

Cellular Networks with Cytoscape

Question 1

a) The average path length of the network

$$L = \text{Total Length} / \text{Total Pair} = 1,8667$$

A-B	1
A-C	1
A-D	1
A-E	2
A-F	3
B-C	2
B-D	2
B-E	3
B-F	4
C-D	2
C-E	1
C-F	2
D-E	1
D-F	2
E-F	1
Total Pairs: 15	Total Length: 28

b) The diameter of the network

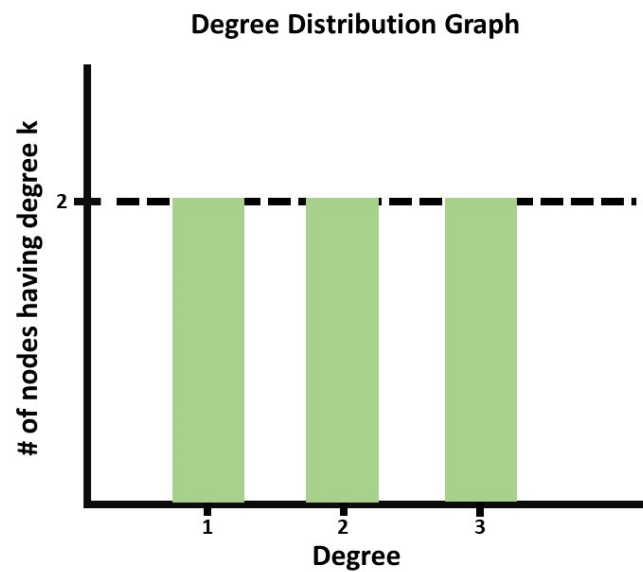
To find the shortest path between the two farthest points, you need to examine all possible routes between these two points. The length of a path is measured by the number of connections. For example, to go from A to F, we can consider different routes such as A-D-E-F or A-C-E-F. After examining all possible routes, you need to determine the shortest path between the two farthest points. We will calculate how many connections are on this path and its length.

When you find the length of the shortest path, you obtain the diameter of the network. The network's diameter is expressed as the length of the shortest path between these two farthest points. Assuming that the farthest two points are A and F, the shortest path would be A-C-E-F. This path has 3 connections (A-C, C-E, E-F), so the **diameter of the network is 3**.

c) The degree distribution graph

Node	Degree
A	3
B	1
C	2
D	2
E	3
F	1

Degree	Node Count
1	2
2	2
3	2



Question 2

Goals: We have quantified the data we have in the first question and manually obtained the average path length, network diameter values, and degree distribution graph. Now we will get the same values by using Analyze Network tools in Cytoscape and we will compare the results. Additionally, we will change the node color and node size based on the degrees of the nodes in the network.

Download the Cytoscape software in Figure 1.

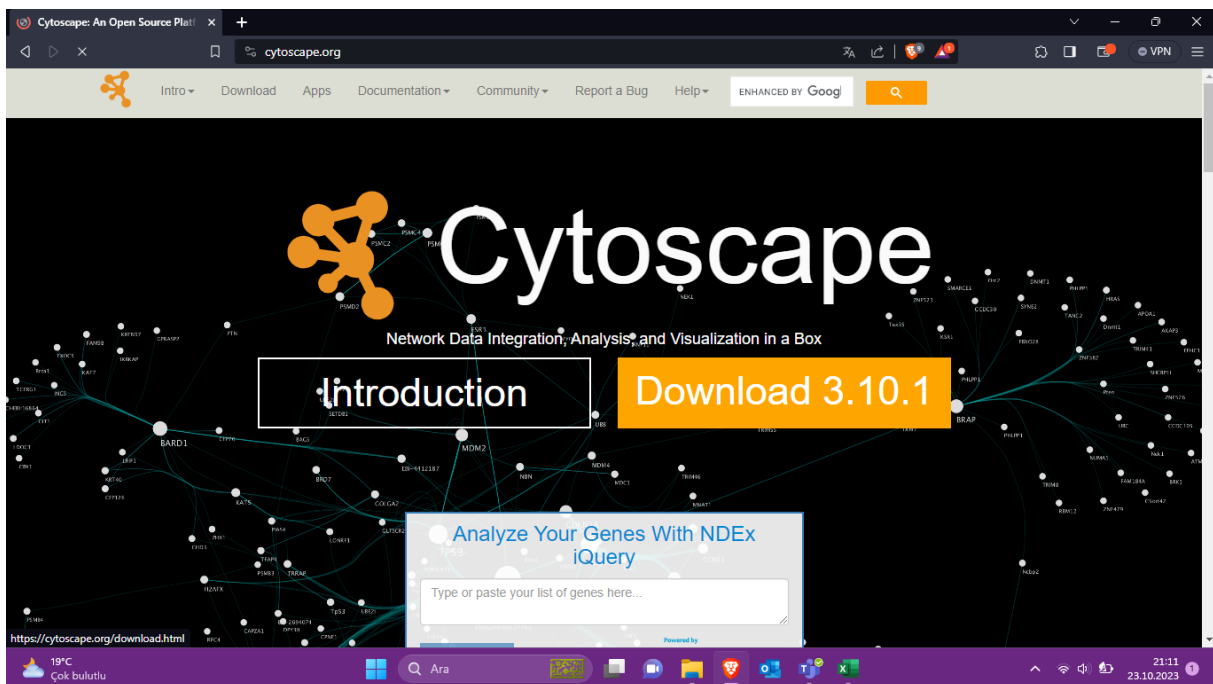
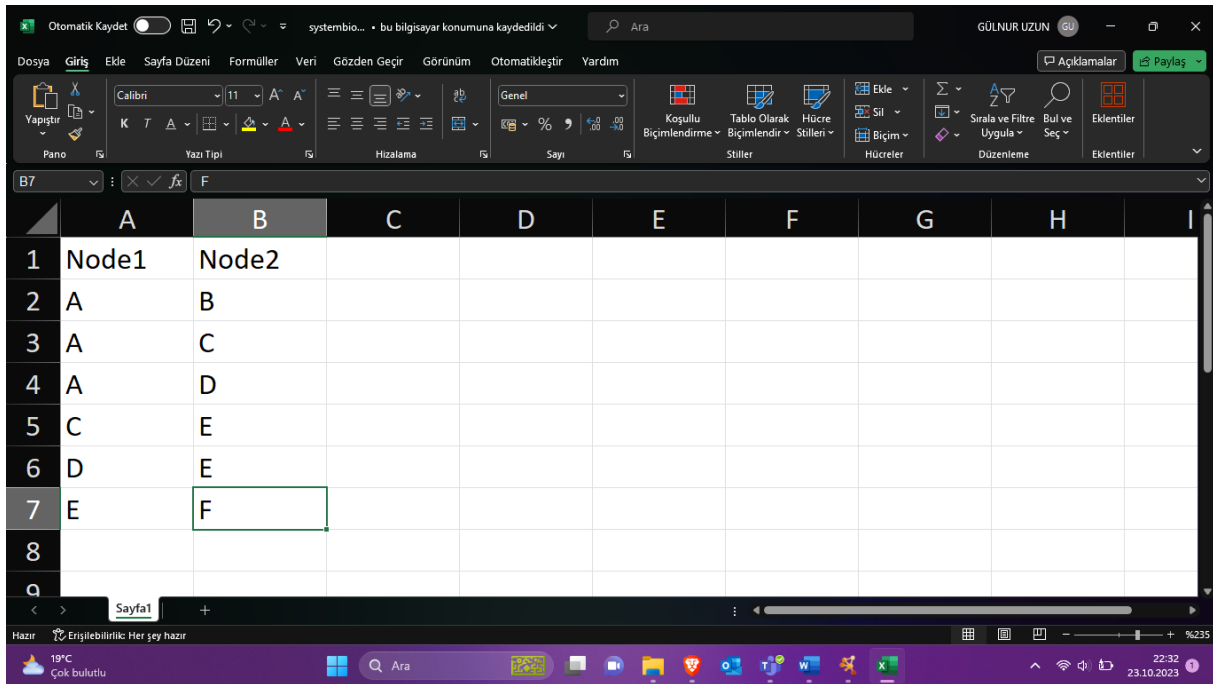


Figure 1. We have downloaded the Cytoscape software in <https://cytoscape.org/>.

We have created the excel file contain information the Node1 and Node2. This excel file including between nodes information; so it including Node1 and Node2 column. We will use this file in Cytoscape (Figure 2).



	A	B	C	D	E	F	G	H	I
1	Node1	Node2							
2	A	B							
3	A	C							
4	A	D							
5	C	E							
6	D	E							
7	E	F							
8									
9									

Figure 2. An excel file containing the Node1 and Node2 columns.

Then, we will import created the excel file in Figure 2 in Cytoscape. To do this, we will following these step: **File-Import-Network from File** (Figure3).

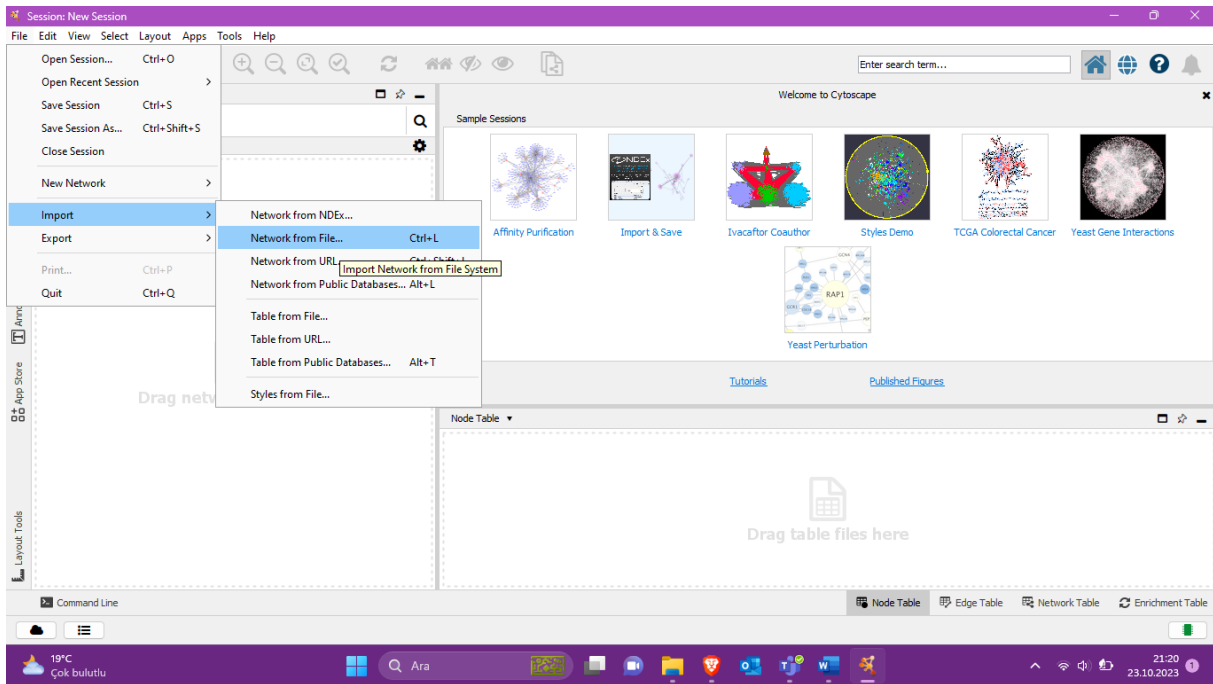


Figure 3. We import the created file by following the File-Import-Network from File path.

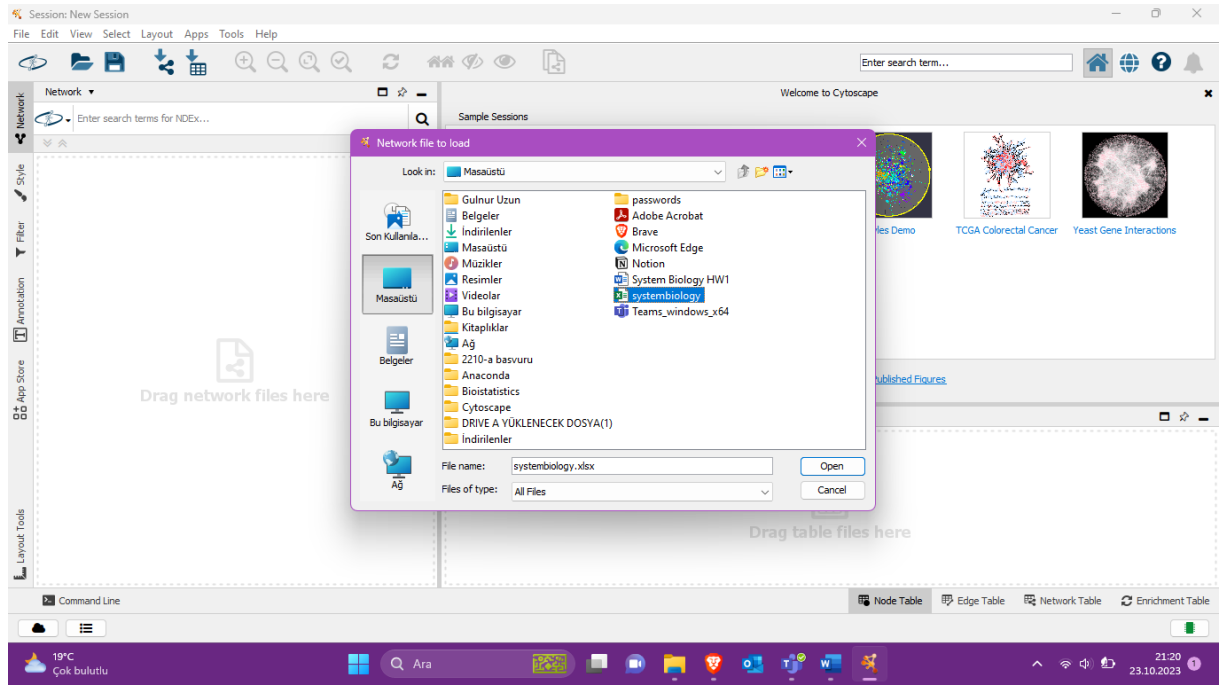


Figure 4. We have selected the systembiology.xlsx file.

After importing the file, according to the nodes information, we obtained an image of network connections, as in the Figure 5.

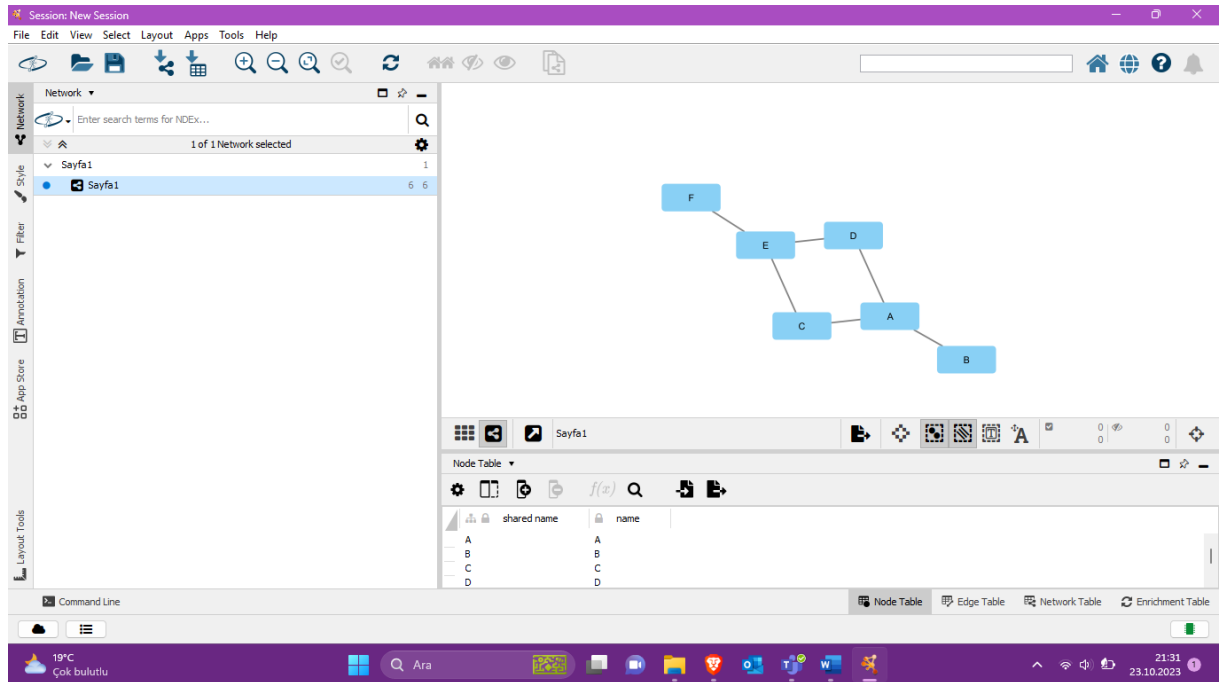


Figure 5. The image we got when we first opened the file in Cytoscape.

Afterward, we will perform network analysis by following the path **Tools-Analysis Network**. In the first question, we manually calculated certain values. We will obtain these manually calculated values here using the Network Analysis tool and compare the results.

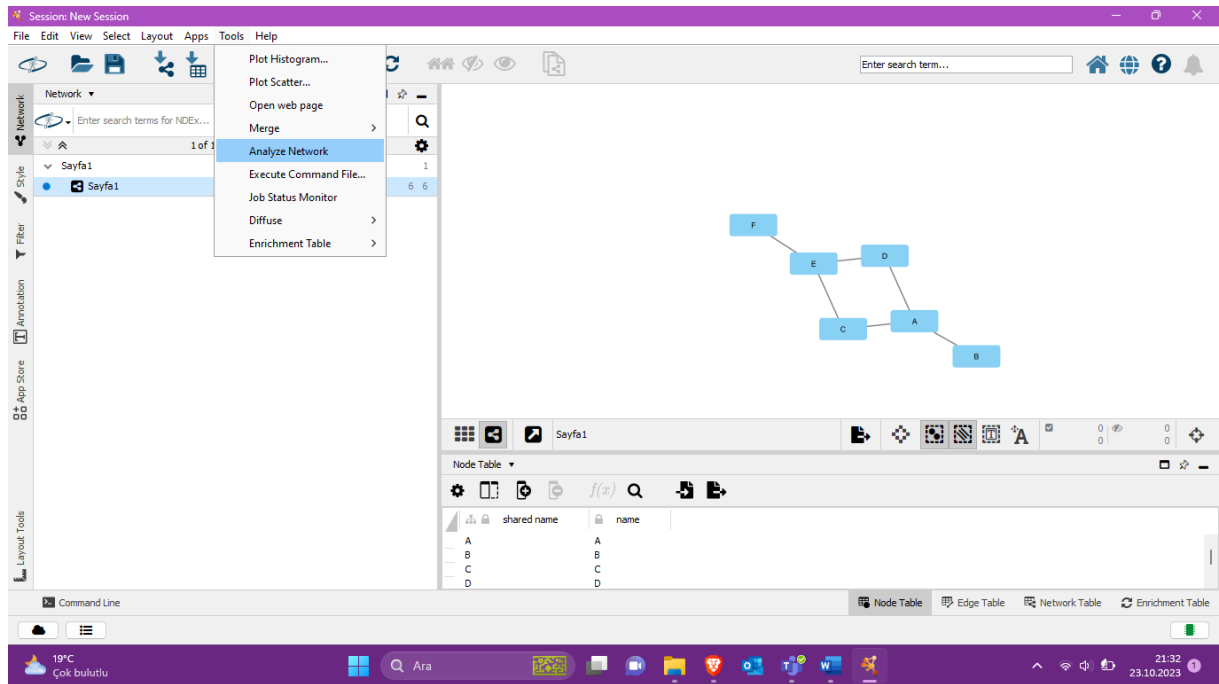


Figure 6. In this step, we following the Tools-Analyze Network pathway for average path length, diameter, and degree distribution graph.

We obtained the **Summary Statistics** (Figure 7) and the **Degree Distribution Graph** (Figure 8) results by following the path in Figure 6.

Summary Statistics	
Number of nodes	6
Number of edges	6
Avg. number of neighbors	2,000
Network diameter	3
Network radius	1
Characteristic path length	1,510
Clustering coefficient	0,000
Network density	0,200
Connected components	1
Multi-edge node pairs	0
Number of self-loops	0
Analysis time (sec)	0,044

Figure 7. Summary Statistics for our network.



Figure 8. Degree Distribution Graph for our network.

In the final stage, an adjustment is required. We will modify the color tones and sizes based on the degrees of the nodes. For color adjustments, we selected the **Fill Color** section in the **Style tab** to determine the color tone. To make size adjustments, we made modifications on **the Height option** in the **Style tab**. As a result, we obtained a network with varying **sizes** and **color tones** based on their **degrees** (Figure 9).

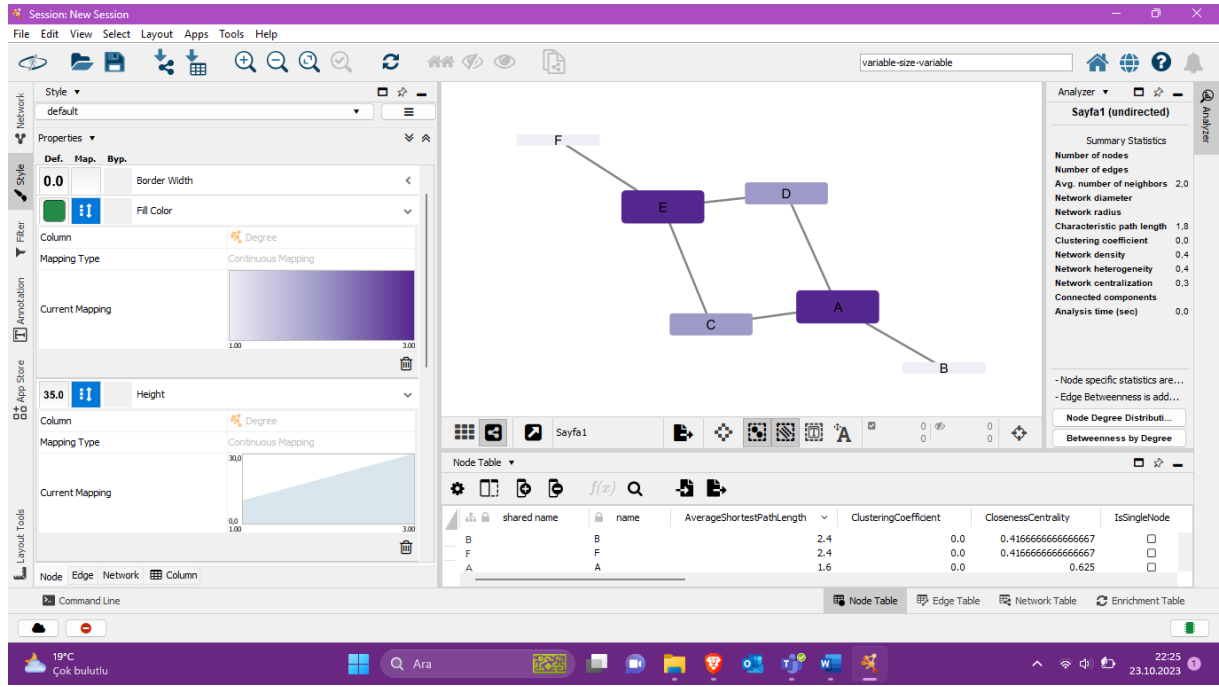


Figure 9. In this step, we change the node size and color suitable degree values.

Table 1 provides a comparison between the results of manual calculations and the results of the analyze network calculations. According to the obtained results, the diameter value is the same for both calculations, but there is a difference of 0.3 in the average path length value.

Table 1. We have compared the results of manual calculation and Network Analysis.

	Manual Calculation	Network Analyze Tool
Average Path Length	1,8667	1,510
Network Diameter	3	3

Question 3

Goals: In this question, our objective is to download the .zip files (with .tab format being important) for the worm (*Caenorhabditis elegans*) and rat (*Rattus norvegicus*) organisms using the BioGRID database. Subsequently, we will perform Network Analysis using the Cytoscape software. Then, we will compare these results for two separate organisms.

Firstly, we accessed the BioGRID database (<https://thebiogrid.org/>) and selected the downloads tab.

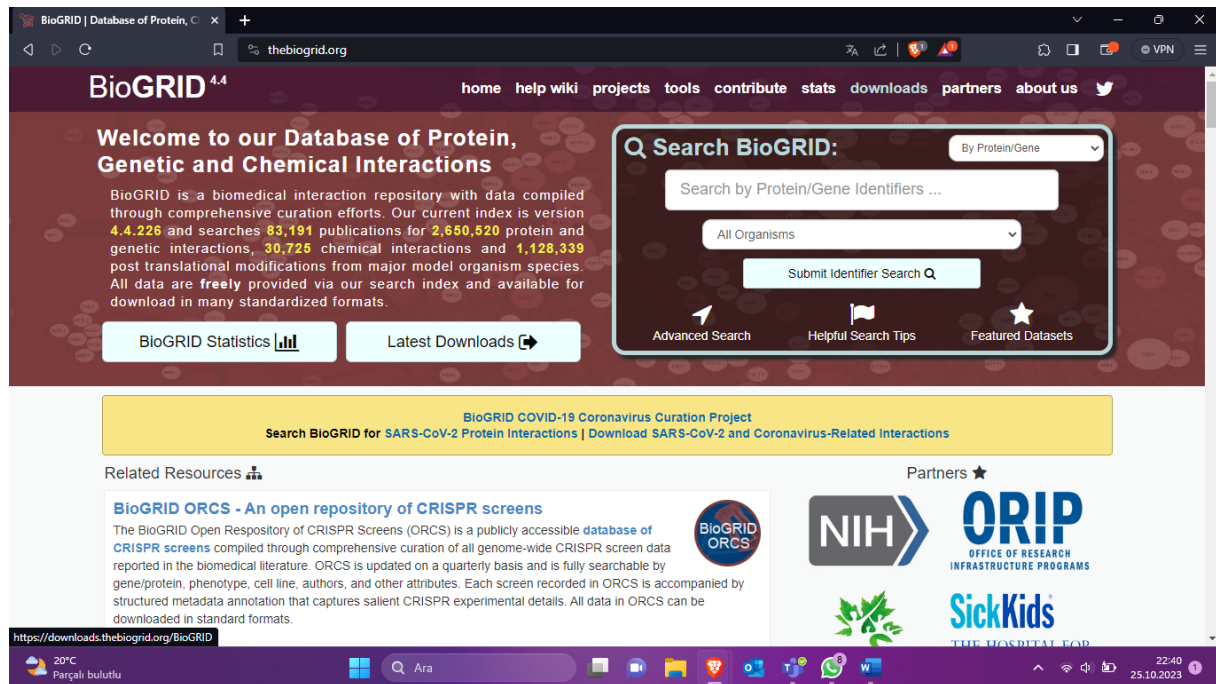


Figure 10. We have selected downloads tab in BioGRID database.

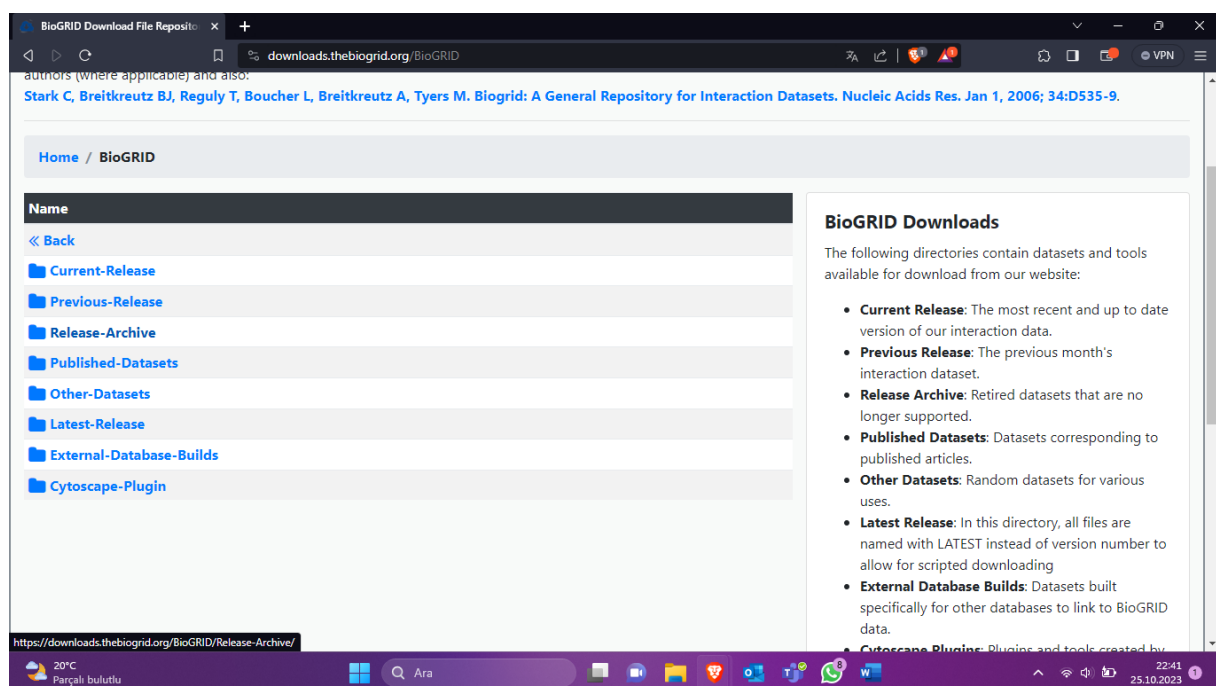


Figure 11. Then we have selected Release-Archive.

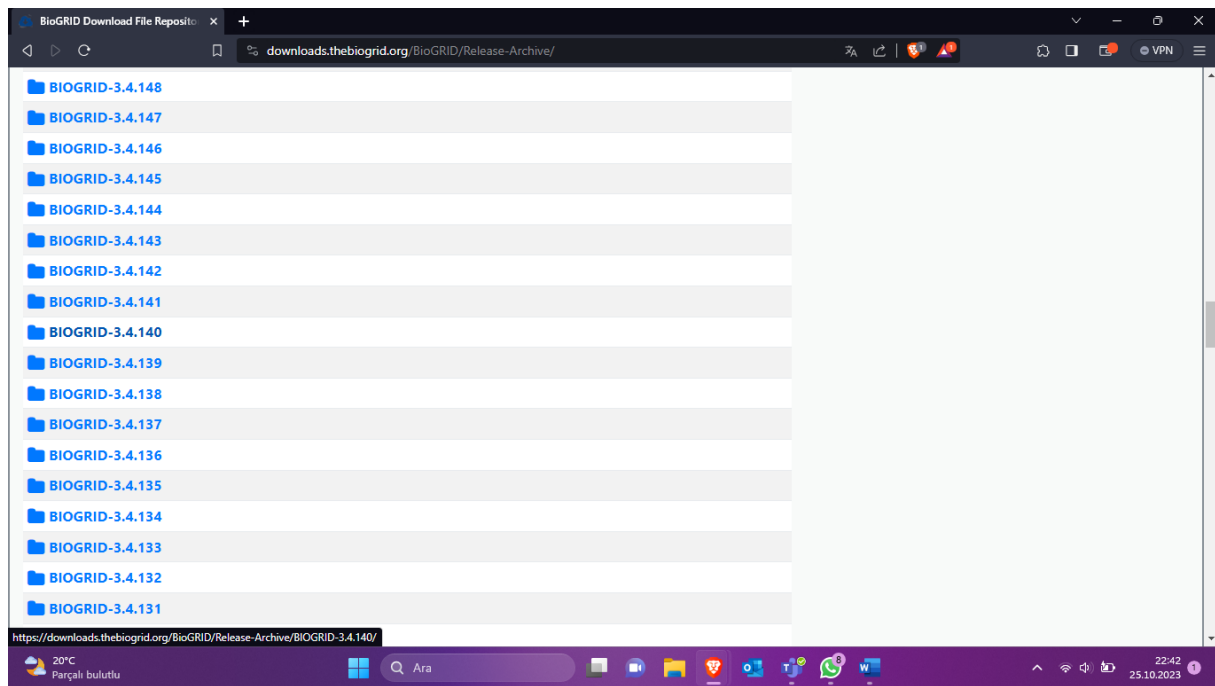


Figure 12. Then, we have opened the BioGRID-3.4.140 folder.

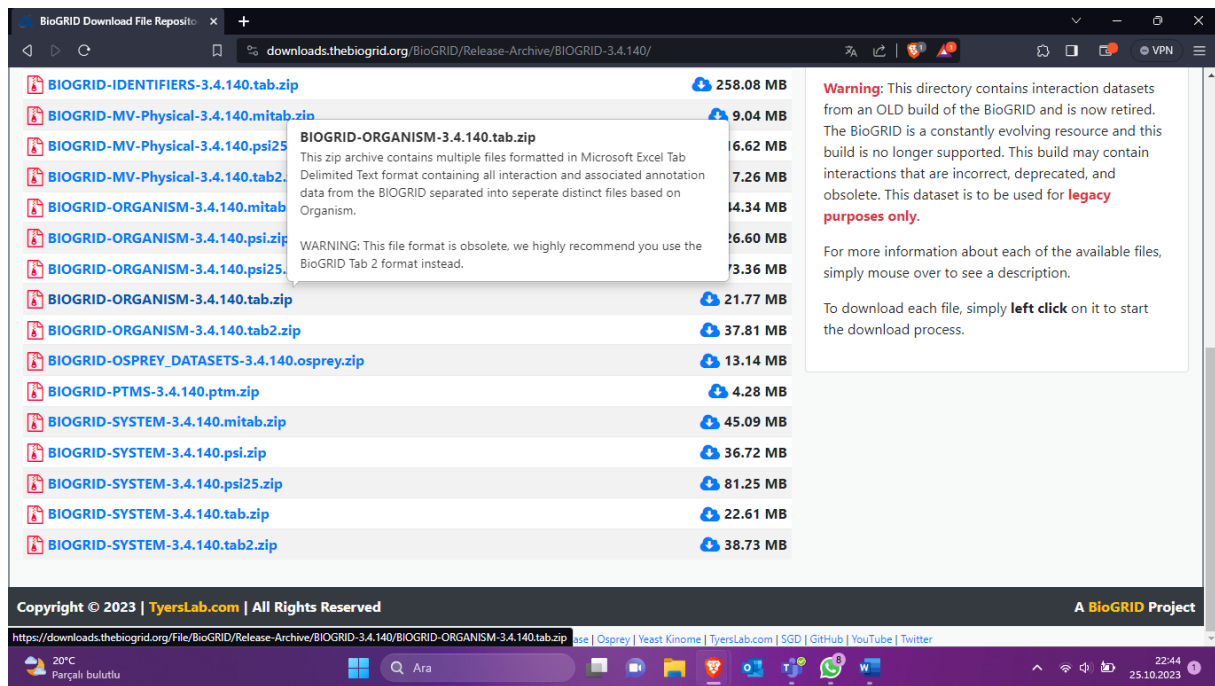


Figure 13. Then new step, we have downloaded BIOGRID-ORGANISM-3.4.140.tab.zip folder.

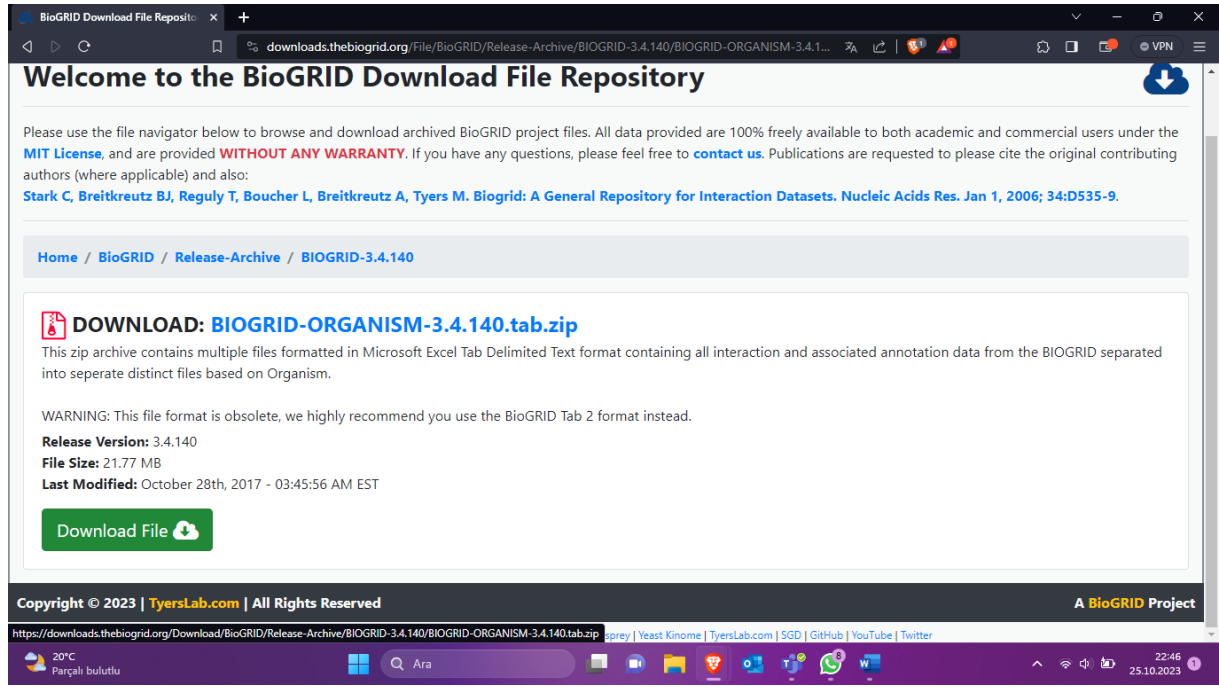


Figure 14. We have selected “Download File” tab, and have downloaded file.

When we opened the file, it contained data sets for various organisms, but the ones we are interested in are *C. elegans* and *R. norvegicus*. Therefore, we selected the files related to these two organisms and organized them in a new folder.

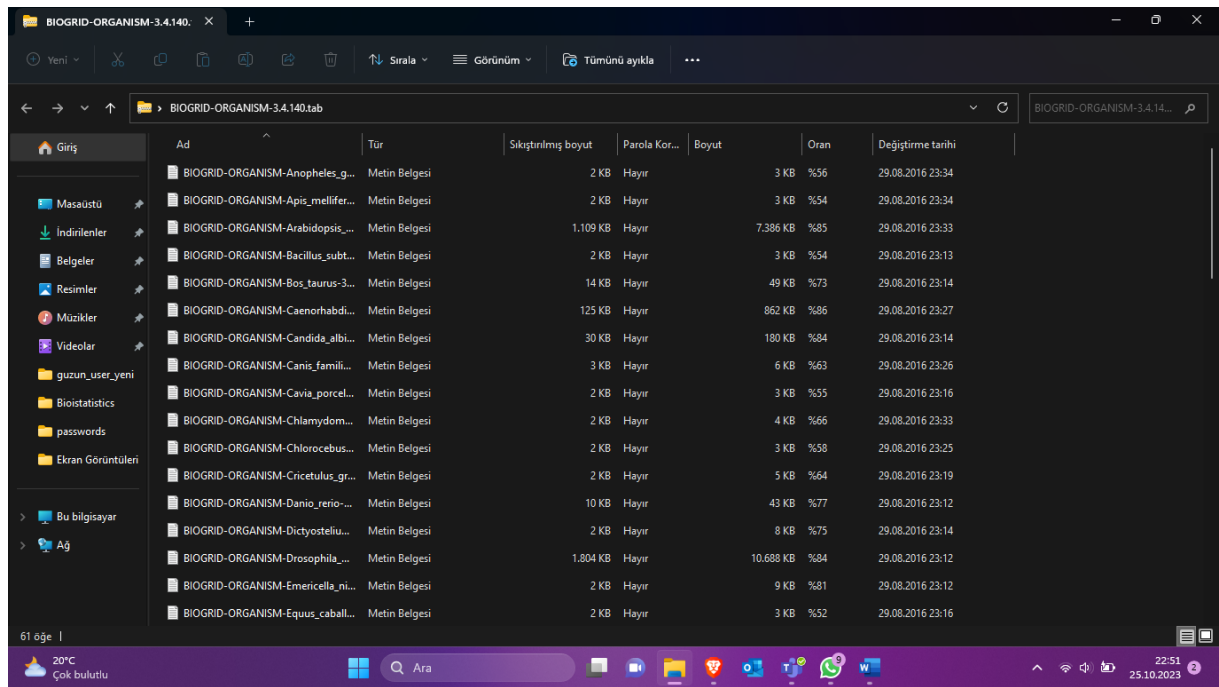


Figure 15. The contents of the file we downloaded.

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11 Stark C, Breitkreutz BJ, Reguly T, Boucher L, Breitkreutz A, Tyers M. BioGRID: A General Repository for Interaction Datasets.
12 Nucleic Acids Res. Jan1;34:D535-9.
13
14 This data is distributed for research purposes only, and is provided WITHOUT ANY WARRANTY.
15
16 -----
17
18 Brief Description of the Columns:
19
20 A.) INTERACTOR_A Unique ID for Interacting Partner A
21 B.) INTERACTOR_B Unique ID for Interacting Partner B
22 C.) OFFICIAL_SYMBOL_FOR_A
23 D.) OFFICIAL_SYMBOL_FOR_B
24 E.) ALIASES_FOR_A List of common names for geneA, separated by '|'
25 F.) ALIASES_FOR_B List of common names for geneB, separated by '|'
26 G.) EXPERIMENTAL_SYSTEM System in which the interaction was shown
27 H.) SOURCE Author/s of the interaction
28 I.) PUBMED_ID PubMed_ID of the paper, separated by ';'
29 J.) ORGANISM_A_ID NCBI ID of Gene A Organism
30 K.) ORGANISM_B_ID NCBI ID of Gene B Organism
31
32 -----
33 File Version: 3.4.140
34
35 -----
36 INTERACTOR_A INTERACTOR_B OFFICIAL_SYMBOL_A OFFICIAL_SYMBOL_B ALIASES_FOR_A ALIASES_FOR_B EXPERIMENTAL_SYSTEM SOURCE PUBMED_ID ORGANISM_A_ID (
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Figure 16. The initial view of the *C. elegans* file in Notepad++.

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2 CELE_A07.2 CELE_W0704.5 soc-2 W0704.5 - Two-hybrid Li S (2004) 14704431 6239 6239
3 CELE_A07.2 ZK792.6 soc-2 let-60 - CELE_ZK792.6[lin-34 Two-hybrid Li S (2004) 14704431 6239 6239
4 B0024.12 B0365.1 gna-1 acly-2 CELE_B0024.12|CeGNA1 CELE_B0365.1 Two-hybrid Li S (2004) 14704431 6239 6239
5 B0024.12 CELE_C25F6.2 gna-1 dlg-1 CELE_B0024.12|CeGNA1 - Two-hybrid Li S (2004) 14704431 6239 6239
6 B0024.12 CELE_C38D4.6 gna-1 pal-1 CELE_B0024.12|CeGNA1 - Two-hybrid Li S (2004) 14704431 6239 6239
7 B0024.12 CELE_W02G9.3 gna-1 W02G9.3 CELE_B0024.12|CeGNA1 - Two-hybrid Li S (2004) 14704431 6239 6239
8 CELE_B0024.14 CELE_B0024.14 crm-1 crm-1 - - Two-hybrid Li S (2004) 14704431 6239 6239
9 CELE_B0024.14 CELE_B0507.1 crm-1 B0507.1 - - Two-hybrid Li S (2004) 14704431 6239 6239
10 CELE_B0024.14 C02C2.1 crm-1 tyr-1 - CELE_C02C2.1 Two-hybrid Li S (2004) 14704431 6239 6239
11 CELE_B0024.14 C34G6.2 crm-1 tyr-4 - CELE_C34G6.2 Two-hybrid Li S (2004) 14704431 6239 6239
12 CELE_B0024.14 CELE_C37C3.6 crm-1 mig-6 - - Two-hybrid Li S (2004) 14704431 6239 6239
13 CELE_B0024.14 CELE_C54D2.2 crm-1 C54D2.2 - - Two-hybrid Li S (2004) 14704431 6239 6239
14 CELE_B0024.14 CELE_F08C6.1 crm-1 adt-2 - - Two-hybrid Li S (2004) 14704431 6239 6239
15 CELE_B0024.14 CELE_F16B4.5 crm-1 F16B4.5 - - Two-hybrid Li S (2004) 14704431 6239 6239
16 CELE_B0024.14 CELE_F23B12.4 crm-1 CELE_F23B12.4 - - Two-hybrid Li S (2004) 14704431 6239 6239
17 CELE_B0024.14 CELE_F29G6.3 crm-1 hpo-34 - - Two-hybrid Li S (2004) 14704431 6239 6239
18 CELE_B0024.14 CELE_F30H5.3 crm-1 F30H5.3 - - Two-hybrid Li S (2004) 14704431 6239 6239
19 CELE_B0024.14 F41H0.8 crm-1 elo-6 - CELE_F41H0.8 Two-hybrid Li S (2004) 14704431 6239 6239
20 CELE_B0024.14 F42D1.2 crm-1 tatr-1 - CELE_F42D1.2 Two-hybrid Li S (2004) 14704431 6239 6239
21 CELE_B0024.14 CELE_F48E8.1 crm-1 lon-1 - - Two-hybrid Li S (2004) 14704431 6239 6239
22 CELE_B0024.14 CELE_F53A9.1 crm-1 F53A9.1 - - Two-hybrid Li S (2004) 14704431 6239 6239
23 CELE_B0024.14 CELE_F53A9.2 crm-1 F53A9.2 - - Two-hybrid Li S (2004) 14704431 6239 6239
24 CELE_B0024.14 CELE_F54B11.7 crm-1 F54B11.7 - - Two-hybrid Li S (2004) 14704431 6239 6239
25 CELE_B0024.14 CELE_F56B3.2 crm-1 F56B3.2 - - Two-hybrid Li S (2004) 14704431 6239 6239
26 CELE_B0024.14 CELE_K07C11.7 crm-1 K07C11.7 - - Two-hybrid Li S (2004) 14704431 6239 6239
27 CELE_B0024.14 CELE_K08E7.5 crm-1 CELE_K08E7.5 - - Two-hybrid Li S (2004) 14704431 6239 6239
28 CELE_B0024.14 CELE_R02F11.1 crm-1 R02F11.1 - - Two-hybrid Li S (2004) 14704431 6239 6239
29 CELE_B0024.14 CELE_R05G6.7 crm-1 yda-1 - R05G6.7 Two-hybrid Li S (2004) 14704431 6239 6239
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31 CELE_B0024.14 T04C12.6 crm-1 act-1 - CELE_T04C12.6 Two-hybrid Li S (2004) 14704431 6239 6239
32 CELE_B0024.14 CELE_T21B6.3 crm-1 T21B6.3 - - Two-hybrid Li S (2004) 14704431 6239 6239
33 CELE_B0024.14 CELE_T21D12.11 crm-1 T21D12.11 - - Two-hybrid Li S (2004) 14704431 6239 6239
34 CELE_B0024.14 CELE_T22F7.3 crm-1 T22F7.3 - - Two-hybrid Li S (2004) 14704431 6239 6239
35 CELE_B0024.14 CELE_T22H2.5 crm-1 scrn-1 - - Two-hybrid Li S (2004) 14704431 6239 6239
36 CELE_B0024.14 CELE_W03G1.5 crm-1 W03G1.5 - - Two-hybrid Li S (2004) 14704431 6239 6239
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Figure 17. The updated version of the *C. elegans* file after removing the preceding descriptions before INTERACTOR_A.

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11 Stark C, Breitkreutz BJ, Reguly T, Boucher L, Breitkreutz A, Tyers M. BioGRID: A General Repository for Interaction Datasets.
12 Nucleic Acids Res. Jan1;34:D535-9.
13
14 This data is distributed for research purposes only, and is provided WITHOUT ANY WARRANTY.
15
16 -----
17 Brief Description of the Columns:
18
19 A.) INTERACTOR_A Unique ID for Interacting Partner A
20 B.) INTERACTOR_B Unique ID for Interacting Partner B
21 C.) OFFICIAL_SYMBOL_FOR_A
22 D.) OFFICIAL_SYMBOL_FOR_B
23 E.) ALIASES_FOR_A List of common names for geneA, separated by '|'
24 F.) ALIASES_FOR_B List of common names for geneB, separated by '|'
25 G.) EXPERIMENTAL_SYSTEM System in which the interaction was shown
26 H.) SOURCE Author/s of the interaction
27 I.) PUBMED_ID PubMed ID of the paper, separated by ';'
28 J.) ORGANISM_A_ID NCBI ID of Gene A Organism
29 K.) ORGANISM_B_ID NCBI ID of Gene B Organism
30
31 -----
32 File Version: 3.4.140
33 -----
34
35 INTERACTOR_A INTERACTOR_B OFFICIAL_SYMBOL_A OFFICIAL_SYMBOL_B ALIASES_FOR_A ALIASES_FOR_B EXPERIMENTAL_SYSTEM SOURCE PUBMED_ID ORGANISM_A_ID (
36
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Figure 18. The initial view of the *R. norvegicus* file in Notepad++.

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2 ETG0442 ETG29382 NOS1 Ccbp1 IHES1[N-NOS]NC-NOS[NOS]bNOS 50-kDaEa-inducedADP-ribosylatedubstrate[BARS-50]Bars[CtBP3/BARS Affinity Capture-MS I
3 ETG0581 ETG116502 BAX Bak1 BCL2L4 - Affinity Capture-Western Henry H (2002) 11850803 9606 10116
4 RP11-491A12.4 ETG24413 NCOA4 Nr3c1 ARA70[ELE1]FTC3[RFG GR]Gor[Gr] Reconstituted Complex Alen P (1999) 9892017 9606 10116
5 ETG25414 ETG25513 Bcar1 Pik3r1 Cas[Crkas]P130CAS PI3KA Affinity Capture-Western Riggins RB (2003) 12692262 10116 10116
6 ETG25414 ETG25513 Bcar1 Pik3r1 Cas[Crkas]P130CAS PI3KA Far Western Riggins RB (2003) 12692262 10116 10116
7 ETG9261 ETG24955 MAPKAPK2 Tsc2 MAPKAP-K2[MK-2]MK2 Rc Biochemical Activity Li Y (2003) 12582162 9606 10116
8 ETG24855 RP1-148E22.1 Tsc2 YWHAB Rc GW128[HEL-S-1]HS1[KCIP-1]YWHAA Affinity Capture-Western Li Y (2003) 12582162 10116 9606
9 ETG5783 ETG24205 PTEN13 Apc FAP-1[FNP1]PTP-BAS[PTP-BL][PTP1E][PTP1L][PTP1E][hPTP1E RATAPC Affinity Capture-Western Erdmann KS (2000) 10951583 9606 1
10 ETG29382 ETG24598 Ccbp1 Nos1 50-kDaEa-inducedADP-ribosylatedubstrate[BARS-50]Bars[CtBP3/BARS bNOS Affinity Capture-Western Riefler GM (2001)
11 ETG24205 ETG5783 Apc PTEN13 RATAPC FAP-1[FNP1]PTP-BAS[PTP-BL][PTP1E][PTP1L][PTP1E][hPTP1E Two-hybrid Erdmann KS (2000) 10951583 10116 9606
12 ETG24205 ETG5783 Apc PTEN13 RATAPC FAP-1[FNP1]PTP-BAS[PTP-BL][PTP1E][PTP1L][PTP1E][hPTP1E Reconstituted Complex Erdmann KS (2000) 10951583 10116 9606
13 ETG66603 ETG85435 Gemin2 Smad9 170001N191rik[Sip1 Madh9]Smad3 Two-hybrid van Grunsven LA (2003) 12714599 10090 10116
14 ETG89816 ETG361512 Picam1 Ehd2 Calm MGEP5 Reconstituted Complex Park SY (2004) 15182197 10116 10116
15 ETG61512 ETG25139 Ehd2 Slc2a4 MGEP5 Glut4 Affinity Capture-Western Park SY (2004) 15182197 10116 10116
16 HSPC277 ETG292925 AATF Tsg101 BFR2[CHE-1]CHE1[DED Rf Two-hybrid Burgdorf S (2004) 14761944 9606 10116
17 ETG292925 HSPC277 Tsg101 AATF Rf BFR2[CHE-1]CHE1[DED Reconstituted Complex Burgdorf S (2004) 14761944 10116 9606
18 ETG8655 ETG310218 DYNNL1 Cez1 DLCL1[DLCS][DNCL1][DNCL1][LC8][LC8a][FIN]hdlc1 CA-1[Cal Affinity Capture-MS Navarro-Lerida I (2004) 14760703 9606 10116
19 ETG8655 ETG24593 DYNNL1 Lcdra DLCL1[DLCS][DNCL1][DNCL1][LC8][LC8a][FIN]hdlc1 Lcdh Affinity Capture-MS Navarro-Lerida I (2004) 14760703 9606 10116
20 ETG8655 ETG24189 DYNNL1 Aldoa DLCL1[DLCS][DNCL1][DNCL1][LC8][LC8a][FIN]hdlc1 Aldol[RNALDOGS Affinity Capture-MS Navarro-Lerida I (2004) 14760703 9606 1
21 ETG8655 ETG64520 DYNNL1 Mta1 DLCL1[DLCS][DNCL1][DNCL1][LC8][LC8a][FIN]hdlc1 - Affinity Capture-MS Navarro-Lerida I (2004) 14760703 9606 10116
22 ETG8655 ETG50688 DYNNL1 Cacnb1 DLCL1[DLCS][DNCL1][DNCL1][LC8][LC8a][FIN]hdlc1 - Affinity Capture-MS Navarro-Lerida I (2004) 14760703 9606 10116
23 ETG8655 ETG24957 DYNNL1 Glu1 DLCL1[DLCS][DNCL1][DNCL1][LC8][LC8a][FIN]hdlc1 Glns Affinity Capture-MS Navarro-Lerida I (2004) 14760703 9606 10116
24 ETG8655 ETG81822 DYNNL1 Actb DLCL1[DLCS][DNCL1][DNCL1][LC8][LC8a][FIN]hdlc1 Actx Affinity Capture-MS Navarro-Lerida I (2004) 14760703 9606 10116
25 ETG8655 ETG287876 DYNNL1 Actg1 DLCL1[DLCS][DNCL1][DNCL1][LC8][LC8a][FIN]hdlc1 Actg Affinity Capture-MS Navarro-Lerida I (2004) 14760703 9606 10116
26 ETG8655 ETG24551 DYNNL1 Mdh1 DLCL1[DLCS][DNCL1][DNCL1][LC8][LC8a][FIN]hdlc1 MDL1[Mdh1]Mor2 Affinity Capture-MS Navarro-Lerida I (2004) 14760703 9606 1
27 ETG8655 ETG81819 DYNNL1 Vim DLCL1[DLCS][DNCL1][DNCL1][LC8][LC8a][FIN]hdlc1 - Affinity Capture-MS Navarro-Lerida I (2004) 14760703 9606 10116
28 ETG8655 ETG499110 DYNNL1 Zfp780b DLCL1[DLCS][DNCL1][DNCL1][LC8][LC8a][FIN]hdlc1 - Affinity Capture-MS Navarro-Lerida I (2004) 14760703 9606 10116
29 ETG8655 ETG24399 DYNNL1 Glud1 DLCL1[DLCS][DNCL1][DNCL1][LC8][LC8a][FIN]hdlc1 Ac2-281[Gdh1]Glud1[Glud1]MRG-2 Affinity Capture-MS Navarro-Lerida I (2004) 14760
30 ETG8655 ETG64158 DYNNL1 Tubal1 DLCL1[DLCS][DNCL1][DNCL1][LC8][LC8a][FIN]hdlc1 Tubal Affinity Capture-MS Navarro-Lerida I (2004) 14760703 9606 10116
31 ETG8655 ETG291081 DYNNL1 Tubb2b DLCL1[DLCS][DNCL1][DNCL1][LC8][LC8a][FIN]hdlc1 RGD1309427[Tubb2 Affinity Capture-MS Navarro-Lerida I (2004) 14760703 9606
32 ETG8655 ETG64845 DYNNL1 Gphn DLCL1[DLCS][DNCL1][DNCL1][LC8][LC8a][FIN]hdlc1 Geph Affinity Capture-MS Navarro-Lerida I (2004) 14760703 9606 10116
33 ETG8655 ETG60416 DYNNL1 Pfkp DLCL1[DLCS][DNCL1][DNCL1][LC8][LC8a][FIN]hdlc1 ATP-PFK[PFK-C][PFK-P Affinity Capture-MS Navarro-Lerida I (2004) 14760703 9606
34 ETG8655 ETG65152 DYNNL1 Pfkcm DLCL1[DLCS][DNCL1][DNCL1][LC8][LC8a][FIN]hdlc1 ATP-PFK[PFK-A][PFK-M Affinity Capture-MS Navarro-Lerida I (2004) 14760703 9606
35 ETG8655 ETG81918 DYNNL1 Par3 DLCL1[DLCS][DNCL1][DNCL1][LC8][LC8a][FIN]hdlc1 Par3 Affinity Capture-MS Navarro-Lerida I (2004) 14760703 9606 10116
36 ETG8655 ETG64962 DYNNL1 Map1lc3b DLCL1[DLCS][DNCL1][DNCL1][LC8][LC8a][FIN]hdlc1 Map1lc3[Mpl3]zbs559 Affinity Capture-MS Navarro-Lerida I (2004) 14760703 9606 10116
```

Figure 19. The updated version of the *R. norvegicus* file after removing the preceding descriptions before INTERACTOR_A.

We formatted the files to the required format. In the next steps, we will first import the file for the *C. elegans* organism and perform network analysis, and then we will import the file for the *R. norvegicus* organism and conduct network analysis.

Firstly we will import *C. elegans* file in Cytoscape.

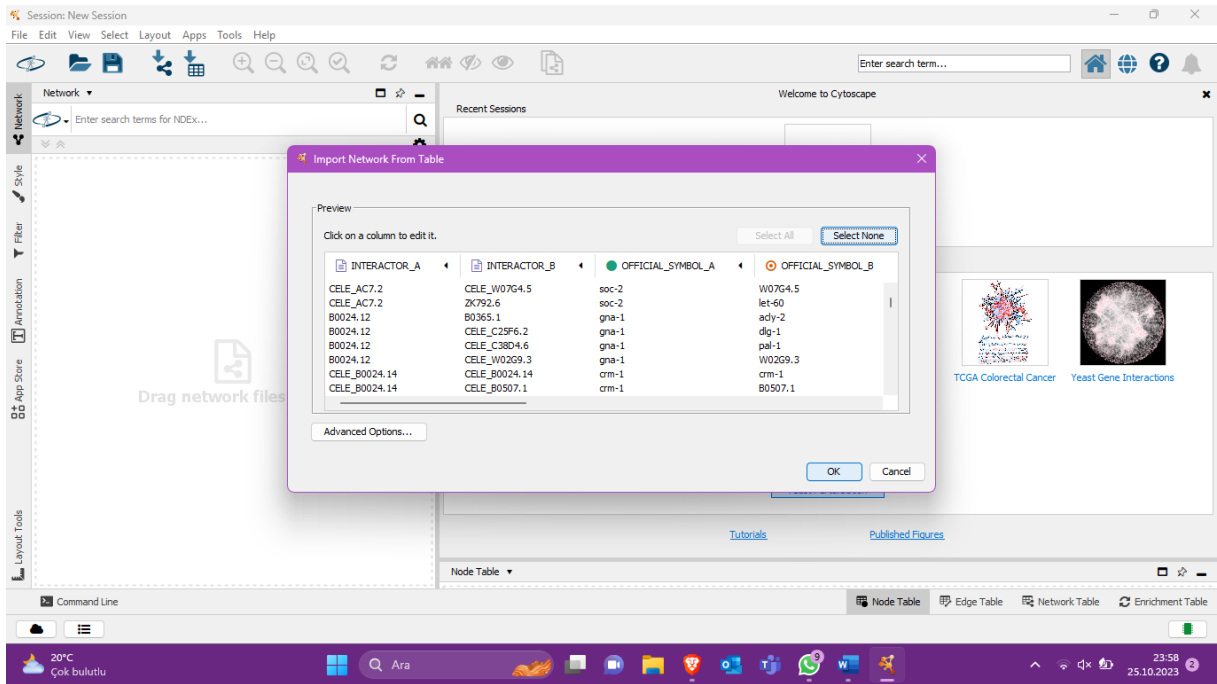


Figure 20. We determine the OFFICIAL_SYMBOL_A and OFFICIAL_SYMBOL_B columns as protein.

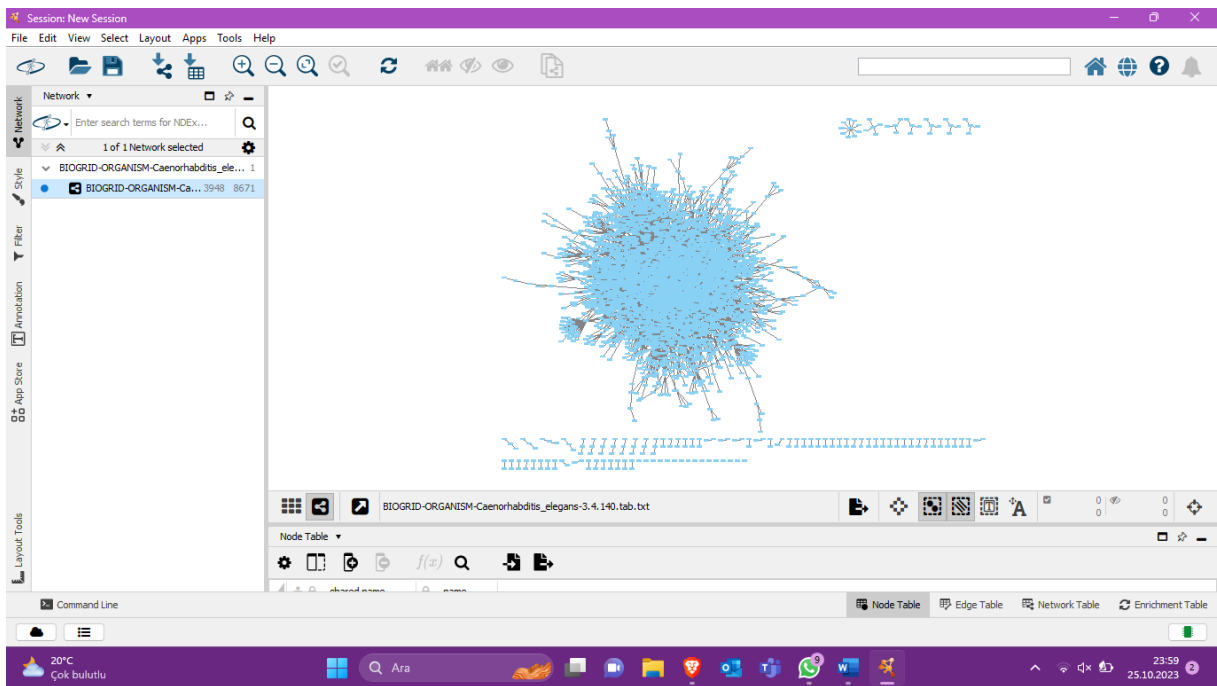


Figure 21. The first image of the *C. elegans* dataset in the Cytoscape.

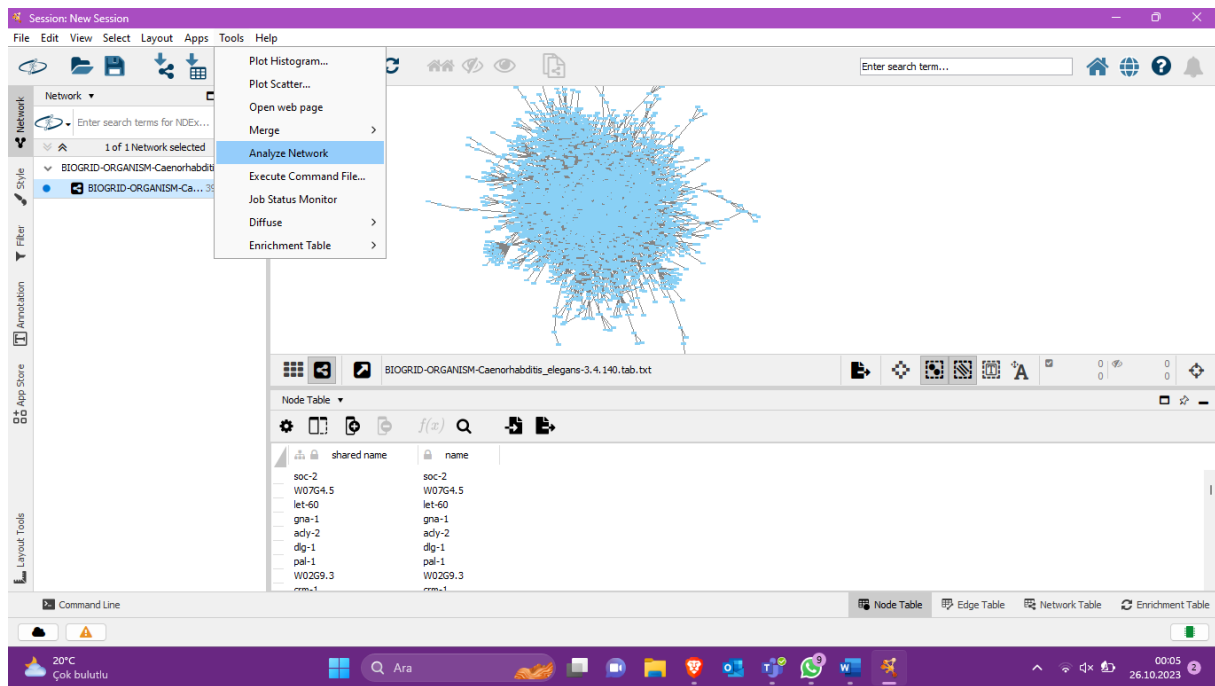


Figure 22. In this step, we following the Tools-Analyze Network pathway for average path length, diameter, and degree distribution graph.

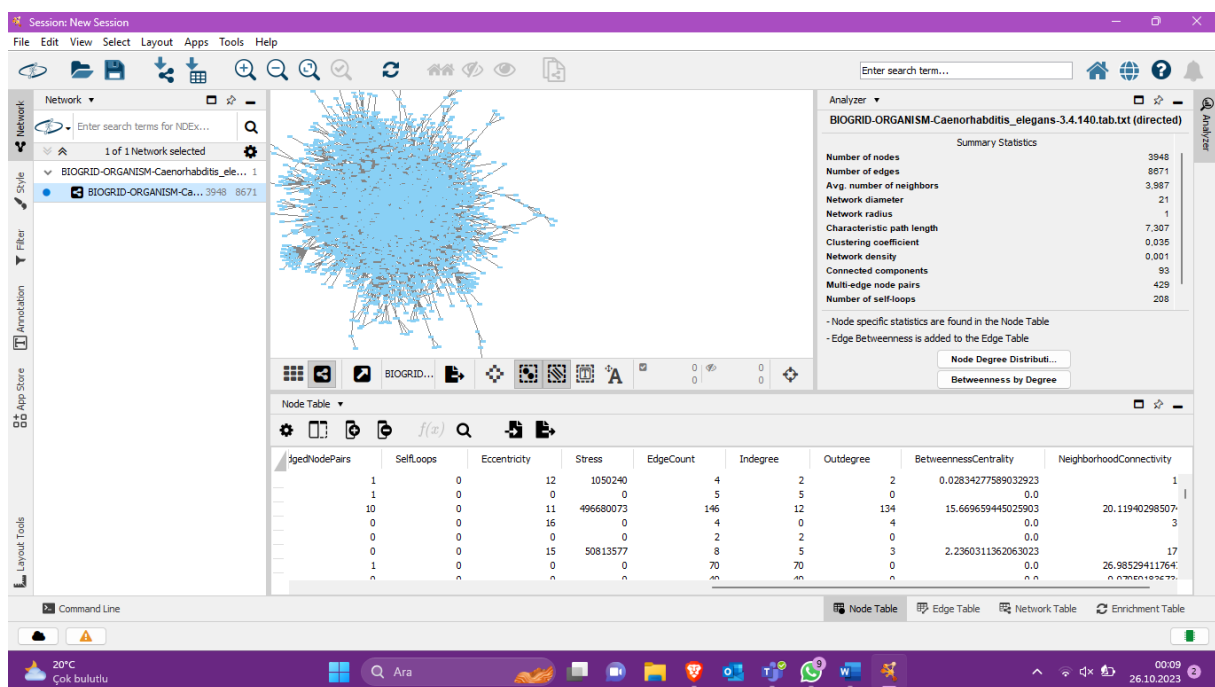


Figure 23. We obtained the analysis results for *C. elegans*.

Analysis results for *C. elegans* organism

Number of nodes and edges : 3948 nodes and 8671.

Average path length: 7,307 Network

Diameter: 21

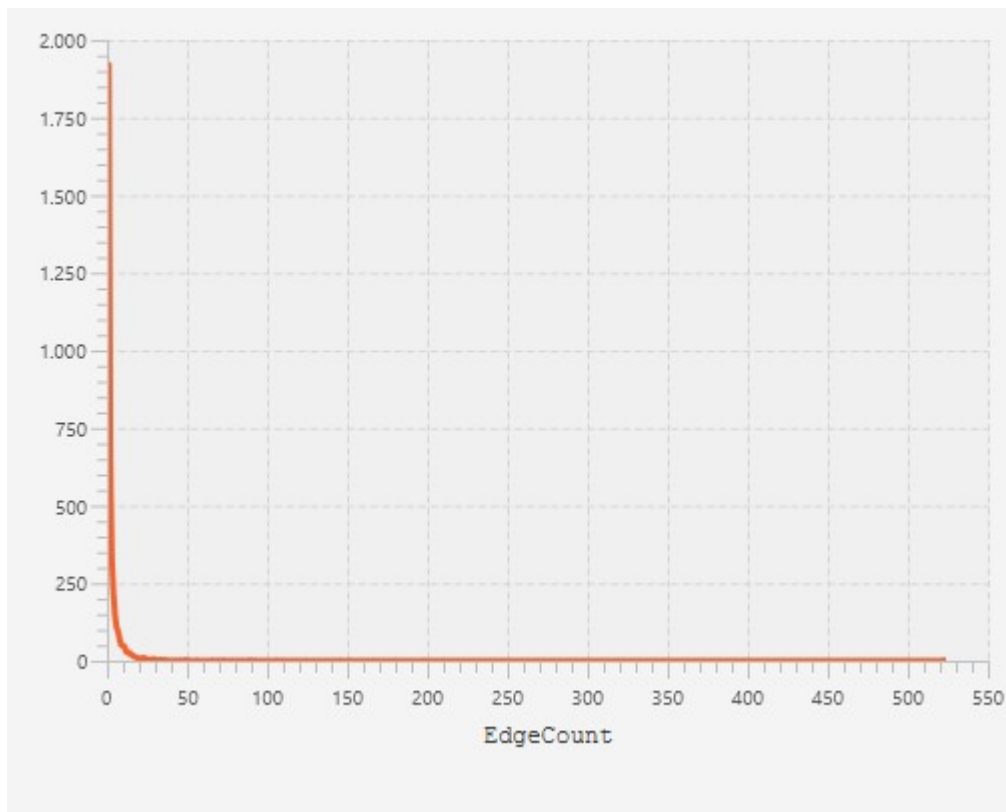


Figure 24. The degree distribution graph for the *C. elegans* dataset's network analysis.

Based on the results and graphs obtained for the *C. elegans* organism, we can say that some nodes have more connections and higher degrees, while others have fewer connections and a lower number of links compared to the rest. In this case, we can conclude that the network exhibits a scale-free smallworld property.

Secondly we will import *R. norvegicus* file in Cytoscape.

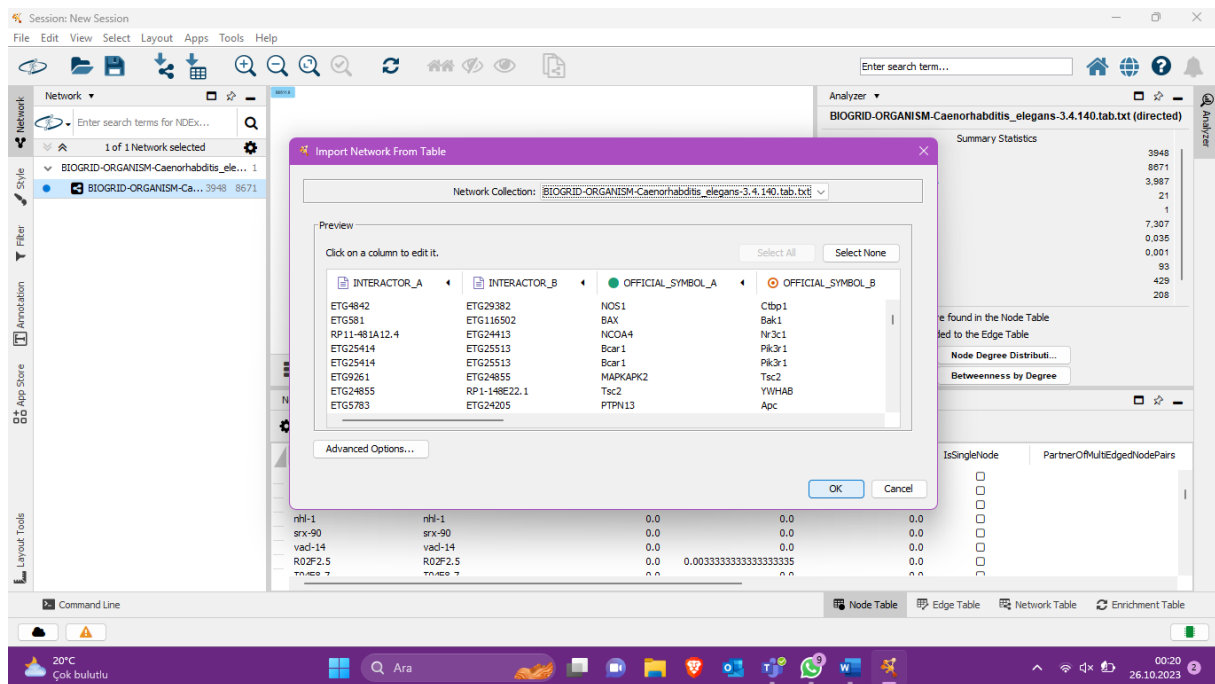


Figure 25. We determine the OFFICIAL_SYMBOL_A and OFFICIAL_SYMBOL_B columns as protein.

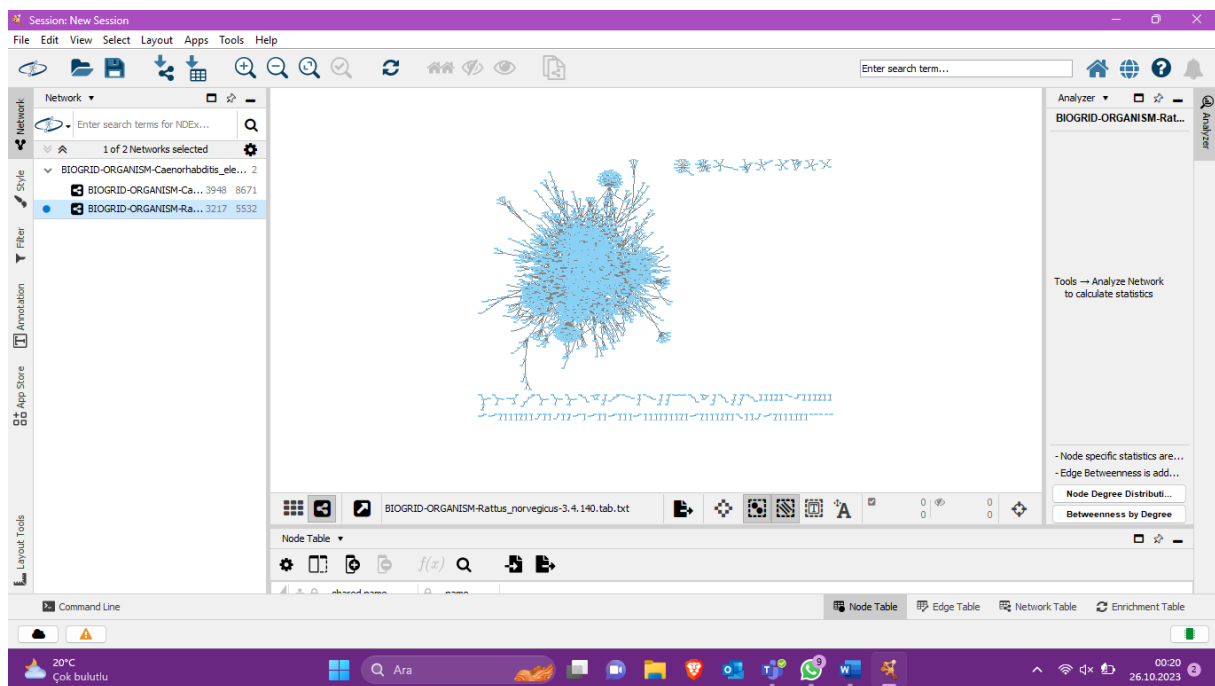


Figure 26. The first image of the *R. norvegicus* dataset in the Cytoscape.

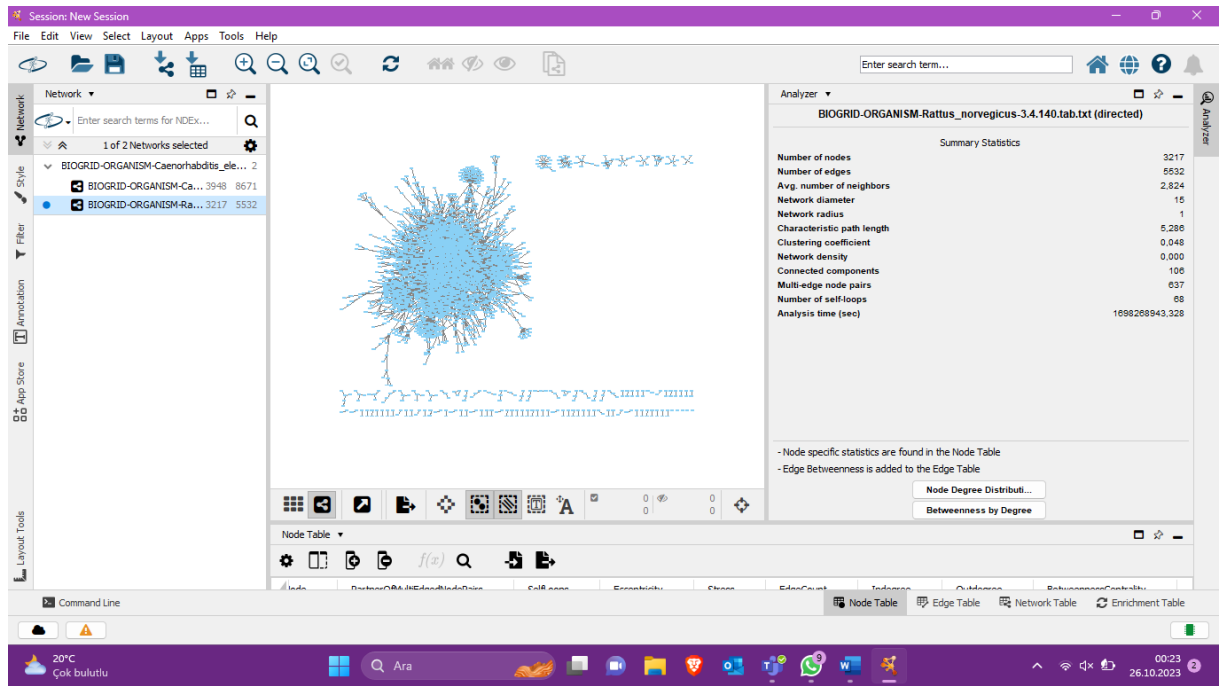


Figure 27. We obtained the analysis results for *R. norvegicus*.

Analysis results for *R. norvegicus* organism

Number of nodes and edges : 3217 nodes and 5532 edges.

Average path length: 5,286

Network diameter: 15

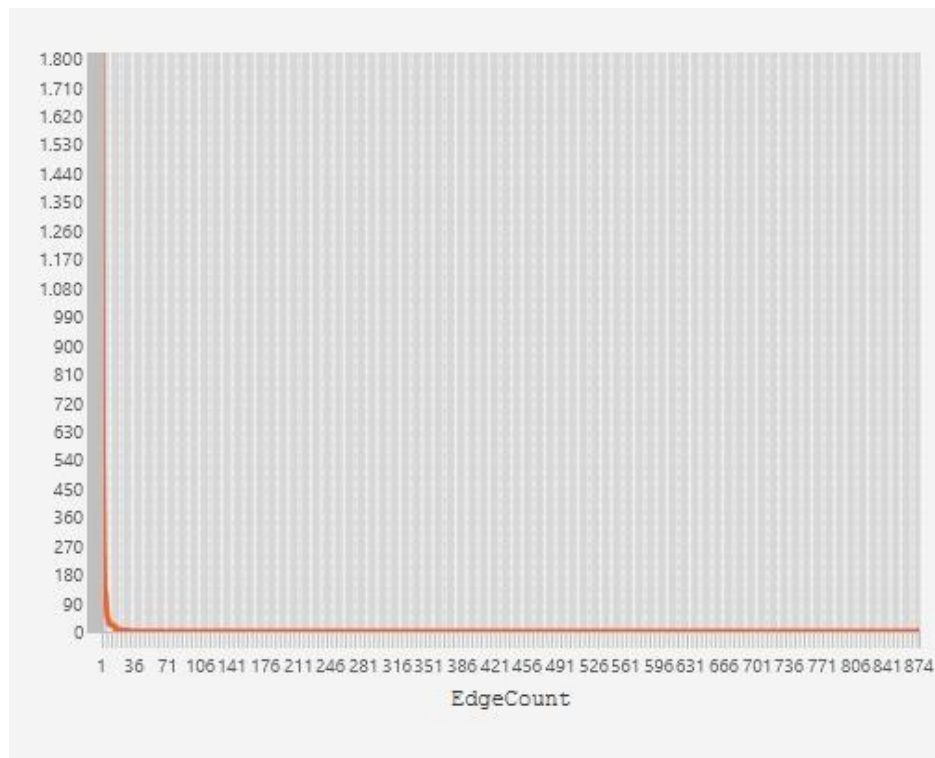


Figure 28. The degree distribution graph for the *R. norvegicus* dataset's network analysis.

Based on the obtained results, we inferred that *C. elegans* and *R. norvegicus* exhibit similar characteristics in terms of the scale-free small-world property. So for *R. norvegicus* organism, we can say that some nodes have more connections and higher degrees, while others have fewer connections and a lower number of links compared to the rest. In this case, we can conclude that the network exhibits a scale-free smallworld property.

When examining the directed and undirected nature for *C. elegans* and *R. norvegicus* organisms (Figure 29-30), it can be observed that the network relationships have bidirectional connections. In other words, we can say that both organisms exhibit undirected characteristics.

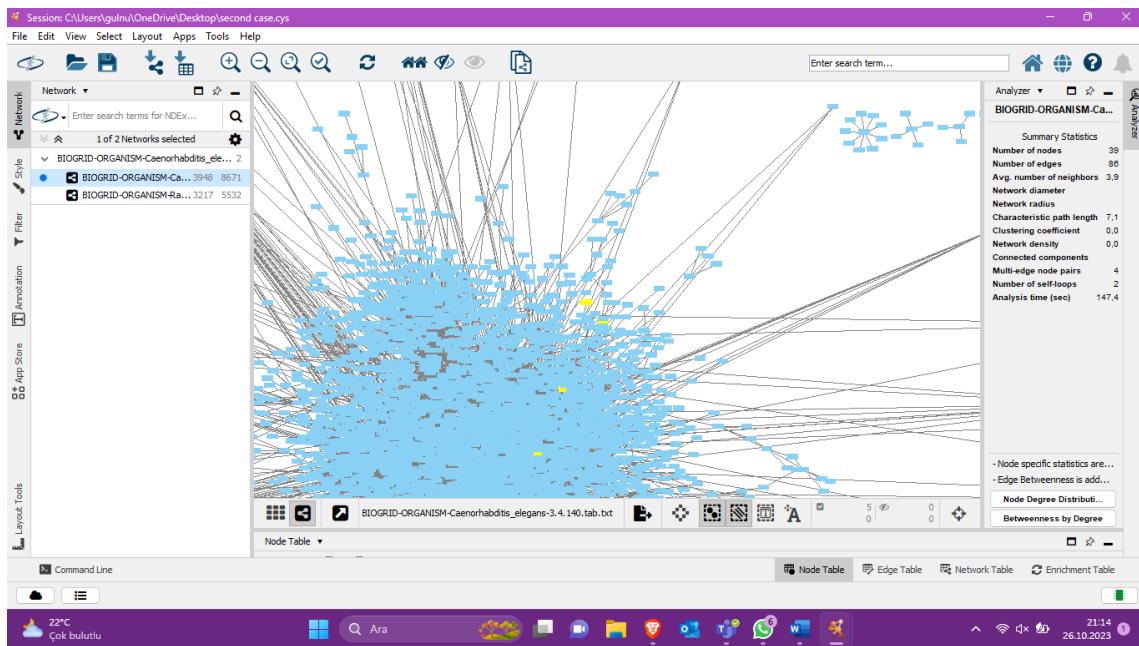


Figure 29. *C. elegans* organism is undirected feature.

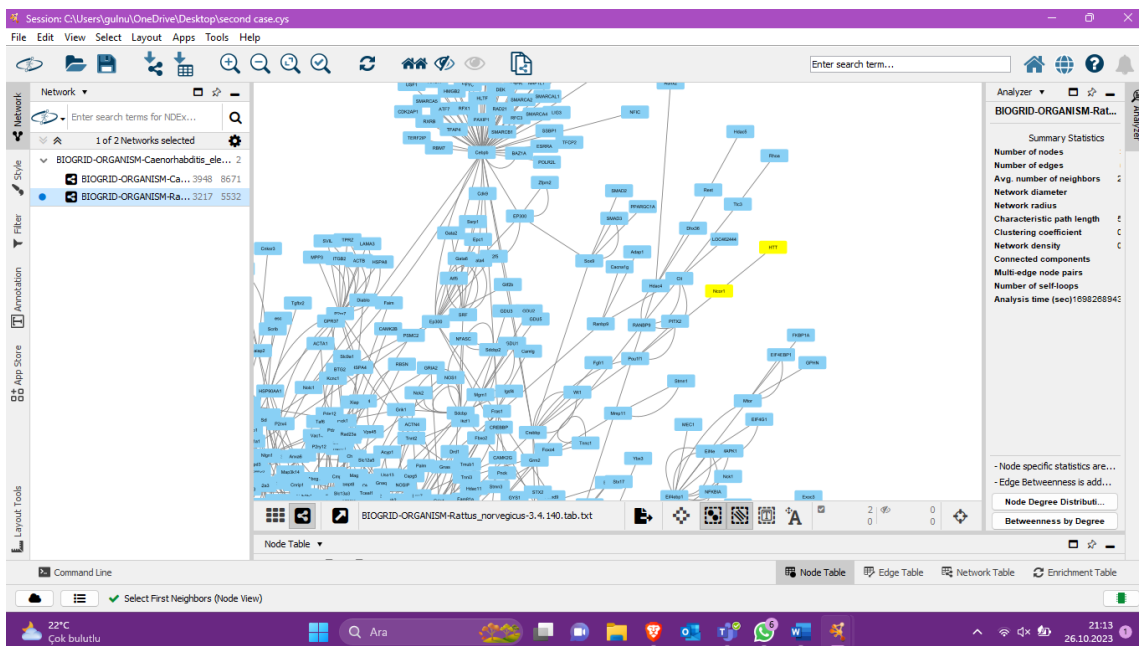


Figure 30. *R. norvegicus* organism is undirected feature.