Proyecto

November 29, 2024

[1]:
```
pip install scipy networkx matplotlib numpy
```

```
Defaulting to user installation because normal site-packages is not writeable
Looking in links: /usr/share/pip-wheels
Requirement already satisfied: scipy in /opt/conda/envs/anaconda-
ai-2024.04-py310/lib/python3.10/site-packages (1.12.0)
Requirement already satisfied: networkx in ./.local/lib/python3.10/site-packages
(3.4.2)
Requirement already satisfied: matplotlib in /opt/conda/envs/anaconda-
ai-2024.04-py310/lib/python3.10/site-packages (3.8.0)
Requirement already satisfied: numpy in /opt/conda/envs/anaconda-
ai-2024.04-py310/lib/python3.10/site-packages (1.26.4)
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ai-2024.04-py310/lib/python3.10/site-packages (from matplotlib) (1.4.4)
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Requirement already satisfied: python-dateutil>=2.7 in /opt/conda/envs/anaconda-
ai-2024.04-py310/lib/python3.10/site-packages (from matplotlib) (2.8.2)
Requirement already satisfied: six>=1.5 in /opt/conda/envs/anaconda-
ai-2024.04-py310/lib/python3.10/site-packages (from python-
dateutil>=2.7->matplotlib) (1.16.0)
Note: you may need to restart the kernel to use updated packages.
```
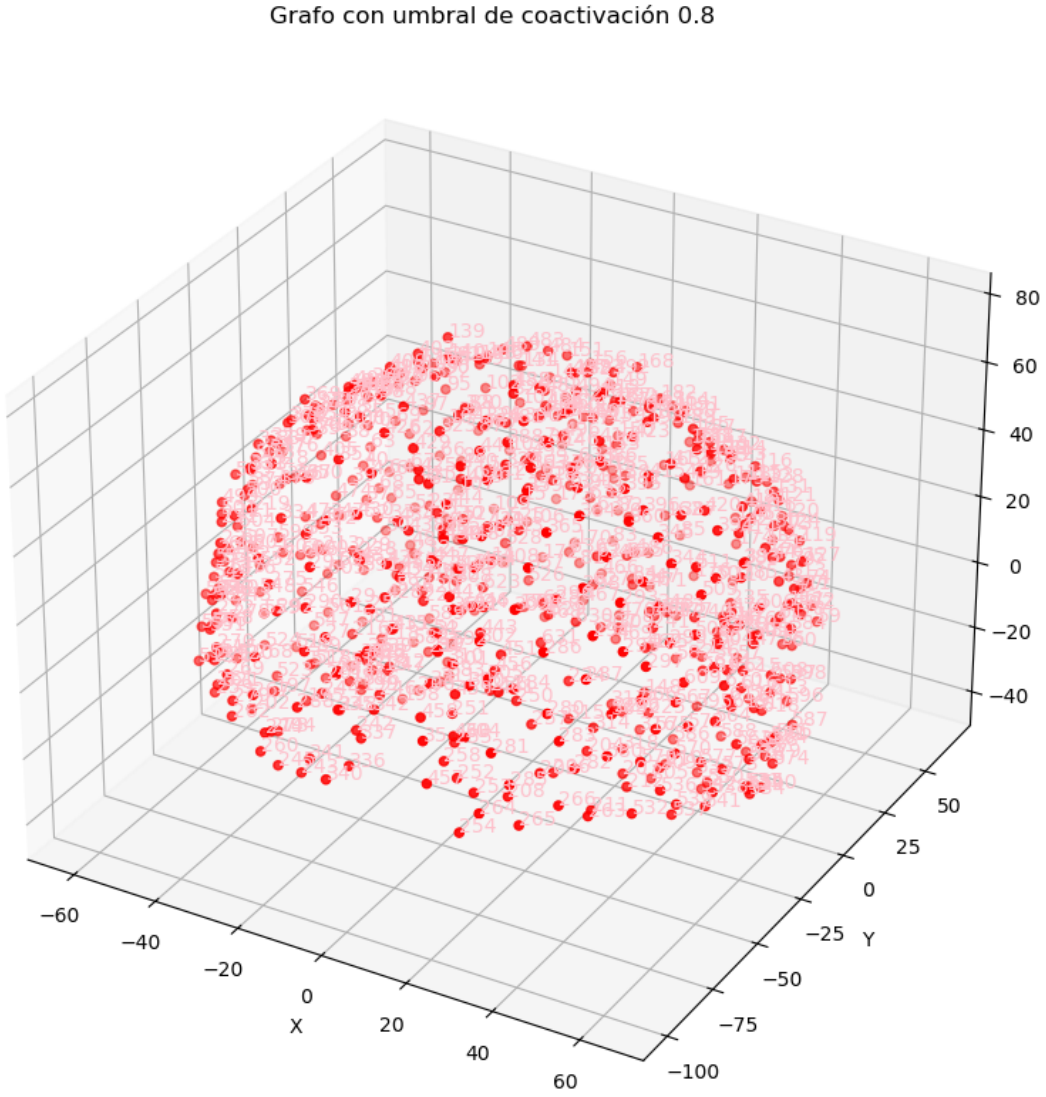
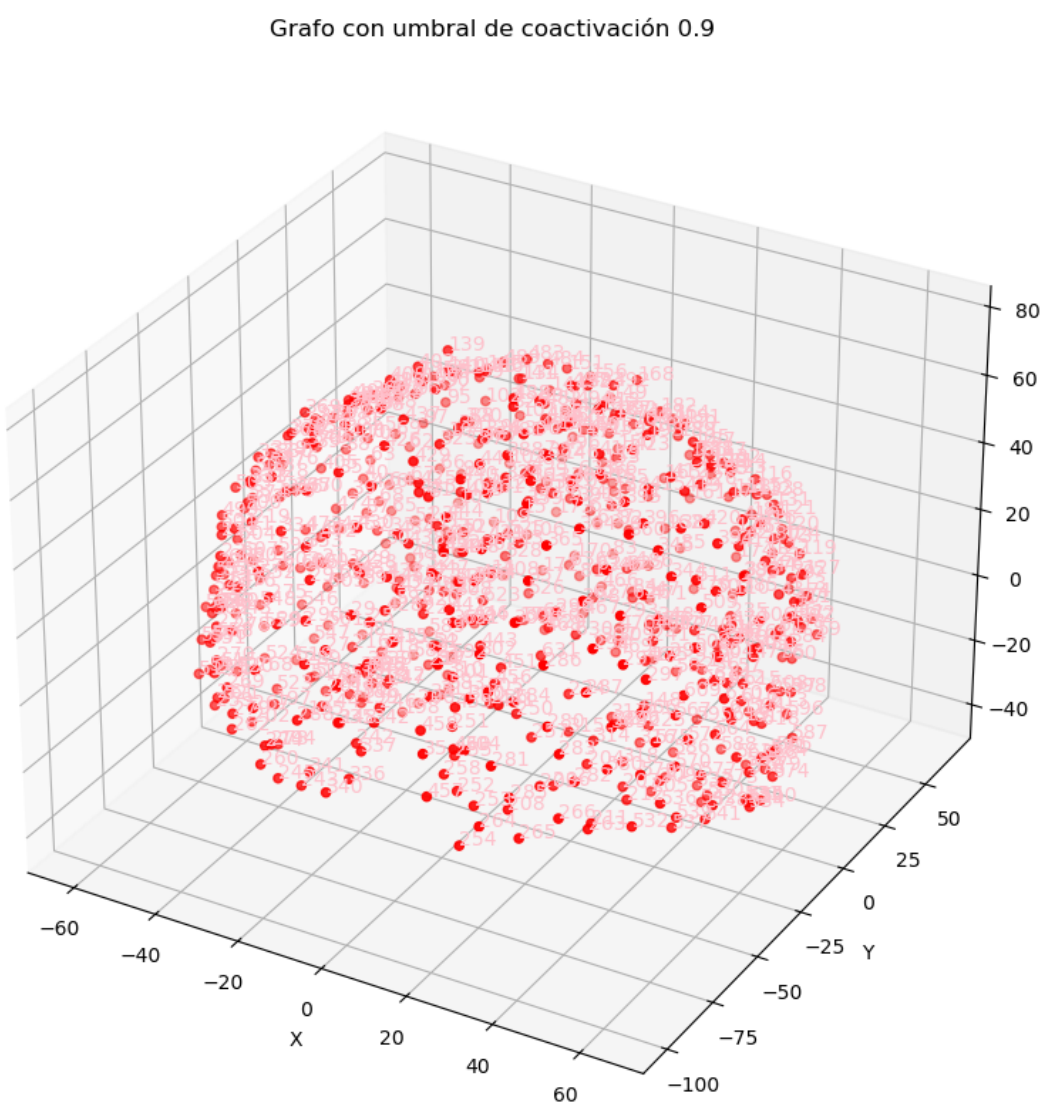

[19]:
```
import numpy as np
import scipy.io as sio
import networkx as nx
import matplotlib.pyplot as plt
from mpl_toolkits.mplot3d import Axes3D
```

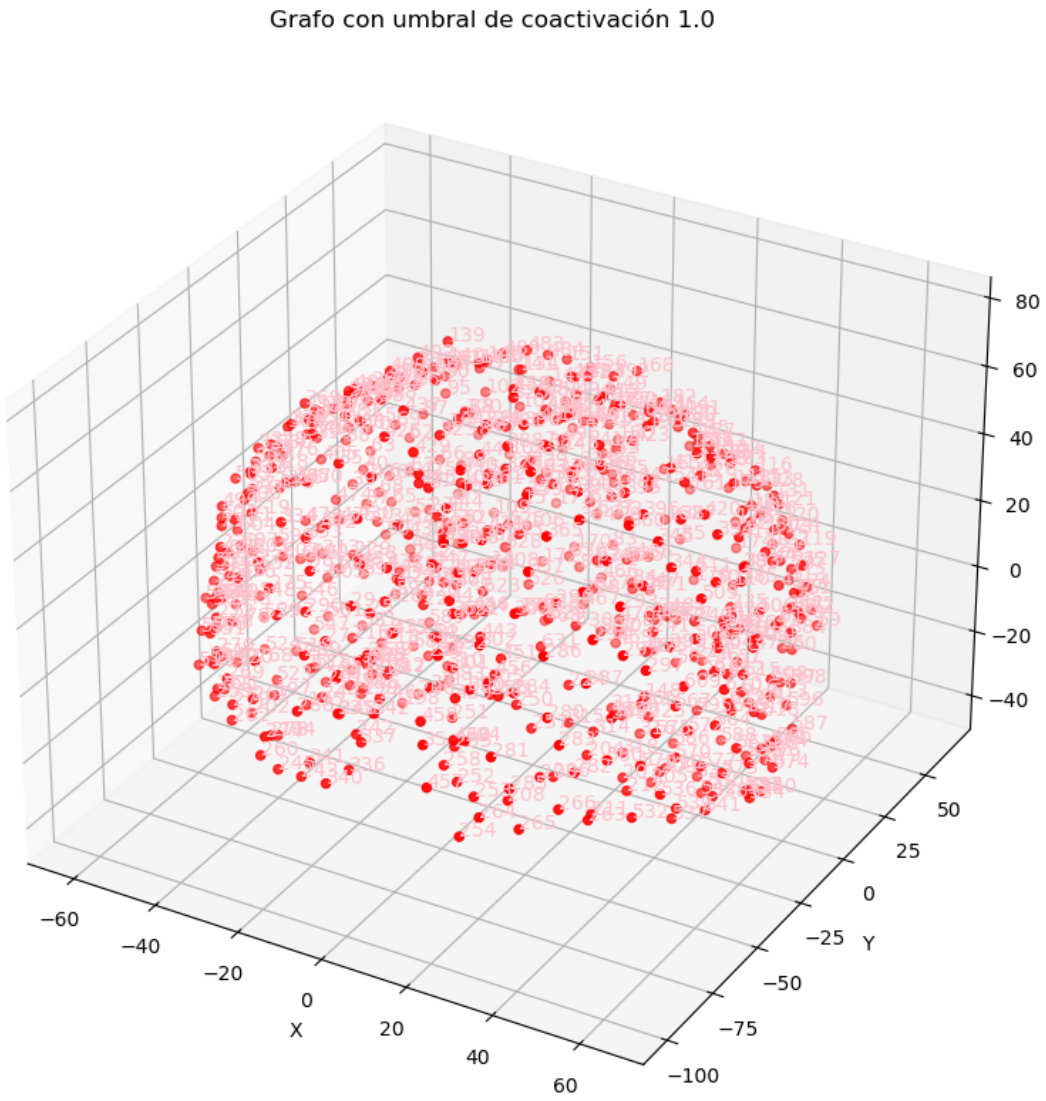
```
mat_data = sio.loadmat('Coactivation_matrix.mat')

print(mat_data.keys())

coactivation_matrix = mat_data['Coactivation_matrix']
coordinates = mat_data['Coord']

coactivation_matrix = np.array(coactivation_matrix)

umbral_1 = 0.8
umbral_2 = 0.9
umbral_3 = 1.0

def graficar_grafo(coactivation_matrix, umbral, coordenadas):
    G = nx.Graph()

    for i in range(coactivation_matrix.shape[0]):
        G.add_node(i, pos=coordenadas[i])

    for i in range(coactivation_matrix.shape[0]):
        for j in range(i+1, coactivation_matrix.shape[1]):
            if coactivation_matrix[i, j] >= umbral:
                G.add_edge(i, j, weight=coactivation_matrix[i, j])

    pos = nx.get_node_attributes(G, 'pos')

    fig = plt.figure(figsize=(10, 10))
    ax = fig.add_subplot(111, projection='3d')

    x_vals = [pos[node][0] for node in pos]
    y_vals = [pos[node][1] for node in pos]
    z_vals = [pos[node][2] for node in pos]

    for (i, j) in G.edges():
        x_vals_edge = [pos[i][0], pos[j][0]]
        y_vals_edge = [pos[i][1], pos[j][1]]
        z_vals_edge = [pos[i][2], pos[j][2]]
        ax.plot(x_vals_edge, y_vals_edge, z_vals_edge, color='b', alpha=0.5)

    ax.scatter(x_vals, y_vals, z_vals, c='r', marker='o')

    for i, (x, y, z) in enumerate(zip(x_vals, y_vals, z_vals)):
        ax.text(x, y, z, str(i), color='pink', fontsize=10)

    ax.set_title(f'Grafo con umbral de coactivación {umbral}')
    ax.set_xlabel('X')
```

```
    ax.set_ylabel('Y')
    ax.set_zlabel('Z')

    plt.show()

graficar_grafo(coactivation_matrix, umbral_1, coordinates)
graficar_grafo(coactivation_matrix, umbral_2, coordinates)
graficar_grafo(coactivation_matrix, umbral_3, coordinates)
```

```
dict_keys(['__header__', '__version__', '__globals__', 'Coactivation_matrix',
'Coord'])
```



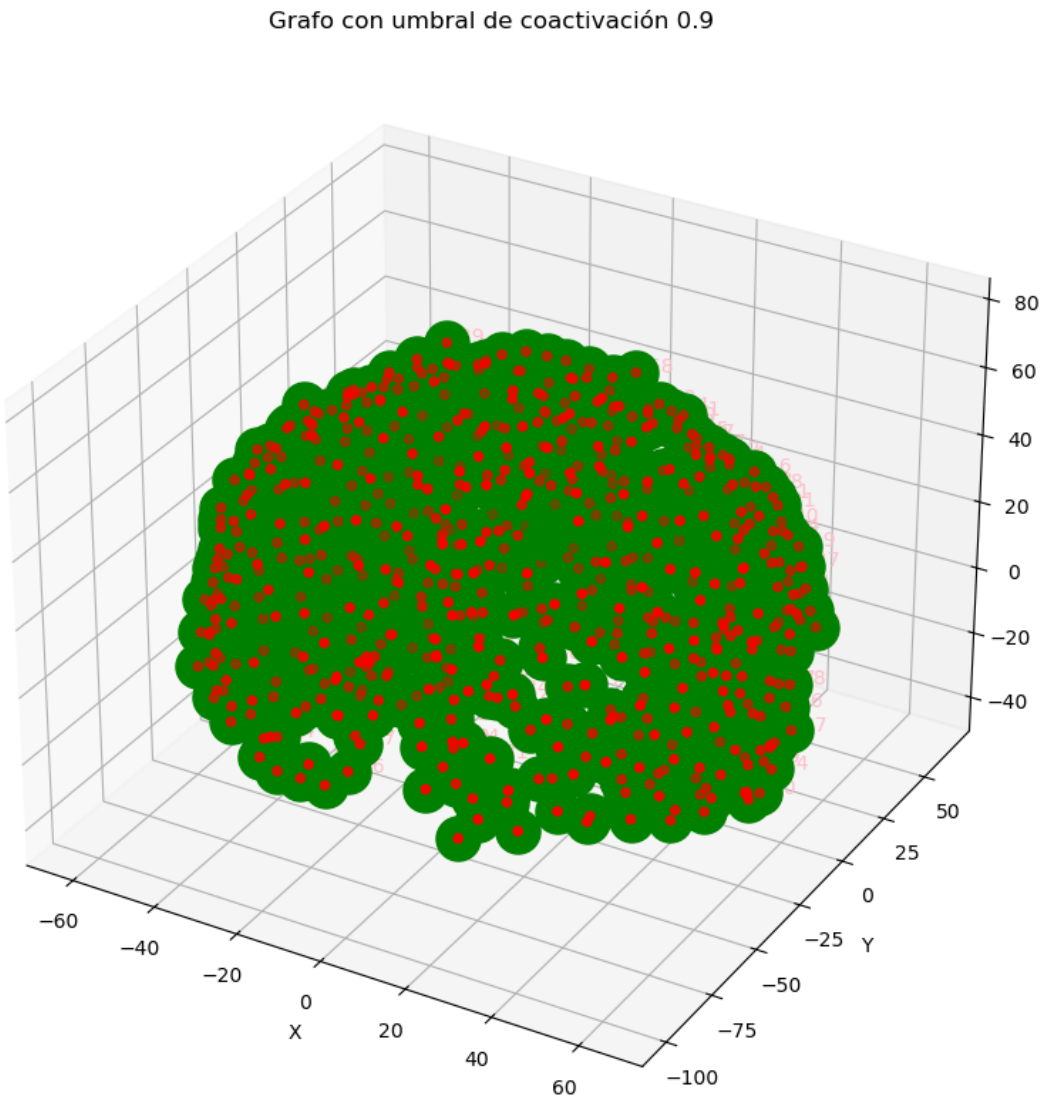

Grafo con umbral de coactivación 0.9
X
Y
−60
−40
−20
0
20
40
60
−100
−75
−50
−25
0
25
50
−40
−20
0
20
40
60
80



[31]:
```
from matplotlib.animation import FuncAnimation

mat_data = sio.loadmat('Coactivation_matrix.mat')
coactivation_matrix = mat_data['Coactivation_matrix']
coordinates = mat_data['Coord']

coactivation_matrix = np.array(coactivation_matrix)

umbral = 0.9

def graficar_grafo_animado(coactivation_matrix, umbral, coordenadas):
    G = nx.Graph()
```

```
for i in range(coactivation_matrix.shape[0]):
    G.add_node(i, pos=coordenadas[i])

for i in range(coactivation_matrix.shape[0]):
    for j in range(i+1, coactivation_matrix.shape[1]):
        if coactivation_matrix[i, j] >= umbral:
            G.add_edge(i, j, weight=coactivation_matrix[i, j])

pos = nx.get_node_attributes(G, 'pos')

degrees = dict(G.degree())

max_degree = max(degrees.values())
hubs = [node for node, degree in degrees.items() if degree == max_degree]

fig = plt.figure(figsize=(10, 10))
ax = fig.add_subplot(111, projection='3d')

x_vals = [pos[node][0] for node in pos]
y_vals = [pos[node][1] for node in pos]
z_vals = [pos[node][2] for node in pos]

for (i, j) in G.edges():
    x_vals_edge = [pos[i][0], pos[j][0]]
    y_vals_edge = [pos[i][1], pos[j][1]]
    z_vals_edge = [pos[i][2], pos[j][2]]
    ax.plot(x_vals_edge, y_vals_edge, z_vals_edge, color='b', alpha=0.5)

node_sizes = [degrees[node] * 50 for node in pos]

scatter = ax.scatter(x_vals, y_vals, z_vals, c='r', marker='o')

for hub in hubs:
    x, y, z = pos[hub]
    ax.scatter(x, y, z, c='g', marker='o', s=500)

for i, (x, y, z) in enumerate(zip(x_vals, y_vals, z_vals)):
    ax.text(x, y, z, str(i), color='pink', fontsize=10)

ax.set_title(f'Grafo con umbral de coactivación {umbral}')
ax.set_xlabel('X')
ax.set_ylabel('Y')
ax.set_zlabel('Z')

def update(num):
    ax.view_init(elev=20, azim=num)
```

```
        return scatter,

    ani = FuncAnimation(fig, update, frames=np.arange(0, 360, 1), interval=50,␣
 ↪blit=False)

    plt.show()

graficar_grafo_animado(coactivation_matrix, umbral, coordinates)
```



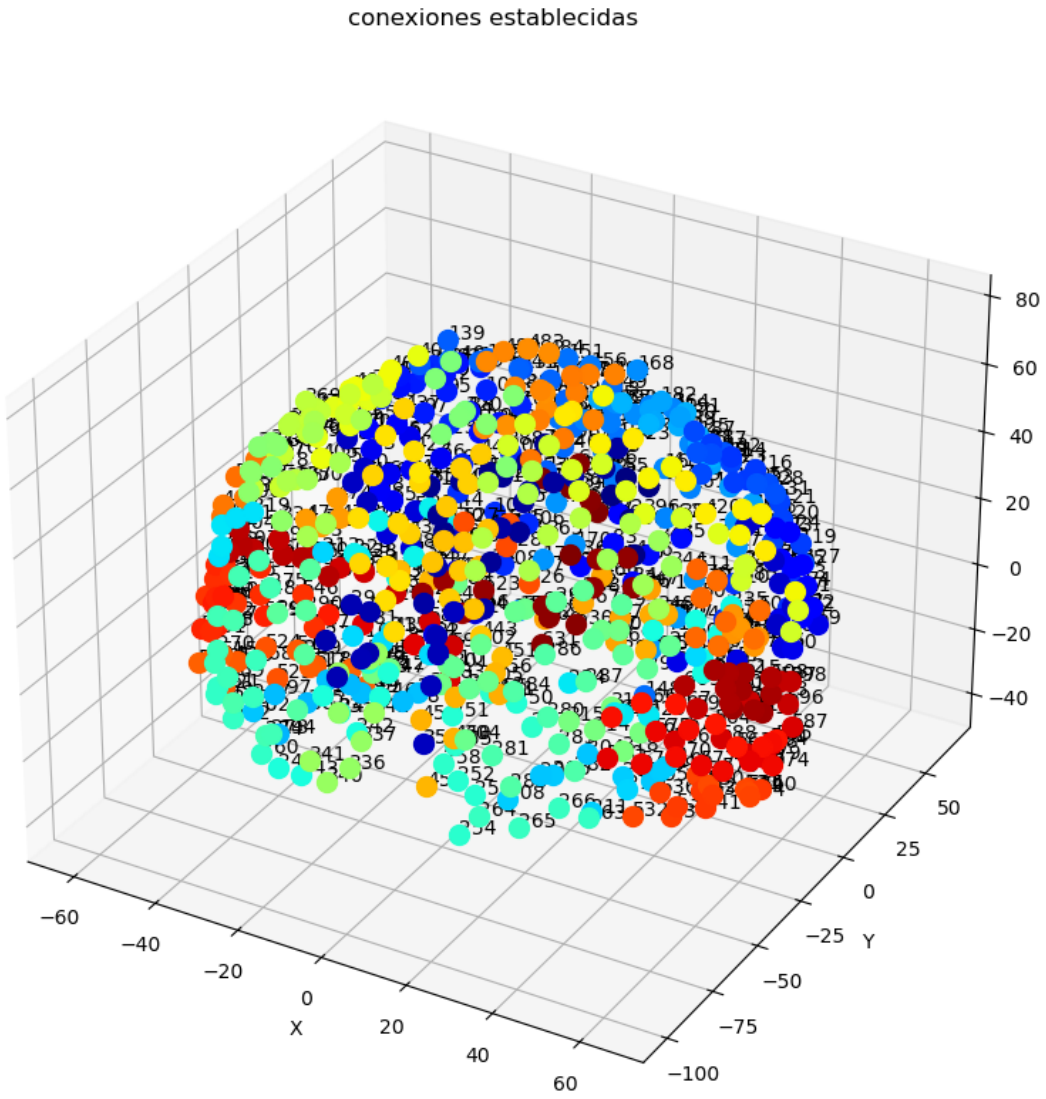
[39]:
```
pip install python-louvain
```

```
Defaulting to user installation because normal site-packages is not writeable
```

```
Looking in links: /usr/share/pip-wheels
Collecting python-louvain
  Downloading python-louvain-0.16.tar.gz (204 kB)
                             204.6/204.6
kB 4.4 MB/s eta 0:00:005 MB/s eta 0:00:01
  Preparing metadata (setup.py) … done
Requirement already satisfied: networkx in ./.local/lib/python3.10/site-
packages (from python-louvain) (3.4.2)
Requirement already satisfied: numpy in /opt/conda/envs/anaconda-
ai-2024.04-py310/lib/python3.10/site-packages (from python-louvain) (1.26.4)
Building wheels for collected packages: python-louvain
  Building wheel for python-louvain (setup.py) … done
  Created wheel for python-louvain: filename=python_louvain-0.16-py3-none-
any.whl size=9389
sha256=64334165196372a655f6eac8205a1e5b33fc09dde965b4cf5e5f6eb11641c1e7
  Stored in directory: /home/bb488668-48f4-4d48-bc2d-
0bcce24566c1/.cache/pip/wheels/d0/b0/d7/6dd26c3817810fa379088eaeb755a01d9a2a411c
37632079d1
Successfully built python-louvain
Installing collected packages: python-louvain
Successfully installed python-louvain-0.16
Note: you may need to restart the kernel to use updated packages.
```

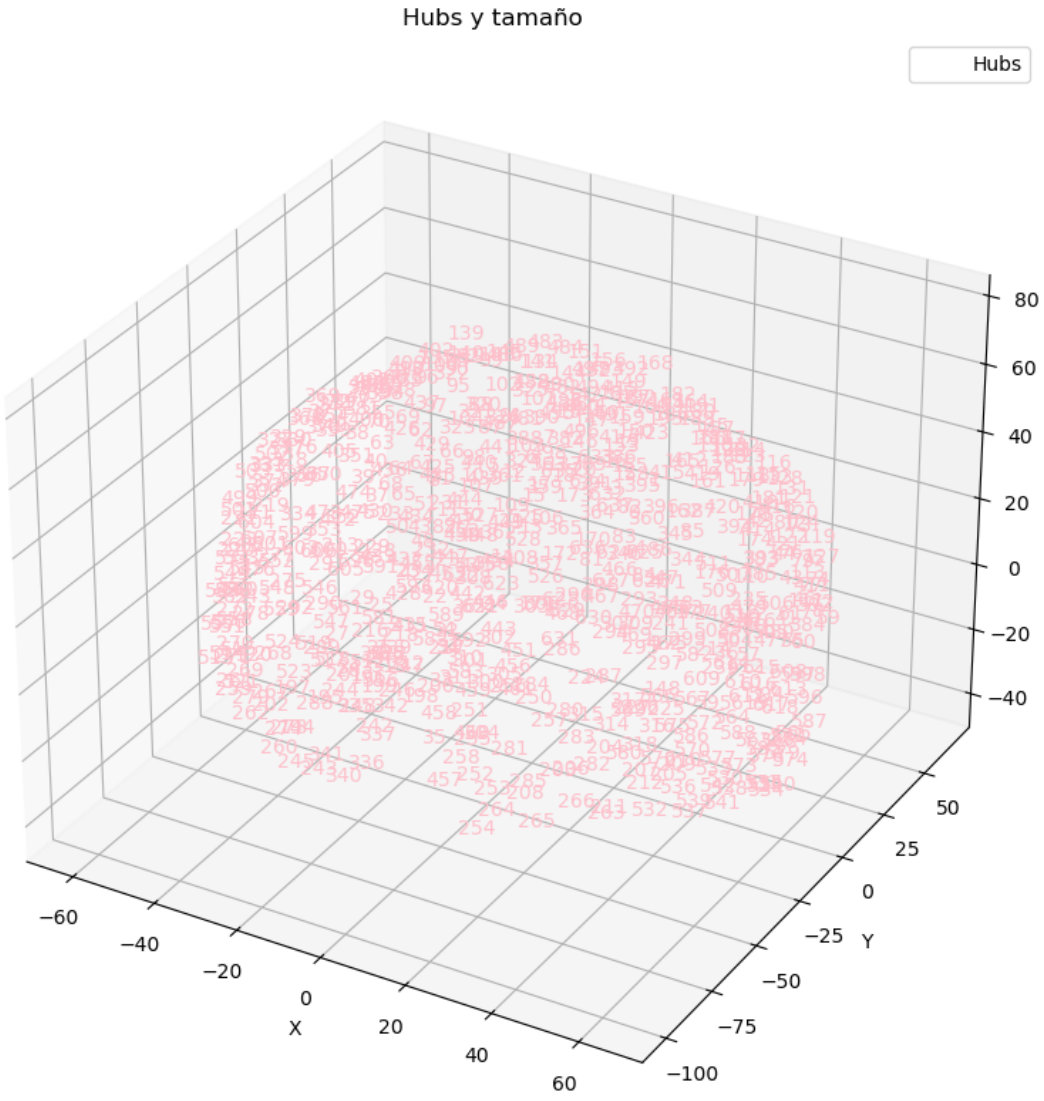
[58]:
```python
from community import community_louvain

coactivation_matrix = np.array(coactivation_matrix)

def graficar_grafo_animado(coactivation_matrix, umbral, coordenadas):
    G = nx.Graph()

    for i in range(coactivation_matrix.shape[0]):
        G.add_node(i, pos=coordenadas[i])

    partition = community_louvain.best_partition(G)

    comunidades = {}
    for node, comm in partition.items():
        if comm not in comunidades:
            comunidades[comm] = []
        comunidades[comm].append(node)

    pos = nx.get_node_attributes(G, 'pos')
    fig = plt.figure(figsize=(10, 10))
    ax = fig.add_subplot(111, projection='3d')

    x_vals = [pos[node][0] for node in pos]
    y_vals = [pos[node][1] for node in pos]
```

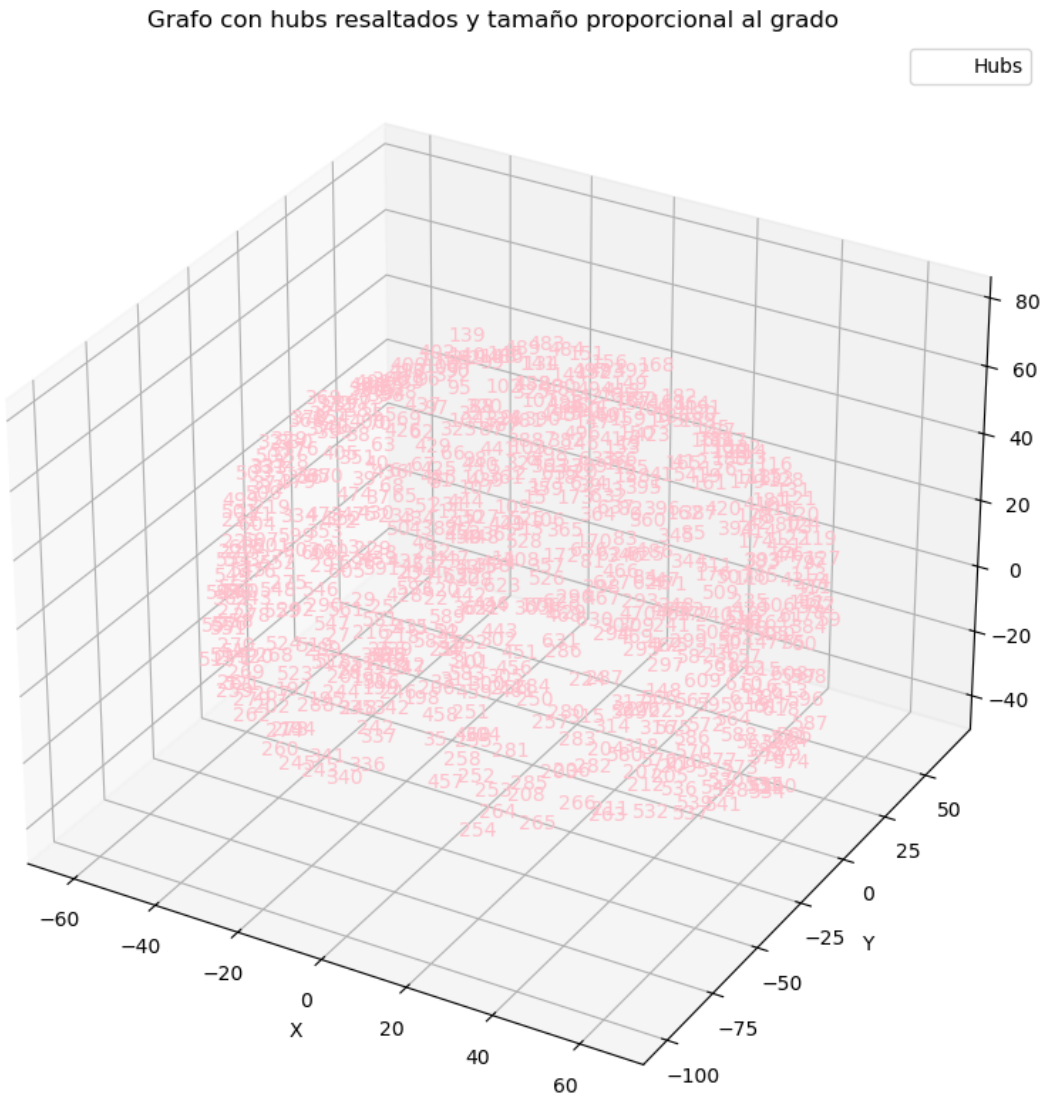
```
    z_vals = [pos[node][2] for node in pos]

    for (i, j) in G.edges():
        x_vals_edge = [pos[i][0], pos[j][0]]
        y_vals_edge = [pos[i][1], pos[j][1]]
        z_vals_edge = [pos[i][2], pos[j][2]]
        ax.plot(x_vals_edge, y_vals_edge, z_vals_edge, color='b', alpha=0.5)

    colores = plt.cm.jet(np.linspace(0, 1, len(comunidades)))
    for idx, comm in enumerate(comunidades.values()):
        color = colores[idx]
        x_vals_comm = [pos[node][0] for node in comm]
        y_vals_comm = [pos[node][1] for node in comm]
        z_vals_comm = [pos[node][2] for node in comm]
        ax.scatter(x_vals_comm, y_vals_comm, z_vals_comm, c=[color],␣
↪marker='o', s=100)

    for i, (x, y, z) in enumerate(zip(x_vals, y_vals, z_vals)):
        ax.text(x, y, z, str(i), color='black', fontsize=10)

    ax.set_title(f'conexiones establecidas')
    ax.set_xlabel('X')
    ax.set_ylabel('Y')
    ax.set_zlabel('Z')

    plt.show()

graficar_comunidades(coactivation_matrix, umbral, coordinates)
```



[60]:
```
grado = dict(G.degree())

max_grado = max(grado.values())
hubs = [node for node, deg in grado.items() if deg == max_grado]

pos = nx.get_node_attributes(G, 'pos')
fig = plt.figure(figsize=(10, 10))
ax = fig.add_subplot(111, projection='3d')

x_vals = [pos[node][0] for node in pos]
y_vals = [pos[node][1] for node in pos]
z_vals = [pos[node][2] for node in pos]
```

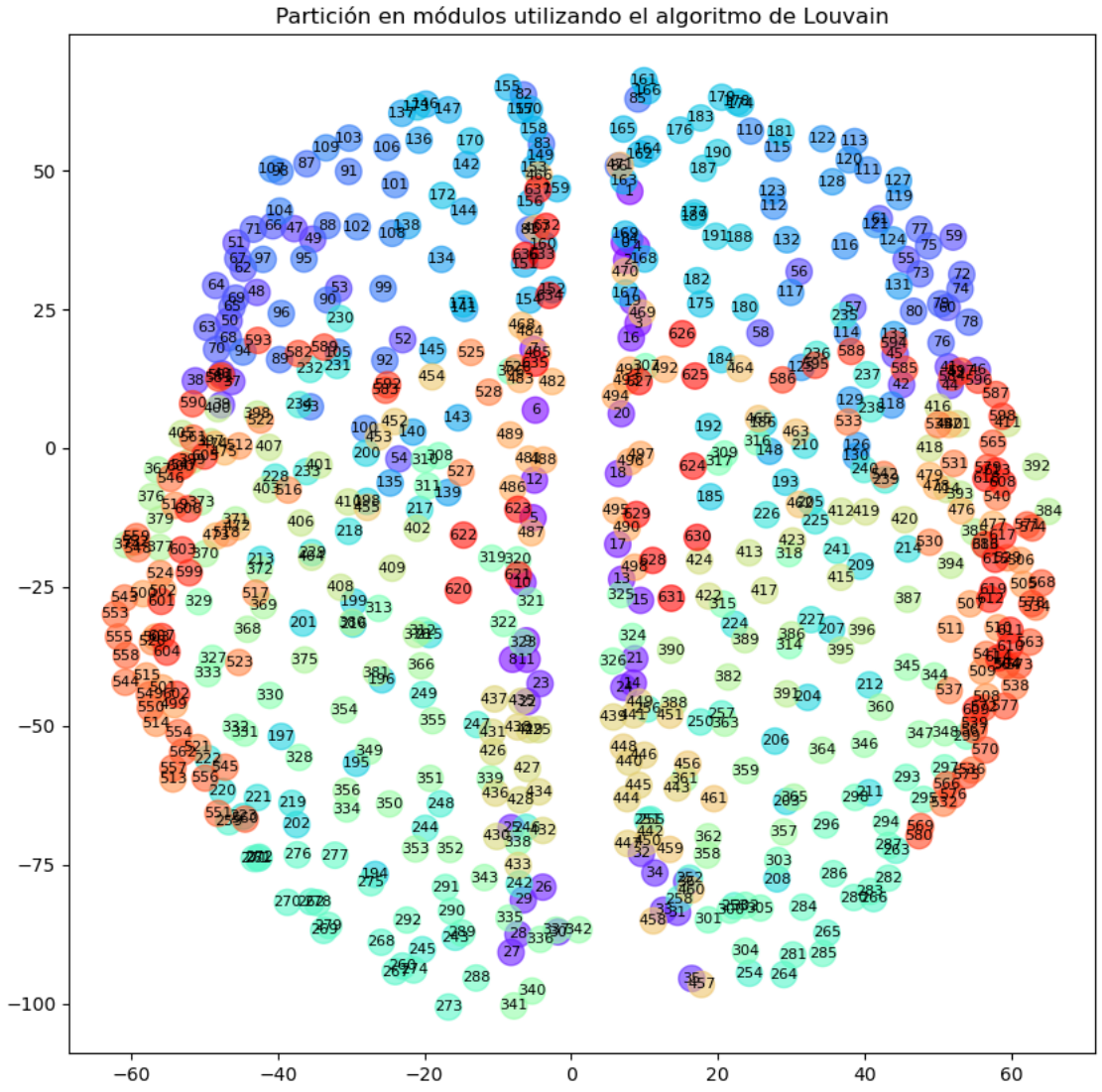
```
    for (i, j) in G.edges():
        x_vals_edge = [pos[i][0], pos[j][0]]
        y_vals_edge = [pos[i][1], pos[j][1]]
        z_vals_edge = [pos[i][2], pos[j][2]]
        ax.plot(x_vals_edge, y_vals_edge, z_vals_edge, color='b', alpha=0.5)

    node_sizes = [grado[node] * 100 for node in G.nodes()]

    ax.scatter(x_vals, y_vals, z_vals, c='r', marker='o', s=node_sizes)

    x_vals_hub = [pos[node][0] for node in hubs]
    y_vals_hub = [pos[node][1] for node in hubs]
    z_vals_hub = [pos[node][2] for node in hubs]
    ax.scatter(x_vals_hub, y_vals_hub, z_vals_hub, c='g', marker='o',␣
 ↪s=[grado[node] * 150 for node in hubs], label='Hubs')

    for i, (x, y, z) in enumerate(zip(x_vals, y_vals, z_vals)):
        ax.text(x, y, z, str(i), color='pink', fontsize=10)

    ax.set_title(f'Hubs y tamaño')
    ax.set_xlabel('X')
    ax.set_ylabel('Y')
    ax.set_zlabel('Z')

    ax.legend()

    plt.show()

graficar_hubs(coactivation_matrix, umbral, coordinates)
```


Hubs y tamaño
Hubs
X
Y
−60
−40
−20
0
20
40
60
80
60
40
20
0
−20
−40
50
25
0
−25
−50
−75
−100



[68]:
```
partition = community_louvain.best_partition(G)

plt.figure(figsize=(10, 10))

pos = nx.get_node_attributes(G, 'pos')
plt.title(f'Partición en módulos utilizando el algoritmo de Louvain')

community_colors = list(partition.values())
plt.scatter([pos[node][0] for node in G.nodes()],
            [pos[node][1] for node in G.nodes()],
            c=community_colors, cmap=plt.cm.rainbow, s=200, alpha=0.6)
```

```
for i, (x, y) in enumerate(zip([pos[node][0] for node in G.nodes()],
                               [pos[node][1] for node in G.nodes()])):
    plt.text(x, y, str(i), color='black', fontsize=8, ha='center', va='center')

plt.show()

num_communities = len(set(partition.values()))
print(f"Se detectaron {num_communities} comunidades.")
print("Partición de nodos:", partition)
```




```
Se detectaron 638 comunidades.
Partición de nodos: {0: 0, 1: 1, 2: 2, 3: 3, 4: 4, 5: 5, 6: 6, 7: 7, 8: 8, 9: 9,
10: 10, 11: 11, 12: 12, 13: 13, 14: 14, 15: 15, 16: 16, 17: 17, 18: 18, 19: 19,
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628: 628, 629: 629, 630: 630, 631: 631, 632: 632, 633: 633, 634: 634, 635: 635,
636: 636, 637: 637}
```
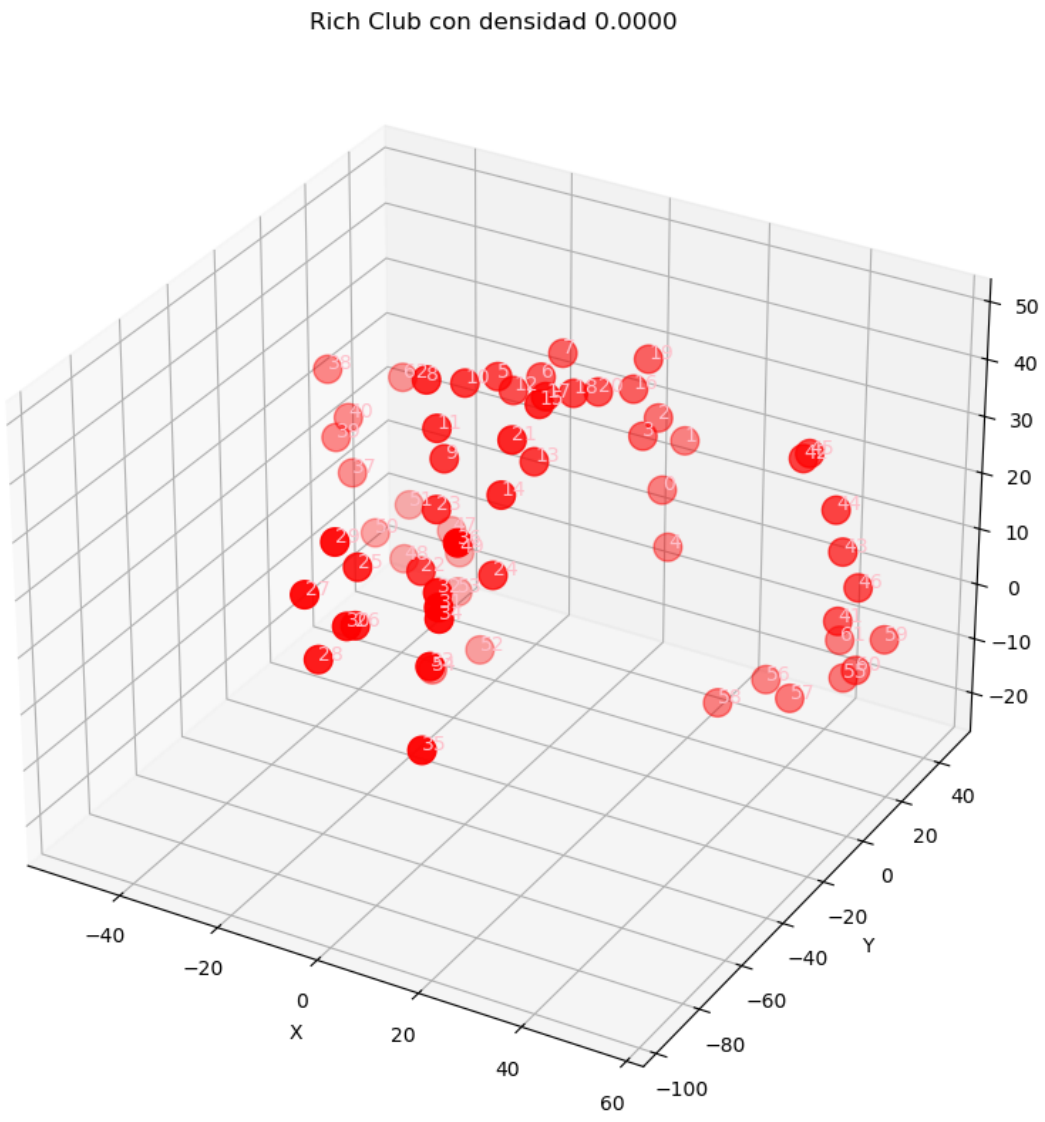

[70]:
```python
grado = dict(G.degree())

sorted_nodes = sorted(grado, key=grado.get, reverse=True)

rich_club_threshold = int(0.1 * len(sorted_nodes))

rich_club_nodes = sorted_nodes[:rich_club_threshold]

rich_club_subgraph = G.subgraph(rich_club_nodes)

density_rich_club = nx.density(rich_club_subgraph)

print(f"Nodos del Rich Club: {rich_club_nodes}")
print(f"Densidad del Rich Club: {density_rich_club:.4f}")

pos = nx.get_node_attributes(G, 'pos')
x_vals = [pos[node][0] for node in rich_club_nodes]
y_vals = [pos[node][1] for node in rich_club_nodes]
```

```python
z_vals = [pos[node][2] for node in rich_club_nodes]

fig = plt.figure(figsize=(10, 10))
ax = fig.add_subplot(111, projection='3d')

for (i, j) in rich_club_subgraph.edges():
    x_vals_edge = [pos[i][0], pos[j][0]]
    y_vals_edge = [pos[i][1], pos[j][1]]
    z_vals_edge = [pos[i][2], pos[j][2]]
    ax.plot(x_vals_edge, y_vals_edge, z_vals_edge, color='b', alpha=0.5)

ax.scatter(x_vals, y_vals, z_vals, c='r', marker='o', s=200)

for i, (x, y, z) in enumerate(zip(x_vals, y_vals, z_vals)):
    ax.text(x, y, z, str(rich_club_nodes[i]), color='pink', fontsize=10)

ax.set_title(f'Rich Club con densidad {density_rich_club:.4f}')
ax.set_xlabel('X')
ax.set_ylabel('Y')
ax.set_zlabel('Z')

plt.show()

# Explicación implicaciones anatómicas y funcionales.
# El Rich Club en el cerebro humano se refiere a un conjunto de nodos altamente␣
 ↪interconectados, generalmente áreas cerebrales clave para la integración de␣
 ↪información.
# Anatómicamente, estos nodos suelen estar ubicados en regiones centrales, como␣
 ↪la corteza prefrontal, que permiten una comunicación eficiente y rápida␣
 ↪entre diferentes áreas del cerebro.
# Funcionalmente, el Rich Club está relacionado con funciones cognitivas␣
 ↪complejas como la toma de decisiones, el lenguaje y la memoria.
# Además, su alta conectividad proporciona resiliencia ante lesiones o␣
 ↪patologías neurológicas, ya que sus redundantes conexiones permiten mantener␣
 ↪la funcionalidad cerebral incluso cuando algunas áreas se ven afectadas.
```

```
Nodos del Rich Club: [0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16,
17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36,
37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56,
57, 58, 59, 60, 61, 62]
Densidad del Rich Club: 0.0000
```

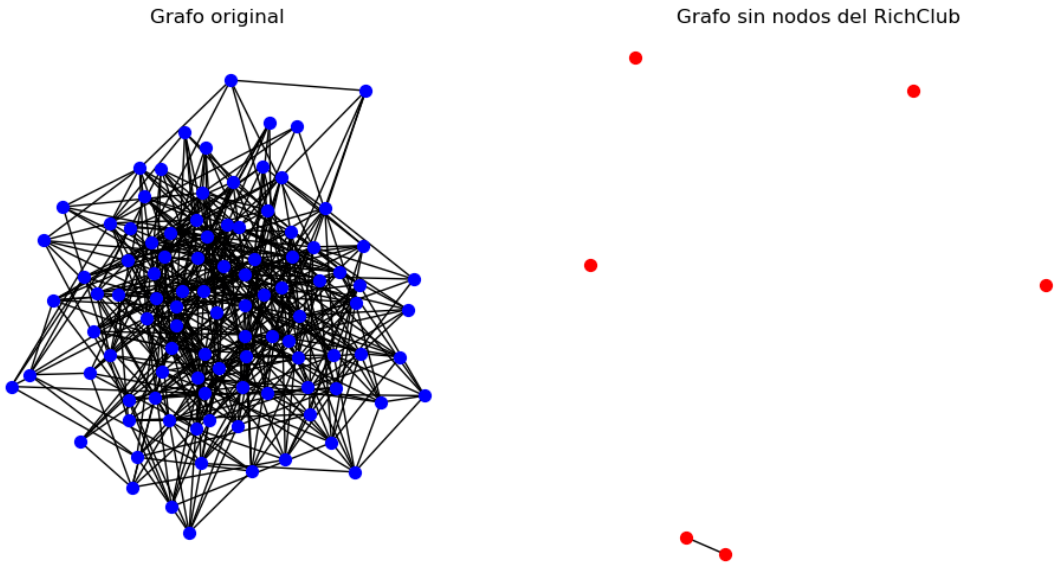


[3]:
```python
G = nx.erdos_renyi_graph(100, 0.1)

degrees = dict(G.degree())

rich_club_nodes = [node for node, degree in degrees.items() if degree > 5]

G_copy = G.copy()

G_copy.remove_nodes_from(rich_club_nodes)

def calculate_topological_properties(G):
    degree = np.mean([d for _, d in G.degree()])
```

```
    clustering_coefficient = nx.average_clustering(G)

    if nx.is_connected(G):
        small_world_coefficient = nx.average_shortest_path_length(G)
    else:
        small_world_coefficient = np.mean(
            [nx.average_shortest_path_length(G.subgraph(c)) for c in nx.
 ↪connected_components(G)]
        )

    centrality_closeness = np.mean(list(nx.closeness_centrality(G).values()))
    centrality_betweenness = np.mean(list(nx.betweenness_centrality(G).
 ↪values()))

    return degree, clustering_coefficient, small_world_coefficient,␣
 ↪centrality_closeness, centrality_betweenness

degree_before, clustering_before, small_world_before, closeness_before,␣
 ↪betweenness_before = calculate_topological_properties(G)

degree_after, clustering_after, small_world_after, closeness_after,␣
 ↪betweenness_after = calculate_topological_properties(G_copy)

print("Propiedades antes de eliminar el RichClub:")
print(f"Grado promedio: {degree_before}")
print(f"Coeficiente de agrupamiento: {clustering_before}")
print(f"Coeficiente de mundo pequeño: {small_world_before}")
print(f"Centralidad de cercanía: {closeness_before}")
print(f"Centralidad de intermediación: {betweenness_before}")

print("\nPropiedades después de eliminar el RichClub:")
print(f"Grado promedio: {degree_after}")
print(f"Coeficiente de agrupamiento: {clustering_after}")
print(f"Coeficiente de mundo pequeño: {small_world_after}")
print(f"Centralidad de cercanía: {closeness_after}")
print(f"Centralidad de intermediación: {betweenness_after}")

# Visualizar los grafos antes y después de la eliminación
plt.figure(figsize=(12, 6))

plt.subplot(1, 2, 1)
nx.draw(G, node_size=50, with_labels=False, node_color='blue')
plt.title("Grafo original")

plt.subplot(1, 2, 2)
nx.draw(G_copy, node_size=50, with_labels=False, node_color='red')
plt.title("Grafo sin nodos del RichClub")
```

```
plt.show()
```

```
Propiedades antes de eliminar el RichClub:
Grado promedio: 10.3
Coeficiente de agrupamiento: 0.1068504714240008
Coeficiente de mundo pequeño: 2.2022222222222223
Centralidad de cercanía: 0.45606373737400135
Centralidad de intermediación: 0.012267573696145125

Propiedades después de eliminar el RichClub:
Grado promedio: 0.3333333333333333
Coeficiente de agrupamiento: 0.0
Coeficiente de mundo pequeño: 0.2
Centralidad de cercanía: 0.06666666666666667
Centralidad de intermediación: 0.0
```

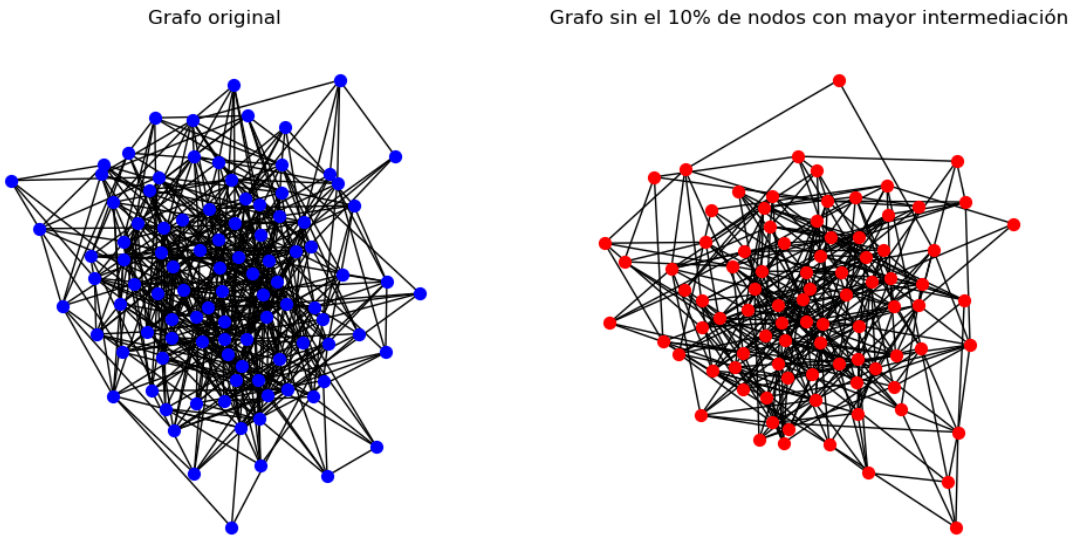


[5]:
```
G = nx.erdos_renyi_graph(100, 0.1)

def calculate_topological_properties(G):
    degree = np.mean([d for _, d in G.degree()])
    clustering_coefficient = nx.average_clustering(G)

    if nx.is_connected(G):
        small_world_coefficient = nx.average_shortest_path_length(G)
    else:
        small_world_coefficient = np.mean(
```

```
            [nx.average_shortest_path_length(G.subgraph(c)) for c in nx.
 ↪connected_components(G)]
        )

    centrality_closeness = np.mean(list(nx.closeness_centrality(G).values()))
    centrality_betweenness = np.mean(list(nx.betweenness_centrality(G).
 ↪values()))

    return degree, clustering_coefficient, small_world_coefficient,␣
 ↪centrality_closeness, centrality_betweenness

betweenness_centrality = nx.betweenness_centrality(G)

sorted_nodes_by_betweenness = sorted(betweenness_centrality.items(), key=lambda␣
 ↪item: item[1], reverse=True)

percentage_to_remove = 0.1

num_nodes_to_remove = int(len(sorted_nodes_by_betweenness) *␣
 ↪percentage_to_remove)

nodes_to_remove = [node for node, _ in sorted_nodes_by_betweenness[:
 ↪num_nodes_to_remove]]

G_copy = G.copy()

G_copy.remove_nodes_from(nodes_to_remove)

degree_before, clustering_before, small_world_before, closeness_before,␣
 ↪betweenness_before = calculate_topological_properties(G)

degree_after, clustering_after, small_world_after, closeness_after,␣
 ↪betweenness_after = calculate_topological_properties(G_copy)

print("Propiedades antes de eliminar los nodos con mayor intermediación:")
print(f"Grado promedio: {degree_before}")
print(f"Coeficiente de agrupamiento: {clustering_before}")
print(f"Coeficiente de mundo pequeño: {small_world_before}")
print(f"Centralidad de cercanía: {closeness_before}")
print(f"Centralidad de intermediación: {betweenness_before}")

print("\nPropiedades después de eliminar los nodos con mayor intermediación:")
print(f"Grado promedio: {degree_after}")
print(f"Coeficiente de agrupamiento: {clustering_after}")
print(f"Coeficiente de mundo pequeño: {small_world_after}")
print(f"Centralidad de cercanía: {closeness_after}")
```

```
print(f"Centralidad de intermediación: {betweenness_after}")

plt.figure(figsize=(12, 6))

plt.subplot(1, 2, 1)
nx.draw(G, node_size=50, with_labels=False, node_color='blue')
plt.title("Grafo original")

plt.subplot(1, 2, 2)
nx.draw(G_copy, node_size=50, with_labels=False, node_color='red')
plt.title(f"Grafo sin el {int(percentage_to_remove * 100)}% de nodos con mayor␣
 ↪intermediación")

plt.show()
```

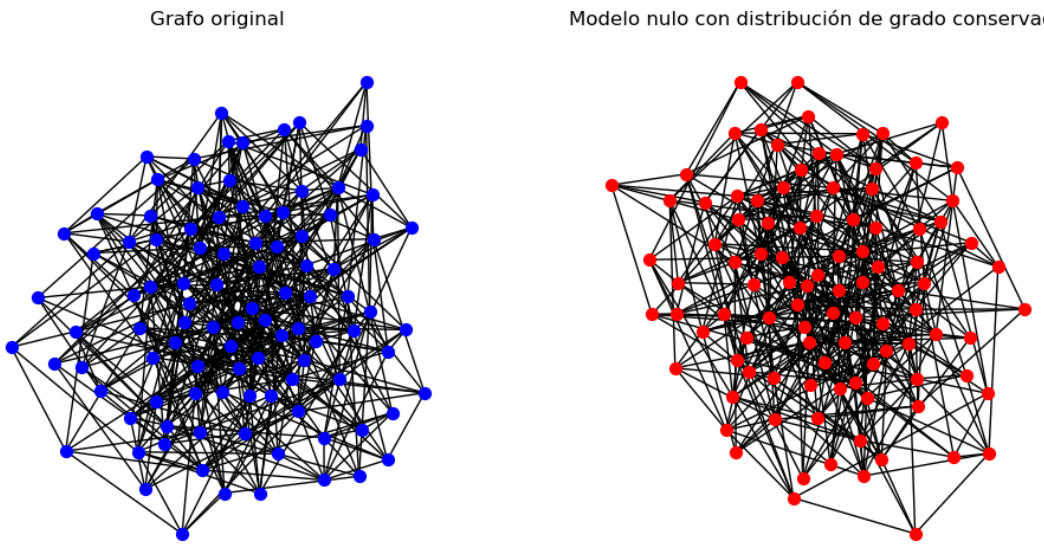
```
Propiedades antes de eliminar los nodos con mayor intermediación:
Grado promedio: 10.28
Coeficiente de agrupamiento: 0.09826262789498079
Coeficiente de mundo pequeño: 2.2155555555555555
Centralidad de cercanía: 0.45343957790206135
Centralidad de intermediación: 0.012403628117913831

Propiedades después de eliminar los nodos con mayor intermediación:
Grado promedio: 8.2
Coeficiente de agrupamiento: 0.09378516545183206
Coeficiente de mundo pequeño: 2.366791510611735
Centralidad de cercanía: 0.42489011344166705
Centralidad de intermediación: 0.01553172171149699
```



[11]:
```
import networkx as nx
import numpy as np
import matplotlib.pyplot as plt

G = nx.erdos_renyi_graph(100, 0.1)

num_edges_original = G.number_of_edges()

degree_sequence = [d for _, d in G.degree()]
G_null = nx.configuration_model(degree_sequence)

G_null = nx.Graph(G_null)

G_null.remove_edges_from([(u, v) for u, v in G_null.edges() if u == v])

def calculate_topological_properties(G):
    degree = np.mean([d for _, d in G.degree()])
    clustering_coefficient = nx.average_clustering(G)

    if nx.is_connected(G):
        small_world_coefficient = nx.average_shortest_path_length(G)
    else:
        small_world_coefficient = np.mean(
            [nx.average_shortest_path_length(G.subgraph(c)) for c in nx.
 ↪connected_components(G)]
        )

    centrality_closeness = np.mean(list(nx.closeness_centrality(G).values()))
    centrality_betweenness = np.mean(list(nx.betweenness_centrality(G).
 ↪values()))

    return degree, clustering_coefficient, small_world_coefficient,␣
 ↪centrality_closeness, centrality_betweenness

degree_original, clustering_original, small_world_original, closeness_original,␣
 ↪betweenness_original = calculate_topological_properties(G)

degree_null, clustering_null, small_world_null, closeness_null,␣
 ↪betweenness_null = calculate_topological_properties(G_null)

print("Propiedades del grafo original:")
print(f"Grado promedio: {degree_original}")
print(f"Coeficiente de agrupamiento: {clustering_original}")
print(f"Coeficiente de mundo pequeño: {small_world_original}")
print(f"Centralidad de cercanía: {closeness_original}")
print(f"Centralidad de intermediación: {betweenness_original}")
```

```python
print("\nPropiedades del modelo nulo con distribución de grado conservada:")
print(f"Grado promedio: {degree_null}")
print(f"Coeficiente de agrupamiento: {clustering_null}")
print(f"Coeficiente de mundo pequeño: {small_world_null}")
print(f"Centralidad de cercanía: {closeness_null}")
print(f"Centralidad de intermediación: {betweenness_null}")

plt.figure(figsize=(12, 6))

plt.subplot(1, 2, 1)
nx.draw(G, node_size=50, with_labels=False, node_color='blue')
plt.title("Grafo original")

plt.subplot(1, 2, 2)
nx.draw(G_null, node_size=50, with_labels=False, node_color='red')
plt.title("Modelo nulo con distribución de grado conservada")

plt.show()
```

```
Propiedades del grafo original:
Grado promedio: 10.14
Coeficiente de agrupamiento: 0.11128045724485344
Coeficiente de mundo pequeño: 2.2185858585858584
Centralidad de cercanía: 0.45252837082962627
Centralidad de intermediación: 0.01243454957740672

Propiedades del modelo nulo con distribución de grado conservada:
Grado promedio: 9.56
Coeficiente de agrupamiento: 0.10541835941835938
Coeficiente de mundo pequeño: 2.2707070707070707
Centralidad de cercanía: 0.4420108633305969
Centralidad de intermediación: 0.012966398680684393
```

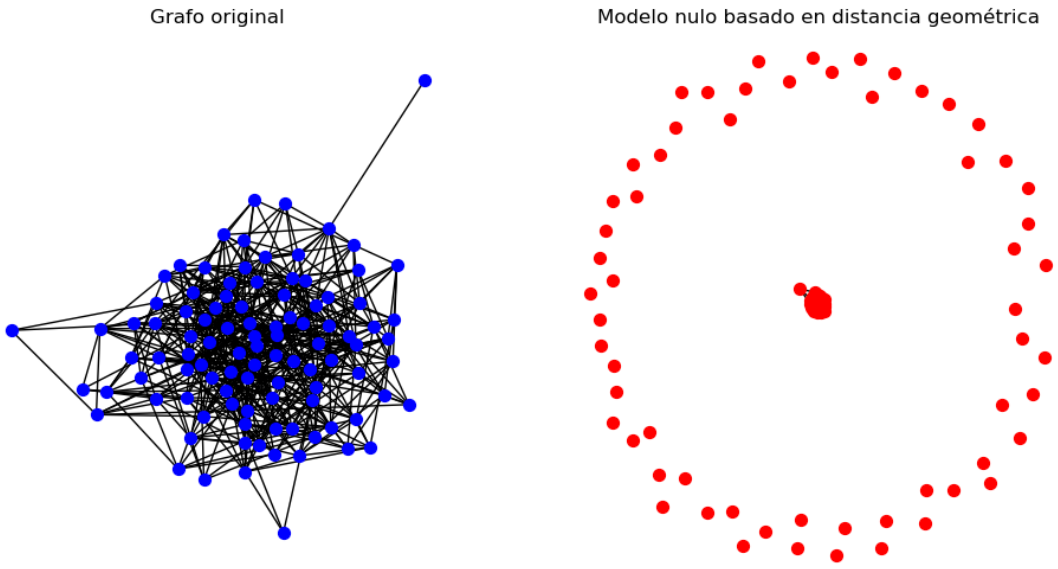


[13]:
```
G = nx.erdos_renyi_graph(100, 0.1)

num_edges_original = G.number_of_edges()

positions = np.random.rand(len(G.nodes()), 2)

def calculate_distances(positions):
    distances = np.linalg.norm(positions[:, np.newaxis] - positions, axis=2)
    np.fill_diagonal(distances, 0)
    return distances

distances = calculate_distances(positions)

def connection_probability(distance, alpha=1):
    return 1 / (1 + alpha * distance)

edges_null = []
for i in range(len(G.nodes())):
    for j in range(i+1, len(G.nodes())):
        p = connection_probability(distances[i, j])
        if np.random.rand() < p:
            edges_null.append((i, j))

G_null = nx.Graph()
G_null.add_nodes_from(G.nodes())
G_null.add_edges_from(edges_null)
```

```
while len(G_null.edges()) > num_edges_original:
    G_null.remove_edge(*list(G_null.edges())[0])

def calculate_topological_properties(G):
    degree = np.mean([d for _, d in G.degree()])
    clustering_coefficient = nx.average_clustering(G)

    if nx.is_connected(G):
        small_world_coefficient = nx.average_shortest_path_length(G)
    else:
        small_world_coefficient = np.mean(
            [nx.average_shortest_path_length(G.subgraph(c)) for c in nx.
 ↪connected_components(G)]
        )

    centrality_closeness = np.mean(list(nx.closeness_centrality(G).values()))
    centrality_betweenness = np.mean(list(nx.betweenness_centrality(G).
 ↪values()))

    return degree, clustering_coefficient, small_world_coefficient,␣
 ↪centrality_closeness, centrality_betweenness

degree_original, clustering_original, small_world_original, closeness_original,␣
 ↪betweenness_original = calculate_topological_properties(G)

degree_null, clustering_null, small_world_null, closeness_null,␣
 ↪betweenness_null = calculate_topological_properties(G_null)

print("Propiedades del grafo original:")
print(f"Grado promedio: {degree_original}")
print(f"Coeficiente de agrupamiento: {clustering_original}")
print(f"Coeficiente de mundo pequeño: {small_world_original}")
print(f"Centralidad de cercanía: {closeness_original}")
print(f"Centralidad de intermediación: {betweenness_original}")

print("\nPropiedades del modelo nulo basado en la distancia geométrica:")
print(f"Grado promedio: {degree_null}")
print(f"Coeficiente de agrupamiento: {clustering_null}")
print(f"Coeficiente de mundo pequeño: {small_world_null}")
print(f"Centralidad de cercanía: {closeness_null}")
print(f"Centralidad de intermediación: {betweenness_null}")

plt.figure(figsize=(12, 6))

plt.subplot(1, 2, 1)
nx.draw(G, node_size=50, with_labels=False, node_color='blue')
plt.title("Grafo original")
```

```
plt.subplot(1, 2, 2)
nx.draw(G_null, node_size=50, with_labels=False, node_color='red')
plt.title("Modelo nulo basado en distancia geométrica")

plt.show()
```

```
Propiedades del grafo original:
Grado promedio: 10.12
Coeficiente de agrupamiento: 0.10226380525219528
Coeficiente de mundo pequeño: 2.2284848484848485
Centralidad de cercanía: 0.4511285528619114
Centralidad de intermediación: 0.012535559678416823

Propiedades del modelo nulo basado en la distancia geométrica:
Grado promedio: 10.12
Coeficiente de agrupamiento: 0.2662006935486566
Coeficiente de mundo pequeño: 0.022173182009247585
Centralidad de cercanía: 0.11730885288549693
Centralidad de intermediación: 0.0005668934240362812
```



[ ]:
```
# Este curso fue bastante interesante en el sentido de que mayoritariamente yo
 ↪desconocía
# como era realizar programación, hacer gráficas fuera de excel o cuestiones
 ↪más sencillas,
# aquí pudimos observar conexiones entre nodos, distribución de estos,
 ↪coeficiente de cluster, incluso como estan relacionados
```

```
# de forma dinámica, hacer comparaciones de gráficos y nodos, en fnción de␣
 ↪neurociencias aplica para las conexiones entre
# neuronas, glía, arborizaciones dendriticas, etc.
```