

Research Article

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Visualizing Social and Neural Connectivity in Autism: Insights from Clustering and Stochastic Models

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Abstract

Autism spectrum disorder (ASD) is characterized by diverse patterns of social interaction, communication, and behavior. This study explores the application of clustering and stochastic migration models to visualize and understand the social and neural connectivity patterns associated with autism. The clustering model, with its strong internal connections and limited external connections, mirrors the tight-knit social groups and communication barriers often observed in individuals with autism. In contrast, the stochastic model, characterized by more dispersed connections and greater adaptability, represents the variability and flexibility seen in social interactions across typical individuals. By comparing these models, we can gain deeper insights into the unique challenges and strengths of individuals with autism, highlighting the importance of personalized interventions. Additionally, these models provide a visual framework for understanding the differences in brain connectivity patterns observed in autism, with implications for both behavioral and neural correlates. This study underscores the value of computational models in advancing our understanding of autism and guiding effective support strategies.

Keywords: Autism, Neural Connectivity, Clustering, Computational Model

1. Introduction

Autism spectrum disorder (ASD) is a complex neurodevelopmental condition characterized by a wide range of symptoms including difficulties in social interaction, communication challenges, and repetitive behaviors. The heterogeneity of autism makes it imperative to explore diverse models that can encapsulate the various behavioral and neural patterns associated with the disorder. Computational models provide a powerful tool to visualize and analyze these patterns, offering insights that can inform both scientific understanding and practical interventions $[1,2]$.

In this study, we employ two distinct computational models to represent and understand the connectivity patterns in individuals with autism: the clustering migration model and the stochastic migration model. The clustering migration model is designed to mimic the formation of tight-knit social groups, a phenomenon frequently observed in individuals with autism [3]. This model features strong internal connections within clusters and weak connections between clusters, reflecting the tendency of individuals with autism to form strong bonds with specific people while experiencing challenges in establishing connections outside their immediate social circle [4]. This model

also incorporates reverberating signals within clusters with limited exits, symbolizing the repetitive behaviors and restricted interest's characteristic of autism [5].

Conversely, the stochastic migration model represents a more dispersed and variable pattern of connections. This model, characterized by medium-strength connections and multiple exits, encapsulates the variability in social interactions observed across the typical individual [6]. Some individuals with autism, though, exhibit greater adaptability and have a wider range of social connections, which this model effectively captures. The stochastic model's representation of multiple exits suggests a higher degree of flexibility in communication and social behavior, contrasting with the more rigid patterns depicted in the clustering model [7].

Recent advancements in understanding synaptic variability and quantum effects have furthered our knowledge of neural dynamics in ASD. For example, the use of perovskite quantum dots in optoelectronic synaptic devices illustrates the impact of quantum effects on synaptic function and variability, highlighting the importance of integrating quantum mechanics into our understanding of neural processes [8,9].

 By comparing these two models, we aim to highlight the diverse social and neural connectivity patterns present in individuals with autism. The clustering model can be seen as a representation of overconnectivity within certain neural networks, while the stochastic model may reflect a more balanced or varied the stochastic model may reflect a more balanced of varied $(2)w_{i,j}$
connectivity pattern [10]. These differences in connectivity have s ignificant implications for understanding the neural basis of **Moderations** $\frac{1}{2}$ autism and for developing tailored interventions [11]. The

Understanding these patterns is crucial for designing effective autism spectrum interventions and support systems. For individuals exhibiting behaviors similar to those in the clustering model, interventions 1. Initia might focus on gradually increasing exposure to new social distri situations and strengthening weak connections, enhancing strategies for supporting individuals and strengthening weak communication skills and providing support to navigate varied social interactions could be also beneficial $[12, 13]$. \mathbb{R}^2 $\frac{1}{2}$ $\frac{1}{\sqrt{2}}$

visualizing and understanding the complex patterns of social $x'_{2i} = r \cos(\theta)$ and neural connectivity in autism. By providing a visual and and neural connectivity in autism. By providing a visual and $\frac{y_{2i} - r}{2i}$ conceptual framework, these models can guide more effective and personalized strategies for supporting individuals with 3.Con and personanzed strategies for supporting individuals with 3.000
autism, ultimately contributing to better outcomes and quality (trian of life. α if the implementation of three distinct models, each representing different aspects of the intervals of the interv **Methodology** $\overline{}$

Methodology

Square: w
This study utilizes computational models to explore the social Hexagon: This study utilizes computational models to explore the social Hexage and neural connectivity patterns associated with autism spectrum Pental disorder (ASD). The methodology involves the implementation Heptodisorder (ASD). of three distinct models, each representing different aspects of connectivity and migration behavior in a simulated neural 4. Med network. The models include clustering migration, stochastic contract of the steps and equations used for each model. migration, and detailed simulations of reverberating signals within neural circuits. These models are described by a series of mathematical equations and visualized using Python libraries. Below, we detail the methodological steps and equations used for each model. I his study utilizes computational models to explore the social Hexag and neural connectivity patterns associated with autism spectrum P entagon: w disorder (ASD). The methodology involves the implementation expression represent *signals with the district models, each representing different aspects* \mathbf{s} σ detailed simulations involve modeling reverse modeling reverse modeling reverse σ **Model 3. Detailed Simulations of Reverberating Signals**

3.1. Models Model 1: Clustering Migration (Graph 1.) Section 3.1 Models

Model 1. Clustering Migration (Graph 1.)

The clustering migration model simulates the formation of tightknit social groups with strong internal connections and weak exit nodes: connections between clusters.

1. Initial Positions: Cells are uniformly distributed along the x -axis: x -axis: $\frac{d}{dx}$ χ -axis: χ -axis: Cells are uniformly distributed along the x-axis: χ -axis: χ

$$
x_i = -200 + \frac{400i}{N-1} \text{ for } i = 0, 1, 2, ..., N-1
$$

2. Migration to Semichele: Cells migrate to form a semichele of radius 8, with clustering effects introduced by adding Gaussian 2. Reve noise: noise:

1)
$$
\theta_{1i} = \frac{i\pi}{N-1}
$$
 for $i = 0,1,2,..., N-1$
\n2) $x'_{1i} = r\cos(\theta_{1i}) + \mathcal{N}(0, \sigma^2)$ where $\mathcal{N}(0, \sigma^2) \sim \mathcal{N}(0, 0.2^2)$
\n3) $y'_{1i} = r\sin(\theta_{1i})$

trial:

3. Connectivity: Strong connections are established within clusters and weak connections between clusters:

(1)=
$$
w_{\text{strong}}
$$
 for $i, j \in C_k$ and $i \neq j$
(2) $w_{i,j} = w_{\text{weak}}$ for $i \in C_m, j \in C_n$ and $i \neq j$ and $m \neq n$

Model 2. Stochastic Migration

The stochastic migration model represents more variable connectivity patterns, highlighting the diversity within the ning effective autism spectrum.

1. Initial Positions: Similar to Model 1, cells are uniformly oder, interventions 1. Initial 1 ostions. Similar to Moder 1, cens are antiomity
ure to new social distributed along the x-axis.

ections, enhancing 2. Stochastic Migration: Cells migrate to a semicircle of radius ate varied $\,8,$ with stochastic variations in their angles: 1. In the provincial variations in their angles. 1. Initial Positions: Similar to Model 1, cells are uniformly distributed and $\frac{1}{2}$

This study underscores the value of computational models in and personalized strategies for supporting individuals with autism, ultimately 2. Stochastic Migration: Cells migrate to a semicircle of radius 8 , with stochastic providing a visual and conceptual framework, these models can guide more effective 2 ⁼ clip ([−] ¹ ⁺ (0, 2), 0,) where (0, 2) [∼] (0, 0.32) ′ = cos (2) ′ = sin (2) 2 ⁼ clip ([−] ¹ ⁺ (0, 2), 0,) where (0, 2) [∼] (0, 0.32) 2 ′ = cos (2) 2 ′ = sin (2) 2. Stochastic Migration: Cells migrate to a semicircle of radius 8 , with stochastic variations in their angles: 2 ⁼ clip ([−] ¹ ⁺ (0, 2), 0,) where (0, 2) [∼] (0, 0.32)

ctive
with 3.Connectivity Patterns: Various geometric patterns are defined dals with 3. Connectivity Patterns: various geometric patterns are defined
ad quality (triangles, squares, hexagons, etc.), with connections established anty (triangles, squares, nexagons, etc.), with connections established
accordingly: μ (trangles, squares, nexagons, etc.), with connections established accordingly: α cordingly: s_{sc} structures, the connections extended according and t_{sc} and $t_{\text{$ T_{trans} (triangles, squares, nexagons, etc.), with connections α ccorumgry. nnectivity Pa sources, hexagons, with connections established accordingly: − 1 + Comparticulari
Comparticulari Detterma: Venicus coompatric nottorna era defin with 3.Conne
clity (trionals

connectivity and migration behavior in a simulated network. The models in a simulated network. The models include \sim $\sum_{n=1}^{\infty}$ study utilizes computational models to explore the social and neural connectivity $\sum_{n=1}^{\infty}$ Triangle: $w_{i,(i+1) \text{ mod } 3} = w_{i,(i+2)} \text{ mod } 3 = 1$ for $i \in \{0,1,2\}$ $\text{Square: } W_{i,(i+1)} \text{ mod } 4 = W_{i,(i+2)} \text{ mod } 4 = 1 \text{ for even } i \in \{3,4,5,6\}$
social Hexagon: $W_{i,(i+1)} \text{ mod } 6 = W_{i,(i+2)} \text{ mod } 6 = 1 \text{ for } i \in \{7,8,9,10,11,12\} \text{ mod } 6 = 1 \$ Pentagon: ,(+1)mod5 = 1 for ⬚ ∈ {13,14,15,16,17} Pentagon: ,(+1)mod5 = 1 for ⬚ ∈ {13,14,15,16,17} Square: ,(+1)mod4 = ,(+2)mod4 = 1 for even ∈ {3,4,5,6} ementation Heptagon: $w_{i,(i+1)}$ mod $7 = 1$ for $\dddot{w}_{i}(t+1)$ = $\{18,19,20,21,22,23,24\}$ Triangle: $w_{i,(i+1) \text{ mod } 3} = w_{i,(i+2) \text{ mod } 3} = 1$ for $i \in \{0,1,2\}$ Square: $w_{i,(i+1)}$ mod4 = $w_{i,(i+2)}$ mod4 = 1 for even $i \in \{3,4,5,6\}$
the social University: with connections established accordingly: the social Hexagon: $w_{i,(i+1)}$ mod $6 = w_{i,(i+2)}$ mod $6 = 1$ for $i \in \{7,8,9,10,11,12\}$ (12)
n spectrum Pontagon: $w_{i,(i+1)}$ mod $5 = 1$ for $\sum_{i=1}^{n} i \in \{1,2,14,15,16,17\}$

4. Medium Strength Random Connections: Additional stochastic connections are added with medium strength: existing signals $wi, j =$ Uniform (0.5,1.5) for $i \neq j$ and $(i, j) \notin$ existing edges 4. Medium Strength Random Connections: Additional connections: Additional connections are additions are added with $\frac{1}{2}$ neural 4. Medium Strength Random Connections: Additional \mathcal{A} , and \mathcal{A} additions: Additional connections: Additional connections are additions are added with \mathcal{A} medium strength: Random Connected neural 4. Medium Strength Random Connect

thon libraries. Model 3. Detailed Simulations of Reverberating Signals

quations used The detailed simulations involve modeling reverberating
quations used The detailed simulations involve modeling reverberating quations used The detailed simulations involve including reversering
signals within neural circuits, highlighting the differences in connectivity and signal propagation. signals within neural circulus, highlighting the differences in

1. Circle Graph with Exits: A circle graph with 20 nodes is mation of tight-
created, with nodes connected in a circular manner and specific
ions and weak exit nodes: exit nodes:

$$
x_i = \cos\left(\frac{2\pi i}{N}\right) \text{ for } i = 0, 1, 2, \dots, N - 1
$$

ted along the

$$
y_i = \sin\left(\frac{2\pi i}{N}\right) \text{ for } i = 0, 1, 2, \dots, N - 1
$$

2. Migration to Semicircle: Cells migrate to form a semicircle of connectivity and signal propagation. -1 The detailed simulations involve modeling reverberating $\overline{}$ including simulations involve modeling reverberating signals within neural circuits, highlighting the differences in explana whale the connectivity and signal propagation. - 1 The detailed simulations involve modeling reverse in the difference in the \sim $\frac{1}{\sqrt{2}}$ μ μ ₂, μ _{1,} μ ₂, μ ₂,

2. Reverberating Signals: Signals propagate with added noise, representing the dynamic nature of neural communication: g Gaussian 2. Reverberating Signals: Signals propagate v during Gaussian 2. Reverberating Signals. Signals propagate with added noise, representing the dynamic nature of n

$$
x'_{i} = x_{i} + \mathcal{N}(0, \sigma^{2})
$$

$$
y'_{i} = y_{i} + \mathcal{N}(0, \sigma^{2})
$$

3. Escape Probability: The escape probability at exits is defined $\frac{1}{2}$ by a Bernoulli trial:

 $\frac{1}{\sqrt{2}}$. Number of $\frac{1}{\sqrt{2}}$ reverses is controlled by the number of $\frac{1}{\sqrt{2}}$

 \sim \sim \sim \sim \sim

$$
P_{\text{escape}} = \begin{cases} 1 & \text{if the signal escapes through the exit} \\ 0 & \text{otherwise} \end{cases}
$$

4. Number of Reverberations: The number of reverberations is $\theta_{2i} = \text{clip}$ controlled by the number of iterations:

Reverberations $= R$ \mathcal{R} α mever of the cells are plotted, with connections α in α

3.2. Visualization and stockastic models are shown side-by-side-by-side-by-side-by-side-by-side for comparison, \bullet Cells are more

The models are visualized using Python's Matplotlib library. For each model, the initial and migrated positions of the cells are plotted, with connections indicated by lines. The clustering nodes sugg and stochastic models are shown side-by-side for comparison, highlighting the differences in connectivity patterns. This model

By applying these models, we aim to capture and analyze the By applying these models, we aim to capture and analyze the connections and greater adaptability [7,0].
diverse connectivity patterns observed in individuals with autism, providing insights into the social and neural dynamics autism, providing insights model social and neural dynamics **or apply** that characterize the autism spectrum. clustering and stochastic models are shown side-by-side for comparison, highlighting patterns observed in the social and individuals with a social and so e and analyze the connections a

4. Results

In this section, we present and interpret the results of the three $\overline{}$ another with 5 ex computational models used to visualize the social and neural connectivity patterns in individuals with autism spectrum Scenario 1: disorder (ASD). The models include the clustering migration model, the stochastic migration model, and the detailed simulations of reverberating signals within neural circuits. d d

Graph 1: Clustering Migration Model **State of visualize the social and neural connection** observation

The first graph depicts the clustering migration model, where cells • Signa initially distributed along the x axis migrate to form a semicircle representing diffi with a radius of 8. This model incorporates a clustering effect by • Li adding Gaussian noise to the positions of the cells. This case tasks or environ-

$$
\theta_{1i} = \frac{i\pi}{N-1} \text{ for } i = 0,1,2,...,N-1
$$

\n
$$
x'_{1i} = r\cos(\theta_{1i}) + \mathcal{N}(0,\sigma^2) \text{ where } \mathcal{N}(0,\sigma^2) \sim \mathcal{N}(0,0.2^2)
$$

\n
$$
y'_{1i} = r\sin(\theta_{1i})
$$

\n
$$
x_i
$$

Observations:

• Cells form distinct clusters with strong internal connections.
• Weak connections are observed between clusters, representing

• Cens form usunct clusters with strong internal connections.
• Weak connections are observed between clusters, representing limited interaction outside immediate social groups.

• The clustering effect introduces slight positional perturbations, $\frac{1}{2}$ and $\frac{1}{2}$ in $\frac{1}{2}$ in $\frac{1}{2}$ in the state of $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{1}{2}$ and \frac emphasizing the tendency of individuals with autism to form tight-knit social groups and experience challenges in connecting interactions. outside these groups. communication, akin to individuals with more fluid social interactions.

This graph effectively models the social dynamics in autism, where strong bonds are formed within specific groups, but communication with external groups is limited [3,4]. Reverberating Signals:

Graph 2: Stochastic Migration Model

The second graph illustrates the stochastic migration model, where cells migrate to form a parabola with height of 8,

defined incorporating stochastic variations in their angles.

This model represents more variable and dispersed connectivity patterns. form a parabola with $\frac{1}{\sqrt{2}}$, including stochastic variations in the intervals. $\sum_{i=1}^{\infty}$ model represents model connectivity patterns. I his model represents more variable and dispersed connectivity Igh the exit end of patterns.

4. Number of Reverberations: The number of reverberations is
\ncontrolled by the number of iterations:
\n
$$
\theta_{2i} = \text{clip} \left(\frac{i\pi}{N-1} + \mathcal{N}(0, \tau^2), 0, \pi \right) \text{ where } \mathcal{N}(0, \tau^2) \sim \mathcal{N}(0, 0.3^2)
$$
\n
$$
x'_{2i} = r \cos(\theta_{2i})
$$
\n
$$
y'_{2i} = r \sin(\theta_{2i})
$$

Observations: Observations:

• Cells are more evenly dispersed along the semicircle, reflecting lotlib library. greater variability in social interactions.

 \cdot the cells \cdot The presence of medium-strength random connections between exis • The presence of medium-strength random connections between nodes suggests flexibility and adaptability in communication. The clustering nodes suggests flexibility and adaptability in communication.

This model captures the diversity within the autism spectrum, This model captures the diversity within the autism spectrum, highlighting individuals highlighting individuals who exhibit a wider range of social connections and greater adaptability [7,6]. this model captures the diversity whilm the addisin spectrum, This model captures the diversity within the autism spectrum, mging matviduals who exhibit a wider range of social connections and greater a

Graph 3: Reverberating Signals in Neural Circuits Graph 3: Reverberating Signals in Neural Circuits

The third graph simulates reverberating signals within neural circuits, highlighting differences in connectivity and signal propagation. Two scenarios are modeled: one with 2 exits and exults of the three $\frac{1}{2}$ another with 5 exits. 1.5 Second graph with 2.5 exits.

sm spectrum Scenario 1: Circle graph with 20 nodes and 2 exits. Ing migration

$$
x_i = \cos\left(\frac{2\pi i}{N}\right), y_i = \sin\left(\frac{2\pi i}{N}\right)
$$

Observations:

el, where cells • Signals reverberate 20 times within the circle before exiting, representing, representing, representing between tasks of the circle before exiting, emicircle representing difficulty in breaking out of behavior loops.

et by • Limited exits symbolize challenges in transitioning between tasks or environments, akin to the repetitive behaviors seen in autism. environments, activities, activities, activities, activities, and the repetitive behaviors seen in an automatic

Scenario 2: Circle graph with 20 nodes and 5 exits.

$$
x_i = \cos\left(\frac{2\pi i}{N}\right), y_i = \sin\left(\frac{2\pi i}{N}\right)
$$

Observations:

• Signals reverberate 5 times within the circle before exiting, ial groups. indicating greater ease in transitioning between states.

nal perturbations, • Multiple exits represent higher flexibility and adaptability in with autism to form neural communication, akin to individuals with more fluid social value of $\frac{1}{\sqrt{2}}$ interactions. communication, akin to individuals with more fluid social interactions.

1 if the signal escapes through the signal escapes through the exit of the exit of the exit of the exit of the

Reverberating Signals:

$$
x'_i = x_i + \mathcal{N}(0, \sigma^2)
$$

$$
y'_i = y_i + \mathcal{N}(0, \sigma^2)
$$

Escape Probability:

escape = {{

escape = {

$P_{\text{escape}} = \begin{cases} 1 & \text{if the signal escapes through the exit} \\ 0 & \text{otherwise} \end{cases}$ 0 otherwise prediction if the signal escapes through the evit The results U otherw.

Escape Probability:

These simulations provide insights into the neural dynamics the unique challenges and strengths of individ underlying autism. The difficulty in breaking out of behavior spectrum, ultimately guiding more effective and loops (as seen in the first scenario) parallels the repetitive intervention strategies. behaviors and restricted interests in autism. The preference for continuous movements, such as watching wheels rolling, can be attributed to the brain's need for predictability and order [14].

Conclusion Γ movements, such as watching when Γ as watching Γ

The results of these computational models highlight the complex social and neural connectivity patterns in individuals with autism. By visualizing these patterns, we can better understand the unique challenges and strengths of individuals on the autism spectrum, ultimately guiding more effective and personalized intervention strategies.

Figure 1: The protoneurons migrate from the midline (simulated as the ventricular wall) to the semicircunference line (cortex). Note the formation of clusters in the first graph, representative of autism and the fluid second graph representative of a typical individual. matter of classes in the first graph, representative of authoritan

For eventy and α parabola, tenerate θ or the international method is communications. The presence of random connections between nodes suggests flexibility and adaptability in communication in the right graph **Graph 2:** Cells are restricted to its clusters and have poor communications with other clusters, characteristic of autism. On the right graph Cells are more evenly along the parabola, reflecting greater variability in social interactions. The presence of mediumstrength

communication in the right graph graph

Model 1: Reverberating Circle with 2 Exits Model 2: Circle with 5 Exits

loops (as seen in the first scenario) parallels the repetitive behaviors and restricted interests in autism (left graph). The preference for continuous movements, such as watching wheels rolling, can be attributed to the brain's need for predictability and order [14]. Right graph represents a typical circuit. The preference for continuous movements, such as watching movements, such as watching watching was well as w **Graph 3:** These simulations provide insights into the neural dynamics underlying autism. The difficulty in breaking out of behavior

\mathbf{n} **5. Discussion**

The computational models employed in this study provide a visual and conceptual framework to understand the diverse social and neural connectivity patterns observed in individuals with autism spectrum disorder (ASD). By comparing the clustering and stochastic migration models, we gain insights into the characteristic behaviors and neural dynamics associated with autism, which have significant implications for intervention and support strategies.

5.1. Clustering Migration Model

The clustering migration model highlights the tendency of individuals with autism to form tight-knit social groups with strong internal connections and weak connections between clusters. This pattern can be interpreted as a reflection of the social dynamics often observed in individuals with autism, who may form strong bonds with specific individuals or groups while experiencing challenges in establishing and maintaining connections outside their immediate social circle [3,4]. The reverberating signals within clusters, with limited exits, symbolize the repetitive behaviors and restricted interest's characteristic of autism [5].

One of the key challenges faced by individuals with autism is difficulty in breaking out of behavior loops. The clustering model's limited exits represent the challenges in transitioning between tasks or environments, which is a common characteristic in autism. Repetitive behaviors and restricted interests, often described as "stimming," provide a sense of predictability and comfort to individuals with autism. These behaviors can be seen as a coping mechanism to deal with overwhelming sensory input or to self-regulate emotions [15]. The model underscores the importance of interventions that gradually introduce new social situations and strengthen weak connections, thereby facilitating greater social flexibility and adaptability [12].

5.2. Stochastic Migration Model

The stochastic migration model, characterized by more variable and dispersed connections, represents the variability in social interactions observed across the autism spectrum [6]. The model captures the diversity within the autism spectrum, highlighting individuals who exhibit a wider range of social connections and greater adaptability. Interventions for these individuals might focus on enhancing communication skills and providing support to navigate varied social interactions [13].

Recent research on synaptic loss and cognitive deficits in neurological conditions further emphasizes the importance of understanding synaptic variability and its impact on neural connectivity and behavior [16]. Additionally, advancements in quantum biology highlight the potential influence of quantum effects on synaptic function, which could provide new insights into the neural mechanisms underlying ASD [17].

The stochastic migration model, characterized by more variable and dispersed connections, represents the variability in social interactions observed across the autism spectrum and typical individual [6]. Some individuals with autism exhibit greater adaptability and have a wider range of social connections. The stochastic model's multiple exits suggest a higher degree of flexibility in communication and social behavior, which contrasts with the more rigid patterns depicted in the clustering model [7].

5.3. Neural Connectivity and Behavioral Correlates

The observed differences in connectivity in the models have parallels in neural connectivity patterns in individuals with autism. Research has shown that individuals with autism

may exhibit overconnectivity within certain brain regions and underconnectivity between regions, leading to difficulties in integrating information across different neural networks [10,11]. The clustering model can be seen as a representation of overconnectivity within specific neural networks, while the stochastic model may reflect a more balanced or varied connectivity pattern.

These neural connectivity patterns can explain some of the behavioral characteristics of autism. For example, the preference for continuous movements and repetitive actions, such as watching wheels rolling, can be understood as a manifestation of the brain's need for predictability and order. Continuous and repetitive actions provide a sense of stability and control, which can be comforting for individuals with autism who might otherwise experience sensory overload or difficulty in processing patterns observed in individuals v complex stimuli $[14]$.

5.4. Implications for Intervention

Understanding these connectivity patterns is crucial for designing Understanding these connectivity patterns is crucial for designing effective interventions and support systems for individuals with autism. For those exhibiting behaviors similar to those in the clustering model, interventions might focus on gradually

6. Attachments

Python Code Graph 1.

import numpy as np

import matplotlib.pyplot as plt

Parameters

 $num_cells = 400$

 $radius = 8$

x positions = np.linspace(-200, 200, num cells)

Model 1: Clustering Migration

theta 1 = np.linspace $(0, np.pi, num_cells)$

 x _migrated_1 = radius * np.cos(theta_1)

y migrated $1 =$ radius * np.sin(theta 1)

Adding some clustering effect by perturbing positions

 $cluster_effect = np.random.normal(0, 0.2, num_cells)$

increasing exposure to new social situations and strengthening weak connections. This approach can help individuals develop the skills needed to navigate more complex social environments and reduce the reliance on repetitive behaviors [12].

For individuals resembling the stochastic model, interventions might focus on enhancing communication skills and providing support to navigate varied social interactions. These interventions can leverage the existing flexibility and adaptability observed in these individuals, helping them to build more robust social networks and improve their overall social functioning [13].

Conclusion

The computational models presented in this study provide valuable insights into the diverse social and neural connectivity patterns observed in individuals with autism. By visualizing these patterns, we can better understand the unique challenges and strengths of individuals on the autism spectrum, ultimately and strengths of marviolatism included support strategies.

and strengths of marviolatism intervention

guiding more effective and personalized support strategies. These models underscore the importance of a nuanced approach to autism intervention, one that recognizes the variability within the spectrum and addresses the specific needs of each individual [18-33].

x migrated 1 += cluster effect

Model 2: Stochastic Migration

np.random.seed(42)

theta_2 = np.linspace(0, np.pi, num_cells) + np.random.normal(0, 0.3, num_cells)

 $\frac{1}{2}$ = np.exp(need 2, 0, np.pi) + 2m.ard mean $\frac{1}{2}$ is defined (0, pi) is easy are classes. theta_2 = np.clip(theta_2, 0, np.pi) # Ensure theta_2 is within [0, pi] to stay above xaxis

x migrated $2 =$ radius * np.cos(theta 2)

y migrated $2 =$ radius * np.sin(theta 2)

Plotting the results

fig, $ax = plt.subplots(1, 2, figsize=(14, 7))$

Plot for Model 1

 $ax[0]$.scatter(x positions, np.zeros(num cells), color='blue', label='Initial Position')

 $ax[0]$.scatter(x migrated 1, y migrated 1, color='red', label='Migrated Position')

```
ax<sup>[0]</sup>.set_title('Model 1: Clustering Migration')
```
ax[0].legend()

ax[0].axis('equal')

```
ax[0].set xlim([-radius*1.5, radius*1.5])
```
ax[0].set $ylim([-1, radius*1.5])$

nx.draw(G2, nx.get node attributes(G2, 'pos'), $ax=ax[1]$, with labels=True, node color='green', edge color='black', node size=500, font color='white')

draw_reverberation(ax[1], G2, exits2, num_reverberations_model2, escape ratio model2, noise multiplier model2)

ax[1].set_title('Model 2: Circle with 5 Exits')

Python code Graph 2.

import numpy as np

import matplotlib.pyplot as plt

import networkx as nx

import matplotlib.animation as animation .
A Function to create a circle graph with exits graph with exits graph with exits graph with exits graph with e

Function to create a circle graph with exits

def create_circle_graph(num_nodes, num_exits, strong_weight=2, weak_weight=0.1):

 $G = nx.Graph()$

 $nodes = range(num nodes)$

for i in nodes:

G.add_node(i, pos= $(np.cos(2 * np.pi * i / num_nodes)$, $np.sin(2 * np.pi * i /$ num_nodes))

G.add edge(i, $(i + 1)$ % num nodes, weight=strong weight)

exits = np.random.choice(nodes, num_exits, replace=False)

for exit in exits:

G.add_edge(exit, (exit + num_nodes // 2) % num_nodes, weight=weak_weight)

return G, exits

Parameters

 $num_nodes = 20$

 $num_exists_model1 = 2$

 $num_exists_model2 = 5$

- $num_reverberations_model1 = 20$
- $num_reverberations_model2 = 5$
- $\text{escape_ratio_model1} = 0.2$
- $\text{escape_ratio_model2} = 0.5$

Create graphs for both models

G1, exits1 = create circle graph(num nodes, num exits model1)

G2, exits2 = create circle graph(num nodes, num exits model2)

Function to draw reverberating signals

def draw reverberation(ax, G, exits, num reverberations, escape ratio):

 $pos = nx.get node attributes(G, 'pos')$

 $nodes = list(G.nodes)$

signals = $[0]$ # Start at node 0

for in range(num reverberations):

```
new signals = []
```
for signal in signals:

```
neighbors = list(G.neighbors(signal))
```
for neighbor in neighbors:

if np.random.rand $()$ > escape ratio or neighbor in exits:

new_signals.append(neighbor)

 ax.plot([pos[signal][0], pos[neighbor][0]], [pos[signal][1], pos[neighbor][1]], color='yellow')

 $signals = new$ signals

Plot settings

fig, $ax = plt.subplots(1, 2, figsize=(14, 7))$

Plot for Model 1

```
nx.draw(G1, nx.get node attributes(G1, 'pos'), ax=ax[0], with labels=True,
node_color='red', edge_color='black', node_size=500, font_color='white')
```

```
draw reverberation(ax[0], G1, exits1, num reverberations model1,
escape ratio model1)
```
ax^[0].set_title('Model 1: Reverberating Circle with 2 Exits')

Plot for Model 2

nx.draw(G2, nx.get node attributes(G2, 'pos'), $ax=ax[1]$, with labels=True, node_color='green', edge_color='black', node_size=500, font_color='white')

draw reverberation(ax[1], G2, exits2, num reverberations model2, escape ratio model2)

ax[1].set_title('Model 2: Circle with 5 Exits')

plt.show()

plt.show()

Plot for Model 2

ax[1].scatter(x_positions, np.zeros(num_cells), color='blue', label='Initial Position')

 $ax[1]$.scatter(x_migrated_2, y_migrated_2, color='green', label='Migrated Position')

```
ax[1].set_title('Model 2: Stochastic Migration')
```
ax[1].legend()

ax[1].axis('equal')

 $ax[1].set xlim([-radius*1.5, radius*1.5])$

 $ax[1].set$ ylim($[-1,$ radius*1.5])

plt.show()

Python codes

Graph 3.

import numpy as np

import matplotlib.pyplot as plt

import networkx as nx

Function to create a circle graph with exits

def create circle graph(num nodes, num exits, strong weight=2, weak weight=0.1):

 $G = nx.Graph()$

 $nodes = range(num nodes)$

for i in nodes:

G.add_node(i, pos=(np.cos(2 * np.pi * i / num_nodes), np.sin(2 * np.pi * i / num_nodes)))

G.add_edge(i, $(i + 1)$ % num_nodes, weight=strong_weight)

exits = np.random.choice(nodes, num_exits, replace=False)

for exit in exits:

G.add_edge(exit, $(exit + num_nodes // 2)$ % num_nodes, weight=weak_weight)

return G, exits

Parameters

num $nodes = 20$

num exits $model1 = 2$

num exits $model2 = 5$

num reverberations $model1 = 20$

num_reverberations_model2 = 5

escape ratio model $1 = 0.2$

escape ratio $model2 = 0.5$

noise multiplier model $1 = 10$

noise multiplier model $2 = 5$

Create graphs for both models

```
G1, exits1 = create circle graph(num nodes, num exits model1)
```
G2, exits 2 = create circle graph(num nodes, num exits model2)

Function to draw reverberating signals with noise and exits

def draw reverberation(ax, G, exits, num reverberations, escape ratio, noise_multiplier):

```
pos = nx.get node attributes(G, 'pos')
```

```
nodes = list(G.nodes)
```

```
signals = [0] # Start at node 0
```

```
for in range(num reverberations):
```
new signals $= []$

for signal in signals:

 $neighbors = list(G.neighbors(signal))$

for neighbor in neighbors:

if np.random.rand $()$ > escape ratio or neighbor in exits:

new signals.append(neighbor)

for in range(noise multiplier):

noise_ $x = np.random.normal(0, 0.02)$

noise $y = np.random.normal(0, 0.02)$

```
ax.plot([pos[signal][0], pos[neighbor][0] + noise x], [pos[signal][1],
pos[neighbor][1] + noise y], color='orange')
```
 $signals = new$ signals

for exit in exits:

ax.plot([pos[exit][0], pos[(exit + num_nodes // 2) % num_nodes][0]],

 $[pos[exit][1], pos[(exit + num nodes // 2) % num nodes][1]].$

color='yellow', linewidth=2, linestyle='dashed')

Plot settings

fig, $ax = plt$.subplots $(1, 2, figsize=(14, 7))$

Plot for Model 1

nx.draw(G1, nx.get node attributes(G1, 'pos'), $ax=ax[0]$, with labels=True, node_color='red', edge_color='black', node_size=500, font_color='white')

draw reverberation($ax[0]$, G1, exits1, num reverberations model1, escape ratio model1, noise multiplier model1)

ax[0].set_title('Model 1: Reverberating Circle with 2 Exits')

Plot for Model 2

Python code graph 3.

Conflict of Interest

Conflict of interest
The author declares no conflict of interest.

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