

```

%Simulate data - Node 3 gives common input to the other nodes (nodes 1 and 2) at a time delay of 1 and 2 samples

cfg
    = [];
cfg.method
    = 'ar';
cfg.ntrials
    = 200;
cfg.triallength
    = 1;
cfg.fsamples
    = 200;
cfg.nsignals
    = 3;
cfg.params(:, :, 1)
    = [0.55    0        0.25;
        0      0.55    0.25;
        0      0      0.55]; %off-diagonal entries simulate 3->1 and 3->2 influence at the first time delay
cfg.params(:, :, 2)
    = [-0.8    0        -0.1;
        0     -0.8     -0.1;
        0      0      -0.8]; %off-diagonal entries simulate 3->1 and 3->2 influence at the second time delay
cfg.noisecov
    = [1 0 0;
        0 1 0;
        0 0 1];

data = ft_connectivitysimulation(cfg);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Calculate power, coherence, and Granger causality based on parametric and
%non-parametric estimates as in Figure 9 b and c

%calculate the fourier coefficients (non-parametric derivation of power)
cfg
    = [];
cfg.method
    = 'mtmfft';
cfg.taper
    = 'dpss';
cfg.output
    = 'fourier';
cfg.tapsmofrq
    = 3;
cfg.foylim
    = [0 100];
freq
    = ft_freqanalysis(cfg, data);

%freqdescriptives calculates the power spectrum
cfg
    = [];
fd
    = ft_freqdescriptives(cfg, freq);

%Parametric (auto-regressive model based) derivation of AR coefficients
%multivariate analysis will compute the auto-regressive coefficients and associated noise covariance matrix

```

```

cfg          = [];
cfg.order    = 2; %model order of 2, this is known a priori (we simulated the data using a model order of 2)
mdata        = ft_mvaranalysis(cfg, data);

%calculate cross-spectral density and transfer functions associated with the auto-regressive model
cfg          = [];
cfg.method   = 'mvar';
cfg.foi      = [0:100];
mfreq        = ft_freqanalysis(cfg, mdata);

%Phase-slope index calculation
cfg          = [];
cfg.method   = 'psi';
cfg.bandwidth = 4;
psi1 = ft_connectivityanalysis(cfg, freq);

%Coherence calculation
cfg          = [];
cfg.method   = 'coh';
cfg.complex  = 'abs';
coh1 = ft_connectivityanalysis(cfg, freq);
coh2 = ft_connectivityanalysis(cfg, mfreq);

%Imaginary part of coherency
cfg          = [];
cfg.method   = 'coh';
cfg.complex  = 'imag';
icoh1 = ft_connectivityanalysis(cfg, freq);

%Partial coherence calculation
cfg          = [];
cfg.method   = 'coh';
cfg.partchannel = 'signal003';
cfg.complex  = 'abs';
pcoh1 = ft_connectivityanalysis(cfg, freq);

%Granger causality calculation
cfg          = [];
cfg.method   = 'granger';
cfg.granger.sfmeth = 'multivariate';
g1 = ft_connectivityanalysis(cfg, freq);

```

```

g1 = ft_checkdata(g1, 'cmbrepresentation', 'full');
g2 = ft_connectivityanalysis(cfg, mfreq);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%now plot the output for the various connectivity measures as in Figure 9 b and c
%output variables 1 - nonparam 2 - param

figure;plot(fd.freq, fd.powspectrum(1,:)); hold on
plot(fd.freq, fd.powspectrum(2,:), 'r');
plot(fd.freq, fd.powspectrum(3,:), 'k');
legend('Power ch 1', 'Power ch 2', 'Power ch 3');
title('Nonparametric Power');

figure;plot(mfreq.freq, squeeze(abs(mfreq.crsspctrm(1,1,:)))); hold on;
plot(mfreq.freq, squeeze(abs(mfreq.crsspctrm(2,2,:)), 'r');
plot(mfreq.freq, squeeze(abs(mfreq.crsspctrm(3,3,:)), 'k');
legend('Power ch 1', 'Power ch 2', 'Power ch 3');
title('Parametric Power');

figure;plot(g1.freq, squeeze(coh1.cohspctrm(1,2,:)); hold on;
plot(g1.freq, squeeze(coh1.cohspctrm(1,3,:), 'r');
plot(g1.freq, squeeze(coh1.cohspctrm(2,3,:), 'k');
plot(g1.freq, squeeze(abs(icoh1.cohspctrm(1,2,:)), 'g');
plot(g1.freq, squeeze(pcoh1.cohspctrm(1,2,:), 'm');
legend('1-2', '1-3', '2-3', '1-2 imaginary', '1-2 | 3');
title('Nonparametric Coherence spectrum');

figure;plot(g1.freq, squeeze(coh2.cohspctrm(1,2,:)); hold on
plot(g1.freq, squeeze(coh2.cohspctrm(1,3,:), 'r');
plot(g1.freq, squeeze(coh2.cohspctrm(2,3,:), 'k');
legend('1-2', '1-3', '2-3');
title('Parametric Coherence spectrum');

figure;plot(g1.freq, squeeze(psi1.psispectrum(1,2,:)); hold on;
plot(g1.freq, squeeze(psi1.psispectrum(1,3,:), 'r');
plot(g1.freq, squeeze(psi1.psispectrum(2,3,:), 'k');
legend('1->2', '1->3', '3->2');title('PSI nonparametric');

figure;plot(g1.freq, squeeze(g1.grangerspectrum(1,2,:));hold on
plot(g1.freq, squeeze(g1.grangerspectrum(2,1,:), 'r');
plot(g1.freq, squeeze(g1.grangerspectrum(3,1,:), 'k');

```

```

plot(g1.freq,squeeze(g1.grangerspctrm(3,2,:)), 'g');
plot(g1.freq,squeeze(g1.grangerspctrm(1,3,:)), 'c');
plot(g1.freq,squeeze(g1.grangerspctrm(2,3,:)), 'y');
title('Granger nonparametric estimates');legend('1->2','2->1','3->1','3->2','1->3','2->3')

figure; plot(g1.freq,squeeze(g2.grangerspctrm(1,2,:)));hold on;
plot(g1.freq,squeeze(g2.grangerspctrm(2,1,:)), 'r');
plot(g1.freq,squeeze(g2.grangerspctrm(3,1,:)), 'k');
plot(g1.freq,squeeze(g2.grangerspctrm(3,2,:)), 'g');
plot(g1.freq,squeeze(g2.grangerspctrm(1,3,:)), 'c');
plot(g1.freq,squeeze(g2.grangerspctrm(2,3,:)), 'y');
legend('1->2','2->1','3->1','3->2','1->3','2->3');title('Granger parametric estimates ');

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Simulate the case time-lagged common input (Figure 9 D-I)
%Node 3 gives common input to the other nodes (nodes 1 and 2) at a time delay of 1 and 2 samples
cfg          = [];
cfg.method    = 'ar';
cfg.ntrials   = 500;
cfg.triallength = 1;
cfg.fsamples  = 200;
cfg.nsignals  = 3;
%Auto-regressive coefficients at time lag 1
cfg.params(:, :, 1) = [0.55  0      0.25;
                      0      0.55  0;
                      0      0      0.55]; %off-diagonal entry simulates 3->1 at the first time delay
%Auto-regressive coefficients at time lag 2
cfg.params(:, :, 2) = [-0.8  0      0;
                      0      -0.8  -0.1;
                      0      0      -0.8]; %off-diagonal simulates 3->2 at the second time delay

cfg.noisecov = [1 0 0;
               0 1 0;
               0 0 1];

cfg.absnoise = 0;

data = ft_connectivitysimulation(cfg);

%Remove the third node from the data to simulate a situation where we do
%not observe the source of common input (Figure 9 D-F)
cfg      = [];
cfg.channel = data.label(1:2);

```

```

data          = ft_selectdata(cfg, data);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Calculate power, coherence, and Granger causality based on parametric and
%non-parametric estimates

%calculate the fourier coefficients (non-parametric derivation of power)
cfg          = [];
cfg.method    = 'mtmfft';
cfg.taper     = 'dpss';
cfg.output    = 'fourier';
cfg.tapsmofrq = 3;
cfg.foilim    = [0 100];
freq         = ft_freqanalysis(cfg, data);

%freqdescriptives calculates the power spectrum
fd           = ft_freqdescriptives([], freq);

%Phase-slope index calculation
cfg          = [];
cfg.method    = 'psi';
cfg.bandwidth = 4;
psi1 = ft_connectivityanalysis(cfg, freq);

%Coherence calculation
cfg          = [];
cfg.method    = 'coh';
cfg.complex    = 'abs';
coh1 = ft_connectivityanalysis(cfg, freq);

%Imaginary part of coherency
cfg          = [];
cfg.method    = 'coh';
cfg.complex    = 'imag';
icoh1 = ft_connectivityanalysis(cfg, freq);

%Granger causality calculation (bivariate)
cfg          = [];
cfg.method    = 'granger';
cfg.sfmethode = 'bivariate';
g1 = ft_connectivityanalysis(cfg, freq);
g1 = ft_checkdata(g1, 'cmbrepresentation', 'full');

```

%%%

%Plot the output for the various connectivity measures:

```
figure;plot(fd.freq, fd.powspectrm(1,:)); hold on
plot(fd.freq, fd.powspectrm(2,:), 'r');
legend('Power ch 1', 'Power ch 2');
title('Nonparametric Power');
```

```
figure;plot(g1.freq, squeeze(coh1.cohspectrm(1,2,:))); hold on;
plot(g1.freq, squeeze(abs(icoh1.cohspectrm(1,2,:))), 'g');
legend('1-2', '1-2 imaginary');
title('Nonparametric Coherence spectrum');
```

```
figure;plot(g1.freq, squeeze(psi1.psispectrm(1,2,:))); hold on;
title('PSI nonparametric');
```

```
figure;plot(g1.freq, squeeze(g1.grangerspectrm(1,2,:)));hold on
plot(g1.freq, squeeze(g1.grangerspectrm(2,1,:)), 'r');
title('Granger nonparametric estimates ');legend('1->2', '2->1')
```

%%%

%Re-run the simulation, this time observing all three nodes as in Figure 9 G-I

```
cfg                = [];
cfg.method          = 'ar';
cfg.ntrials         = 200;
cfg.triallength     = 1;
cfg.fsampl          = 200;
cfg.nsignal         = 3;
cfg.params(:, :, 1) = [0.55    0        0.25;
                       0        0.55    0;
                       0        0        0.55]; %this simulates 3->1 at the first time delay
cfg.params(:, :, 2) = [-0.8    0        0;
                       0       -0.8    -0.1;
                       0        0     -0.8]; %this simulates 3->2 at the second time delay
cfg.noisecov        = [1 0 0;
                       0 1 0;
                       0 0 1];

data = ft_connectivitysimulation(cfg);
```

%%%

%Calculate power, coherence, and Granger causality based on non-parametric estimates

%calculate the fourier coefficients (non-parametric derivation of power)

```
cfg = [];  
cfg.method = 'mtmfft';  
cfg.taper = 'dpss';  
cfg.output = 'fourier';  
cfg.tapsmofrq = 3;  
cfg.foilim = [0 100];  
freq = ft_freqanalysis(cfg, data);
```

%freqdescriptives calculates the power spectrum

```
cfg = [];  
cfg.complex = 'complex';  
cfg.jackknife = 'yes';
```

```
fd = ft_freqdescriptives(cfg, freq);
```

```
ntrl = length(data.trial);  
nsmp = size(data.trial{1},2);  
data.cfg.trl = [1:nsmp:(ntrl-1)*nsmp+1;nsmp:nsmp:ntrl*nsmp]';  
data.cfg.trl(:,3) = 0;
```

```
cfg = [];  
cfg.t_ftimwin = 1;  
cfg.toi = 0.5;  
cfg.order = 2; %model order of 2, this is known a priori (we simulated the data using a model order of 2)  
mdata = ft_mvaranalysis(cfg, data);
```

%calculate cross-spectral density and transfer functions associated with the auto-regressive model

```
cfg = [];  
cfg.method = 'mvar';  
cfg.foi = [0:100];  
mfreq = ft_freqanalysis(cfg, mdata);
```

%Phase-slope index calculation

```
cfg = [];  
cfg.method = 'psi';  
cfg.bandwidth = 4;  
psi1 = ft_connectivityanalysis(cfg, freq);
```

%Coherence calculation

```

cfg          = [];
cfg.method    = 'coh';
cfg.complex   = 'abs';
coh1 = ft_connectivityanalysis(cfg, freq);
coh2 = ft_connectivityanalysis(cfg, mfreq);

```

%Partial coherence calculation

```

cfg          = [];
cfg.method    = 'coh';
cfg.partchannel = 'signal003';
cfg.complex   = 'abs';
pcoh1 = ft_connectivityanalysis(cfg, freq);

```

%Granger causality calculation

```

cfg          = [];
cfg.method    = 'granger';
cfg.granger.sfmethode = 'multivariate';
g1 = ft_connectivityanalysis(cfg, freq);
g1 = ft_checkdata(g1, 'cmbrepresentation', 'full');
g2 = ft_connectivityanalysis(cfg, mfreq);

```

```

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

```

%now plot the output for the various connectivity measures:

%out put variables 1 - nonparam 2 - param

```

figure;plot(fd.freq, fd.powspectrum(1,:)); hold on
plot(fd.freq, fd.powspectrum(2,:), 'r');
plot(fd.freq, fd.powspectrum(3,:), 'k');
legend('Power ch 1', 'Power ch 2', 'Power ch 3');
title('Nonparametric Power');

```

```

figure;plot(mfreq.freq, squeeze(abs(mfreq.crsspectrum(1,1,:)))); hold on;
plot(mfreq.freq, squeeze(abs(mfreq.crsspectrum(2,2,:))),'r');
plot(mfreq.freq, squeeze(abs(mfreq.crsspectrum(3,3,:))),'k');
legend('Power ch 1', 'Power ch 2', 'Power ch 3');
title('Parametric Power');

```

```

figure;plot(g1.freq, squeeze(coh1.cohspectrum(1,2,:))); hold on;
plot(g1.freq, squeeze(coh1.cohspectrum(1,3,:)),'r');

```



```

plot(g1.freq,squeeze(coh1.cohspctrm(2,3,:)), 'k');
plot(g1.freq,squeeze(pcoh1.cohspctrm(1,2,:)), 'm');
legend('1-2', '1-3', '2-3', '1-2 | 3');
title('Nonparametric Coherence spectrum');

figure;plot(g1.freq,squeeze(coh2.cohspctrm(1,2,:))); hold on
plot(g1.freq,squeeze(coh2.cohspctrm(1,3,:)), 'r');
plot(g1.freq,squeeze(coh2.cohspctrm(2,3,:)), 'k');
legend('1-2', '1-3', '2-3');
title('Parametric Coherence spectrum');

figure;plot(g1.freq,squeeze(psi1.psispctrm(1,2,:))); hold on;
plot(g1.freq,squeeze(psi1.psispctrm(1,3,:)), 'r');
plot(g1.freq,squeeze(psi1.psispctrm(2,3,:)), 'k');
legend('1->2', '1->3', '3->2');title('PSI nonparametric');

figure;plot(g1.freq,squeeze(g1.grangerspctrm(1,2,:)));hold on
plot(g1.freq,squeeze(g1.grangerspctrm(2,1,:)), 'r');
plot(g1.freq,squeeze(g1.grangerspctrm(3,1,:)), 'k');
plot(g1.freq,squeeze(g1.grangerspctrm(3,2,:)), 'g');
plot(g1.freq,squeeze(g1.grangerspctrm(1,3,:)), 'c');
plot(g1.freq,squeeze(g1.grangerspctrm(2,3,:)), 'y');
title('Granger nonparametric estimates');legend('1->2', '2->1', '3->1', '3->2', '1->3', '2->3')

figure; plot(g1.freq,squeeze(g2.grangerspctrm(1,2,:)));hold on;
plot(g1.freq,squeeze(g2.grangerspctrm(2,1,:)), 'r');
plot(g1.freq,squeeze(g2.grangerspctrm(3,1,:)), 'k');
plot(g1.freq,squeeze(g2.grangerspctrm(3,2,:)), 'g');
plot(g1.freq,squeeze(g2.grangerspctrm(1,3,:)), 'c');
plot(g1.freq,squeeze(g2.grangerspctrm(2,3,:)), 'y');
legend('1->2', '2->1', '3->1', '3->2', '1->3', '2->3');title('Granger parametric estimates ');

```

```

the call to "ft_connectivitysimulation" took 0 seconds
the input is raw data with 3 channels and 200 trials
Warning: the data does not contain a trial definition
Warning: reconstructing sampleinfo by assuming that the trials are consecutive
segments of a continuous recording
the call to "ft_selectdata" took 0 seconds
processing trials

```

processing trial 200/200 nfft: 200 samples, datalength: 200 samples, 5 tapers

the call to "ft_freqanalysis" took 1 seconds

the input is freq data with 3 channels, 101 frequencybins and no timebins

the call to "ft_selectdata" took 0 seconds

the call to "ft_freqdescriptives" took 0 seconds

Warning: the data does not contain a trial definition

Warning: reconstructing sampleinfo by assuming that the trials are consecutive segments of a continuous recording

the call to "ft_selectdata" took 0 seconds

preprocessing

preprocessing trial 200 from 200

the call to "ft_preprocessing" took 0 seconds

the call to "ft_redefinetrial" took 0 seconds

computing AR-model [-----|]

the call to "ft_mvaranalysis" took 0 seconds

the input is mvar data

Warning: could not determine dimord of "dof" in the following data

dimord: 'chan_chan_lag'

label: {3x1 cell}

coeffs: [3x3x2 double]

noisecov: [3x3 double]

dof: 200

fsampleorig: 200

cfg: [1x1 struct]

not including "dof" in selection

the call to "ft_selectdata" took 0 seconds

computing MAR-model based TFR

processing timewindow 1 from 1

the call to "ft_freqanalysis_mvar" took 0 seconds

selection fourierspctrm along dimension 2

averaging crsspctrm over rpt

removing dimension rpt from crsspctrm

the call to "ft_connectivityanalysis" took 1 seconds

selection fourierspctrm along dimension 2

averaging crsspctrm over rpt

removing dimension rpt from crsspctrm

the call to "ft_connectivityanalysis" took 1 seconds

selection crsspctrm along dimensions 1 and 2

```
selection transfer along dimensions 1 and 2
the call to "ft_connectivityanalysis" took 0 seconds
selection fourierspctrm along dimension 2
averaging crsspctrm over rpt
removing dimension rpt from crsspctrm
the call to "ft_connectivityanalysis" took 1 seconds
selection fourierspctrm along dimension 2
Warning: partialisation on single trial observations is not supported, removing
trial dimension
the call to "ft_connectivityanalysis" took 0 seconds
selection fourierspctrm along dimension 2
computing multivariate non-parametric spectral factorization on 3 channels
computing spectral factorization [-----]
the call to "ft_connectivityanalysis" took 1 seconds
selection crsspctrm along dimensions 1 and 2
selection transfer along dimensions 1 and 2
the call to "ft_connectivityanalysis" took 0 seconds
the call to "ft_connectivitysimulation" took 1 seconds
the call to "ft_selectdata" took 0 seconds
the input is raw data with 2 channels and 500 trials
Warning: the data does not contain a trial definition
Warning: reconstructing sampleinfo by assuming that the trials are consecutive
segments of a continuous recording
the call to "ft_selectdata" took 0 seconds
processing trials
processing trial 500/500 nfft: 200 samples, datalength: 200 samples, 5 tapers

the call to "ft_freqanalysis" took 1 seconds
the input is freq data with 2 channels, 101 frequencybins and no timebins
the call to "ft_selectdata" took 0 seconds
the call to "ft_freqdescriptives" took 0 seconds
selection fourierspctrm along dimension 2
averaging crsspctrm over rpt
removing dimension rpt from crsspctrm
the call to "ft_connectivityanalysis" took 2 seconds
selection fourierspctrm along dimension 2
averaging crsspctrm over rpt
removing dimension rpt from crsspctrm
the call to "ft_connectivityanalysis" took 2 seconds
selection fourierspctrm along dimension 2
averaging crsspctrm over rpt
removing dimension rpt from crsspctrm
```

```

the call to "ft_connectivityanalysis" took 2 seconds
selection fourierspctrm along dimension 2
Warning: The field cfg.sfmethode is deprecated, please specify it as
cfg.granger.sfmethode instead of cfg.
computing pairwise non-parametric spectral factorization on 1 channel pairs
computing spectral factorization [-----|]
the call to "ft_connectivityanalysis" took 0 seconds
the call to "ft_connectivitysimulation" took 0 seconds
the input is raw data with 3 channels and 200 trials
Warning: the data does not contain a trial definition
Warning: reconstructing sampleinfo by assuming that the trials are consecutive
segments of a continuous recording
the call to "ft_selectdata" took 0 seconds
processing trials
processing trial 200/200 nfft: 200 samples, datalength: 200 samples, 5 tapers

the call to "ft_freqanalysis" took 0 seconds
Warning: The option cfg.complex is deprecated, support is no longer guaranteed

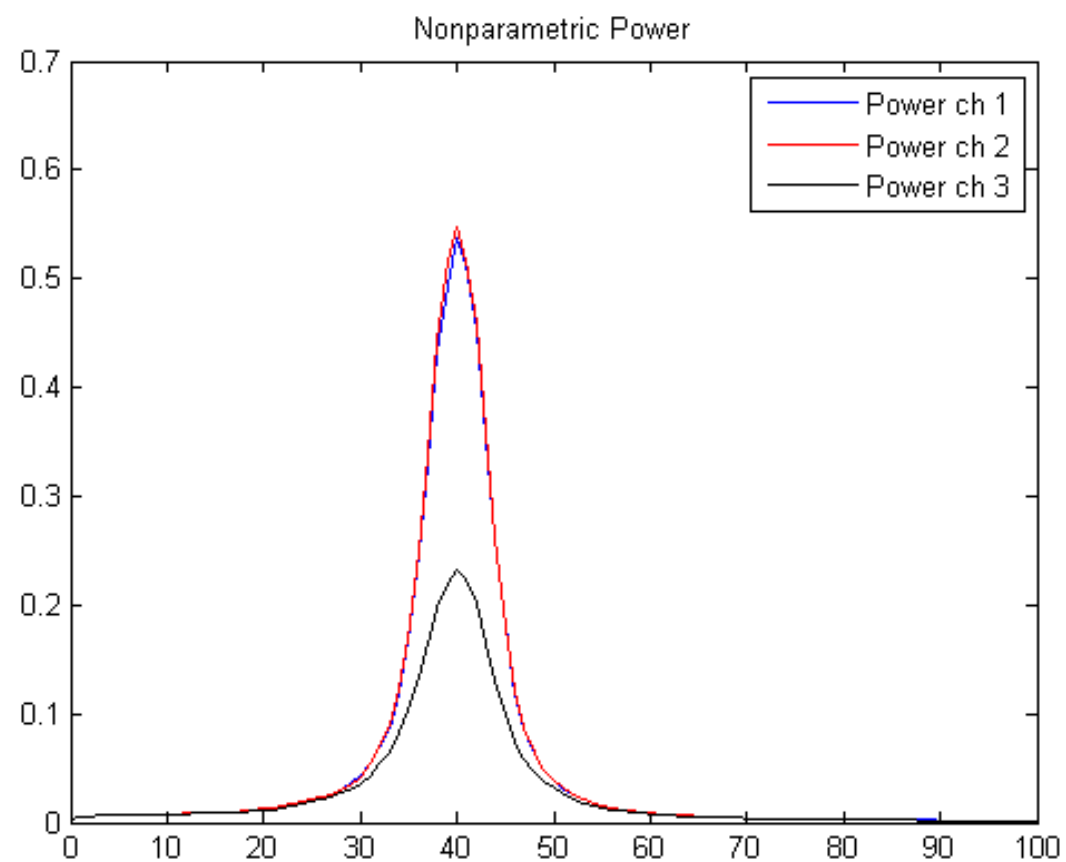
the input is freq data with 3 channels, 101 frequencybins and no timebins
the call to "ft_selectdata" took 0 seconds
computing jackknife powspctrm
computing power... [-----|]
the call to "ft_freqdescriptives" took 0 seconds
the call to "ft_selectdata" took 0 seconds
preprocessing
preprocessing trial 200 from 200

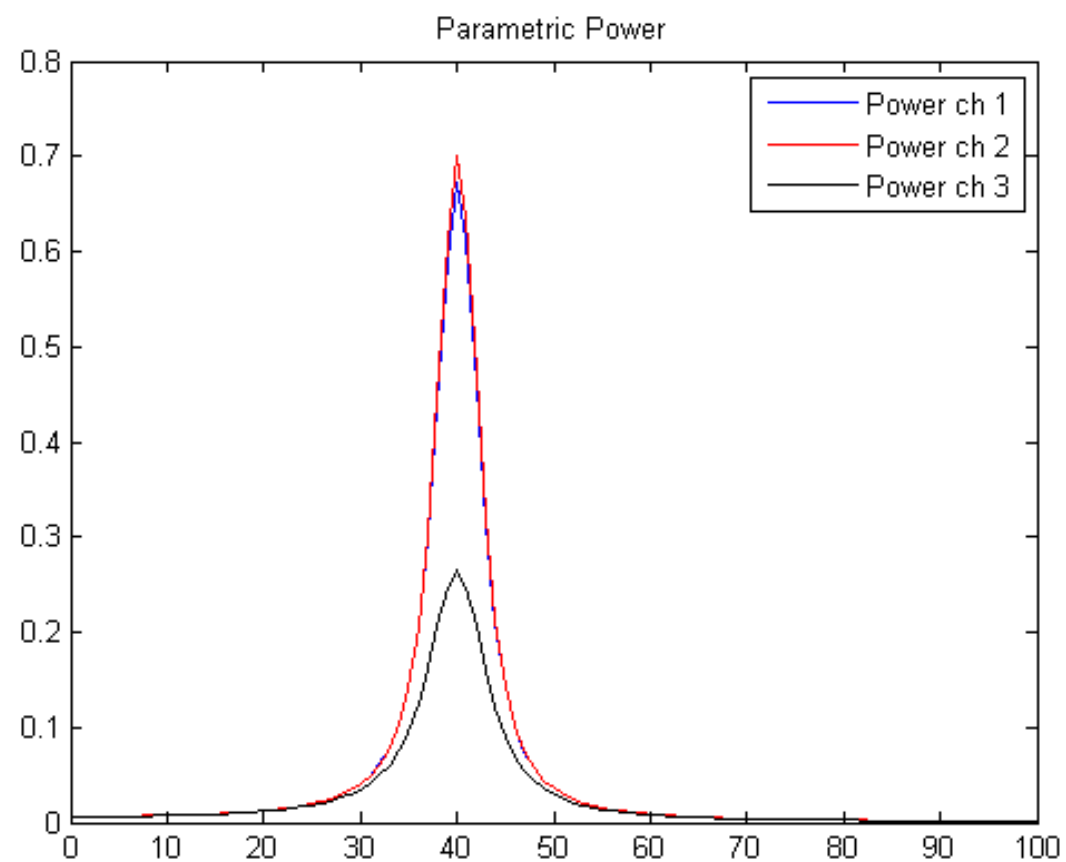
the call to "ft_preprocessing" took 0 seconds
the call to "ft_redefinetrial" took 0 seconds
computing AR-model [-----|]
the call to "ft_mvaranalysis" took 0 seconds
the input is mvar data
Warning: could not determine dimord of "dof" in the following data
    dimord: 'chan_chan_lag'
    label: {3x1 cell}
    coeffs: [3x3x2 double]
    noisecov: [3x3 double]
    dof: 200
    fsampleorig: 200
    cfg: [1x1 struct]

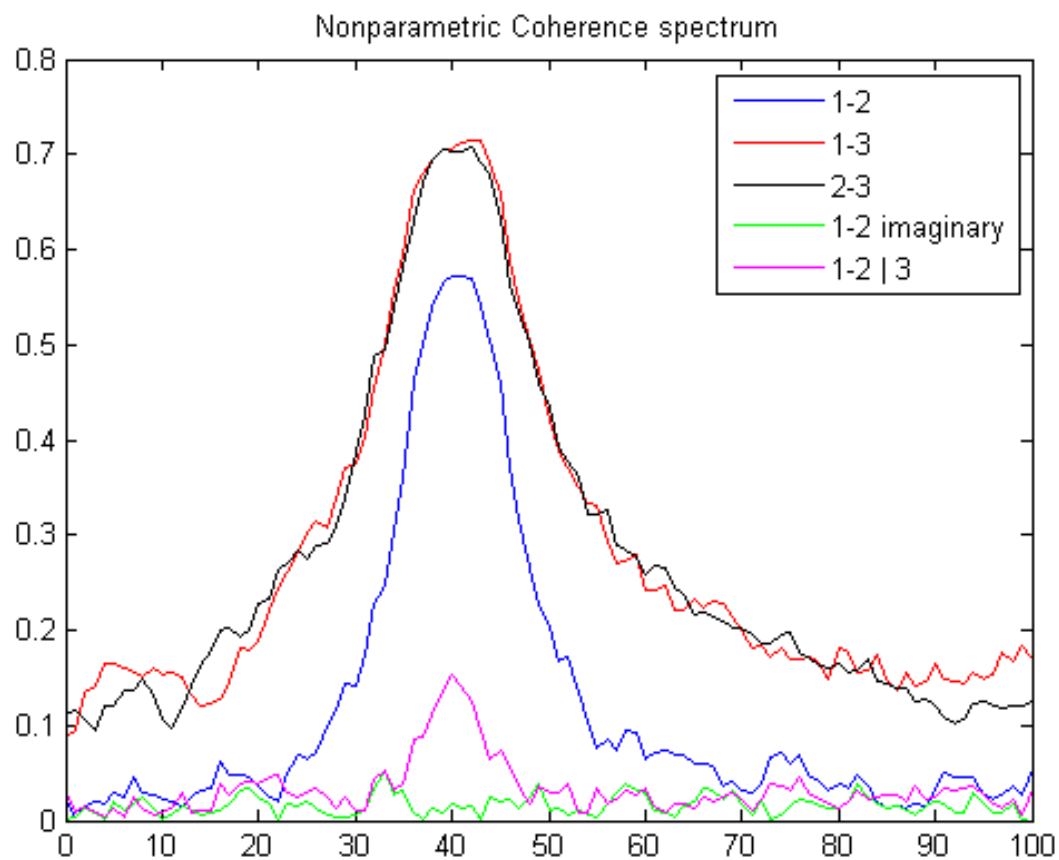
```

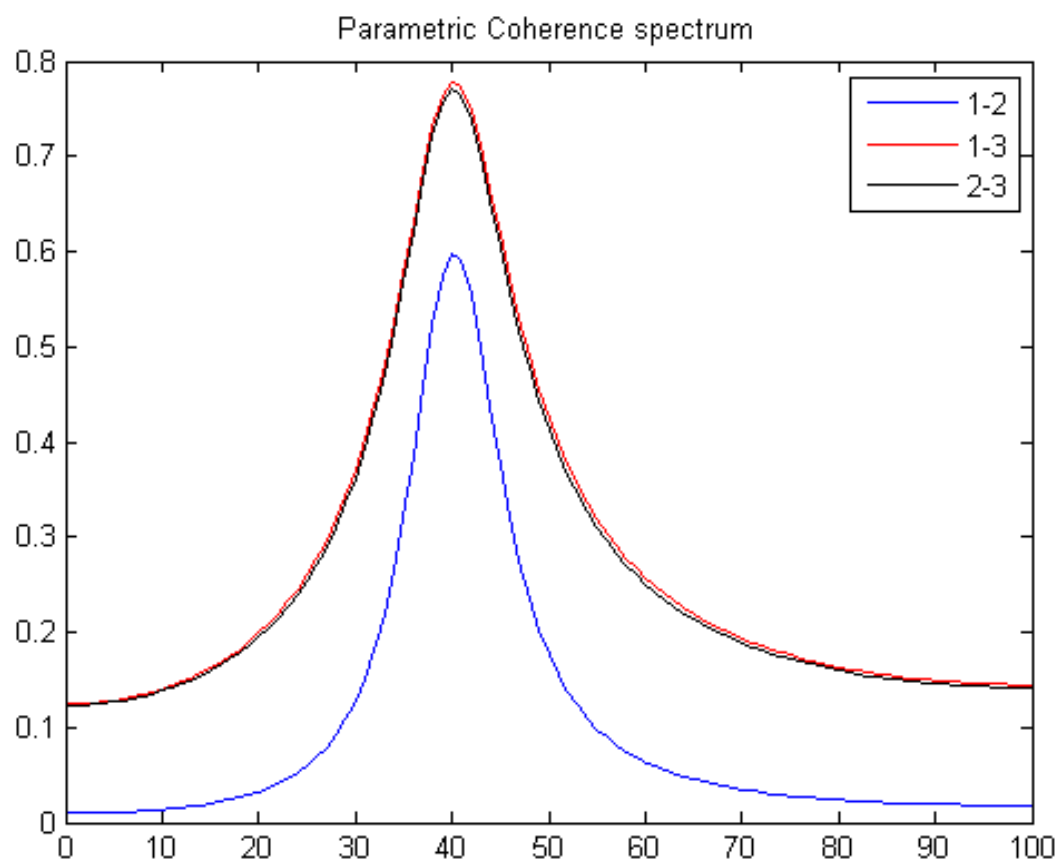
not including "dof" in selection
the call to "ft_selectdata" took 0 seconds
computing MAR-model based TFR
processing timewindow 1 from 1

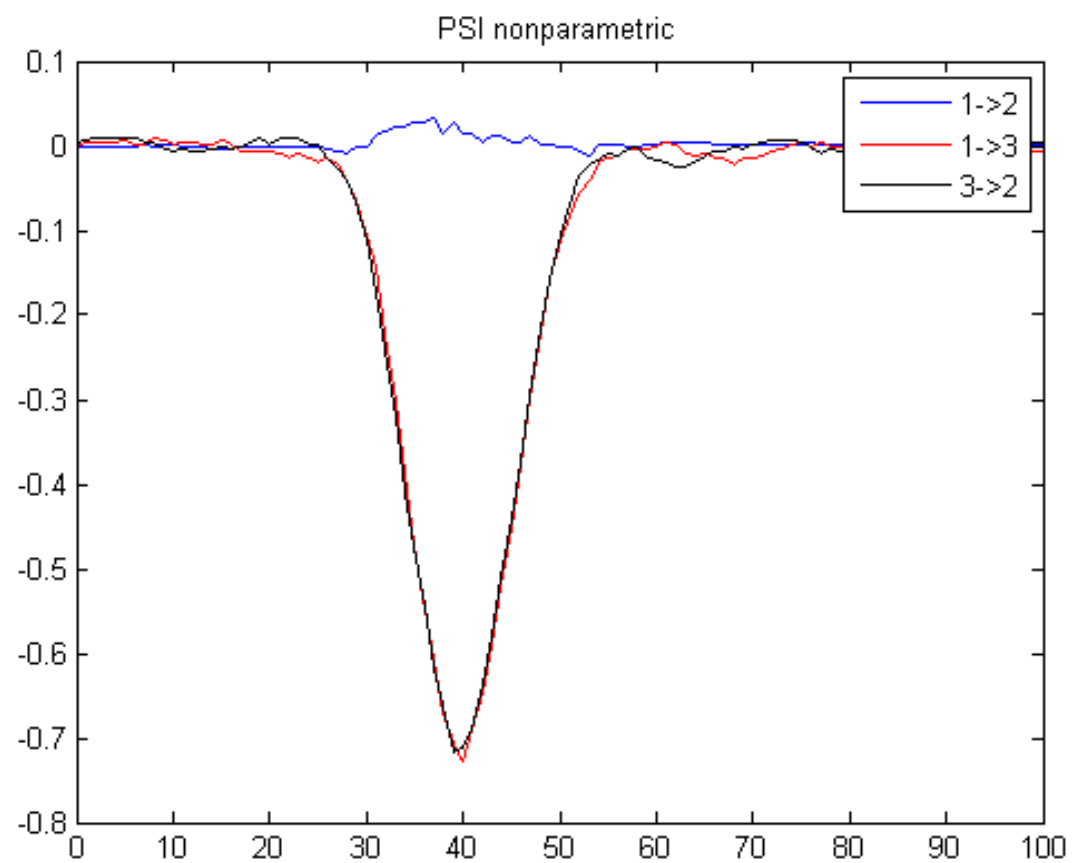
the call to "ft_freqanalysis_mvar" took 0 seconds
selection fourierspctrm along dimension 2
averaging crsspctrm over rpt
removing dimension rpt from crsspctrm
the call to "ft_connectivityanalysis" took 1 seconds
selection fourierspctrm along dimension 2
averaging crsspctrm over rpt
removing dimension rpt from crsspctrm
the call to "ft_connectivityanalysis" took 1 seconds
selection crsspctrm along dimensions 1 and 2
selection transfer along dimensions 1 and 2
the call to "ft_connectivityanalysis" took 0 seconds
selection fourierspctrm along dimension 2
Warning: partialisation on single trial observations is not supported, removing
trial dimension
the call to "ft_connectivityanalysis" took 0 seconds
selection fourierspctrm along dimension 2
computing multivariate non-parametric spectral factorization on 3 channels
computing spectral factorization [-----]
the call to "ft_connectivityanalysis" took 1 seconds
selection crsspctrm along dimensions 1 and 2
selection transfer along dimensions 1 and 2
the call to "ft_connectivityanalysis" took 0 seconds

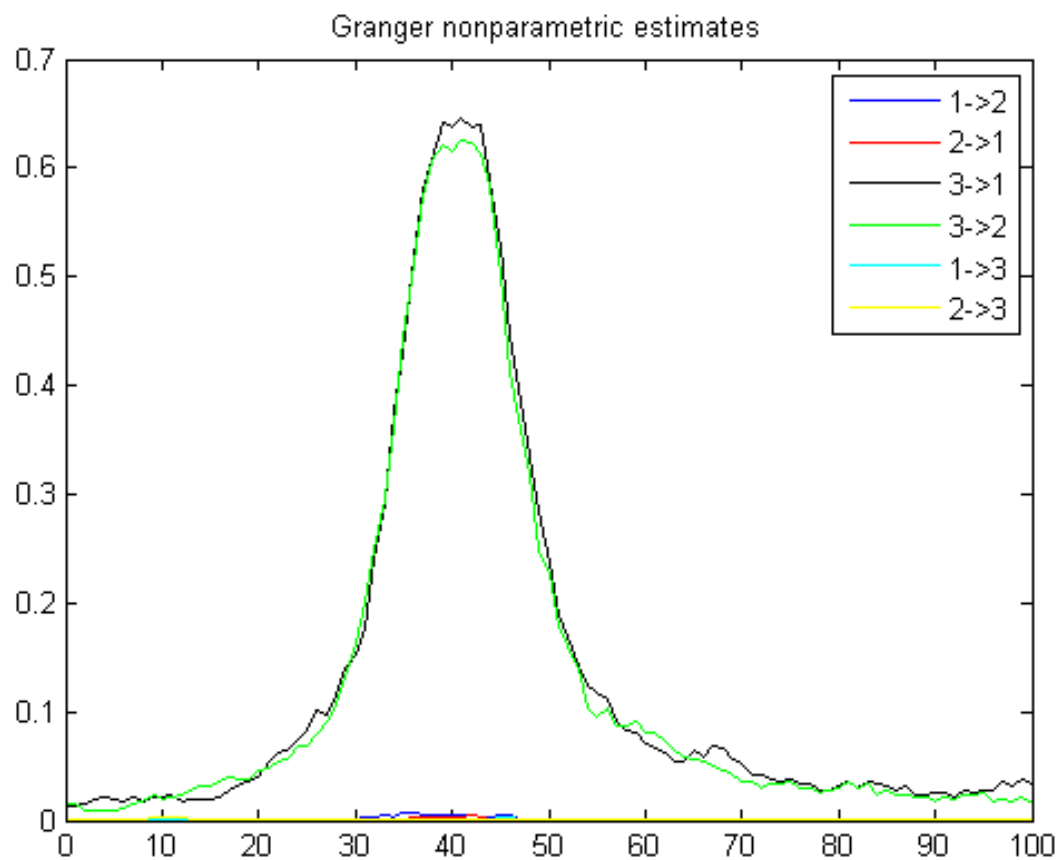


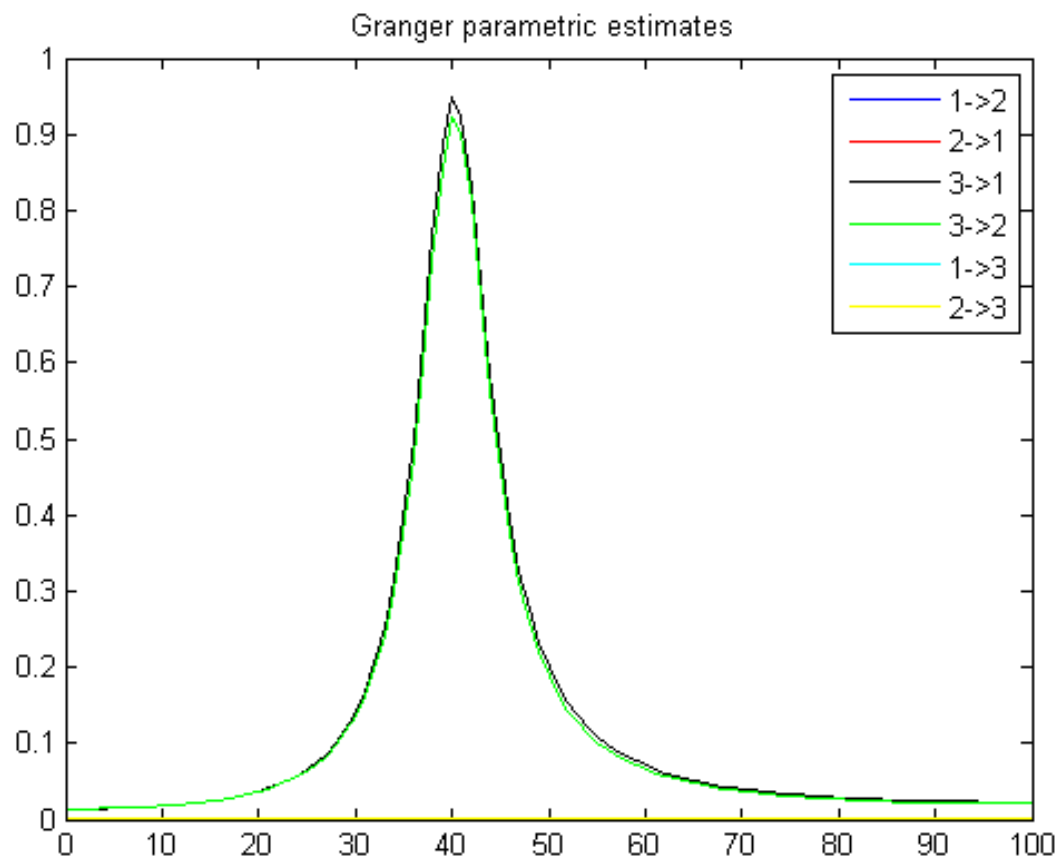


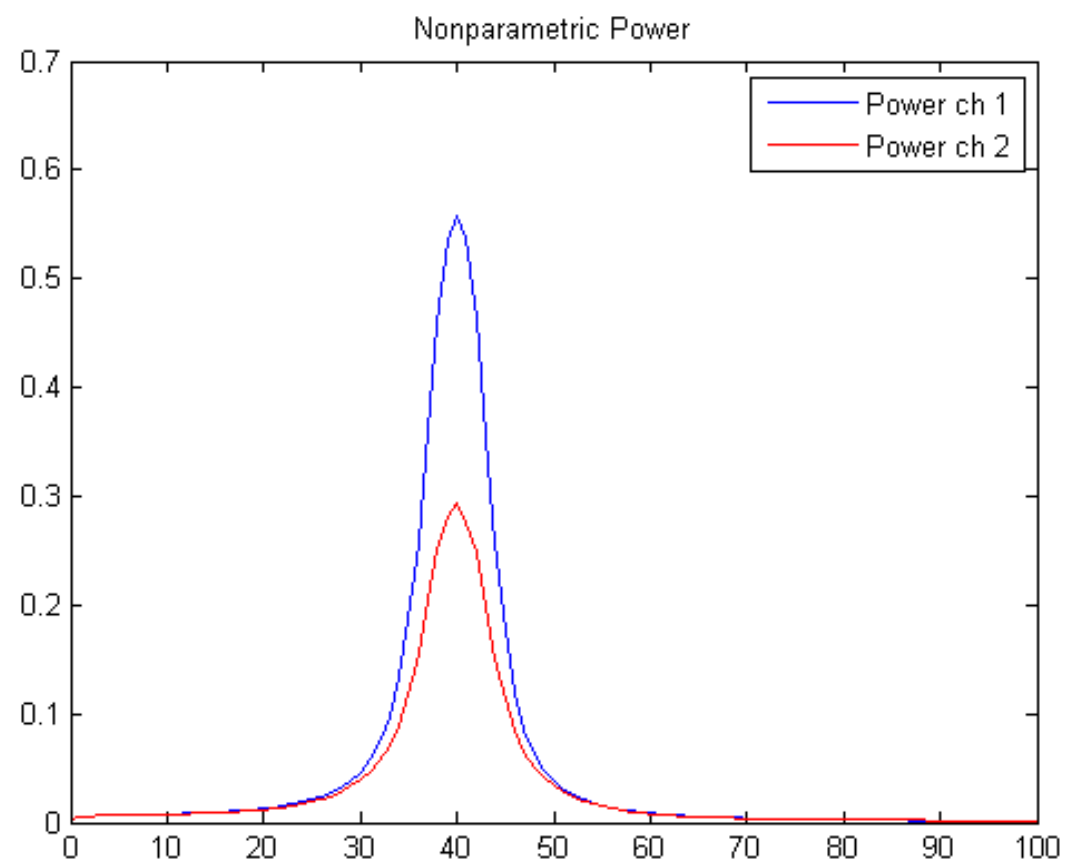


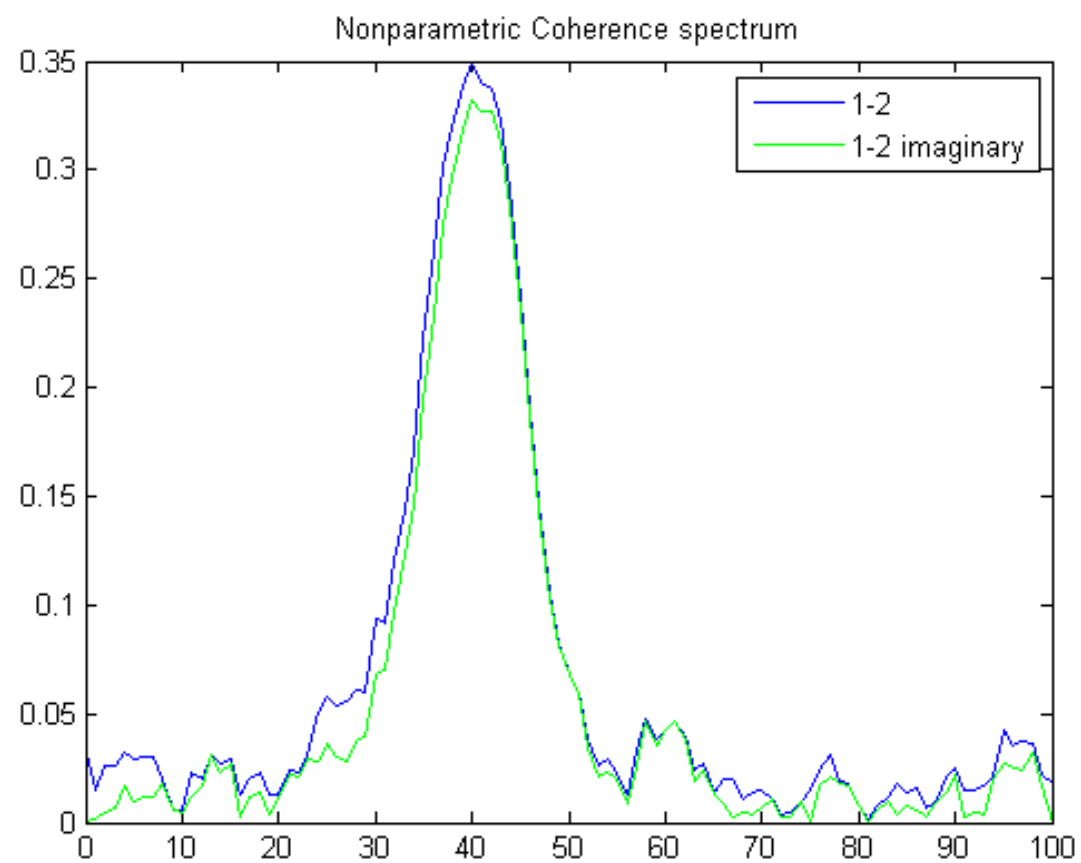


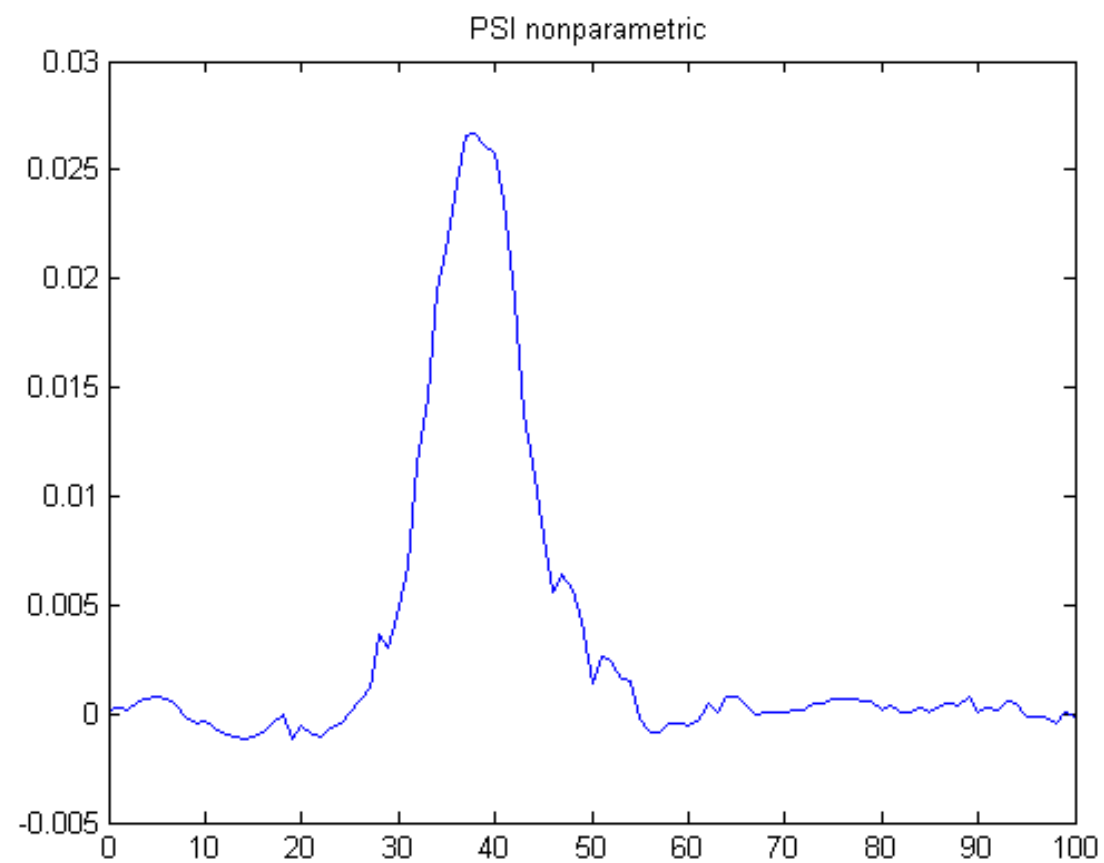


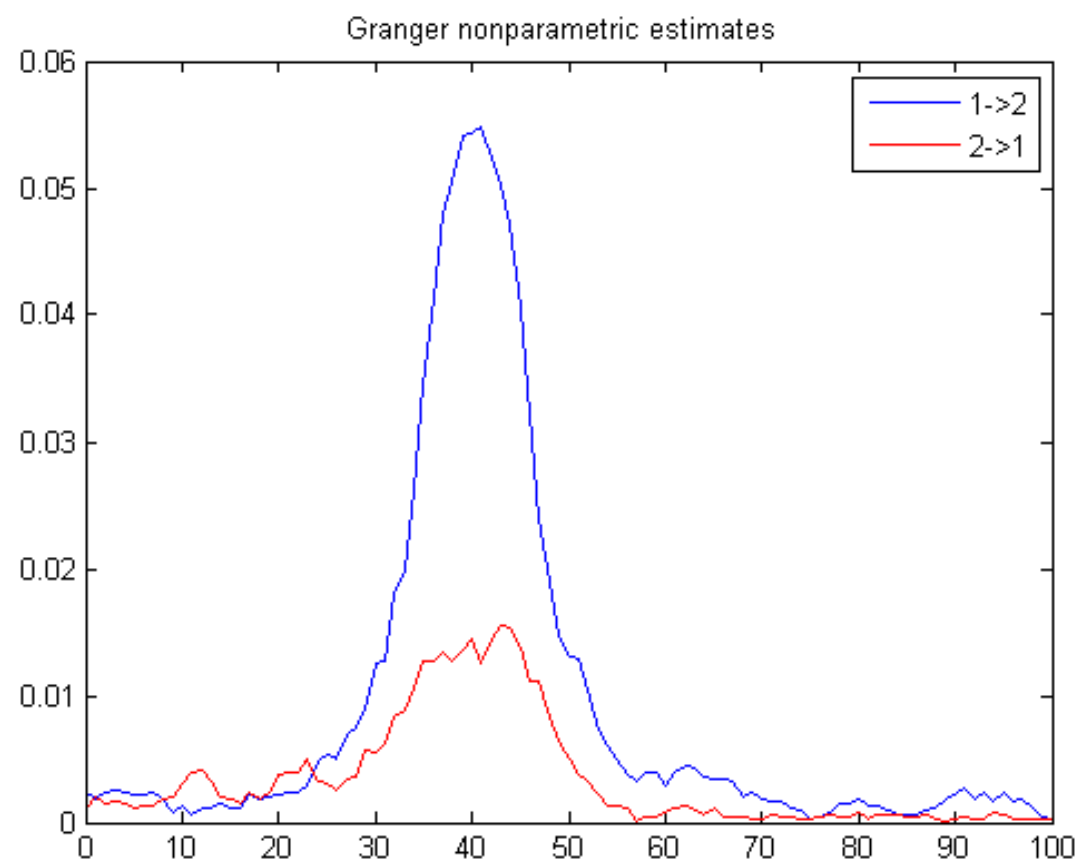


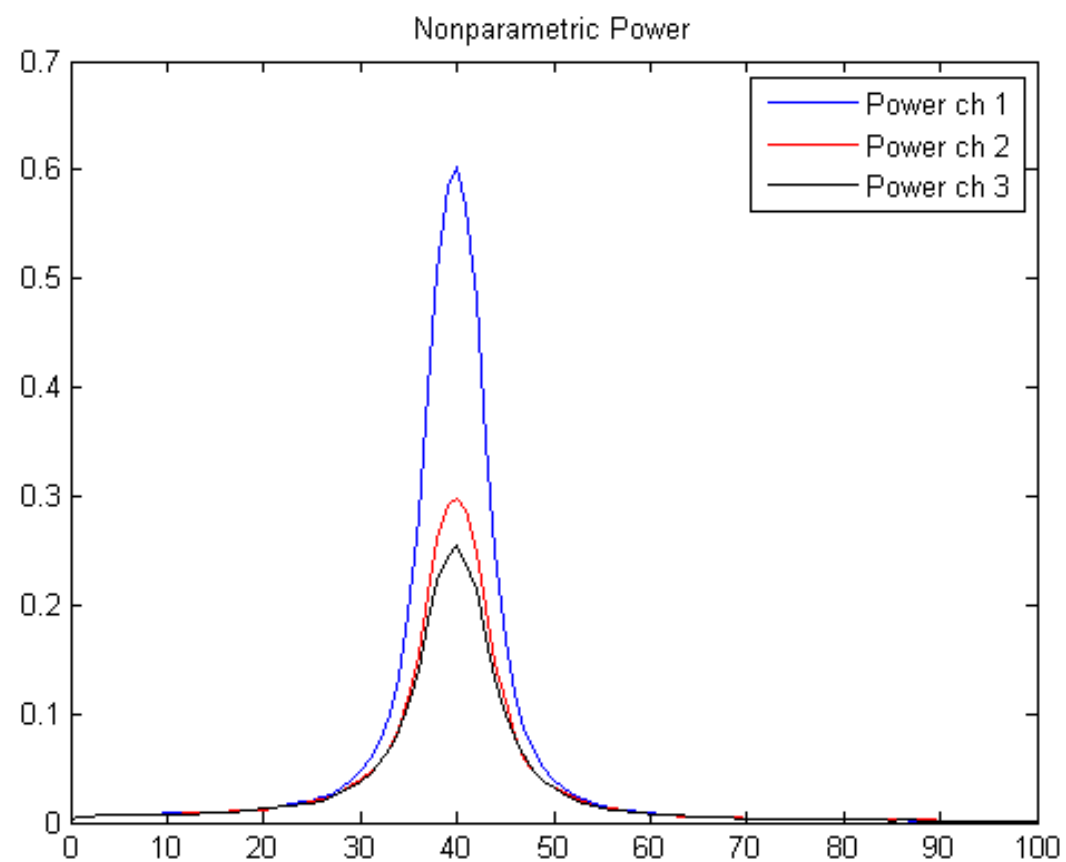


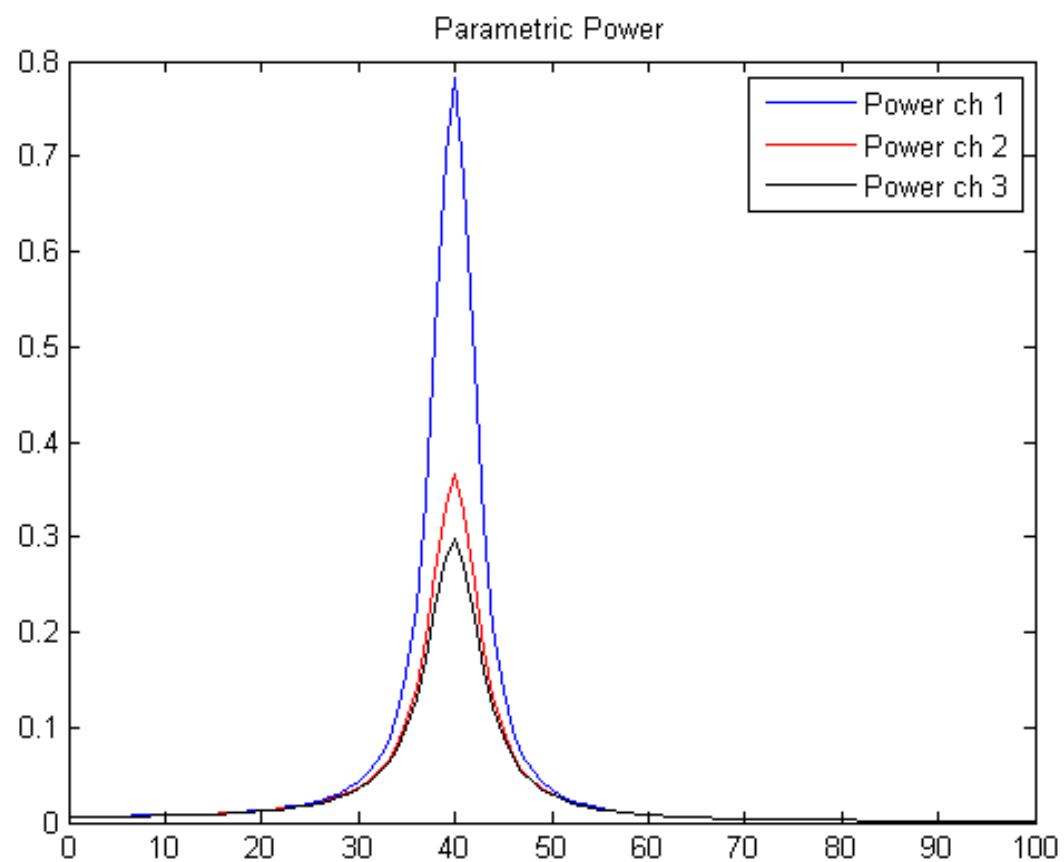


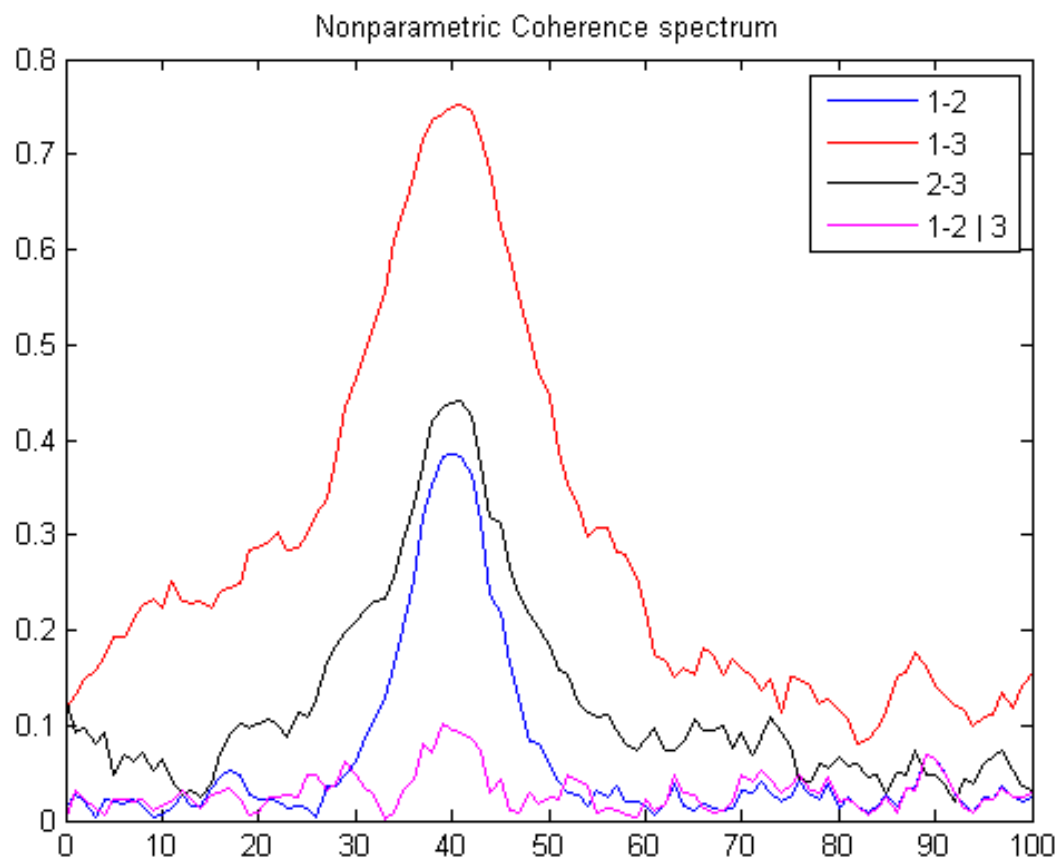


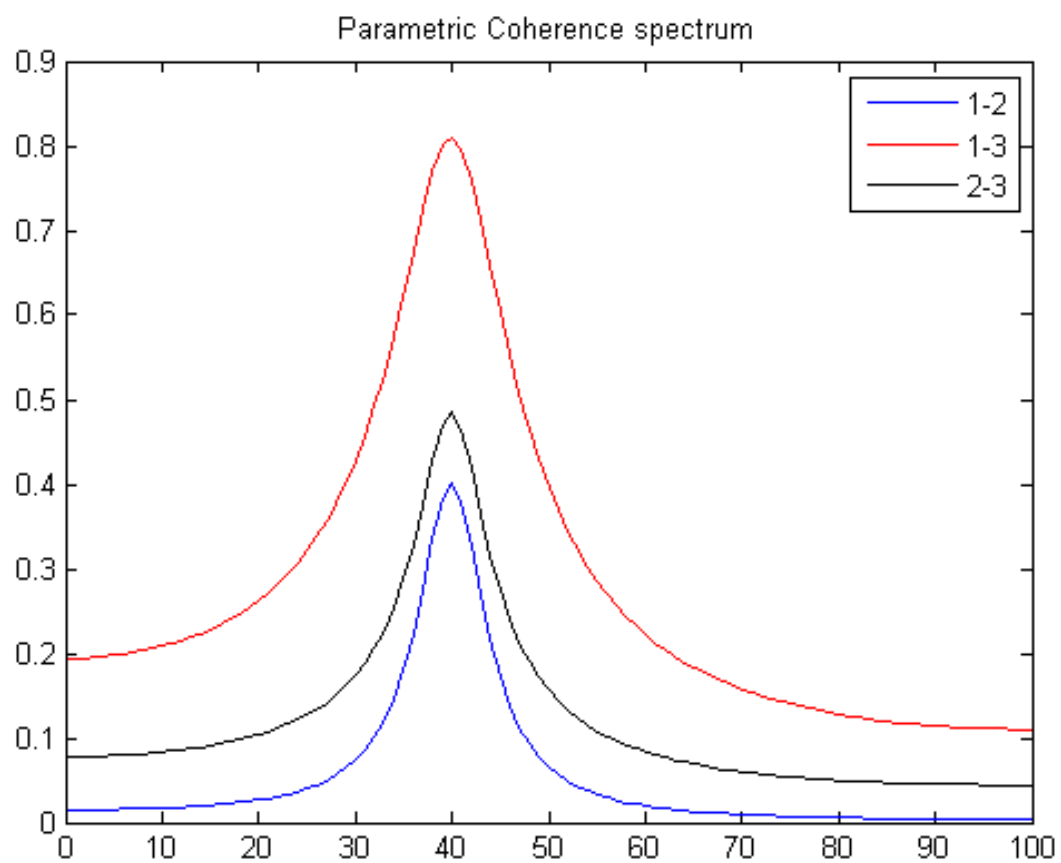


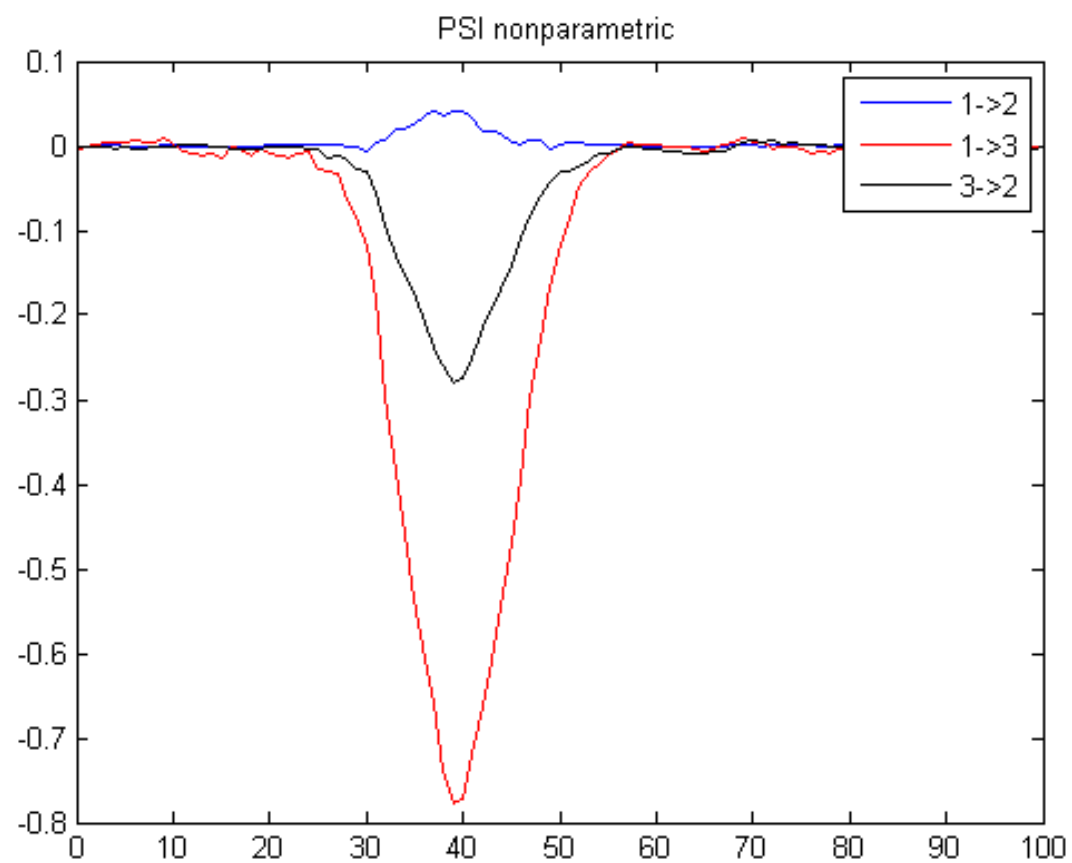


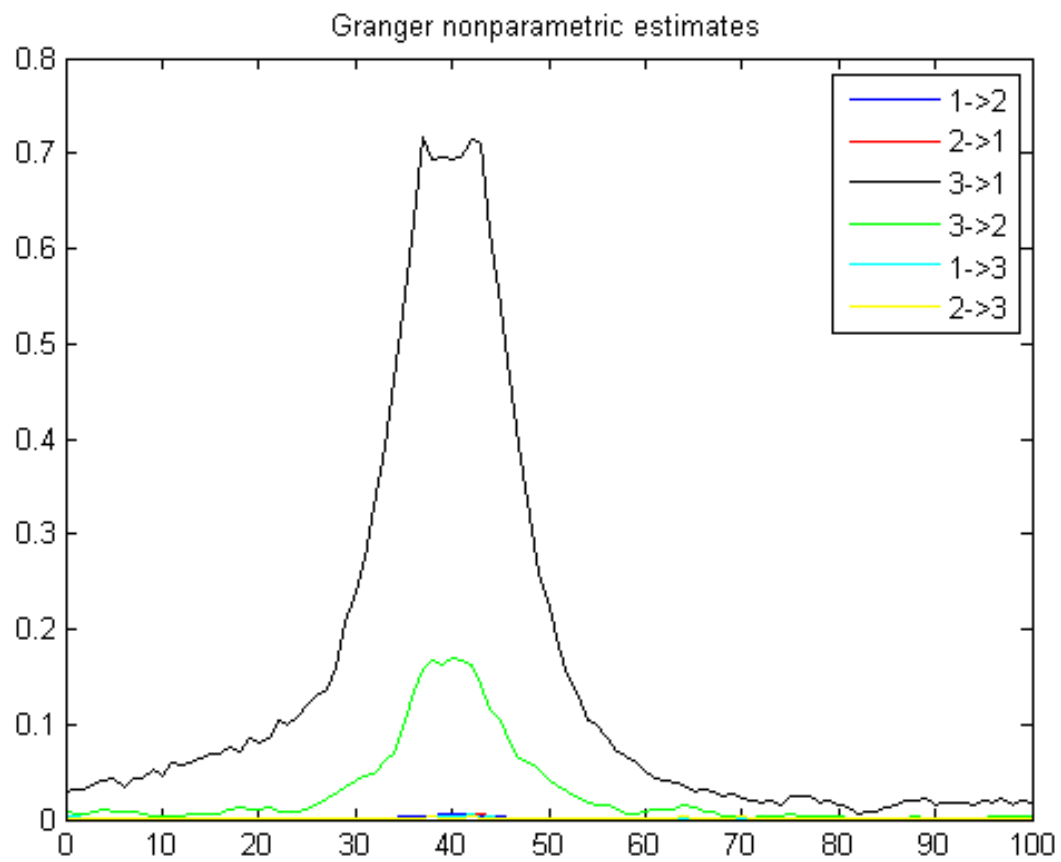


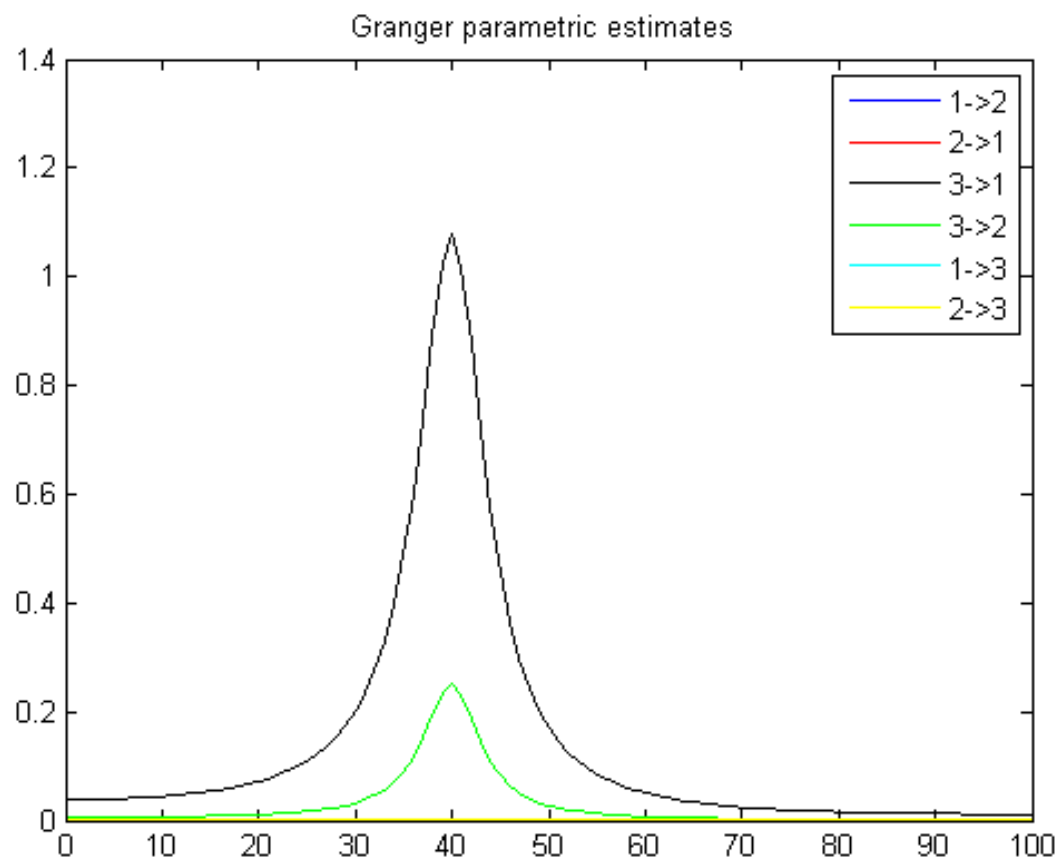












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