3D Slicer

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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
Imaging Modalities

- PET CT: [Link](http://nucmed.wikispaces.com/Wendt+Talk+6)
- OCT: [Link](http://spie.org/x88950.xml?pf=true&ArticleID=x88950)
- PET CT: [Link](http://nucmed.wikispaces.com/Wendt+Talk+6)
- PET CT: [Link](http://nucmed.wikispaces.com/Wendt+Talk+6)
- PET CT: [Link](http://nucmed.wikispaces.com/Wendt+Talk+6)
- 4D Ultrasound: [Link](http://ultrasoundcarespecialist.com/html/anib_3d4d.html)

This is just a partial list

- X ray radiography
- Magnetic resonance imaging (MRI)
- Nuclear medicine
- Computed Tomography
- Tomography
- Ultrasound
- Optical Coherence Tomography
- Photoacoustic imaging
- Thermography
- Light Microscopy
  - Bright, dark field
  - Phase contrast
  - Fluorescence
  - Confocal

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Examples of Complexity

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


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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


Volume rendering
The Increasing Importance of MIC

– More data and modalities: gigabytes to terabytes
– More complexity
  • fMRI, molecular imaging dMRI, 4DUS
– More applications
  • Discovery, Diagnosis
  • Therapy monitoring
Different Styles of Research

• Group Comparisons
• Subject Specific Analysis (SSA)

• Technologies are often developed for group comparisons
• Additional scientific research is necessary to use such technologies for SSA
Group Comparisons

- Often used in basic imaging research
- Targets normal appearing structures. Questions: What is the...
  - Typical appearance
  - Normal variability
- Extensive resources are deployed: personnel, computational
- Most of our research is of this type, it's the easiest way to get results suitable for publication

Subject Specific Analysis

• Targets focal pathology:
  • Where is the pathology?
  • What are important surrounding structures

• Limited resources:
  – Time
  – Personnel
  – Computational

• Interactive work is the norm

Lack of quality in the processing pipeline can **NOT** be compensated by adding subjects (you have only one subject)
Subject Specific Analysis (SSA)

- Quick and good enough is better than slow and perfect!
- Image processing problems cannot be compensated by adding subjects (you have only one)
- Interactive work is the norm

"Ron's rules for tools" is an informal set of rules that developers should keep in mind when working on interactive tools for translational clinical research. If you follow them, you will create tools that many people will use.
  - You make it, I break it.
  - Your tool does not exist, until it works on my laptop with my data.
  - I am lazy. I do not like to move the mouse or to type.
  - No more than one simple parameter.
  - I have Attention deficit disorder: Make your algorithm fast.
SSA Challenges

• Many patients have visible pathology. Most MIC technology was developed for analysis of healthy looking subjects
• Tools need to be robust, easy to learn, and quick
• Due to the “valley of death”, very little technology has made it from research into clinical devices
3D Slicer

- Platform for subject specific analysis
- An end-user application
- A platform for delivering software tools
  - 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 and for sharing them
  - Cross-platform
Easy to Use, Easy to Extend

What does a developer need?
• Easily Deployable
• Extensible and Reconfigurable
• Rich Utility Libraries
• Stable Base

What does a user expect?
• Easy Install and Upgrade
• “Standard” Clinical Behavior
• Advanced Functionality
• Consistent Interface
• Easily Deployable
• Extensible and Reconfigurable
• Rich Utility Libraries

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

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Courtesy S. Pujol, S. Pieper
Slicer As A Platform

- Both basic and high-end features
  - Powerful visualization and layouts
  - Multi-modality, time series, segmentation, registration, dMRI
  - Dicom, PACS, device interfaces
  - Extensible through Python, Plug-ins
  - “App store” for sharing extensions

- Support and training
- Cross-platform
- Research software
  - not FDA approved
1997: Slicer started as the masters thesis of David Gering, in a collaboration between the Surgical Planning Lab (Harvard) and CSAIL (MIT)
3D Slicer Today

• Community Effort
Slicer Community At A Glance

3D Slicer project analysis from Ohloh.net

http://www.ohloh.net/p/3376

Slicer version 4 re-architecture and cleanup

Total number of 3D Slicer downloads in 2013: 61463, (160 per day)

Mailing list rosters:
- slicer-users: >1000
- slicer-devel: >600

http://massmail.spl.harvard.edu/public-archives/slicer-users/
http://massmail.spl.harvard.edu/public-archives/slicer-devel/

http://download.slicer.org/stats
Features

CLI Plug-ins
Shareable across several platforms

- MevisLab
- NiftyView
- 3D Slicer
- GIMIAS

Quantitative imaging
Line, scatter, bar charts

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

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

OpenIGTLink

Navigation software

Scanner

Tracking devices

Robot

Image

Transform

Status

Command
OpenIGTLink: API for Devices

Use an iPhone to control scan plane acquisition

Tokuda J., et al. CARS 2012, June 27-30, Pisa Italy
US Tracking: 2011: Bench

Movie courtesy Ungi, Lasso, Fichtinger
US Tracking 2012: To Bedside

Research setup in AMIGO showing BK ProFocus and TRUS BK 8848 transrectal probe with orientation spatial sensor, interfaced to 3DSlicer via PlusServer library and OpenIGTLink.

Sketch courtesy Wendy Plesniak
3D Printing

- 3D printing is a commodity today
- Is revolutionizing 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
Clinical Example 3

Image Guided Therapy
Interfacing to clinical devices

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

Images courtesy A. Golby
Clinical Example 4

Image-guided navigation to localize and excise parathyroid adenoma
AMIGO Parathyroid Team

• Surgeon: Daniel Ruan, MD
• Radiologist: Thomas Lee, MD
• Navigation Scientist: Jayender Jagadeesan, PhD

AMIGO Support Team
• Techs/Nurses: Dan Kacher, Janice Fairhurst, Angela Kanan, Shivon Cesar, Sue Sheehan, Sandra Lawson, Julia Bousquet, Sean Jackson, Nikita Aristarkhov
Problems with Diagnosis and Surgical Resection

- Small glands hidden behind the thyroid gland
- As small as a rice grain
- Numerous sensitive structures around the parathyroid making surgical resection difficult
- Damage to laryngeal nerve could lead to hoarseness, inability to speak and difficulty in breathing
Intraoperative MRI

• Fiducials placed on the patient for enabling “Patient-to-Image” registration
• Cardiac coil utilized for imaging the patient
• Cartridge built to house the cardiac coil and EM flat plate transmitter
• Imaging
  – Gross T1 3mm slices
  – Hi-res T2 images
Intraoperative Guidance

- Module developed in 3D Slicer
- Software and ATC hardware decoupled
  - OpenIGTLink communication
- Wizard Workflow

Preop Planning ➔ Setup instruments ➔ Calibration

Log Data ➔ Refine Registration (Optional) ➔ Setup Displays ➔ Register Patient
Diagnostic Imaging

Jayender et. al, Segmentation of parathyroid tumors from DCE-MRI using Linear Dynamic System analysis, ISBI 2013

DCE MRI

CT

Sestamibi scans
Intraoperative Video

x 2 speed
Result of Navigation System

Smart Pointer

How accurate was the smart pointer in localizing the tumor?

Not accurate

Very accurate

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Slide courtesy of Jayender Jagadeesan
Postoperative scan
Clinical Research Example 5

Only 20% of smokers develop COPD

Multi-center study funded by the National Heart, Lung and Blood Institute (NHLBI).
Co-PIs: Drs. James Crapo, Edwin Silverman.

Genetic factors

21 clinical sites
3 image analysis centers:
  • Denver
  • Boston
  • Iowa

2 imaging platforms:
  • VIDA
  • Slicer
Emphysema Classification for Gene Discovery

- Identification of emphysema patterns based on local histogram classification
  - Normal
  - Severe CLE
  - Mild CLE
  - PLE
  - Moderate CLE
  - Paraseptal

- Centrilobular (CLE) and panacinar (PLE) emphysema
- GWAS in 9000 smokers
- New genetic markers for emphysema were found near the CHRNA3/5 locus on 15q25 and near MMP12 and MMP3 on 11q22


Slide courtesy R. San Jose
Phenotype Extraction In The Lung

Airways

Extraction

Sizing

Phenotype

Population Study

Vessels

Airway Wall corresponding to a 10 mm internal Perimeter

Smoker Control

Severe Disease

San Jose Estepar R et al, Automatic Airway Analysis for Genome-Wide Association Studies in COPD, ISBI 2012

San Jose Estepar R et al, Computational Vascular Morphometry for the Assessment of Pulmonary Vascular Disease based on Scale-Space Particles, ISBI 2012

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
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

- Slicer use
- Feature request
- New capability
- End user
- Analysis, research
- New algorithms, features
- Application developer
- OS, compilers
- Toolkit updates
- Re-architecture

End user \\
Feature request \\
New capability \\
Slicer use \\
Analysis, research \\
New algorithms, features \\
Application developer \\
OS, compilers \\
Toolkit updates \\
Re-architecture \\
Platform Engineering
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
- 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
Special thanks to Jean-Christophe Fillion-Robin, Julien Finet, Steve Pieper, Nicole Aucoin, Andrey Fedorov, Jim Miller, Andas Lasso
Open Source (OS)

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

• Extensible
Upsides for Industry

- Potential advantages:
  - Compared to closed systems more people track changes and detect problems
  - Easy access to world class algorithms and architectures.
  - Community can be engaged
- Open Source approaches are practical
  - Costs are potentially lower
  - They permit the organization to focus on its key product skills, not on commodity capabilities
Challenges for Industry

• Avoid leakage of proprietary information through clear rules and strategies
• Monitor the open source community for shifting focus and direction
• Internal development is likely to be needed for key features.
• Summary: Risks are manageable, but need to be managed
From Tools to Medical Product

• Open Source facilitates scientific exchange
  BTW: Open Source means no restriction on use
  (i.e. no restriction on commercial use)
• All Medical Products are closed source
due to significant regulatory requirements

• How to bridge?
From Open to Closed Source

Open source

Plug-ins

Closed source

3D Slicer
MITK
MedINRIA
Mevis Lab
synigo.via, Advantage
Windows, Vitrea
CTK: An example of OPM

- Common infrastructure elements
- International and transatlantic group of contributors
- Free Open Source Software under a BSD license
- Dicom, application hosting, CLI, Widgets and more

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Plug-Ins: The Key for Translation

- Example: One CTK plug-in on different platforms
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 and 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
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
Acknowledgments

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

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www.na-mic.org

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spl.harvard.edu

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www.ncigt.org
Traumatic Brain Injury Facts

- There are approximately 1.5 million new cases of non-fatal traumatic brain injury (TBI) in the US every year.
- The worldwide incidence of this condition has been estimated to amount to at least 6.8 million TBI cases every year.
- The financial burden of this condition in the USA alone amounts to over $56 billion annually
- More than half of the cases are classified as moderate or severe

- NA-MIC collaboration:
  - UCLA: Jack vanHorn, Andrey Imiria, Paul Vespa
  - UTAH: Guido Gerig, Marcel Prastawa, Bo Wang
  - Kitware: Stephen Aylward, Danielle Pace

Brain images of patients with traumatic brain injury undergo dramatic changes.

**FLAIR**  
**GRE**  
**T1**  
**T2**
Example Traumatic Brain Injury

Neuroimage analysis required for creation of technology:

- EM segmenter
  (Prastawa et al.)
- Non-rigid registration
  (Pace et al.)
Longitudinal change: acute vs. chronic


- red: acute
- green: chronic
The UCLA group had acquired good quality DWI data in both acute and chronic patients. Once segmentation and registration work on TBI subjects, parcellation of the grey matter and analysis of the white matter are possible.
Connectograms

Connectograms use parcellated gray matter regions to analyze the white matter.

Sample Summary:
N=100
Right-handed
Males
25-36 years old

A. Irimia et al. / NeuroImage: Clinical 1 (2012) 1-17
Personalized Connectomics

Streamlines, which are reduced by more than 20% as a result of brain trauma.

Characterizing Fiber Pathway Damage in TBI

SSA: The Effects of Pathology

• Focal pathology introduces focal changes, which make it difficult to define general rules upon which algorithms are based

• Example: Effect of brain tumors on fractional anisotropy of adjacent white matter.
FA Changes Around a Tumor

Asymmetric colorization of the corpus callosum indicates reduction in FA.

FA = 0.11
FA = 0.16
FA = 0.24
Dislocation of Normal Anatomy

The cortico-spinal tract is moved backwards, not toward the midline.