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Translational Research in the Field of Medical Image Computing and Computer Assisted Intervention

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- Institutsleiter, Fraunhofer MEVIS
- Principal Investigator, National Alliance for Medical Image Computing, and Neuroimage Analysis Center,
- Research Director, National Center for Image Guided Therapy

Acknowledgments

National Alliance for Medical Image Computing
www.na-mic.org

Neuroimage Analysis Center
nac.spl.harvard.edu

Surgical Planning Laboratory, Brigham and Women's Hospital
spl.harvard.edu

National Center For Image Guided Therapy
www.ncigt.org

- Ferenc Jolesz, MD, my mentor
- Collaborators and colleagues

Introduction

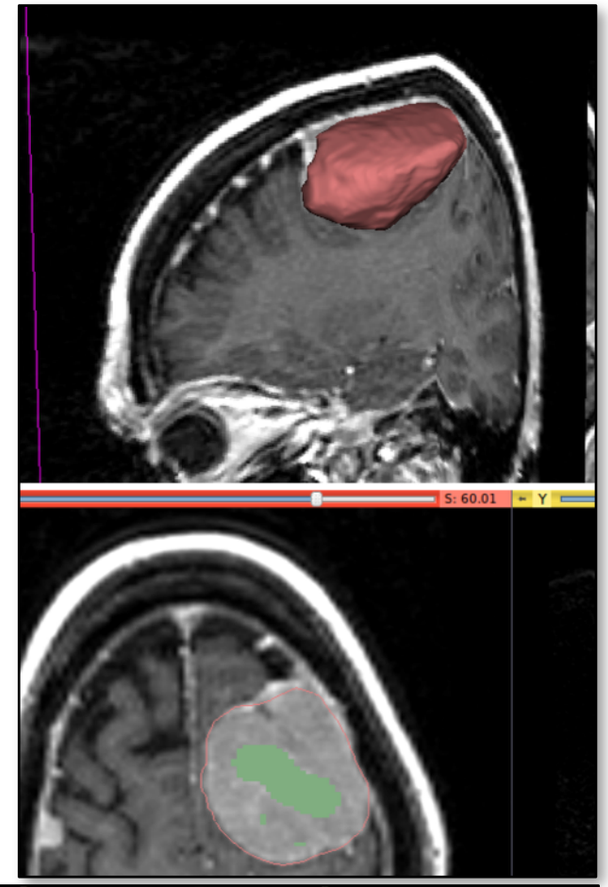
- **Medical Image Computing**
- 3D Slicer
- NA-MIC
- Open source

What is MIC

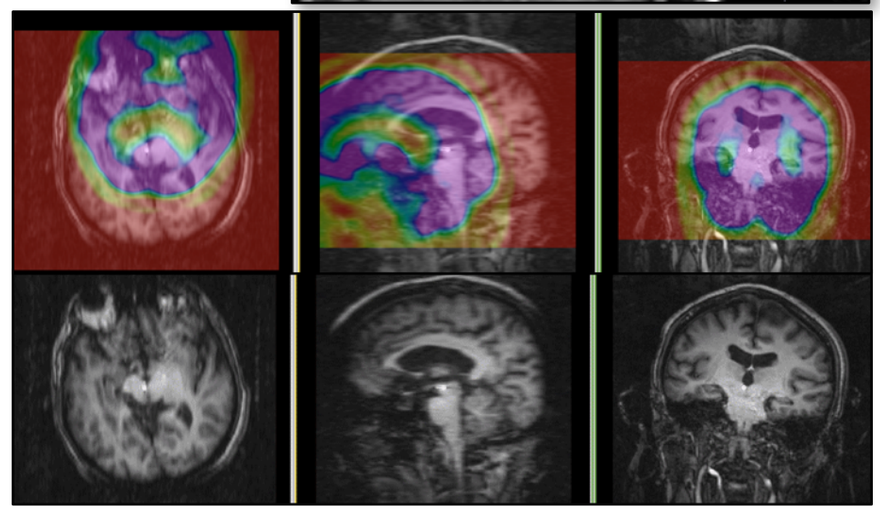
- Goal: extraction of clinically relevant information and knowledge from medical images using computational methods such as:
  - image segmentation
  - image registration
  - image-based physiological modeling
  - visualization

http://wiki.slicer.org/slicerWiki/index.php/Documentation/Nightly/Modules/RobustStatisticsSegmenter

result



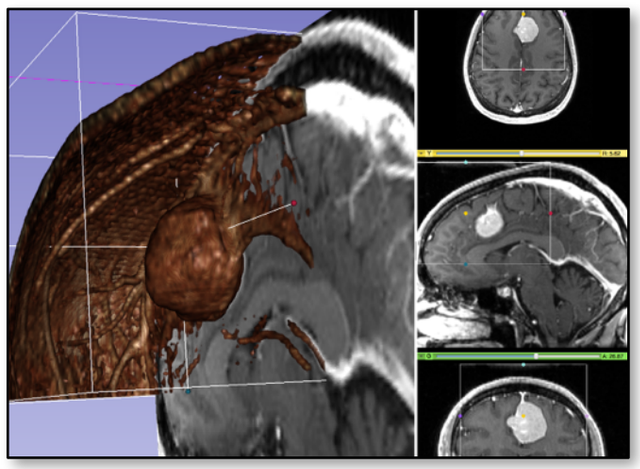
initialization



before

after

http://wiki.slicer.org/slicerWiki/index.php/Documentation:Nightly:Registration:RegistrationLibrary:RegLib_C14

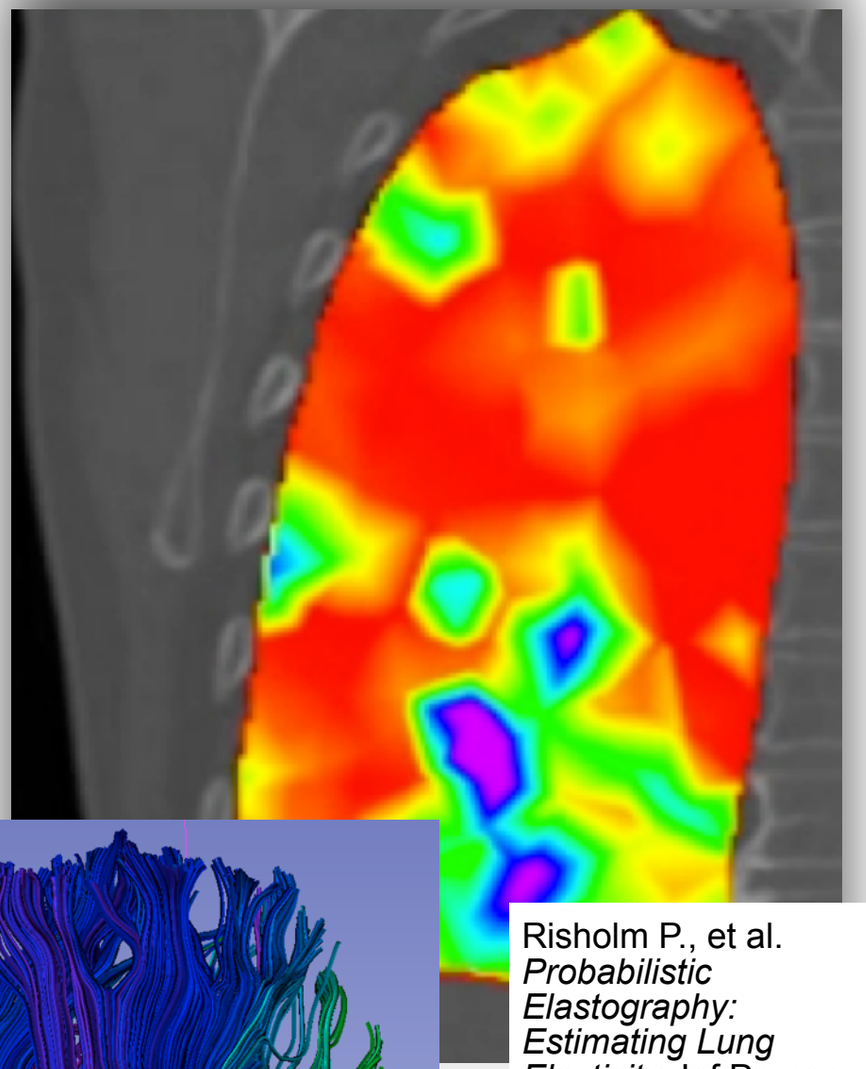


Volume rendering

Increasing Importance of MIC

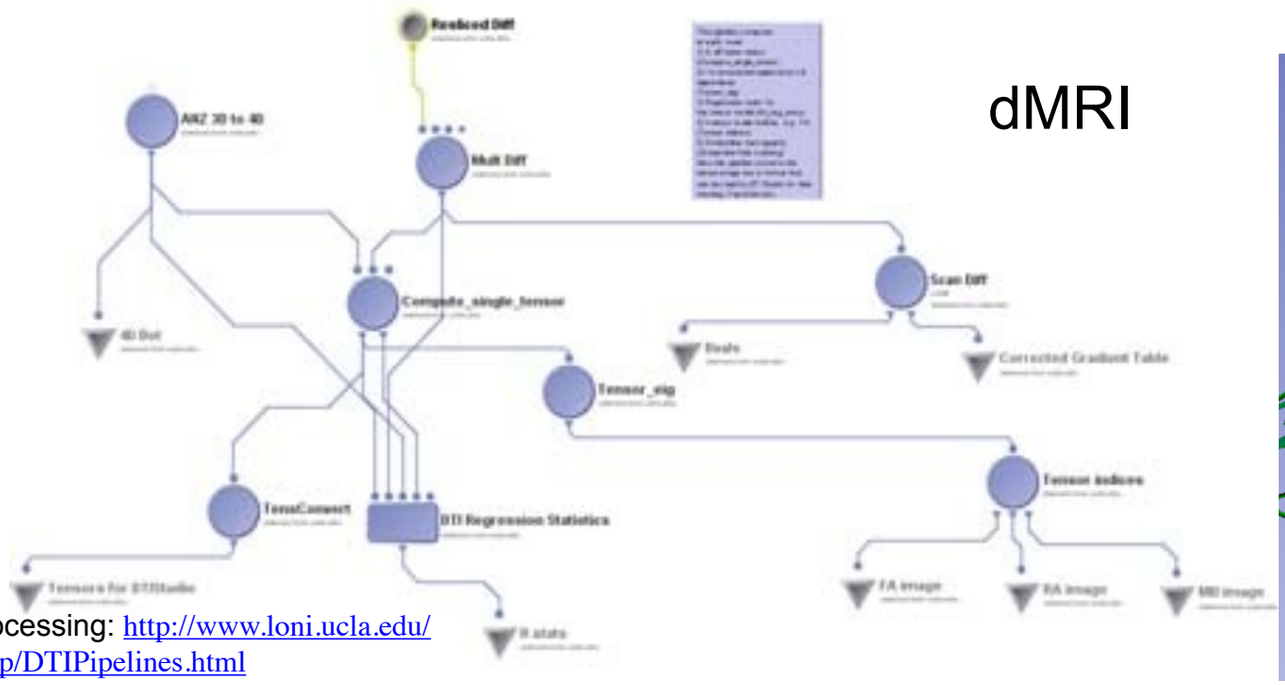
- More data:
  gigabytes to terabytes
- More complexity
  fMRI,parametric maps, dMRI, 4D ultrasound
- More applications
  Discovery, Diagnosis
  Therapy monitoring

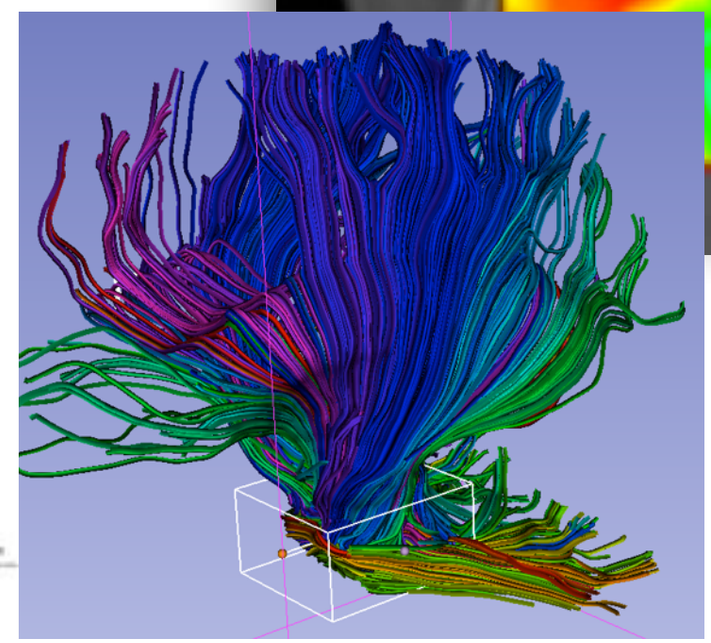
Parametric map of emphysema severity



Risholm P., et al. *Probabilistic Elastography: Estimating Lung Elasticity*. Inf Process Med Imaging. 2011;22:699-710. PMID: 21761697.

dMRI





DTI processing: http://www.loni.ucla.edu/~ophillip/DTIPipelines.html

From Research To Clinical Tools

Questions and answers

- Can it be done?
  - Prototypes
- **Is it worth doing?**
  - Tools
- Standard of care
  - Commercially available clinical “devices” with regulatory approval

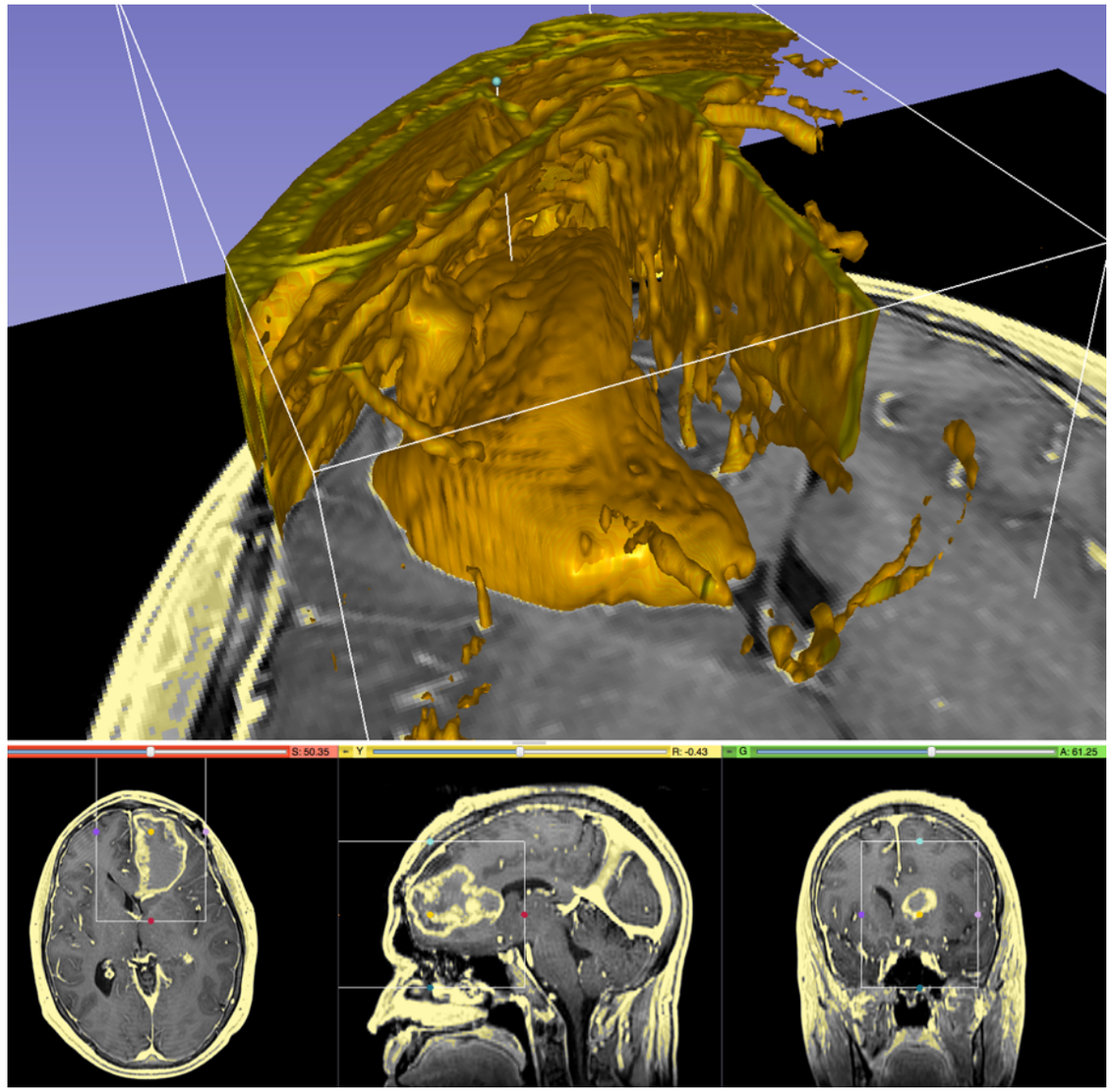
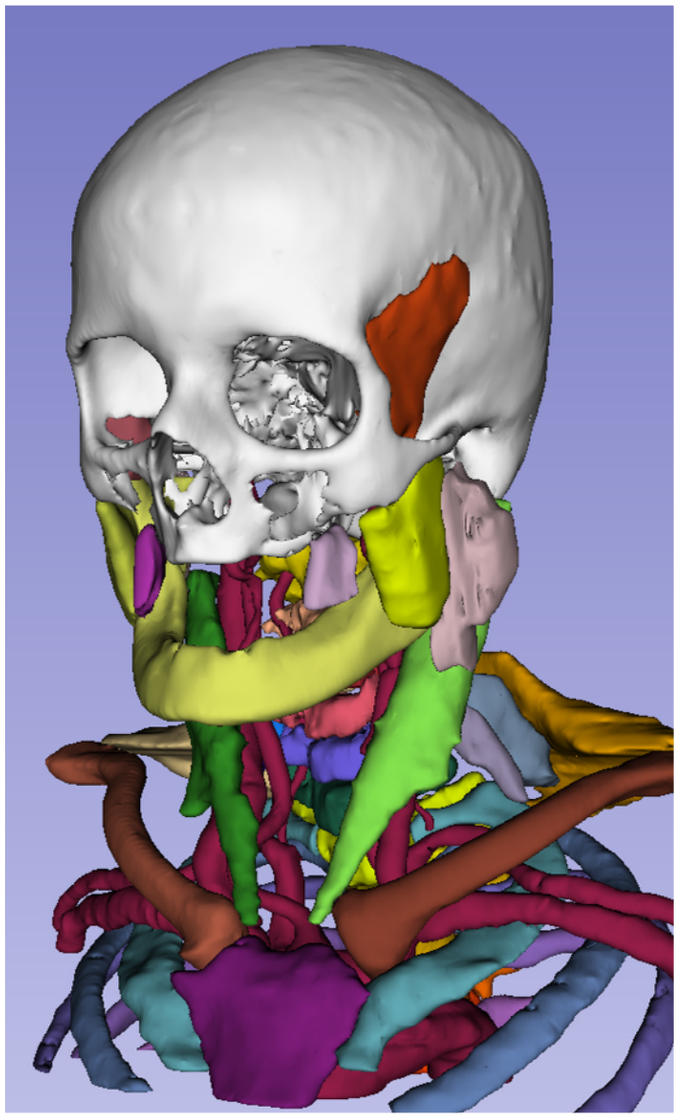


Image provided by R. Kikinis

Translation Requires Tools

- A **prototype** works for the grad student's thesis
  - Not portable
  - Unstable, no support
- A **tool** works in your environment
  - Easy to install
  - Easy to use
  - Stable, supported
- Significant resources are needed to get from a prototype to a tool

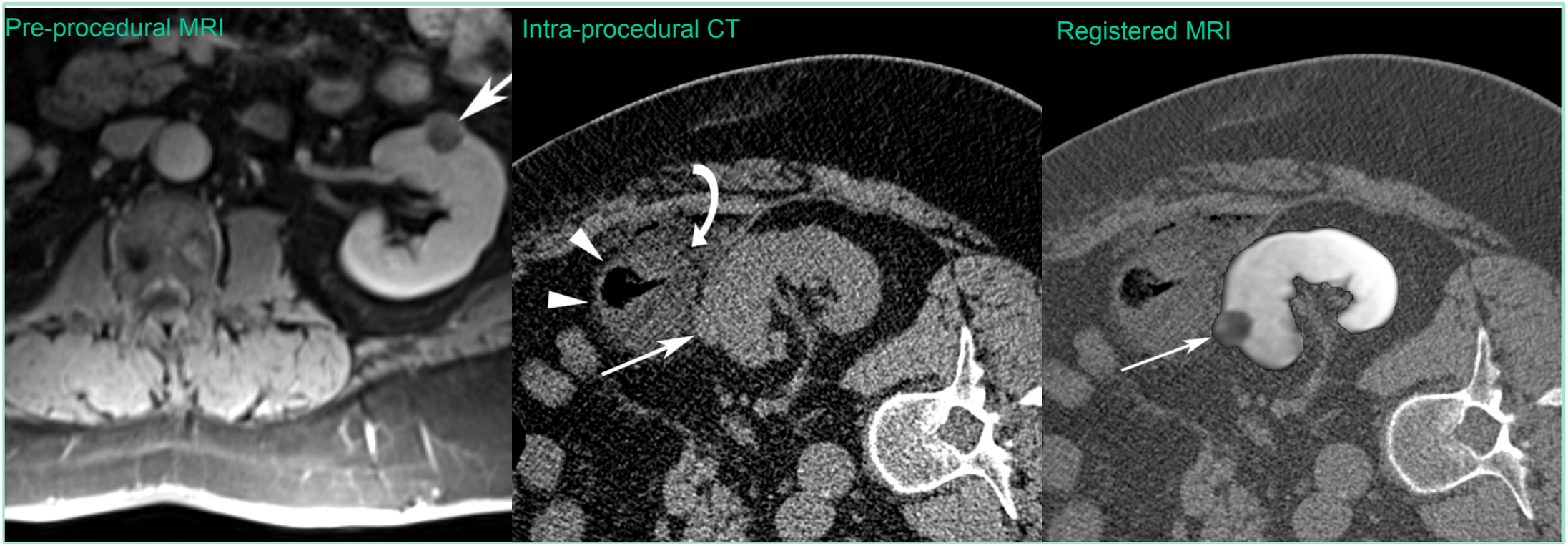


Atlas provided by M. Jakab

The Valley of Death

The translation pipeline is failing to create tools enabling biomedical research

- Scientist: Tools do not help academic promotion
- Funding agencies: Toolmaking is not innovative
- Companies: not proven, it is too risky



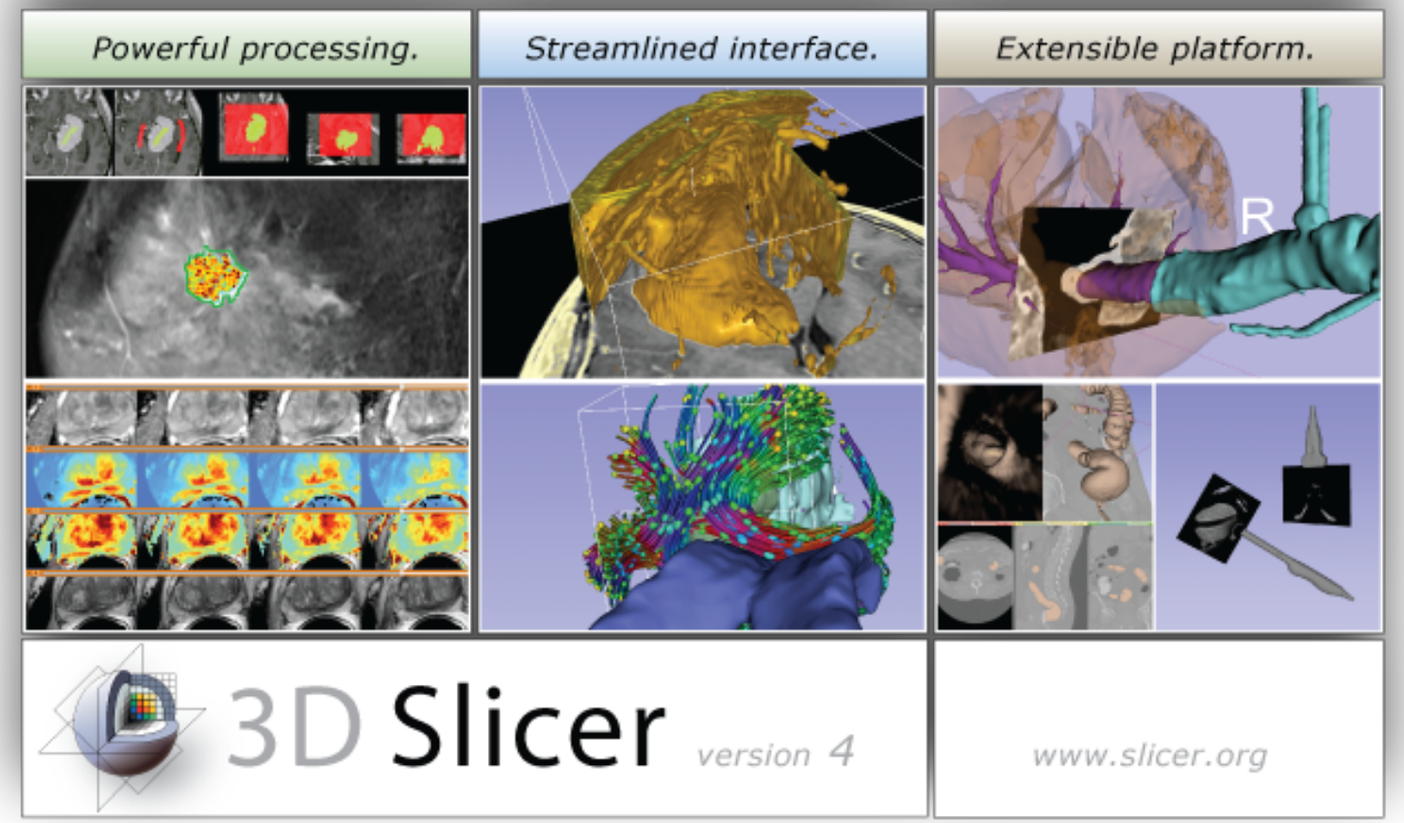
Oguro et al, Int J Comput Assist Radiol Surg, 2011
Elhawary et al, Acad Rad, 2010

Introduction

- Medical Image Computing
- **3D Slicer**
- NA-MIC
- Open source

3D Slicer

- An end-user application
- A platform for delivering software tools
- Targets subject specific analysis

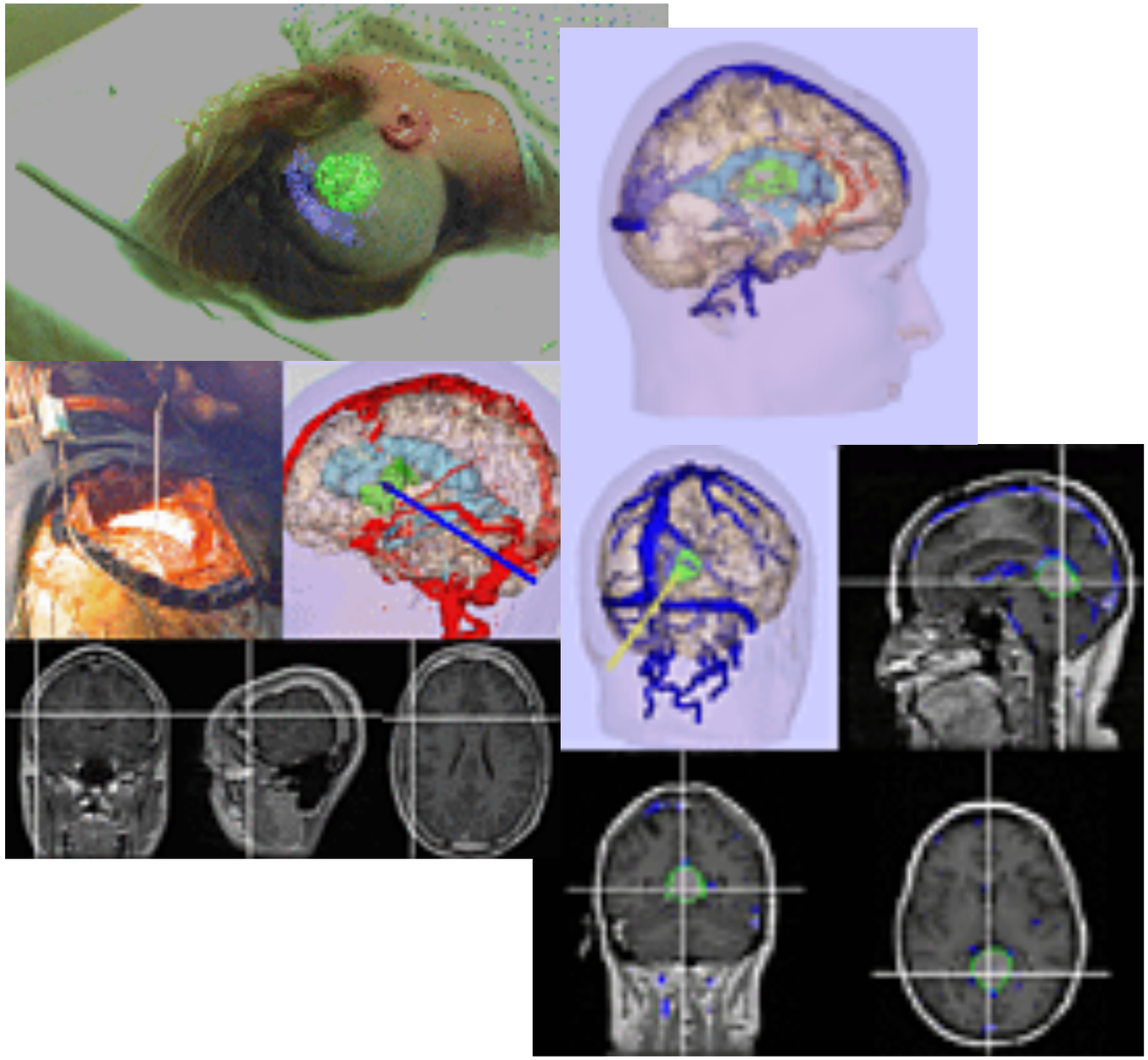


  - Free open source software
    - Enables scientific collaboration
    - License allows painless translation to proprietary clinical tools
  - Well-engineered high-performance core
    - Software engineering methodology, multi-platform
  - Many options for extensions
  - Fully leverages the NA-MIC Kit

Picture courtesy Wendy Plesniak

3D Slicer History

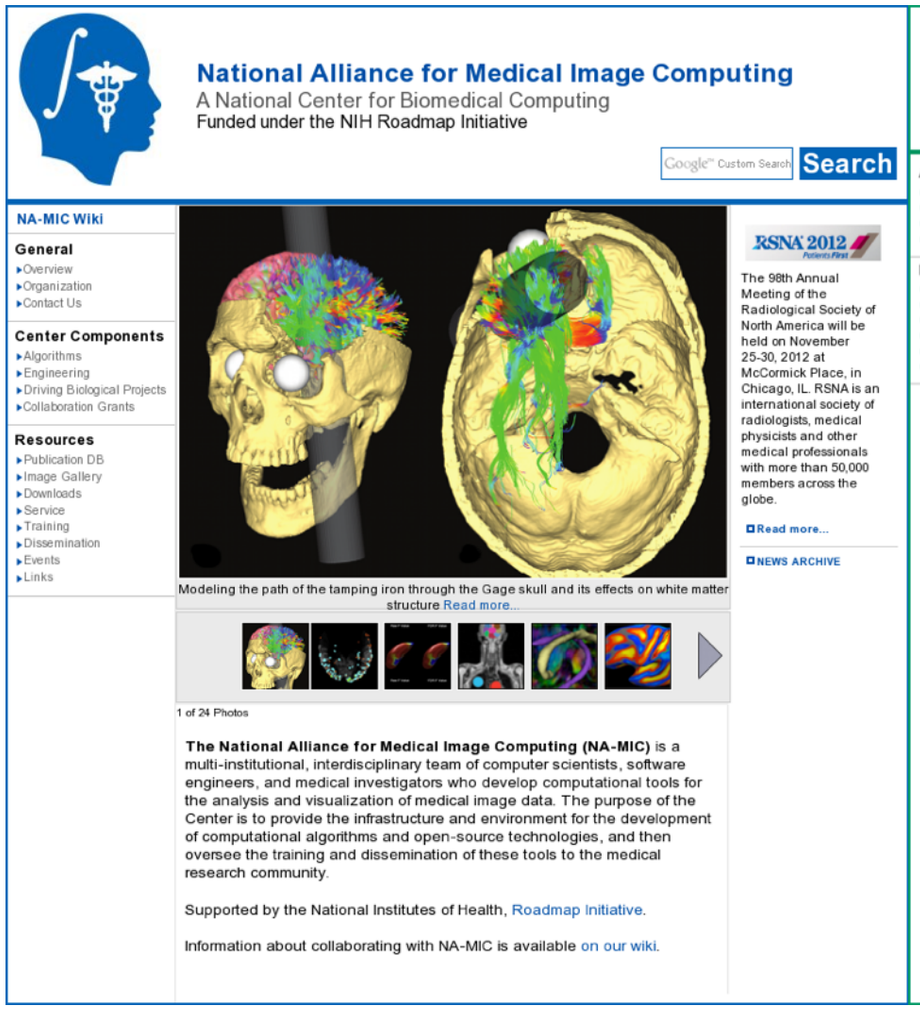
1997: Slicer started as the masters thesis of David Gering, a collaboration between the Surgical Planning Lab (Harvard) and the CSAIL (MIT)

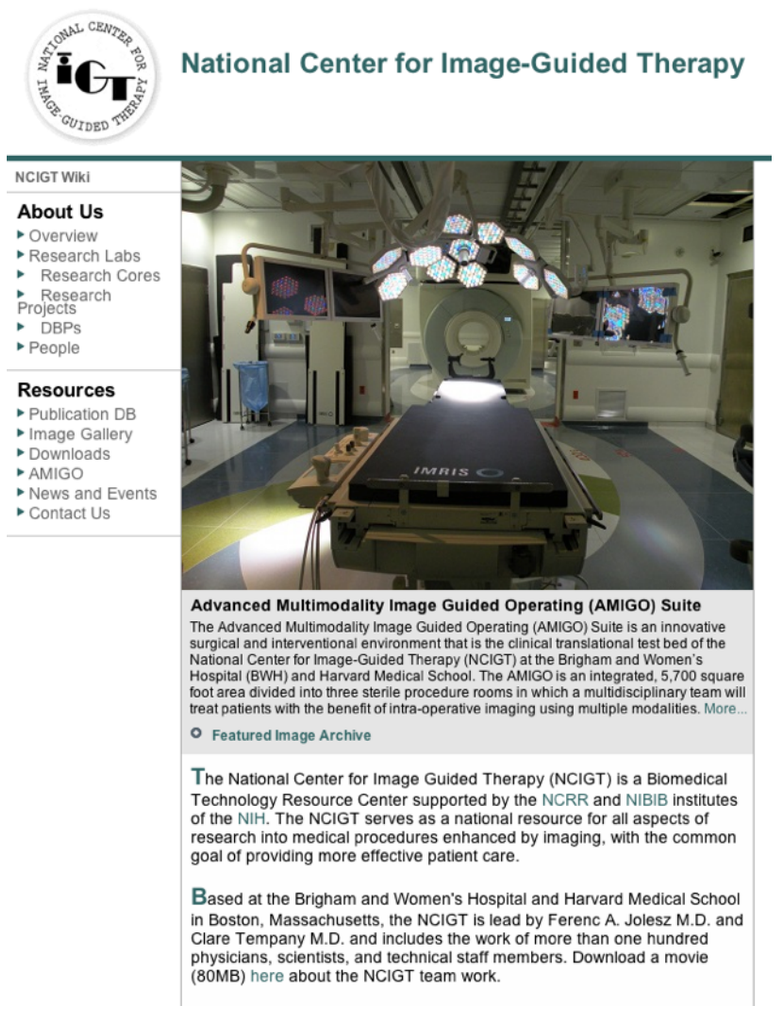


Images Courtesy of the CSAIL, MIT

3D Slicer Today

- Multi-institution effort
- Professionally engineered core

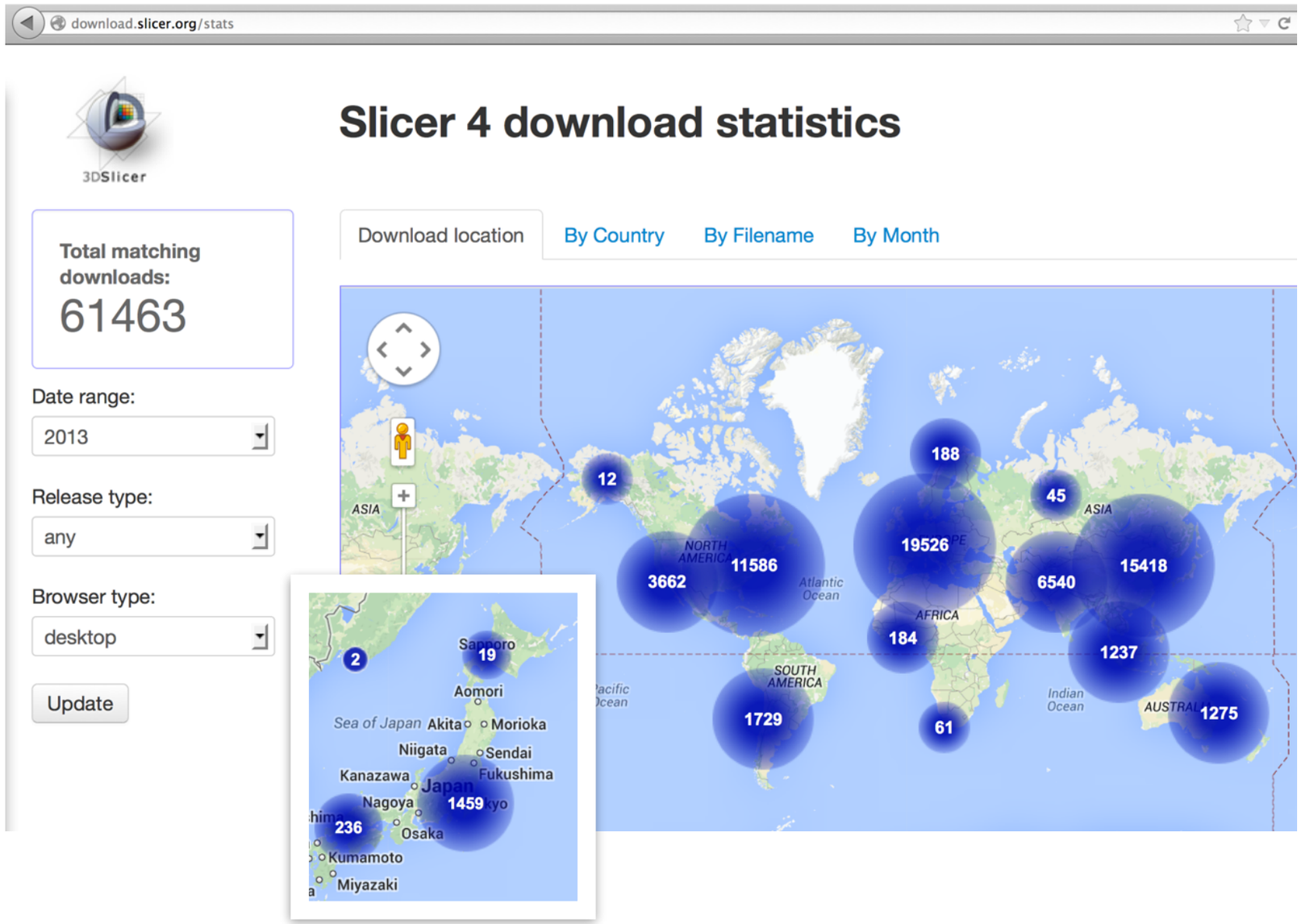


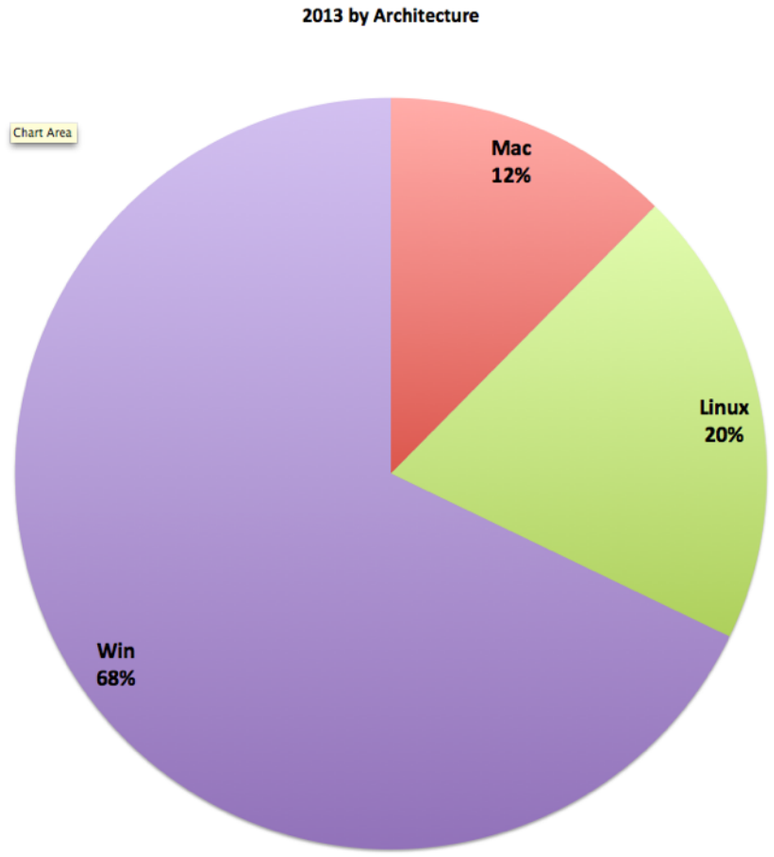


PI: Ron Kikinis, M.D.

PIs: Ferenc Jolesz, M.D., Clare Tempany, M.D.

Impact acceleration

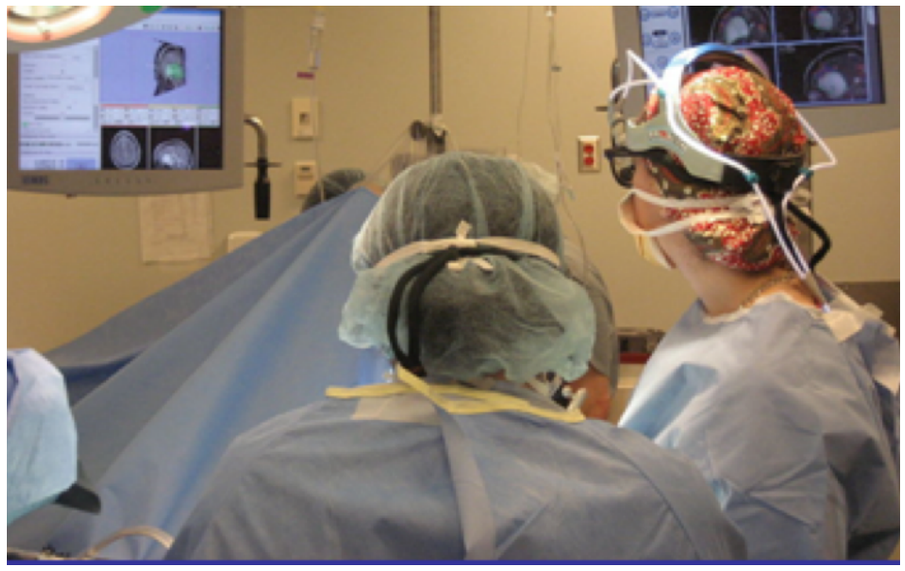




Slicer2 and Slicer3 Downloads: 69,000+ in 3.5 Years, 54 / day

Slicer4 Downloads 2013: 61,000+ in 1 Year, 168 / day

Easy to Use, Easy to Extend



What does a user expect ?

- Easy Install and Upgrade
- “Standard” Clinical Behavior
- Advanced Functionality
- Consistent Interface
- Easily Deployable
- Extensible and Reconfigurable
- Rich Utility Libraries

3DSlicer

What does a developer need ?

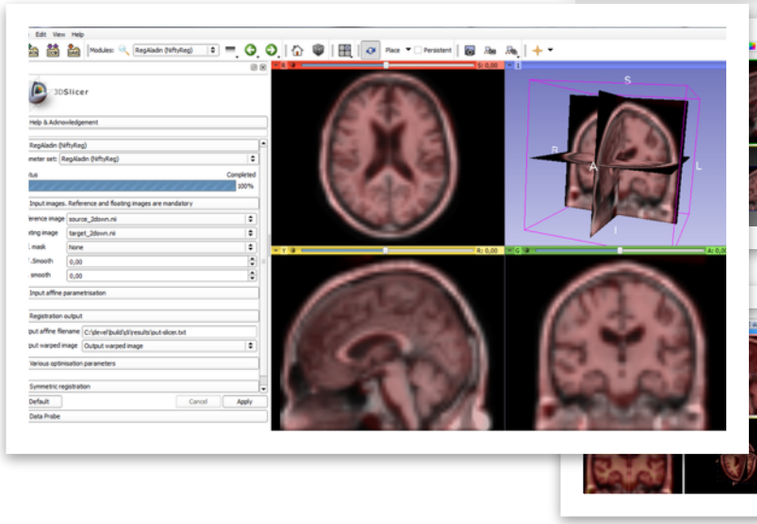
- Easily Deployable
- Extensible and Reconfigurable
- Rich Utility Libraries
- Stable Base

3D Slicer: a cross platform system for translating innovative algorithms into clinical research applications

Courtesy S. Pujol, S. Pieper

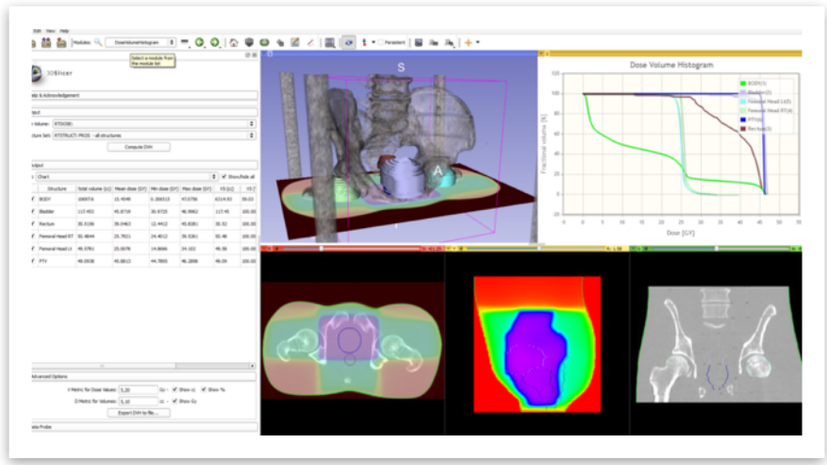
Features

CLI Plug-ins
Shareable across several platforms

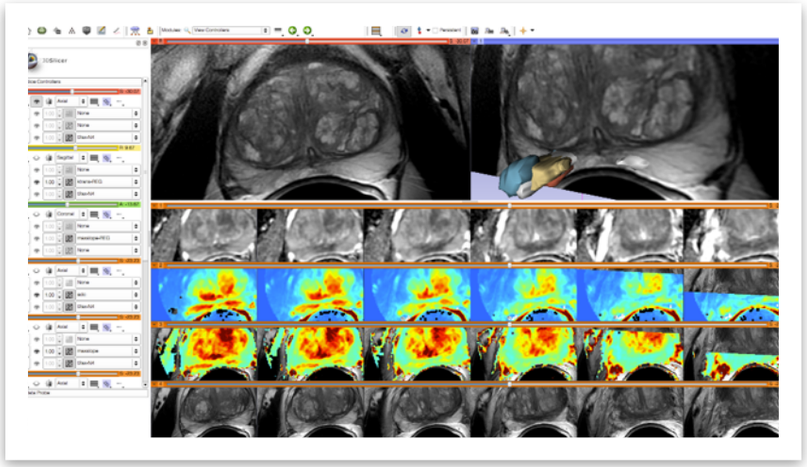


- Volume Rendering
- .mrb files
- Layouts
- Sceneviews
- Annotations
- DICOM

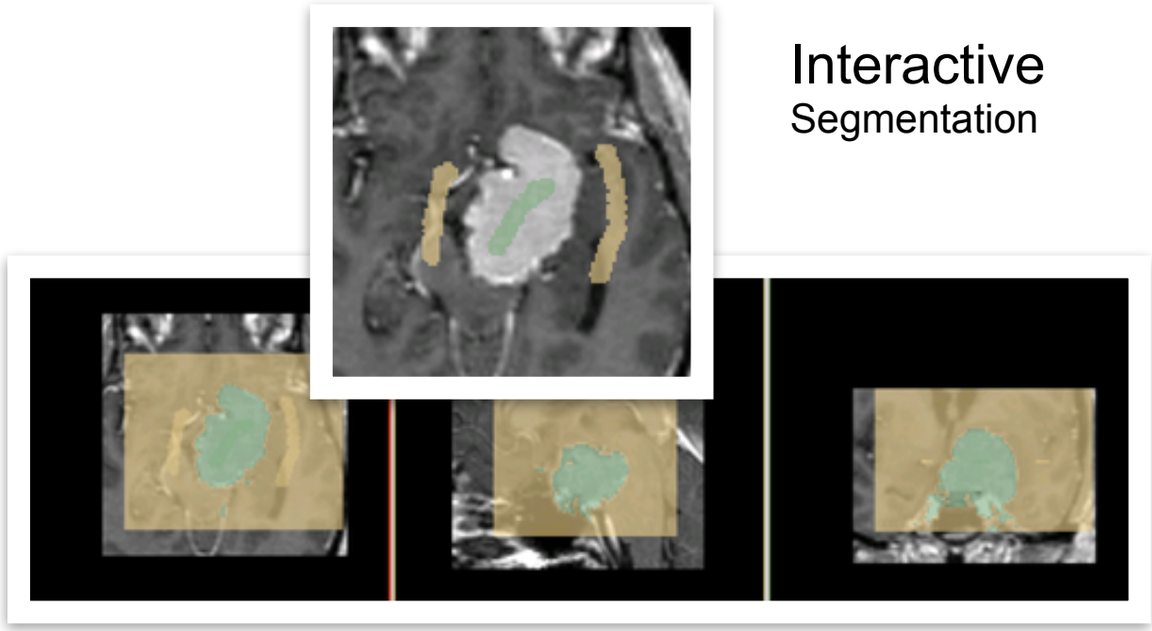
Quantitative imaging
Line, scatter, bar charts



Support for multi-dimensional data
Compare view, Lightbox, crosshair

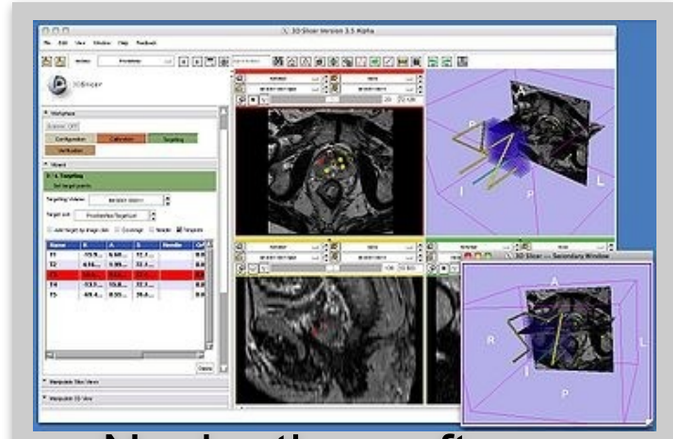


Interactive
Segmentation



Slicer and Devices

- Two-way communication
  - Imaging devices
  - Optical tracking devices
  - Robotic devices
  - More


Navigation software

Image

Transform

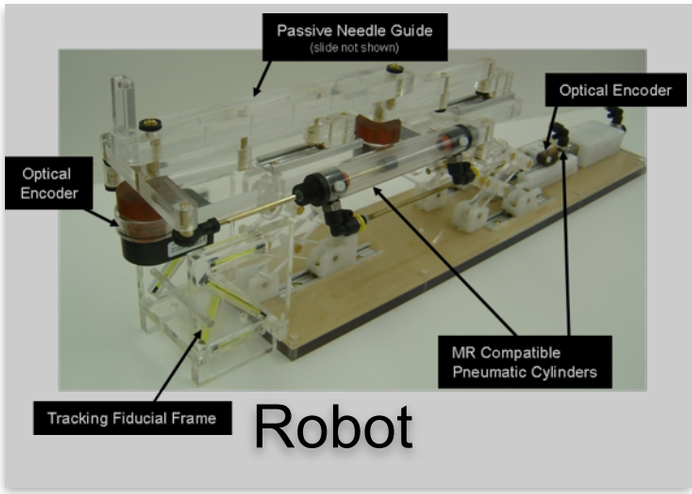

Scanner

OpenIGTLink

Tracking devices

Status

Command



Robot

Slide courtesy J. Tokuda

3D Printing

- 3D printing is a commodity today
- Will revolutionize prototyping
- Hardware increasingly resembles software: the value is in the design

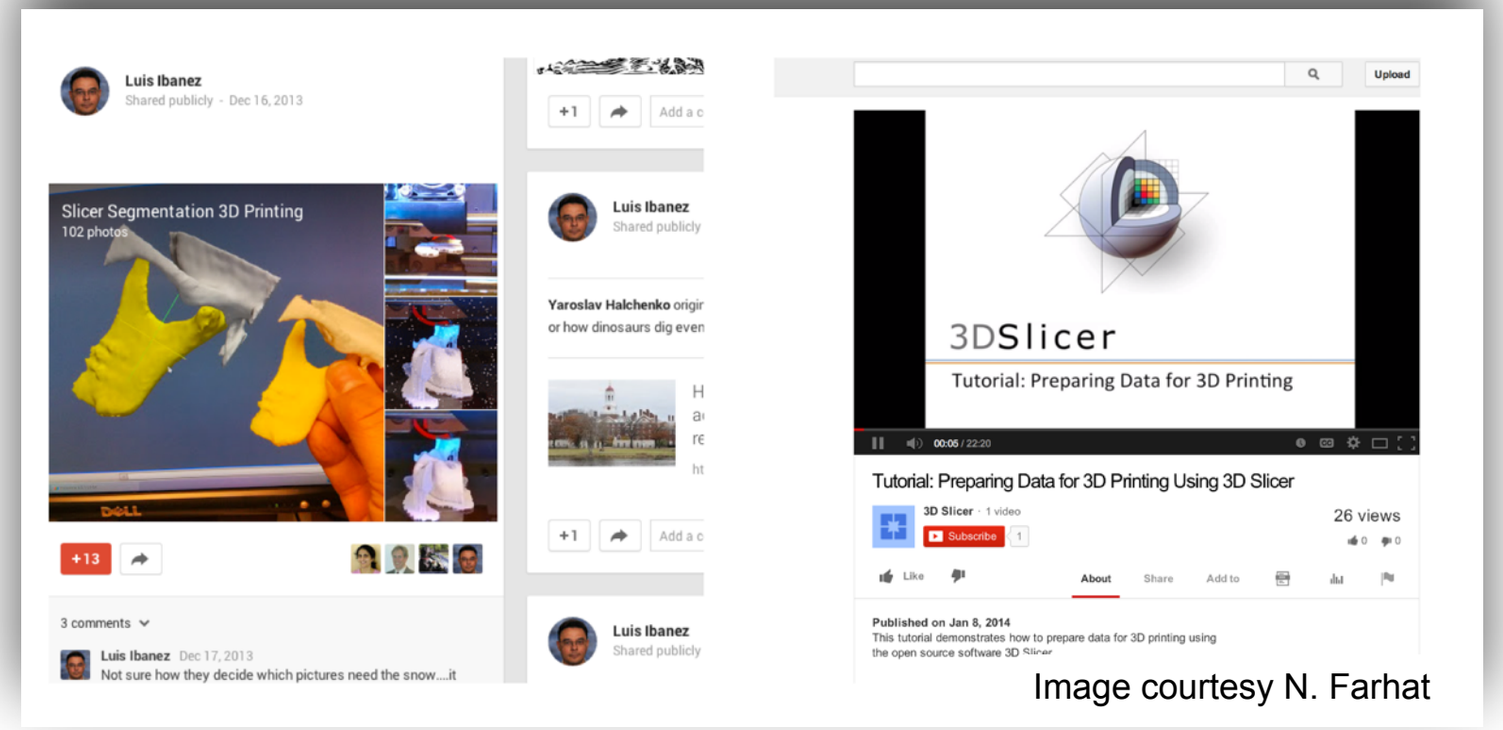


Image courtesy N. Farhat

Web Capabilities

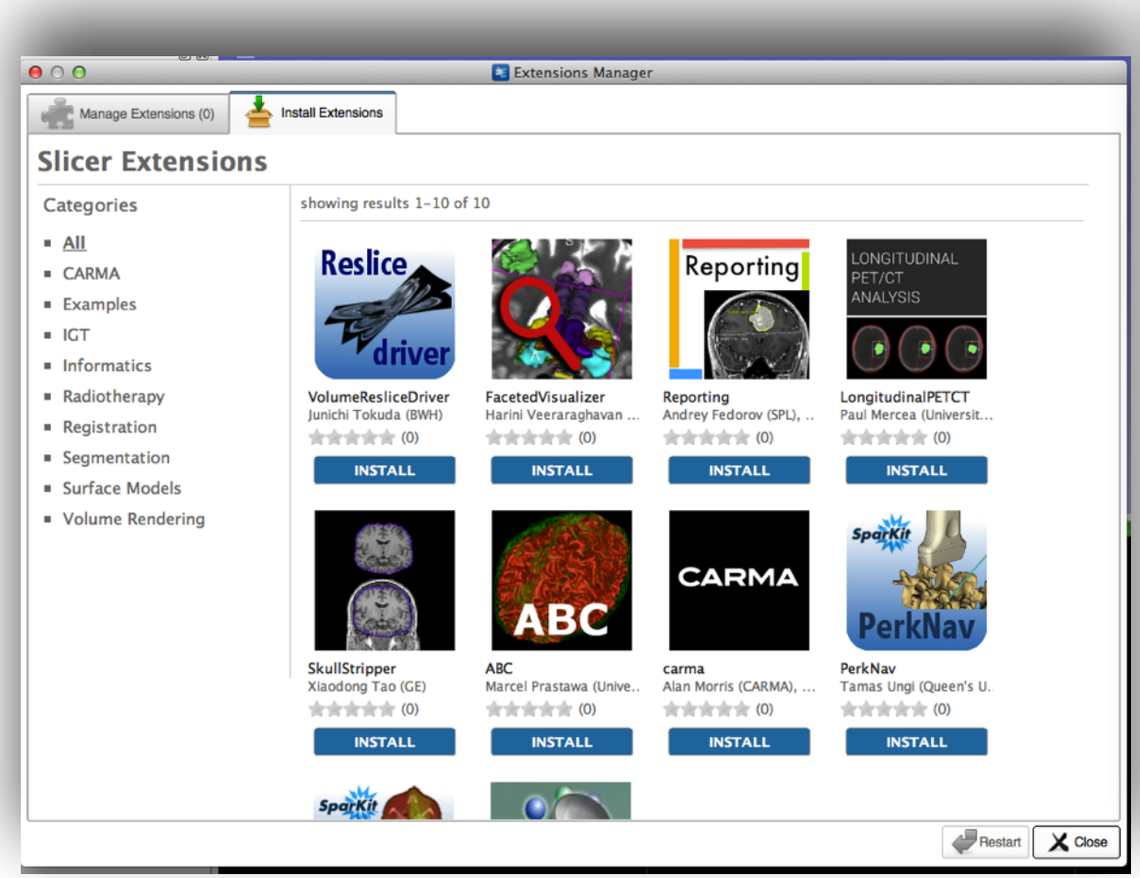
QtWebKit enables Web services

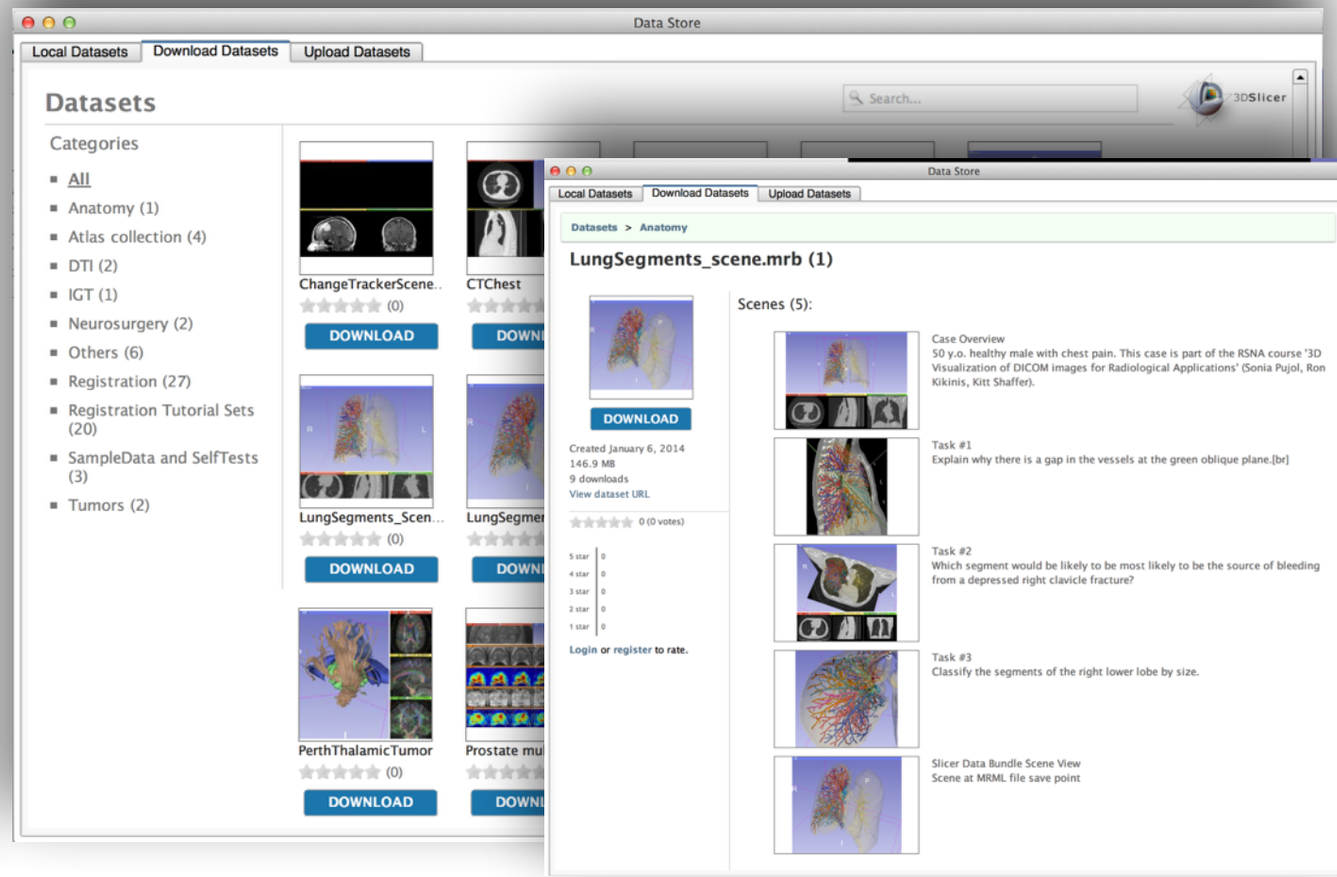
Extension Manager and catalog

- Share plug-ins with users
- Easy Installation

Data Store

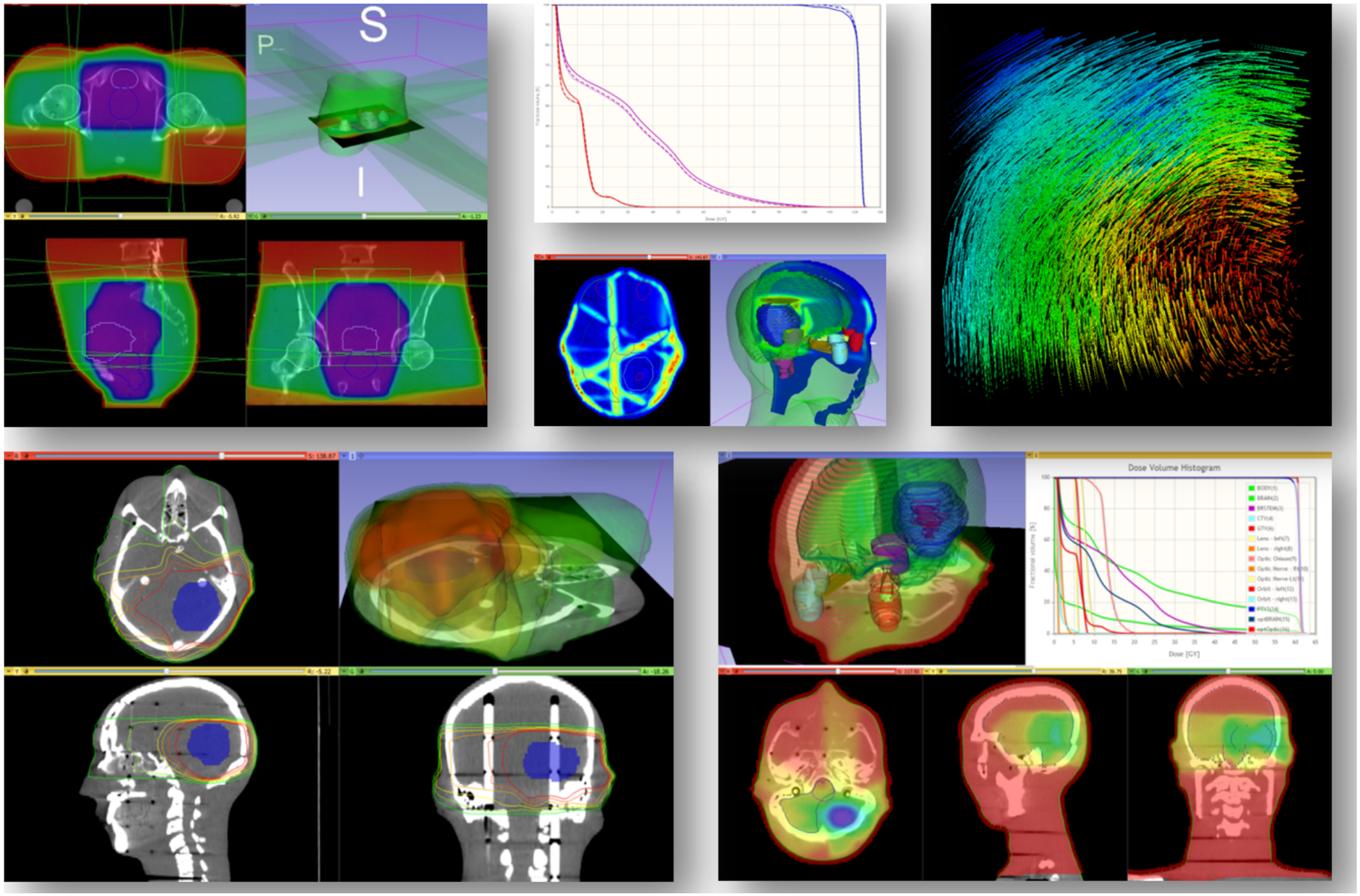
- Web-based public repository of .mrb files allows sharing
- Sceneviews are exposed in the web interface





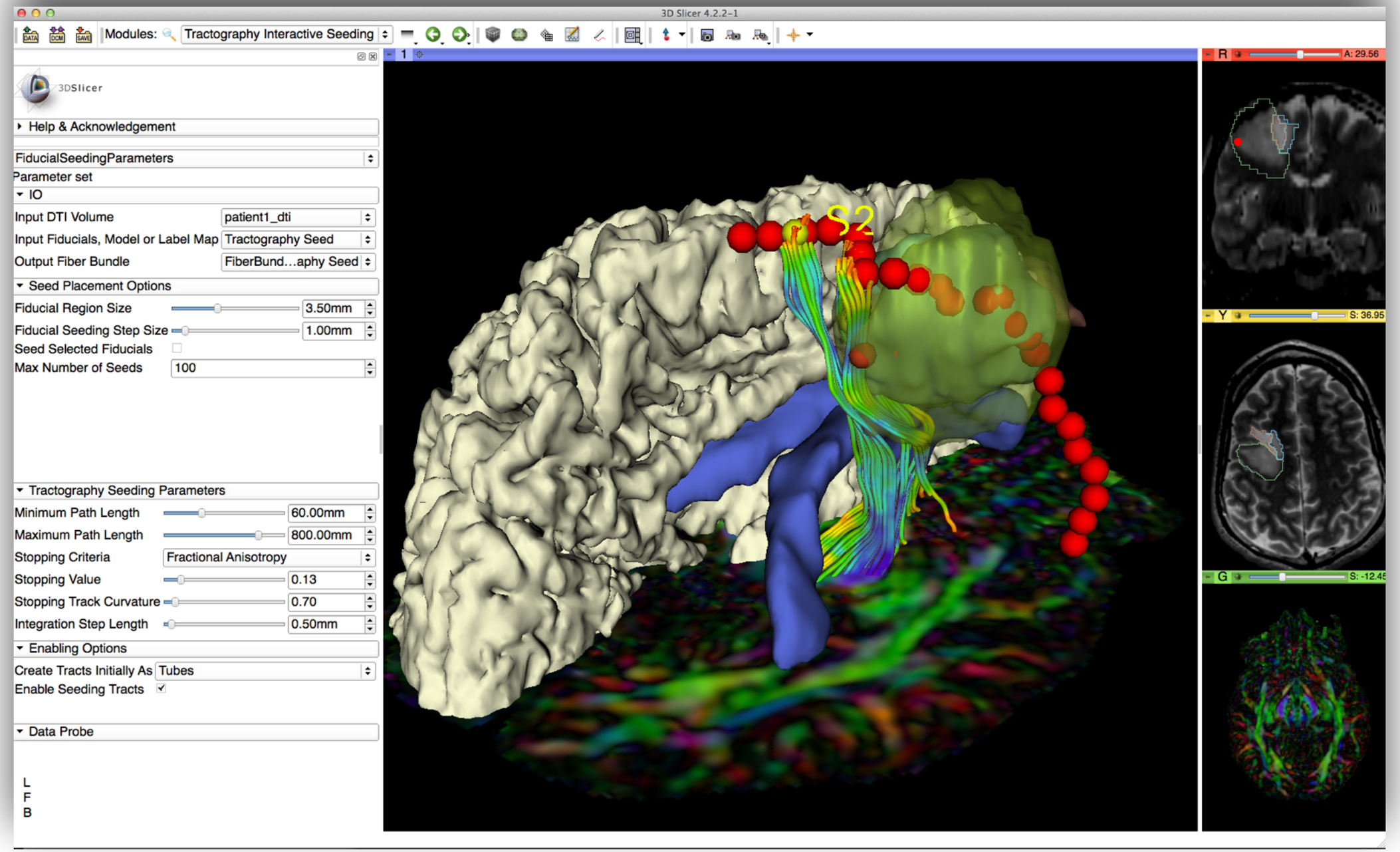
Clinical Example 1

- Radiotherapy research extensions: Dicom RT, dose distributions and many more….



Clinical Example 2

- Surgical planning



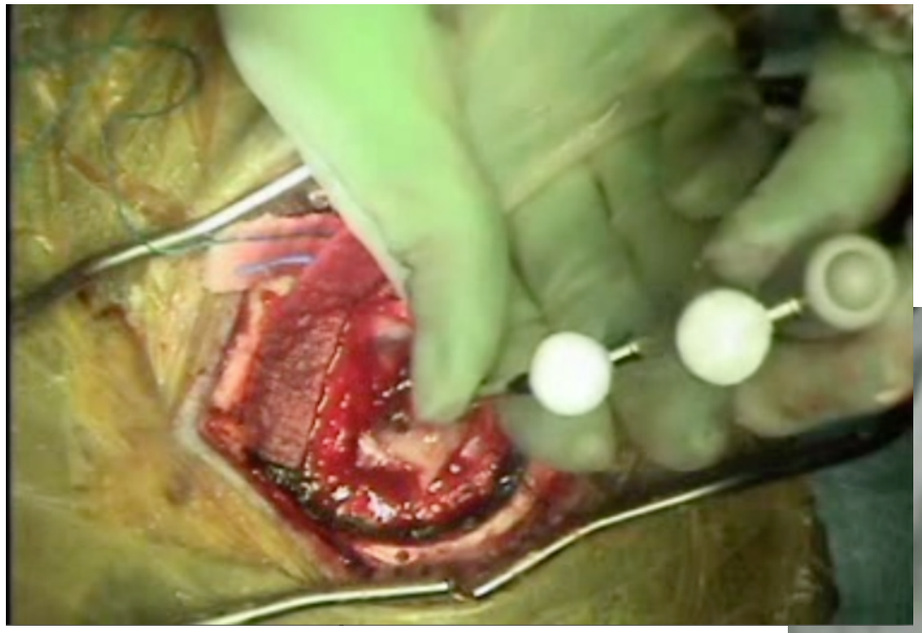
Courtesy S. Pujol, A. Golby

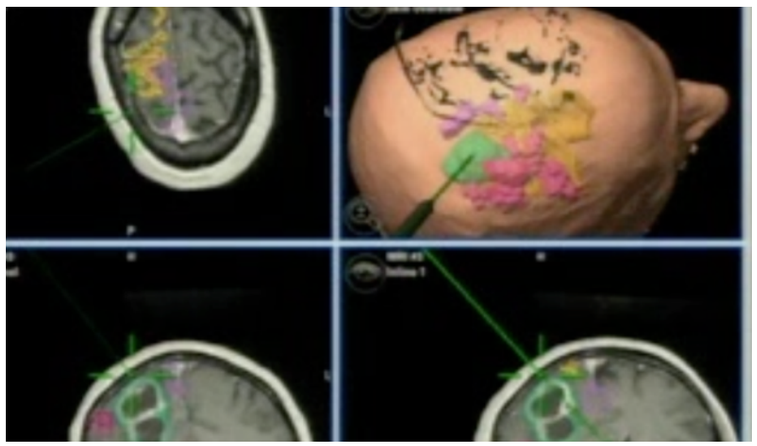
Clinical Example 3

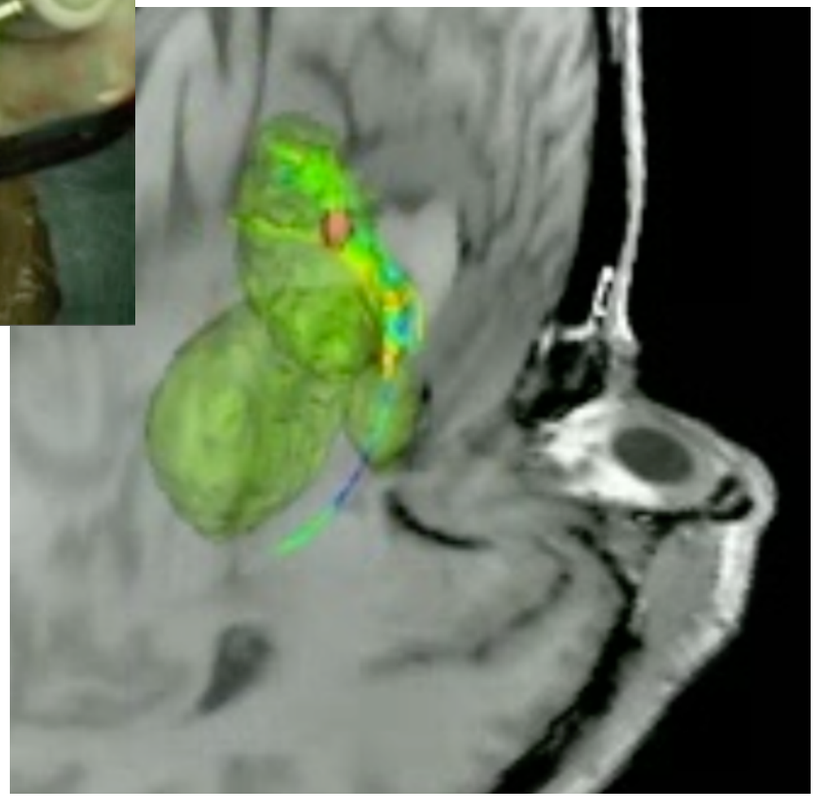
Image Guided Therapy

Interfacing to clinical devices

- Intraoperative Fiber Tracking
- Relies on pre-op data
- Slicer+Brainlab







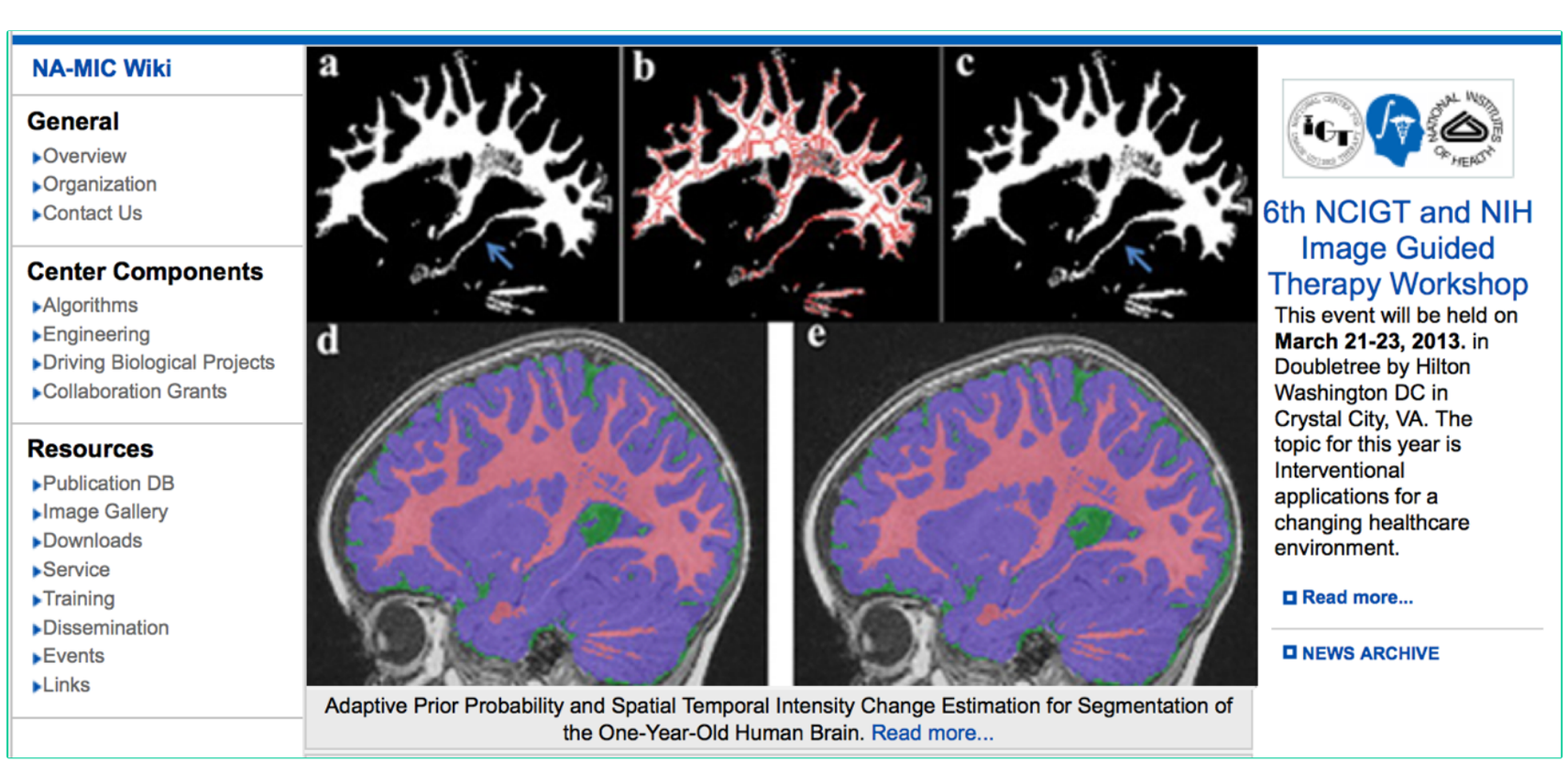
Images courtesy A. Golby

Introduction

- Medical Image Computing
- 3D Slicer
- **NA-MIC**
- Open source

NA-MIC

- The National Alliance for Medical Image Computing (NA-MIC), is a distributed community of researchers
- Focus on
  - Subject specific image analysis
  - NA-MIC kit, including 3D Slicer as a platform for dissemination
- Funded by NIH through the NCBC program since 2004



NA-MIC in Numbers

- 3D Slicer software used worldwide as platform for development and sharing
- Large impact on NIH grantees: 31 funded collaborations across schizophrenia, lupus, autism, lung disease, cardiac disease, brain cancer, liver, colon, prostate, musculoskeletal disorders.
- International funding: Canada, Germany, Spain, Italy, Japan, Australia.
- “Common Toolkit”: joint transatlantic effort
- Trained 55 engineers, 35 grad students, 20 post-docs.
- 2000+ investigators trained in 63 workshops
- 500+ full size papers, including awards
- 15 “Project-weeks”, weeklong working events twice a year: over 650 participants

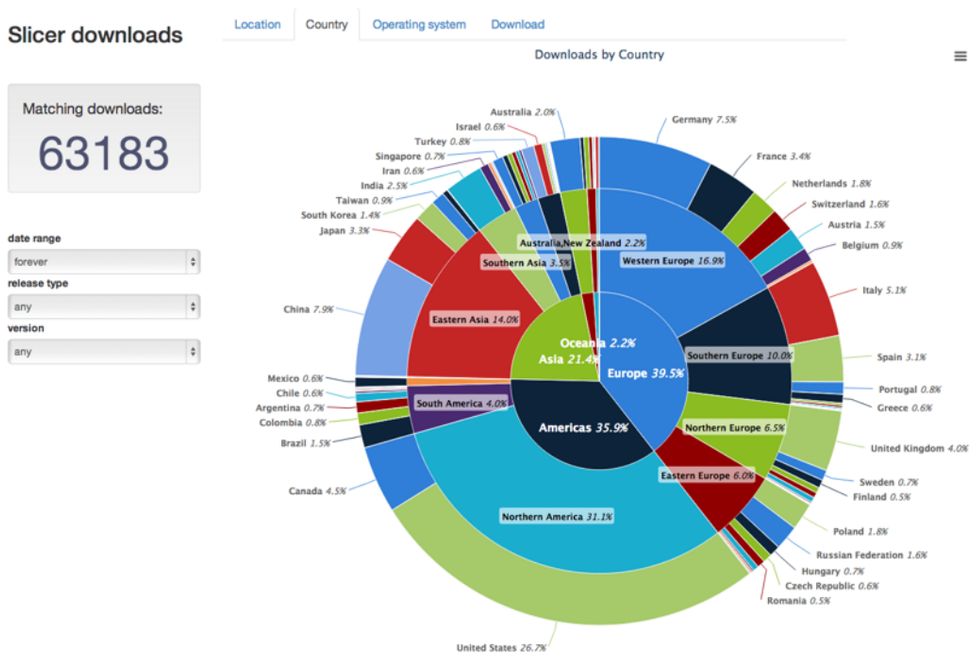
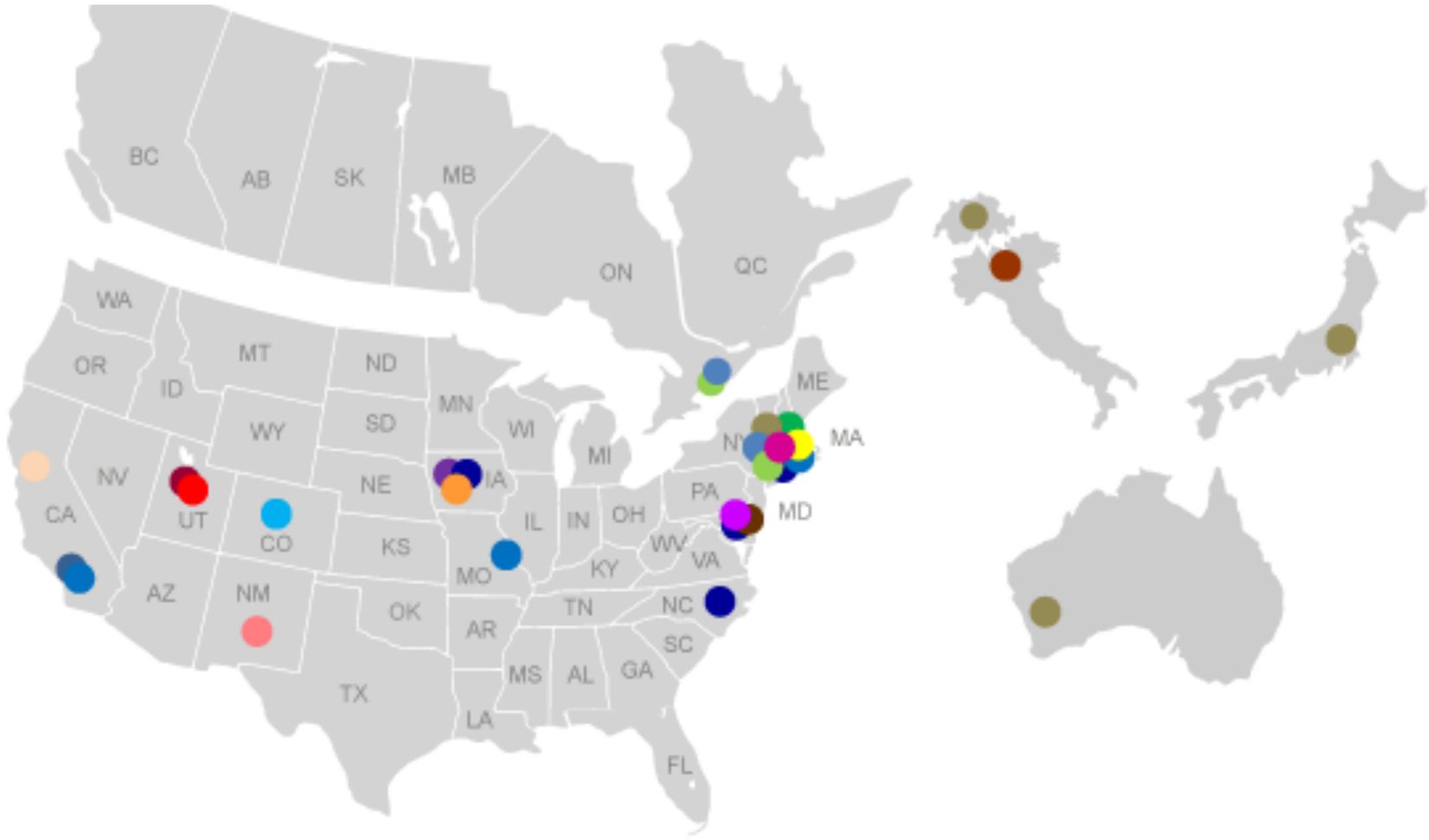


Image courtesy M. Halle

NA-MIC Community

- Autism
- Brain Cancer
- Depression
- Head and Neck Cancer
- Huntington's Disease
- Lupus
- Schizophrenia
- Traumatic Brain Injury
- VCFS
- Neuroimage Analysis
- Lung Disease
- Atrial Fibrillation
- Cardiovascular Disease
- Liver Cancer
- Colon Cancer
- Prostate Cancer
- Orthopedic Injury
- Neuromuscular Dynamics
- Image Informatics



Active

R01MH084795 · U41RR019703 · NSF CCF-0916526 · R01EB008171 · U01HL089897 · R01CA124377 · R01CA131718 · R01CA11128
R01EB005973 · U54EB005149-05S2 · U54GM072970 · P41RR013218 · R01EB006733 · R01NS050568 · R21EB009900 · U54EB005149-05S3
UL1RR025758 · U54LM008748 · U24RR025736 · U24RR021992 · U24RR021382 · U24RR026057 · AIST, Japan · UWA, Australia
Mario Negri Institute, Italy · CO-ME, Switzerland · OCAIRO, Canada

Completed

U54EB005149-04S1

Picture 2011, courtesy Kapur, Jakab, Kikinis

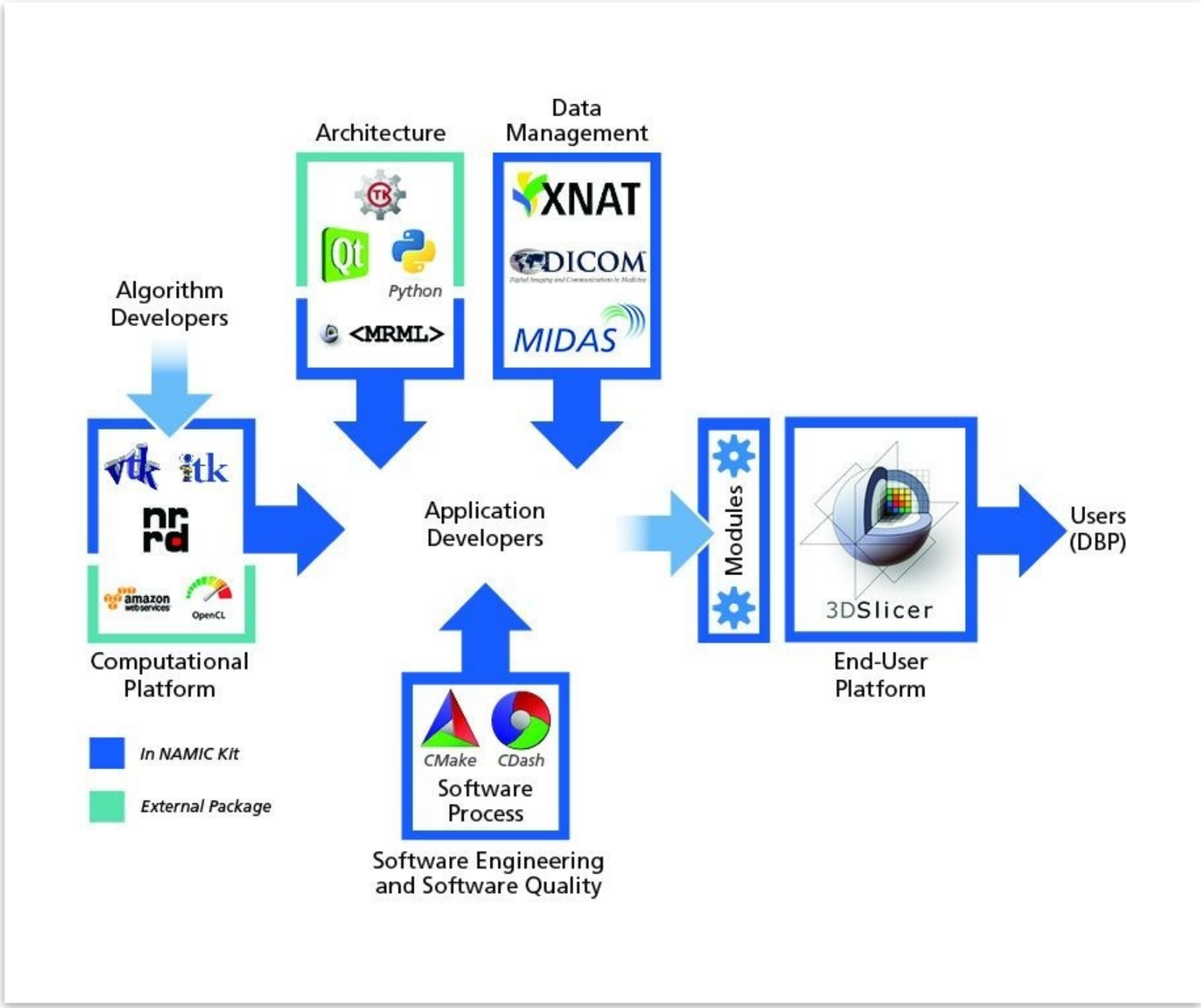
The NA-MIC Kit

The NA-MIC Kit is a free open source platform to support translational research in MIC

Slicer is built on the NA-MIC Kit

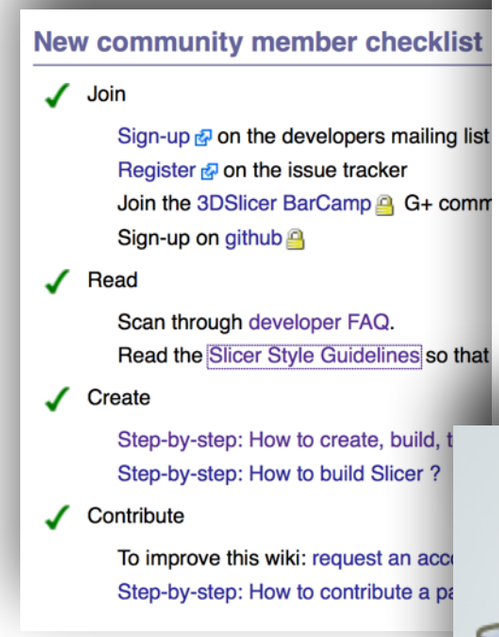
Common Features

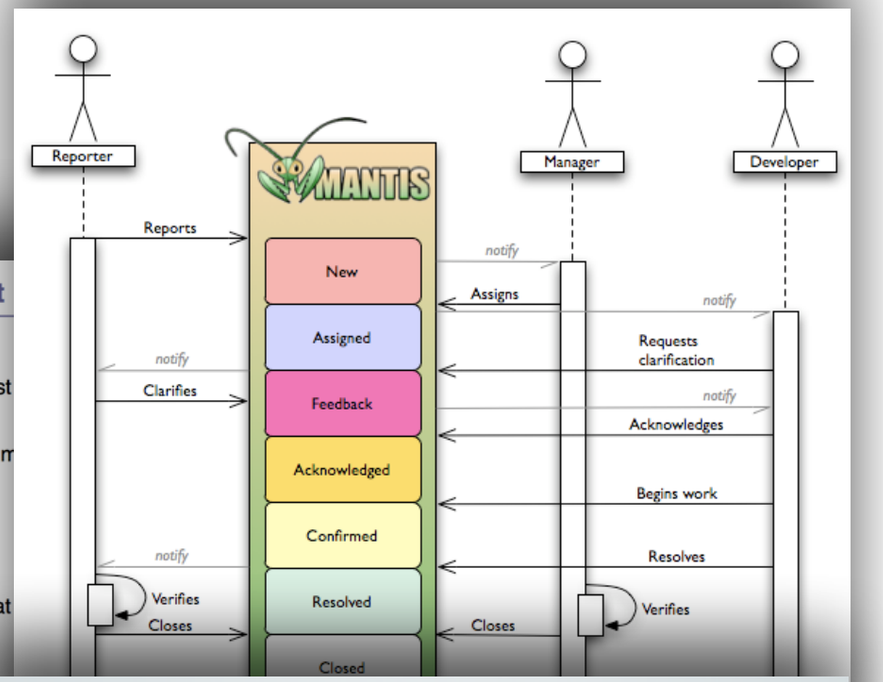
- BSD style Open Source
- No known IP liabilities
- Compiled on all supported platforms
- Optimized Interoperability of the components

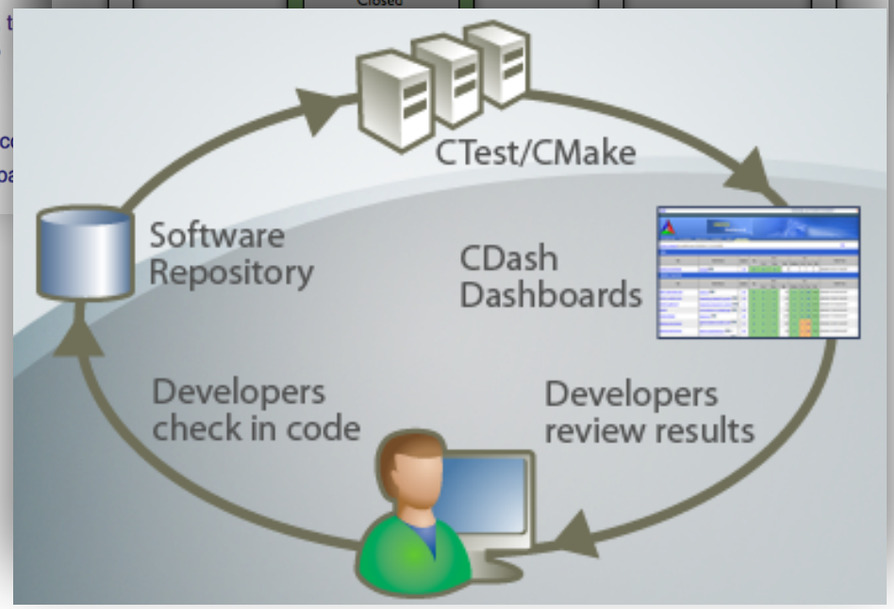


Principled Software Process

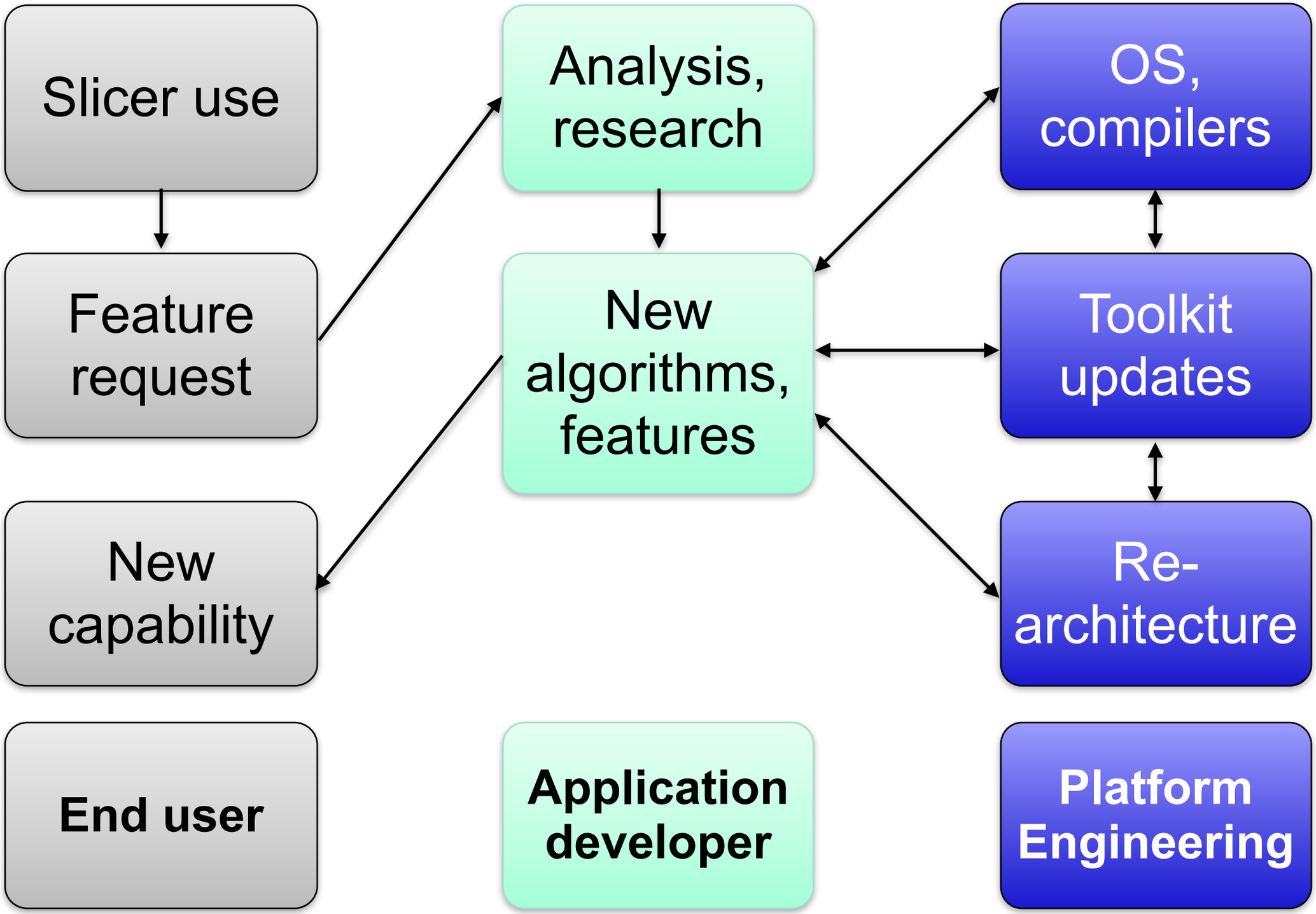
- Documented workflows
- Github is used as repository
  - distributed
  - allows offline work
  - sharing with granularity
- Slim trunk, most functionality is in plug-ins







Slicer Development Process



Application Development

- Algorithm research comes first
- Implementation workflow once the algorithms are known:
  - Create individual modules as plug-ins
  - Create workflows based on the modules
  - Use the extension manager for distribution

Platform Engineering

- The Slicer platform is based on many toolkits and libraries
- Operating systems change constantly
- Ongoing effort is needed for updating the versions used by the NA-MIC kit and Slicer
- Modifications and patches are pushed downstream to the toolkits and libraries

What it takes

- Money, money, money
- Time, time, time

  – Platform engineering for translational MIC is expensive and difficult to find funding for
  – It takes time to bring together an interdisciplinary community

Work

- 1 Ph.D. thesis is one to two person-years of actual work
- Slicer represents over 100 person years in direct effort

In a Nutshell, Slicer4...

... has had 20,538 commits made by 97 contributors
representing 397,670 lines of code

... is mostly written in C++
with an average number of source code comments

... has a well established, mature codebase
maintained by a large development team
with decreasing Y-O-Y commits ← work moved to plug-ins

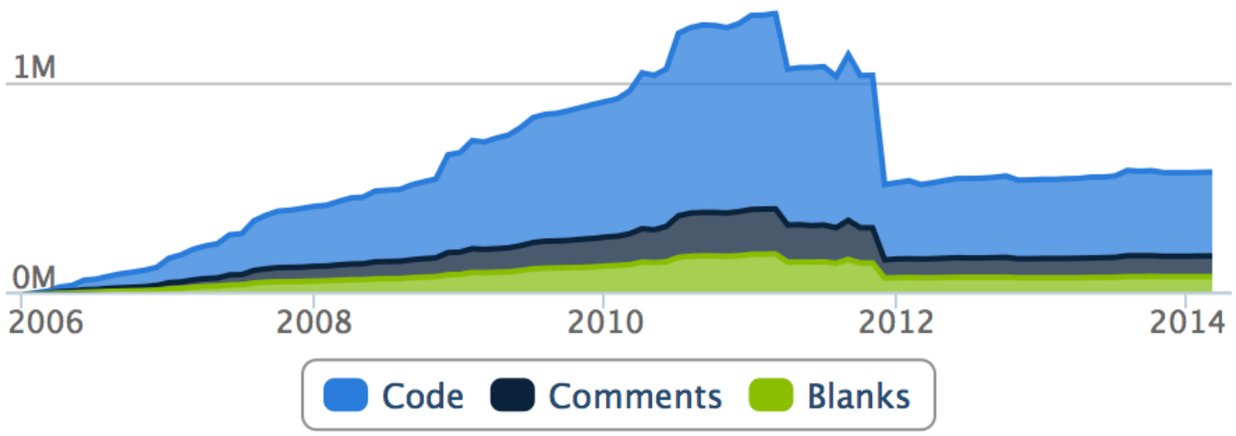
... took an estimated 105 years of effort (COCOMO model)
starting with its first commit in January, 2006
ending with its most recent commit 2 days ago

http://www.ohloh.net/p/slicer

Languages

C++	51%	C	27%
XML	9%	10 Other	13%

Lines of Code



NA-MIC Kit Engineering Team

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blezek
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demian
domibel
dpace
fedorov
finetjul
francois_budin
freudling
gcasey
haehn
harveerar
hayes
hjohnson
hliu
hong
hyang
ibanez
ilknur.kabul
inorton
jcfr
jcross186
joe.snyder
johan.andruejol
jvs
karthik
kedar_p
kerstin
kquintus
lantiga
lassoan
lauren
lorensen
maddah
malaterre
matthew.bowman
mccormic
mike
millerjv
mscully
naucoin
nicky
nobyhata
padfield
partyd
pieper
pinter
pkarasev
pkarasev3
pohl
rjosest
rsierra
samset
sankhesh
sylvain
taox
taylor
tgl
tokuda
tringo
ungi
vmagnotta
vrnova
wjp
ygao
yumin
zach.mullen
zack.galbreath

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Introduction

- Medical Image Computing
- 3D Slicer
- NA-MIC
- **Open source**

Why Open Source

- Collaborate and move freely
  - Good match for the migratory lifestyle of scientist
  - Advantageous for collaborations
  - Neutral territory in multi-vendor settings
- Extensible

Why Open Source (OS) For Complex Software?

- Potential advantages to industrial development activities:
  - Access to world class algorithms and architectures.
  - Training is current and user-focused.
  - Active community is more capable to track advances in hardware and systems computer architecture than closed systems.
  - Community can be engaged to the extent desired
- Open Source approaches are practical
  - Costs are potentially lower, even when a minimal level of sophisticated management is necessary.
  - They permit the organization to focus on its key product skills.

What are the risks of OS use in a big industrial development?

- It can't be assumed that the OS environment/community will have a canned solution to every need. Some internal development will likely be needed.
- Internal staff will need to have clear rules and supported strategies for interaction with the OS community to avoid leakage of proprietary information, product and market strategies, etc.
  - The "crown jewels" can always be kept as private extensions
- OS communities and their development approaches are subject to their own market forces and dominant interests, which may, over time, diverge from the industrial needs.
- Summary: these risks are manageable, as long as the company sets things up correctly and stays alert.

Conclusions

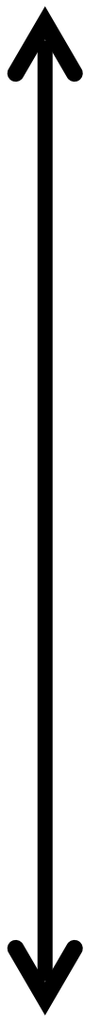
- Free Open Source Software
  - Facilitates translation: bridging the valley of death
  - Is a win-win proposition: the OPM principle
  - Requires proper policies and governance
- Slicer and the NA-MIC kit are a good example of FOSS for translational work

From Tools to Medical Product

- Open Source facilitates scientific exchange
  - Open Source means **no restriction on use** (i.e. no restriction on commercial use)
- Medical Products are closed source
  - Significant Regulatory Requirements
- How to accomplish the transition?

From Open to Closed Source

Open source



Closed source

3D Slicer

MITK

MedINRIA

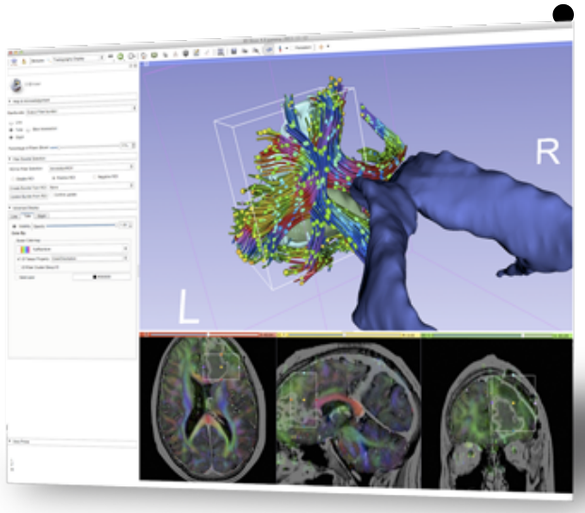
Plug-ins

Mevis Lab

syngo.via , Advantage Windows, Vitrea

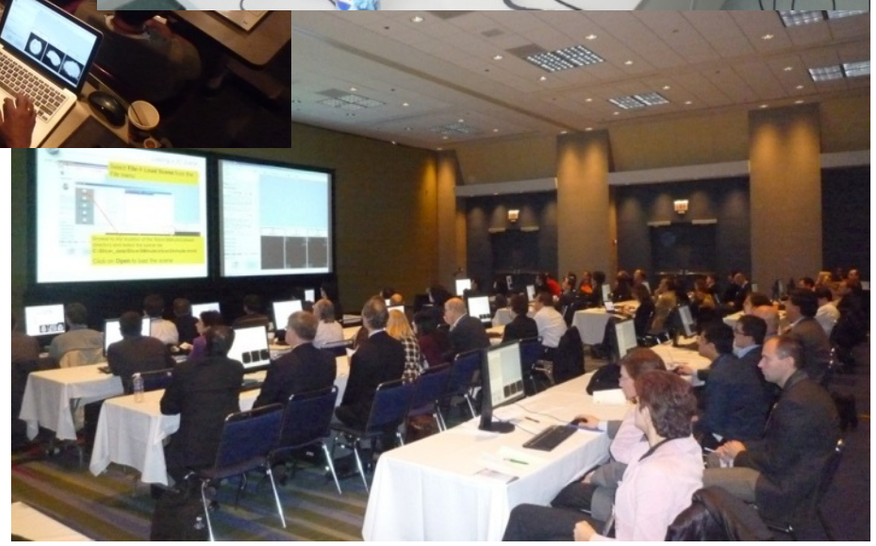
Social Engineering

- How to build an Open Community?
  - Mutual Self Interest:
    If I get more out of something than I put into it, it is attractive
  - Community building:
    - Us versus them.
    - Combine social media with in-person events.
    - Interdisciplinary nature is an additional challenge



User Training Events

- Hands-on training workshops at national and international venues
- More than 2,700 clinicians, clinical researchers scientists trained since 2005



Project Week

- Every 6 months, alternating between Boston and Utah
- A working week: Focus on programming and platform updates
- In-person nature encourages socializing
- A key for community building

16th Project Week: Salt Lake City, Utah, January 2013

•80 attendees: 17 academic institutions, 4 companies

•54 Projects: TBI, Atrial Fibrillation, Slicer 4 Extensions, Huntington's Disease, Head and Neck Cancer, Stroke, IGT, Radiation Therapy, Medical Robotics, Infrastructure Engineering

17th Project Week: MIT, Summer June 2013

•104 attendees: 22 academic institutions, 13 companies

•75 Projects: Huntington's Disease, TBI, Atrial Fibrillation and Cardiac Image Analysis, Radiation Therapy, IGT and Device Integration with 3D Slicer, COPD, and Infrastructure Engineering

Acknowledgments

National Alliance for Medical Image Computing
www.na-mic.org

Neuroimage Analysis Center
nac.spl.harvard.edu

Surgical Planning Laboratory, Brigham and Women's Hospital
spl.harvard.edu

National Center For Image Guided Therapy
www.ncigt.org

- Ferenc Jolesz, MD, my mentor
- Collaborators and colleagues