DUDTeN Manual

Directed and UnDirected Temporal Network

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Contents

1. Introduction

The DUDTeN software is created to estimate dynamic functional connectivity (DFC) (also known as time-varying functional connectivity (TVC)) and calculate undirected and directed temporal measures in a very simple way. Only, load your data, select the options, save the result, and see them.

You can load the data (raw or preprocessed) and derive the DFC, apply transformation and/or normalization, save the result and/or show them. Also, you can load the temporal network, thresholded temporal network, etc., and calculate the measures, apply normalization and/or thresholding, save the result and/or show them. Furthermore, you can see the data in a specific window.

DUDTeN is a user-friendly software that users can investigate the Temporal Networks only by selecting the options, with no need to write codes. So, this software helps to accelerate the studies in the temporal network field.

1.1. About DUDTeN

DUDTeN is developed in MATLAB software, under a 64-bit Windows. All the codes were hand-written codes, and no toolbox was used. Only, I used *boxcoxlm.m* (https://www.mathworks.com/matlabcentral/fileexchange/10419-box-cox-power-transformation-for-linear-models) to apply Box-Cox transformation. I used [1] and [2] to create the codes for deriving DFC and calculating binary undirected temporal measures. I created the codes for calculating two weighted undirected temporal measures and some binary and weighted directed temporal measures that have been introduced in [3] and [4], respectively.

To derive DFC, in the DUDTeN, I created the codes of two methods of Spatial Distance (SD) and Jackknife Correlation (JC). These methods are the newest approaches to estimate TVC time-series with the highest temporal resolution. Both JC and SD methods obtain a unique connectivity estimate for each time-point. For more details about the SD and JC methods, see [1] and [2], respectively. In order to post-process the time-varying functional connectivity time-series, I created the codes of the Fisher, BoxCox, and Fisher&BoxCox transformations (see [5]). To normalize the time-varying functional connectivity time-series, the Z-score was created. By using DUDTeN, it's possible to derive TVC from any type of time-series data (such as fMRI BOLD, EEG, etc.). For more details, see *Section 3.1*.

To investigate the properties of the undirected and directed temporal networks at the global or the local level (per edge or node), I created the codes of some undirected and directed temporal measures. These measures are shown in Tables 1 and 2. For more details about the definition of directed and undirected measures, see [4] and [1, 3], respectively. You can select the r parameter for the measures of Directed Reachability Latency and Reachability Latency. Nodal Reachability Latency can only calculate with $r = 1$. Before calculating the measures, you can select a variance-based thresholding method (1SD/2SD/None). For more details, see *Section 3.2* and *Section 4.1*.

Table 1. Undirected temporal measures

Name of Measure	Type of Measure		
	Edge	Nodal	Global
Fluctuability		✓	✓
Volatility	✓	✓	✓
Reachability Latency		✓	✓
Temporal Efficiency		✓	✓
Burstiness	✓	✓	
Temporal Degree Centrality		✓	
Temporal Closeness Centrality		✓	
Weighted Volatility	✓	✓	✓
Weighted Temporal Degree Centrality		✓	

Table 2. Directed temporal measures

Name of Measure	Type of Measure		
	Edge	Nodal	Global
Directed Fluctuability			✓
Directed Volatility			✓
Directed Reachability Latency			✓
Directed Temporal Efficiency			✓
Directed Burstiness	✓		
Directed Temporal Degree Centrality		✓	
Directed Temporal Closeness Centrality		✓	
Weighted Directed Volatility			✓
Weighted Directed Temporal Degree Centrality		✓	

I am very grateful to Ms. Farahani for contributing to understanding the definitions of temporal network theory and its related measures.

In the future, I will add other methods to estimate TVC/DFC and other directed (binary/weighted) and undirected (binary/weighted) temporal measures.

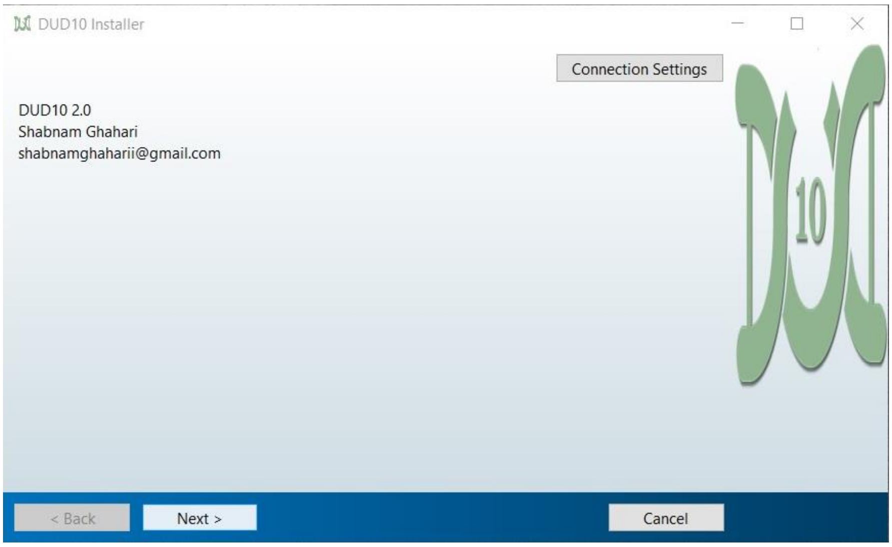
DUDTeN is created based on the definitions in the network neuroscience [1-4] and was used to investigate the temporal network of the human brain in [3, 4, 6]. Nevertheless, this software can be used for studying any temporal network in any field.

1.2. How to install DUDTeN

To install **DUDTeN**, follow the steps below:

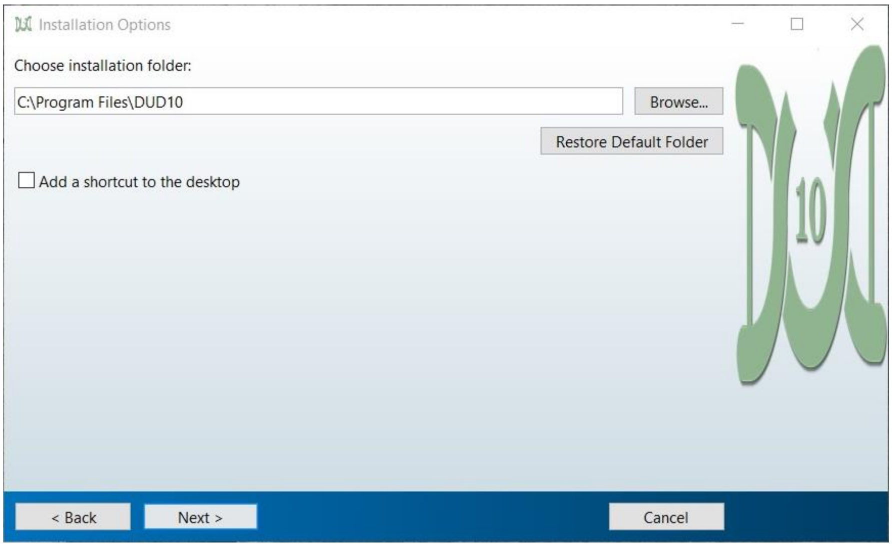
1- Double click the *DUDTeN.exe* or *DUDTeN_MRT.exe* to run it.

The *DUDTeN_MRT* executable file contains version 9.4 (R2018a) of the MATLAB Runtime.



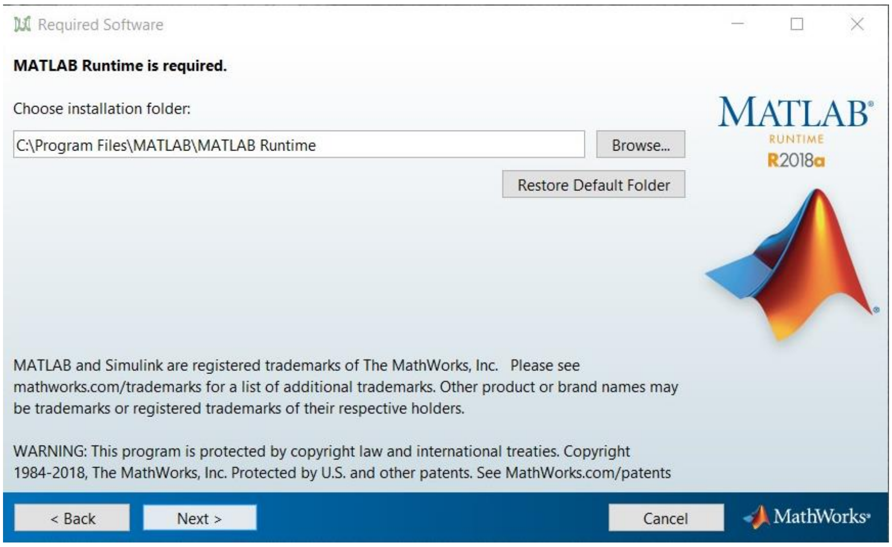
2- Click *Next* to advance to the Installation Options page.

You can select *Add a shortcut to the desktop*.



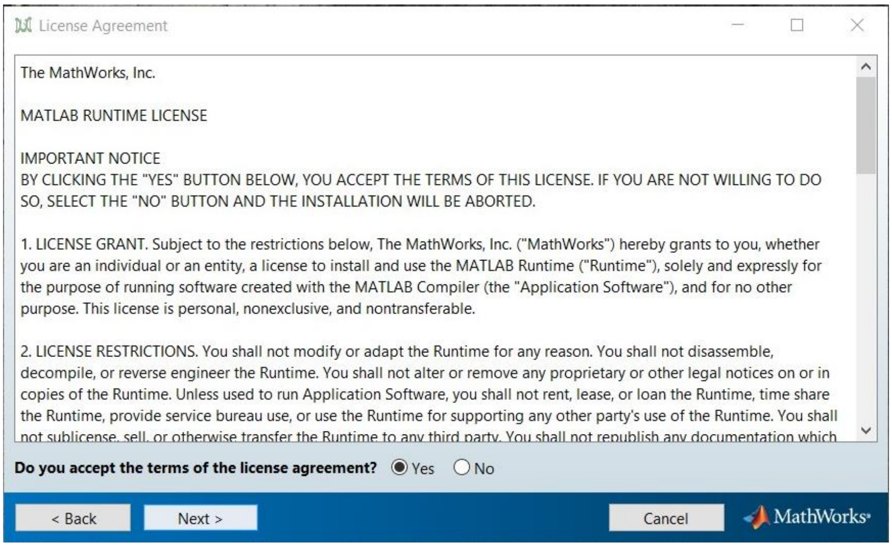
3- Click *Next* to advance to the Required Software page.

If the correct version of the MATLAB Runtime exists on the system, this page displays a message that indicates you do not need to install a new version. If the same version was installed despite receiving this message, you can uninstall it after finishing the installation of DUDTeN.

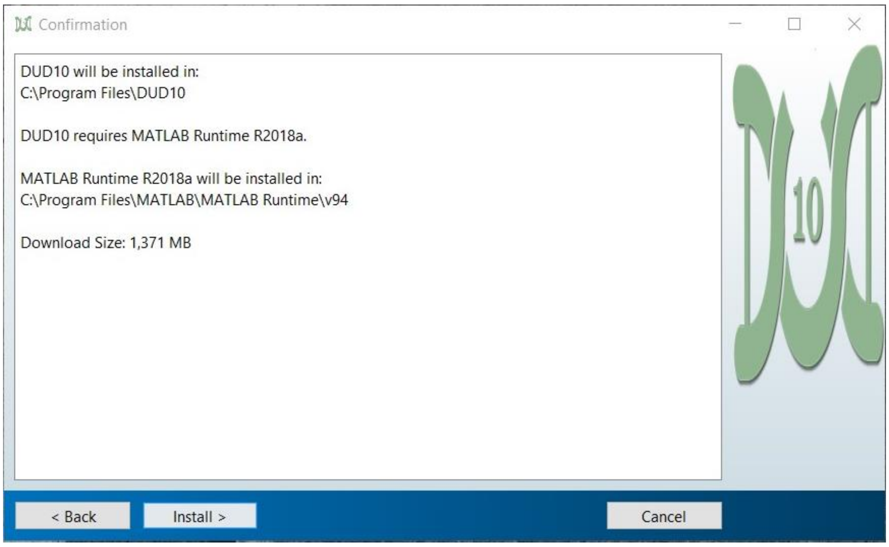


4- Click *Next* to advance to the License Agreement page.

Read the license agreement. Check *Yes* to accept the license.



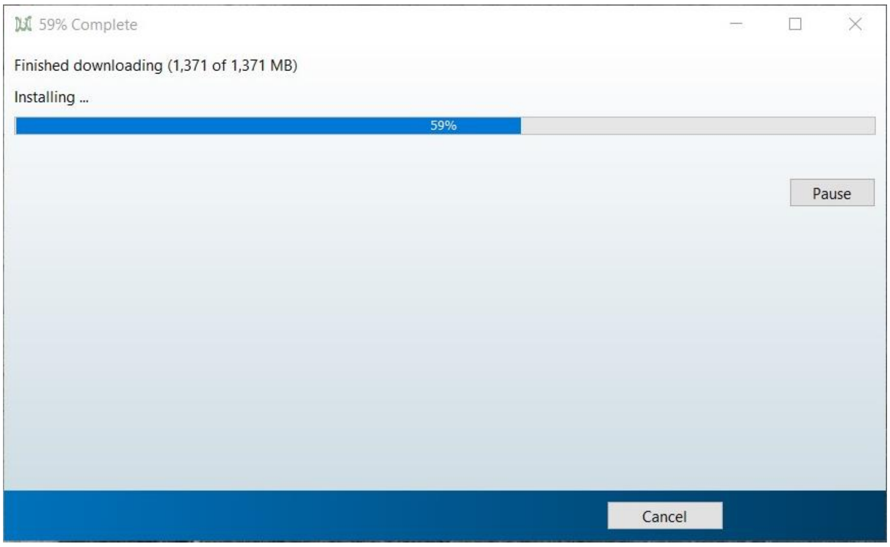
5- Click *Next* to advance to the Confirmation page.



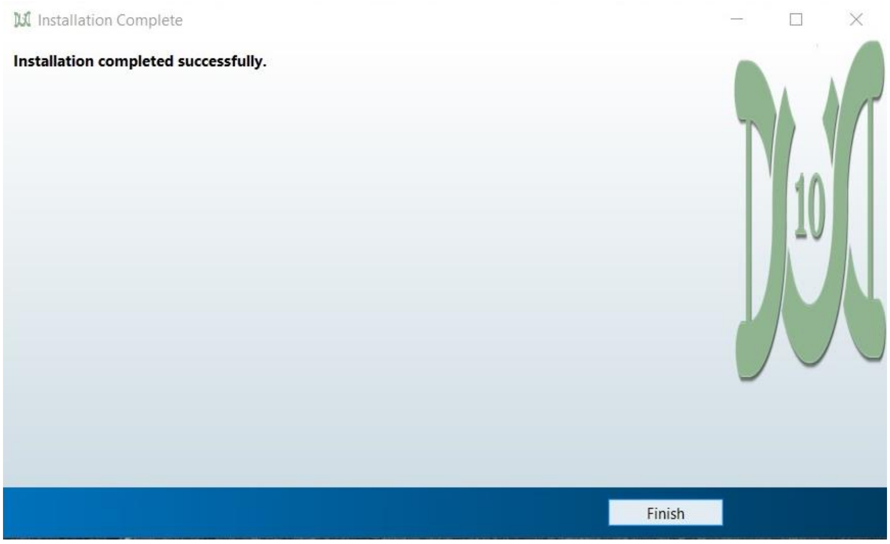
6- Click *Install*.

The installer installs DUDTeN.

If needed, for *DUDTeN* executable file, the installer also downloads (about 1.4 GB) and installs the MATLAB Runtime (2018a).



7- Click *Finish*.



8- Run **DUDTeN**

a- If you select the *Add a shortcut to the desktop* at the Installation Options page, run the software by double-clicking the *DUD10* icon.

b- If you don't select the *Add a shortcut to the desktop* at the Installation Options page, go to the folder in which you installed the software. If you accepted the default settings, you can find the folder in the following location: *C:\Program Files\DUD10*. Run the software by double-clicking the *DUD10* icon.

2. DUDTeN

When double-clicking the *DUD10* icon, the software is run (Fig. 1). If select a submenu, all the changes are shown in this window. In each submenu and its options, error and help boxes were created to help the users perform the steps correctly. In the following, I explained the menus, submenus, and their options.

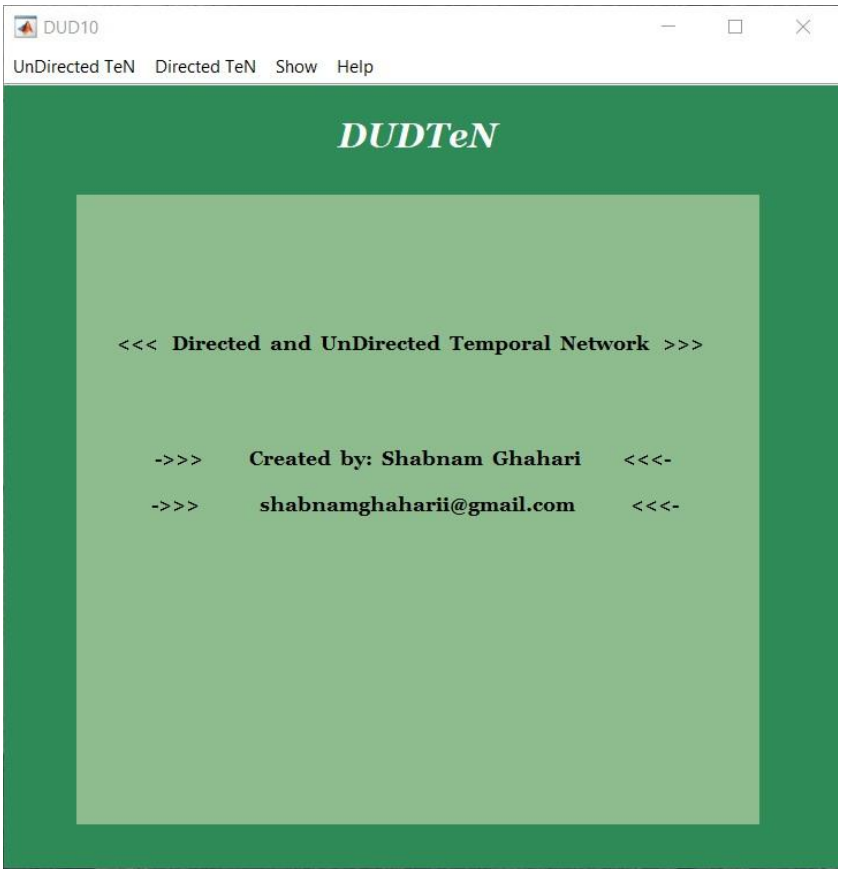


Fig. 1. DUDTeN window

3. UnDirected TeN

UnDirected Temporal Network can be created using methods such as Sliding Window, Tapered Sliding Window, and so on. To quantify the connectivity time-series, several measures have been introduced (such as Fluctuability, Temporal Degree Centrality, etc.).

3.1. DFC

As mentioned in *Section 1.1*, I created the codes of Spatial Distance and Jackknife Correlation methods for estimating DFC/TVC. Three Transformations (Fisher, BoxCox, and Fisher&BoxCox) were created that can be used for DFC time-series (such as derived from BOLD time-series). Z-score normalization was created for standardizing DFC time-series.

To estimate DFC, after starting DUDTeN, select the "DFC" under "UnDirected TeN" menu. So, the "DynamicFC" window is opened (Fig. 2). Then, follow the steps below:

1. Press "Load data" button.
   A 2D numeric array can be loaded that each row is a time-series.
   When data is loaded, each time-series is normalized by demeaning and scaling the standard deviation to 1.

2. Choose a method for deriving DFC.
   2.1. To derive the DFC using SD method, select "Spatial Distance" option.
   2.2. To derive the DFC using JC method, select "Jackknife Correlation" option.

3. Choose a transformation.
   3.1. Select the "Fisher" option to apply the Fisher Transformation.
   3.2. Select the "BoxCox" option to apply the BoxCox Transformation.
   When selecting this option, "BoxCox parameter" window is opened that you should determine a range for setting the λ parameter. The default λ range was let from -5 to 5 in increments of 0.1. Before applying the BoxCox transformation to each connectivity time-series, the smallest value is scaled to 1 [5], and after applying this transformation, the BC-transformed DFC time-series is scaled back so that the post-BC mean is equal to the mean of the raw DFC time-series [5].
   3.3. Select the "Fisher & BoxCox" option to apply the Fisher Transformation first and then BoxCox Transformation.
   In this case, the mean is scaled back to the mean of the Fisher-transformed DFC time-series.
   3.4. Select the "None" option for no Transformation.

4. Choose a normalization method.
   4.1. Select the "Z-score" option to standardize each connectivity time-series by subtracting the mean and dividing by the standard deviation.
   4.2. Select the "None" option for no Normalization.

5. Press "Run" button.
   DFC is estimated using the selected options.
   A 3D numeric array (double) is created (Nodes×Nodes×Timepoints).

6. Press "Save" button.
   Save the results with your chosen name in a mat file.

7. Press "Show" button.
   When selecting this option, "Show 3D" window is opened that you should determine a time-point of the undirected temporal network for showing in the Table. Then, "Show" window is opened (see *Section 5.*).

When selecting the "DFC" under "UnDirected TeN" menu, a message is displayed in the "DUDTeN" window (Fig. 3). Also, in the steps of loading data, run, and save, a message is shown in the "DUDTeN" window to help you know that the steps were done correctly. All the selected options are displayed (which method is selected, etc.). When the steps of the run and save are done correctly, also, a message box is opened that shows all the selected options. In each step, for example, if you want to select two options in a specific part, an error is shown. If you mistakenly choose an option and get an error for selecting another one, you must disable the wrong option and then choose the correct one. If you run, don't save the result, and want to close the "DynamicFC" window, a message is displayed to remind you that you didn't save the result.

In *Section 7.1.*, an example of estimating DFC is presented.

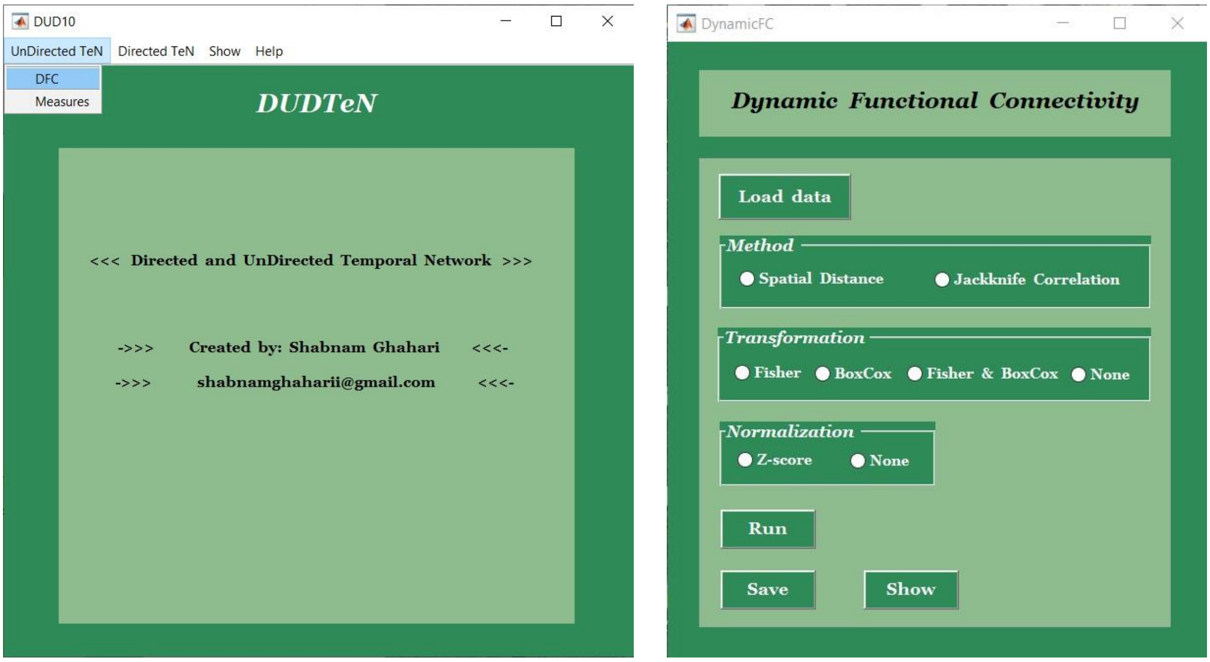


Fig. 2. Select the "DFC" under "UnDirected TeN" menu (Left). So, the "DynamicFC" window is opened (Right).

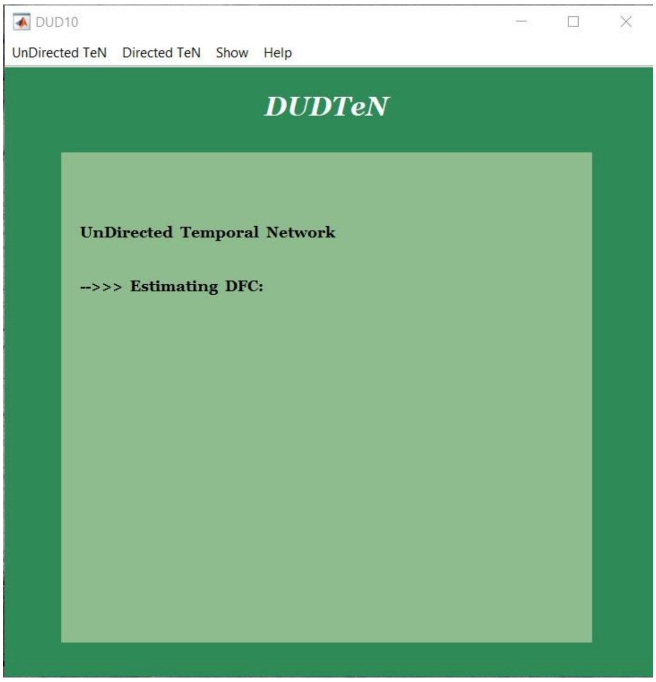


Fig. 3. Selecting the "DFC" under the "UnDirected TeN" menu displays a message in the "DUDTeN" window.

3.2. Measures

As mentioned in *Section 1.1*, I created the codes to calculate the undirected temporal measures. Table 1 shows the name of measures and the type of them that exist in the DUDTeN. A total of 18 measures were created. Two methods for thresholding based on variance (1SD and 2SD) were created that can be applied to the undirected temporal network. Z-score normalization was created for standardizing the undirected temporal network (each connectivity time-series).

To investigate the undirected temporal network features, after starting DUDTeN, select the "Measures" under "UnDirected TeN" menu. Therefore, the "UDMeasures" window is opened (Fig. 4). Then, follow the steps below:

1. Press "Load data" button.
   A 3D numeric array can be loaded (Nodes×Nodes×Timepoints) that each matrix (Nodes×Nodes) is symmetric.

2. Choose a normalization method.
   2.1. Select the "Z-score" option to standardize each connectivity time-series of the undirected temporal network by subtracting the mean and dividing by the standard deviation.
   2.2. Select the "None" option for no Normalization.

3. Choose a thresholding (variance-based) method.
   3.1. To apply the one standard deviation thresholding, select "1SD" option.
   The binary undirected temporal network is created by setting edges exceeding one standard deviation to 1, and otherwise 0, for each connectivity time-series.
   The weighted undirected temporal network is created by setting edges with less than one standard deviation to 0, in each connectivity time-series.
   3.2. To apply the two standard deviations thresholding, select "2SD" option.
   In order to create a binary undirected temporal network, for each connectivity time-series, the edges with more than two standard deviations are set to 1 and otherwise to 0.
   To create a weighted undirected temporal network, edges with less than two standard deviations are set to 0, in each connectivity time-series.
   3.3. Select the "None" option for no Thresholding.

4. Choose a binary measure or a weighted measure.
   4.1. When selecting the "Fluctuability" option, a window is opened that you can choose the type of this measure (*Nodal Fluctuability* or *Global Fluctuability*).
   4.2. When selecting the "Volatility" option, a window is opened that you can choose the type of this measure (*Volatility per edge*, *Nodal Volatility*, or *Global Volatility*).
   4.3. When selecting the "Temporal Efficiency" option, a window is opened that you can choose the type of this measure (*Nodal Temporal Efficiency* or *Global Temporal Efficiency*).
   4.4. When selecting the "Reachability Latency" option, a window is opened that you can choose the type of this measure. If *Reachability Latency* is selected, "Reachability Latency parameter" window is opened that you should determine the

r parameter (between 0 and 1). For *Temporal Diameter* or *Nodal Temporal Diameter*, the *r* equals 1.

4.5. When selecting the "Burstiness" option, a window is opened that you can choose the type of this measure (*Burstiness per edge* or *Nodal Burstiness*).

4.6. Select the "Temporal Closeness Centrality" option that is a nodal measure.

4.7. Select the "Temporal Degree Centrality" option that is a nodal measure.

4.8. When selecting the "Weighted Volatility" option, a window is opened that you can choose the type of this measure (*Weighted Volatility per edge*, *Nodal Weighted Volatility*, or *Global Weighted Volatility*).

4.9. Select the "Weighted Temporal Degree Centrality" option that is a weighted nodal measure.

5. Press "Run" button.
   The undirected temporal measure is calculated using the selected options.
   For edge measures, a 2D numeric array (double) is created (Nodes×Nodes).
   For nodal measures, a numeric column vector (double) is created (Nodes×1).
   For global measures, a numeric value (double) is created.

6. Press "Save" button.
   Save the results with your chosen name in a mat file.

7. Press "Show" button.
   When selecting this option, "Show" window is opened (see *Section 5.*) and the calculated undirected temporal measure is displayed in the Table.

In the loading data step, if even one matrix (Nodes×Nodes) of the 3D numeric array (Nodes×Nodes×Timepoints) is asymmetric, the file is not loaded. Furthermore, the "Data file" window is opened that shows the time-point of the asymmetric matrices (Nodes×Nodes).

When selecting the "Measures" under "UnDirected TeN" menu, a message is displayed in the "DUDTeN" window (Fig. 5). Also, in the steps of loading data, run, and save, a message is shown in the "DUDTeN" window to help you know that the steps were done correctly. All the selected options are displayed (which method is selected, etc.). When the steps of the run and save are done correctly, also, a message box is opened that shows all the selected options. In each step, for example, if you want to select two options in a specific part, an error is shown. If you mistakenly choose an option and get an error for selecting another one, you must disable the wrong option and then choose the correct one. If you run, don't save the result, and want to close the "UDMeasures" window, a message is displayed to remind you that you didn't save the result.

In *Section 7.2.*, an example of calculating three undirected temporal measures is presented.

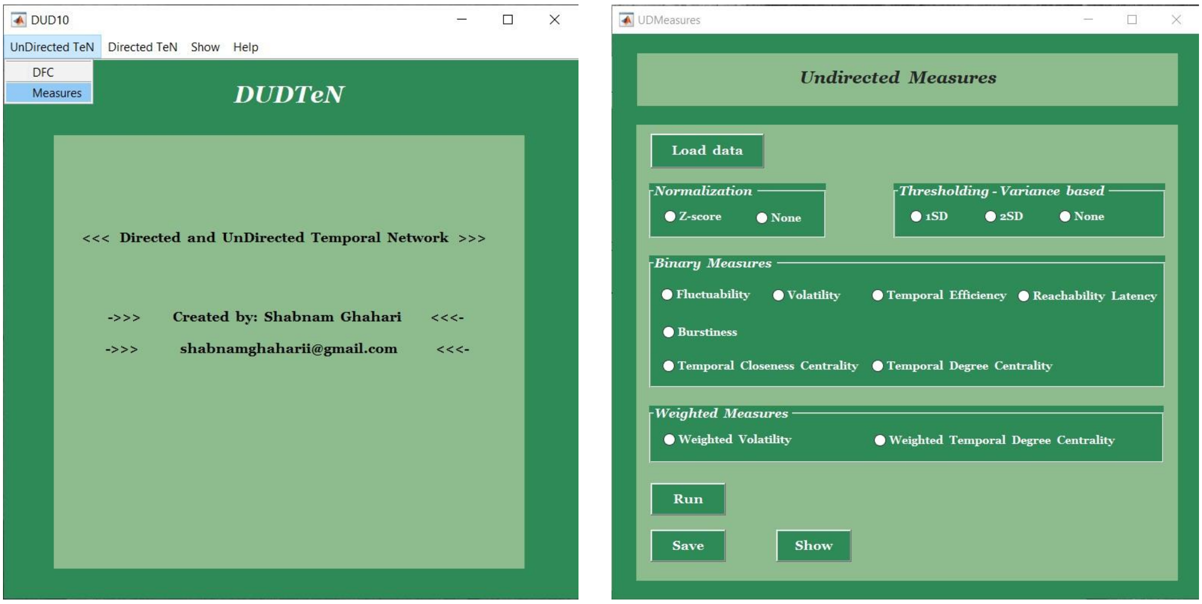


Fig. 4. Select the "Measures" under "UnDirected TeN" menu (Left). So, the "UDMeasures" window is opened (Right).

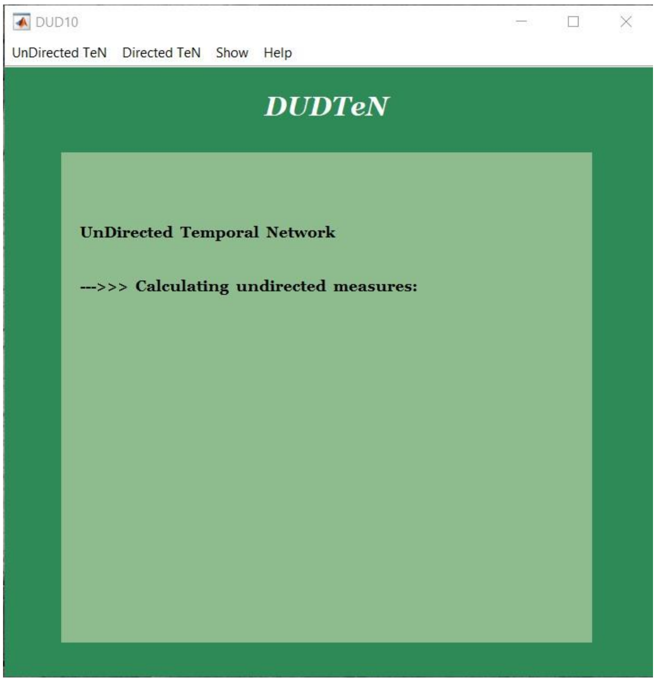


Fig. 5. Selecting the "Measures" under "UnDirected TeN" menu shows a message in the "DUDTeN" window.

4. Directed TeN

Directed Temporal Network can be created using methods such as Direct Directed Transfer Function (dDTF), Generalized Partial Directed Coherence (GPDC), and so on. In order to quantify the connectivity time-series, several measures have been introduced (such as Directed Fluctuability, Directed Temporal Degree Centrality, etc.).

4.1. Measures

As mentioned in *Section 1.1*, I created the codes to calculate the directed temporal measures. Table 2 shows the name of measures and the type of them that exist in the DUDTeN. A total of 10 measures were created. Two methods for thresholding based on variance (1SD and 2SD) were created that can be applied to the directed temporal network. Z-score normalization was created for standardizing the directed temporal network (each connectivity time-series).

To investigate the directed temporal network features, after starting DUDTeN, select the “Measures” under “Directed TeN” menu. Therefore, the “DMeasures” window is opened (Fig. 6). Then, follow the steps below:

1. Press “Load data” button.
   A 3D numeric array can be loaded (Nodes×Nodes×Timepoints) that each matrix (Nodes×Nodes) is asymmetric.

2. Choose a normalization method.
   2.1. Select the “Z-score” option to standardize each connectivity time-series of the directed temporal network by subtracting the mean and dividing by the standard deviation.
   2.2. Select the “None” option for no Normalization.

3. Choose a thresholding (variance-based) method.
   3.1. To apply the one standard deviation thresholding, select “1SD” option.
   The binary directed temporal network is created by setting edges exceeding one standard deviation to 1, and otherwise 0, for each connectivity time-series.
   The weighted directed temporal network is created by setting edges with less than one standard deviation to 0, in each connectivity time-series.
   3.2. To apply the two standard deviations thresholding, select “2SD” option.
   In order to create a binary directed temporal network, for each connectivity time-series, the edges with more than two standard deviations are set to 1 and otherwise to 0.
   To create a weighted directed temporal network, edges with less than two standard deviations are set to 0, in each connectivity time-series.
   3.3. Select the “None” option for no Thresholding.

4. Choose a binary measure or a weighted measure.
   4.1. Select the “D Fluctuability” option that is a global measure.
   4.2. Select the “D Volatility” option that is a global measure.
   4.3. Select the “D Temporal Efficiency” option that is a global measure.
   4.4. When selecting the “D Reachability Latency” option, a window is opened that you can choose the type of this measure. If *Directed Reachability Latency* is selected, “Directed Reachability Latency parameter” window is opened that you should determine the *r* parameter (between 0 and 1). For *Directed Reachability Latency (r = 1)*, the *r* equals 1.
   4.5. Select the “Directed Burstiness” option that is an edge measure.

4.6. When selecting the "D Temporal Closeness Centrality" option, a window is opened that you can choose the type of this measure (*Temporal in-Closeness Centrality* or *Temporal out-Closeness Centrality*).
4.7. When selecting the "D Temporal Degree Centrality" option, a window is opened that you can choose the type of this measure (*Temporal in-Degree Centrality* or *Temporal out-Degree Centrality*).
4.8. Select the "Weighted Directed Volatility" option that is a weighted global measure.
4.9. When selecting the "Weighted Directed Temporal Degree Centrality" option, a window is opened that you can choose the type of this measure (*Weighted Temporal in-Degree Centrality* or *Weighted Temporal out-Degree Centrality*).

5. Press "Run" button.
   The directed temporal measure is calculated using the selected options.
   For edge measures, a 2D numeric array (double) is created (Nodes×Nodes).
   For nodal measures, a numeric row/column vector (double) is created (1×Nodes/Nodes×1).
   For global measures, a numeric value (double) is created.

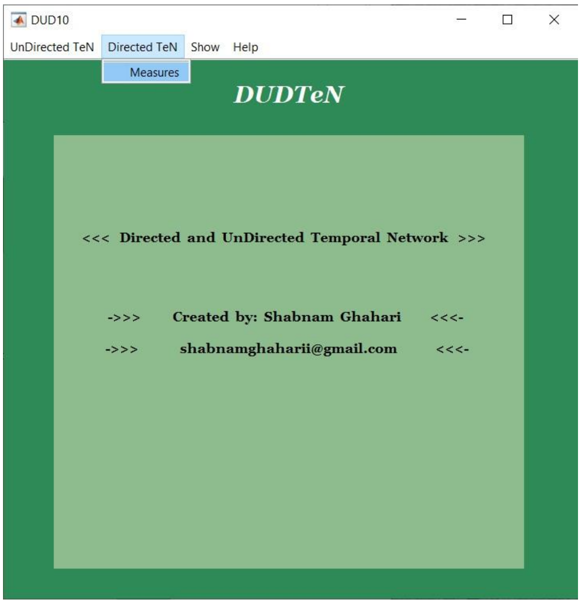
6. Press "Save" button.
   Save the results with your chosen name in a mat file.

7. Press "Show" button.
   When selecting this option, "Show" window is opened (see *Section 5.*) and the calculated directed temporal measure is displayed in the Table.

In the loading data step, if even one matrix (Nodes×Nodes) of the 3D numeric array (Nodes×Nodes×Timepoints) is symmetric, the file is not loaded. Furthermore, the "Data file" window is opened that shows the time-point of the symmetric matrices (Nodes×Nodes).

When selecting the "Measures" under "Directed TeN" menu, a message is displayed in the "DUDTeN" window (Fig. 7). Also, in the steps of loading data, run, and save, a message is shown in the "DUDTeN" window to help you know that the steps were done correctly. All the selected options are displayed (which method is selected, etc.). When the steps of the run and save are done correctly, also, a message box is opened that shows all the selected options. In each step, for example, if you want to select two options in a specific part, an error is shown. If you mistakenly choose an option and get an error for selecting another one, you must disable the wrong option and then choose the correct one. If you run, don't save the result, and want to close the "DMeasures" window, a message is displayed to remind you that you didn't save the result.

In *Section 7.3.*, an example of calculating two directed temporal measures is presented.



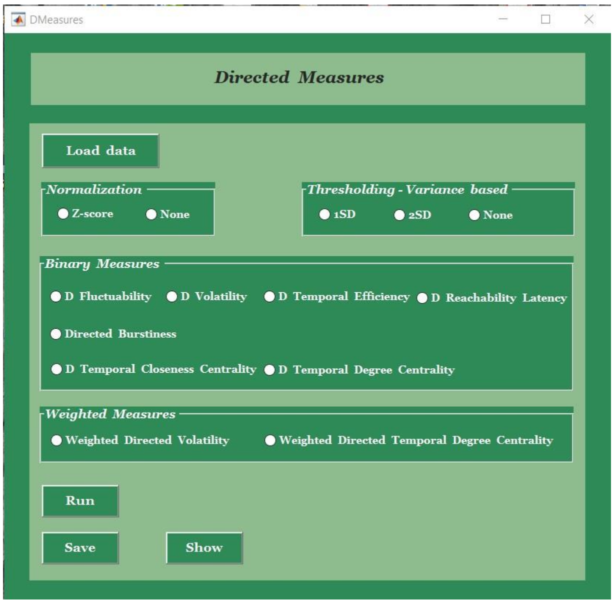


Fig. 6. Select the "Measures" under "Directed TeN" menu (Left). So, the "DMeasures" window is opened (Right).

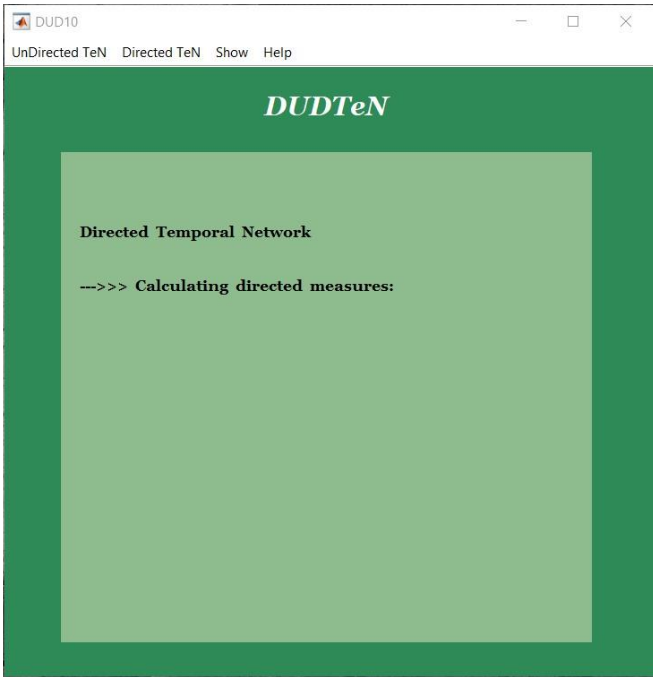


Fig. 7. Selecting the "Measures" under "Directed TeN" menu shows a message in the "DUDTeN" window.

5. Show

The "Show Data" under "Show" menu was created to display the data that loaded or the results in a Table (Fig. 8).

Only a 2D numeric array or a 3D numeric array (by selecting a number from the third dimension) can be shown. For this purpose, press "Load" button. After loading the data, the details of the loaded data are presented in front of "Load" button. These details are the name and size of the file, and for a 3D numeric array, the chosen number from the third dimension. The loaded data is displayed in the Table (see *Section 7.1.* and *Section 7.2.*).

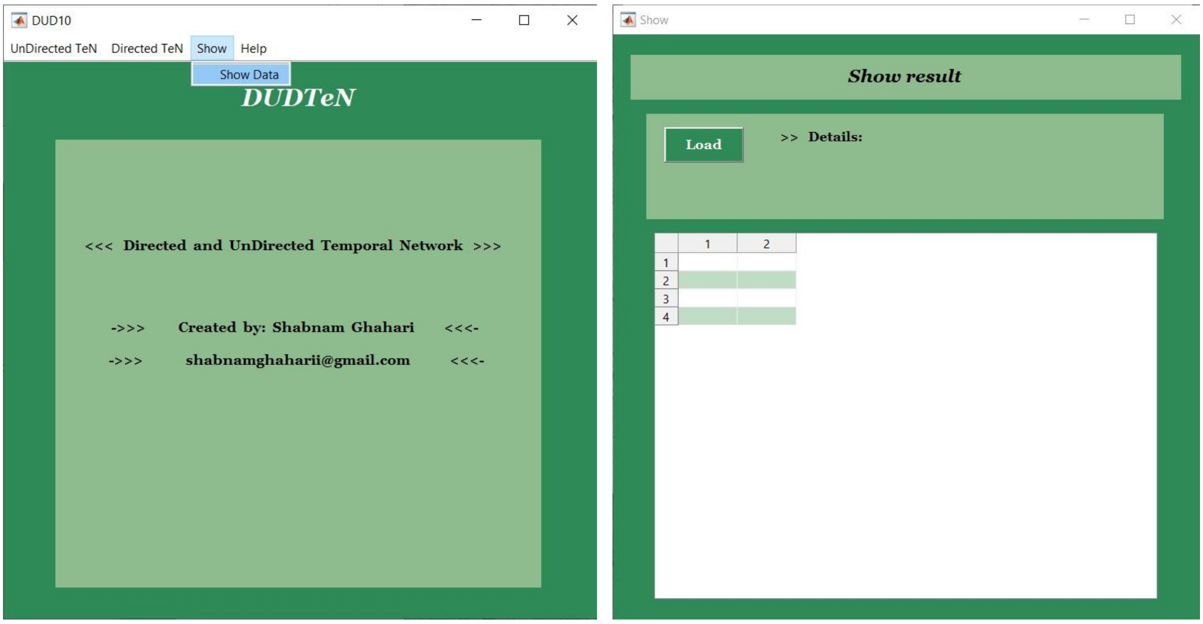


Fig. 8. Select the "Show Data" under "Show" menu (Left). So, the "Show" window is opened (Right).

6. Help

The "Manual" under "Help" menu (Fig. 9) was created for opening the *Manual_DUDTeN_v2.pdf*.

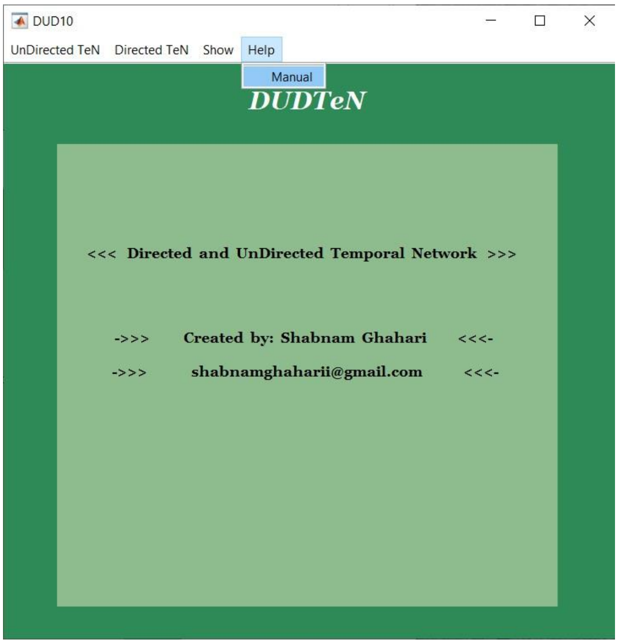


Fig. 9. Select the "Manual" under "Help" menu, so the *Manual_DUDTeN_v2.pdf* is opened.

7. Examples

7.1. Example of estimating DFC

I select the preprocessed BOLD time-series of 7 Regions of Interest (ROIs). The length of each time-series is 64 time-points. The fMRI data recorded with TR = 2s. These time-series were stored in a *.mat file that each row is an ROI time-series. This *.mat file is a 2D numeric array. So, the size of the matrix is 7×64.

First of all, in the "DUDTeN" window, I select "Show Data" under "Show" menu to illustrate the time-series (Fig. 8). Thus, "Show" window is opened. I press the "Load" button, then the "Load" window is opened that I should select the *.mat file and press the *open*. When the file is loaded, the details of the *.mat file are shown in this window (Fig. 10). In the Table, the time-series of ROIs are displayed, by moving the scroll, I can see all the data.

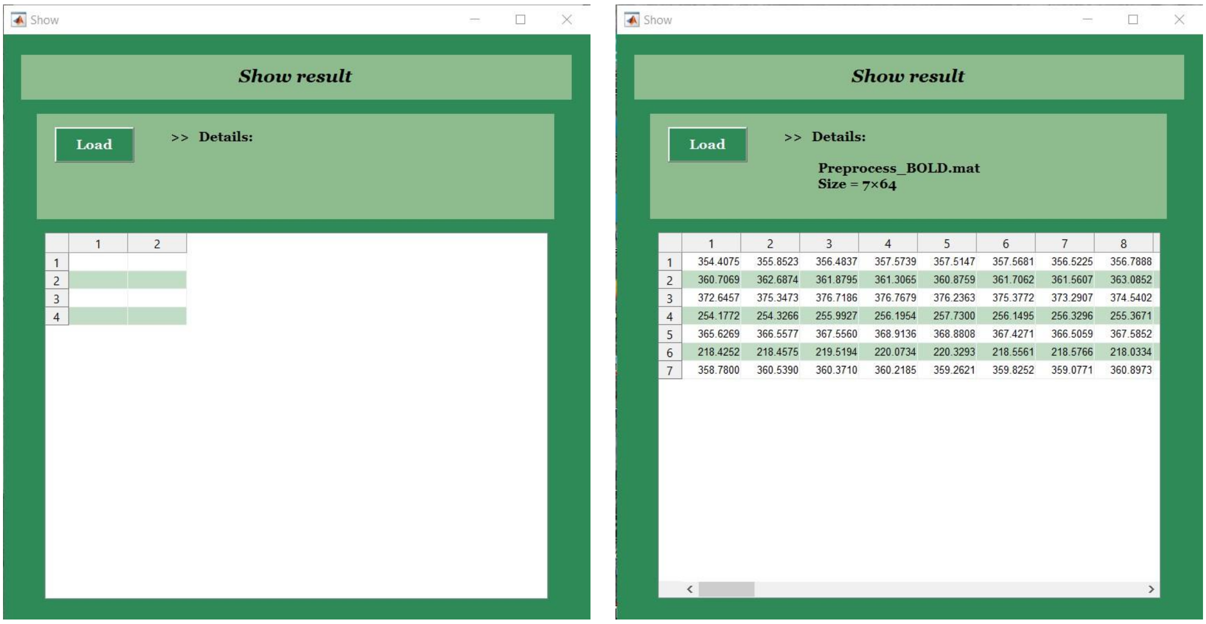


Fig. 10. Press "Load" button and select the file (Left). The loaded file (Right).

I want to derive DFC using the Spatial Distance method, then apply Fisher transformation first and then BoxCox transformation to the raw DFC time-series, and in the end, convert the transformed DFC time-series into Z-values.

Therefore, I select "DFC" under "UnDirected TeN" menu in the "DUDTeN" window (Fig. 2). Then, "DynamicFC" window is opened. I press the "Load data" button. A help-message box is opened to remind me that I can only load a 2D numeric array (Fig. 11). This help-message box is only opened for the first time of loading. When pressing the *ok* button, "Load time-series" window is opened and I select *.mat file. When the data is loaded, a message is shown in the "DUDTeN" window that appears as Fig. 12.

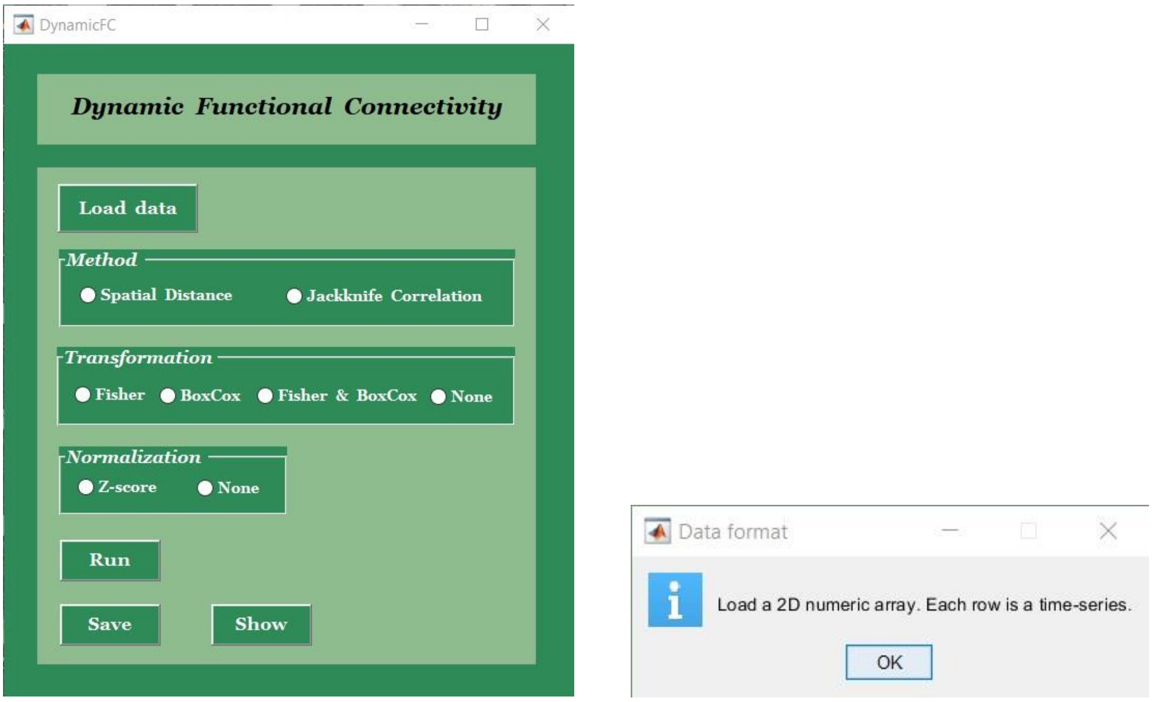


Fig. 11. Press “Load data” button (Left), so a help-message box is opened (Right). After pressing *ok*, I can select the file.

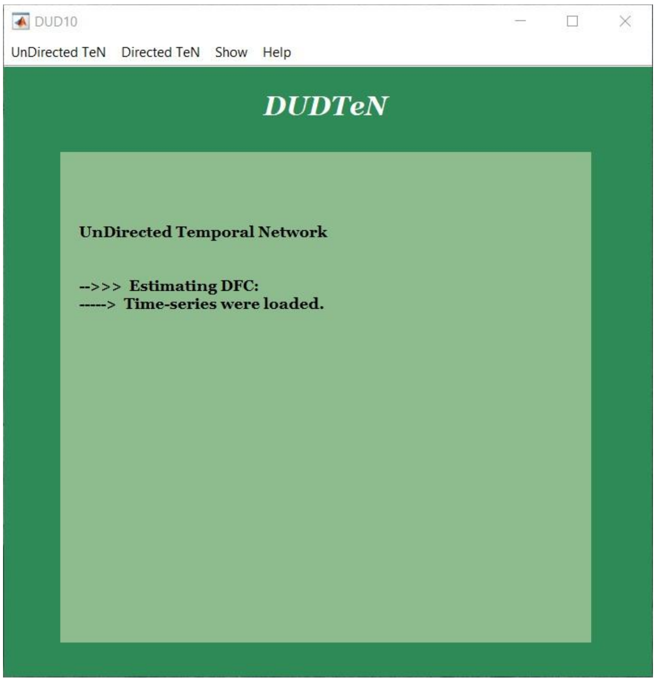


Fig. 12. After loading the file, a message appears in the “DUDTeN” window.

In the *Method* section, I choose “Spatial Distance”. In the *Transformation* section, I choose “Fisher & BoxCox”, then “BoxCox parameter” window is opened that I should determine the range of λ parameter. I let the λ range from -15 to 15 in increments of 0.01 (Fig. 13). In the *Normalization* section, I choose “Z-score” (Fig. 14).

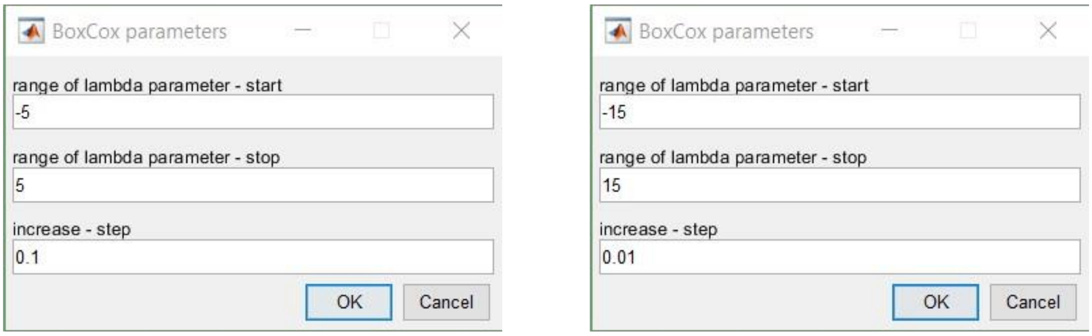


Fig. 13. "BoxCox parameter" window (Left). I change the default and let the λ range from -15 to 15 in increments of 0.01 (Right).

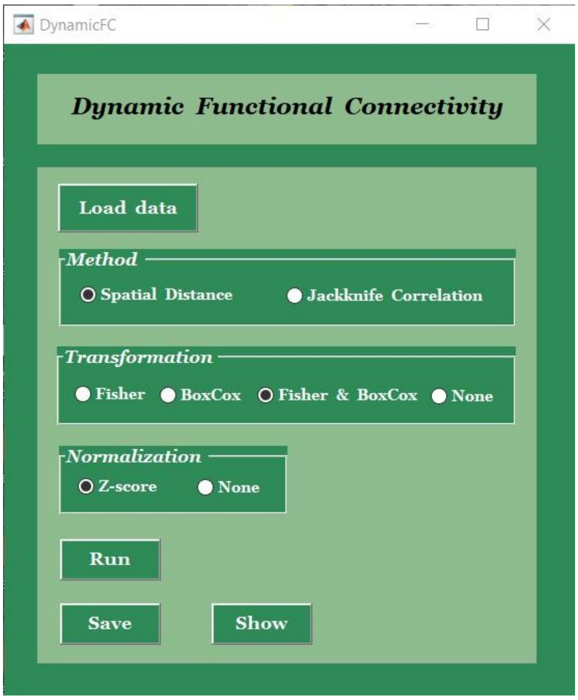


Fig. 14. The selected options.

Finally, I press the "Run" button. When the run is complete, "DFC" window is opened that shows the selected options (Fig. 15). Also, a message is shown in the "DUDTeN" window that appears as Fig. 15. A 3D numeric array (double) is created that is the undirected temporal network. The size of this array is 7×7×64. For example, the connectivity time-series between ROIs 1 and 2 is *array(1, 2, :)*.

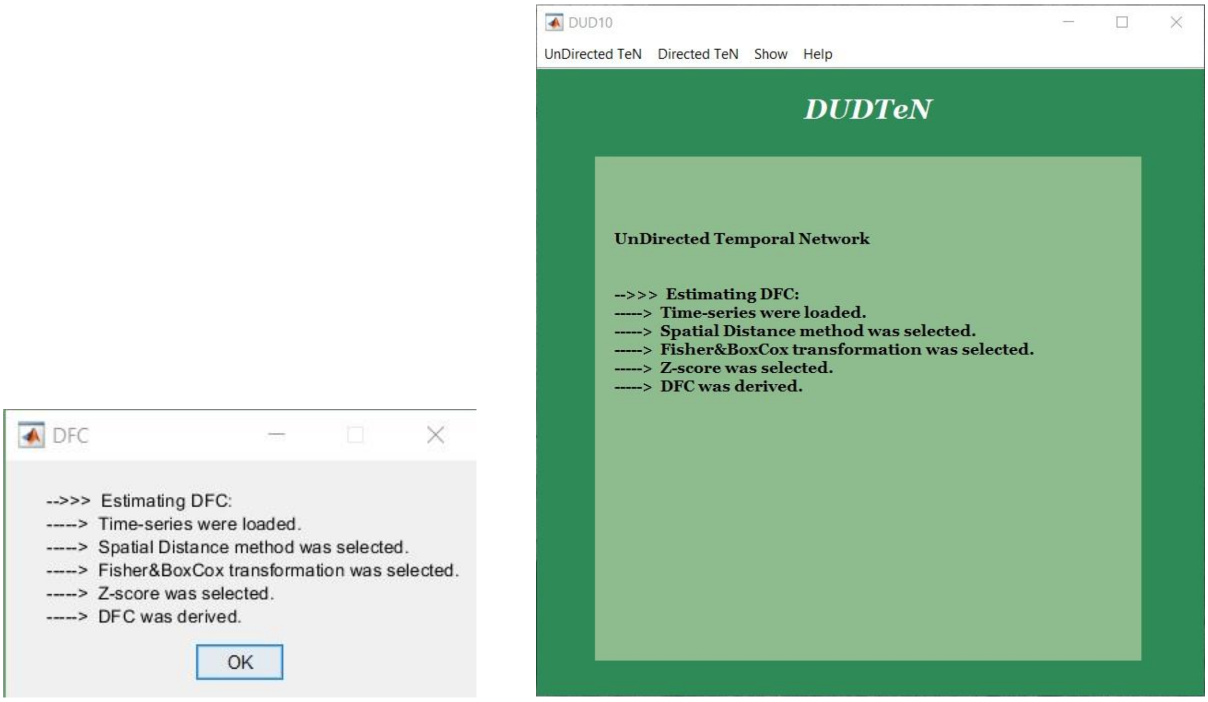


Fig. 15. When the run is complete, a message box is opened (Left) and a message is shown in "DUDTeN" window (Right).

Pressing "Save" button opens "Save DFC" window that I should select a name for saving the result. When the result is saved, a message is displayed in the "DFC" and the "DUDTeN" windows (Fig. 16).

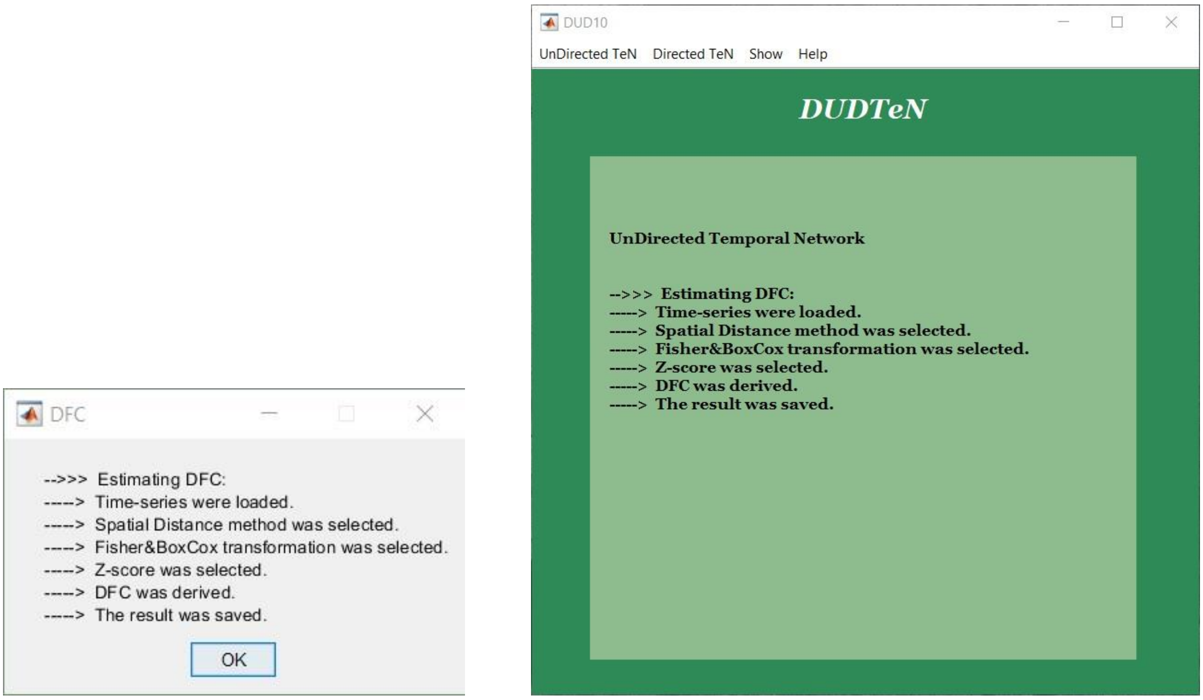
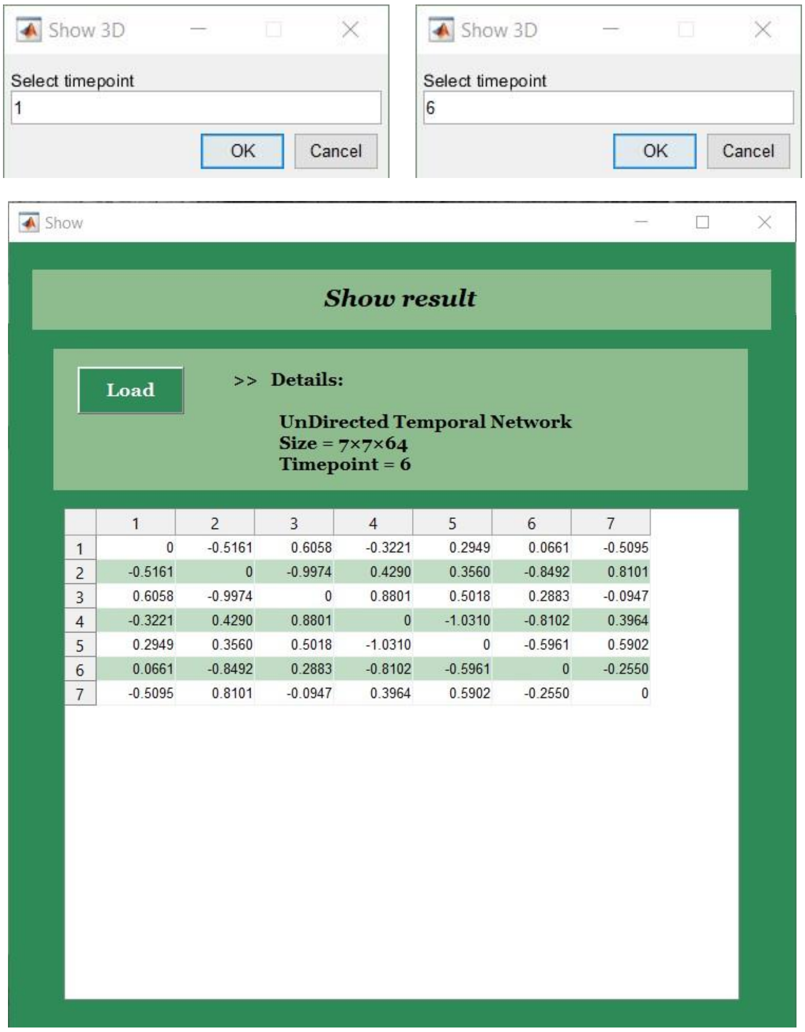


Fig. 16. When the result is saved, a message box is opened (Left) and a message is shown in "DUDTeN" window (Right).

I can also press “Show” button to illustrate the result. Then “Show result” window is opened that I should choose the time-point which I want to display (Fig. 17). I choose the time-point of 6, then press the *ok*, so the “Show” window is opened and the time-graphlet at the time-point of 6 is displayed in the Table (Fig. 17).



	1	2	3	4	5	6	7
1	0	-0.5161	0.6058	-0.3221	0.2949	0.0661	-0.5095
2	-0.5161	0	-0.9974	0.4290	0.3560	-0.8492	0.8101
3	0.6058	-0.9974	0	0.8801	0.5018	0.2883	-0.0947
4	-0.3221	0.4290	0.8801	0	-1.0310	-0.8102	0.3964
5	0.2949	0.3560	0.5018	-1.0310	0	-0.5961	0.5902
6	0.0661	-0.8492	0.2883	-0.8102	-0.5961	0	-0.2550
7	-0.5095	0.8101	-0.0947	0.3964	0.5902	-0.2550	0

Fig. 17. “Show result” window (Top - Left). I change the default (Top - Right). The time-graphlet at the time-point of 6 is displayed in the Table (Bottom).

7.2. Example of calculating UnDirected Temporal Measures

I have an undirected temporal network. The size of this network is 10×10×104. I want to calculate three measures of Fluctuability (Global), Reachability Latency (*r=0.5*), and Weighted Temporal Degree Centrality. For creating the binary undirected temporal network, I want to threshold this network by using two standard deviations variance-based method. It is better to convert the connectivity time-series into Z-values before applying the thresholding method. In order to create the weighted undirected temporal network, I only want to convert the connectivity time-series into Z-values.

First, I want to calculate the Fluctuability. Thus, I select “Measures” under “UnDirected TeN” menu in the “DUDTeN” window (Fig. 4). Then, “UDMeasures” window is opened. I press the

"Load data" button. A help-message box is opened to remind me that I can only load a 3D numeric array (Fig. 18). This help-message box is only opened for the first time of loading. When pressing the *ok* button, "Load Undirected Temporal Network" window is opened and I select *.mat file. When the data is loaded, a message is shown in the "DUDTeN" window (Fig. 19).

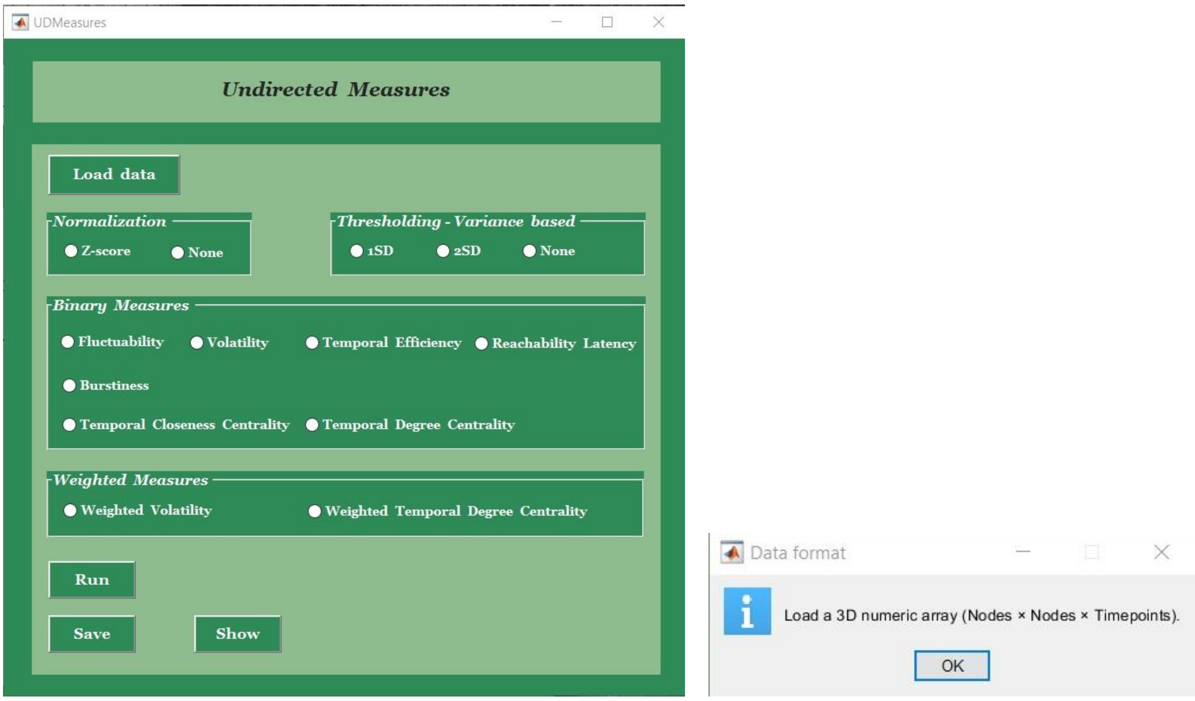


Fig. 18. Press "Load data" button (Left), so a help-message box is opened (Right). After pressing *ok*, I can select the file.

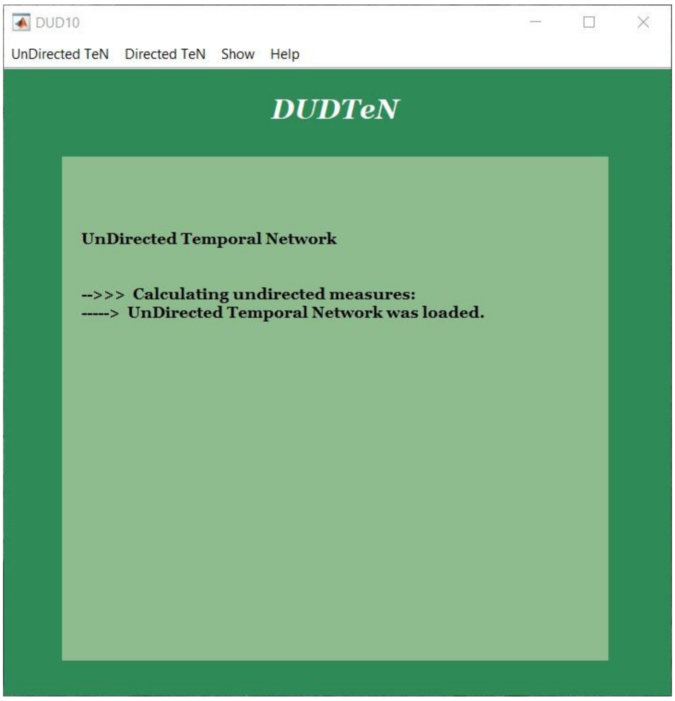


Fig. 19. After loading the file, a message appears in the "DUDTeN" window.

In the *Normalization* section, I choose "Z-score". In the *Thresholding – variance based* section, I choose "2SD". In the *Binary Measures* section, I choose "Fluctuability", then a window is opened that I should select the type of Fluctuability. I select the *Global* (Fig. 20) and press the *ok* (Fig. 21).

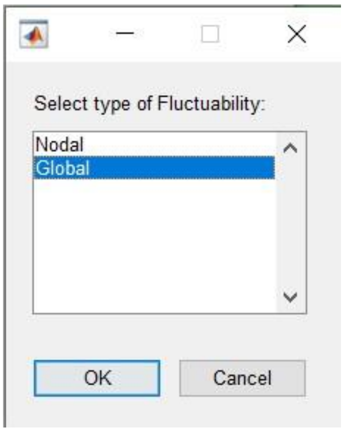


Fig. 20. When choosing "Fluctuability" option, a window is opened and I select the *Global* and press the *ok*.

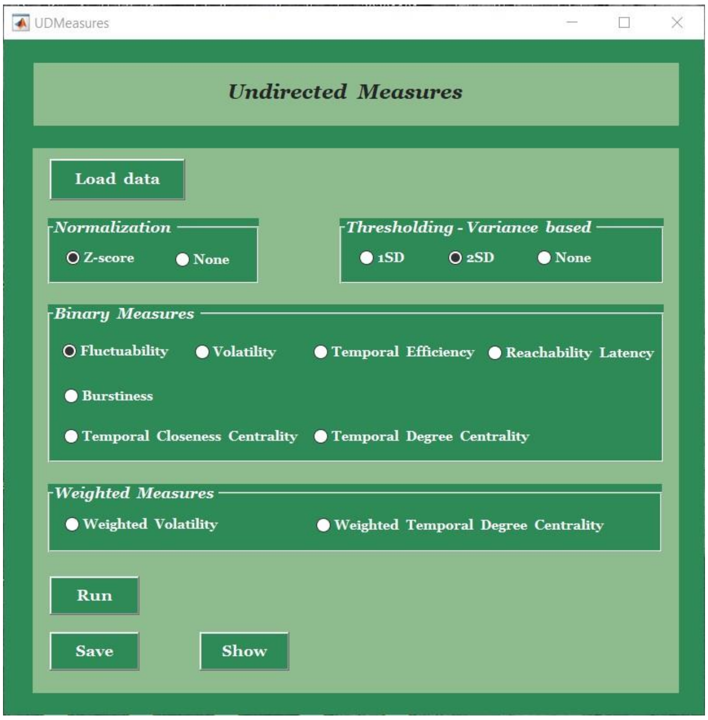


Fig. 21. The selected options.

Finally, I press the "Run" button. When the run is complete, "UnDirectedTeN" window is opened that shows the selected options (Fig. 22). Also, a message is shown in the "DUDTeN" window (Fig. 22). A numeric value is created that is the value of Global Fluctuability.

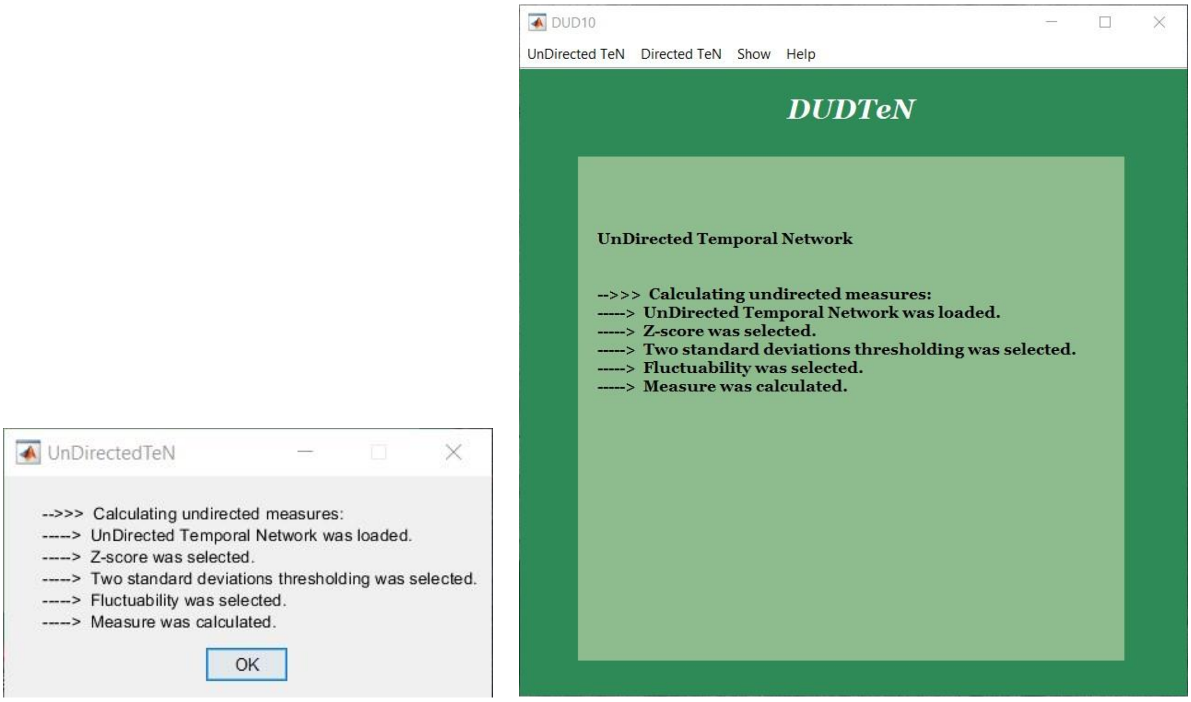


Fig. 22. When the run is complete, a message box is opened (Left) and a message is shown in "DUDTeN" window (Right).

Pressing "Save" button opens "Save Measure" window that I should select a name for saving the result. When the result is saved, a message is displayed in the "UnDirectedTeN" and the "DUDTeN" windows (Fig. 23).

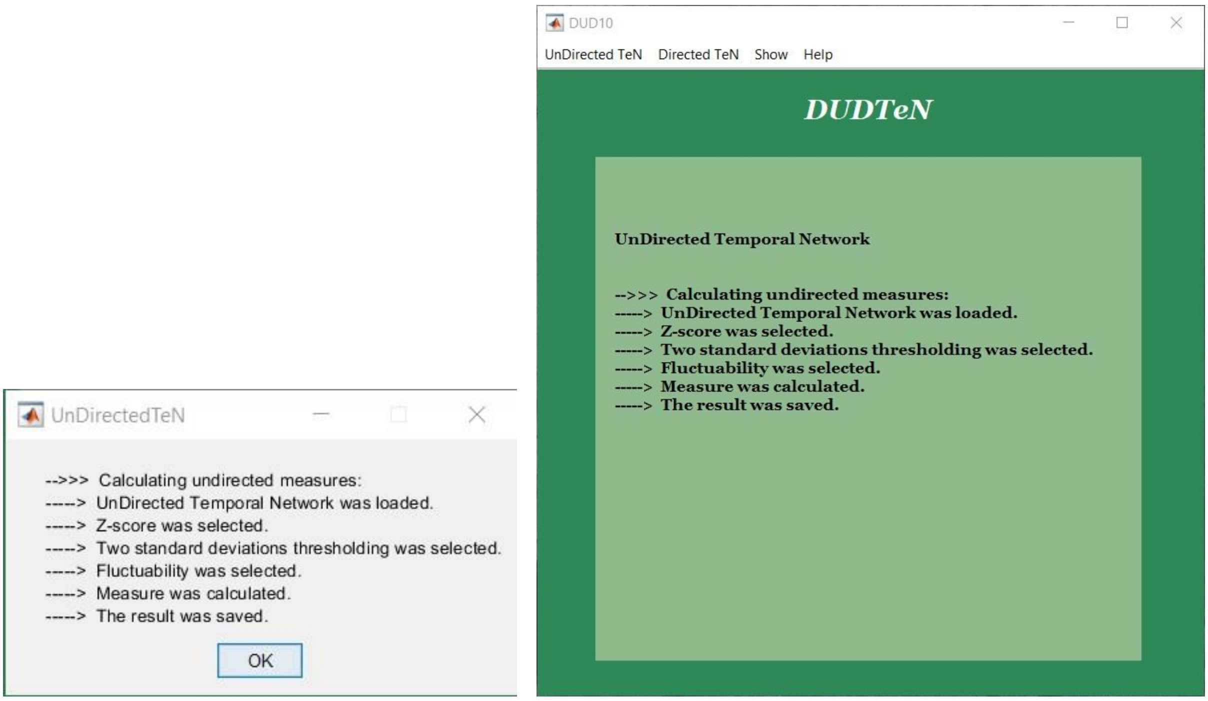


Fig. 23. When the result is saved, a message box is opened (Left) and a message is shown in "DUDTeN" window (Right).

I also press "Show" button to illustrate the result. So, the "Show" window is opened and the value of Global Fluctuability is displayed in the Table (Fig. 24).

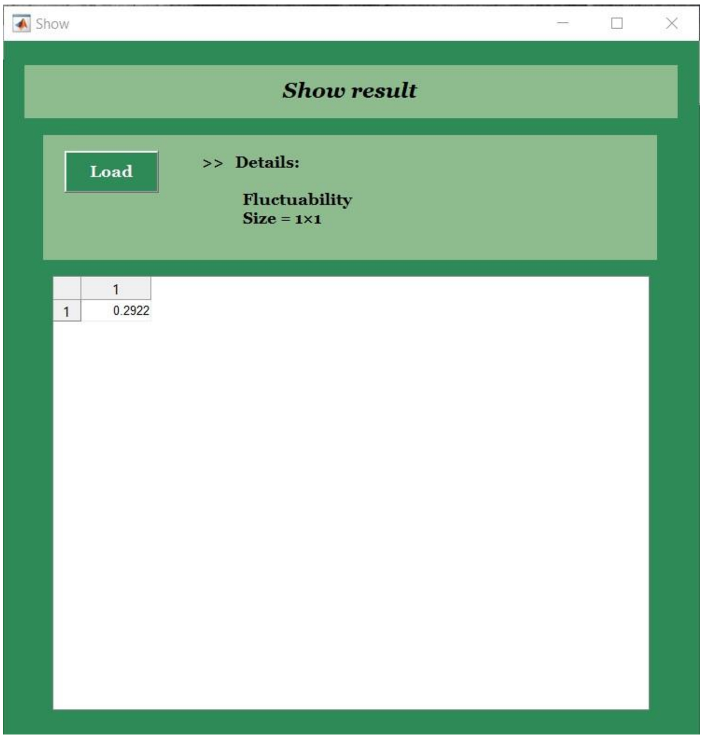


Fig. 24. The value of Global Fluctuability is displayed in the Table.

For estimating the Reachability Latency (*r=0.5*), since I loaded the data, I only change the options (disable the previous option and select the new one). In the *Binary Measures* section, I disable "Fluctuability" and choose "Reachability Latency", then a window is opened that I should select the type of Reachability Latency. I select the *Reachability Latency* (Fig. 25), then "Reachability Latency parameter" window is opened and I set the *r* parameter to the default value (*0.5*) and press the *ok* (Fig. 25). Fig. 26 shows the selected options.

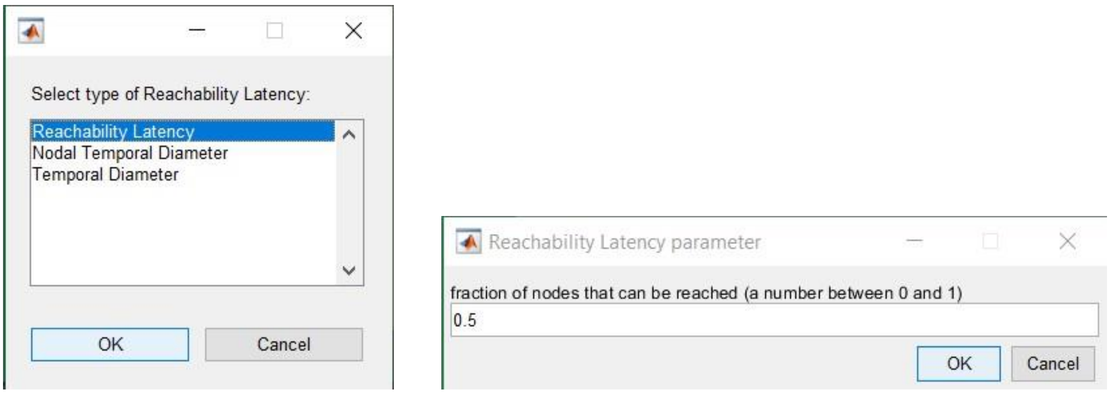


Fig. 25. When choosing "Reachability Latency" option, a window is opened and I select the *Reachability Latency* (Left), another window is opened (Right) and I set the *r* parameter to *0.5* and press the *ok*.

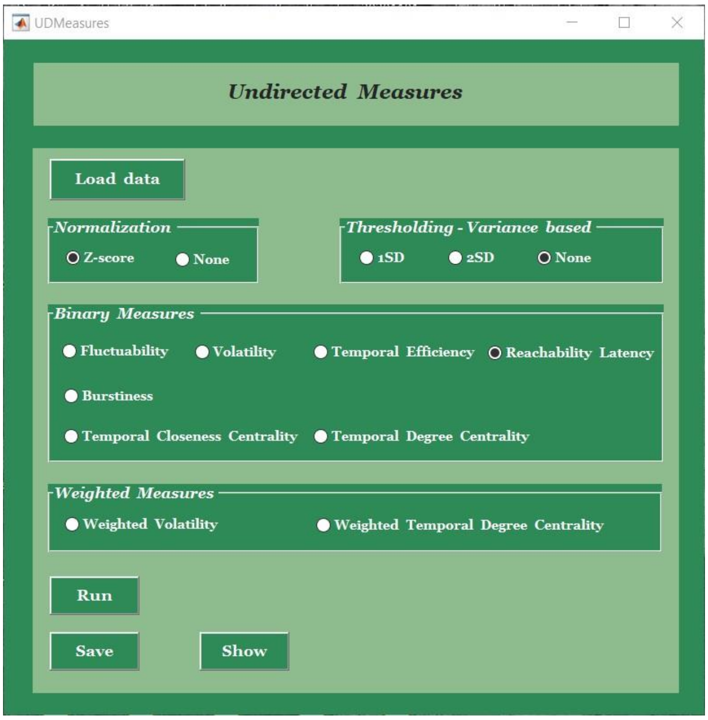
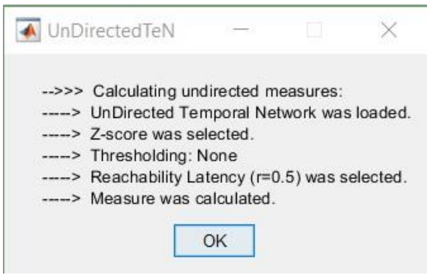


Fig. 26. The selected options.

In the end, I press the "Run" button (Fig. 27). A numeric value is created. I press "Save" button for saving the result. Then, I press "Show" button to illustrate the result. So, the "Show" window is opened and the value of Reachability Latency is displayed in the Table.



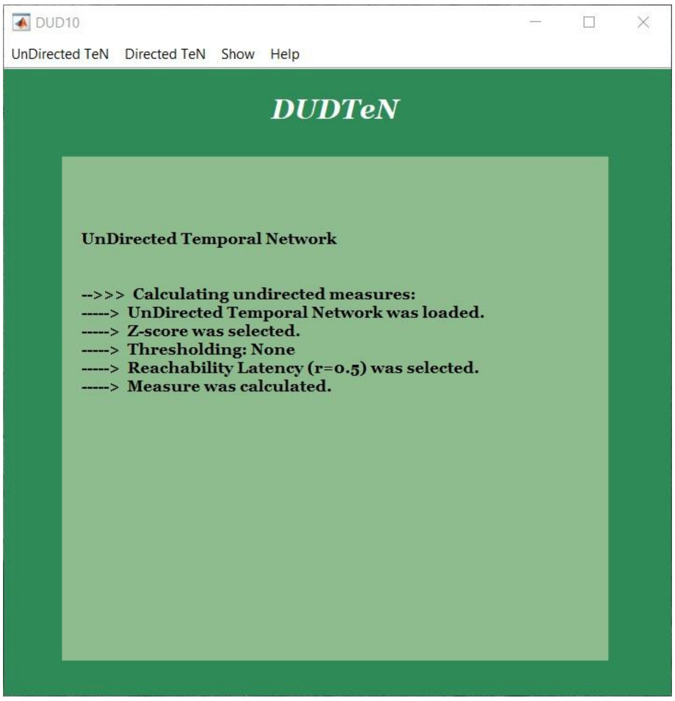


Fig. 27. When the run is complete, a message box is opened (Left) and a message is shown in "DUDTeN" window (Right).

To calculate the Weighted Temporal Degree Centrality, since I loaded the data, I only change the options (disable the previous option and select the new one). In the *Thresholding – variance based* section, I disable “2SD” and choose “None”. In the *Binary Measures* section, I disable “Reachability Latency”, then in the *Weighted Measures* section, I choose “Weighted Temporal Degree Centrality” (Fig. 28).

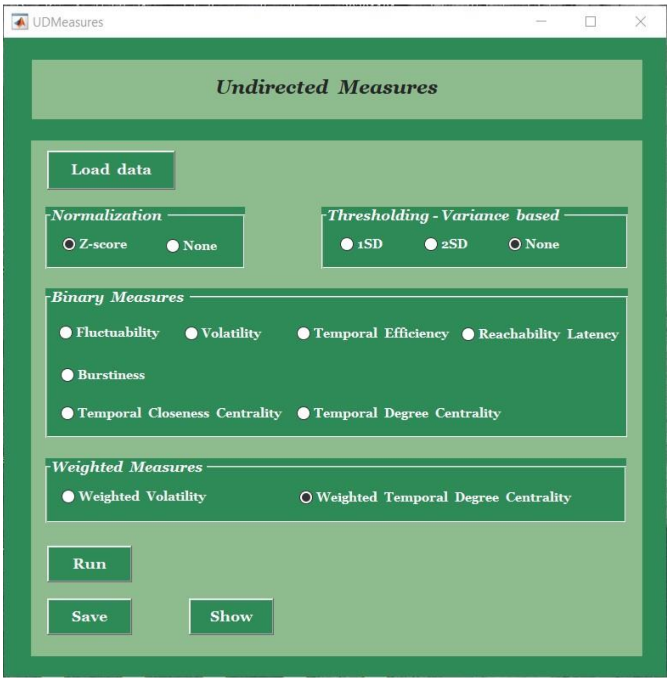


Fig. 28. The selected options.

Finally, I press the “Run” button (Fig. 29). A numeric column vector is created. I press “Save” button for saving the result.

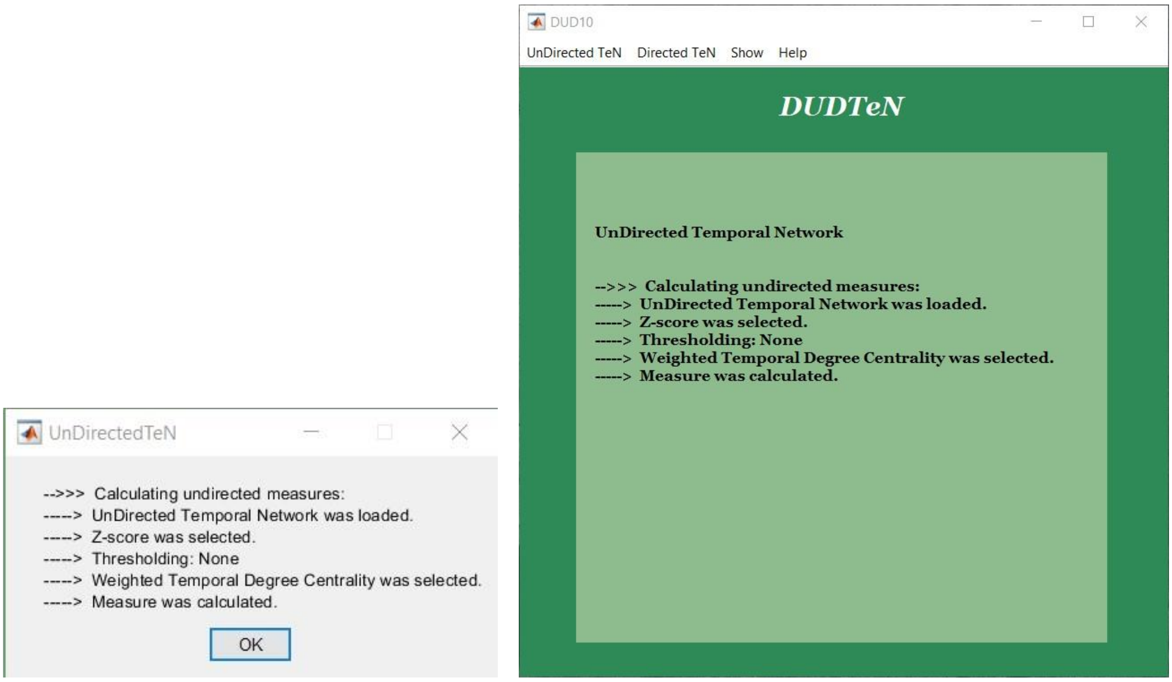


Fig. 29. When the run is complete, a message box is opened (Left) and a message is shown in “DUDTeN” window (Right).

I also press “Show” button to illustrate the result. So, the “Show” window is opened and the values of Weighted Temporal Degree Centrality are displayed in the Table (Fig. 30).

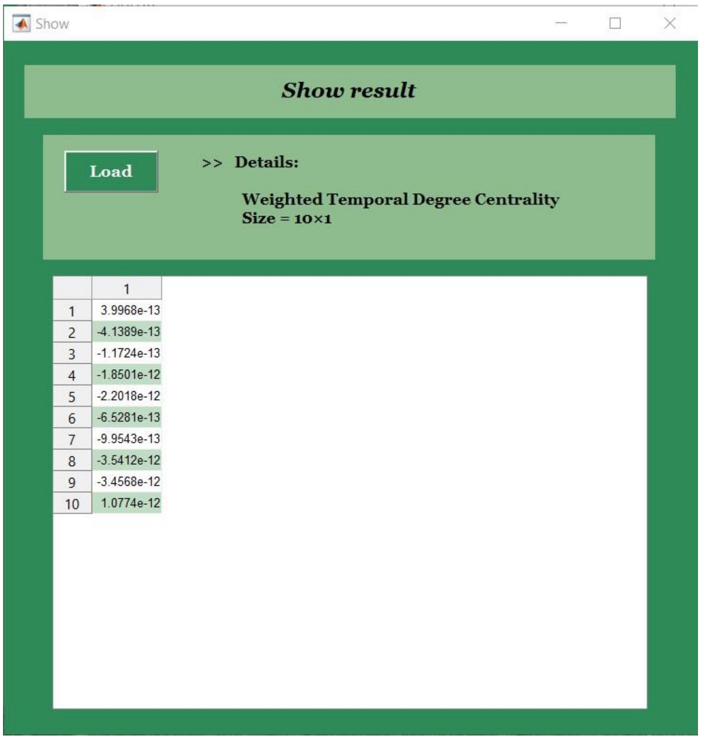
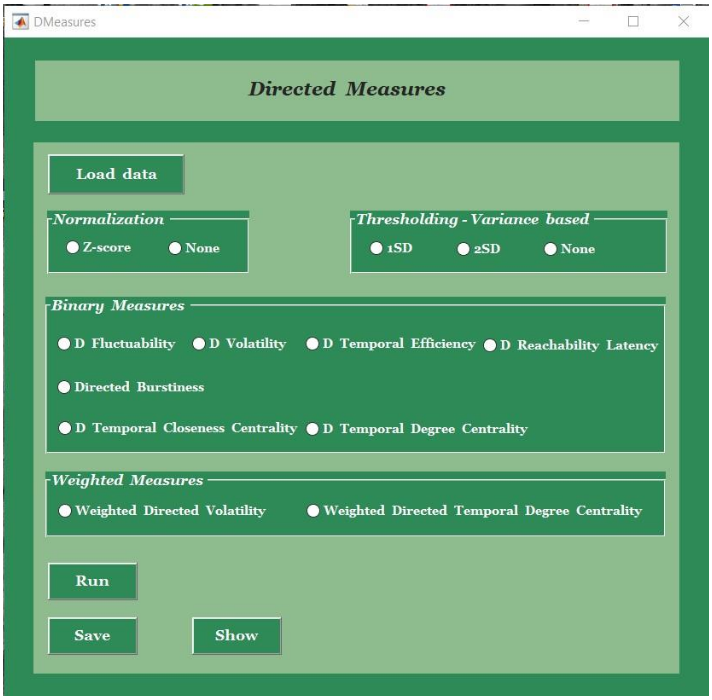


Fig. 30. The values of Weighted Temporal Degree Centrality are displayed in the Table.

7.3. Example of calculating Directed Temporal Measures

I have two directed temporal networks (binary and weighted). The size of these networks is 9×9×100. These networks were standardized (Z-values) and thresholded (one standard deviations variance-based method). I want to calculate two measures of Temporal in-Closeness Centrality and Weighted Directed Volatility.

First, I want to calculate the Temporal in-Closeness Centrality. Thus, I select “Measures” under “Directed TeN” menu in the “DUDTeN” window (Fig. 6). Then, “DMeasures” window is opened. I press the “Load data” button. A help-message box is opened to remind me that I can only load a 3D numeric array (Fig. 31). This help-message box is only opened for the first time of loading. When pressing the *ok* button, “Load Directed Temporal Network” window is opened and I select *.mat file of the binary directed temporal network. When the data is loaded, a message is shown in the “DUDTeN” window (Fig. 32).



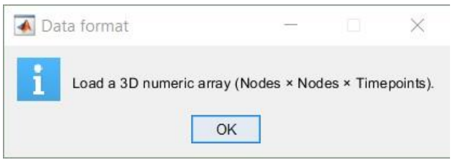


Fig. 31. Press "Load data" button (Left), so a help-message box is opened (Right). After pressing *ok*, I can select the file.

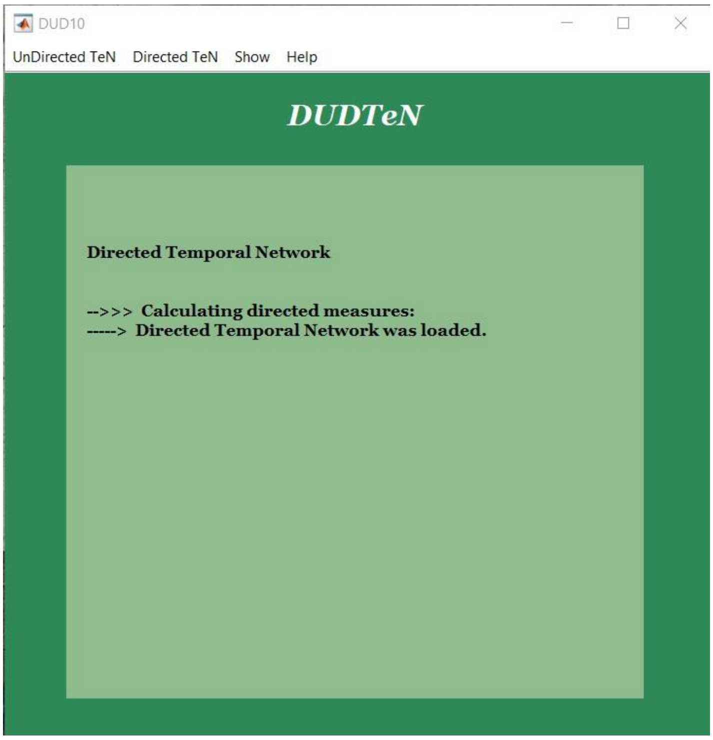


Fig. 32. After loading the file, a message appears in the "DUDTeN" window.

In the *Normalization* section, I choose "None". In the *Thresholding – variance based* section, I choose "None". In the *Binary Measures* section, I choose "D Temporal Closeness Centrality", then a window is opened that I should select the type of Directed Temporal Closeness Centrality. I select the *Temporal in-Closeness Centrality* (Fig. 33) and press the *ok* (Fig. 34).

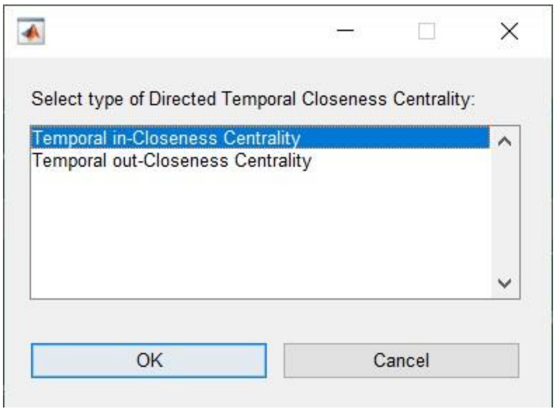


Fig. 33. When choosing "D Temporal Closeness Centrality" option, a window is opened and I select the *Temporal in-Closeness Centrality* and press the *ok*.

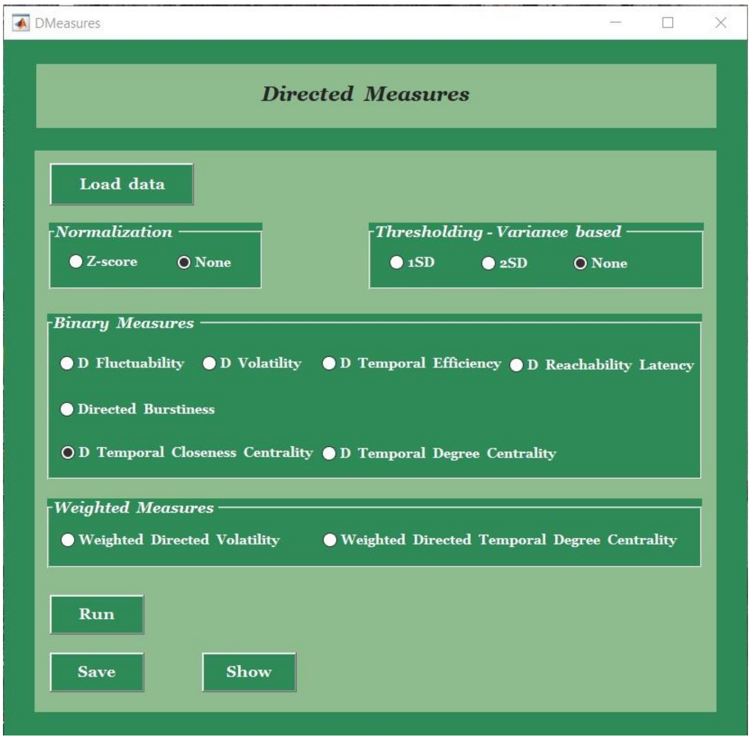


Fig. 34. The selected options.

Finally, I press the "Run" button. When the run is complete, "DirectedTeN" window is opened that shows the selected options (Fig. 35). Also, a message is shown in the "DUDTeN" window (Fig. 35). A numeric row vector is created that is the values of Temporal in-Closeness Centrality.

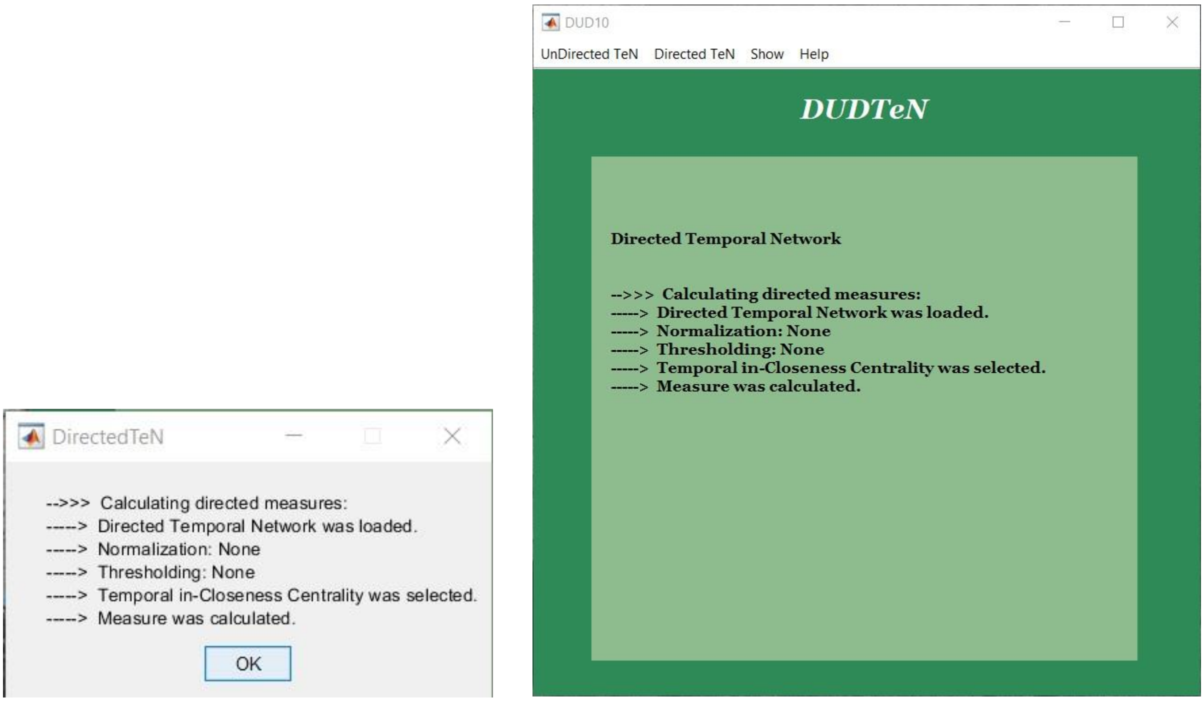


Fig. 35. When the run is complete, a message box is opened (Left) and a message is shown in "DUDTeN" window (Right).

Pressing "Save" button opens "Save Measure" window that I should select a name for saving the result. When the result is saved, a message is displayed in the "DirectedTeN" and the "DUDTeN" windows (Fig. 36).

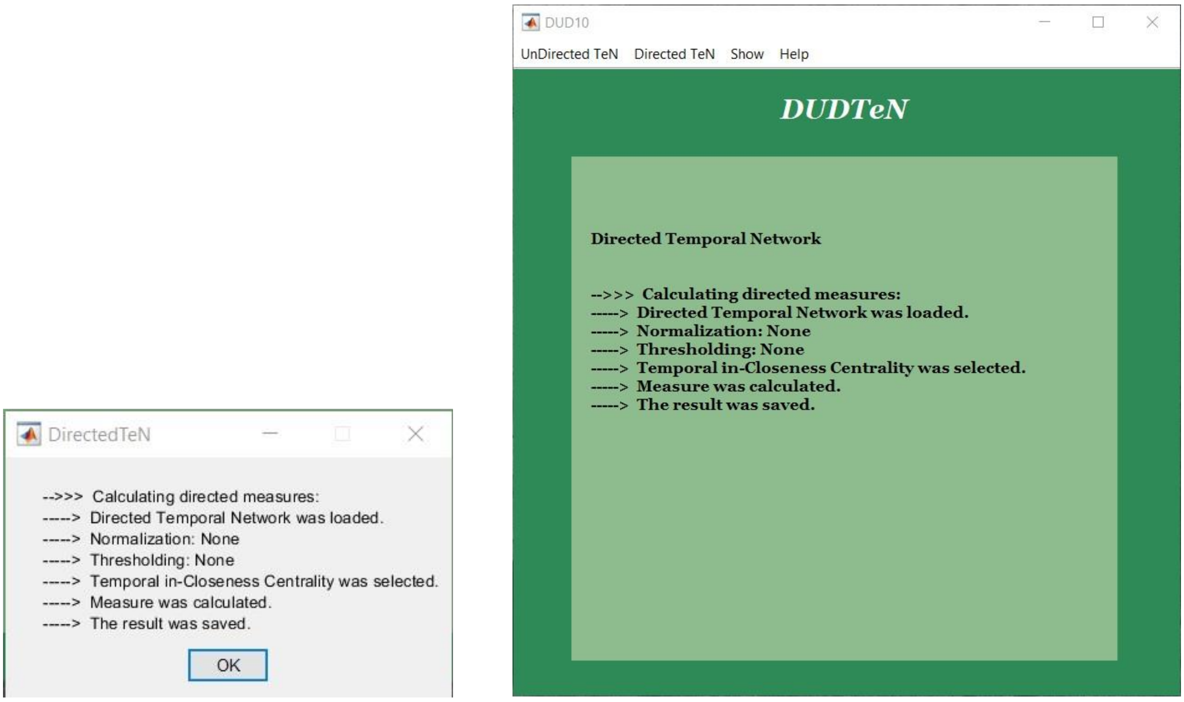


Fig. 36. When the result is saved, a message box is opened (Left) and a message is shown in "DUDTeN" window (Right).

I also press "Show" button to illustrate the result. So, the "Show" window is opened and the values of Temporal in-Closeness Centrality are displayed in the Table (Fig. 37).

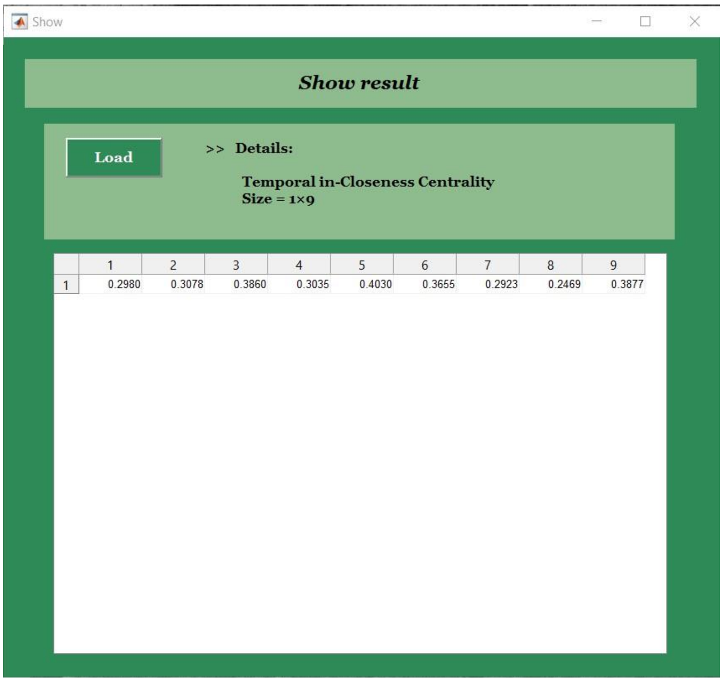


Fig. 37. The values of Temporal in-Closeness Centrality are displayed in the Table.

To calculate the Weighted Directed Volatility, I press the "Load data" button. "Load Directed Temporal Network" window is opened and I select *.mat file of the weighted directed temporal network. Then, I change the options (disable the previous option and select the new one). In the *Binary Measures* section, I disable "D Temporal Closeness Centrality", then in the *Weighted Measures* section, I choose "Weighted Directed Volatility" (Fig. 38).

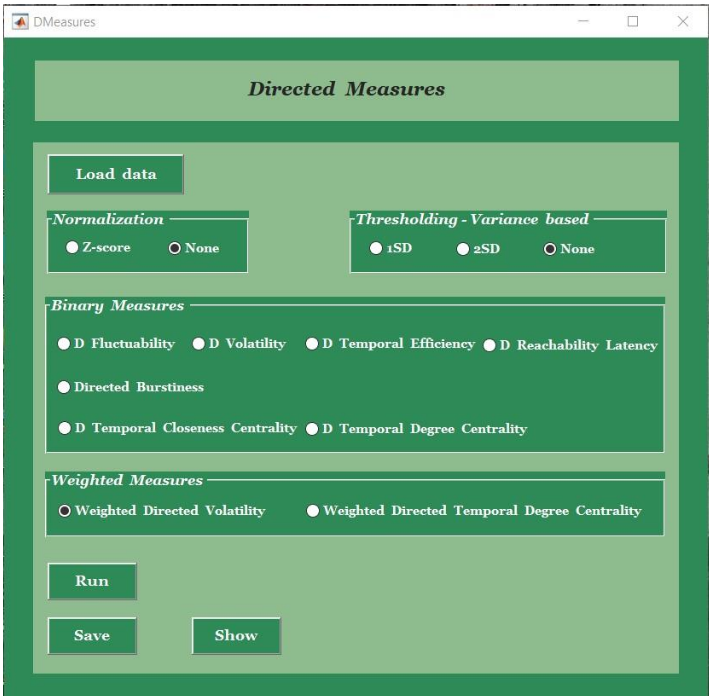


Fig. 38. The selected options.

Finally, I press the "Run" button (Fig. 39). A numeric value is created that is the value of Weighted Directed Volatility. I press "Save" button for saving the result.

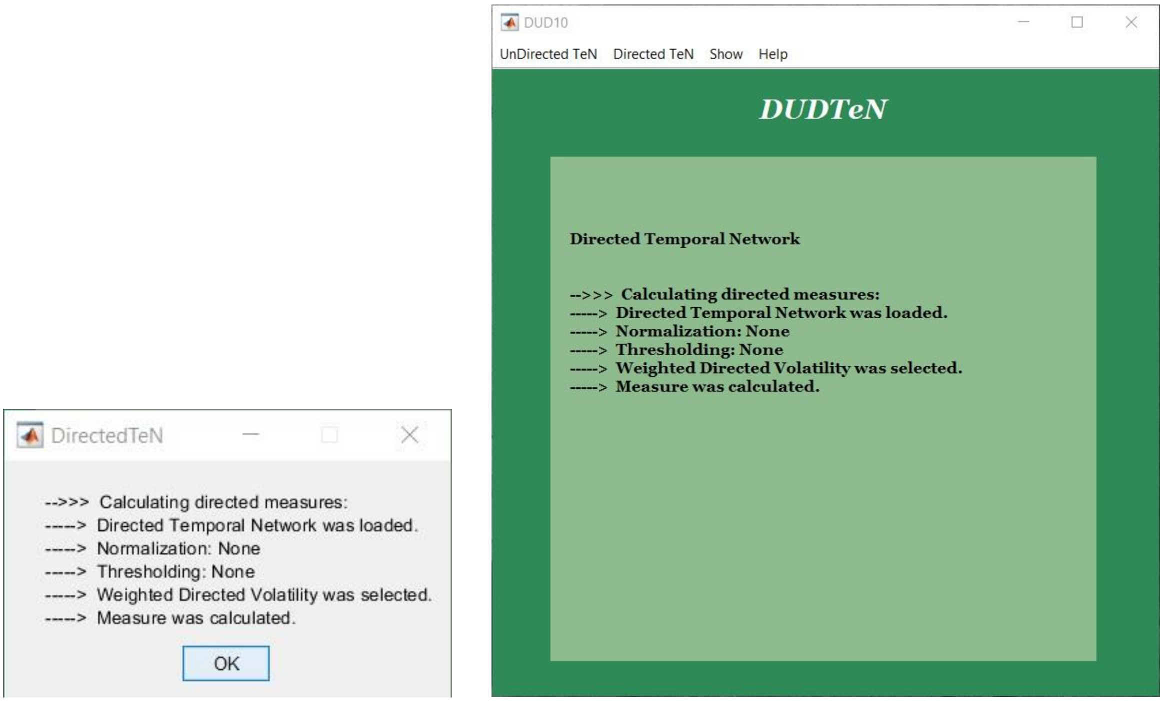


Fig. 39. When the run is complete, a message box is opened (Left) and a message is shown in "DUDTeN" window (Right).

I also press "Show" button to illustrate the result. So, the "Show" window is opened and the value of Weighted Directed Volatility is displayed in the Table (Fig. 40).

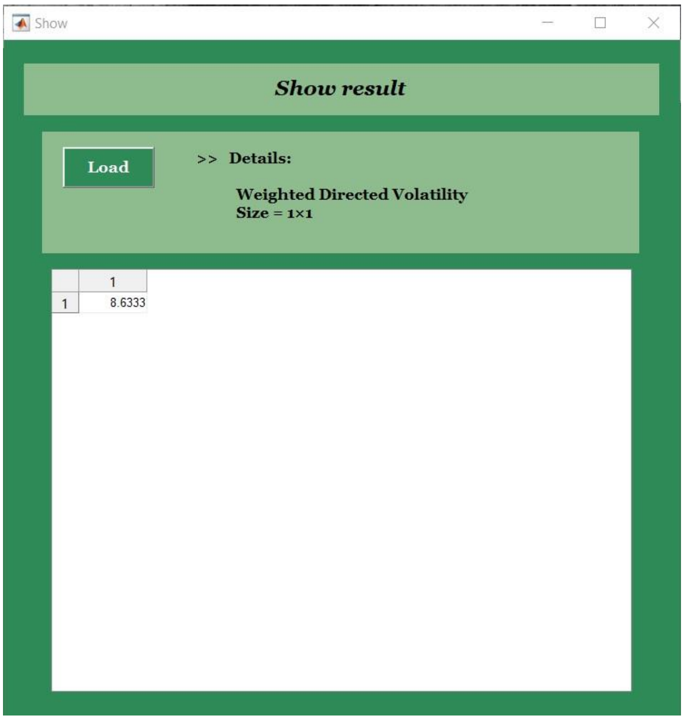


Fig. 40. The value of Weighted Directed Volatility is displayed in the Table.

8. References

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