 1.0]
Mean Muscle Activation	0.789294	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.33.4 Worm Motion and Activity Figures

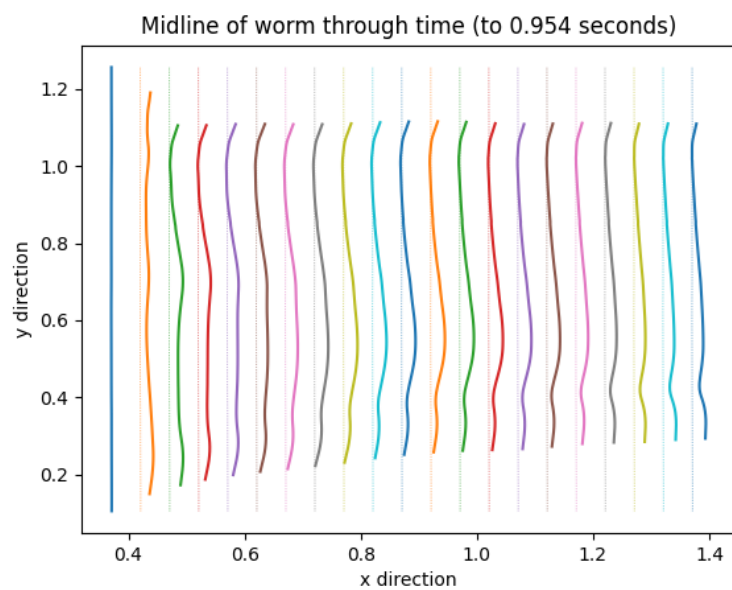


Figure 323: Midline of worm through time.

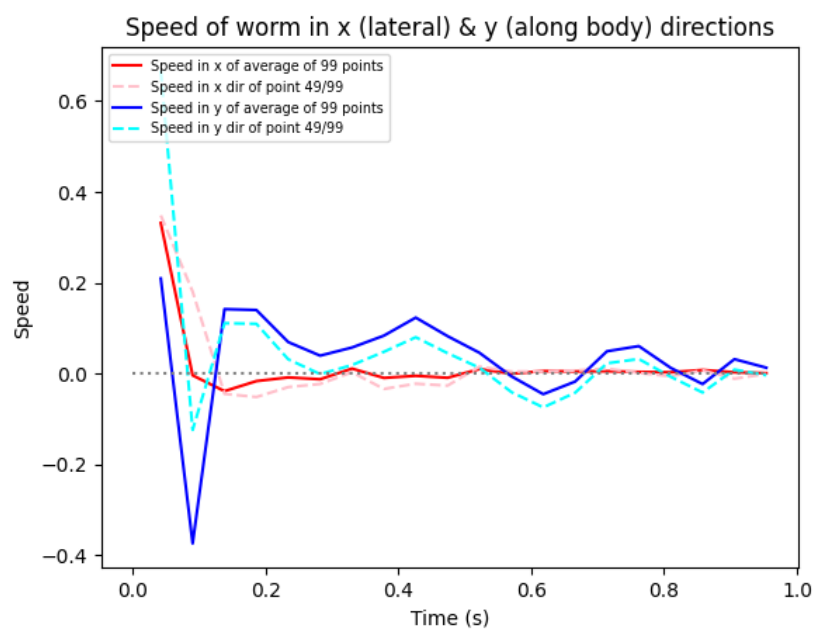


Figure 324: Speed of worm along body directions.

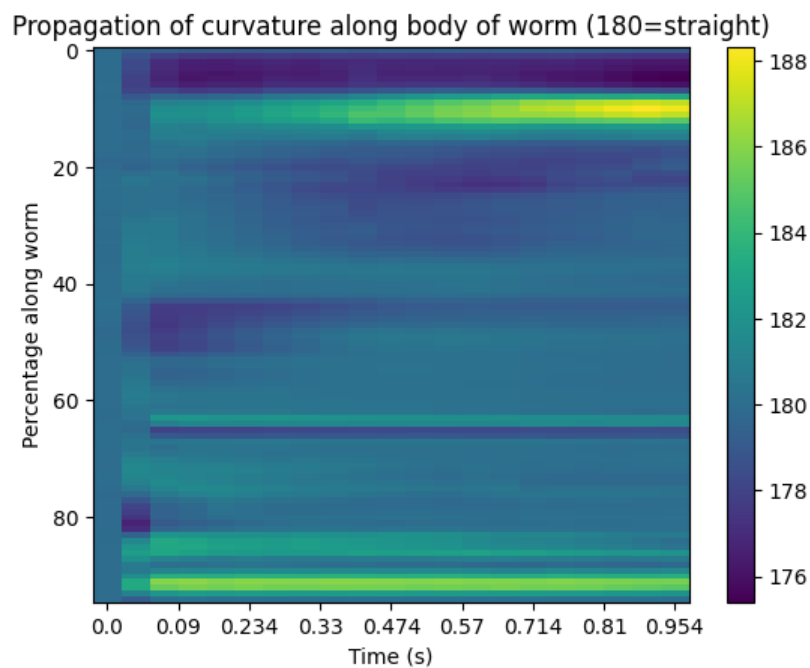


Figure 325: Propagation of curvature along body of worm.

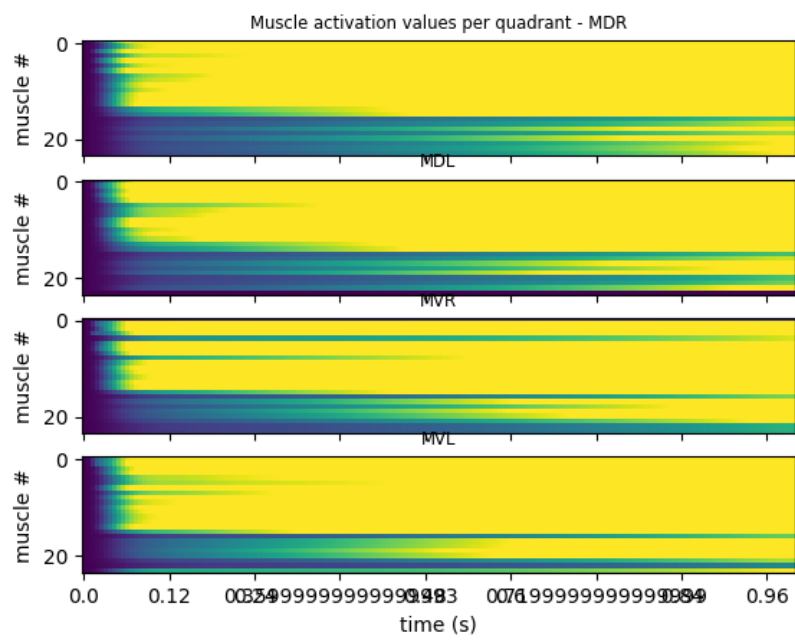


Figure 326: Muscle activities per quadrant.

6.33.5 Trace Figures

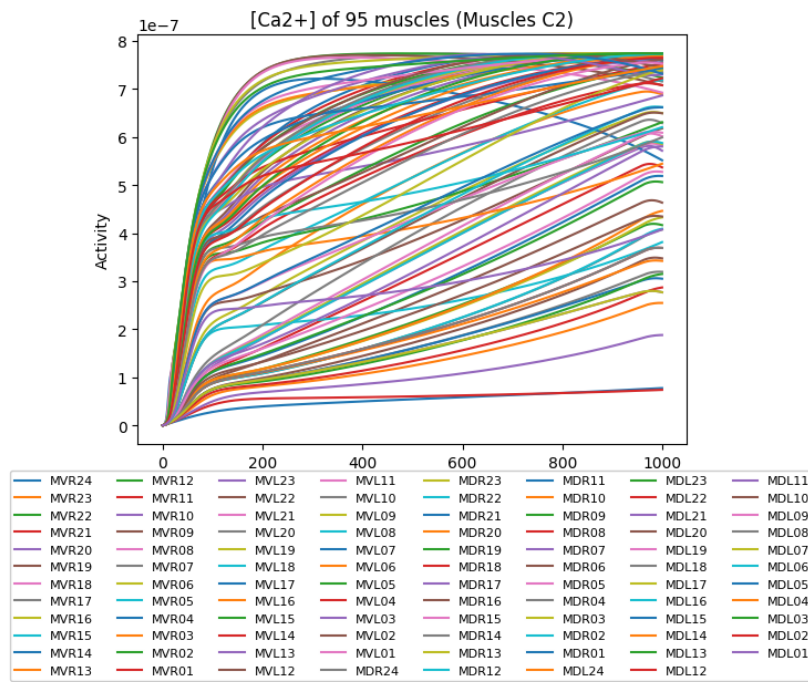
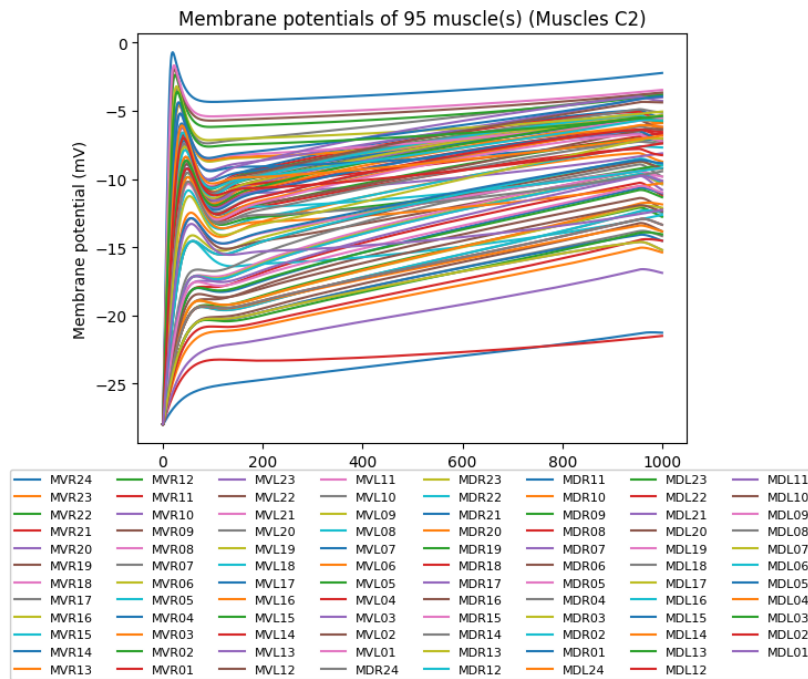


Figure 327: Traces of muscle activity and potentials.



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Figure 328: Traces of muscle activity.

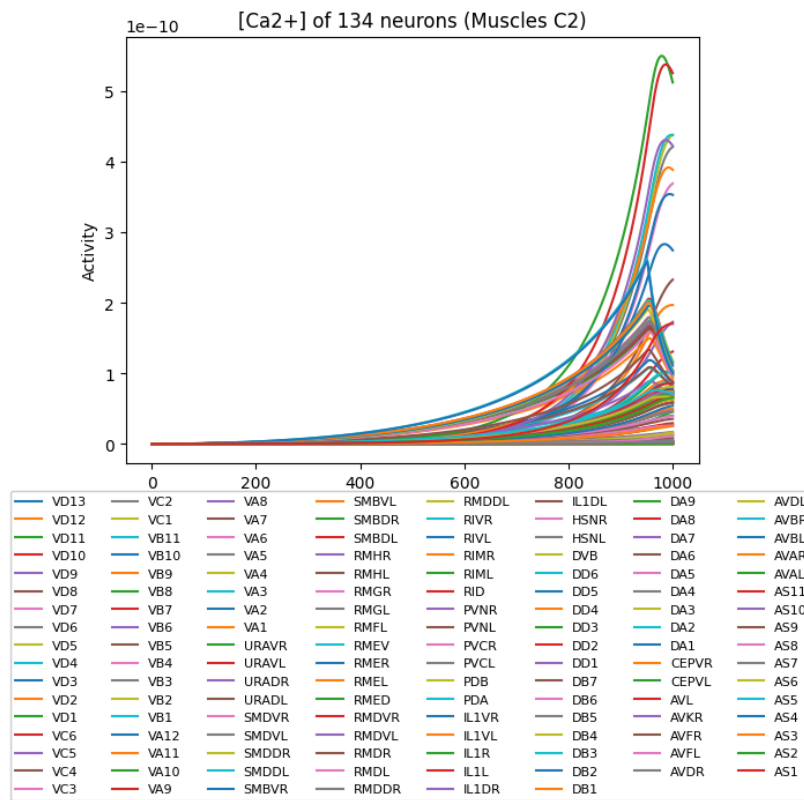
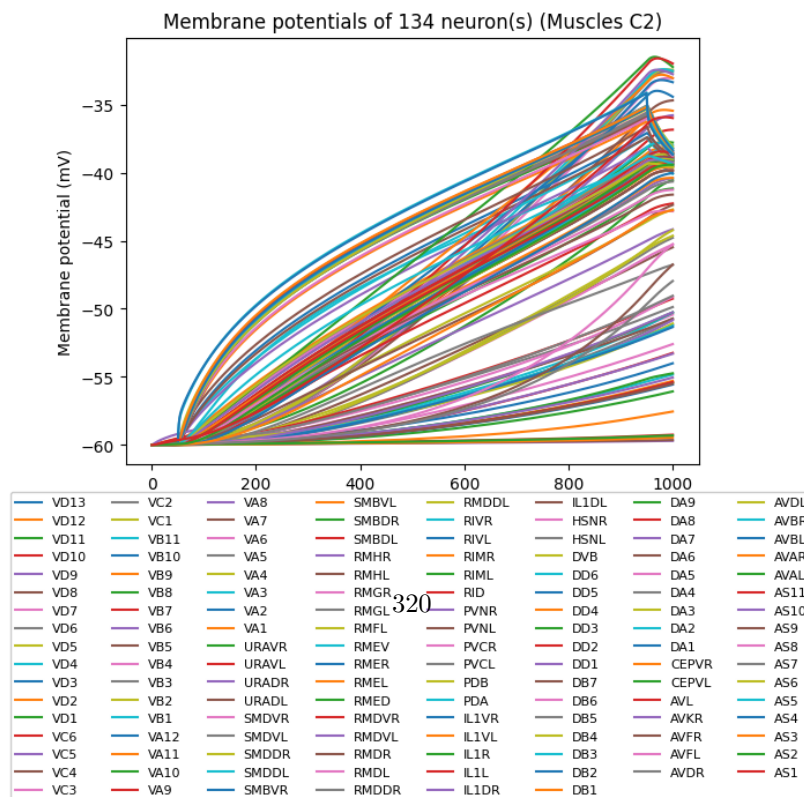


Figure 329: Traces of neuron activity and potentials.



6.33.6 Compact Morphology Grid

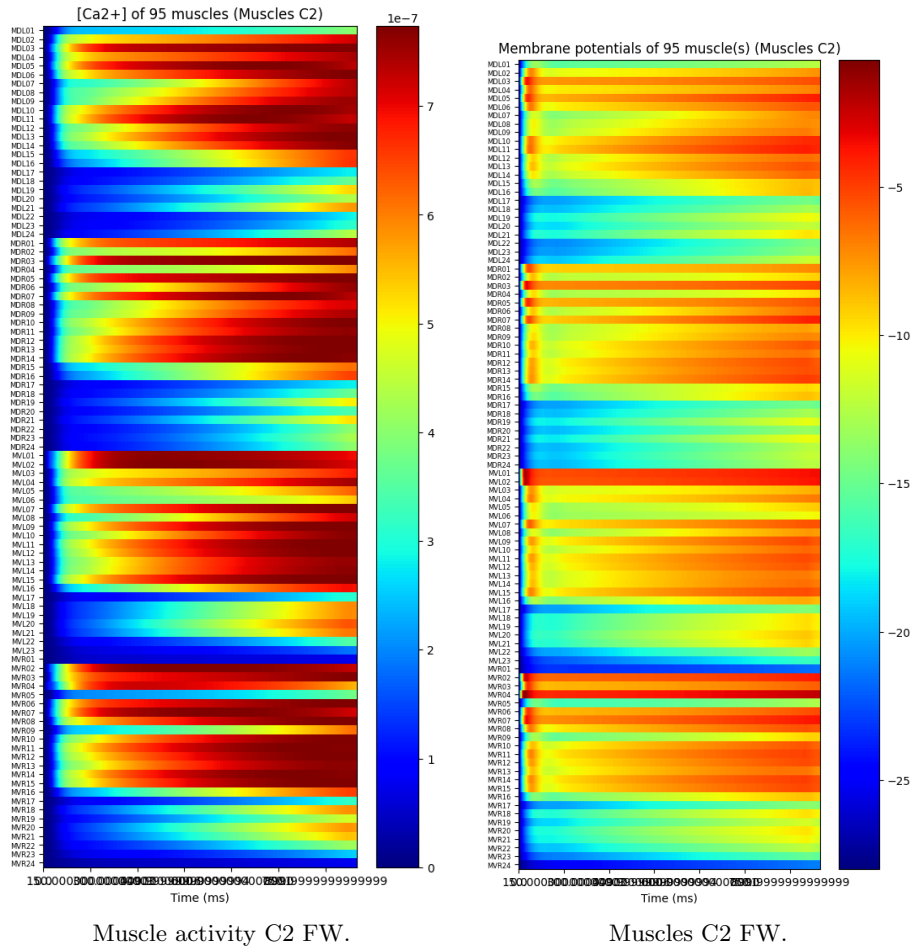


Figure 331: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).

6.33.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.6 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 135: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	1.9 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[=-----]	1.0 / 10
Overall Severity	[=====]	4.6 / 10

6.34 Movement Analysis: AVB_forward_light

This section provides an in-depth kinematic breakdown, locomotion state classification, undulation mechanics, and phenotype severity assessment for simulation run C2_Muscles_2026-08-21_15-51-38-AVB_forward_light.

6.34.1 Locomotion State Classification

Table 136: Behavioral State Breakdown for AVB_forward_light

Locomotion State	Time Fraction (%)
Forward Crawling	12.1%
Backward Crawling	26.7%
Stationary	0.0%
Reversal	14.6%
Omega Turns	29.1%
Shallow Turns	17.6%
Irregular / Abnormal	0.0%

6.34.2 Kinematic & Velocity Dynamics

Table 137: Kinematic and Velocity Metrics for AVB_forward_light

Kinematic Metric	Value	Unit / Scale
Net Displacement	0.0403	mm
Gross Distance	0.1426	mm
Path Efficiency (Net/Gross)	0.2824	[0.0 – 1.0]
Mean Speed	0.1431	mm/s
Maximum Forward Velocity	0.7181	mm/s
Maximum Backward Velocity	0.6649	mm/s
Median Velocity	0.0869	mm/s
Velocity Std Deviation	0.1852	mm/s
Velocity RMS	0.2341	mm/s
Fraction Time Moving Forward	43.4%	ratio
Fraction Time Moving Backward	55.4%	ratio
Fraction Time Stationary	0.0%	ratio
Acceleration (Mean)	-0.4871	mm/s ²
Maximum Acceleration	168.7893	mm/s ²
Acceleration RMS	22.4432	mm/s ²
Velocity Autocorrelation	0.7753	correlation
Reversal Frequency	24.0964	s ⁻¹
Mean Curvature	3901.942	rad/mm
Omega Turn Count	48	count

6.34.3 Undulation Wave Mechanics

Table 138: Undulation Wave Parameters for AVB_forward_light

Undulation Parameter	Value	Unit
Crawl Amplitude	0.0068	rad (bending)
Dominant Frequency	0.0	Hz
Wavelength	0.82	mm
Wave Velocity	0.0	mm/s
Phase Coherence	0.79	[0.0 – 1.0]
Mean Muscle Activation	0.790137	relative
Mean Hydrodynamic Pressure	0.0	Pa

6.34.4 Worm Motion and Activity Figures

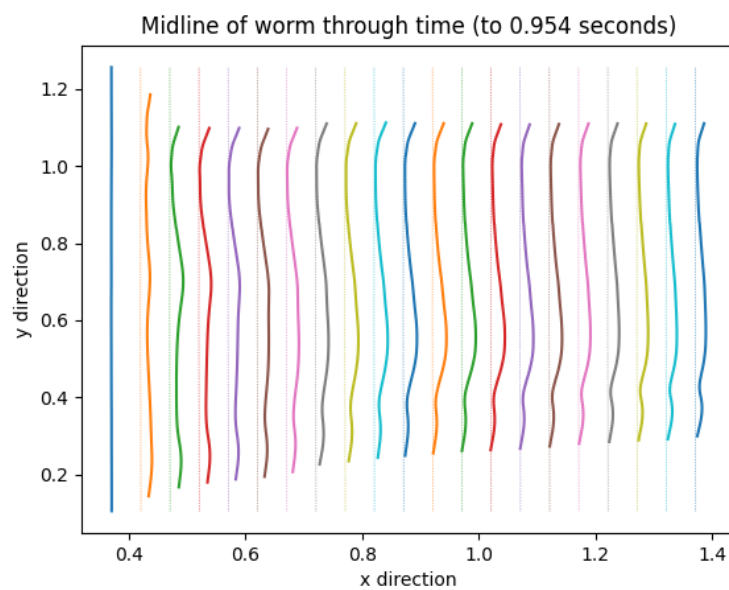


Figure 333: Midline of worm through time.

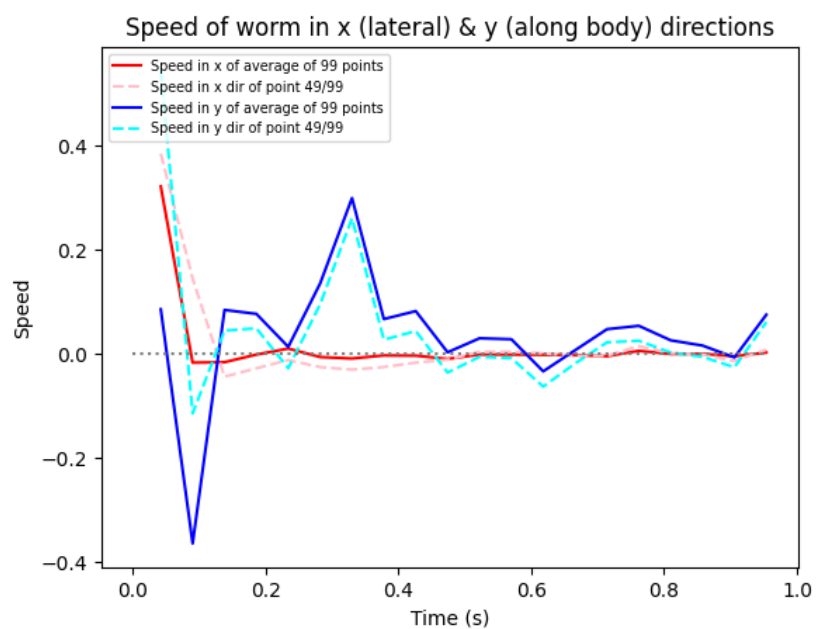


Figure 334: Speed of worm along body directions.

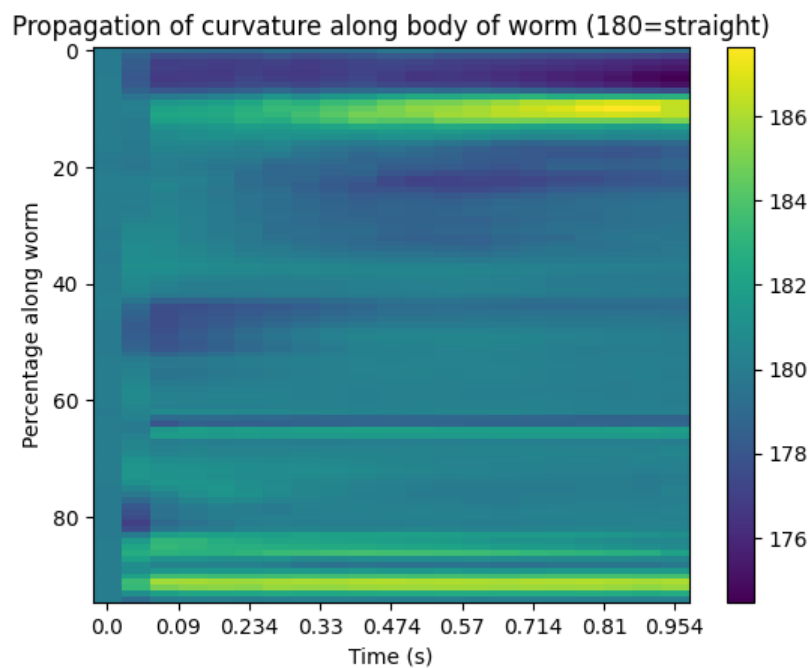


Figure 335: Propagation of curvature along body of worm.

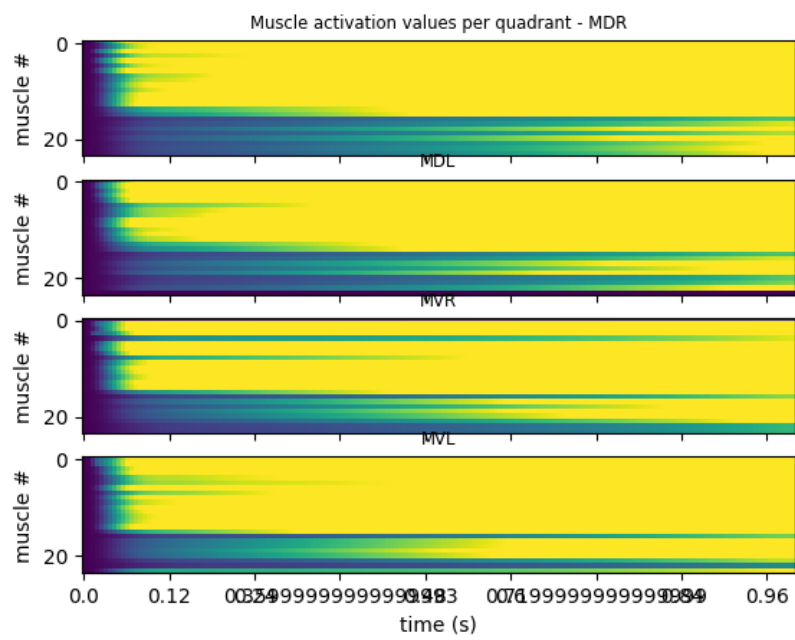


Figure 336: Muscle activities per quadrant.

6.34.5 Trace Figures

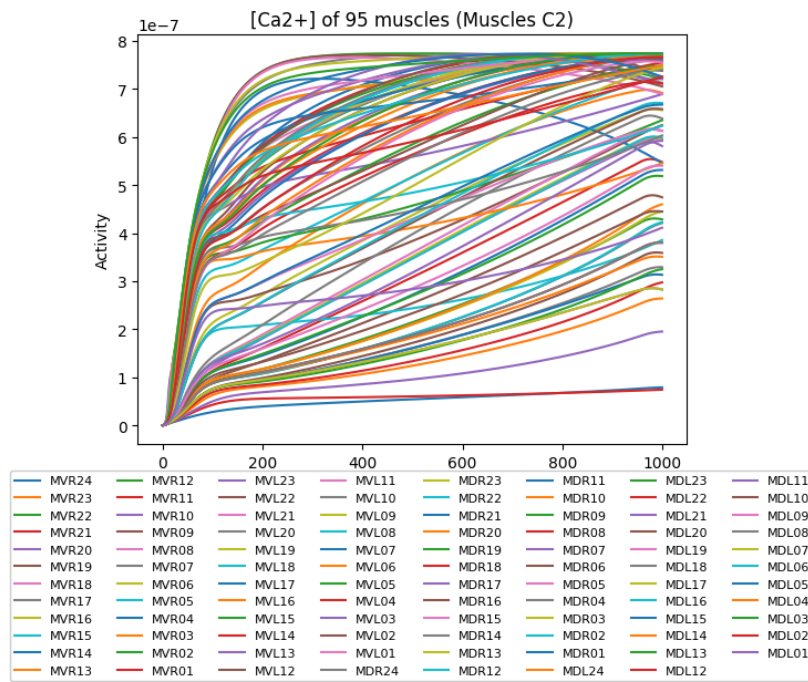
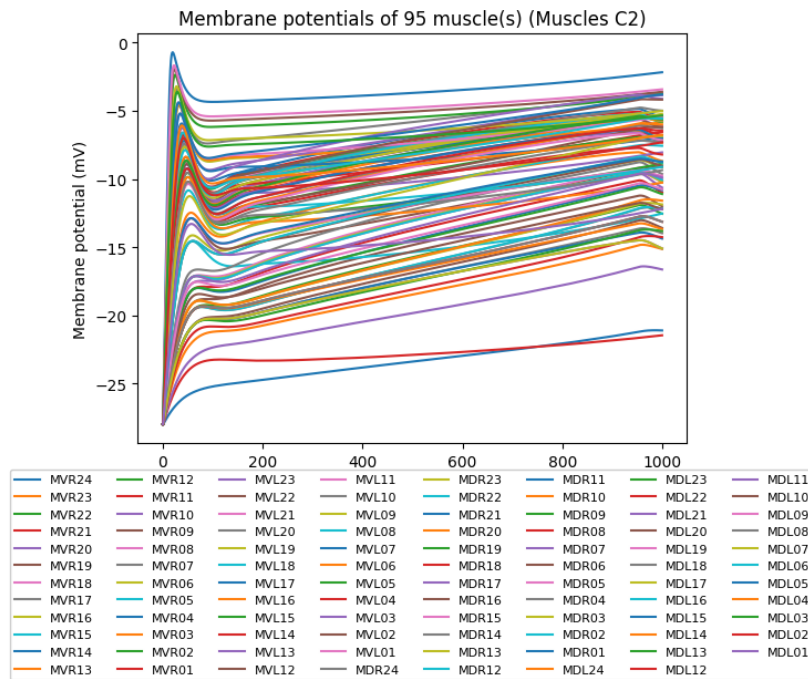


Figure 337: Traces of muscle activity and potentials.



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Figure 338: Traces of muscle activity.

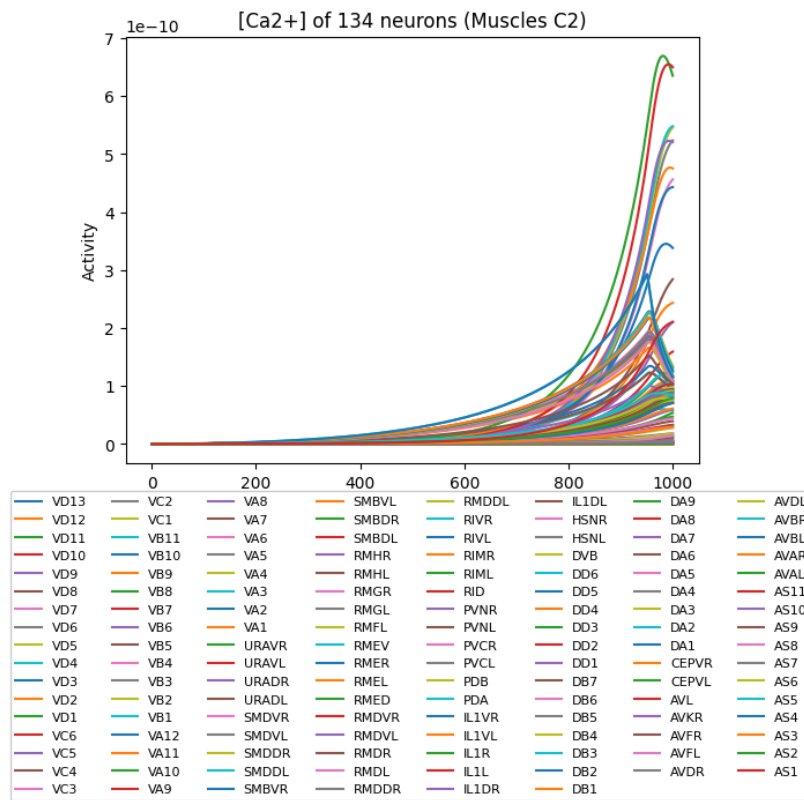
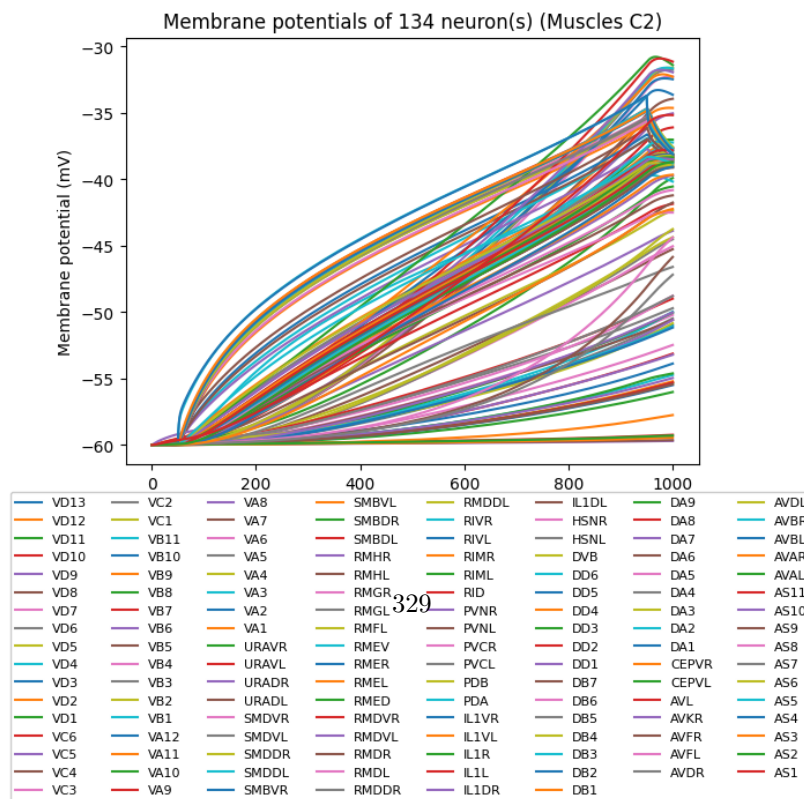


Figure 339: Traces of neuron activity and potentials.



6.34.6 Compact Morphology Grid

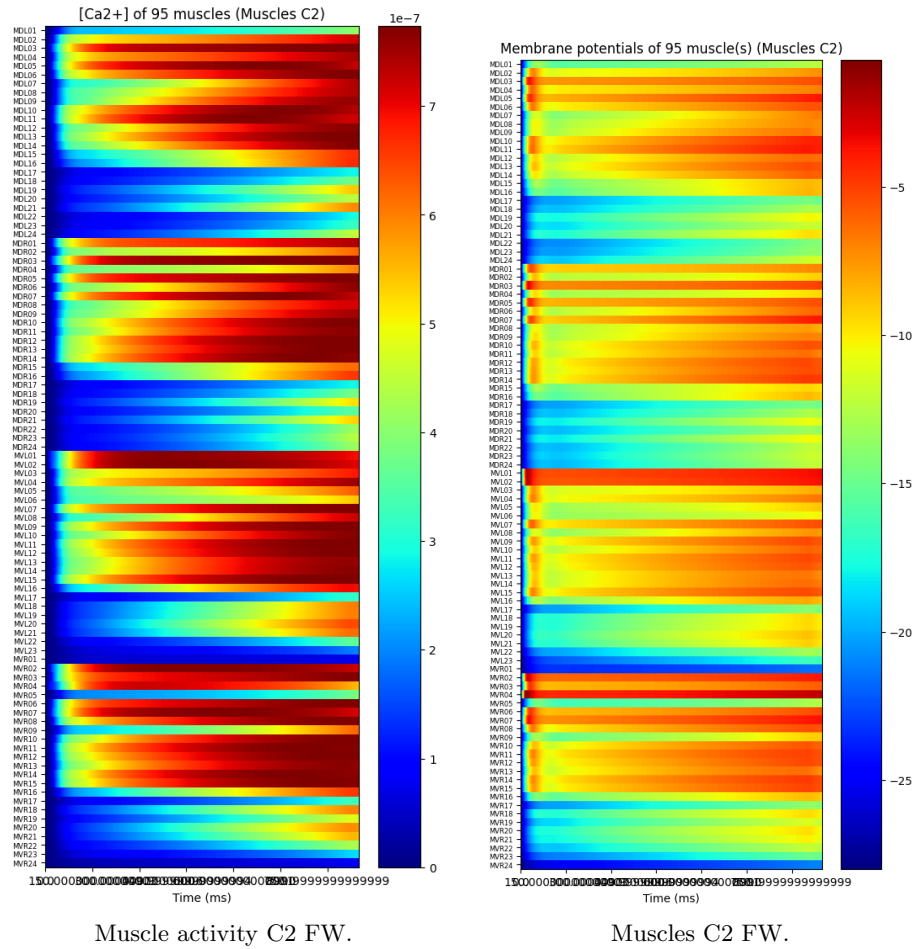


Figure 341: Muscle activity and morphology, shown as a 2x1 grid for compact comparison (row 1 of 2).

6.34.7 Phenotype Severity & Diagnostic Classification

- **Paralysis / Movement Failure Diagnosis:** HYPERKINETIC
- **Overall Phenotype Severity:** 4.7 / 10.0 (MODERATE PHENOTYPE)
- **Mutation Classification:** Slightly degenerate

Table 139: Phenotype Severity Ratings (0.0 = Normal, 10.0 = Severe Defect)

Domain	Scale	Score / 10
Locomotion	[-----]	0.0 / 10
Turning	[=====]	10.0 / 10
Undulation	[=-----]	2.1 / 10
Muscle Output	[=====]	10.0 / 10
Symmetry	[=-----]	1.2 / 10
Overall Severity	[=====]	4.7 / 10

7 Conclusions

From the simulations, it is clear that there is no easy way to make something artificially which is better than what nature did. Most subjects performed somewhat same or way worse. Not even potentiations produced outlying results.

Almost all simulations have failed to show a correct undulation which the original unmutated *C. elegans* had. This also shows that knocking out or potentiating motor connections will likely not produce results which are moving more or further. This also shows that if even possible, finding a "better" mutation will be much more computationally expensive than most simulations.

References

- [1] The openworm github repository,
<https://github.com/openworm/OpenWorm>
- [2] Official c302 repository,
<https://github.com/openworm/c302>
- [3] LEMS file examples,
<https://github.com/openworm/c302/tree/master/examples>
- [4] Cell list of muscles,
https://raw.githubusercontent.com/openworm/c302/master/c302/c302_Muscles.py
- [5] c302 configuration scripts,
<https://github.com/openworm/c302/tree/master/c302>