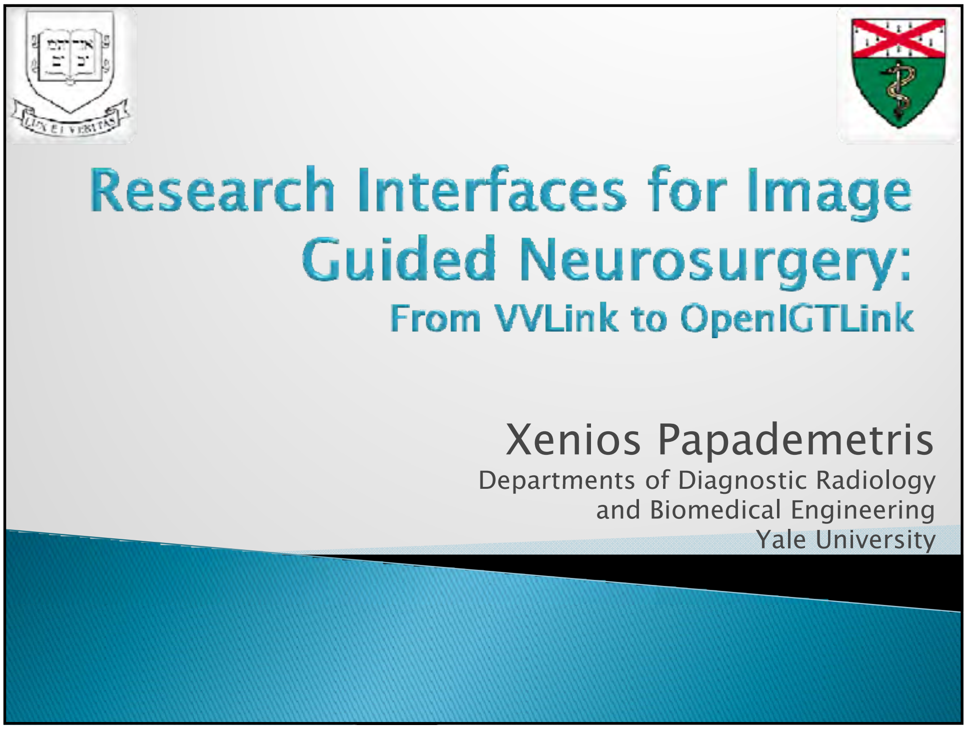
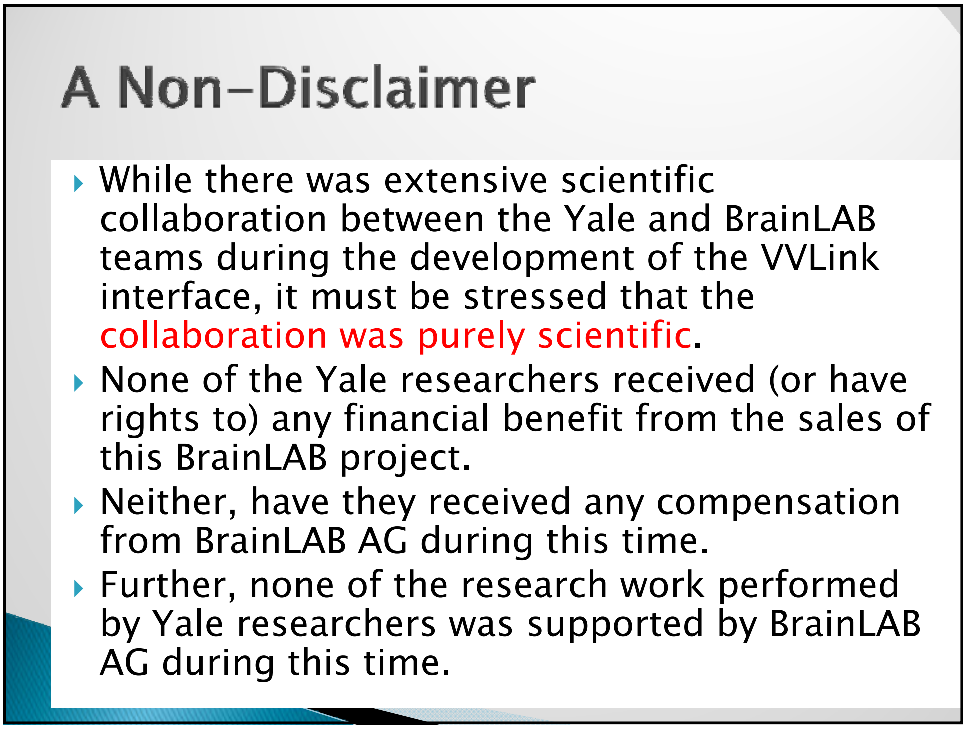


Research Interfaces for Image Guided Neurosurgery:

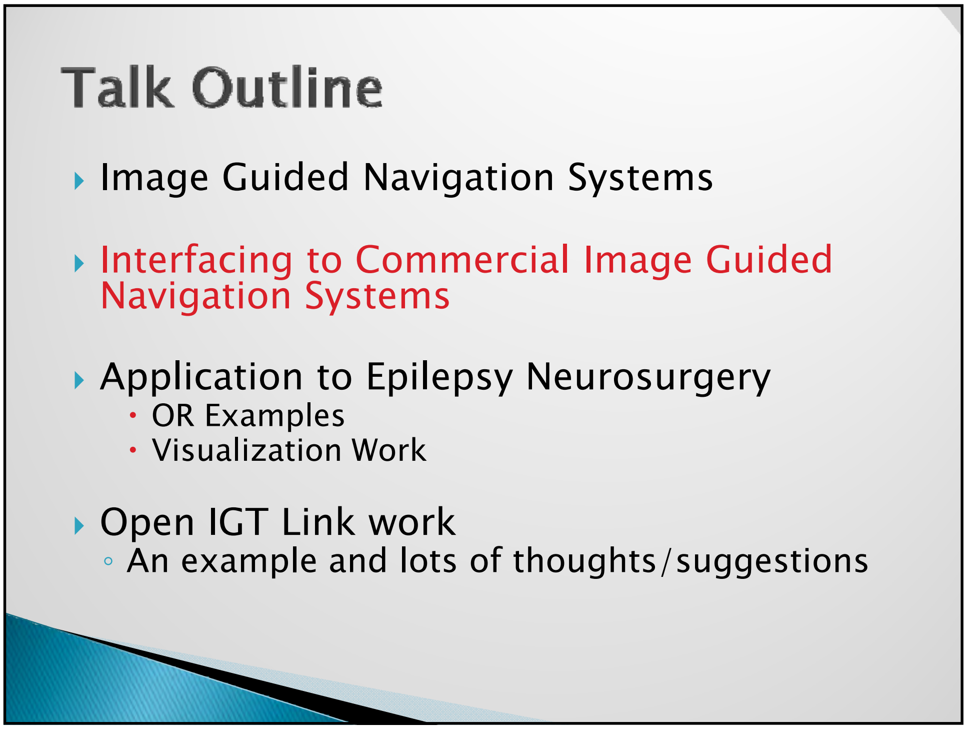
From VVLink to OpenIGTLink

Xenios Papademetris
Departments of Diagnostic Radiology
and Biomedical Engineering
Yale University



A Non-Disclaimer

- While there was extensive scientific collaboration between the Yale and BrainLAB teams during the development of the VVLink interface, it must be stressed that the collaboration was purely scientific.
- None of the Yale researchers received (or have rights to) any financial benefit from the sales of this BrainLAB project.
- Neither, have they received any compensation from BrainLAB AG during this time.
- Further, none of the research work performed by Yale researchers was supported by BrainLAB AG during this time.



Talk Outline

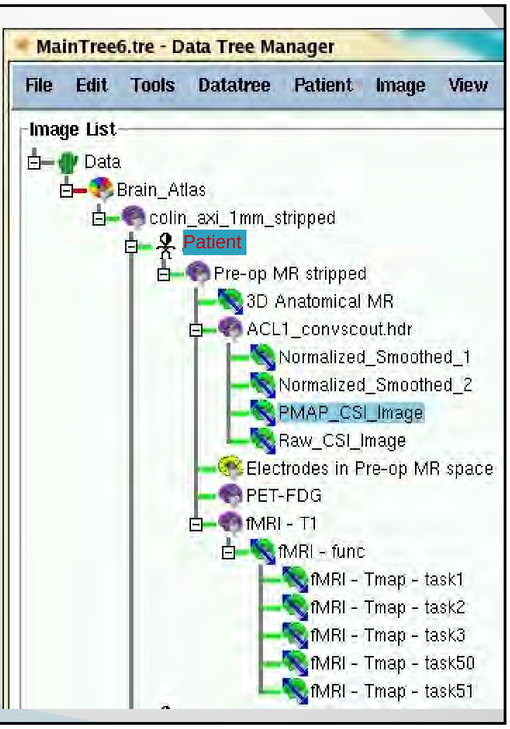
- Image Guided Navigation Systems
- Interfacing to Commercial Image Guided Navigation Systems
- Application to Epilepsy Neurosurgery
  - OR Examples
  - Visualization Work
- Open IGT Link work
  - An example and lots of thoughts/suggestions

Image Guided Navigation Systems

BrainLAB, Neurosurgery 2002

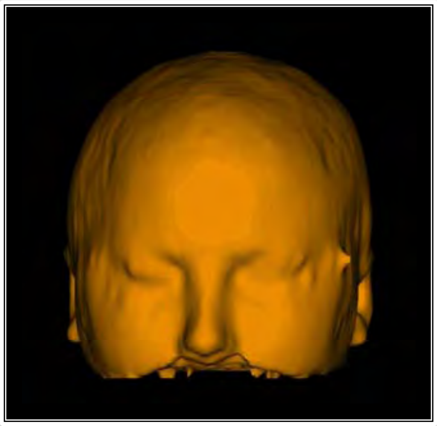
Procedure

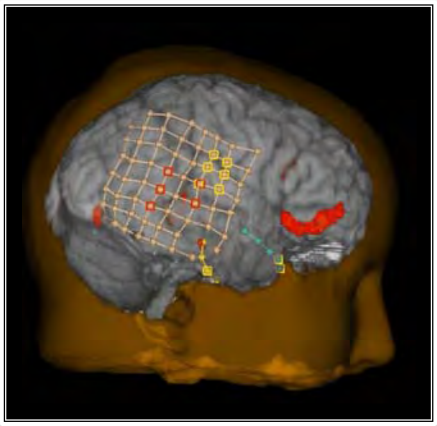
- Structural and Functional Imaging
- Surgical Planning
- Patient to Image Registration
- Track the position of the tools and display their position over the images.
  - Real Time Navigation.



Data
Brain_Atlas
colin_axi_1mm_stripped
Patient
Pre-op MR stripped
3D Anatomical MR
ACL1_convscout.hdr
Normalized_Smoothed_1
Normalized_Smoothed_2
PMAP_CSI_Image
Raw_CSI_Image
Electrodes in Pre-op MR space
PET-FDG
fMRI - T1
fMRI - func
fMRI - Tmap - task1
fMRI - Tmap - task2
fMRI - Tmap - task3
fMRI - Tmap - task50
fMRI - Tmap - task51

Putting it all together ...



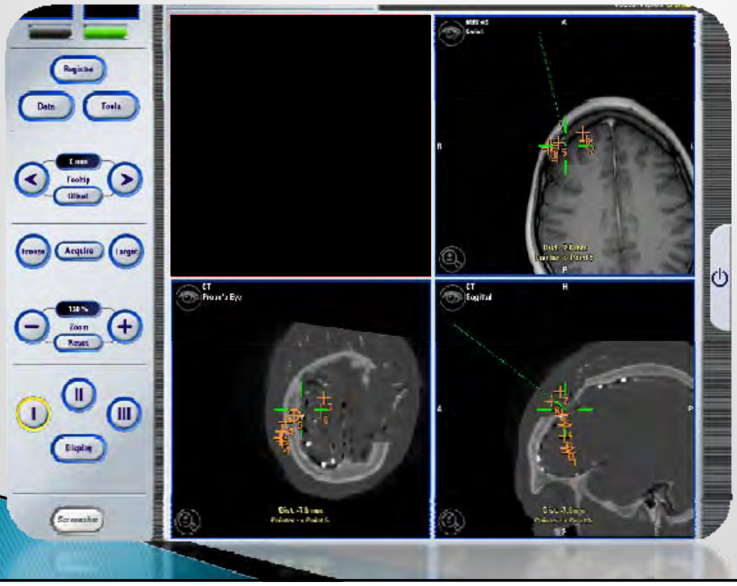


YALE

BioImage Suite

www.bioimagesuite.org

BrainLAB VVCranial System

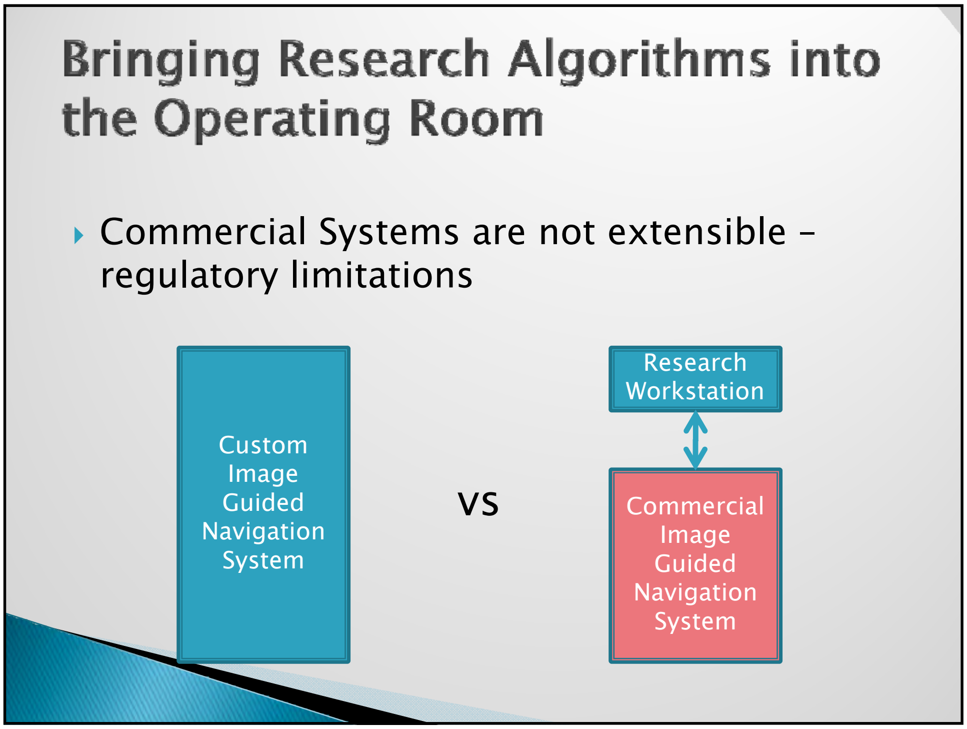


Research + Surgery = Trouble

- Image Analysis Research
  - Flexibility
  - Adaptability
  - Constant Change

- Image Guided Neurosurgery Platforms
  - Stability
  - Reliability

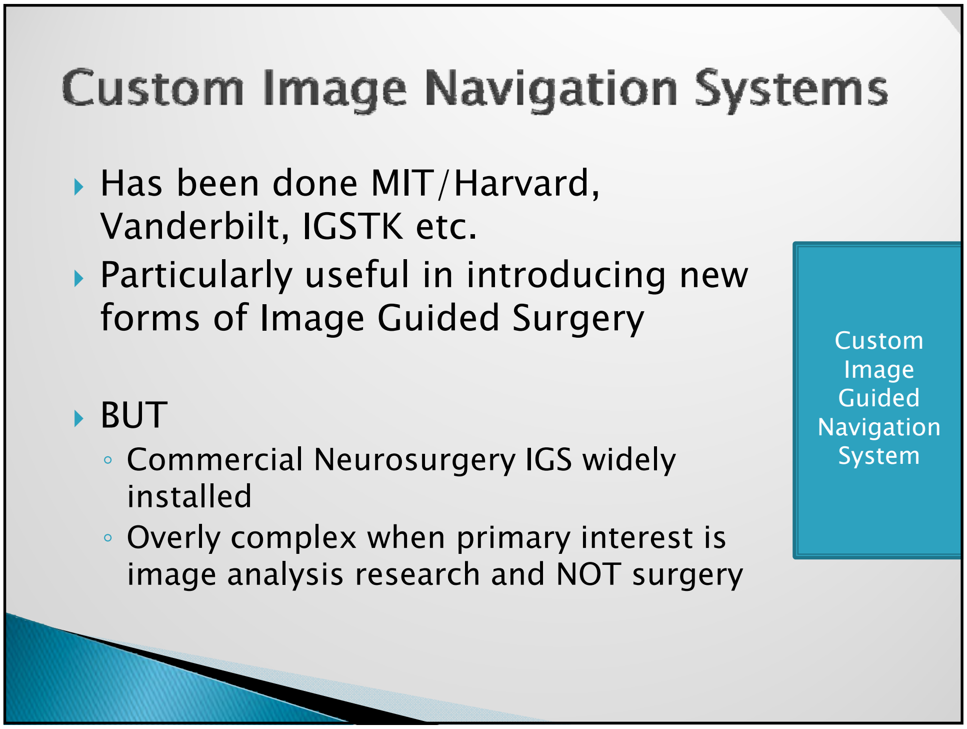
How can we accomplish both?



Bringing Research Algorithms into the Operating Room

- Commercial Systems are not extensible – regulatory limitations

Custom Image Guided Navigation System
VS
Research Workstation
Commercial Image Guided Navigation System



Custom Image Navigation Systems

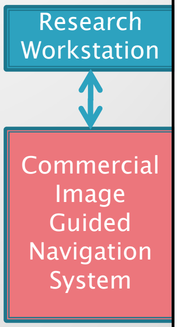
- Has been done MIT/Harvard, Vanderbilt, IGSTK etc.
- Particularly useful in introducing new forms of Image Guided Surgery

- BUT
  - Commercial Neurosurgery IGS widely installed
  - Overly complex when primary interest is image analysis research and NOT surgery

Custom Image Guided Navigation System

The Case for Research Interfaces

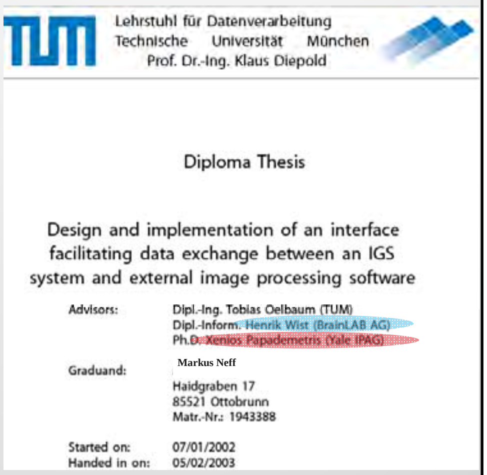
- Allows Surgeons to use familiar interface
- Researchers can focus on task at hand, not the clinical aspects of surgery
- Takes Vendor/FDA out of the research loop
- Stability – a program is as stable as its least stable part
- Licensing/ Programming Language/OS neutrality


Research Workstation

Commercial Image Guided Navigation System

The VVLink Story

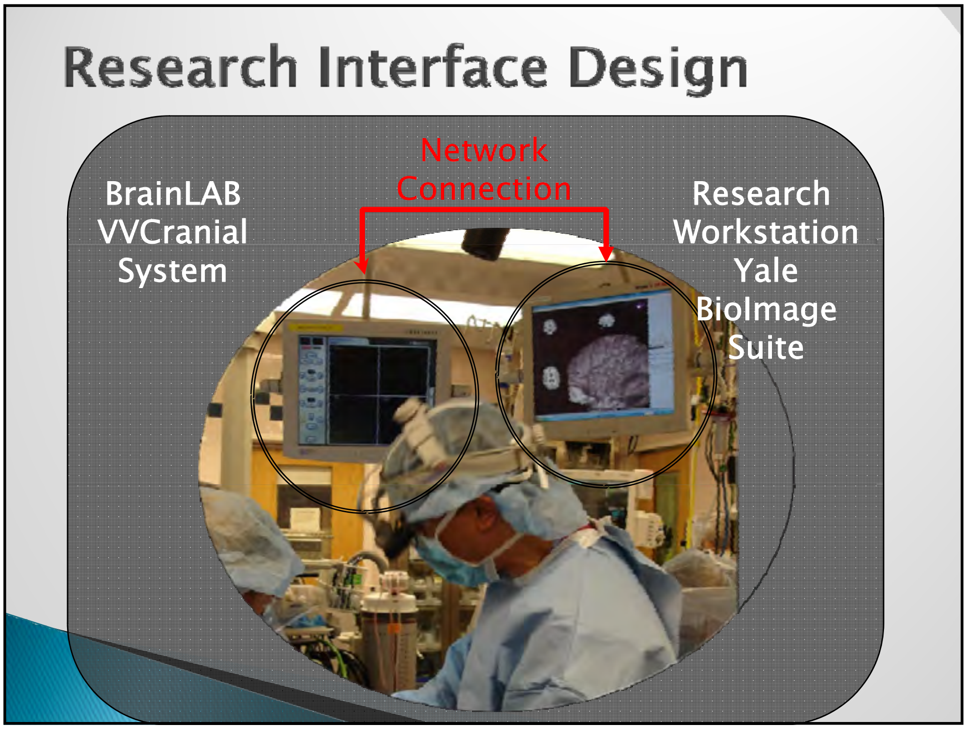
- Original Design June 2002
- M.Sc. Thesis of Markus Neff (2003)
- First restricted release (July 2005)
- Commercial Availability ~ Fall 2005


Lehrstuhl für Datenverarbeitung
Technische Universität München
Prof. Dr.-Ing. Klaus Diepold

Diploma Thesis

Design and implementation of an interface facilitating data exchange between an IGS system and external image processing software

Advisors:	Dipl.-Ing. Tobias Oelbaum (TUM) Dipl.-Inform. Henrik Wist (BrainLAB AG) Ph.D. Xenios Papademetris (Yale IPAG)
Graduand:	Markus Neff Haidgraben 17 85521 Ottobrunn Matr.-Nr.: 1943388
Started on:	07/01/2002
Handed in on:	05/02/2003

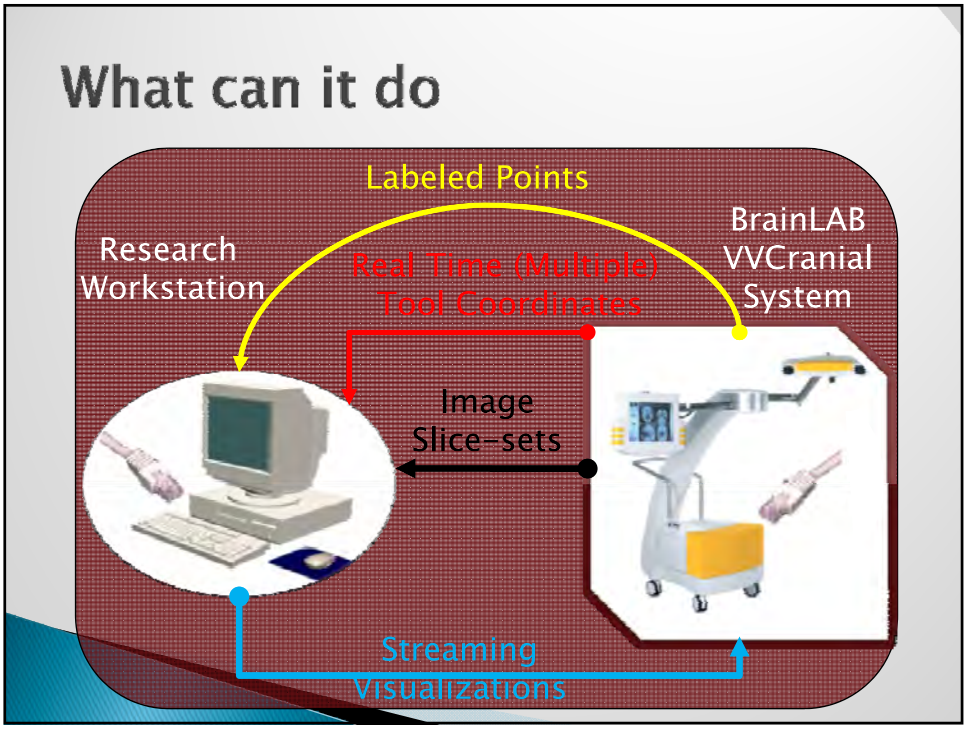


Research Interface Design

BrainLAB VVCranial System

Network Connection

Research Workstation Yale BioImage Suite



What can it do

Labeled Points

Research Workstation

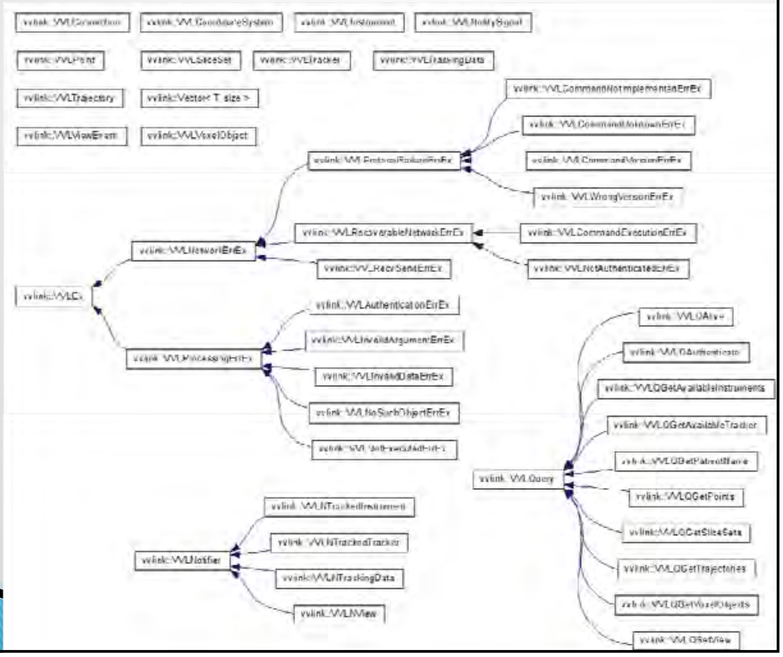
BrainLAB VVCranial System

Real Time (Multiple) Tool Coordinates

Image Slice-sets

Streaming Visualizations

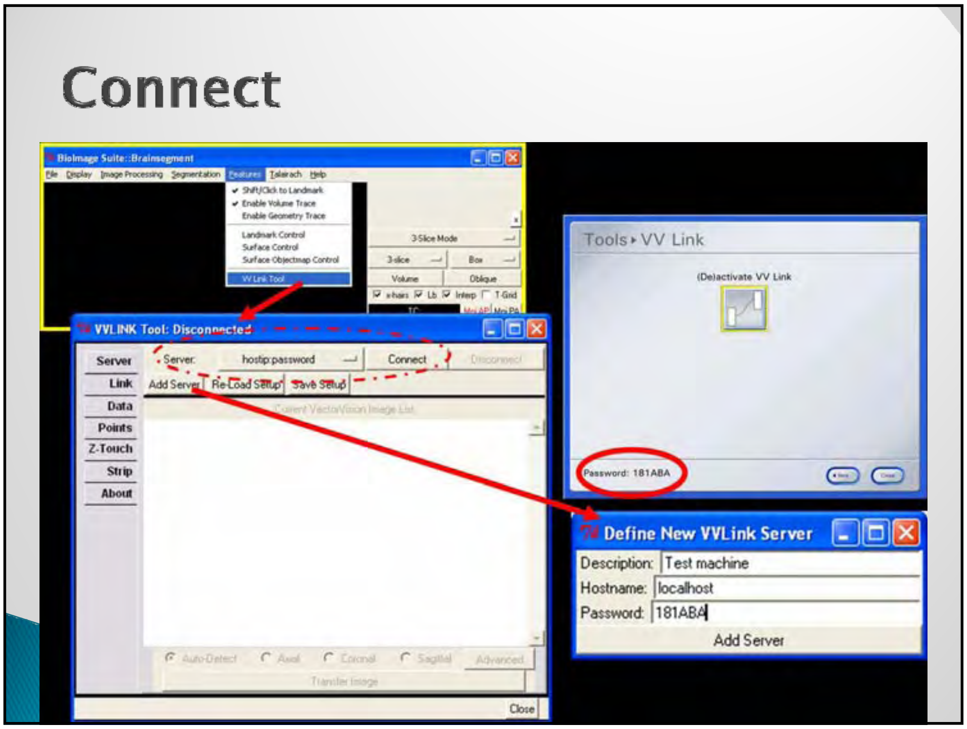
VTK-based API


vvlink::VVLConnection
vvlink::VVLCoordinateSystem
vvlink::VVLInstrument
vvlink::VVLNotifySignal
vvlink::VVLPoint
vvlink::VVLSliceSet
vvlink::VVLTracker
vvlink::VVLTrackingData
vvlink::VVLTrajectory
vvlink::Vector< T, size >
vvlink::VVLViewFrame
vvlink::VVLVoxelObject
vvlink::VVLCommandNotImplementedErrEx
vvlink::VVLCommandUnknownErrEx
vvlink::VVLProtocolFailureErrEx
vvlink::VVLCommandVersionErrEx
vvlink::VVLWrongVersionErrEx
vvlink::VVLRecoverableNetworkErrEx
vvlink::VVLCommandExecutionErrEx
vvlink::VVLNetworkErrEx
vvlink::VVL_RecvSendErrEx
vvlink::VVLNotAuthenticatedErrEx
vvlink::VVLEx
vvlink::VVLAuthenticationErrEx
vvlink::VVLInvalidArgumentErrEx
vvlink::VVLProcessingErrEx
vvlink::VVLInvalidDataErrEx
vvlink::VVLNoSuchObjectErrEx
vvlink::VVLQAlive
vvlink::VVLQAuthenticate
vvlink::VVLQGetAvailableInstruments
vvlink::VVLQGetAvailableTracker
vvlink::VVLQGetPatientName
vvlink::VVLQuery
vvlink::VVLQGetPoints
vvlink::VVLQGetSliceSets
vvlink::VVLQGetTrajectories
vvlink::VVLQGetVoxelObjects
vvlink::VVLQGetView
vvlink::VVLNTrackedInstrument
vvlink::VVLNTrackedTracker
vvlink::VVLNotifier
vvlink::VVLNTrackingData
vvlink::VVLNView

System in Action

- Initialization Procedure
  1. Enable VVLink on BrainLAB System
  2. Connect from client system
  3. Accept connection on BrainLAB System
  4. Transfer one image over to establish coordinate system mapping

(See BioImage Suite manual for details `www.bioimagesuite.org/doc`)



Connect

BioImage Suite::Brainsegment

VVLINK Tool: Disconnected

Server: hostip:password

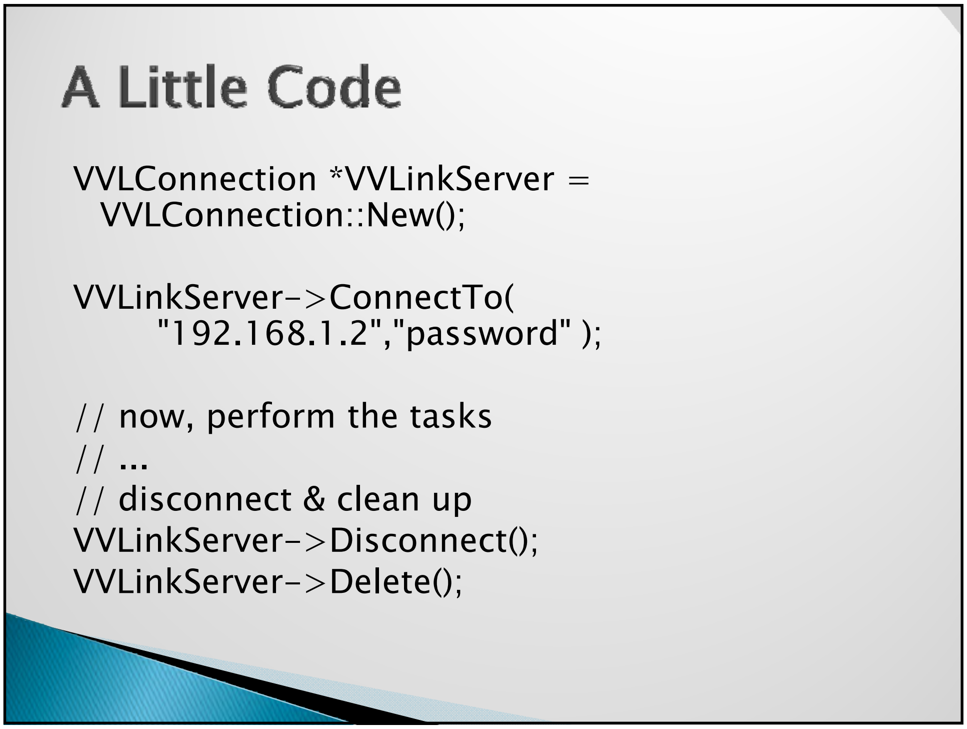
Tools ▸ VV Link

(De)activate VV Link

Password: 181ABA

Define New VVLink Server

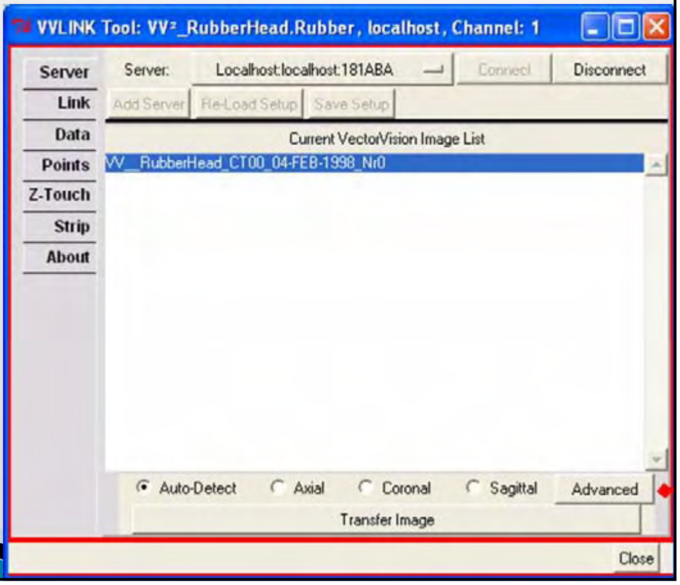
Description: Test machine
Hostname: localhost
Password: 181ABA



A Little Code

```
VVLConnection *VVLinkServer =
  VVLConnection::New();

VVLinkServer->ConnectTo(
       "192.168.1.2","password" );

// now, perform the tasks
// ...
// disconnect & clean up
VVLinkServer->Disconnect();
VVLinkServer->Delete();
```

Step 2 : Transfer Image



VVLINK Tool: VV²_RubberHead.Rubber, localhost, Channel: 1

Server: Localhost:localhost:181ABA

Current VectorVision Image List

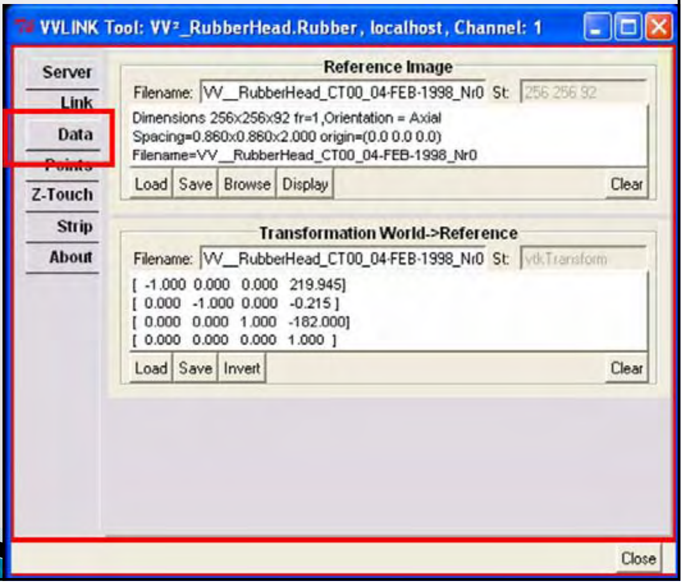
VV__RubberHead_CT00_04-FEB-1998_Nr0

● Auto-Detect ○ Axial ○ Coronal ○ Sagittal

Transfering an Image

```
const vvlink::VVLSliceSet *sliceSet =
  VVLSliceSets->GetSliceSet( imagename );

vtkMatrix4x4* matrix=
  sliceSet->GetOrthogonalTransformation();
vtkImageData* img=
  sliceSet->GetOrthogonalVolume();
vtkLookupTable* lut=
  sliceSet->GetLookupTable();
```

Initialization Completed



Reference Image

Filename: VV__RubberHead_CT00_04-FEB-1998_Nr0 St: 256 256 92

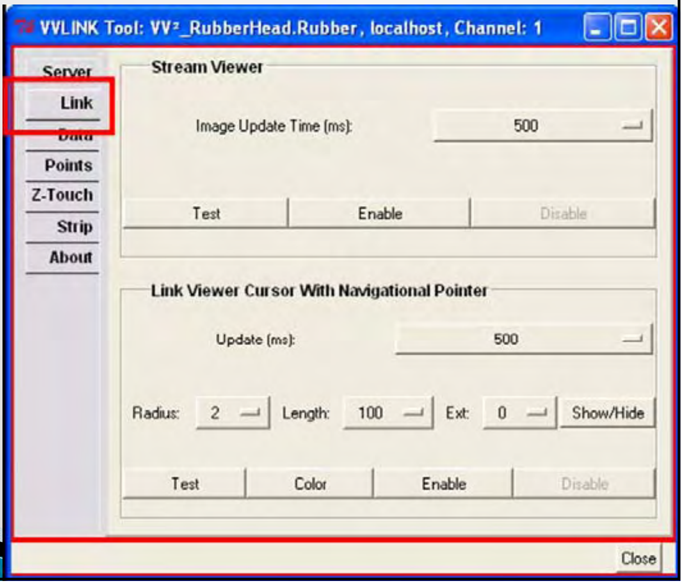
```
Dimensions 256x256x92 fr=1,Orientation = Axial
Spacing=0.860x0.860x2.000 origin=(0.0 0.0 0.0)
Filename=VV__RubberHead_CT00_04-FEB-1998_Nr0
```

Transformation World->Reference

Filename: VV__RubberHead_CT00_04-FEB-1998_Nr0 St: vtkTransform

```
[ -1.000  0.000   0.000   219.945]
[  0.000  -1.000  0.000   -0.215 ]
[  0.000  0.000   1.000   -182.000]
[  0.000  0.000   0.000   1.000  ]
```

Navigation



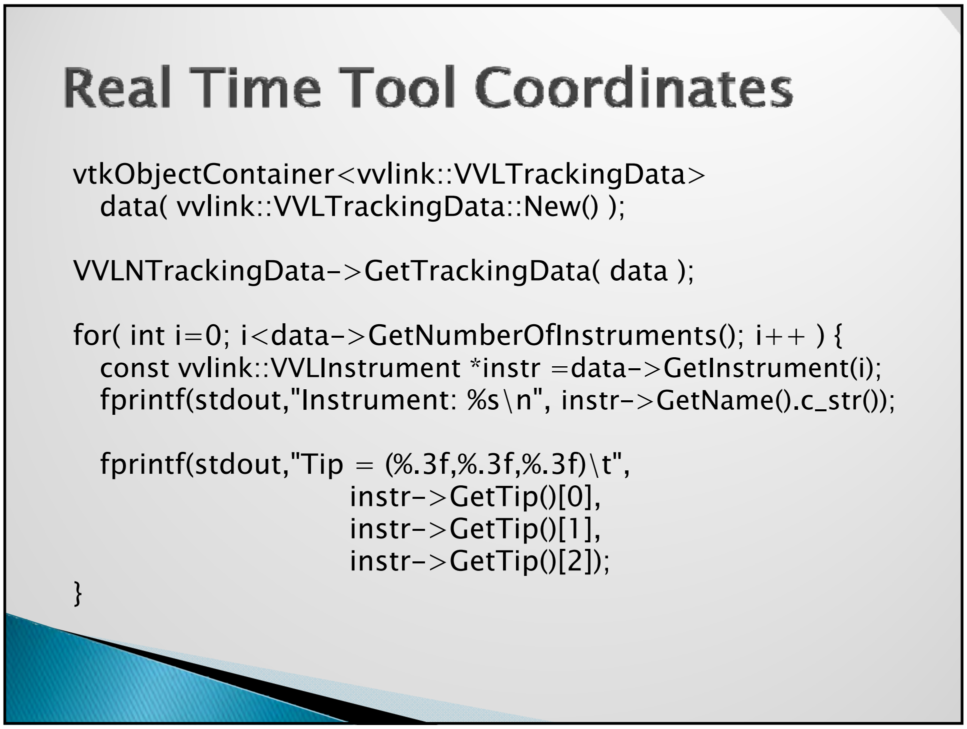
Stream Viewer

Image Update Time (ms): 500

Link Viewer Cursor With Navigational Pointer

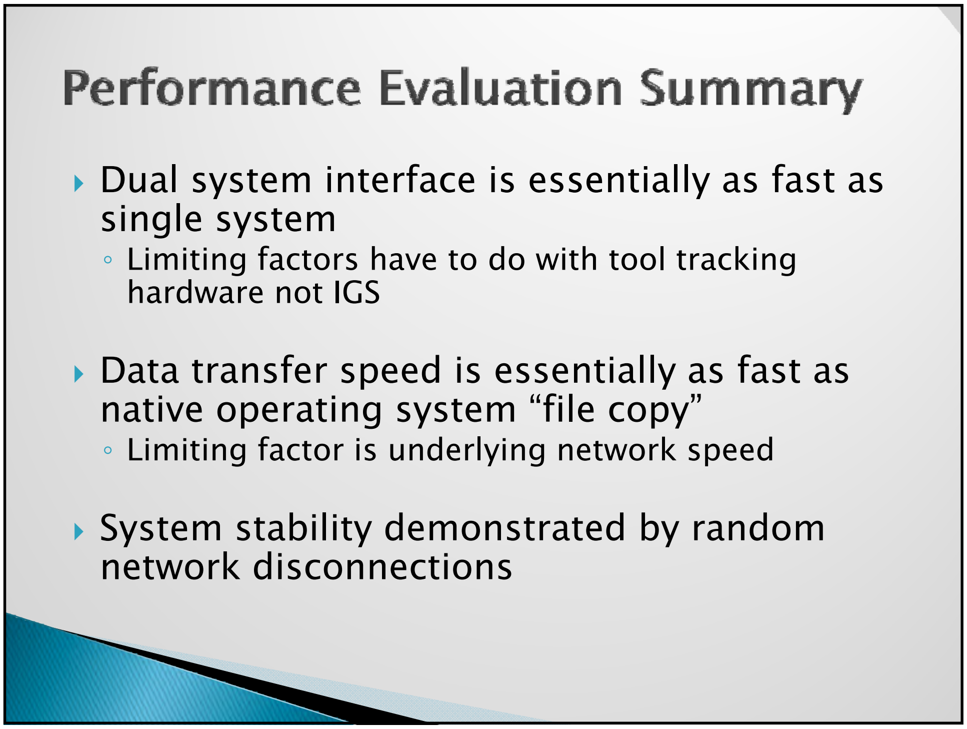
Update (ms): 500

Radius: 2 Length: 100 Ext: 0



Real Time Tool Coordinates

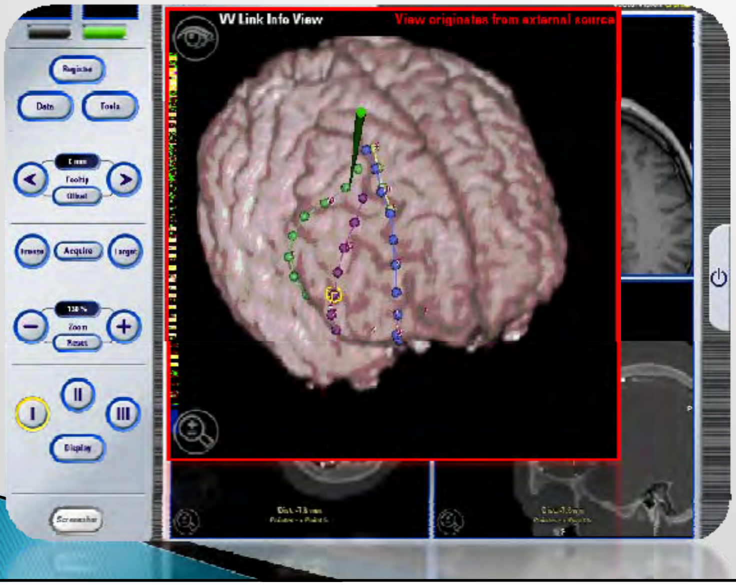
```
vtkObjectContainer<vvlink::VVLTrackingData>
   data( vvlink::VVLTrackingData::New() );

VVLNTrackingData->GetTrackingData( data );

for( int i=0; i<data->GetNumberOfInstruments(); i++ ) {
   const vvlink::VVLInstrument *instr =data->GetInstrument(i);
   fprintf(stdout,"Instrument: %s\n", instr->GetName().c_str());

   fprintf(stdout,"Tip = (%.3f,%.3f,%.3f)\t",
                              instr->GetTip()[0],
                              instr->GetTip()[1],
                              instr->GetTip()[2]);
}
```



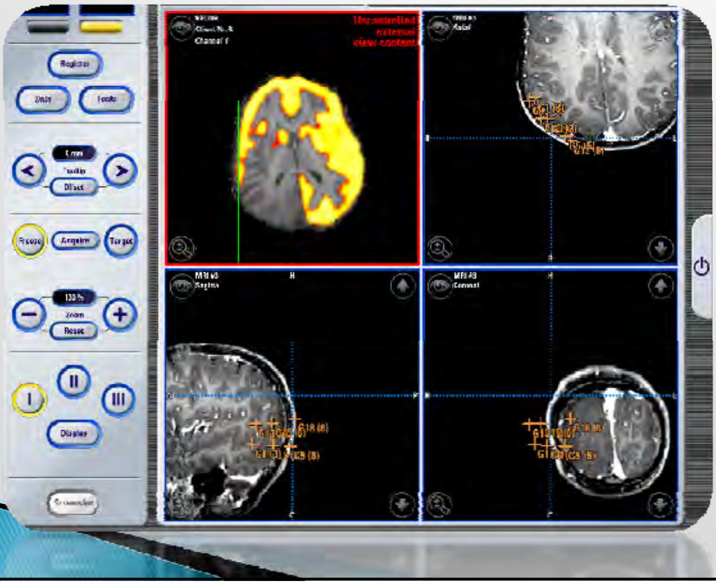
Performance Evaluation Summary

- Dual system interface is essentially as fast as single system
  - Limiting factors have to do with tool tracking hardware not IGS
- Data transfer speed is essentially as fast as native operating system “file copy”
  - Limiting factor is underlying network speed
- System stability demonstrated by random network disconnections

In Action I



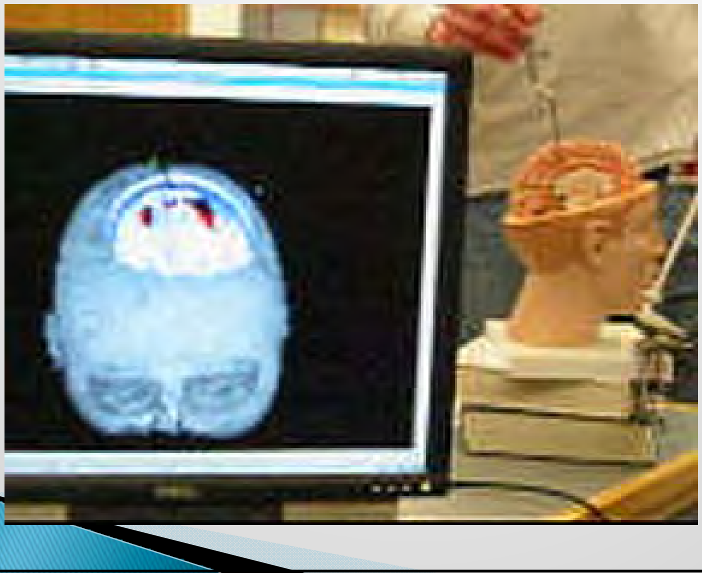
In Action II

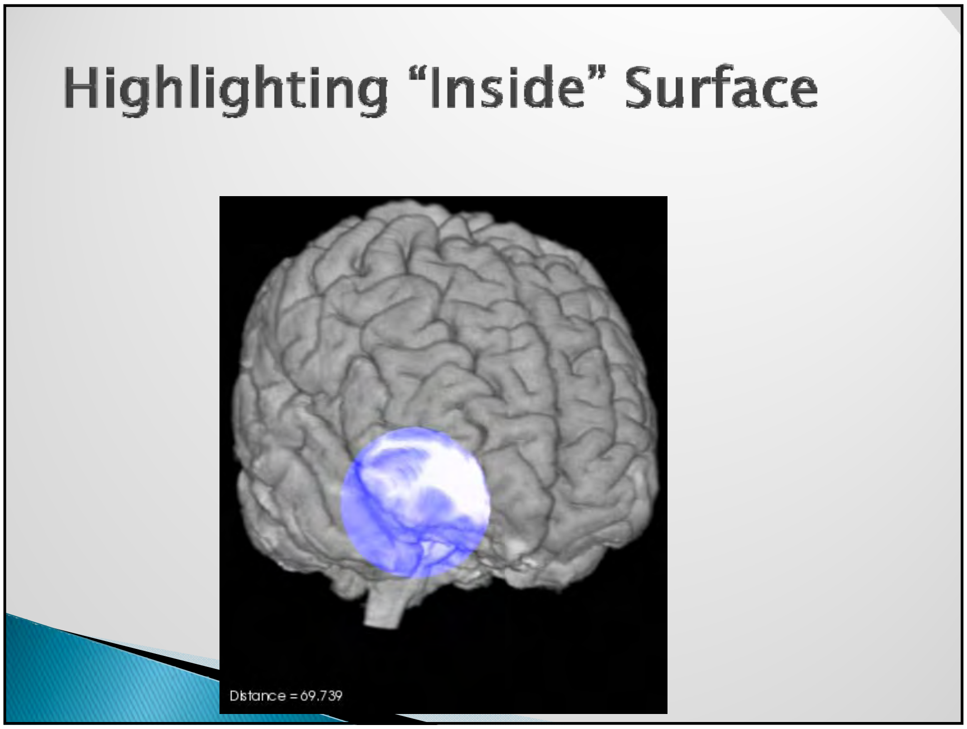


Non-Orthogonal Volume Cropping

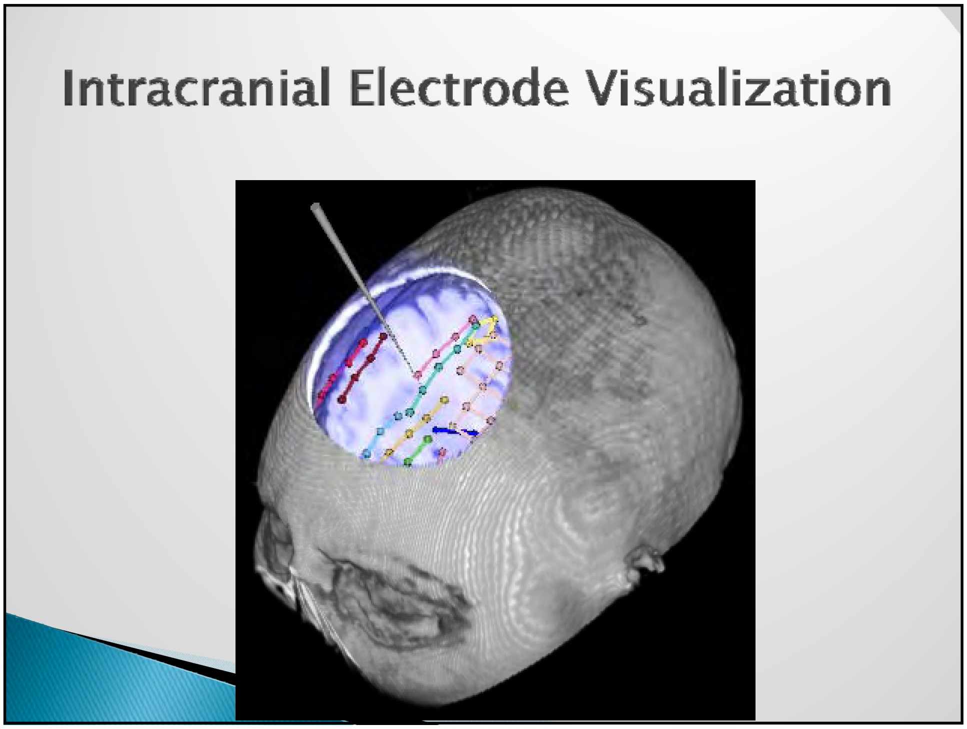
- Planar Cropping can be problematic as it removes “too much” i.e. half a brain
- Often removes the context around which navigation is taking place
- In recent work we have explored non-orthogonal cropping techniques for visualization (Joshi et al IEEE TVCG in-press)
  - Sperical, Cubical, Cylindrical probes
  - Highlighting of “inside” surface
  - Adaptive Cropping (e.g. leave function but remove anatomy)

Setup VVLink



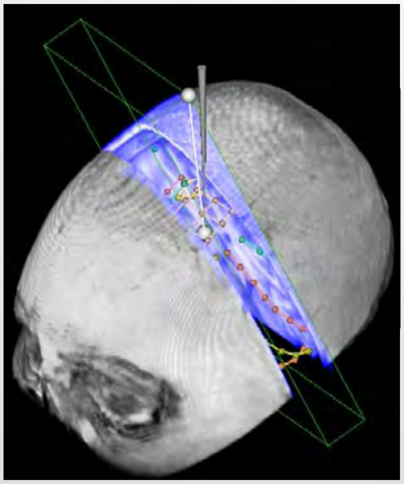


Highlighting “Inside” Surface



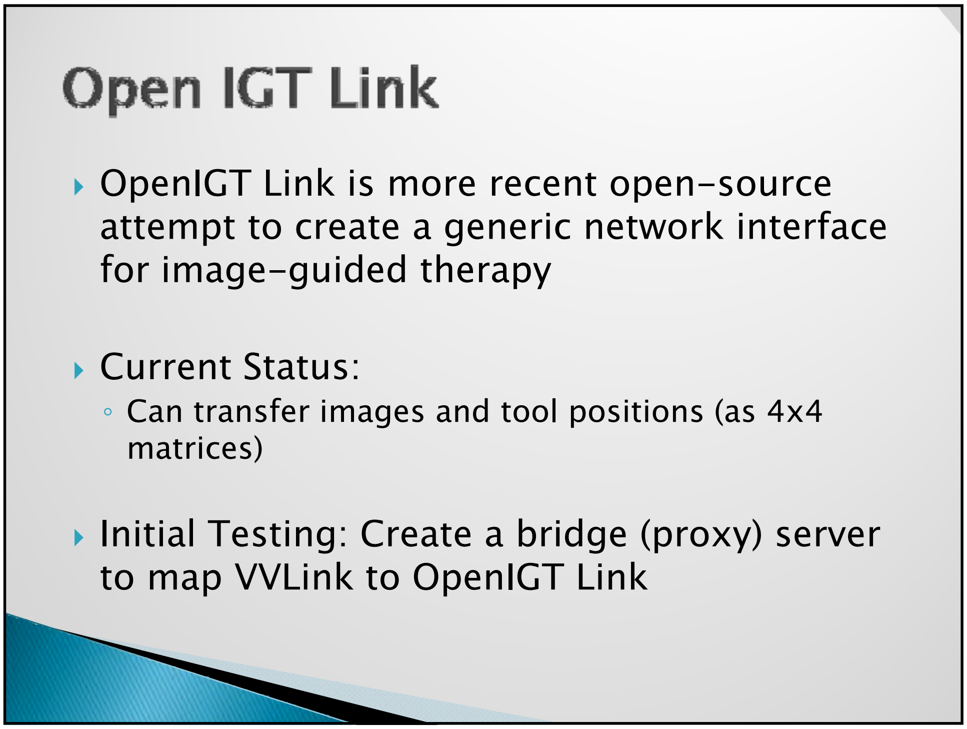
Intracranial Electrode Visualization

Probe Cut



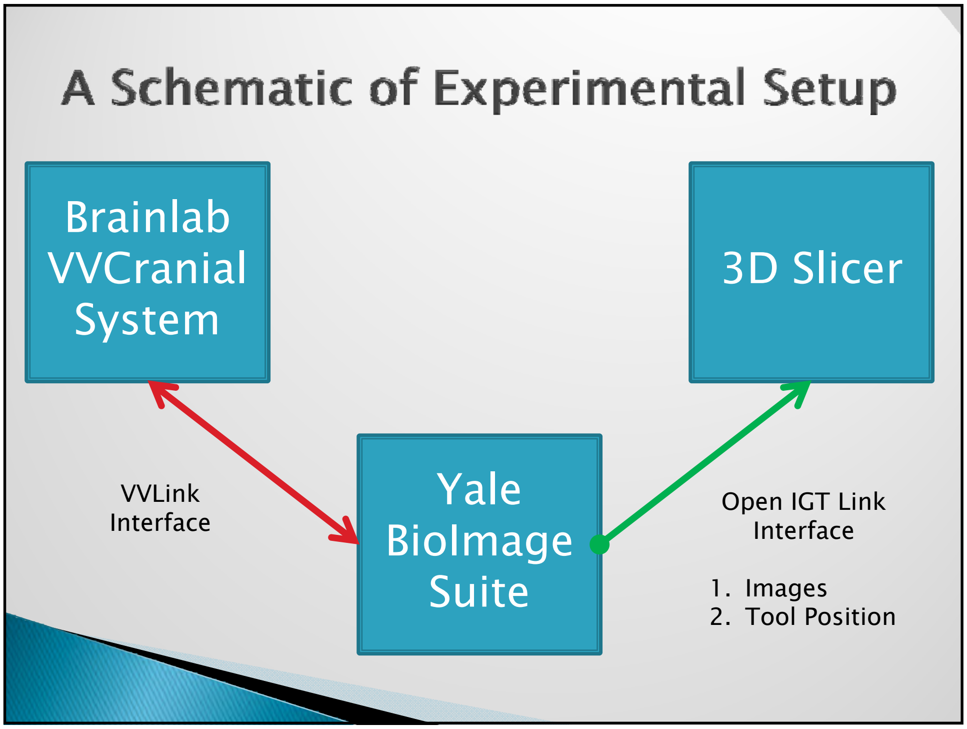
Conclusions

- Access to Image Guided Navigation Systems is key to testing image analysis algorithms in the Operating Room
- Developed such an interface -- in collaboration with BrainLAB
  - Medtronic has also moved in the same direction (STEALTHLink)
- Eliminates the need for custom IGS design/testing and implementation if image analysis is the driving application.



Open IGT Link

- OpenIGT Link is more recent open-source attempt to create a generic network interface for image-guided therapy
- Current Status:
  - Can transfer images and tool positions (as 4x4 matrices)
- Initial Testing: Create a bridge (proxy) server to map VVLink to OpenIGT Link



A Schematic of Experimental Setup

Brainlab VVCranial System

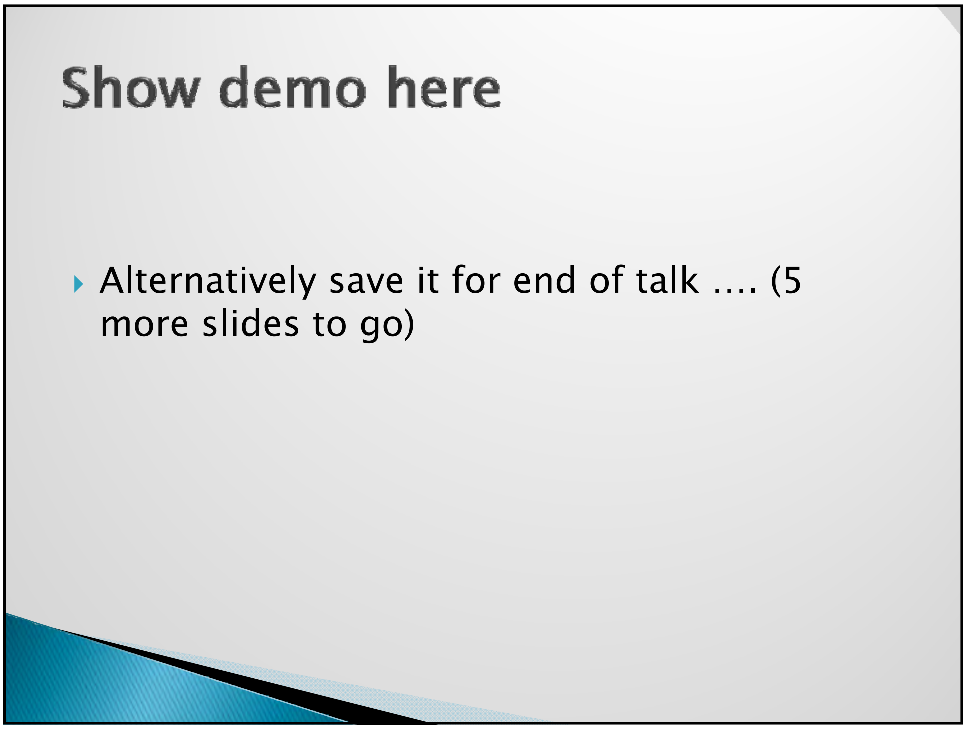
3D Slicer

VVLink Interface

Yale BioImage Suite

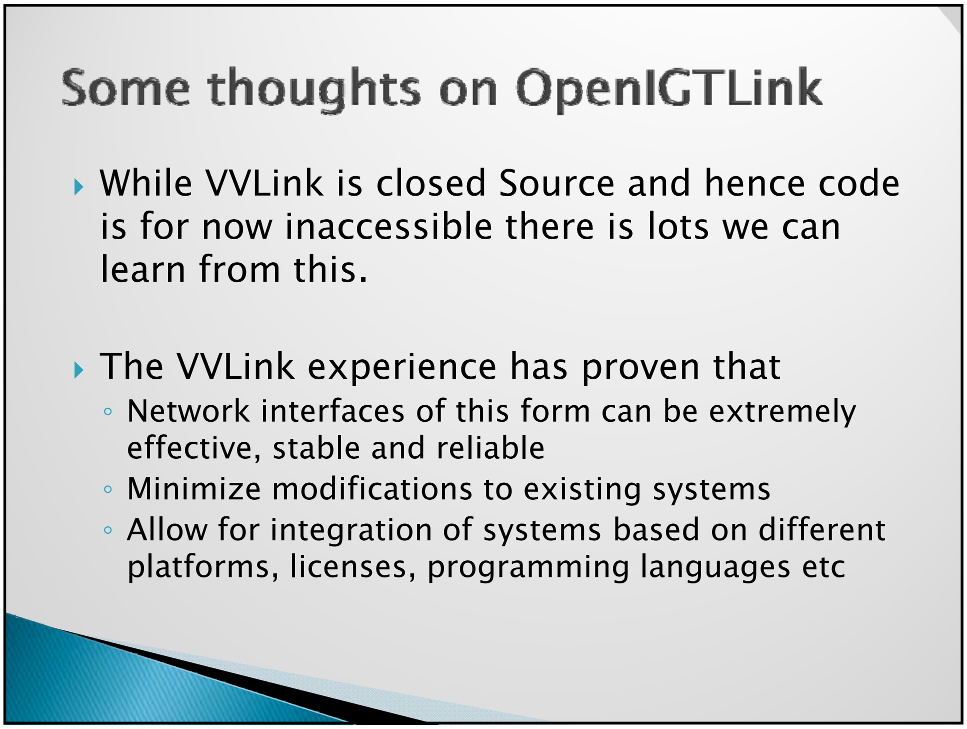
Open IGT Link Interface

1. Images
2. Tool Position



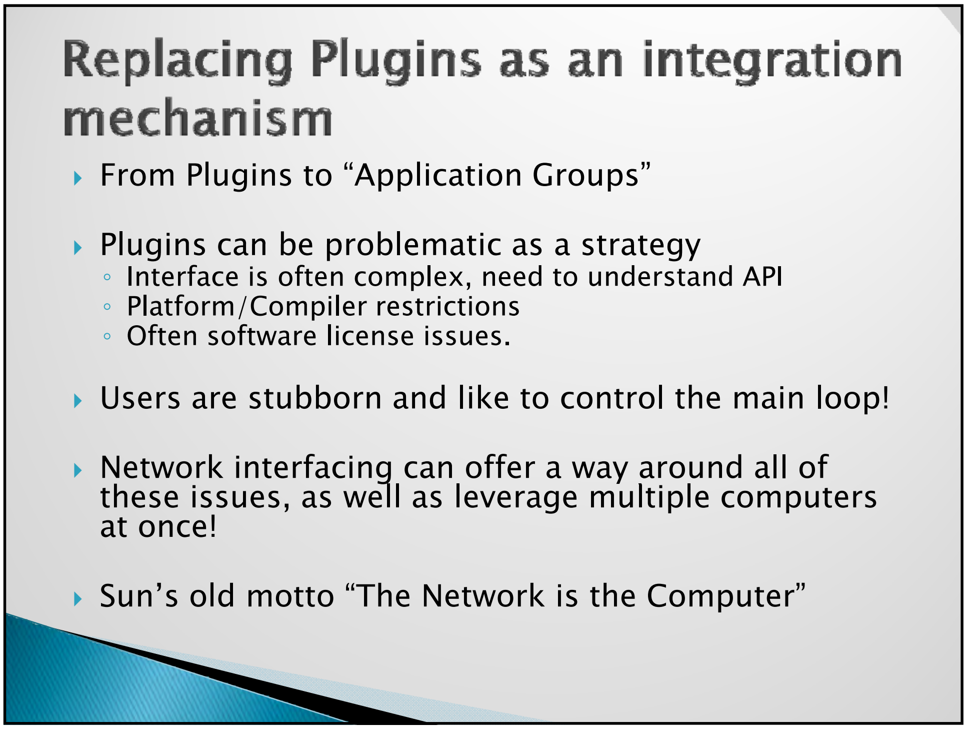
Show demo here

- Alternatively save it for end of talk …. (5 more slides to go)



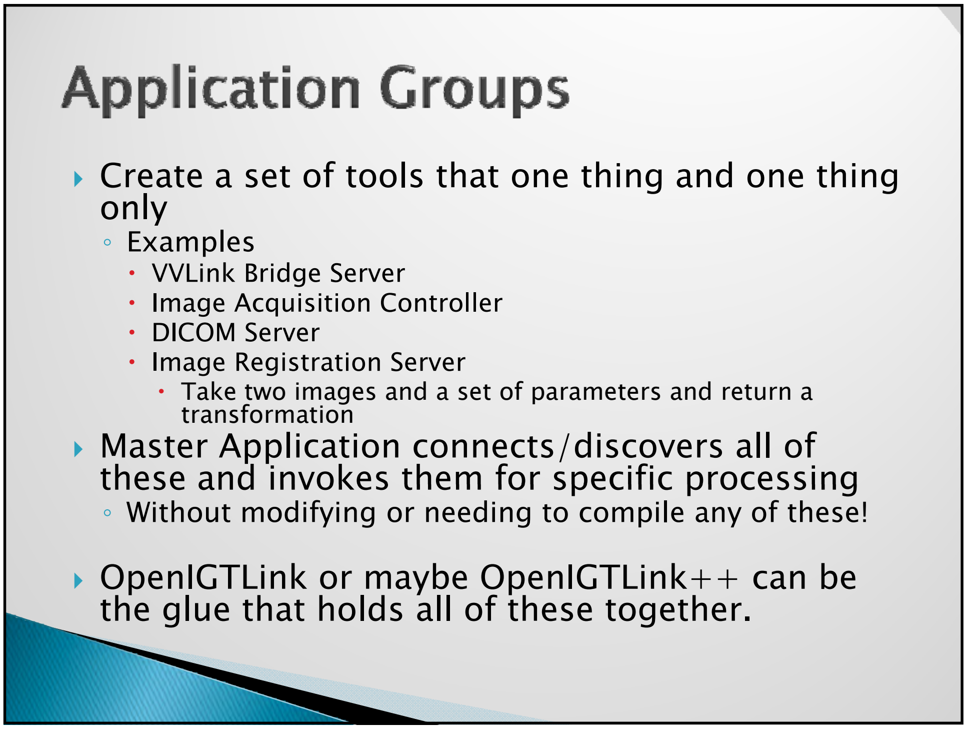
Some thoughts on OpenIGTLink

- While VVLink is closed Source and hence code is for now inaccessible there is lots we can learn from this.
- The VVLink experience has proven that
  - Network interfaces of this form can be extremely effective, stable and reliable
  - Minimize modifications to existing systems
  - Allow for integration of systems based on different platforms, licenses, programming languages etc



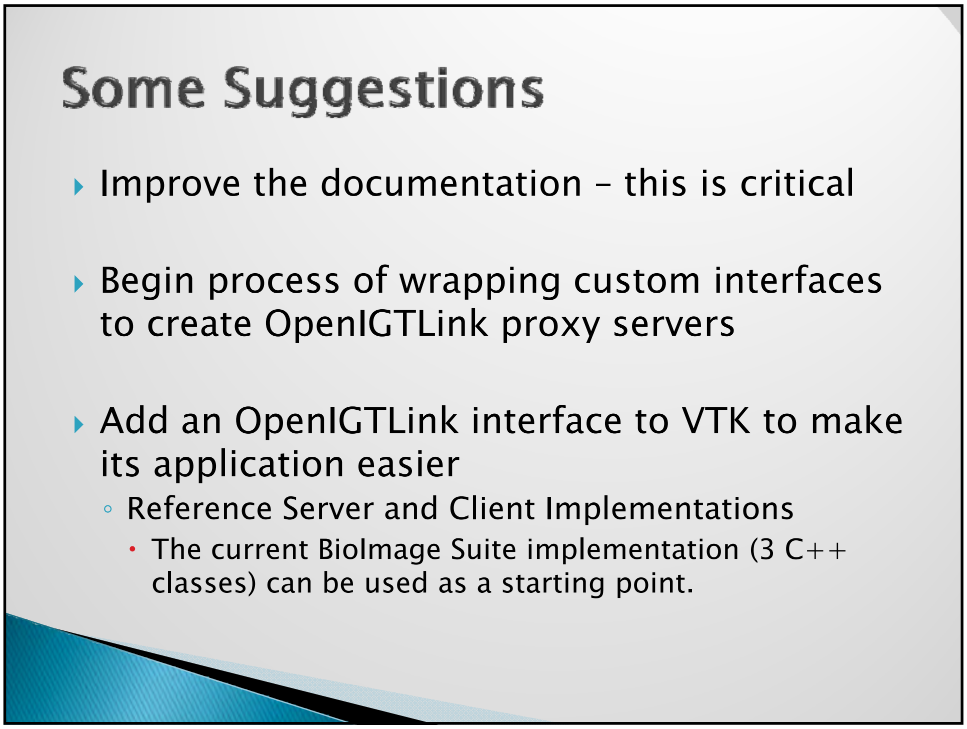
Replacing Plugins as an integration mechanism

- From Plugins to “Application Groups”
- Plugins can be problematic as a strategy
  - Interface is often complex, need to understand API
  - Platform/Compiler restrictions
  - Often software license issues.
- Users are stubborn and like to control the main loop!
- Network interfacing can offer a way around all of these issues, as well as leverage multiple computers at once!
- Sun’s old motto “The Network is the Computer”



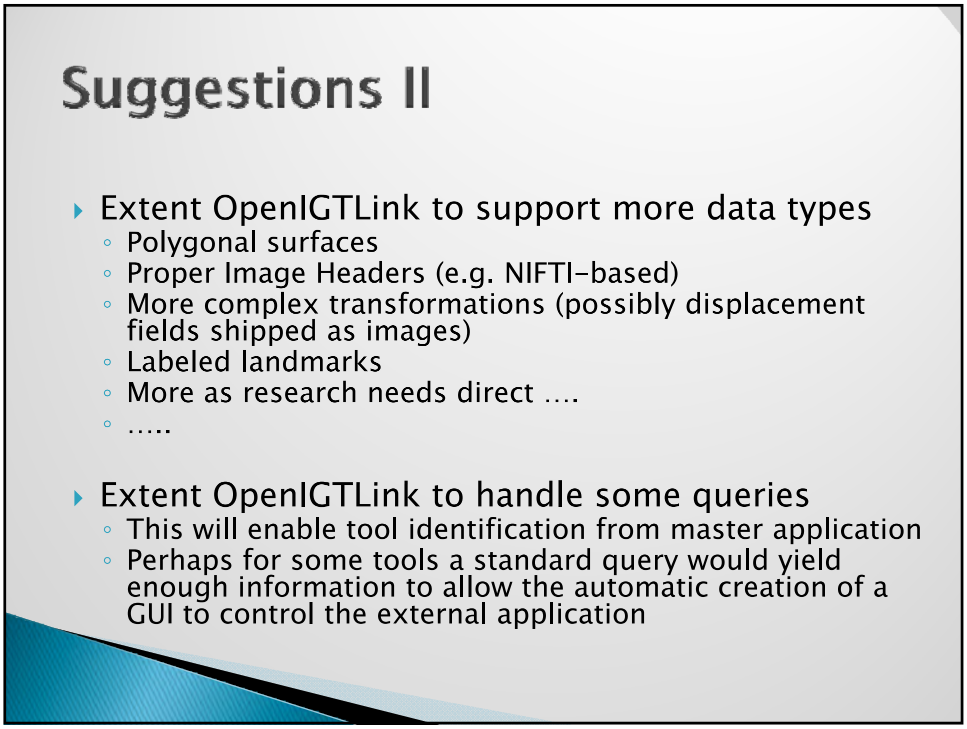
Application Groups

- Create a set of tools that one thing and one thing only
  - Examples
    - VVLink Bridge Server
    - Image Acquisition Controller
    - DICOM Server
    - Image Registration Server
      - Take two images and a set of parameters and return a transformation
- Master Application connects/discovers all of these and invokes them for specific processing
  - Without modifying or needing to compile any of these!
- OpenIGTLink or maybe OpenIGTLink++ can be the glue that holds all of these together.



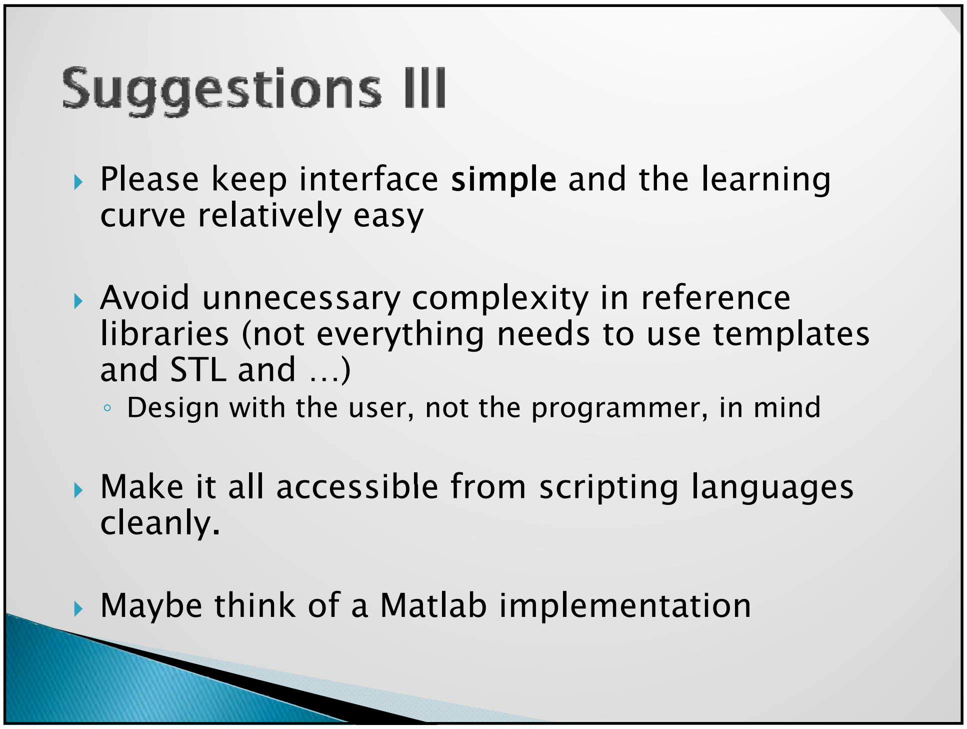
Some Suggestions

- Improve the documentation – this is critical
- Begin process of wrapping custom interfaces to create OpenIGTLink proxy servers
- Add an OpenIGTLink interface to VTK to make its application easier
  - Reference Server and Client Implementations
    - The current BioImage Suite implementation (3 C++ classes) can be used as a starting point.



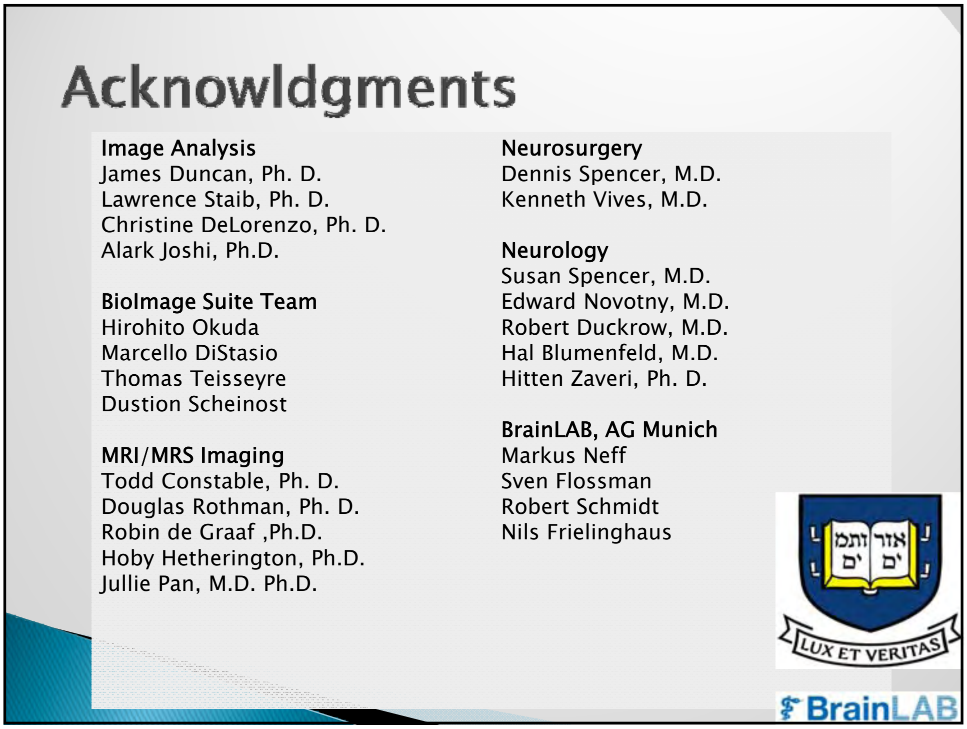
Suggestions II

- Extent OpenIGTLink to support more data types
  - Polygonal surfaces
  - Proper Image Headers (e.g. NIFTI-based)
  - More complex transformations (possibly displacement fields shipped as images)
  - Labeled landmarks
  - More as research needs direct ….
  - …..
- Extent OpenIGTLink to handle some queries
  - This will enable tool identification from master application
  - Perhaps for some tools a standard query would yield enough information to allow the automatic creation of a GUI to control the external application



Suggestions III

- Please keep interface **simple** and the learning curve relatively easy
- Avoid unnecessary complexity in reference libraries (not everything needs to use templates and STL and …)
  - Design with the user, not the programmer, in mind
- Make it all accessible from scripting languages cleanly.
- Maybe think of a Matlab implementation



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Nils Frielinghaus

LUX ET VERITAS

BrainLAB

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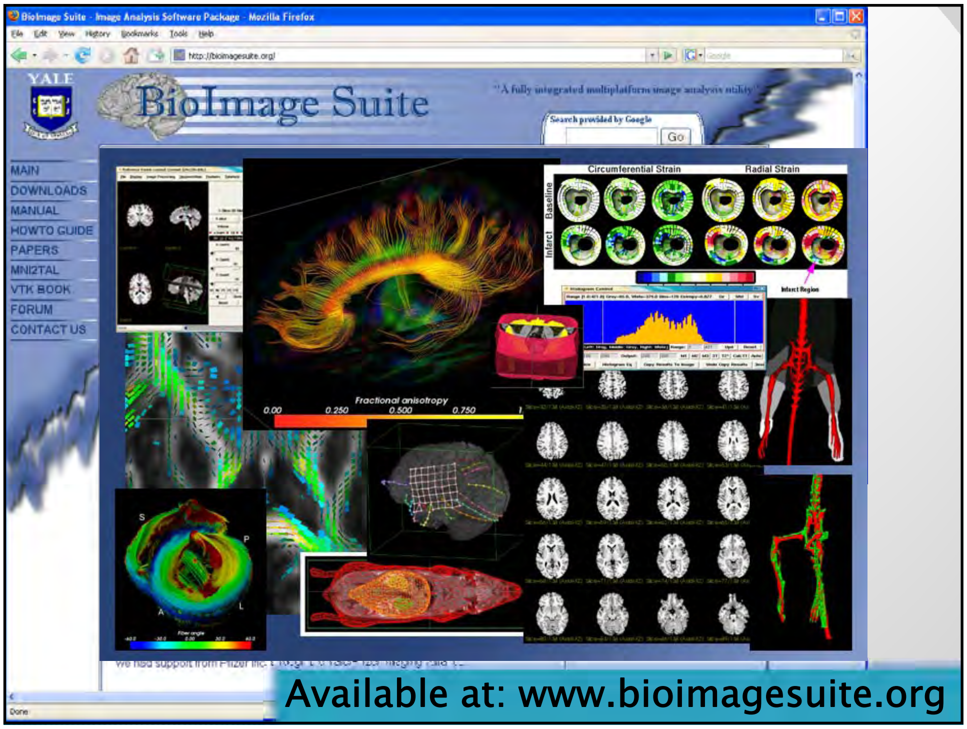
- R21EB007770 (Papademetris, X. PI)

NITRC

The Source for Neuroimaging Tools and Resources

nitrc.nih.gov


BioImage Suite - Image Analysis Software Package - Mozilla Firefox
File Edit View History Bookmarks Tools Help
http://bioimagesuite.org/
YALE
BioImage Suite
"A fully integrated multiplatform image analysis utility"
Search provided by Google
Go
MAIN
DOWNLOADS
MANUAL
HOWTO GUIDE
PAPERS
MNI2TAL
VTK BOOK
FORUM
CONTACT US
Circumferential Strain
Radial Strain
Baseline
Infarct
Infarct Region
Fractional anisotropy
0.00
0.250
0.500
0.750
Done

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