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) 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. As well as, you can show the data in a specific window.

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

1.1. About DUDTeN

DUDTeN is developed in MATLAB software, under a 64-bit Windows. All of the codes were handwritten codes by me, 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 undirected binary temporal measures. I introduced two undirected weighted temporal measures [3] and created those codes.

To derive DFC, in the DUDTeN, I introduced two methods of Spatial Distance (SD) and Jackknife Correlation (JC). These methods are the newest approaches to estimate DFC time-series with the highest temporal resolution. Both JC and SD methods obtain unique connectivity estimate for each time point. See [1] for more details about the SD method and see [2] for more details about the JC method. In order to post-process the dynamic functional connectivity time-series, I introduced the Fisher, BoxCox, and Fisher&BoxCox transformations (see [4]). To normalize the dynamic functional connectivity time-series, the Z-score was introduced. By using DUDTeN, it's possible to derive DFC for any type of time-series (such as fMRI BOLD, EEG, etc.). For more details see *Section 3.1.*

To investigate the properties of the undirected temporal network at the global level or the local level (per edge or node), I introduced nine undirected temporal measures [1, 3]. These measures are shown in Table 1. You can select the r parameter for the measure of Reachability Latency. Nodal Reachability Latency only can 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.*

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		✓	

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

The directed temporal measures will be developed soon.

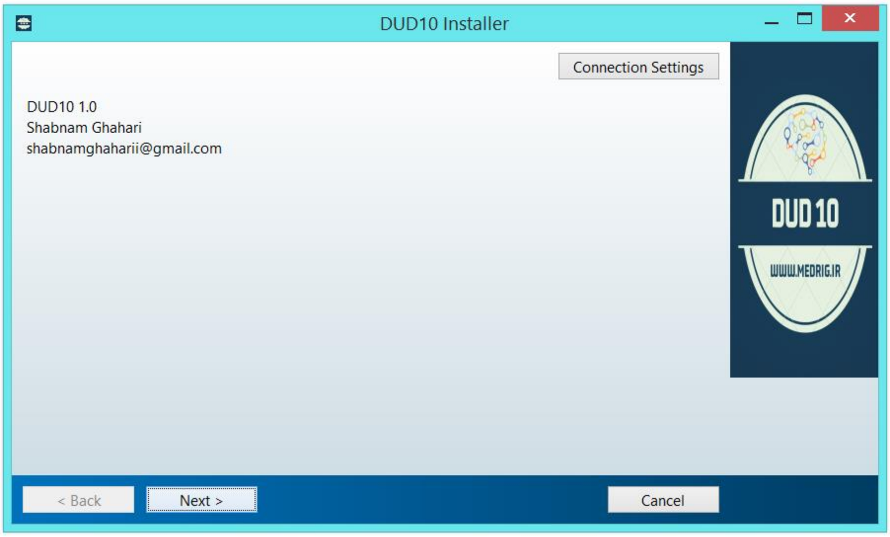
In the future, I will add other methods to estimate DFC.

DUDTeN is created based on the definitions in the network neuroscience [1, 2, 3] and was used to investigate the temporal network of the human brain in [5] and [3], but this software could be used for studying any temporal network in any field.

1.2. How to install DUDTeN

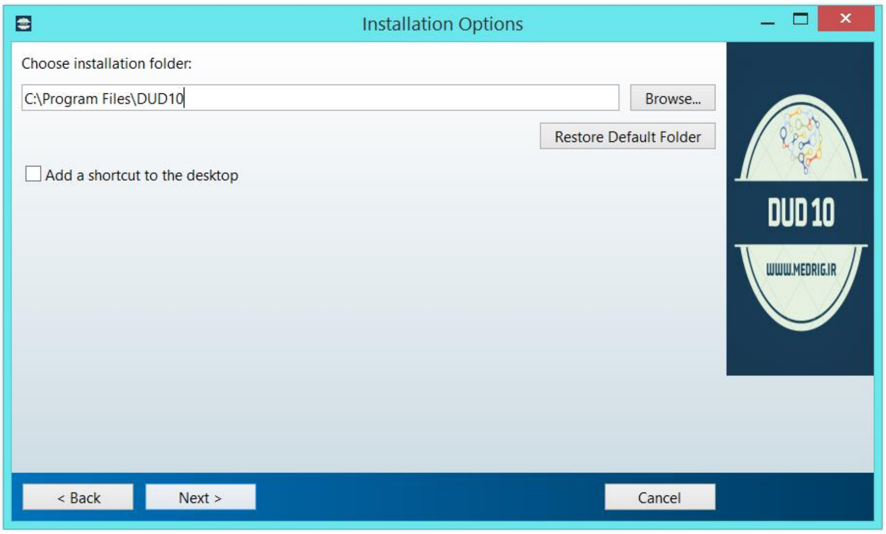
To install **DUDTeN**, follow the steps below:

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



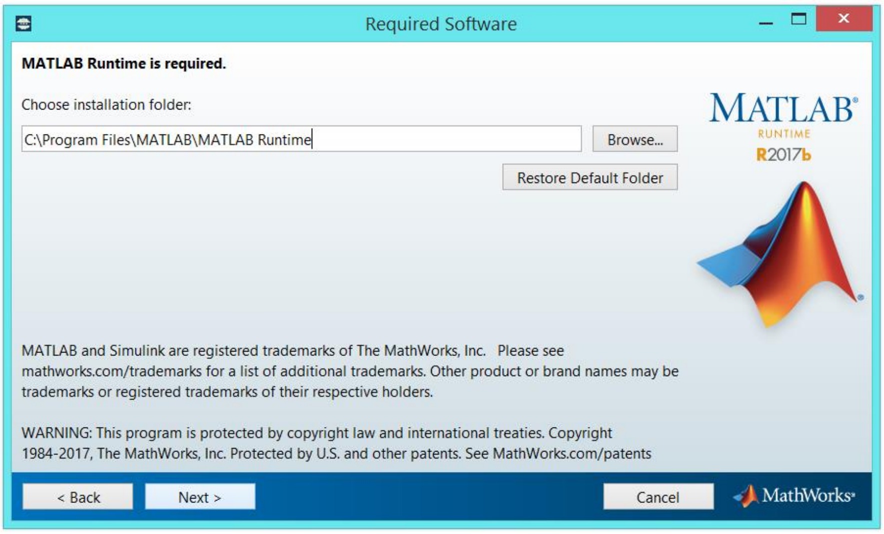
2- Click *Next* to advance to the Installation Options page.

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



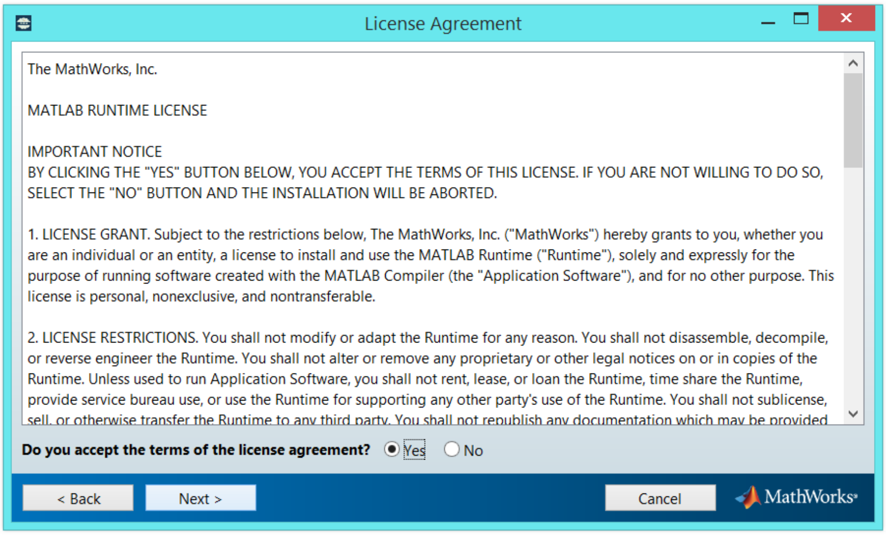
3- Click *Next* to advance to the Required Software page.

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 you receive this message, nevertheless install the same version, you can uninstall it after finishing the installation of DUDTeN.

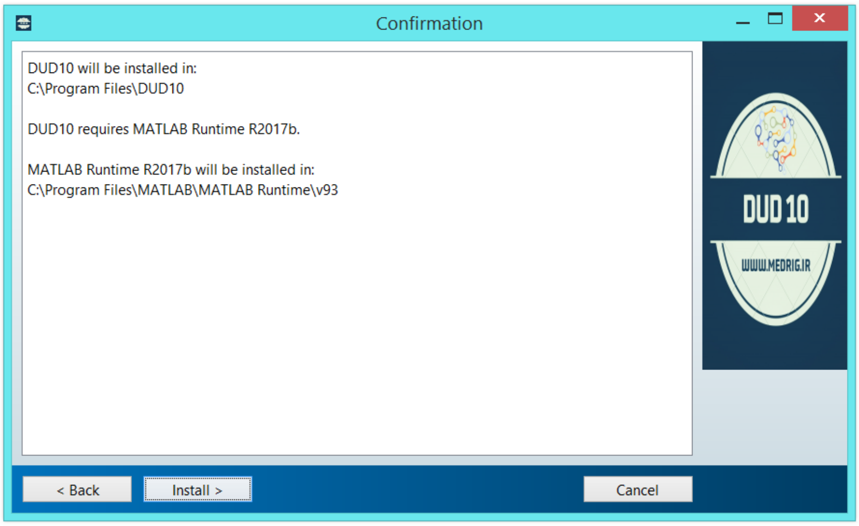


4- Click *Next* to advance to the License Agreement page.

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

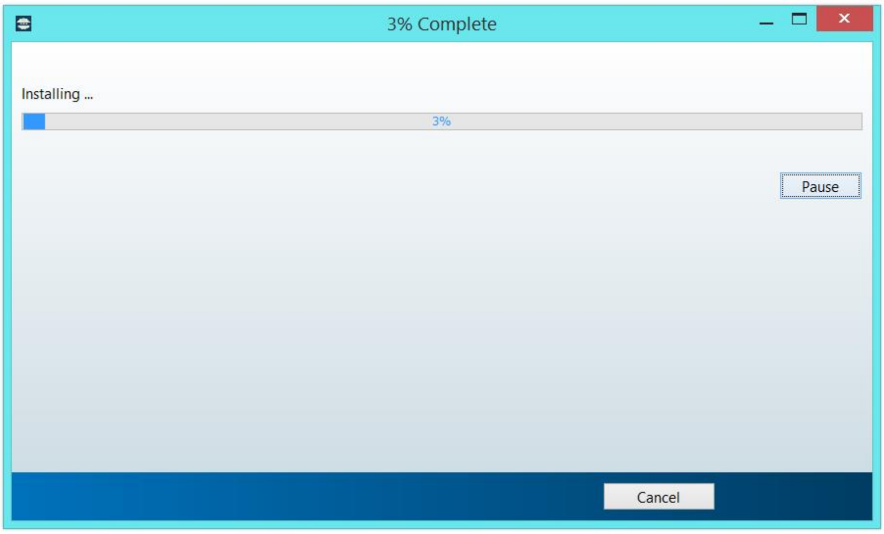


5- Click *Next* to advance to the Confirmation page.

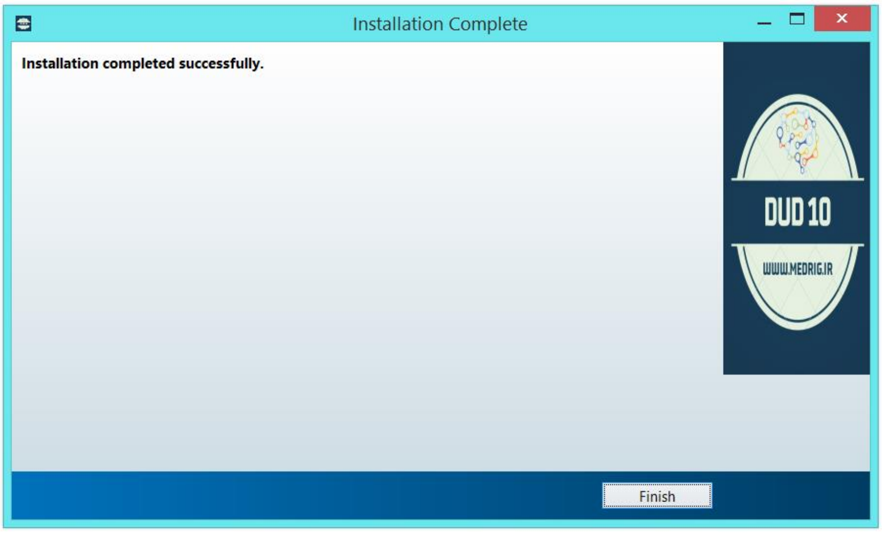


6- Click *Install*.

The installer installs DUDTeN.



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 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 of the changes are shown in this window. In each submenu and their options, error and help boxes are created that helps the users to do the steps correctly. In the following, I explained the menus and submenus with their options.

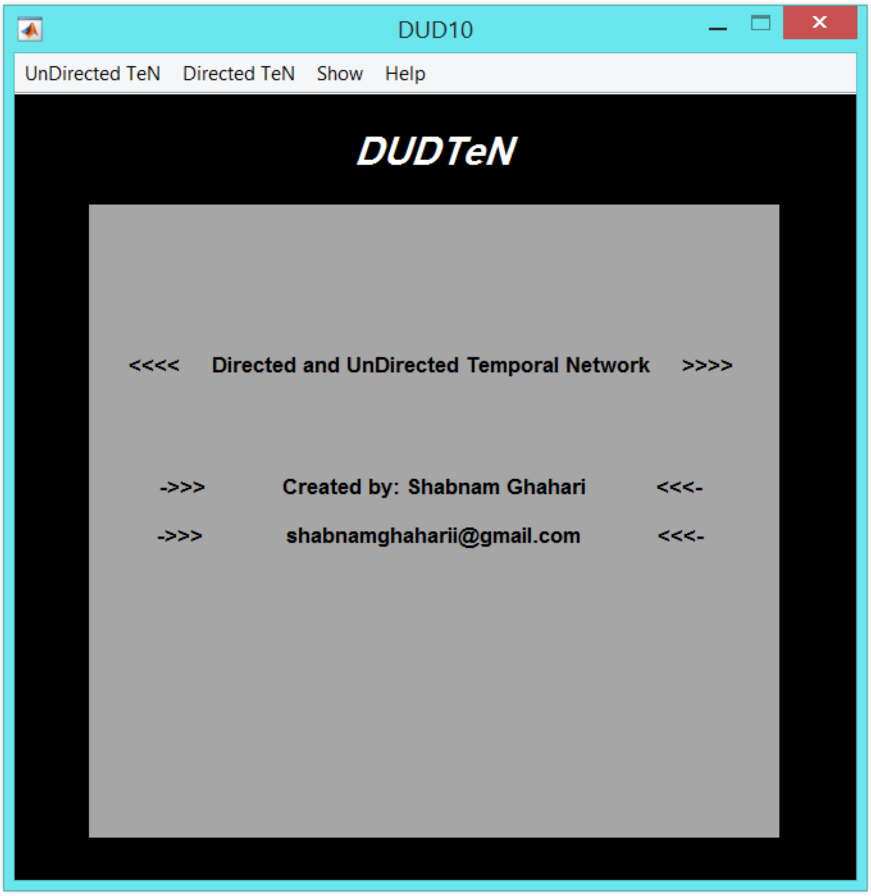


Fig. 1. DUDTeN window

3. UnDirected TeN

UnDirected Temporal Network could be create using DFC methods (such as Sliding Window, Tapered Sliding Window, etc.). In order to quantify the connectivity time-series, several measures are introduced (such as Fluctuability, Temporal Degree Centrality, etc.).

3.1. DFC

As discussed in *Section 1.1*, I created the codes for deriving DFC using Spatial Distance and Jackknife Correlation methods. Three Transformations (Fisher, BoxCox, and Fisher&BoxCox) are introduced that can be used for DFC time-series (such as derived from BOLD time-series). Z-score normalization is created for standardizing DFC time-series.

To estimate DFC, after starting DUDTeN, select the “DFC” under “UnDirected TeN” menu. So, the “DynamicFC” window opens (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 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 opens that you should determine a range for setting 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 was scaled to 1 [4], and after applying this transformation, the BC-transformed DFC time-series was scaled back so that the post-BC mean equaled the mean of the raw DFC time series [4].
   3.3. Select the “Fisher & BoxCox” option to first apply the Fisher Transformation and then BoxCox Transformation.
   In this case, the mean was scaled back to the mean of the Fisher-transformed DFC time-series.
   3.4. Select the “None” option to don’t apply a 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 to don’t apply Normalization.

5. Press “Run” button.
   Estimate DFC 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.

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

When selecting the “DFC” under “UnDirected TeN” menu, in the “DUDTeN” window a message is shown that appears as Fig. 3. Also, in steps of loading data, run, and save, a message is shown in the “DUDTeN” window which helps you to know that the steps were done correctly. All of the options that you choose are shown (which method selected and …). When the steps of the run and save done correctly, also, a message box is opened that present all of the options selected. 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 option, you must disable the wrong option and then choose the correct option. When you want to close the “DynamicFC” window, if you run and don’t save the result, a message is shown to remind you that you didn’t save the result.

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

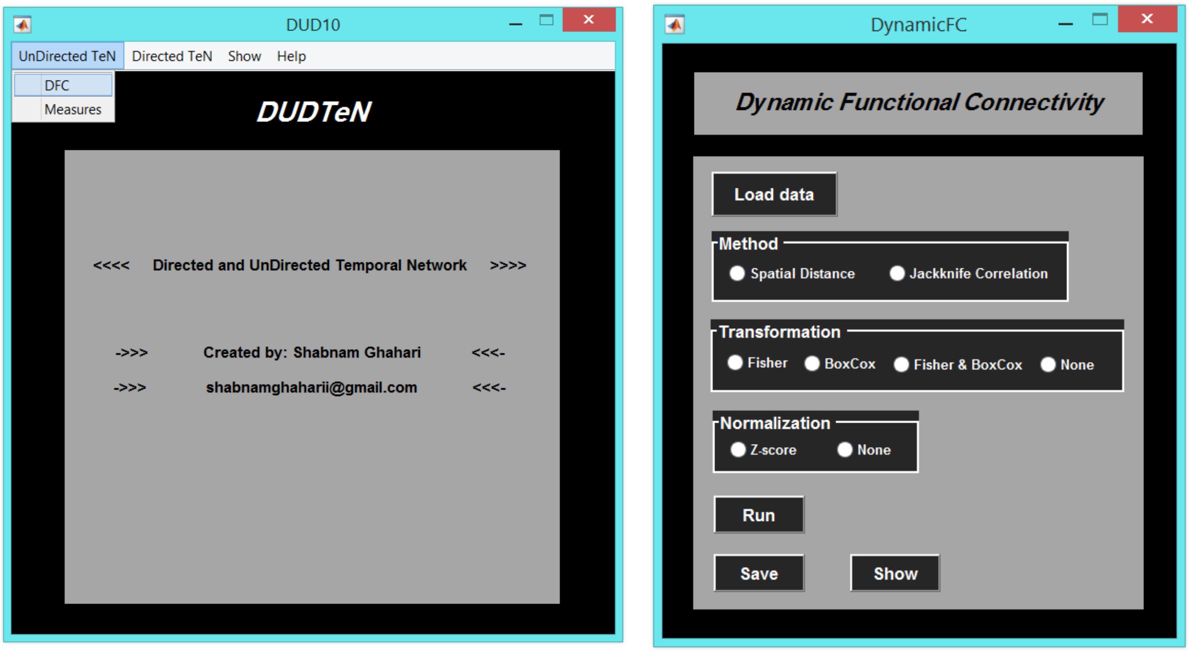


Fig. 2. Select the “DFC” under “UnDirected TeN” menu (Left). So, the “DynamicFC” window opens (Right).

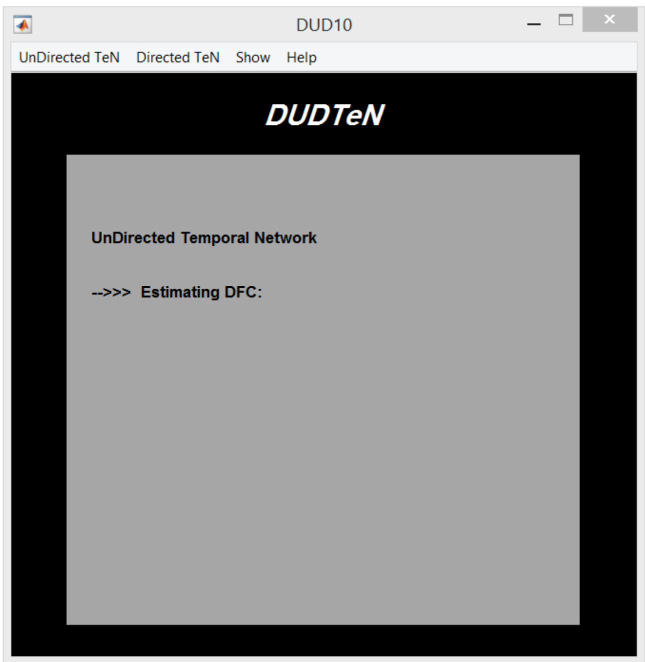


Fig. 3. By selecting the “DFC” under “UnDirected TeN” menu, a message is shown in the “DUDTeN” window.

3.2. Measures

As discussed in *Section 1.1*, I created the codes to calculate the undirected temporal measures. In Table 1, the name of measures and the type of them that introduced in the DUDTeN are illustrated. In total, 18 measures are created. Two methods for thresholding based on variance (1SD and 2SD) are introduced that can be applied to the undirected temporal network. Z-score normalization is 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 opens (Fig. 4). Then, follow the steps below:

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

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 to don't apply 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 set to 1 and the rest set to 0.
   To create a weighted undirected temporal network, edges with less than two standard deviations set to 0, in each connectivity time series.
   3.3. Select the "None" option to don't apply a Thresholding.

4. Choose a binary measure or a weighted measure.
   4.1. When selecting the "Fluctuability" option, a window opens that you can choose the type of this measure (*Nodal Fluctuability* or *Global Fluctuability*).
   4.2. When selecting the "Volatility" option, a window opens 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 opens 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 opens that you can choose the type of this measure. If *Reachability Latency* selected, "Reachability Latency parameter" window opens 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 opens 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 opens 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.
   Calculate the undirected temporal measure 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.

7. Press “Show” button.
   When selecting this option, “Show” window opens (see *Section 5.*) and the calculated undirected temporal measure is illustrated in the Table.

When selecting the “Measures” under “UnDirected TeN” menu, in the “DUDTeN” window a message is shown that appears as Fig. 5. Also, in steps of loading data, run, and save, a message is shown in the “DUDTeN” window which helps you to know that the steps were done correctly. All of the options that you choose are shown (which measure selected and …). When the steps of the run and save done correctly, also, a message box is opened that present all of the options selected. 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 option, you must disable the wrong option and then choose the correct option. When you want to close the “UDMeasures” window, if you run and don’t save the result, a message is shown to remind you that you didn’t save the result.

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

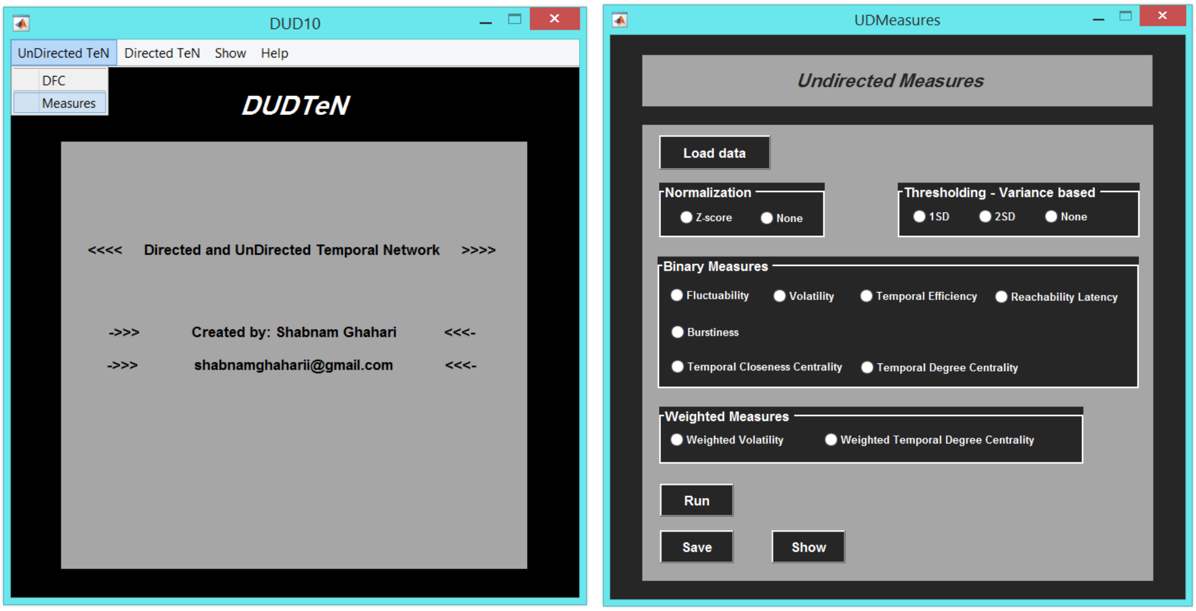


Fig. 4. Select the “Measures” under “UnDirected TeN” menu (Left). So, the “UDMeasures” window opens (Right).

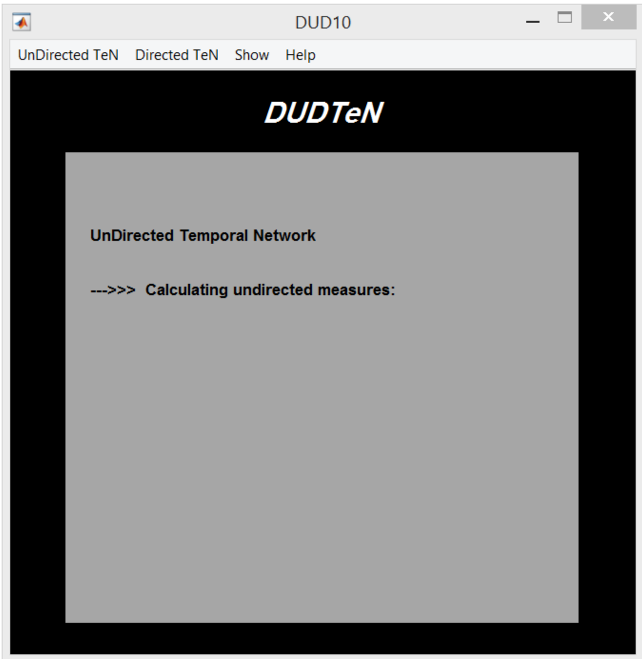


Fig. 5. By selecting the “Measures” under “UnDirected TeN” menu, a message is shown in the “DUDTeN” window.

4. Directed TeN

The “Directed TeN” menu in the “DUDTeN” window introduces for the Directed Temporal Network. This menu has a submenu of “Measures” that is for calculating the directed temporal measures. This submenu will be developed in the near future.

5. Show

The “Show Data” under “Show” menu created for illustrating the data that loaded or the results, in a table (Fig. 6).

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

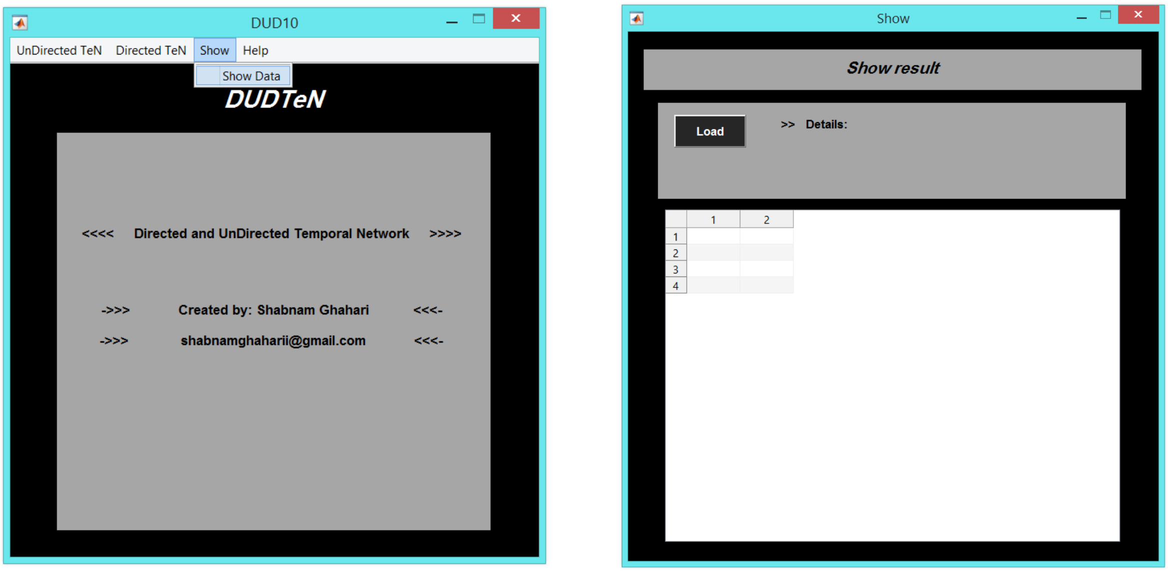


Fig. 6. Select the “Show Data” under “Show” menu (Left). So, the “Show” window opens (Right).

6. Help

The “Manual” under “Help” menu (Fig. 7) created for opening the *Manual_DUDTeN.pdf*.

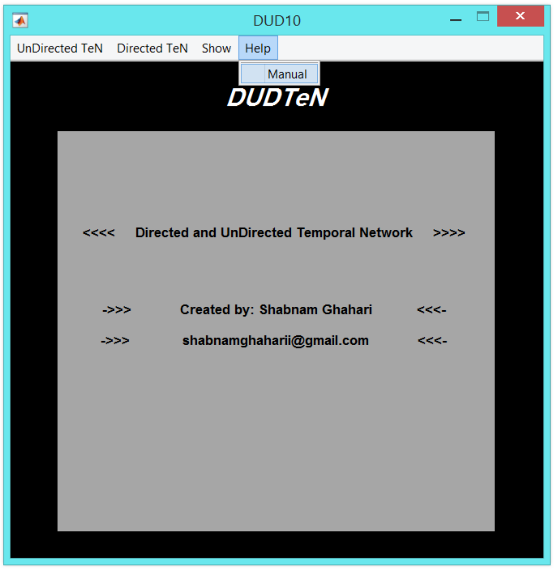


Fig. 7. Select the “Manual” under “Help” menu, so, the *Manual_DUDTeN.pdf* opens.

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 placed 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. 6). Thus, "Show" window is opened. I press the "Load" button, then the "Load" window opens that I should select the *.mat file and press the *open*. When the file loaded, the details of the *.mat file are shown in this window (Fig. 8). In the table, the time-series of ROIs are presented, by moving the scroll, I can see all of the data.

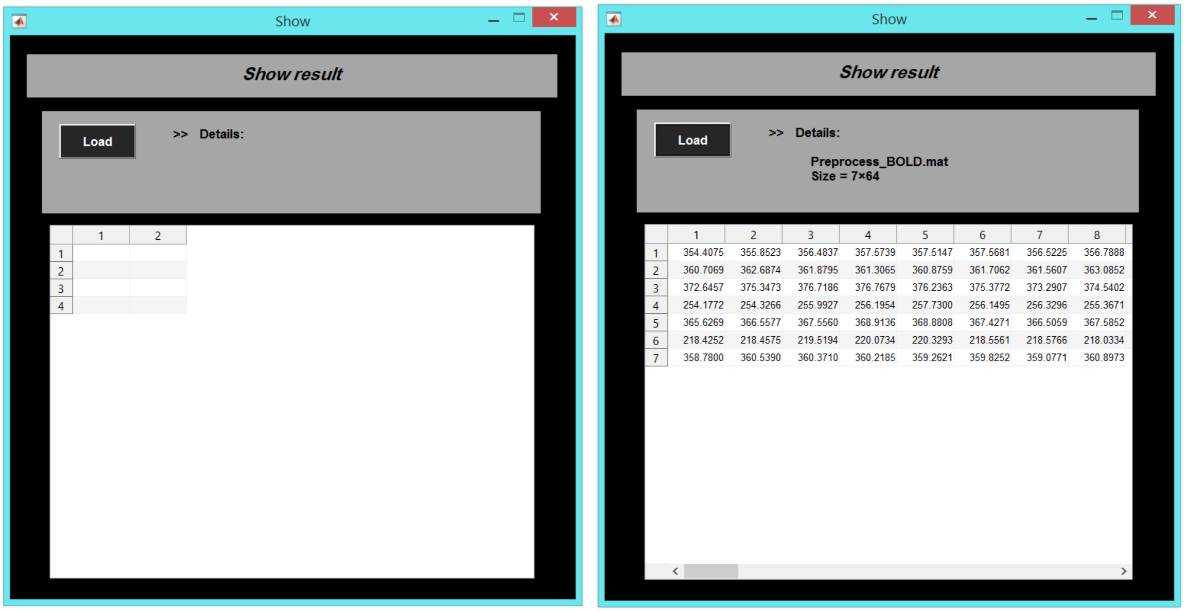
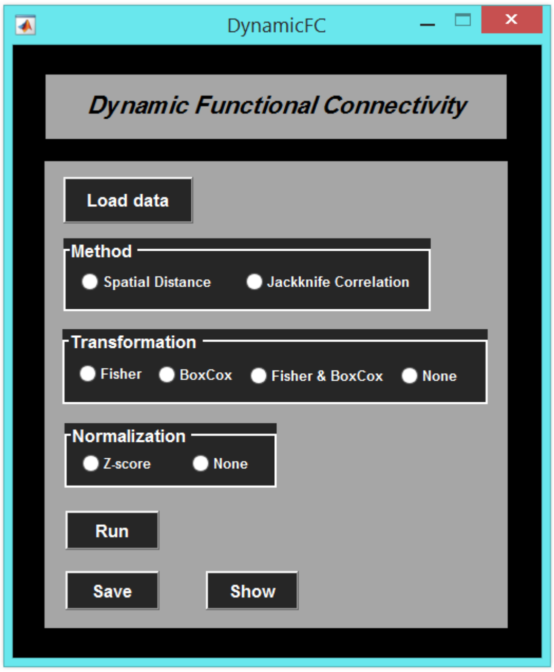


Fig. 8. Press "Load" button and select the file (Left). The loaded file (Right).

I want to derive DFC using Spatial Distance method, then first apply Fisher transformation 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. In the "DUDTeN" window, a message is shown that appears as Fig. 3. I press the "Load data" button. A help-message box opens to remind me that I can load only a 2D numeric array (Fig. 9). This help-message box opens only for the first time of loading. When pressing the *ok* button, "Load time-series" window opens and I select *.mat file. When the data is loaded, in the "DUDTeN" window, a message is shown that appears as Fig. 10.



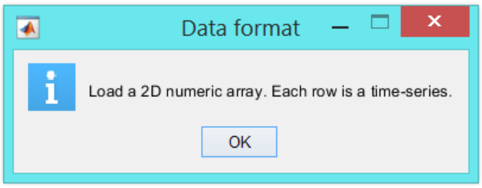


Fig. 9. Press “Load data” button (Left), so, a help-message box opens (Right). After pressing *ok*, I can select the file.

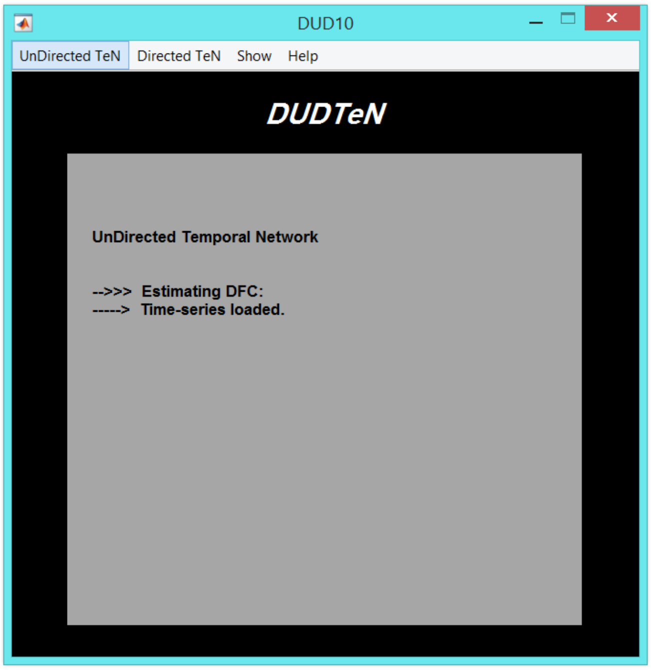
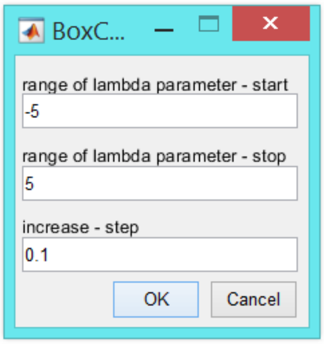


Fig. 10. After loading the file, a message shows in the “DUDTeN” window.

In the *Method* section, I choose “Spatial Distance”. In the *Transformation* section, I choose “Fisher & BoxCox”, then “BoxCox parameter” window opens that I should determine the range of λ parameter. I let the λ range from -15 to 15 in increments of 0.01 (Fig. 11). In the *Normalization* section, I choose “Z-score” (Fig. 12).



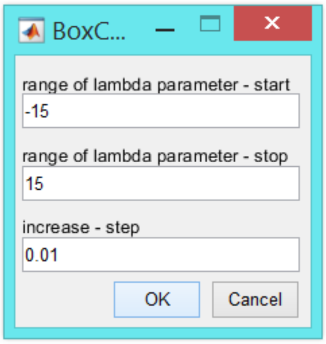


Fig. 11. "BoxCox parameter" window (Left). I change the default and let the λ range from -15 to 15 in increments of 0.01 (Right).

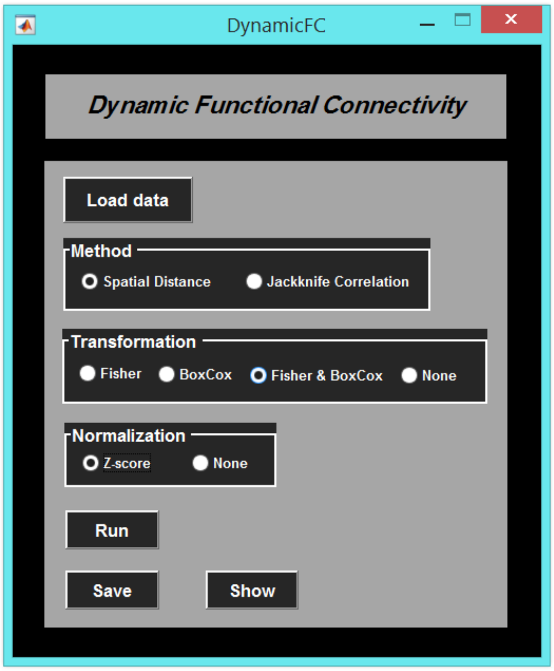


Fig. 12. The selected options.

Finally, I press the "Run" button. When the run is complete "DFC" window opens that presents the options that I selected and expresses *DFC derived* which means the run was done (Fig. 13). Also, in the "DUDTeN" window, a message is shown that appears as Fig. 13. 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, :)*.

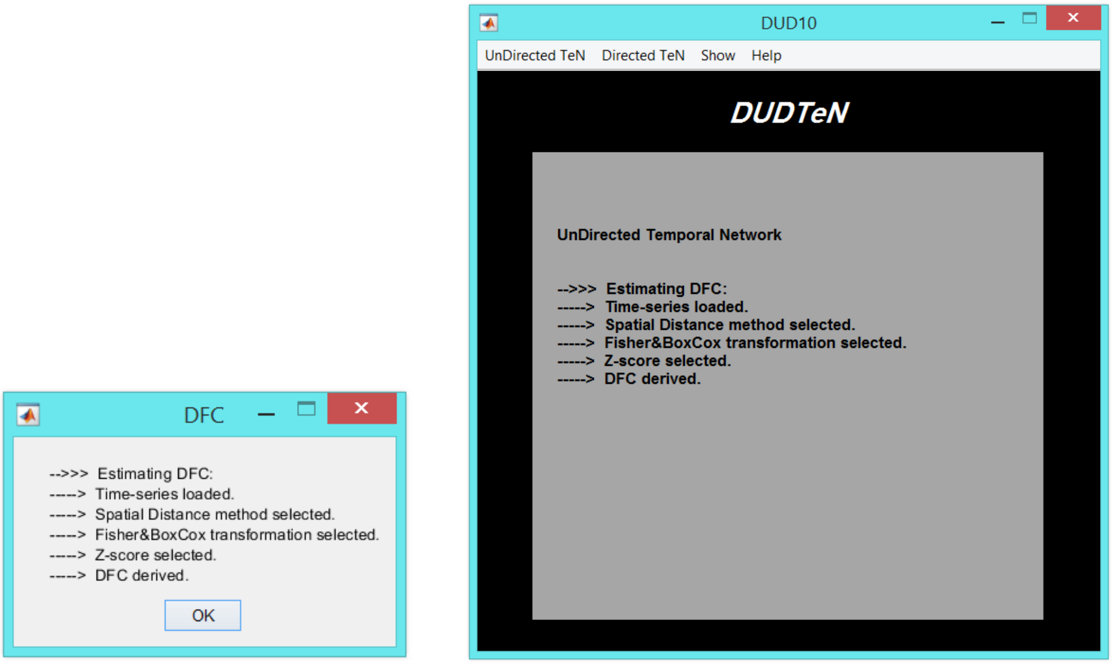


Fig. 13. When the run is complete, a message box opens (Left) and a message is shown in "DUDTeN" window (Right).

By pressing "Save" button, "Save DFC" window opens that I should select a name for saving the result. When the result is saved, a message presents in the "DFC" window and also in the "DUDTeN" window that expresses the result was saved (Fig. 14).

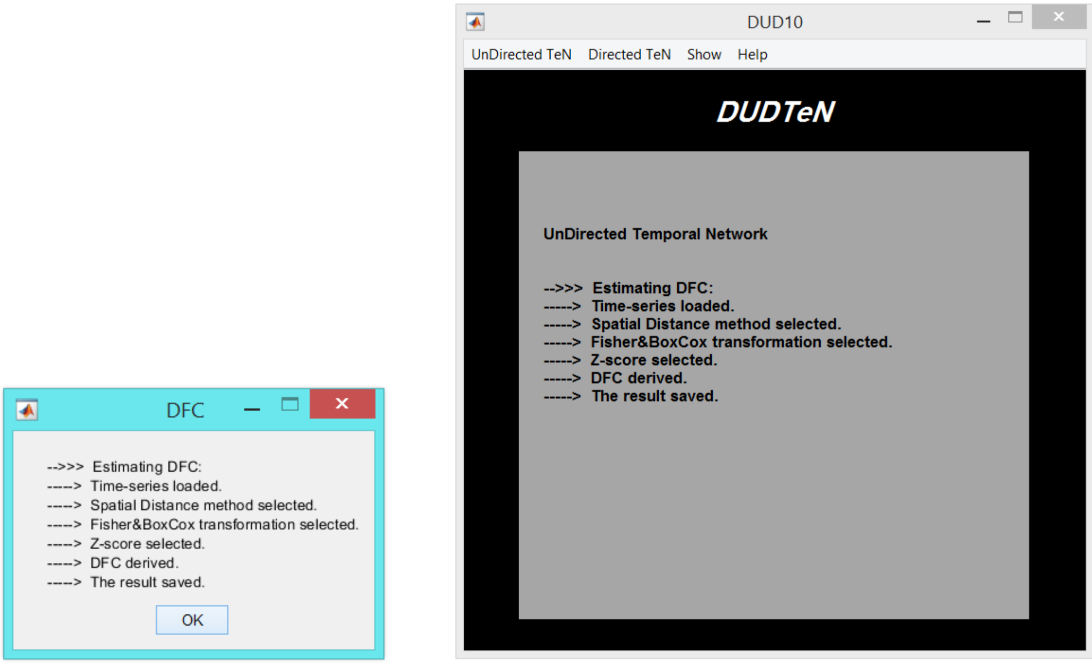


Fig. 14. When the result is saved, a message box opens (Left) and a message is shown in "DUDTeN" window (Right).

I can also press "Show" button to illustrate the result. Then "Show result" window is opened that I should choose the time point that I want to display (Fig. 15). I choose time point of 6, then press the *ok*, so the “Show” window opens and the time-graphlet at the time point of 6 display in the table (Fig. 15).

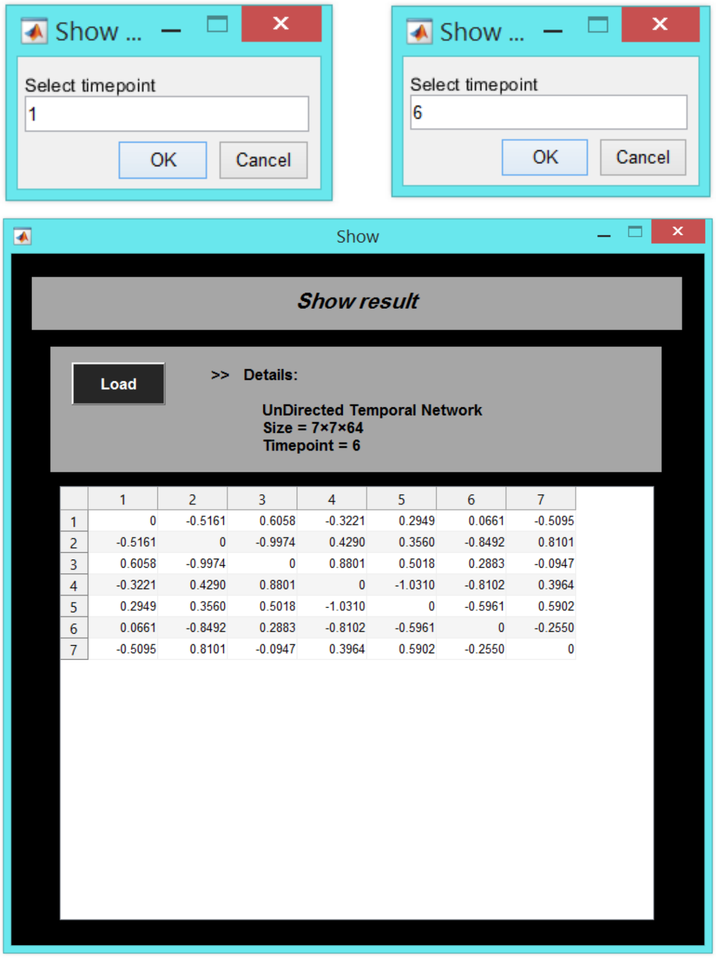


Fig. 15. “Show result” window (Top - Left). I change the default (Top - Right). The time-graphlet at the time point of 6 is displayed in the table (Bottom).

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 two measures of Weighted Temporal Degree Centrality and Fluctuability (Global). For creating the binary undirected temporal network, I want to threshold this network by using two standard deviations variance-based method. So, before applying the thresholding method is better to convert the connectivity time-series into Z-values. In order to create the weighted undirected temporal network, I don’t want to use any thresholding and only 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 opens. In the “DUDTeN” window, a message is shown that appears as Fig. 5. I press the “Load data” button. A help-message box opens to remind me that I can load only a 3D numeric array (Fig. 16). This help-message box opens only for the first time of loading. When pressing the *ok* button, “Load Undirected Temporal Network” window opens and I select *.mat file. When the data is loaded, in the “DUDTeN” window, a message is shown that appears as Fig. 17.

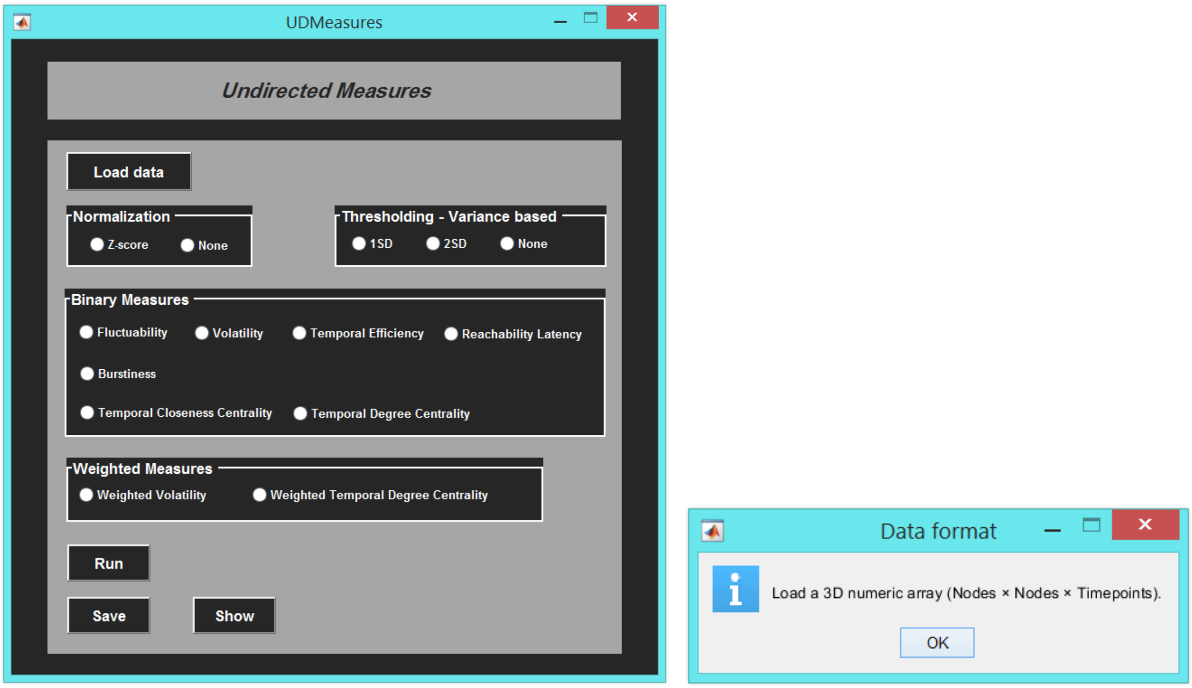


Fig. 16. Press “Load data” button (Left), so, a help-message box opens (Right). After pressing *ok*, I can select the file.

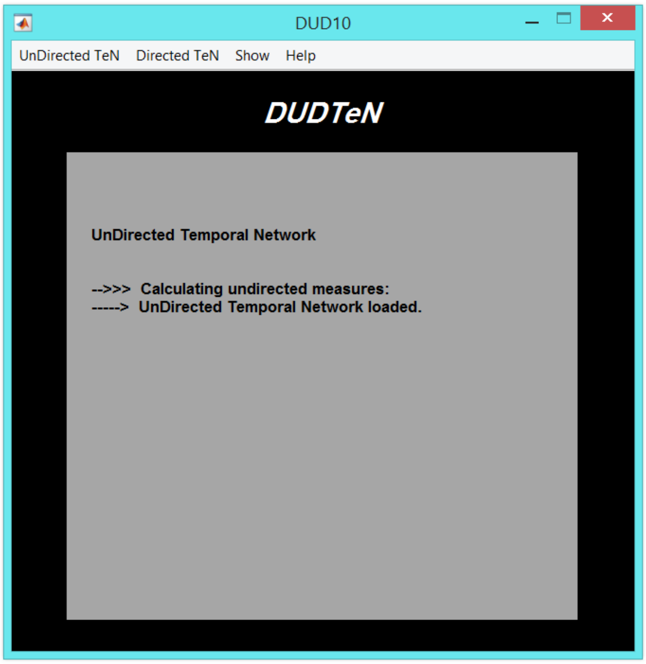


Fig. 17. After loading the file, a message shows in the “DUDTeN” window.

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 opens that I should select the type of Fluctuability. I select the *Global* (Fig. 18) and press the *ok* (Fig. 19).

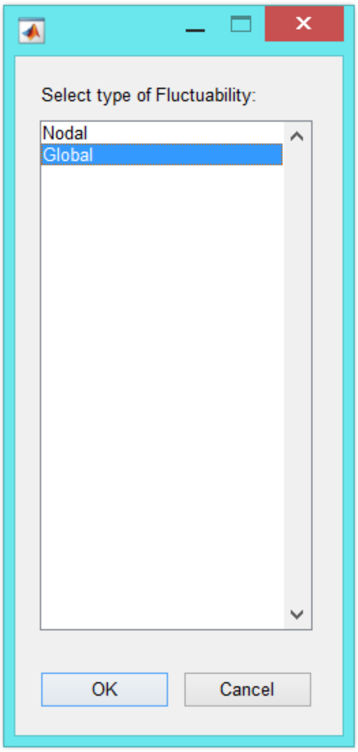


Fig. 18. When choosing "Fluctuability" option, a window opens and I select the *Global* and press the *ok*.

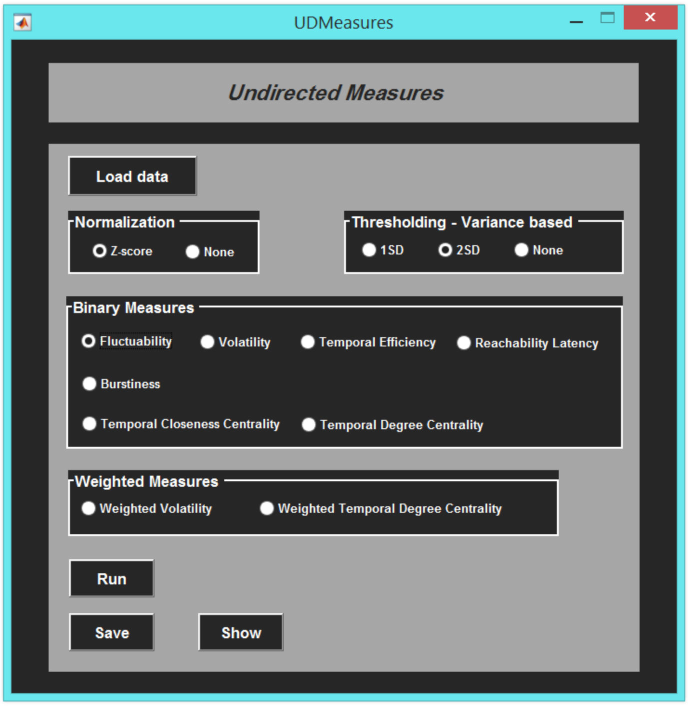


Fig. 19. The selected options.

Finally, I press the "Run" button. When the run is complete "UnDirectedTeN" window opens that presents the options that I selected and expresses *measure calculated* which means the run was done (Fig. 20). Also, in the "DUDTeN" window, a message is shown that appears as Fig. 20. A numeric value is created that is the value of Global Fluctuability.

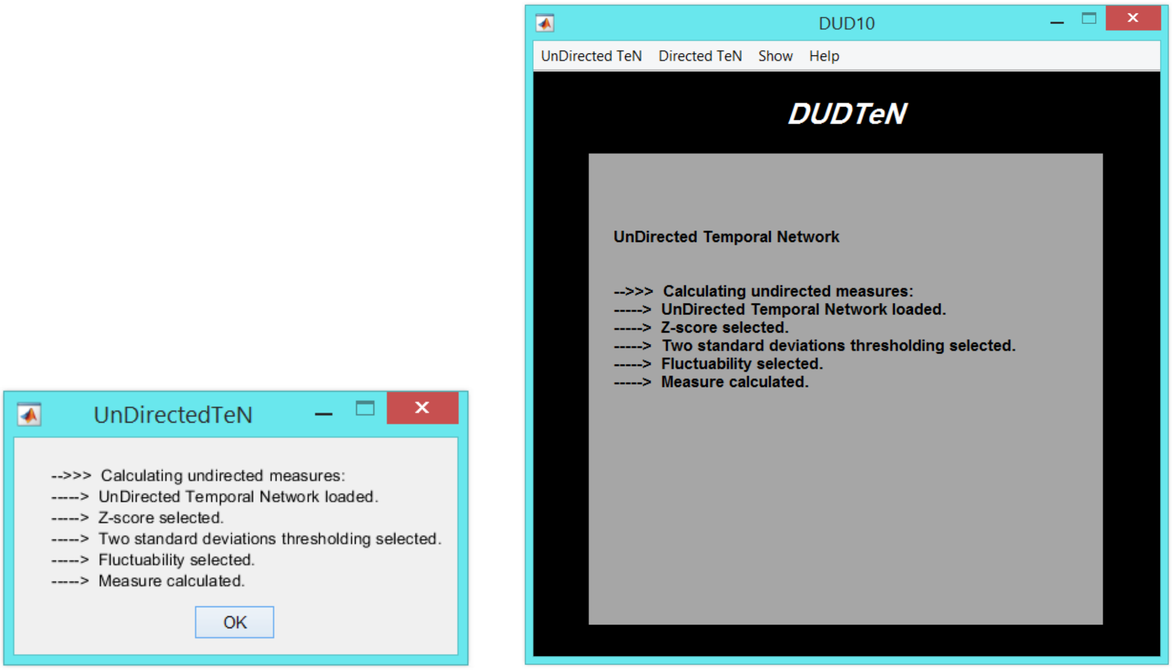


Fig. 20. When the run is complete, a message box opens (Left) and a message is shown in "DUDTeN" window (Right).

By pressing "Save" button, "Save Measure" window opens that I should select a name for saving the result. When the result is saved, a message presents in the "UnDirectedTeN" window (Fig. 21) and also in the "DUDTeN" window (Fig. 21) that expresses the result was saved.

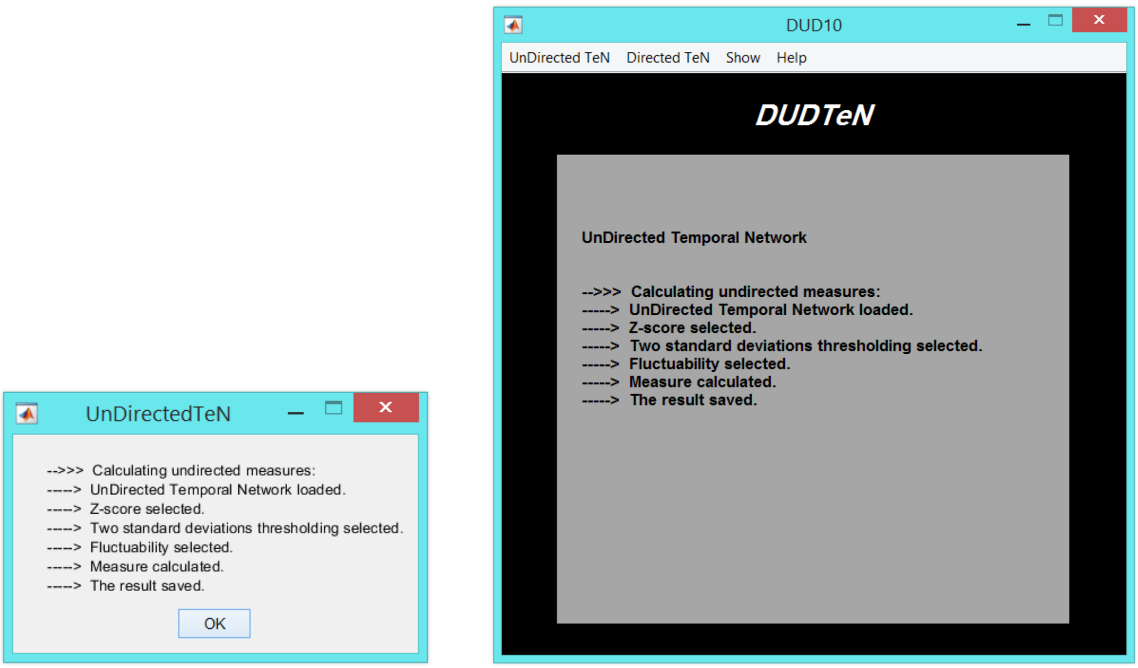


Fig. 21. When the result is saved, a message box opens (Left) and a message is shown in "DUDTeN" window (Right).

I also press "Show" button to illustrate the result. So, the "Show" window opens and the value of Global Fluctuability display in the table (Fig. 22).

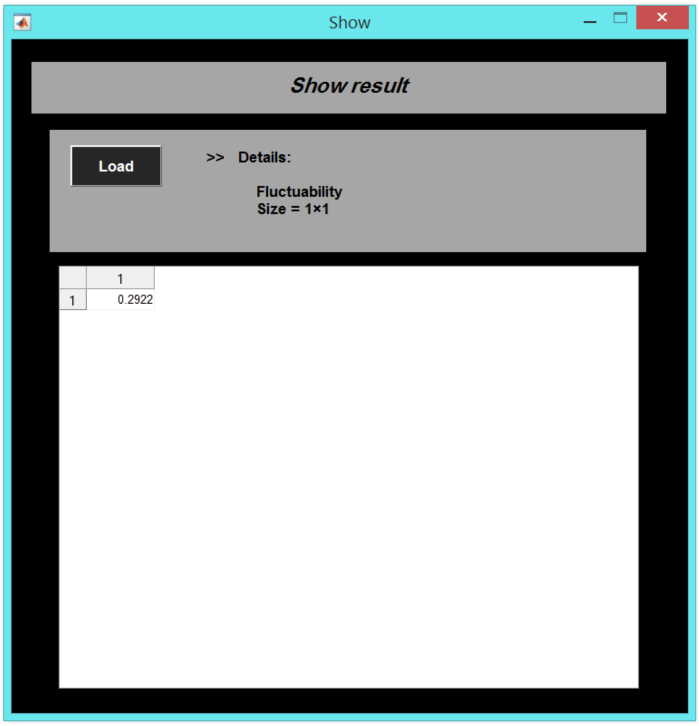


Fig. 22. The value of Global Fluctuability is displayed in the table.

To calculate the Weighted Temporal Degree Centrality, because I loaded the data, I only change the options (disable previous option and select the new). In the *Thresholding – variance based* section, I disable "2SD" and choose "None". In the *Binary Measures* section, I disable "Fluctuability", then in the *Weighted Measures* section, I choose "Weighted Temporal Degree Centrality" (Fig. 23).

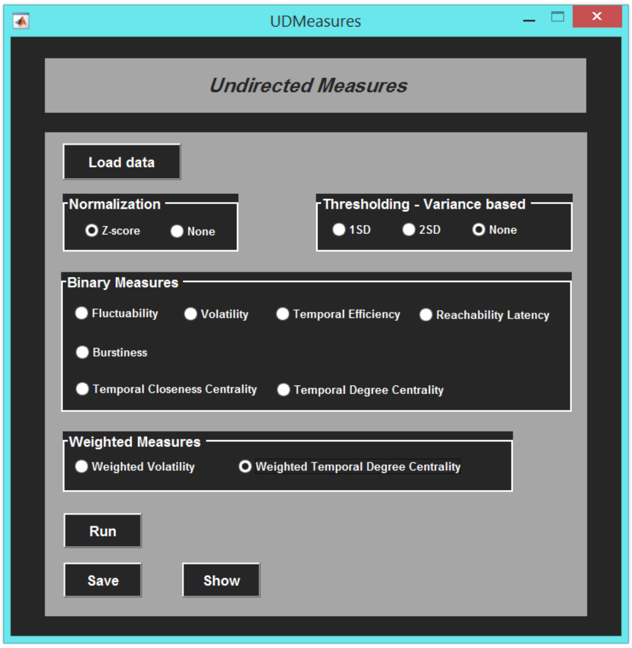


Fig. 23. The selected options.

Finally, I press the “Run” button (Fig. 24). A numeric column vector is created. I press “Save” button for saving the result.

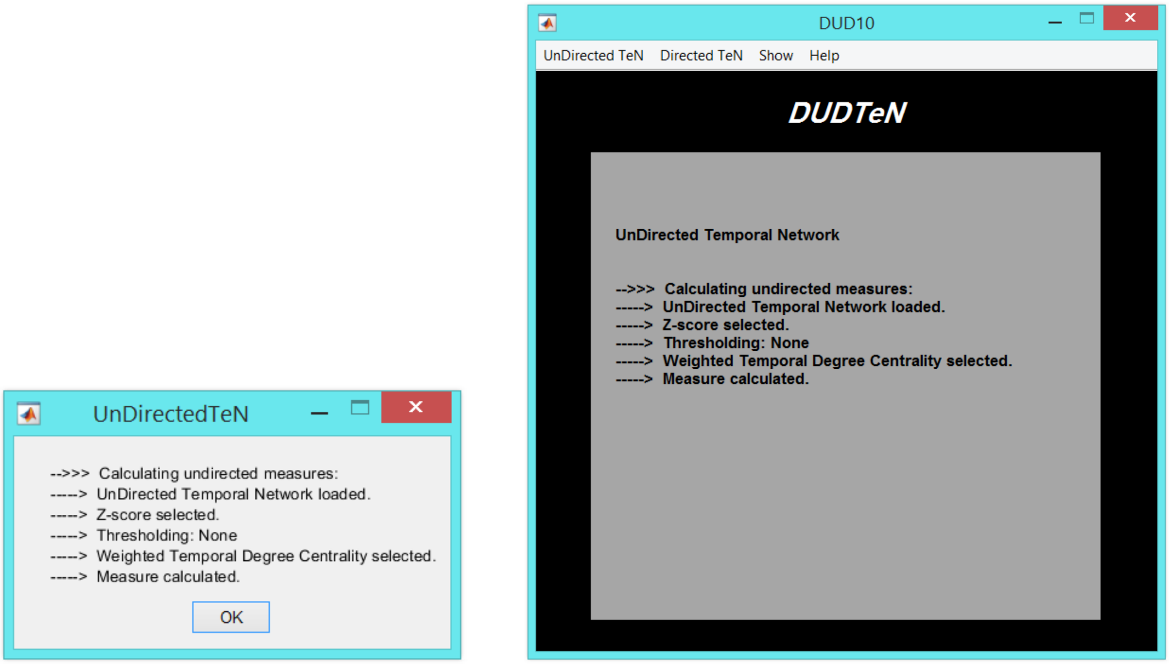


Fig. 24. When the run is complete, a message box opens (Left) and a message is shown in “DUDTeN” window (Right).

I also press “Show” button to illustrate the result. So, the “Show” window opens and the values of Weighted Temporal Degree Centrality display in the table (Fig. 25).

Fig. 25. The values of Weighted Temporal Degree Centrality is displayed in the table.

8. References

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