A Tutorial for Time Series Classification Utility (TSCU)

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Time Series Classification Utility (TSCU) is a collection of MATLAB® and C functions written to create an easy to use framework for classification of time series. If you have a collection of time series that needs to be classified, then continue reading this tutorial.

- Author : Huseyin Kaya
- Website: http://timewarping.org
- Sources: https://github.com/hkayabilisim/TSCU

Installation

TSCU is written in MATLAB®, so there is no setup; just download the package and run from MATLAB® Command Window. The complete package is available for free from GitHub. You have these two options:

Option 1 Use Download ZIP option to download the package in a zip file. If you choose this way you have to download the whole package to obtain the most current version of the utility.

Option 2 Another option is to use a command line to fetch the git repository. In this way, it is easy to update the package by using suitable `git` options. To check out the repository you can use the following command. If you don't have git on your command line, then you should install to the operating system. For further information, please take a look at http://git-scm.com.

```
# git clone https://github.com/hkayabilisim/TSCU.git
```

In both methods, you will end up with a directory named TSCU. Open your MATLAB® Command Window, and go to the TSCU/src directory. Now you are ready to run TSCU. But please be patient. Just read this tutorial and follow the step by step instructions.

Compiling MEX functions

In the **TSCU/src** directory, you will see some MEX functions and their precompiled versions for Windows XP SP3 and Mac OS X. If someshow you need to compile it again, than you should issue the following commands. If everything goes smoothly, then you will see the compiled mex files on the same directory. If not, you need to configure MEX. A good starting point is here.

```
mex tscu_saga_register.c tscu_saga_util.c
```

```
mex tscu_saga_warp.c     tscu_saga_util.c
mex tscu_dtw.c
```

```
Building with 'Xcode with Clang'.
MEX completed successfully.
Building with 'Xcode with Clang'.
MEX completed successfully.
Building with 'Xcode with Clang'.
MEX completed successfully.
```

Loading a time series dataset

For this tutorial we will use UCR time series repository which contains more than 40 different datasets. You can send an e-mail to Dr. Keogh to download all of them. For the time being, we will use the only one available for public access: Synthetic Control Dataset. If you haven't already downloaded it, then go ahead and run the following commands to fetch the dataset into the MATLAB workspace.

```
ucr_address='http://www.cs.ucr.edu/~eamonn/time_series_data';
trnfile='synthetic_control_TRAIN';
tstfile='synthetic_control_TEST';
urlwrite([ucr_address '/' trnfile],trnfile);
urlwrite([ucr_address '/' tstfile],tstfile);
trn=load(trnfile);
tst=load(tstfile);
```

Before going on to the next steps, let me explain the meanings of the above commands. By using urlwrite functions, you fetch the remote files and save to the current directory. Then you load it with the load command. Synthetic Control Dataset has two parts, training and testing, so we are downloading both of them.

Dataset format

The format of the dataset is very simple.

```
<label_1> <x1_1> <x1_2> ... <x1_n>
<label_2> <x2_1> <x2_2> ... <x2_n>
...
<label_m> <xm_1> <xm_2> ... <xm_n>
```

Every line corresponds to a single time series. The first column is used to store the class labels. So the length of time series is the number of columns minus 1. It will be same for testing set since the length of all time series in a repository is constant.

```
n = size(trn,2)-1;
fprintf('The length of time series: %d\n',n);
```

```
The length of time series: 60
```

You can find the number of time series in each set by counting the number of rows. In this dataset, each set has 300 time series. But in general they are not required to be equal.

```
trnsize = size(trn,1);
tstsize = size(tst,1);
fprintf('The number of time series in traning: %d\n',trnsize);
fprintf('The number of time series in testing: %d\n',tstsize);
```

```
The number of time series in traning: 300
The number of time series in testing: 300
```

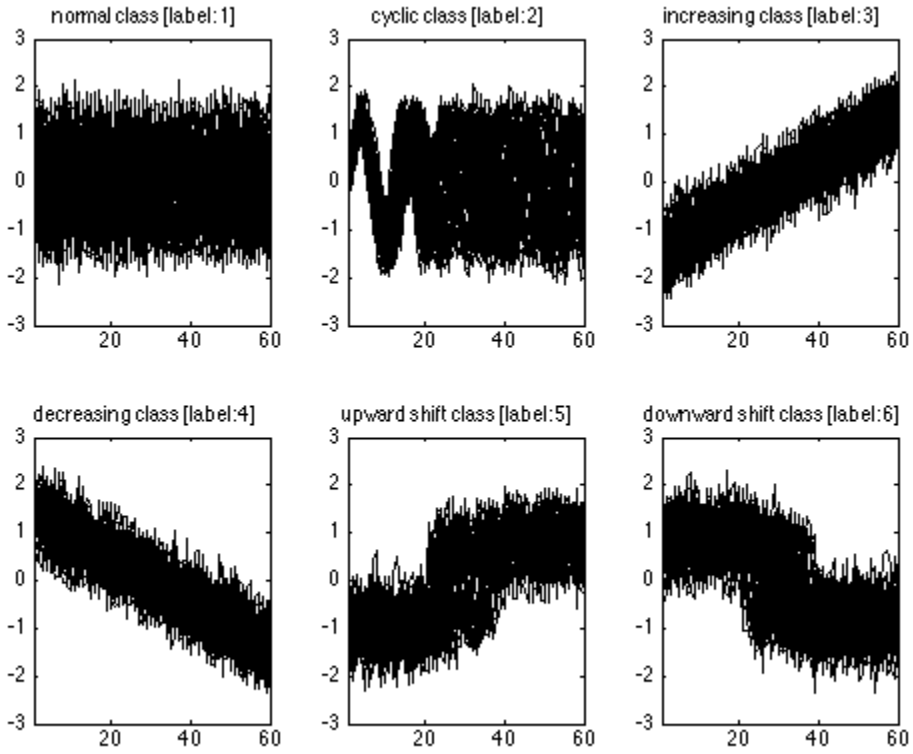
Now lets find out the class labels. As I said before, the class labels are in the first column. You can determine the class labels by using unique. In this dataset, there are 6 different class labels: 1,2,3,4,5 and 6.

```
labels=unique(trn(:,1));
fprintf('The unique labels: %s\n',num2str(labels','%2d'));
```

```
The unique labels: 1 2 3 4 5 6
```

If you are curious and want to see at least one of the time series, than you can always use plot function. Here I will plot all of the time series in the training set. I know that there are 6 classes in this dataset, So I will use a 2x3 subplot figure. For each class I find the time series belonging to that class by using `trn(:,1)==i`. Here I use the first column because it contains the labels. Then I plot the time series starting from the second column to the end. You can see the class names on top of each plot. As you see, the class names are self-explaining.

```
figure
classnames={'normal'    ,'cyclic',      'increasing',...
            'decreasing','upward shift','downward shift'};
for i=1:6
    subplot(2,3,i);
    plot(trn(trn(:,1)==i,2:end)','k');
    xlim([1 n]);
    box on;
    title(sprintf('%s class [label:%d]',classnames{i},i));
end
```



Classification with default setttings

We have a time series dataset, so we are ready to do a classification by using the default settings. This is very simple, just run the function tscu by giving training and testings sets in the arguments. In order to use this function, you have to be in the **TSCU/src** directory or the directory **TSCU/src** should be on your path. Here, I assume you are in **TSCU/src** directory.

```
tscu(trn,tst);
```

```
Size of training set.....................: 300
Size of testing set......................: 300
Time series length.......................: 60
Classification method....................: K-NN
Alignment method.........................: NONE
Displaying input data....................: no
No cross validation is chosen............: 0
Displaying alignments....................: none
Dumping distance matrix..................: no
Class information........................: 1 [TRN: 50 TST: 50]
Class information........................: 2 [TRN: 50 TST: 50]
Class information........................: 3 [TRN: 50 TST: 50]
Class information........................: 4 [TRN: 50 TST: 50]
Class information........................: 5 [TRN: 50 TST: 50]
Class information........................: 6 [TRN: 50 TST: 50]
Overall Accuracy.........................: 0.880
Overall Error............................: 0.120
Producer Accuracy........................: 0.440   1.000   0.980   1.000   0.940   0.920
User Accuracy............................: 1.000   0.833   0.891   0.862   0.887   0.885
Kappa....................................: 0.856
Z-value..................................: 5.439
Confusion matrix.........................:
Confusion matrix
          1     2     3     4     5     6    UA    TO
    1    22     0     0     0     0     0 1.000    22
    2    10    50     0     0     0     0 0.833    60
    3     3     0    49     0     3     0 0.891    55
    4     4     0     0    50     0     4 0.862    58
    5     5     0     1     0    47     0 0.887    53
    6     6     0     0     0     0    46 0.885    52
   PA 0.440 1.000 0.980 1.000 0.940 0.920
   TO    50    50    50    50    50    50         300

Classification time (sec)................: 10.47
The end of TSCU..........................: FINISHED
```

If you see an output similar to the above, then you are in a right track. By default TSCU provides several information lines explaining what is going on during classification. Here I like to explain some of them.

Size of training/testing set: It is good to know the size of the dataset. For example, if it is too big, then I may decide to use parallel programming feature.

Time series length: It is same for all time series in a repository. Actually, the classification and alignment algorithms in TSCU can deal with varying time series length. But the convention in UCR repository is to keep it fixed.

Classification method: By default, 1-nearest neighbor algorithm is used. Another option is to use Support Vector Machine (SVM) which will be explained in later sections.

Alignment method: Here you see **NONE** which is equivalent to say there is no alignment between time series. Other options are **DTW**, **CDTW**, **SAGA** and **CREG** which will be explained later.

Displaying input data: Sometimes you may need to display the input data to better understand the dataset or put in a document or whatever.

Class information: Displays the distribution of time series in the training and testing sets.

Overall Accuracy: This is perhaps the most important output of TSCU. Here you may want to see a number close to to 1. In this example it is 0.88 (88%). In the output, there are other performance evaluation metrics which I will cover later.

Using Dynamic Time Warping

We know that, correcting time shifts between time series increases the performance of time series classification. Dynamic Time Warping (**DTW**) is the most well known alignment method in the literature. Can we increase the overall accuracy if we use DTW? Let's use the option *Alignment* and see what happens.

If you see an error message similar to the below, than you need to compile MEX files. Please consult to the Installation section in the beginning of this tutorial.

```
        Undefined function 'tscu_dtw' for input arguments of type 'double'.
```

```
tscu(trn,tst,'Alignment','DTW');
```

```
        Size of training set.....................: 300
        Size of testing set......................: 300
        Time series length.......................: 60
        Classification method....................: K-NN
        Alignment method.........................: DTW
        Displaying input data....................: no
        No cross validation is chosen............: 0
        Displaying alignments....................: none
        Dumping distance matrix..................: no
        Class information........................: 1 [TRN: 50 TST: 50]
        Class information........................: 2 [TRN: 50 TST: 50]
        Class information........................: 3 [TRN: 50 TST: 50]
        Class information........................: 4 [TRN: 50 TST: 50]
        Class information........................: 5 [TRN: 50 TST: 50]
        Class information........................: 6 [TRN: 50 TST: 50]
        Overall Accuracy.........................: 0.993
        Overall Error............................: 0.007
        Producer Accuracy........................: 0.960   1.000   1.000   1.000
        User Accuracy............................: 1.000   0.980   1.000   1.000
        Kappa....................................: 0.992
        Z-value..................................: 24.884
        Confusion matrix.........................:
        Confusion matrix
                  1     2     3     4     5     6    UA    TO
            1    48     0     0     0     0     0 1.000    48
```

```
   2     1    50     0     0     0     0 0.980    51
   3     0     0    50     0     0     0 1.000    50
   4     0     0     0    50     0     0 1.000    50
   5     1     0     0     0    50     0 0.980    51
   6     0     0     0     0     0    50 1.000    50
  PA 0.960 1.000 1.000 1.000 1.000 1.000
  TO    50    50    50    50    50    50          300

Classification time (sec).............: 16.22
The end of TSCU.......................: FINISHED
```

As you see, the overall accuracy is increased to 99.3%. This is an important improvement in the classification. Let's take a closer look at confusion matrices. If you sum the off-diagonal elements of a confusion matrix, you can obtain the number of misclassification. In case of **DTW** it is only 2. Whereas the number of misclassifications in the previous case (no alignment) was 36. By looking at this dramatic change, we can say that, using an alignment method improves classification performance.

On the other hand DTW is a bit slower than previos case (no alignment) if you look at the classification times. This is understandable as DTW requires more calculations than measuring standard Euclidean distance.

Using Constrained Dynamic Time Warping

This time I changed alignment method and used Constrained Dynamic Time Warping (CDTW). This is achieved by changing `DTW` with `CDTW`. You can also append additional options to the tscu function. For example you can make TSCU to display the input data by using `DisplayInputData` option. It will plot all training and testing data grouped into class labels. So you will see 6 figures iwhich has two subplots in each.

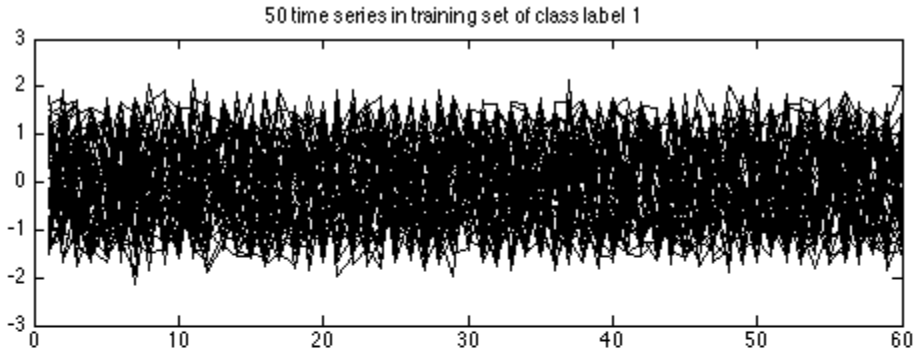
The overall accuracy, when CDTW is used, is dropped to 98.7% but it is not a significant decrease. The number of misclassifications is only 4. So again we see a dramatic gain by using another alignment algorithm.

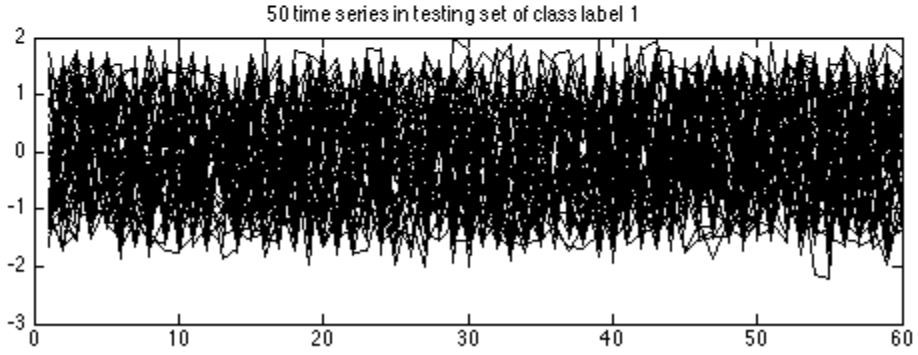
In the output, you should see a line containing *DTW band width*. The band width here refers to the width of the diagonal band in the distance matrix of two time series. CDTW is `constrained` because it is not allowed to work outside of this band. It is defined in percentage because the length of time series can vary widely between datasets. TSCU uses the default value of 6%. Other than the constraining band, CDTW is identical to DTW.

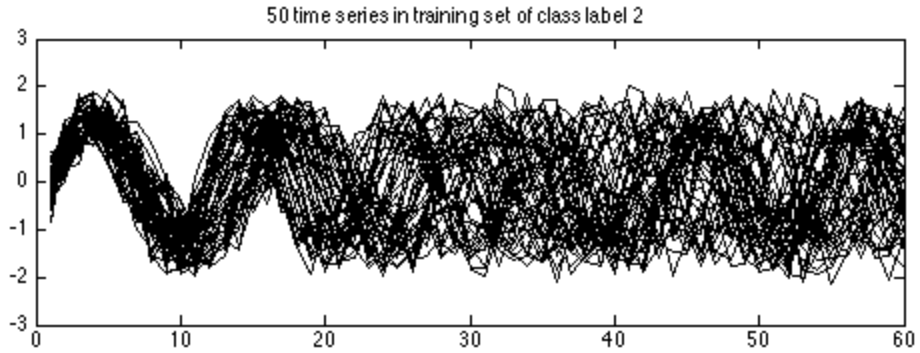
```
tscu(trn,tst,'Alignment','CDTW','DisplayInputData','yes');
```

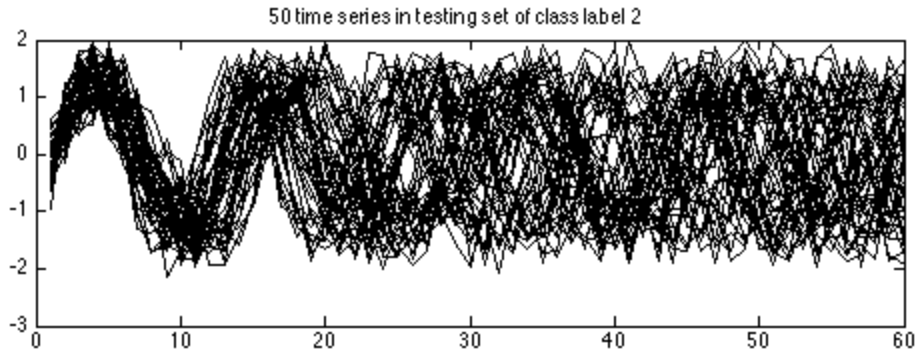
```
Size of training set..................: 300
Size of testing set...................: 300
Time series length....................: 60
Classification method.................: K-NN
Alignment method......................: CDTW
Displaying input data.................: yes
No cross validation is chosen.........: 0
DTW band width (%)....................:  6.00
Displaying alignments.................: none
Dumping distance matrix...............: no
Class information.....................: 1 [TRN: 50 TST: 50]
Class information.....................: 2 [TRN: 50 TST: 50]
```

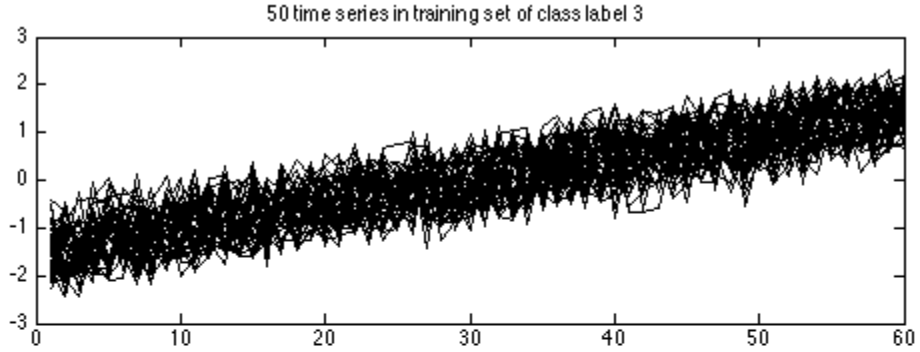
```
Class information.....................: 3 [TRN: 50 TST: 50]

Class information.....................: 4 [TRN: 50 TST: 50]
Class information.....................: 5 [TRN: 50 TST: 50]
Class information.....................: 6 [TRN: 50 TST: 50]
Overall Accuracy......................: 0.987
Overall Error.........................: 0.013
Producer Accuracy.....................: 0.960   1.000   1.000   1.000
User Accuracy.........................: 1.000   0.962   1.000   0.962
Kappa.................................: 0.984
Z-value...............................: 17.514
Confusion matrix......................:
Confusion matrix
          1     2     3     4     5     6    UA    TO
    1    48     0     0     0     0     0 1.000    48
    2     2    50     0     0     0     0 0.962    52
    3     0     0    50     0     0     0 1.000    50
    4     0     0     0    50     0     2 0.962    52
    5     0     0     0     0    50     0 1.000    50
    6     0     0     0     0     0    48 1.000    48
   PA 0.960 1.000 1.000 1.000 1.000 0.960
   TO    50    50    50    50    50    50         300

Classification time (sec).............: 14.17
The end of TSCU.......................: FINISHED
```

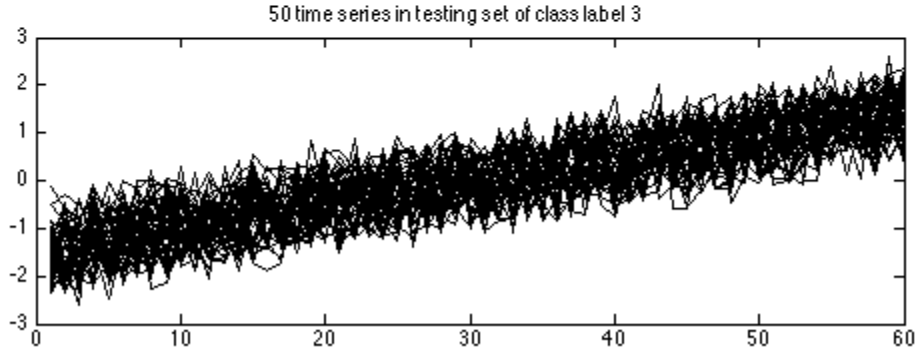


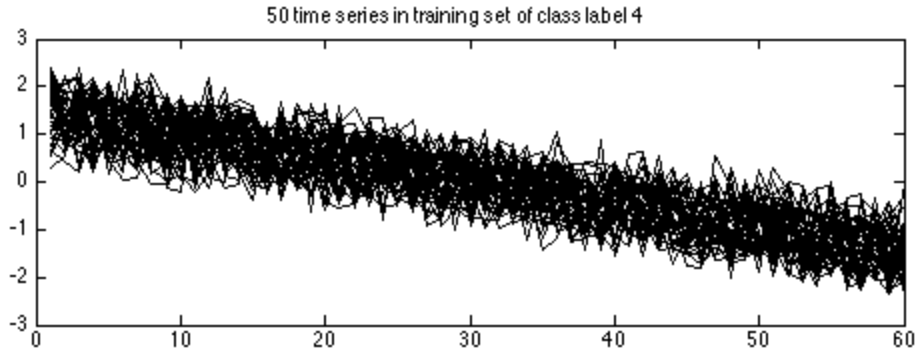


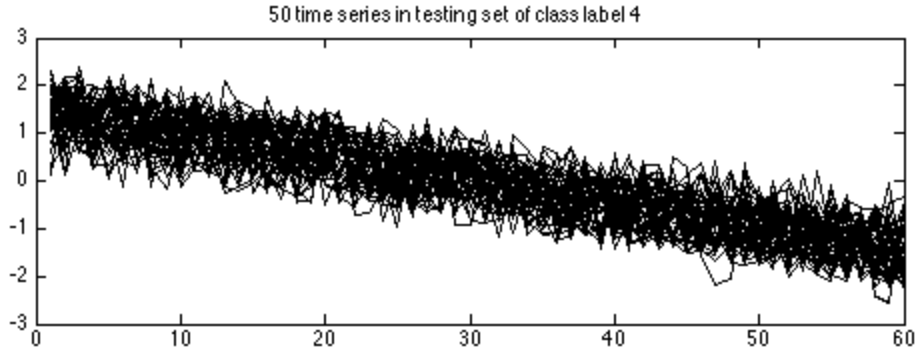

50 time series in training set of class label 2
3
2
1
0
-1
-2
-3
0
10
20
30
40
50
60

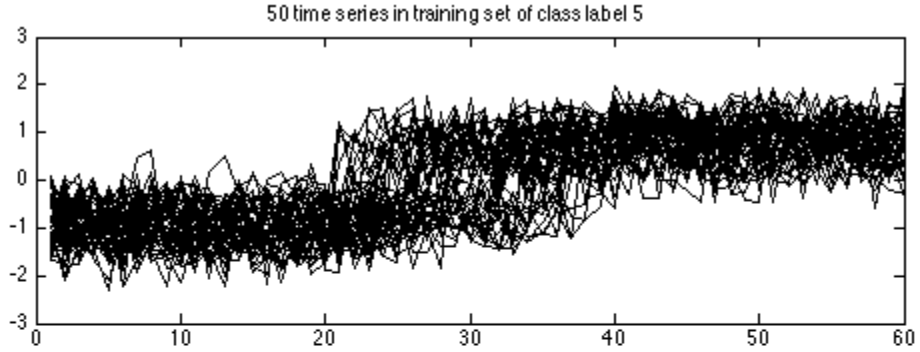

50 time series in testing set of class label 2
2
1
0
-1
-2
-3
0
10
20
30
40
50
60

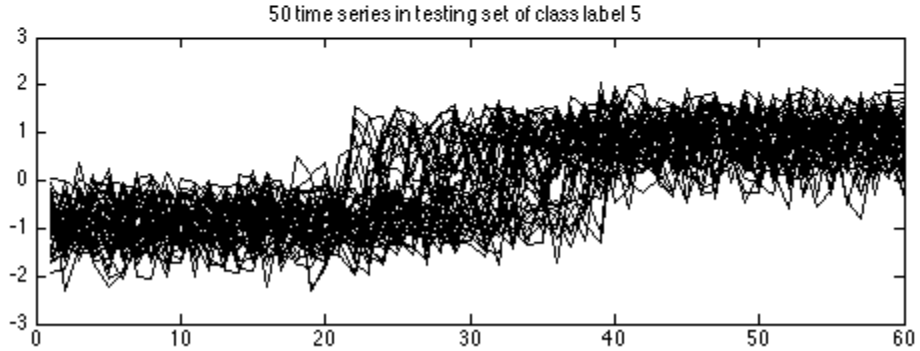

50 time series in training set of class label 3
3
2
1
0
-1
-2
-3
0
10
20
30
40
50
60

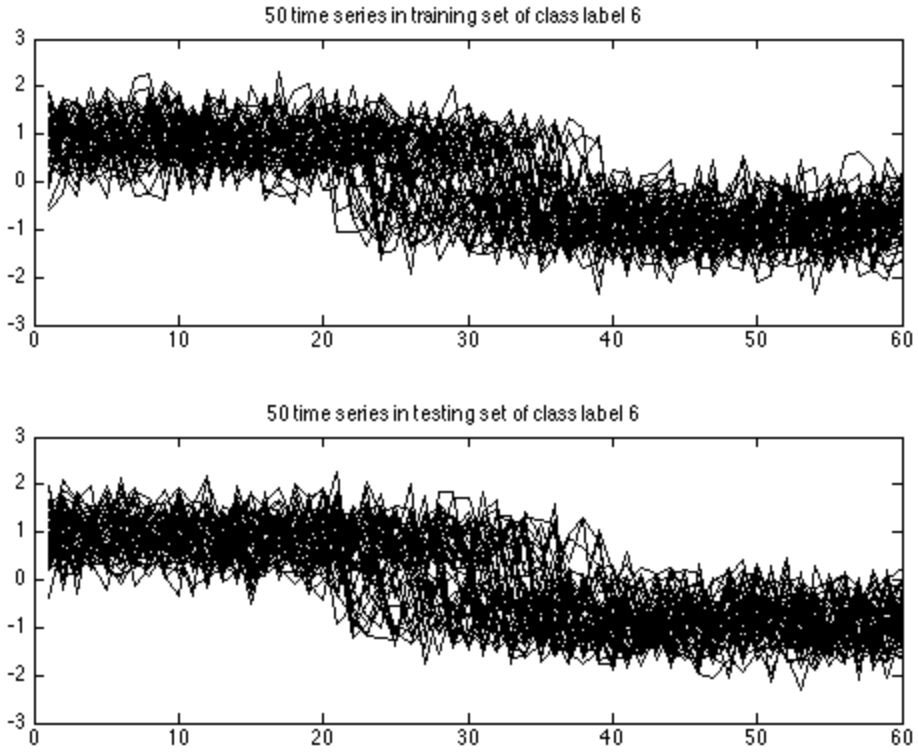

50 time series in testing set of class label 3
3
2
1
0
-1
-2
-3
0
10
20
30
40
50
60


50 time series in training set of class label 4
3
2
1
0
-1
-2
-3
0
10
20
30
40
50
60


50 time series in testing set of class label 4
3
2
1
0
-1
-2
-3
0
10
20
30
40
50
60


50 time series in training set of class label 5
3
2
1
0
-1
-2
-3
0
10
20
30
40
50
60


50 time series in testing set of class label 5
3
2
1
0
-1
-2
-3
0
10
20
30
40
50
60



Changing band width in CDTW

You can change the band width used in Constrained Dynamic Time Warping (CDTW) by using `DTWbandwidth` option. Here I will set it to 100% which is equivalent to using DTW. But this time, I want to get rid of information messages. To do this, you can use `LogLevel` option. By setting it to `Alert`, you won't get `Info` messages which is the default for `LogLevel`. We prevented the info messages, but how will I know the results? You should assign the output to a variable. The output variable is simply a structure containing all the information. Now let's run it. You should obtain the same accuracy as DTW: 99.3%.

```
out=tscu(trn,tst,'Alignment','CDTW','LogLevel','Alert','DTWbandwidth',100);
fprintf('Overall accuracy : %8.3f\n',out.perf.OA);
```

```
        Overall accuracy :    0.993
```

Displaying alignments

In time series classification, a distance calculation between any two time series requires an alignment. Depending on the size of the dataset, the number of alignments could be millions. In our Synthetic Control Dataset case, there are 300 time series in each training and testing sets. The default classification algorithm is 1-NN, so there will be 300x300=90000 distance calculations. This means that 90000 different alignments will take place.

In some cases, you may want to analyze a specific alignment. For instance you may want to display the warping functions of your alignment method. Whatever the reason, you can display a specific alignment by using `DisplayAlignment` option. But you should define which time series do you want. For this we

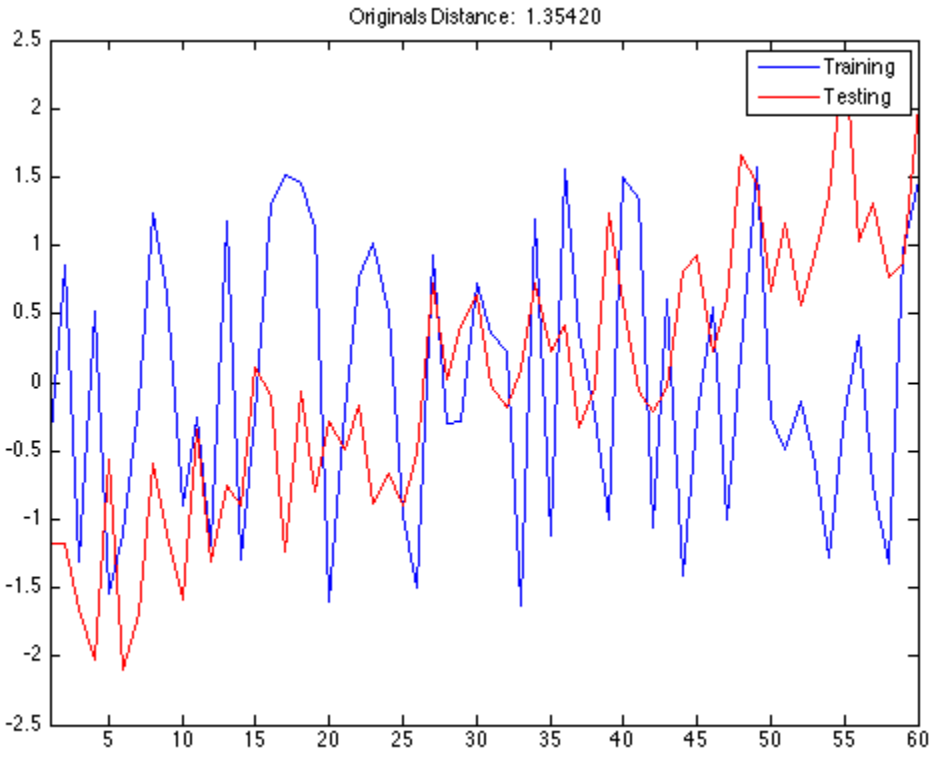
use a cell with elements. In the first element you should give the indexes of time series in the training set as an array. Likewise in the second array, you specify the indexes of time series in the testing set. I should give an example. Let's say I want to display the alignment between the 42nd time series in the training set and the 142nd element in the testing set, then I should use the following cell.

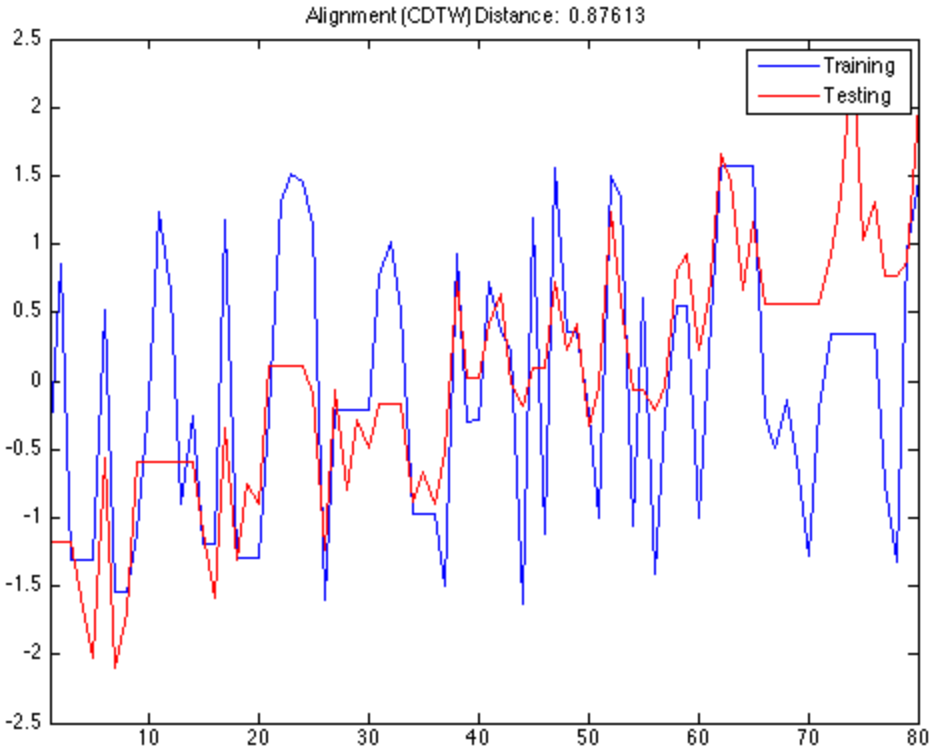
```
{[42],[142]}
```

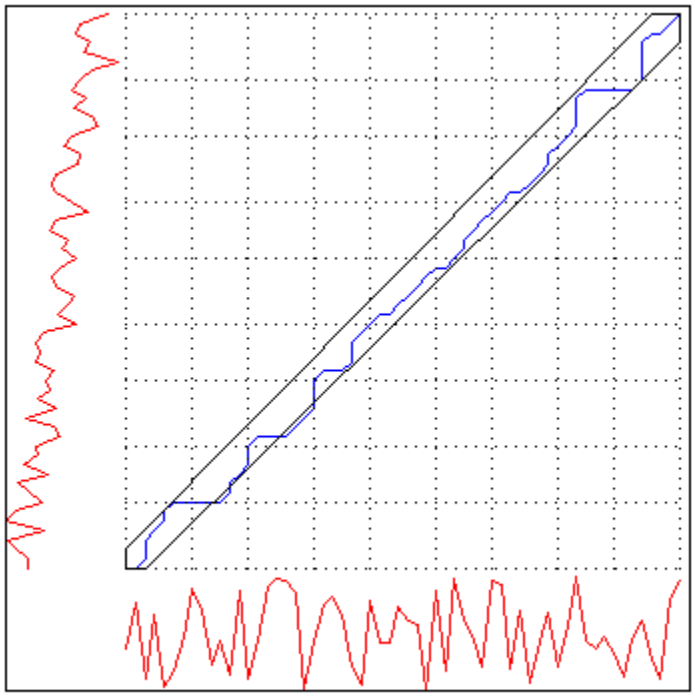
Let's try it. A side note here: as you use more and more options, you can wrap the lines by using `...`. I still don't want to see the info messages. So I used a proper log level. Running this command, you will obtain four figures:

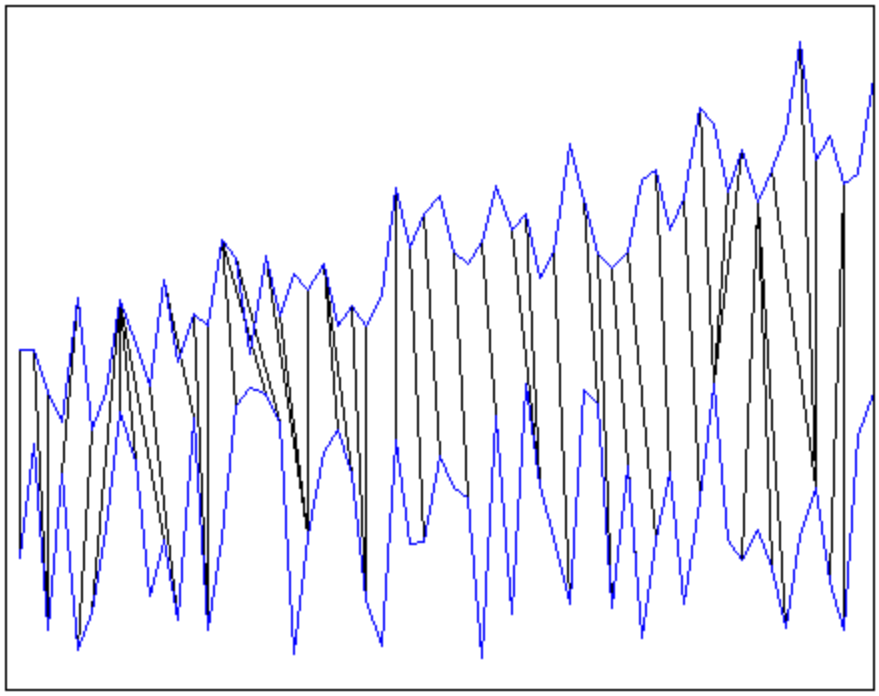
- original signals
- aligned signals
- warping between the time series
- mapping between the time series

```
tscu(trn,tst,'Alignment','CDTW','LogLevel','Alert',...
    'DisplayAlignment',{42,142});
```




Alignment (CDTW) Distance: 0.87613
Training
Testing
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
10
20
30
40
50
60
70
80





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