Real-Time FMRI Tools & Automation in AFNI & SUMA

SSCC / NIMH & NINDS / NIH / DHHS / USA / EARTH

SSCC NIMH

NIMH National Institute of Mental Health

NATIONAL INSTITUTE OF NEUROLOGICAL DISORDERS AND STROKE

NATIONAL INSTITUTES OF HEALTH

DEPARTMENT OF HEALTH & HUMAN SERVICES•USA

Z.S.S 12-13

Why bother?

- Image quality control
  - Spikes, distortion, ghosting, noise, …
  - Amount of motion
  - Operator error

Cox, RW et al. 95,
Cohen, MS et al. 98,
Frank, J. et al 99,
Voyvodic, J. 99

- Functional localization
  - Localizer prior to main FMRI experiment for BCI or high-res imaging
  - Pre operative scanning
  - As Q/A in clinical settings or difficult / rare subject population
  - 'scan to criteria'

Weiskopf, N. et al 04

Yang, S. et al 08

- Teaching

Weiskopf, N et al. 2007

MEDICAL COLLEGE OF WISCONSIN

- Feedback and Biofeedback
  - Reduce motion
  - Alter/interfere brain function
  - Control of task/ stimulus computer
  - Classification/BCI
  - Signals in vegetative state

Yang, S. et al. 05

deCharms. RC. et al. 04
deCharms. RC. et al. 05
Posse S. et al. 03

LaConte SM. et al. 07
Yoo S. et al. 04

Owen AM et al 06

Image Quality Control

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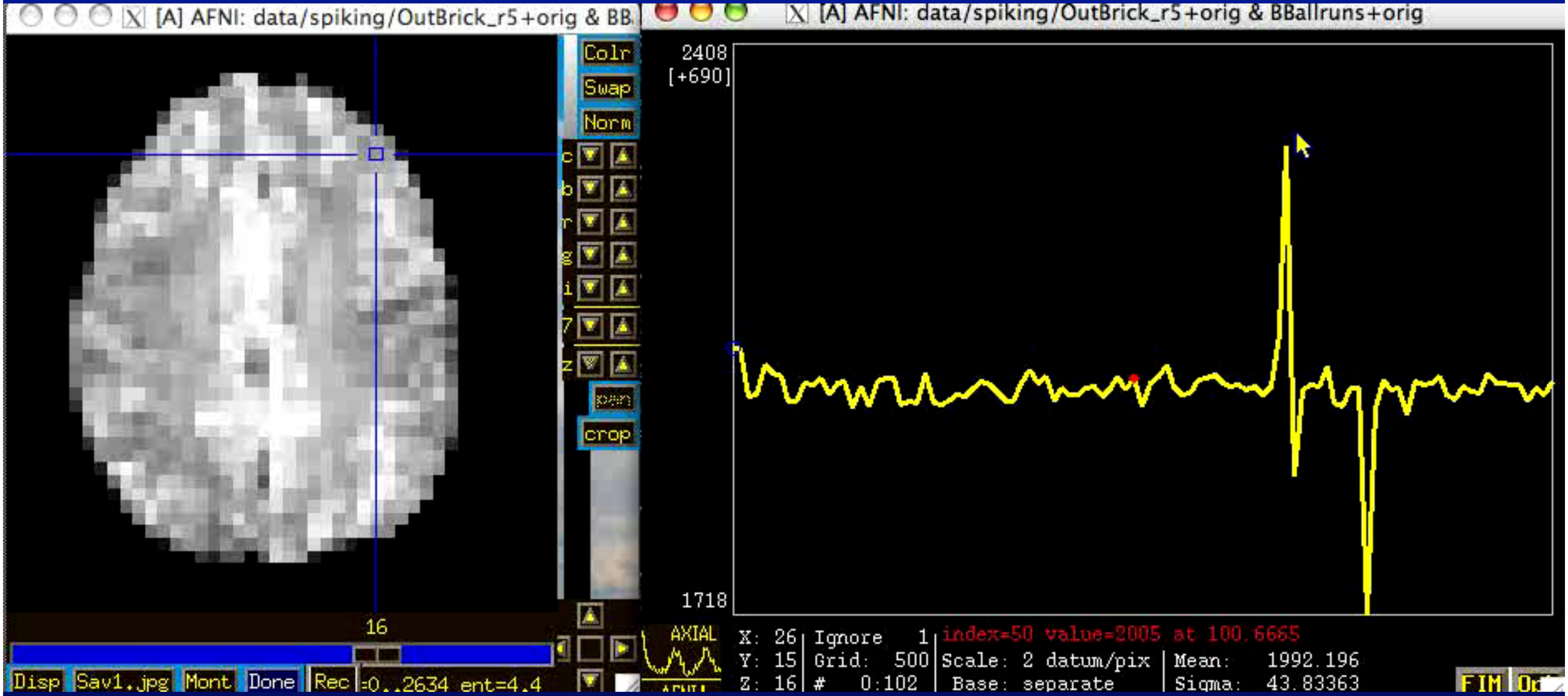

[A] AFNI: data/spiking/OutBrick_r5+orig & BB

[A] AFNI: data/spiking/OutBrick_r5+orig & BBallruns+orig

```
X:  26| Ignore    1|index=50 value=2005 at 100.6665
Y:  15| Grid:   500|Scale: 2 datum/pix | Mean:    1992.196
Z:  16| #    0:102 | Base: separate    | Sigma:   43.83363
```

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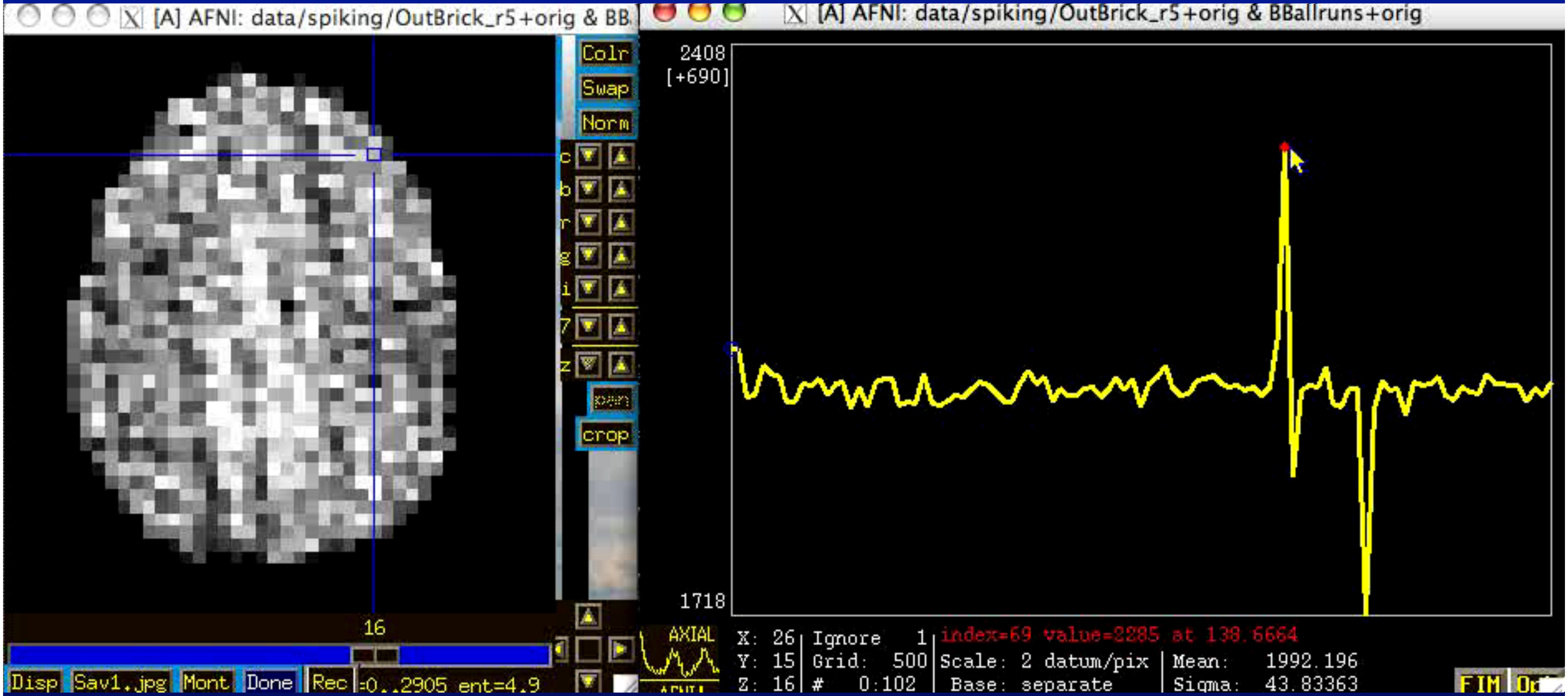
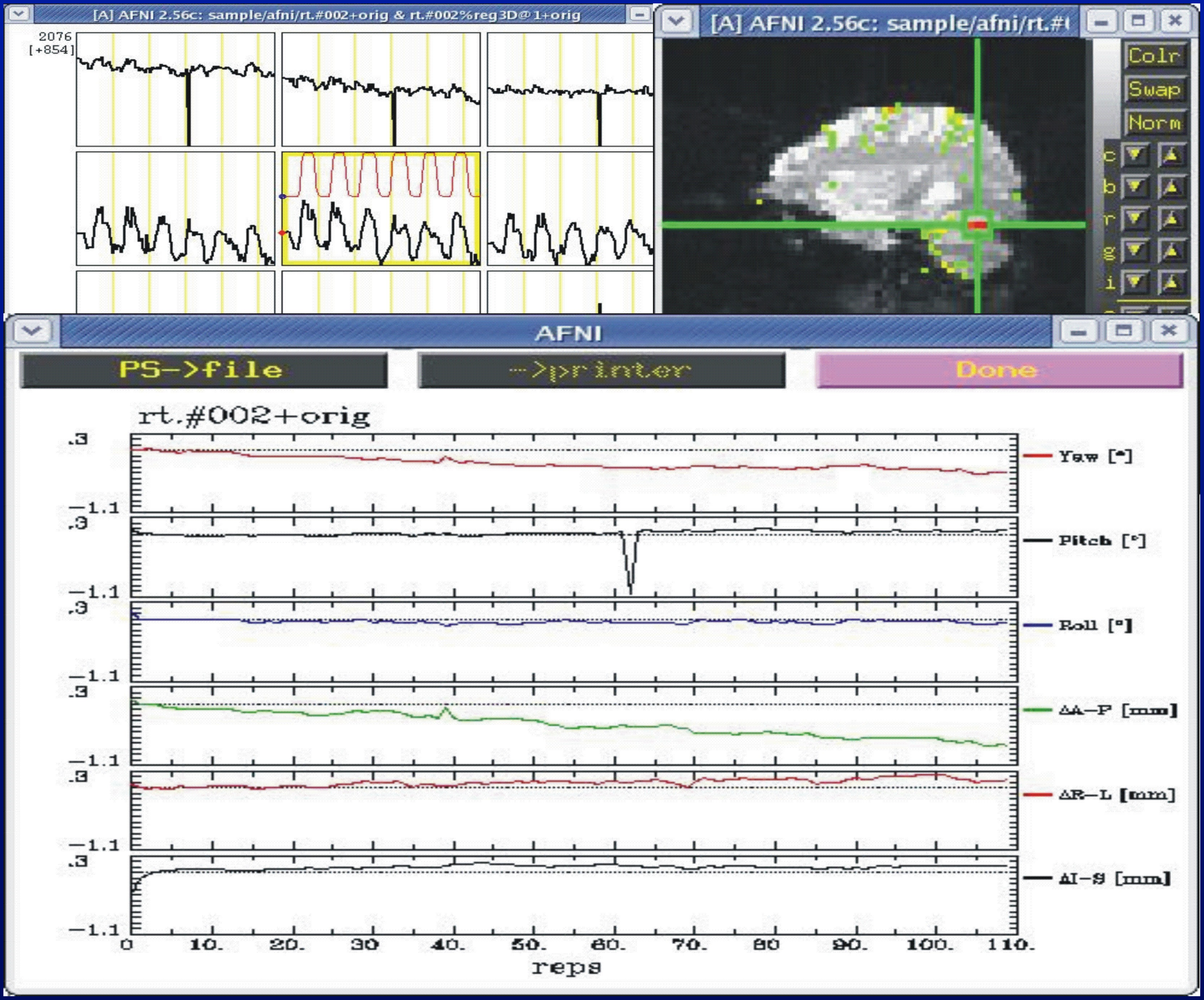

[A] AFNI: data/spiking/OutBrick_r5+orig & BB
[A] AFNI: data/spiking/OutBrick_r5+orig & BBallruns+orig
Colr
Swap
Norm
c
b
r
g
i
7
z
pan
crop
16
Disp
Sav1.jpg
Mont
Done
Rec
2408
[+690]
1718
AXIAL
FIM
Op

```
=0..2905 ent=4.9
```

```
X: 26 | Ignore   1 | index=69 value=2285 at 138.6664
Y: 15 | Grid:  500 | Scale: 2 datum/pix  | Mean:    1992.196
Z: 16 | #    0:102 |  Base: separate     | Sigma:   43.83363
```

Image Quality Control



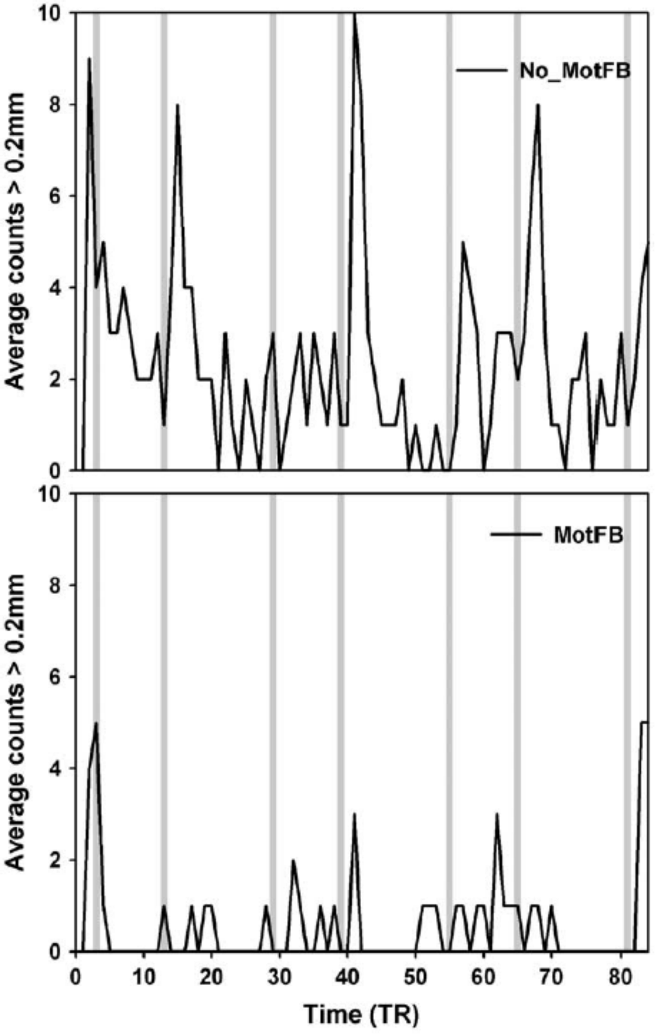
Real-time Estimation of Functional Activation

Real-time Estimation of subject movement

Reduce Motion with Feedback

- Feedback and Biofeedback
  - Reduce motion

Yang, S. et al. 08



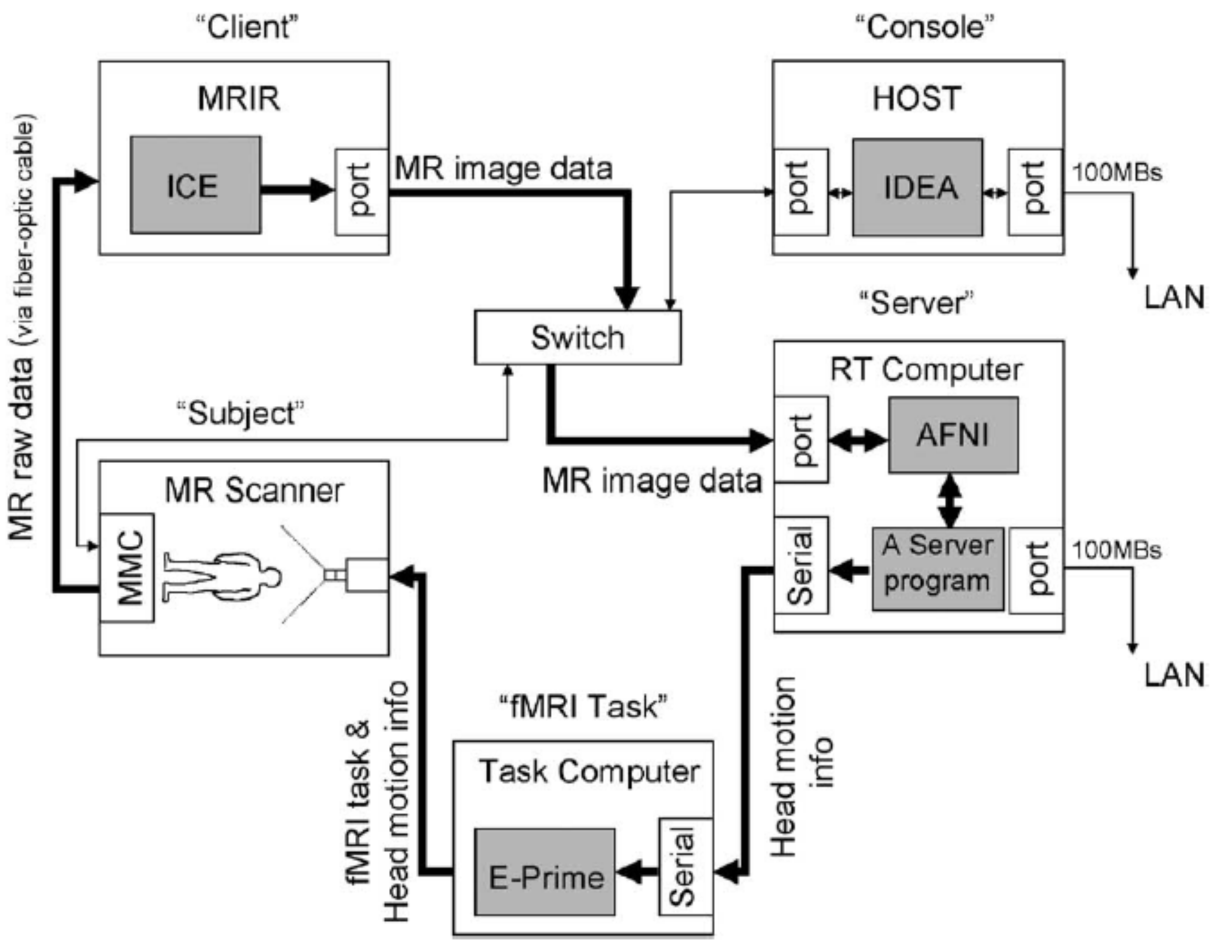


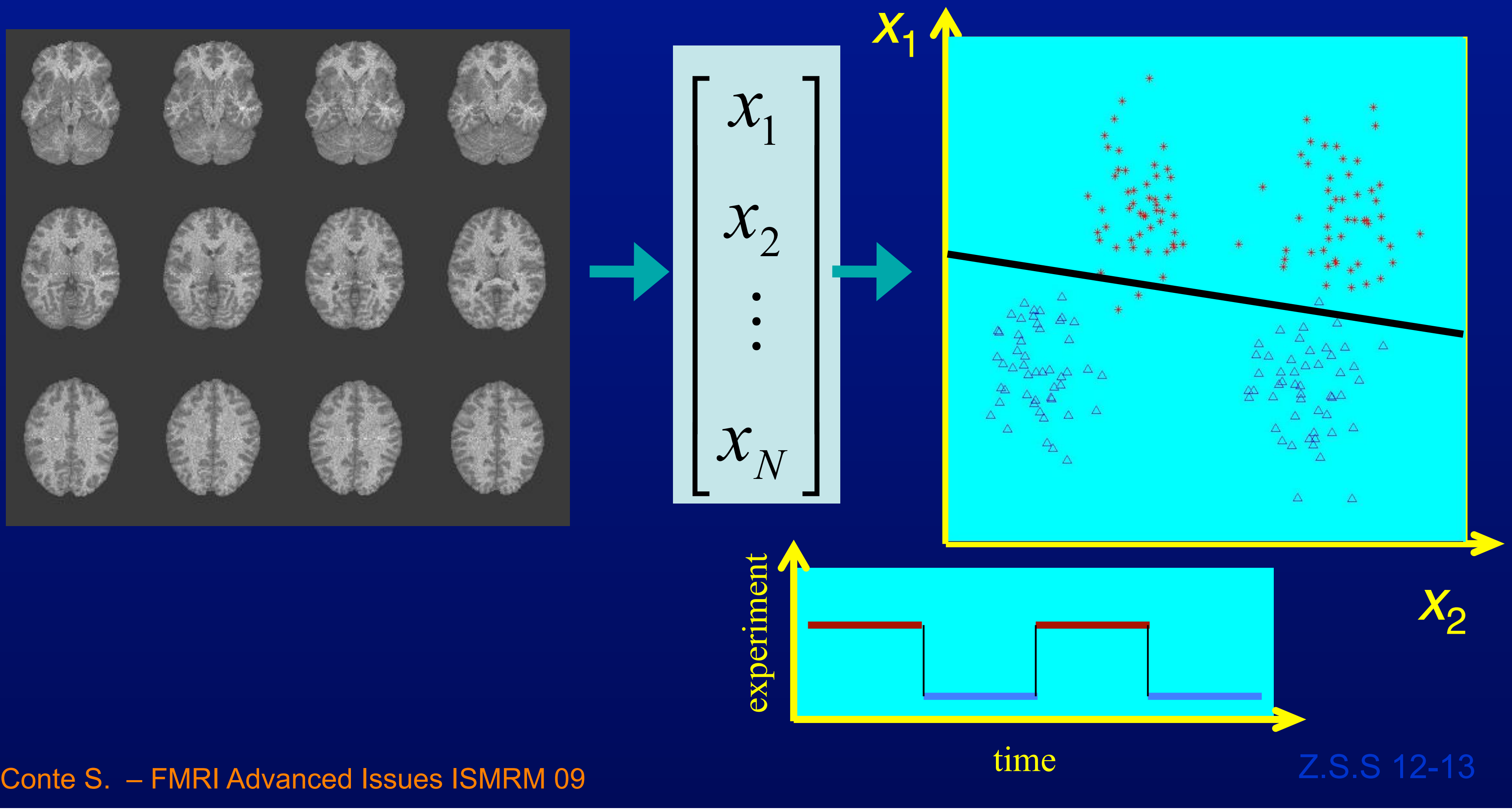
Fig. 2. Configuration of the real-time analysis system and data flow schematic.

Fig.6 from Yang, S. et al. Neuroimage 05

Fig.2 from Yang, S. et al. Neuroimage 05

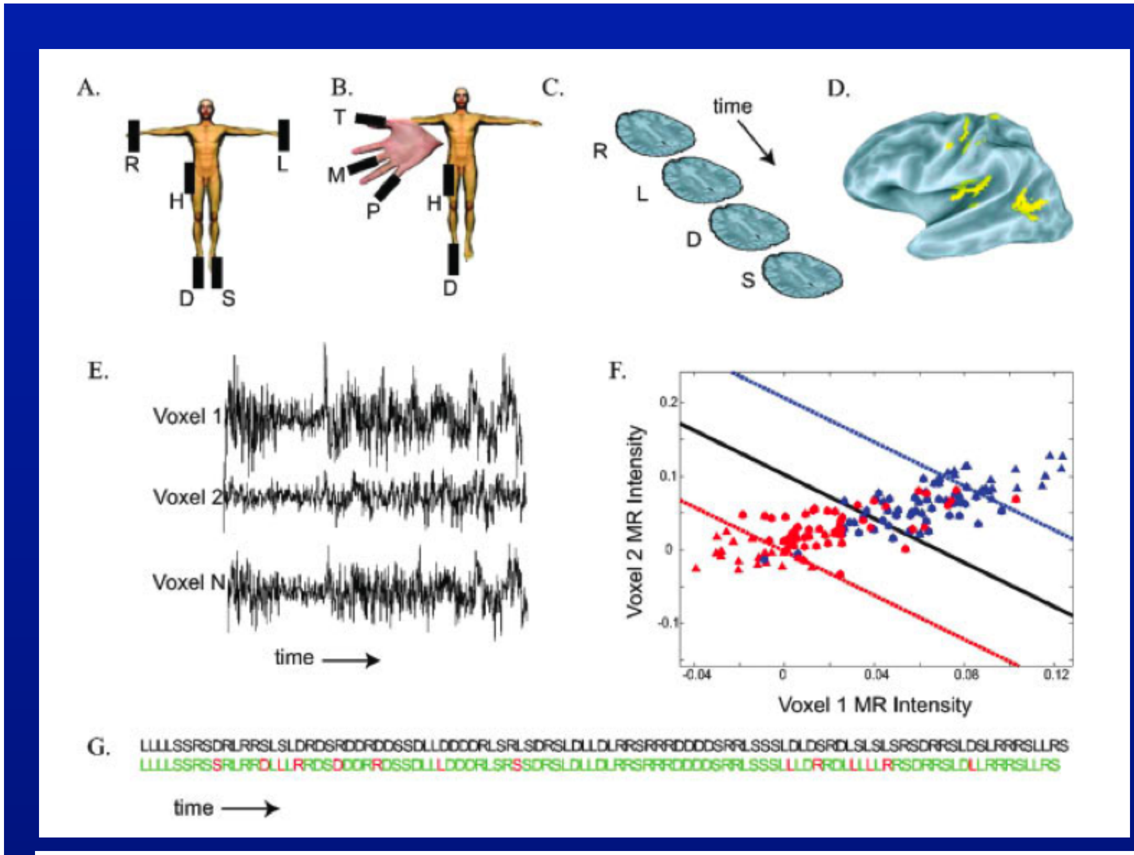
Classification

- Classification maps high dimensional pattern into a set of classes
  - This allows a complex brain activation pattern to be identified with a set of classes or brain states.
  - Useful in to providing intuitive feedback from activation of multiple areas
  - Useful for inferring brain state



From LaConte S. – FMRI Advanced Issues ISMRM 09

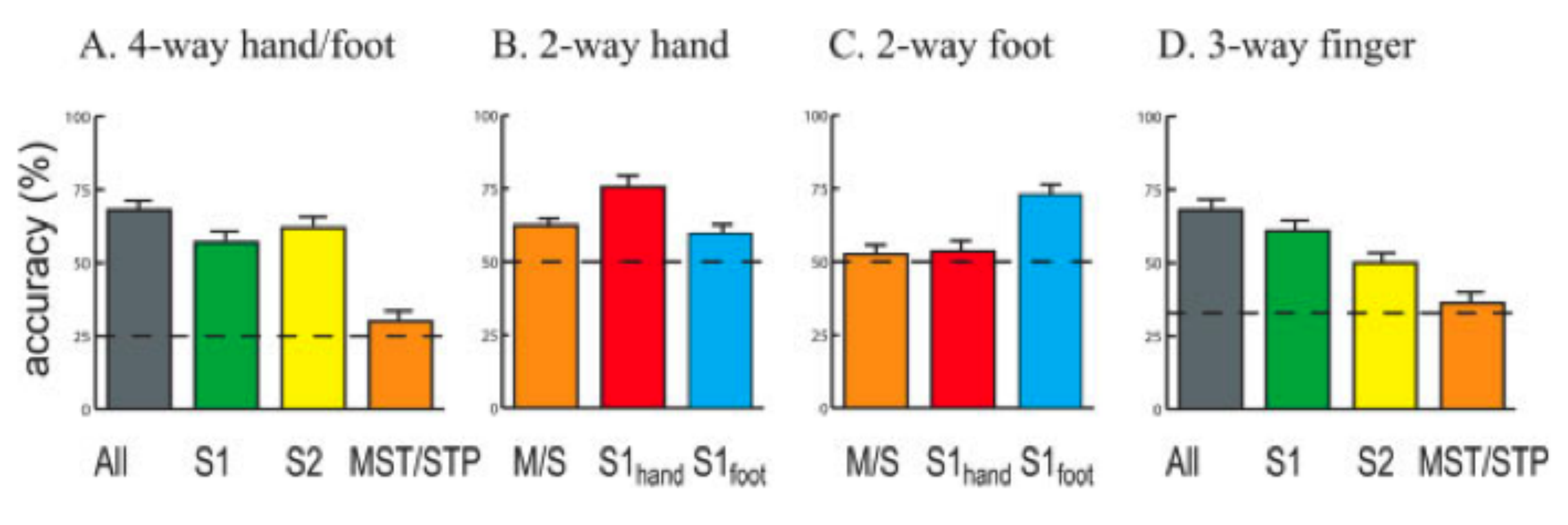
Single 2 second event



A.
R
L
H
D
S
B.
T
M
P
H
D
C.
time
R
L
D
S
D.
E.
Voxel 1
Voxel 2
Voxel N
time
F.
Voxel 2 MR Intensity
0.2
0.1
0
-0.1
-0.04
0
0.04
0.08
0.12
Voxel 1 MR Intensity
G.
LLLLSSRSDRLRRSLSLDRDSRDDRDDSSDLLDDDDRLSRLSDRSLDLLDLRRSRRRDDDDSRRLSSSLDLDSRDLSLSLSRSDRRSLDSLRRRSLLRS
LLLLSSRSSRLRRDLLLRRDSDDDRRDSSDLLLDDDRLSRSSDRSLDLLDLRRSRRRDDDDSRRLSSSLLLDRRDLLLLRRSDRRSLDLLRRRSLLRS
time

From fast randomized event related FMRI

Figs.1 and 3 from Beauchamp, M.S. et al. HBM 09



Brain Computer Interface

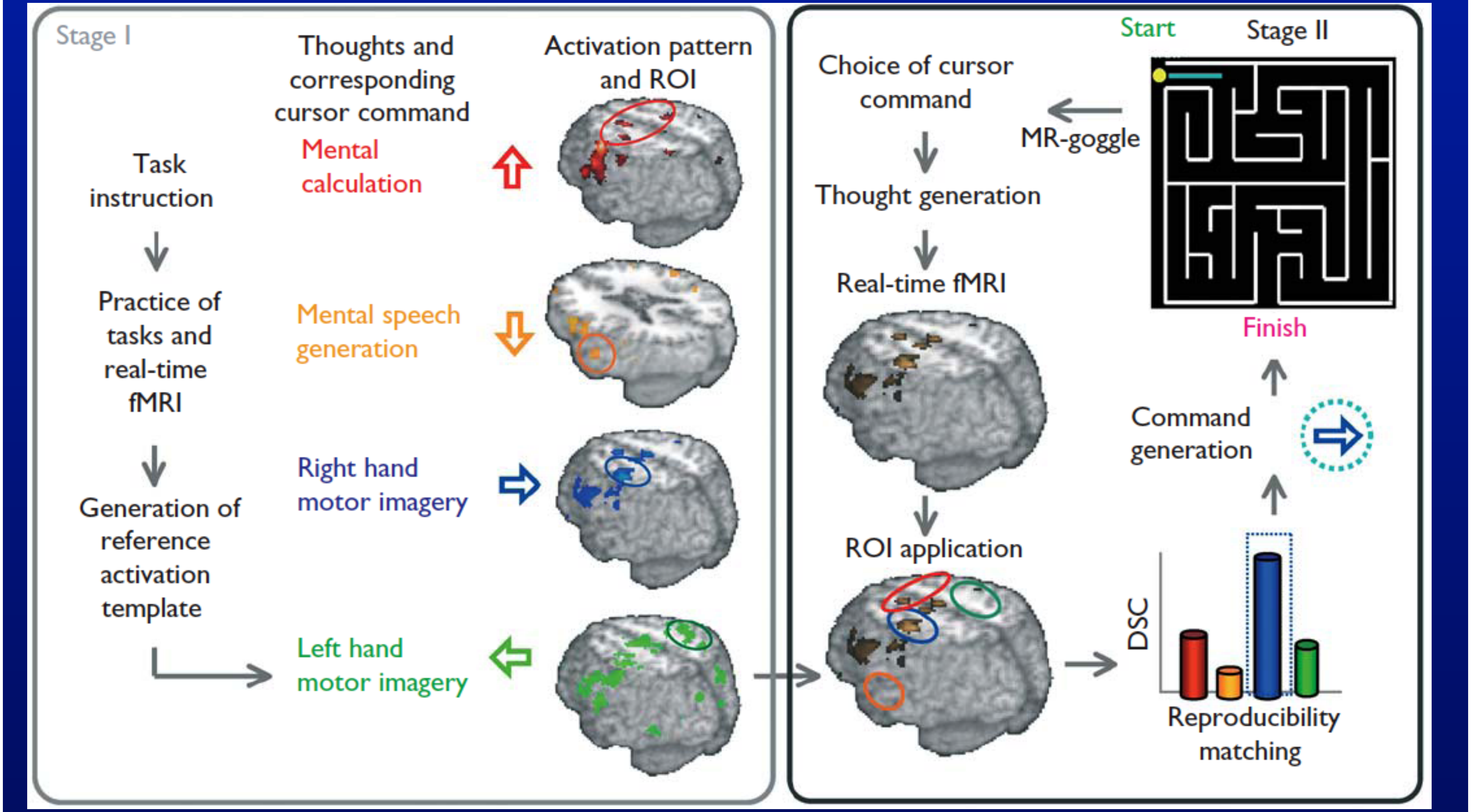
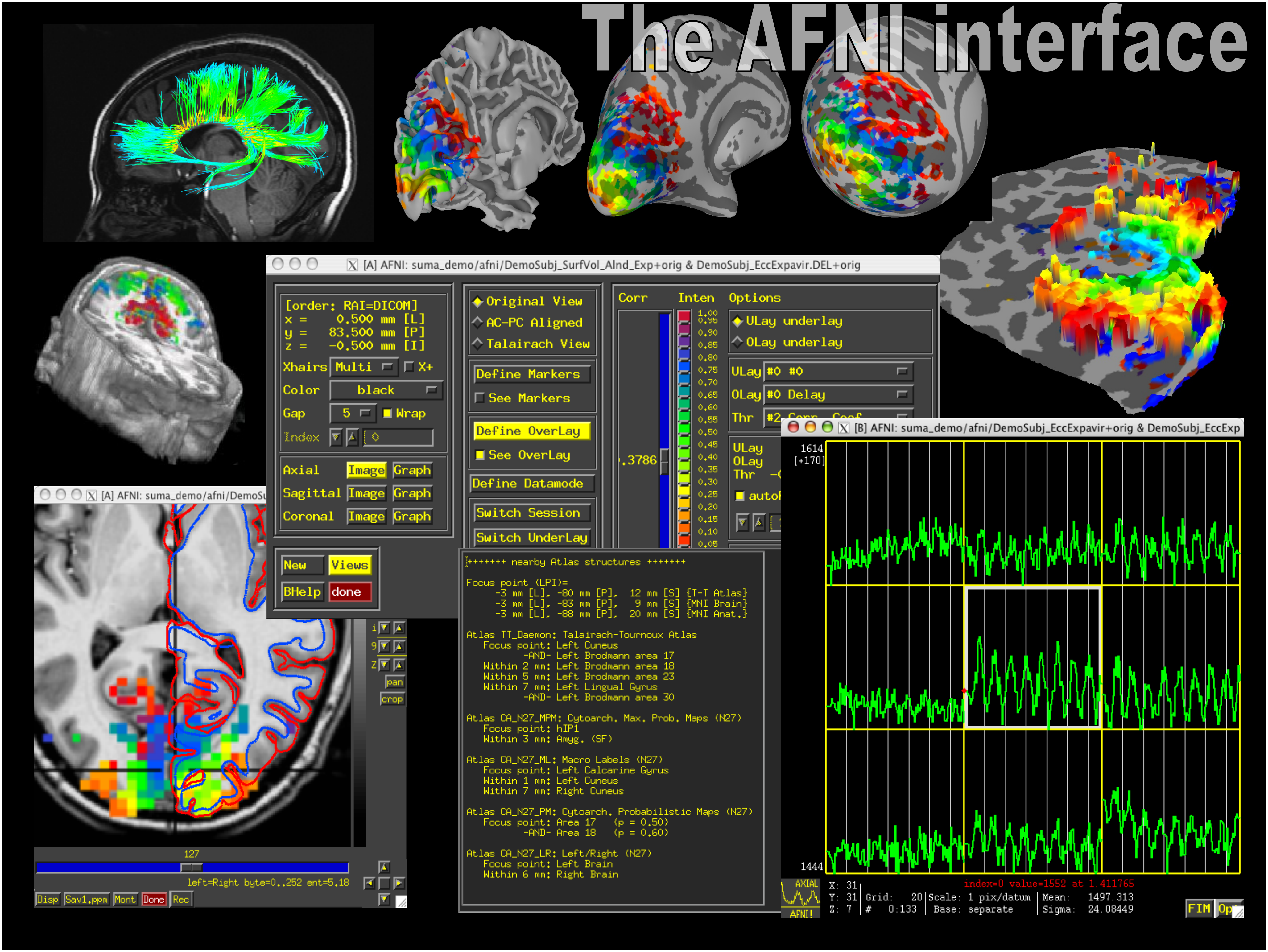


Fig.1 Yoo S. et al. Neuroreport 04

The AFNI interface



[A] AFNI: suma_demo/afni/DemoSubj_SurfVol_Alnd_Exp+orig & DemoSubj_EccExpavir.DEL+orig

```
[order: RAI=DICOM]
x =     0.500 mm [L]
y =    83.500 mm [P]
z =    -0.500 mm [I]
```

Xhairs: Multi · Color: black · Gap: 5 · ■ Wrap · Index: 0

ULay: #0 #0 · OLay: #0 Delay · Thr: #2 Corr. Coef

```
+++++++ nearby Atlas structures +++++++

Focus point (LPI)=
      -3 mm [L], -80 mm [P],  12 mm [S] {T-T Atlas}
      -3 mm [L], -83 mm [P],   9 mm [S] {MNI Brain}
      -3 mm [L], -88 mm [P],  20 mm [S] {MNI Anat.}

Atlas TT_Daemon: Talairach-Tournoux Atlas
   Focus point: Left Cuneus
          -AND- Left Brodmann area 17
   Within 2 mm: Left Brodmann area 18
   Within 5 mm: Left Brodmann area 23
   Within 7 mm: Left Lingual Gyrus
          -AND- Left Brodmann area 30

Atlas CA_N27_MPM: Cytoarch. Max. Prob. Maps (N27)
   Focus point: hIP1
   Within 3 mm: Amyg. (SF)

Atlas CA_N27_ML: Macro Labels (N27)
   Focus point: Left Calcarine Gyrus
   Within 1 mm: Left Cuneus
   Within 7 mm: Right Cuneus

Atlas CA_N27_PM: Cytoarch. Probabilistic Maps (N27)
   Focus point: Area 17    (p = 0.50)
          -AND- Area 18    (p = 0.60)

Atlas CA_N27_LR: Left/Right (N27)
   Focus point: Left Brain
   Within 6 mm: Right Brain
```

[A] AFNI: suma_demo/afni/DemoSu

```
127
left=Right byte=0..252 ent=5.18
```

[B] AFNI: suma_demo/afni/DemoSubj_EccExpavir+orig & DemoSubj_EccExp

```
                 index=0 value=1552 at 1.411765
X: 31 |
Y: 31 |Grid:    20|Scale: 1 pix/datum |Mean:    1497.313
Z: 7  |#    0:133 | Base: separate    |Sigma:   24.08449
```

The players

Scanner

Real Time Setup

RT Plugin

Image Monitor

AFNI

Plugin

Real Time Receiver

Stimulus Display

The players

Scanner

Real Time Setup

RT Plugin

Image Monitor

AFNI

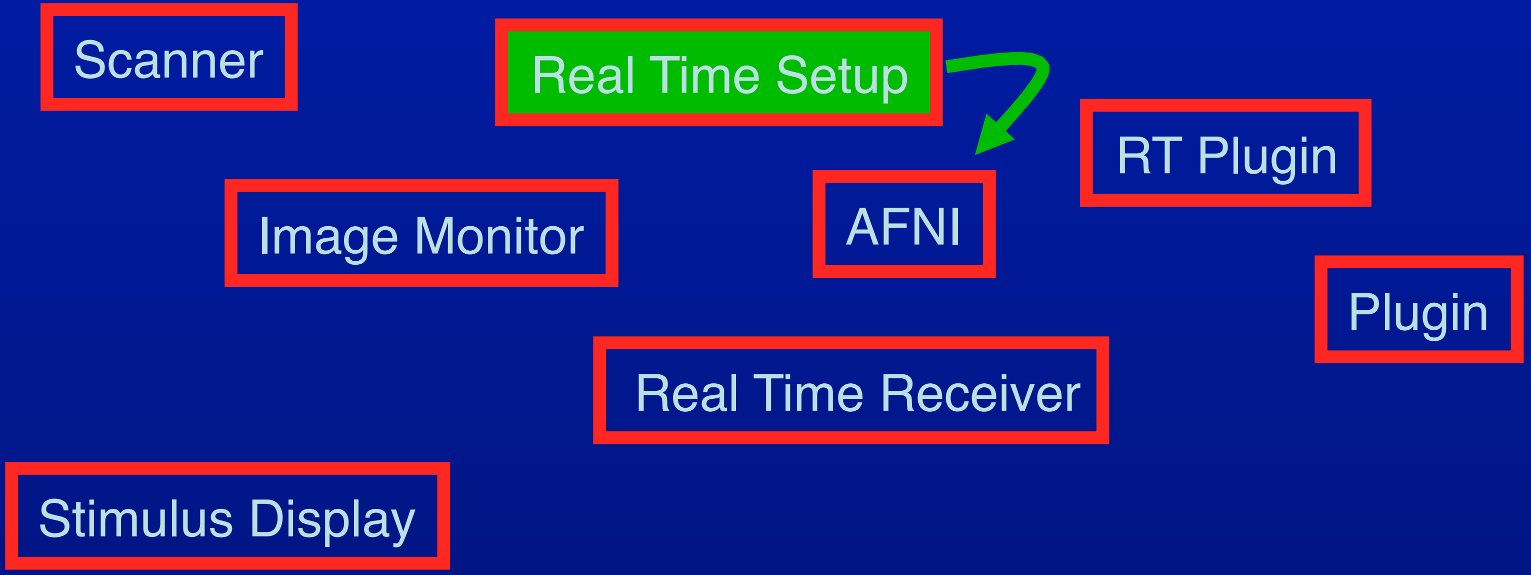
Plugin

Real Time Receiver

Stimulus Display

- Scanner
  - A user-supplied machine to acquire and reconstruct images in real time

The players



Scanner

Real Time Setup

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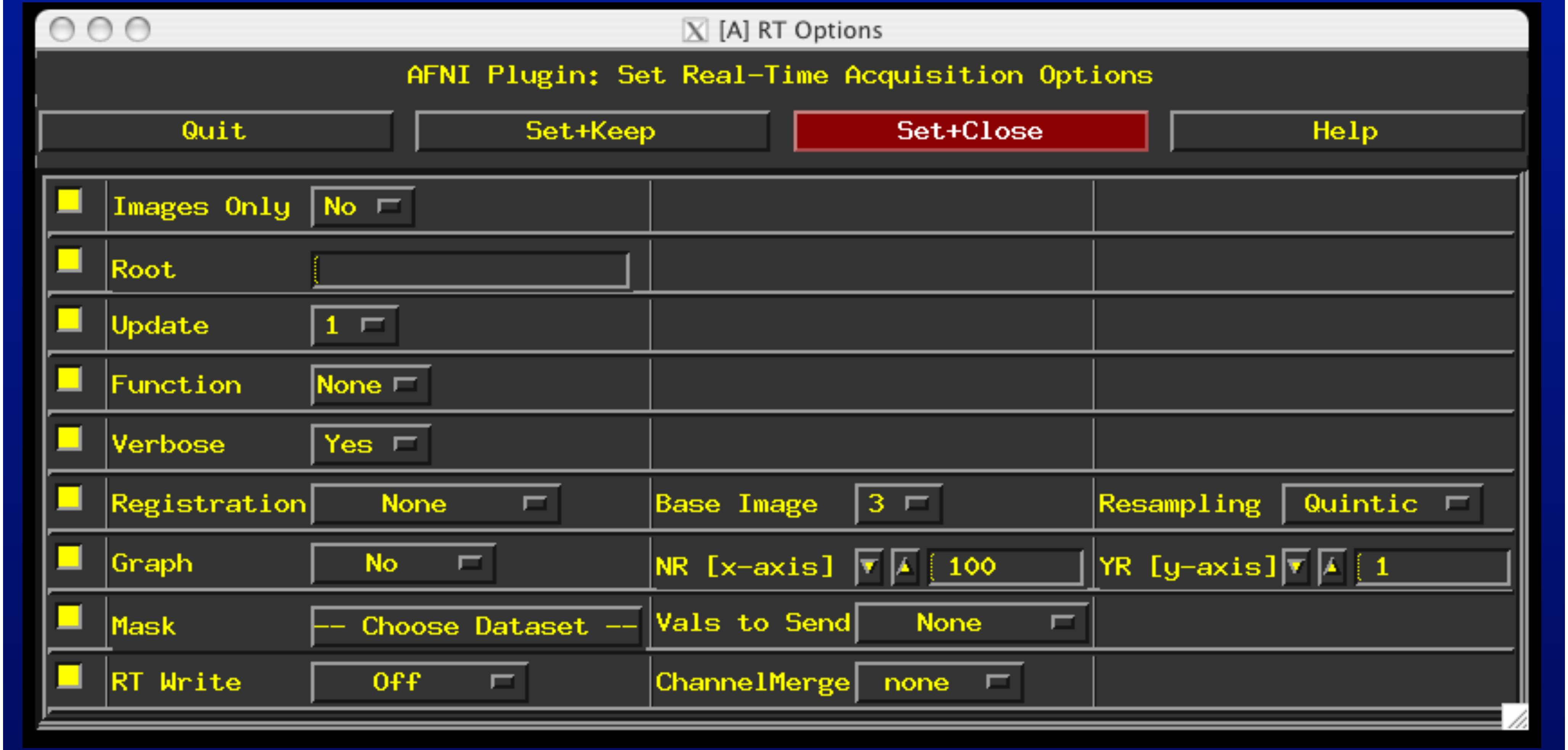
Real Time Receiver

Stimulus Display

- Real Time Setup
  - A user-supplied set of commands that tell AFNI what to do with incoming data
  - Can be done from shell commands or from within C code
  - Communicates with AFNI through TCP/IP socket
  - Sets up ROIs for AFNI*

Setting up AFNI's RT plugin

- Manually
  - Good for learning and demo

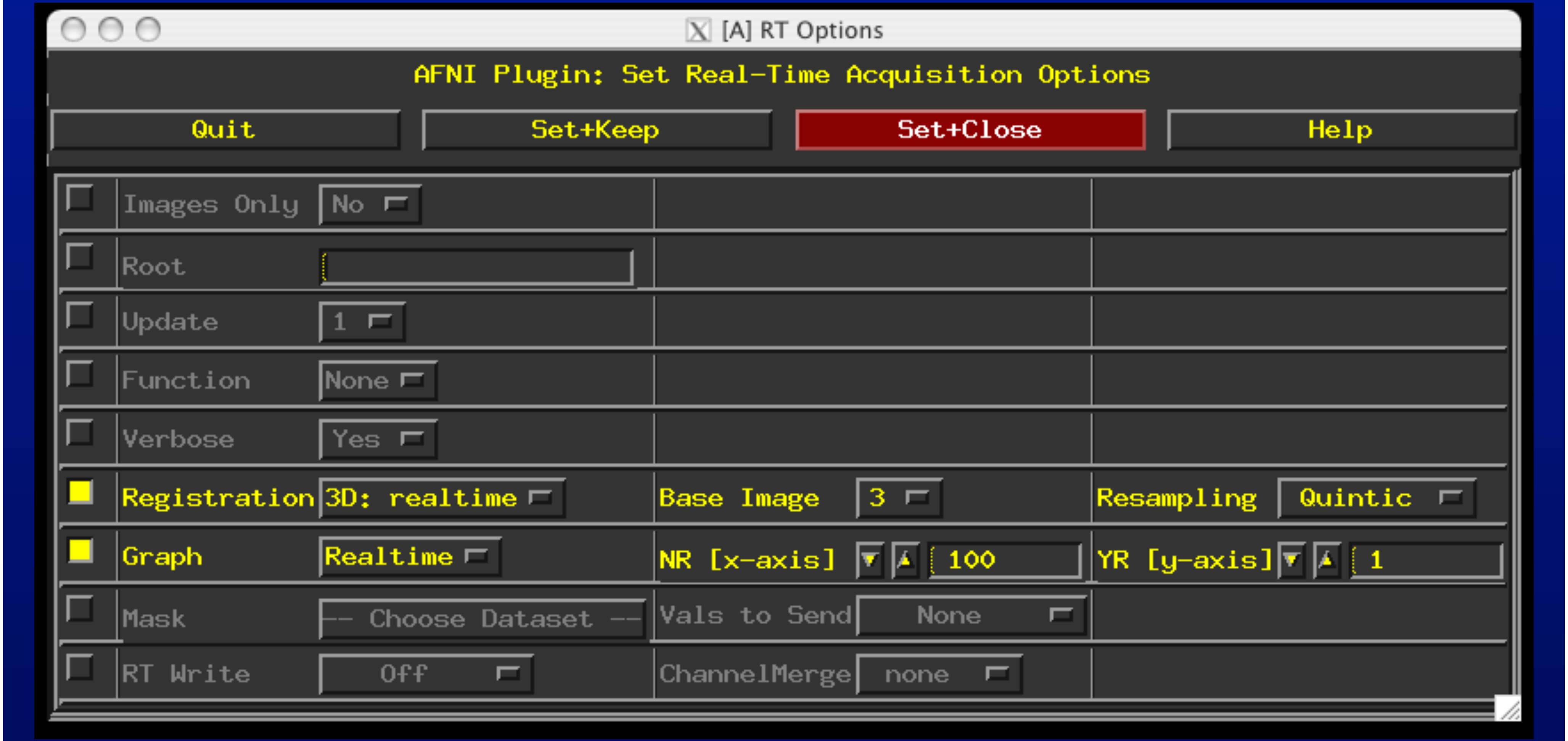


■	Images Only	No				
■	Root					
■	Update	1				
■	Function	None				
■	Verbose	Yes				
■	Registration	None	Base Image	3	Resampling	Quintic
■	Graph	No	NR [x-axis]	100	YR [y-axis]	1
■	Mask	-- Choose Dataset --	Vals to Send	None		
■	RT Write	Off	ChannelMerge	none		

Setting up AFNI's RT plugin

- Via Environment Variables

```
setenv AFNI_REALTIME_Registration      3D:_realtime
setenv AFNI_REALTIME_Graph            Realtime
```



[A] RT Options

AFNI Plugin: Set Real-Time Acquisition Options

□	Images Only	No				
□	Root					
□	Update	1				
□	Function	None				
□	Verbose	Yes				
☑	Registration	3D: realtime	Base Image	3	Resampling	Quintic
☑	Graph	Realtime	NR [x-axis]	100	YR [y-axis]	1
□	Mask	-- Choose Dataset --	Vals to Send	None		
□	RT Write	Off	ChannelMerge	none		

Setting up AFNI

- Manually
- Environment variables
  - See README.environment (~250 variables)
- Layout files
  - Size and position windows just so
- Via plugout_drive
  - Details will follow
- Via *image_monitor* module -drive options

```
-drive_wait 'OPEN_WINDOW axialgraph keypress=A'
-drive_afni 'CLOSE_WINDOW axialimage'
```

Demo time

- Get bootcamp data http://afni.nimh.nih.gov/pub/dist/edu/data/CD.tgz

```
cd AFNI_data6/realtime.demos
```

- Motion monitoring

```
tcsh demo.1.run1
```

  - illustrates real-time data acquisition and motion correction by AFNI
- Motion & function
  - See demo.2.fback.0.README for instructions
  - Illustrates acquisition, motion correction and feedback
    - Remove option “-show_demo_gui yes” from demo.2.fback.1.receiver if it proves troublesome

ROI selection options

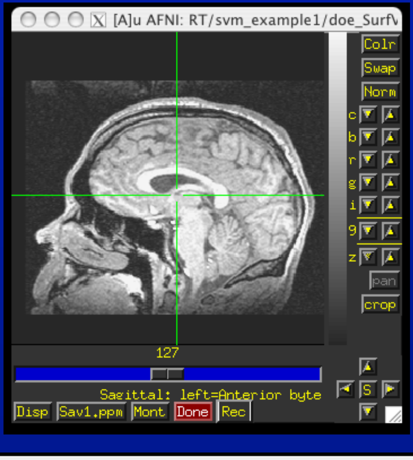
- Standard atlases
  - TT_Daemon :
    - Created by tracing Talairach and Tournoux brain illustrations.
    - Contibuted by Jack Lancaster and Peter Fox of RIC UTHSCSA
  - CA_N27_MPM, CA_N27_ML, CA_N27_PM :
    - Anatomy Toolbox's atlases, some created from cytoarchitectonic
    - studies of 10 human post-mortem brains
    - contributed by Simon Eickhoff, Katrin Amunts and Karl Zilles of IME, Julich,
- FreeSurfer, subject-based
- Functional localizer
- Etc.

Standard-space atlas ROI selection

```
@fast_roi -region CA_N27_ML::Hip \
          -region CA_N27_ML::Amygda \
          -base TT_N27_r2+tlrc. \
          -anat doe_SurfVol_Alnd_Exp+orig. \
          -roi_grid blur_vr_run1_motor_AFB003+orig. \
          -prefix hip_amy -time
```

- less than 1min including skull stripping and xform to TLRC
- A couple of seconds for generating more ROIs

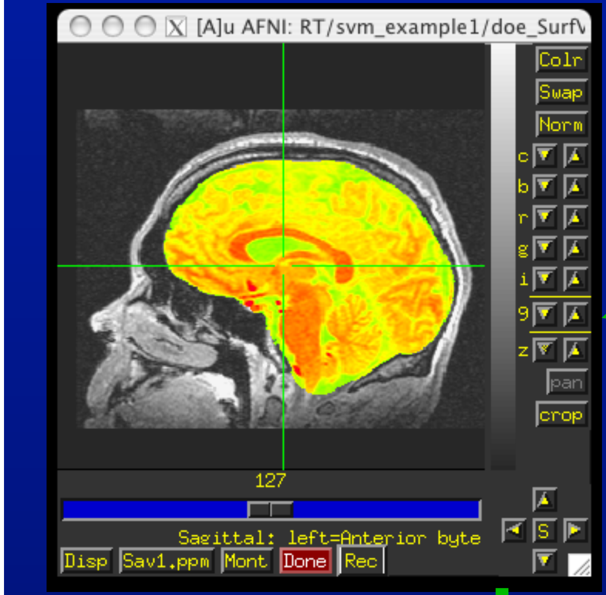
Atlas-based ROIs


[A]u AFNI: RT/svm_example1/doe_SurfV
Colr
Swap
Norm
c
b
r
g
i
9
z
pan
crop
127
Sagittal: left=Anterior byte
S
Disp
Sav1.ppm
Mont
Done
Rec

1- Strip skull

2- Find xform to atlas space

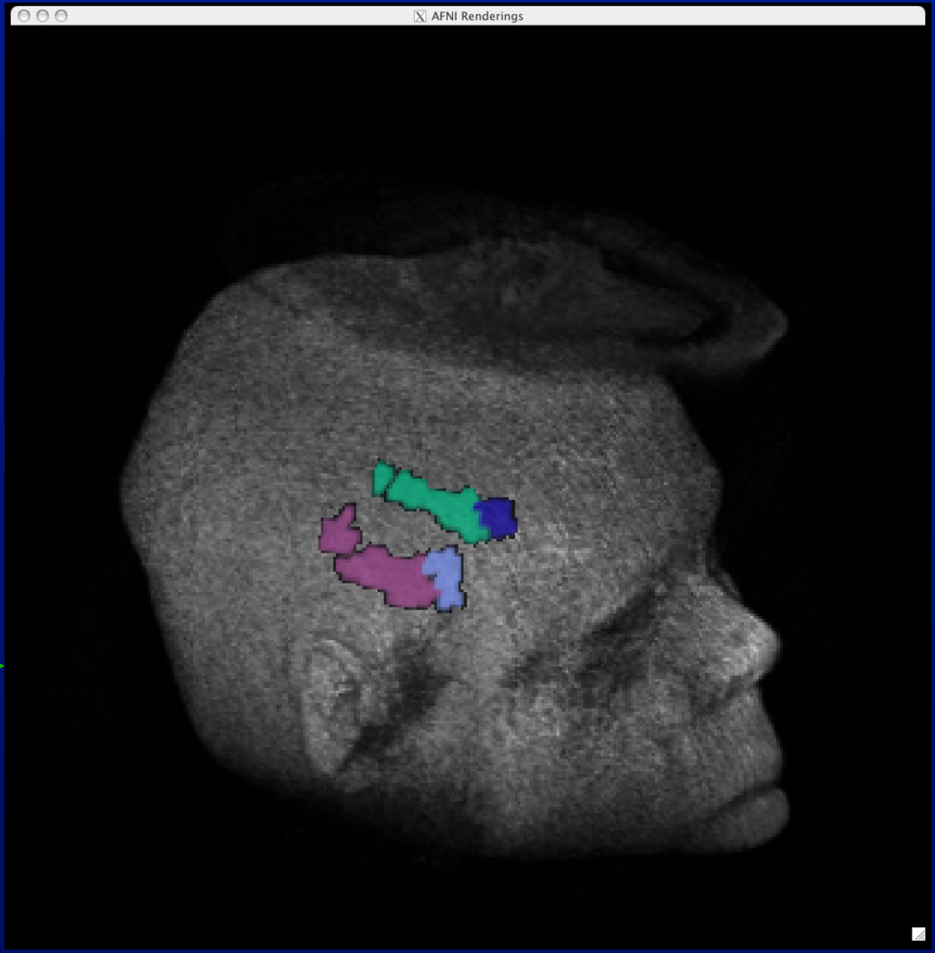
(about 40 secs, 2.5GhZ cpu)


[A]u AFNI: RT/svm_example1/doe_SurfV
Colr
Swap
Norm
c
b
r
g
i
9
z
pan
crop
127
Sagittal: left=Anterior byte
S
Disp
Sav1.ppm
Mont
Done
Rec

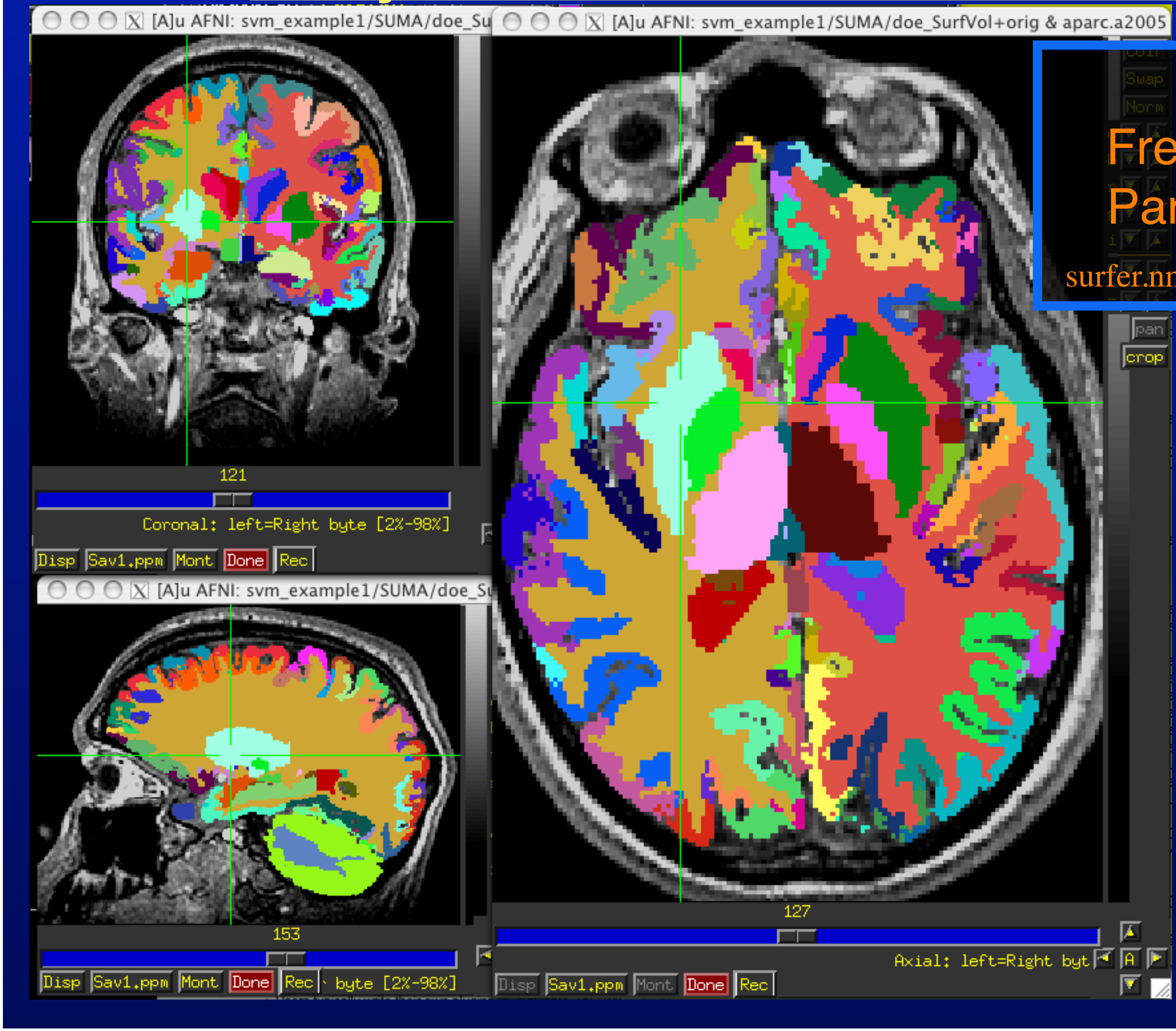
3- Identify ROIs

4- Xform ROIs to native space

(about 2 seconds)



Subject-based Anatomical ROIs

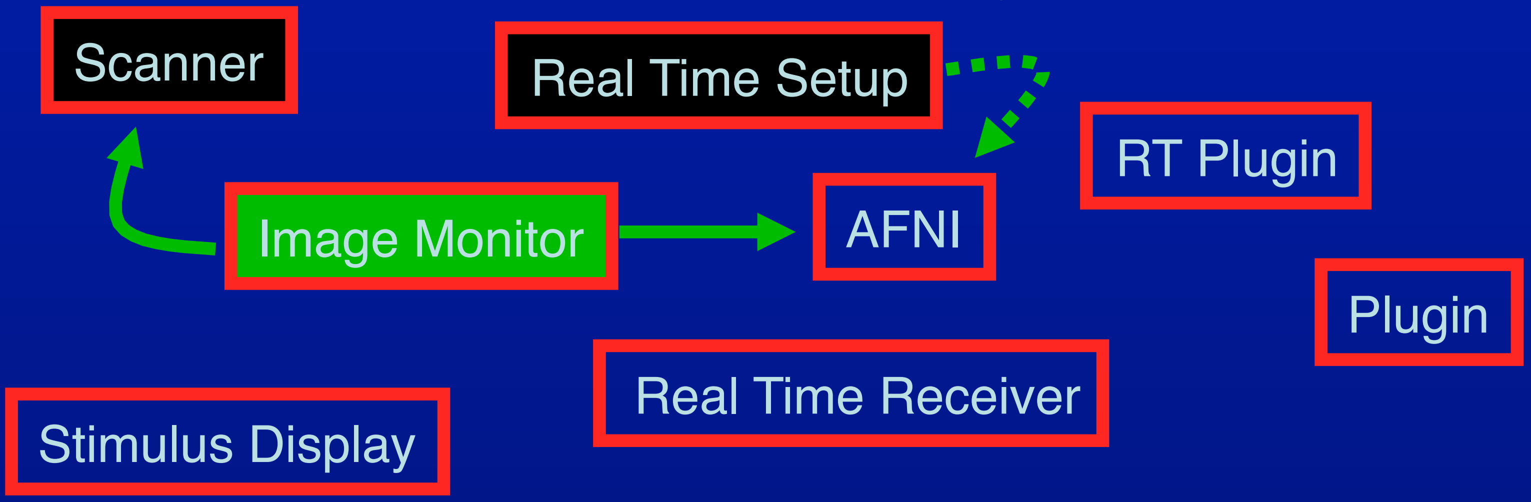


[A]u AFNI: svm_example1/SUMA/doe_Su
[A]u AFNI: svm_example1/SUMA/doe_SurfVol+orig & aparc.a2005
121
Coronal: left=Right byte [2%-98%]
Disp
Sav1.ppm
Mont
Done
Rec
[A]u AFNI: svm_example1/SUMA/doe_Su
153
Disp
Sav1.ppm
Mont
Done
Rec
byte [2%-98%]
Swap
Norm
pan
crop
127
Axial: left=Right byt
A
Disp
Sav1.ppm
Mont
Done
Rec

From FreeSurfer's Parcellations

surfer.nmr.mgh.harvard.edu

The players



Scanner

Real Time Setup

RT Plugin

Image Monitor

AFNI

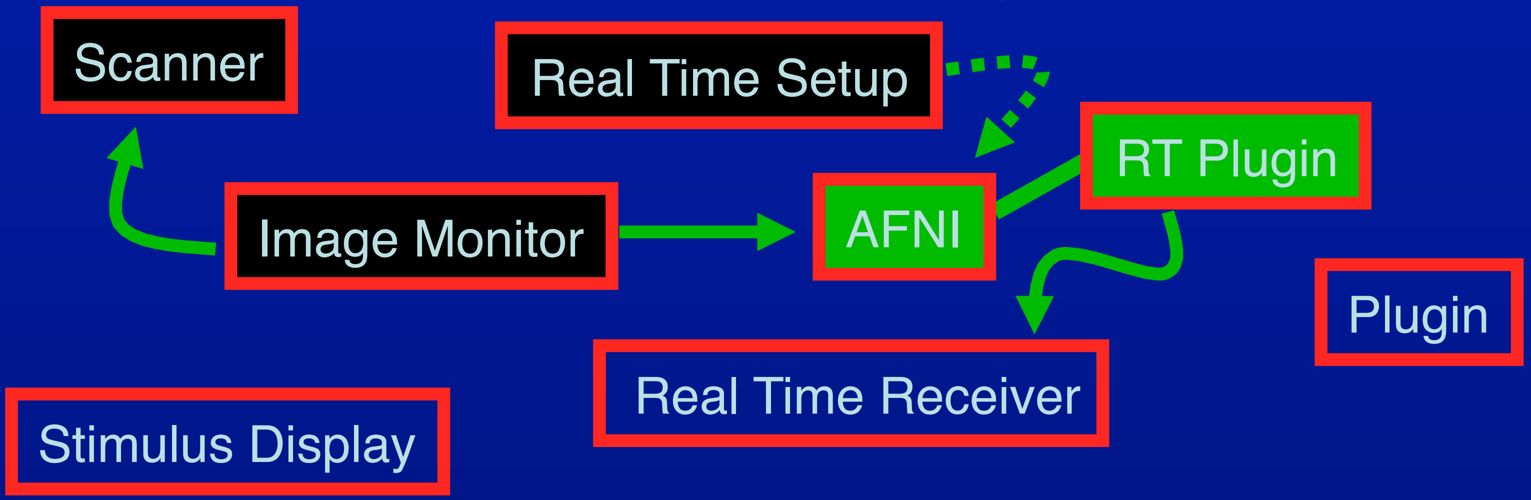
Plugin

Real Time Receiver

Stimulus Display

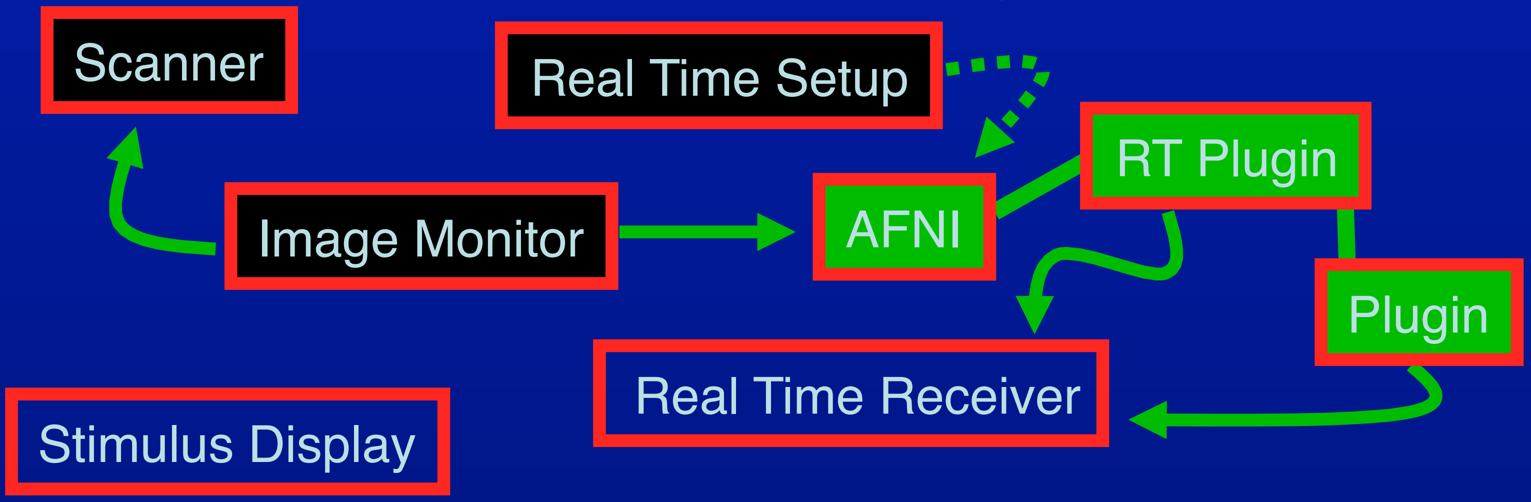
- Image Monitor
  - An AFNI- or user- supplied program to wait for new images
    - AFNI-supplied programs monitor files only:
      - Imon (Monitors GE's old dreaded I files)
      - Dimon (Monitors GE's DICOM images)
      - RTfeedme (Breaks up timeseries dataset and sends it to AFNI)
    - User-supplied programs usually interface with scanner software
      - SIEMENS TRIO/ALLEGRA via functors (S. LaConte BCM, E. Stein NIDA)
    - Often only program that runs on scanner computer
  - Image Monitor sends new images or volumes to AFNI over TCP/IP socket

The players



- AFNI/RT plugin take incoming images/volumes and processes them per the setup instructions
  - Assemble images/volumes into time series
  - Perform image registration
  - Perform (multi*) linear regression
  - Send results to Real Time Receiver through TCP/IP socket
    - Raw, volume registered, or residual volume*
    - ROI based results
  - Send raw or processed volumes to plugins registered to receive them
    - Much faster than TCP/IP (just a data pointer is passed)
    - Plugins can also communicate with Real Time Receiver

The players



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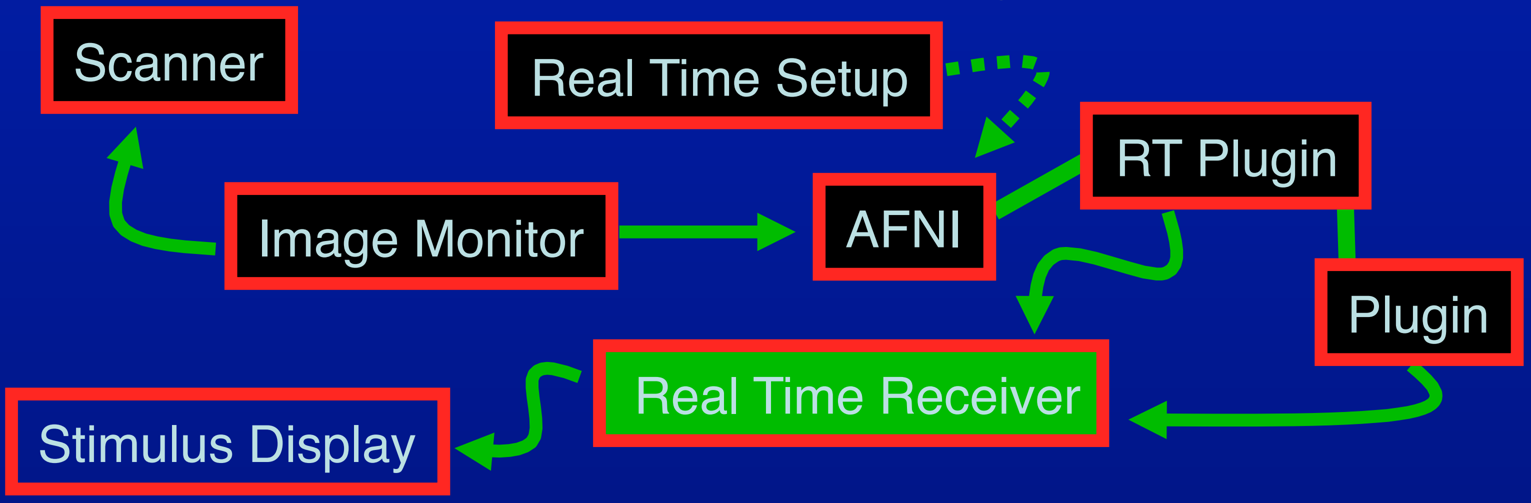


- Real Time Receiver (e.g. serial_helper.c or realtime_receiver.py)
  - AFNI- or User- supplied application that expects incoming data from AFNI and acts on it
    - Motion parameters
    - ROI-based data, all values or just average
    - Entire volumes of raw, or preprocessed data
    - Data from any RT plugin such as 3dsvm
  - Process incoming data to your liking
  - Optionally forward results to Stimulus Display either by serial connection, or TCP/IP*

Image Monitor (Dimon)

Dimon:

- monitor acquisition of Dicom or GE-Ifiles
- optionally write to3d script for creation of AFNI datasets
- optionally send volumes to afni's realtime plugin

```
------------------------------------------------------------------------
find first volume (wait forever, scanning may not have started)
    wait for volume:
        check every 2 seconds or every -sleep_init ms
        check slices to see if a volume is acquired
    once found:
        note grid, orientation, byte order, etc.
        if realtime:
            comm: open link
                try to open TCP channel to afni RT plugin
                check whether channel is ready for data
            comm: send control info
                send acquisition style (2D+zt), zorder, time pattern,
                    TR, FOV, grid, datum, orientation, origin, etc.
            comm: send volume
```

Image Monitor (Dimon), part II

```
set signal handlers, and note between-volume sleep time
for each found volume
    while no new volume is yet found
        check whether the scanner has stalled (run cancelled?)
        sleep for one TR, or -sleep_vol ms, or -sleep_frac fraction of TR
    if this is a new run
        comm: send "end of (previous) run" message
    track volume statistics
    check orientation
    comm: if connection not yet established, send control info
    comm: send volume
upon termination (ctrl-c or -quit and no more data)
    show run statistics
    possibly create to3d script
    comm: terminate connection
```

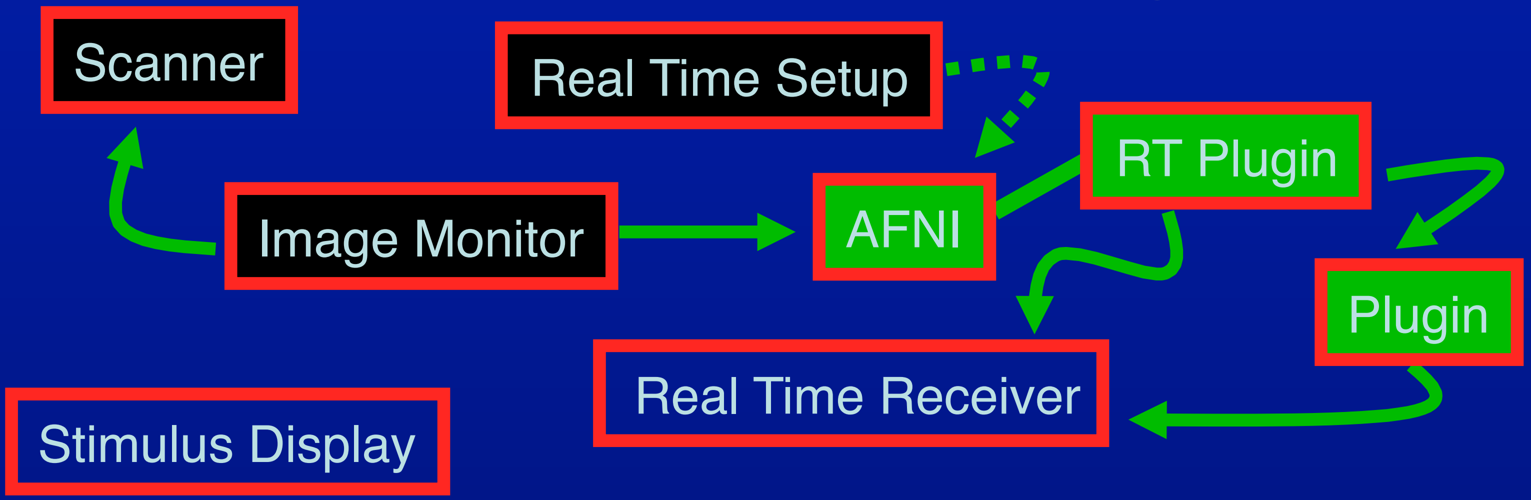
Plug_realtime

```
plug_realtime:
    init: register work process with afni (to be called regularly)
    plugin main: sets plugin control variables
---------------------------------------------------------------------------
main work process: asynchronously from main afni loop
    if new connection, initialize
    if data is bad or no new data after timeout
        write vol. to disk, plot final motion params, comm:close
    if new data: warn user and process
        process control info:  TR, grid, orientation, DRIVE comds., etc.
        prepare to receive data from multiple channels
        setup new dataset
    if done with data: finish_dataset and cleanup
    while there is data to read
        store into images
        if we have a full volume
            add volume to dataset
            possibly register volume to base
                update registration graph
            possibly run regression
            comm: compute and send TR data to realtime receiver
```

Realtime_receiver.py

```
set signal handlers to close all ports on exit
    open incoming socket and wait for connection...
    forever:
        process one run
            wait for the real-time plugin to talk to us
            check magic HELLO for type/amount of data to receive:
                only motion
                motion plus N ROI averages
                motion plus N voxel values (with coordinates, etc.)
        open outgoing serial port
        while no run termination, process one TR
            read incoming TCP data
            compute outgoing results
            write to serial port
    close data ports
```

RT SVM plugin*



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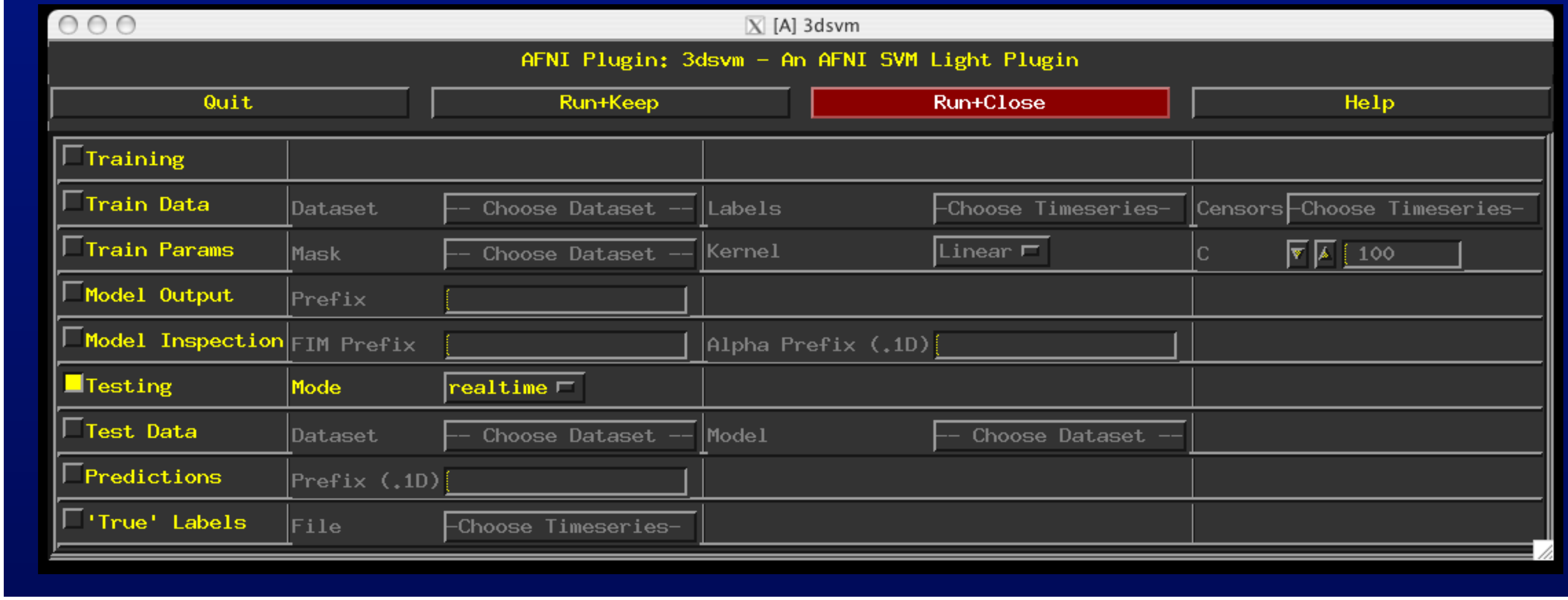
Real Time Receiver

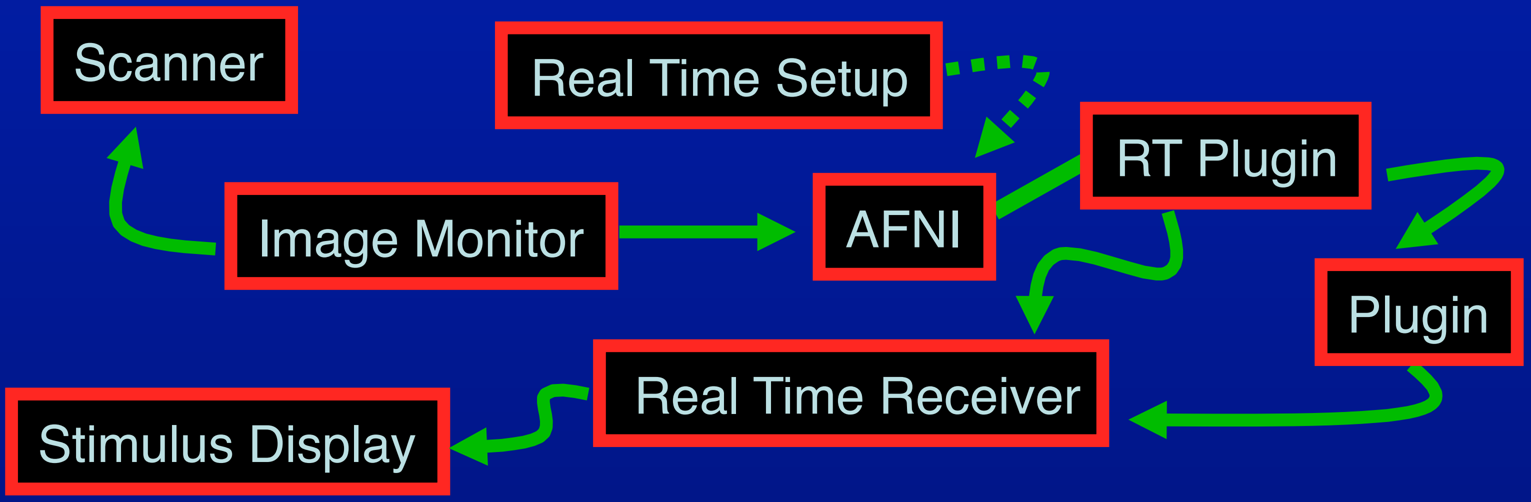
Stimulus Display

- SVM plugin is being modified to accept RT data
  - Given training models, classification is done in real-time



□ Training						
□ Train Data	Dataset	-- Choose Dataset --	Labels	-Choose Timeseries-	Censors	-Choose Timeseries-
□ Train Params	Mask	-- Choose Dataset --	Kernel	Linear	C	100
□ Model Output	Prefix					
□ Model Inspection	FIM Prefix		Alpha Prefix (.1D)			
☑ Testing	Mode	realtime				
□ Test Data	Dataset	-- Choose Dataset --	Model	-- Choose Dataset --		
□ Predictions	Prefix (.1D)					
□ 'True' Labels	File	-Choose Timeseries-				

Real Time SVM*



Scanner

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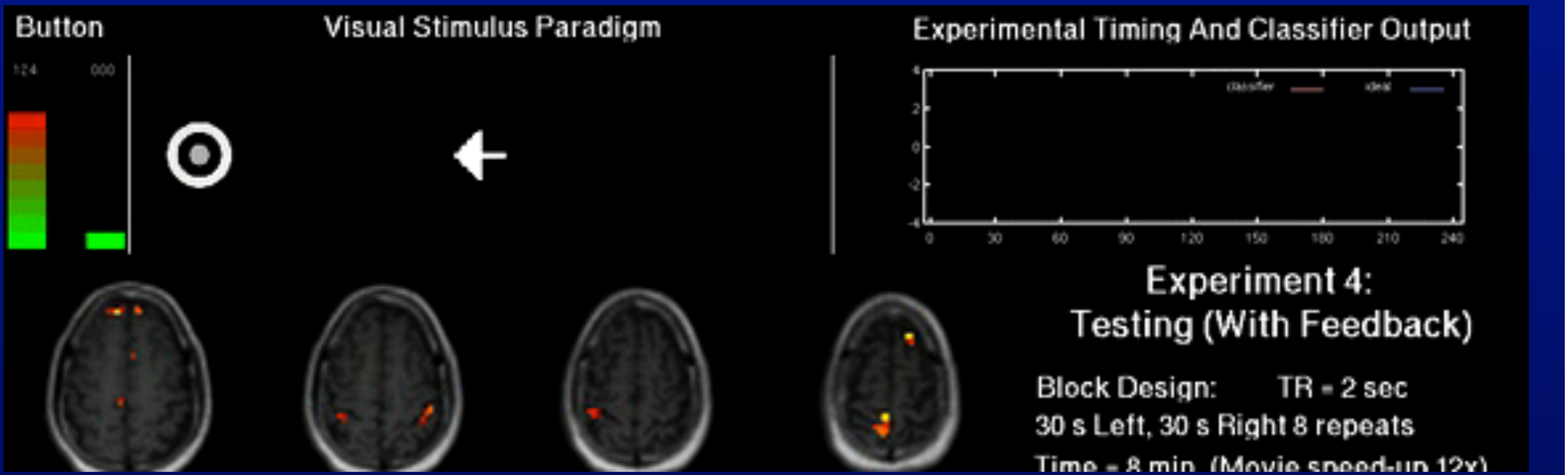
Real Time Receiver

Stimulus Display



Button

Visual Stimulus Paradigm

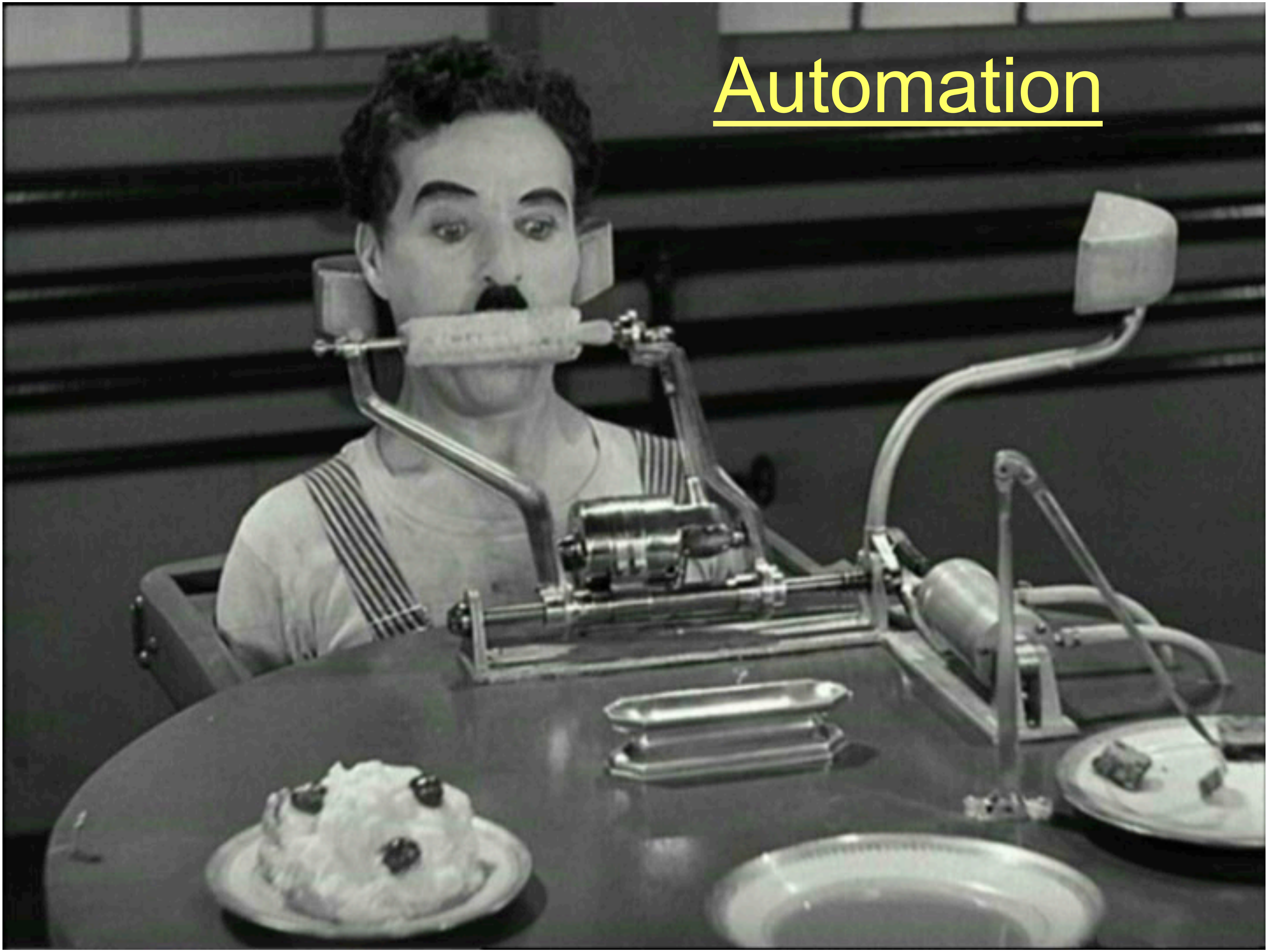
Experimental Timing And Classifier Output

Experiment 4:
Testing (With Feedback)

Block Design: TR = 2 sec
30 s Left, 30 s Right 8 repeats
Time = 8 min (Movie speed-up 12x)

*Movie generated with Real Time setup in S. LaConte et al. HBM 2007

Automation



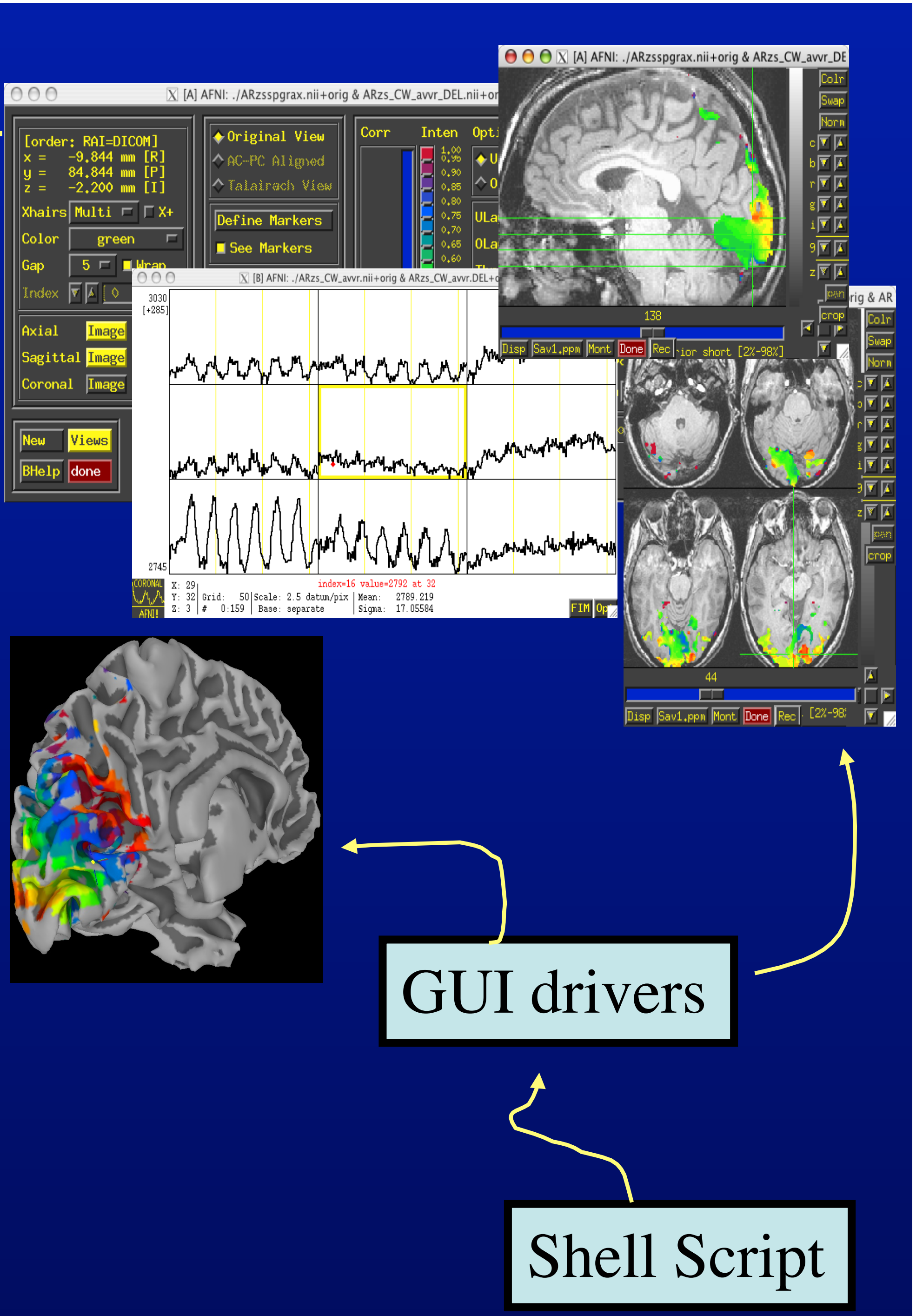
Automating Navigation

Other applications can communicate with AFNI via a program which sends a series of commands for execution.

+ Program called via “system” function (shell invocation)

+ No need to manage sockets or format and transmit commands

+ User Interaction with GUI is uninterrupted



[A] AFNI: ./ARzsspgrax.nii+orig & ARzs_CW_avvr_DEL.nii+orig

```
[order: RAI=DICOM]
x =   -9.844 mm [R]
y =   84.844 mm [P]
z =   -2.200 mm [I]
```

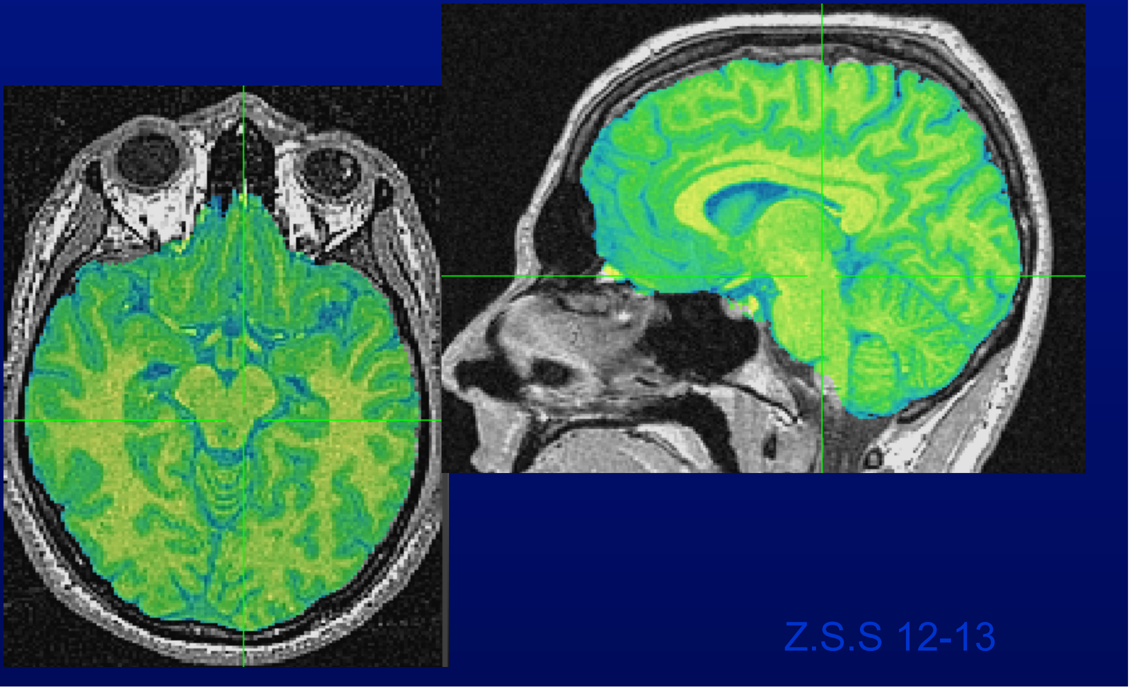
```
index=16 value=2792 at 32
X: 29  Grid:   50  Scale: 2.5 datum/pix  Mean:  2789.219
Y: 32  #    0:159  Base: separate        Sigma:  17.05584
Z: 3
```

GUI drivers

Shell Script

Cycling trough 300 volumes

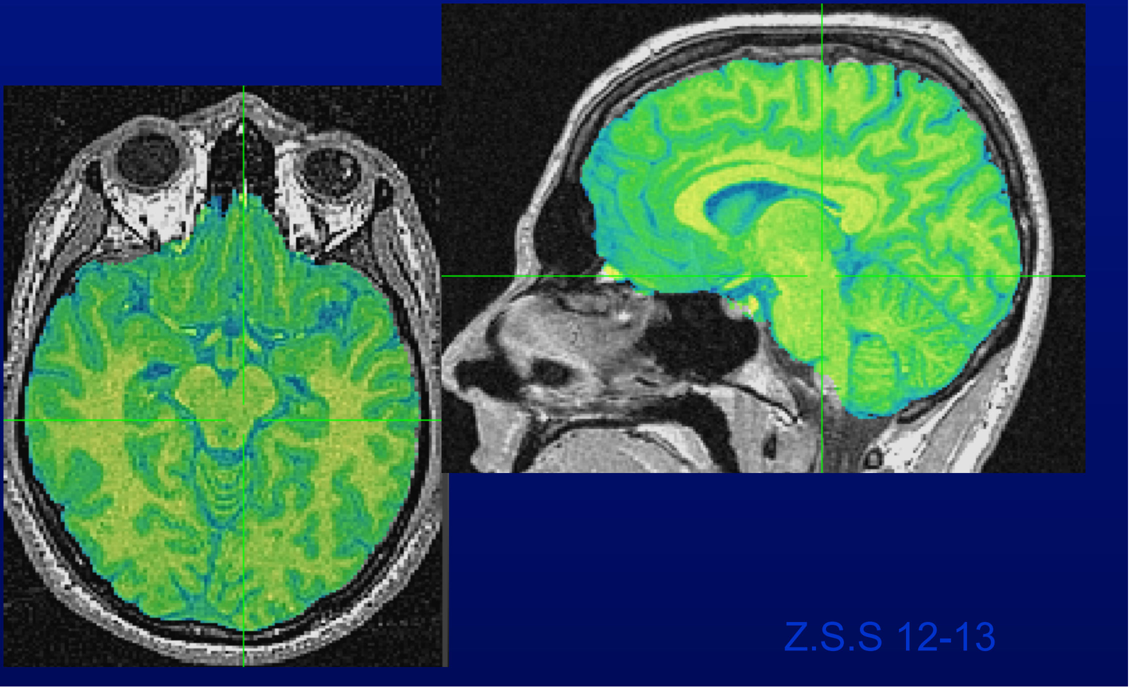
```
while ($cnt < 300)
plugout_drive      -com "SWITCH_UNDERLAY  A anat_${cnt}+orig"
                   -com "SWITCH_OVERLAY A anat.ns_${cnt}+orig"
                   -com 'OPEN_WINDOW A coronalimage opacity=0.5'
                   -com 'OPEN_WINDOW A axialimage keypress=v  opacity=0.4'
                   -quit
     echo "Enter new number or hit enter for next brain:"
     set ans = $<
     if (“$ans” == “”) then
        @ cnt ++
     else
        set cnt = `expr $cnt + $ans`
     endif
 end
```



Cycling trough 300 volumes

Loop over all volumes

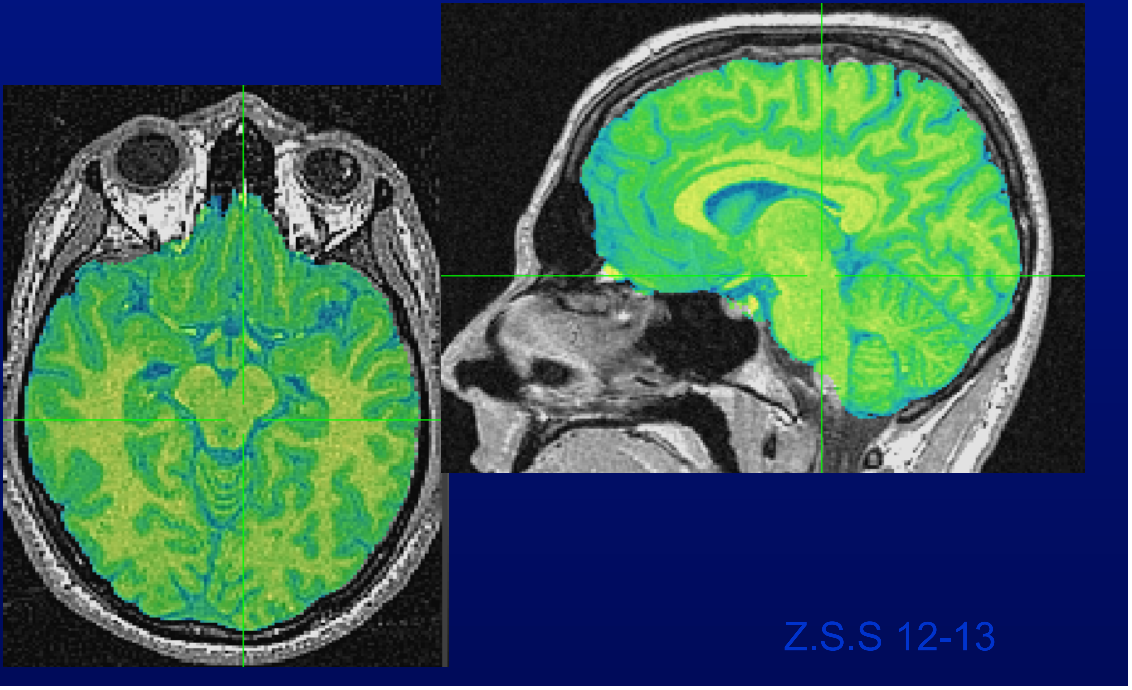
```
while ($cnt < 300)
plugout_drive     -com "SWITCH_UNDERLAY  A anat_${cnt}+orig"
                  -com "SWITCH_OVERLAY A anat.ns_${cnt}+orig"
                  -com 'OPEN_WINDOW A coronalimage opacity=0.5'
                  -com 'OPEN_WINDOW A axialimage keypress=v  opacity=0.4'
                  -quit
    echo "Enter new number or hit enter for next brain:"
    set ans = $<
    if (“$ans” == “”) then
        @ cnt ++
    else
        set cnt = `expr $cnt + $ans`
    endif
end
```



Cycling trough 300 volumes

Switch background volume

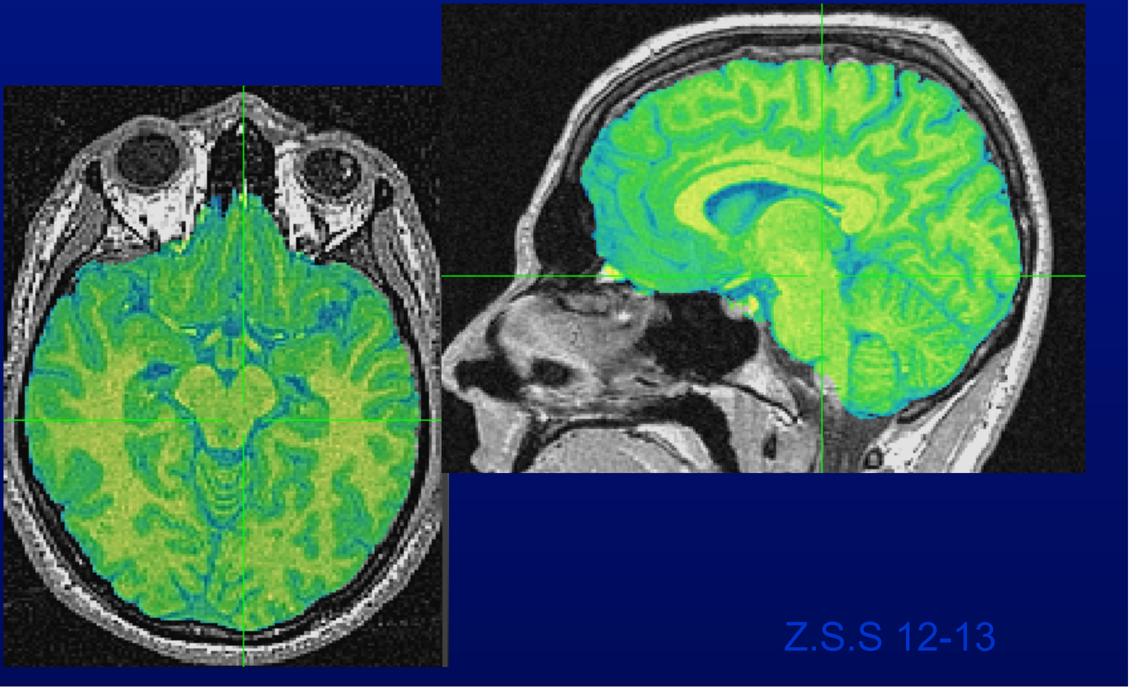
```
while ($cnt < 300)
plugout_drive      -com "SWITCH_UNDERLAY  A anat_${cnt}+orig"
                   -com "SWITCH_OVERLAY A anat.ns_${cnt}+orig"
                   -com 'OPEN_WINDOW A coronalimage opacity=0.5'
                   -com 'OPEN_WINDOW A axialimage keypress=v  opacity=0.4'
                   -quit
     echo "Enter new number or hit enter for next brain:"
     set ans = $<
     if (“$ans” == “”) then
          @ cnt ++
     else
          set cnt = `expr $cnt + $ans`
     endif
end
```



Cycling trough 300 volumes

Switch foreground volume

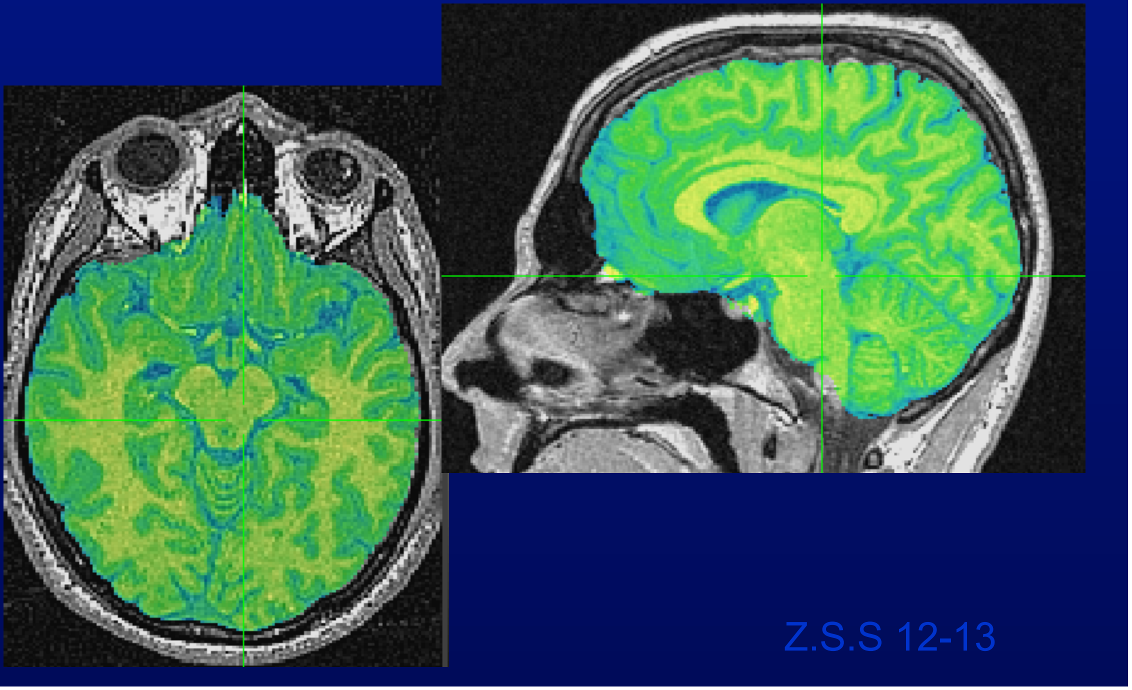
```
while ($cnt < 300)
plugout_drive      -com "SWITCH_UNDERLAY  A anat_${cnt}+orig"
                   -com "SWITCH_OVERLAY A anat.ns_${cnt}+orig"
                   -com 'OPEN_WINDOW A coronalimage opacity=0.5'
                   -com 'OPEN_WINDOW A axialimage keypress=v  opacity=0.4'
                   -quit
     echo "Enter new number or hit enter for next brain:"
     set ans = $<
     if (“$ans” == “”) then
        @ cnt ++
     else
        set cnt = `expr $cnt + $ans`
     endif
 end
```



Cycling trough 300 volumes

Open coronal image with low opacity

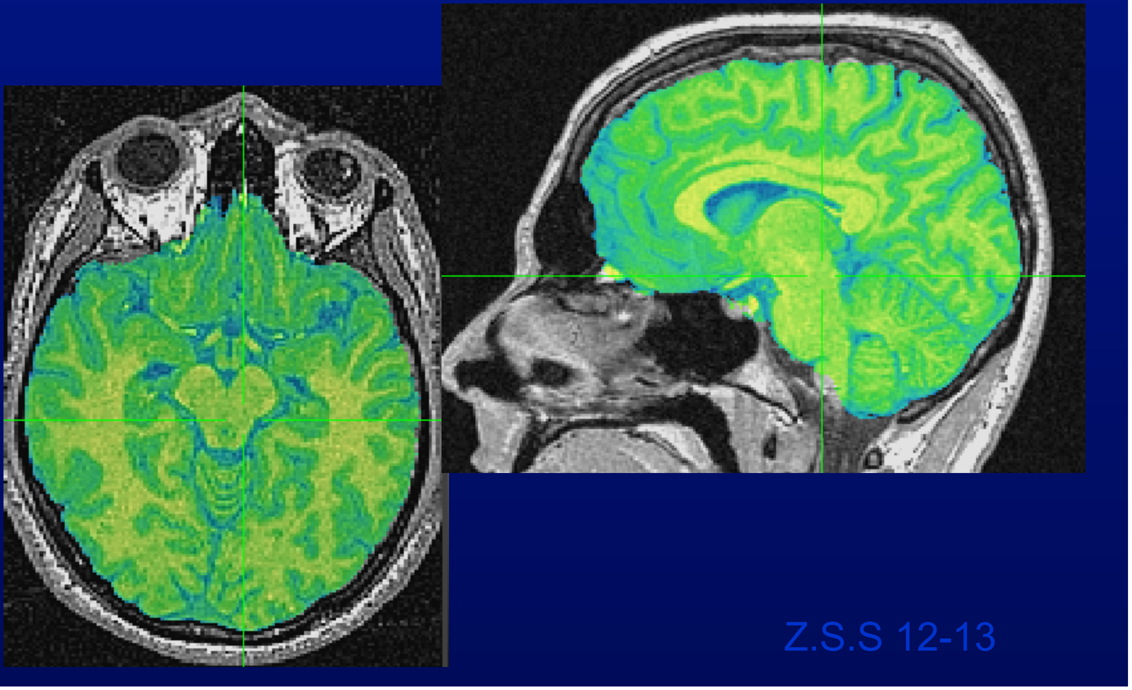
```
while ($cnt < 300)
plugout_drive      -com "SWITCH_UNDERLAY  A anat_${cnt}+orig"
                   -com "SWITCH_OVERLAY A anat.ns_${cnt}+orig"
                   -com 'OPEN_WINDOW A coronalimage opacity=0.5'
                   -com 'OPEN_WINDOW A axialimage keypress=v  opacity=0.4'
                   -quit
     echo "Enter new number or hit enter for next brain:"
     set ans = $<
     if (“$ans” == “”) then
         @ cnt ++
     else
         set cnt = `expr $cnt + $ans`
     endif
 end
```



Cycling trough 300 volumes

Open axial image and start video mode

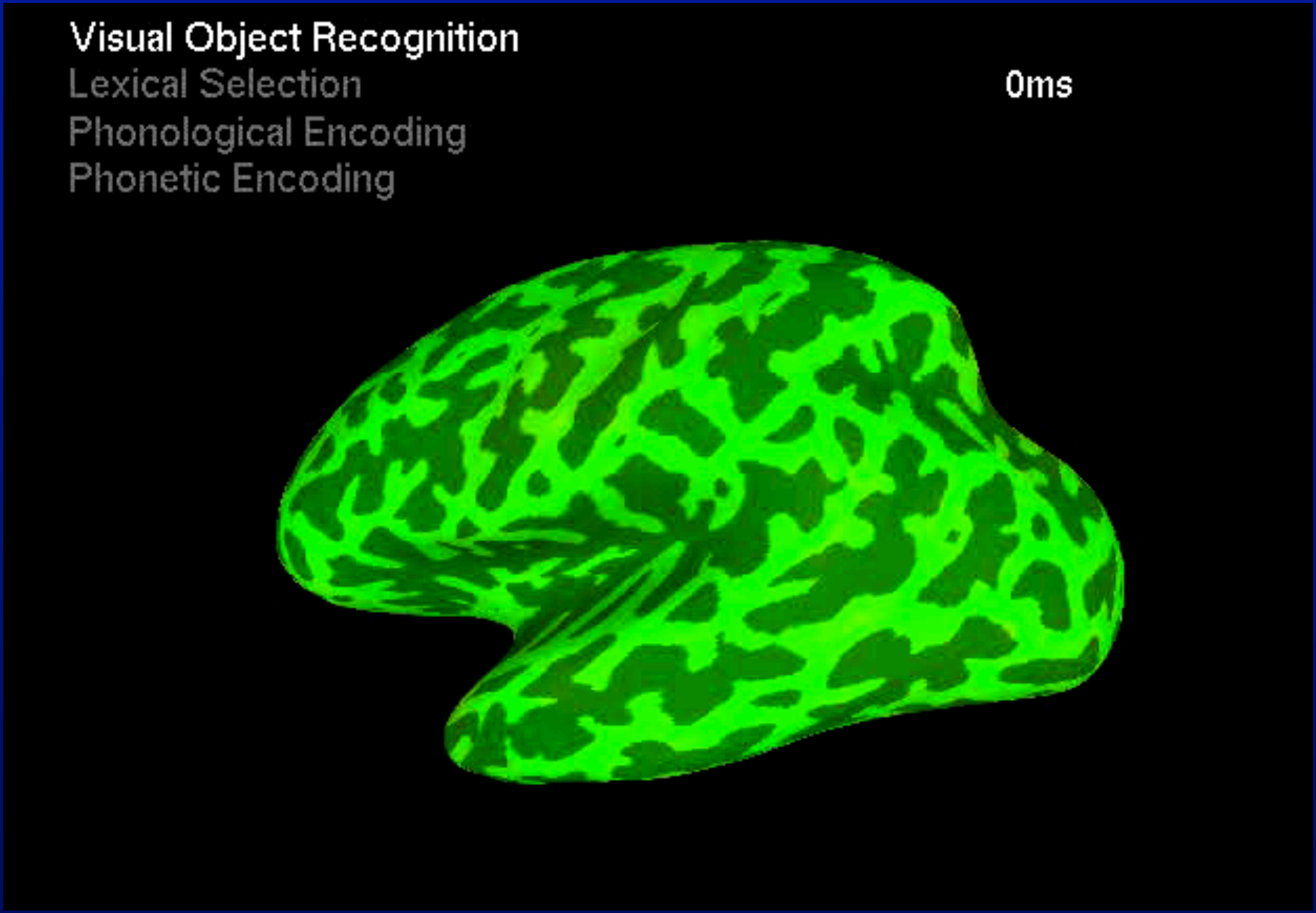
```
while ($cnt < 300)
plugout_drive      -com "SWITCH_UNDERLAY  A anat_${cnt}+orig"
                   -com "SWITCH_OVERLAY A anat.ns_${cnt}+orig"
                   -com 'OPEN_WINDOW A coronalimage opacity=0.5'
                   -com 'OPEN_WINDOW A axialimage keypress=v  opacity=0.4'
                   -quit
     echo "Enter new number or hit enter for next brain:"
     set ans = $<
     if (“$ans” == “”) then
          @ cnt ++
     else
          set cnt = `expr $cnt + $ans`
     endif
end
```



SUMA Movie Sample

Use this link if viewing pdf. Video courtesy of Chunmao Wang.

http://afni.nimh.nih.gov/sscc/staff/ziad/Misc_Download/Beauteous/ChunmaoWang.lh_lat_inflated.mpg



"Help" sources

- Readme files
  - README.driver
  - README.environment
  - README.realtime
- Demo material available on:

  http://afni.nimh.nih.gov
- Automation Demos scripts
  - `@DriveAfni` script
  - `@DriveSuma` script
  - `@DO.examples`
  - `@Install_TSrestMovieDemo`
  - `@Install_InstaCorr_Demo`
  - `Scripts in class data under:`
    - `AFNI_data6/realtime.demos/`
- Sample programs
  - `rtfeedme.c`
  - `Dimon.c`
  - `serial_helper.c`
  - `realtime_receiver.py`
- Talk to us, we're interested in applications