Visualize and analyze medical images in 3D Slicer

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3D Slicer – Overview

- Desktop application for Windows, Mac, and Linux
- 5.0.3 released, 5.2.0 in the works
- Over 1.1 million downloads since 2011
3D Slicer – History

- Pre-Slicer BWH/GE work on volumetric software and image guided therapy
- Vision of Ron Kikinis: a unified platform to avoid reinventing the wheel
- MIT AI Lab Collaboration
  - Dave's neurosurgery thesis 1999
  - Delphine's virtual endoscopy thesis 2002
  - Lauren's tractography thesis 2006

Courtesy of Ron Kikinis, M.D.
3D Slicer – Today

- Professionally engineered
- Documented & tested
- Extensively scriptable in Python
- Based on the best software libraries
  - VTK, ITK, Qt, WebEngine, DCMTK, ...
  - Python ecosystem (numpy, PyTorch/MONAI, ...)
- Dozens of tutorials, hundreds of videos
- Very active online forum: ~16K posts / y
- Scientific publications: Over 15,000 citations on Google Scholar
- Twice a year developer project week
3D Slicer Software License

- BSD-style very permissive license
- Explicitly written for BWH / 3D Slicer goals
  - Promote multi-site collaboration
  - Encourage industry involvement
  - Allow use in medical products
- Written in 2005 after NIH workshop and consultation with legal experts
- Adopted by dozens of academic & commercial sites
- Contributor agrees
  - Applies to code and data
  - Allows re-licensing under same terms
  - No GPL "reciprocal licenses"
  - No known patent restrictions

For more information, please see:
http://www.slicer.org

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Lawrence Rosen, Eve Waterfall, Brian Hicks

Courtesy of Ron Kikinis, M.D.
100% Open and Non-Restrictive Processes

• Public source repository: [github.com/Slicer](https://github.com/Slicer) organization
  – Slicer source code and issues tracker

• Open discussion forum: [discourse.slicer.org](https://discourse.slicer.org)

• Weekly [developer video conferences](https://www.slicer.org) open to anyone (10am EST Tuesdays)

• Twice-yearly Project Weeks
  Next one here in Las Palmas! [projectweek.na-mic.org](https://projectweek.na-mic.org)

• "Meritocracy" to form group decisions

Courtesy of Ron Kikinis, M.D.
3D Slicer Extensions – “App Store”

- 150+ Extensions from hundreds of developers
  Independent add-ons to core platform
- Built & tested nightly for Windows, Mac, Linux
- Different styles
  - Pure Python / Pure C++ / Hybrid C++ & Python
  - Extra modules to full custom app (aka "Solution")
- Everything we provide is open source
- Anyone can build compatible extensions under preferred distribution license
Modular and Reusable

- Medical Reality Markup Language (MRML)
  - In-memory dynamic scene description
  - Event-driven
  - Serializable to XML (.mrml)
  - Medical Reality Bundle (.mrb)
- Logic implements algorithms
  - Decoupled from UI for reuse in CLI or other app
- Graphical User Interface (GUI) modifies MRML and responds to events
- Displayable Managers and Widgets map between MRML and 2D / 3D rendered views

"Lego bricks, not jigsaw puzzle pieces!"

Courtesy of Ron Kikinis, M.D.
Interoperability

- Common and research formats
  - Images (nrrd, nii.gz, ...)
  - Models (stl, ply, obj, ...)
  - Tables (csv, txt)
  - Point lists (json)
  - etc.

- DICOM
DICOM

• DICOM: Digital Imaging and Communications in Medicine
• The industry standard for storage and transfer of medical images

```plaintext
(0008,0008) CS [ORIGINAL\PRIMARY\AXIAL] # 22, 3 ImageType
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(0008,0013) TM [161402] # 6, 1 InstanceCreationTime
(0008,0016) UI =CTImageStorage # 26, 1 SOPClassUID
(0008,0018) UI [1.2.840.113619.2.55.3.671756986.106.1316467036.466.1] # 52, 1 SOPInstanceUID
(0008,0020) DA [20110920] # 8, 1 StudyDate
(0008,0021) DA [20110920] # 8, 1 SeriesDate
(0008,0060) CS [CT] # 2, 1 Modality
(0008,0070) LO [GE MEDICAL SYSTEMS] # 18, 1 Manufacturer
(0008,0090) PN (no value available) # 0, 0 ReferringPhysicianName
(0008,103e) LO [PELVIS CURATIVE] # 16, 1 SeriesDescription
(0010,0010) PN [RANDO^PROSTATE] # 14, 1 PatientName
(0010,0020) LO [TEST PHYS PROSTATE] # 18, 1 PatientID

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(0020,0032) DS [-250\-250\105] # 14, 3 ImagePositionPatient
(0020,0037) DS [\0.0\0.0\0.0\0.0\0.0] # 20, 6 ImageOrientationPatient

…
(0028,0010) US 512 # 2, 1 Rows
(0028,0011) US 512 # 2, 1 Columns
(0028,0030) DS [9.76562e-1\9.76562e-1] # 22, 2 PixelSpacing
(0028,0010) US 16 # 2, 1 BitsAllocated
(0028,0011) US 16 # 2, 1 BitsStored
(0028,0012) US 15 # 2, 1 HighBit
(0028,0013) US 0 # 2, 1 PixelRepresentation
(7fe0,0010) OW 0018\0018\0018\0018\0018\0018\0018\0018\0018... # 524288, 1 PixelData
```
Modalities

• Image
  – Common: CT, MR, US, PET, ...
  – 4D Ultrasound

• Segmentation: SEG

• Structured report: SR

• Radiation therapy
  – Dose: RTDOSE
  – Structure set: RTSTRUCT
  – Plan: RTPLAN
  – Planar image: RTIMAGE
DICOM via DICOMweb

- DICOM Standard for web-based medical imaging
- RESTful API services
DICOM via Kheops

- Web-based DICOM database management
- Slicer plugin: download and open in Slicer
Features: Visualization

1. 2D (slice) and 3D views, chart views
2. Configurable layout
3. Multi-modality image fusion (foreground, background, label map)
4. Transforms, vector and tensor field visualization
5. Surface and volume rendering
6. Time sequence data
Features: Registration

- Manual: translation, rotation in 3D
- Automatic: rigid, deformable, with various similarity metrics, initialization methods, optimizers, masking, etc.
- Extensions: structure-based registration, Elastix, etc.
Features: Segmentation

• Also known as contouring
• Delineates structures of interest
  – Manual contouring: slow
  – Semi-automatic: some interaction
  – Automatic: still needs editing
• Omnipresent in medical imaging
  – Surgical/radiation therapy **planning**
  – Intra-surgery **navigation**
  – Volume/shape **analysis**
  – 3D printing (**interventions**)
  – **Education**
Representing Segmentations

• Each optimal for
  • *either* storage (D)
  • *or* analysis (A,C)
  • *or* visualization (B,E)

• Imposed needs
  • Conversion
  • Simultaneous
    – Visualization
    – Transformation
Segment Editor

- Overlapping structures
- Real-time 3D surface visualization
- Direct file export (e.g. for 3D printing)
- Control over geometry
- Advanced masking options
- Standard medical terminologies
- Unique editing tools
Segment Editor: Example Workflow
Segment Editor: Simple Manual Tools

- Paint
- Erase
- Draw
- Scissors
Segment Editor: Semi-Automated Tools

- Threshold
- Fill between slices
- Level tracing
- Grow from seeds
Segment Editor: Fully Automated (AI)

MONAI Label – Multi-label DeepEdit method

• Integrated in 3D Slicer already
• Training possible starting 5 segmented image per structure
• Large GPU needed for training (cloud option available via e.g. Amazon)

Díaz-Pinto, MICCAI 2022
Translational medical R&D

**Bench**
- Can it be done?
- Gov’t grants
- Not robust

**Bedside**
- Patient ready
- For-profit companies
- Closed source

“Valley of death”: Gap between funding models

Nature 453, 840-842 (2008) | doi:10.1038/453840a
Building on a platform

LINES OF SOURCE CODE - ILLUSTRATED THROUGH LUMPNAV
(NAVIGATION SOFTWARE FOR BREAST CANCER SURGERY)

- Qt 29.2%
- VTK 27.6%
- Python 9.9%
- Numpy 6.8%
- DCMTK 5.2%
- ITK 13.1%
- 3DSlicer core 3.5%
- SlicerIGT 1.6%
- BrainsTools ext 1.3%
- CTK 1.7%
- Plus toolkit 1.4%
- SlicerIGT ext 0.2%
- LumpNav ext 0.01%
Appendix
3D Slicer – Overview

- Medical image computing platform: import/export, visualization, segmentation, registration, quantification, real-time guidance
- Application framework: customizable, extensible custom modules
- Completely free (BSD)
  - Built from $$$ OPM
- Multi-platform (Windows, Linux, MacOS)
- User and developer support
- Training courses, documentation, tutorials

Many devices – one application

- Hardware abstraction
- Visualization / Analysis

- Local
- Ethernet
- Wi-Fi

data transfer protocol

all sorts of devices
Intra-op. contouring & navigation for breast surgery

Source: Queen’s University
Example: Central Line Tutor
TrainUS platform
Example: Craniosynostosis collaborative VR
Augmented reality

REALITY

ULTRASOUND PROBE

AUGMENTED REALITY

TUMORS