3D Reconstruction of Individual Anatomy From Medical Image Data: Survey

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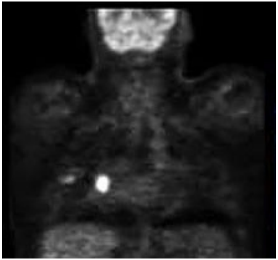
Introduction

Medical technology has transformed



CT Scan

using X-rays and a computer to take multiple, successive tomographic images.

MRI

using nuclear magnetic resonance to create images by changing the strength of the magnetic field.

PET Scans

using isotopes that emit positrons or positively charged electrons to evaluate the chemical activity.

Achieving the visualization work

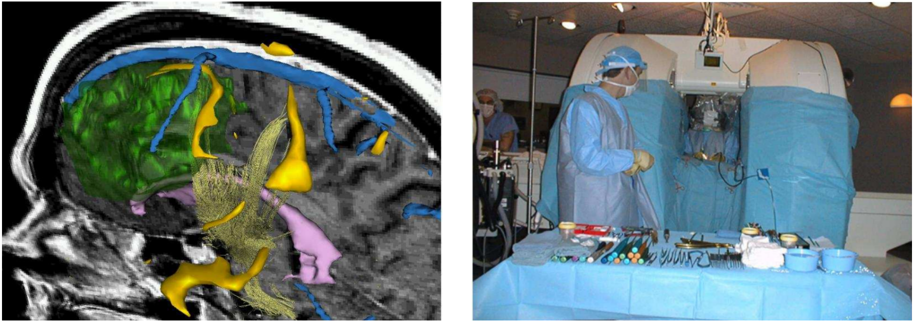


Figure: Three dimensional reconstruction of medical images can provide the direct, real sense for doctors and play an important role in clinical medicine.

Creating 3D Printable Models

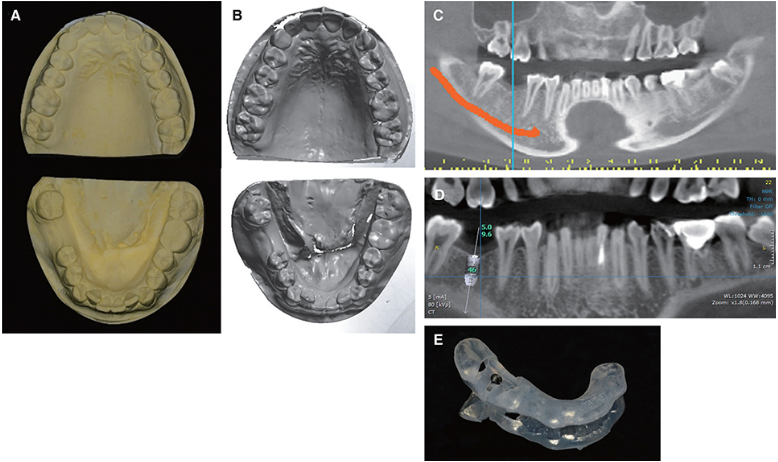


Figure: Three dimensional reconstruction of medical images can generate 3D printable anatomic models from real medical scans.

Method

Segment in 3D medical images

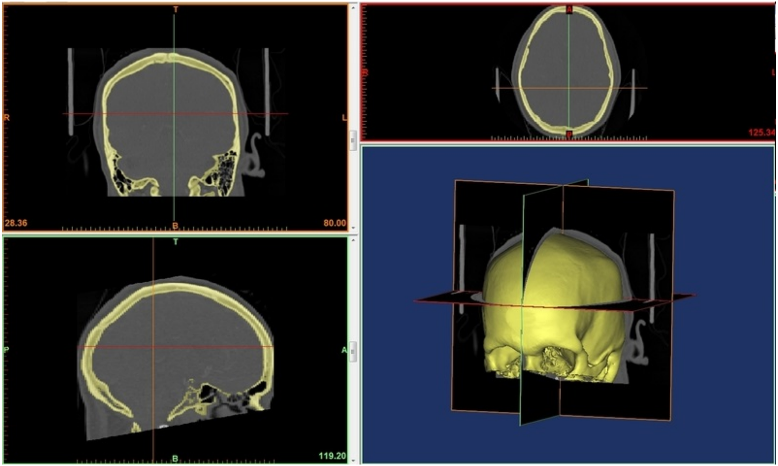
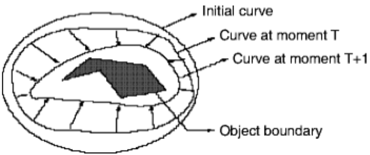


Figure: Firstly, we need to achieve the separation or segregation of information from the required target region per sliced image.

Active Contours/Surfaces Model

- Active contours, or snakes, are computer-generated curves that move within images to find object boundaries.
- By being a deformable model, snakes can adapt to differences and noise in stereo matching and motion tracking.



Demo

Energy formulation

$$E^*_{\text{snake}} = \int_0^1 E_{\text{snake}}(\mathbf{v}(s))\,ds = \int_0^1 (E_{\text{internal}}(\mathbf{v}(s)) + E_{\text{external}}(\mathbf{v}(s)) + E_{\text{con}}(\mathbf{v}(s)))\,ds$$

- A simple elastic snake is defined by a set of n points $\mathbf{v}_i$
- The energy function of the snake is the sum of its external energy E_{external}, internal energy E_{internal}, and the constraint forces introduced by the user E_{con}

Internal energy

- The internal energy of the snake is composed of the continuity of the contour E_{cont} and the smoothness of the contour E_{curv}.

$$E_{\text{internal}} = E_{\text{cont}} + E_{\text{curv}}$$

- This can be expanded as

$$E_{\text{internal}} = \frac{1}{2}\left(\alpha(s)\left\|\frac{d\bar{v}}{ds}(s)\right\|^2 + \beta(s)\left\|\frac{d^2\bar{v}}{ds^2}(s)\right\|^2\right)$$

Active Contours/Surfaces Model

External energy

$$E_{\text{external}} = w_{\text{line}} E_{\text{line}} + w_{\text{edge}} E_{\text{edge}}$$

- The line functional is the intensity of the image $E_{\text{line}} = \textbf{filter}(I(x, y))$. w_{line} will determine whether the line will be attracted to either dark lines or light lines.
- The edge functional is based on the image gradient $E_{\text{edge}} = -\left|\nabla I(x, y)\right|^2$.

References

- Wiki: Active Contour Model
- Lec11: Active Contour and Level Set for Medical Image Segmentation
- Active Contours/Snakes: K. Grauman of University of Texas at Austin
- Snakes: Active Contour Models - Michael Kass, Andrew Witkin of Schlumberger Palo Alto Research
- Active Contours, Deformable Models, and Gradient Vector Flow - Chenyang Xu and Jerry L. Prince of The Image Analysis and Communications Lab
- Learning Active Contour Models for Medical Image Segmentation - Department of Eye and Vision Science, Institute of Ageing and Chronic Disease, University of Liverpool

Deep Learning Methods

Active contour methods is semi-automatic segmentation algorithms. Can we obtain interactive image segmentation methods more flexible and efficient?

There are two main type of approaches:

- Deep Learning method based on an active contour framework. **DAC, DCAC, DSAC, DACN,...**
- Only deep learning models based on sufficiently large dataset. **UNet, DoubleUNet, 3DUnet, Med3D,...**

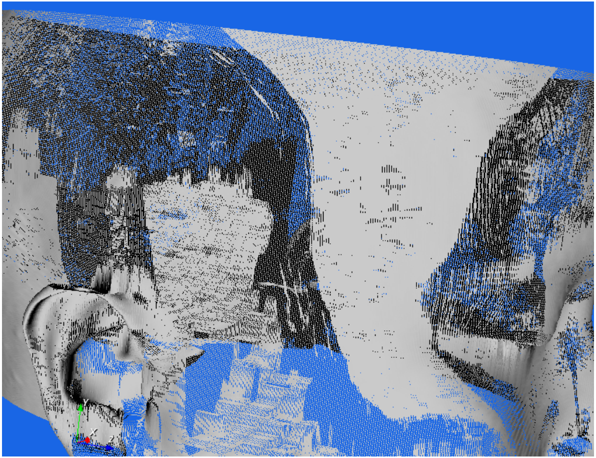
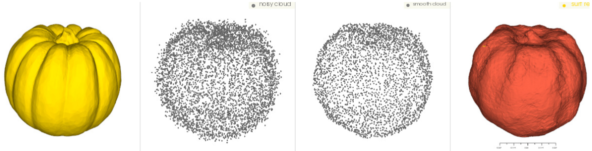


Figure: A 3d mesh generates from the point cloud associated with the 2D medical images will be used for visualization after the segmentation.

Geometry Processing



- An object is loaded and noise is added to its vertices.
- The point cloud is smoothened with MLS
- Imposes a minimum distance among mesh points where.
- A triangular mesh is extracted from this set of sparse points.

Development

Kitware - ITK

- An open-source segmentation and registration toolkit, freely available, cross-platform system for high-performance, N-dimensional image analysis.
- Extensive suite of algorithms for processing, registering, segmenting, analyzing, and quantifying scientific data.

Kitware - ITK

Pros

- Providing extensive suite of leading-edge algorithms.
- Developing in both Python and C++ packaging, and supporting NumPy, SciPy bridge.
- Supporting cross-platform system.

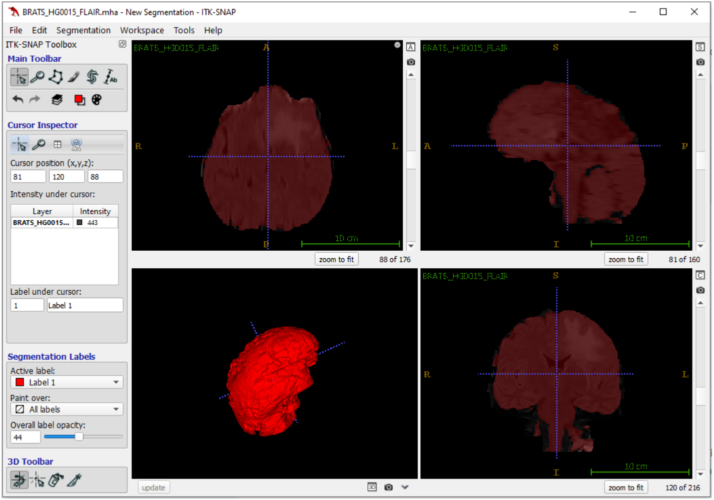
Source: Insight Toolkit

Kitware - VTK

- An open-source software system for image processing, 3D graphics, volume rendering and visualization.
- Including many advanced algorithms (e.g., surface reconstruction, implicit modelling, decimation) and rendering techniques (e.g., hardware-accelerated volume rendering, LOD control).

Source: Visualization Toolkit

ITK-SNAP



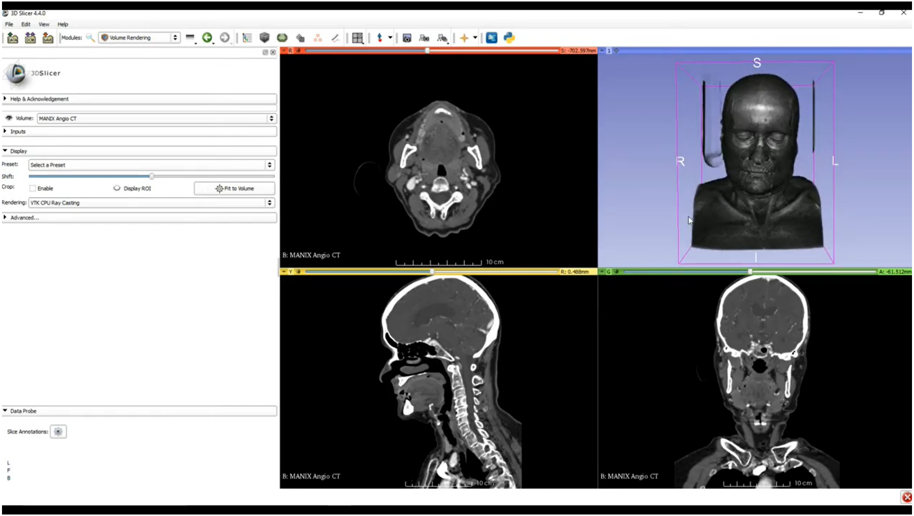
Source: Insight Toolkit-SNAP

3D Slicer

- An open source software platform for medical image informatics, image processing, and three-dimensional visualization.
- Built over two decades through support from the National Institutes of Health and a worldwide developer community, Slicer brings free, powerful cross-platform processing tools to physicians, researchers, and the general public.

Source: 3D Slicer

3D Slicer


3D Slicer 4.4.0
File Edit View Help
Modules: Volume Rendering
3DSlicer
Help & Acknowledgement
Volume: MANIX Angio CT
Inputs
Display
Preset: Select a Preset
Shift:
Crop: Enable Display ROI Fit to Volume
Rendering: VTK CPU Ray Casting
Advanced...
Data Probe
Slice Annotations:
B: MANIX Angio CT
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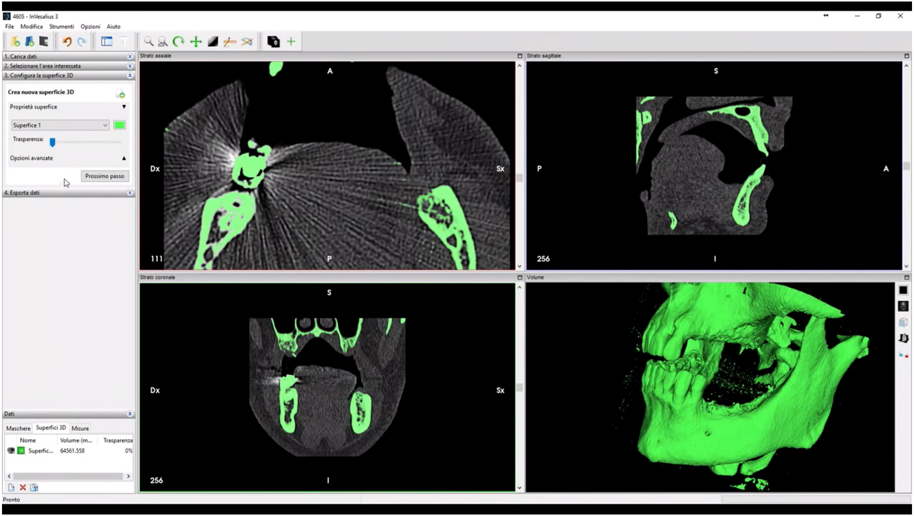
INVESALIUS 3.0

- A free software for reconstruction of computed tomography and magnetic ressonance images.
- Mainly used for rapid prototyping, teaching, forensics, and in the medical field.
- Possible to use it on the Microsoft Windows, GNU/Linux and Apple Mac OS X platforms.

Source: Invesalius

INVESALIUS 3.0



Pros

- Capability of execution on different operating systems and act as a platform to encourage the use and development of medical images in Brazil.
- Minimal or null acquisition cost.
- Support printable 3D output.

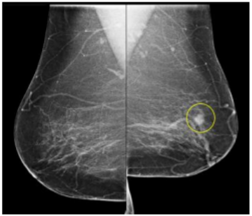
Application

Working with clinicians

Doctors specify the problem

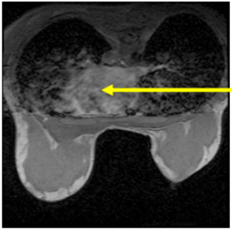
$$E^{\text{imp}}(\mathbf{x}) = \phi(V_t,\mathbf{x}) A_p t_s \int_0^{E_{\max}} N_0^{\text{rel}}(V_t,\varepsilon) G(\varepsilon) D(\varepsilon) \exp^{-\mu_{\text{lucite}}(\varepsilon) h_{\text{plate}}} \exp^{-h\mu(\varepsilon)} \, d\varepsilon$$

Doctors are unimpressed by mathematics, algorithm details, ….



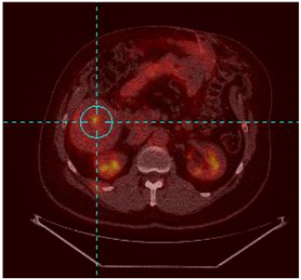
Doctors are impressed by results that enable them to work better

Confidence builds slowly, but can drop like a stone

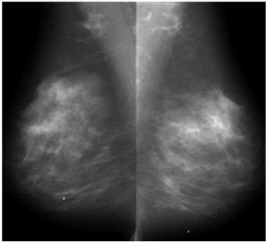


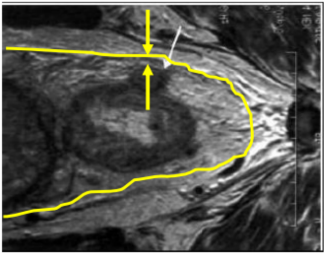
Algorithm: "this is a rapidly enhancing region, suggestive of cancer

What clinicians need



Focal enhancement of FDG in liver*





It is recommended that the circumferential resection margin be at least 1mm if surgery is to be an option

	Right	Left
Volume of Fibroglandular Tissue (cm^3)	129.5	123.3
Volume of Breast (cm^3)	631.7	645.5
Volumetric Breast Density (%)	20.5	19.1

1.5 mGy	9.1 kPa	19.8%

Tools they can trust & provide the information they need

Numbers!!!

Accuracy

Response to therapy: If error in measurement m_i is ε_i, then error $(m_1 - m_2) = \varepsilon_1 + \varepsilon_2$

Applications have been developed

In medical imaging, many applications require visualization and analysis of 3D objects. The medical image visualization technology has been applied practically in clinical fields:

- Computer-aided diagnosis.
- E-learning in medicine.
- Virtual surgery.

Source: Insight Toolkit

There are variety of medical image viewing software: some paid, some targeted at medical students, others at seasoned experts, each with different specifications, systems requirements, ad-ons, and capabilities. Those are often developed with a focus on one or more of the following functions:

- Simple viewing of medical images
- Teaching
- Mini-PACS servers
- Research

Source: Top 25 free dicom viewers
Blue Sky Plan: Plan Dental Surgery

E-learning in medicine

The objective of the curricula of medical education is to offer the physicians with the best possible knowledge and clinical skills. Those are often developed with a focus on one or more of the following functions:

- Visualize internal organs.
- Simulate the processes inside the human body.
- Simulate the processes of surgery, treatment action.
- Learning management system.
- Track, manage, and report student's progress.
- Provide training courses and certification.
- Translation, search and look up definitions.
- Interacting through the internet with the specialists and blogging.

Moisaka: Healthcare Digital e-Learning Solutions

Virtual surgery

Nowaday, 3D printing, realistic mannequins, and virtual reality are transforming how surgeons learn. Most surgery simulators fall into one of two categories:

- **Mannequins:** great because they offer haptic feedback.
- **Screen-based simulators:** cool because virtual mannequins can automatically, consistently, and objectively measure the surgeon's performance

Free screen-based surgery simulators: **Touch Surgery**, **Surgery Squad**, **Buckingham Virtual Tympanum**, **Operate Now**.

$\Longrightarrow$ Lack of practical application in reality - Just Game

Current efficient AR/VR surgery application:

XRHealth[Page][Demo], **AccuVein**[Page][Demo], **Augmedics**[Page][Demo], **BlueSkyPlan**[Page][Demo],...

Community

NIPY

- NIPY is a community of practice devoted to the use of the Python programming language in the analysis of neuroimaging data.

Link: NIPY Main Page

Embodi3D

- Embodi3D is the largest and fastest growing library of 3D printable anotomic models generated from real medical scans on the internet.

Link: Embodi3D Main Page

Top Healthcare AR/VR Companies

These companies intend to be at the forefront of VR and AR healthcare.

- **FundamentalVR**[Page][Demo].
- **Karuna Labs**[Page][Demo].
- **OxfordVR**[Page][Demo].
- **Augmedics**[Page][Demo].
- **Surgical Theater**[Page][Demo].
- **EchoPixel Theater**[Page][Demo].
- **Medivis**[Page][Demo].
- **Health Scholars**[Page][Demo].
- **Vicarious Surgicals**[Page][Demo].
- **Touch Surgery**[Page][Demo].
- **Proprio Vision**[Page][Demo].
- **ImmersiveTouch**[Page][Demo].
- **OSSO VR**[Page][Demo].
- **SentiAR**[Page][Demo].
- **Medical Augmented Intelligence**[Page][Demo].
- **HoloAnatomy**[Page][Demo].
- **SyncThink**[Page][Demo].
- **XRHealth**[Page][Demo].