

CHRONUX functions for signal conditioning: removing slow fluctuations

locdetrend

remove running line fit (using local linear regression)-
continuous processes

usage: `data=locdetrend(data,Fs,movingwin)`

Note that units of Fs, movingwin have to be consistent. If Fs in Hz, movingwin in secs.

- ◆ `data` (data as a matrix times x channels or a single vector)
- ◆ `Fs` (sampling frequency) - optional. Default 1
- ◆ `movingwin` (length of moving window, and stepsize)
[window winstep] - optional.

Default. `window=full length of data` (global detrend).

`winstep=window -- global detrend`

- ◆ `output data:` (locally detrended data)

CHRONUX functions for signal conditioning: removing line elements (eg. 60 Hz)

rmlinesc

removes significant sine waves from data (continuous data).

usage: `data=rmlinesc(data,params,p,plt,f0)`

◆ `data` (data as a matrix times x channels or a single vector)

◆ `params` structure containing parameters - has the following fields: `tapers`, `Fs`, `fpass`, `pad`.

Note that units of `Fs`, `fpass` have to be consistent (eg. Hz)

`tapers`: parameters for calculating Slepian tapers, $N\Delta tW$ and `K`, the number of tapers.

`fpass`: frequency band to be used

`pad`: padding factor for the FFT

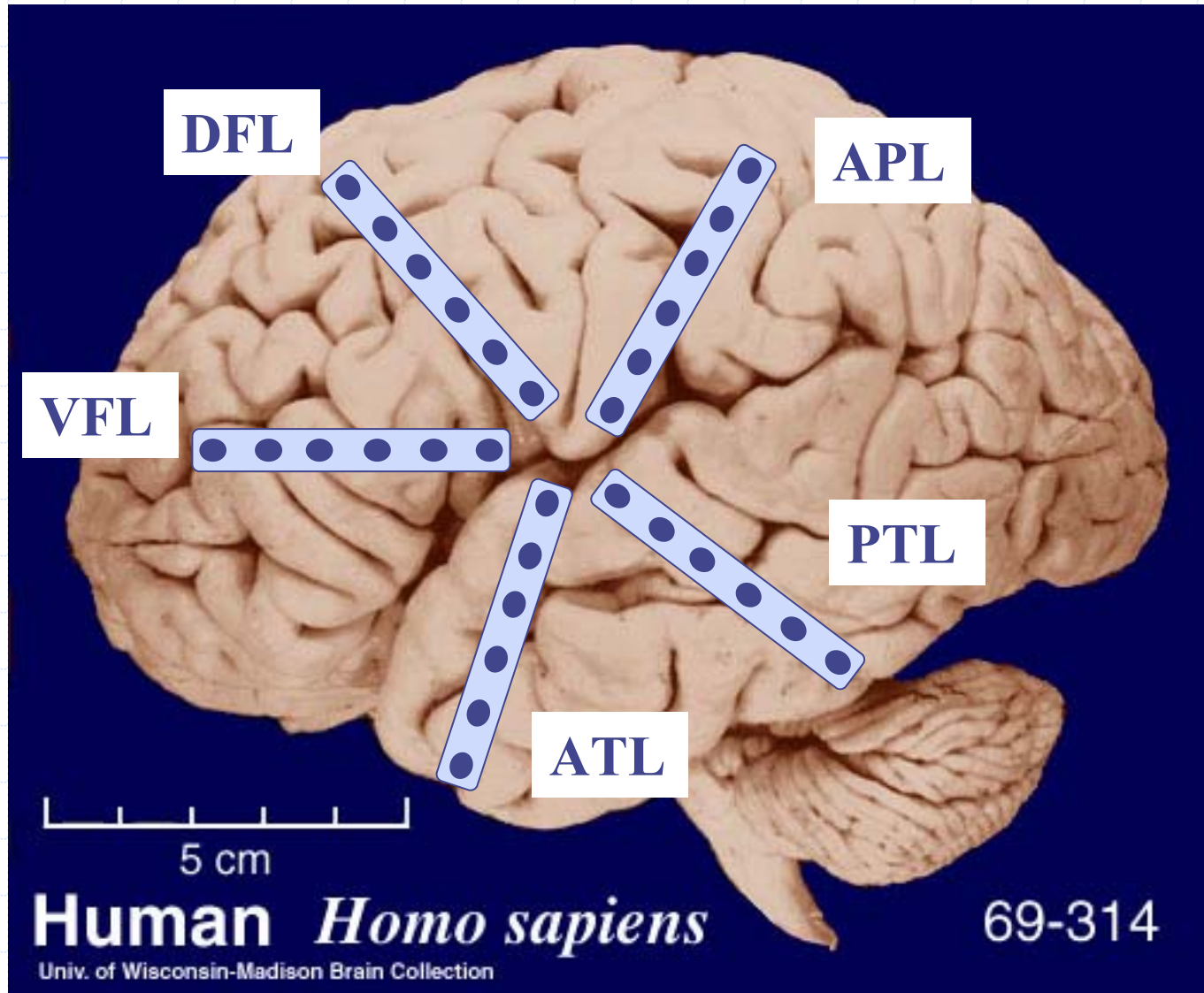
`p`: p-value for F-test

`f0`: frequencies of lines to be removed

if unspecified the F statistic is used to determine the appropriate lines for removal

◆ `output data`: (data with significant lines removed)

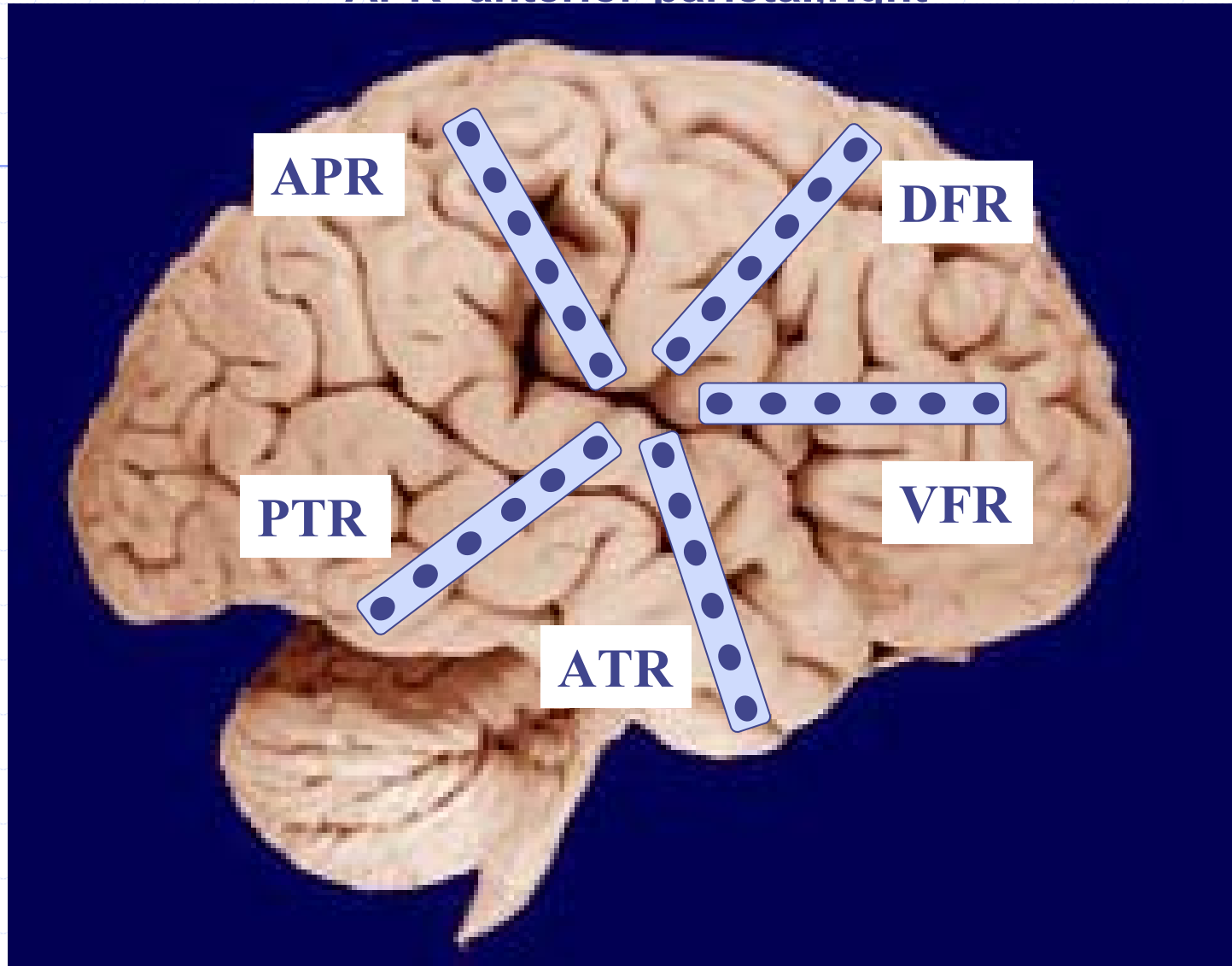
DFL=dorsal-frontal, left VFL=ventral-frontal, left
APL=anterior-parietal, left



ATL=anterior-temporal, left PTL=posterior-temporal, left

MTL=medial-temporal, left (not-shown, depth electrodes)

DFR=dorsal-frontal,right VFR=ventral-frontal,right
APR=anterior-parietal,right



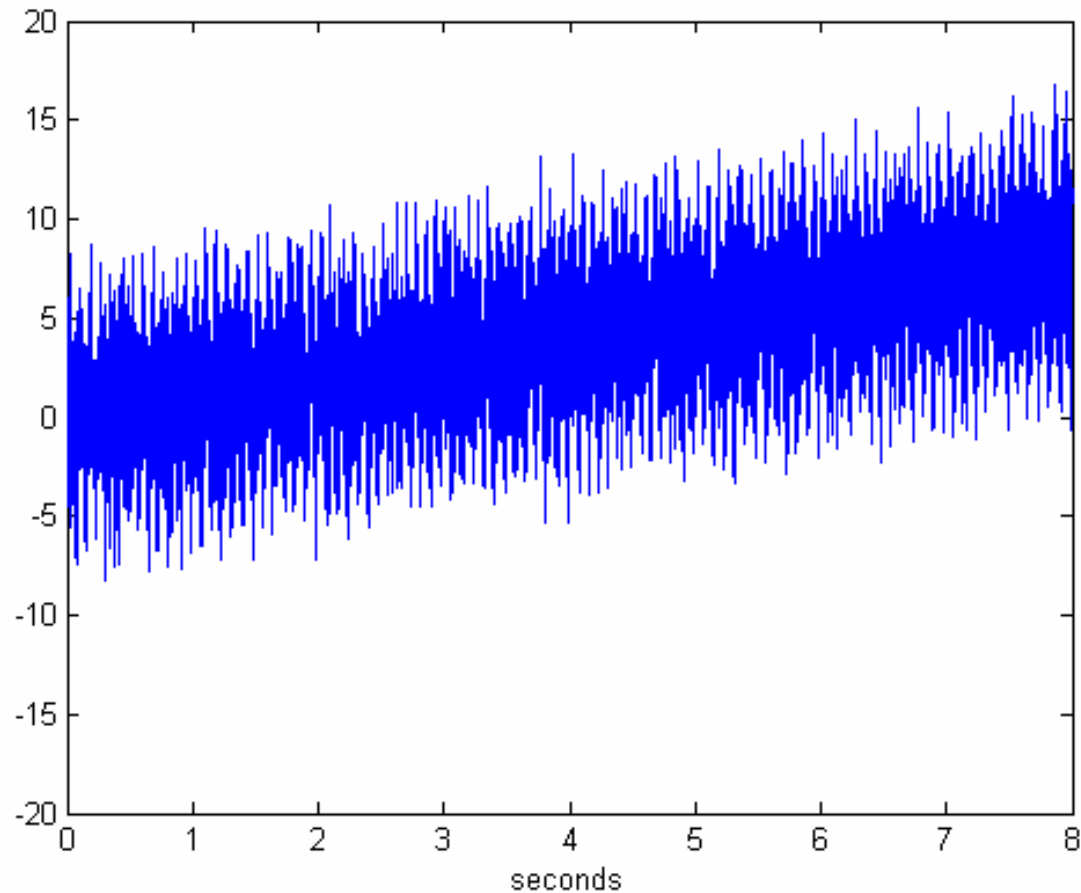
ATR=anterior-temporal,right PTR=posterior-temporal,right
MTR=medial-temporal,right (not-shown, depth electrodes)

Human Electrocorticography (EcoG)

- ◆ Recordings obtained from a patient with intractable epilepsy undergoing evaluation for surgery (all procedures involving patients were approved by the IRB of the Weill Medical College of Cornell University, NYC).
- ◆ 60 electrodes are located on the surface of the cortex, under the dura: 6 electrodes/strip, 5 strips/hemisphere. In addition, 16 depth electrodes (wires) are located in the middle-temporal lobe (8 wires/hemisphere).
- ◆ Recordings made while the patient performed a simple maze navigation task.
- ◆ Sampling Rate: 500 Hz
- ◆ Sample Duration: 8 seconds

Human Electrocardiography (EcoG): Problems when recording at bedside.

- ◆ 60 Hz line noise (50 Hz in Europe).
- ◆ Capacitative and inductive coupling to the alternating current used in the power distribution supplying the hospital room, OR, laboratory. Sources: room lighting, TVs, other medical equipment.
- ◆ Slow drifts in baseline voltage. Electrostatic charge distributions change as patient moves in the hospital bed.
- ◆ Transient voltage spikes generated by capacitative discharge of electrostatic charges built up around patient.
- ◆ Heart EKG, chest movements.



$$S=2*\sin(2*\pi*12*t)-5*\sin(2*\pi*40*t)+\text{normrnd}(0,1,[1\ 4000])+t$$

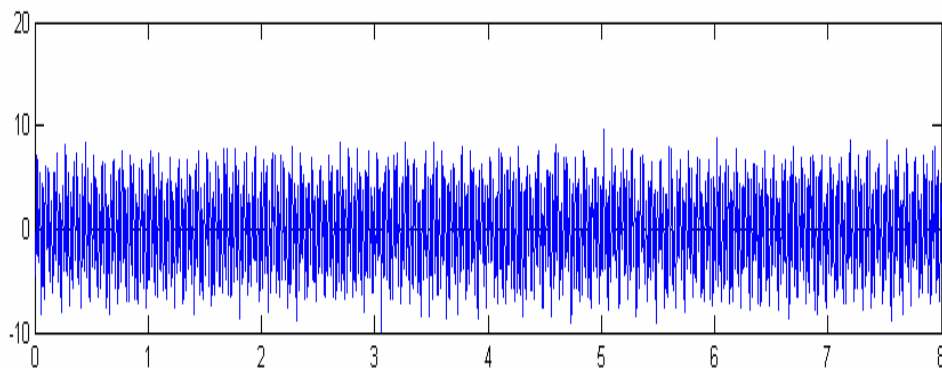
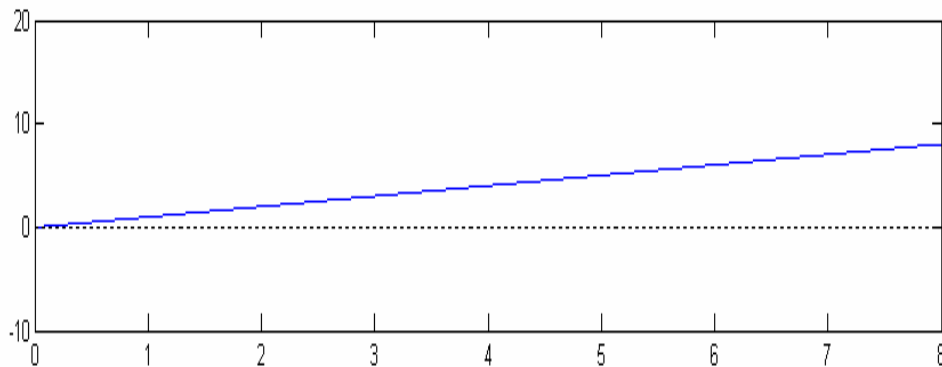
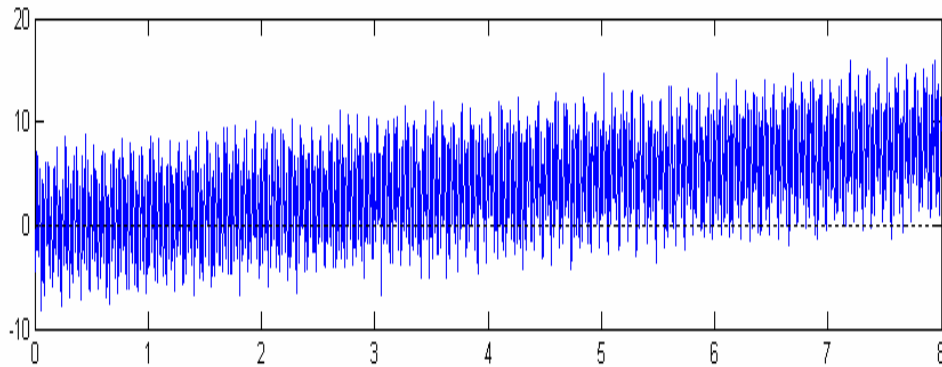
$$N=4000 \quad F_s=500 \text{ Hz} \quad t=(1:N)/F_s$$

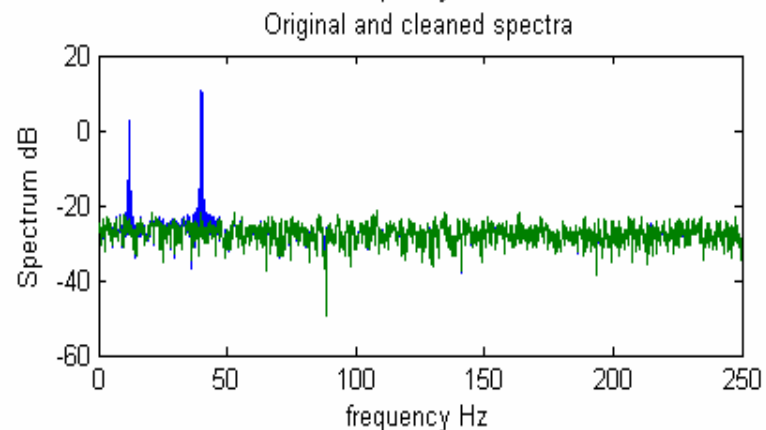
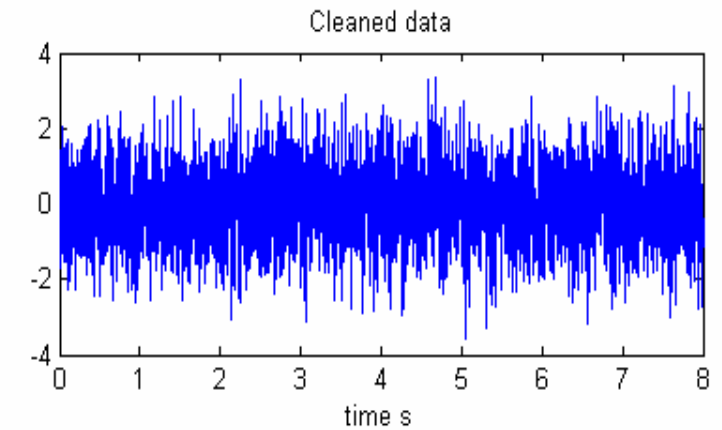
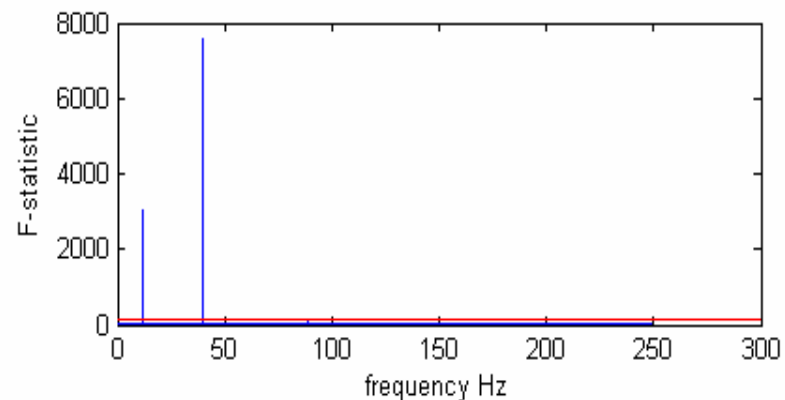
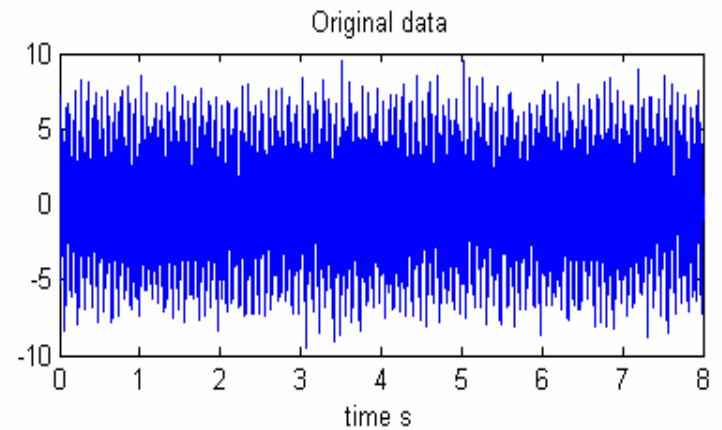
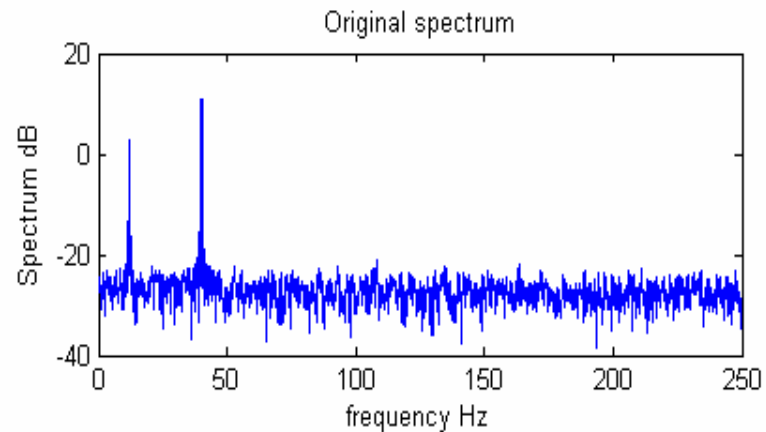
$S(t)$

$S(t) - LDs(t)$ where

$LDs(t) = \text{locdetrend}(S(t), F_s)$

$LDs(t)$

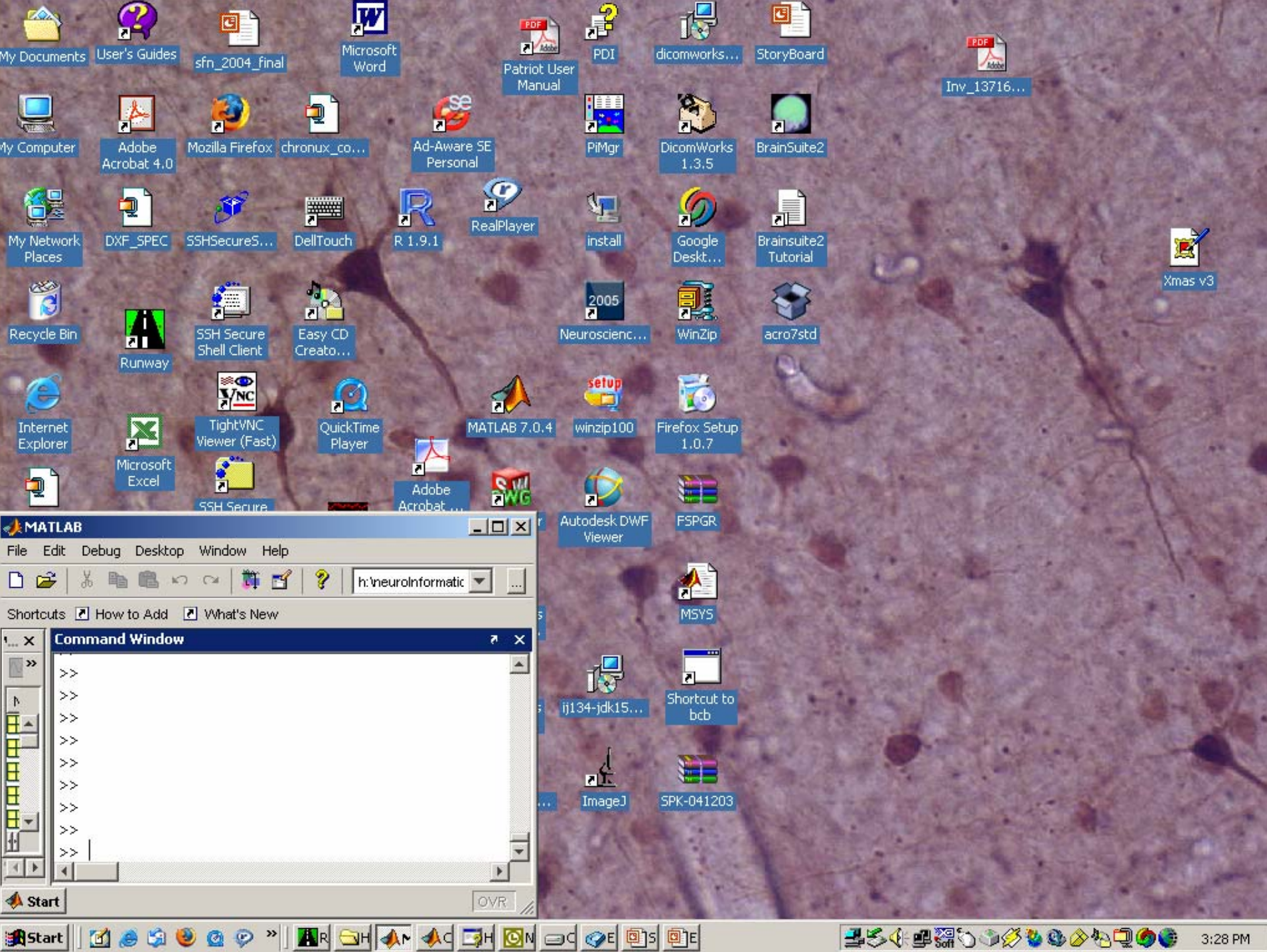




```
rmlinesc(LDs,params,.05,'y');  
Ktapers=4; NW=(Ktapers+1)/2;  
params.tapers = [NW Ktapers];  
params.pad = 5; params.Fs = 500;  
params.fpass = [0 params.Fs/2];
```

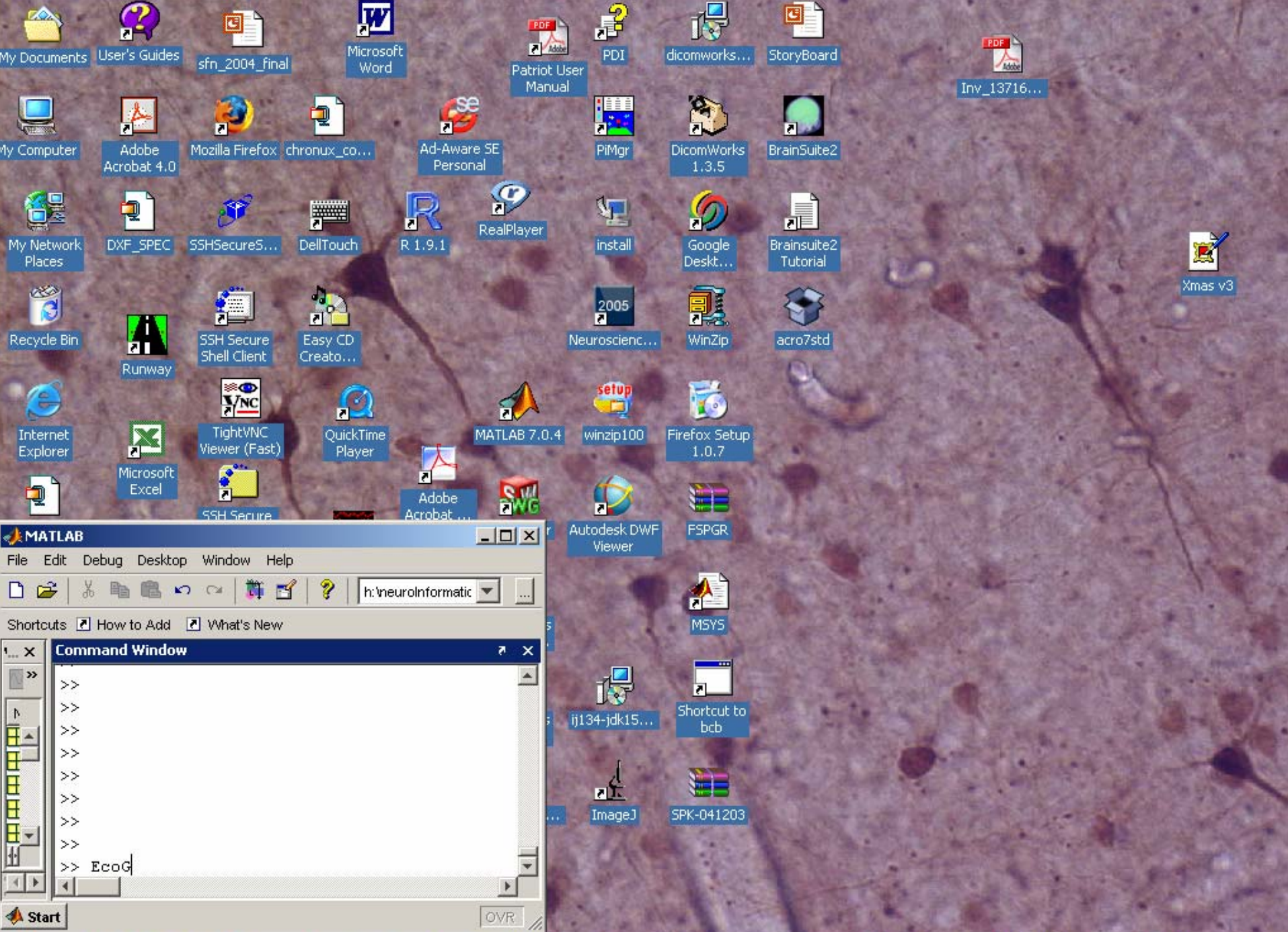
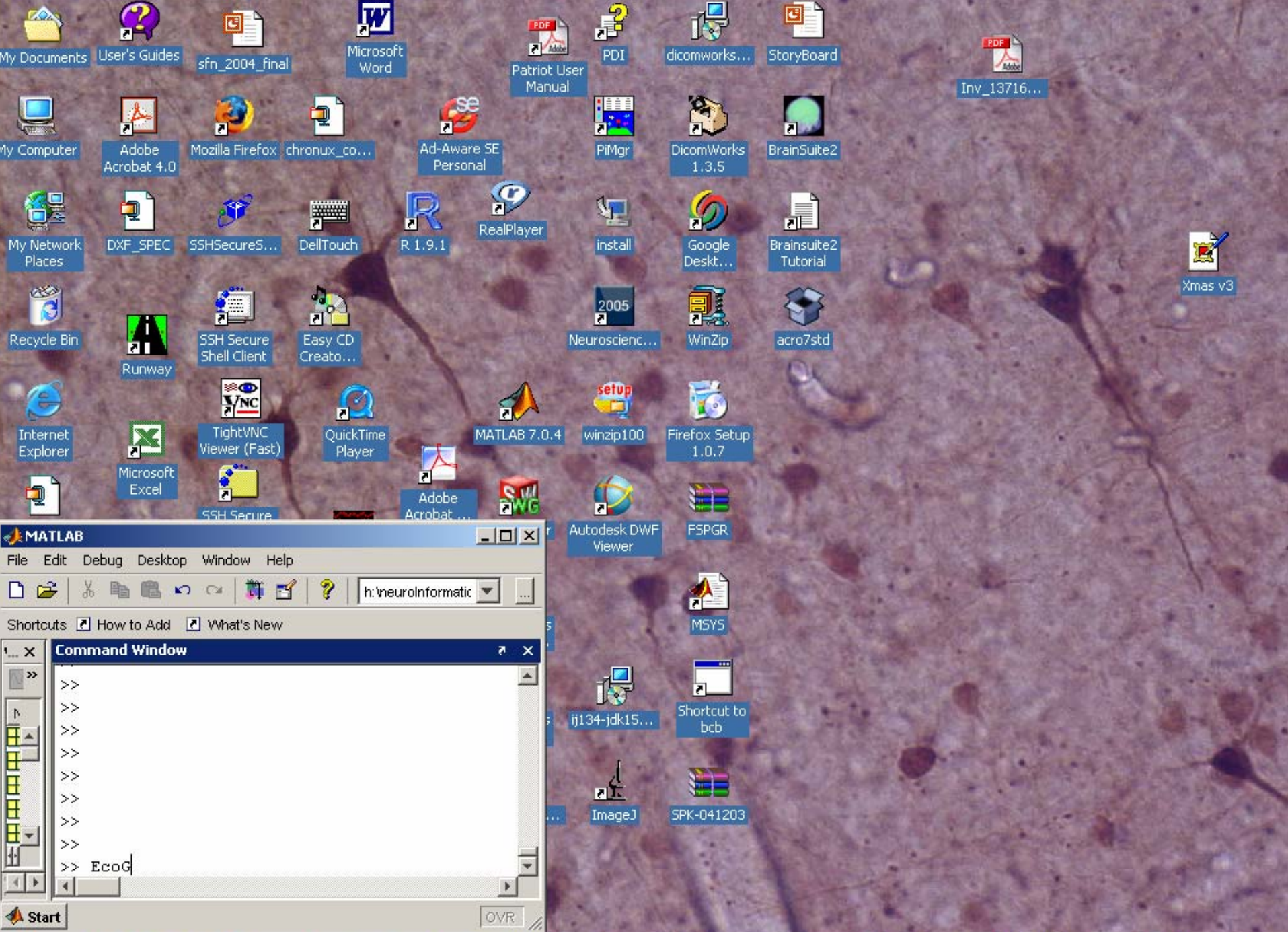
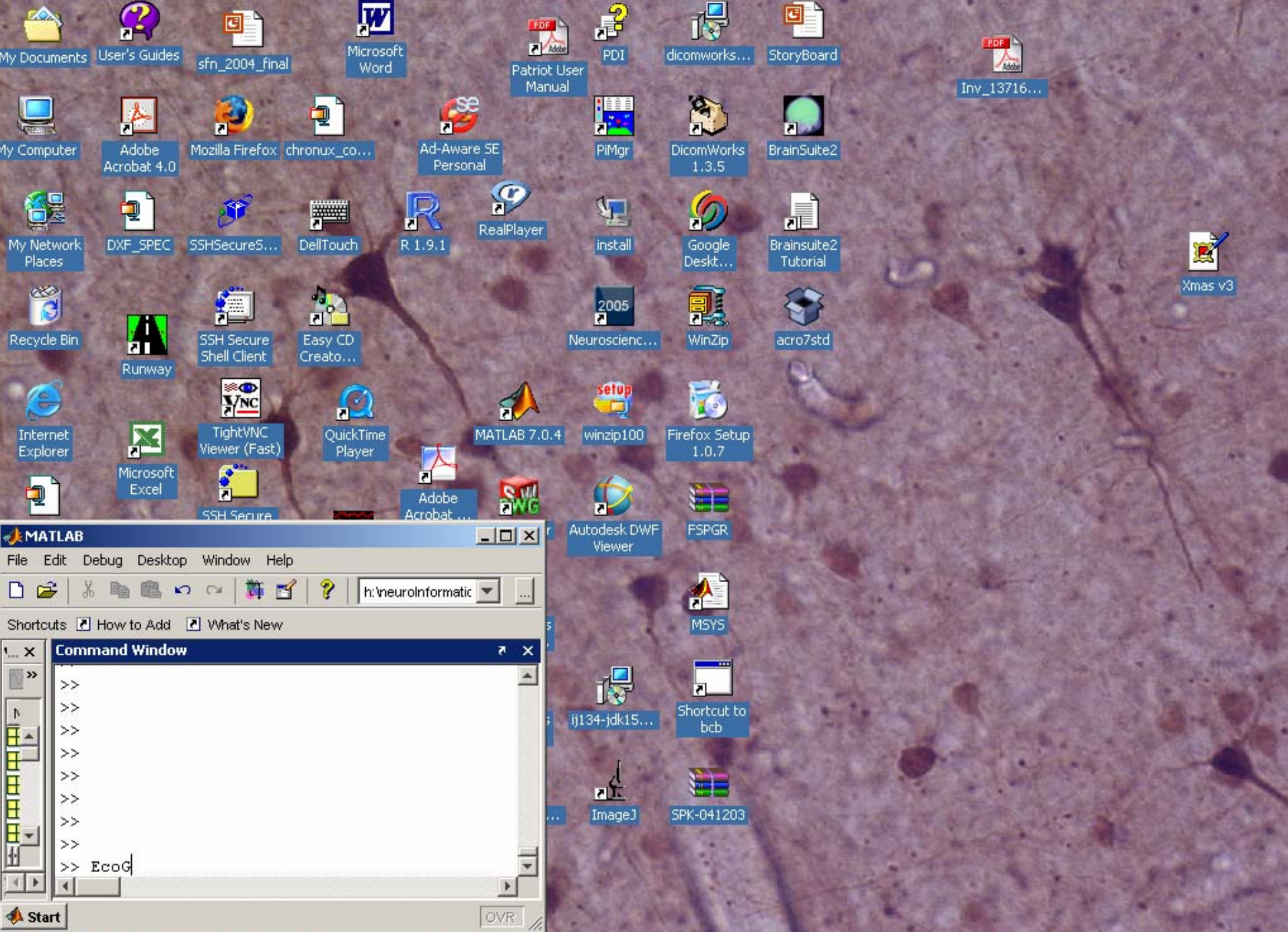
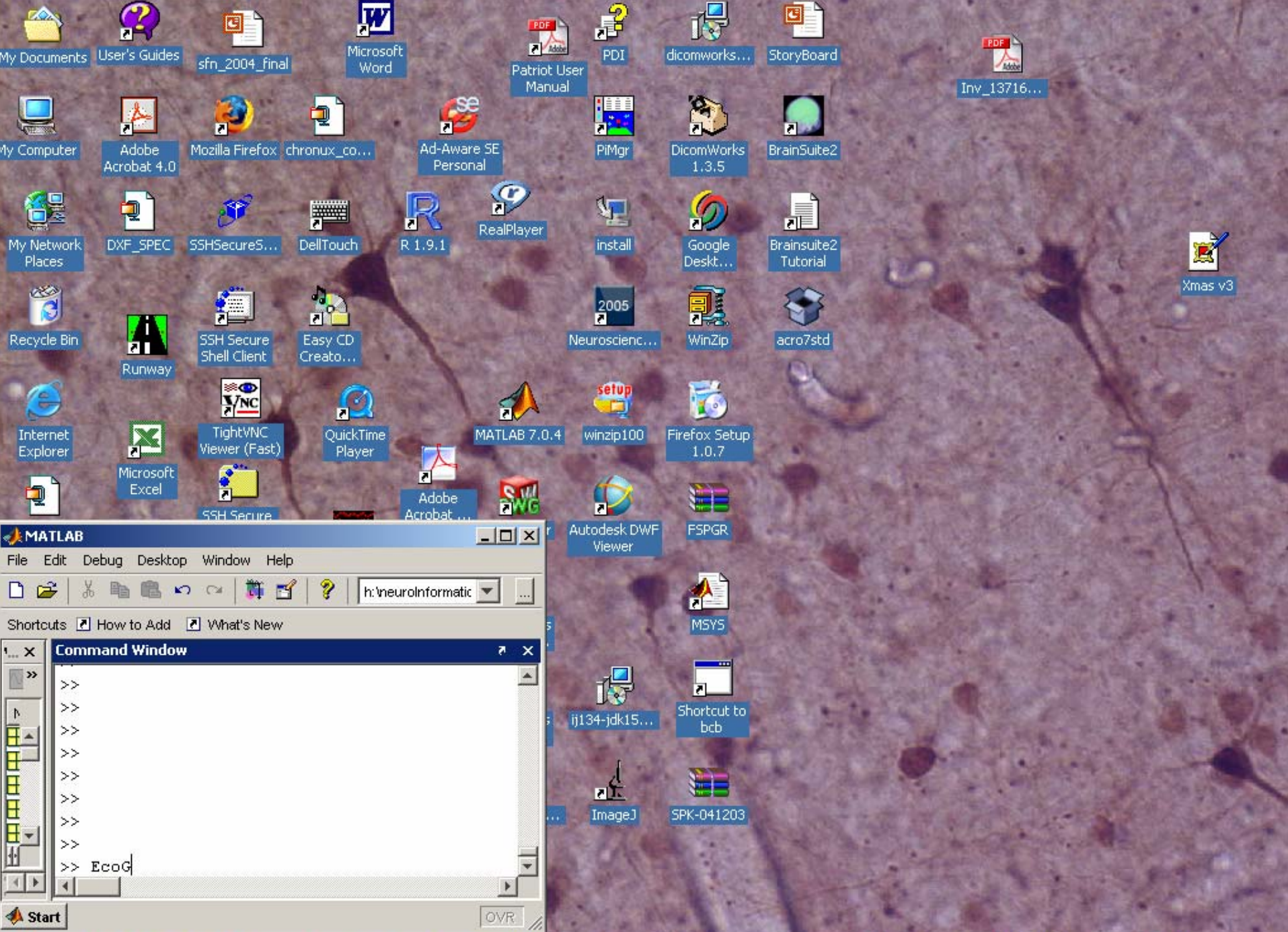
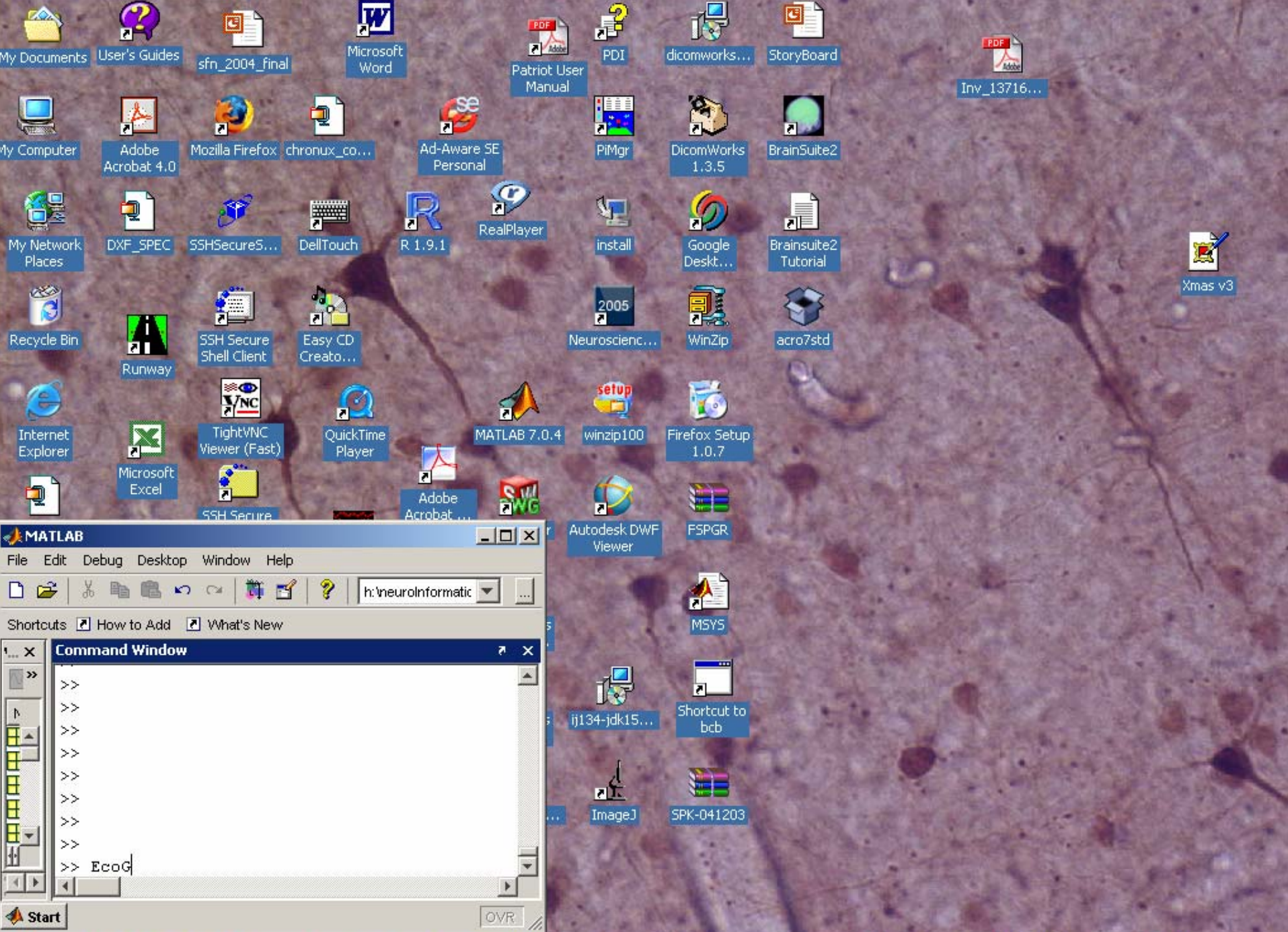
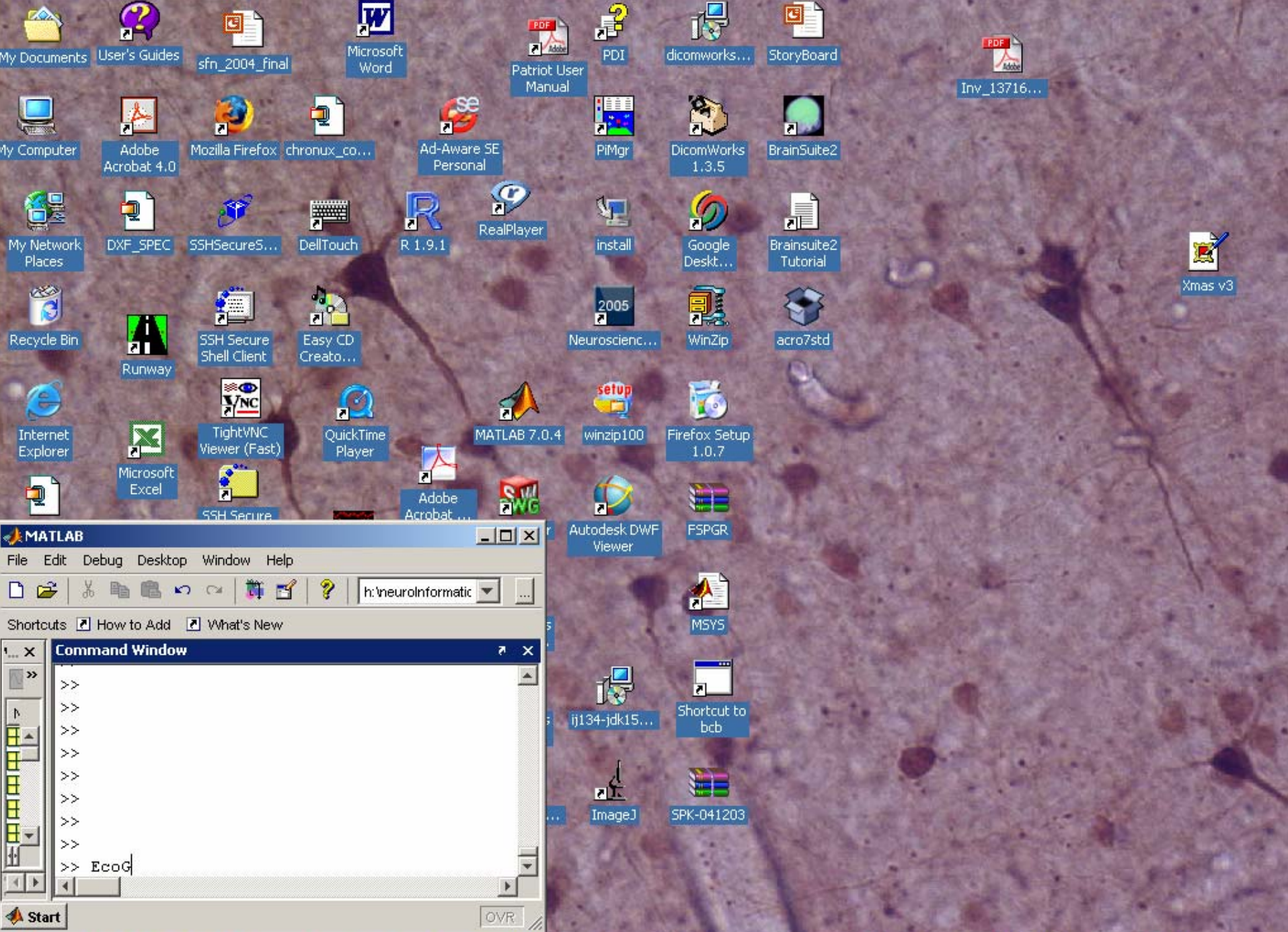
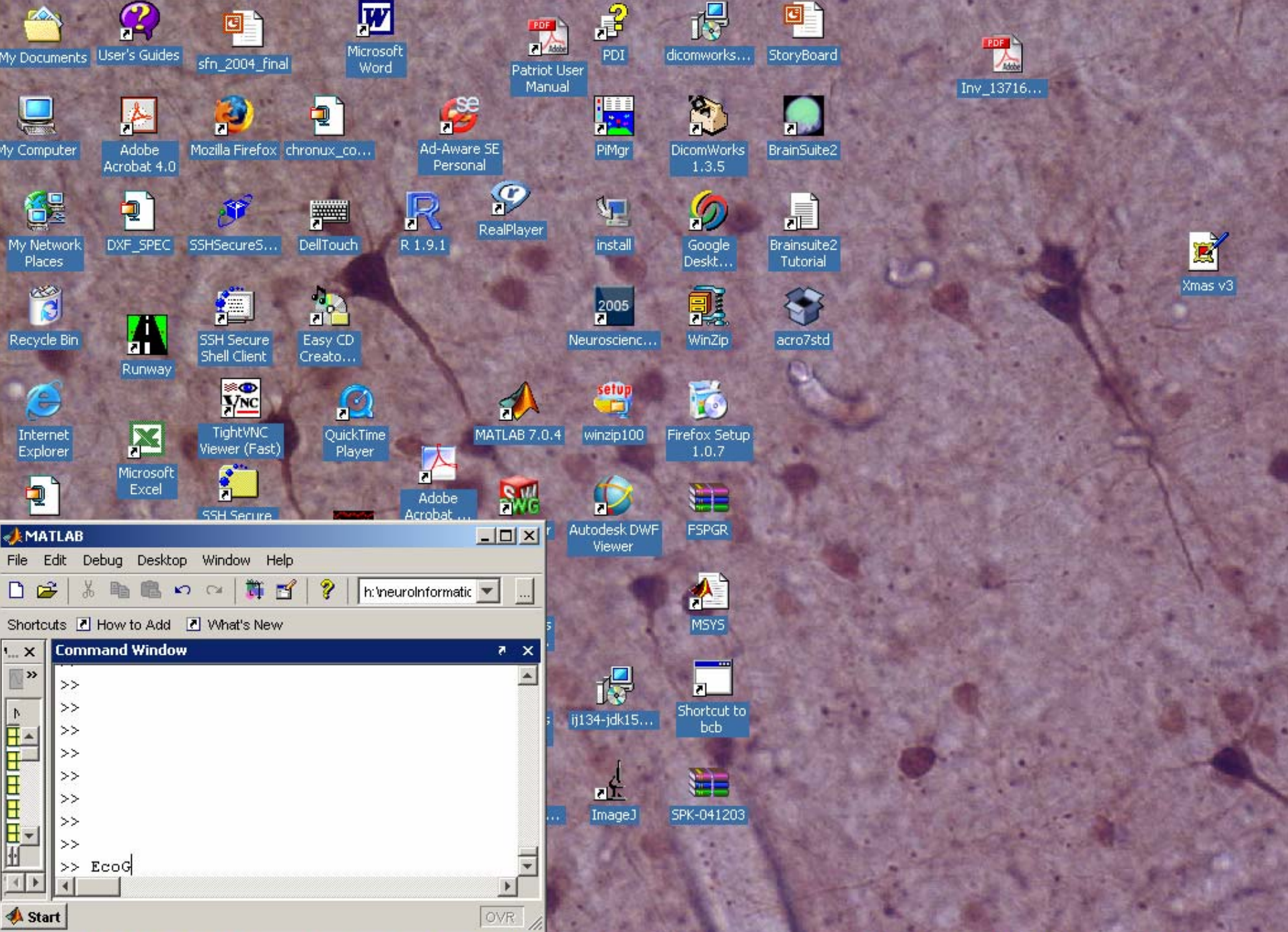
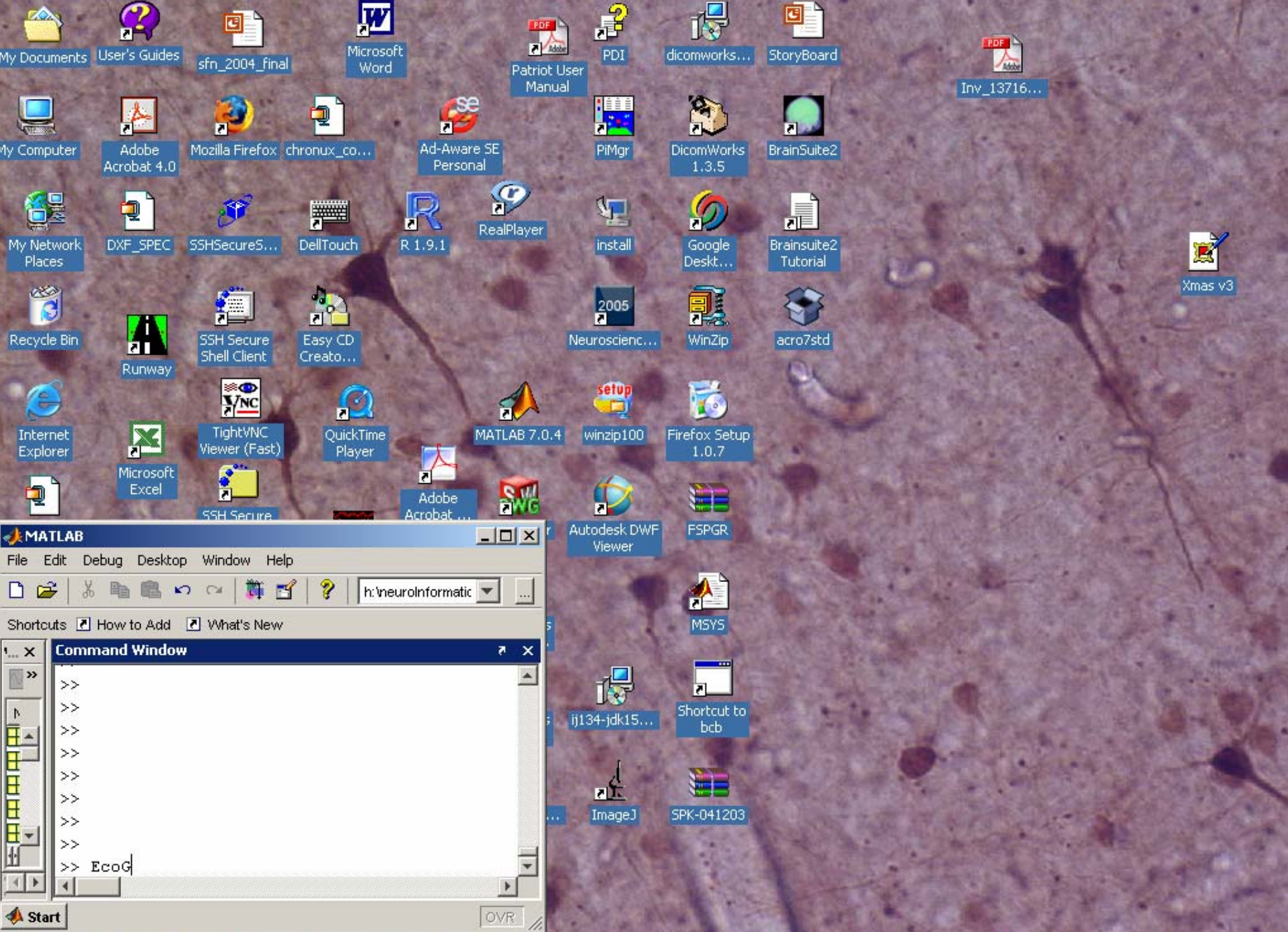
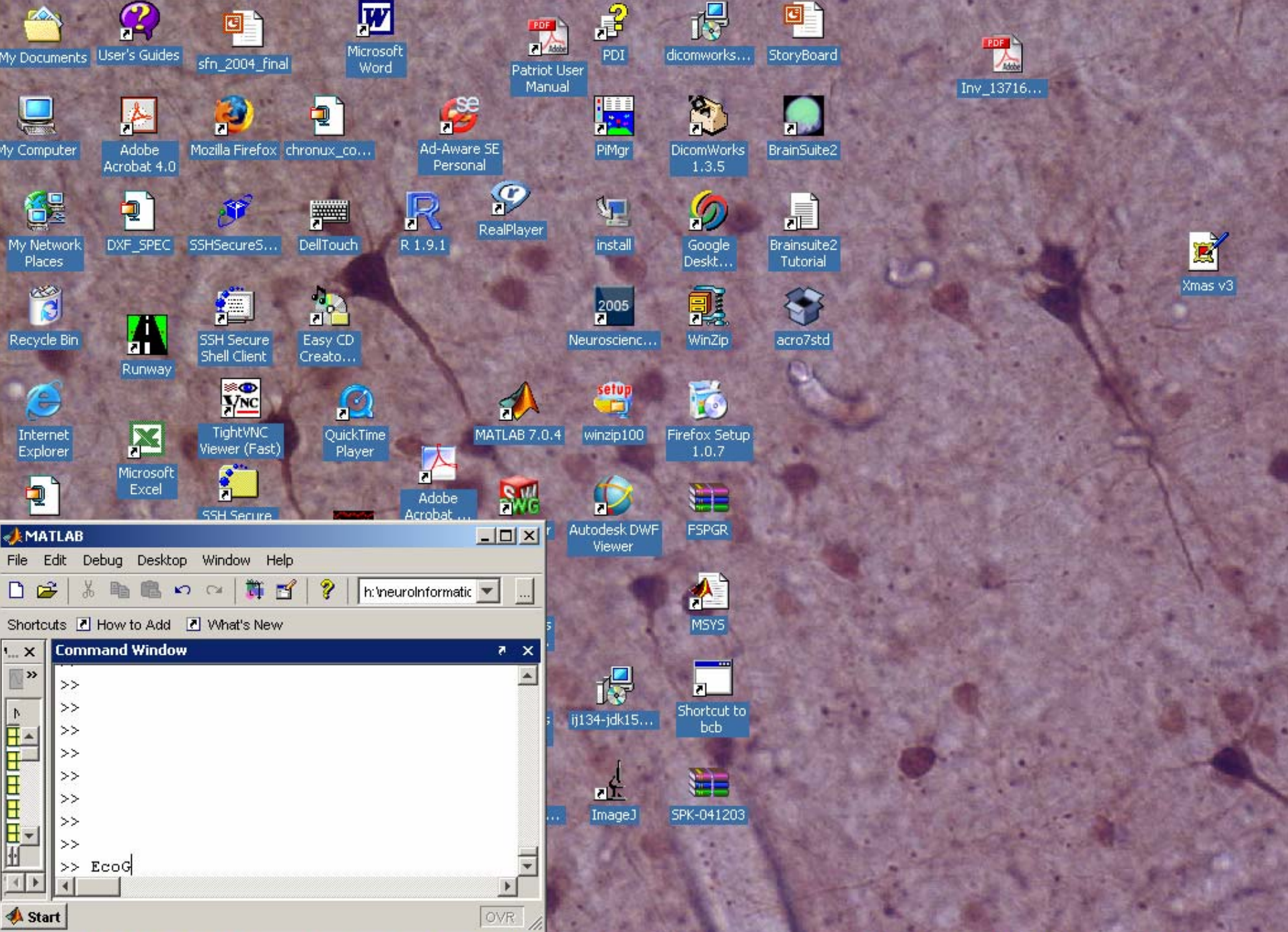
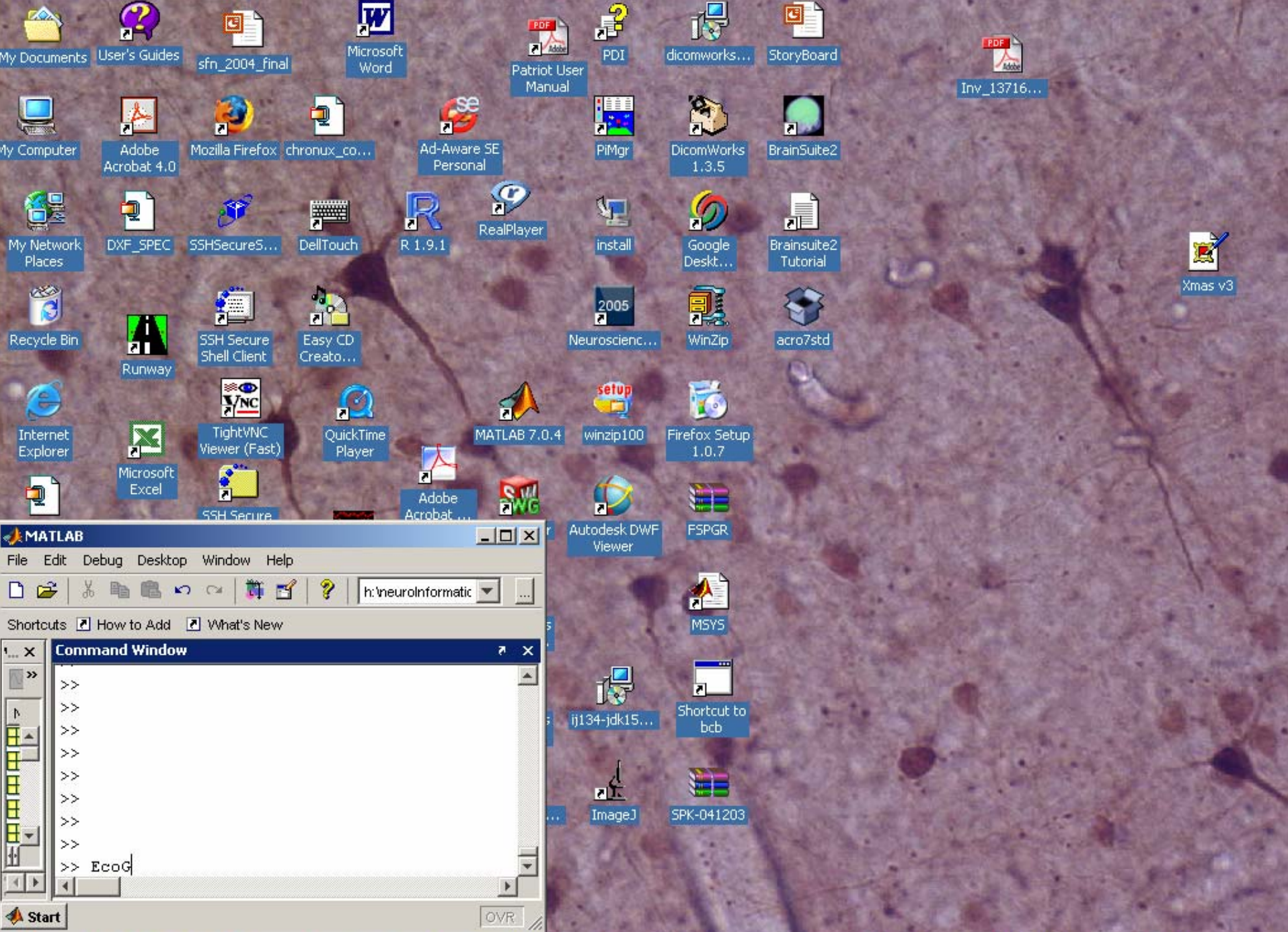
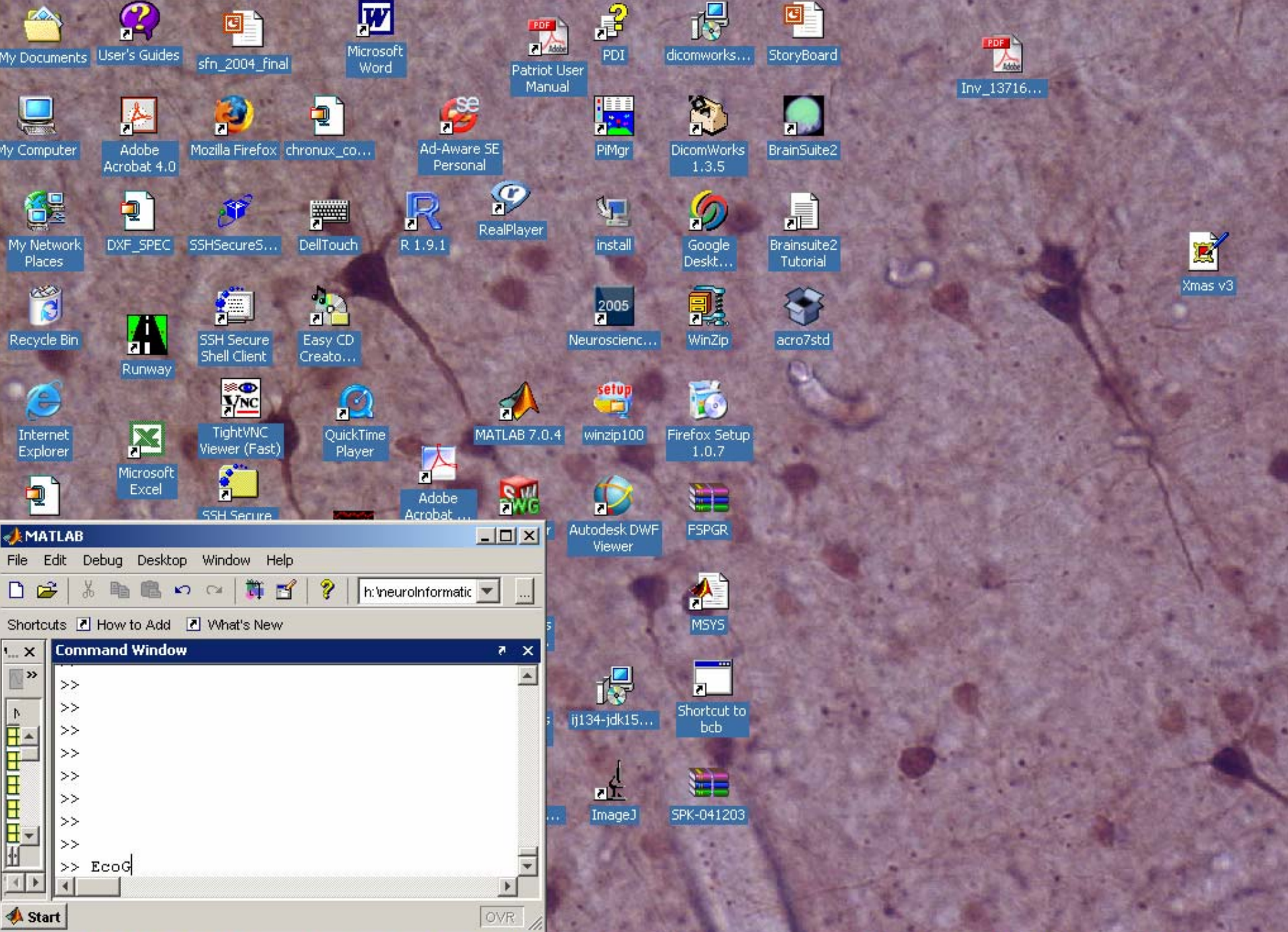
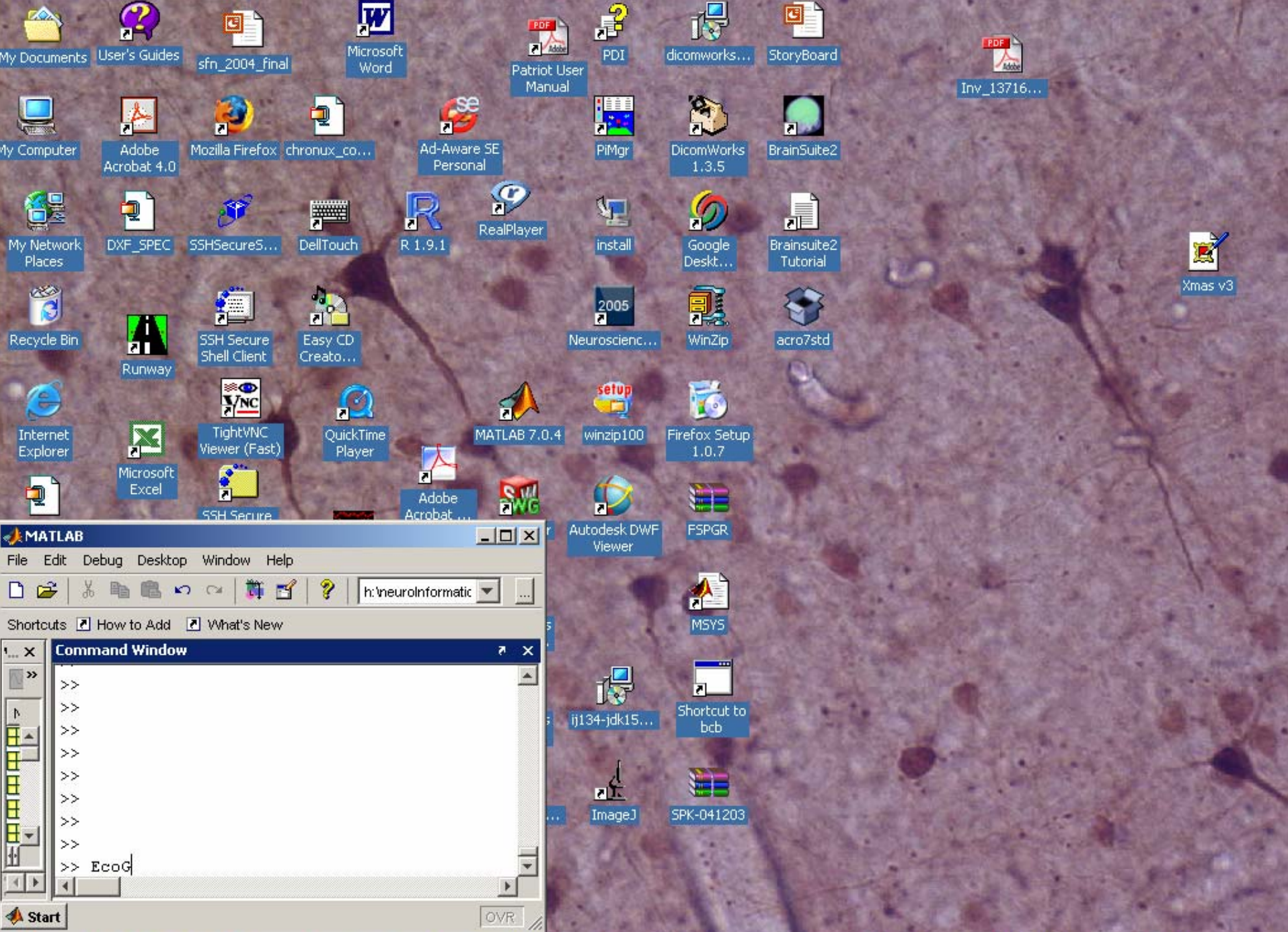
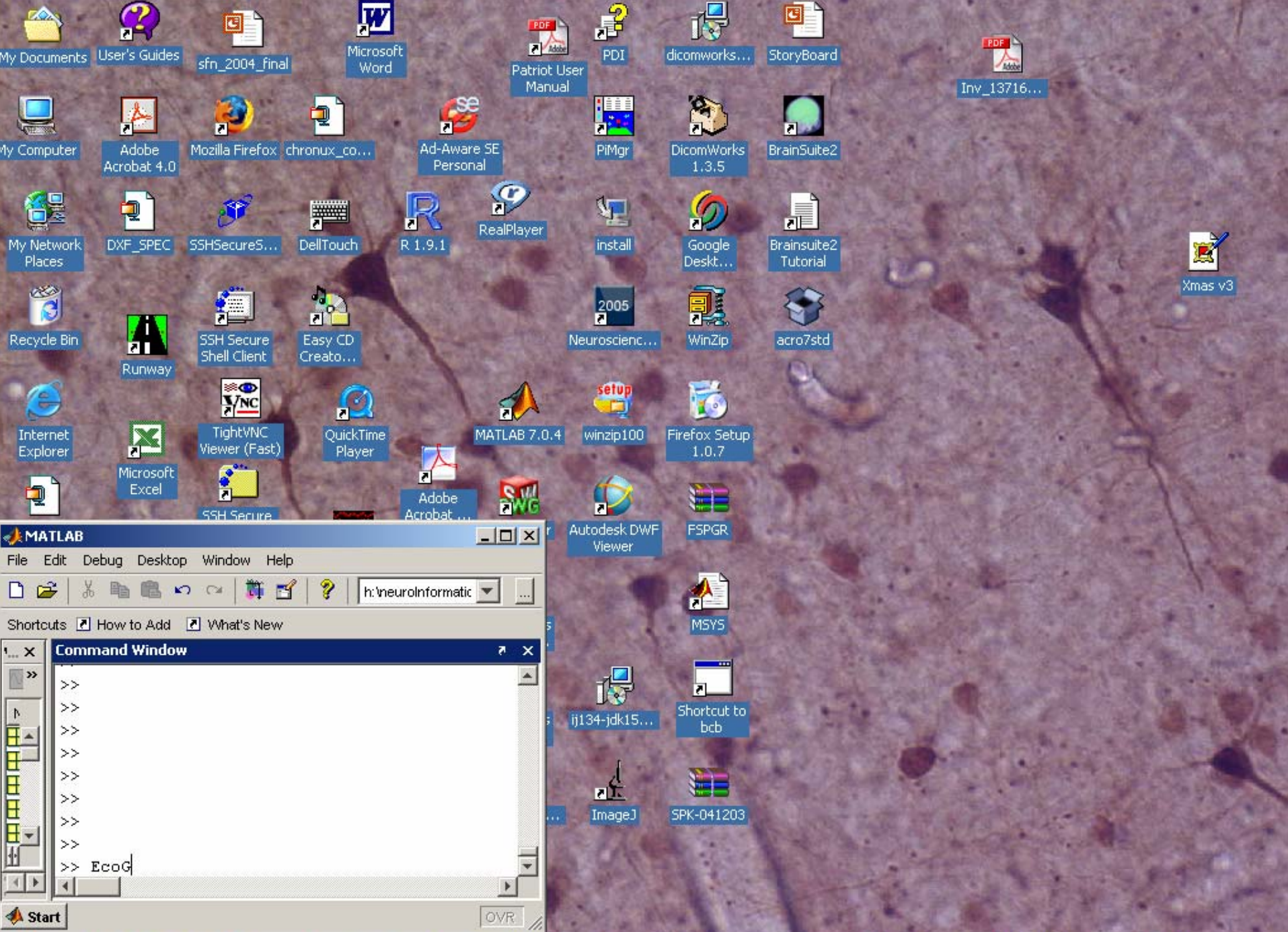
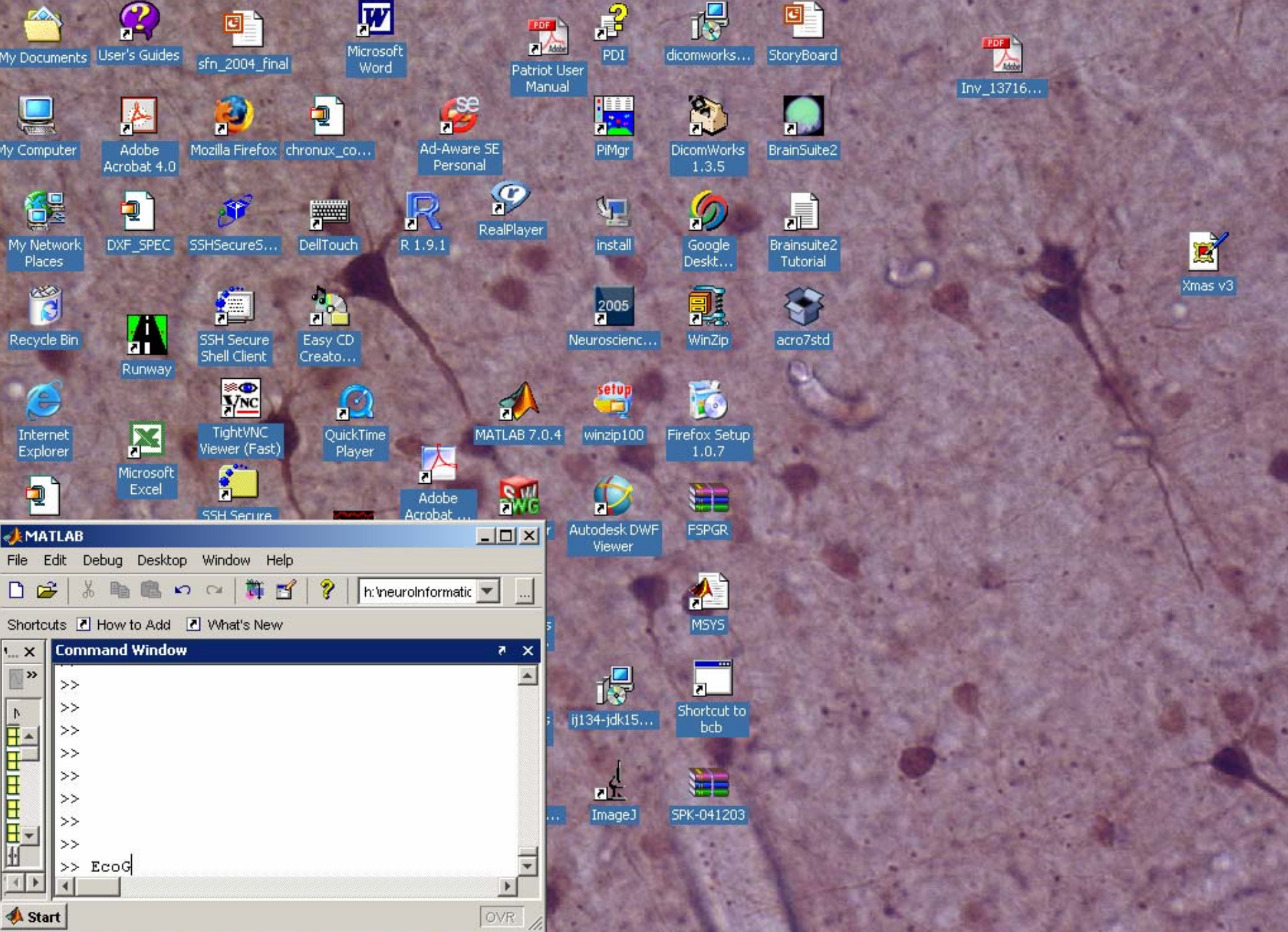
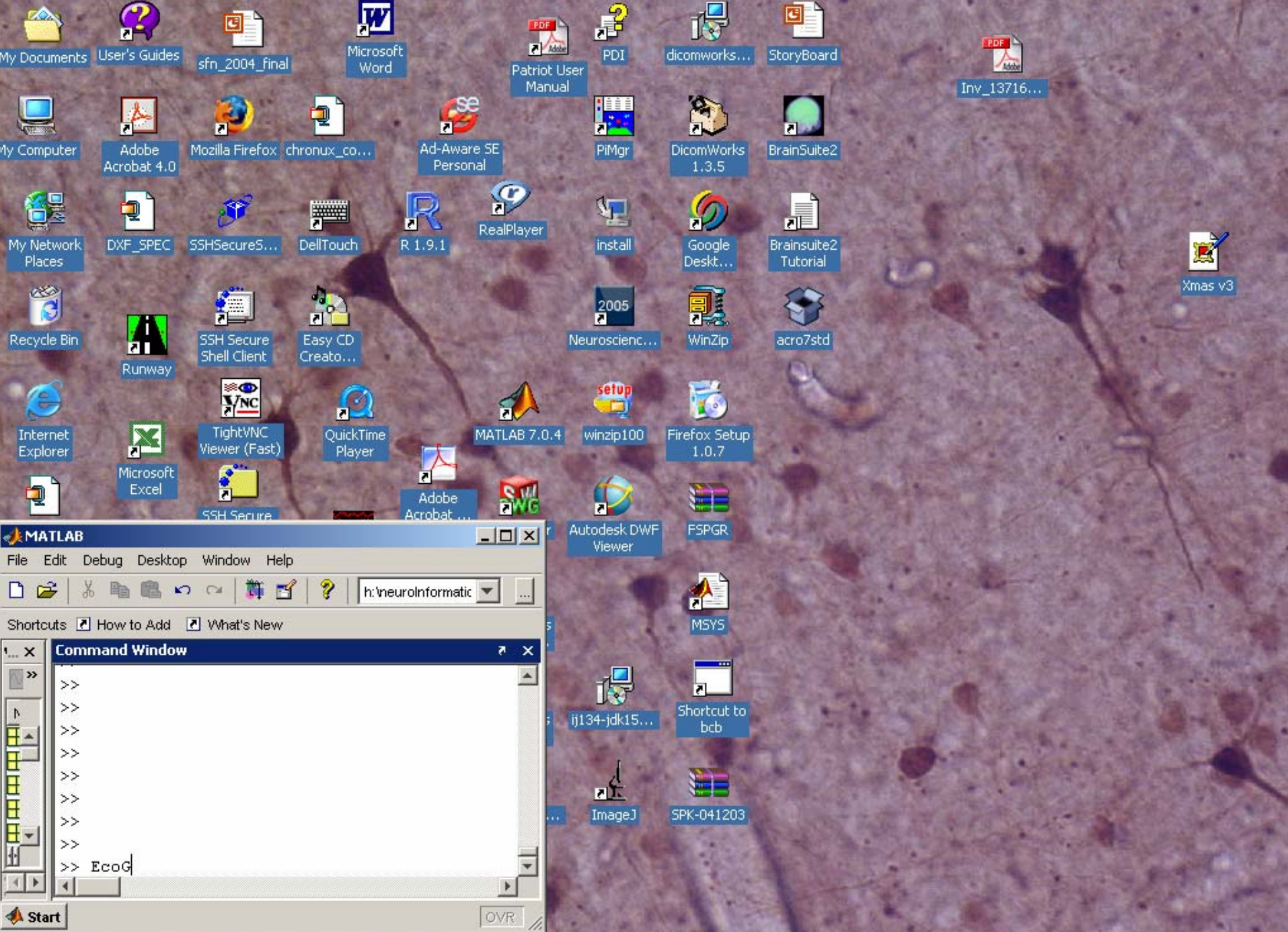
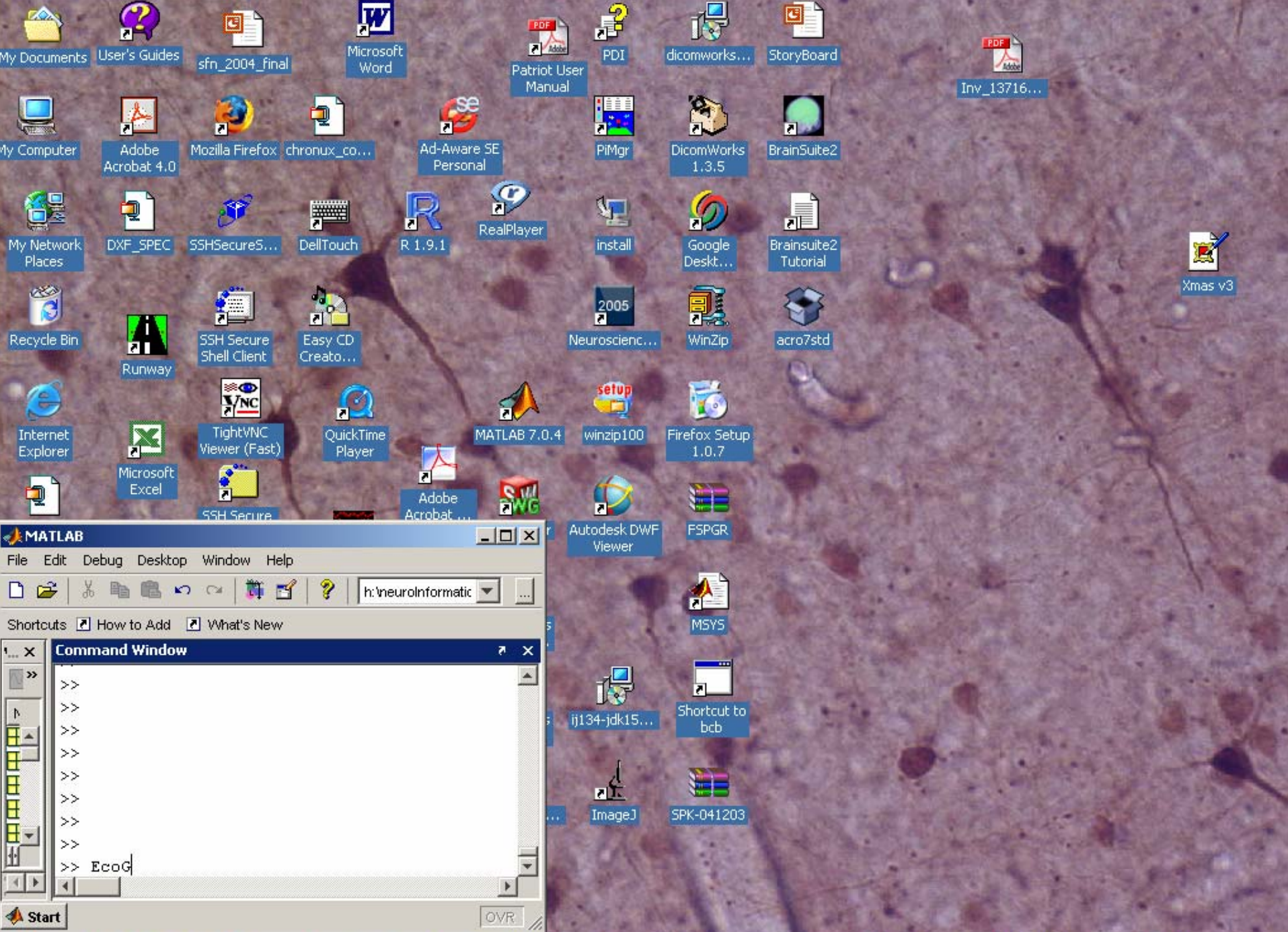
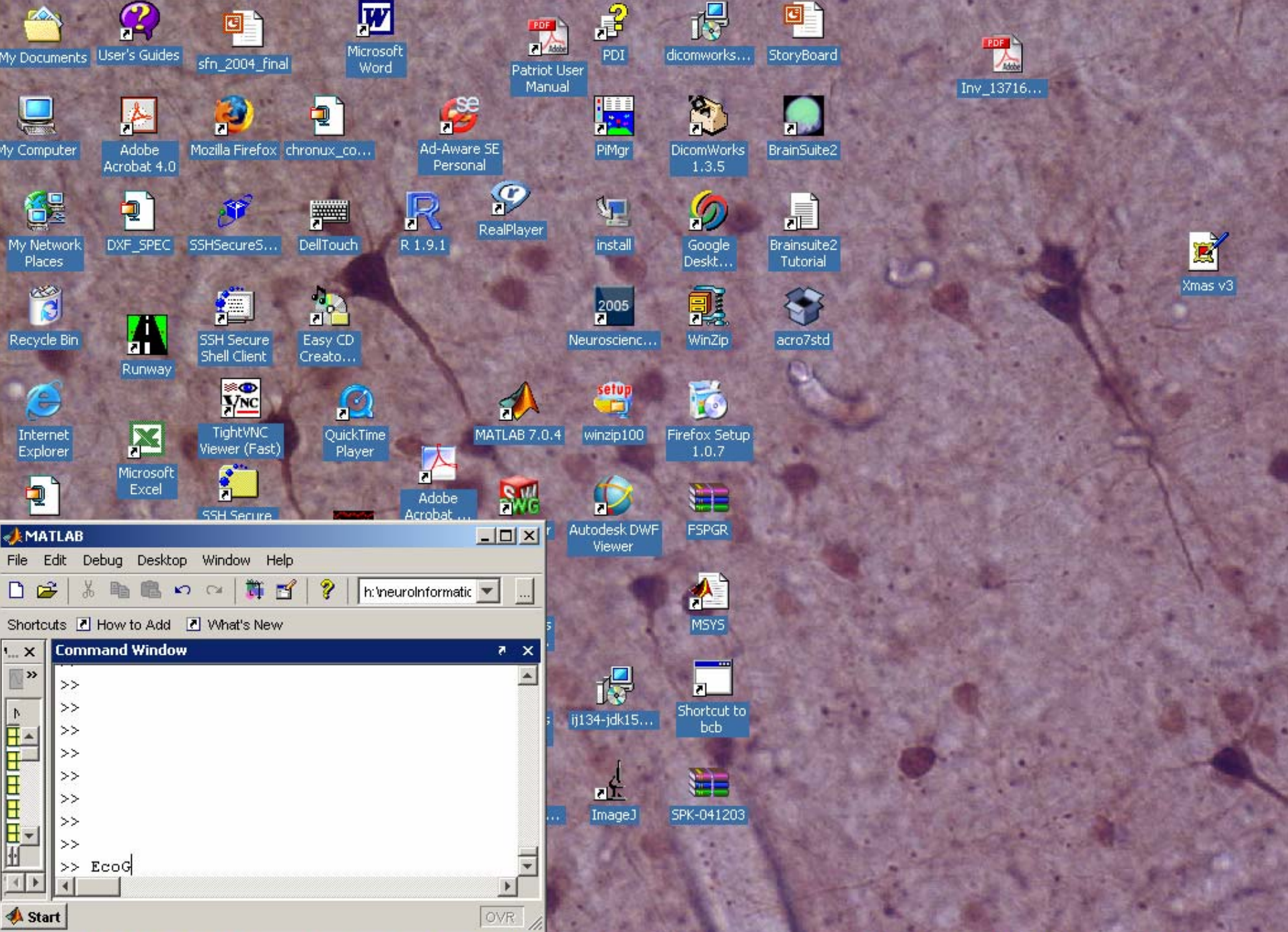
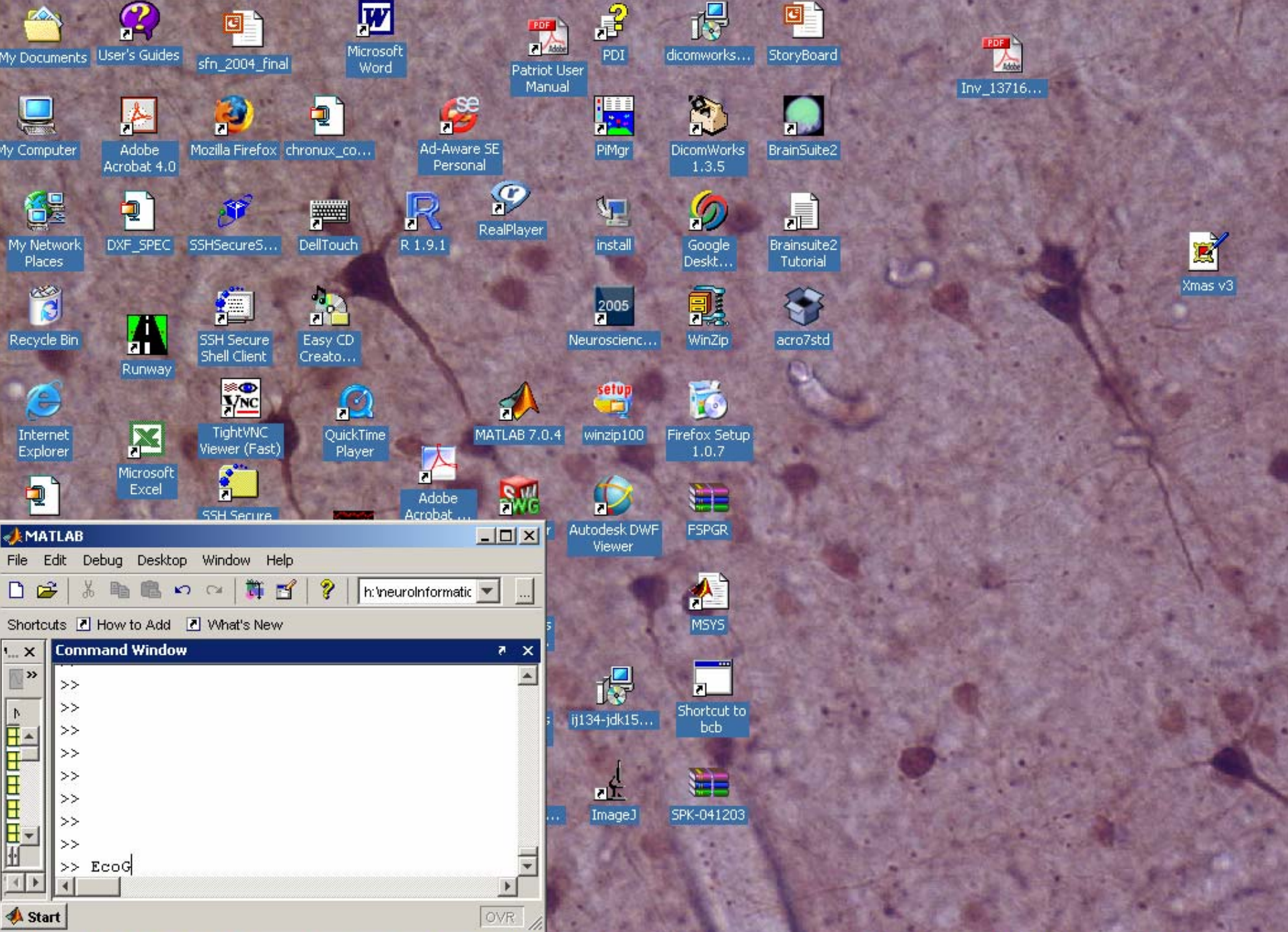
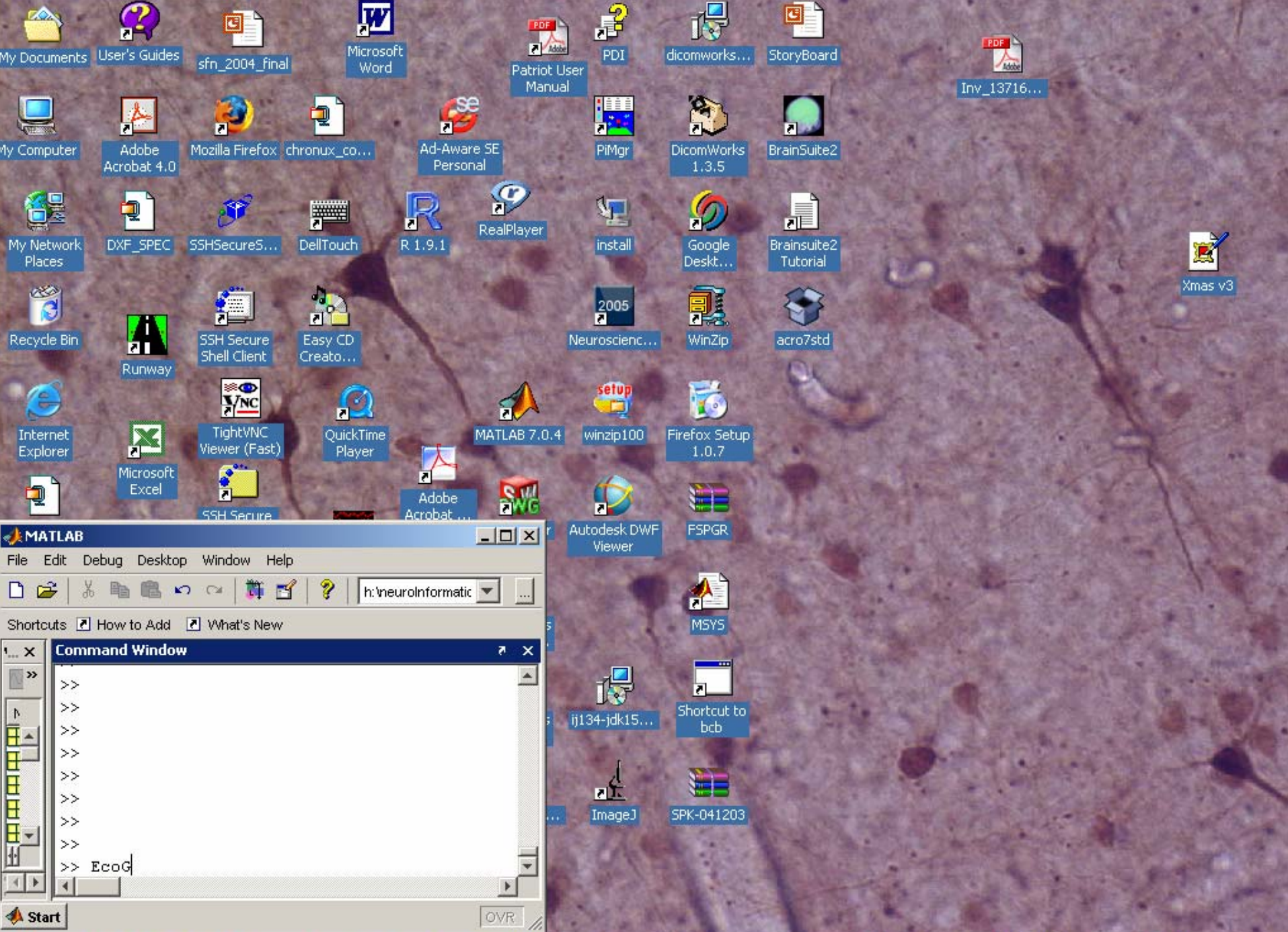
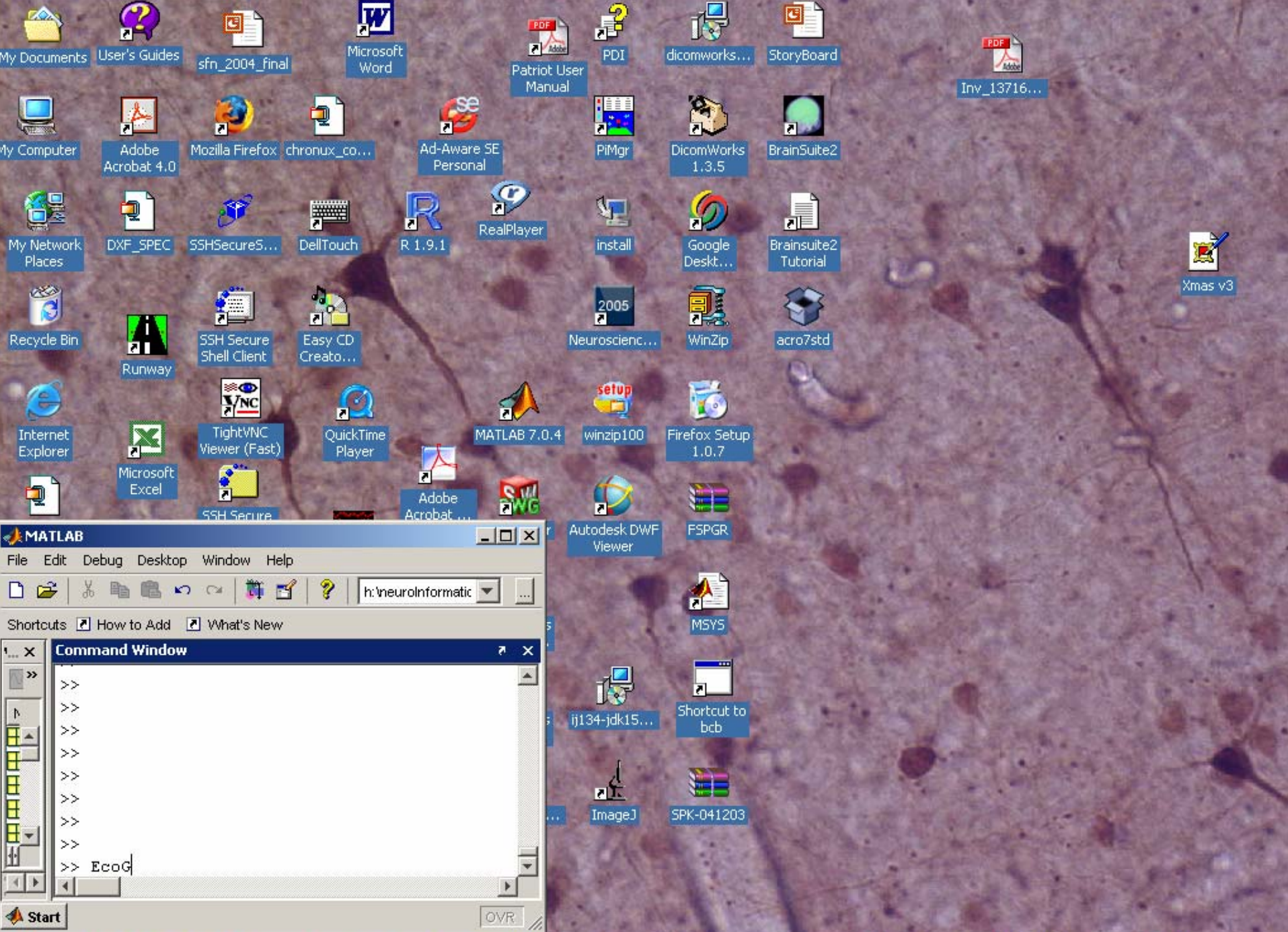
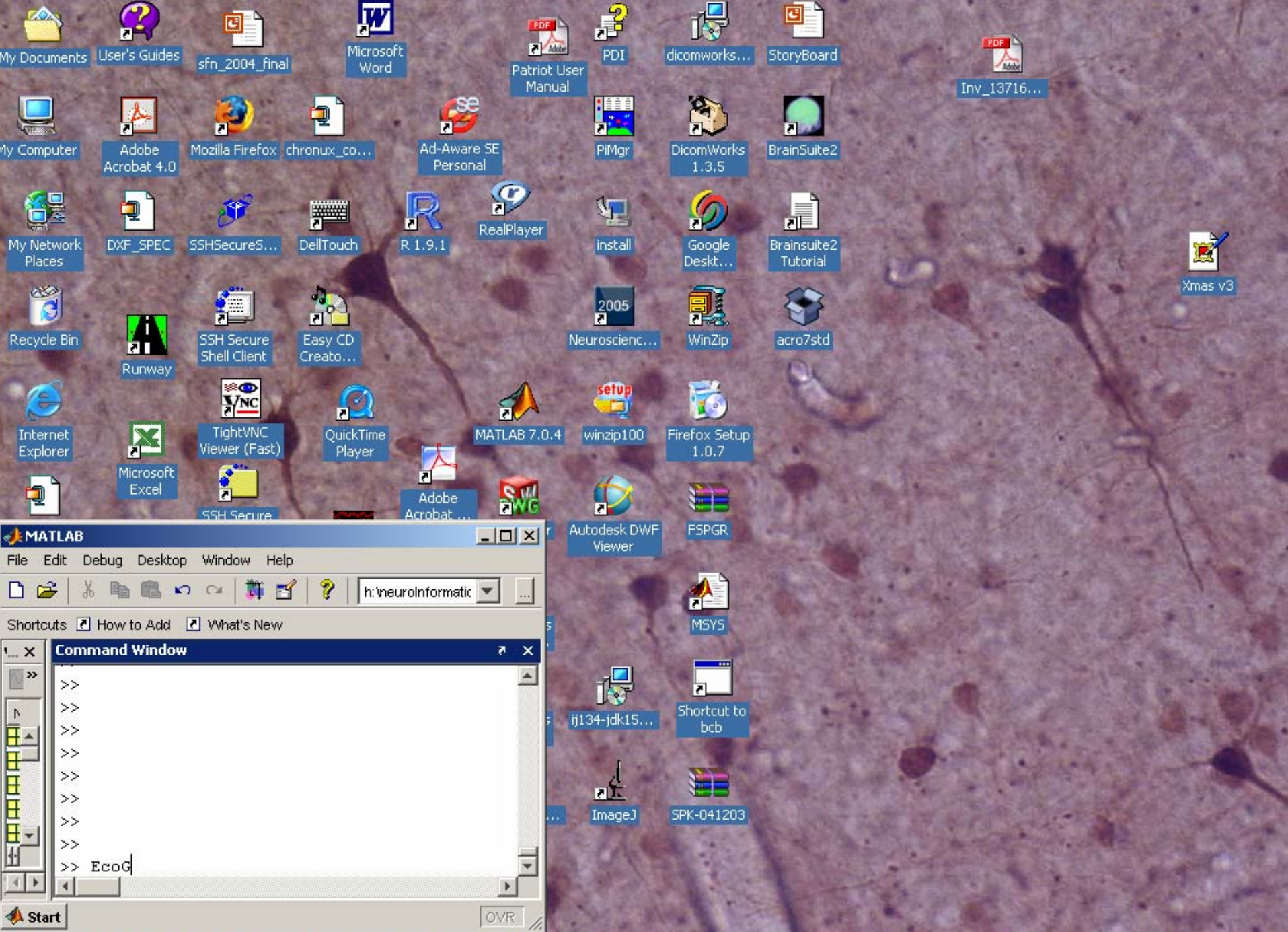
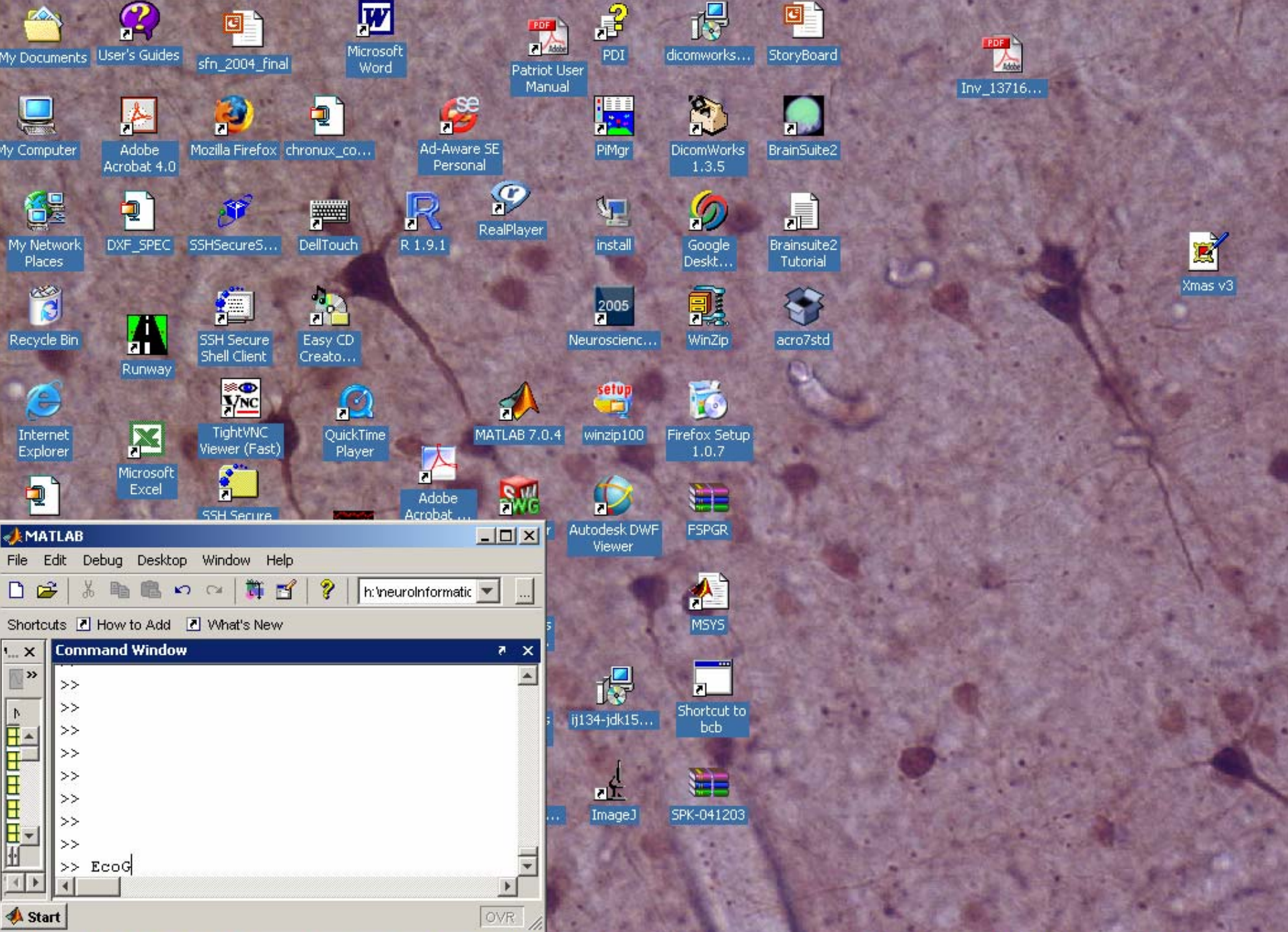
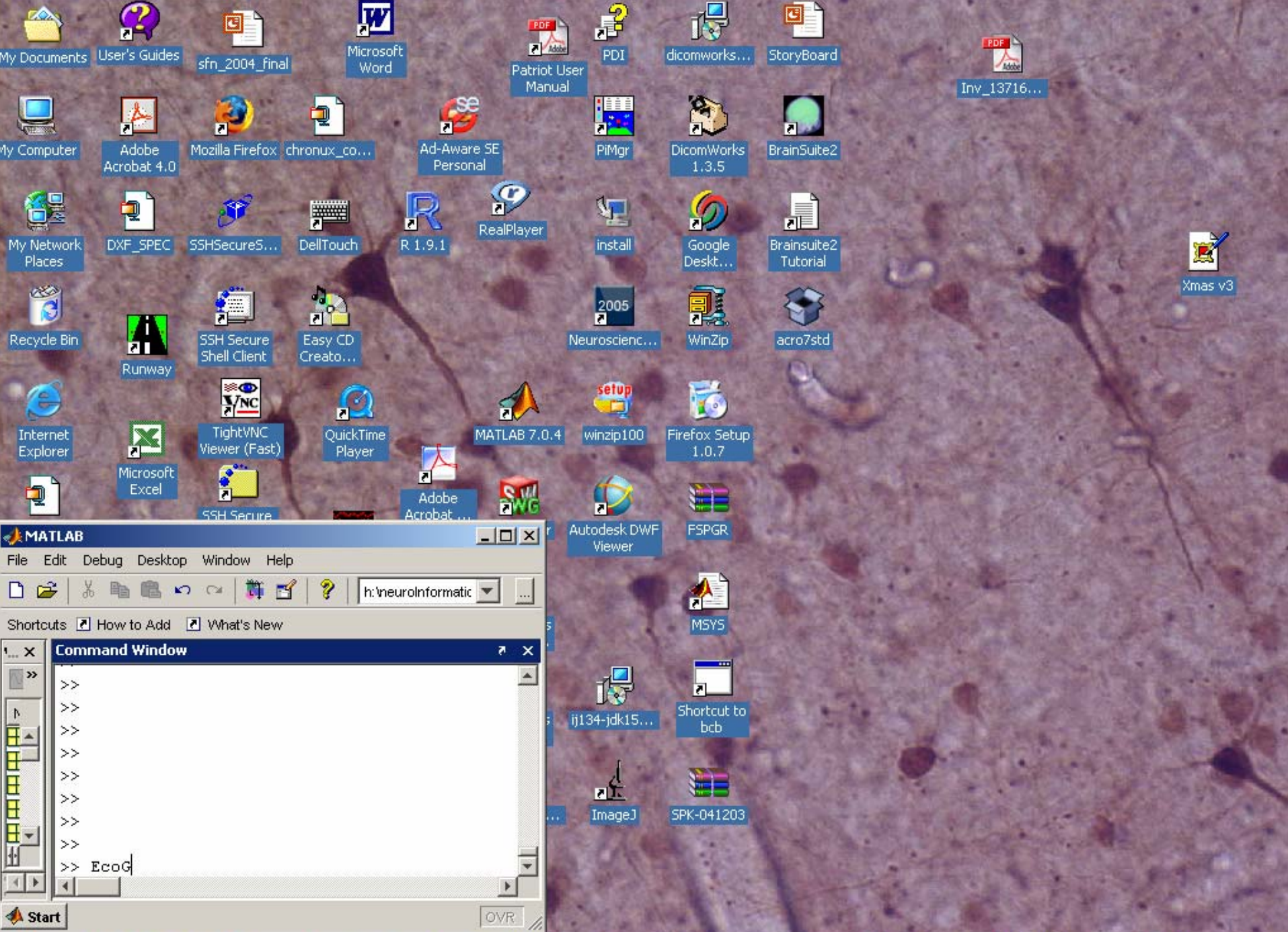
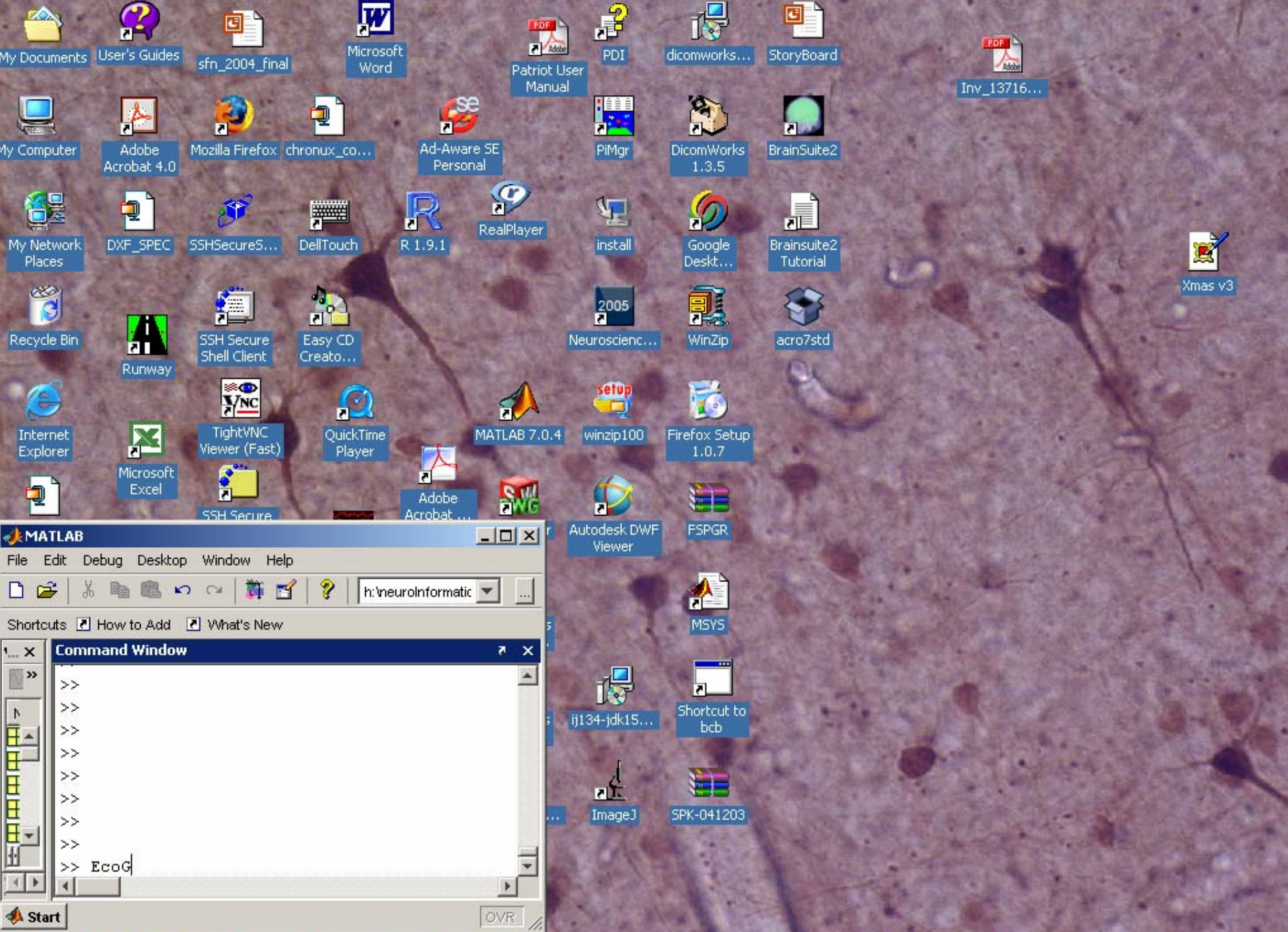
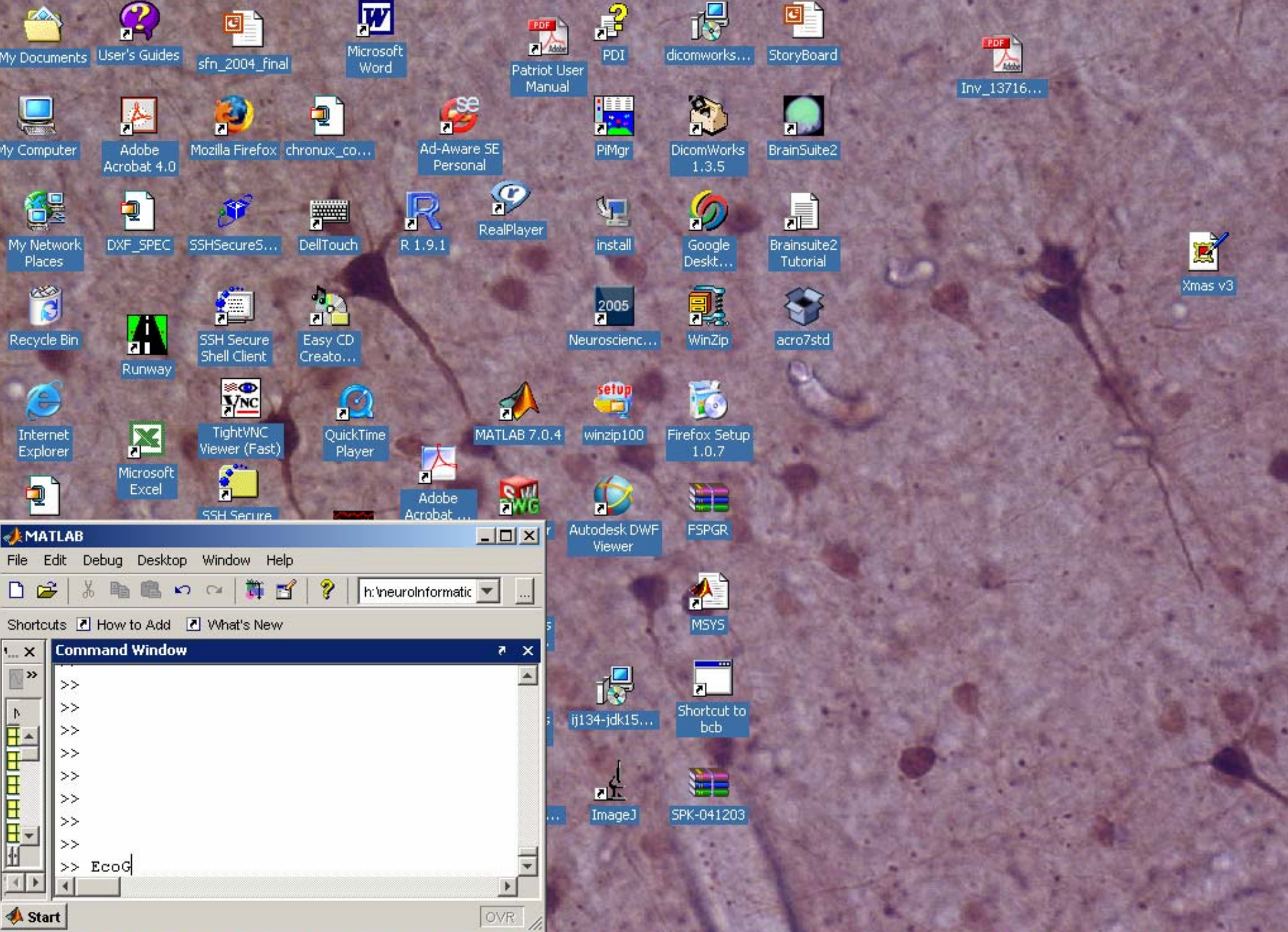
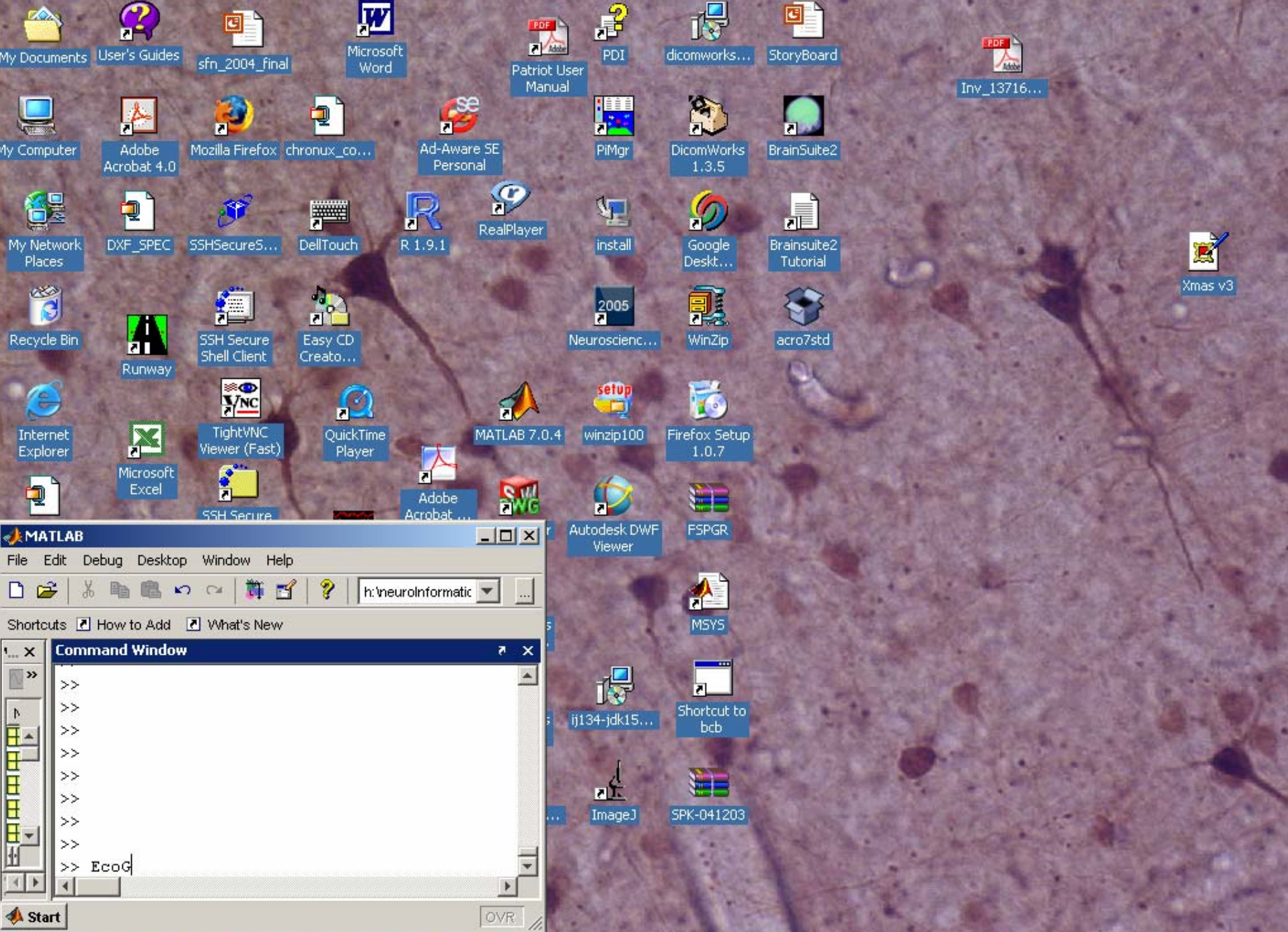
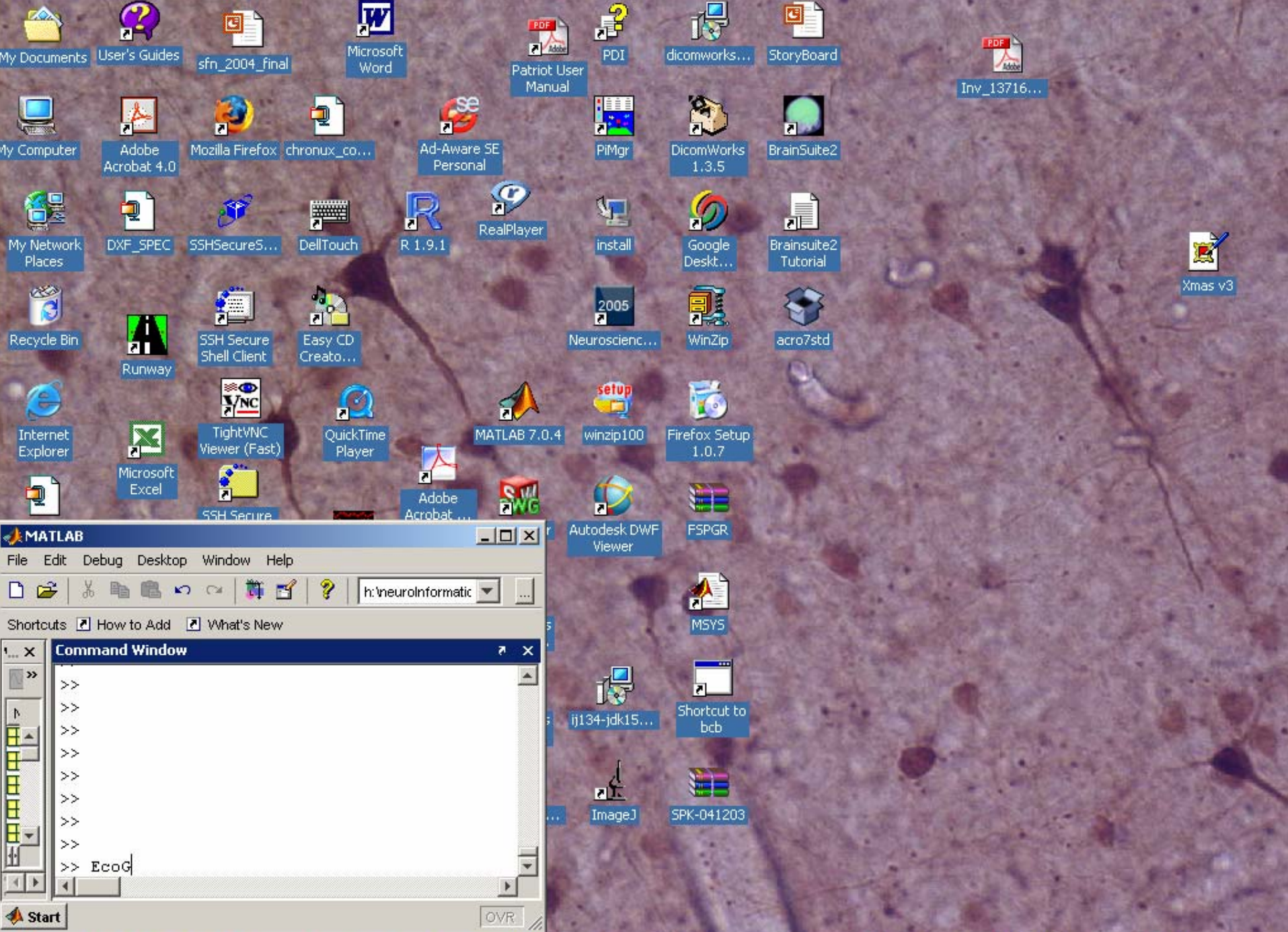
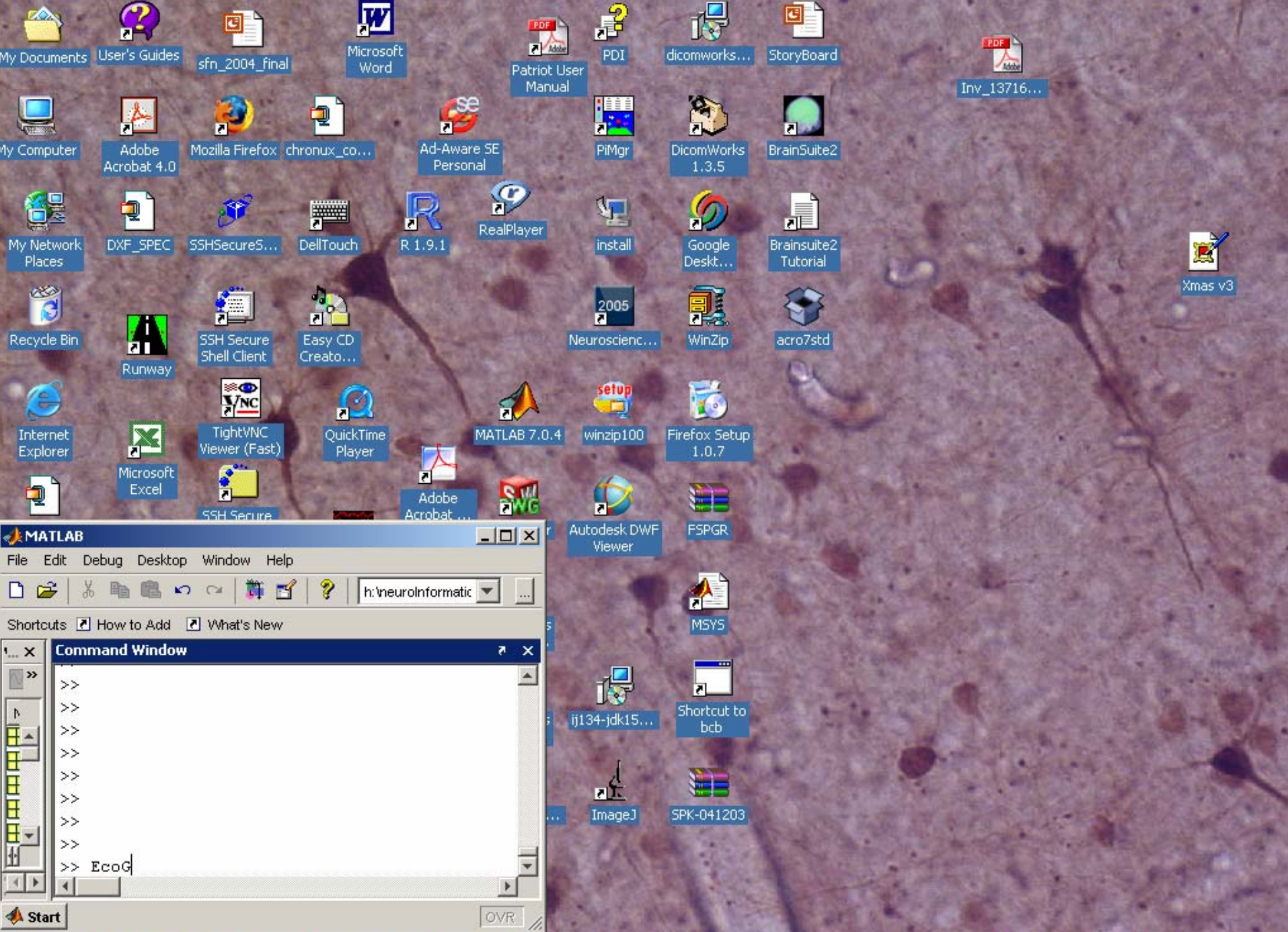
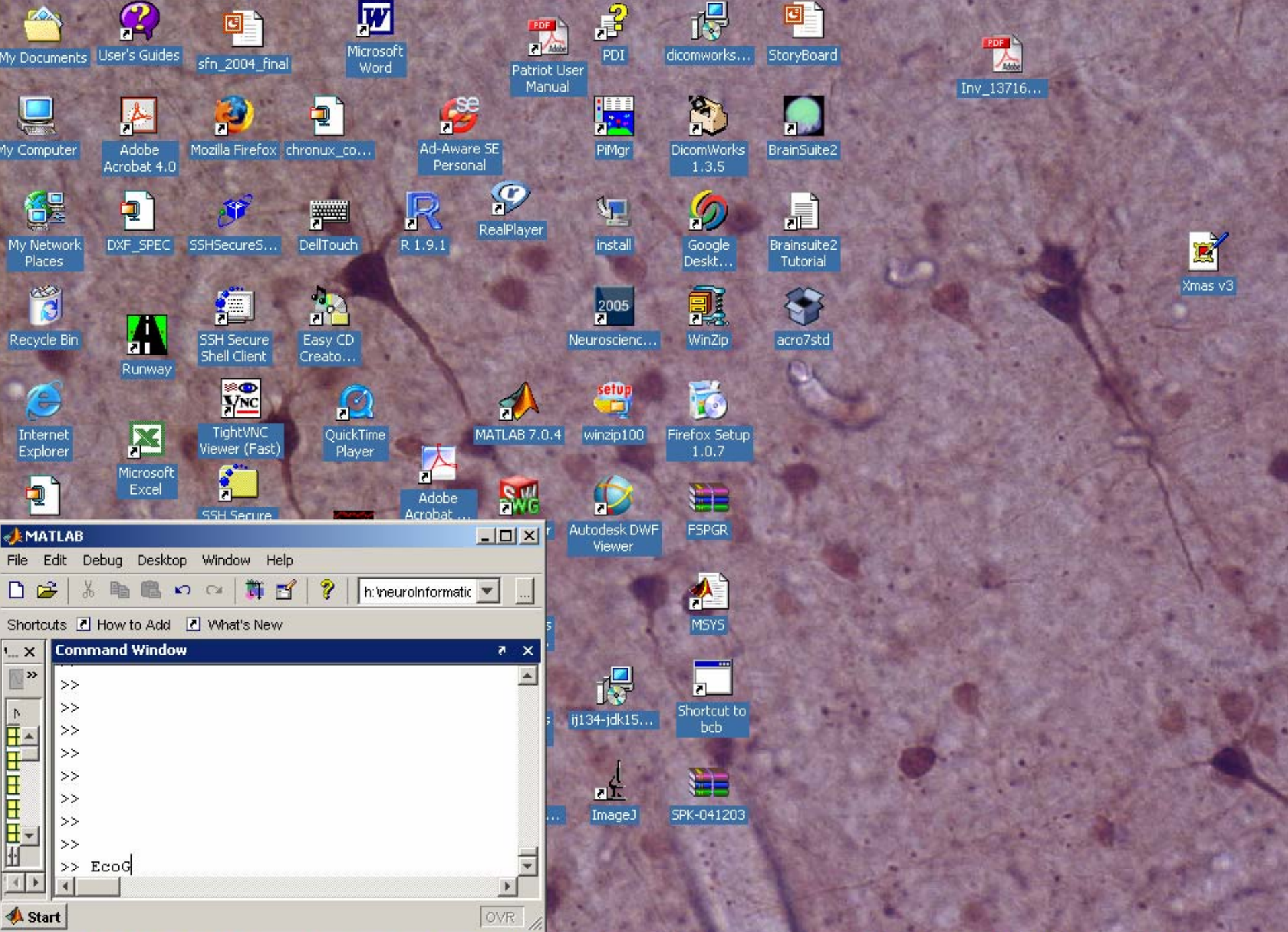
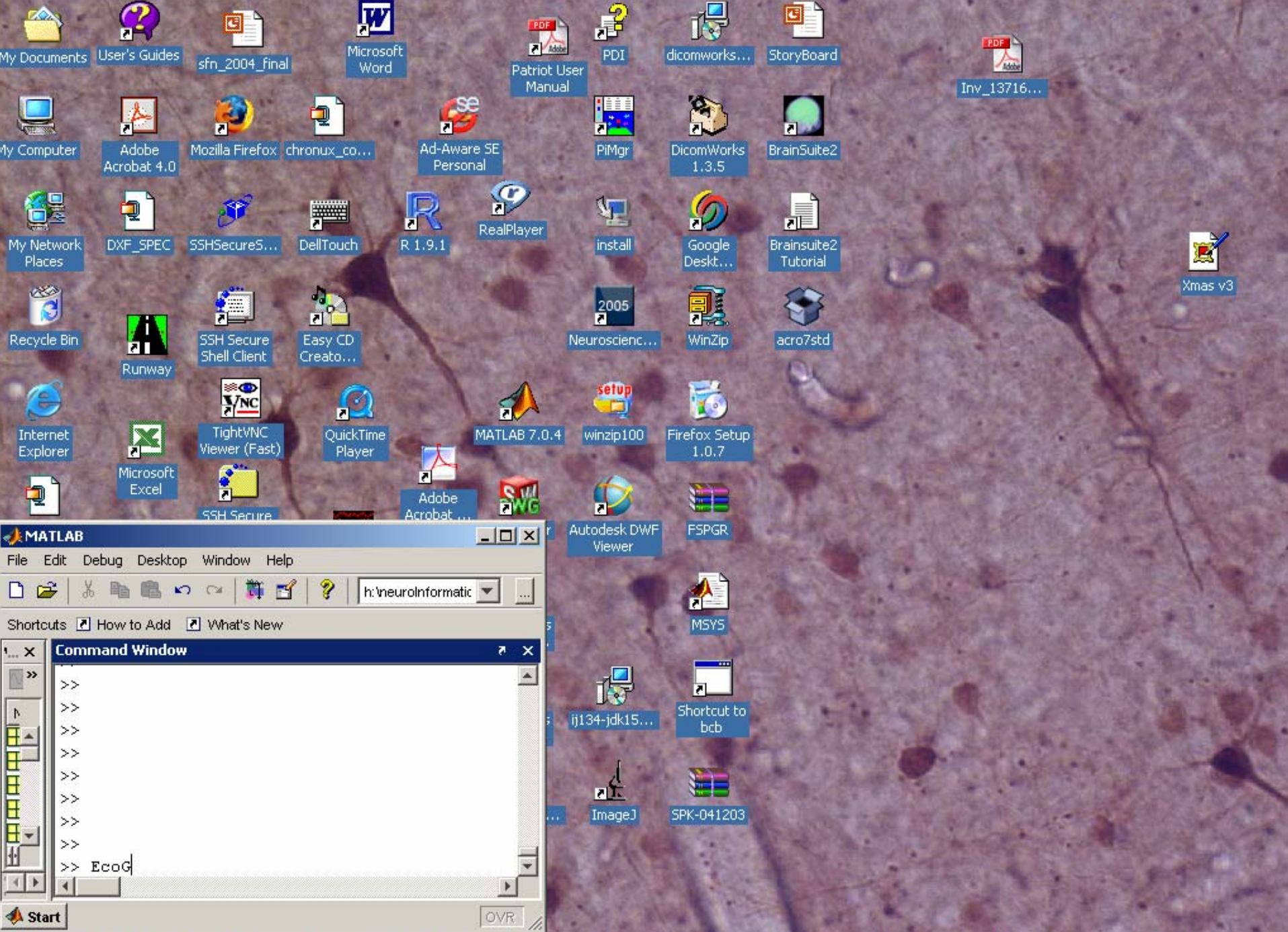
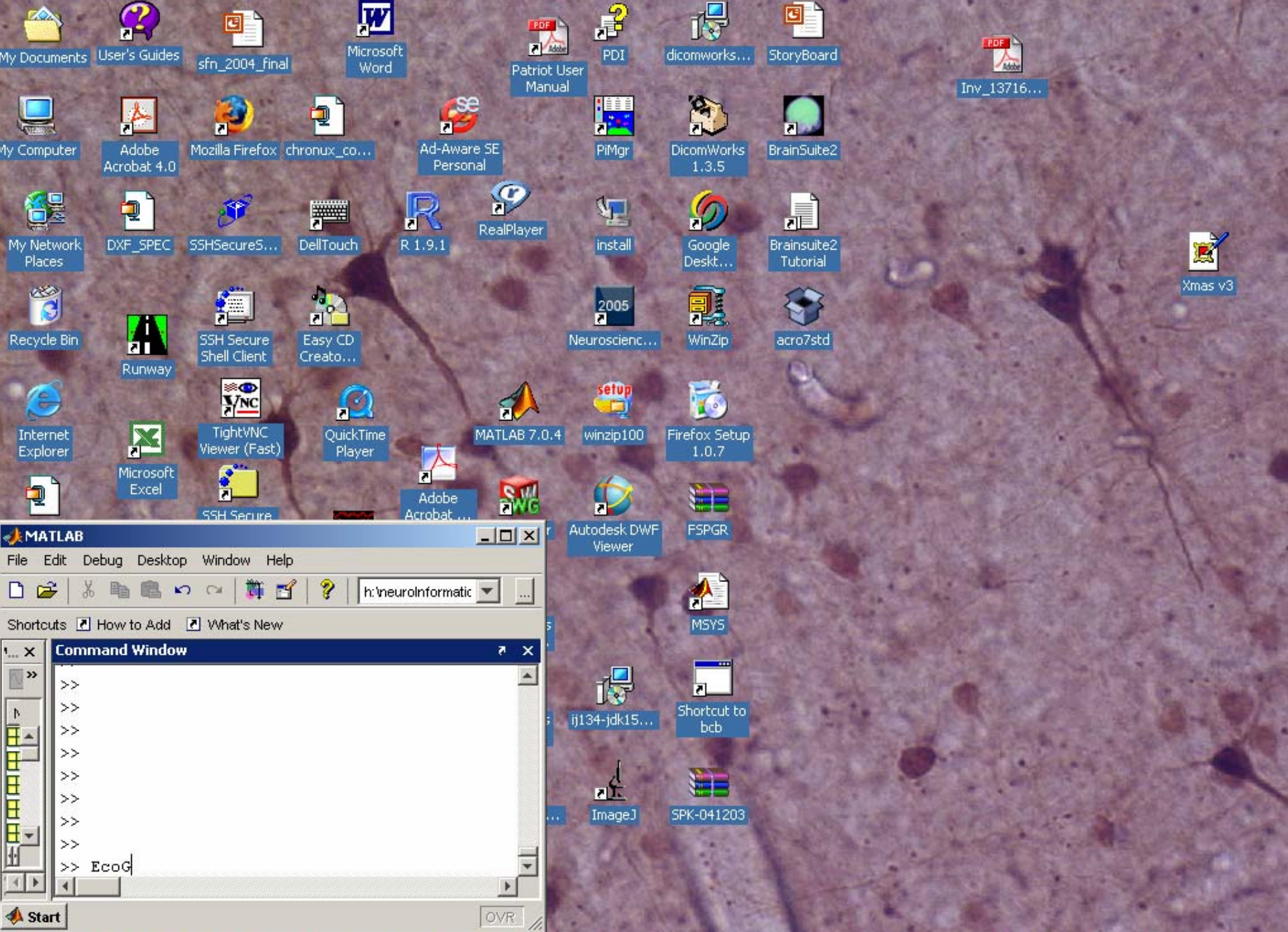
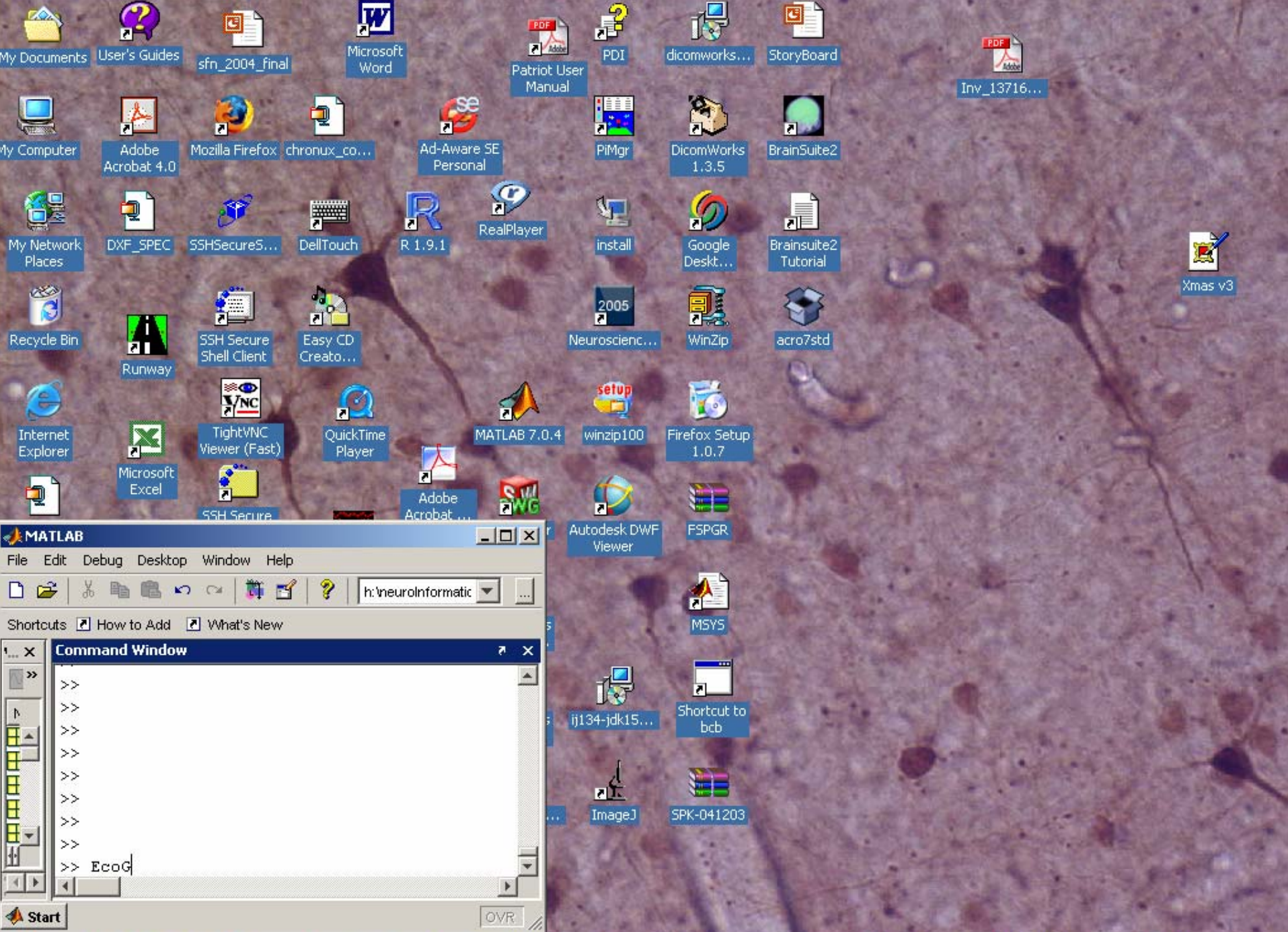
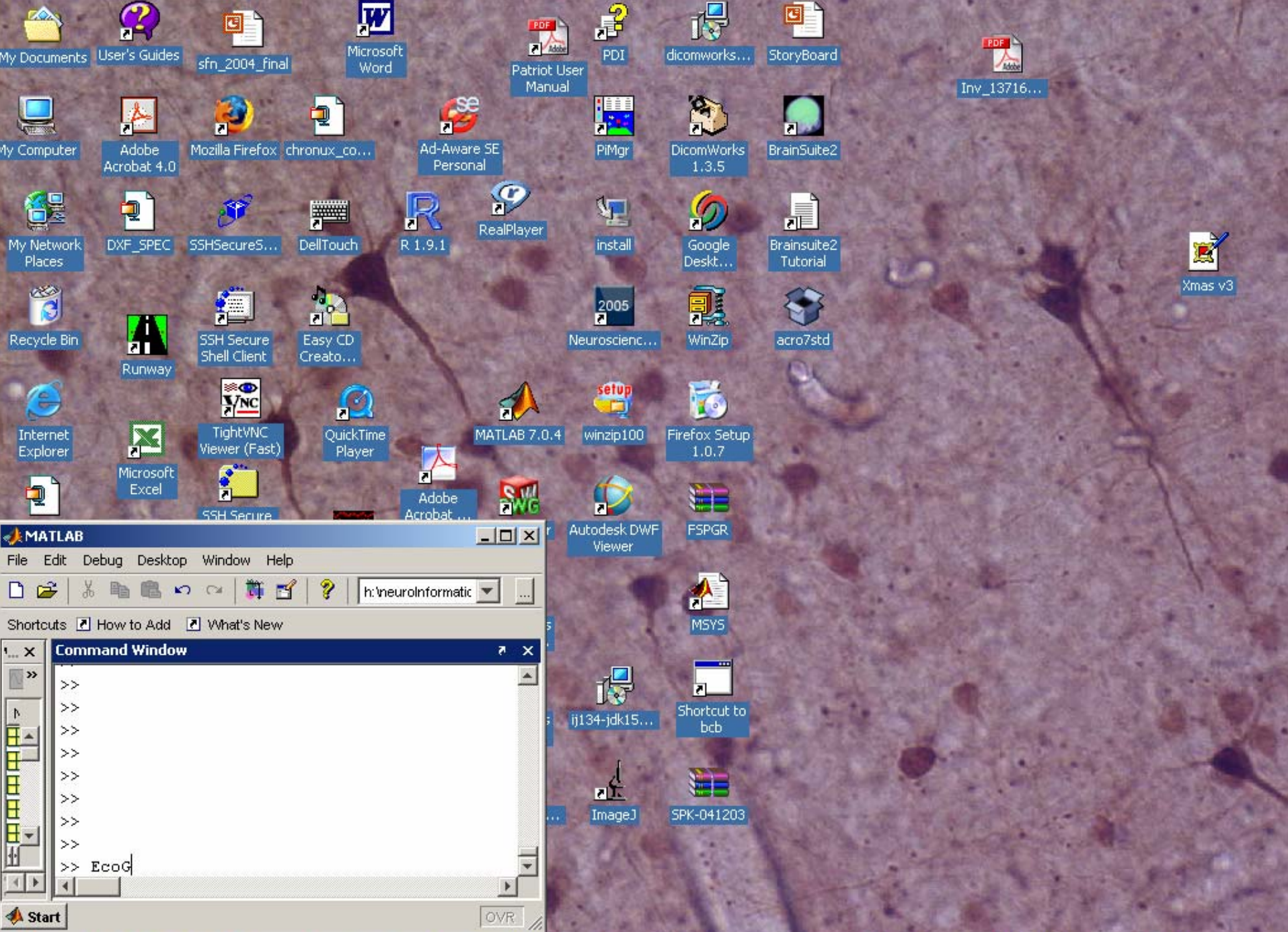
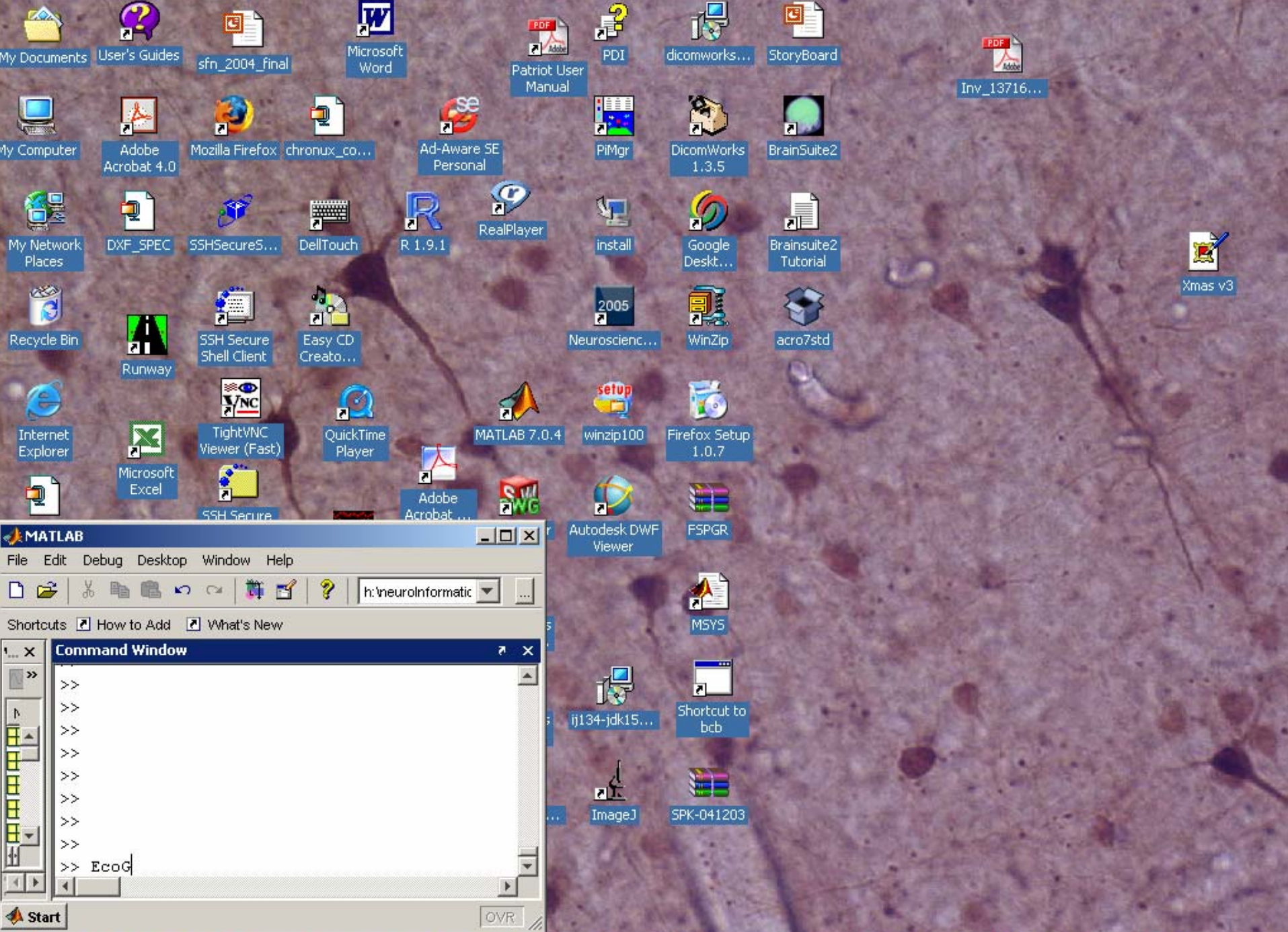
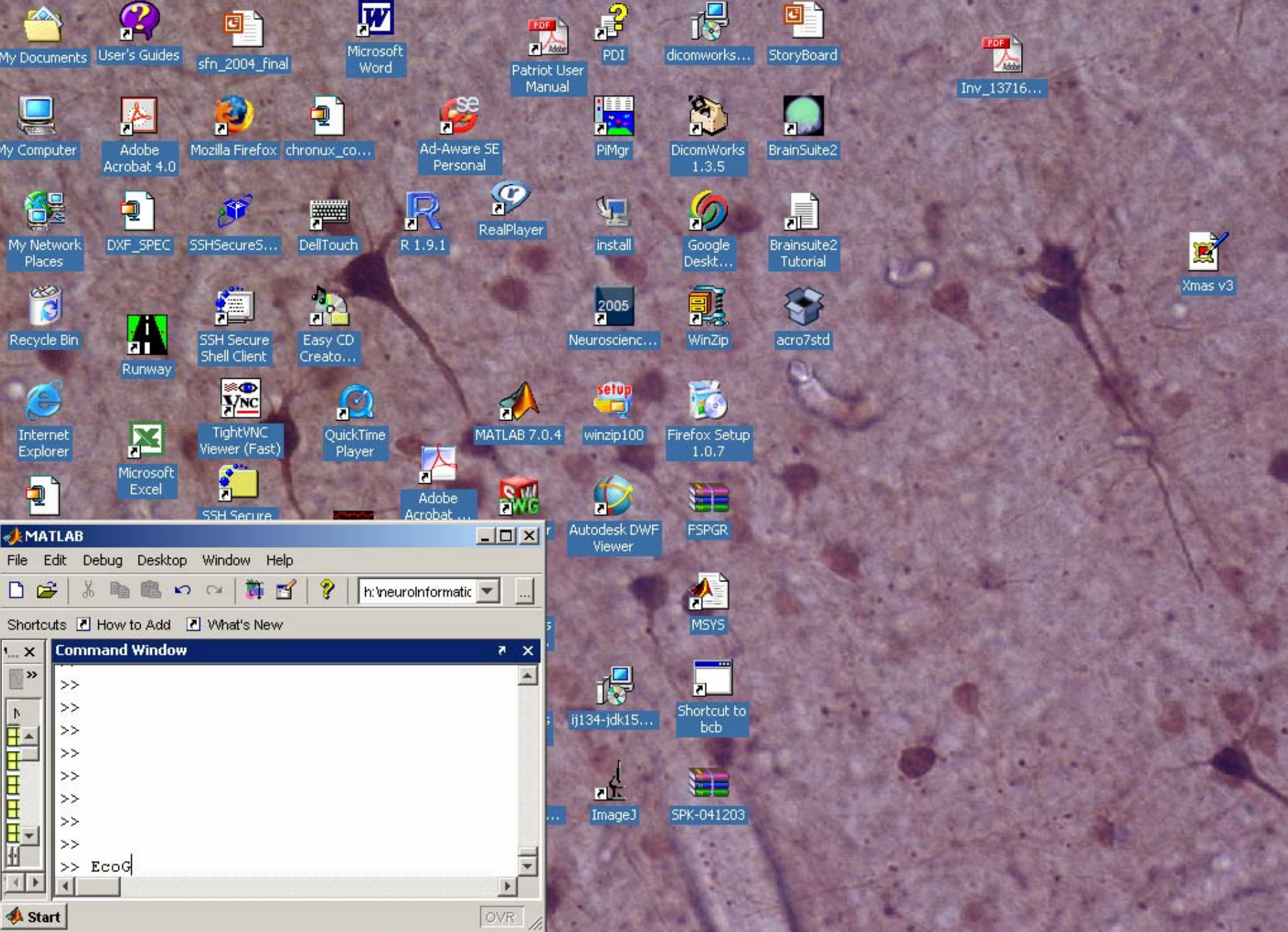
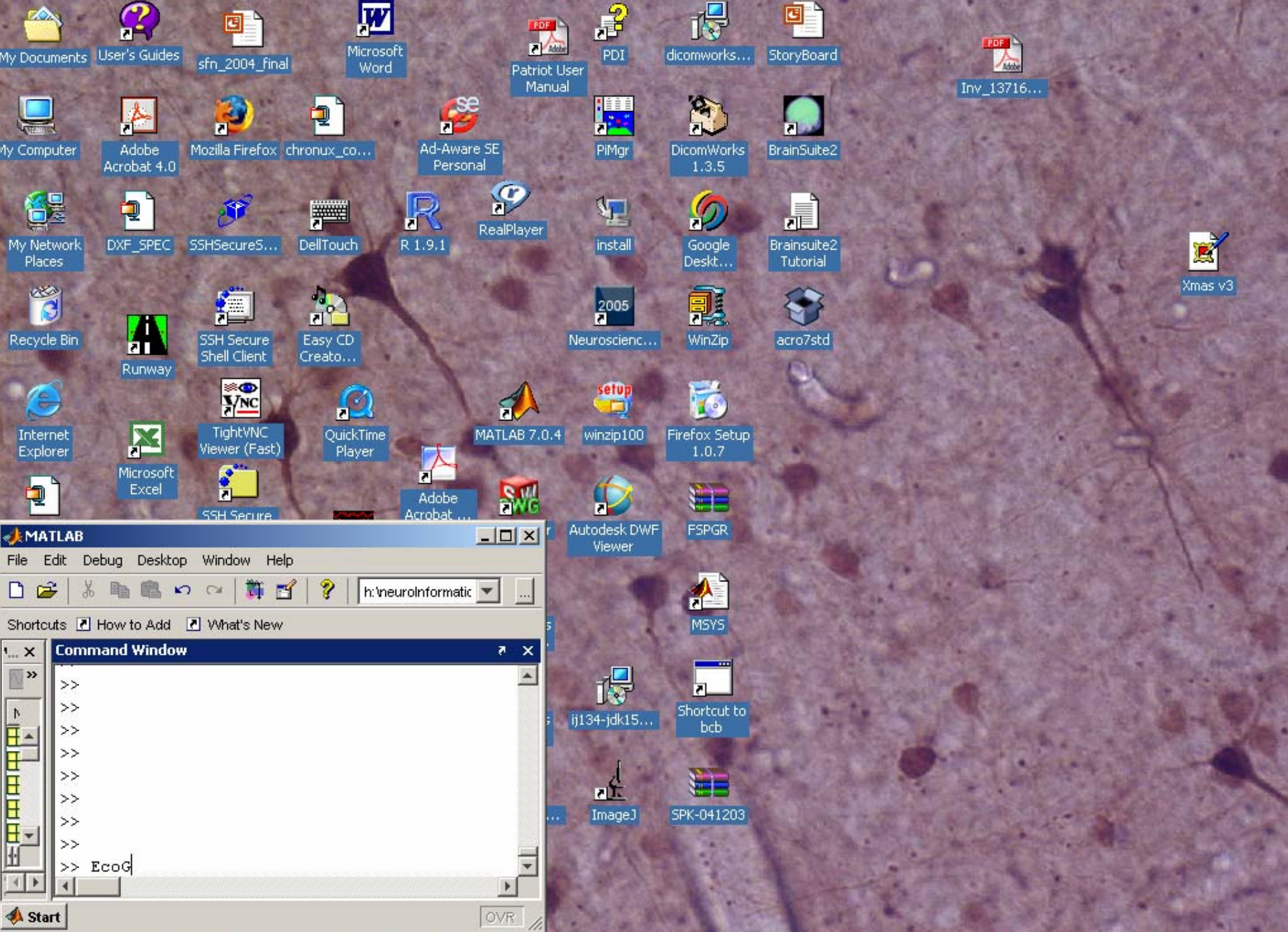
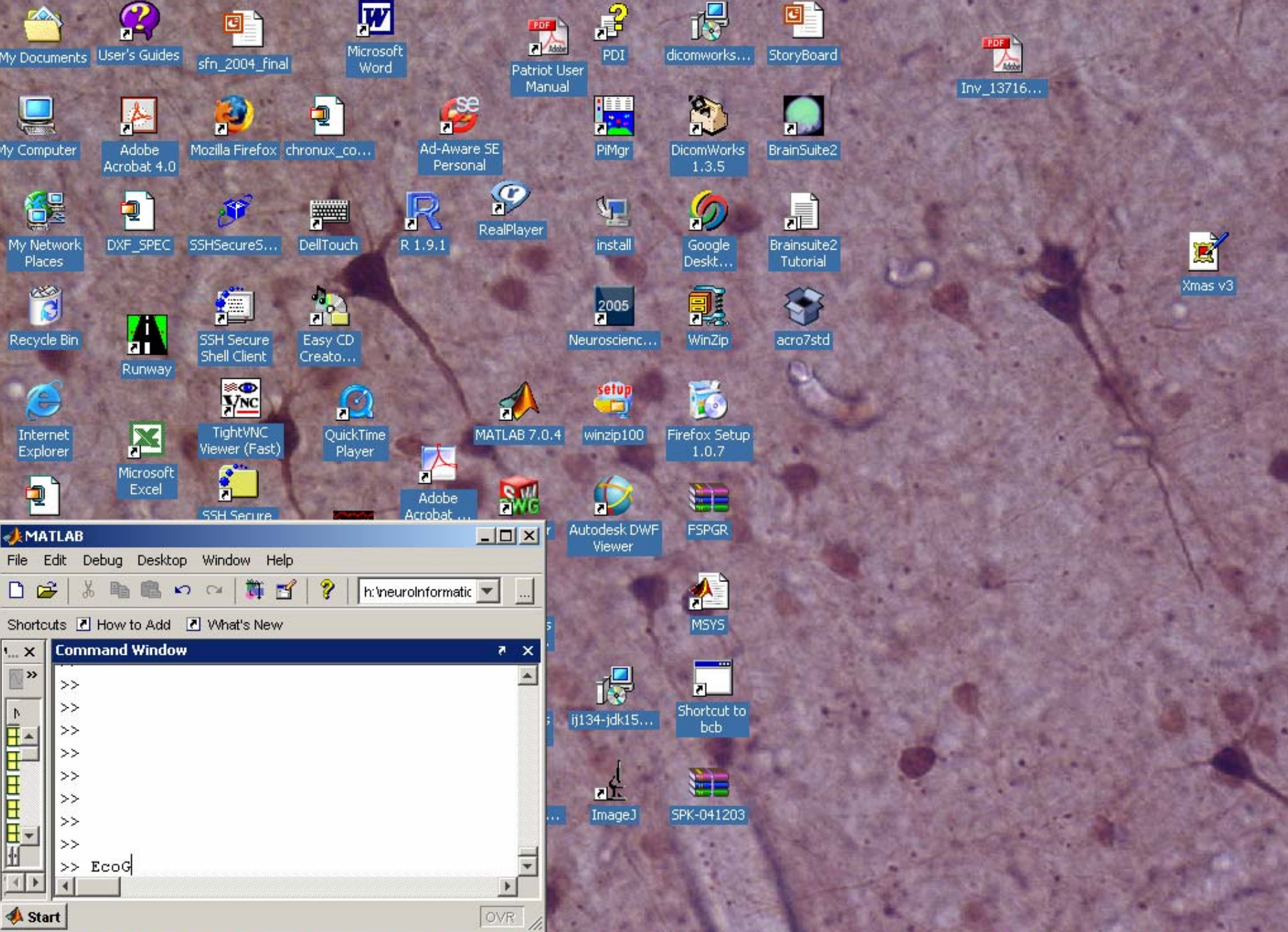
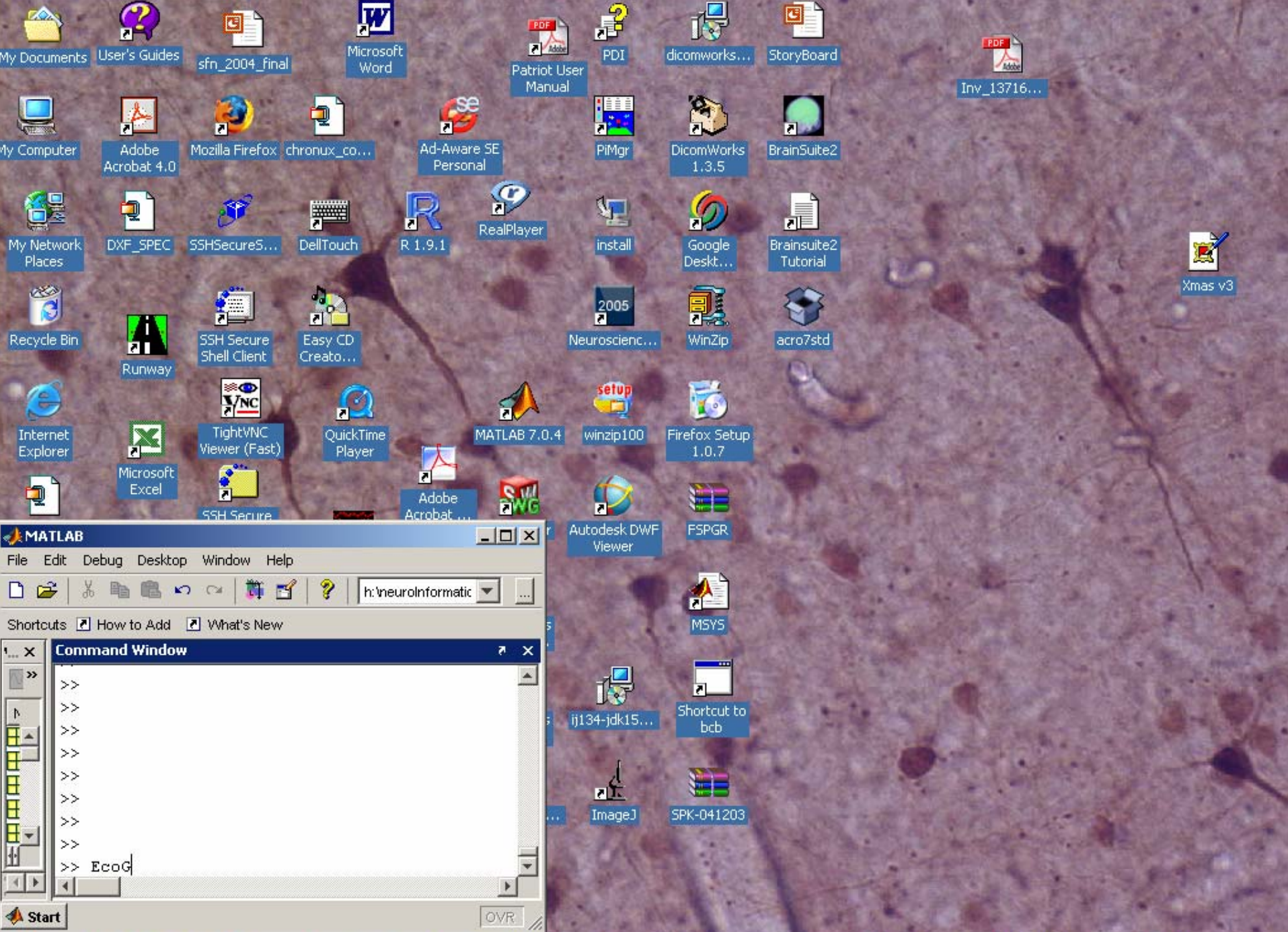
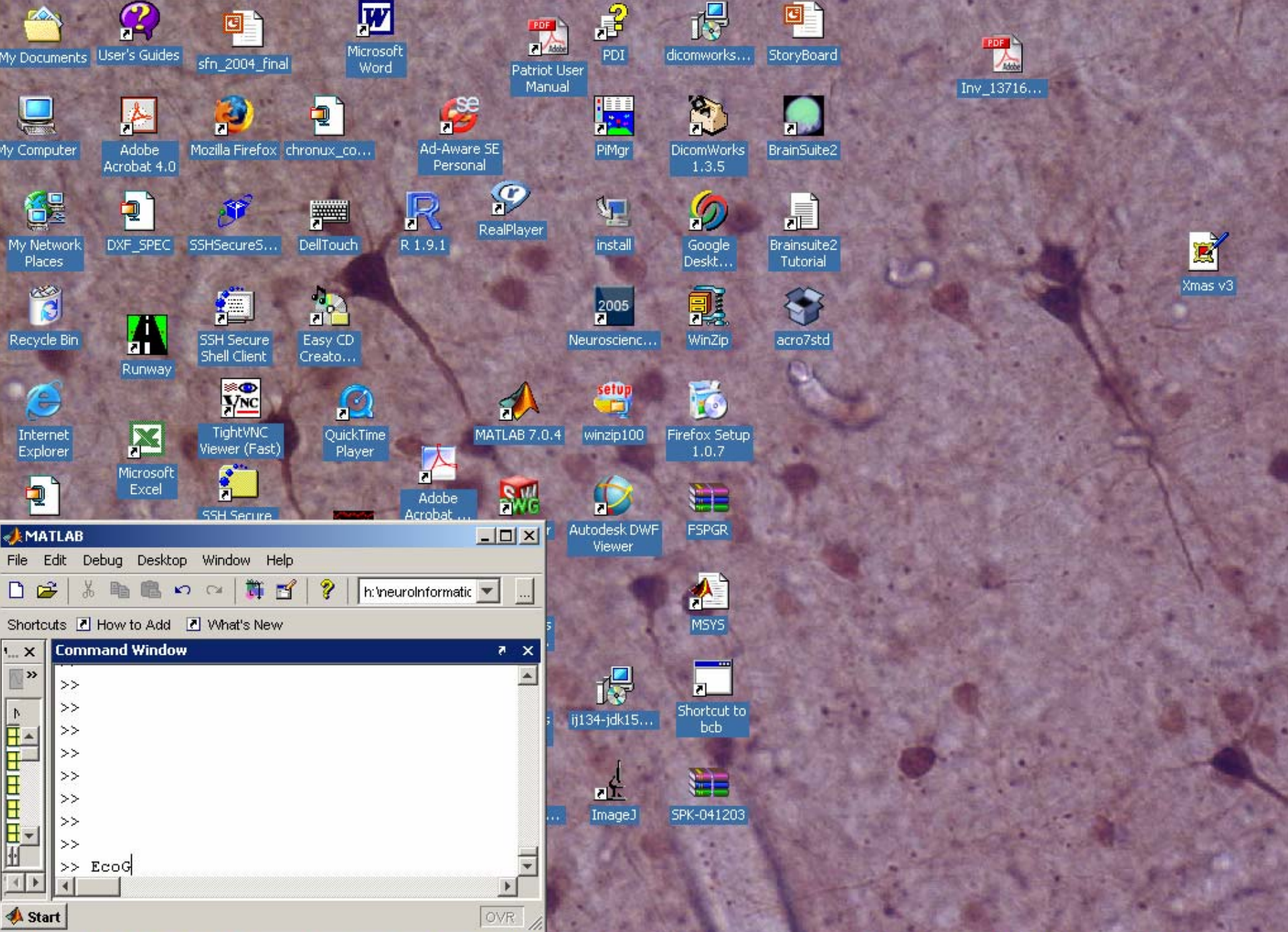
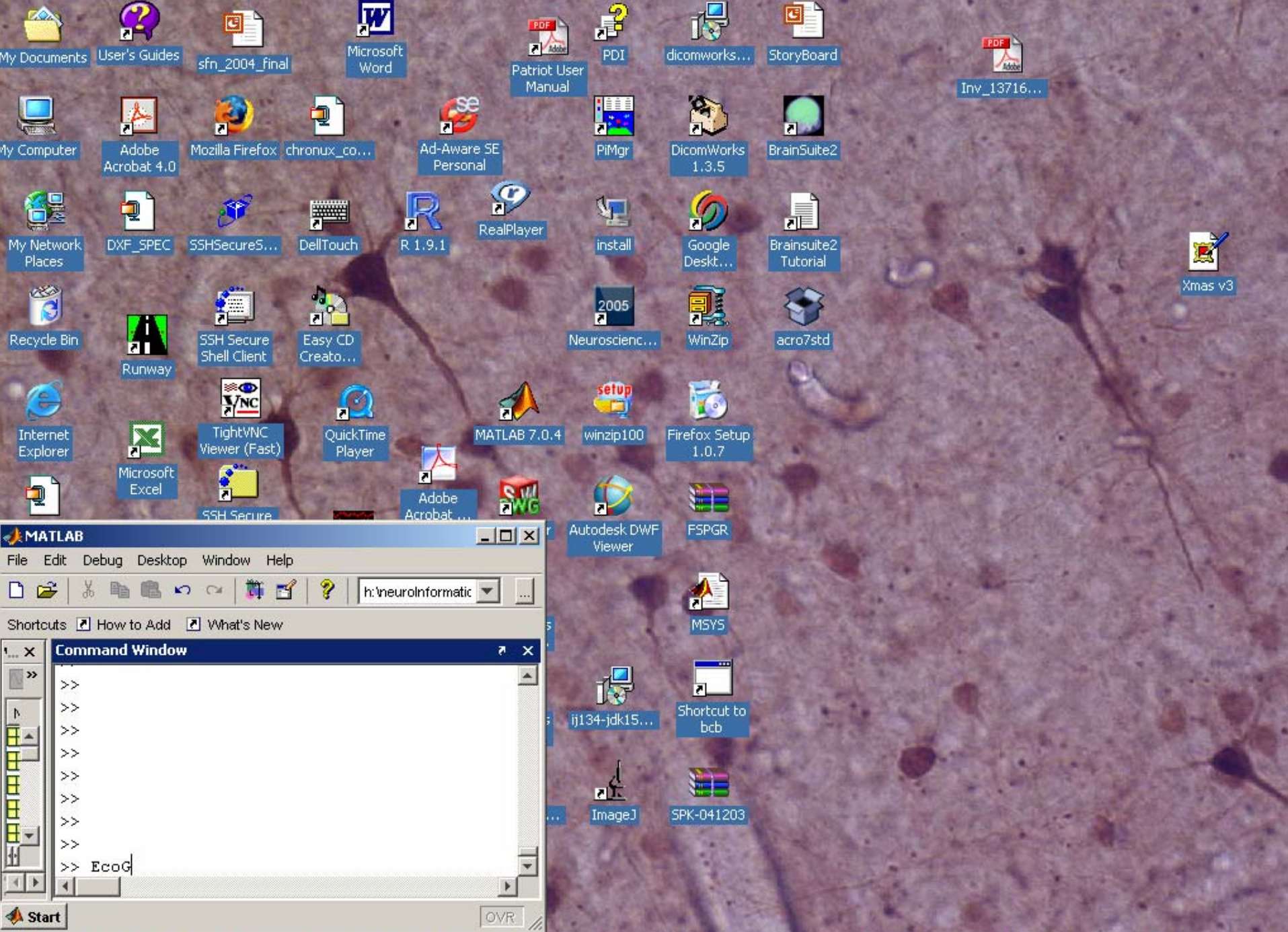
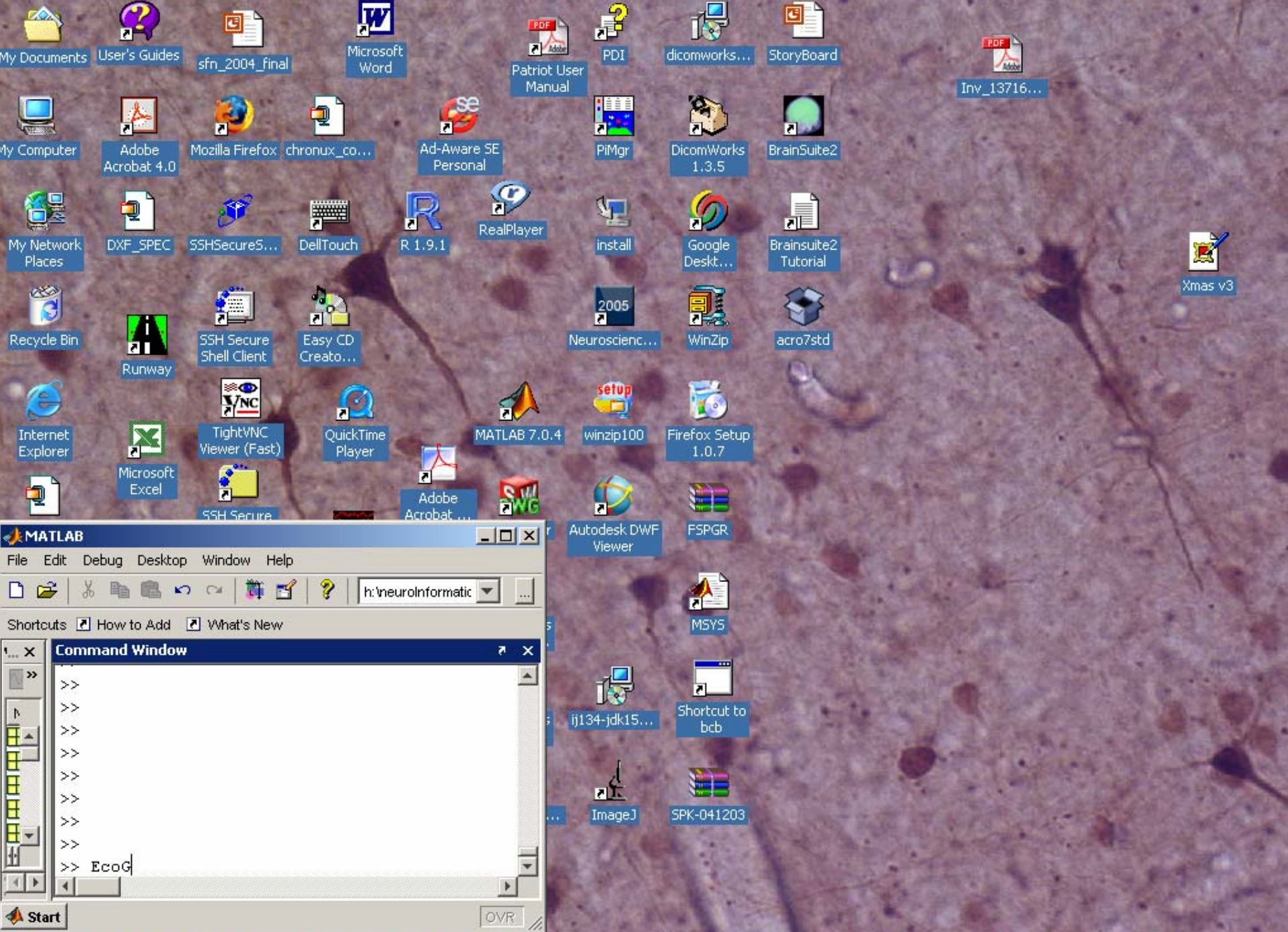
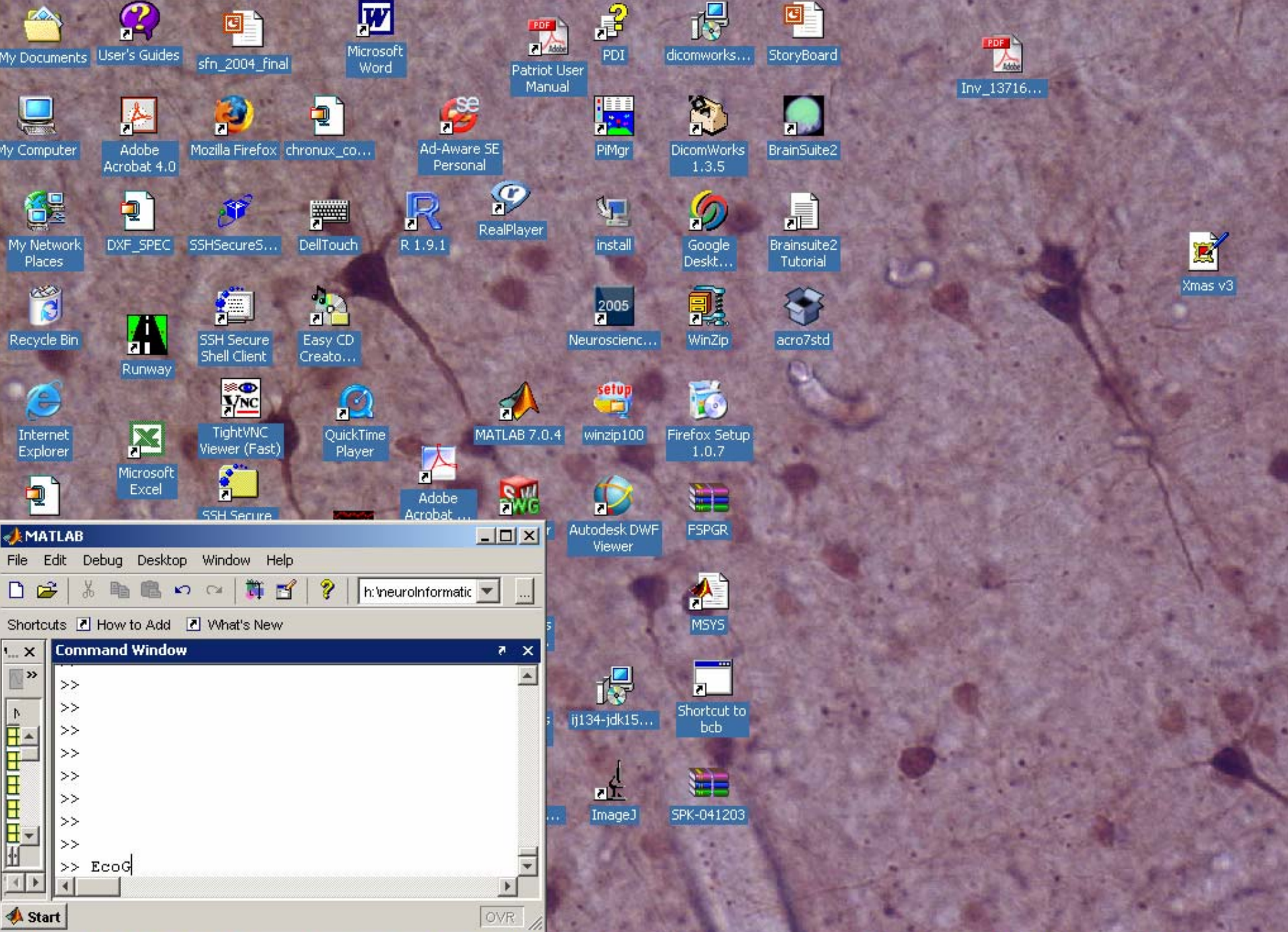
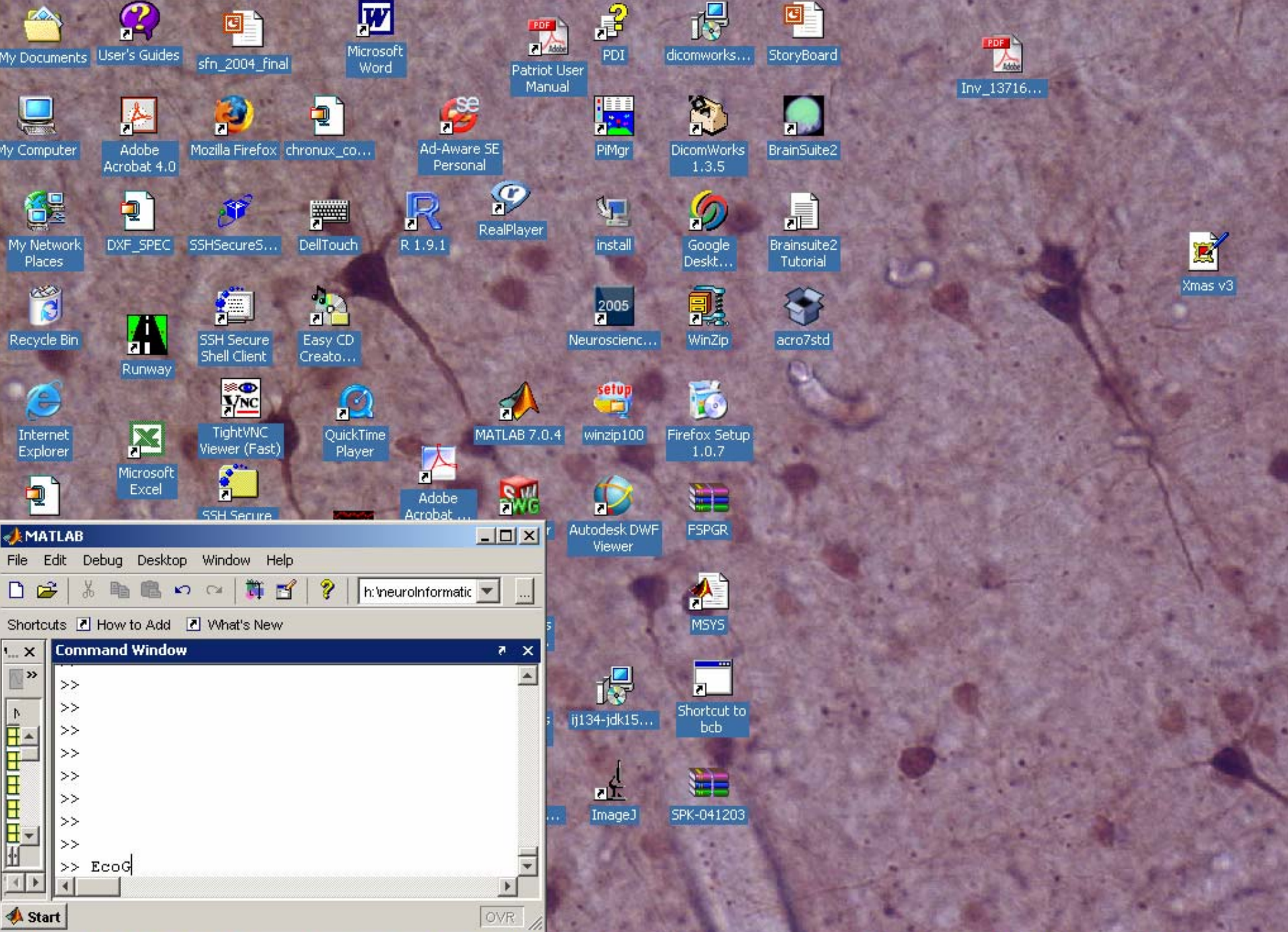
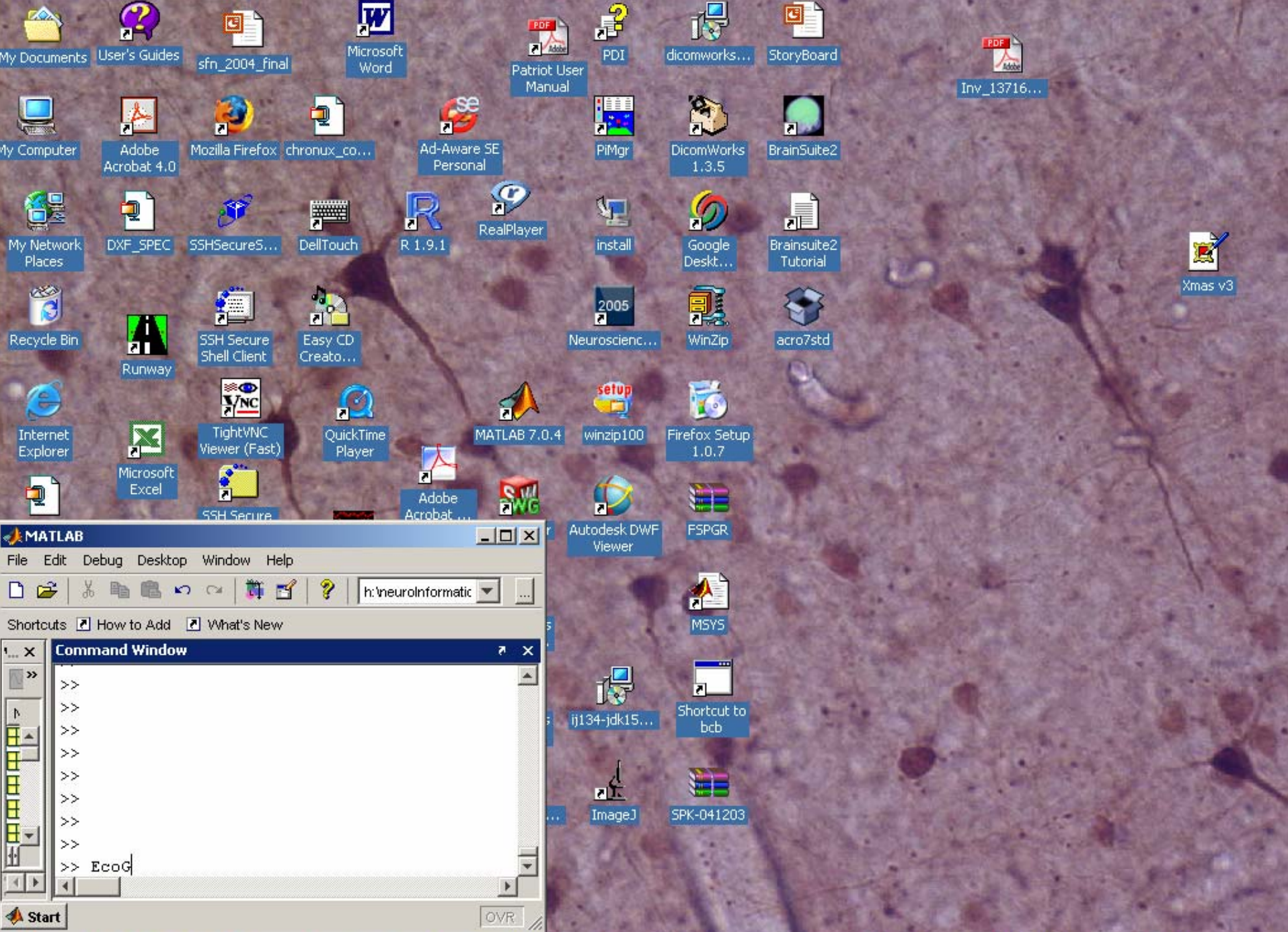
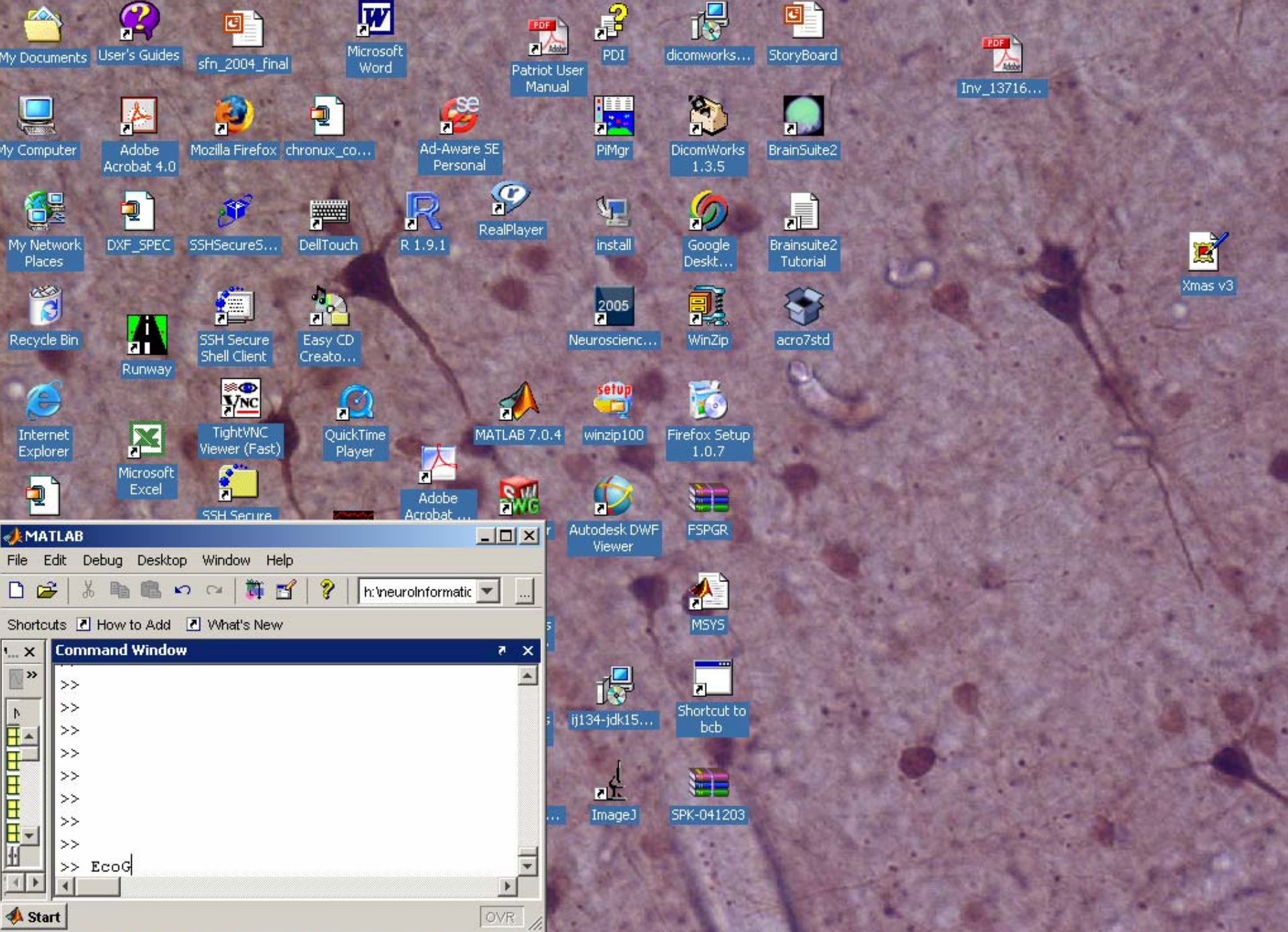
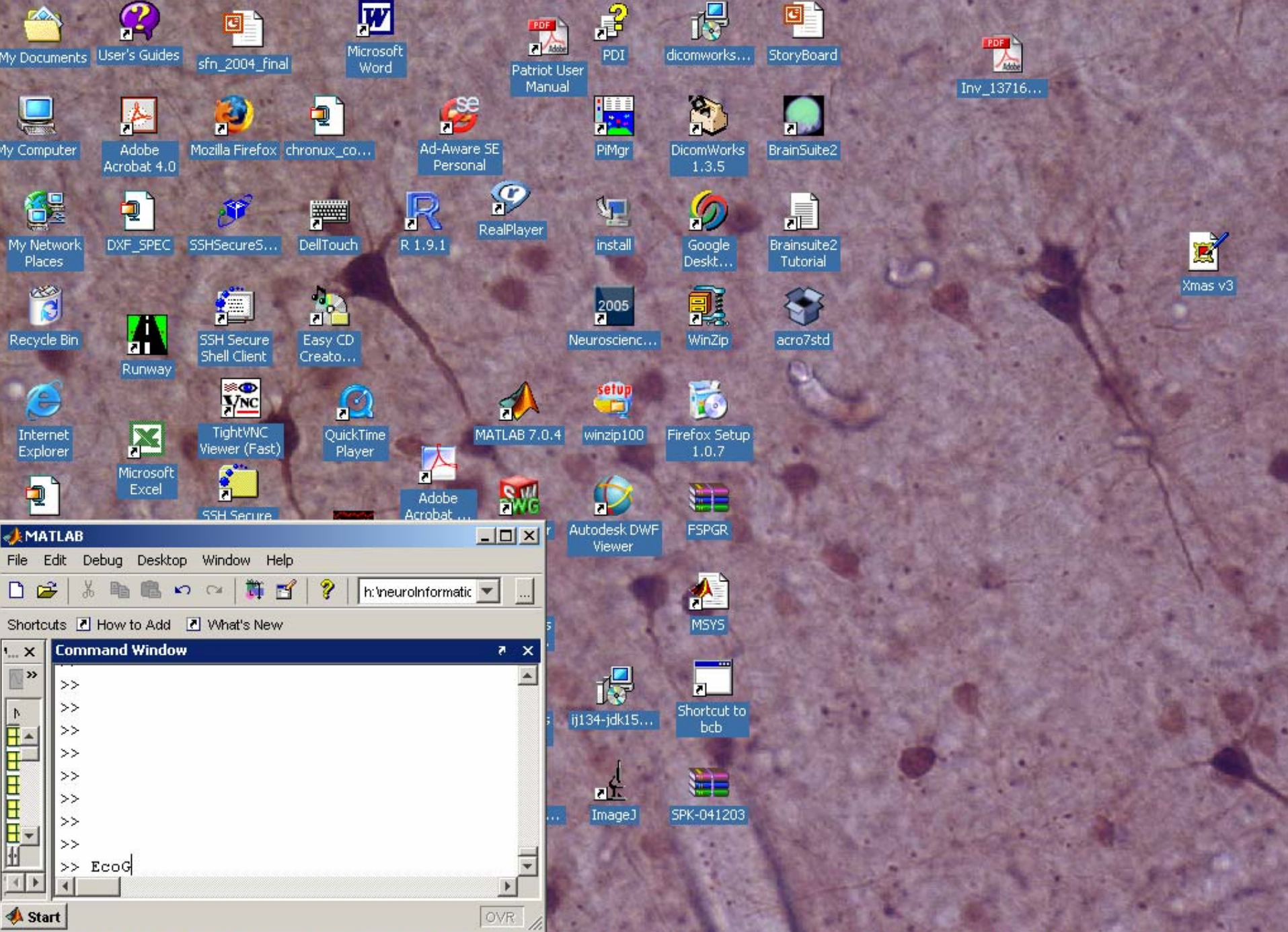
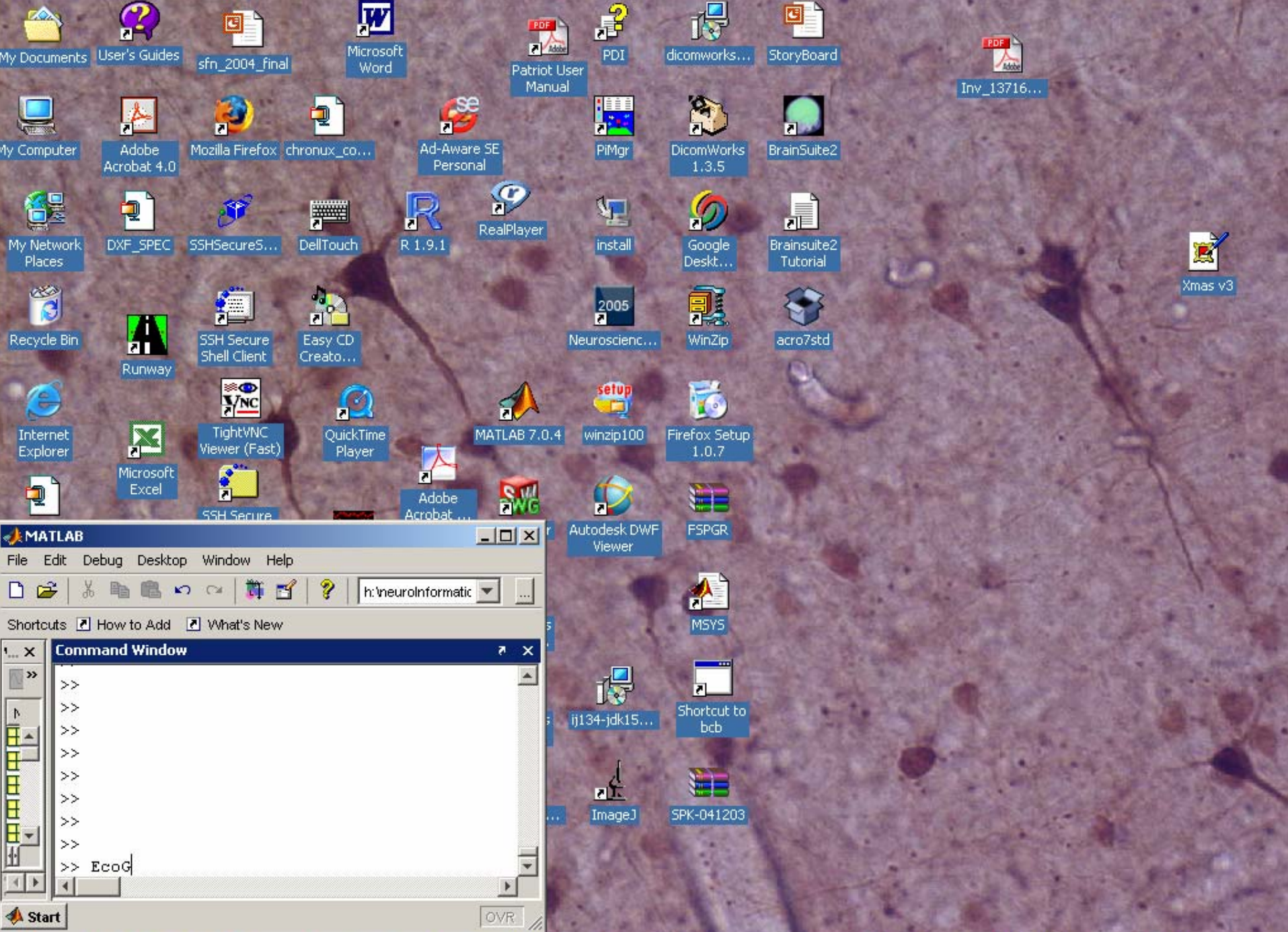
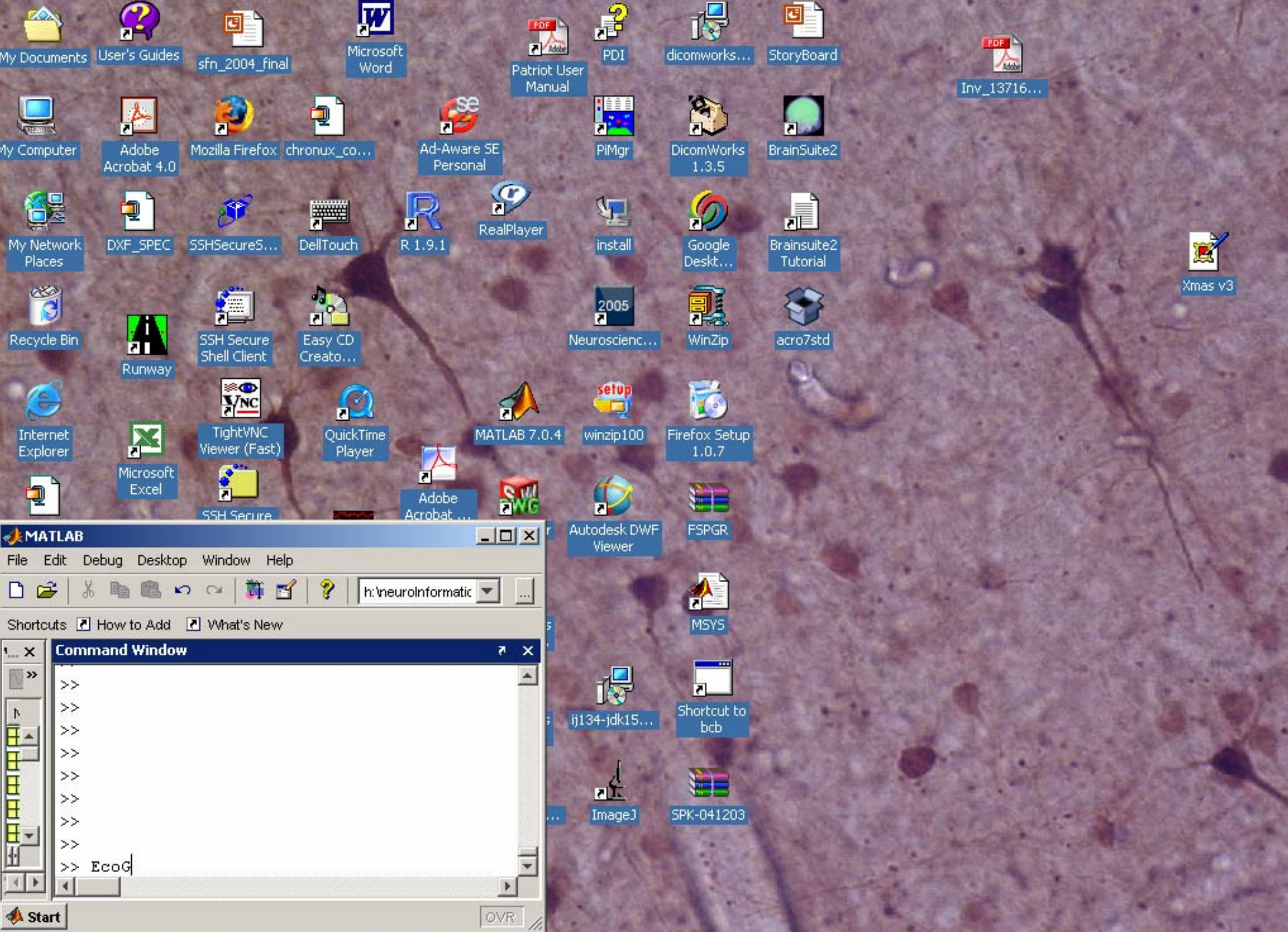
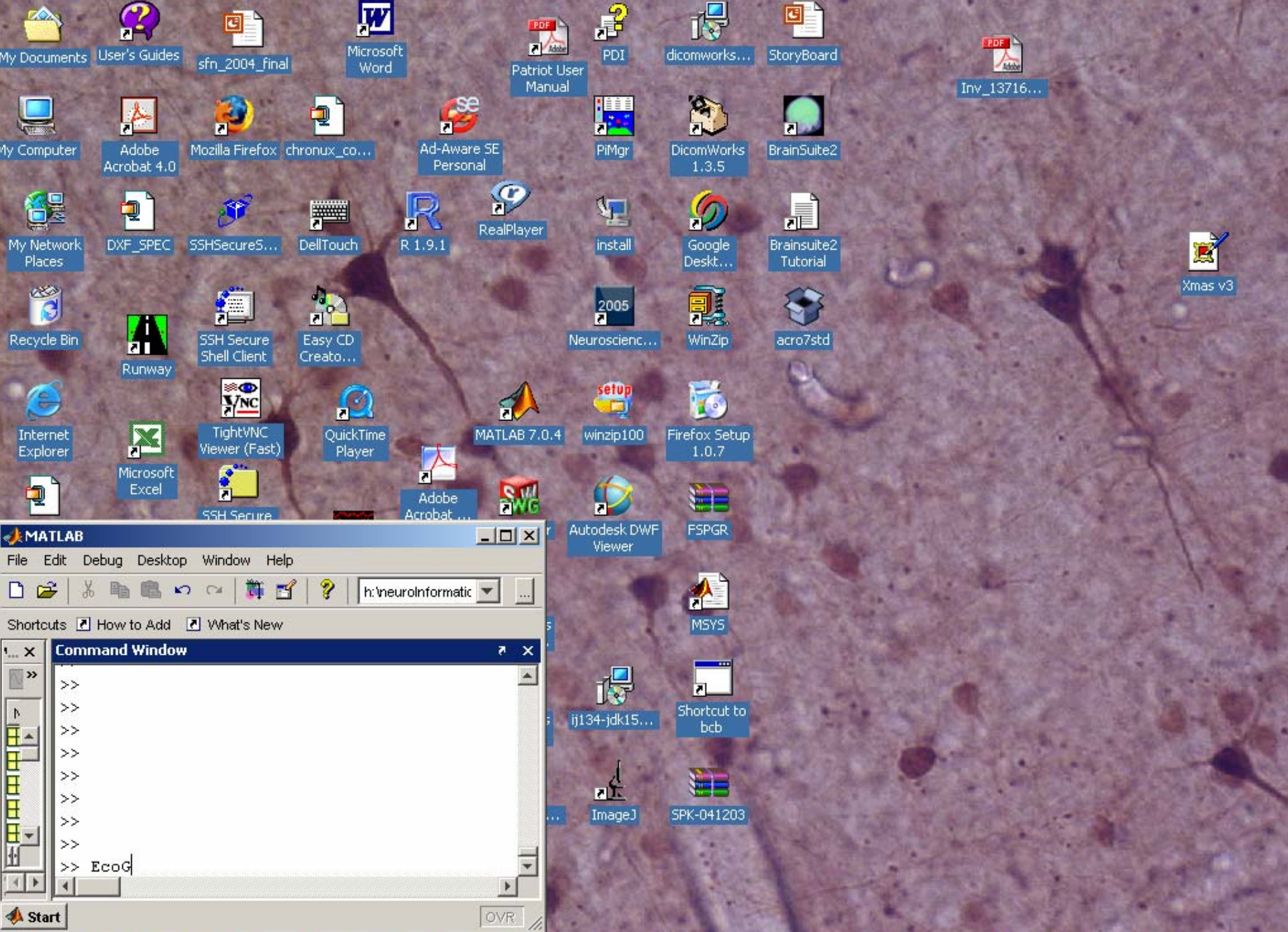
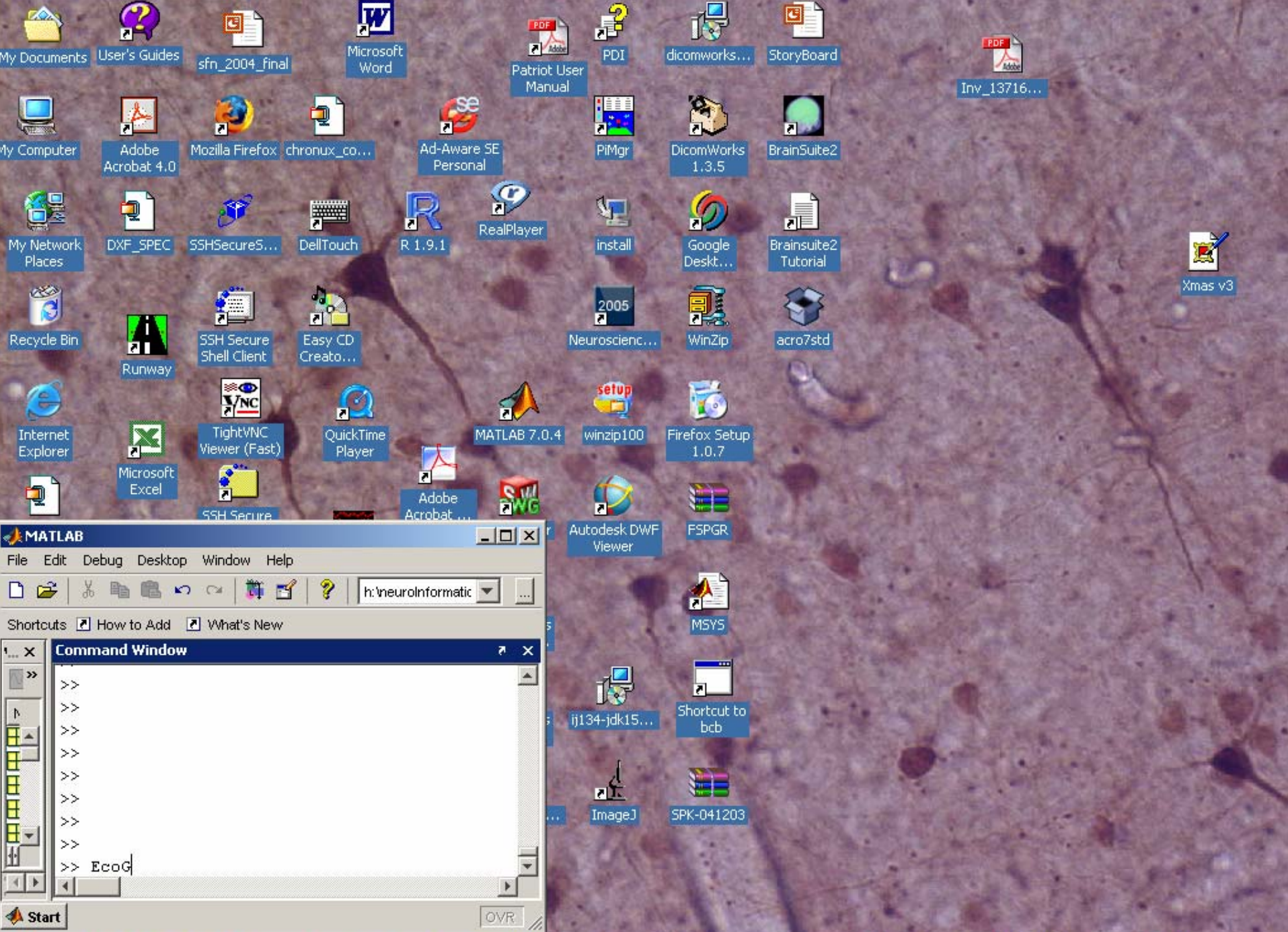
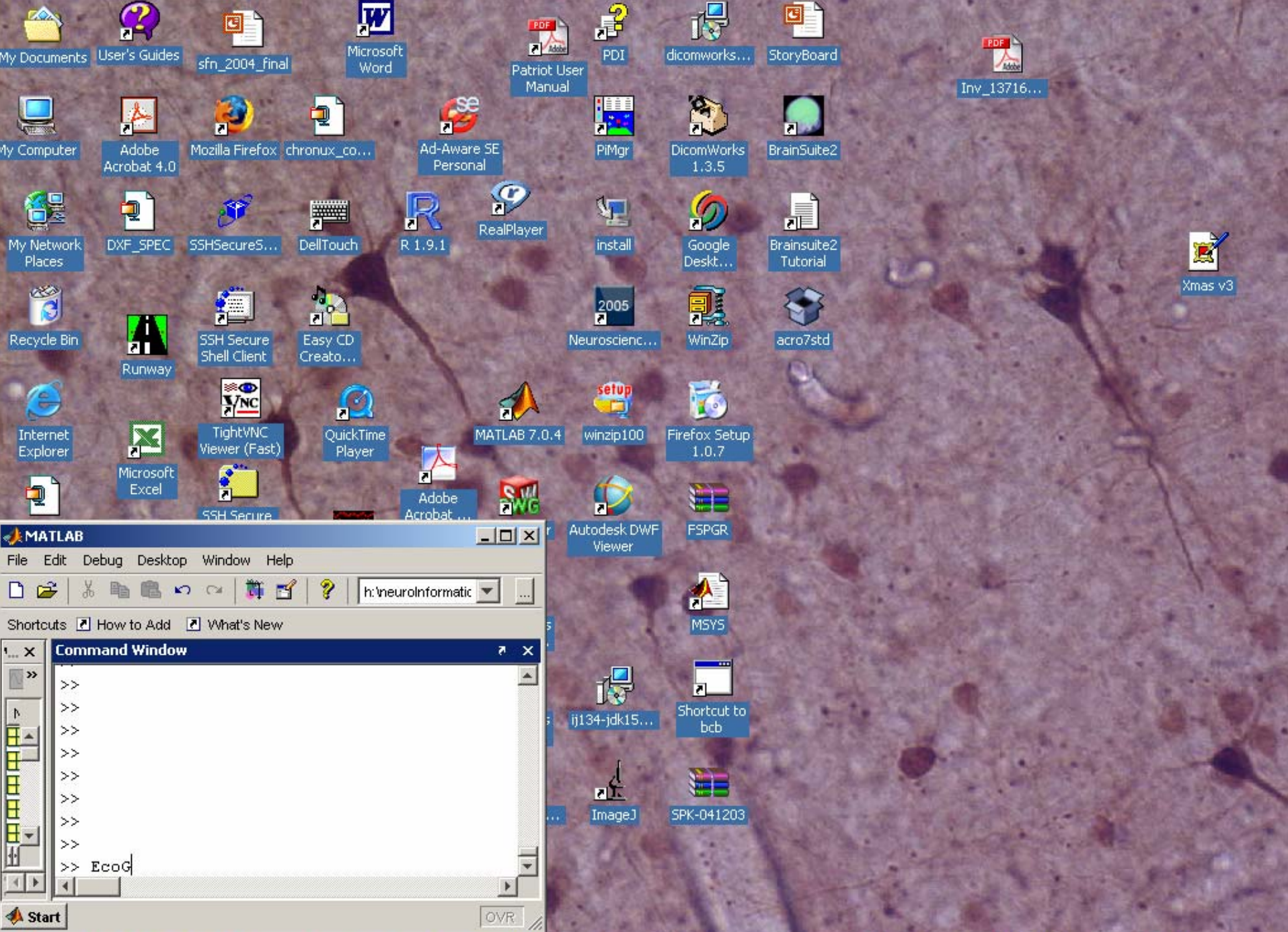
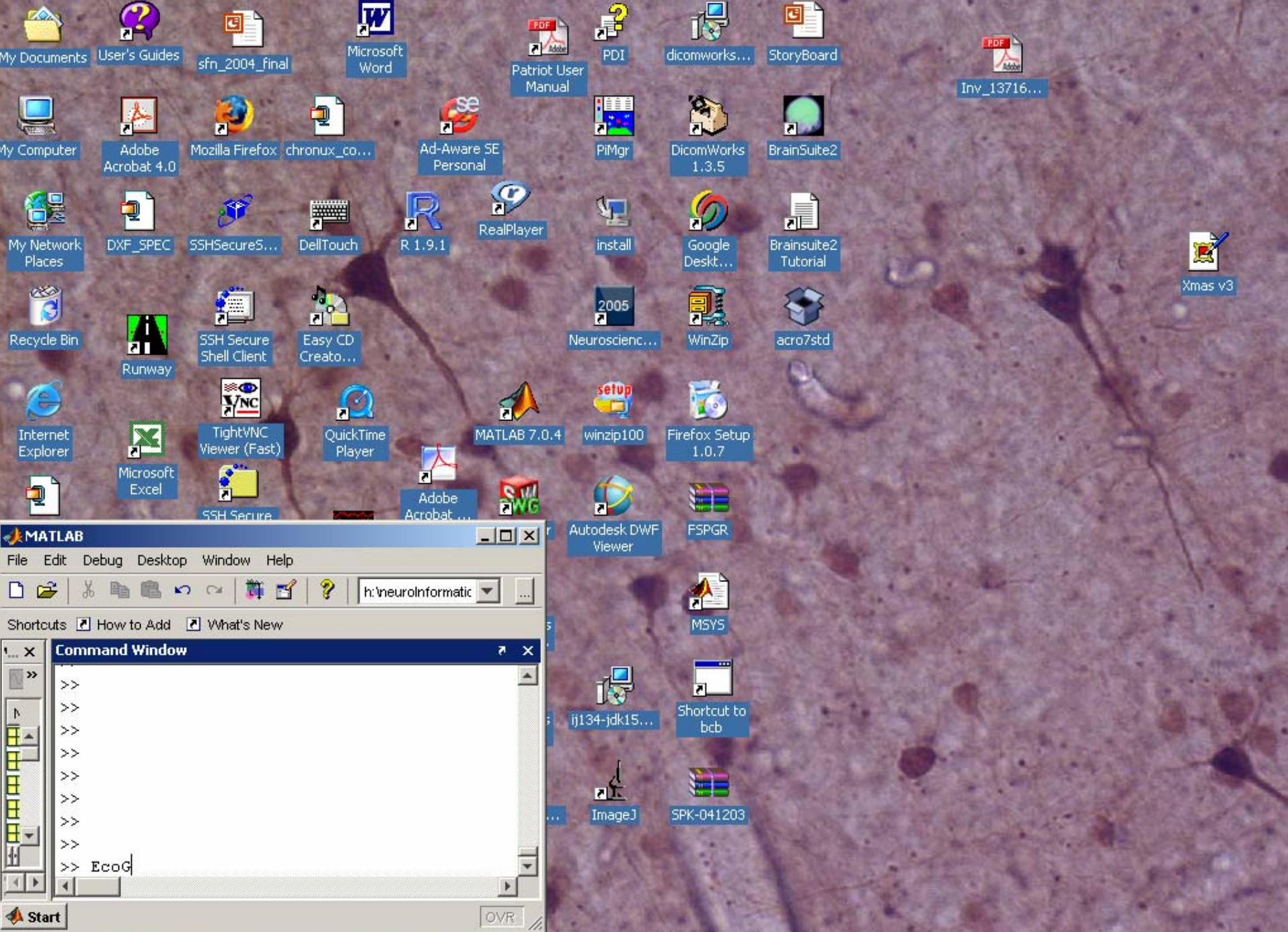
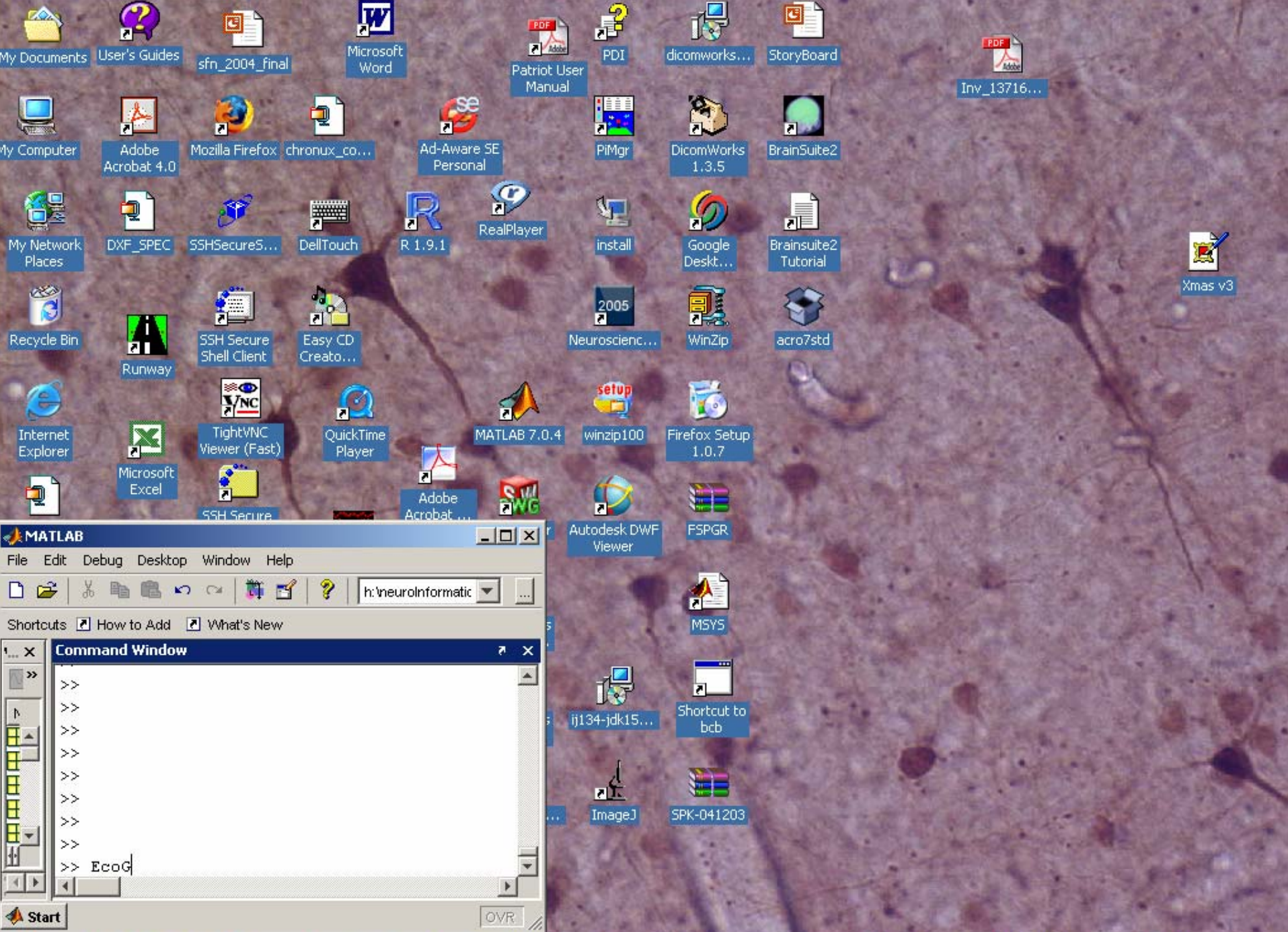
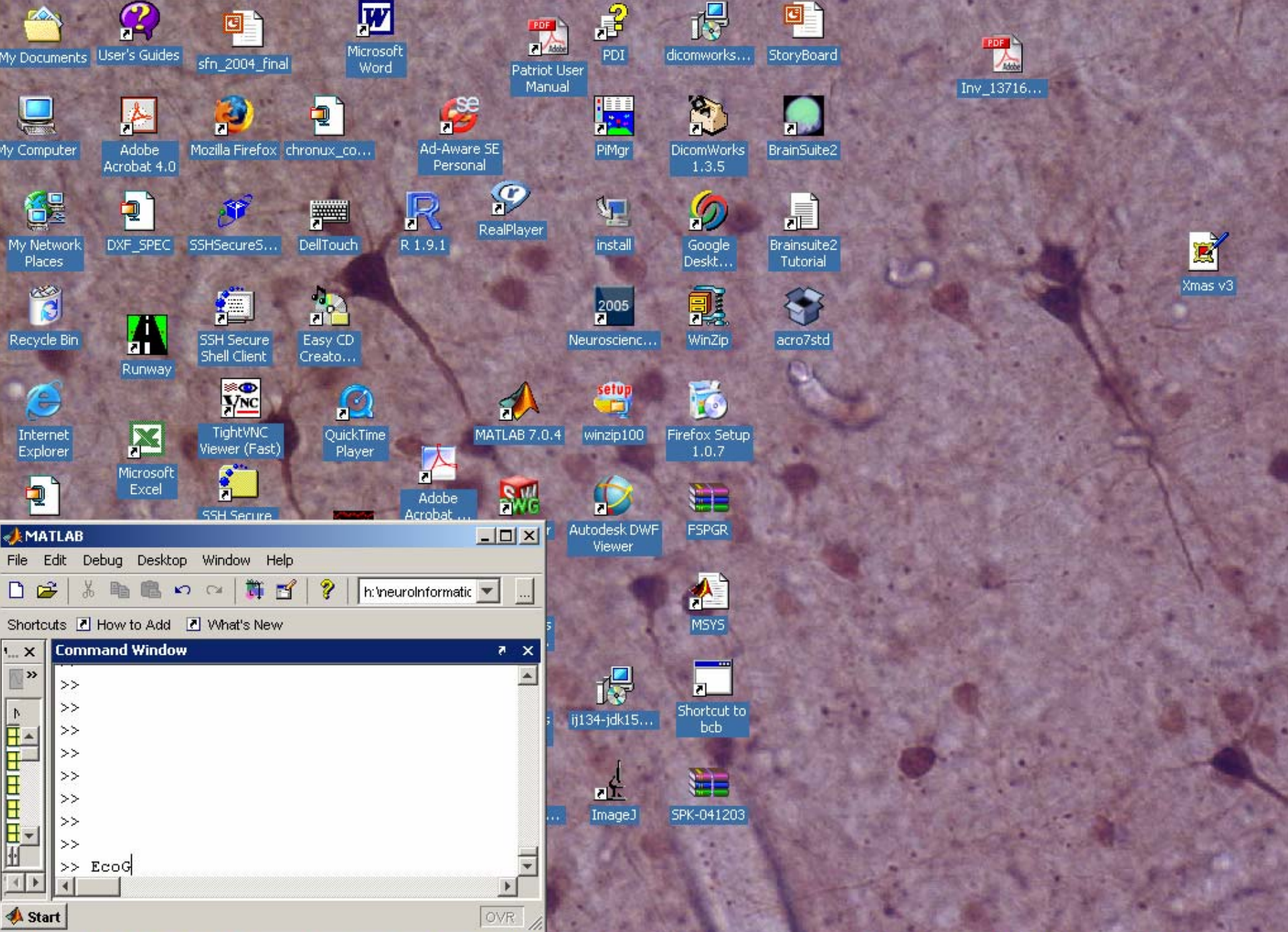
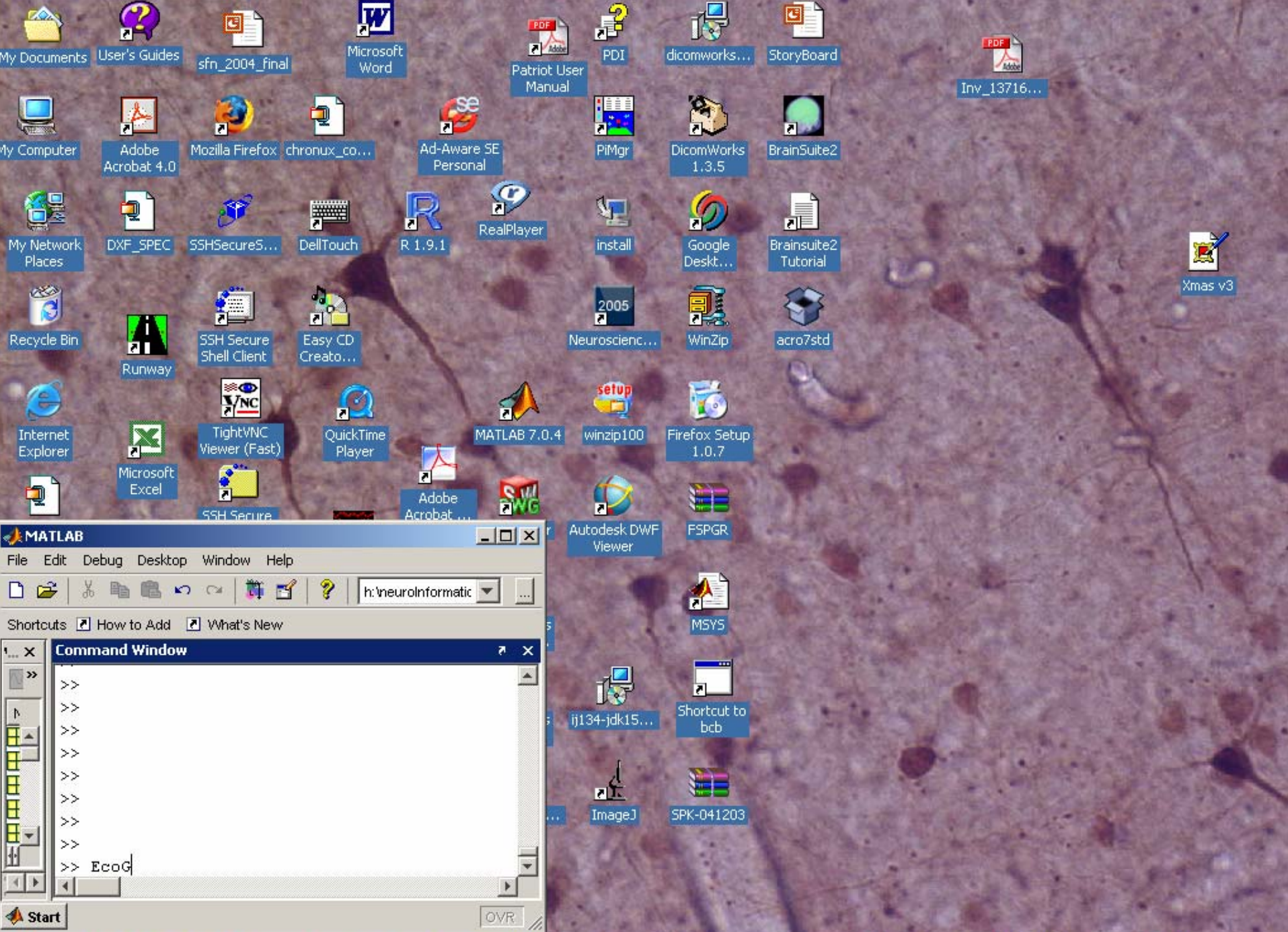
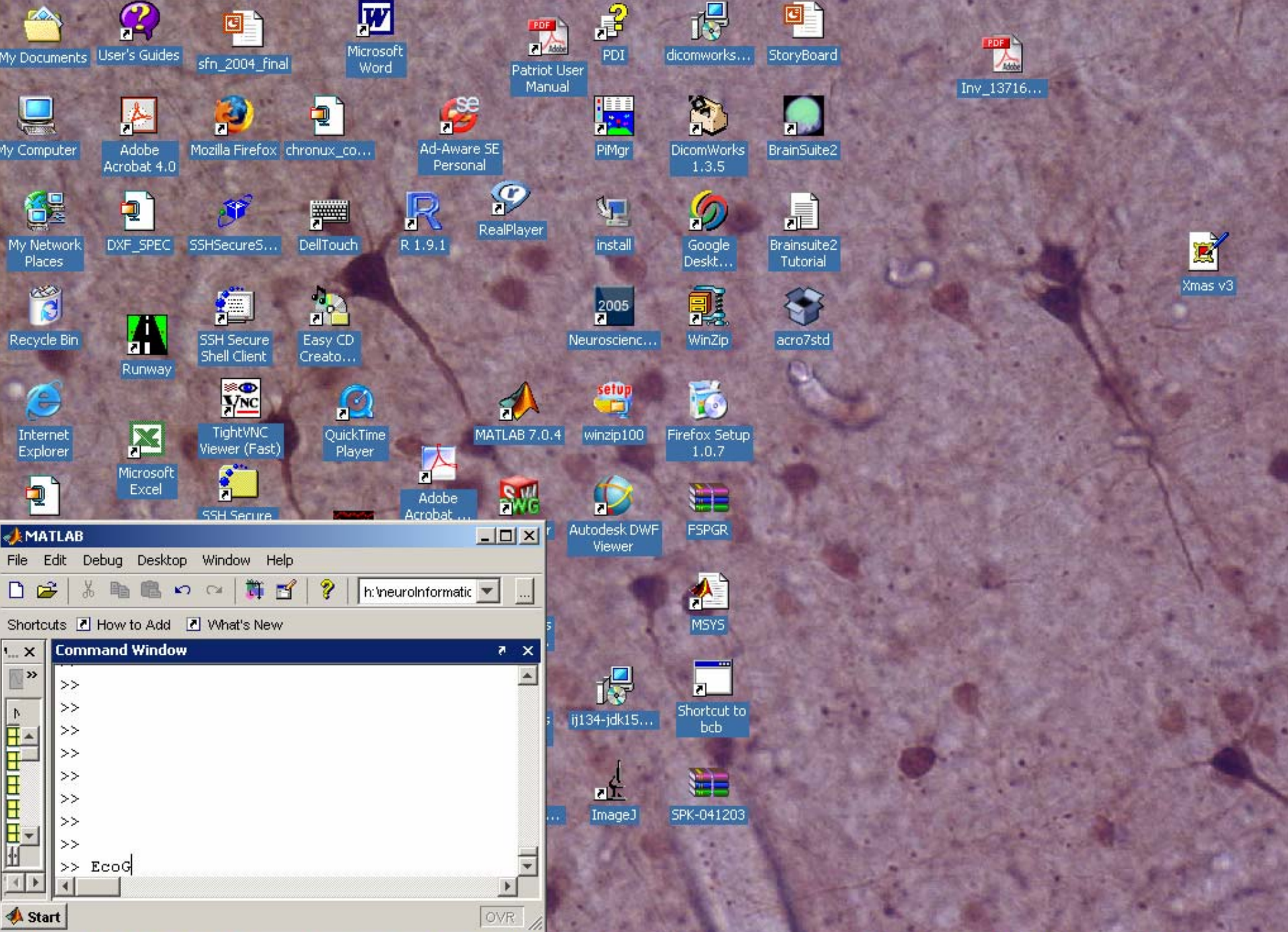
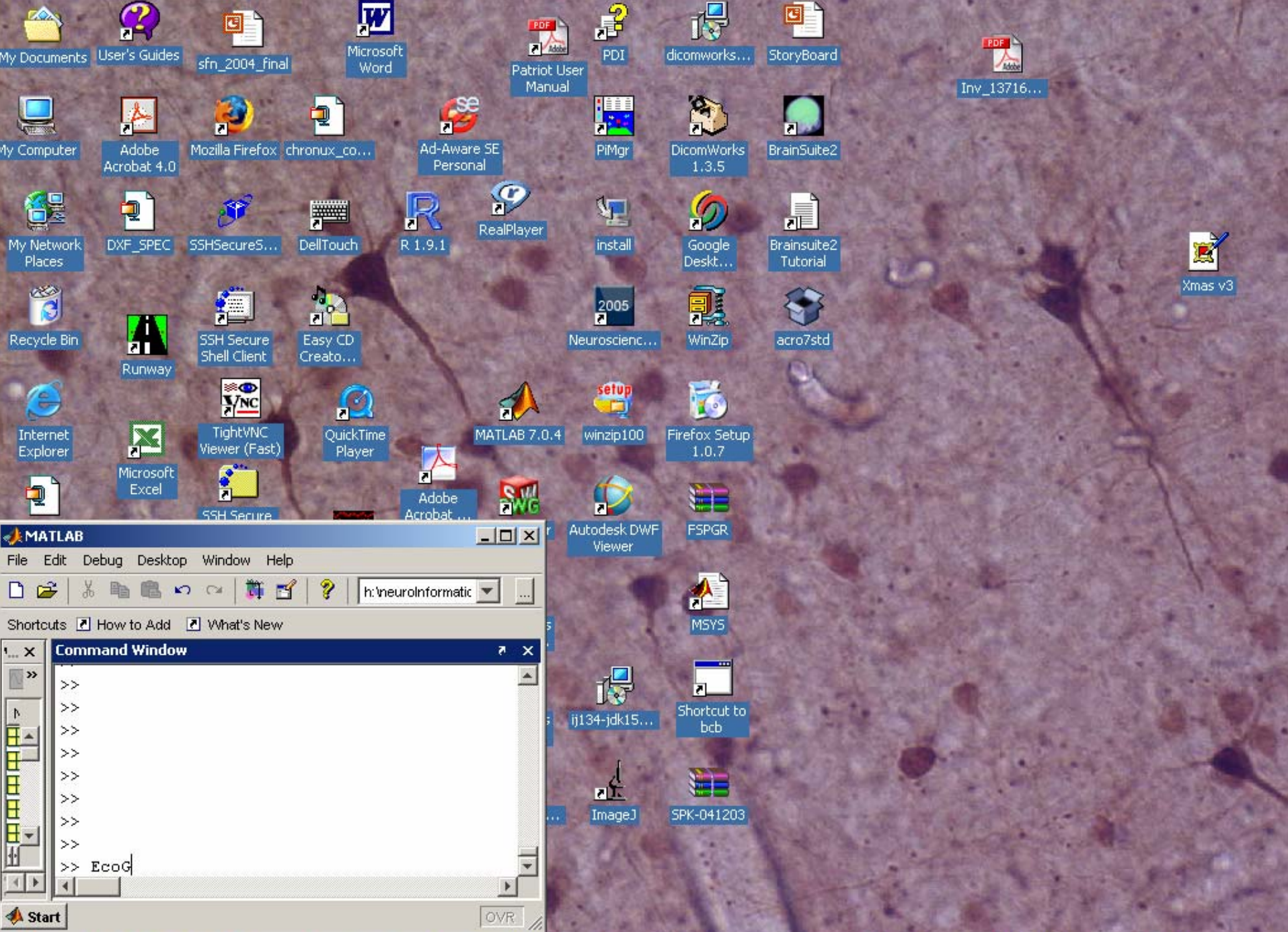
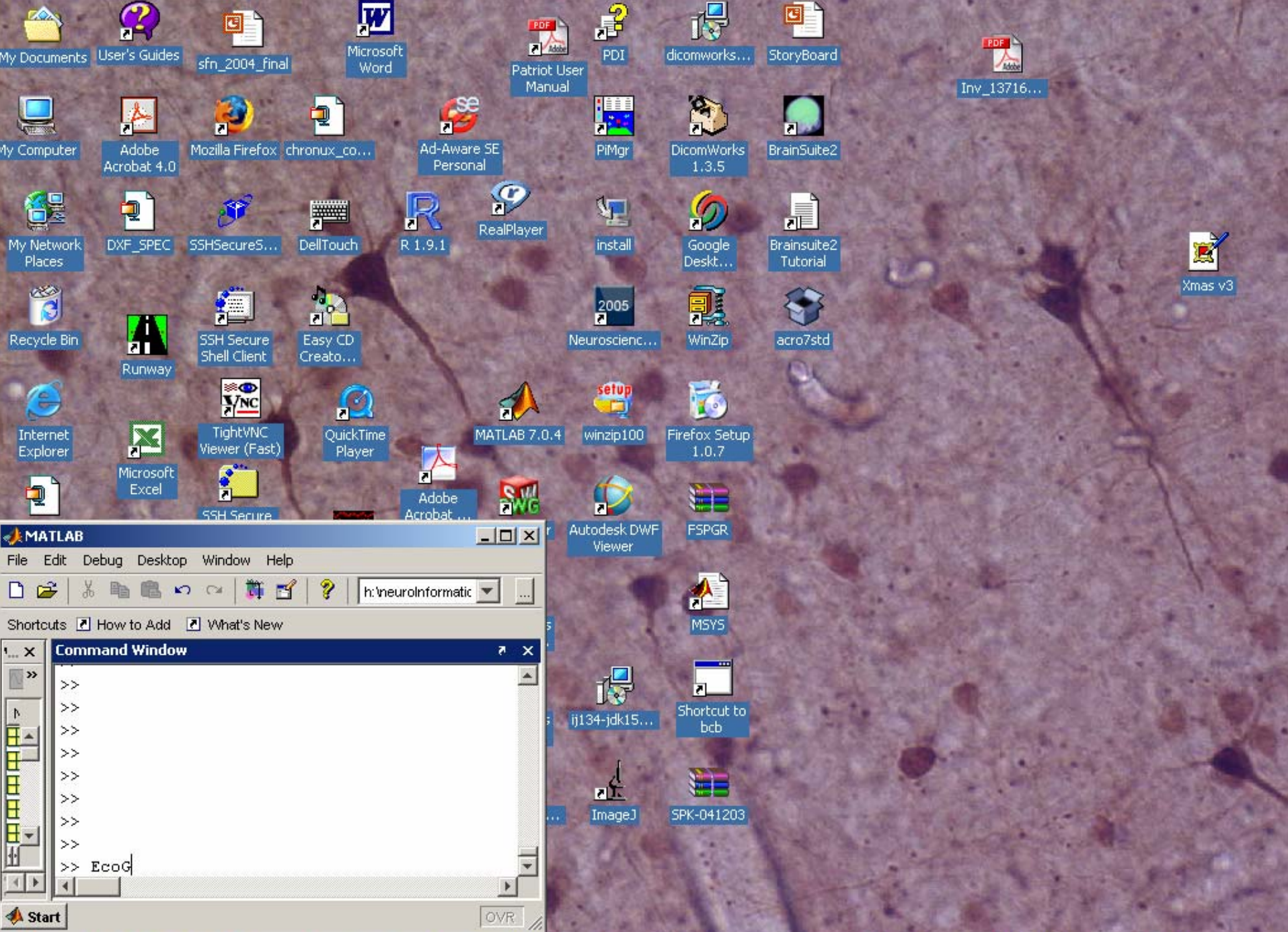
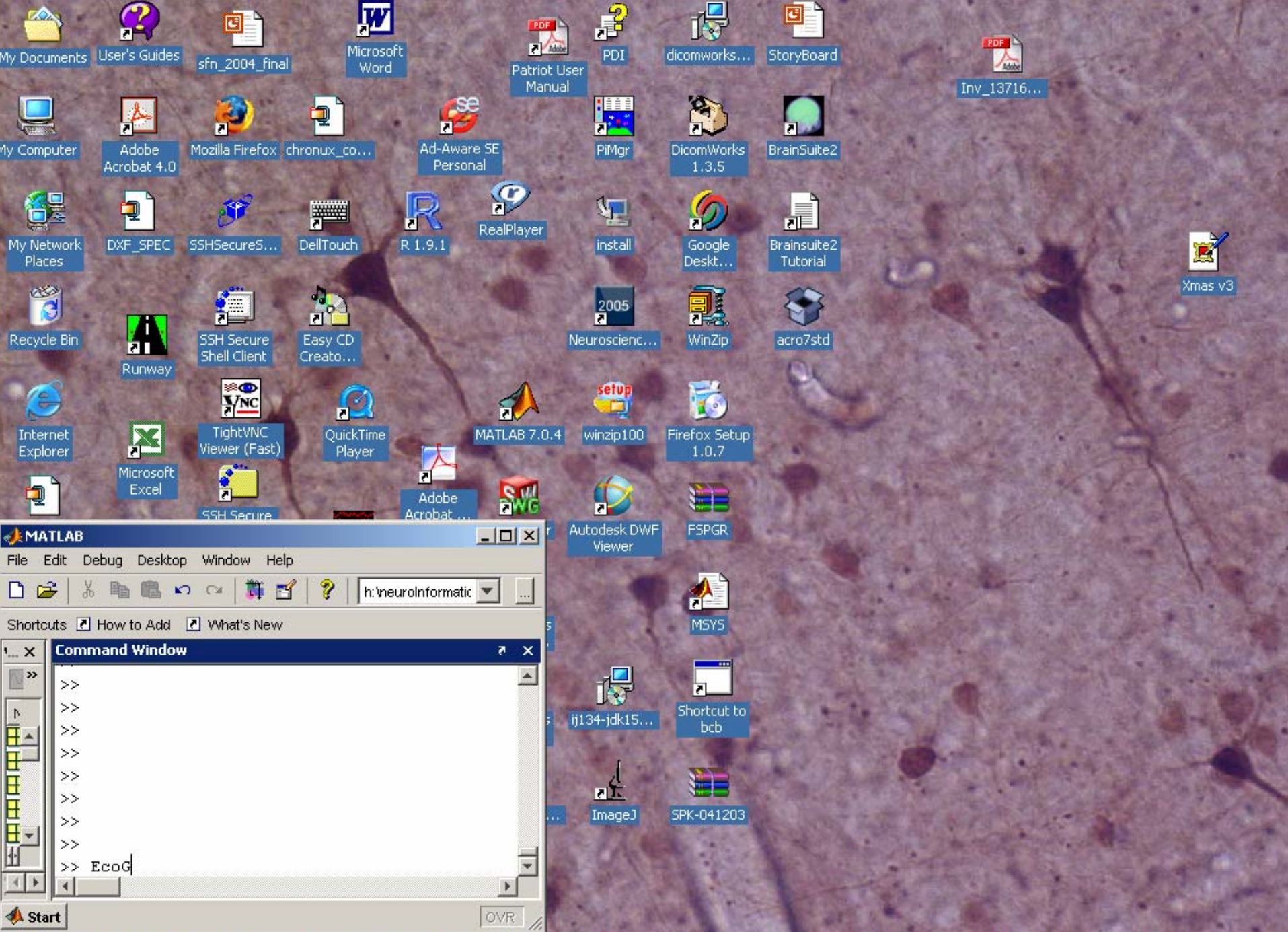
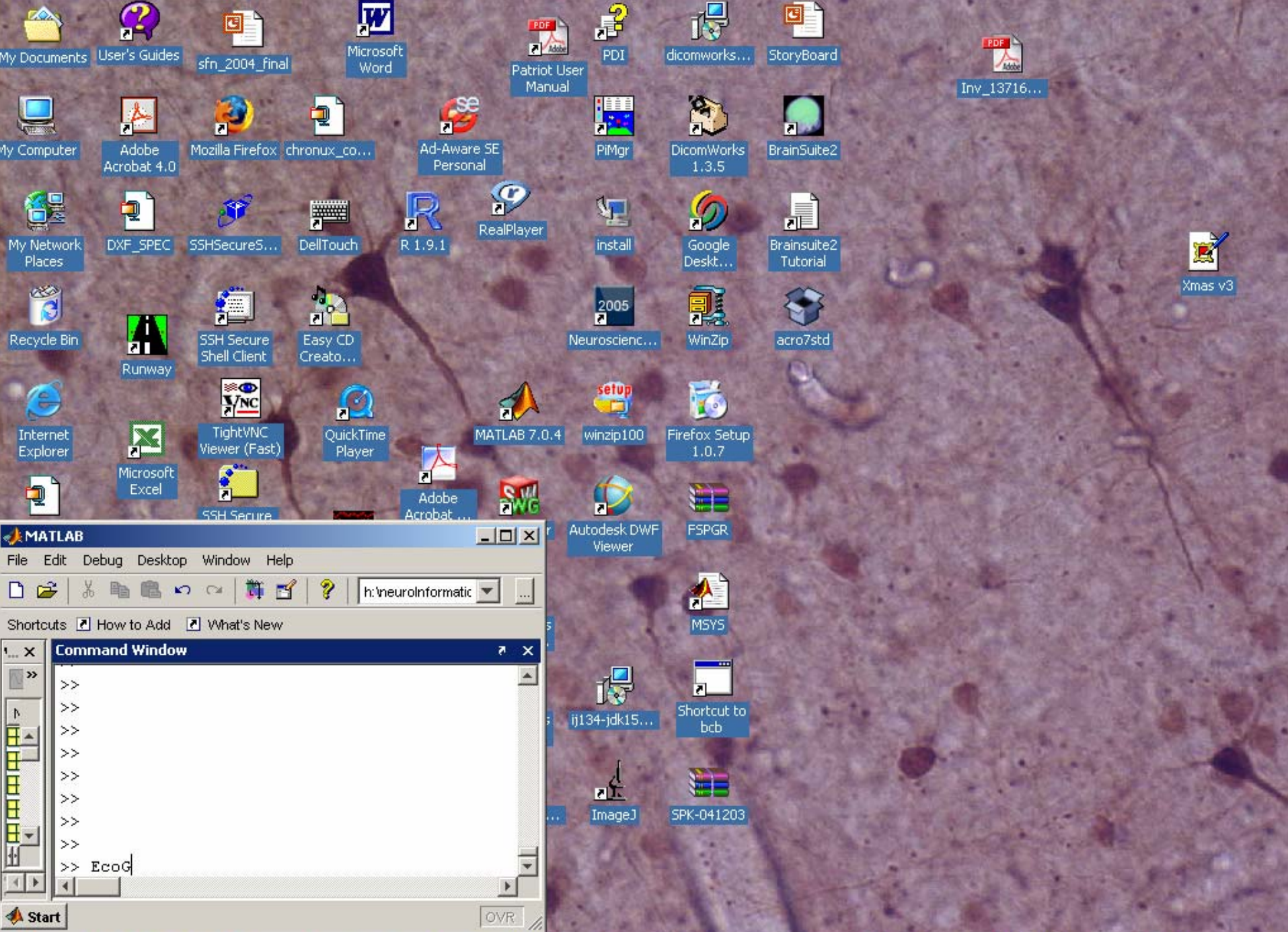
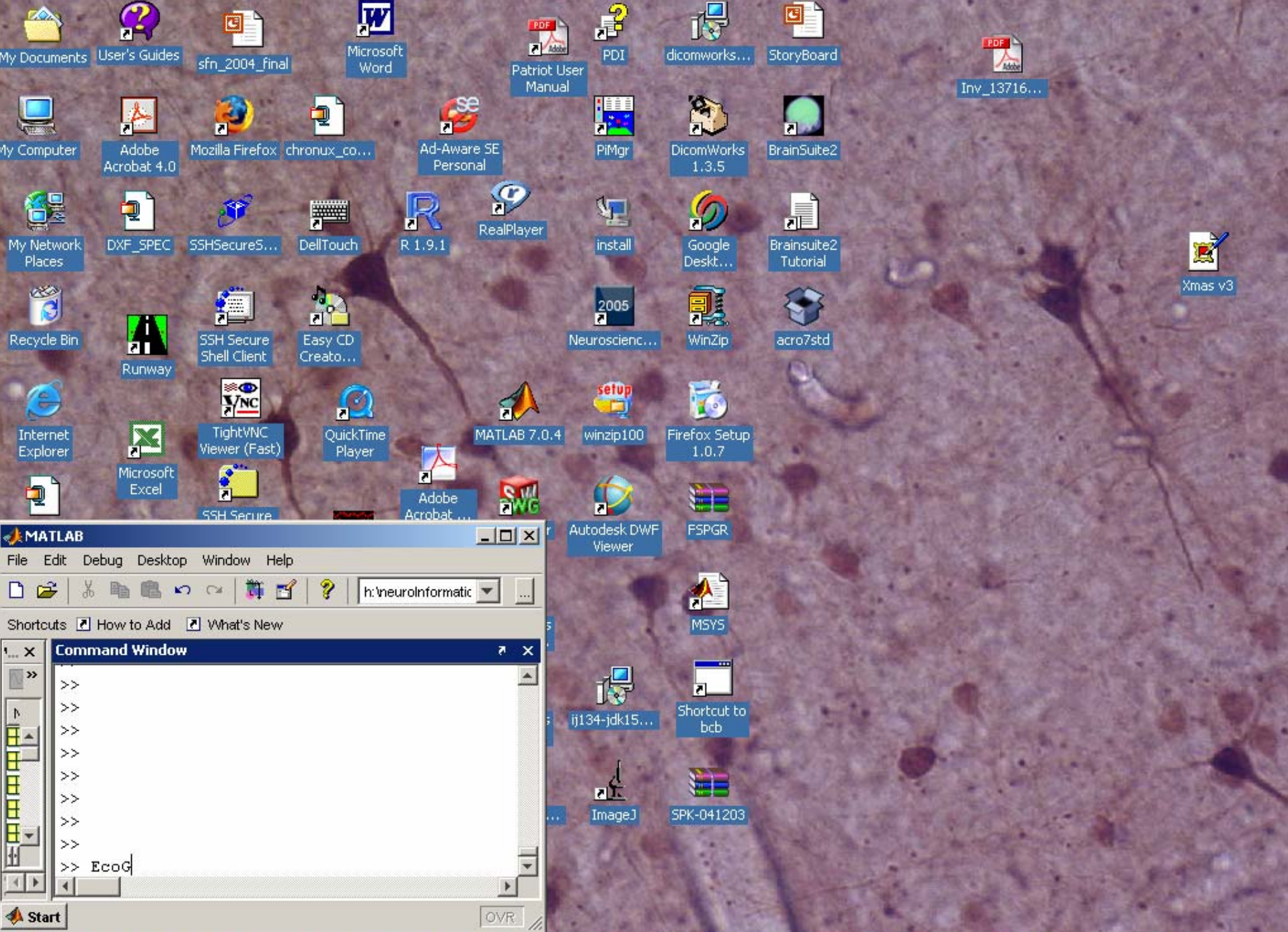
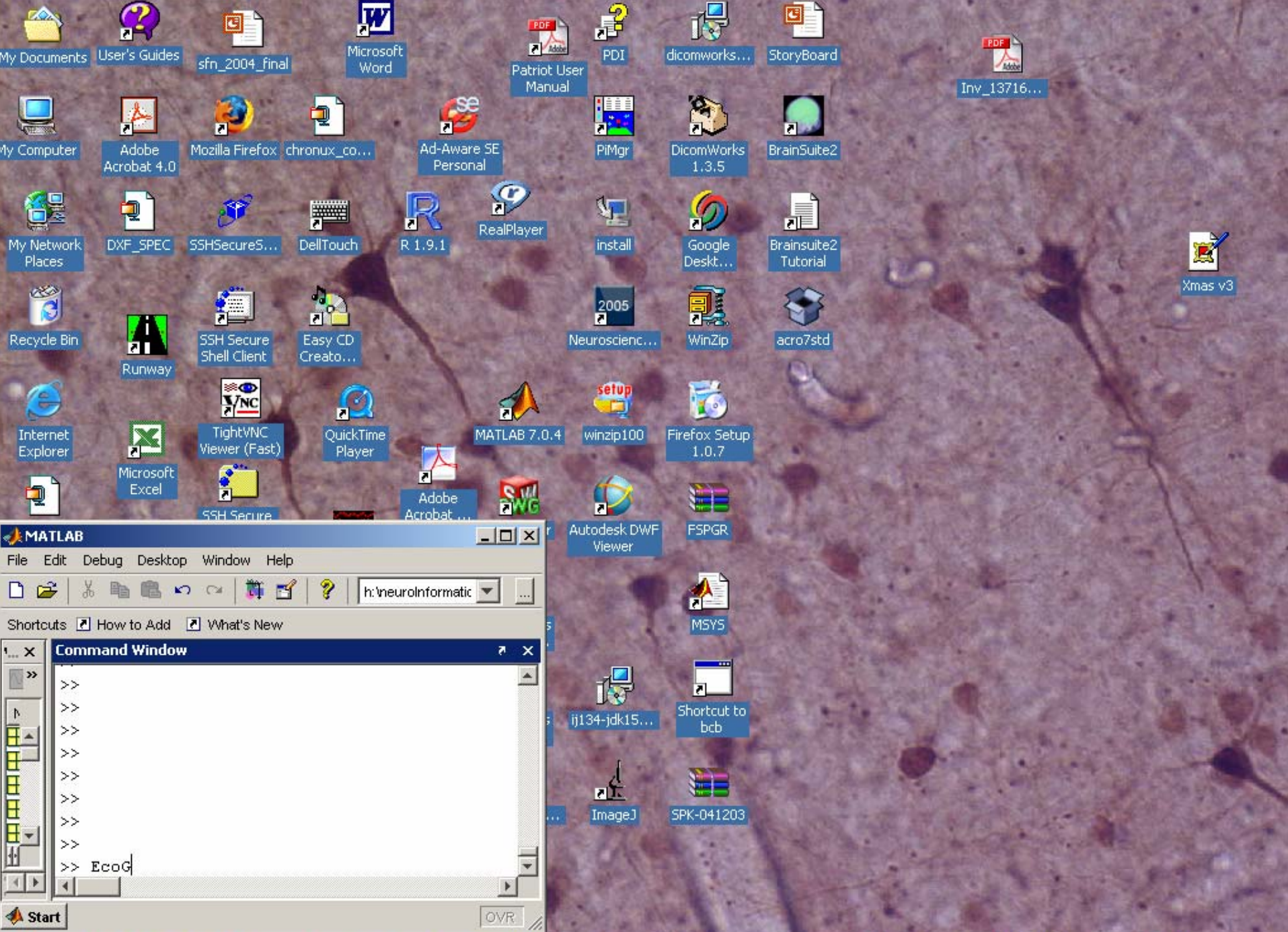
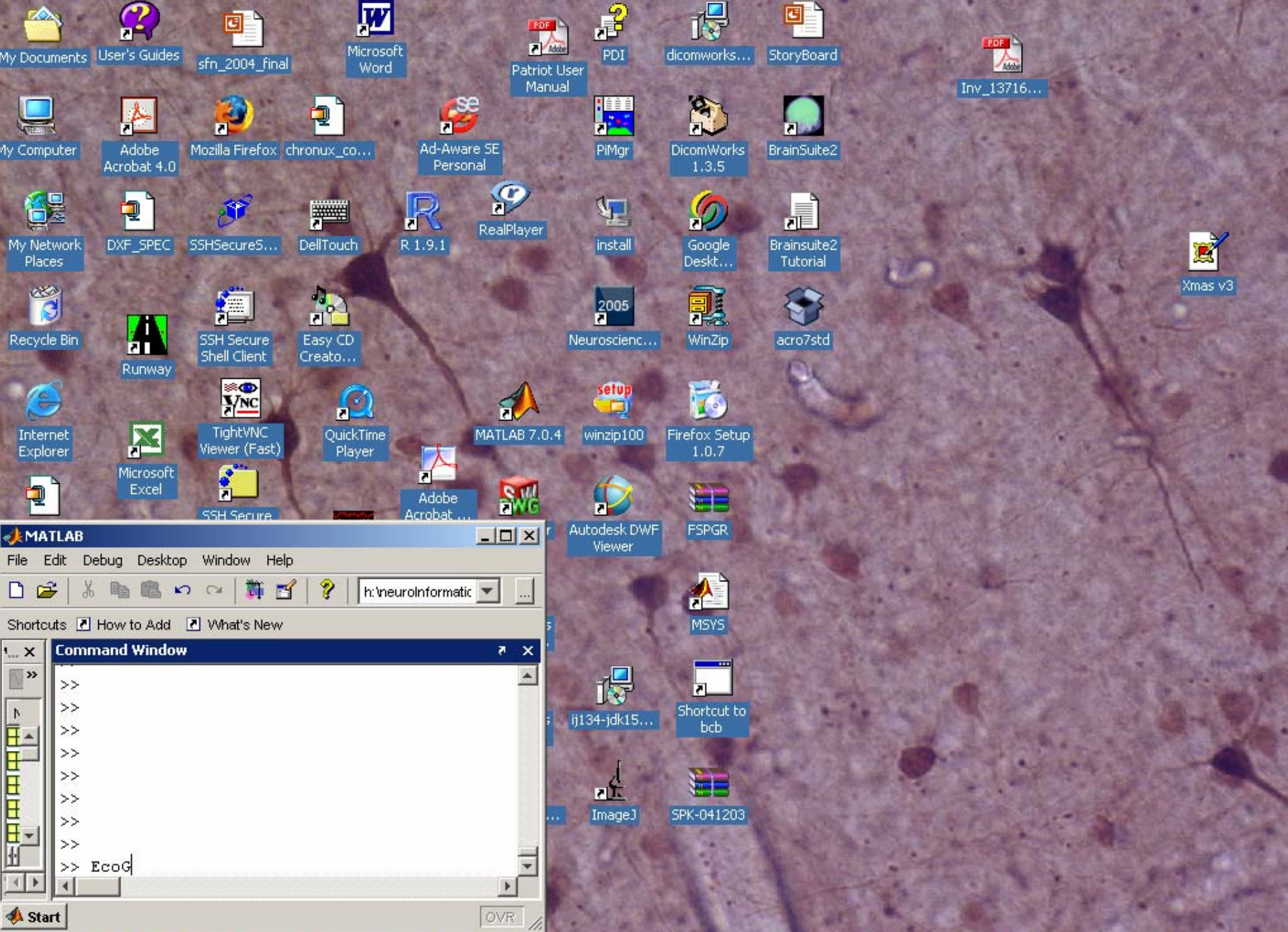
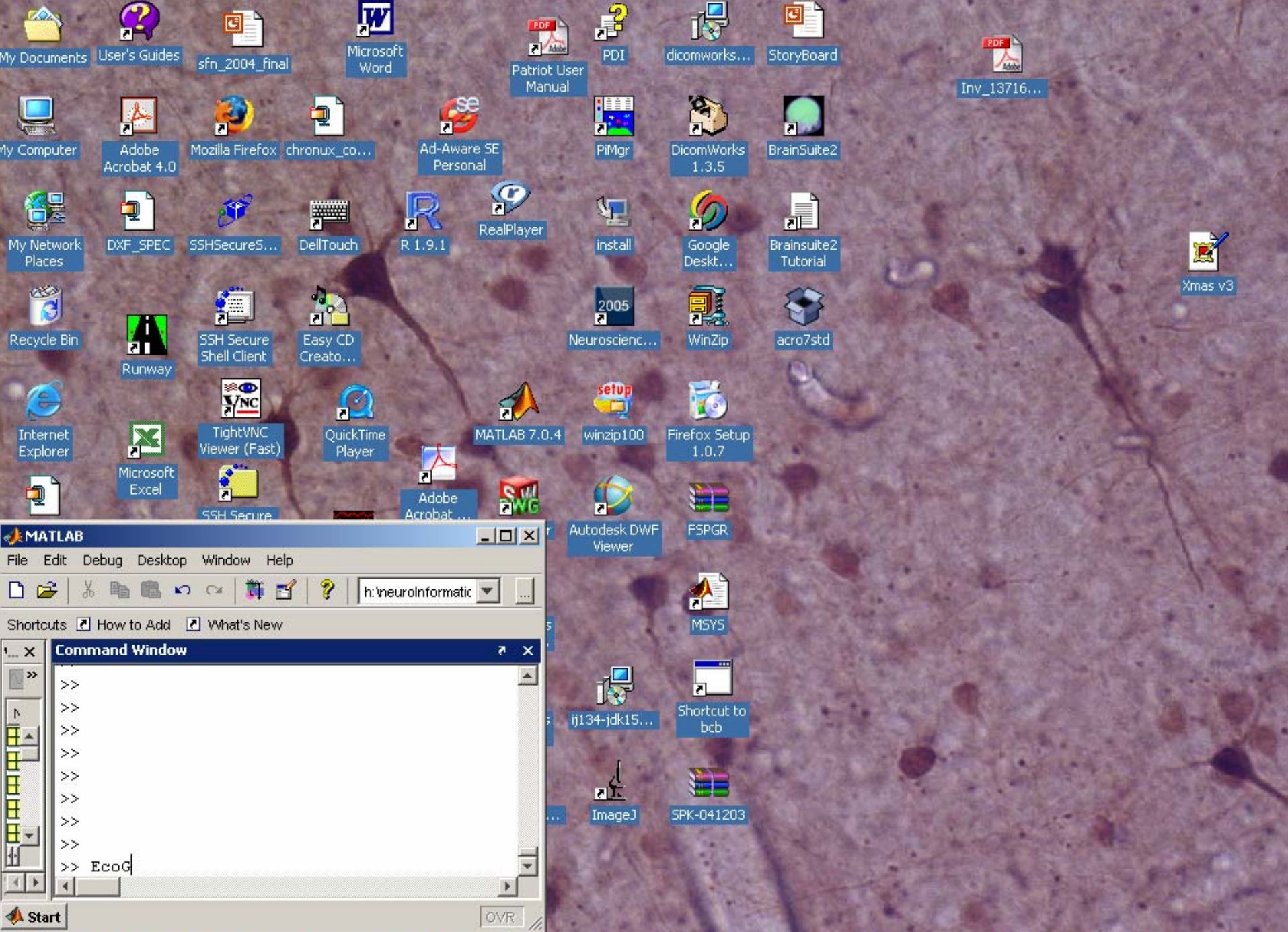
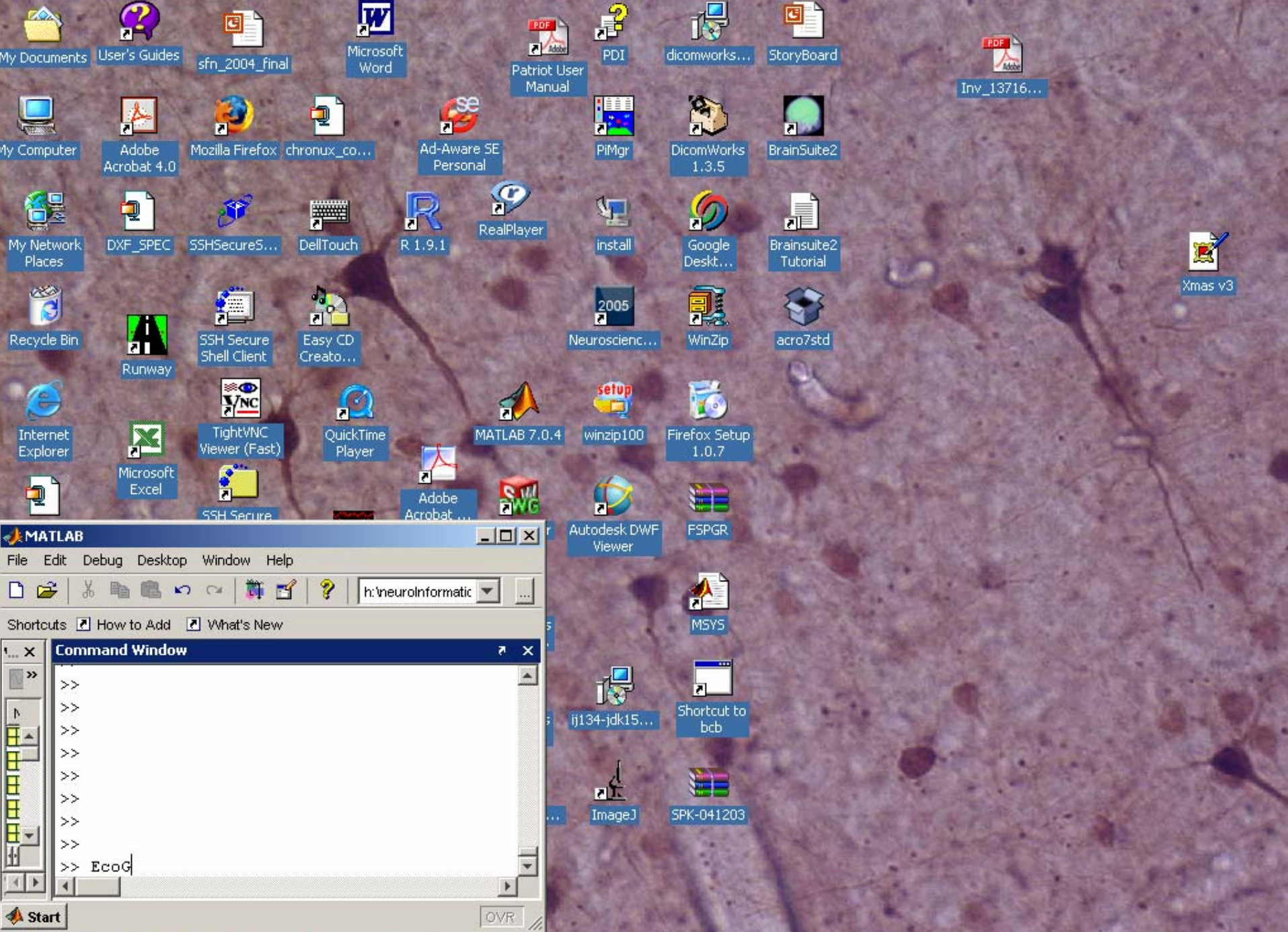
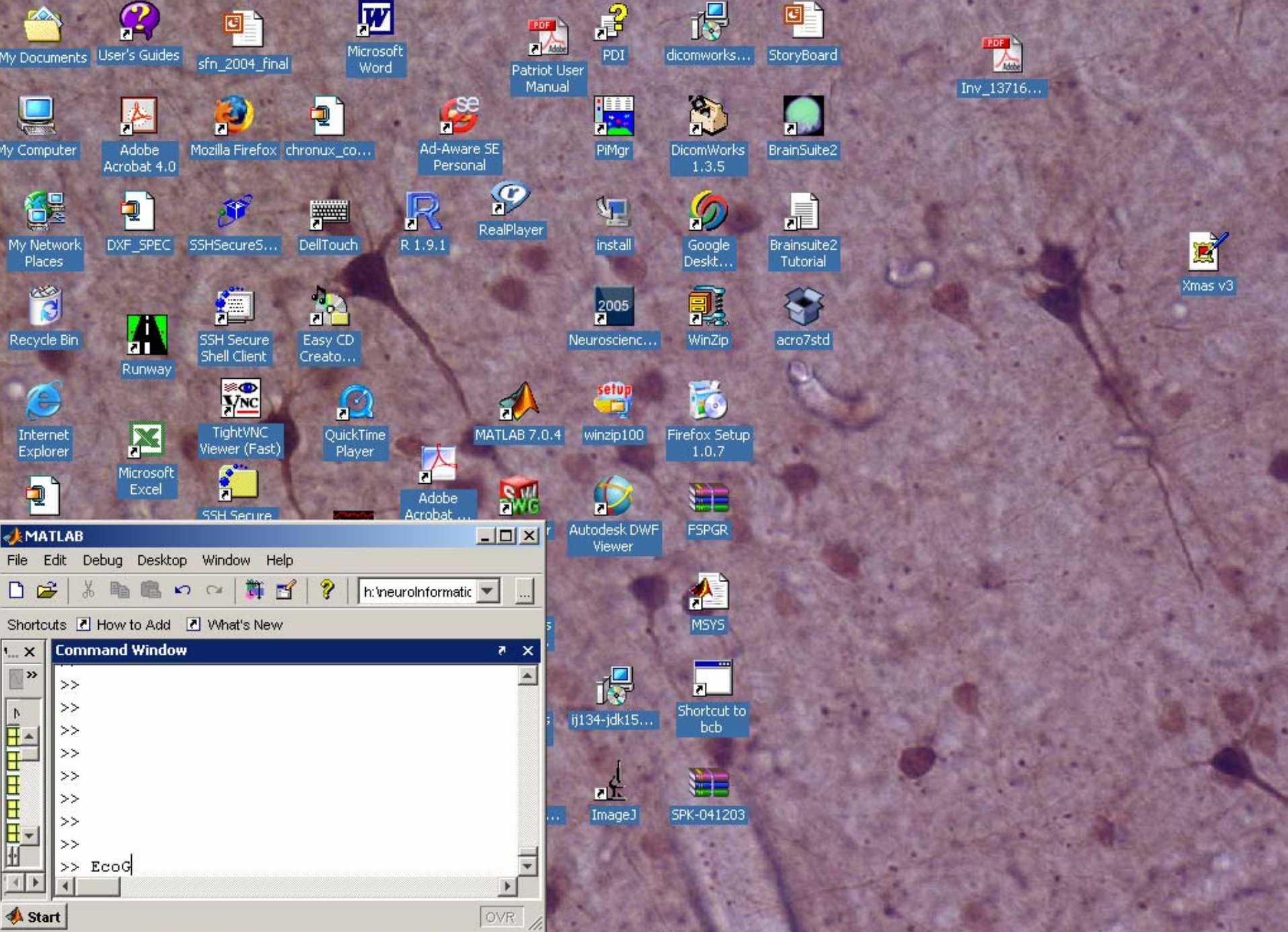
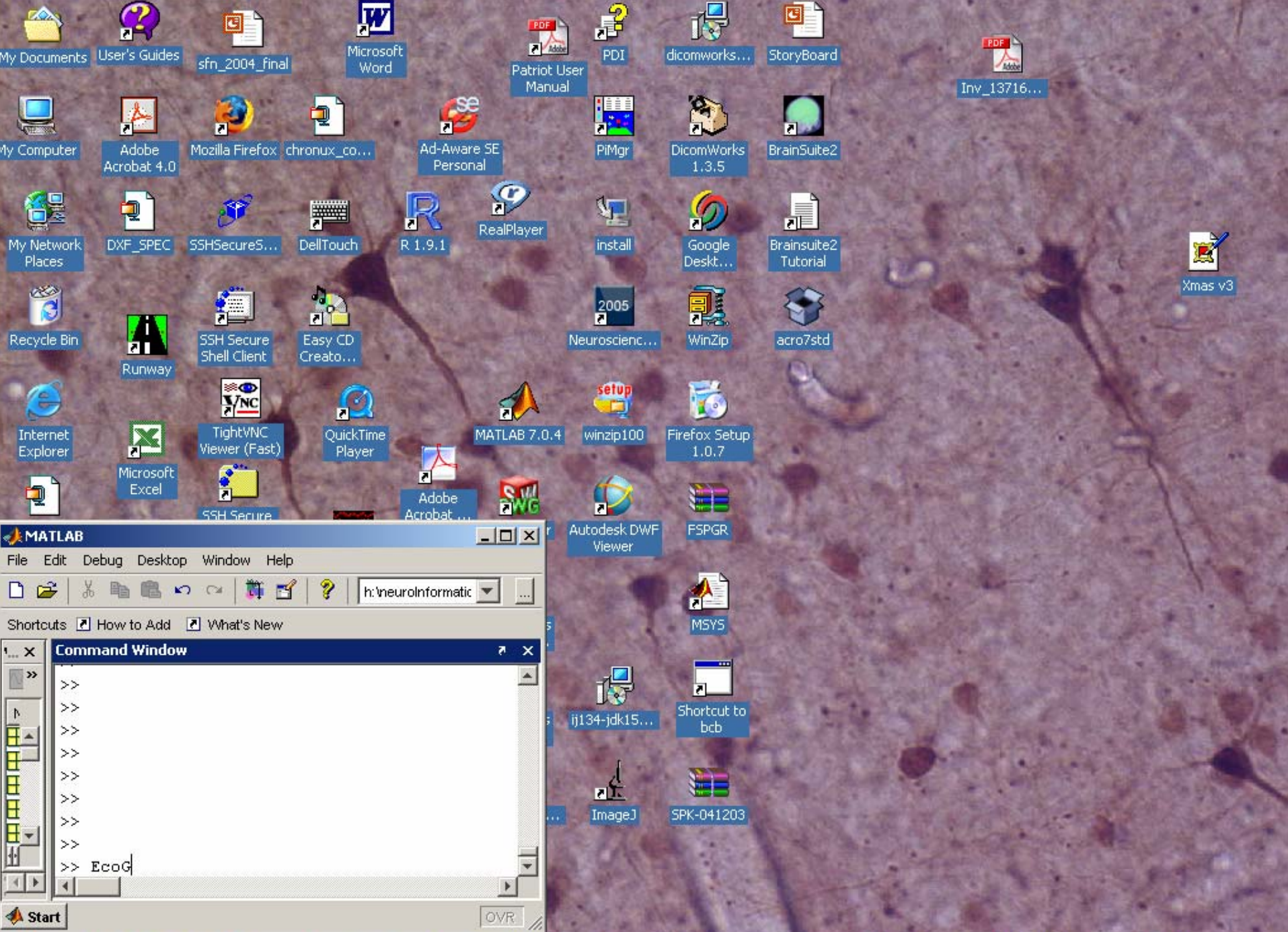
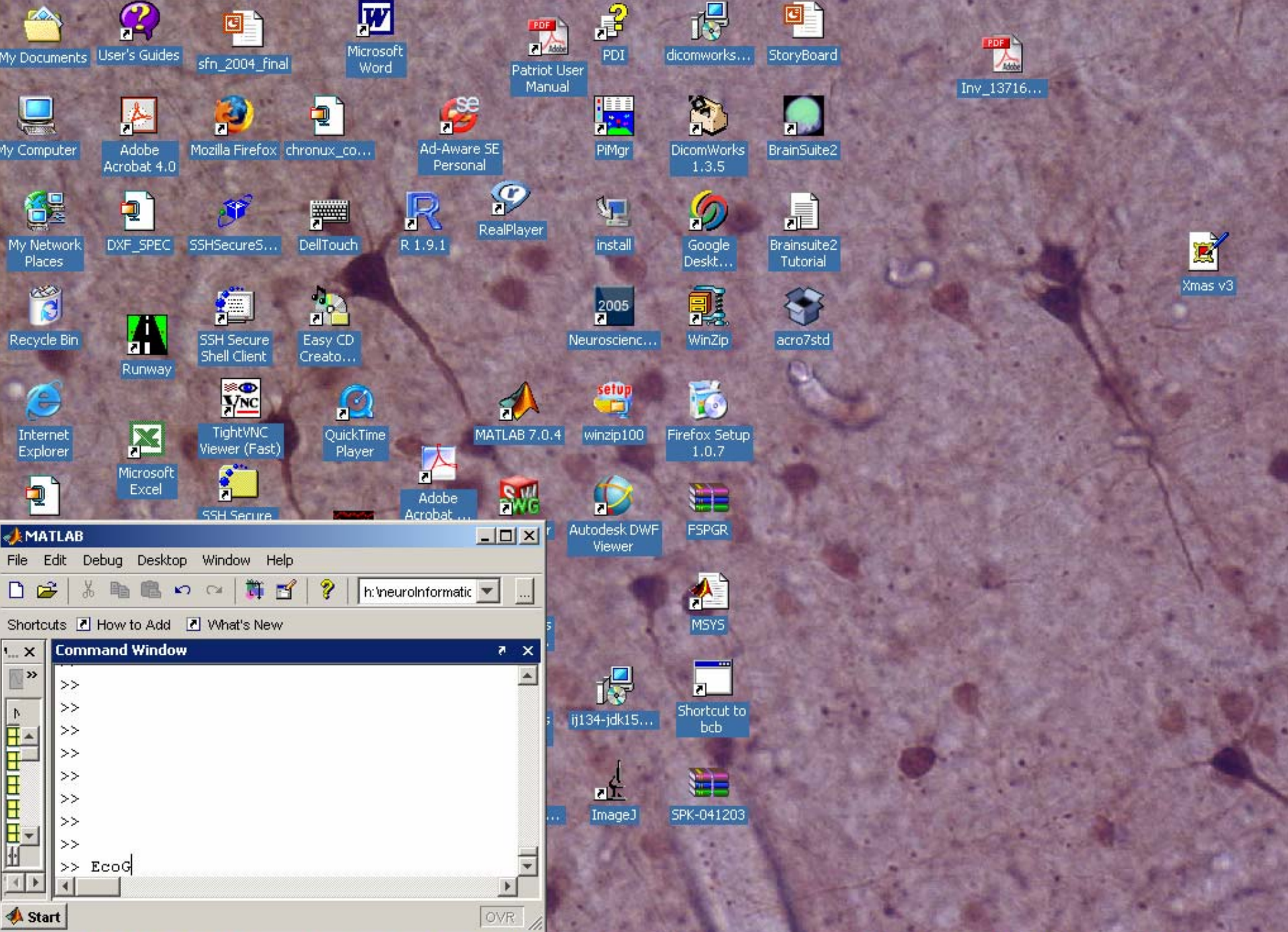
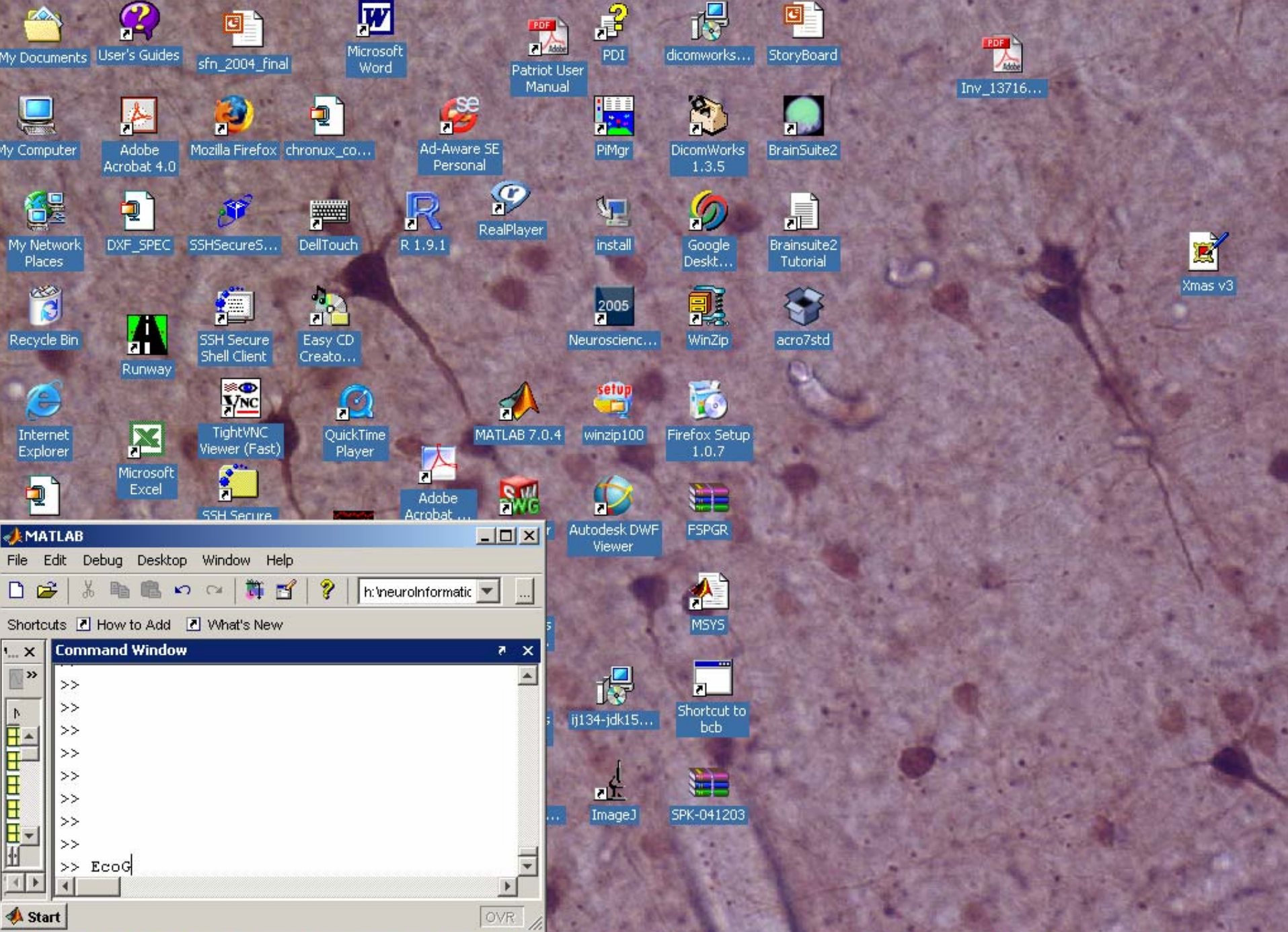
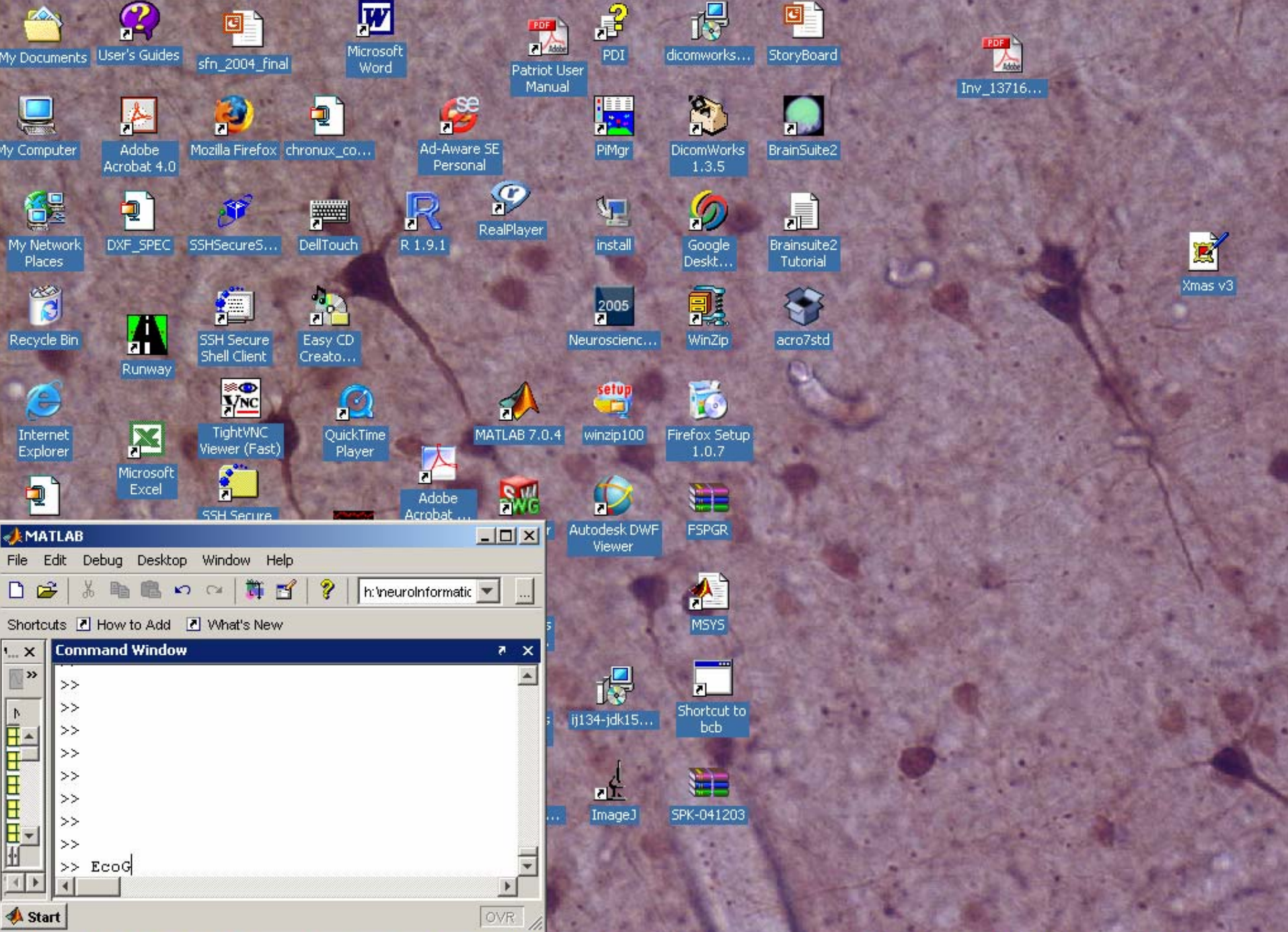
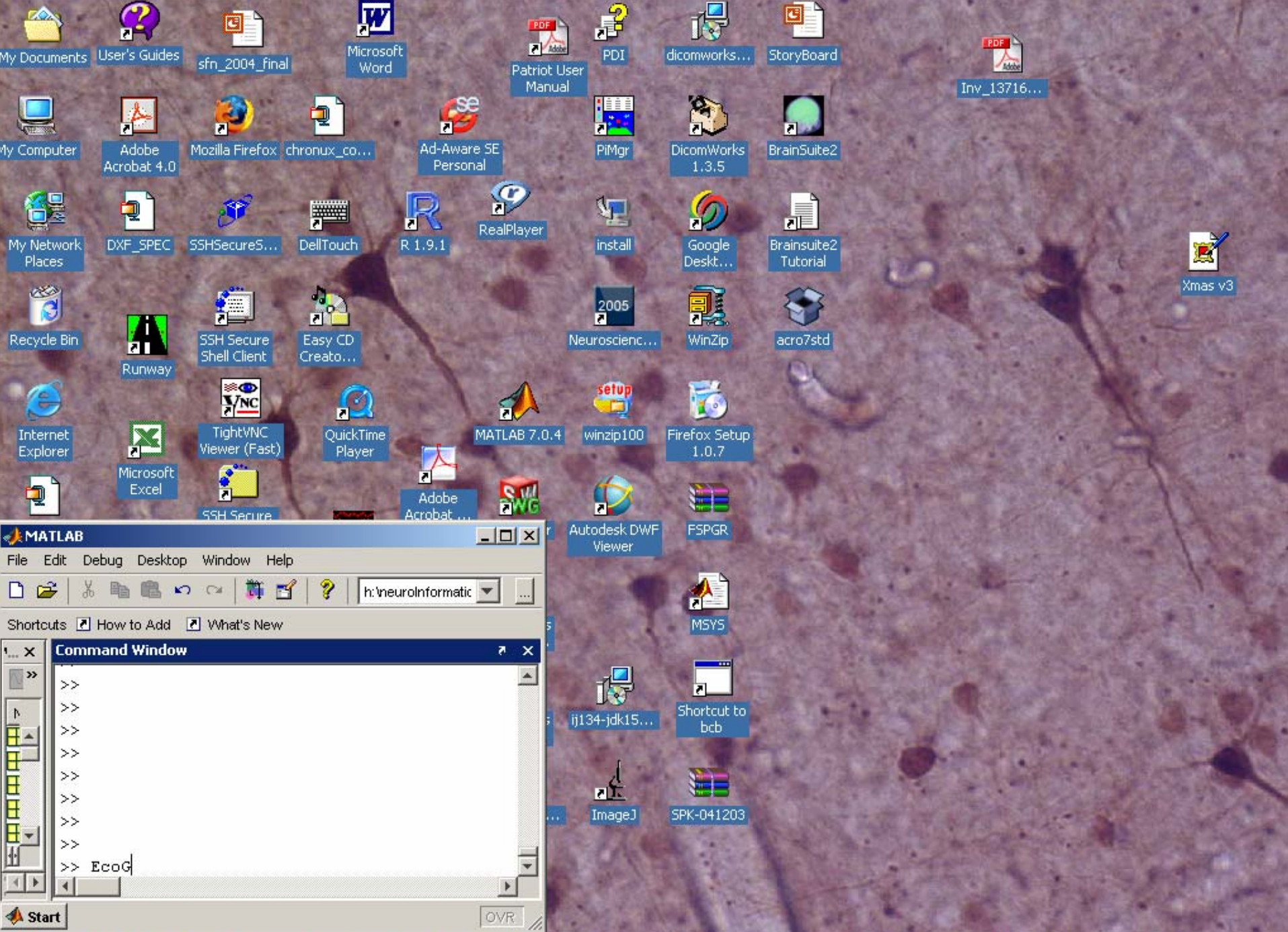
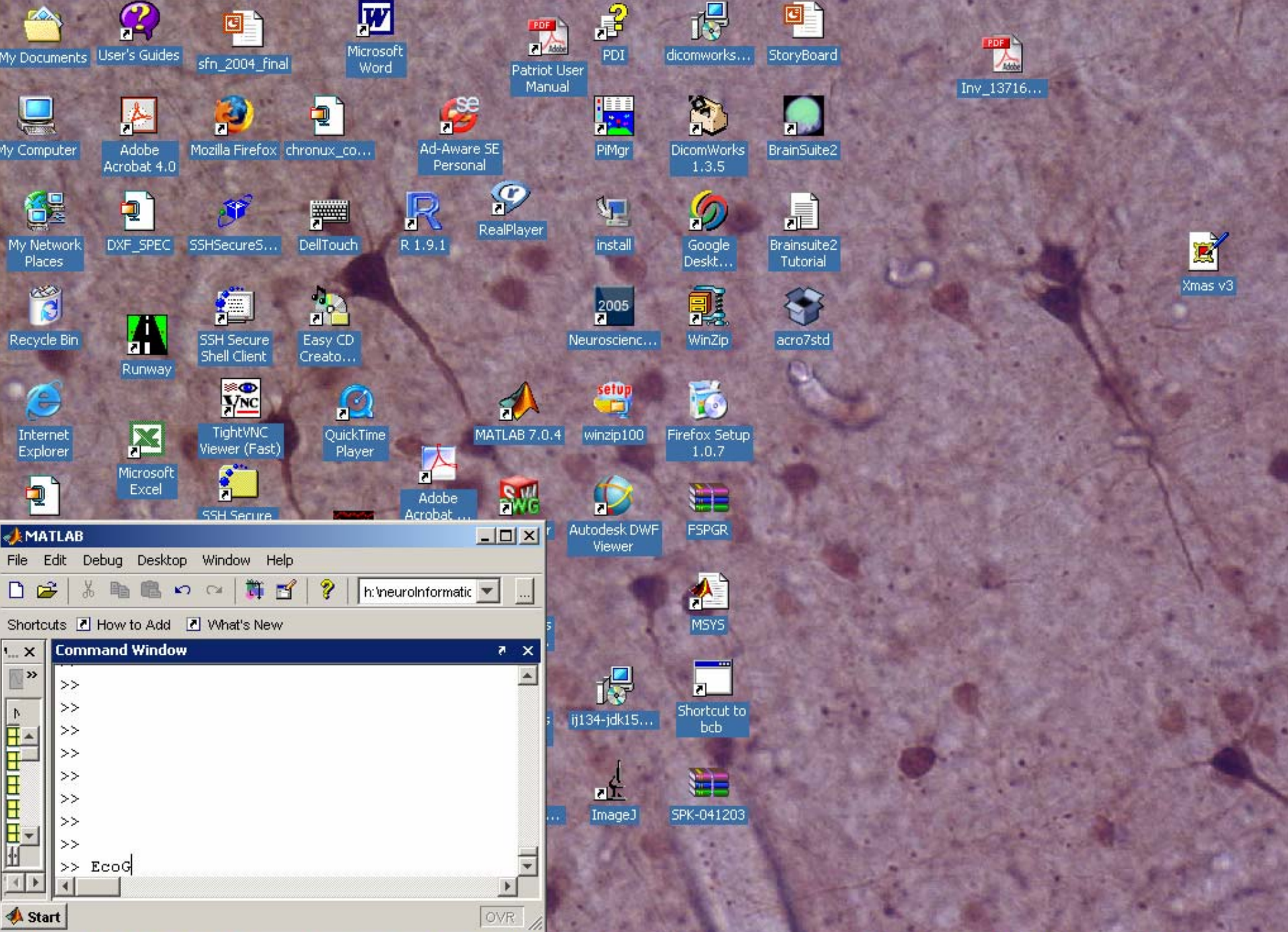
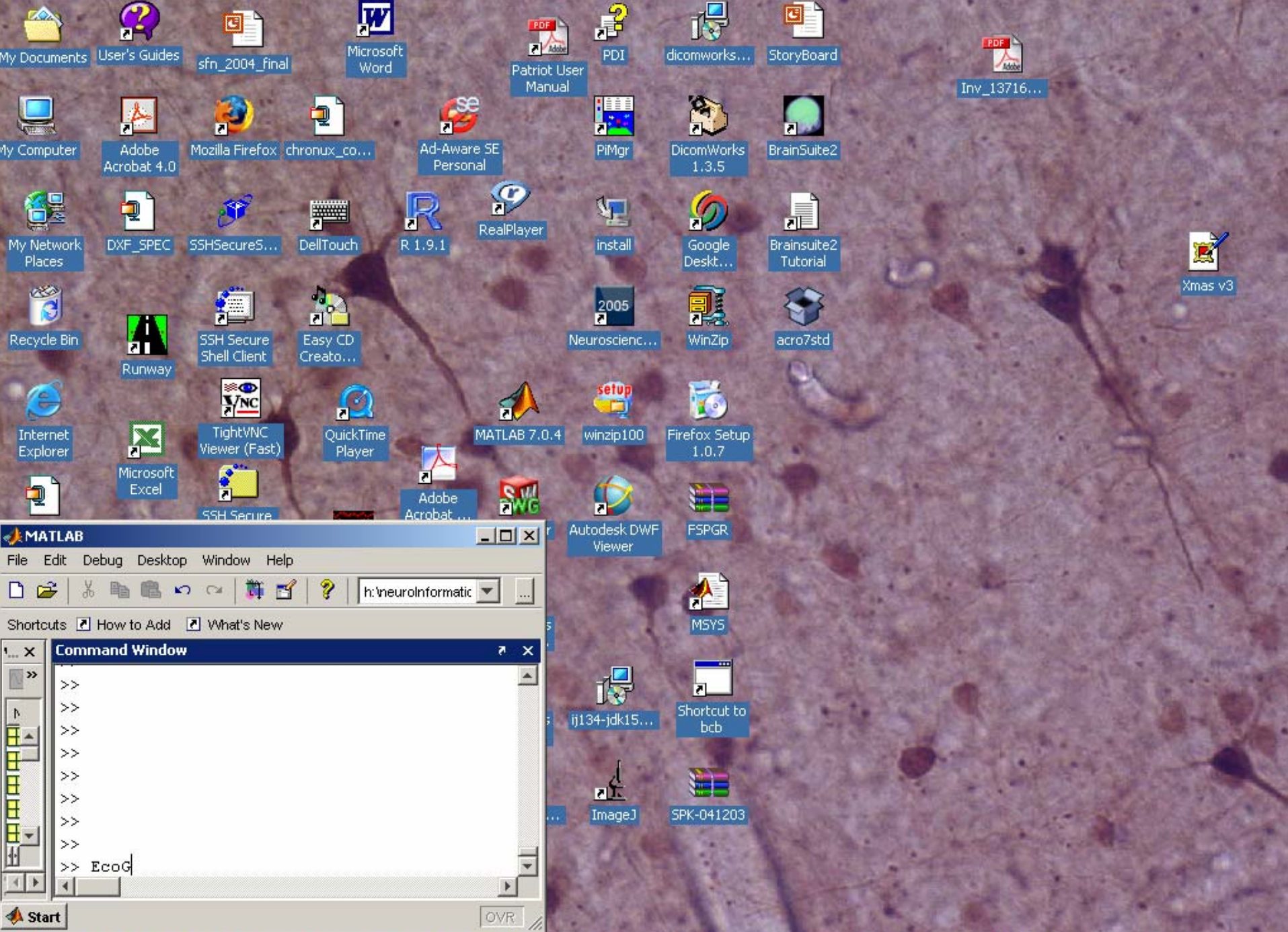
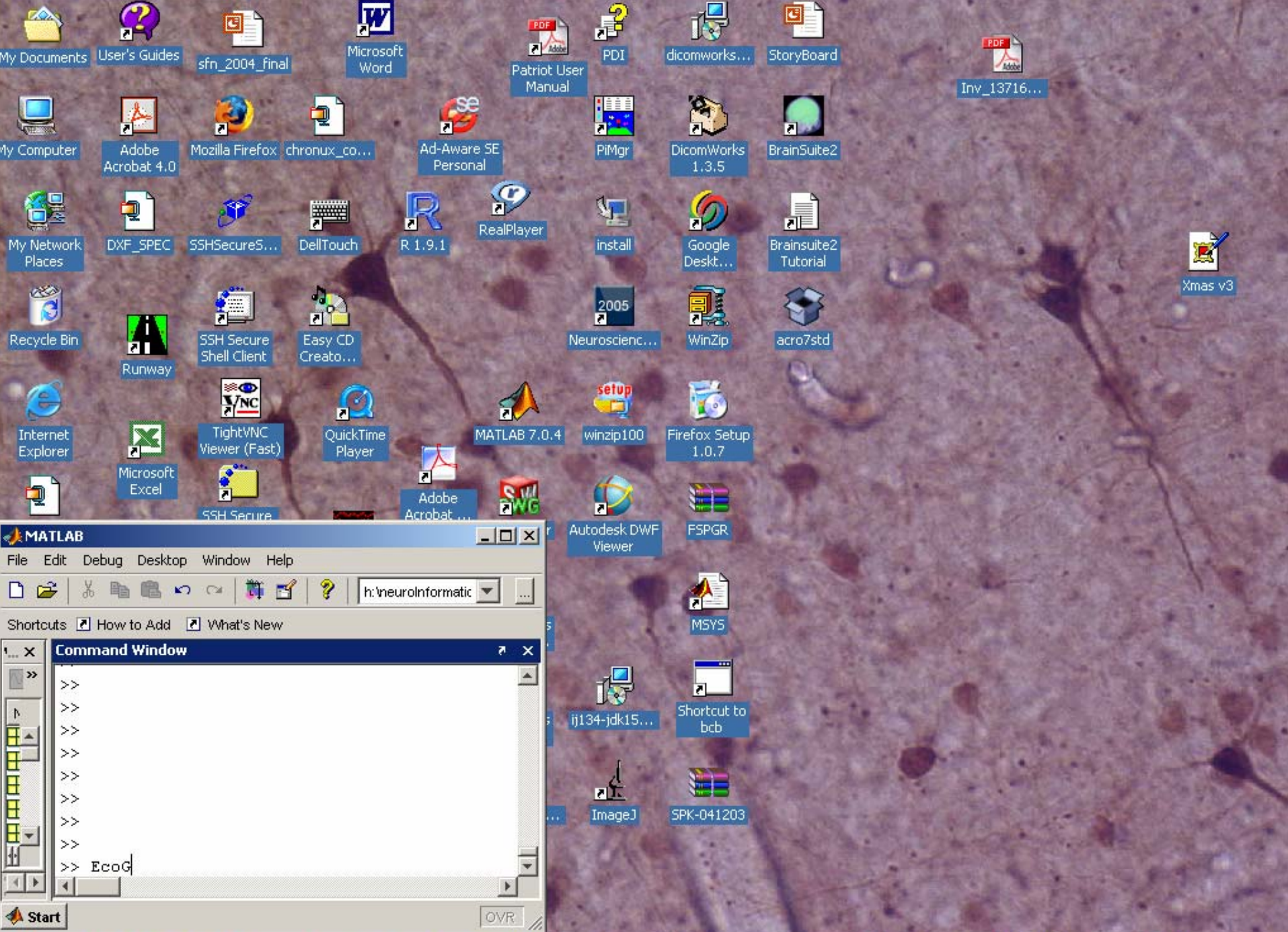
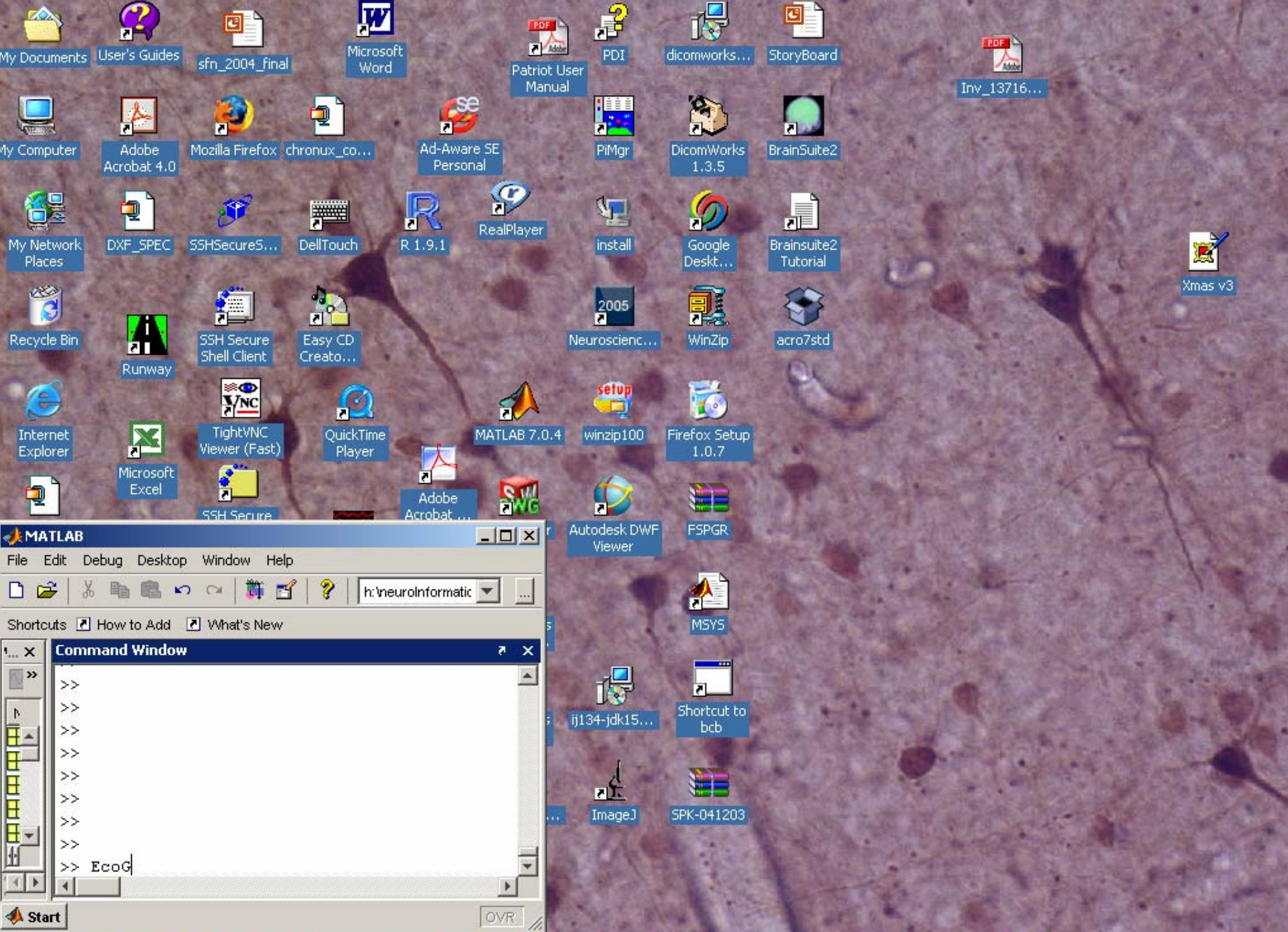
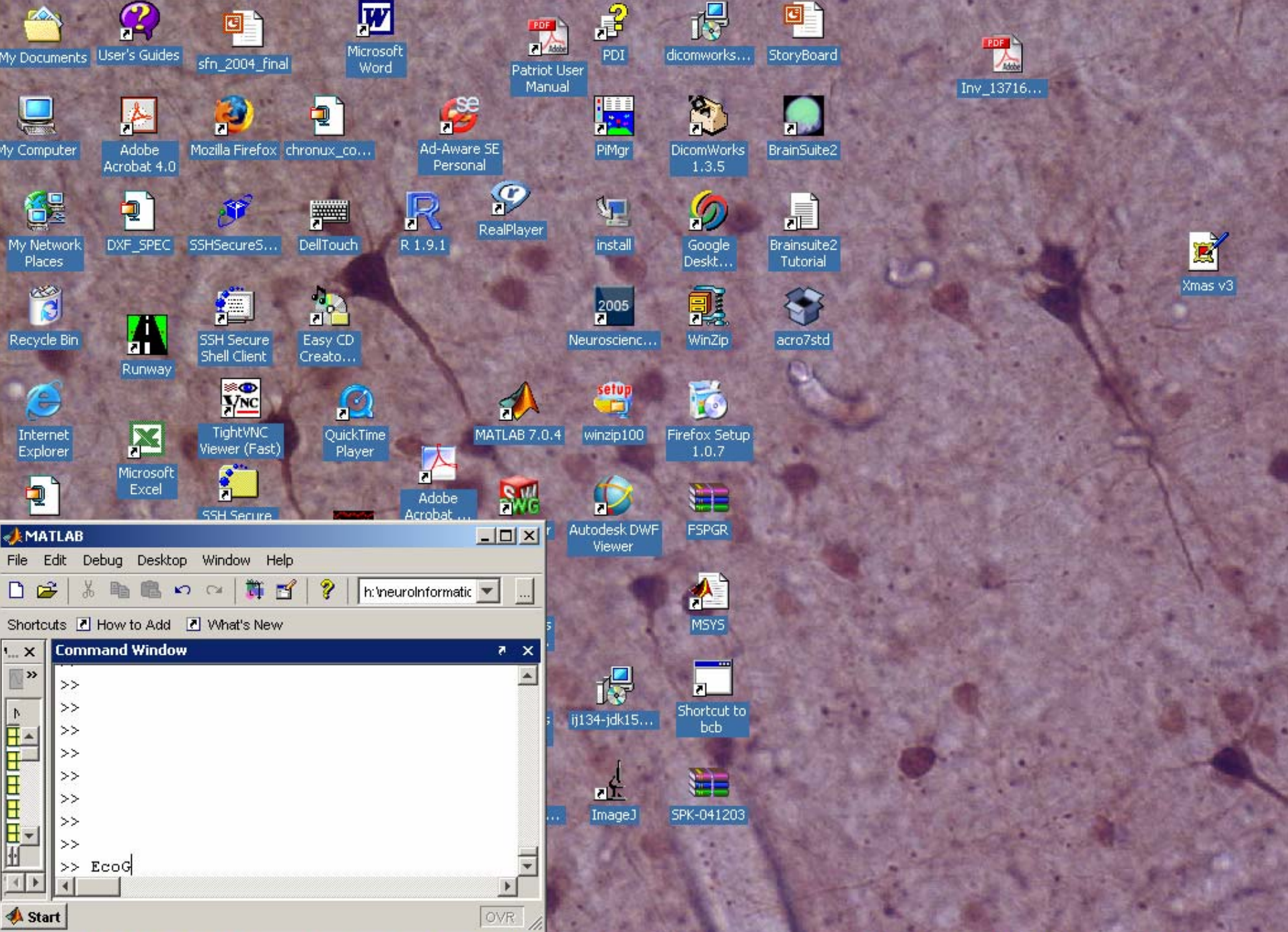
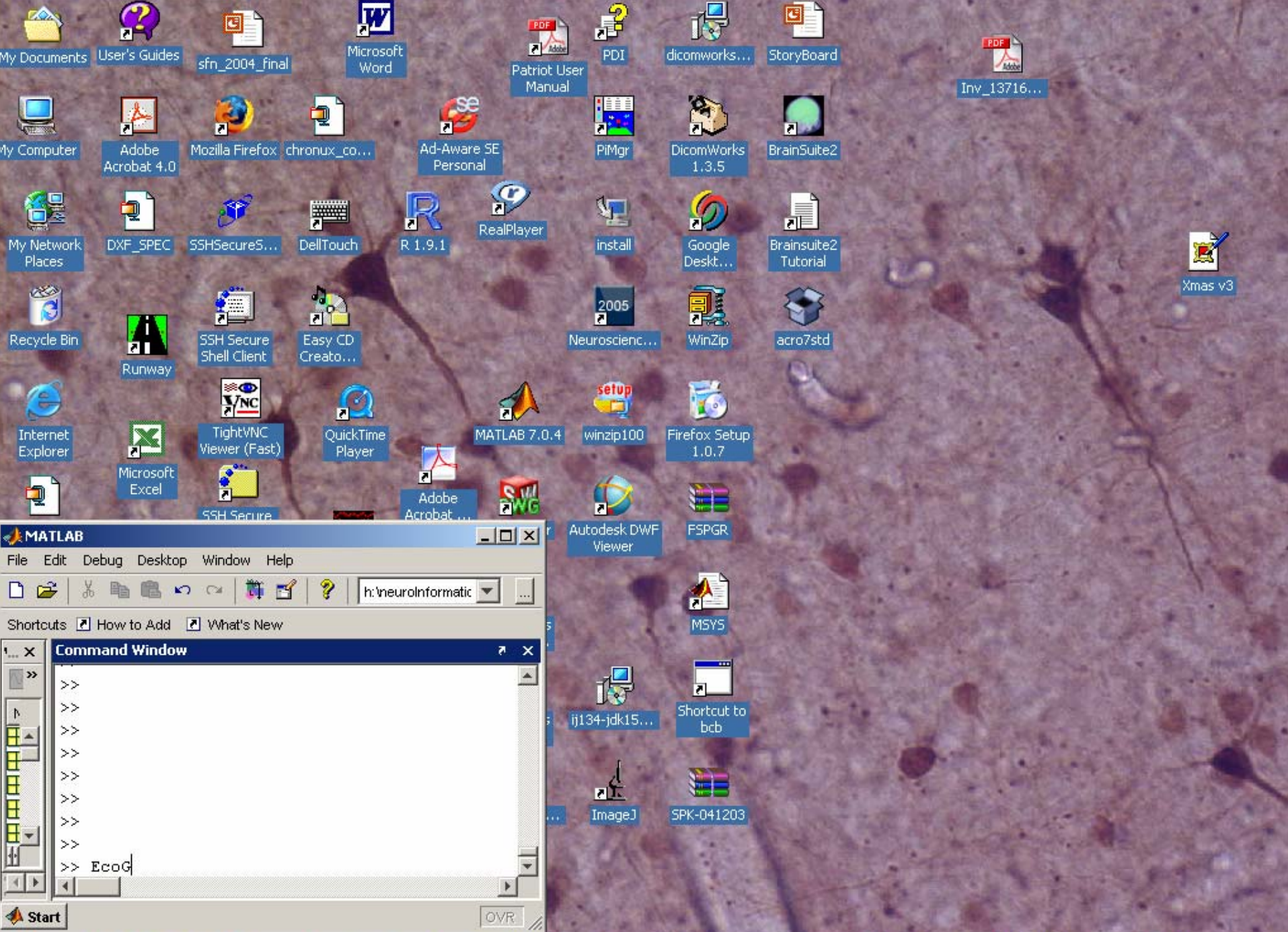
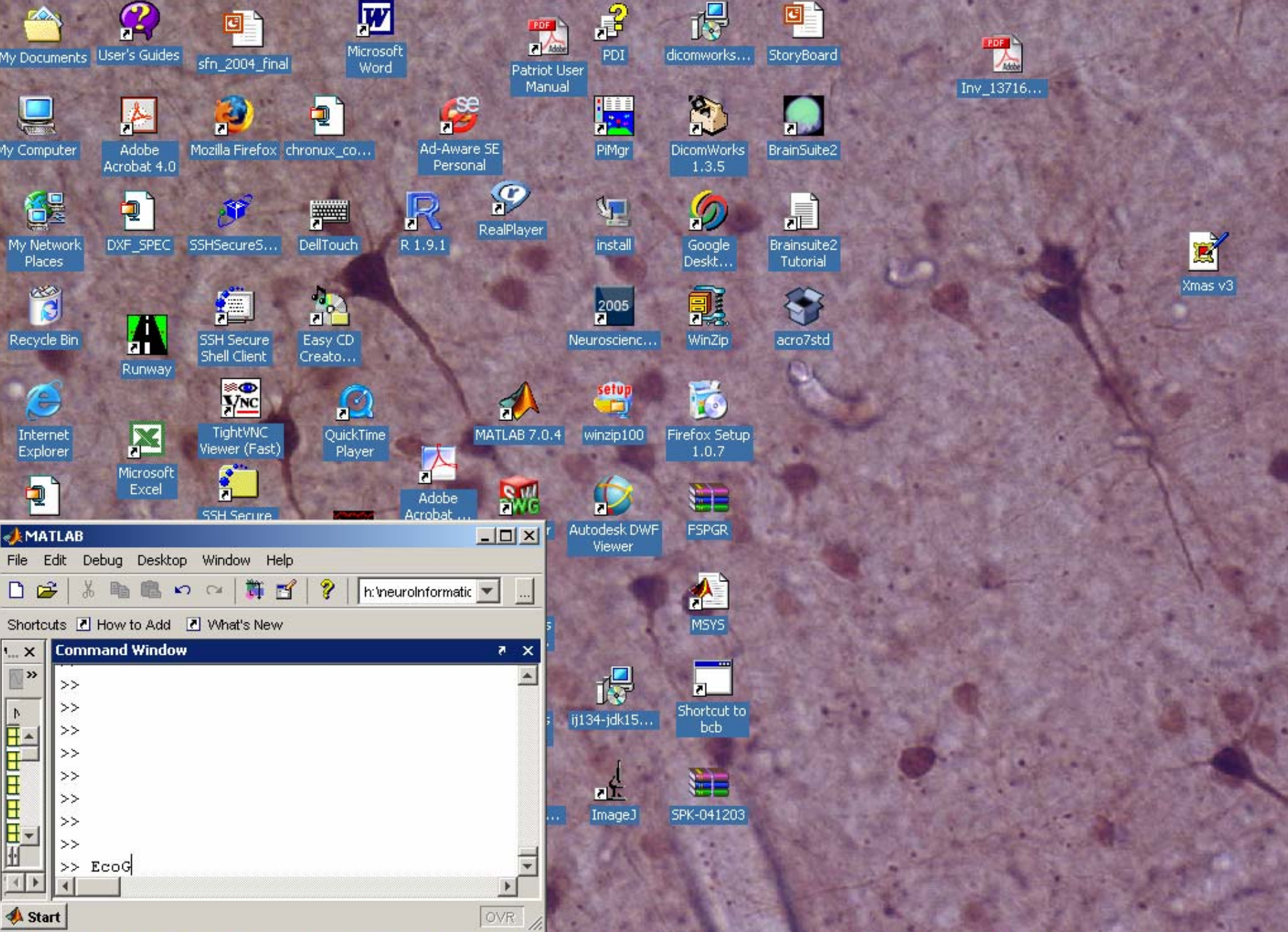
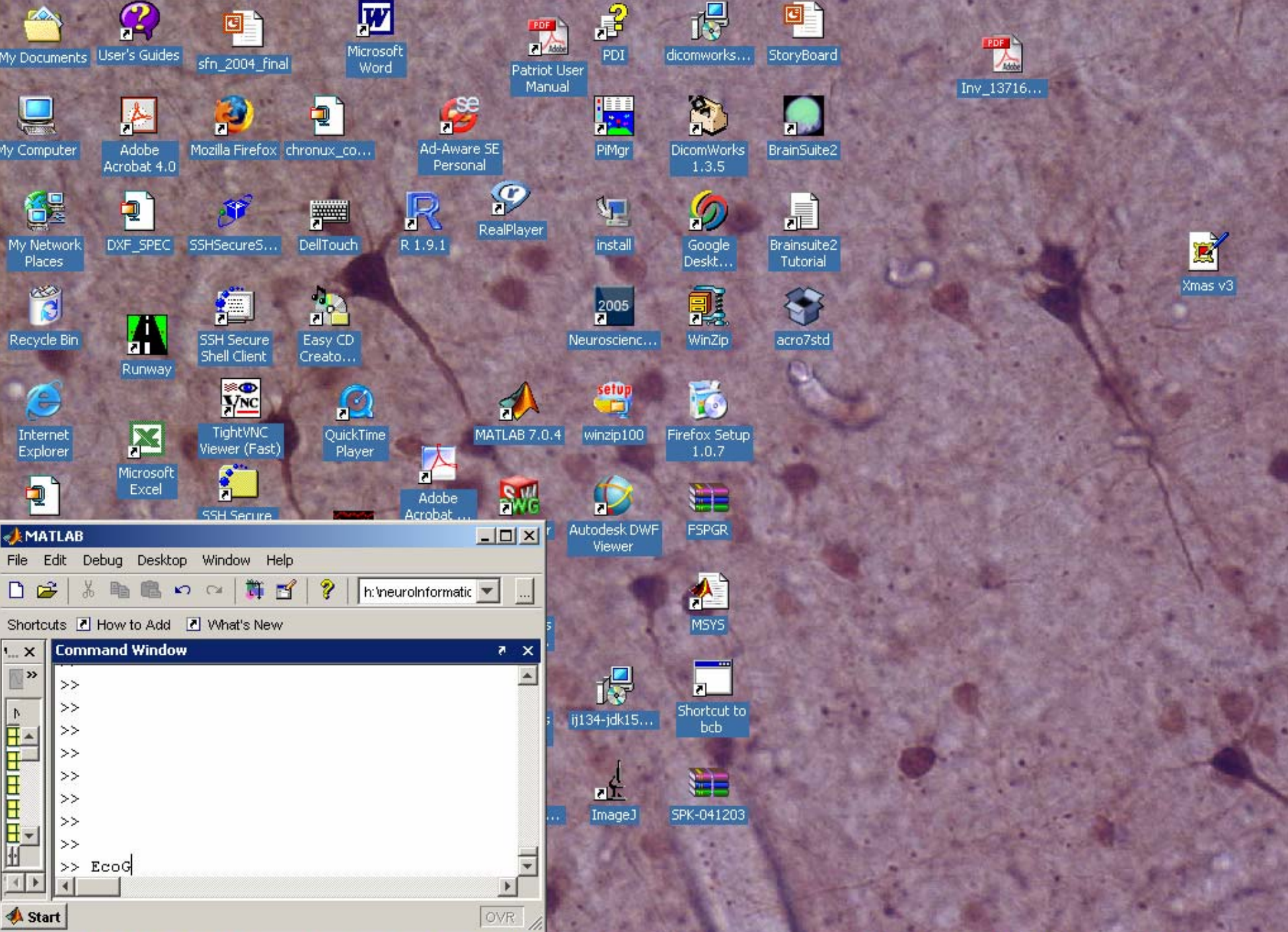
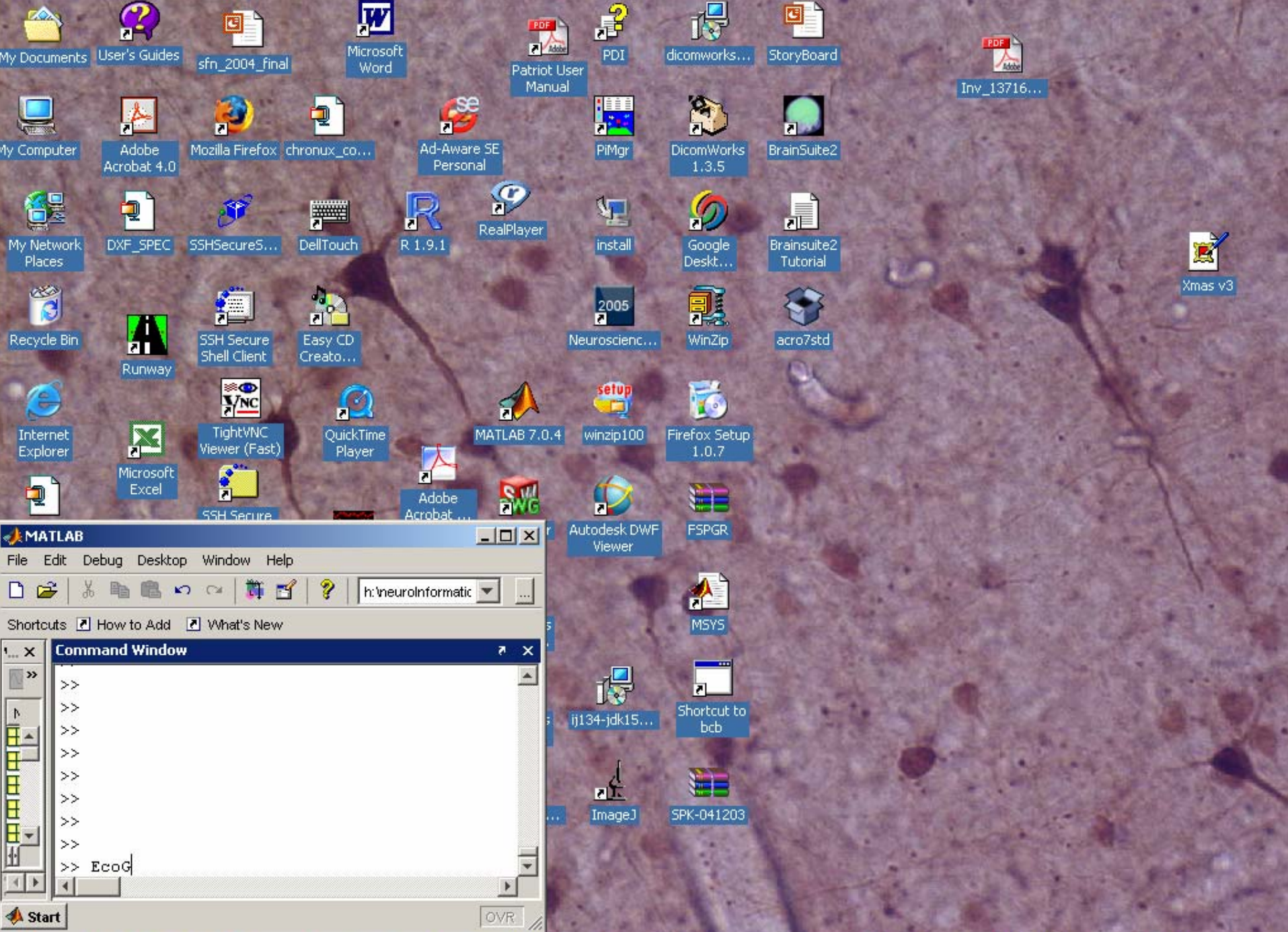
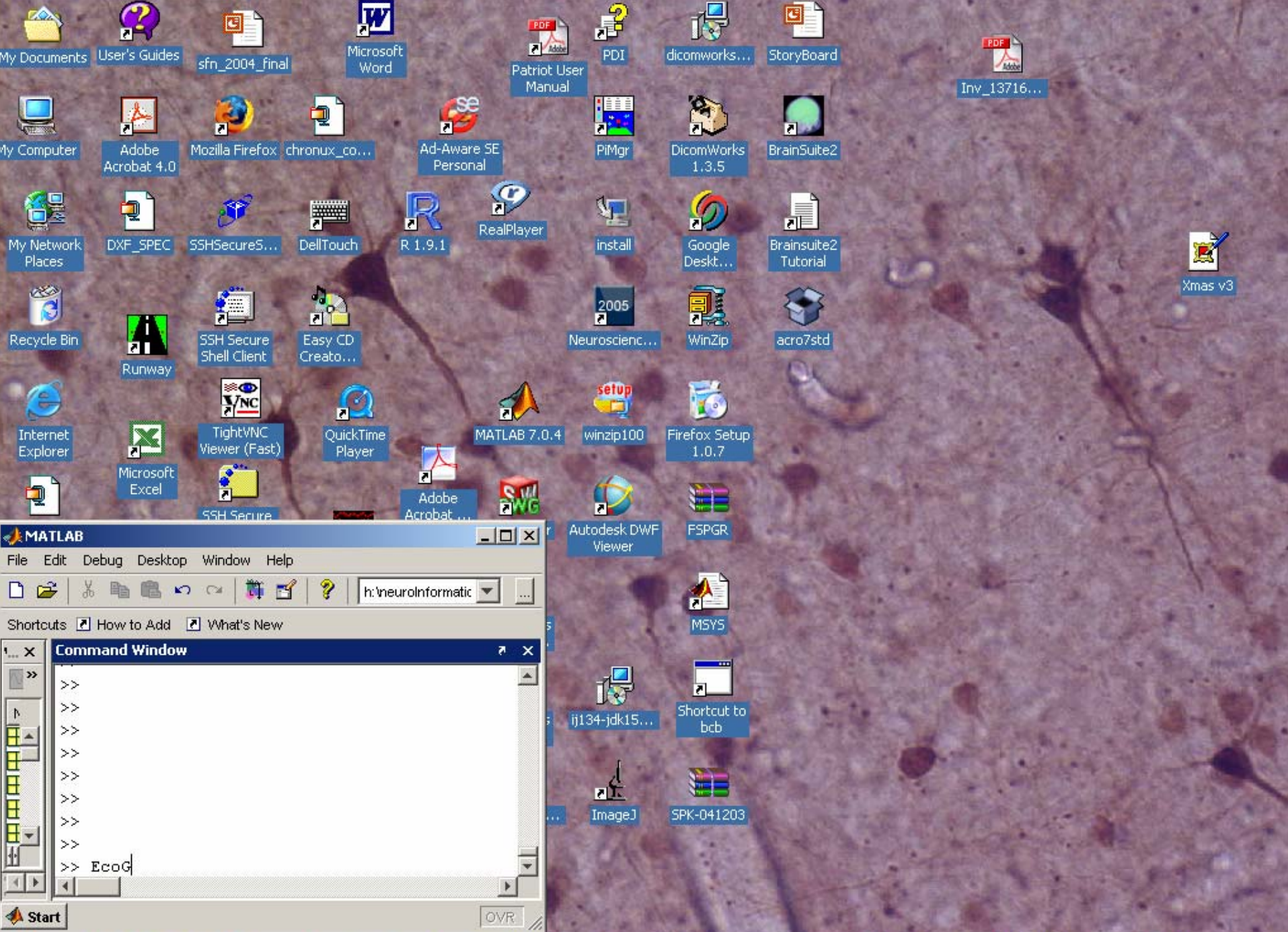
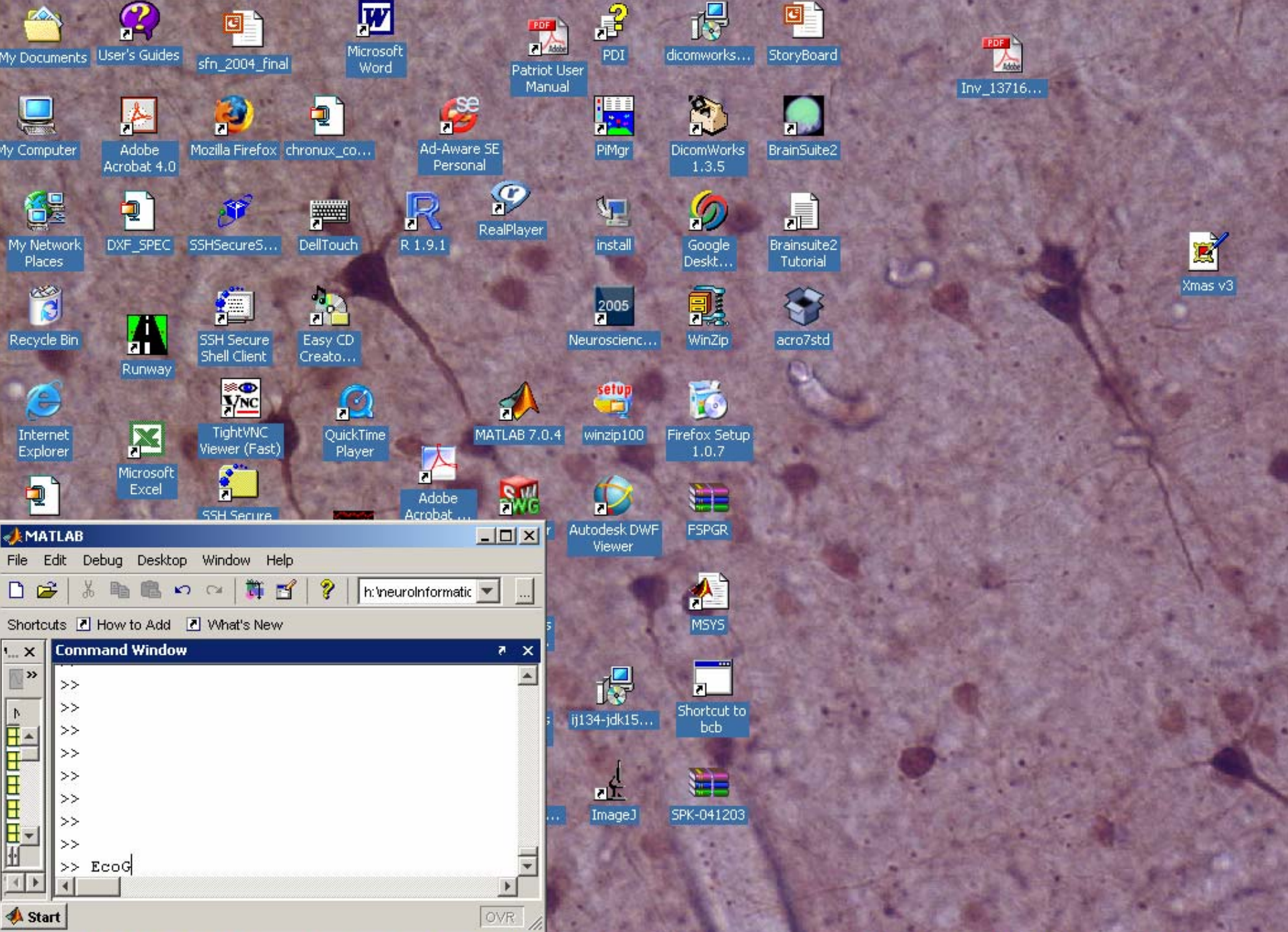
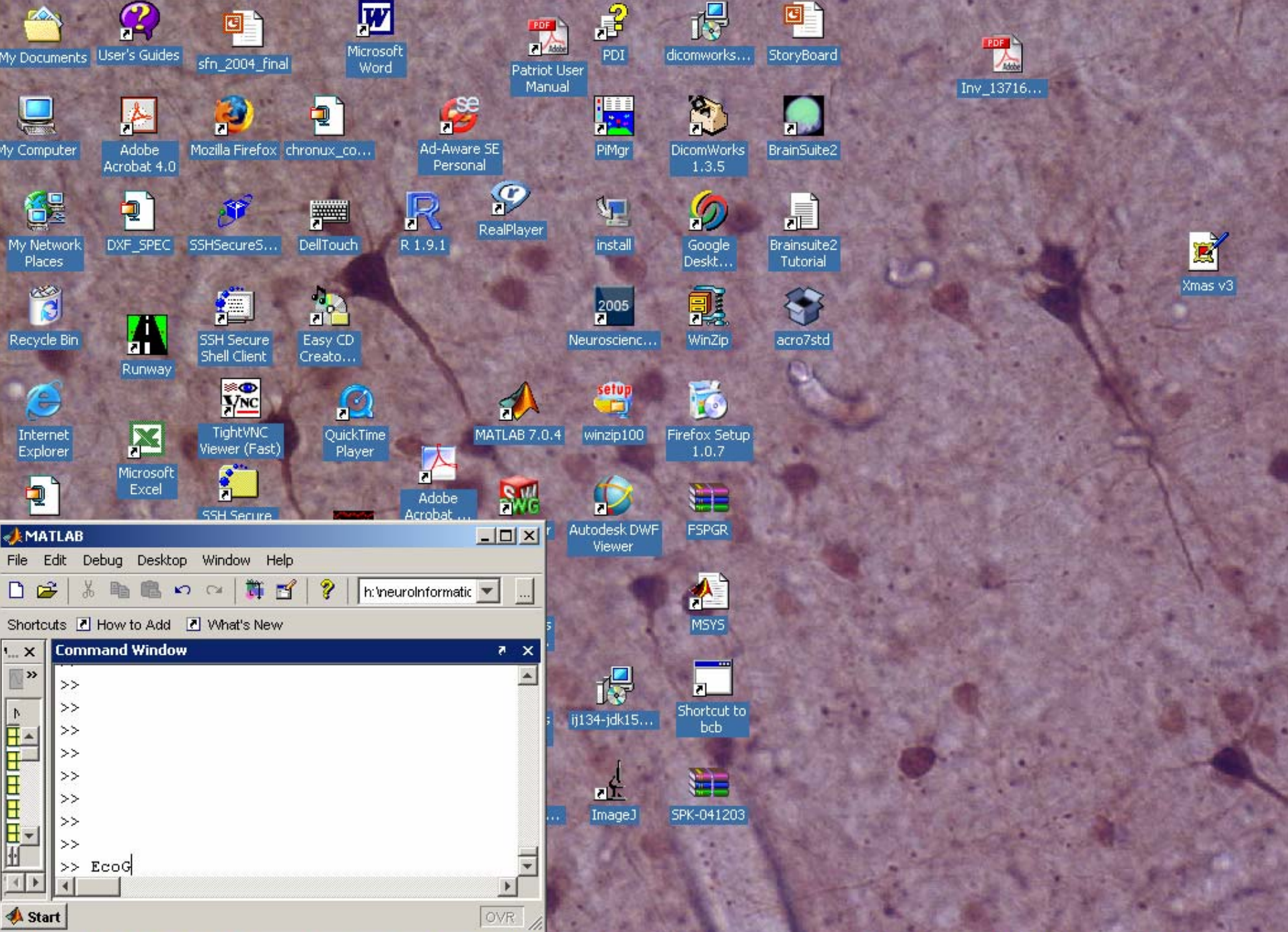
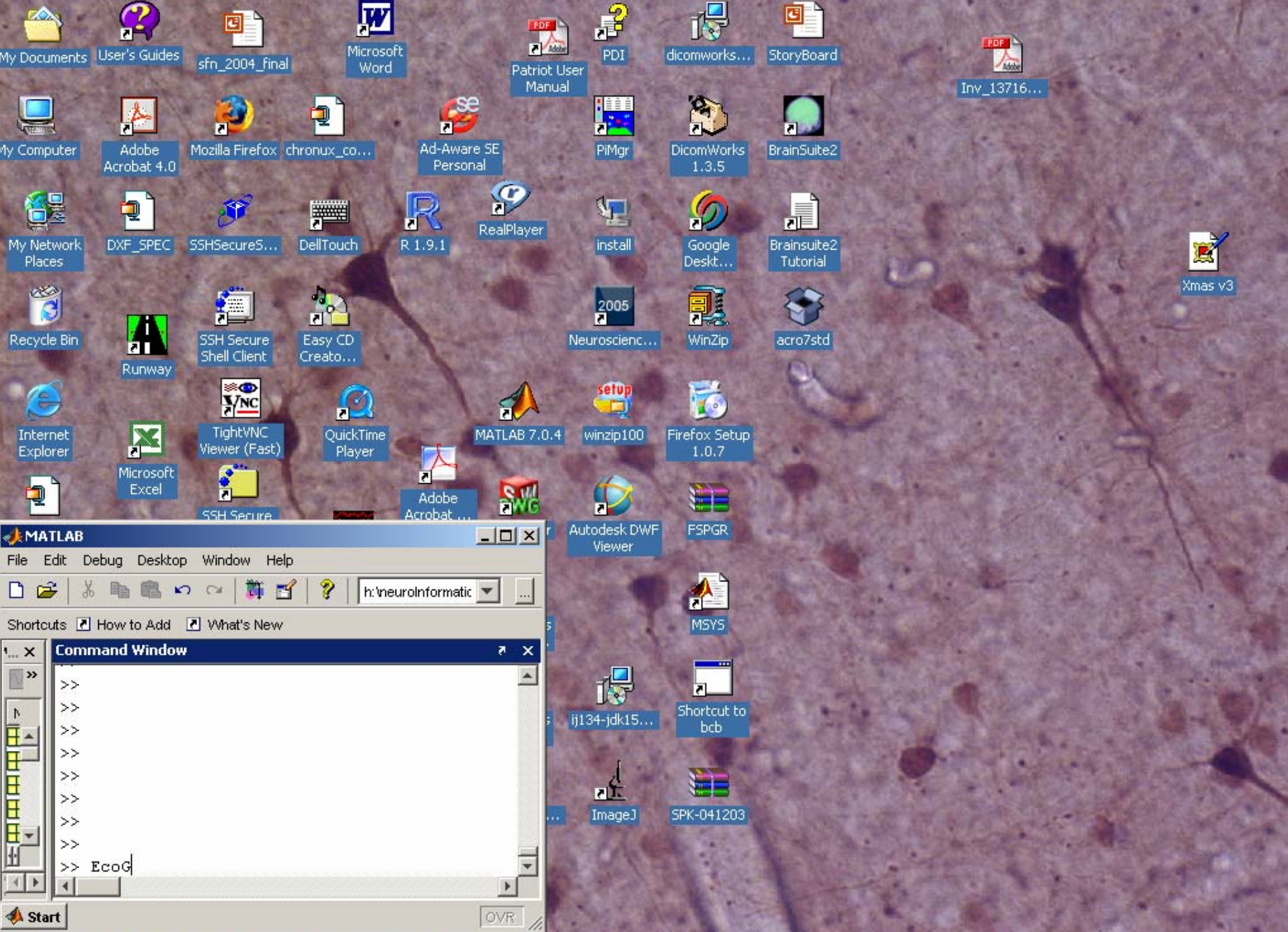
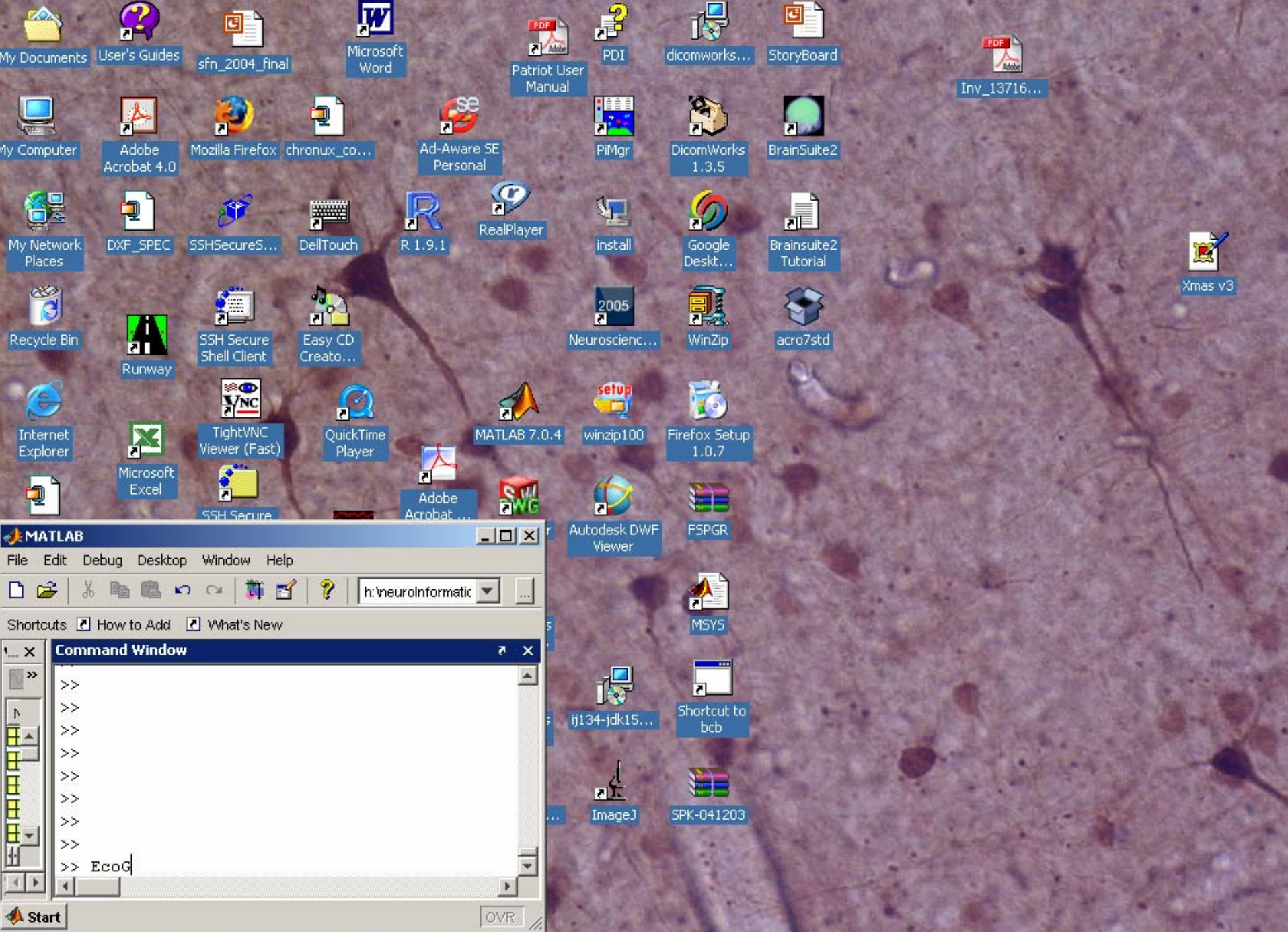
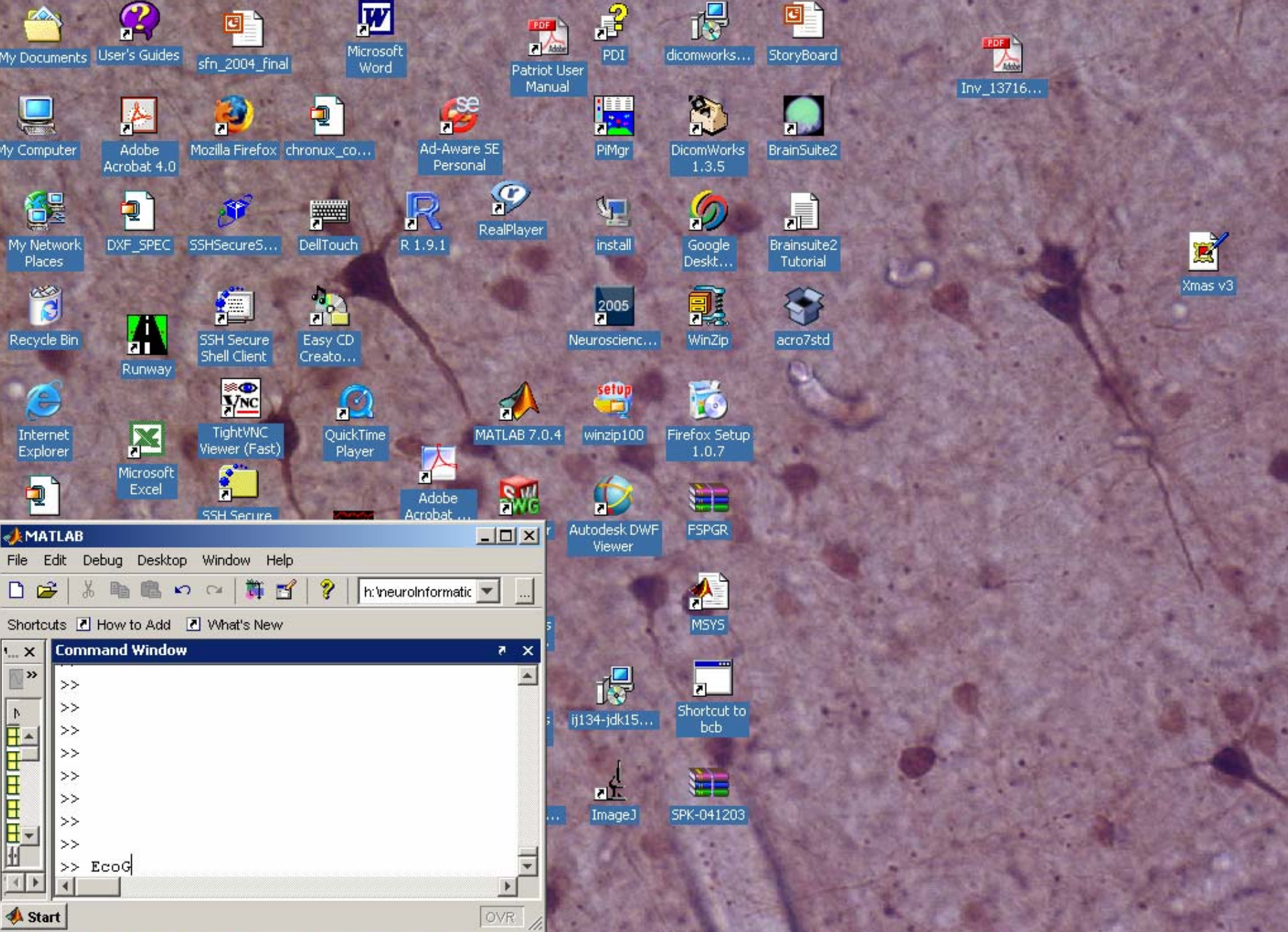
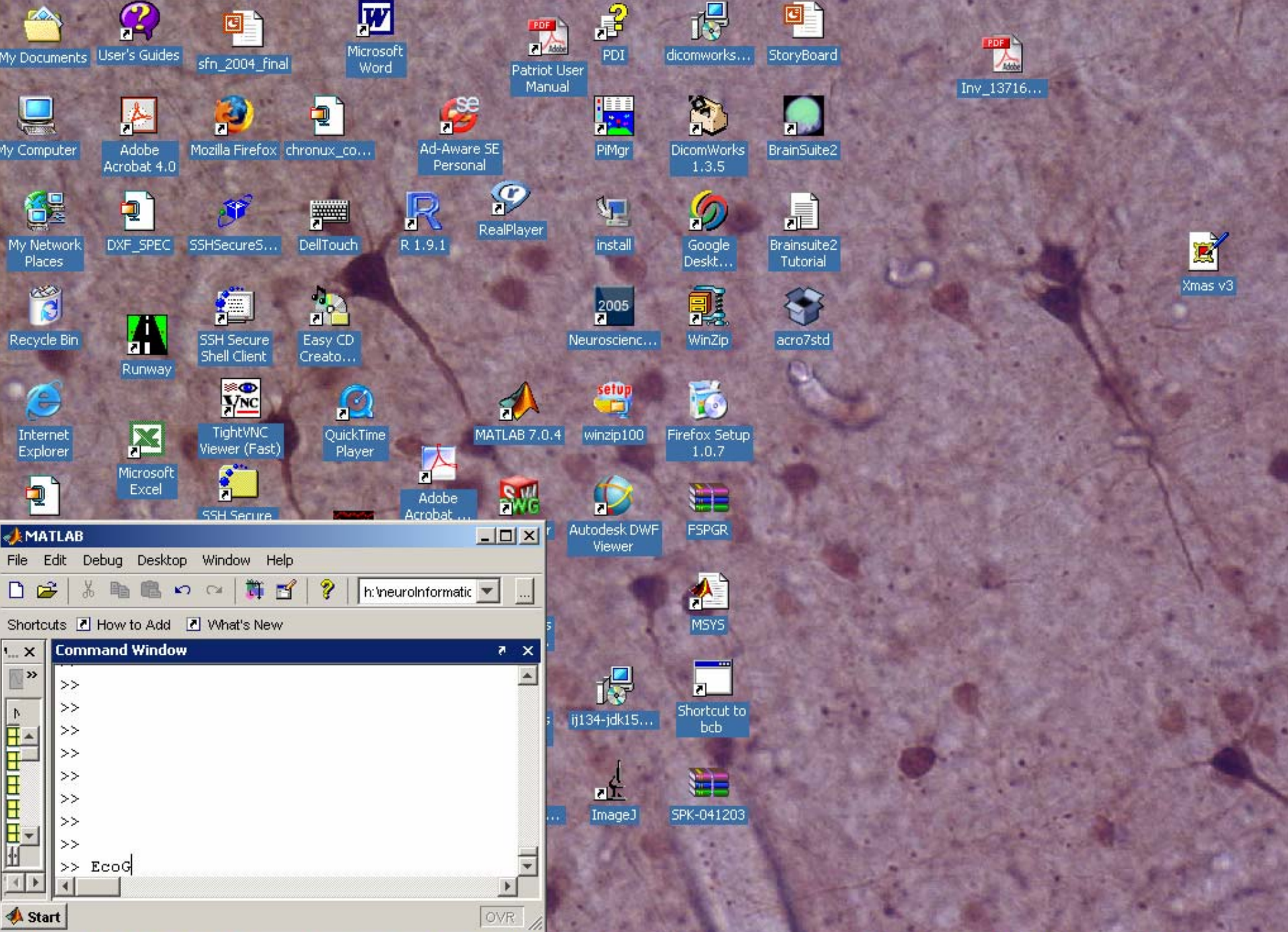
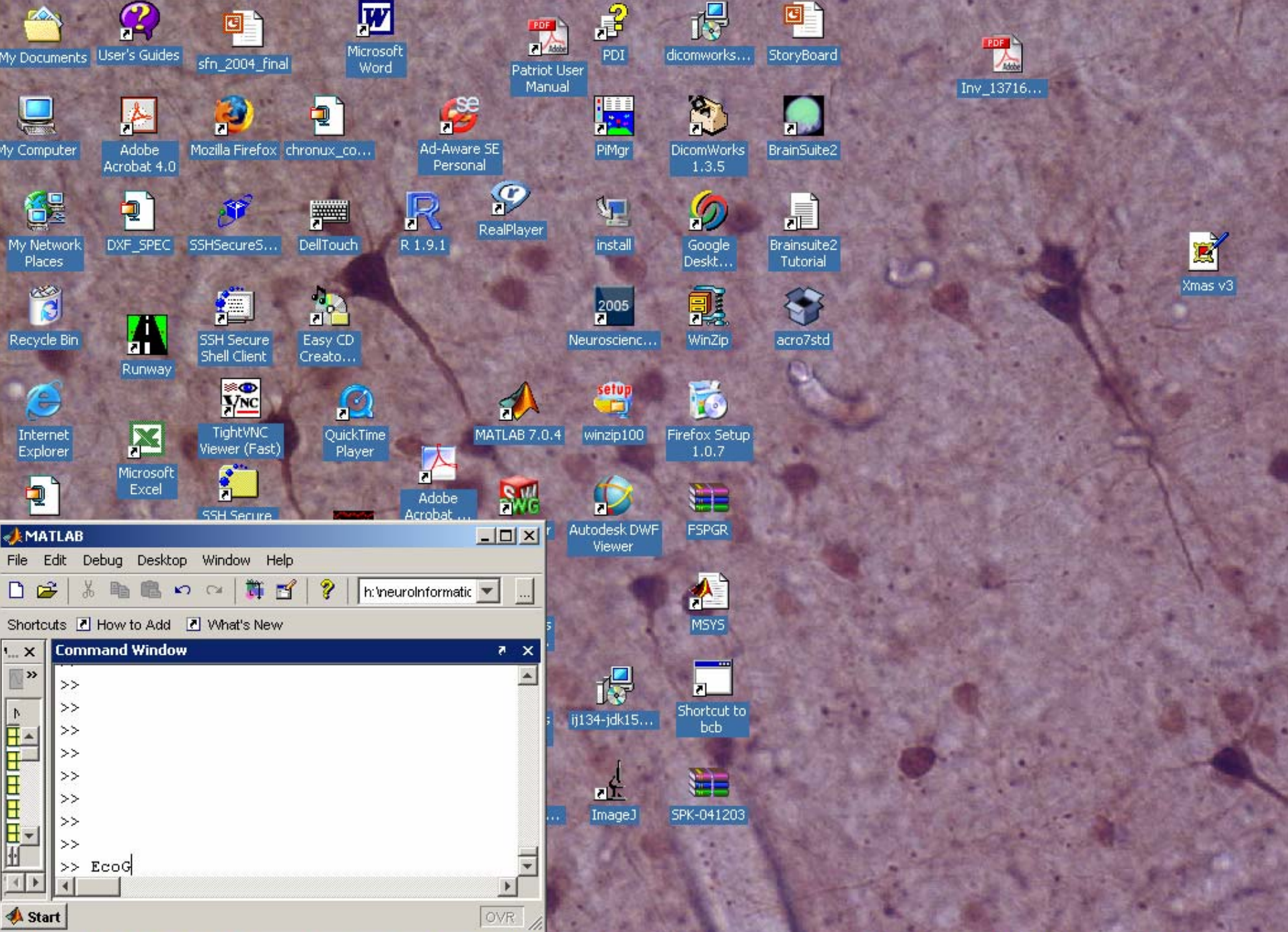
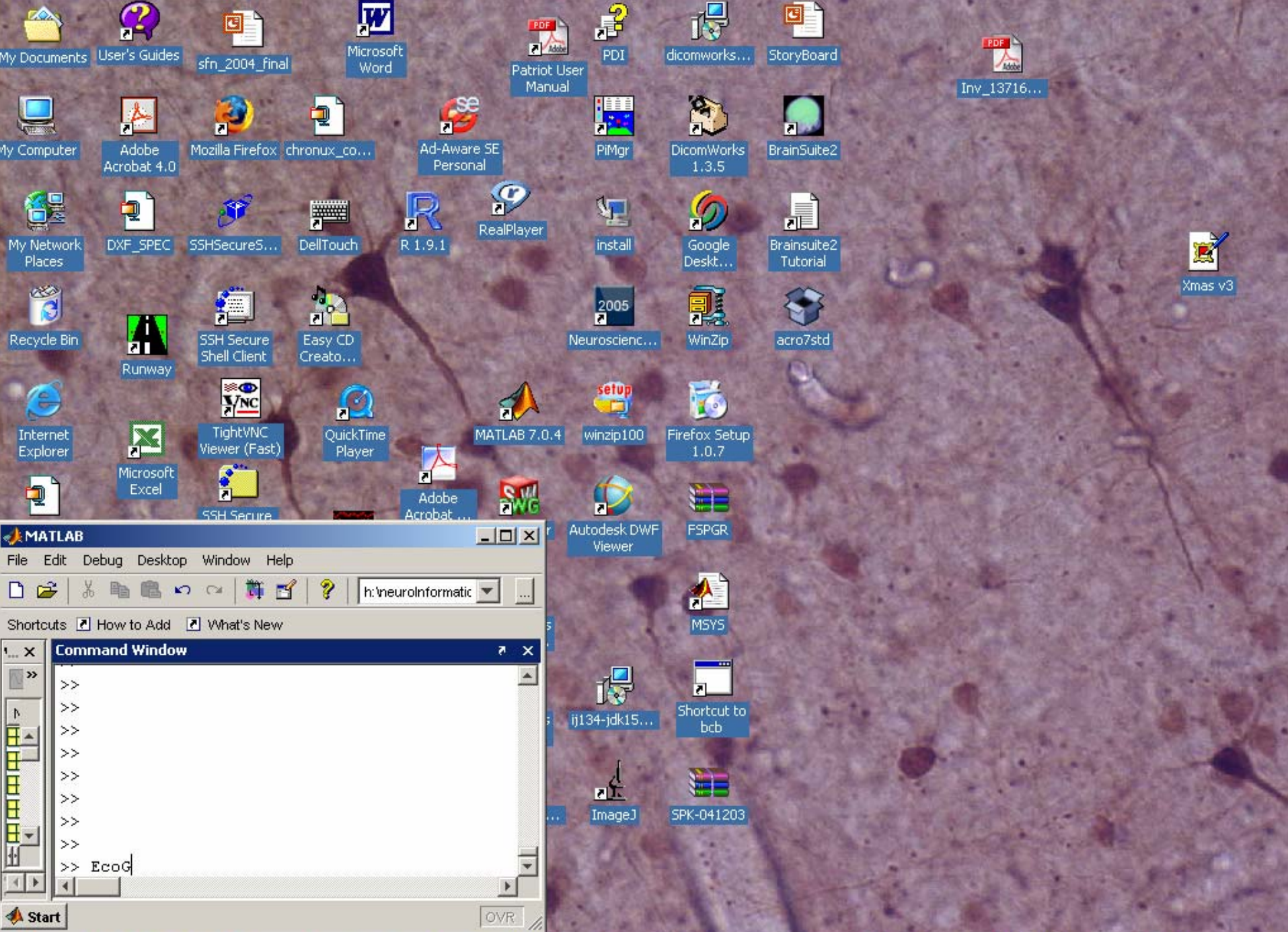
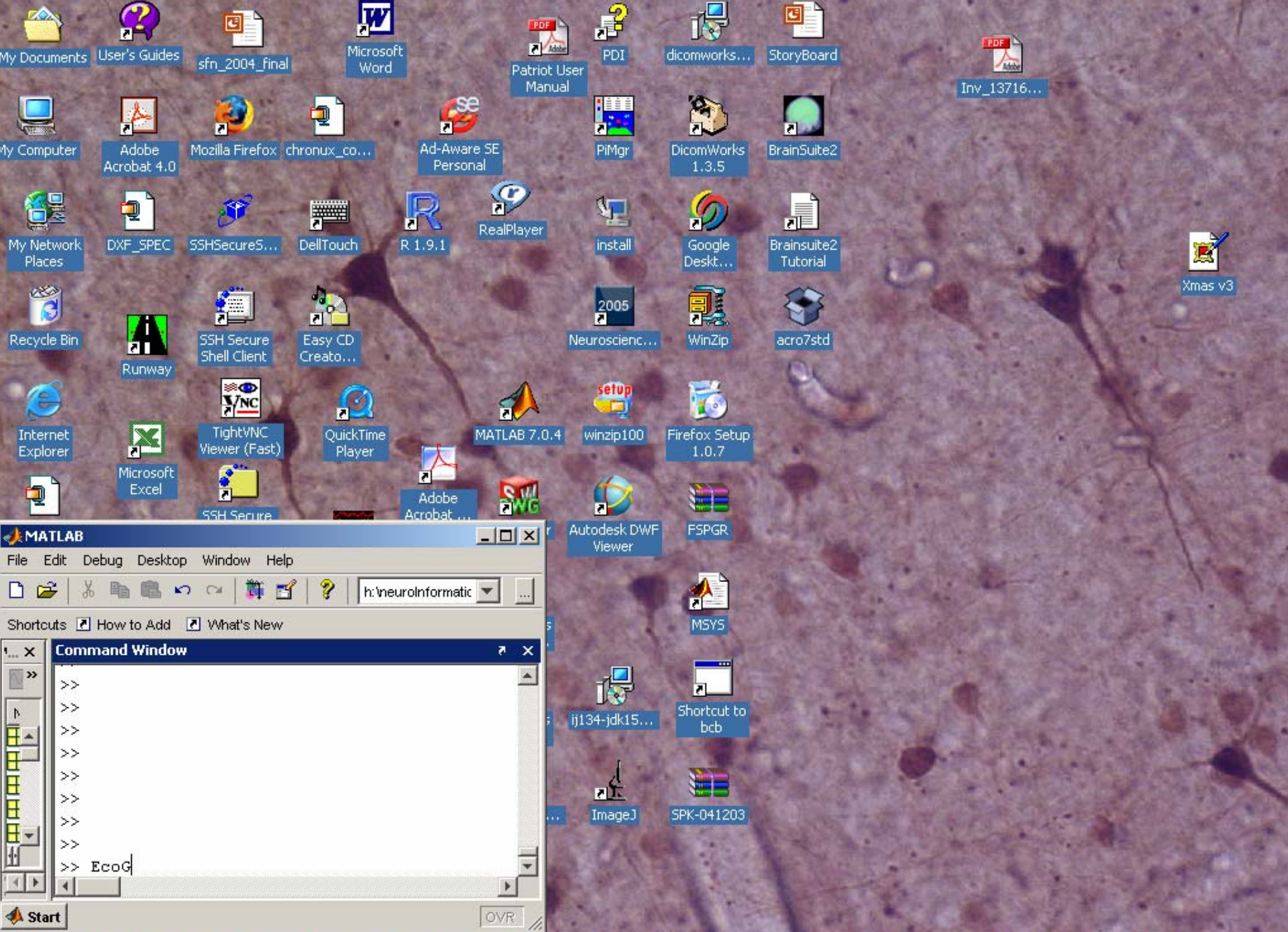
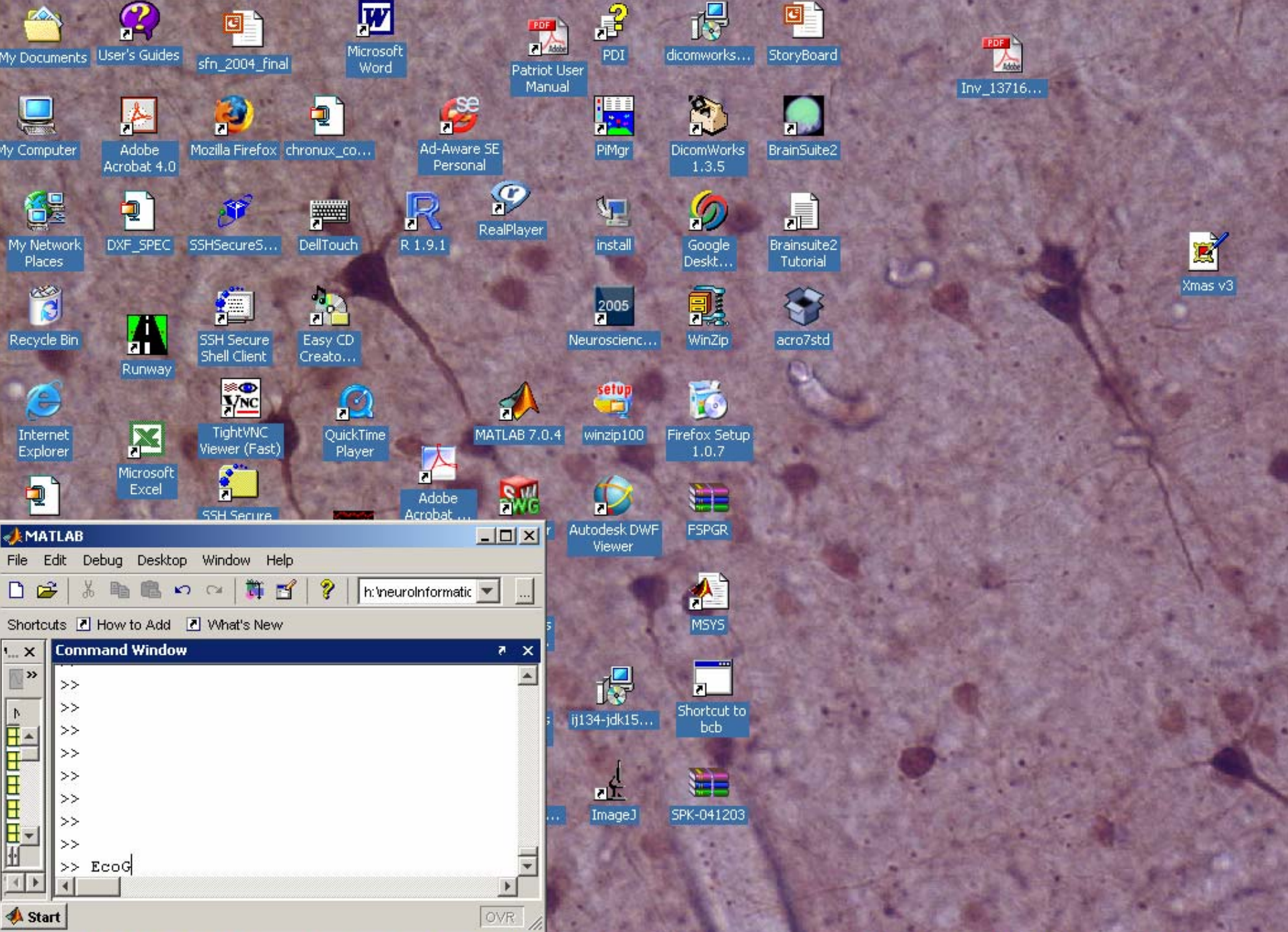
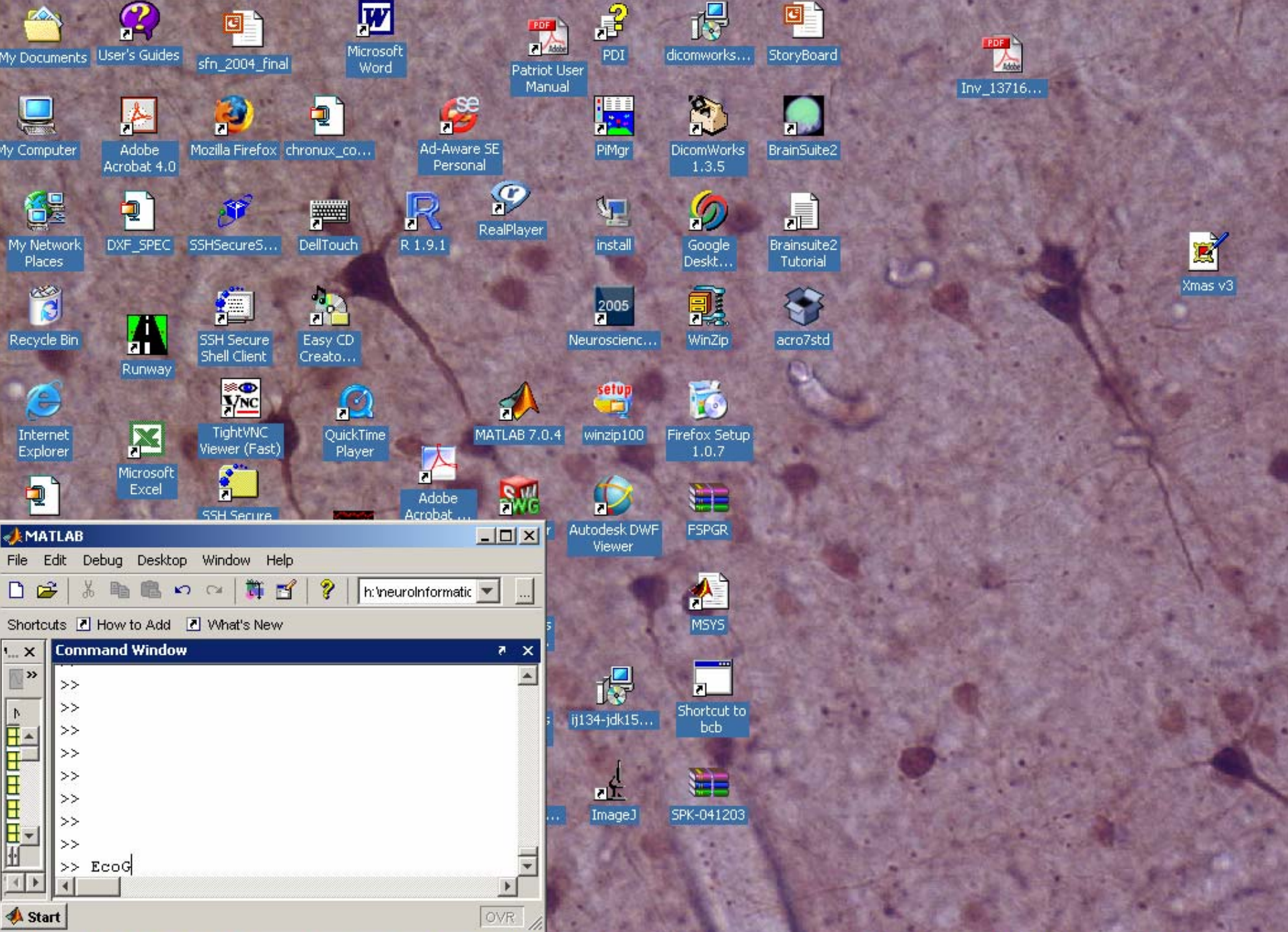
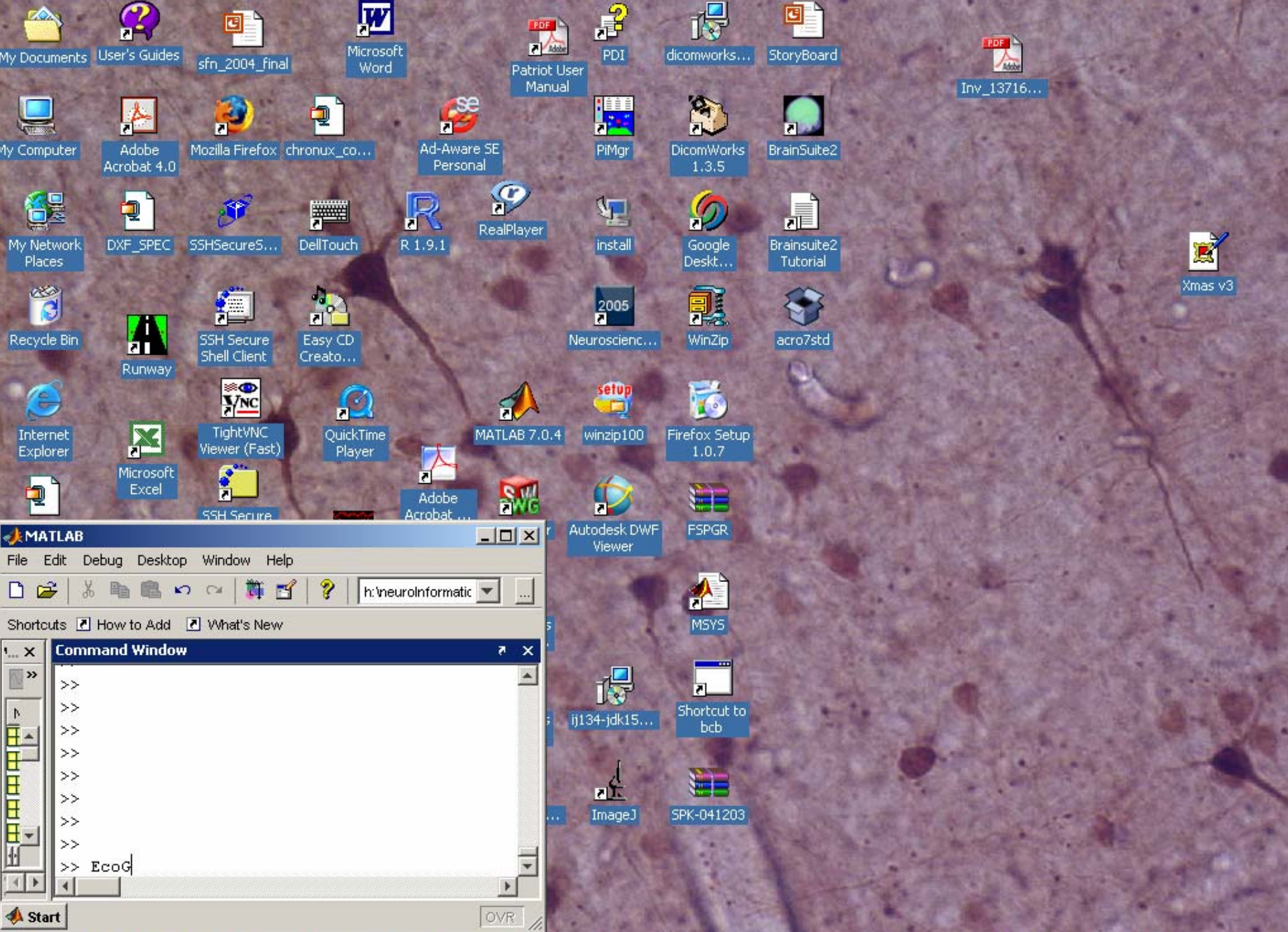
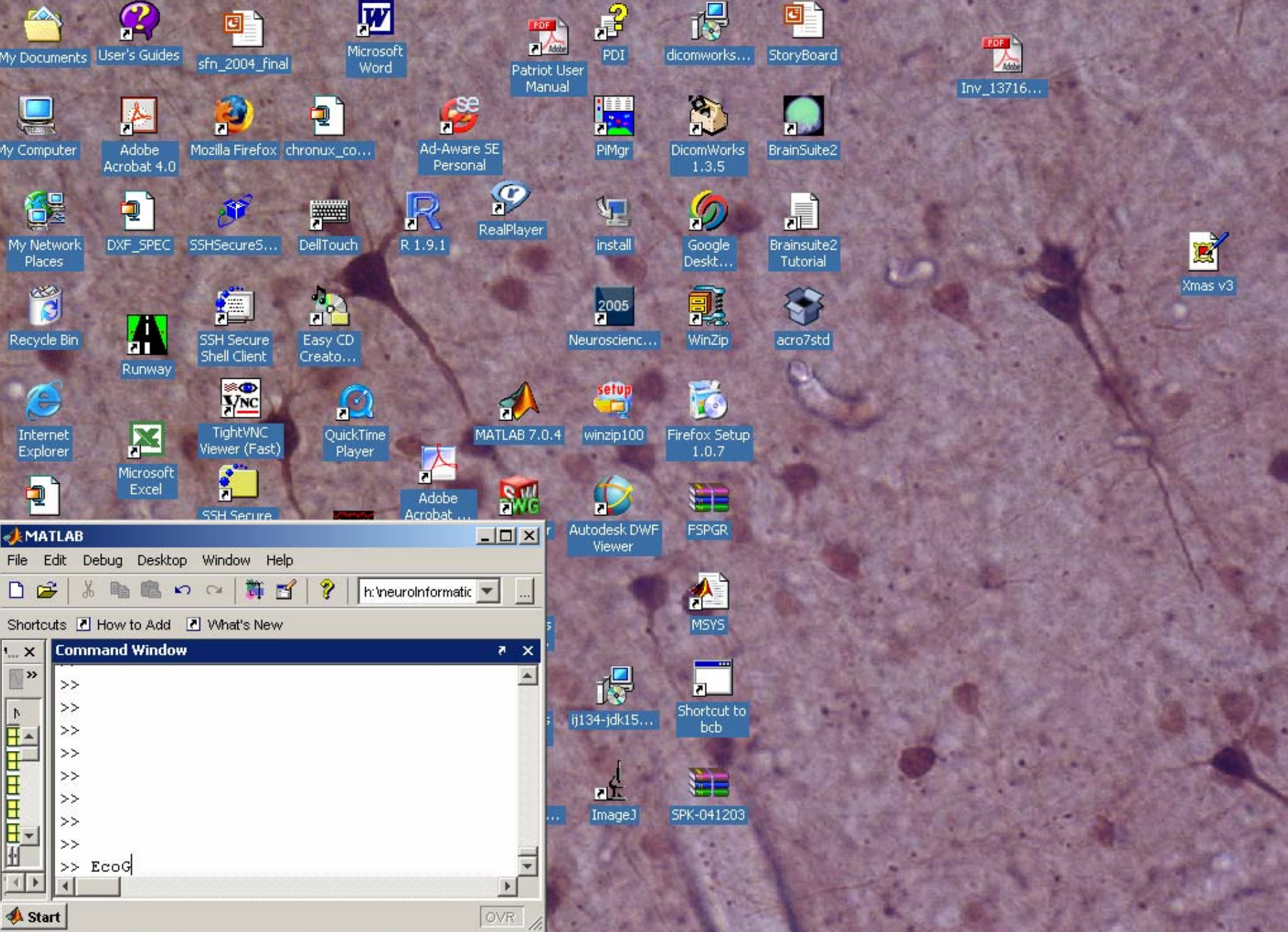
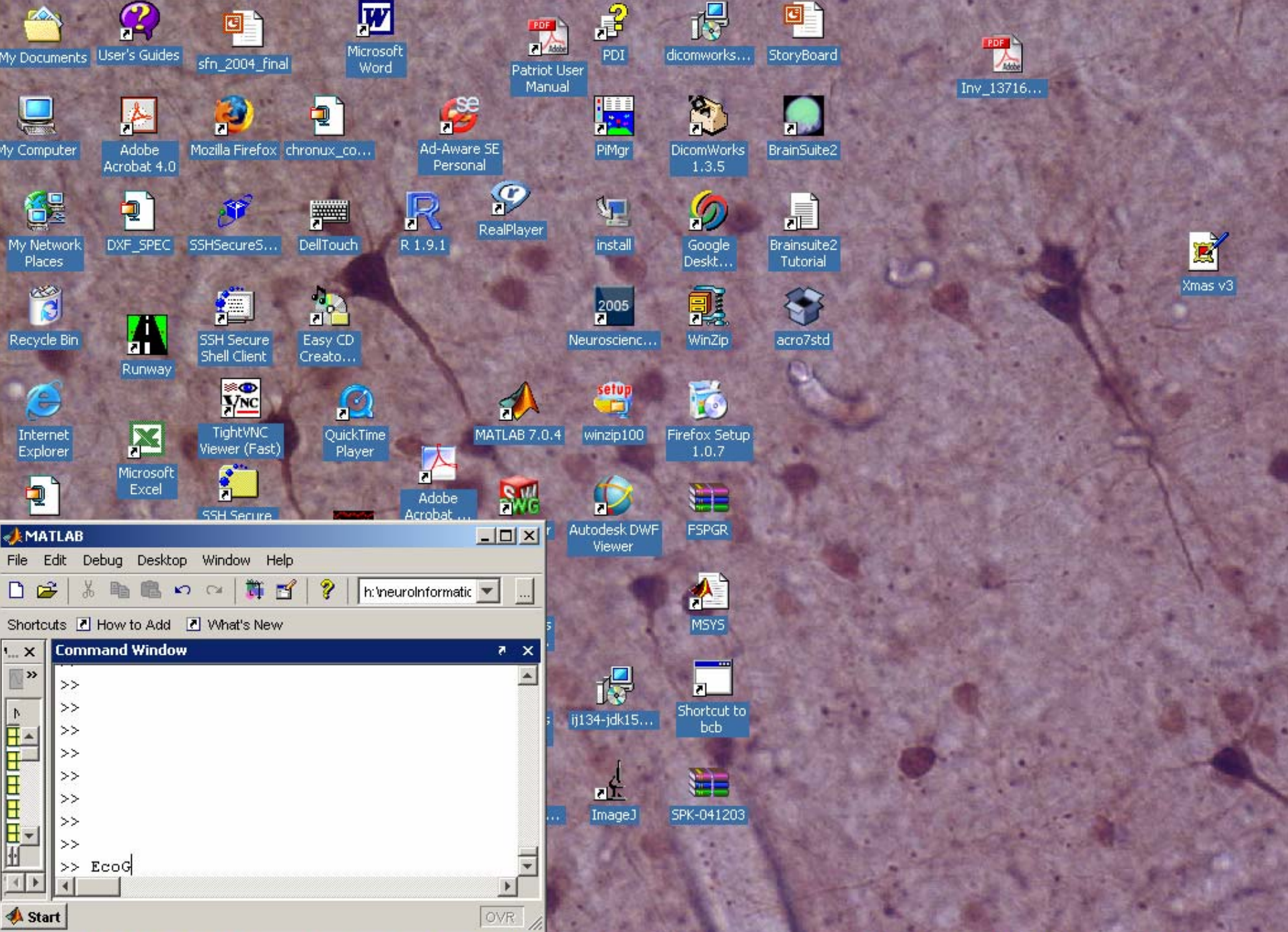
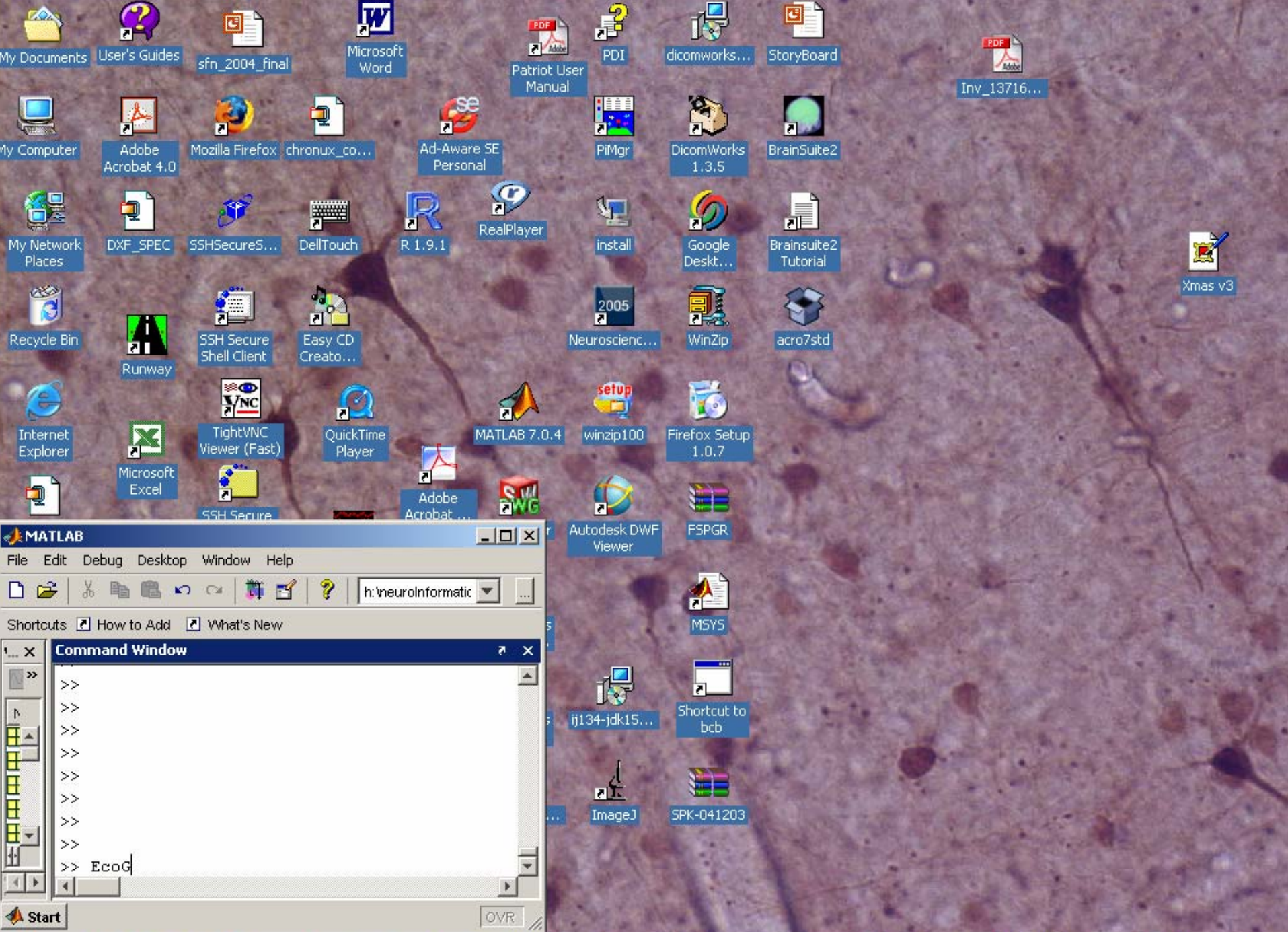
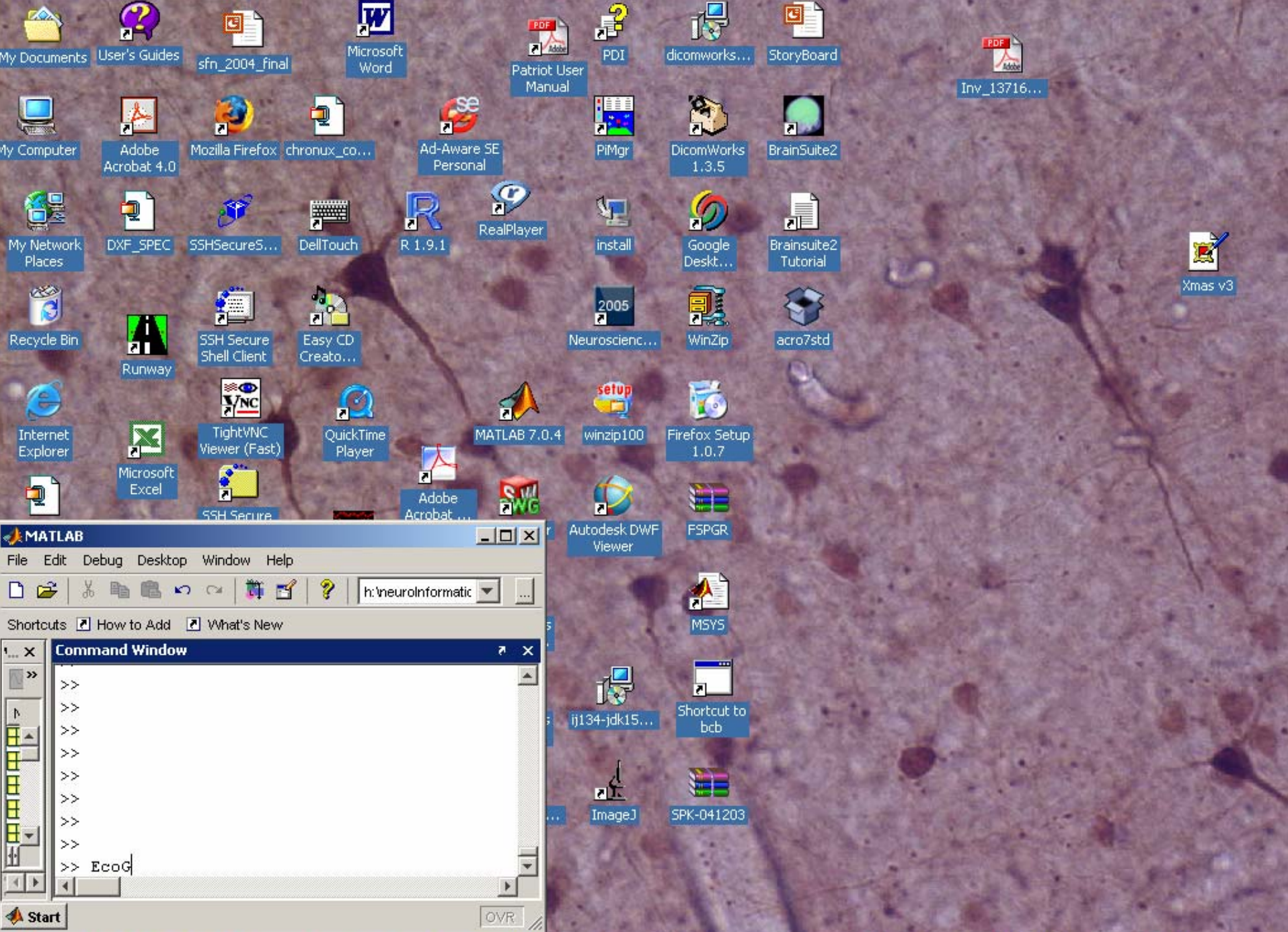
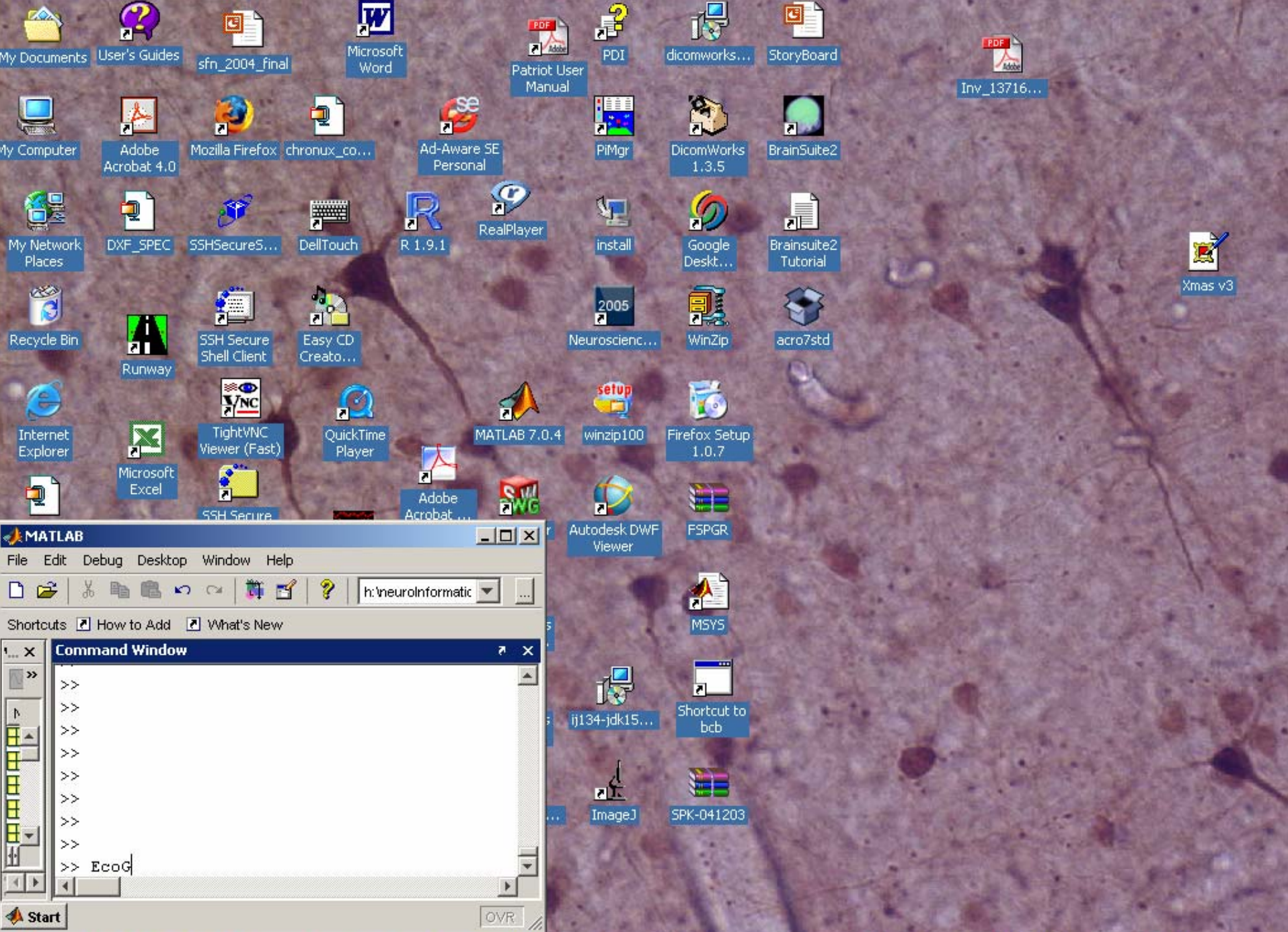
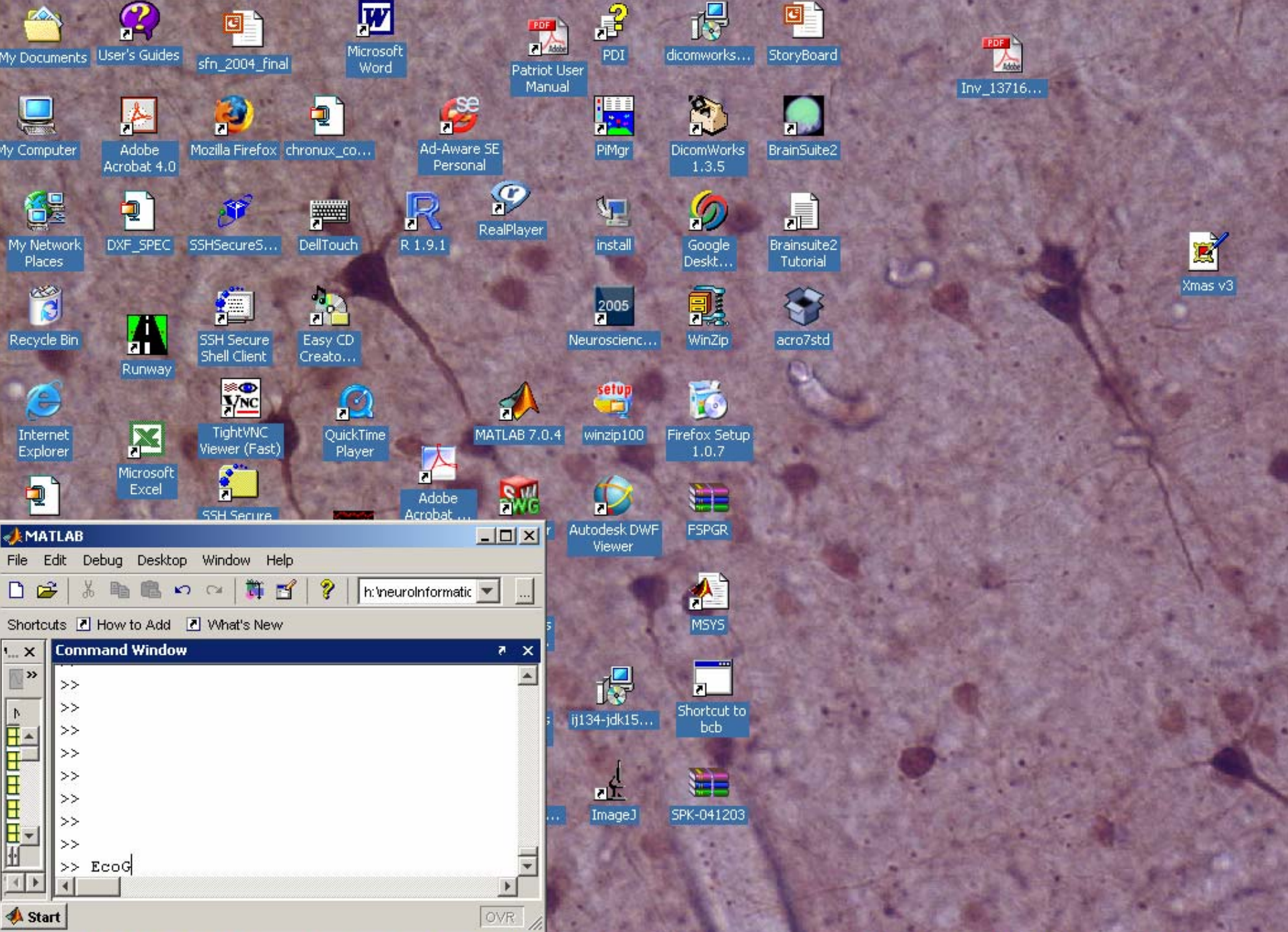
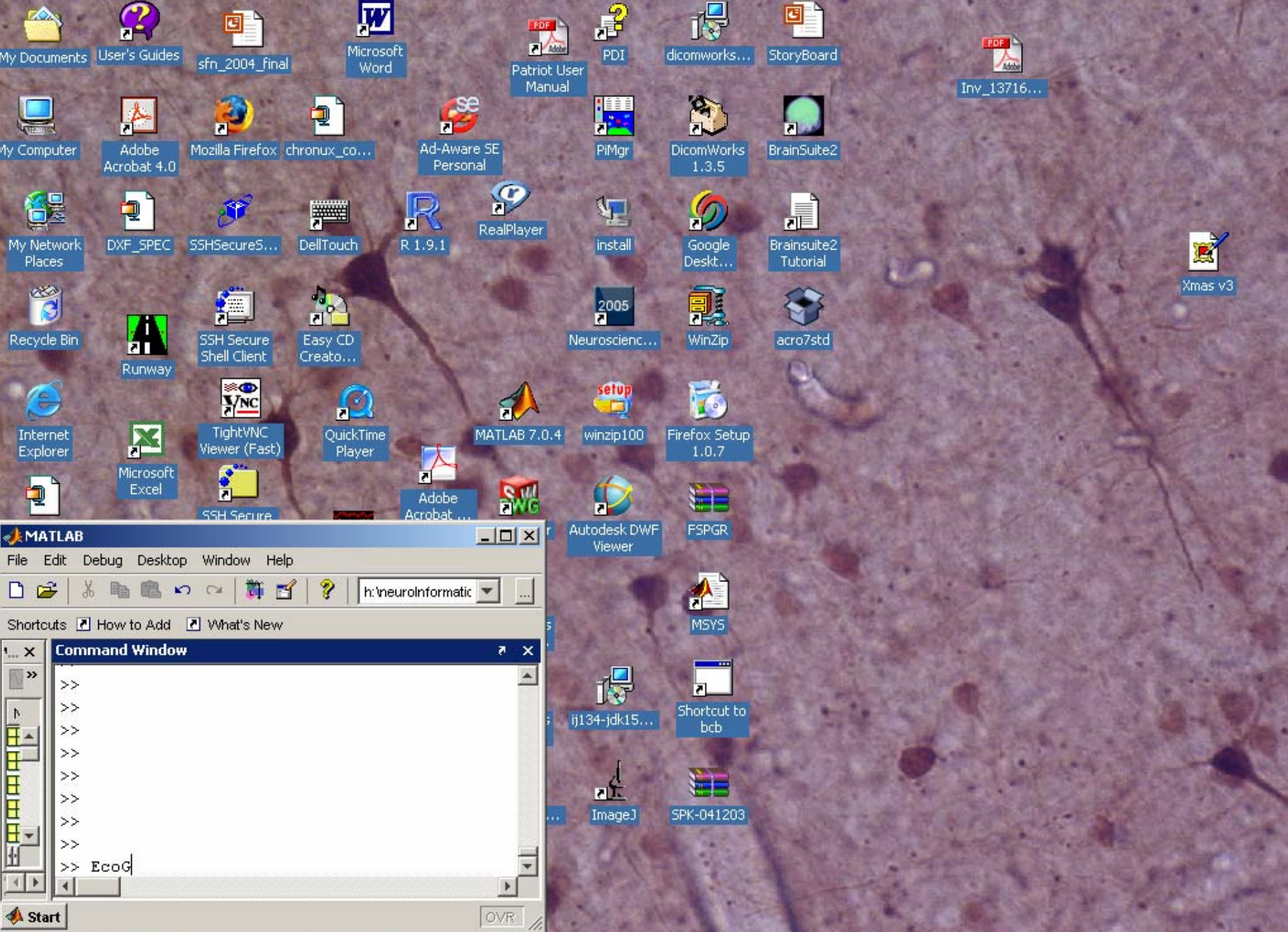
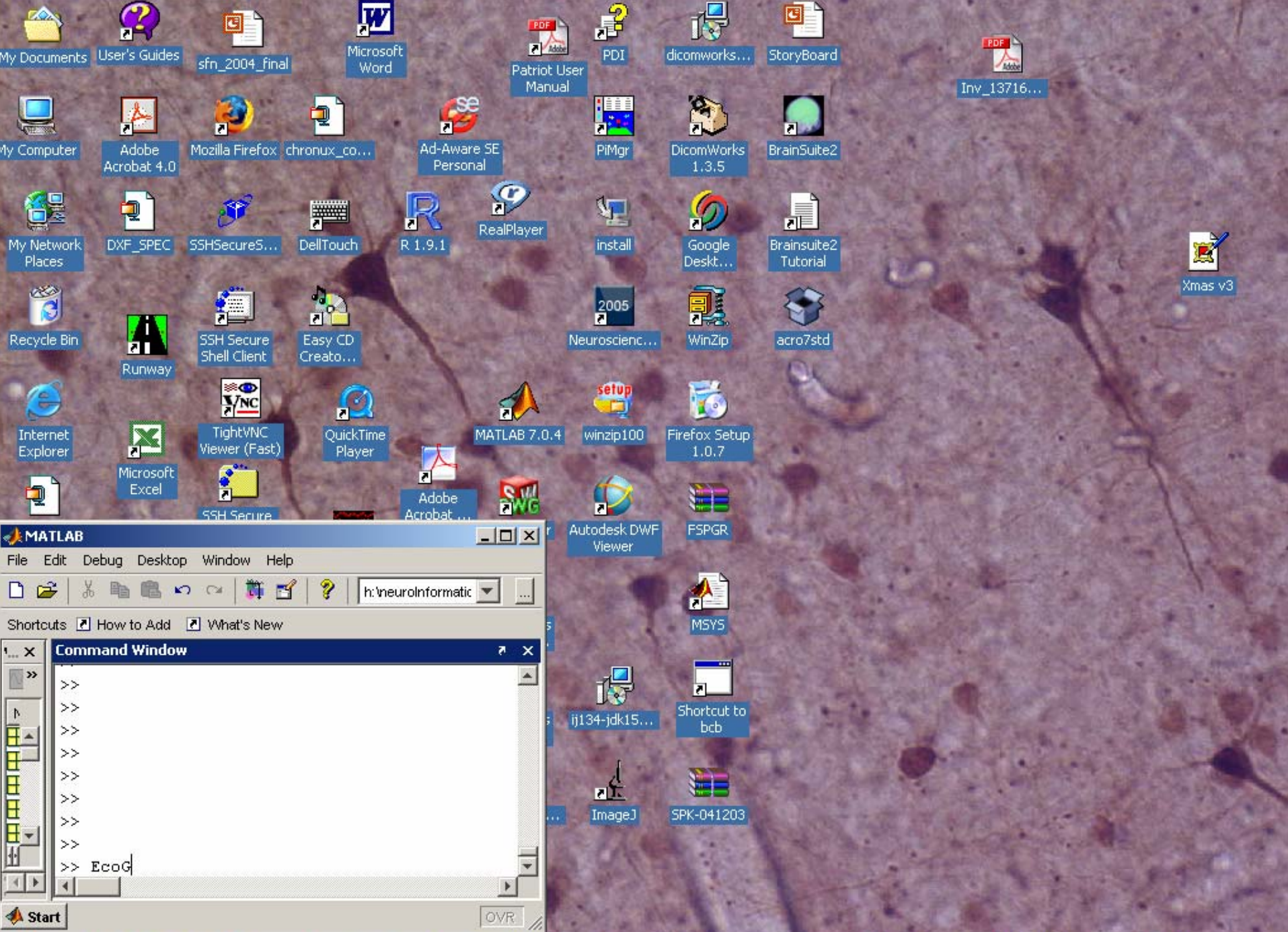
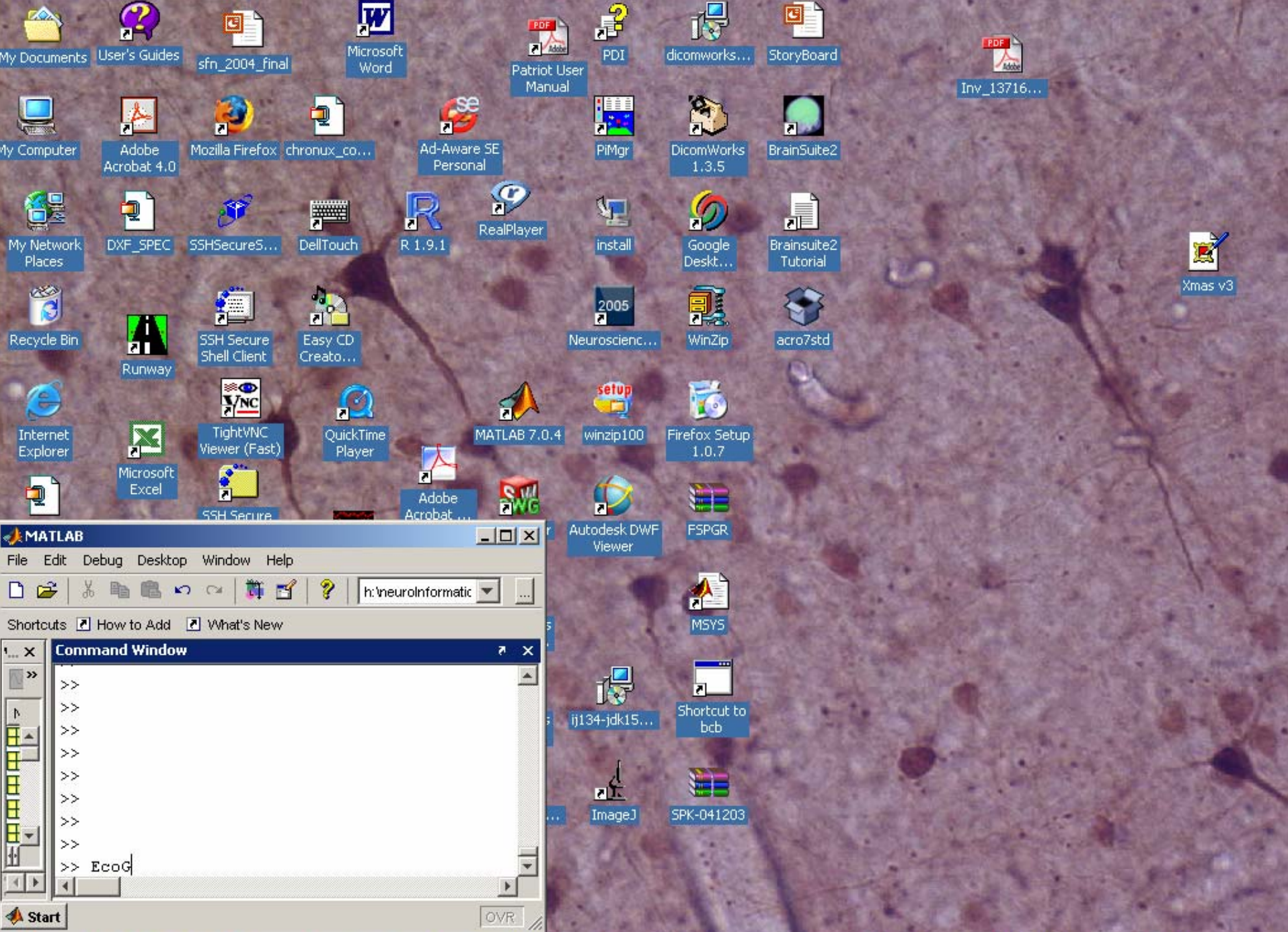
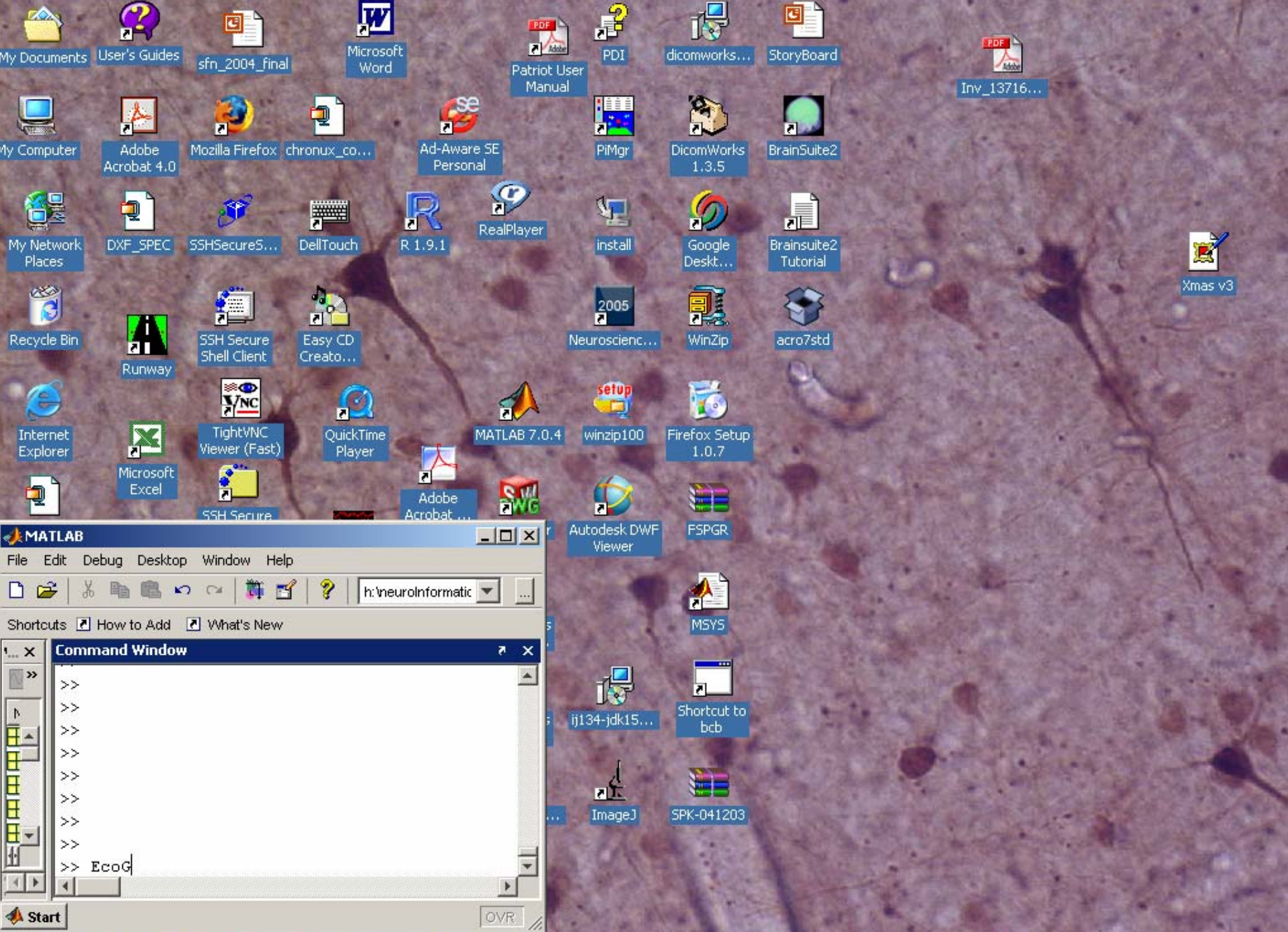
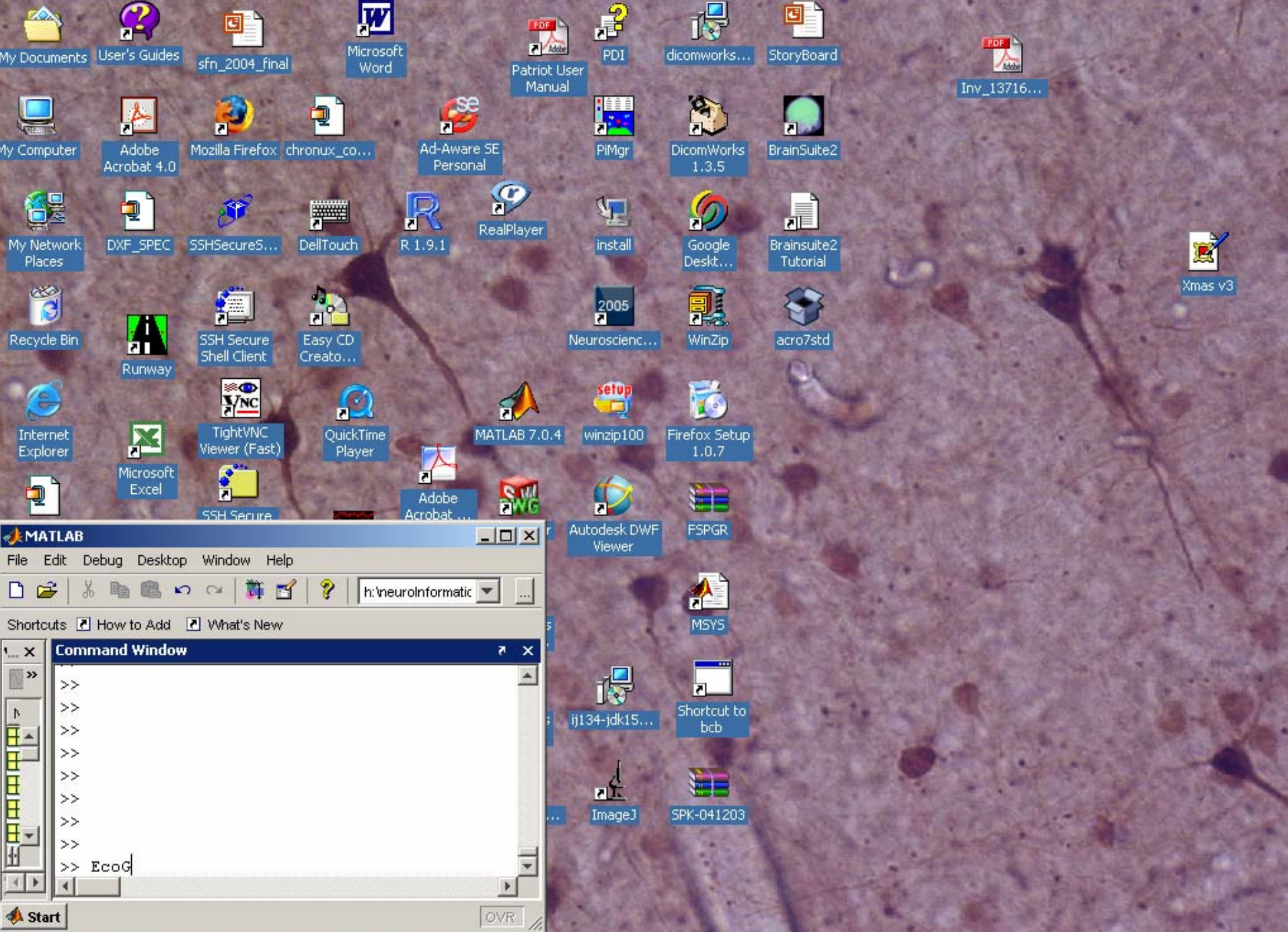
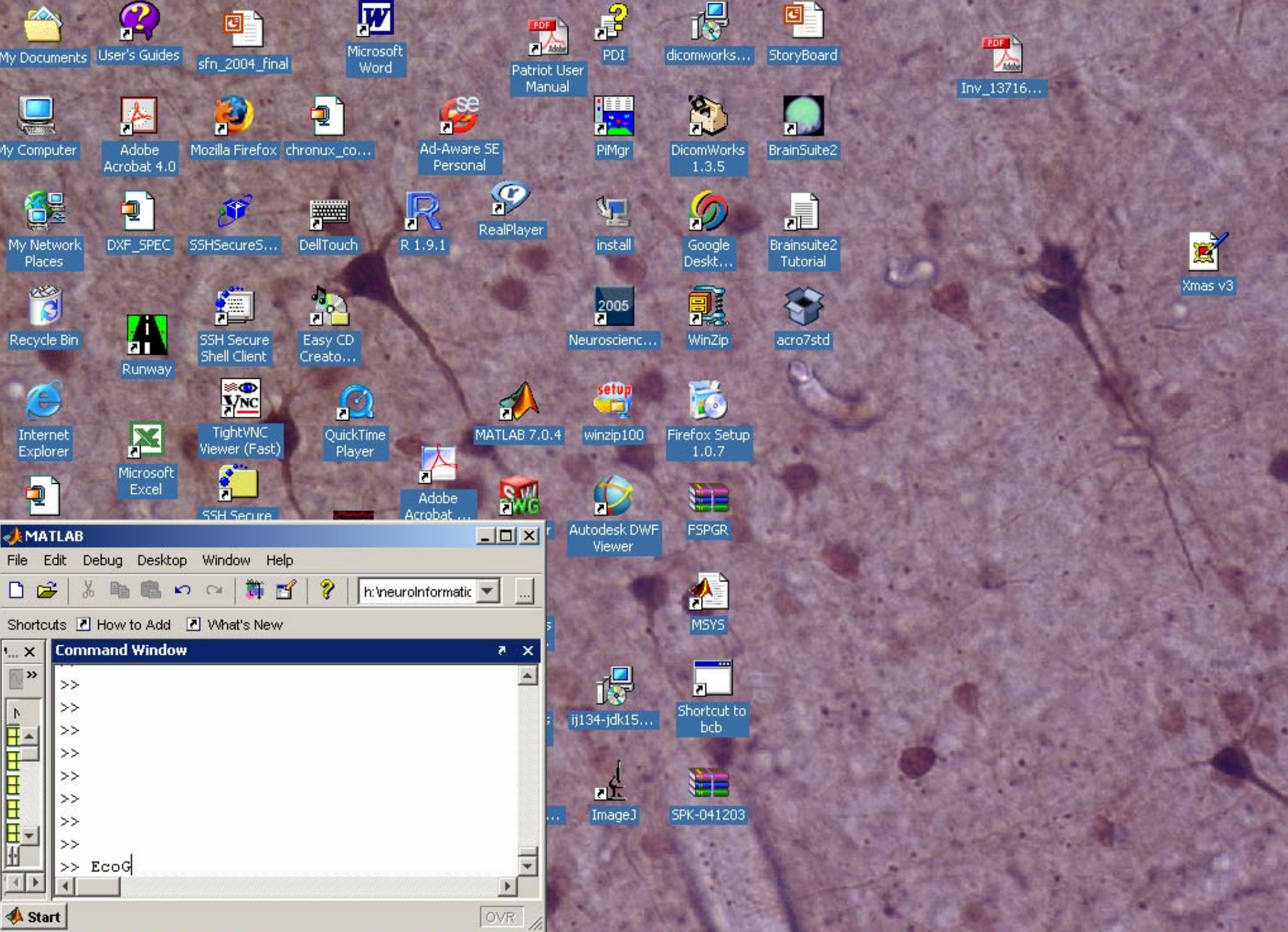
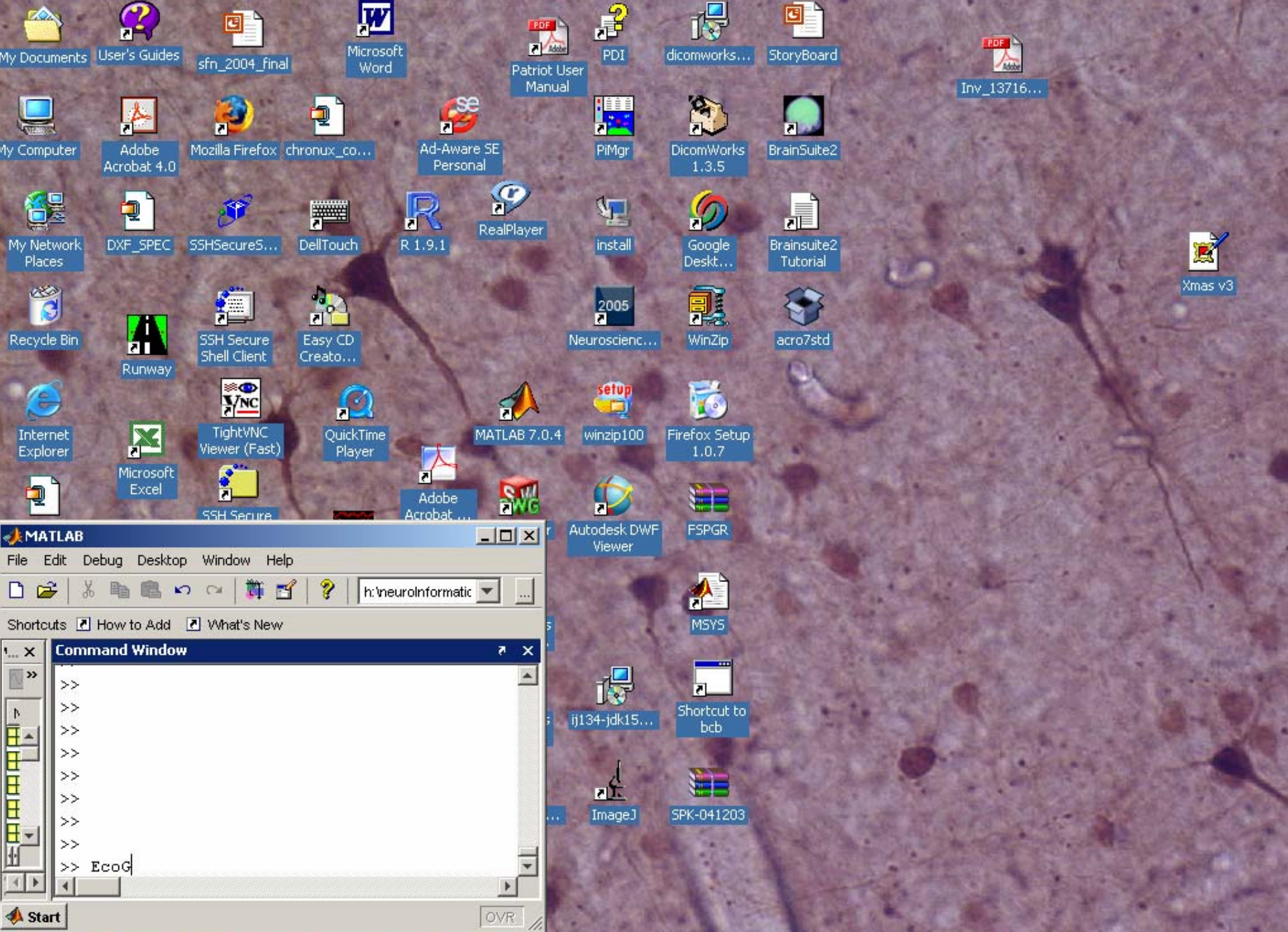
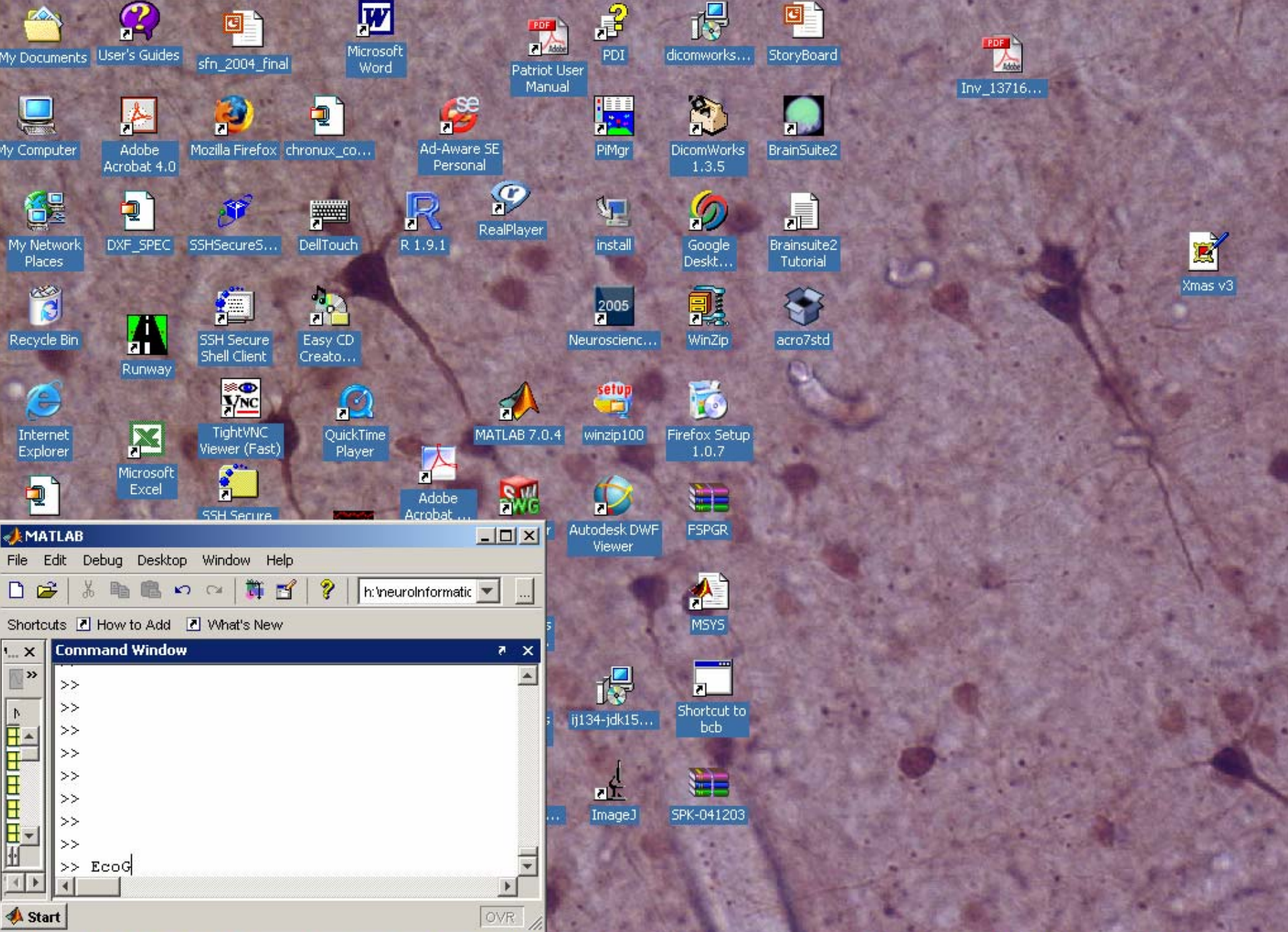
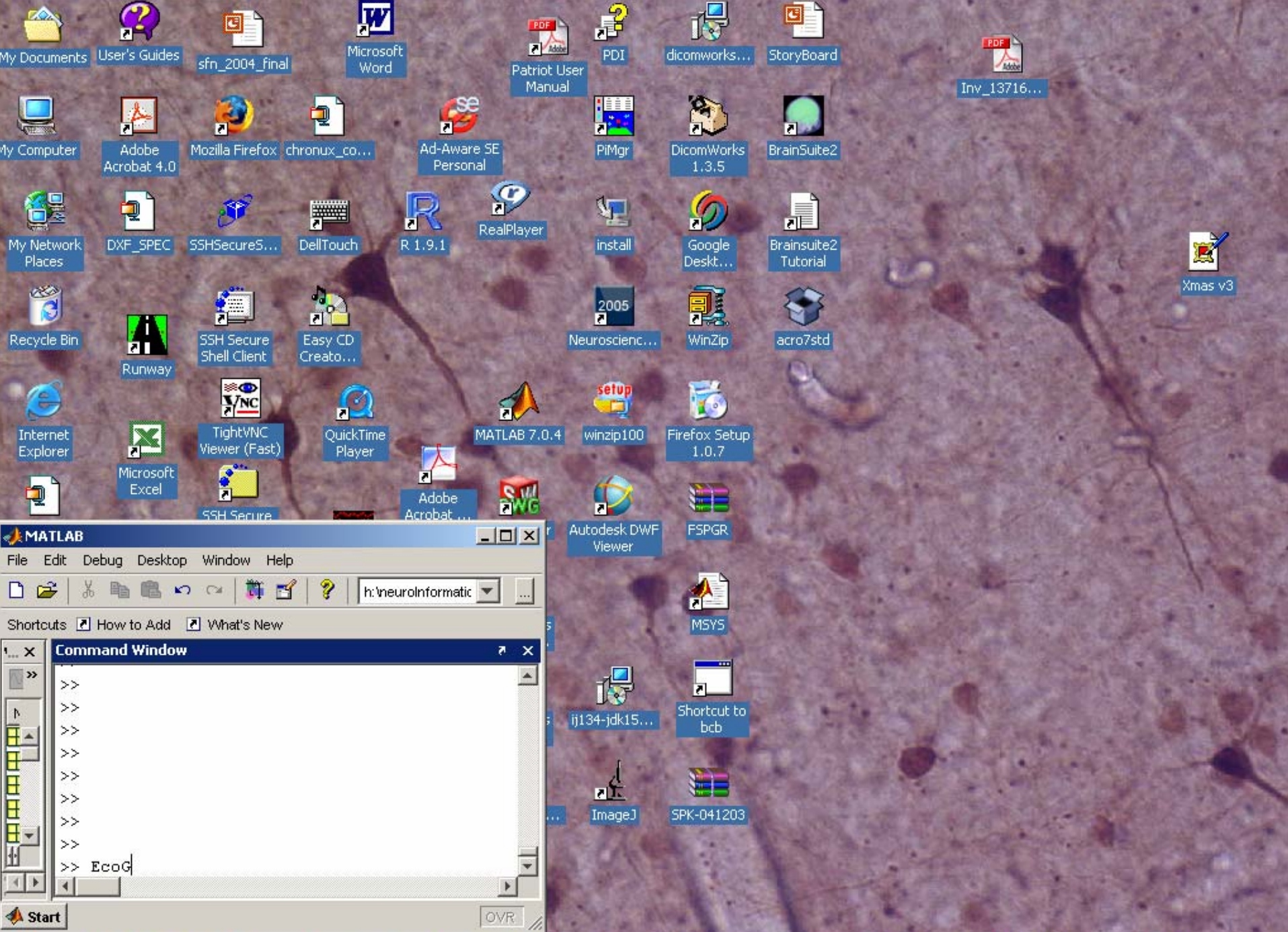
Alternative Approach for Signal Conditioning

- ◆ Combine SVD with spectral analysis
- ◆ Look for the subspace that does not contain noise and major artifacts
- ◆ Reconstruct a set of signals from the subspace for further analysis



◆ >> **EcoG**

- ◆ Loads EcoG_dataV6.mat
should be compatible with all versions of MATLAB, 6 and above
- ◆ Defines variables: ATR, ATL, PTR, PRL, DFL, DFR, etc.
- ◆ Generates two figures: 1) voltage traces for all channels from left hemisphere; 2) same for right hemisphere.
- ◆ 8 seconds of data shown

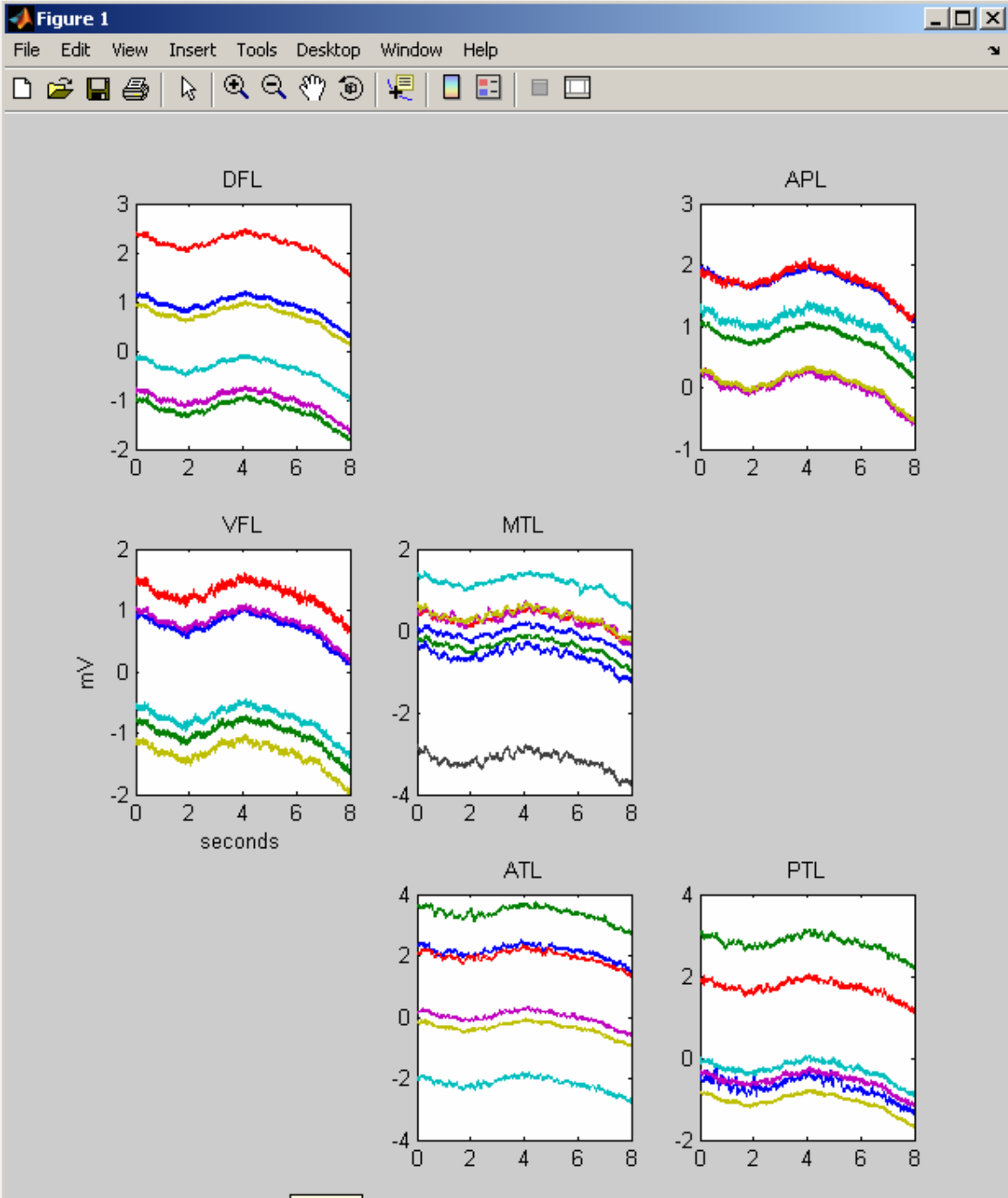


```
Editor - h:\neuroinformatics\EcoG2005\EcoG.m
File Edit Text Cell Tools Debug Desktop Window Help
[Icons]
85 - set(gca,'XTick',[0:1000:4000],'XTickLabel',
86 - subplot(3,3,7); plot(PTR); title('PTR');
87 - set(gca,'XTick',[0:1000:4000],'XTickLabel',
88 - subplot(3,3,8); plot(ATR); title('ATR');
89 - set(gca,'XTick',[0:1000:4000],'XTickLabel',
90 - set(gcf,'Units','pixels','Position',sschop)
91 - h2=gcf;
92 - figure(h1);
93 -
94 - display(['Type ''return'' when ready to con
95 - keyboard
96 - close all
97 -
98 - %generate d
99 - %from the I
100 - Single_Channel_from_Each_BrainRegion;
101 - display(['Hit UPARROW or type ''return'' wh
102 - keyboard
103 -
104 - frontal=[DFL VFL DFR VFR]; %group char
105 - temporal=[PTL ATL PTR ATR ];

Shortcuts How to Add What's New

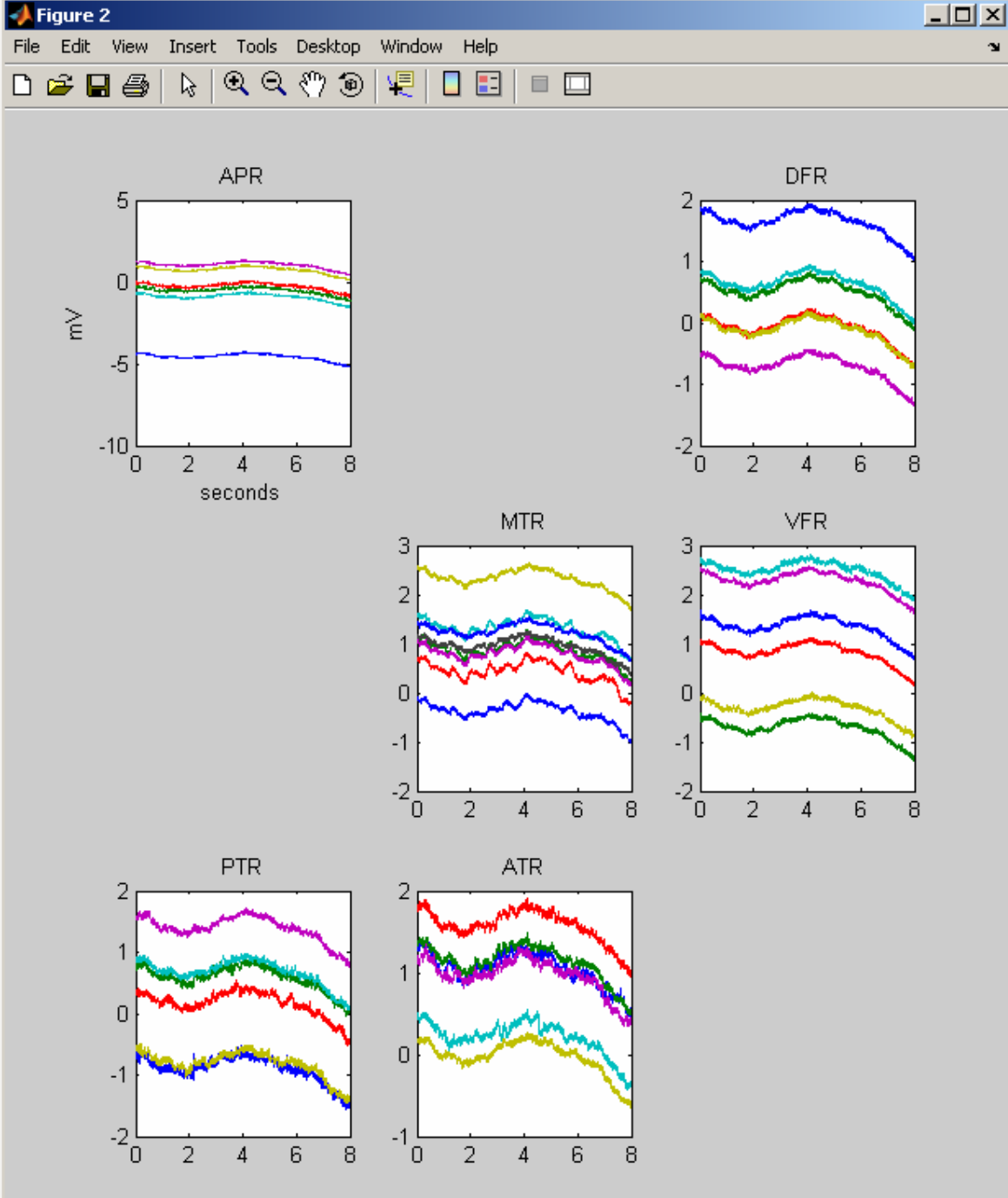
Command Window
>>
>>
>>
>>
>>
>> EcoG
Type 'return' when ready to continue
K>>

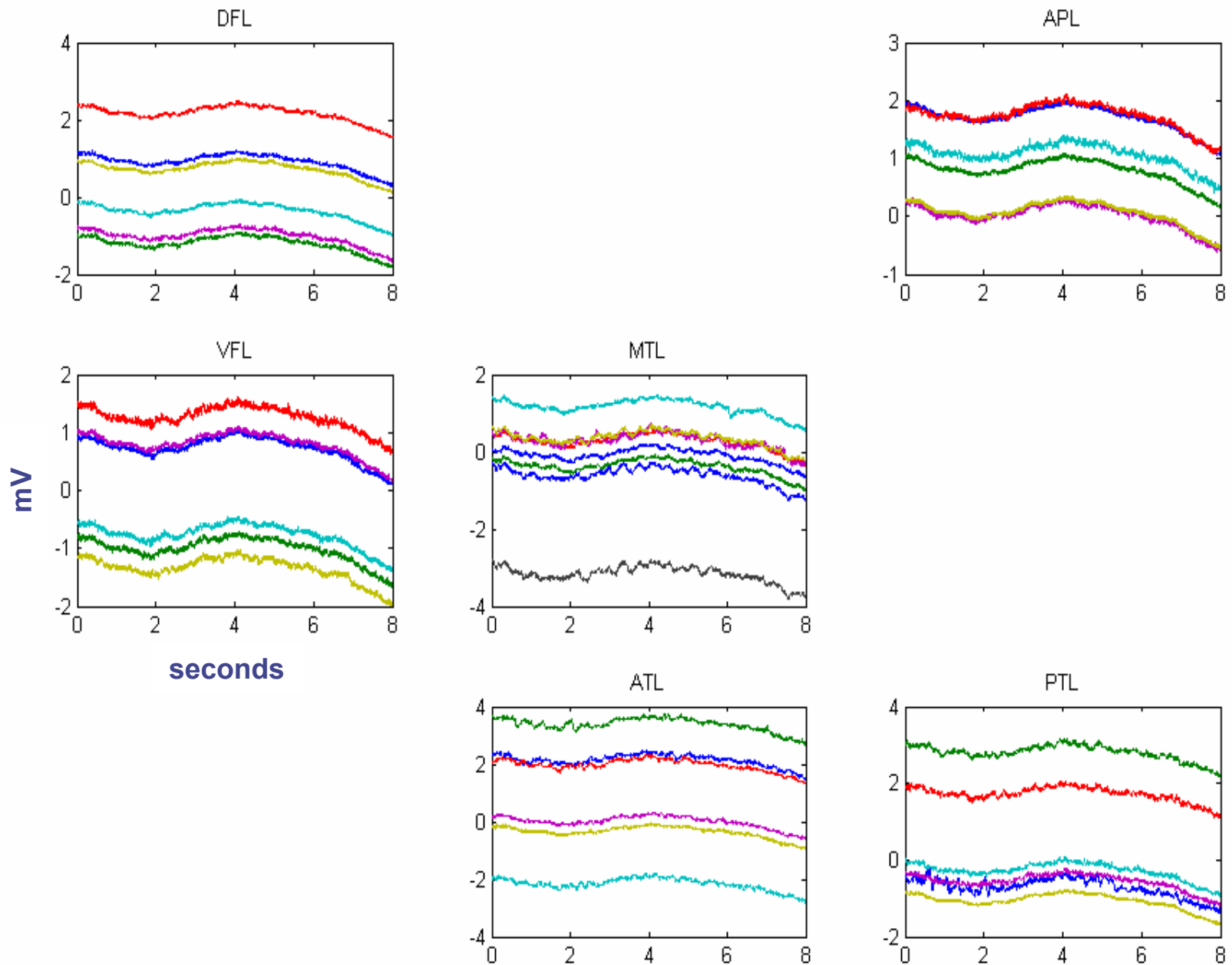
Start Waiting for input
```



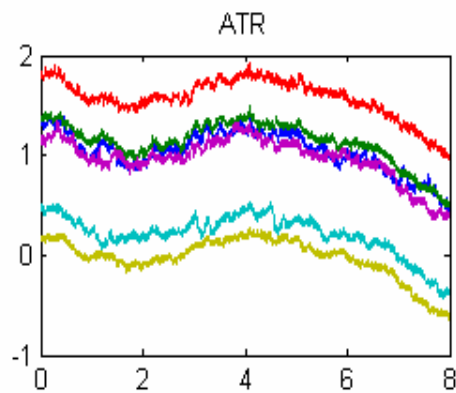
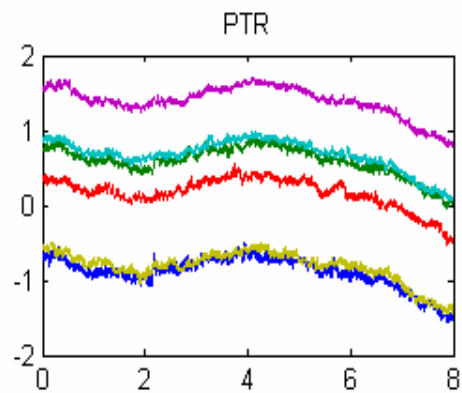
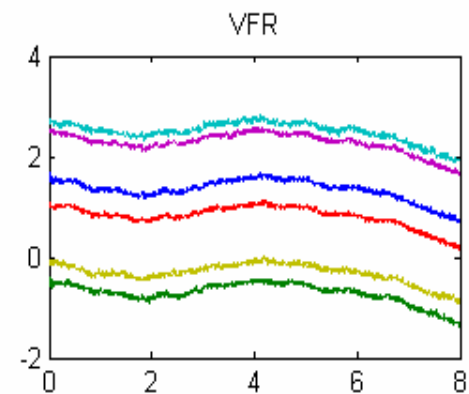
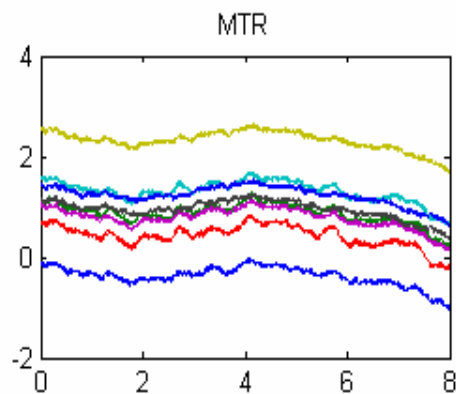
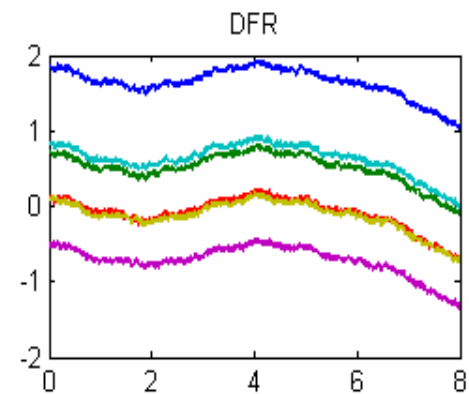
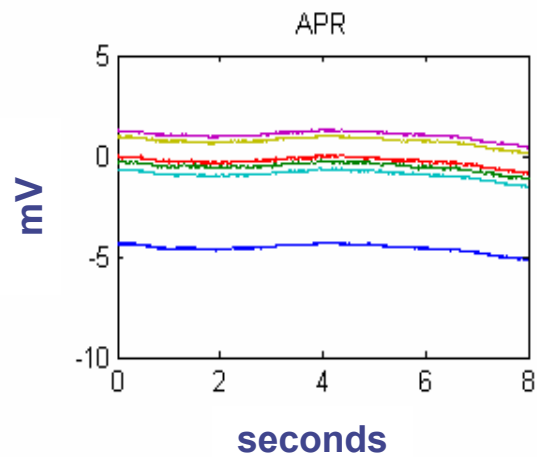
```
Editor - h:\neuroinformatics\EcoG2005\EcoG.m
File Edit Text Cell Tools Debug Desktop Window Help
[Icons]
85 set(gca,'XTick',[0:1000:4000],'XTickLabel',
86 subplot(3,3,7); plot(PTR); title('PTR');
87 set(gca,'XTick',[0:1000:4000],'XTickLabel',
88 subplot(3,3,8); plot(ATR); title('ATR');
89 set(gca,'XTick',[0:1000:4000],'XTickLabel',
90 set(gcf,'Units','pixels','Position',sschop)
91 h2=gcf;
92 figure(h1);
93
94 display(['Type 'return' when ready to con
95 keyboard
96 close all
97
98 %generate d
99 %from the I
100 Single_Channel_from_Each_BrainRegion;
101
102 display(['Hit UPARROW or type 'return' wh
103 keyboard
104
105 frontal=[DFL VFL DFR VFR]; %group char
temporal=[PTL ATL PTR ATR];

Shortcuts [?] How to Add [?] What's New
Command Window
>>
>>
>>
>>
>>
>> EcoG
Type 'return' when ready to continue
K>>
Start Waiting for input
```





Left Hemisphere (all channels)



Right Hemisphere (all channels)



◆ >> **return**

◆ Generates figure showing one channel of recording for each cortical region in right hemisphere

```

File Edit Text Cell Tools Debug Desktop Window Help
[Icons]
85 - set(gca,'XTick',[0:1000:4000],'XTickLabel',
86 - subplot(3,3,7); plot(PTR); title('PTR');
87 - set(gca,'XTick',[0:1000:4000],'XTickLabel',
88 - subplot(3,3,8); plot(ATR); title('ATR');
89 - set(gca,'XTick',[0:1000:4000],'XTickLabel',
90 - set(gcf,'Units','pixels','Position',sschop)
91 - h2=gcf;
92 - figure(h1);
93
94 - display(['Type 'return' when ready to con
95 - keyboard
96 - close all
97
98 - %generate 1
99 - %from the I
100
101 - Single_Channel_from_Each_BrainRegion;
102
103 - display(['Hit UPARROW or type 'return' wh
104 - keyboard
105

```

MATLAB

File Edit Debug Desktop Window Help

[Icons]

Shortcuts [X] How to Add [X] What's New

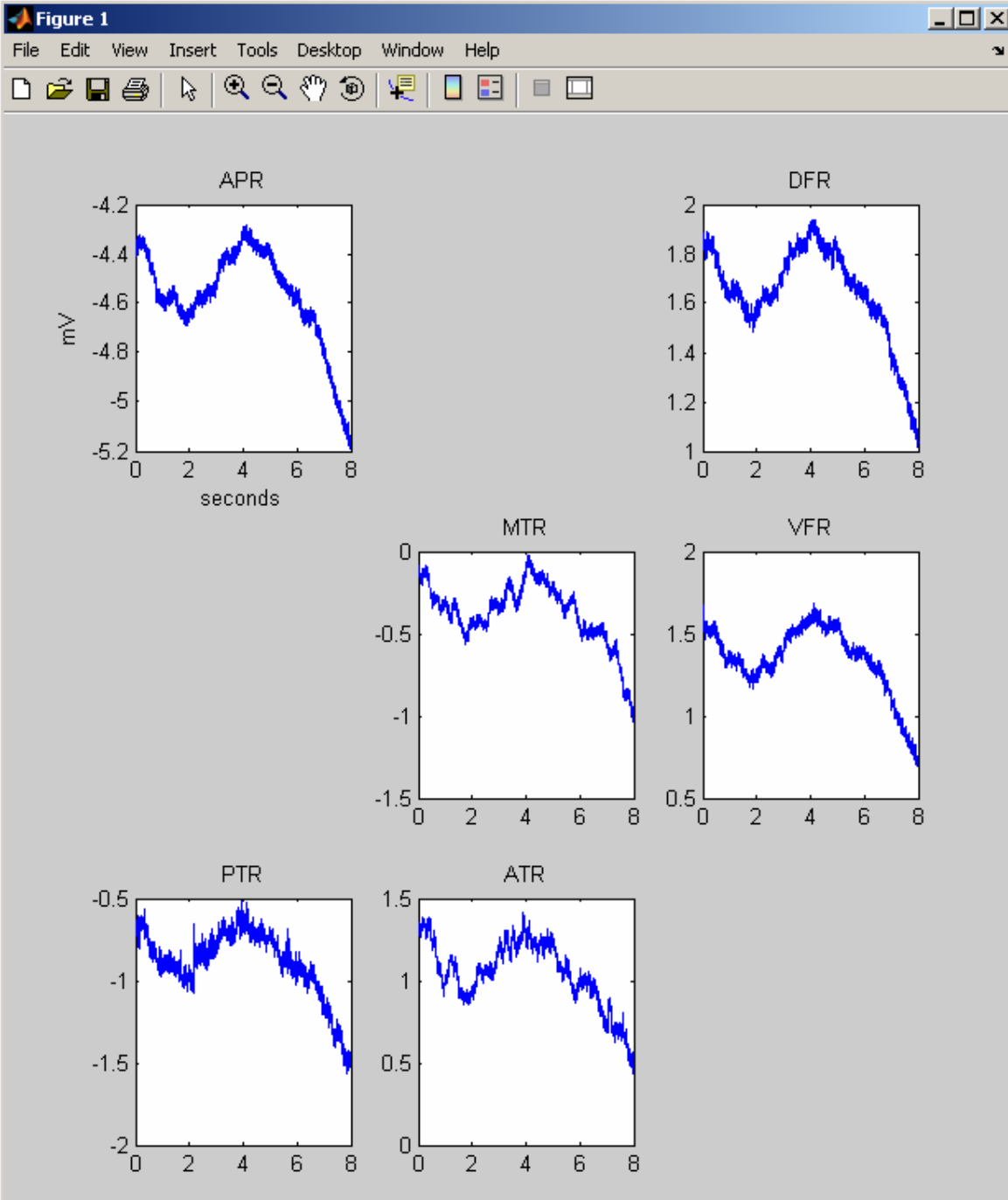
Command Window

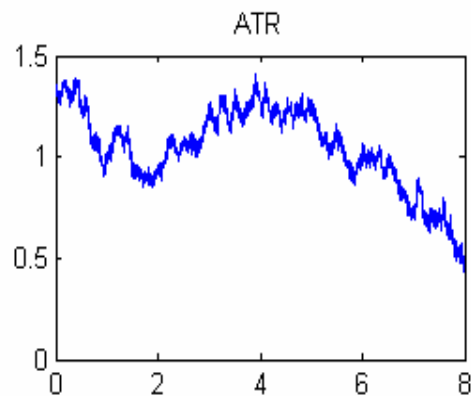
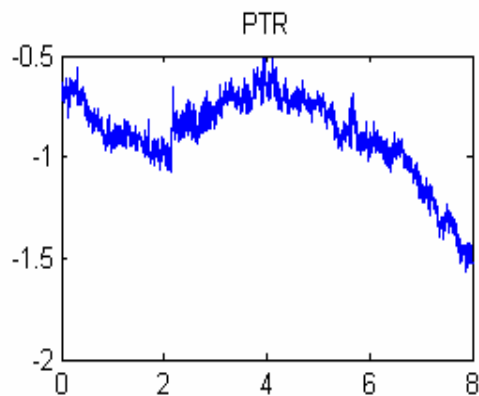
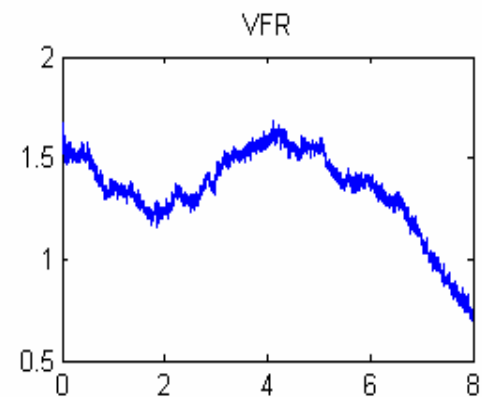
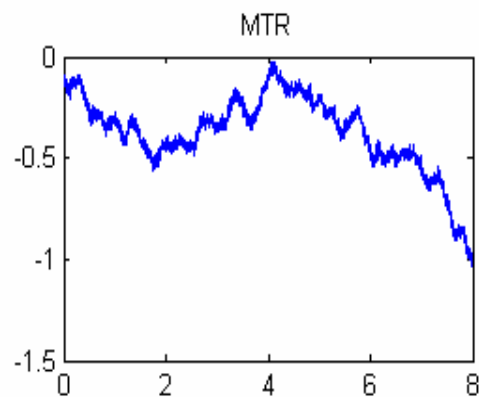
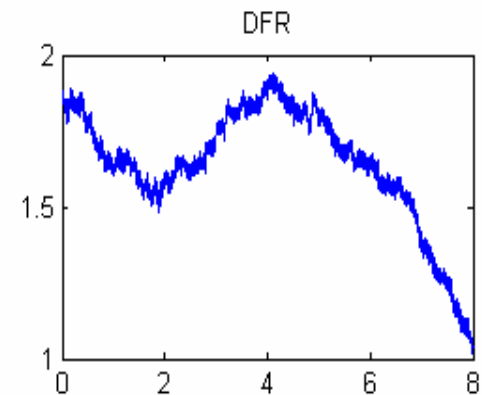
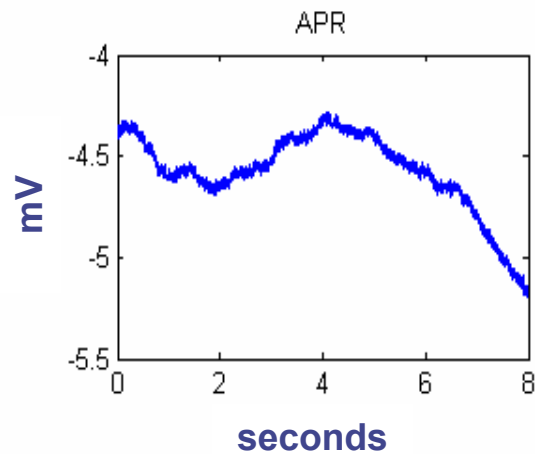
```

>>
>>
>>
>> EcoG
Type 'return' when ready to continue
K>> return
Hit UPARROW or type 'return' when ready to c
K>>

```

Start Waiting for input





Right Hemisphere (one channel from each site)

◆ `>> return`
(or *uparrow*)

◆ **locdetrend** is run on each channel

◆ `Fs=500` Hz (sampling rate)

◆ `movingwin = [1. 0.5]`

■ window length = 1 second

■ window step = 0.5 seconds

◆ Ex. `dfrontal(:,13) =`

locdetrend(`frontal(:,13)`,`Fs`,`movingwin`);

◆ generates figure showing a detrended channel, `dfrontal(:,13)` and the original time series, `frontal(:,13)`

```
Editor - h:\neuroInformatics\EcoG2005\EcoG.m
File Edit Text Cell Tools Debug Desktop Window Help
[Icons]
120 dparietal=locdetrend(parietal,Fs,movingwin)
121 dMT=locdetrend(MT,Fs,movingwin);
122 dbrain=[dfrontal dtemporal dparietal dMT];
123
124 %figure d
125 %from the
126 %comparing
127 Single_Channel_BeforeAfter_Locdetrend;
128
129 display(['Hit UPARROW or type ''return'' wh
130 keyboard
131 close all
132
133 locdetrend_Demo;
134 % generate figure
135 % Right Hemisphere
136 % mtspectrumc(dat
137 % after detrendin
138 % compare with t
```

MATLAB

File Edit Debug Desktop Window Help

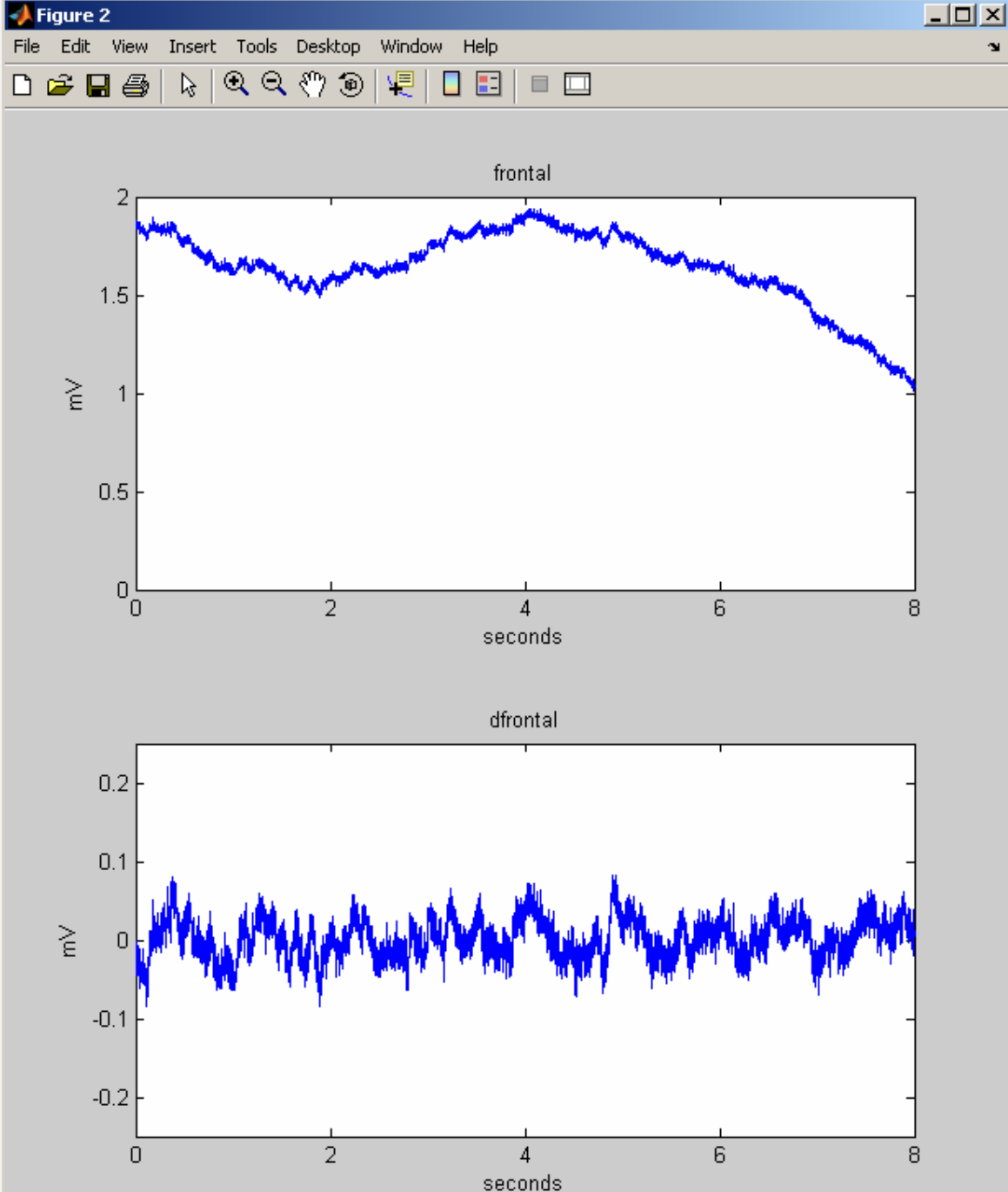
[Icons] h:\neuroInformatic

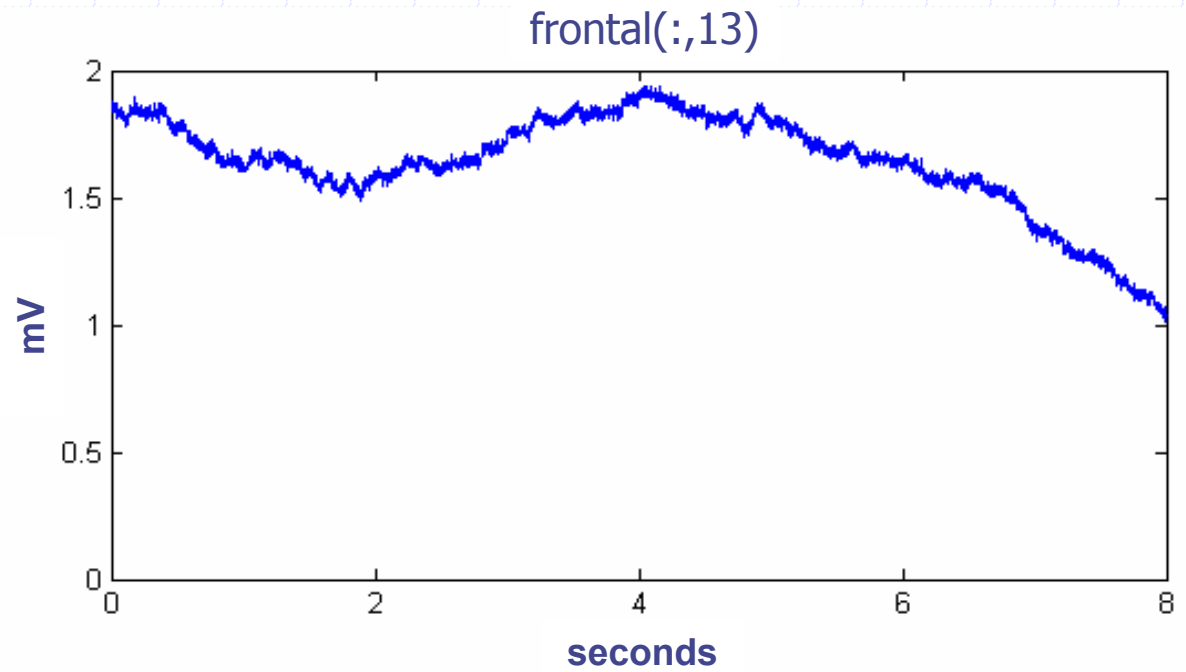
Shortcuts How to Add What's New

Command Window

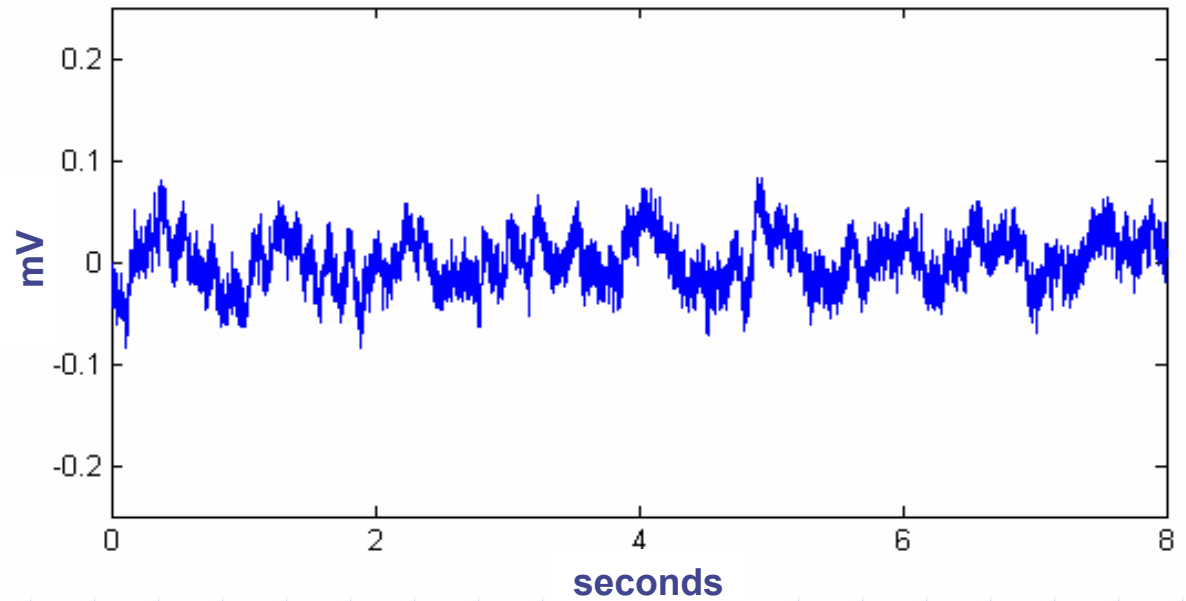
```
>>
>>
>> EcoG
Type 'return' when ready to continue
K>> return
Hit UPARROW or type 'return' when ready to c
K>> return
Hit UPARROW or type 'return' when ready to c
K>>
```

Start Waiting for input



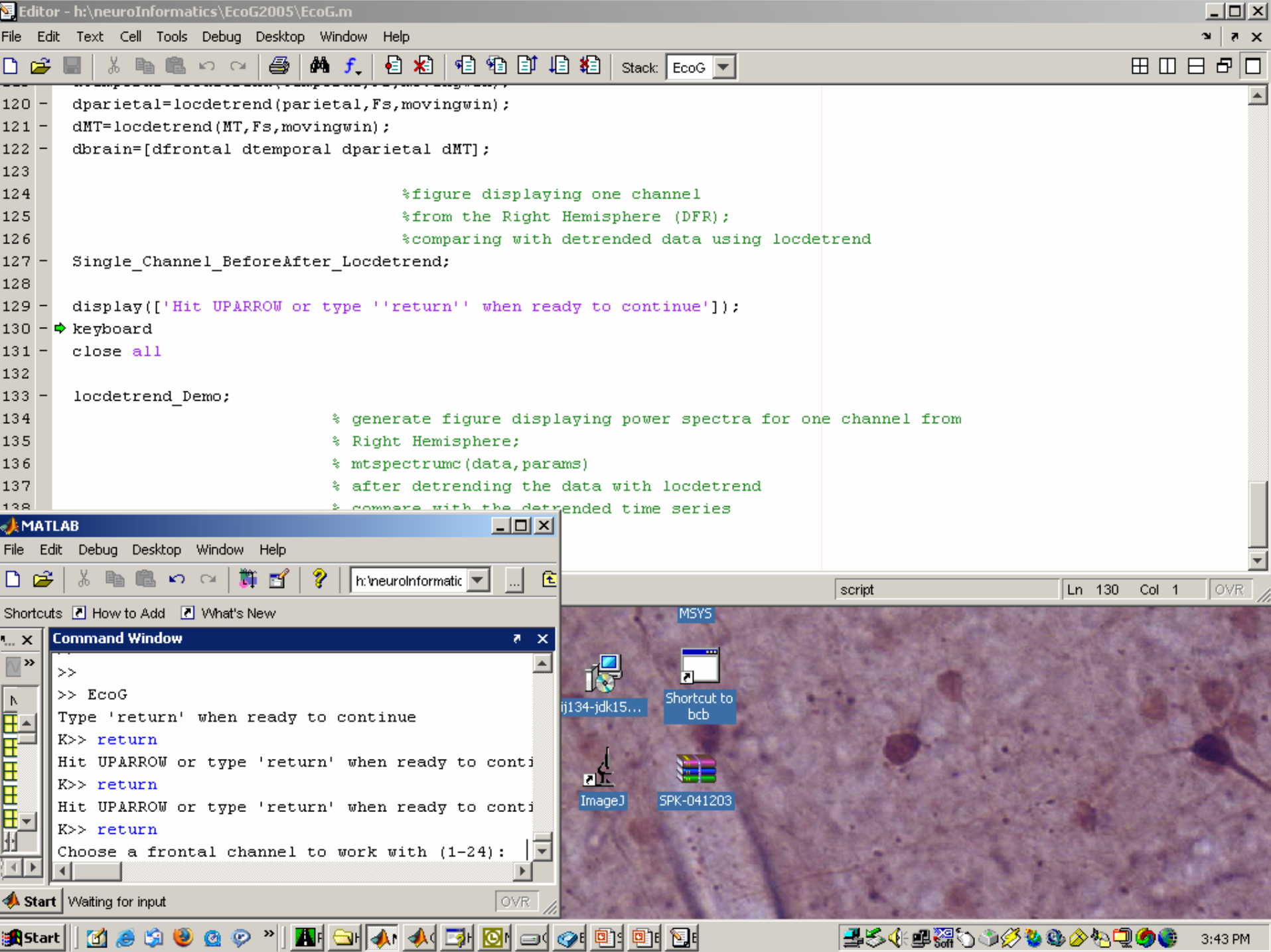


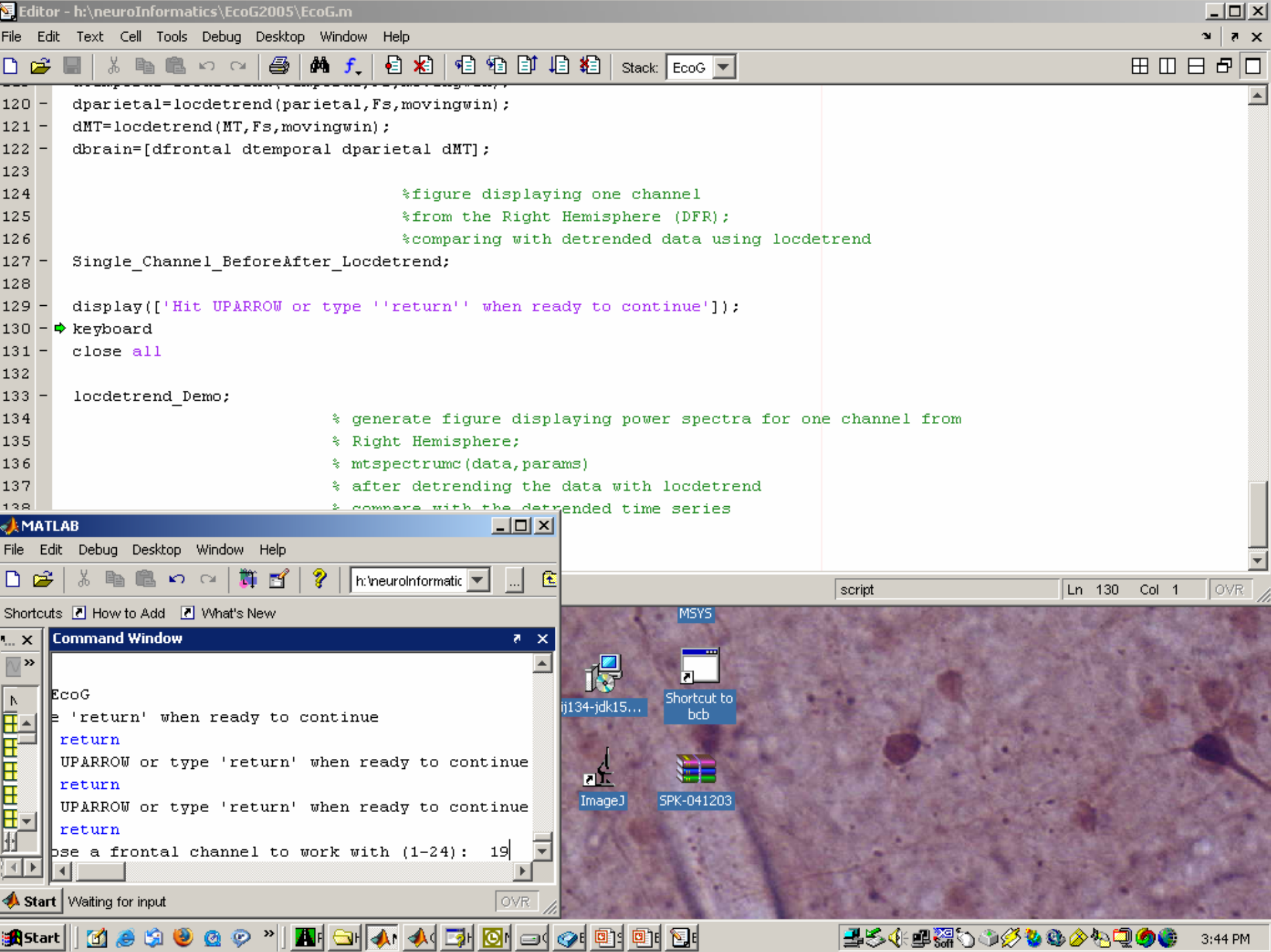
```
dfrontal(:,13) = locdetrend(frontal(:,13),Fs,movingwin);
```

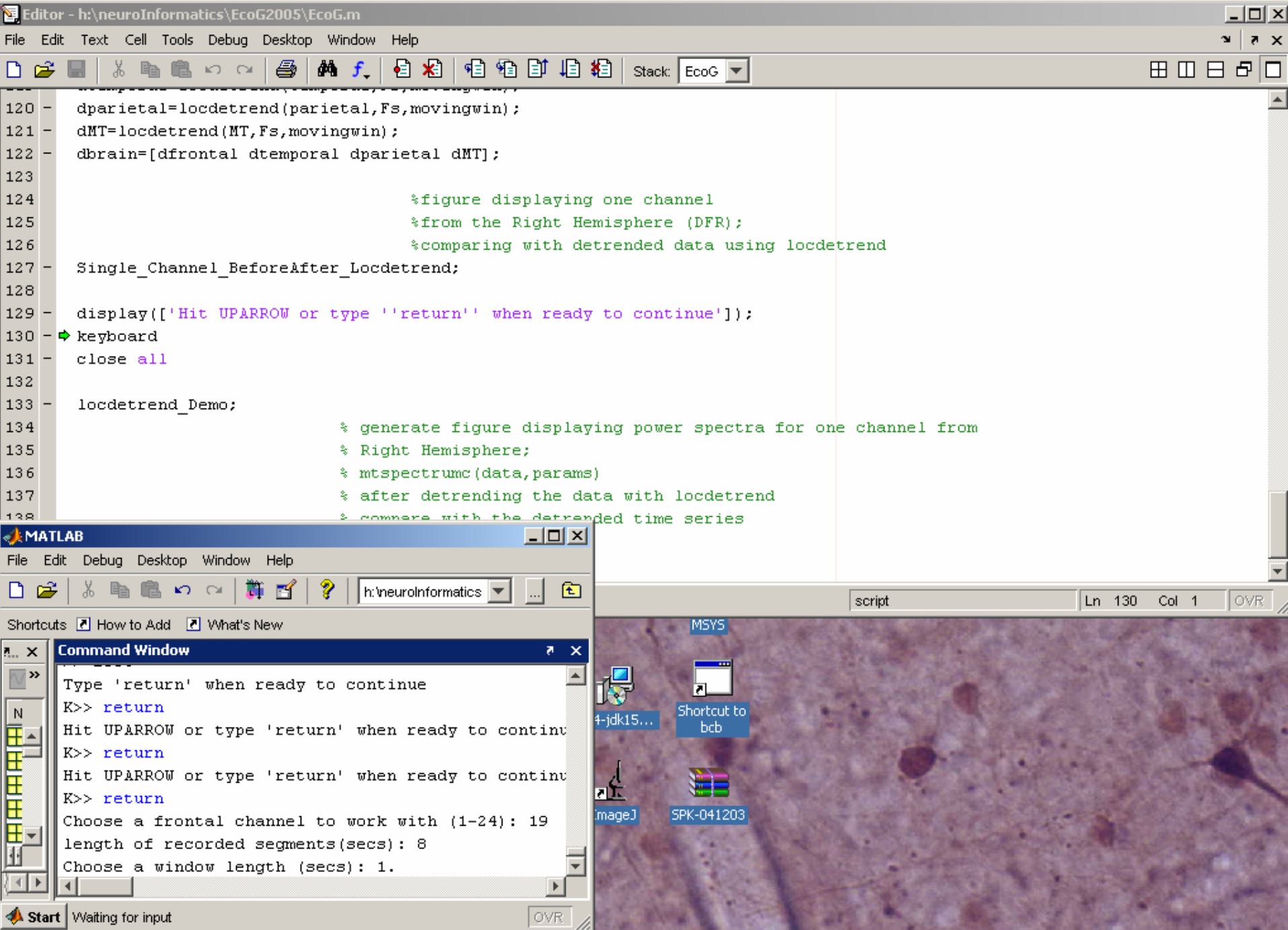


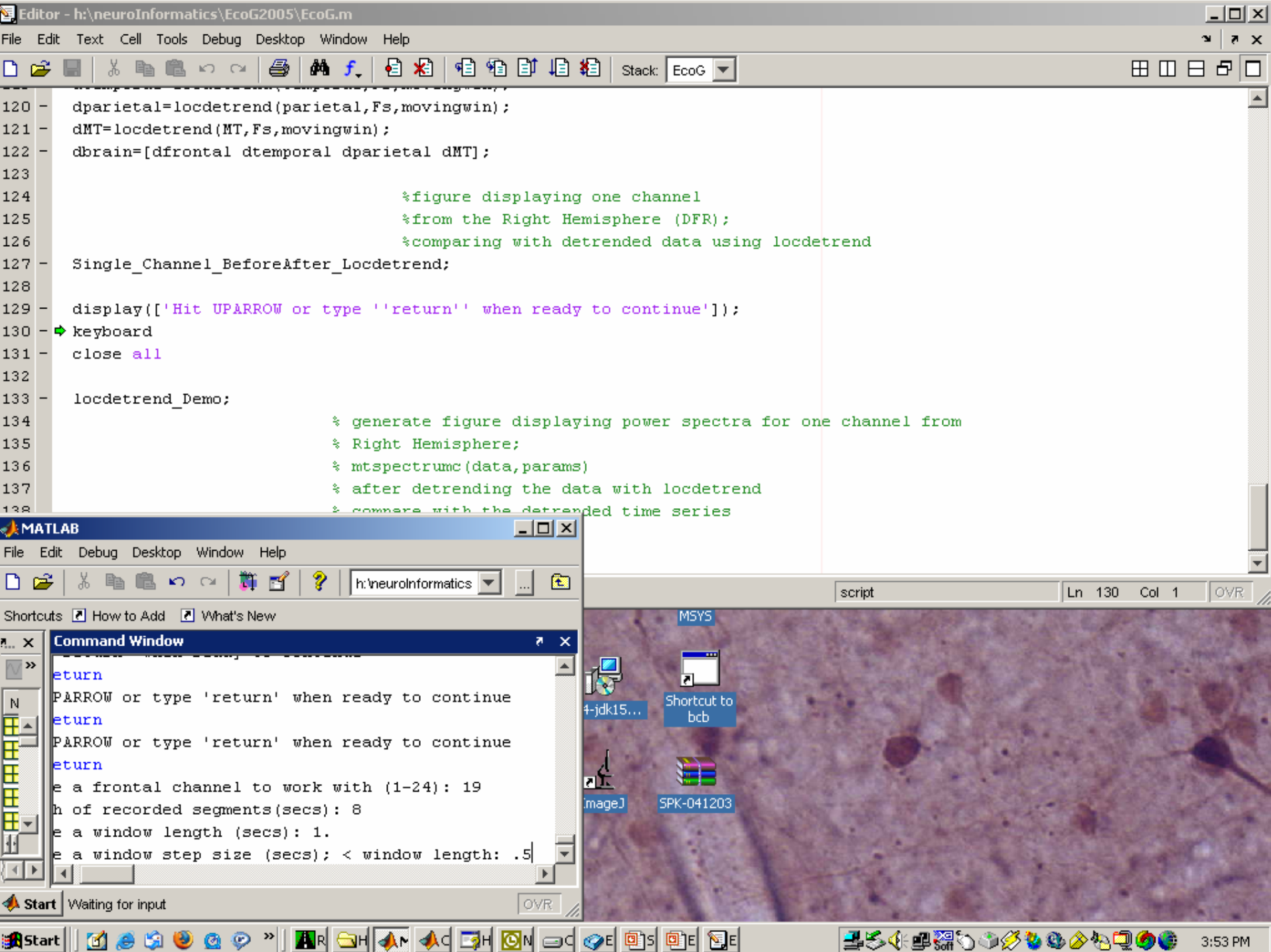
◆ >> **Locdetrend_Demo**

- ◆ **locdetrend** is run on a channel selected from the frontal lobe EcoG leads.
- ◆ **movingwin**: you will be prompted for
 - window length
 - window step
- ◆ Generates a sequence of figures illustrating windowed samples of EcoG signal, the signal mean and the best fitting line to the sample.
- ◆ Also shows how the results of the linear regression are locally weighted and combined into a estimate of the entire 8 second signal.



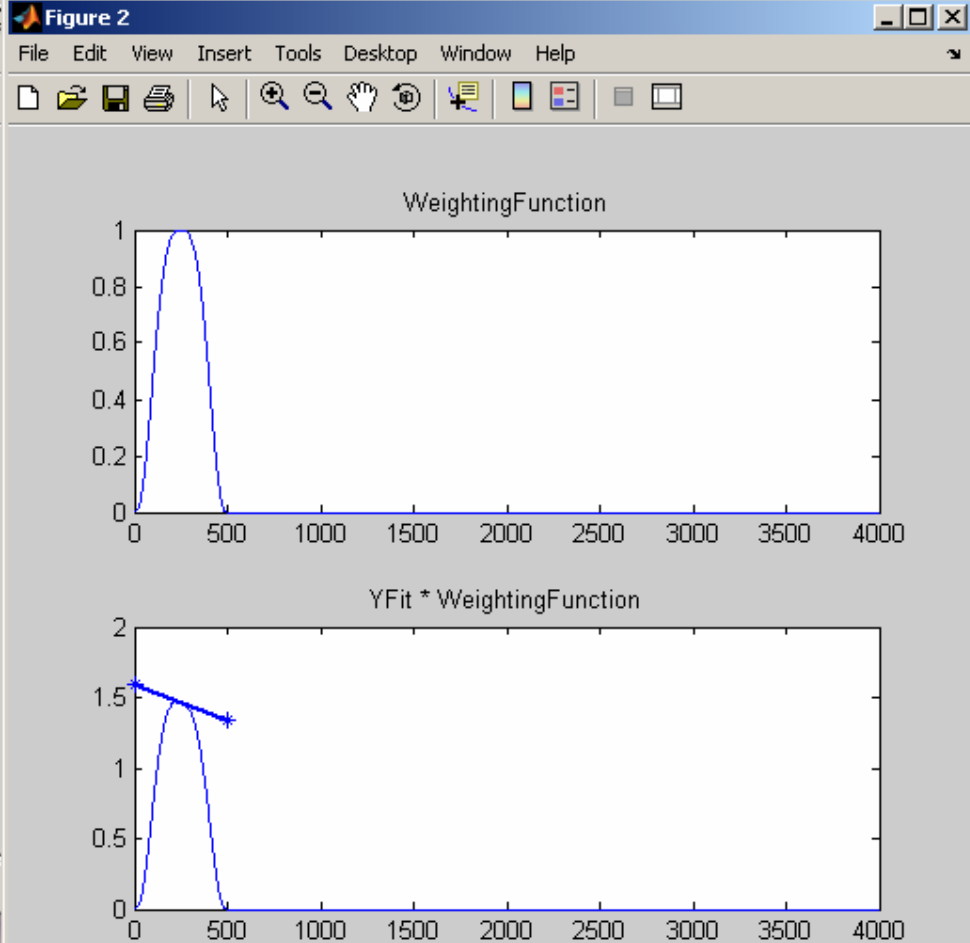
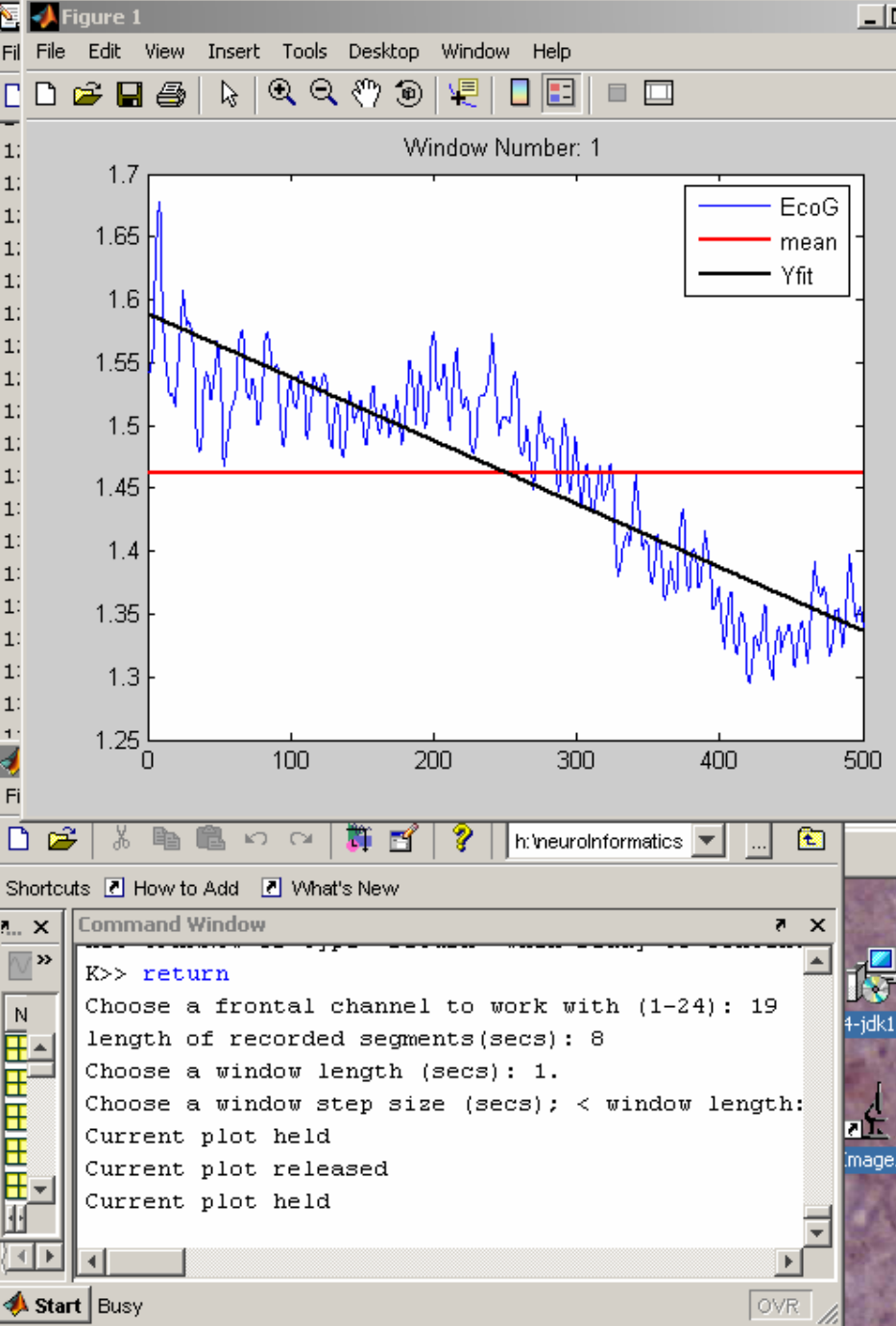


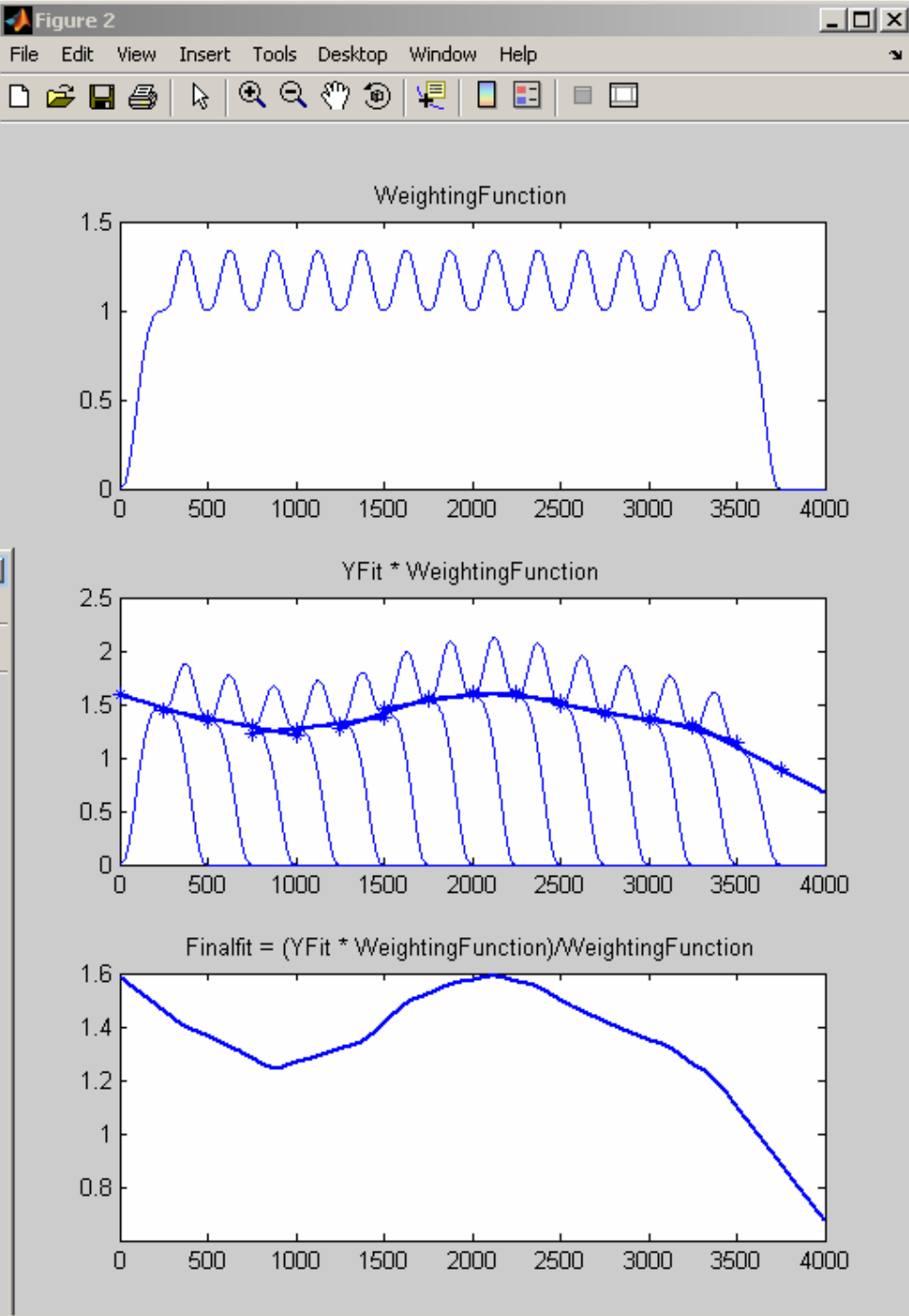
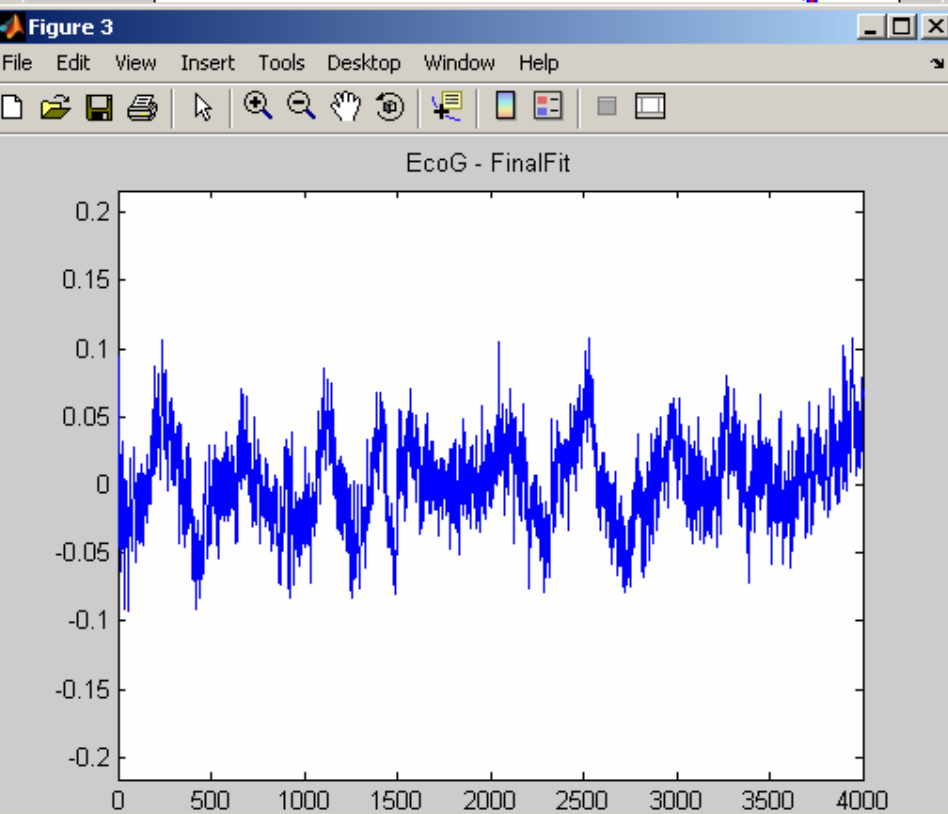
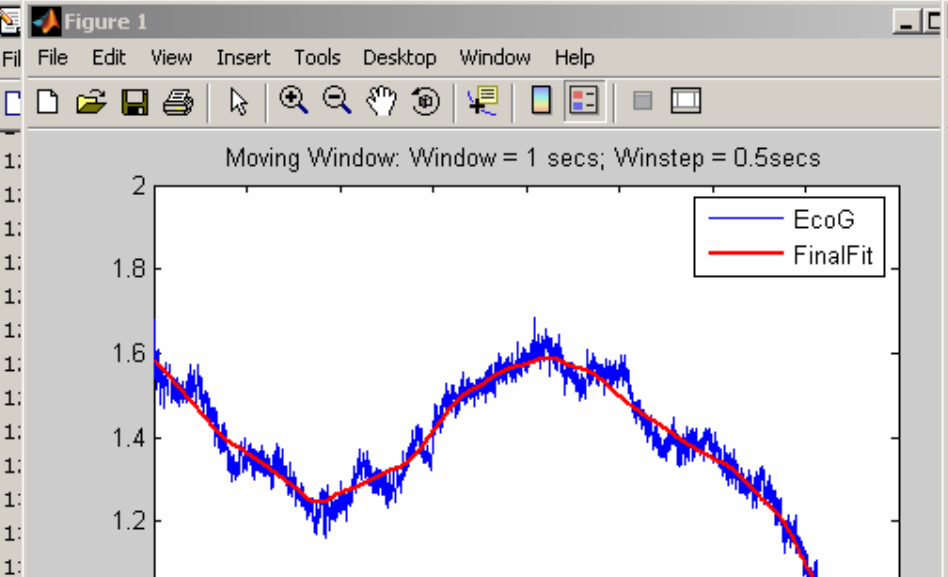


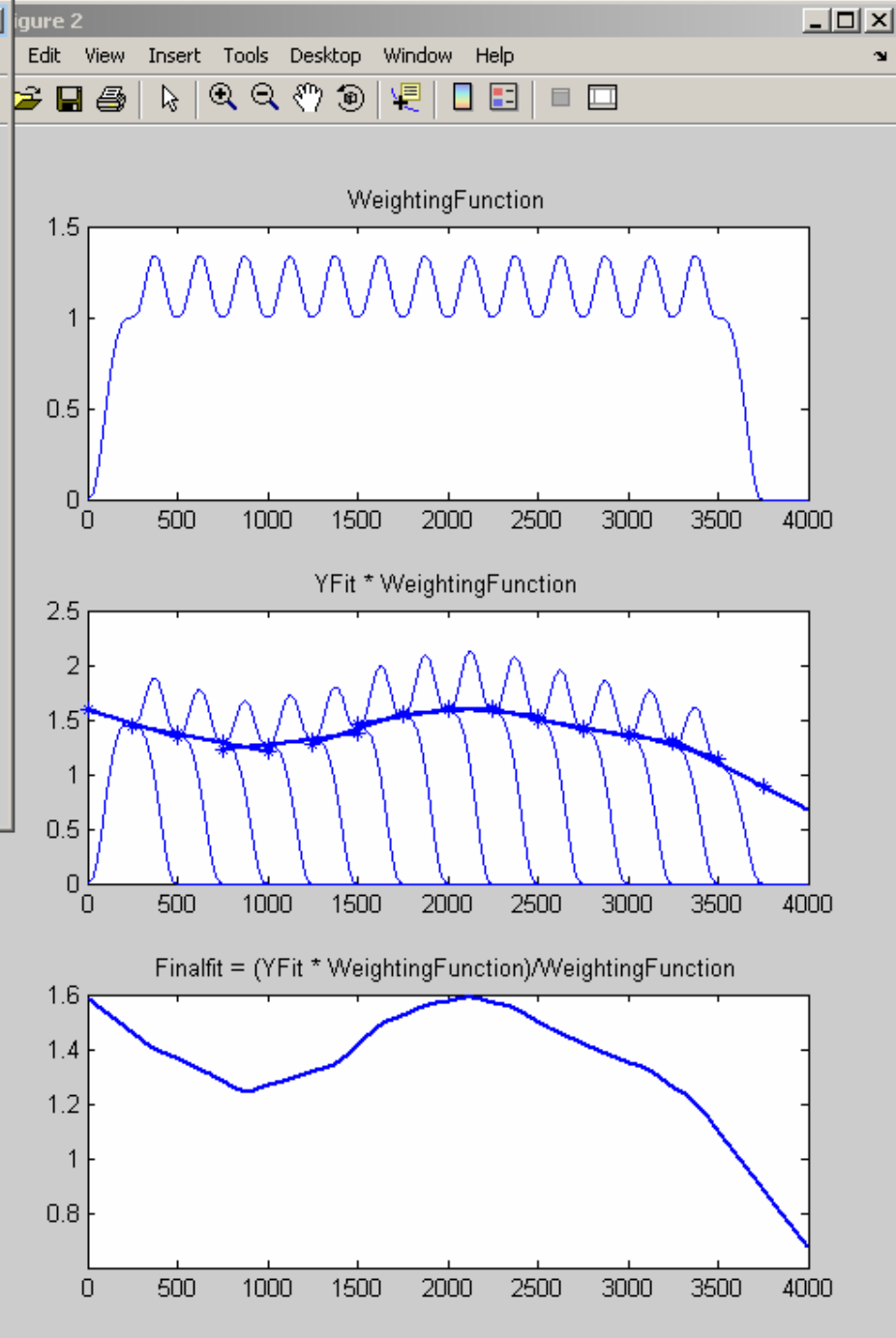
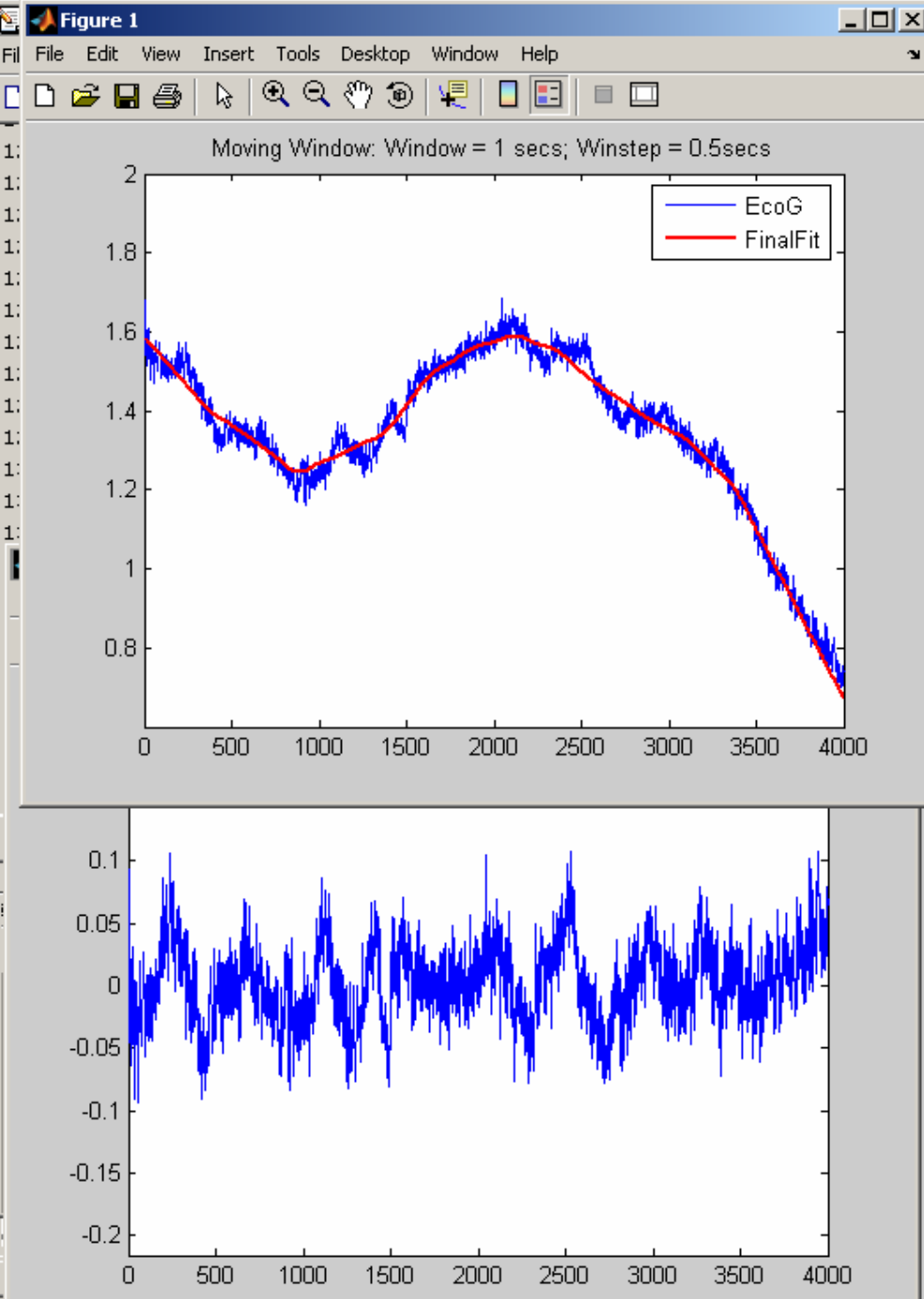


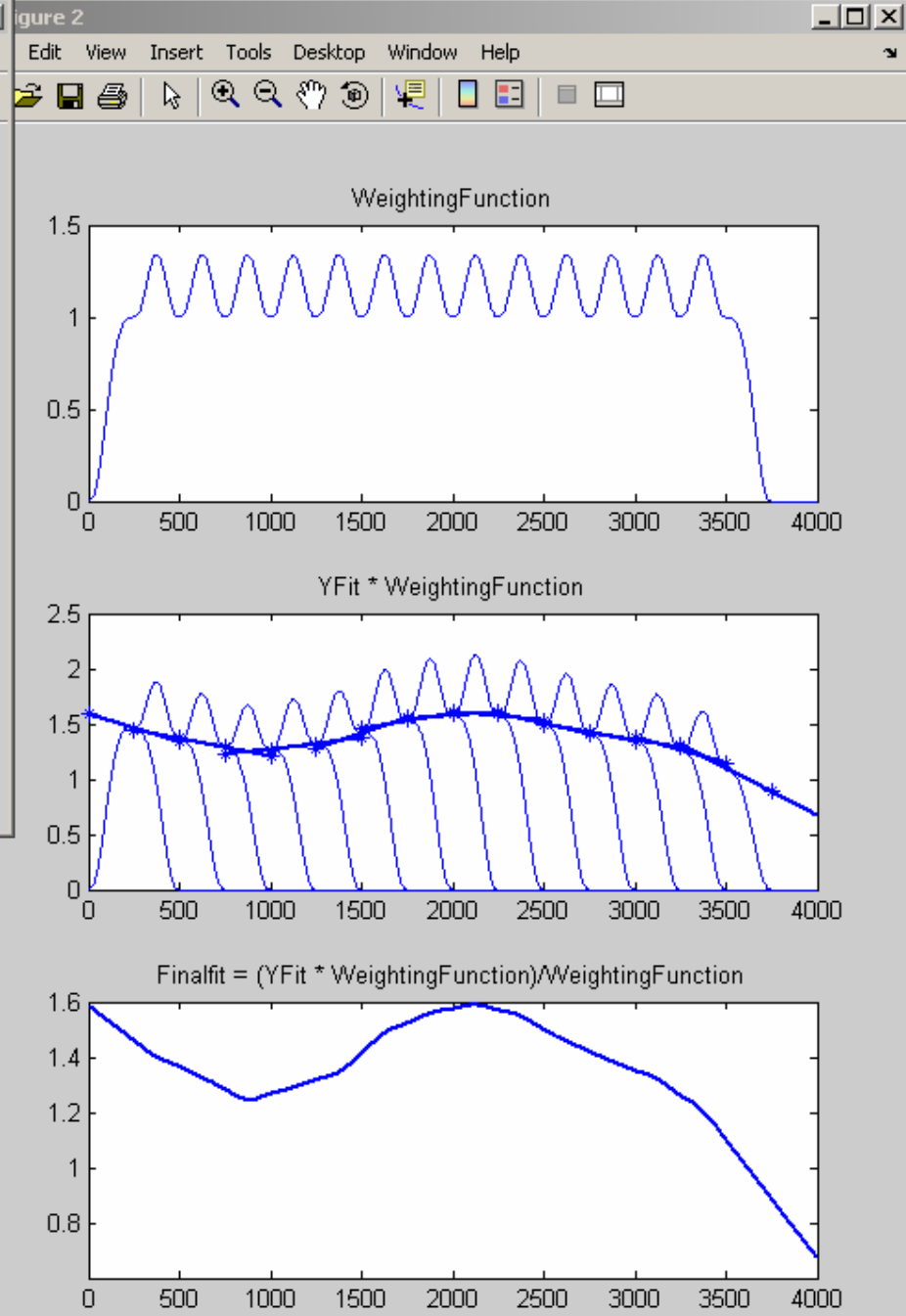
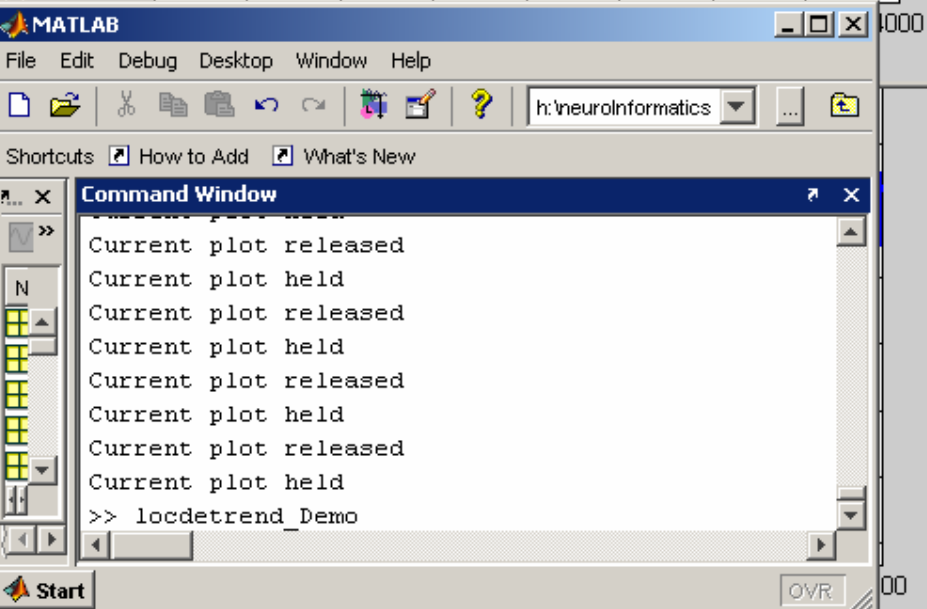
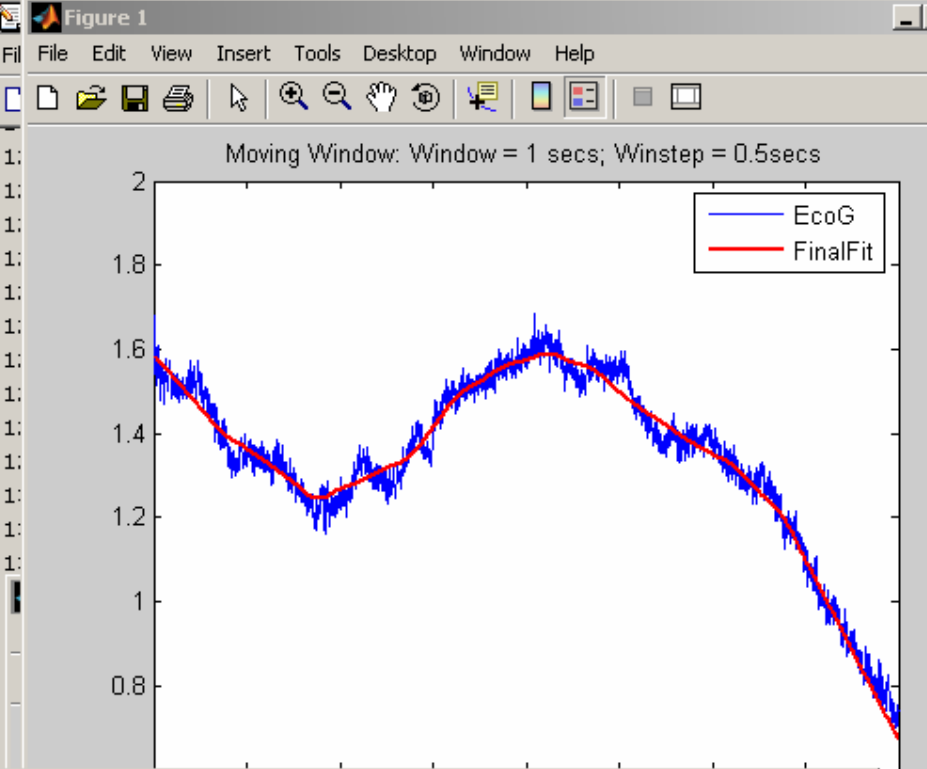
```
Editor - h:\neuroInformatics\EcoG2005\EcoG.m
File Edit Text Cell Tools Debug Desktop Window Help
[Icons]
Stack: EcoG
120 - dparietal=locdetrend(parietal,Fs,movingwin);
121 - dMT=locdetrend(MT,Fs,movingwin);
122 - dbrain=[dfrontal dtemporal dparietal dMT];
123
124             %figure displaying one channel
125             %from the Right Hemisphere (DFR);
126             %comparing with detrended data using locdetrend
127 - Single_Channel_BeforeAfter_Locdetrend;
128
129 - display(['Hit UPARROW or type 'return' when ready to continue']);
130 - keyboard
131 - close all
132
133 - locdetrend_Demo;
134             % generate figure displaying power spectra for one channel from
135             % Right Hemisphere;
136             % mtspectrumc(data,params)
137             % after detrending the data with locdetrend
138             % compare with the detrended time series

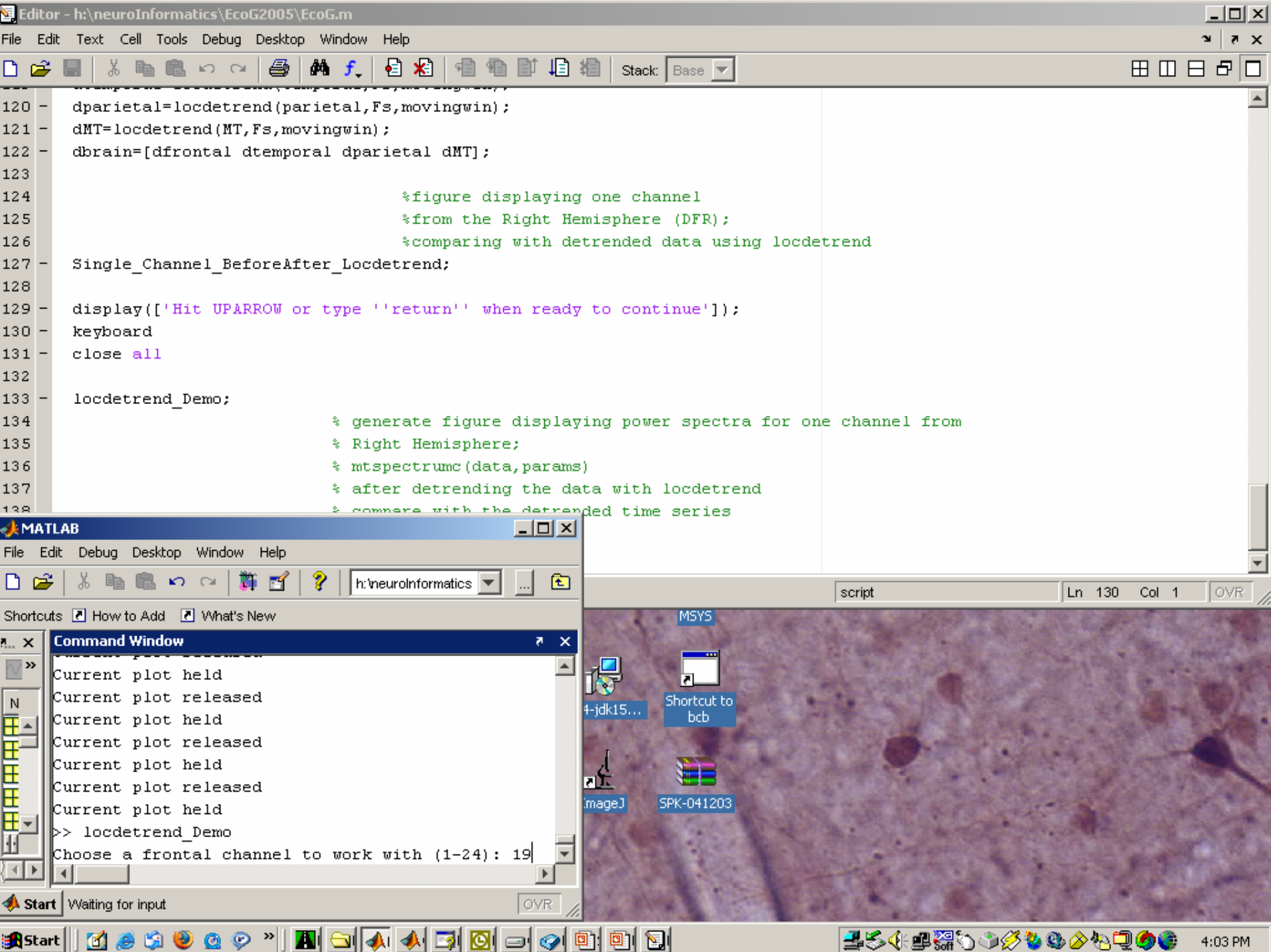
MATLAB
File Edit Debug Desktop Window Help
[Icons]
h:\neuroInformatics
Shortcuts How to Add What's New
Command Window
>>
return
PARROW or type 'return' when ready to continue
return
PARROW or type 'return' when ready to continue
return
e a frontal channel to work with (1-24): 19
h of recorded segments(secs): 8
e a window length (secs): 1.
e a window step size (secs); < window length: .5
Start Waiting for input
OVR
```

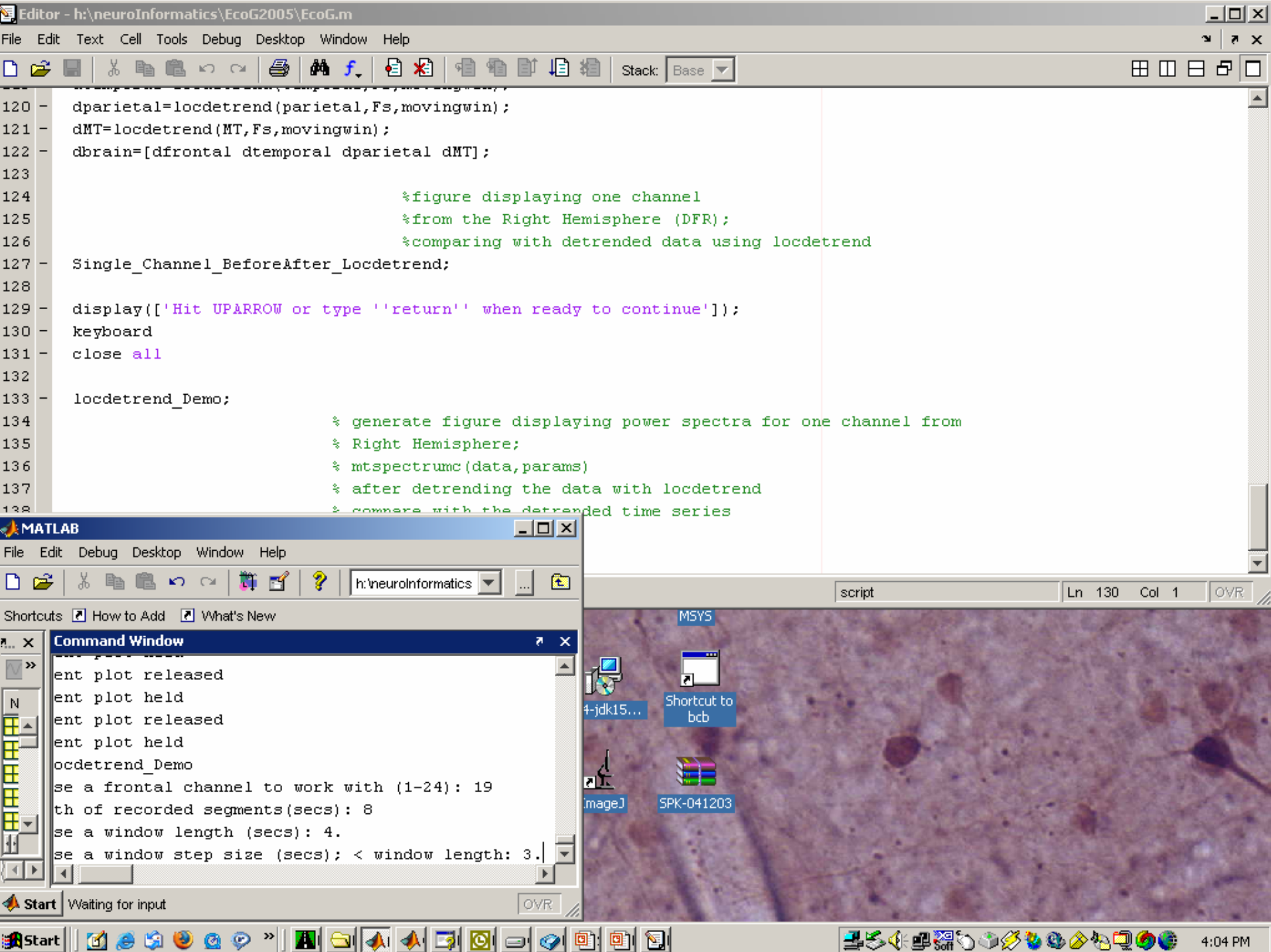



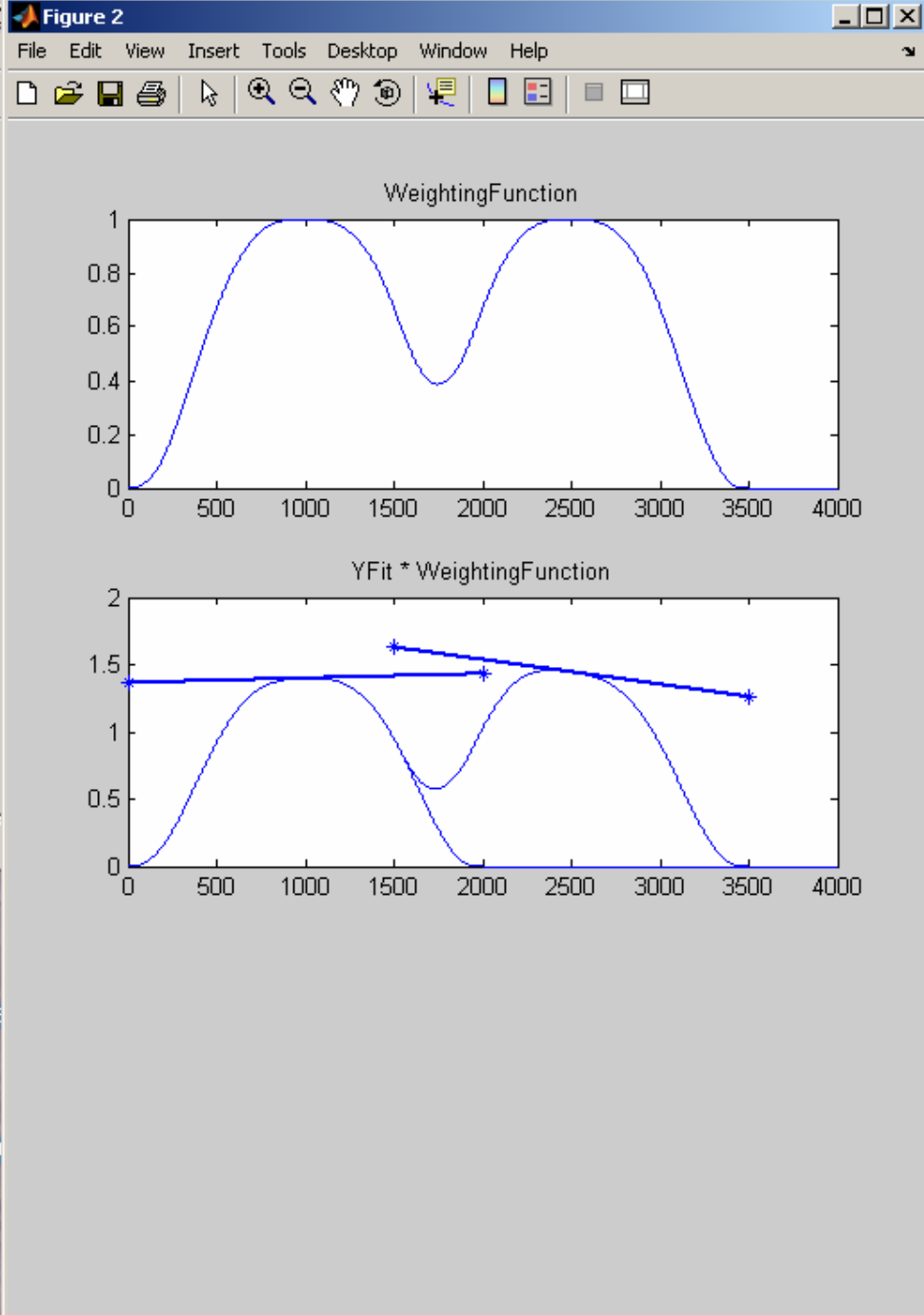
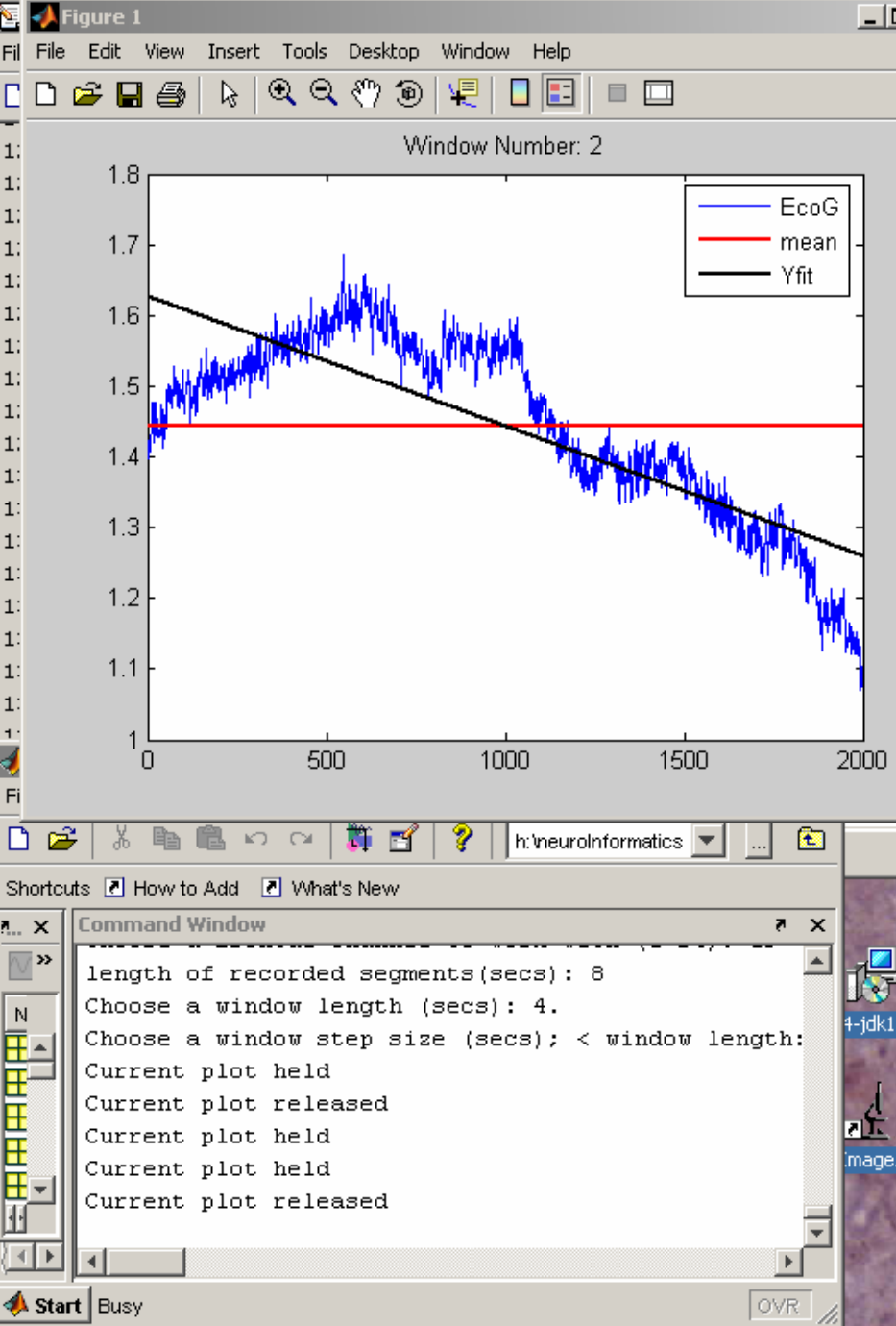


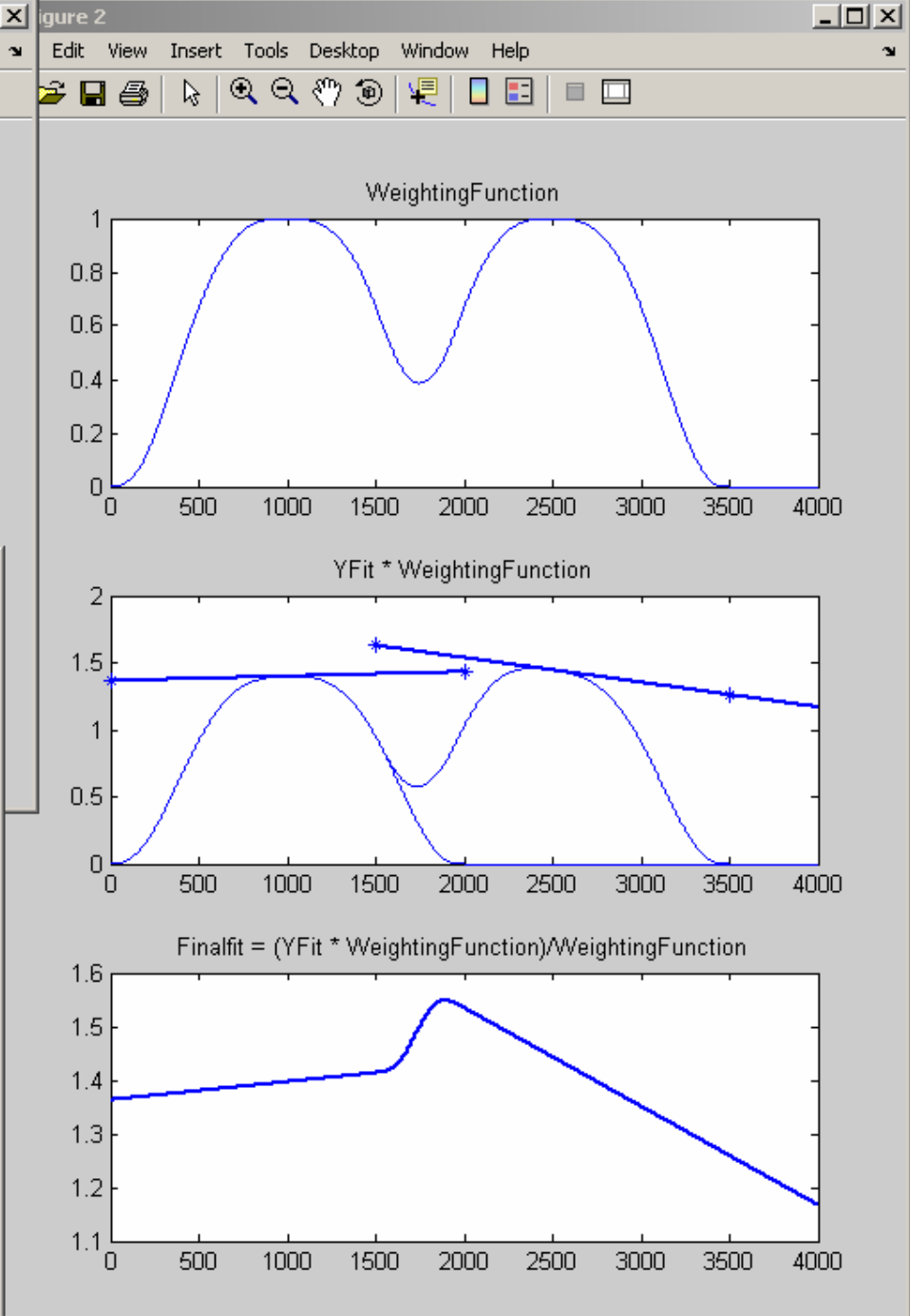
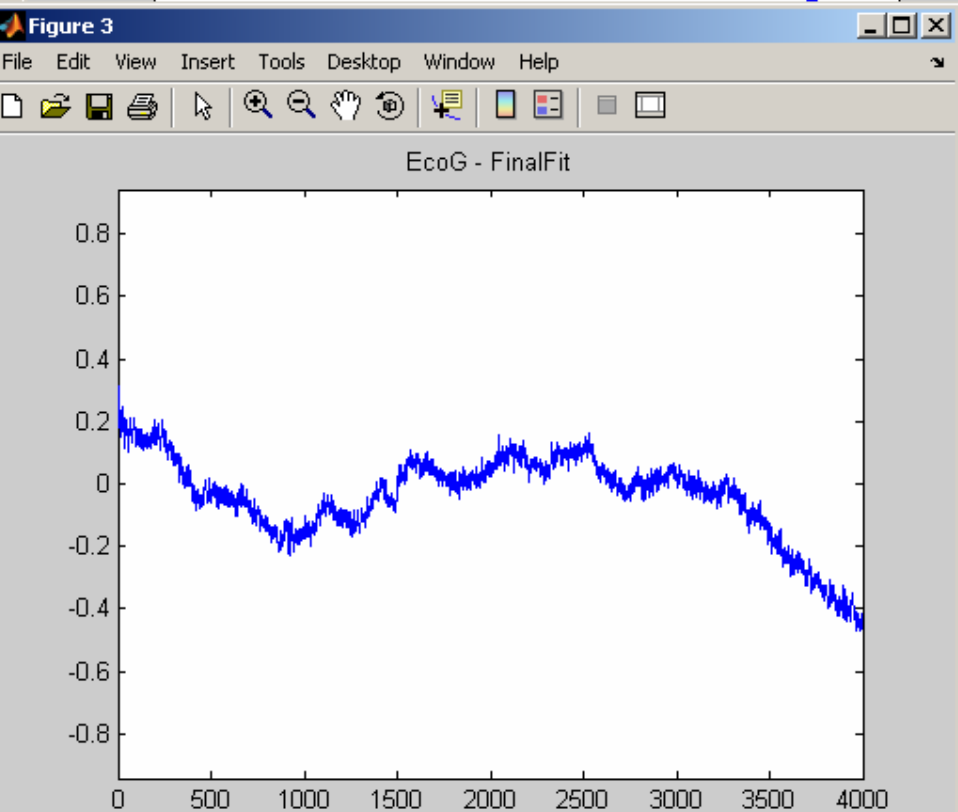
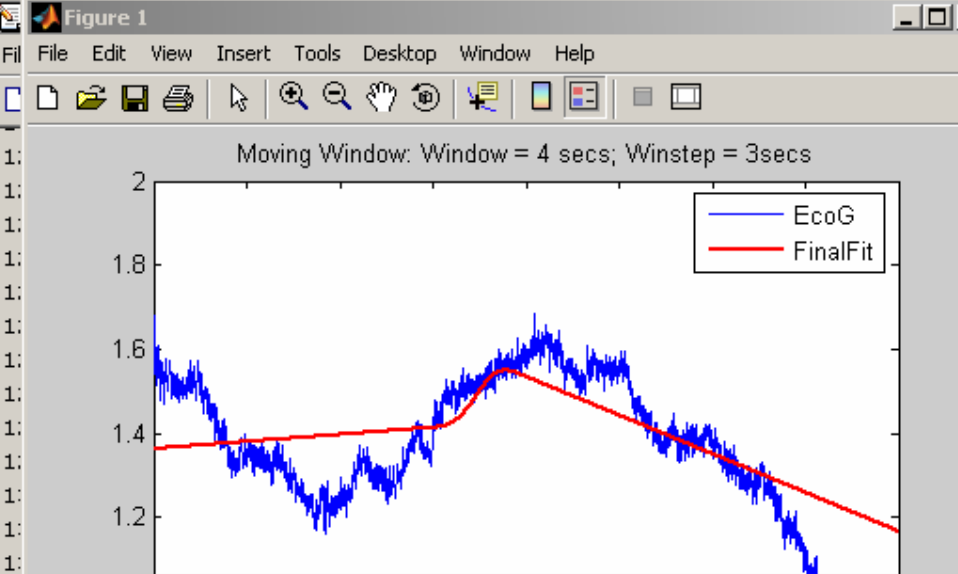












How much detrending should be done? That is, how does one choose the window and winstep parameter values?

- ◆ The intermediate stage of detrending acts like a low-pass filter.
- ◆ The longer the window, the 'smoother' the signal will be that you subtract from your original, and hence, the more high-frequency content will be preserved in the residual.
- ◆ While its important to smooth the signal before subtracting from the original, remember not to smother it.
- ◆ Simple moving averages (low-pass filtering operations) produce significant distortions.

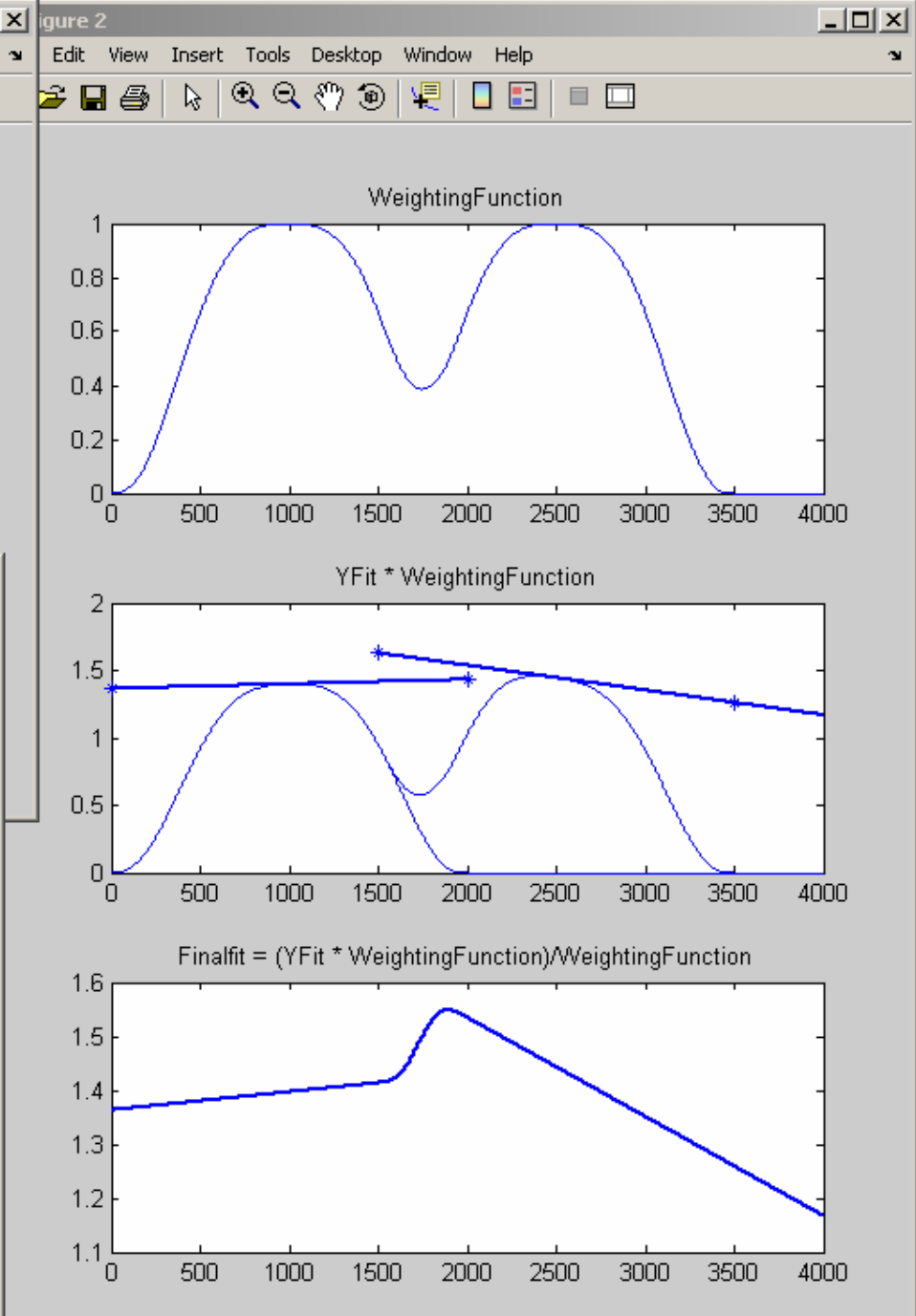
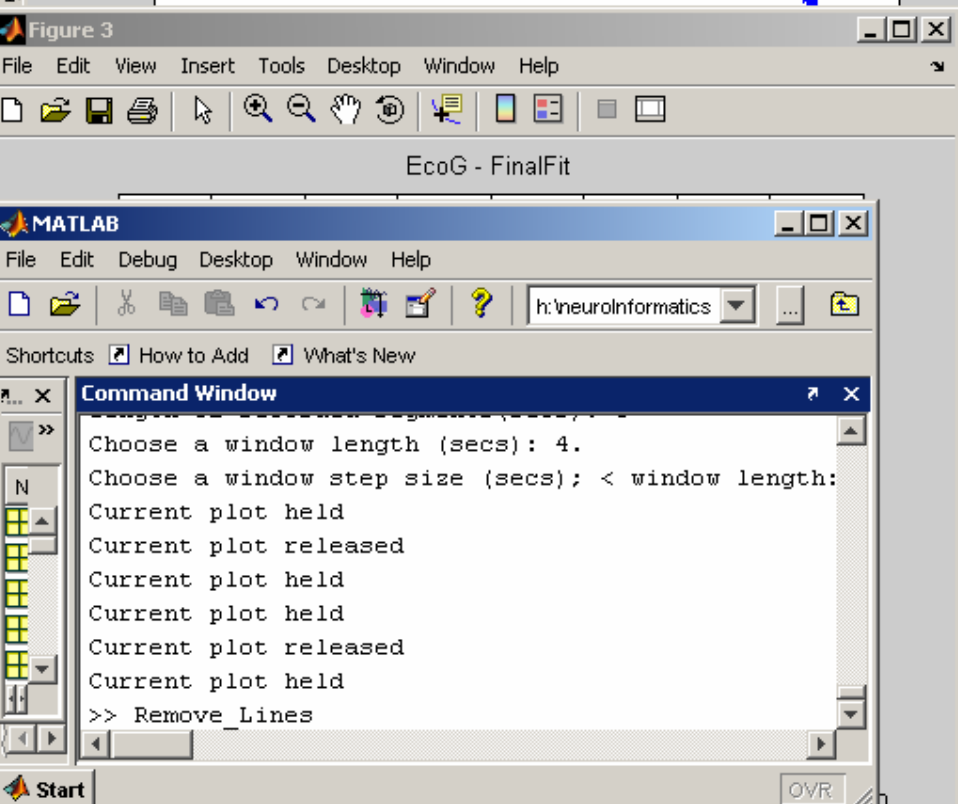
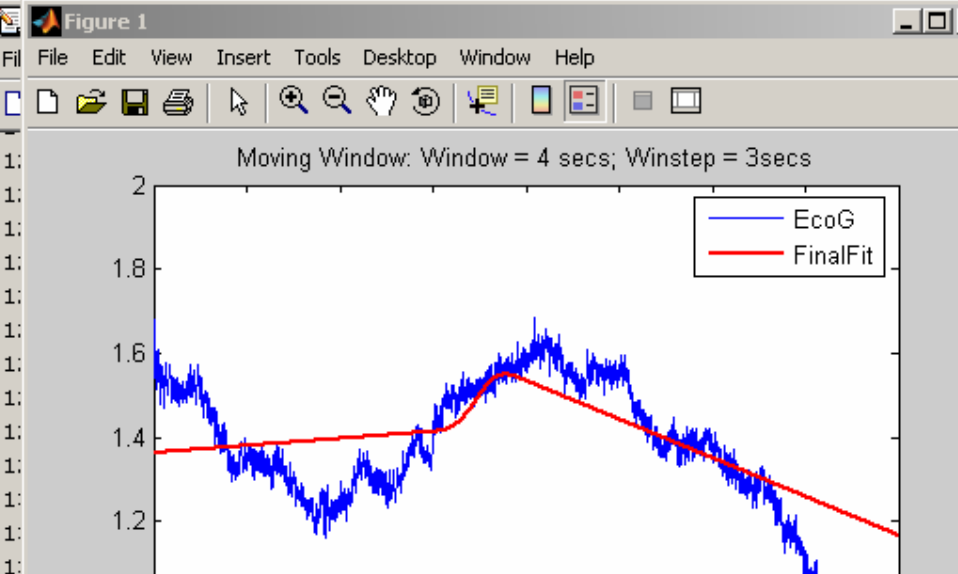
◆ >> **Remove_Lines**

◆ Multi-taper power spectra calculated for one, right hemisphere dorsal-frontal channel, DFR, after detrending.

◆ **[S,f] = mtspectrumc(dDFR,params)**

◆ with

- $K_{\text{tapers}}=8$; $NW=(K_{\text{tapers}}+1)/2$
- `params.tapers=[NW Ktapers]`
- `params.pad=5`
- `params.Fs=500`
- `params.fpass=[0 params.Fs/2]`




```
Editor - h:\neuroinformatics\EcoG2005\Remove_Lines.m
File Edit Text Cell Tools Debug Desktop Window Help

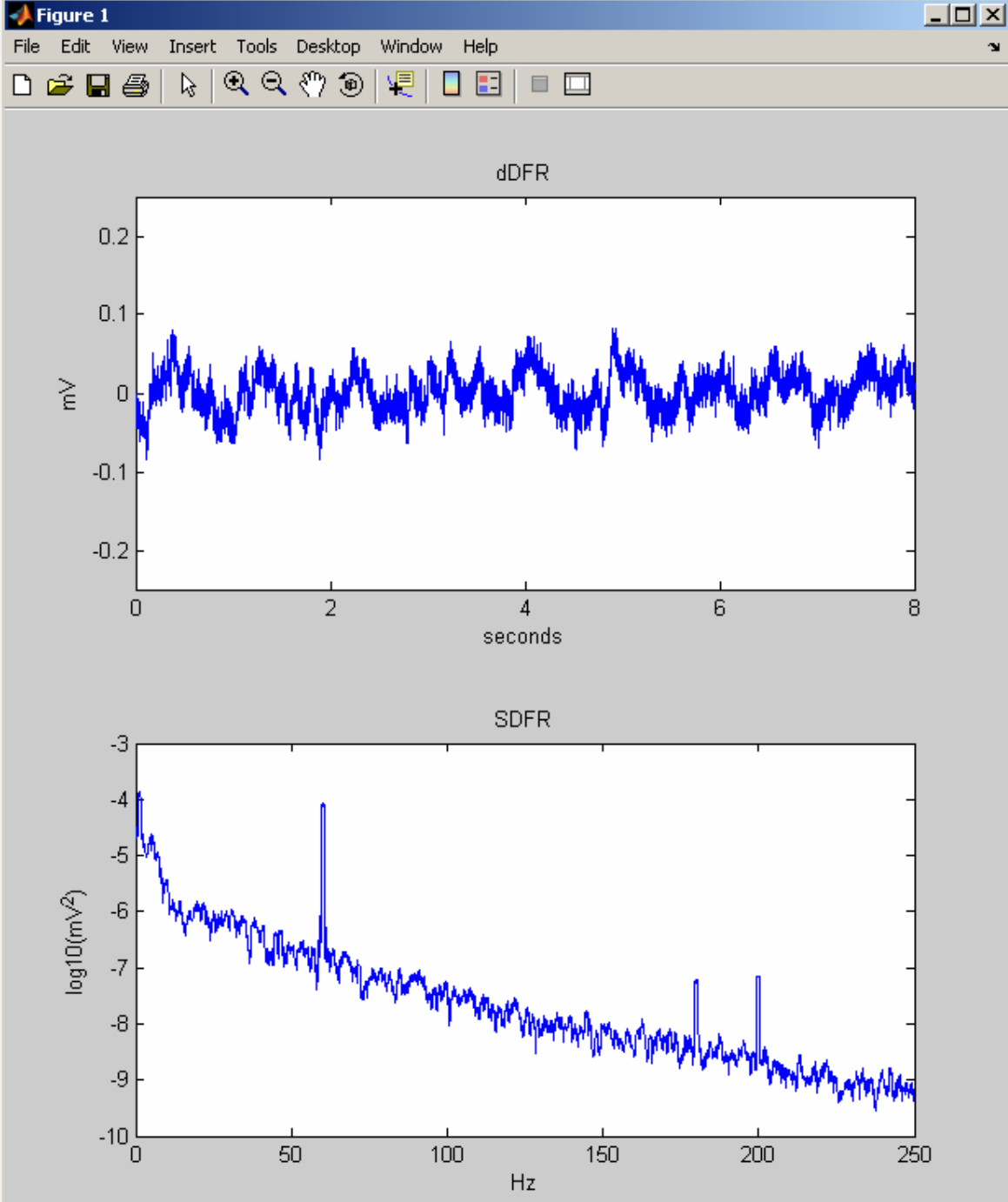
39 %after detrending
40 Ktapers=8;
41 NW=(Ktapers+1)/2;
42 params.tapers = [ NW Ktapers ];
43 params.Fs=500;
44 params.fpass = [ 0 params.Fs/2];
45 params.pad = 5;
46 params.err=[2 .05];
47
48 display(['Type ''return'' when ready to con
49 keyboard %pause
50 close all
51 %line removal us
52 %significant harr
53 %these may be no
54 %the right hemisp
55 %correction
56 dnlfrontal=rmlinesc(dDFR,params,.05,'y');
57 set(gcf,'Units','pixels','Position',ssrml);
58
59 display(['Hit UPARROW or type ''return'' m

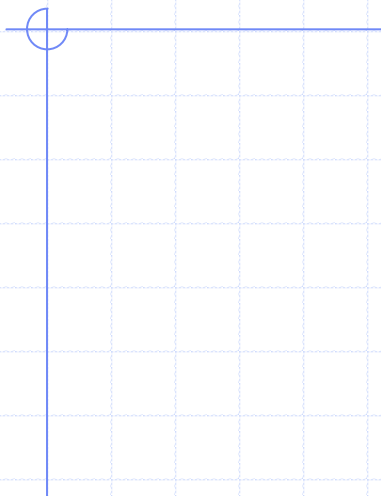
EcoG.m x Remove_Lines.m x

Shortcuts How to Add What's New

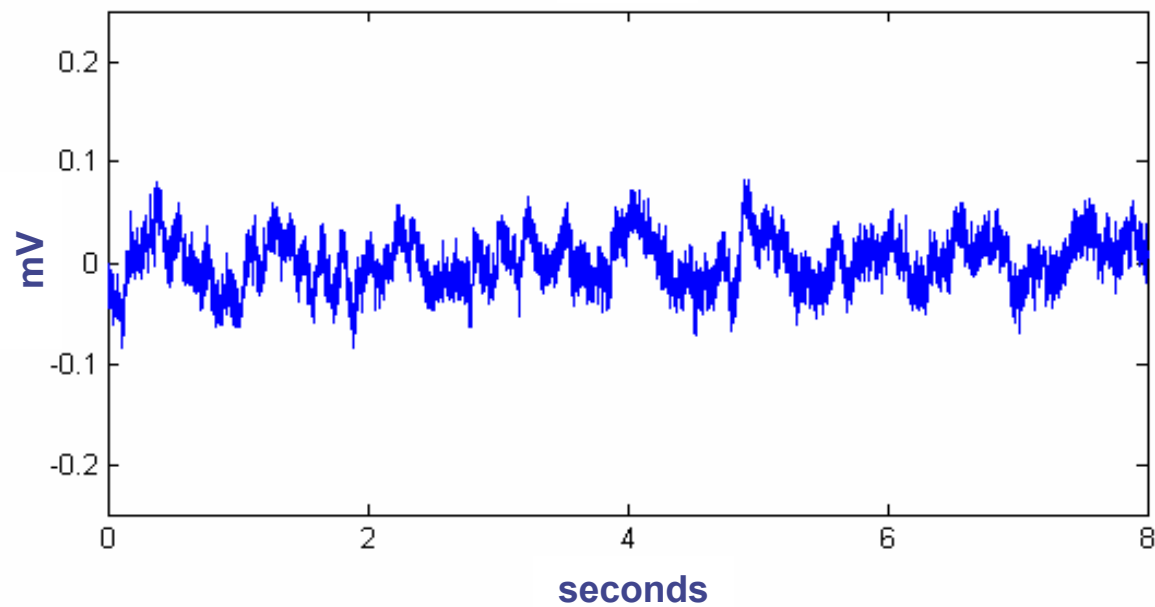
Command Window
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>> Remove_Lines
Type 'return' when ready to continue
K>>

Start Waiting for input
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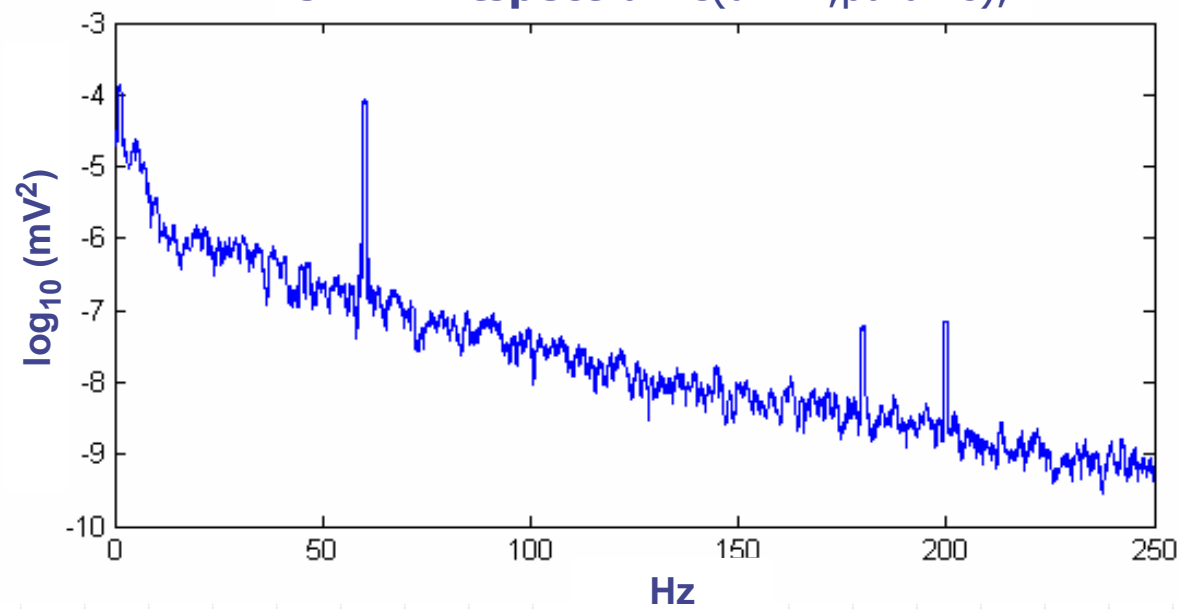




dDFR

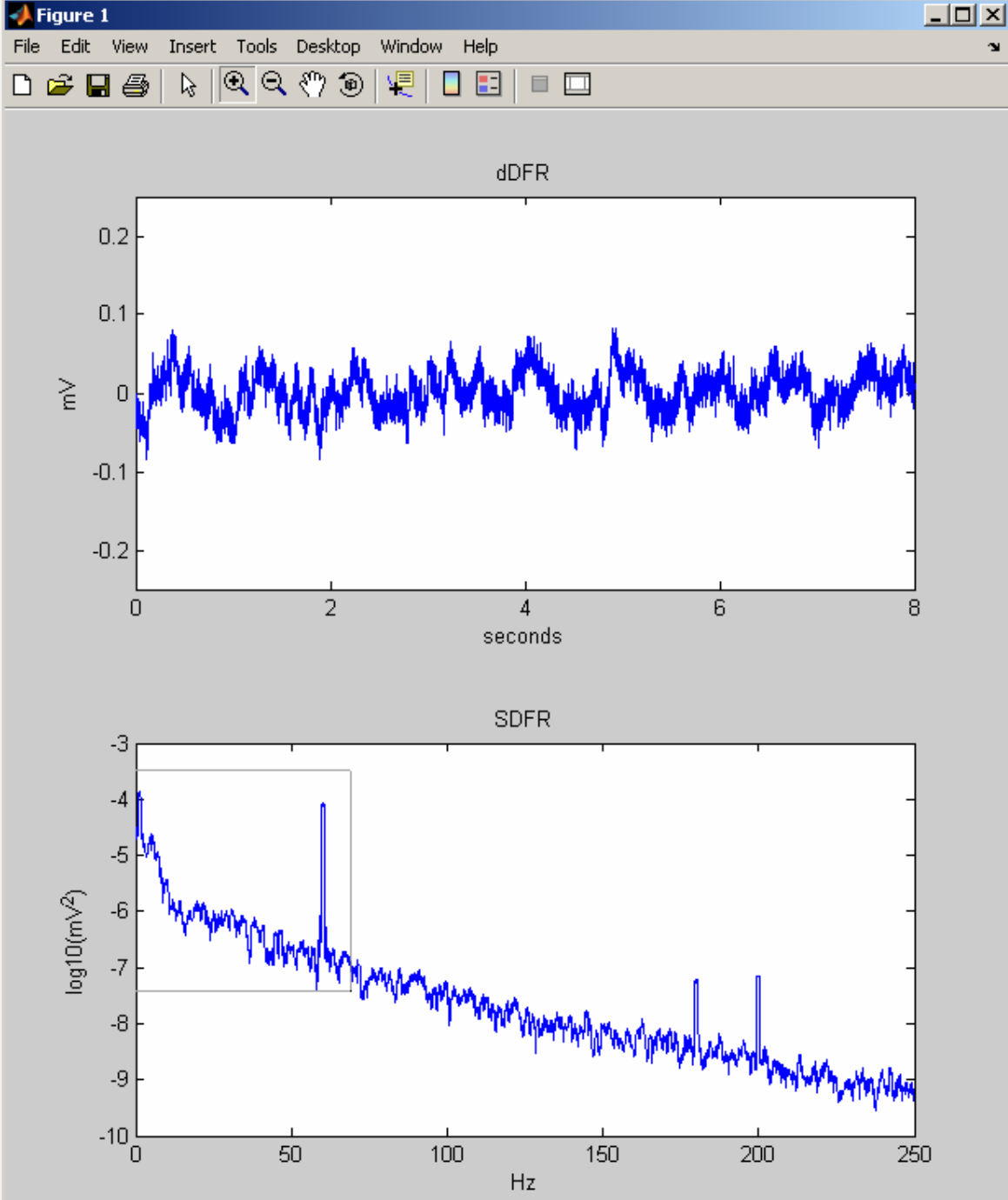


`SDFR=mtspectrumc(dDFR,params);`



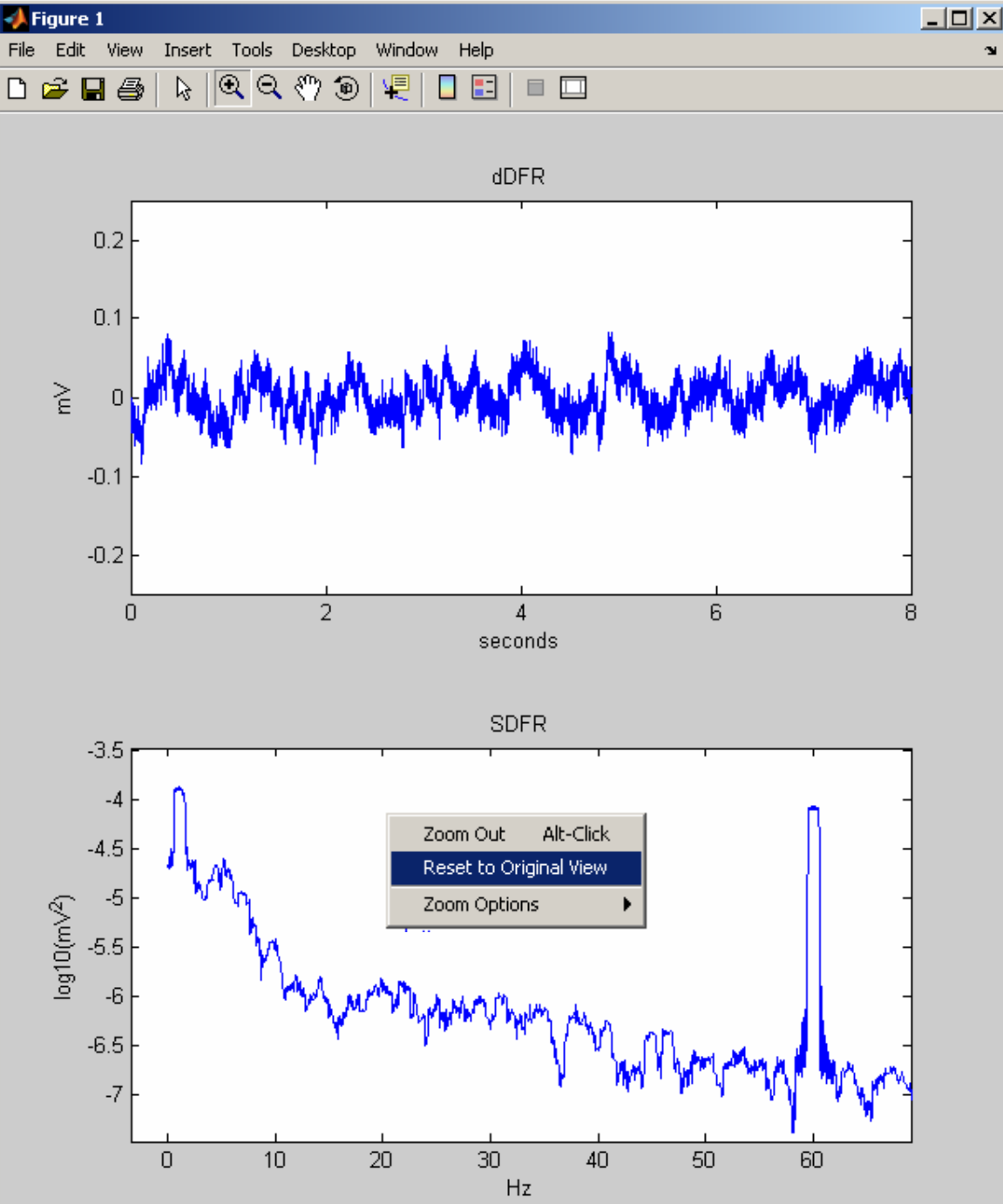
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[Icons]
39 %after detrending
40 Ktapers=8;
41 NW=(Ktapers+1)/2;
42 params.tapers = [ NW Ktapers ];
43 params.Fs=500;
44 params.fpass = [ 0 params.Fs/2];
45 params.pad = 5;
46 params.err=[2 .05];
47
48 display(['Type 'return' when ready to con
49 keyboard %pause
50 close all
51 %line removal us
52 %significant har
53 %these may be no
54 %the right hemis
55 %correction
56 dnlfrontal=rmlinesc(dDFR,params,.05,'y');
57 set(gcf,'Units','pixels','Position',ssrml);

MATLAB
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Shortcuts How to Add What's New
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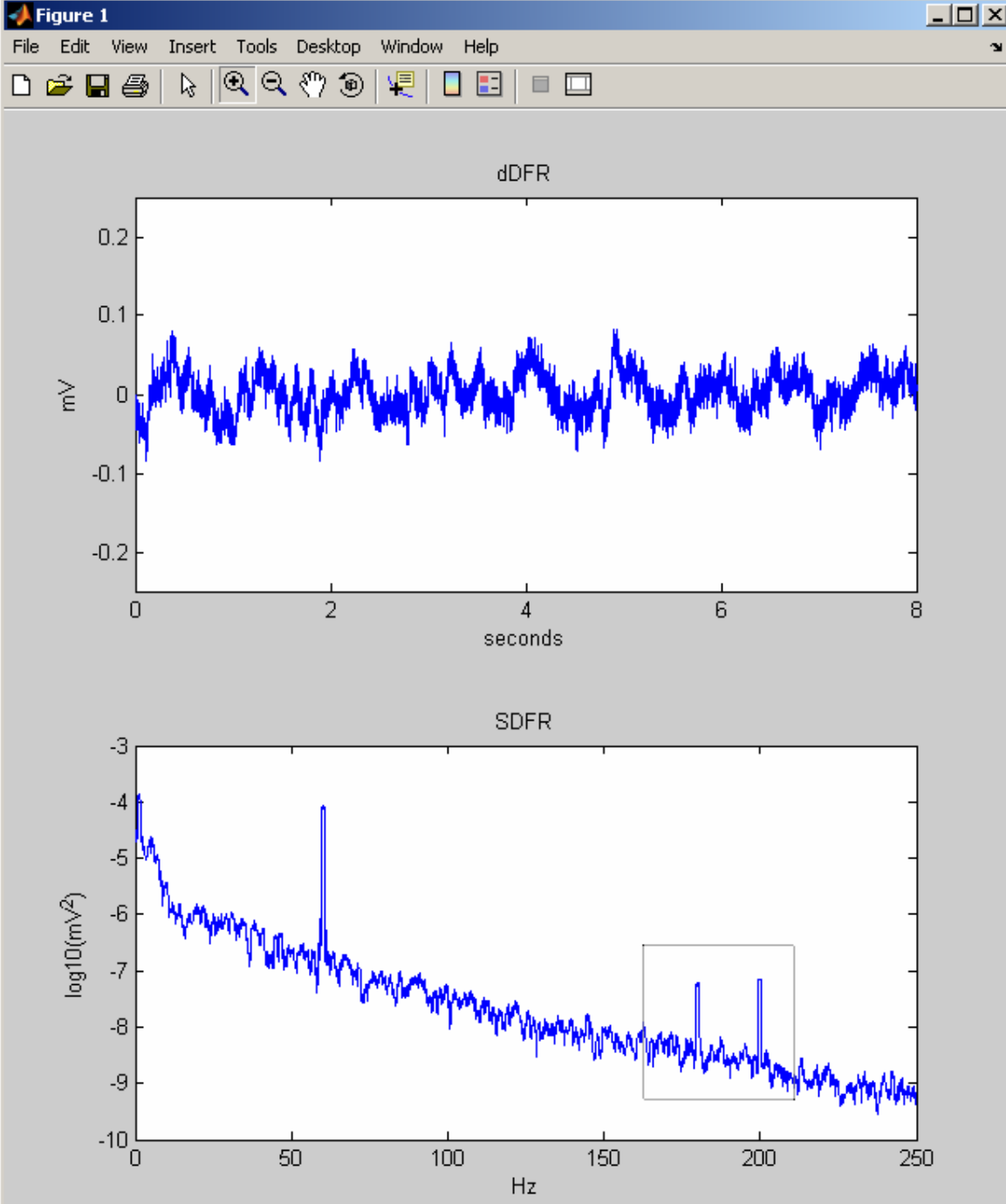
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[Icons]
39 %after detrending
40 Ktapers=8;
41 NW=(Ktapers+1)/2;
42 params.tapers = [ NW Ktapers ];
43 params.Fs=500;
44 params.fpass = [ 0 params.Fs/2];
45 params.pad = 5;
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54 %the right hemis
55 %correction
56 dnlfrontal=rmlinesc(dDFR,params,.05,'y');
57 set(gcf,'Units','pixels','Position',ssrml);

MATLAB
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Shortcuts How to Add What's New
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File Edit Text Cell Tools Debug Desktop Window Help
[Icons]
39 %after detrending
40 Ktapers=8;
41 NW=(Ktapers+1)/2;
42 params.tapers = [ NW Ktapers ];
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44 params.fpass = [ 0 params.Fs/2];
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56 dnlfrontal=rmlinesc(dDFR,params,.05,'y');
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MATLAB
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[Icons]
Shortcuts How to Add What's New
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Type 'return' when ready to continue
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Start Waiting for input
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```

Editor - h:\neuroinformatics\EcoG2005\Remove_Lines.m
File Edit Text Cell Tools Debug Desktop Window Help

39 %after detrending
40 - Ktapers=8;
41 - NW=(Ktapers+1)/2;
42 - params.tapers = [ NW Ktapers ];
43 - params.Fs=500;
44 - params.fpass = [ 0 params.Fs/2];
45 - params.pad = 5;
46 - params.err=[2 .05];
47
48 - display(['Type 'return' when ready to con
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51
52 %line removal us
53 %significant harr
54 %these may be no
55 %the right hemisp
56 %correction
57 - dnlfrontal=rmlinesc(dDFR,params,.05,'y');
58 - set(gcf,'Units','pixels','Position',ssrml);

```

MATLAB

File Edit Debug Desktop Window Help

Shortcuts How to Add What's New

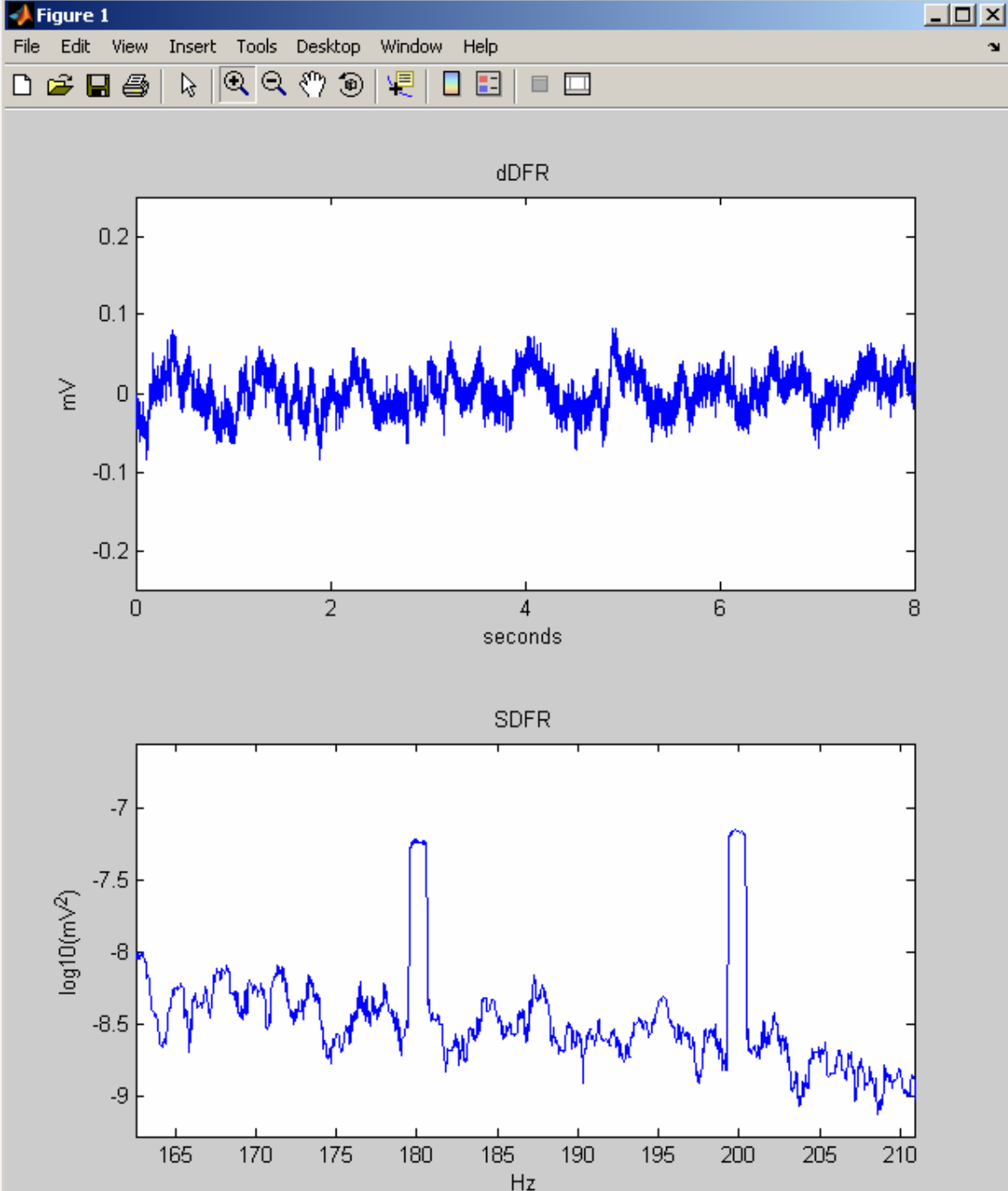
Command Window

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Current plot held
>> Remove_Lines
Type 'return' when ready to continue
K>>

```

Start Waiting for input



Line-removal from one channel, dDFR.

◆ `>> return rmlinesc(dDFR,params,.05,'y')`

◆ with parameters

- `params.tapers = [4.5 8]`
- `params.Fs = 500`
- `params.fpass = [0 params.Fs/2]`
- `params.pad = 5`

◆ Note that we will use the result of the F-test to determine which frequencies to remove (`f0` is not explicitly specified), thus we must modify the p-value to compensate for multiple comparisons across many frequencies. This is done automatically in `rmlinesc`.

```
Editor - h:\neuroInformatics\EcoG2005\Remove_Lines.m
File Edit Text Cell Tools Debug Desktop Window Help

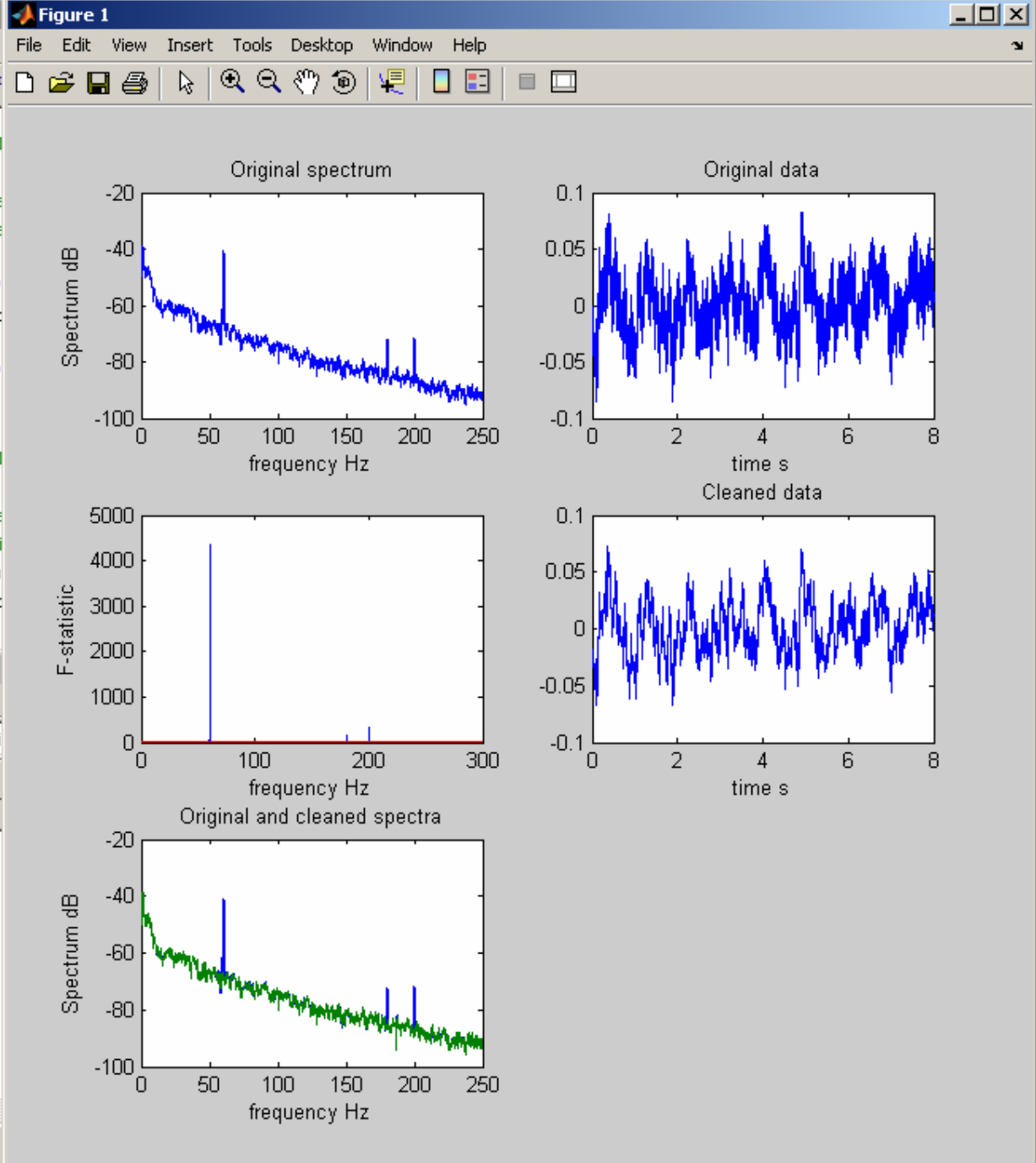
50 - close all
51         %line removal
52         %significant
53         %these may be
54         %the right he
55         %correction
56 - dnlfrontal=rmlinesc(dDFR,params,.05,'y'
57 - set(gcf,'Units','pixels','Position',ssr
58
59 - display(['Hit UPARROW or type 'return'
60 - keyboard %pause
61
62         %line removal
63         %significant
64         %significance
65         %throw out si
66 - dnlfrontal=rmlinesc(dDFR,params,.5,'y')
67 - set(gcf,'Units','pixels','Position',ssr
68

MATLAB
File Edit Debug Desktop Window Help

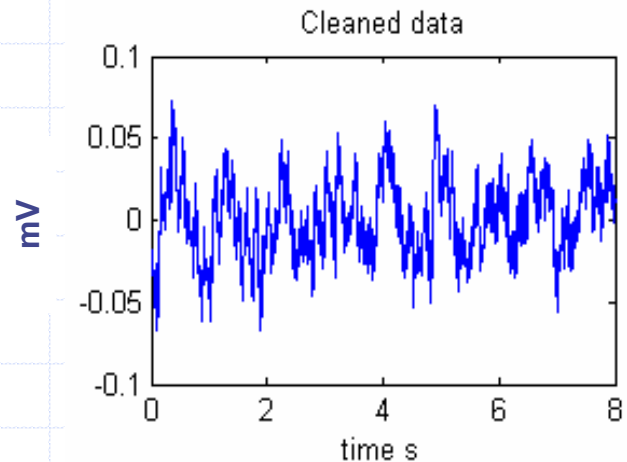
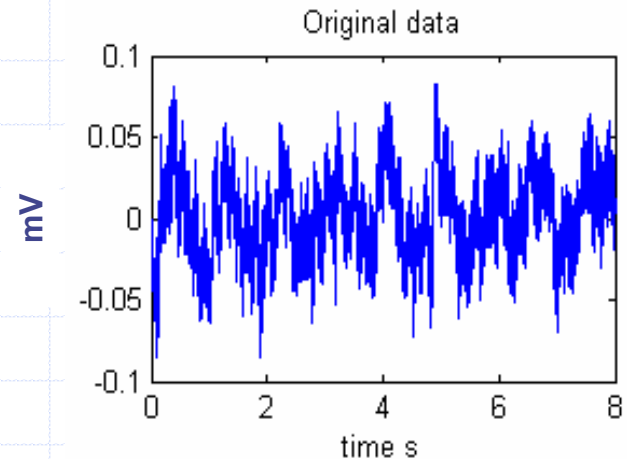
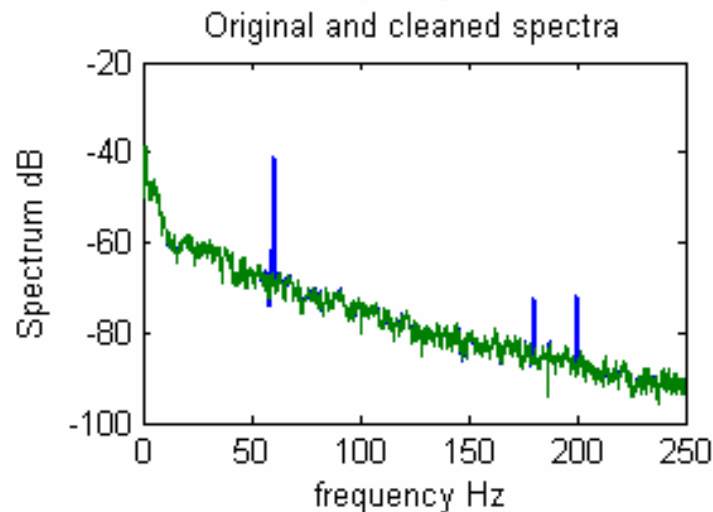
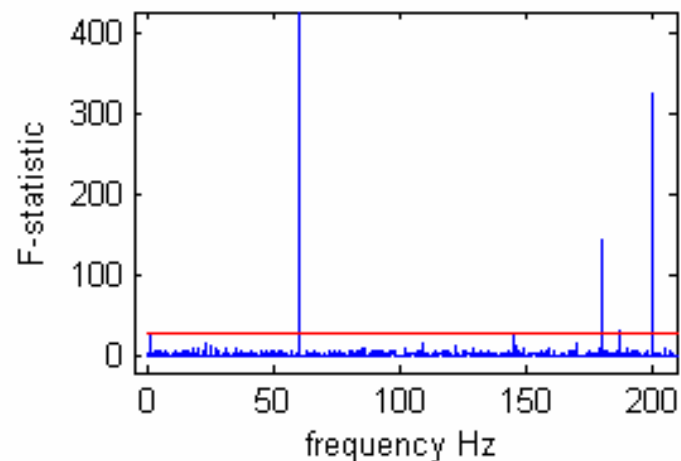
Shortcuts How to Add What's New

Command Window
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Current plot held
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Current plot held
>> Remove_Lines
Type 'return' when ready to continue
K>> return
Hit UPARROW or type 'return' when ready
K>>

Start Waiting for input
```



Relying on the F-statistic to identify line-elements requires choosing a significance level that must then be corrected for multiple comparisons. It is possible to discard physiology and keep artifact.



Editor - h:\neuroInformatics\EcoG2005\Remove_Lines.m

```
50 - close all
51         %line removal
52         %significant
53         %these may be
54         %the right he
55         %correction
56 - dnlfrontal=rmlinesc(dDFR,params,.05,'y'
57 - set(gcf,'Units','pixels','Position',ssr
58
59 - display(['Hit UPARROW or type ''return'
60 - keyboard %pause
61
62         %line removal
63         %significant
64         %significance
65         %throw out si
66 - dnlfrontal=rmlinesc(dDFR,params,.5,'y')
67 - set(gcf,'Units','pixels','Position',ssr
68
```

MATLAB

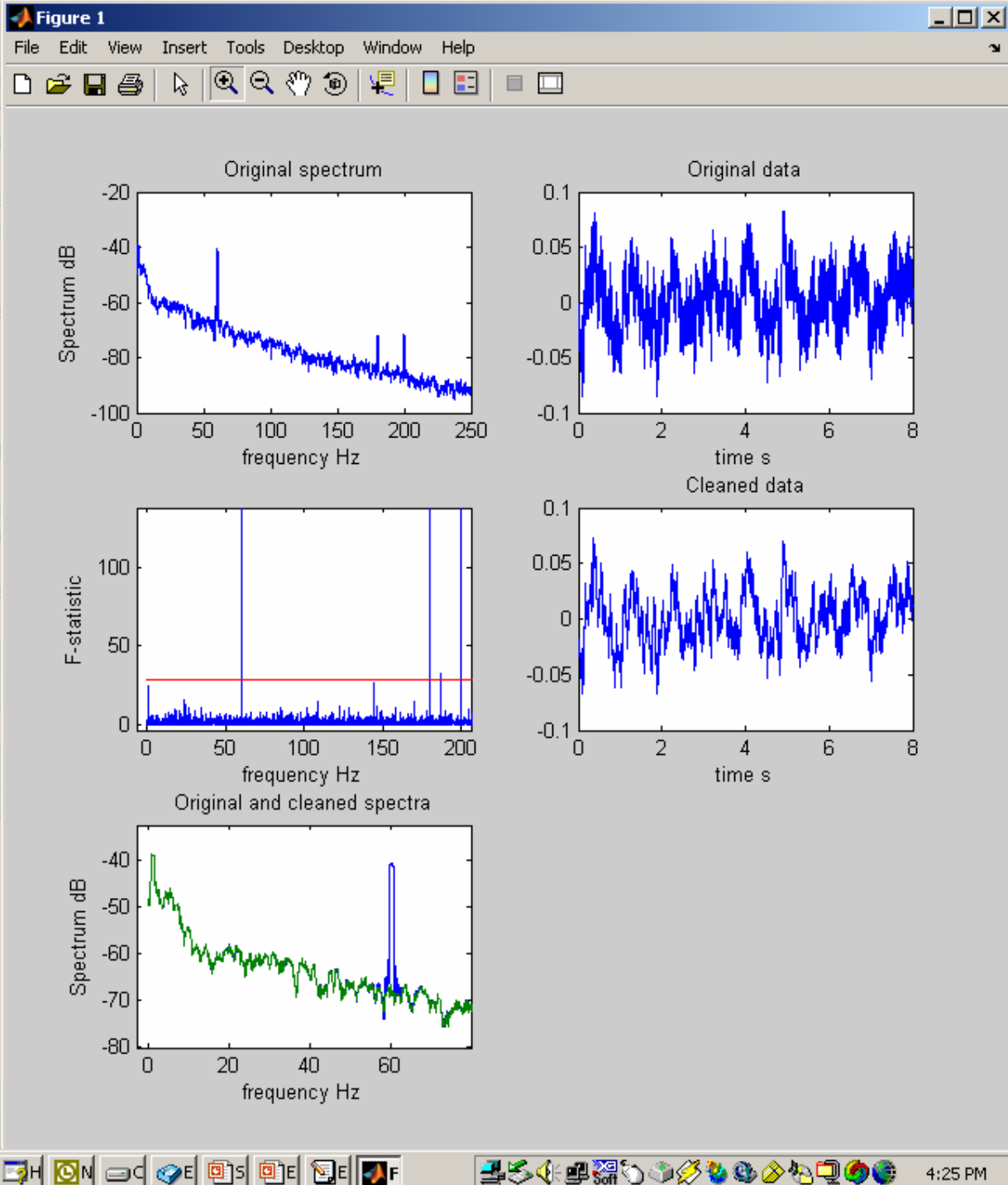
File Edit Debug Desktop Window Help

Shortcuts How to Add What's New

Command Window

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>>
Current plot held
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>> Remove_Lines
Type 'return' when ready to continue
K>> return
Hit UPARROW or type 'return' when ready
K>>
```

Start Waiting for input

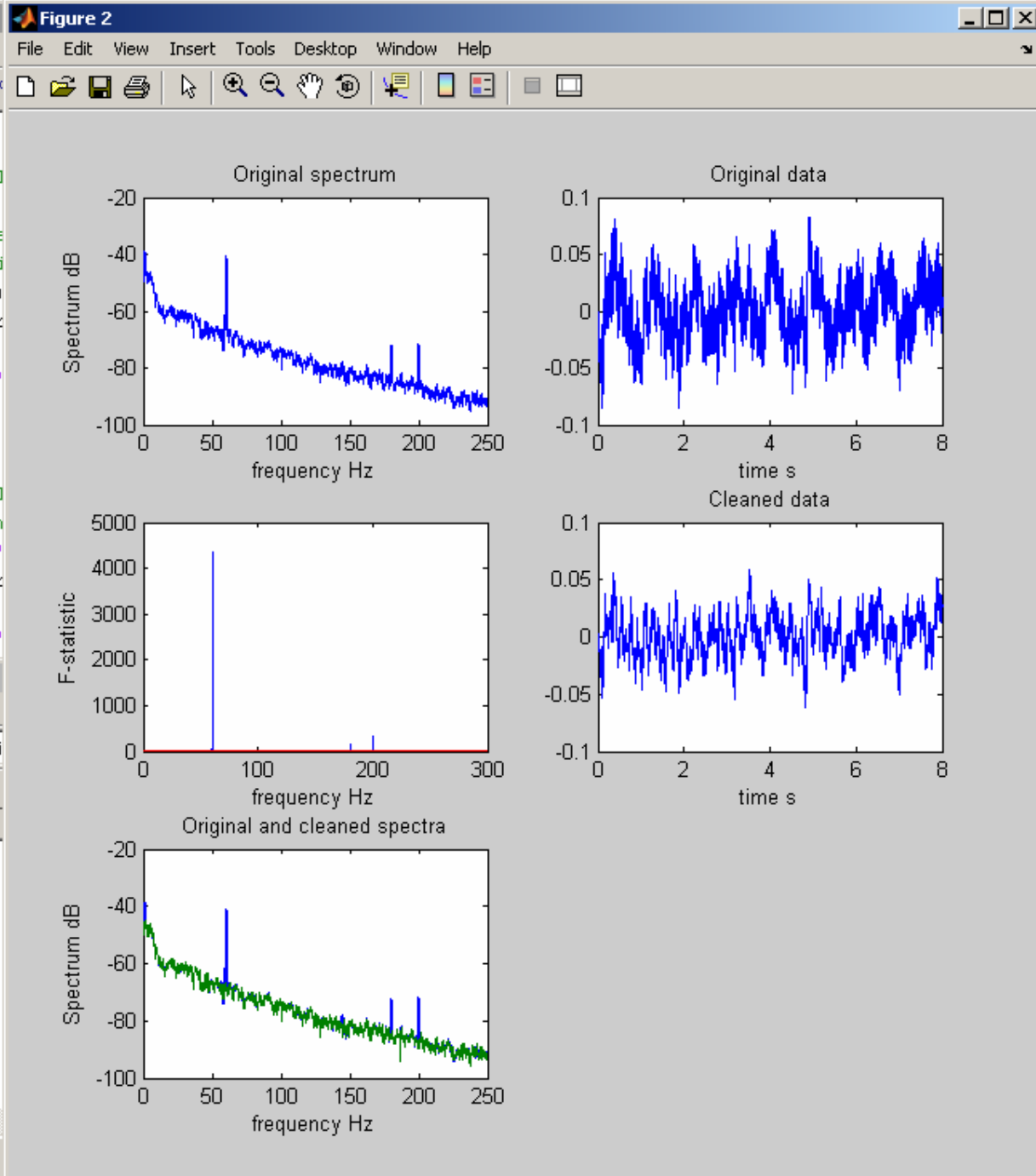


Line-removal from one channel, dDFR.

- ◆ `>> return`
- ◆ `rmlinesc(dDFR,params,.5,'y')`
- ◆ with
 - `params.tapers = [4.5 8]`
 - `params.Fs = 500`
 - `params.fpass = [0 params.Fs/2]`
 - `params.pad = 5`
- ◆ Here, an unusually low value is chosen for the F-statistic (by choosing p to be very large, 0.5).

```
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File Edit Text Cell Tools Debug Desktop Window Help
[Icons]
60 - keyboard %pause
61
62 %line removal
63 %significant
64 %significance
65 %throw out si
66 - dnlfrontal=rmlinesc(dDFR,params,.5,'y')
67 - set(gcf,'Units','pixels','Position',ssr
68
69 - display(['Hit UPARROW or type ''return'
70 - keyboard %pause
71
72 - f0=60;
73 %line removal
74 %the spectrum
75 - dnlfrontal=rmlinesc(dDFR,params,.05,'y'
76 - set(gcf,'Units','pixels','Position',ssr
77
78 - display(['Hit UPARROW or type ''return'

MATLAB
File Edit Debug Desktop Window Help
[Icons]
Shortcuts [How to Add] [What's New]
Command Window
>>
Current plot released
Current plot held
>> Remove_Lines
Type 'return' when ready to continue
K>> return
Hit UPARROW or type 'return' when ready
K>> return
Hit UPARROW or type 'return' when ready
K>>
Start Waiting for input
```



Editor - h:\neuroInformatics\EcoG2005\Remove_Lines.m

```
60 - keyboard %pause
61
62 %line removal
63 %significant
64 %significance
65 %throw out si
66 - dnlfrontal=rmlinesc(dDFR,params,.5,'y')
67 - set(gcf,'Units','pixels','Position',ssr
68
69 - display(['Hit UPARROW or type ''return''
70 - keyboard %pause
71
72 - f0=60;
73 %line removal
74 %the spectrum
75 - dnlfrontal=rmlinesc(dDFR,params,.05,'y')
76 - set(gcf,'Units','pixels','Position',ssr
77
78 - display(['Hit UPARROW or type ''return''
```

MATLAB

File Edit Debug Desktop Window Help

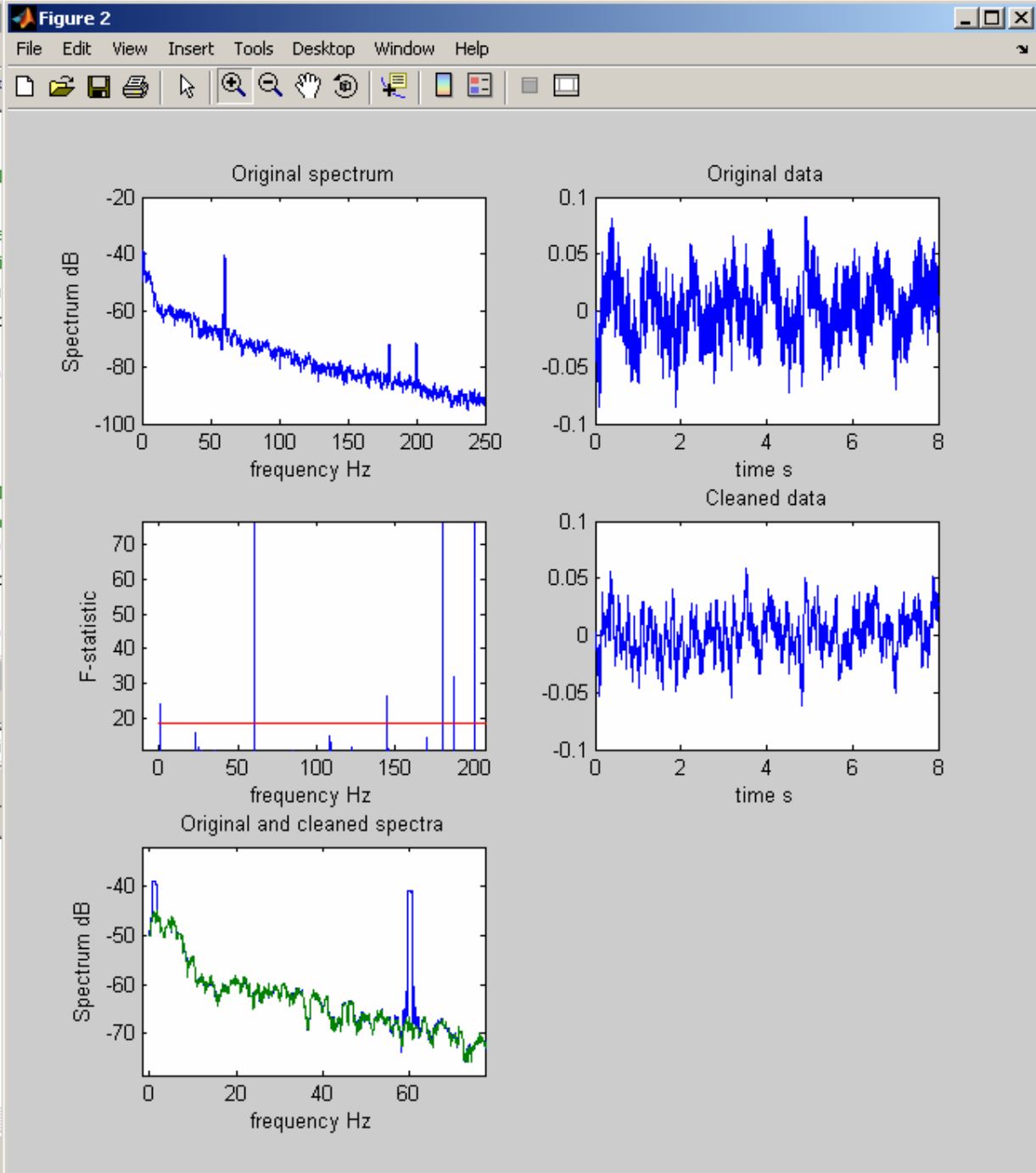
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Shortcuts How to Add What's New

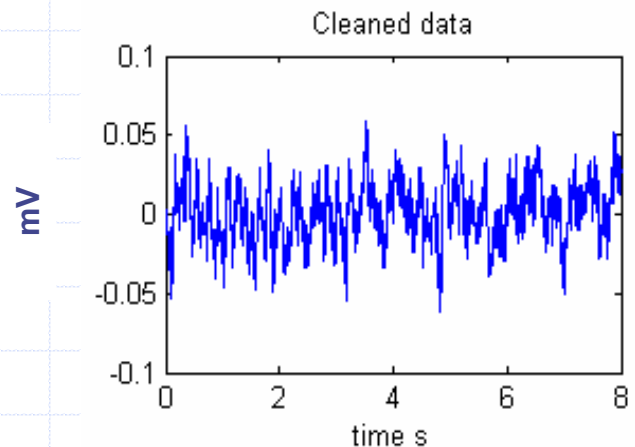
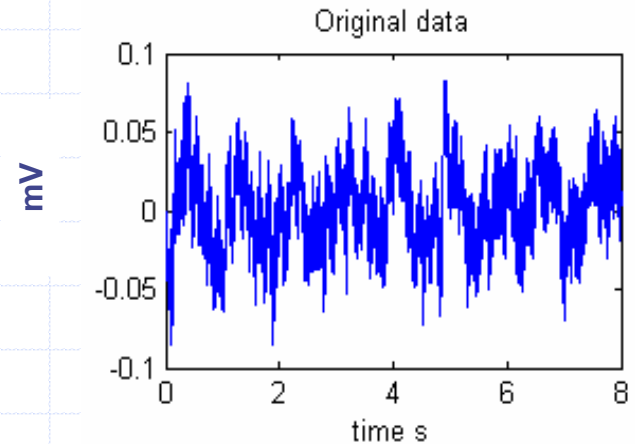
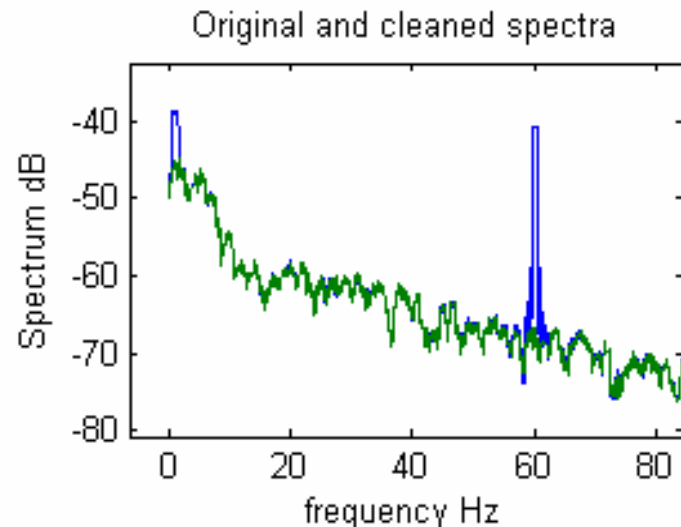
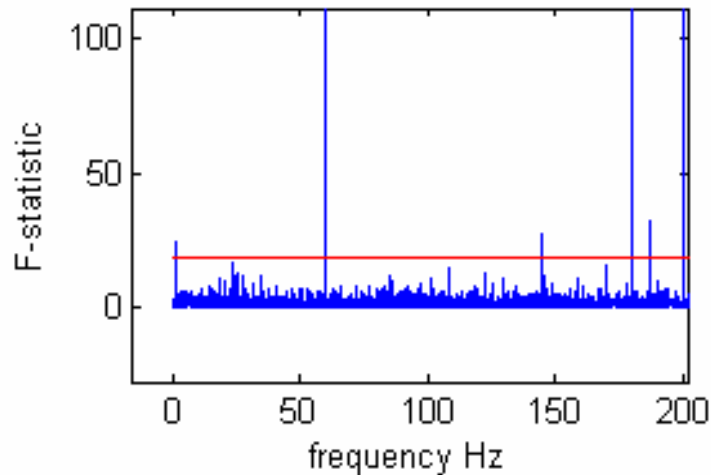
Command Window

Current plot released
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>> Remove_Lines
Type 'return' when ready to continue
K>> return
Hit UPARROW or type 'return' when ready
K>> return
Hit UPARROW or type 'return' when ready
K>>

Start Waiting for input



Relying on the F-statistic to identify line-elements requires choosing a significance level that must then be corrected for multiple comparisons. It is possible to discard physiology and keep artifact.



Line-removal from one channel, dDFR.

◆ `>> return`

◆ `rmlinesc(dDFR,params,.05,'y',f0)`

◆ with

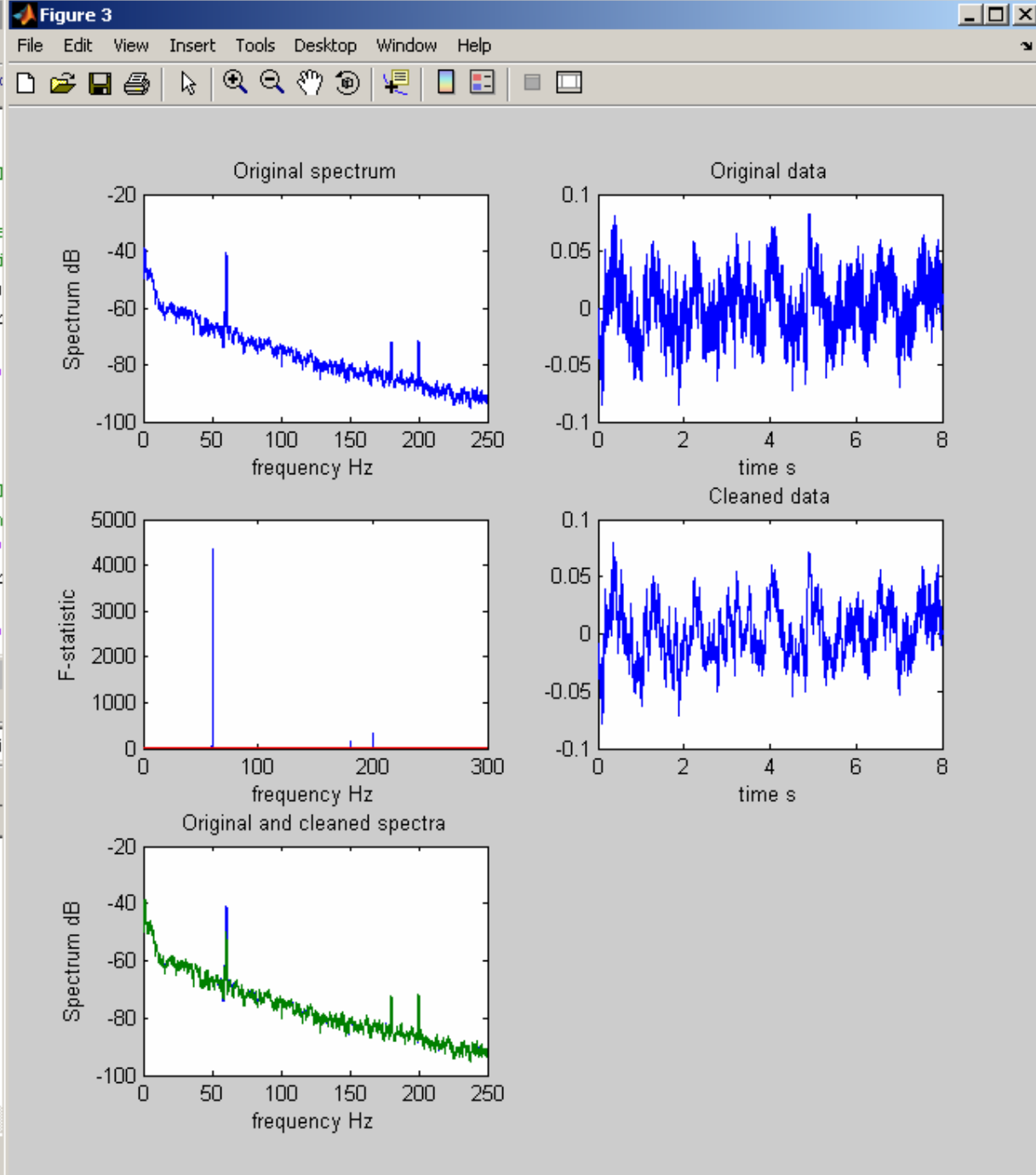
- `f0 = 60 Hz`
- `params.tapers = [2.5 4]`
- `params.Fs = 500`
- `params.fpass = [0 params.Fs/2]`
- `params.pad = 5`

◆ Here a single frequency is examined, so p-value = 0.05. No correction is made for multiple comparisons.


```
Editor - h:\neuroInformatics\EcoG2005\Remove_Lines.m
File Edit Text Cell Tools Debug Desktop Window Help
[Icons]
60 - keyboard %pause
61
62 %line removal
63 %significant
64 %significance
65 %throw out si
66 - dnlfrontal=rmlinesc(dDFR,params,.5,'y')
67 - set(gcf,'Units','pixels','Position',ssr
68
69 - display(['Hit UPARROW or type ''return'
70 - keyboard %pause
71
72 - f0=60;
73 %line removal
74 %the spectrum
75 - dnlfrontal=rmlinesc(dDFR,params,.05,'y'
76 - set(gcf,'Units','pixels','Position',ssr
77
78 - display(['Hit UPARROW or type ''return'

MATLAB
File Edit Debug Desktop Window Help
[Icons]
Shortcuts How to Add What's New

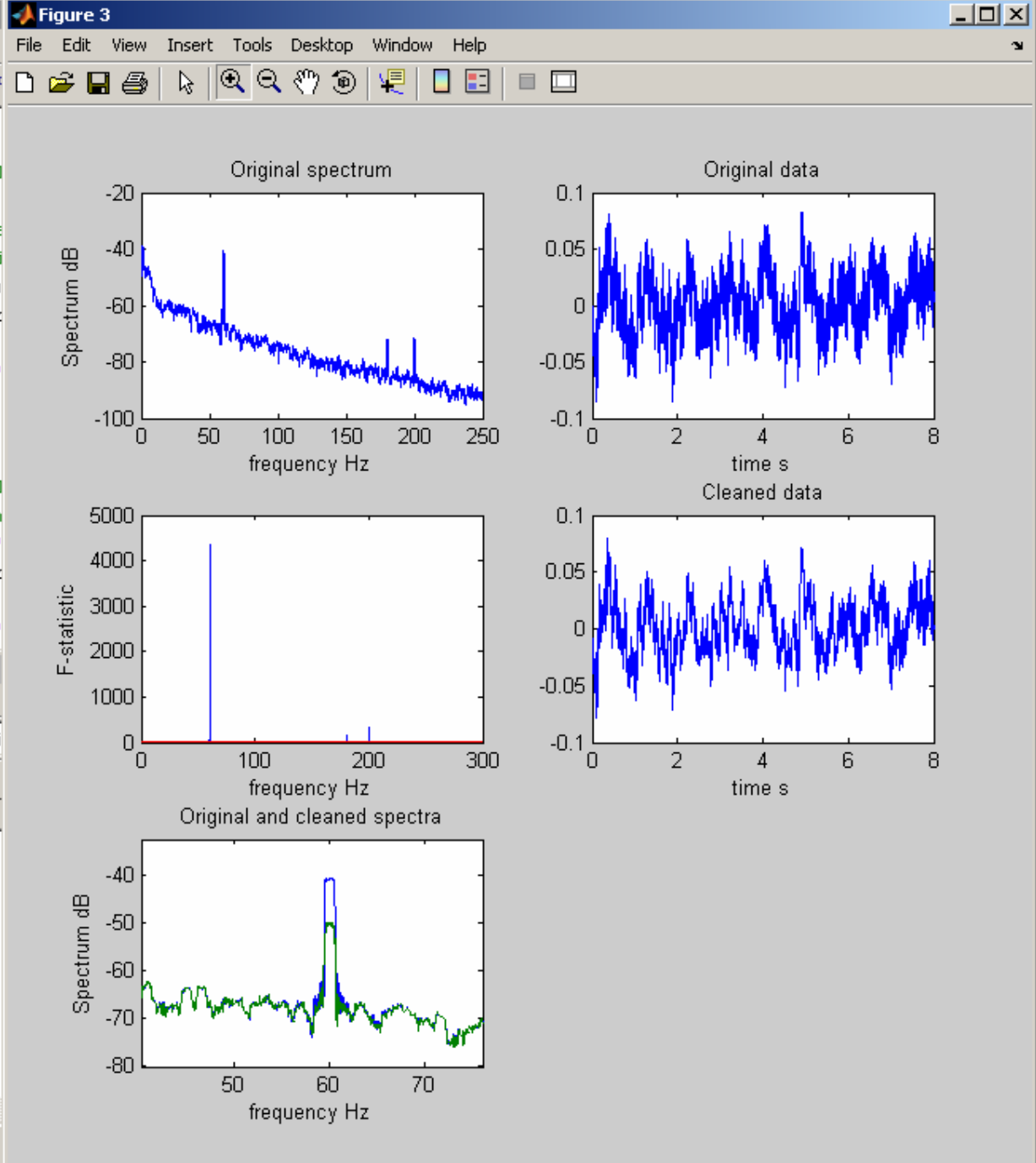
Command Window
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K>> return
Hit UPARROW or type 'return' when ready
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Start Waiting for input
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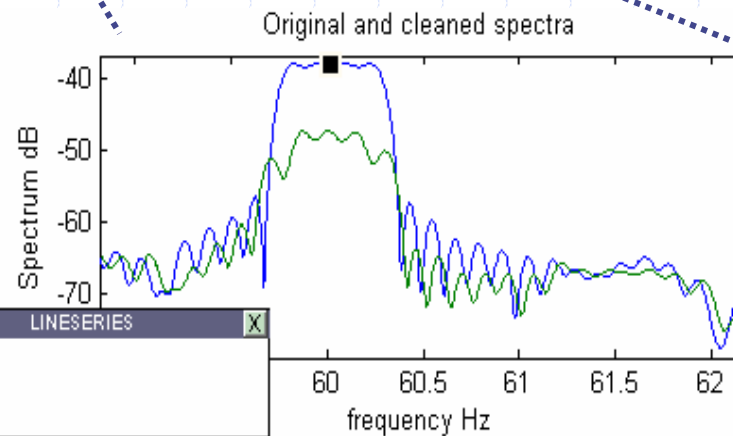
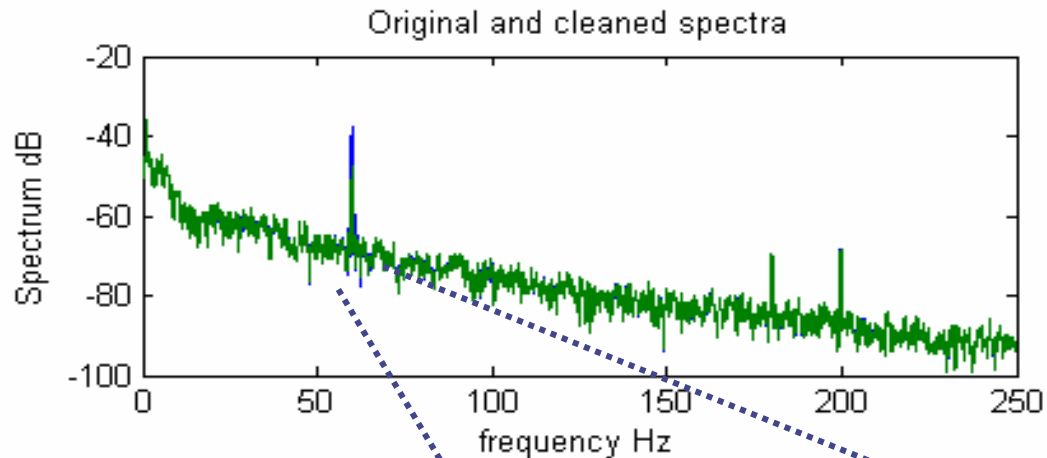


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File Edit Text Cell Tools Debug Desktop Window Help
[Icons]
60 - keyboard %pause
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62 %line removal
63 %significant
64 %significance
65 %throw out si
66 - dnlfrontal=rmlinesc(dDFR,params,.5,'y')
67 set(gcf,'Units','pixels','Position',ssr
68
69 display(['Hit UPARROW or type ''return''
70 keyboard %pause
71
72 f0=60;
73 %line removal
74 %the spectrum
75 - dnlfrontal=rmlinesc(dDFR,params,.05,'y')
76 set(gcf,'Units','pixels','Position',ssr
77
78 display(['Hit UPARROW or type ''return''

MATLAB
File Edit Debug Desktop Window Help
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Shortcuts [How to Add] [What's New]

Command Window
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K>>
Start Waiting for input
```





The “60 Hz” line noise is actually at 60.025 Hz. Set $f_0 = 60.025$, and to catch the third harmonic, set f_0 to $60.025 * 3 = 180.075$.

Line-removal from one channel, dDFR.

◆ >> return

◆ cleanDFR1=
rmlinesc(dDFR,params,.05,'y',f0)

◆ with

■ **f0 = 60.025**

◆ Then, cleanDFR2=
rmlinesc(cleanDFR1,params,.05,'y',f0)

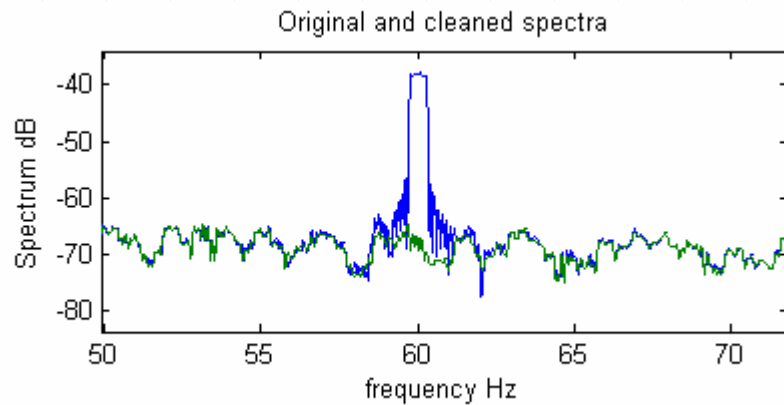
◆ with

■ **f0 = 180.075**

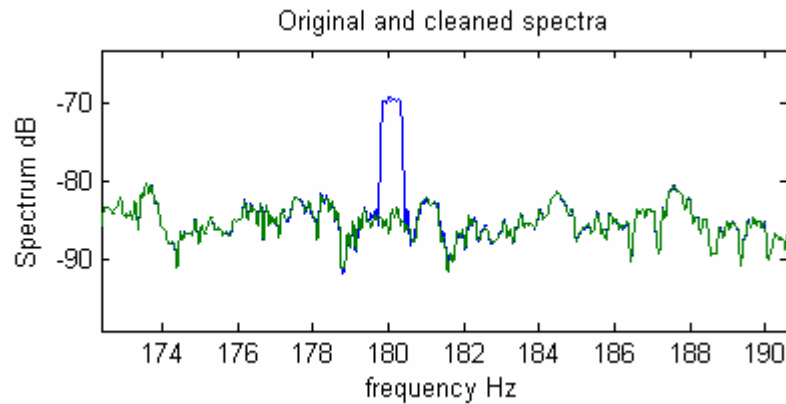
◆ Then, cleanDFR3=
rmlinesc(cleanDFR2,params,.05,'y',f0)

◆ with

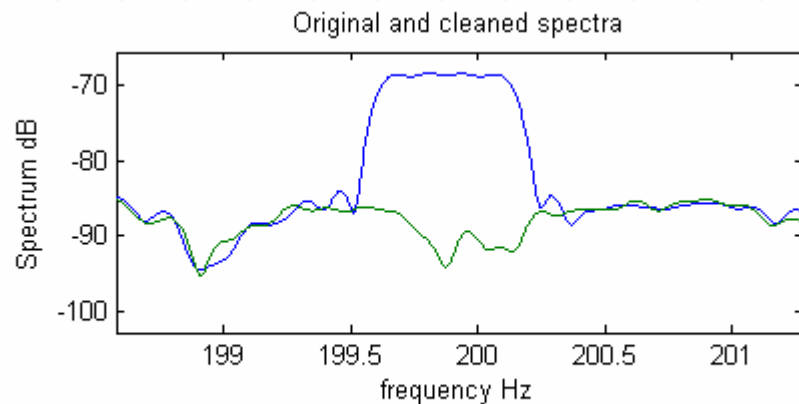
■ **f0 = 199.88**



$$f_0 = 60.025$$



$$f_0 = 180.075$$

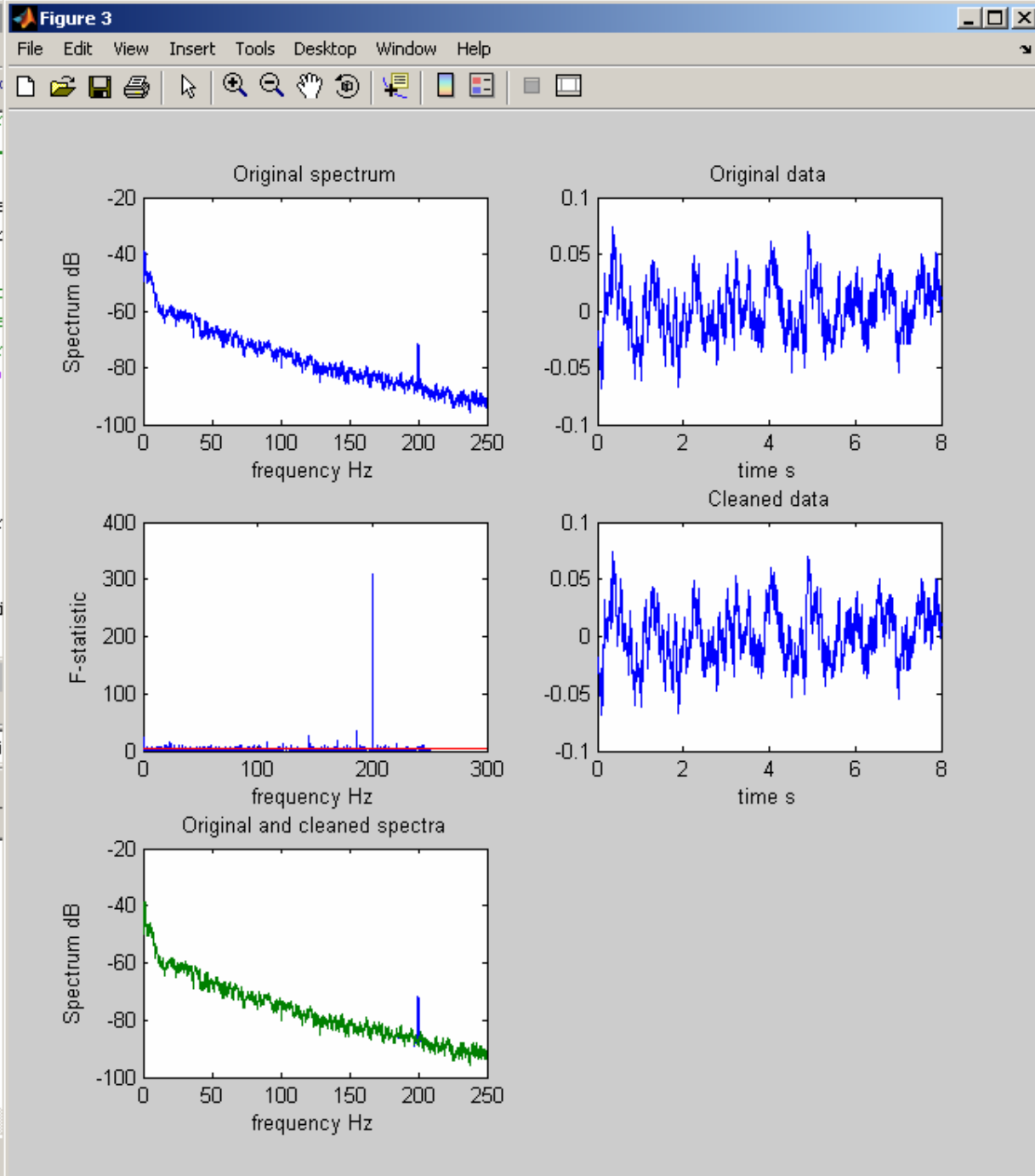


$$f_0 = 199.88$$

Blue = original spectra

Green = cleaned spectra

```
Editor - h:\neuroInformatics\EcoG2005\Remove_Lines.m
File Edit Text Cell Tools Debug Desktop Window Help
[Icons]
101 %output of the
102 %60.025, 180.
103 %the output.
104 - dnlfrontal3=rmlinesc(dnlfrontal2,params
105 - set(gcf,'Units','pixels','Position',ssr
106
107 %show the set
108 %the right he
109 %clean DFR ch
110 - display(['Hit UPARROW or type ''return''
111 - keyboard
112
113 - figure
114
115 - [nolineSDFR,f,Serr]=mtspectrumc(dnlfron
116 - subplot(2,1,1); plot(f,log10(SDFR));
117 - set(gca,'XLim',[0 params.Fs/2]);
118 - xlabel('Hz'); ylabel('log10(mV^2)'); ti
119
MATLAB
File Edit Debug Desktop Window Help
[Icons]
Shortcuts [How to Add] [What's New]
Command Window
K>> return
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Hit UPARROW or type 'return' when ready
K>> return
Hit UPARROW or type 'return' when ready
K>>
Start Waiting for input
```




```
Editor - h:\neuroInformatics\EcoG2005\Remove_Lines.m
File Edit Text Cell Tools Debug Desktop Window Help
[Icons]
122 - xlabel('Hz'); ylabel('log10(mV^2)'); title('SDFR');
123 - set(gcf,'Units','pixels','Position',[100 100 800 600]);
124
125 % generate figure
126 % Right Hemisphere
127 % compares spectra
128 % successive
129 % after detrending
130
131 display(['Hit UPARROW or type ''return'' to continue']);
132 keyboard
133 close all
134 %line removal
135 %the spectrum
136 %params.pad =
137 %used in the
138
139 params.pad=1;
140 f0=60.025;
141 dnlfrontal=rmlinesc(dDFR,params,.05,'y')
```

MATLAB

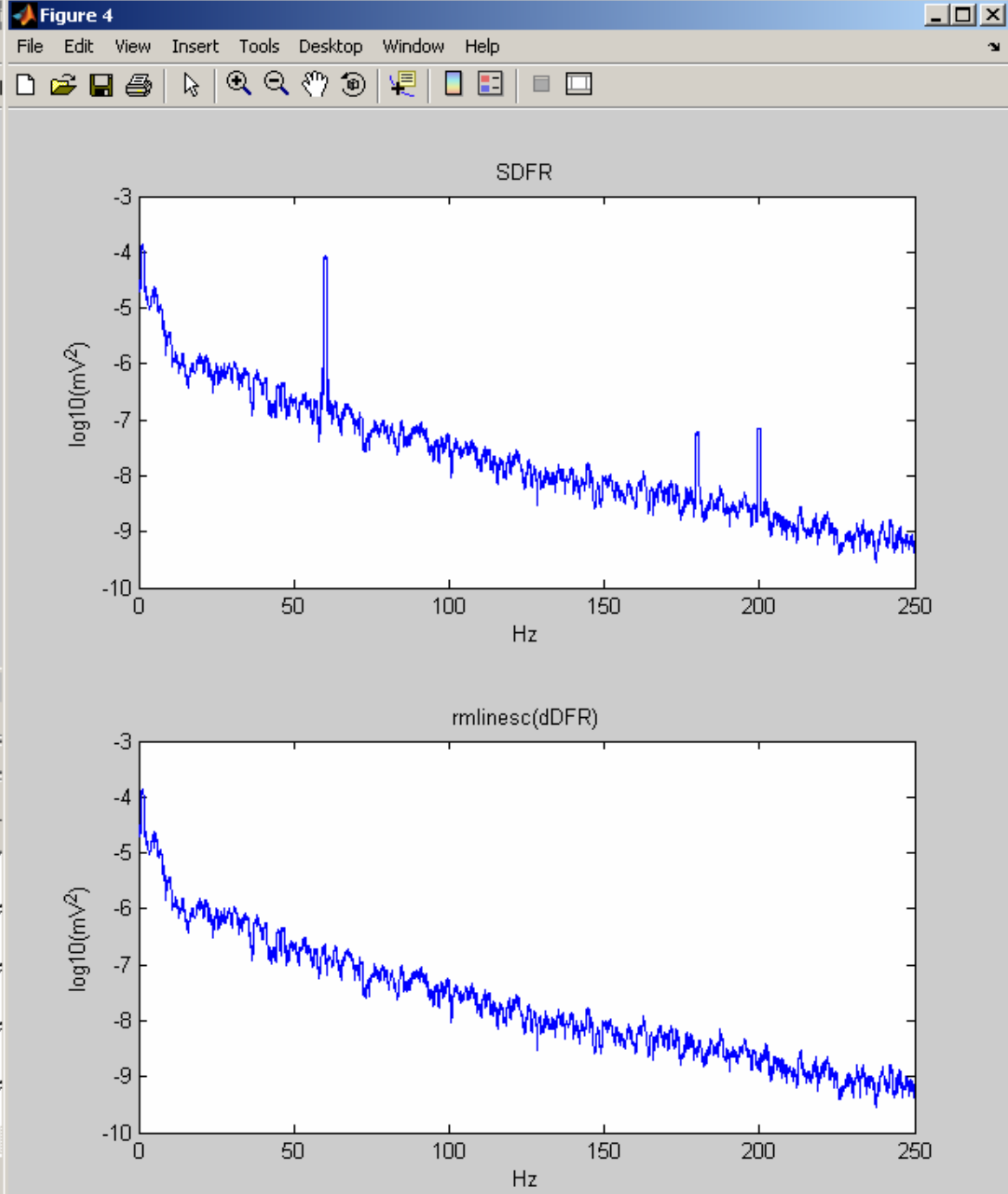
File Edit Debug Desktop Window Help

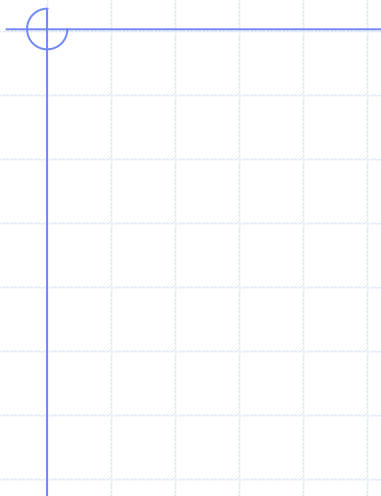
Shortcuts [?] How to Add [?] What's New

Command Window

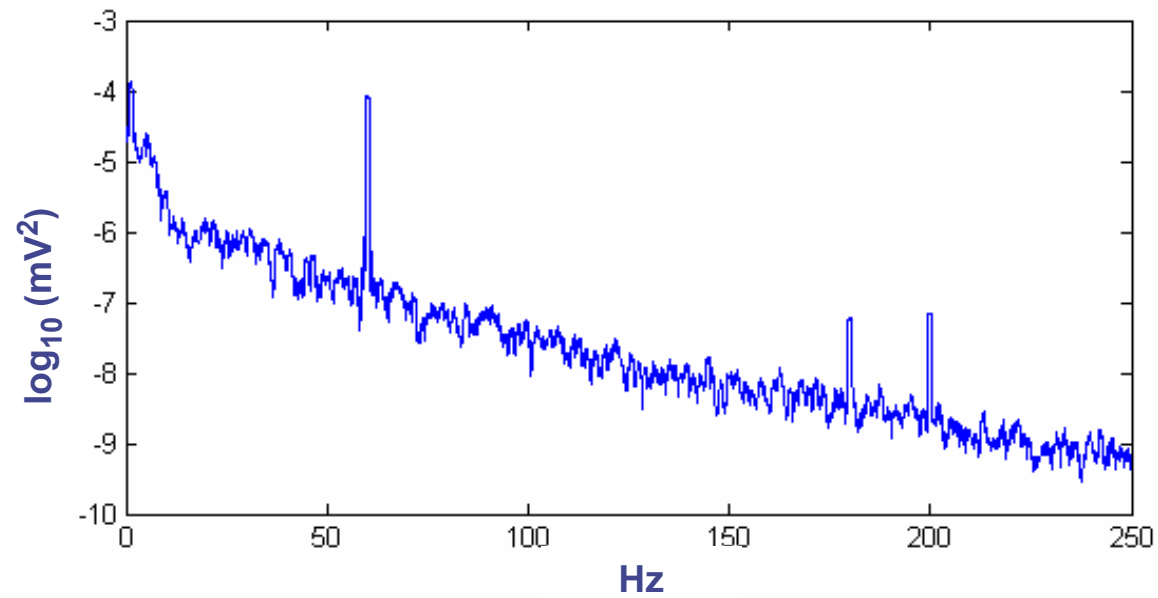
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Hit UPARROW or type 'return' when ready to continue
K>> return
Hit UPARROW or type 'return' when ready to continue
K>> return
Hit UPARROW or type 'return' when ready to continue
K>> return
Hit UPARROW or type 'return' when ready to continue
K>>
```

Start Waiting for input

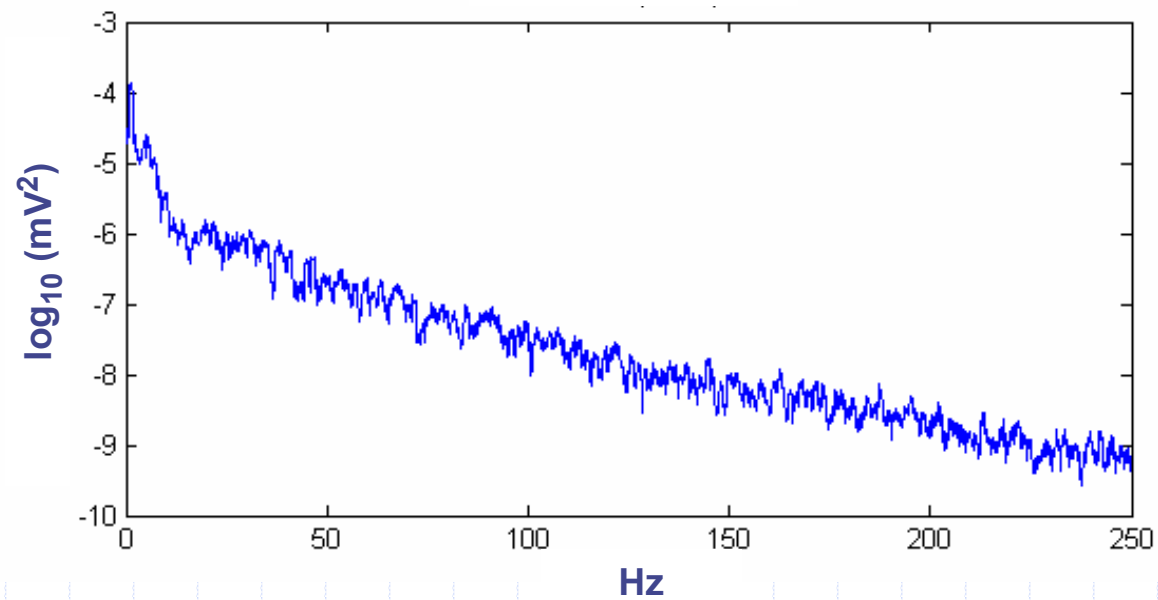




SDFR



rmlinesc(dDFR)



```
Editor - h:\neuroInformatics\EcoG2005\Remove_Lines.m
File Edit Text Cell Tools Debug Desktop Window Help
[Icons]
122 - xlabel('Hz'); ylabel('log10(mV^2)'); title('Original spectrum');
123 - set(gcf,'Units','pixels','Position',[100 100 500 500]);
124
125 % generate figure
126 % Right Hemisphere
127 % compares spectra
128 % successive
129 % after detrending
130
131 display(['Hit UPARROW or type ''return'' to continue']);
132 keyboard
133 close all
134
135 %line removal
136 %the spectrum
137 %params.pad =
138 %used in the
139
140 params.pad=1;
141 f0=60.025;
142 dnlfrontal=rmlinesc(dDFR,params,.05,'y')
```

MATLAB

File Edit Debug Desktop Window Help

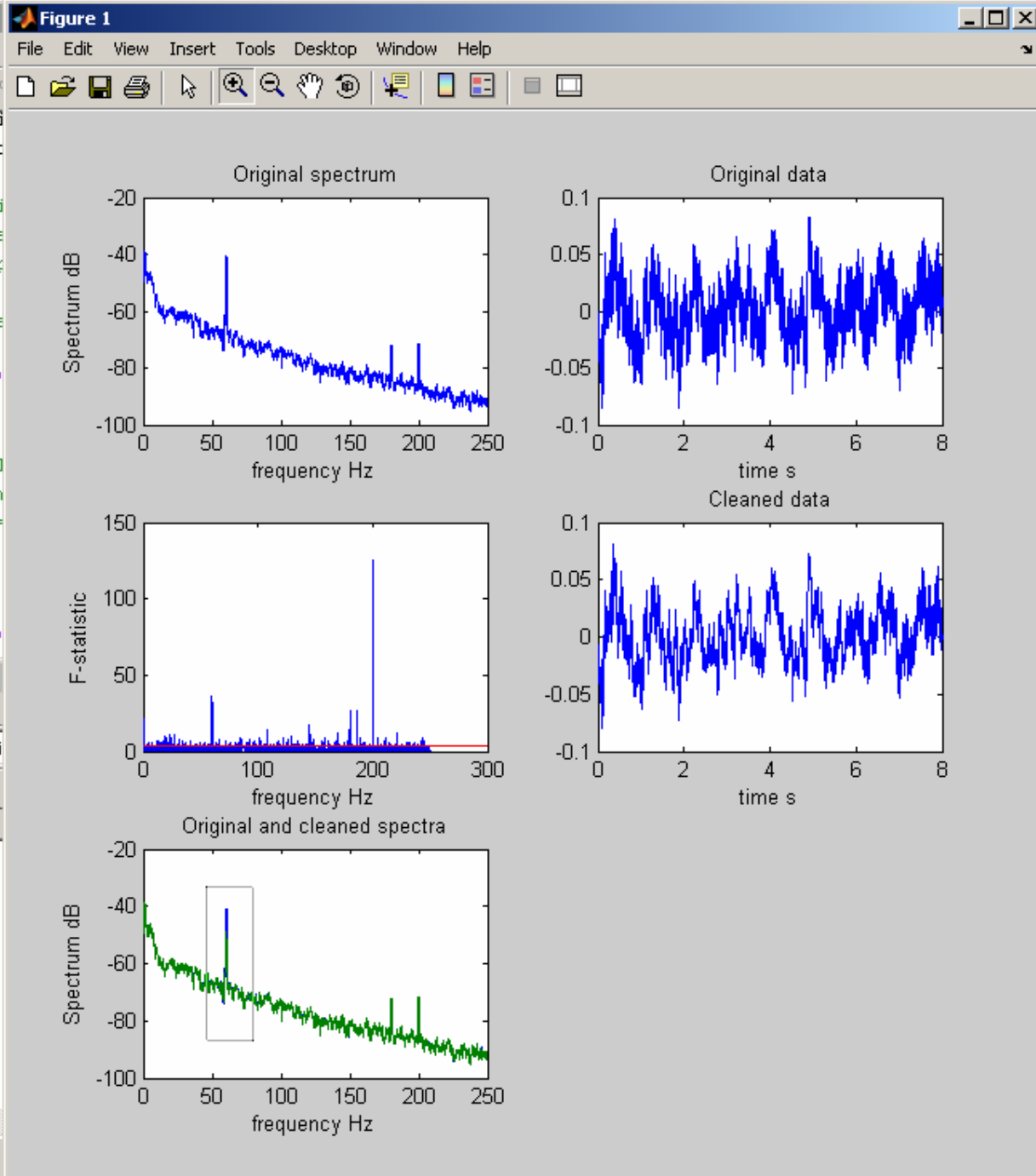
[Icons]

Shortcuts [?] How to Add [?] What's New

Command Window

```
>> Hit UPARROW or type 'return' when ready
K>> return
Hit UPARROW or type 'return' when ready
K>> return
Hit UPARROW or type 'return' when ready
K>> return
Hit UPARROW or type 'return' when ready
K>> return
>>
```

Start



Editor - h:\neuroinformatics\EcoG2005\Remove_Lines.m

```
122 - xlabel('Hz'); ylabel('log10(mV^2)'); title('log10(mV^2) vs frequency Hz');
123 - set(gcf,'Units','pixels','Position',sscanf('100 100 400 400'));
124 -
125 - % generate figure
126 - % Right Hemisphere
127 - % compares spectra
128 - % successive
129 - % after detrending
130 -
131 - display(['Hit UPARROW or type ''return'' to continue'])
132 - keyboard
133 - close all
134 -
135 - %line removal
136 - %the spectrum
137 - %params.pad =
138 - %used in the
139 -
140 - params.pad=1;
141 - f0=60.025;
142 - dnlfrontal=rmlinesc(dDFR,params,.05,'y')
```

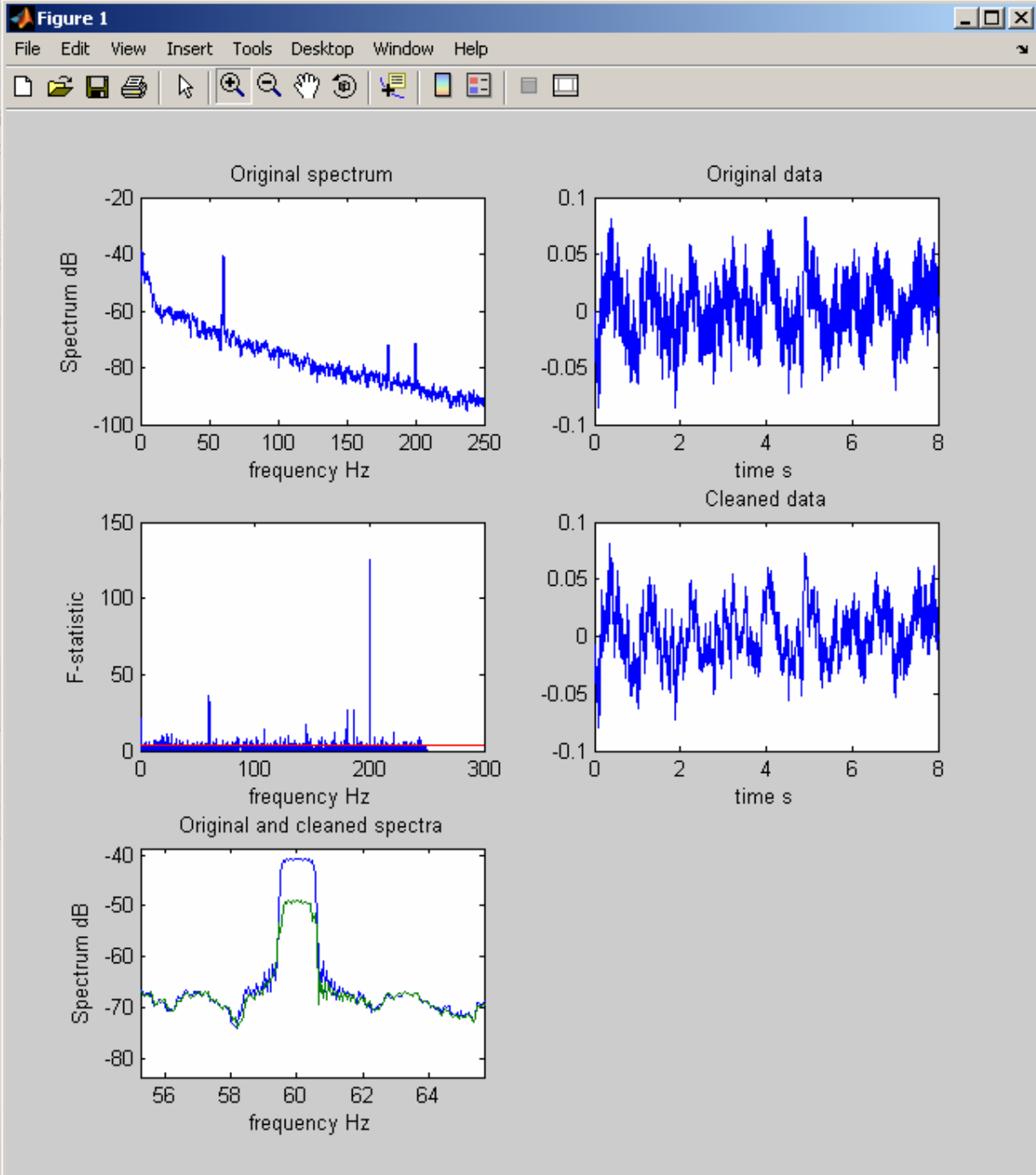
MATLAB

File Edit Debug Desktop Window Help

Shortcuts How to Add What's New

Command Window

```
>>
Hit UPARROW or type 'return' when ready
K>> return
Hit UPARROW or type 'return' when ready
K>> return
Hit UPARROW or type 'return' when ready
K>> return
Hit UPARROW or type 'return' when ready
K>> return
>>
```



Line-removal from one channel, dDFR.

◆ `>> return`

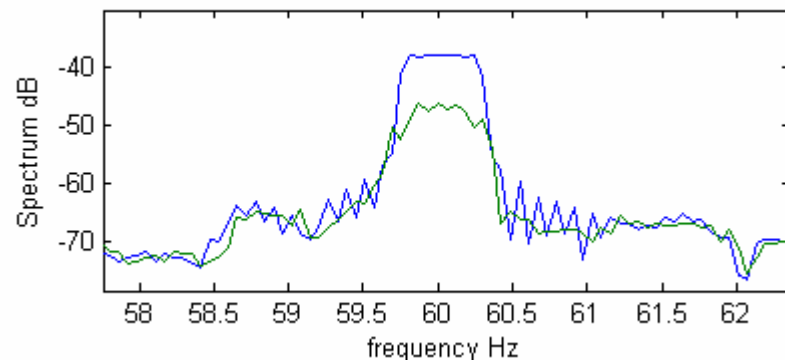
◆ `cleanDFR=`
`rmlinesc(dDFR,params,.05,'y',f0)`

◆ `with`

■ `f0 = 60.025`

◆ But now with `params.pad = 1`, instead of `params.pad = 5`.

Original and cleaned spectra



Pad factor controls the amount of zero-padding that is done when calculating the FFT. A higher pad value computes the FFT on a finer frequency grid. If the grid is not of sufficient resolution it is difficult to isolate line elements in the spectra.

Alternative Approach for Signal Conditioning

- ◆ Combine SVD with spectral analysis
 - ◆ Look for the subspace that does not contain noise and major artifacts
 - ◆ Reconstruct a set of signals from the subspace for further analysis
-
- ◆ >>DeNoise_SVD


```
Editor - h:\neuroinformatics\EcoG2005\Remove_Line.m
File Edit Text Cell Tools Debug Desktop Window Help
122 - xlabel('Hz'); ylabel('log10(mV^2)'); title('Original spectrum');
123 - set(gcf,'Units','pixels','Position',[100 100 500 500]);
124 -
125 - % generate figure
126 - % Right Hemisphere
127 - % compares spectra
128 - % successive
129 - % after detrending
130 -
131 - display(['Hit UPARROW or type ''return'' to continue']);
132 - keyboard
133 - close all
134 -
135 - %line removal
136 - %the spectrum
137 - %params.pad =
138 - %used in the
139 -
140 - params.pad=1;
141 - f0=60.025;
142 - dnlfrontal=rmlinesc(dDFR,params,.05,'y');
```

MATLAB

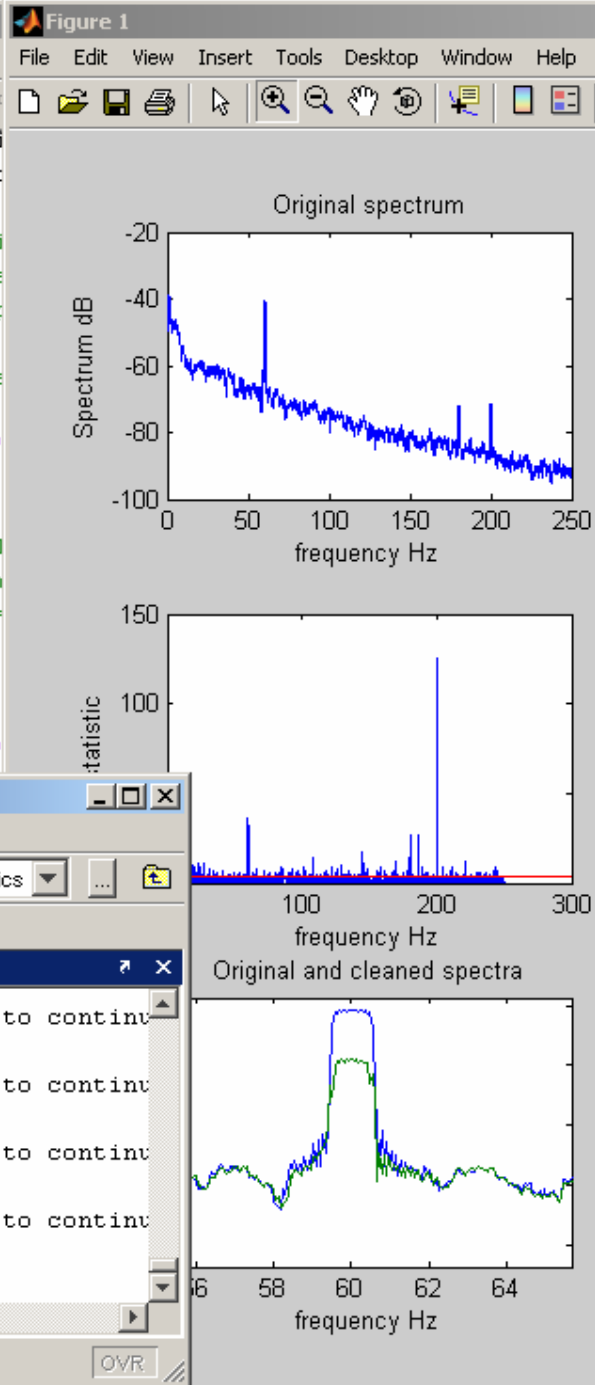
File Edit Debug Desktop Window Help

h:\neuroinformatics

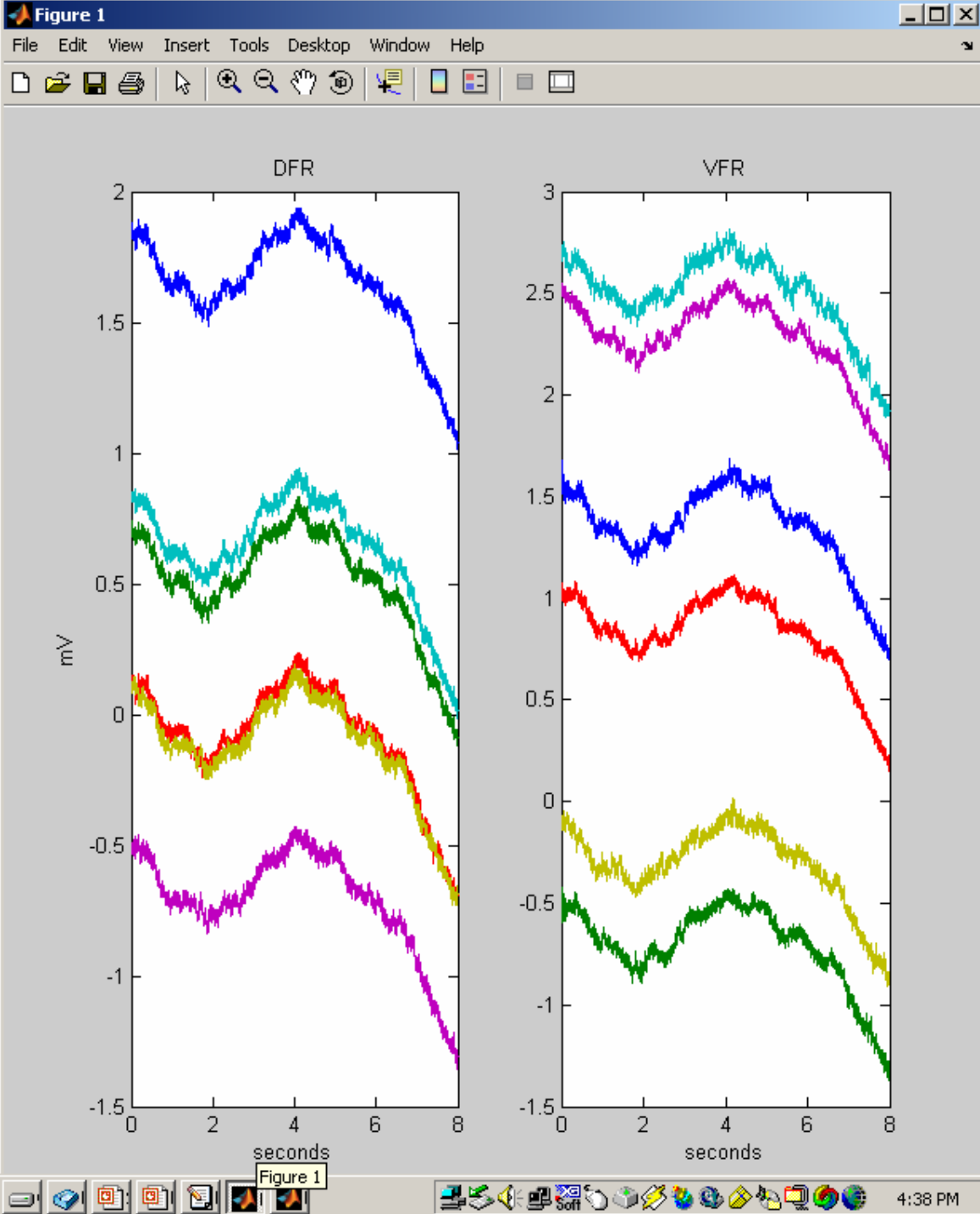
Shortcuts How to Add What's New

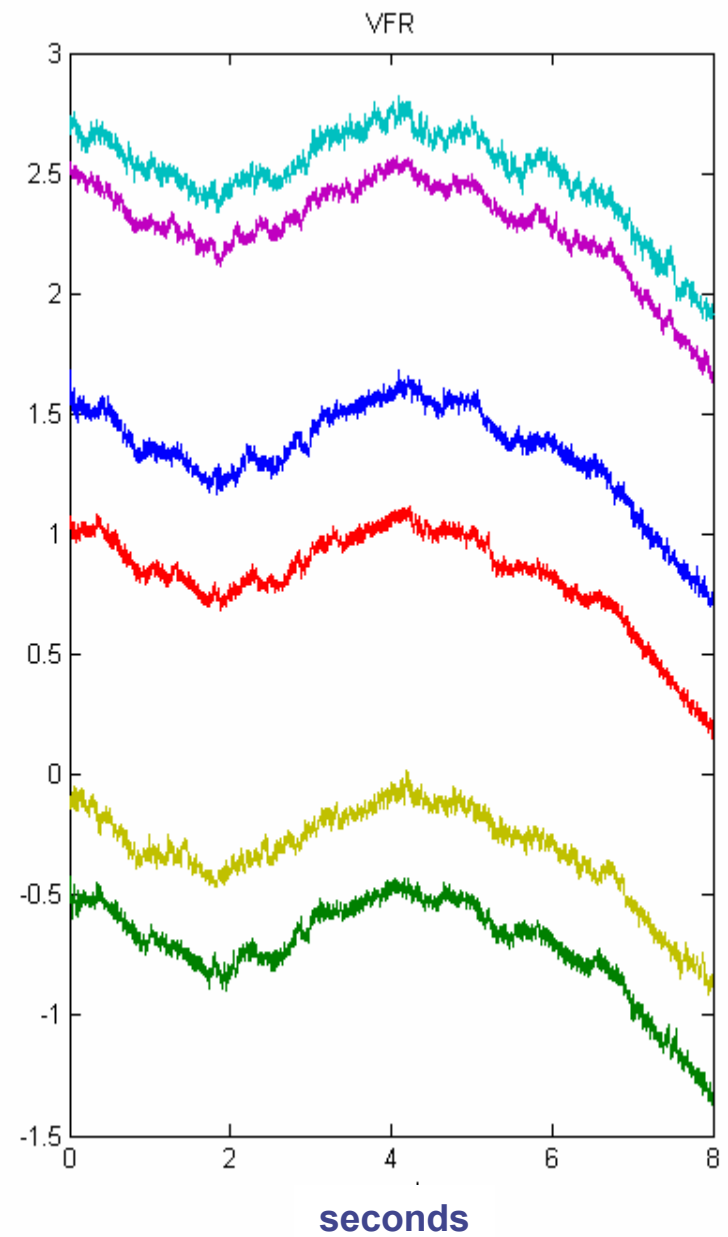
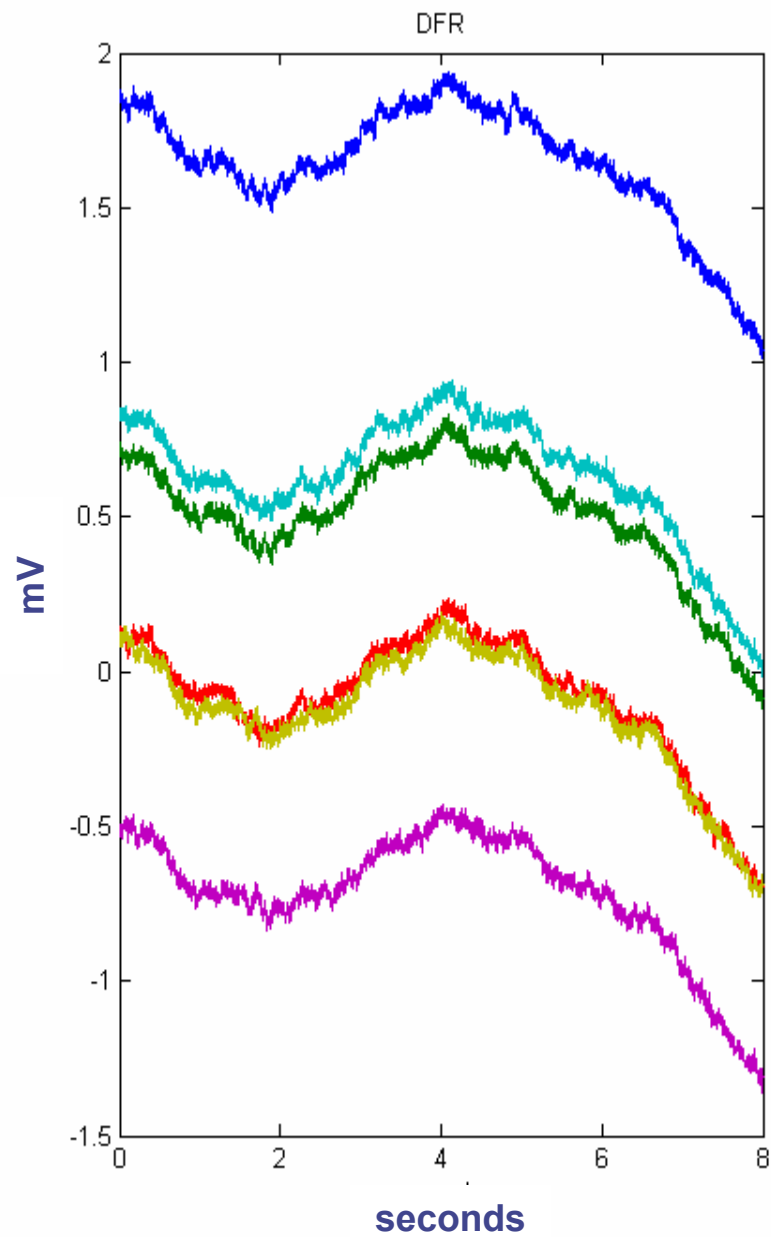
Command Window

```
>> Hit UPARROW or type 'return' when ready to continue
K>> return
Hit UPARROW or type 'return' when ready to continue
K>> return
Hit UPARROW or type 'return' when ready to continue
K>> return
Hit UPARROW or type 'return' when ready to continue
K>> return
>> DeNoiseSVD
```



```
Editor - h:\neuroInformatics\EcoG2005\DeNoiseSVD.m
File Edit Text Cell Tools Debug Desktop Window Help
[Icons]
52 - hold
53 - plot(log10(diag(FS)), '*')
54 - ylabel('log10'); xlabel('row in S');
55 - title('Singular values for svd of FrontalR')
56 - set(gcf, 'Units', 'pixels', 'Position', sschop)
57 - h2=gcf;
58
59 - figure(h1);
60
61 - display(['Type ''return'' when ready to con
62 - keyboard %pause
63
64 %generate t
65 %of the ter
66
67 Ktapers=20;
68 NW=(Ktapers+1)/2;
69 params.tapers=[NW Ktapers];
70 params.Fs=500;
71 params.fpass=[0 params.Fs/2];
72 params.pad=4;
73 params.err=[2 .05];
EcoG.m Remove_Lines.m DeNoiseSVD.m
Shortcuts How to Add What's New
Command Window
K>> return
Hit UPARROW or type 'return' when ready to c
K>> return
Hit UPARROW or type 'return' when ready to c
K>> return
>> DeNoiseSVD
Current plot held
Type 'return' when ready to continue
K>>
Start Waiting for input
```



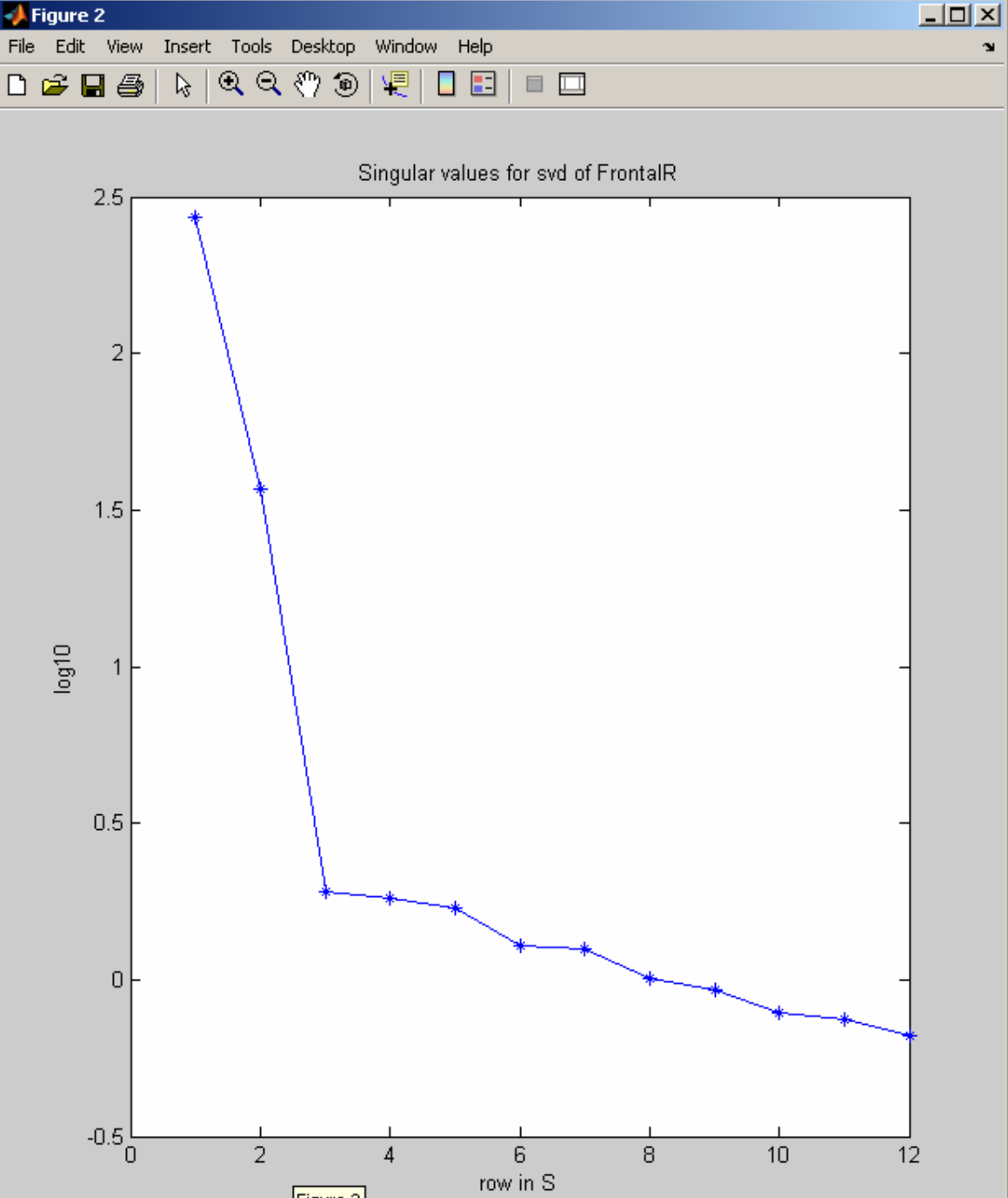


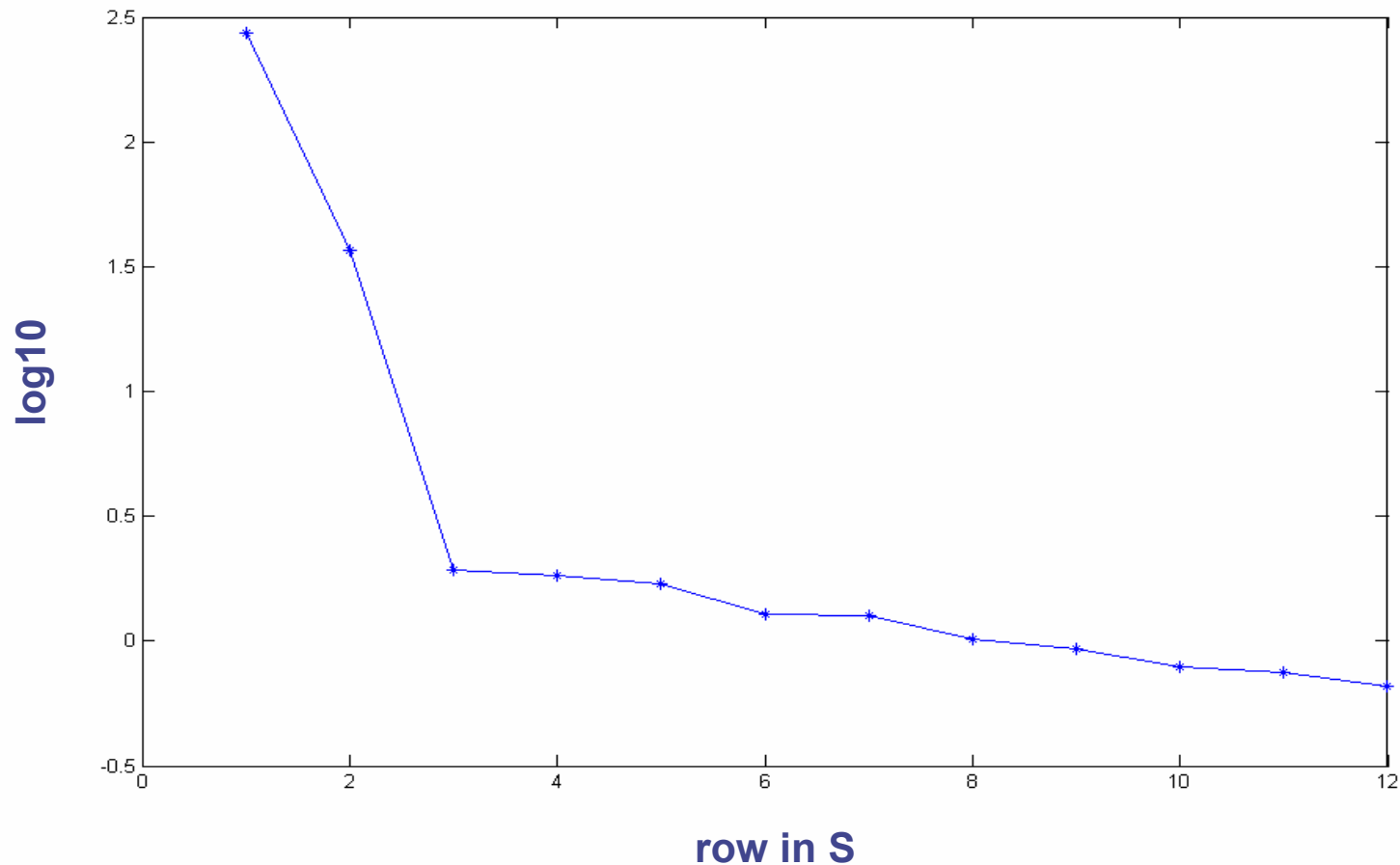
FrontalR = [DFR(:,1:6) VFR(:,1:6)]

Multivariate analysis

- ◆ FrontalR is a rectangular matrix, 4000 rows (times samples) x 12 columns (recording channels)
- ◆ in MATLAB, we can produce a factorization of this matrix by singular value decomposition with:
 - `[U,S,V] = svd(FrontalR,0);`
 - ◆ Columns in U are the temporal modes of FrontalR
 - ◆ Columns in V are the “spatial” modes of FrontalR
 - ◆ `diag(S)` gives the singular values of FrontalR
 - ◆ “economy size” decomposition
- ◆ `>> return`

```
Editor - h:\neuroInformatics\EcoG2005\DeNoiseSVD.m
File Edit Text Cell Tools Debug Desktop Window Help
52 - hold
53 - plot(log10(diag(FS)), '*')
54 - ylabel('log10'); xlabel('row in S');
55 - title('Singular values for svd of FrontalR')
56 - set(gcf, 'Units', 'pixels', 'Position', sschop)
57 - h2=gcf;
58
59 - figure(h1);
60
61 - display(['Type 'return' when ready to con
62 - keyboard %pause
63
64 %generate t
65 %of the ter
66
67 Ktapers=20;
68 NW=(Ktapers+1)/2;
69 params.tapers=[NW Ktapers];
70 params.Fs=500;
71 params.fpass=[0 params.Fs/2];
72 params.pad=4;
73 params.err=[2 .05];
EcoG.m x Remove_Lines.m x DeNoiseSVD.m x
Shortcuts How to Add What's New
Command Window
K>> return
Hit UPARROW or type 'return' when ready to c
K>> return
Hit UPARROW or type 'return' when ready to c
K>> return
>> DeNoiseSVD
Current plot held
Type 'return' when ready to continue
K>>
Start Waiting for input
```





First two singular values account for ~96% of the total variance in the data. We will compare the spectra of the first two temporal modes with that of the other modes. Guess is that line noise and slow fluctuation artifacts reside in the first two temporal modes.

◆ >> **return**

◆ Multi-taper power spectra
calculated for each of the temporal
modes in U

◆ [US(:,1),f] =
mtspectrumc(U(:,1),params)

◆ with

- Ktapers=20; NW=(Ktapers+1)/2
- params.tapers=[NW Ktapers]
- params.pad=5
- params.Fs=500
- params.fpass=[0 params.Fs/2]


```

Editor - h:\neuroInformatics\EcoG2005\DeNoiseSVD.m
File Edit Text Cell Tools Debug Desktop Window Help
52 - hold
53 - plot(log10(diag(FS)), '*')
54 - ylabel('log10'); xlabel('row in S');
55 - title('Singular values for svd of FrontalIR')
56 - set(gcf, 'Units', 'pixels', 'Position', sschop)
57 - h2=gcf;
58
59 - figure(h1);
60
61 - display(['Type 'return' when ready to con
62 - keyboard %pause
63
64 %generate t
65 %of the ter
66 - Ktapers=20;
67 - NW=(Ktapers+1)/2;
68 - params.tapers=[NW Ktapers];
69 - params.Fs=500;
70 - params.fpass=[0 params.Fs/2];

```

MATLAB

File Edit Debug Desktop Window Help

Shortcuts How to Add What's New

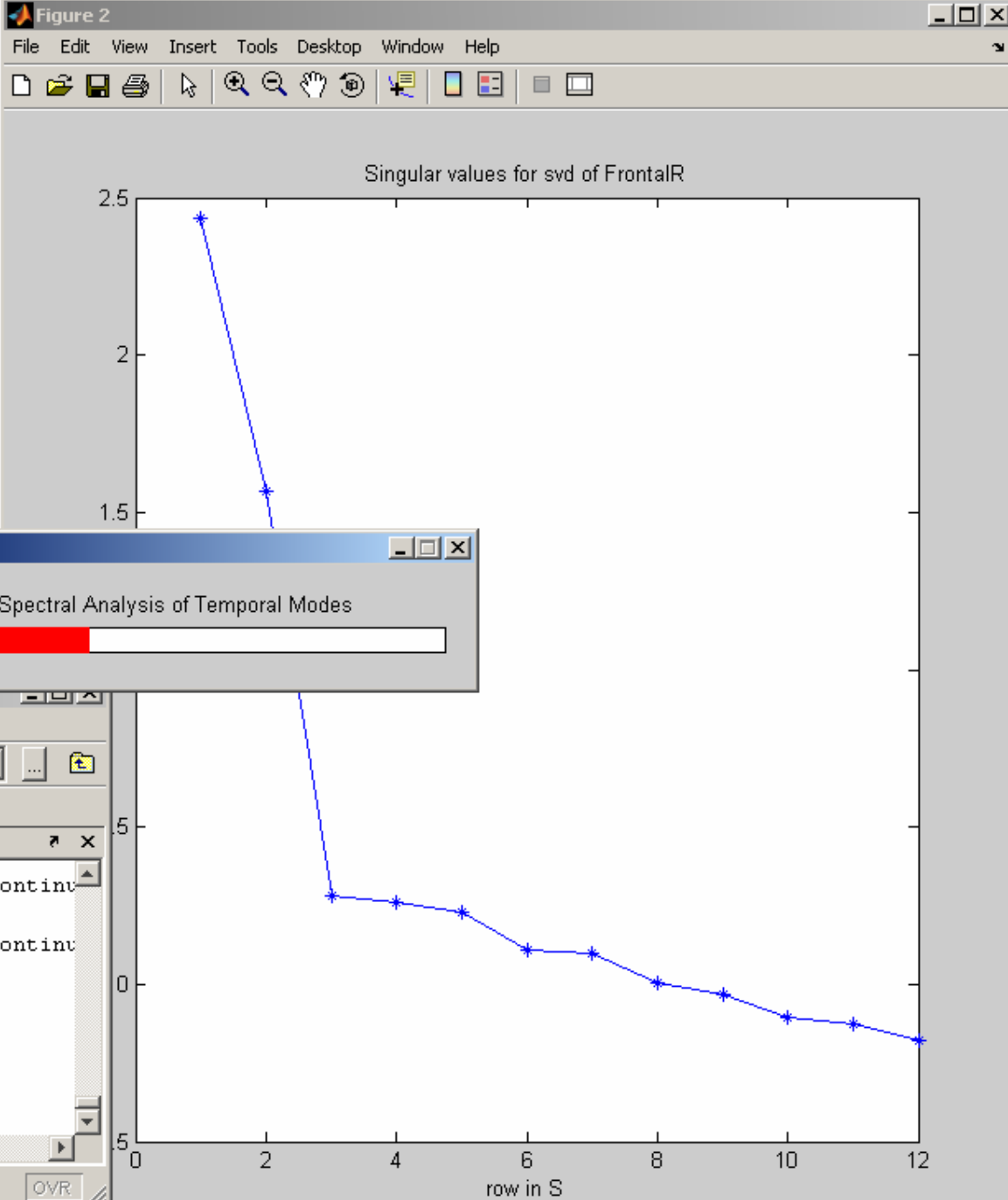
Command Window

```

Hit UPARROW or type 'return' when ready to continue
K>> return
Hit UPARROW or type 'return' when ready to continue
K>> return
>> DeNoiseSVD
Current plot held
Type 'return' when ready to continue
K>> return

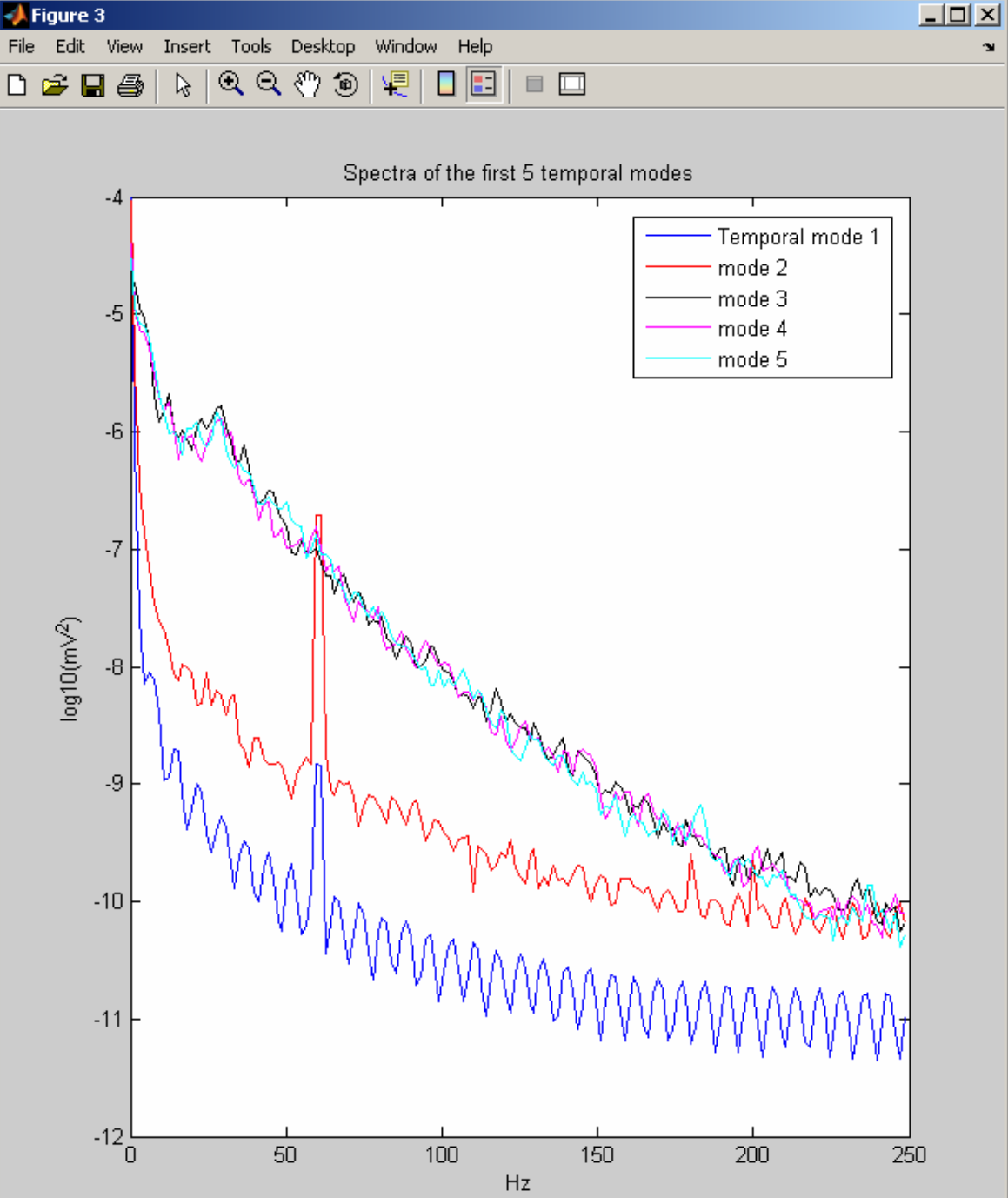
```

Start Busy OVR

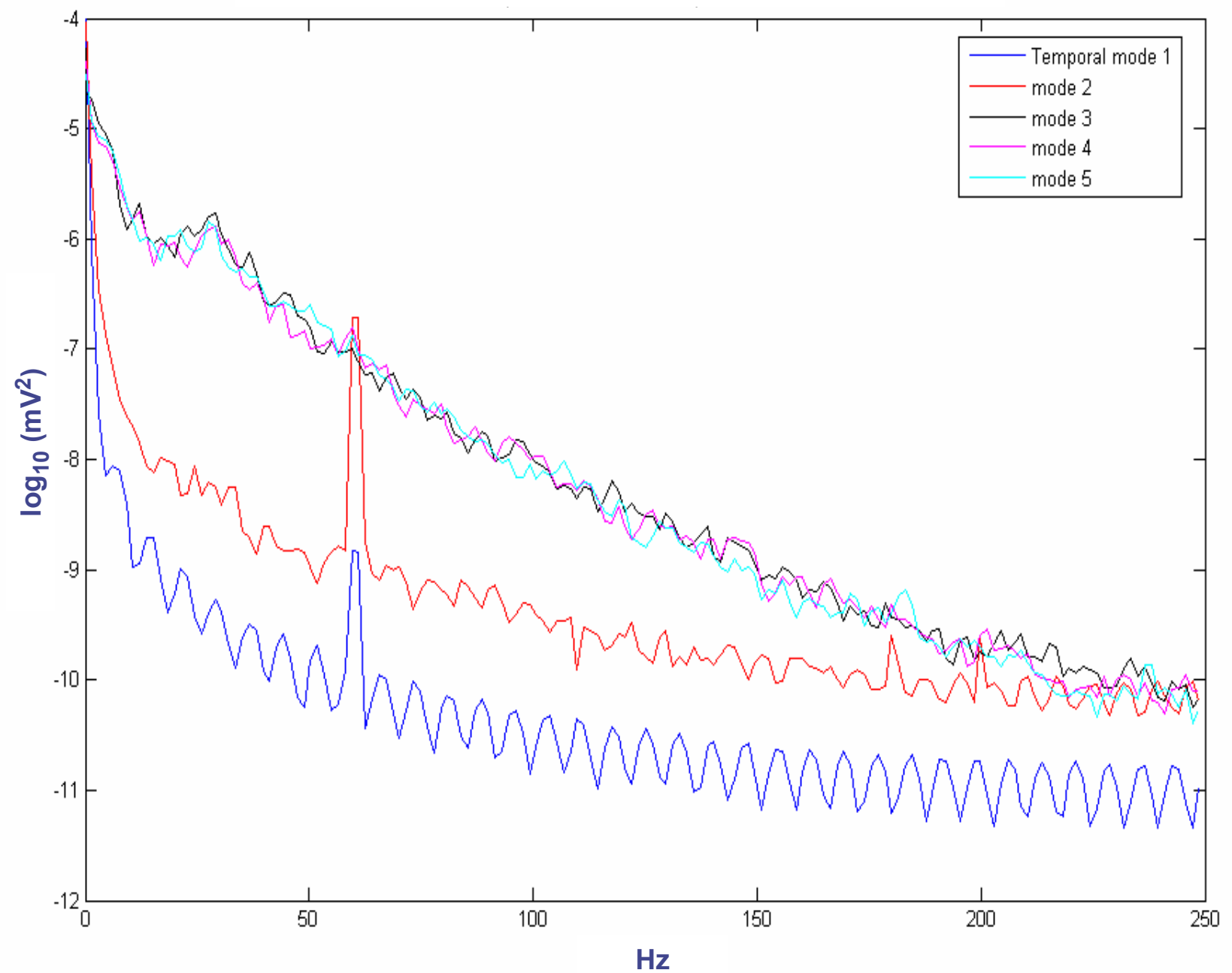


```
Editor - h:\neuroinformatics\EcoG2005\DeNoiseSVD.m
File Edit Text Cell Tools Debug Desktop Window Help
[Icons]
89 - plot(fsub,log10(SData(:,3)),'k')
90 - plot(fsub,log10(SData(:,4)),'m')
91 - plot(fsub,log10(SData(:,5)),'c')
92 - legend('Temporal mode 1','mode 2','mode 3',
93 - ylabel('log10(mV^2)')
94 - xlabel('Hz')
95 - title('Spectra of the first 5 temporal modes
96 - set(gcf,'Units','pixels','Position',sschop)
97
98 - display(['Hit UPARROW or type ''return'' wh
99 - keyboard
100
101 - FrontalRsvd=FU(3:end,3:end)*FS(3:end,3:end)
102 - figure
103 - subplot(2,1,1)
104 - plot(FrontalRsvd(:,1))
105 - set(gca,'YLim',[-.15 .15])
106 - set(gca,'Xtick',[0:500:4000],'XTickLabel',
107 - xlabel('seconds'); ylabel('mV'); title('rec

MATLAB
File Edit Debug Desktop Window Help
[Icons]
Shortcuts [?] How to Add [?] What's New
Command Window
Hit UPARROW or type 'return' when ready to c
K>> return
>> DeNoiseSVD
Current plot held
Type 'return' when ready to continue
K>> return
Current plot held
Hit UPARROW or type 'return' when ready to c
K>>
Start Waiting for input
```



Spectra of the first 5 temporal modes



◆ We drop the first two temporal modes and construct a set of signals from the remaining modes.

◆ $U(3:end,3:end)*S(3:end,3:end)*V(3:end,3:end)'$

◆ = FrontalRsvd

◆ >> Hit UPARROW or type return

```

Editor - h:\neuroinformatics\EcoG2005\DeNoiseSVD.m
File Edit Text Cell Tools Debug Desktop Window Help
89 - plot(fsub,log10(SData(:,3)),'k')
90 - plot(fsub,log10(SData(:,4)),'m')
91 - plot(fsub,log10(SData(:,5)),'c')
92 - legend('Temporal mode 1','mode 2','mode 3',
93 - ylabel('log10(mV^2)')
94 - xlabel('Hz')
95 - title('Spectra of the first 5 temporal mode
96 - set(gcf,'Units','pixels','Position',sschop)
97
98 - display(['Hit UPARROW or type ''return'' wh
99 - keyboard
100
101 - FrontalRsvd=FU(3:end,3:end)*FS(3:end,3:end)
102 - figure
103 - subplot(2,1,1)
104 - plot(FrontalRsvd(:,1))
105 - set(gca,'YLim',[-.15 .15])
106 - set(gca,'Xtick',[0:500:4000],'XTickLabel',
107 - xlabel('seconds'); ylabel('mV'); title('rec

```

MATLAB

File Edit Debug Desktop Window Help

Shortcuts [How to Add](#) [What's New](#)

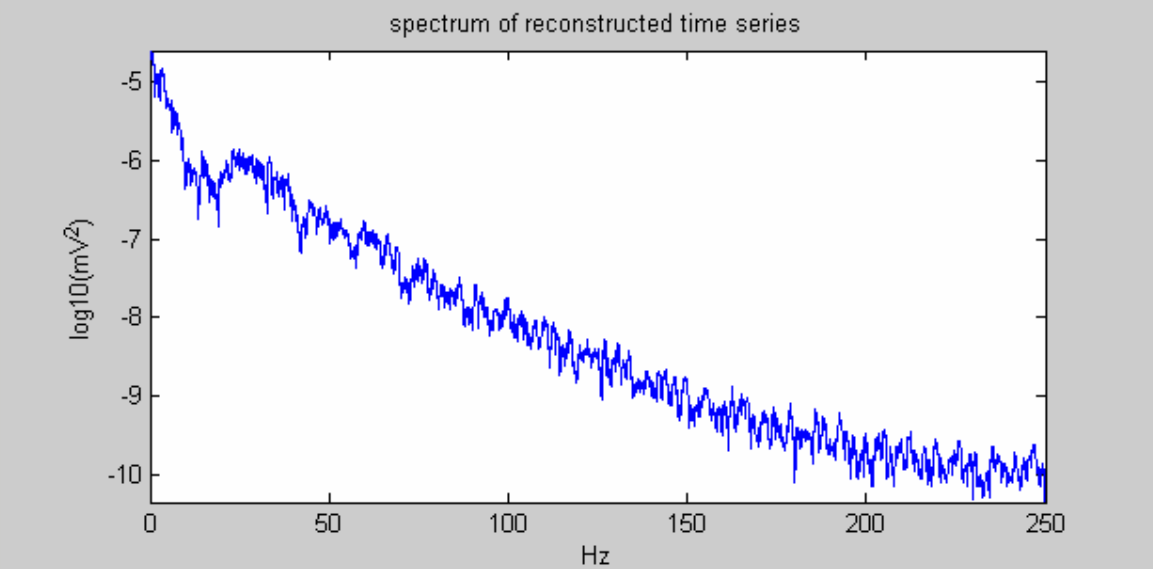
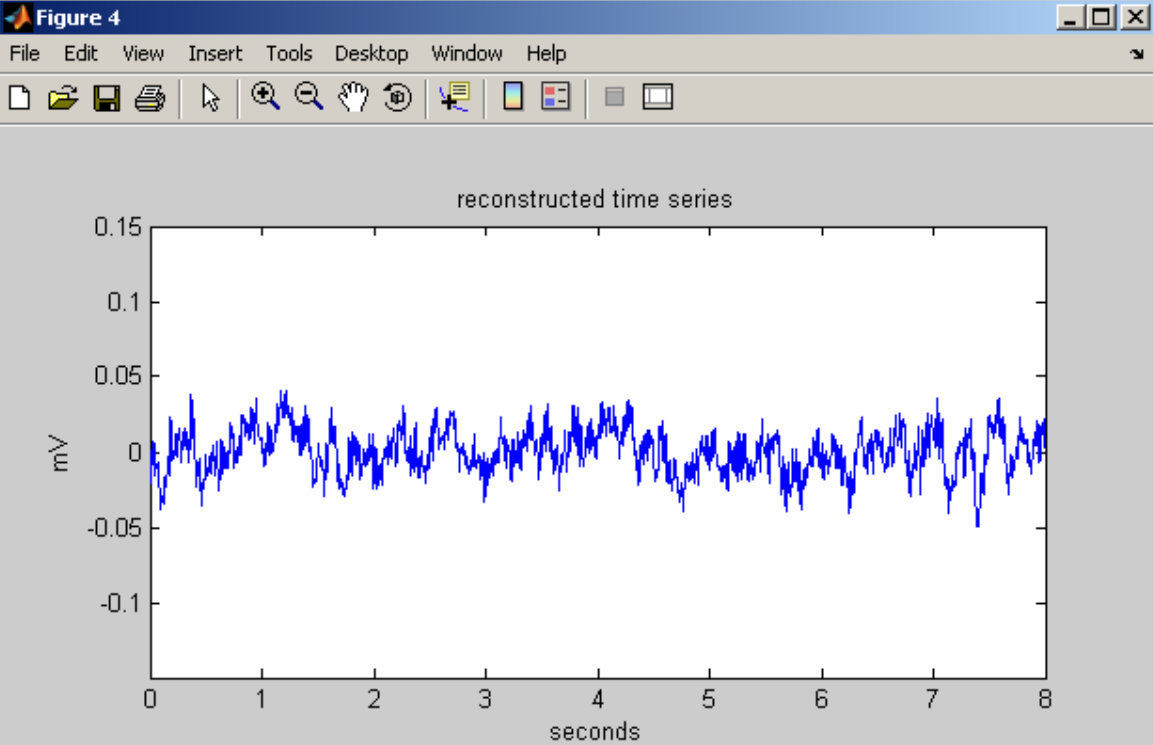
Command Window

```

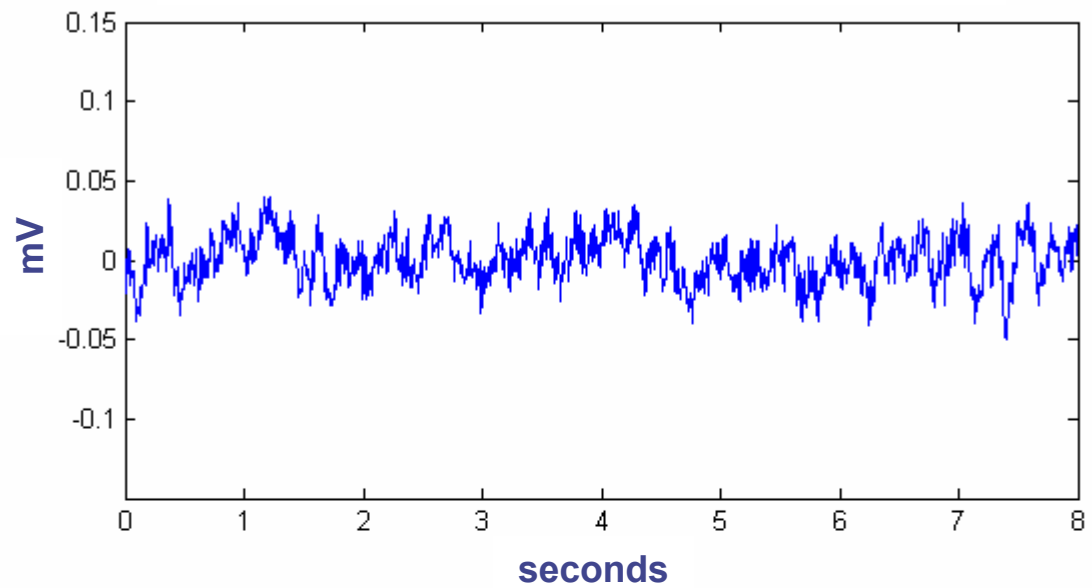
>> DeNoiseSVD
Current plot held
Type 'return' when ready to continue
K>> return
Current plot held
Hit UPARROW or type 'return' when ready to c
K>> return
Done
>>

```

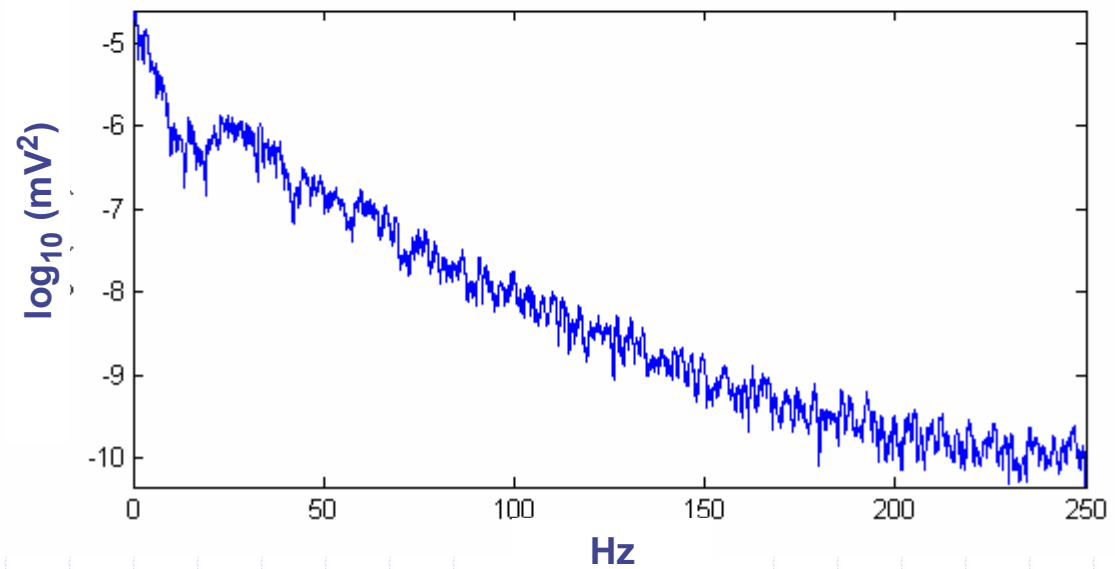
Start



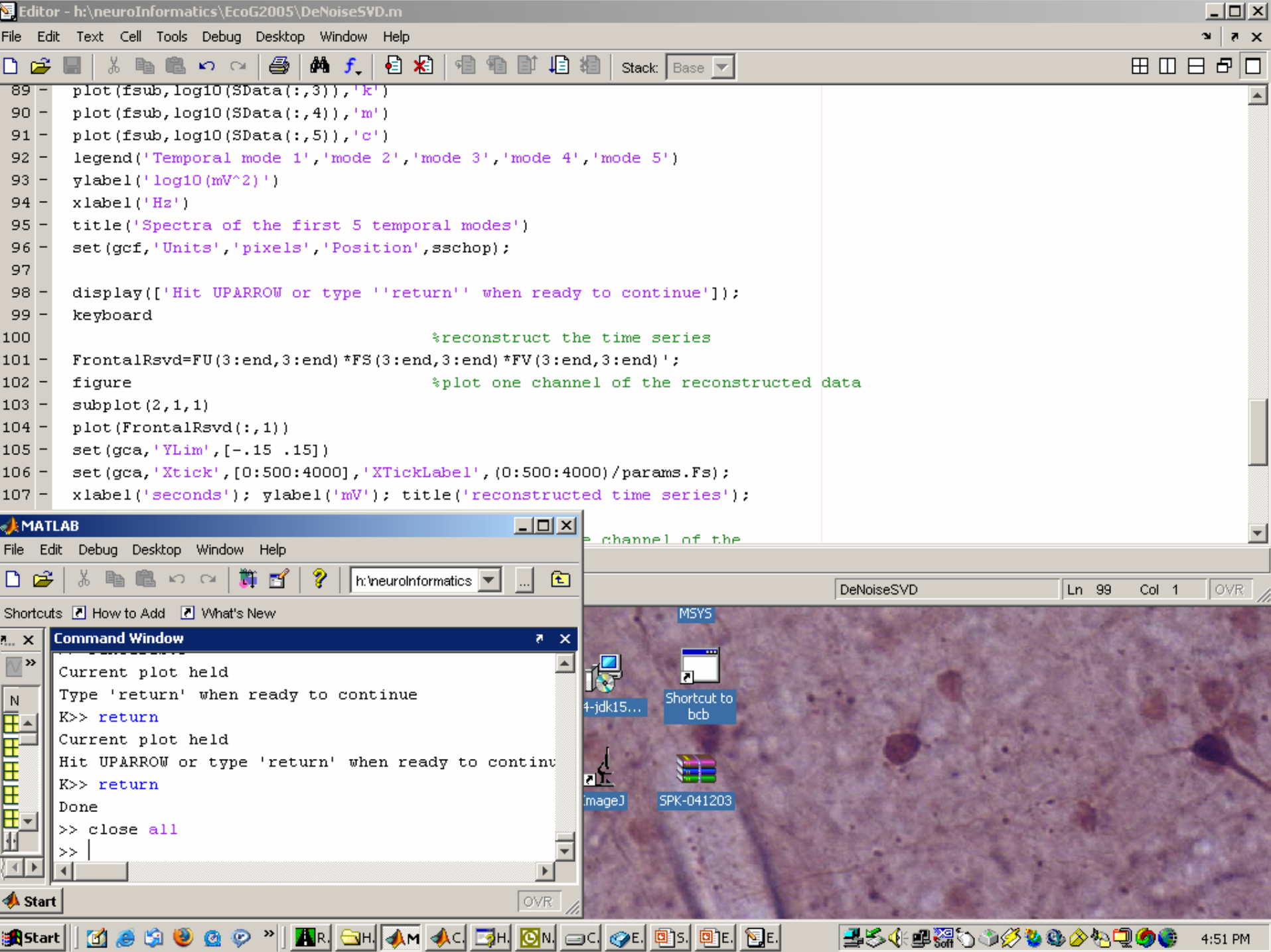
reconstructed signal (FrontalRsvd)

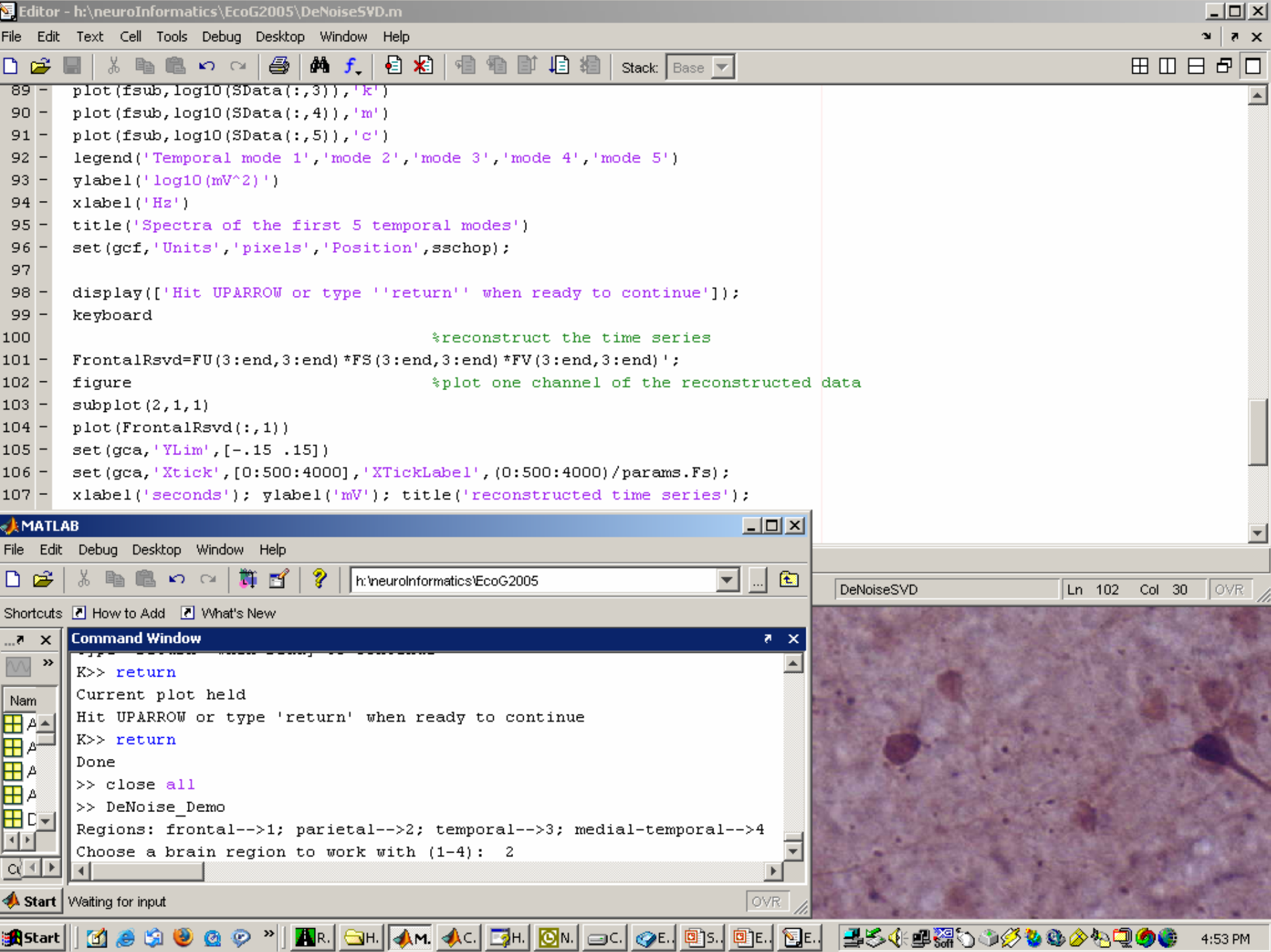


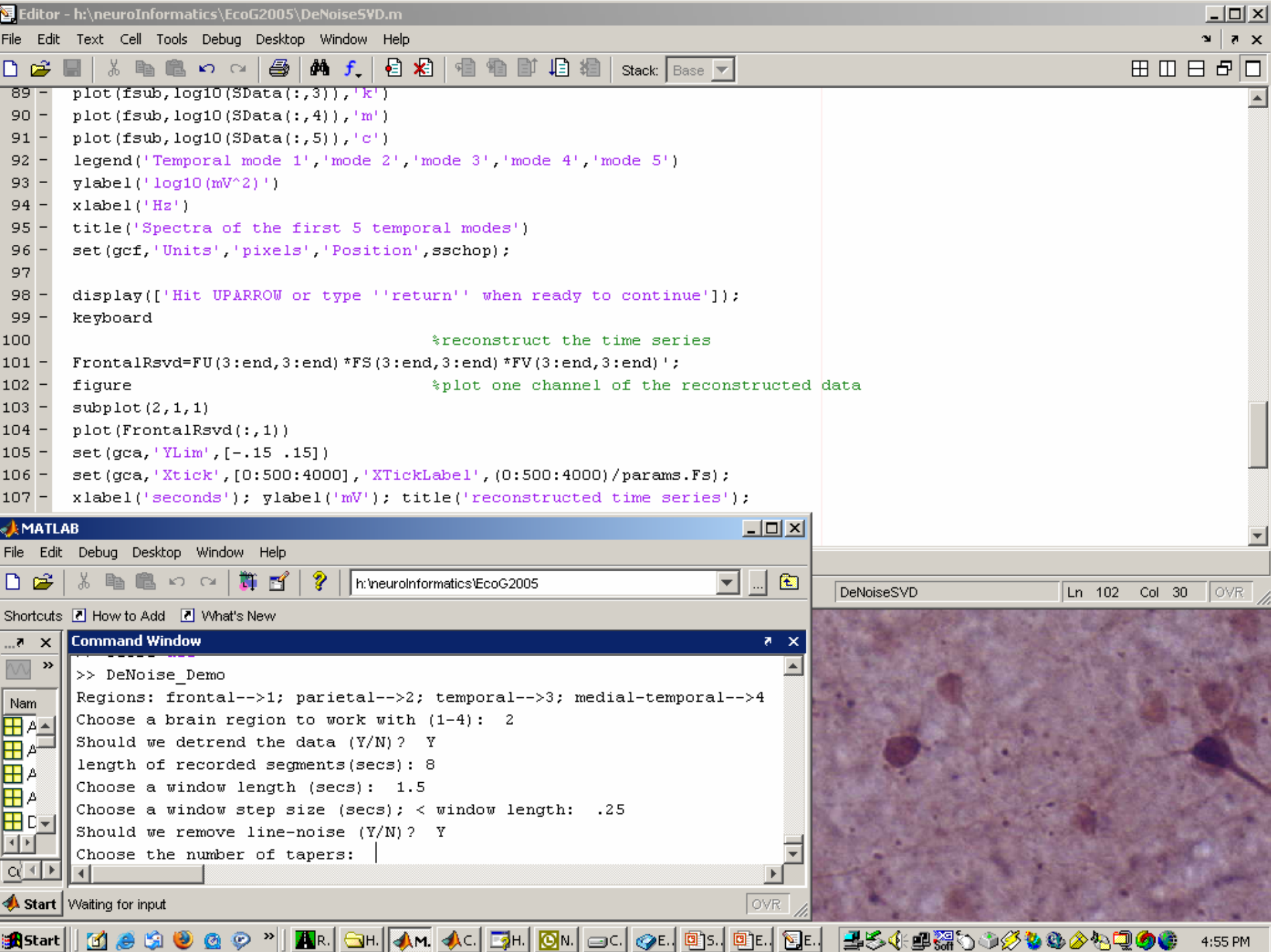
Spectrum of reconstructed signal



- ◆ Note that neither **locdetrend** nor **rmlinesc** were used in this approach to signal conditioning.
- ◆ Yet the slow, large fluctuations in voltage were removed as well as all the line elements at 60.025, 180.075 and 199.88 Hz.
- ◆ Approach is more useful as a demonstration of SVD than as a method for removing the electrical artifacts common in EcoG recordings.







```
Editor - h:\neuroInformatics\EcoG2005\DeNoiseSVD.m
File Edit Text Cell Tools Debug Desktop Window Help
[Icons]
89 - plot(fsub,log10(SData(:,3)),'k')
90 - plot(fsub,log10(SData(:,4)),'m')
91 - plot(fsub,log10(SData(:,5)),'c')
92 - legend('Temporal mode 1','mode 2','mode 3',
93 - ylabel('log10(mV^2)')
94 - xlabel('Hz')
95 - title('Spectra of the first 5 temporal mode
96 - set(gcf,'Units','pixels','Position',sschop)
97
98 - display(['Hit UPARROW or type ''return'' w
99 - keyboard
100
101 - FrontalRsvd=FU(3:end,3:end)*FS(3:end,3:end)
102 - figure
103 - subplot(2,1,1)
104 - plot(FrontalRsvd(:,1))
105 - set(gca,'YLim',[-.15 .15])
106 - set(gca,'Xtick',[0:500:4000],'XTick
107 - xlabel('seconds'); ylabel('mV');
```

MATLAB

File Edit Debug Desktop Window Help

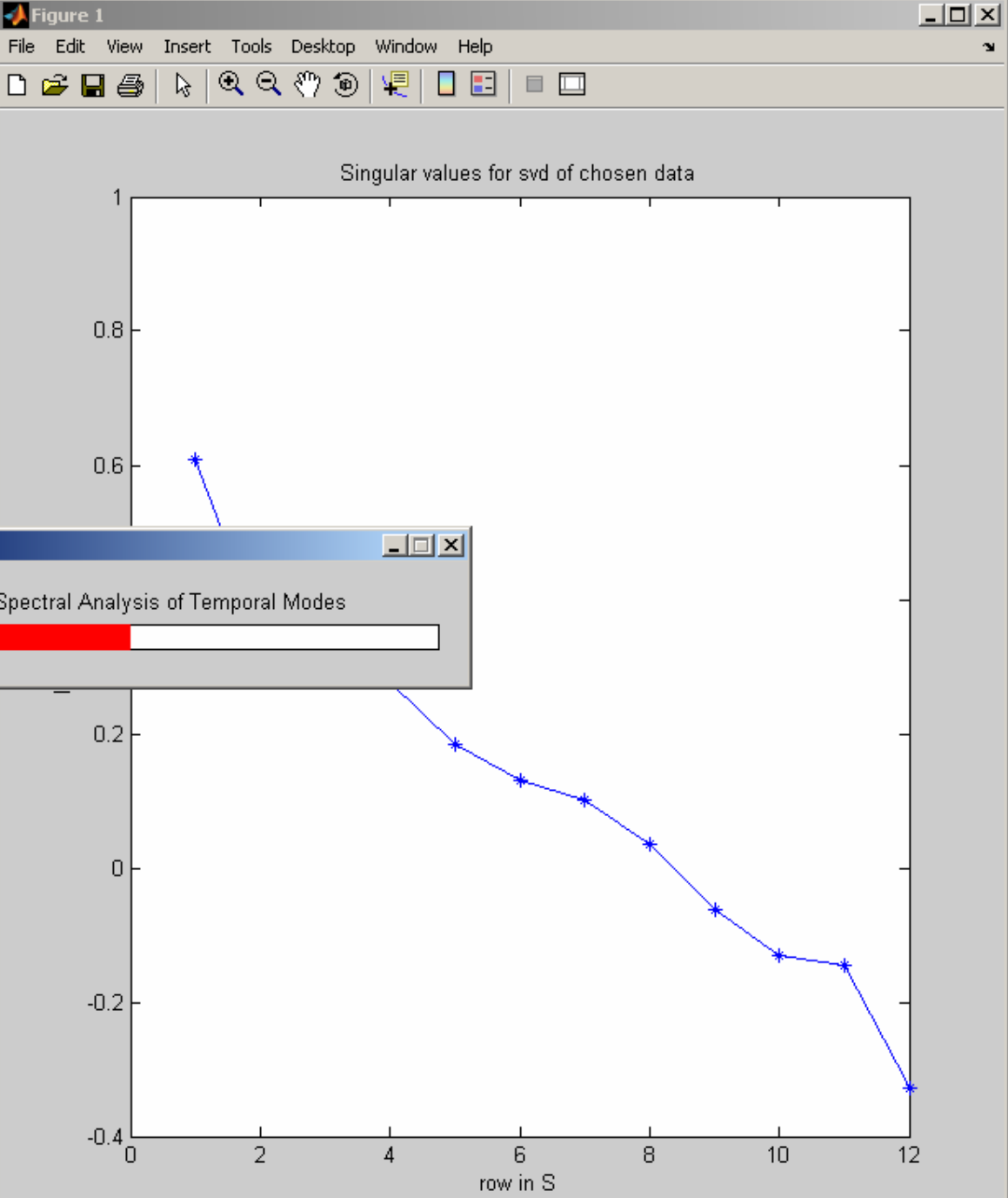
[Icons]

Shortcuts [How to Add](#) [What's New](#)

Command Window

```
>> length of recorded segments(secs): 8
Choose a window length (secs): 1.5
Choose a window step size (secs): < window
Should we remove line-noise (Y/N)? Y
Choose the number of tapers: 9
Choose a padding factor: 4
Choose a significance level for F-test: .
Current plot held
```

Start Busy



```
Editor - h:\neuroInfo05\EcoG2005\DeNoise_Demo.m
File Edit Text Cell Tools Debug Desktop Window Help
161 - fsub = f(1:200:end);
162
163 - figure
164 - plot(fsub, log10(SCU(:,1)))
165 - hold
166 - plot(fsub, log10(SCU(:,2)), 'r')
167 - plot(fsub, log10(SCU(:,3)), 'k')
168 - plot(fsub, log10(SCU(:,4)), 'm')
169 - plot(fsub, log10(SCU(:,5)), 'c')
170 - legend('Temporal mode 1', 'mode 2', 'mode 3',
171 - ylabel('log10(mV^2)')
172 - xlabel('Hz')
173 - title('Spectra of the first 5 temporal mode
174 - set(gcf, 'Units', 'pixels', 'Position', sschop)
175
176
177 - display(['Type ''return'' when ready to exi
178 - keyboard
179
180
181 - return;

EcoG.m x Remove_Lines.m x DeNoiseSVD.m x DeNoise_Demo.m

Shortcuts How to Add What's New

Command Window
Choose a window step size (secs): < window
Should we remove line-noise (Y/N)? Y
Choose the number of tapers: 9
Choose a padding factor: 4
Choose a significance level for F-test: .
Current plot held
Current plot held
Type 'return' when ready to exit
K>>

Start Waiting for input
```

