REAL-TIME FMRI:
setup, image monitoring, statistics, and feedback

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

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

QuickTime® and a decompressor are needed to see this

Weiskopf, N et al. 2007

- 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

Outline

- This talk will focus on AFNI's interface for real-time FMRI
  - Examples of how real-time FMRI can be useful
  - A brief intro to the interactive interface
  - Demo I: simple image monitoring
  - Demo II: Demo I + GLM
  - Demo III: Feedback

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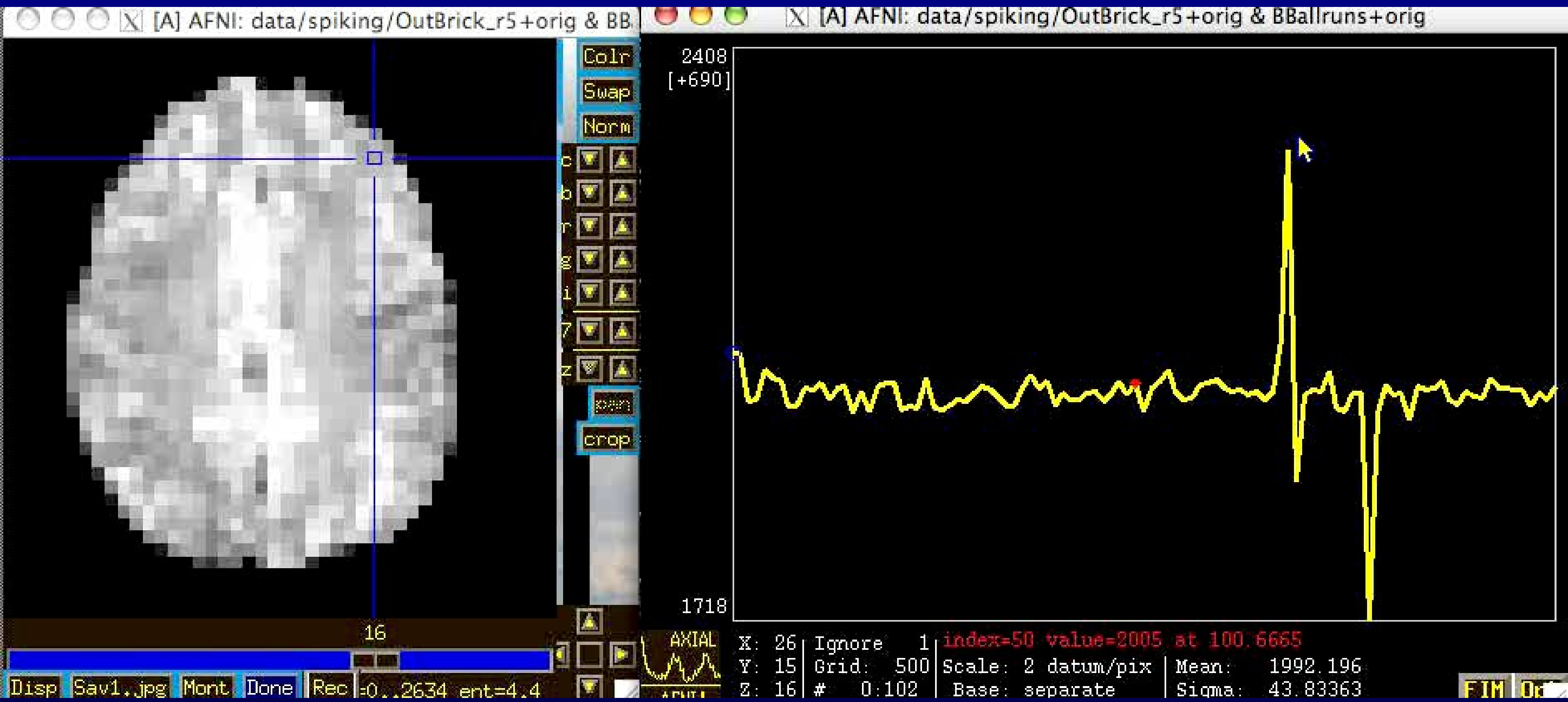
Weiskopf, N et al. 2007



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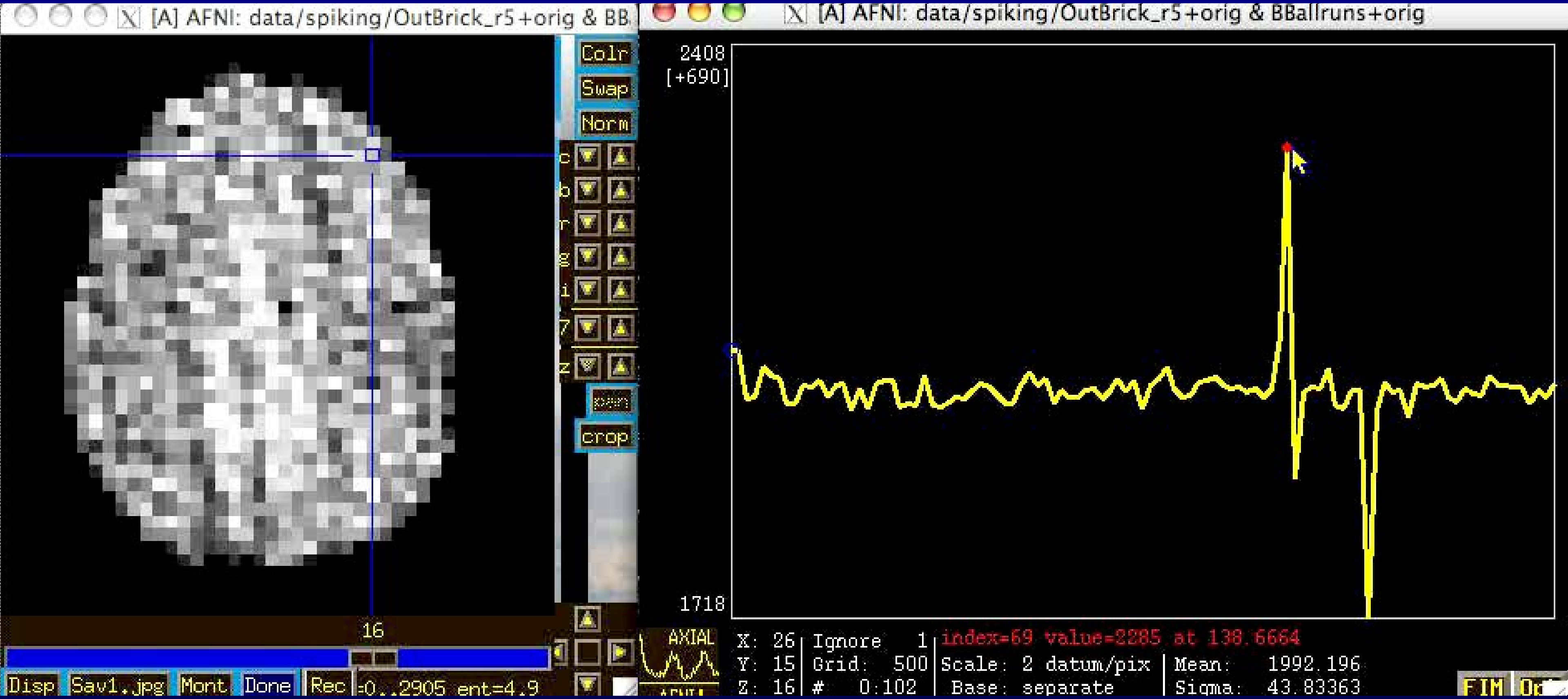

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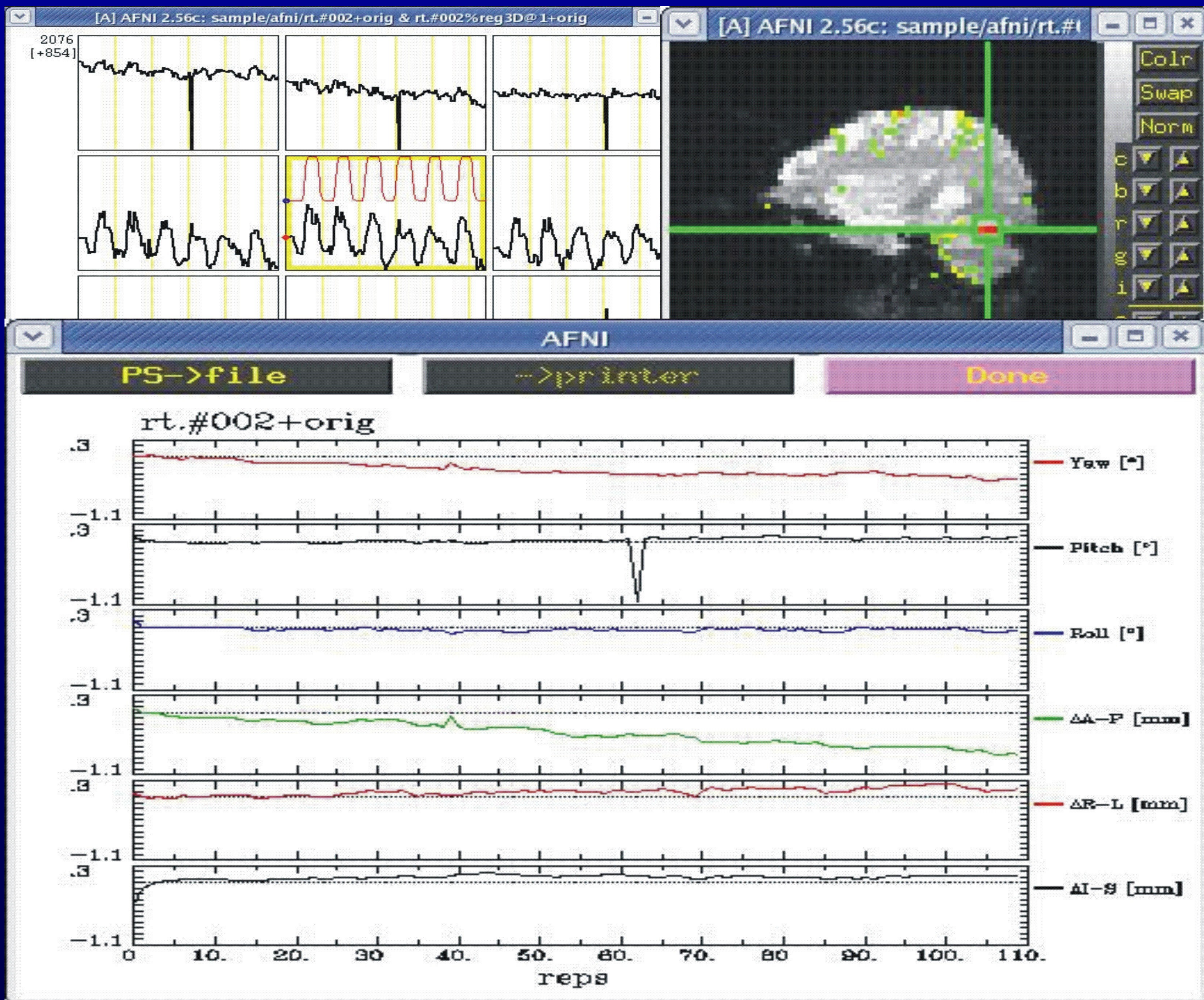
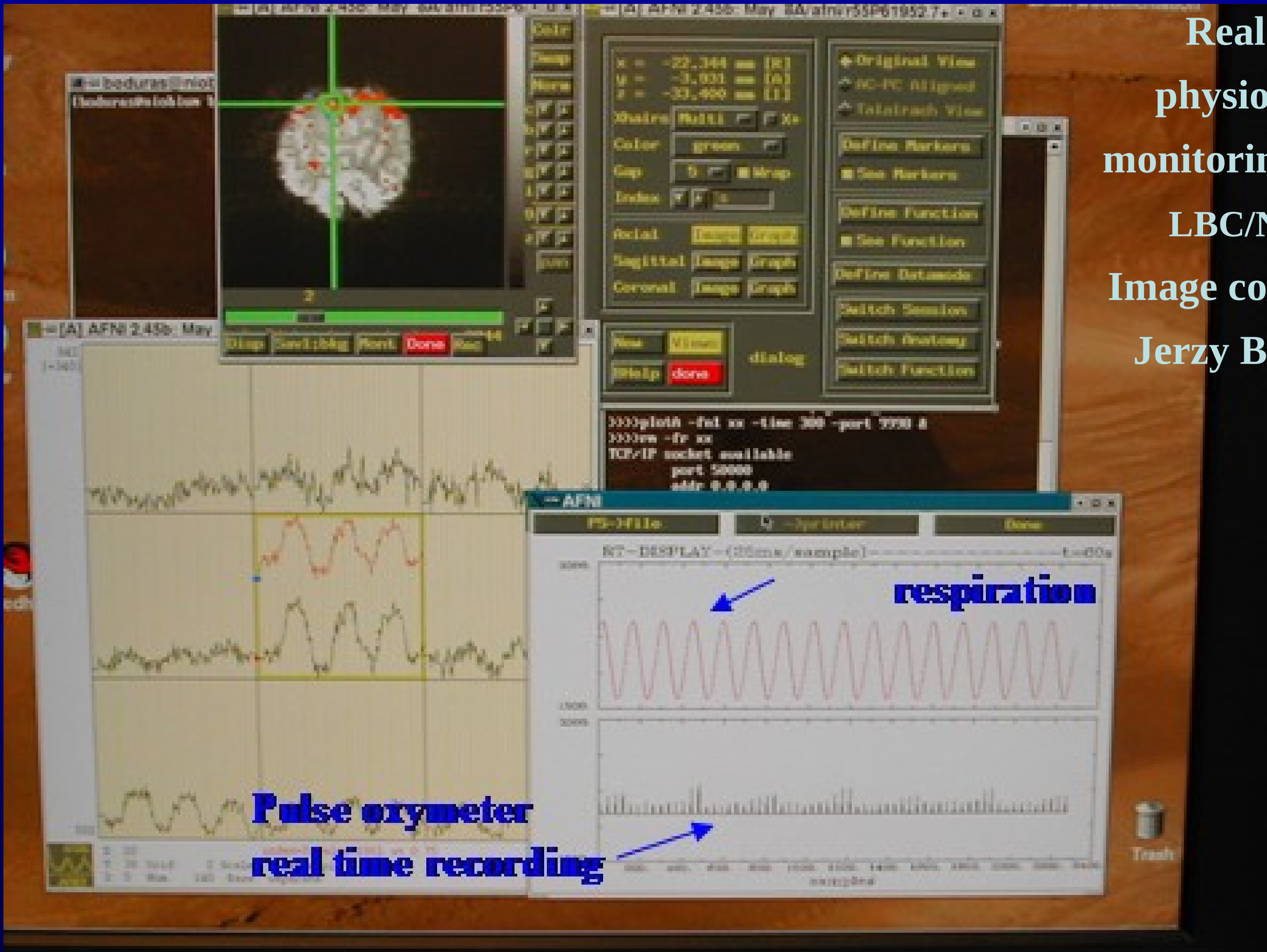


Real-time Estimation of Functional Activation

Real-time Estimation of subject movement

Image Quality Control



Real time physiological monitoring at FIM/ LBC/NIMH

Image courtesy of Jerzy Bodurka

Image Quality Control

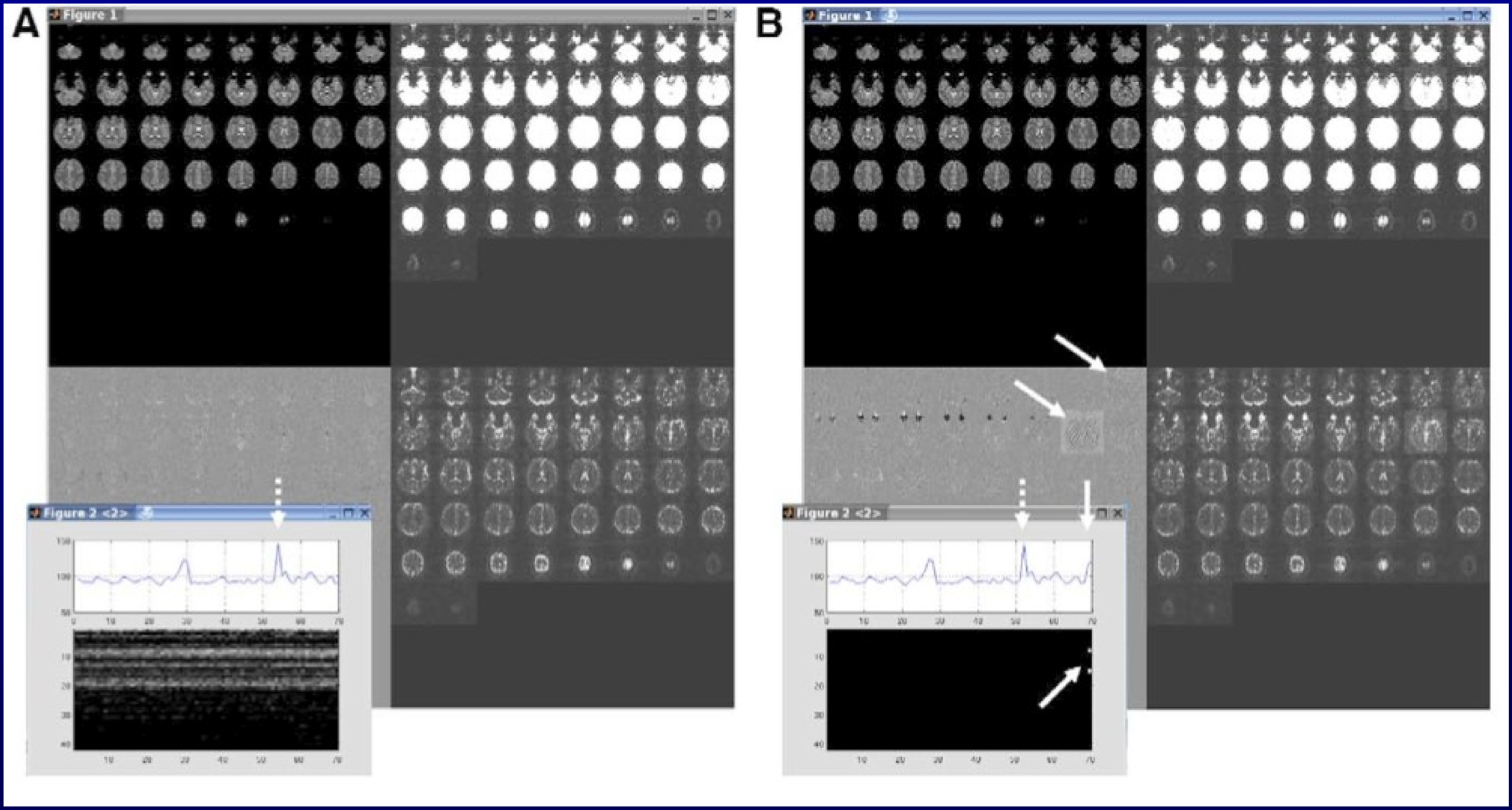
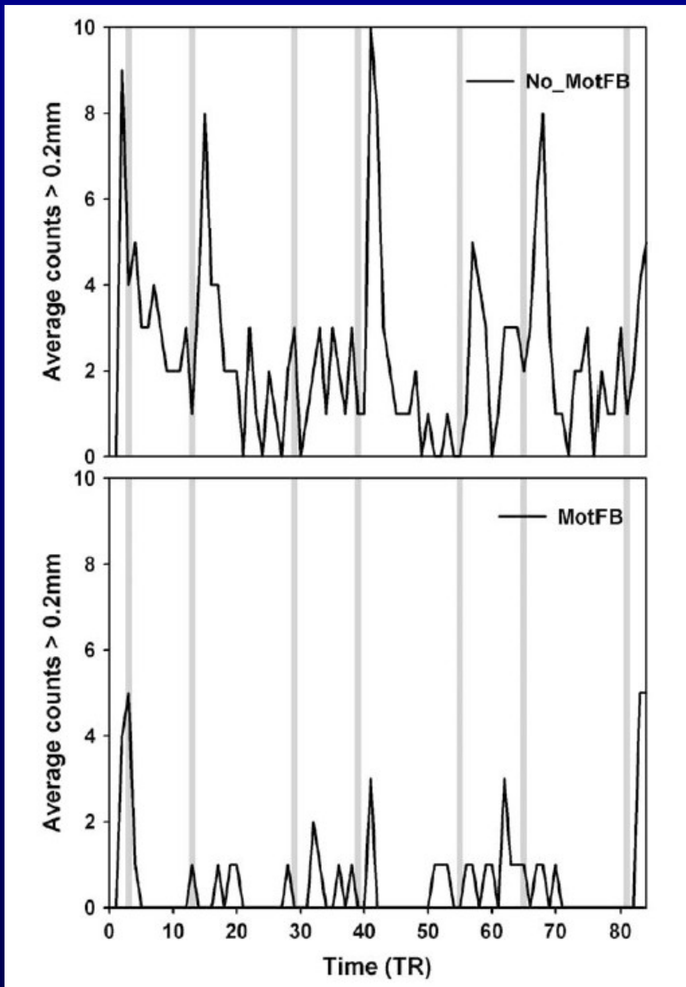


Fig. 1. From Weiskopf, N. et al. MRI 07

Reduce Motion with Feedback

- Feedback and Biofeedback
  - Reduce motion

Yang, S. et al. 08



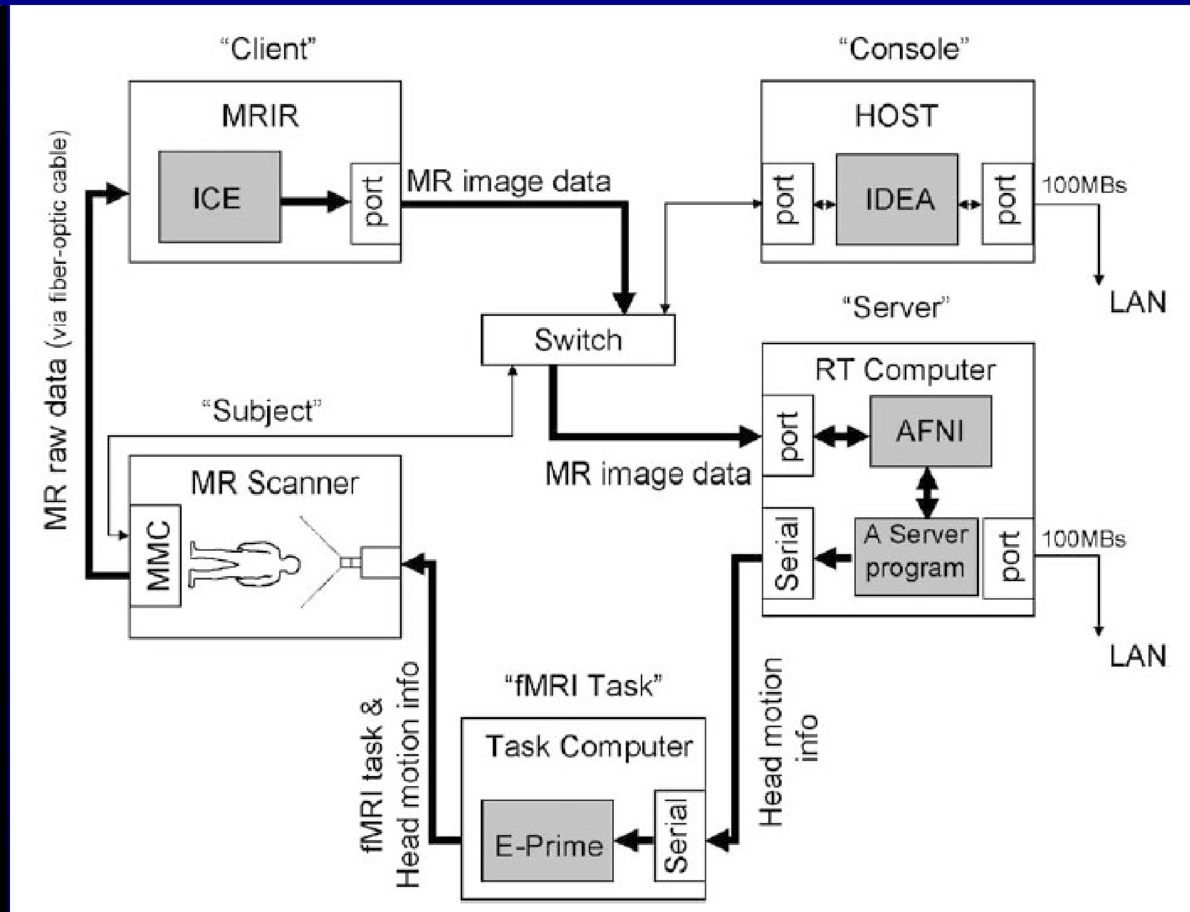


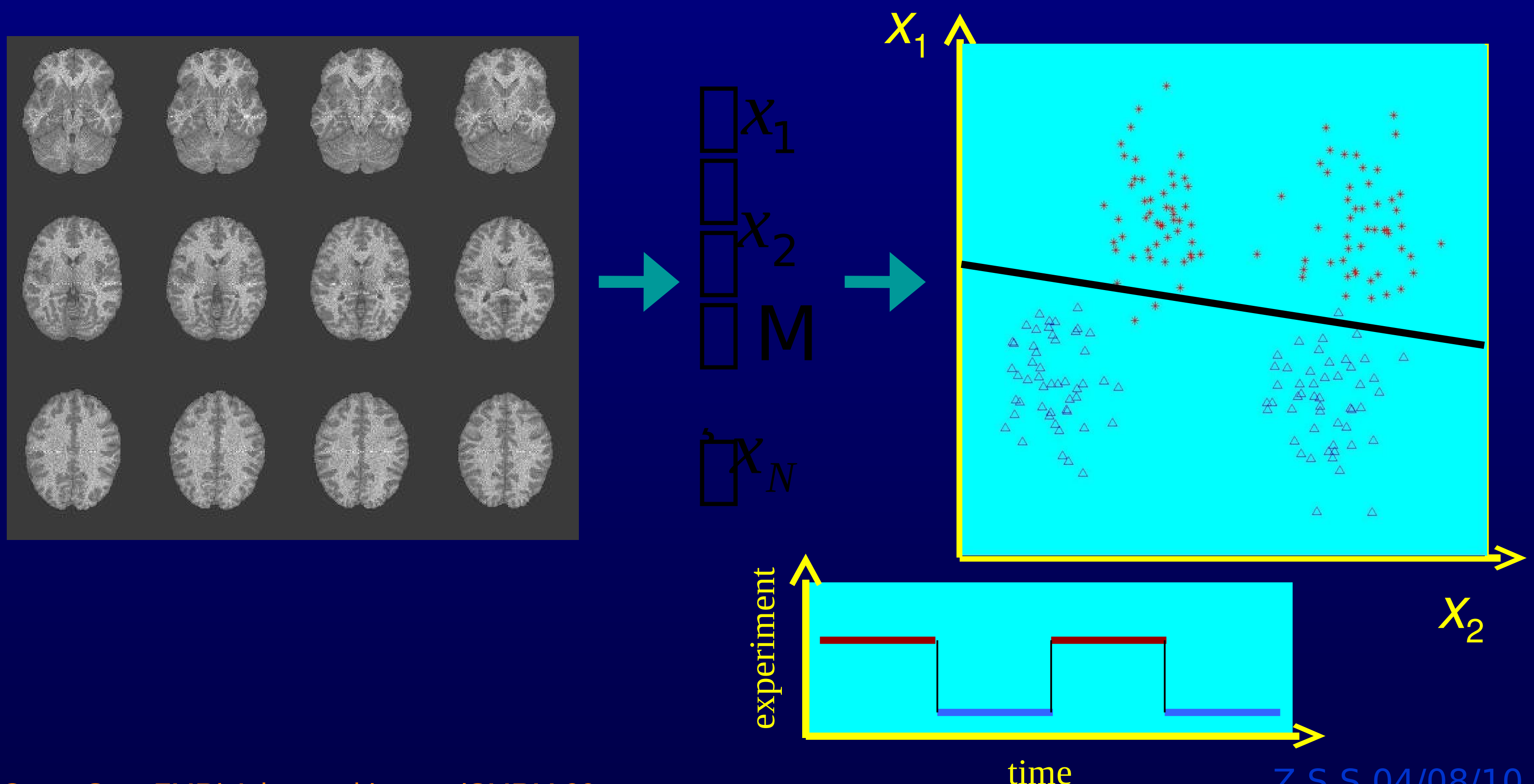
Fig. 2. Configuration of the real-time analysis system and data flow schematic.

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

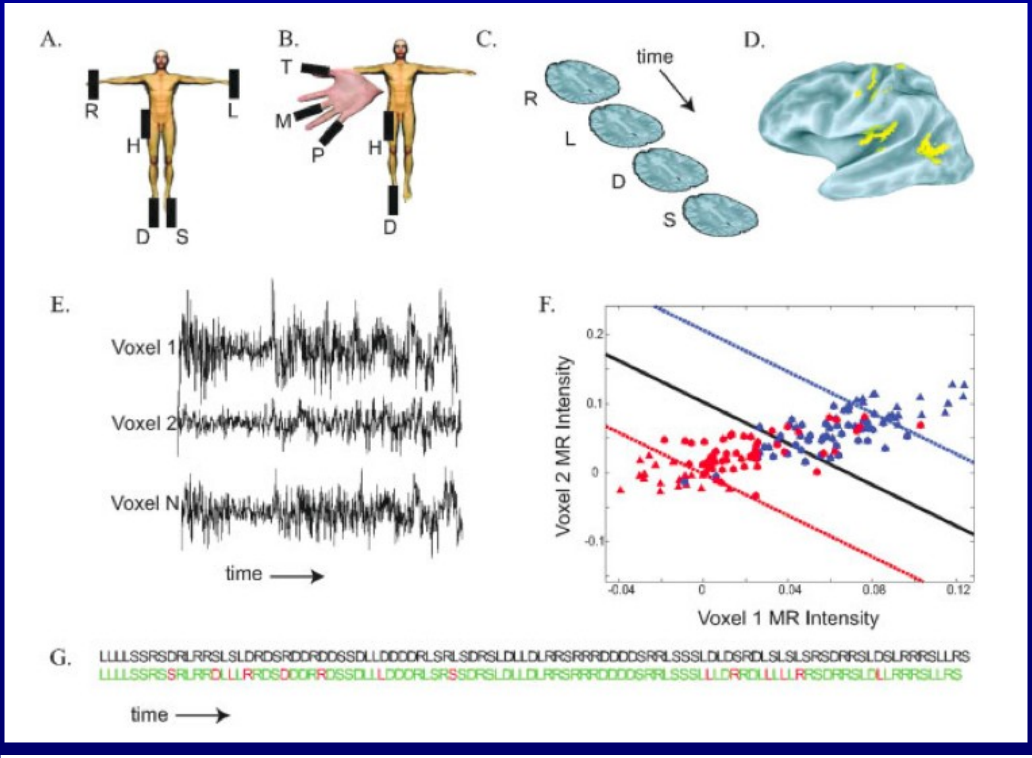
Fig.2 from Yang, S. et al. Neuroimage 05

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



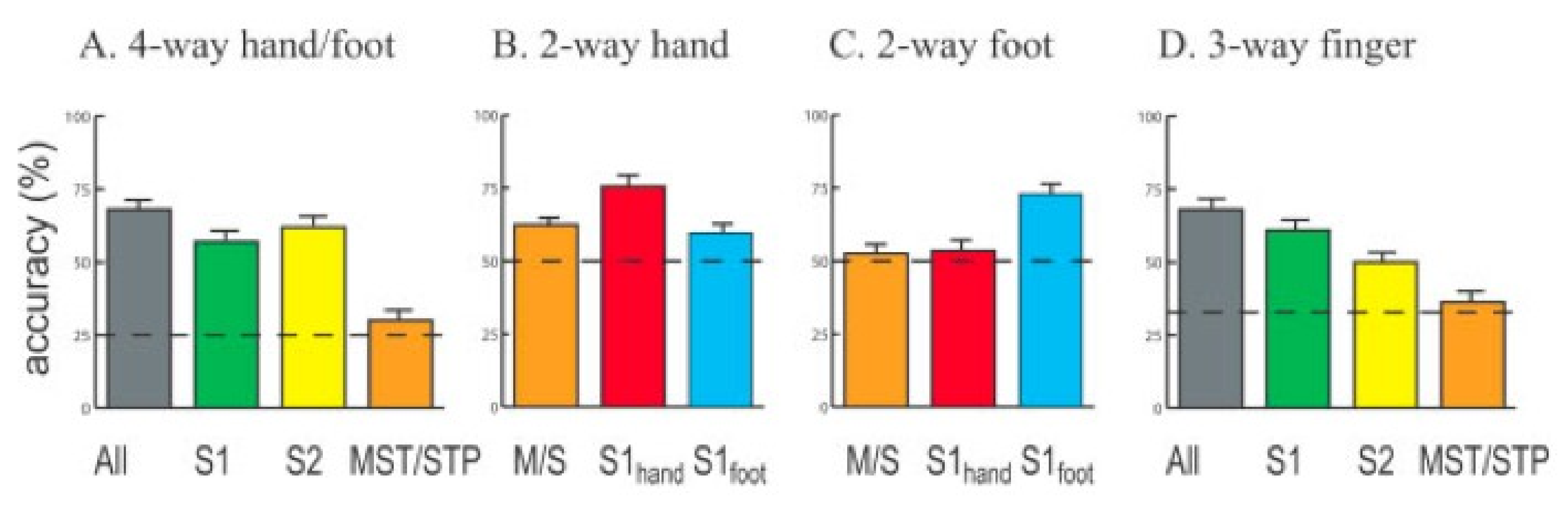
From LaConte S. – FMRI Advanced Issues ISMRM 09



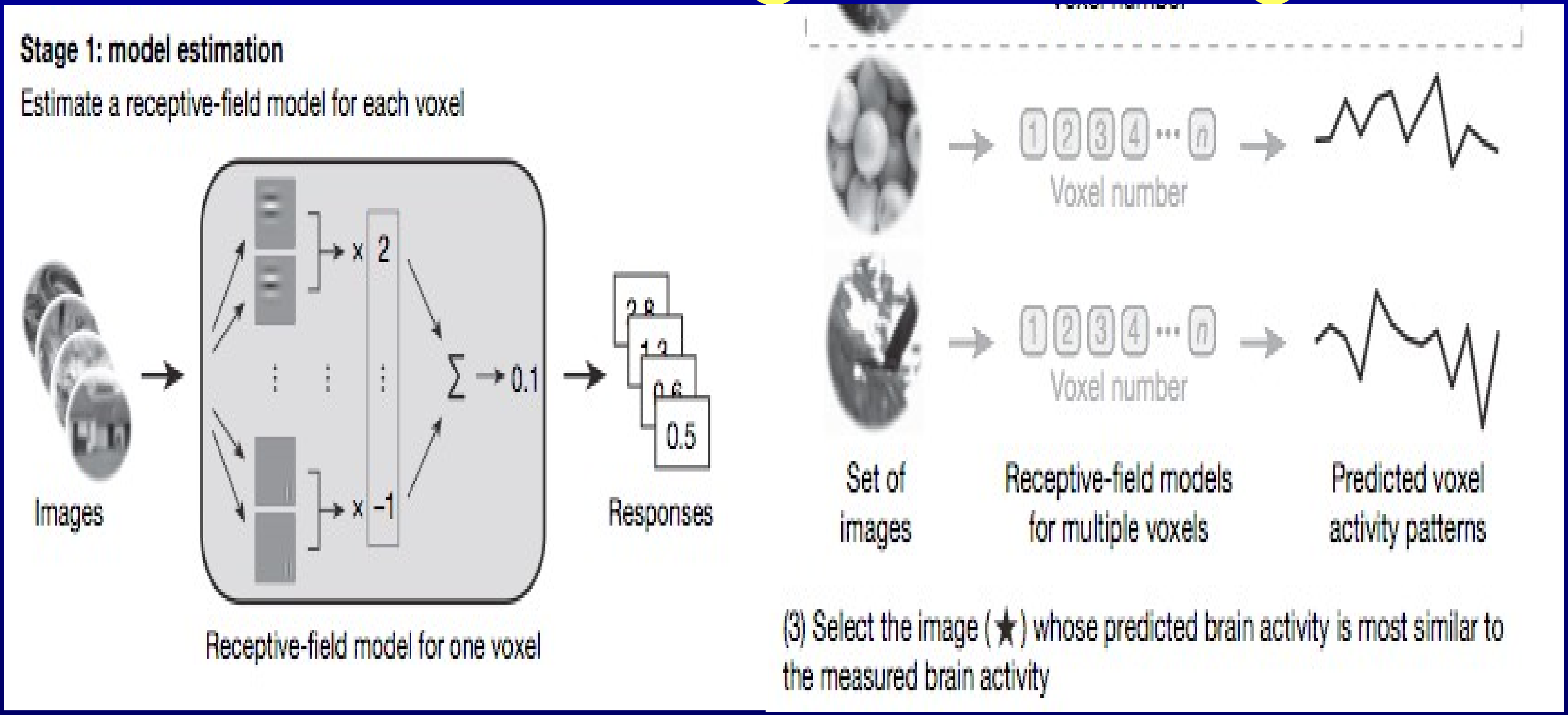
Single 2 second event

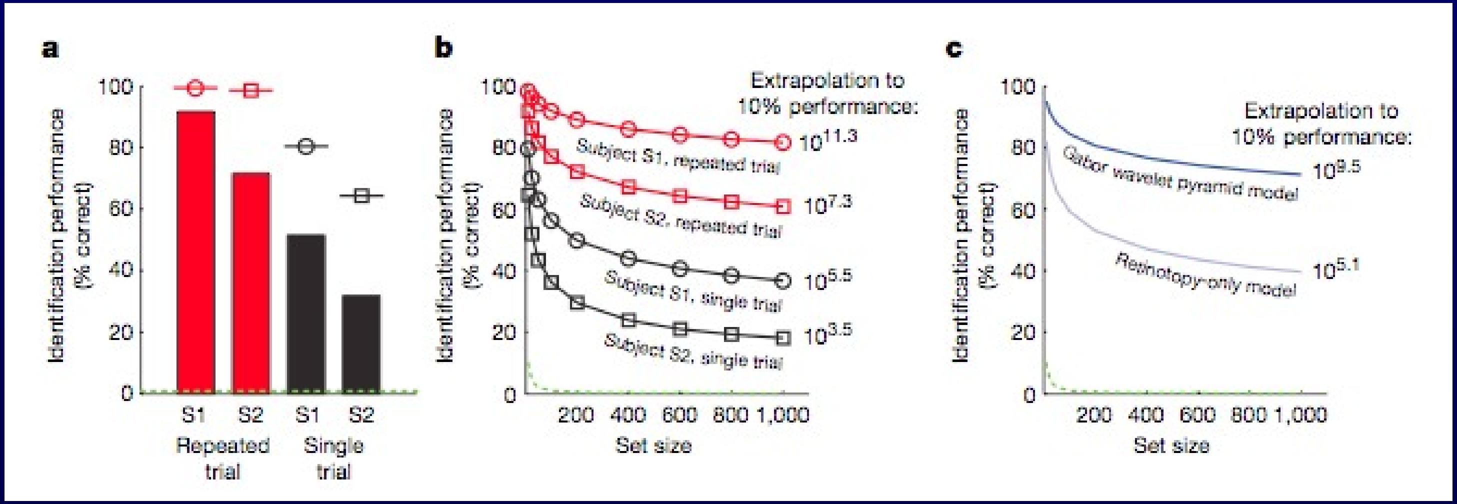
From fast randomized event related FMRI

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



Predicting new images





Figs.1 and 4 from Kay K. et al. Nature 08

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Brain Computer Interface

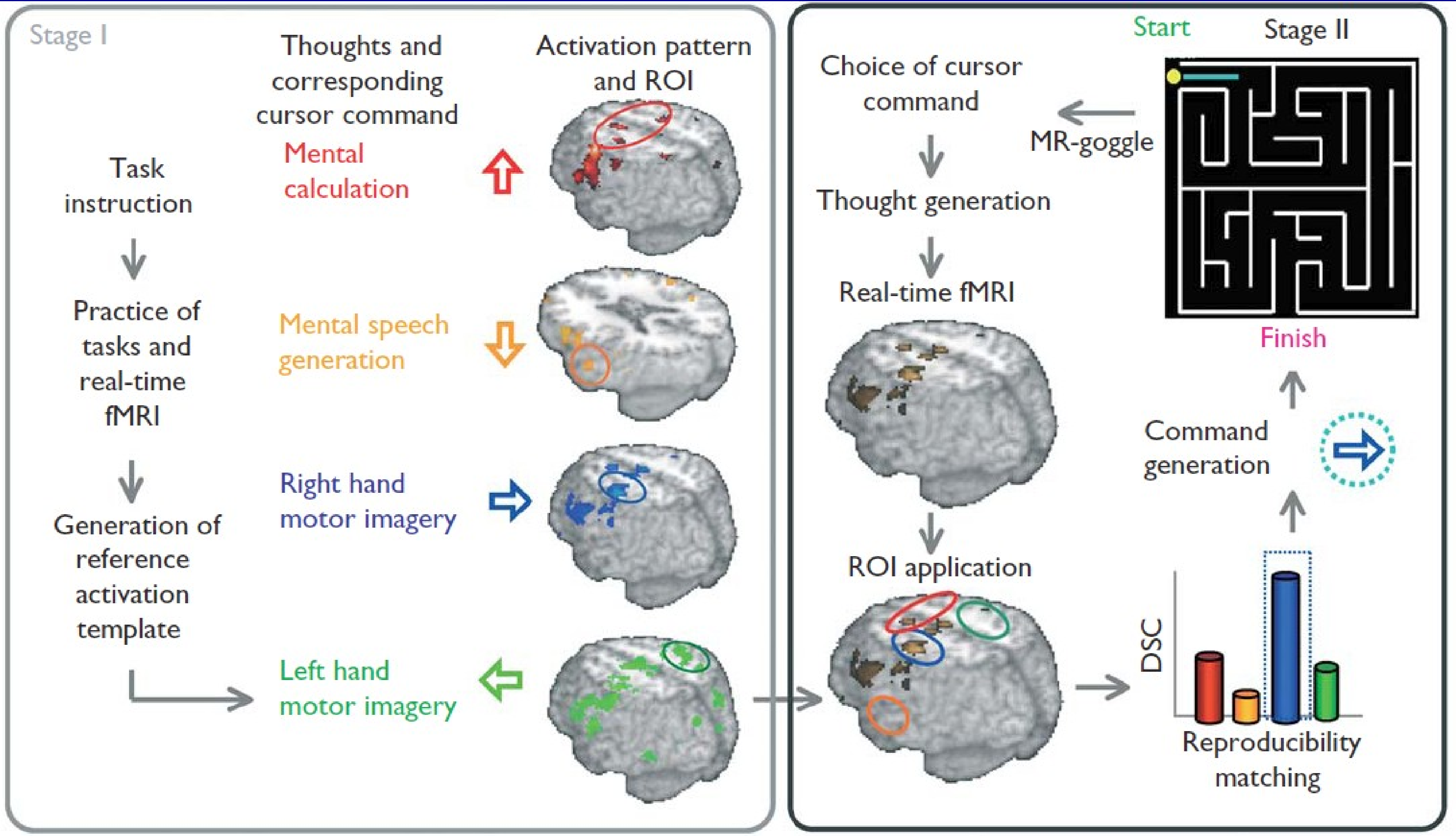
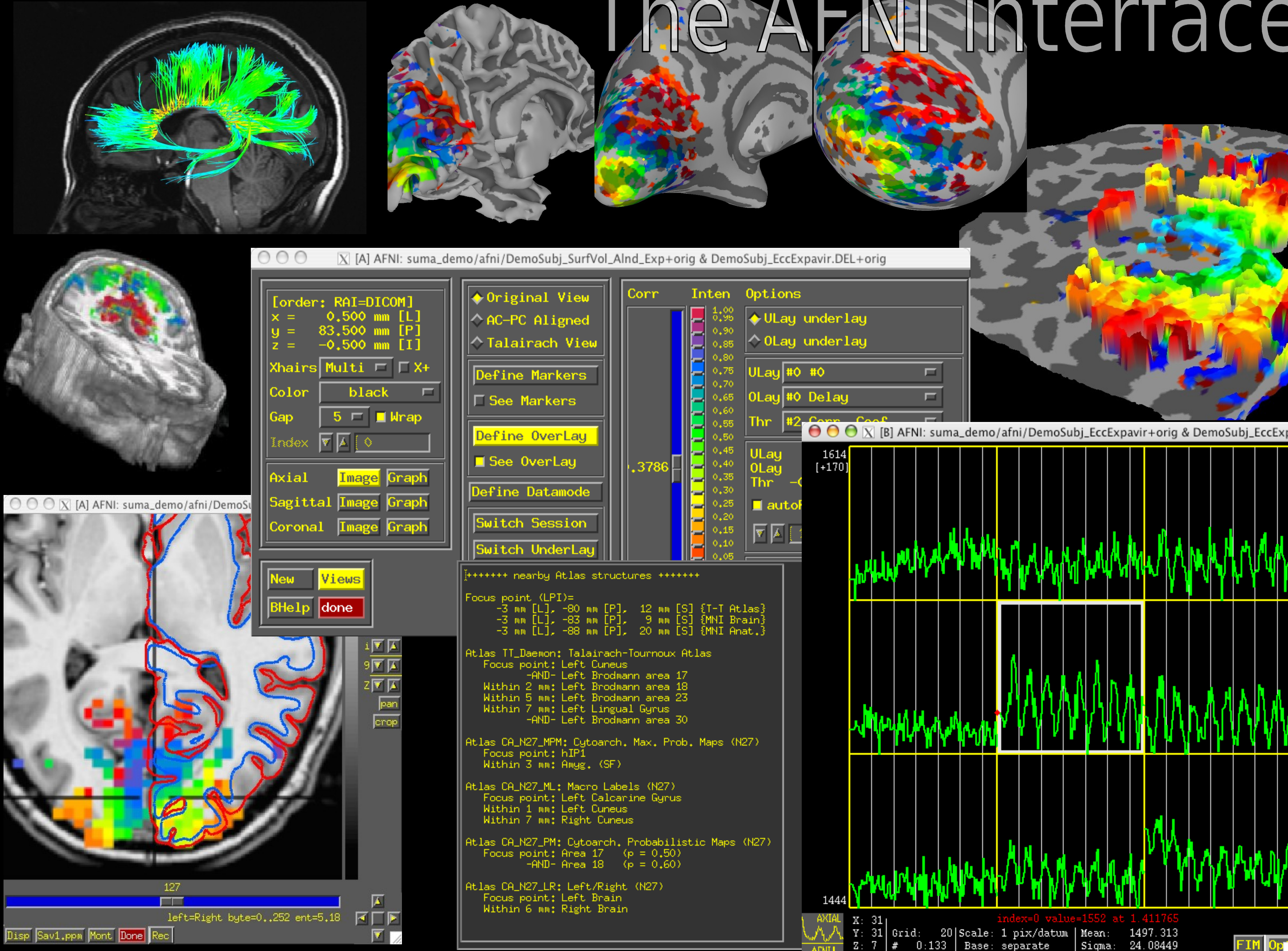


Fig.1 Yoo S. et al. Neuroreport 04

Why bother?

- Reviews:
  - Weiskopf N et al.: Real-time functional magnetic resonance imaging: methods and applications. *Magnetic Resonance Imaging 25 (2007)*
  - Yang S et al.: Real-Time Functional Magnetic Resonance Imaging and its Applications. in *Brain Mapping Research Developments, Bakker LN ed., Nova Publishing, New Jersey (2008)*
  - deCharms RC: Applications of real-time fMRI. *Nature Reviews Neuroscience **9** (2008)*
  - deCharms RC: Reading and controlling human brain activation using real-time functional magnetic resonance imaging. *Trends in Cognitive Sciences **11** (2007)*

The AFNI interface



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

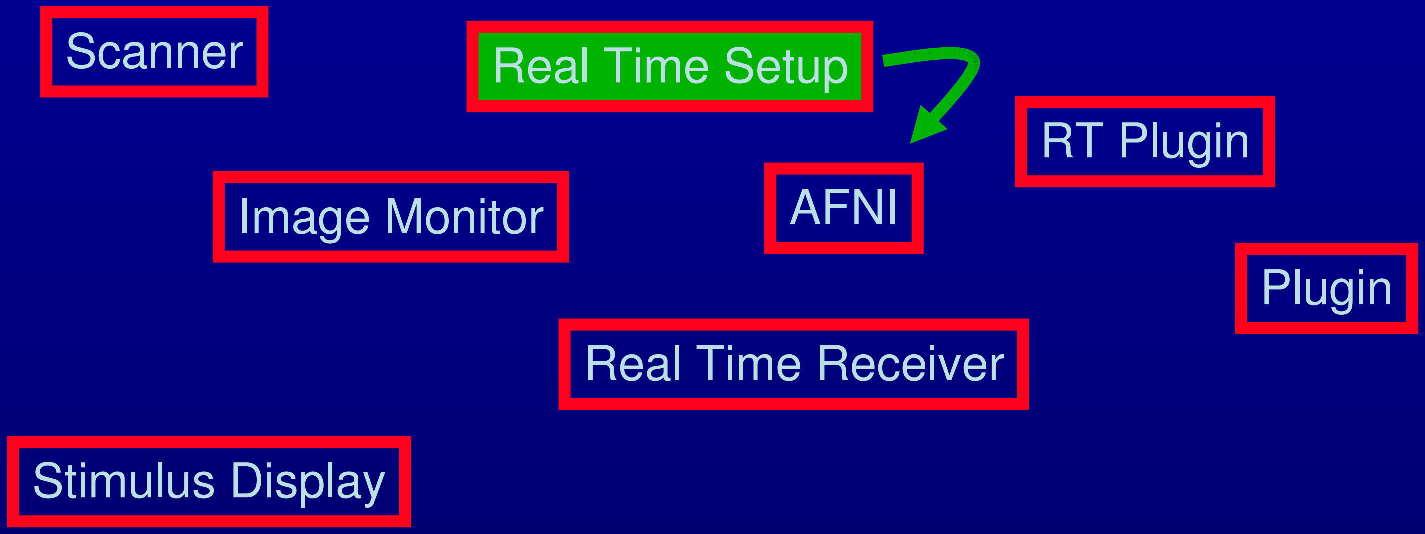
Plugin

Real Time Receiver

Stimulus Display

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

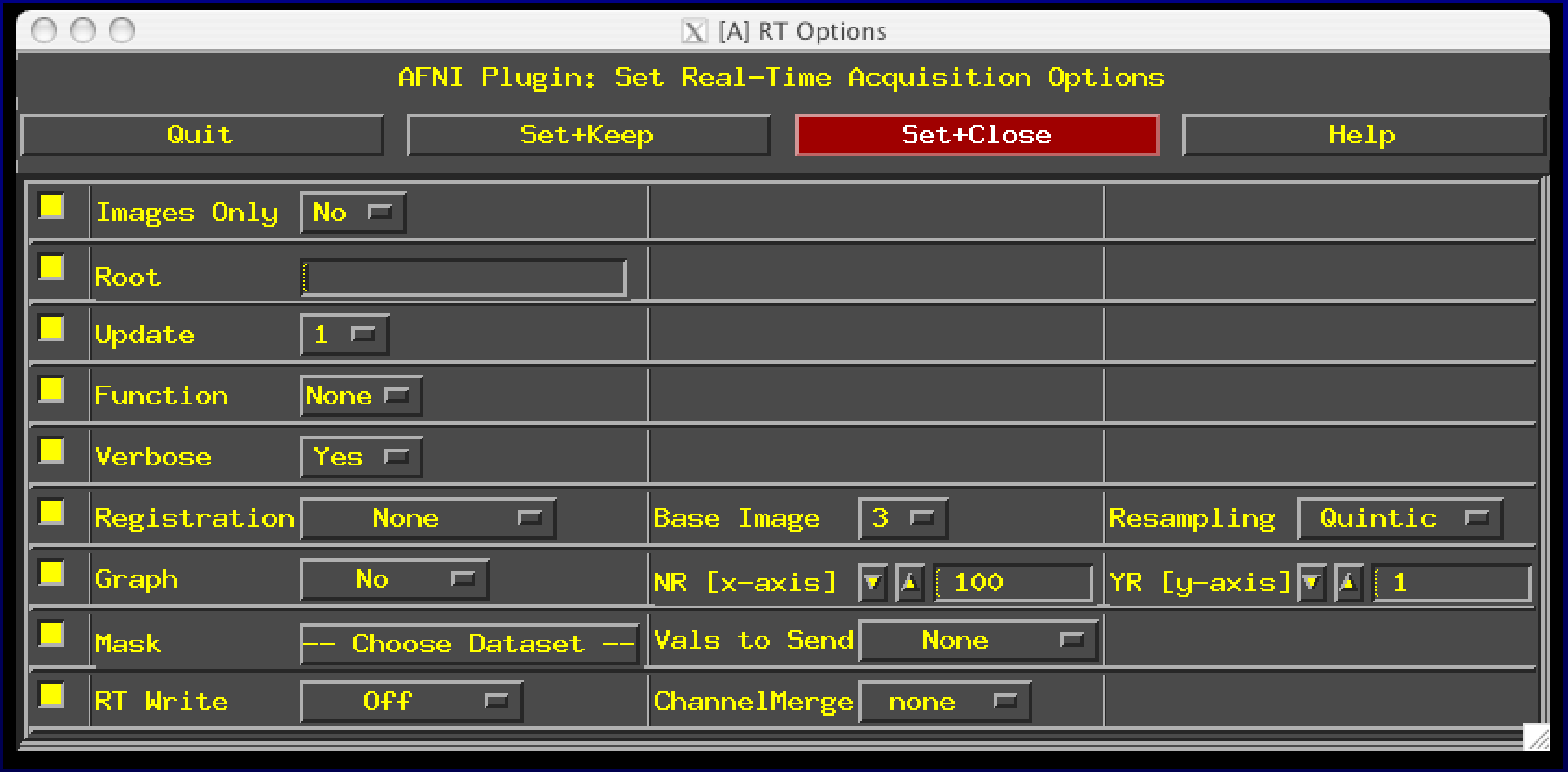
The players



- 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

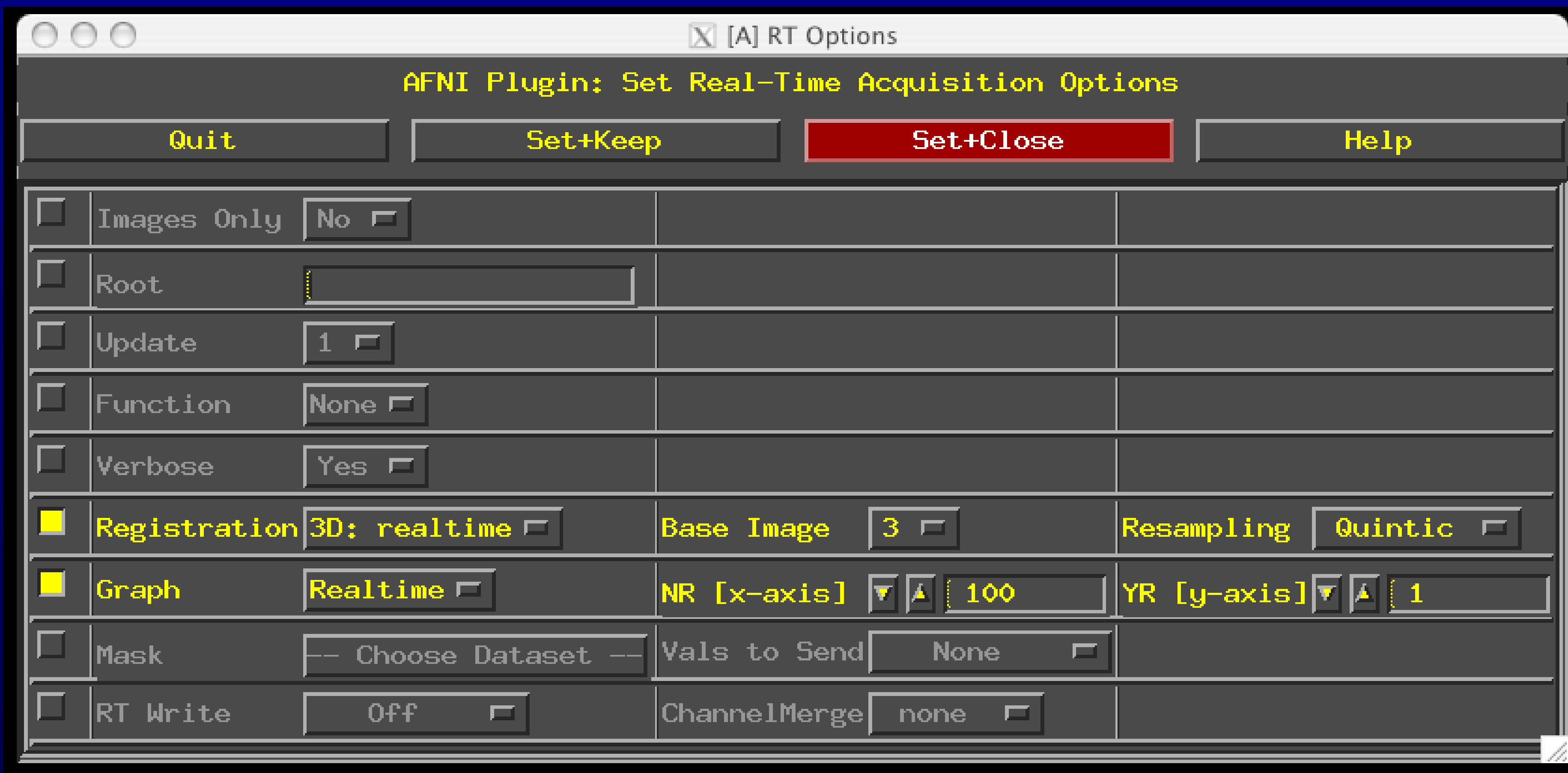
- Manually
  - Good for learning and demo



Setting up AFNI's RT plugin

- Via Environment Variables

setenv AFNI_REALTIME_Registration 3D:_realtime
setenv AFNI_REALTIME_Graph Realtime



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

- Motion monitoring
- Motion & function

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.

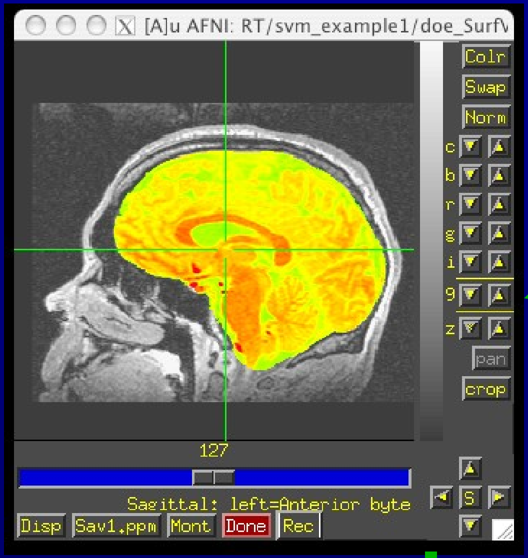
Standard-space atlas ROI selection

```
@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

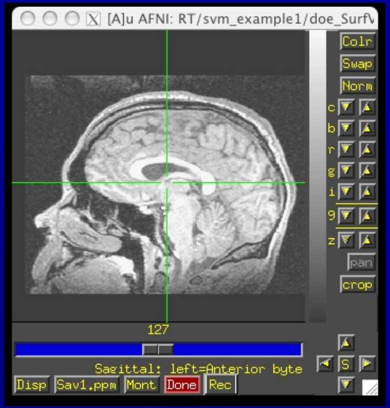
Atlas-based ROIs



1- Strip skull

2- Find xform to atlas space

(about 40 secs, 2.5GhZ cpu)



3- Identify ROIs

4- Xform ROIs to native space

(about 2 seconds)

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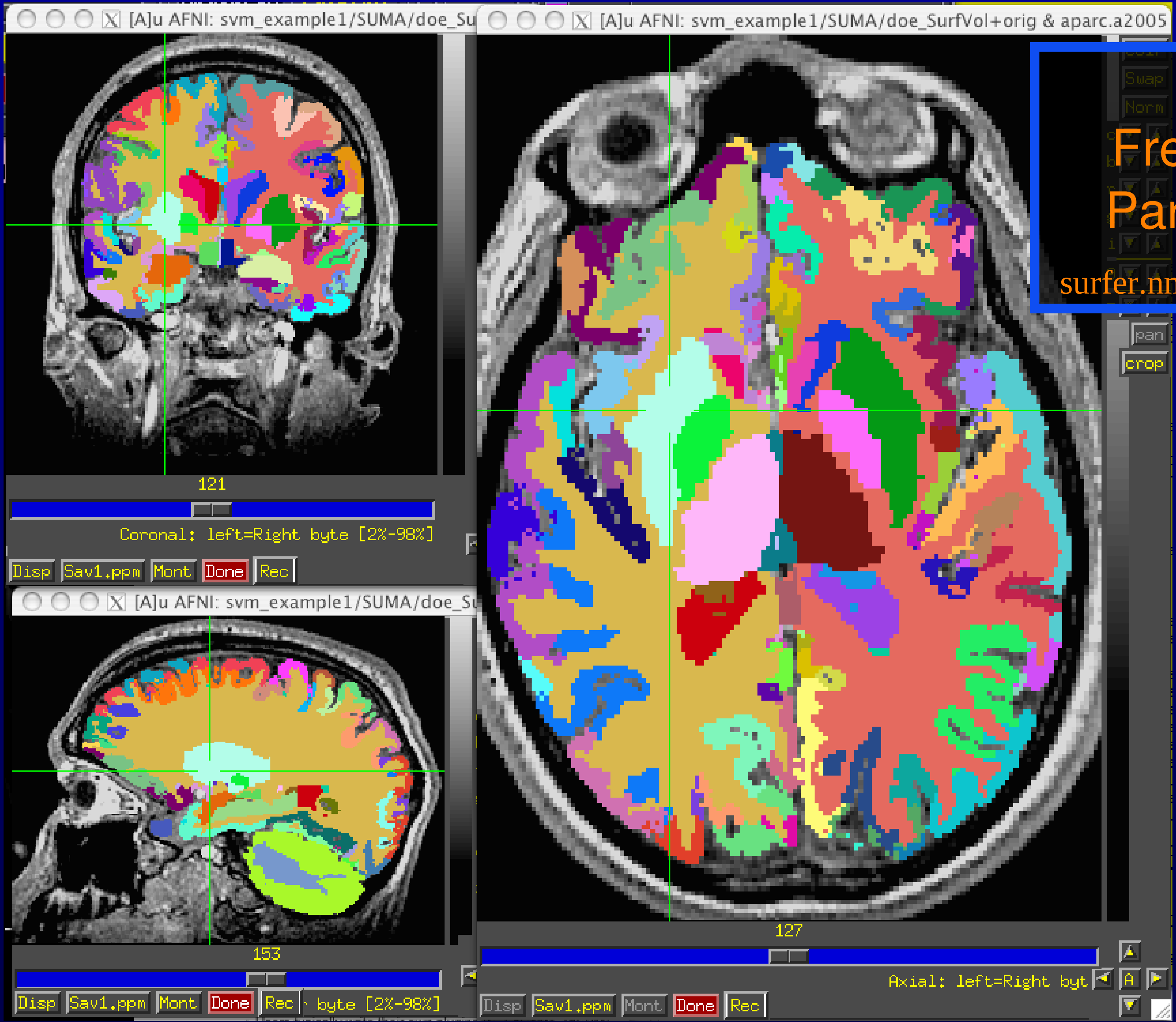
Subject-based Anatomical ROIs



From FreeSurfer's Parcellations

surfer.nmr.mgh.harvard.edu

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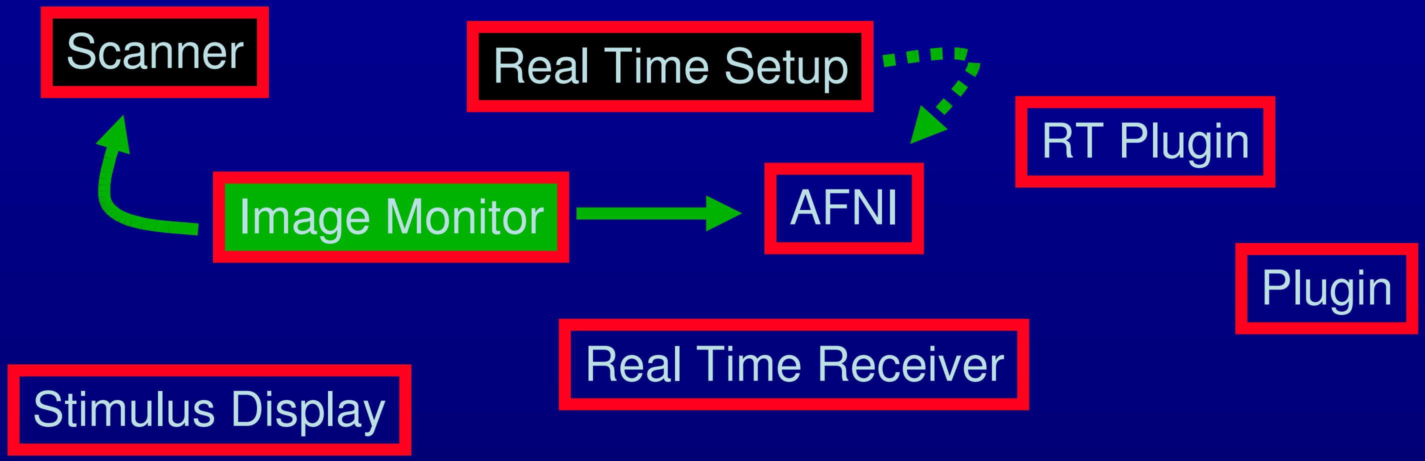
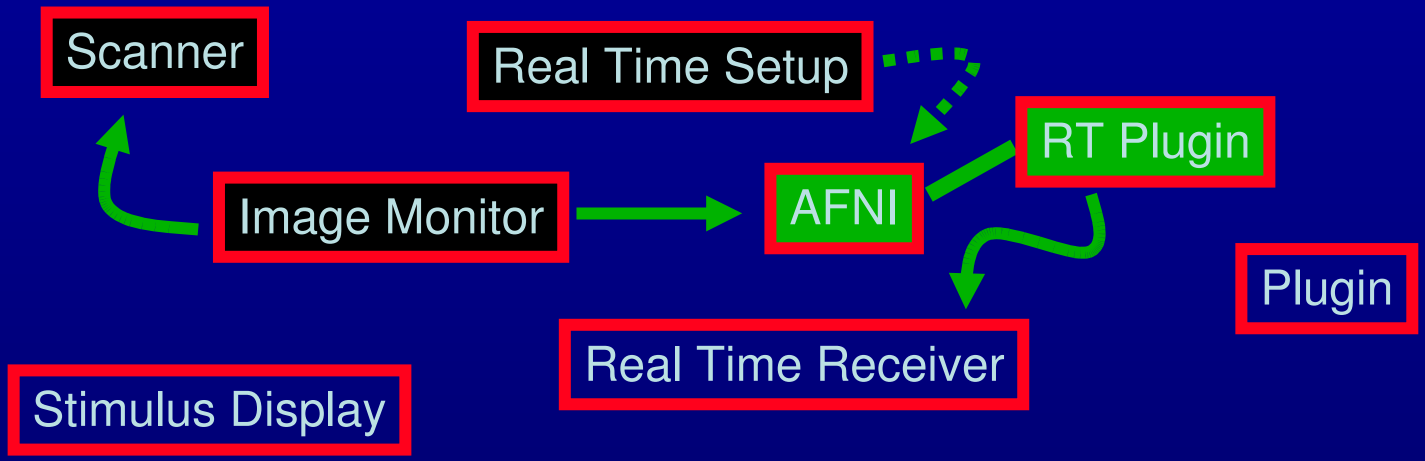
The players



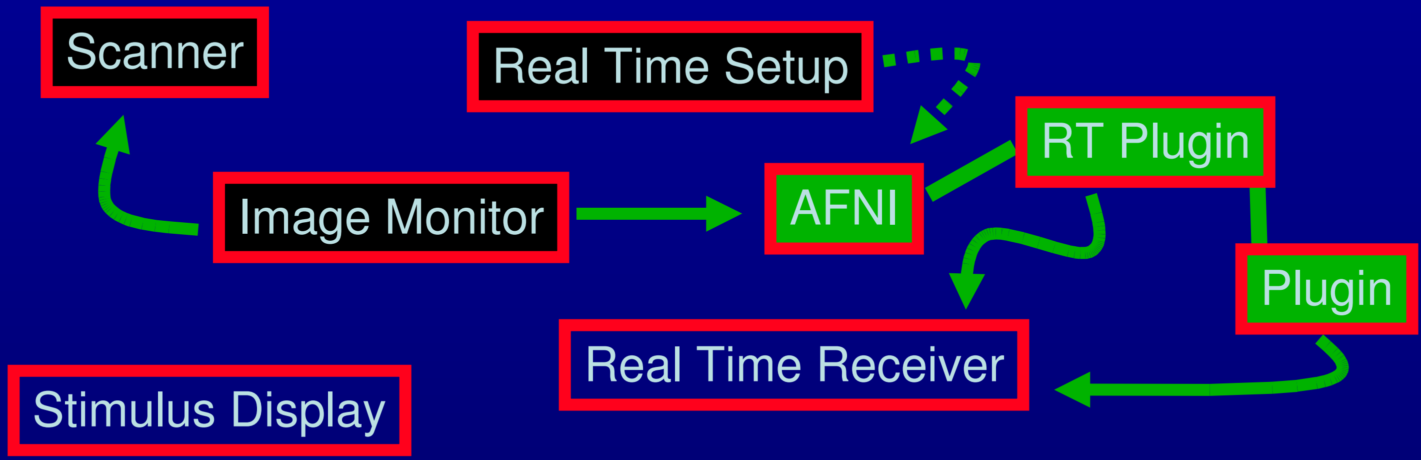
- Image Monitor
  - An AFNI- or user- supplied program to wait for new images
    - AFNI-supplied programs monitor files only:
      - Imon (Monitors GE's old dreaded I files)
      - Dimon (Monitors GE's DICOM images)
      - RTfeedme (Breaks up timeseries dataset and sends it to AFNI)
    - User-supplied 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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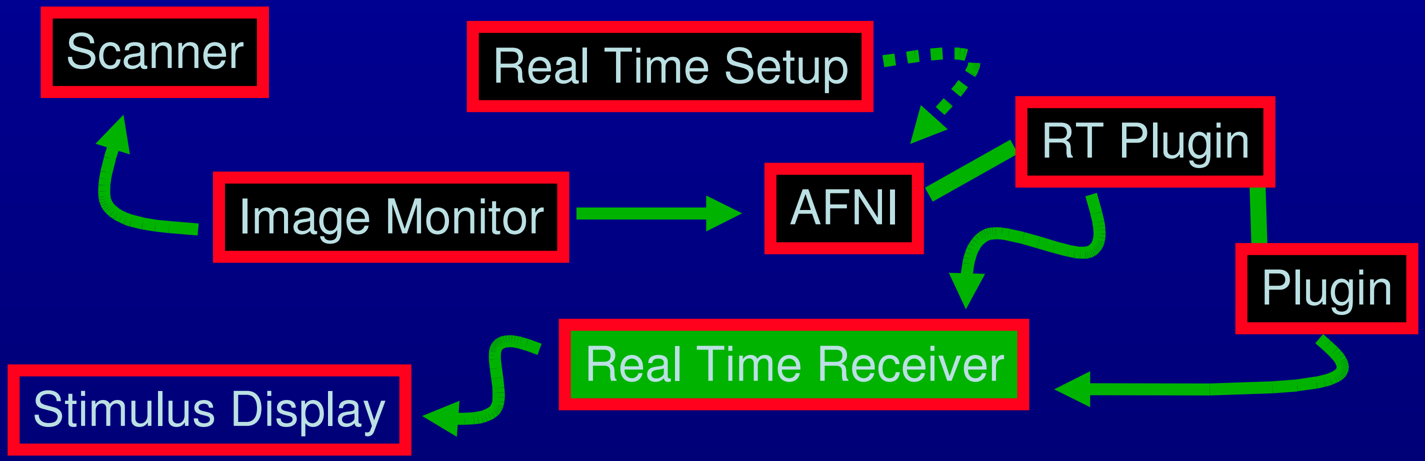


- Real Time Receiver (e.g. serial_helper.c or realtime_receiver.py)
  - AFNI- or User- supplied application that expects incoming data from AFNI and acts on it
    - Motion parameters
    - ROI-based data, all values or just average
    - Entire volumes of raw, or preprocessed data
    - Data from any 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

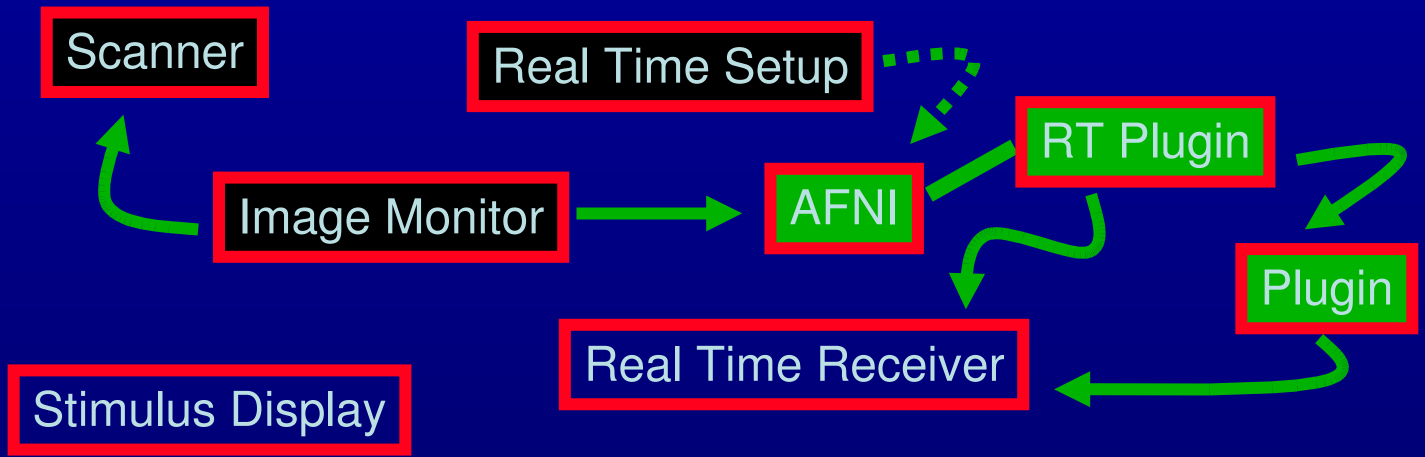
plug_realtime:
    init: register work process with afni (to be called regularly)
    plugin main: sets plugin control variables
----
main work process: asynchronously from main afni loop
    if new connection, initialize
    if data is bad or no new data after timeout
        write vol. to disk, plot 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

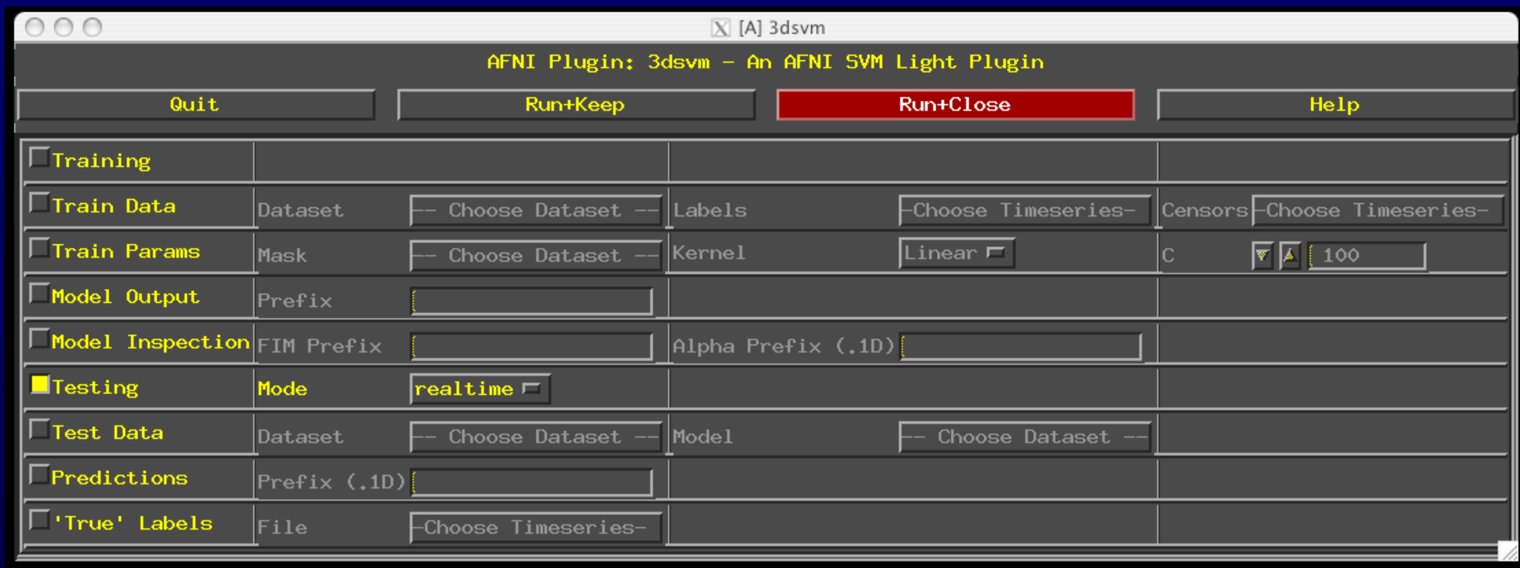
set signal handlers to close all ports on exit

- 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

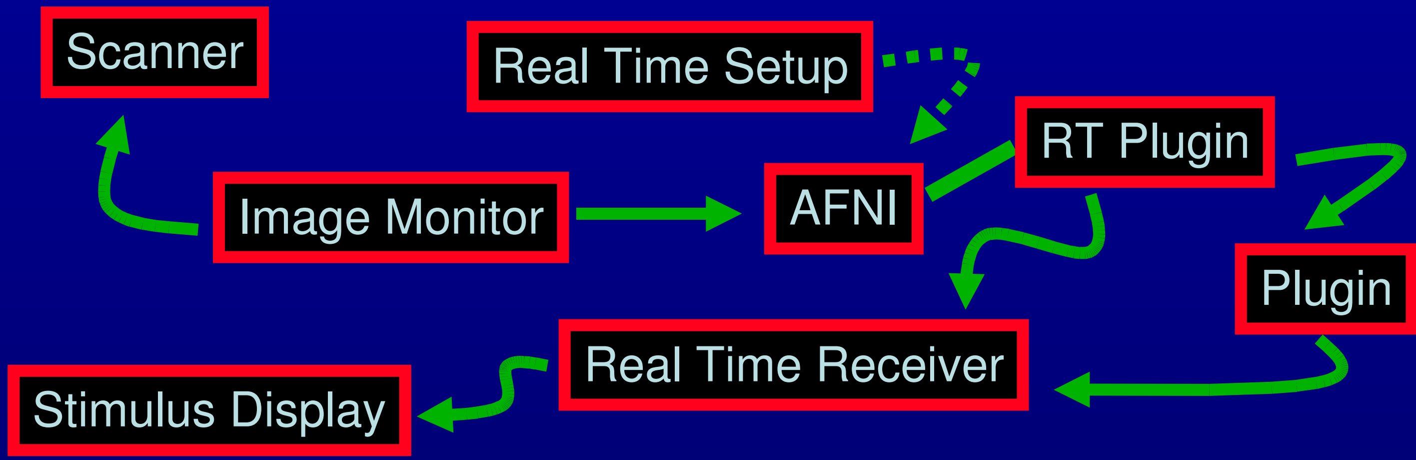
RT SVM plugin*



- SVM plugin is being modified to accept RT data
  - Given training models, classification is done in real-time
  - Classification can go to text, or to Real Time Receiver



Real Time SVM*



QuickTimeS and a
YUV420 codec decompressor
are needed to see this picture.

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

Receiver example

- Example from demo

Strategy for Manipulating Activation

Adapted from deCharms RC. TCS 07

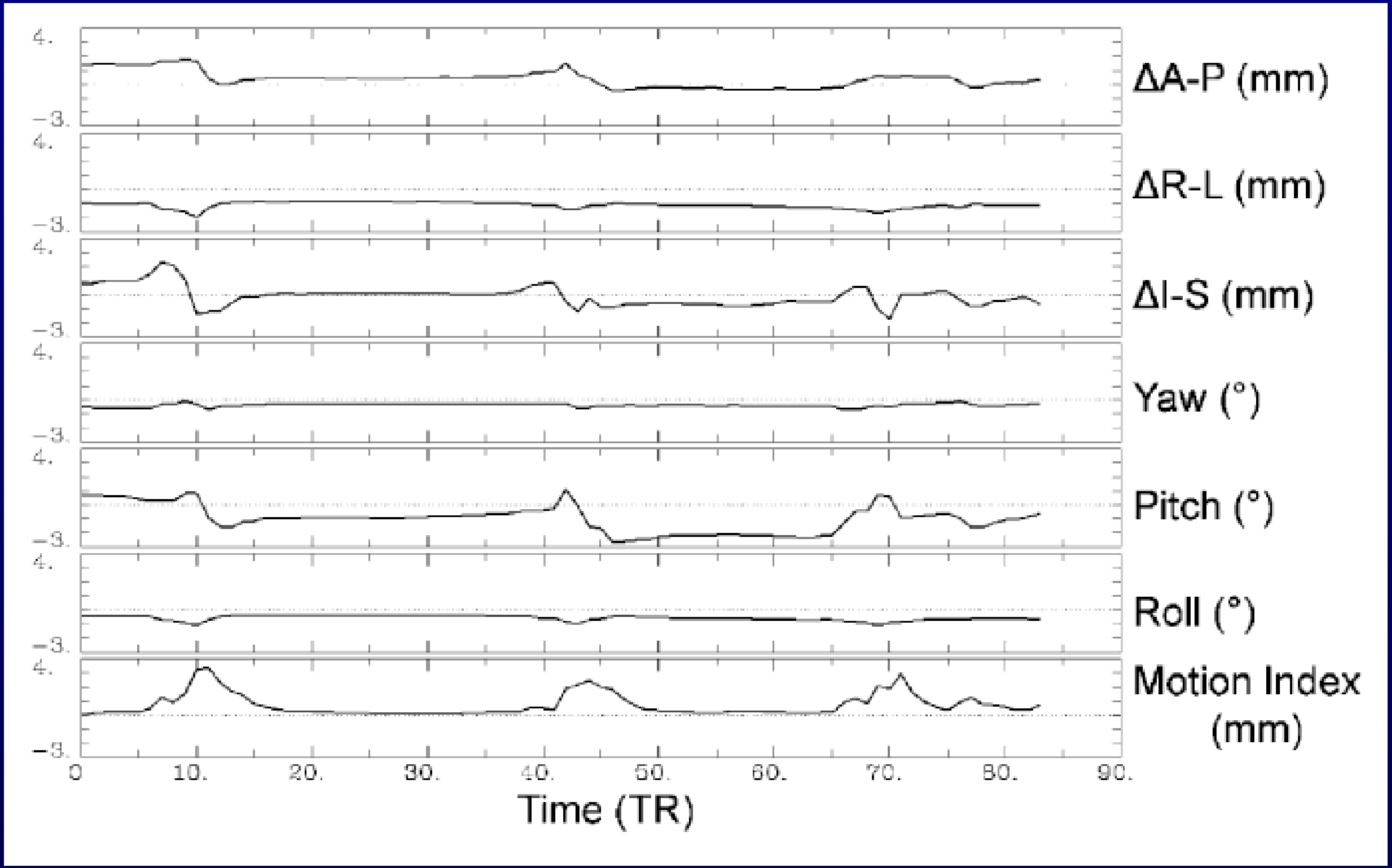
- Providing strategy may be critical
  - Subjects overestimate ability to control activation
  - Start by providing strategy that activates ROIs regions providing feedback
- See literature on control of various areas
  - Somatomotor cortex
    - Posse 2001, Yoo 2002, deCharms 2004, Yoo 2004
  - Parahippocampal place area
    - Weiskopf 2004
  - Amygdala
    - Posse 2003
  - Insular cortex
    - Caria 2007
  - Anterior cingulate cortex
    - Weiskopf 2003, Yoo 2004, Birbaumer 2007, deCharms 2005

From LaConte S. – FMRI Advanced Issues ISMRM 09

Feedback Design

- If incidental to task, minimize interference

Too much information

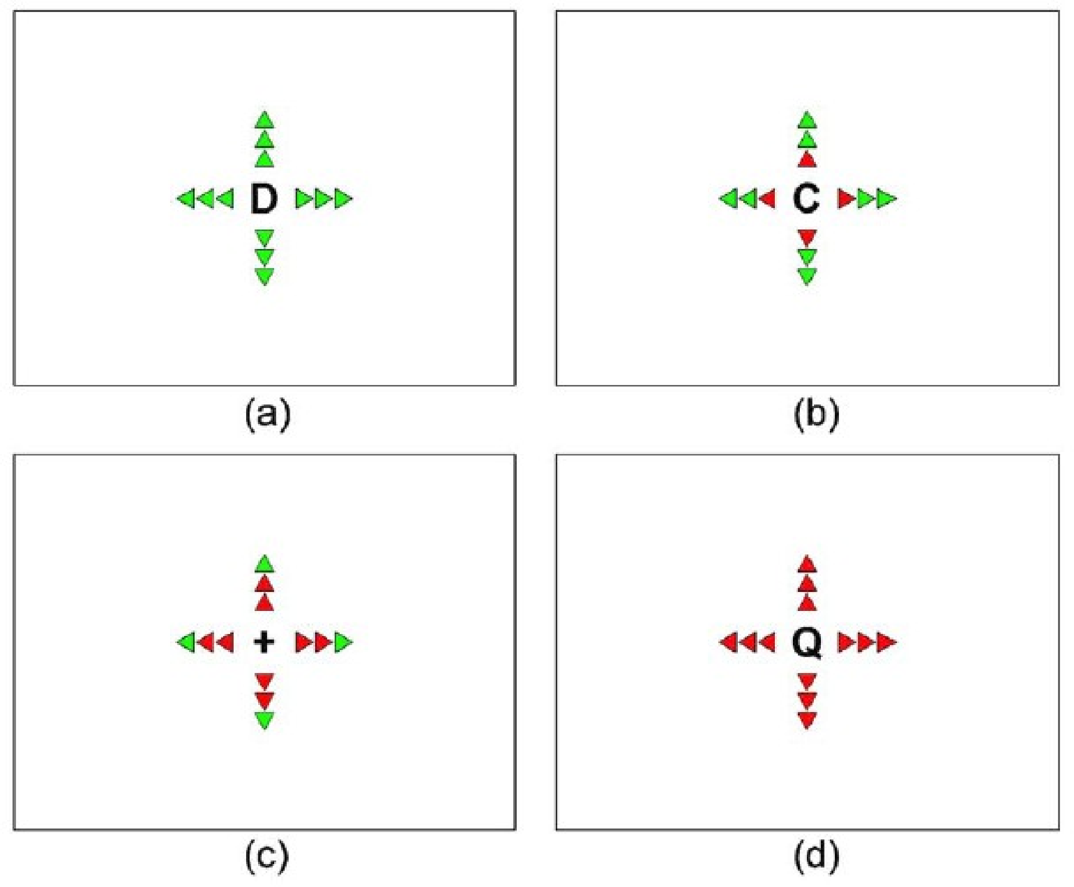


Feedback Design

- If incidental to task, minimize interference

Enough information

Minimum Task Interference



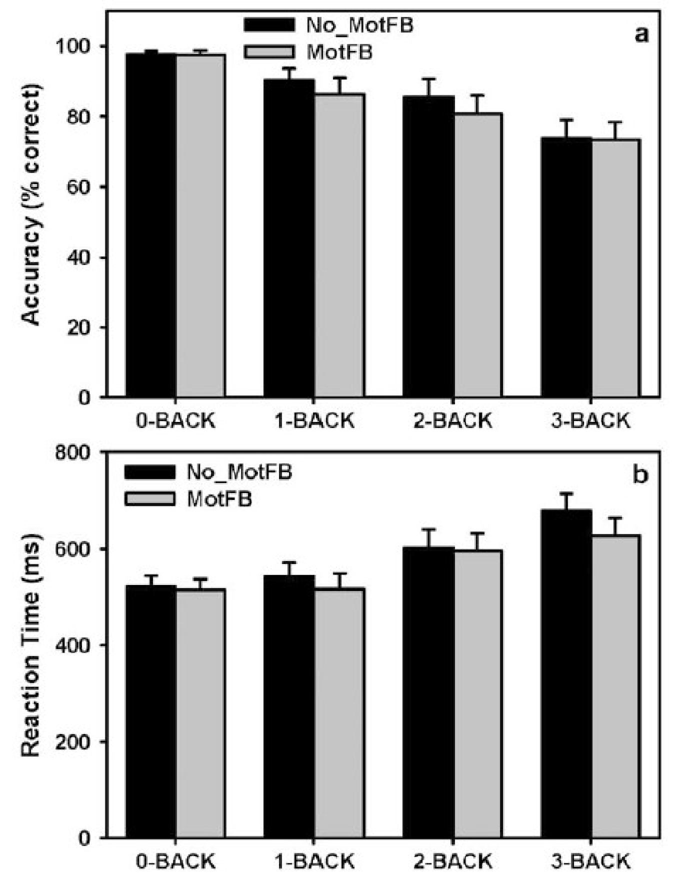


Fig.7 from Yang, S. et al. Neuroimage 05

Fig.3 from Yang, S. et al. Neuroimage 05

Feedback Design

- Make it appealing to subject
  - Turns out few get excited about graphs
  - Fire on the beach = much more exciting

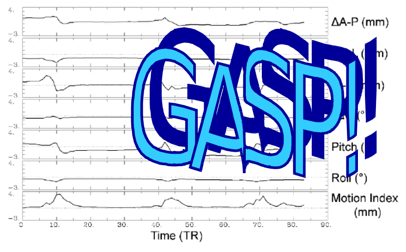


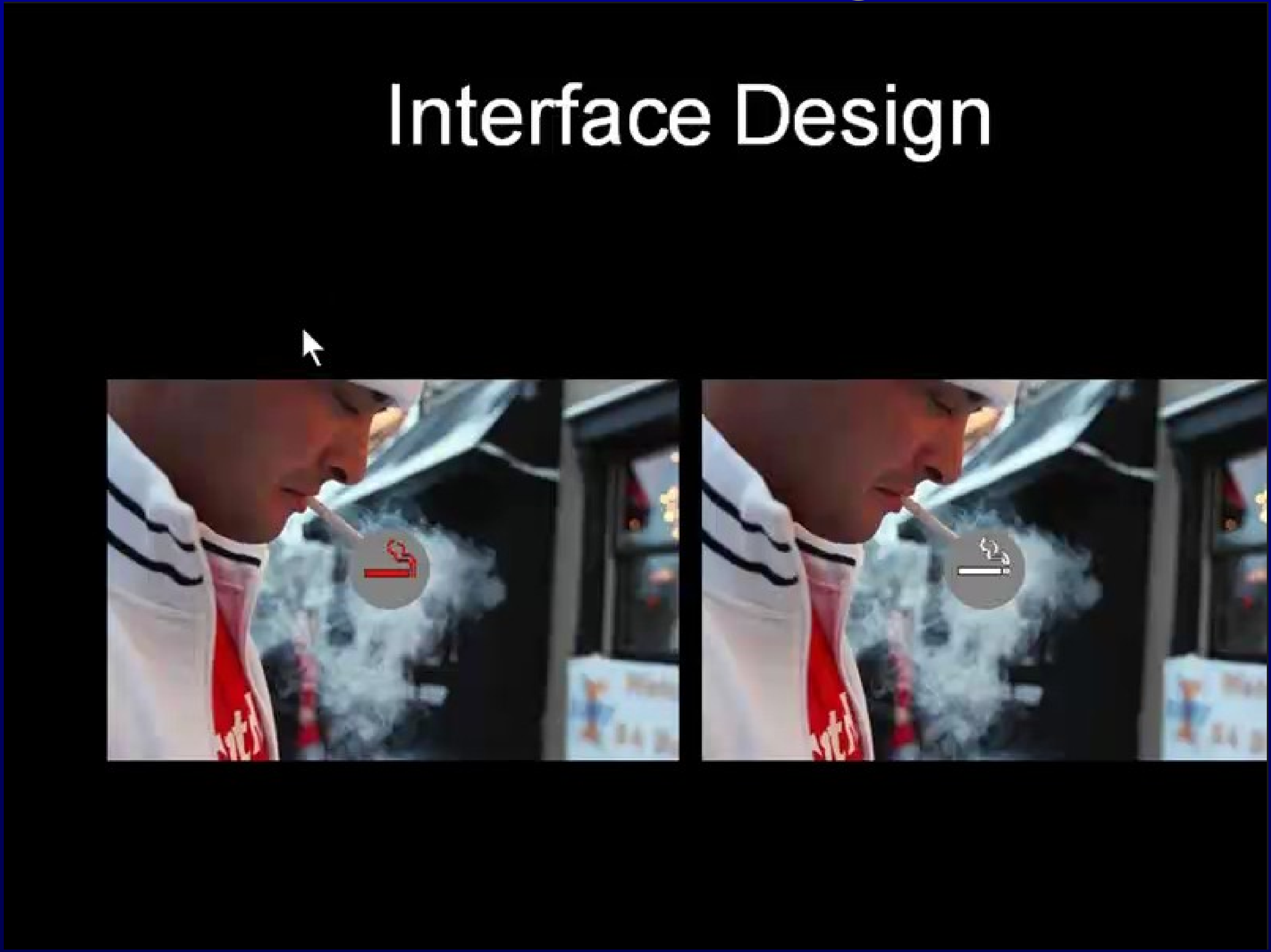
Figure 1d from deCharms RC. Nature 08

Feedback Design

- OMG! Asteroids!
  - Keeps subject interested
  - History trace helps subject cope with FMRI response lag

Courtesy of Zhang Y., Kurup P., Ross T. and Stein A. NIDA/NIH

Feedback Design



From S. LaConte ISMRM 09

Feedback Design

From S. LaConte ISMRM 09

Feedback Design

From S. LaConte ISMRM 09

Feedback Design

From S. LaConte ISMRM 09

What to feedback ?

- Which signal to use?
  - From original time series
  - From filtered* time series
  - From regression (Beta/T/R) analysis
- Typically from one or more ROIs
  - Anatomical Atlas based
  - Single subject anatomy based
  - Group function based
  - Single subject localizer
- Combining information from multiple ROIs
  - Encode signals in VR scene
  - Classifiers (ROI or whole brain), if models are known
- What about noise confounds?
  - Control for respiration/cardiac with real-time RETROICOR*
  - Include other physiological covariates in real-time*
  - Include real-time baseline modeling

deCharms RC. 08

LaConte SM. 07

Automation

QuickTimeS and a
decompressor
are needed to see this picture.

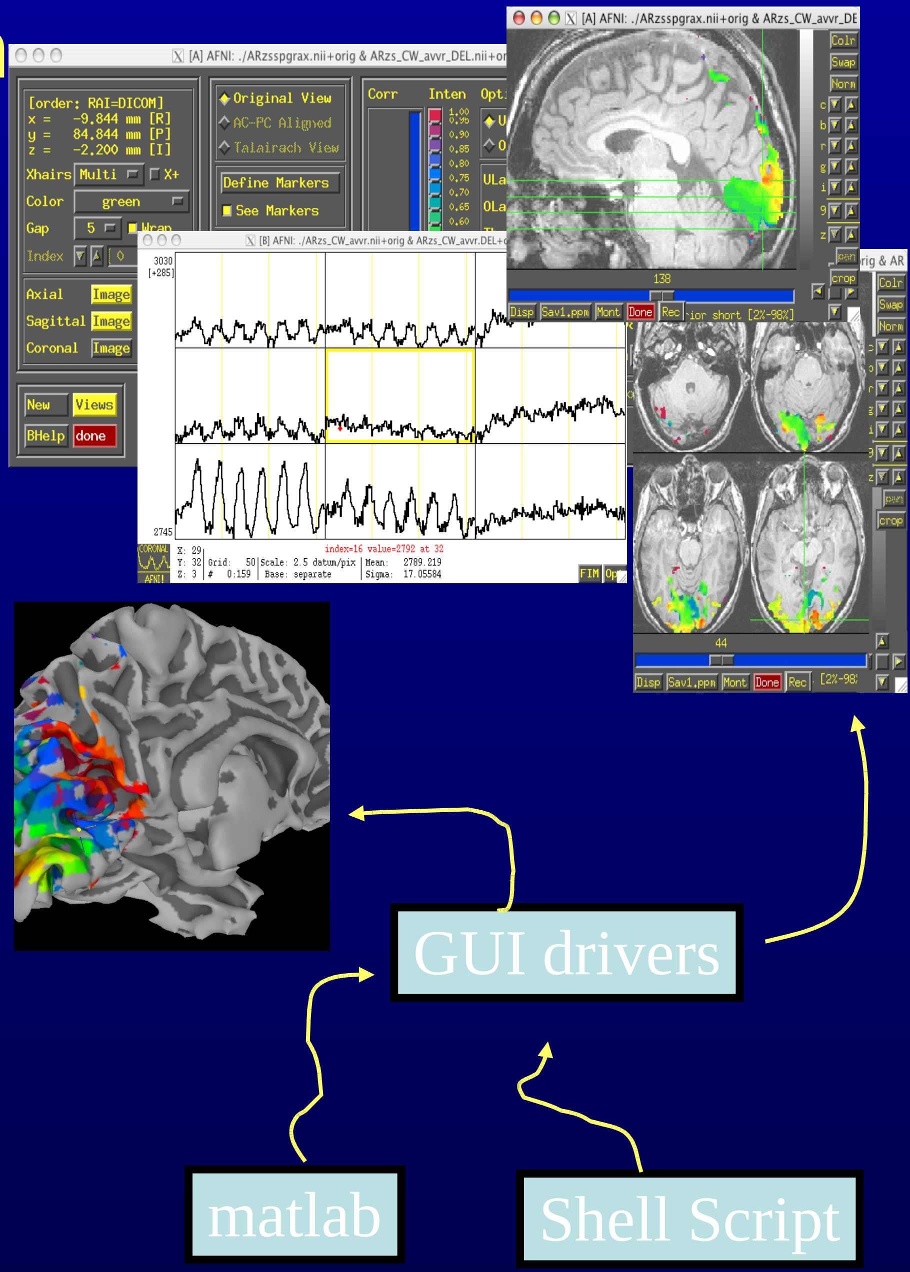
Automating Navigation

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

+ Program called via "system" function (shell invocation)

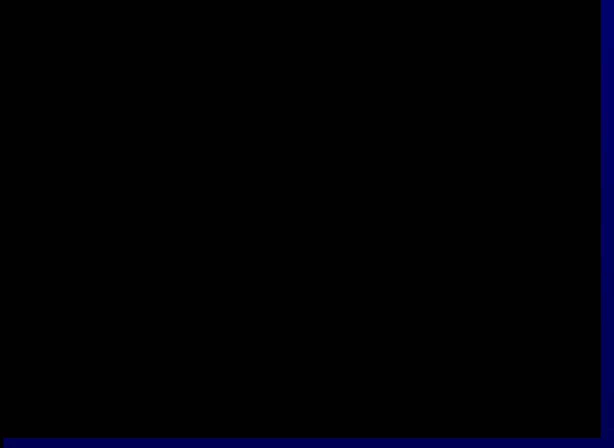
+ No need to manage sockets or format and transmit commands

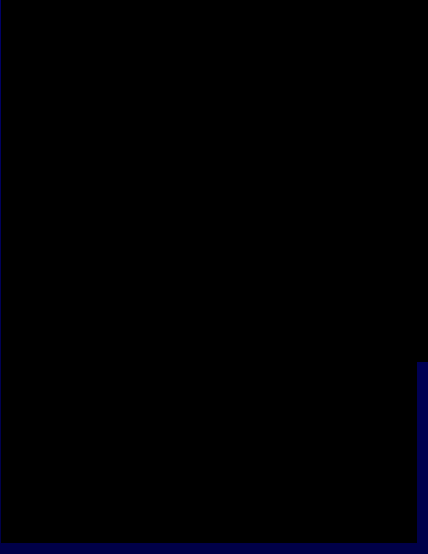
+ User Interaction with GUI is uninterrupted



Cycling trough 300 volumes

```
while ($cnt < 300)
plugout_drive      -com "SWITCH_UNDERLAY  A ${WithSkull[$cnt]}"
                   -com "SWITCH_OVERLAY A ${WithNoSkull[$cnt]}"
                   -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 = $< && set cnt = `expr $cnt + $ans`
 end
```

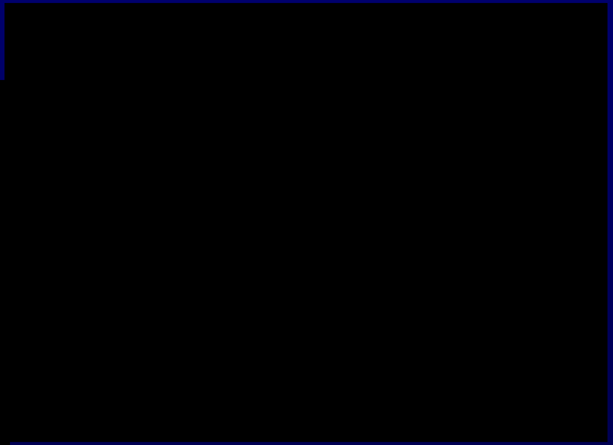


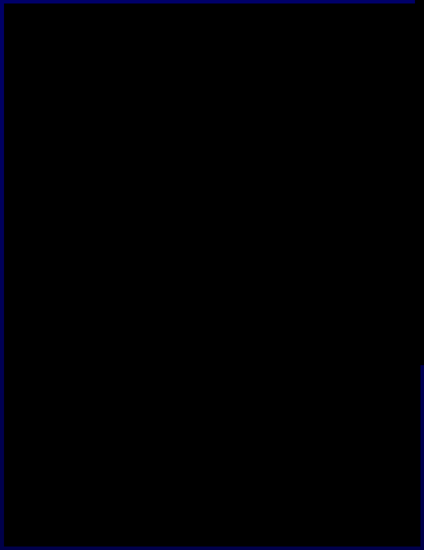


Cycling trough 300 volumes

Loop over all volumes

```
while ($cnt < 300)
plugout_drive      -com "SWITCH_UNDERLAY  A ${WithSkull[$cnt]}"
                   -com "SWITCH_OVERLAY A ${WithNoSkull[$cnt]}"
                   -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 = $< && set cnt = `expr $cnt + $ans`
 end
```

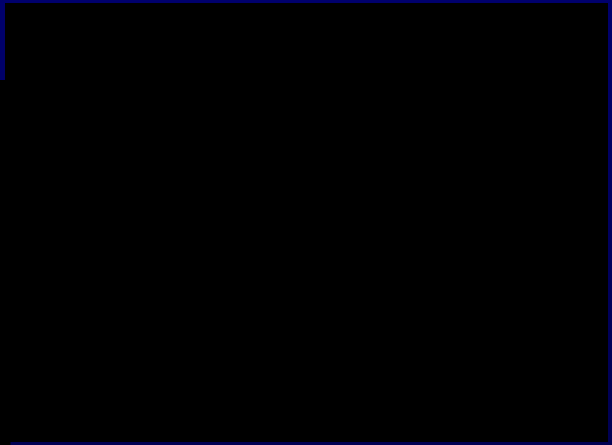


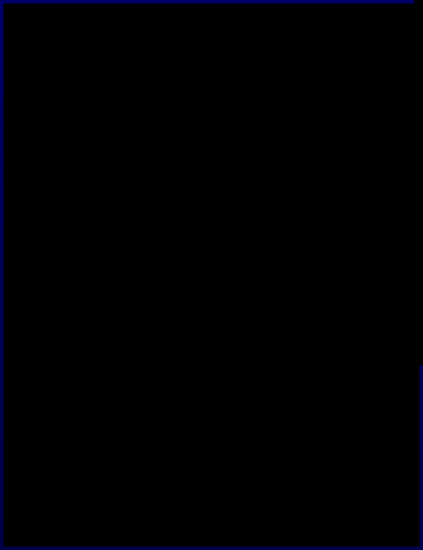


Cycling trough 300 volumes

Switch background volume

```
while ($cnt < 300)
plugout_drive      -com "SWITCH_UNDERLAY  A ${WithSkull[$cnt]}"
                   -com "SWITCH_OVERLAY A ${WithNoSkull[$cnt]}"
                   -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 = $< && set cnt = `expr $cnt + $ans`
 end
```





Cycling trough 300 volumes

Switch foreground volume

```
while ($cnt < 300)
plugout_drive      -com "SWITCH_UNDERLAY  A ${WithSkull[$cnt]}"
                   -com "SWITCH_OVERLAY A ${WithNoSkull[$cnt]}"
                   -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 = $< && set cnt = `expr $cnt + $ans`
 end
```

Cycling trough 300 volumes

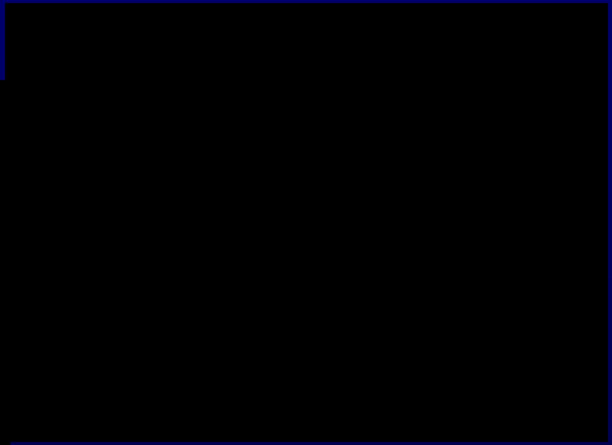
Open coronal image with low opacity

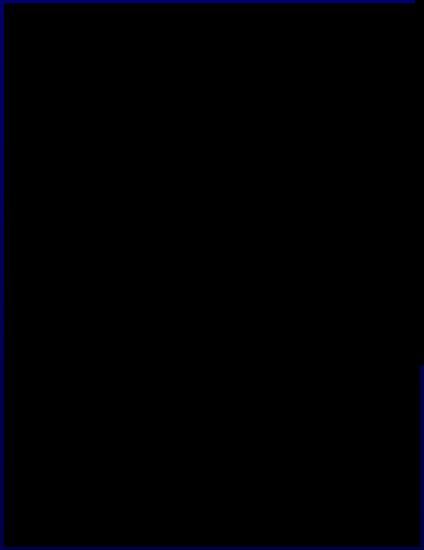
```
while ($cnt < 300)
plugout_drive       -com "SWITCH_UNDERLAY  A ${WithSkull[$cnt]}"
                    -com "SWITCH_OVERLAY A ${WithNoSkull[$cnt]}"
                    -com 'OPEN_WINDOW A coronalimage opacity=0.5'
                    -com 'OPEN_WINDOW A axialimage keypress=v  opacity=0.4'
                    -quit
     echo "Enter new number or hit enter for next brain:"
     set ans = $< && set cnt = `expr $cnt + $ans`
 end
```

Cycling trough 300 volumes

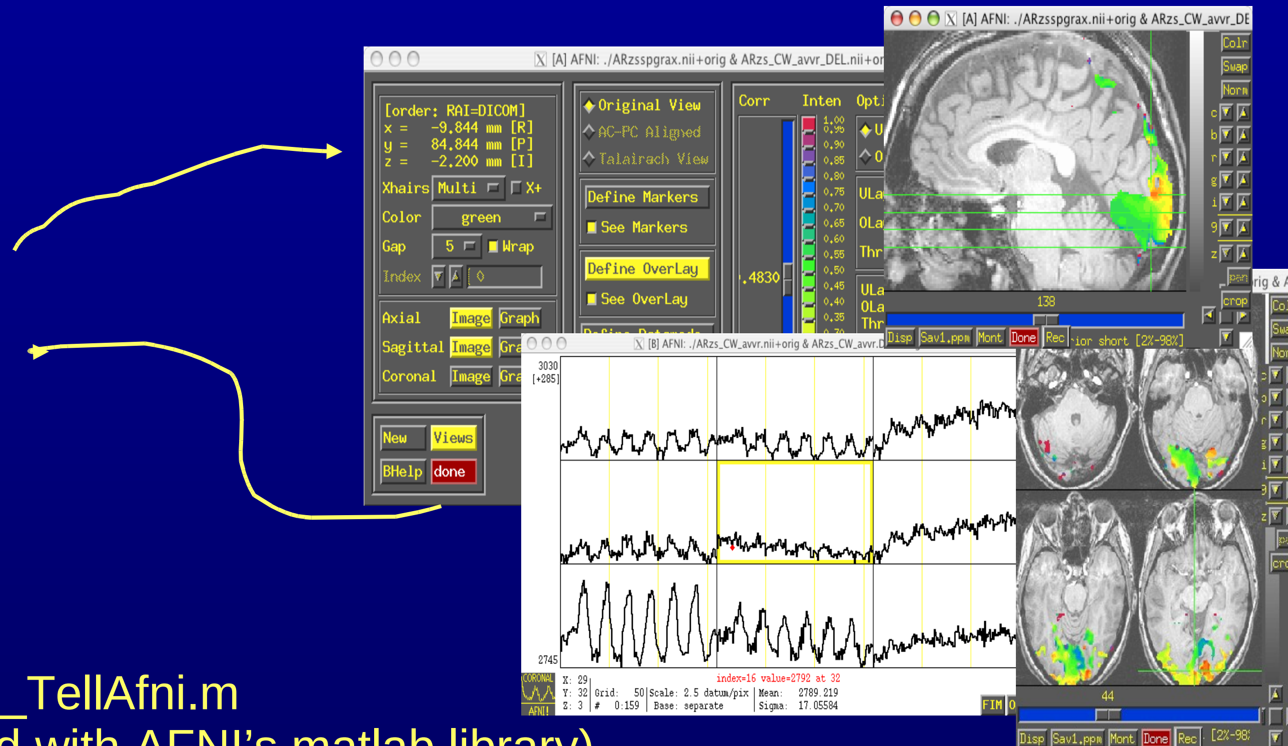
Open axial image and start video mode

```
while ($cnt < 300)
plugout_drive       -com "SWITCH_UNDERLAY  A ${WithSkull[$cnt]}"
                    -com "SWITCH_OVERLAY A ${WithNoSkull[$cnt]}"
                    -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 = $< && set cnt = `expr $cnt + $ans`
 end
```





Automating Navigation from MATLAB



Excerpts from: Test_TellAfni.m

(Distributed with AFNI’s matlab library)

```
cs(1) = NewCs('open_window', '', 'axialimage', 'keypress=" "');
cs(2) = NewCs('OPEN_PANEL', '', 'Define_Overlay');
cs(3) = NewCs('Set_Function', 'A', 'ARzs_CW_avvr.DEL');
cs(4) = NewCs('SET_DICOM_XYZ', '', '-6 86 -3');
cs(5) = NewCs('SET_SUBBRICKS', '', '-1 0 2');
cs(6) = NewCs('SET_THRESHNEW','', 1e-9, '*p');
err = TellAfni(cs);
```

Automation demo

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

"Help" sources

- Readme files
  - README.driver
  - README.environment
  - README.realtime
- Demo material available on:
  http://afni.nimh.nih.gov
- Automation
  - ***@DriveAfni*** script
  - ***@DriveSuma*** script
  - ***@DO.examples***
- Sample programs
  - ***rtfeedme.c***
  - ***Dimon.c***
  - ***serial_helper.c***
  - ***realtime_receiver.py***
- Talk to us, we're interested in applications

Acknowledgments

Robert Cox
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Stephen LaConte
Thomas Ross

Julien Doyon

STOP!

NIFTI
Neuroimaging Informatics Technology Initiative

- Initiated and directed by Michael F. Huerta and Yuan Liu
- The goal is to provide coordinated and targeted service, training, and research to speed the development and enhance the utility of informatics tools related to neuroimaging.
  - To address the Tower of Babel problem resulting from the multitude of tools.
- DFW its: co n form data exchange

NIFTI-1

- An extensible extension of ANALYZE™-7.5 file format
  + Header fields clearly defined and interpretation agreed upon
- NIFTI-1 was devised to suit FMRI analyses
  + Information about time series and statistical parameters in header
  + NIFTI does allow for extensions
    - No standard for the format of the extensions or conventions for interpreting them
  + Code/Documentation available on NITRC website
  + Format adherence is voluntary

GIFTI-1

- NIFTI's counterpart for surfaces and surface-based data
- Format is XML based
  - Format is mainly intended for data exchange
  - Performance was a concern, but focus was more on flexibility and ease of extension
- APIs now available for C, MATLAB, and Python
- Code/Documentation, and Sample data available on NITRC website
- At least 7 applications use GIFTI:
  - AFNI/SUMA, BrainVisa, BrainVoyager, Caret, CRkit, FreeSurfer, VisTrails, and SurfStat

We must work together, or else

QuickTime™ and a
decompressor
are needed to see this picture.

Visualization

- The more complicated the processing, the more important it is to easily access the data at various stages of the process and for each subject
- Unpredictable errors creep into the data at various levels of the analysis
  - Scanner
  - Subject
  - Stimulus delivery
  - Processing software
  - Postdoc error

Thank You