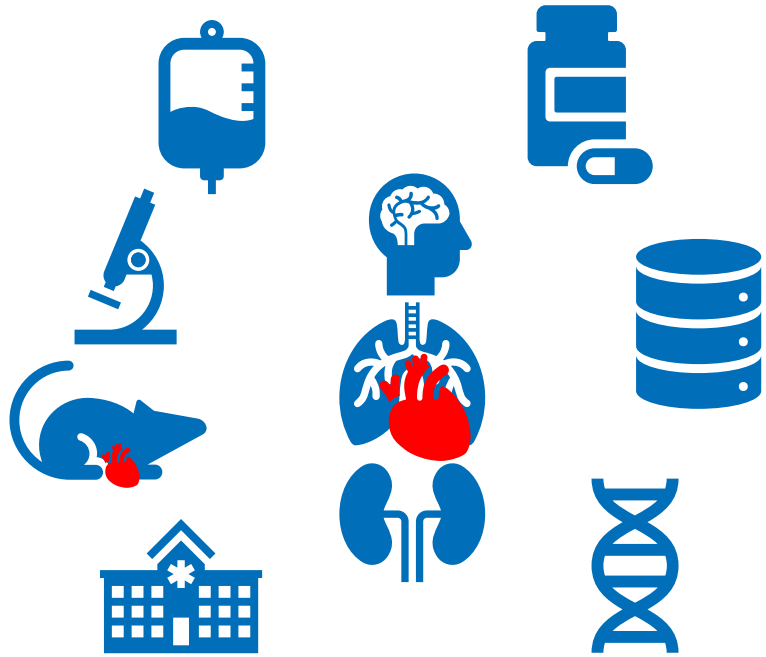
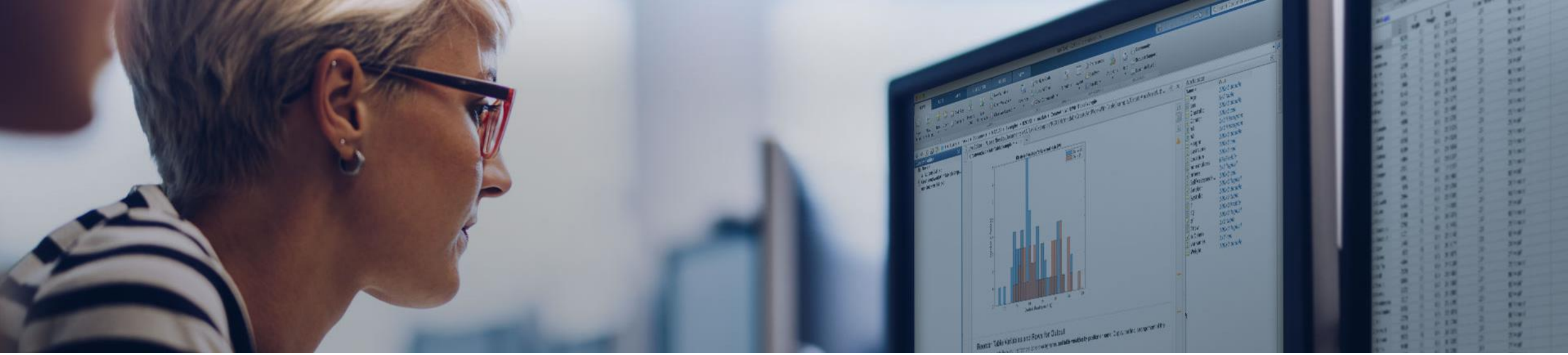
Medical Image Analysis (with AI)



Rob Holt, PhD
Manager, Biological Sciences
28 October 2024



- Millions of engineers and scientists worldwide use MATLAB and Simulink.

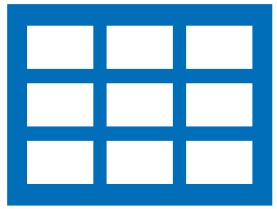
5 million+
users in 185 countries

100,000+
businesses, governments, and universities

All the top 10 pharmaceutical and medical device companies

MATLAB Has Strong Cross-Compatibility

MATLAB Natively Supports Read, Write, Analyze, and AI Applications for:

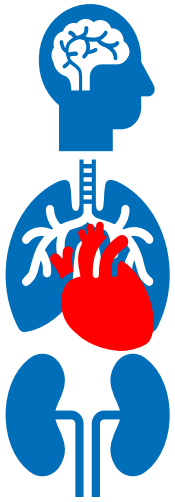


Tabular Data

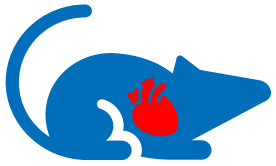
Signal

Text

Genetic Data



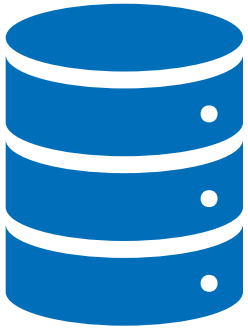
Clinical



Preclinical

Microscopy

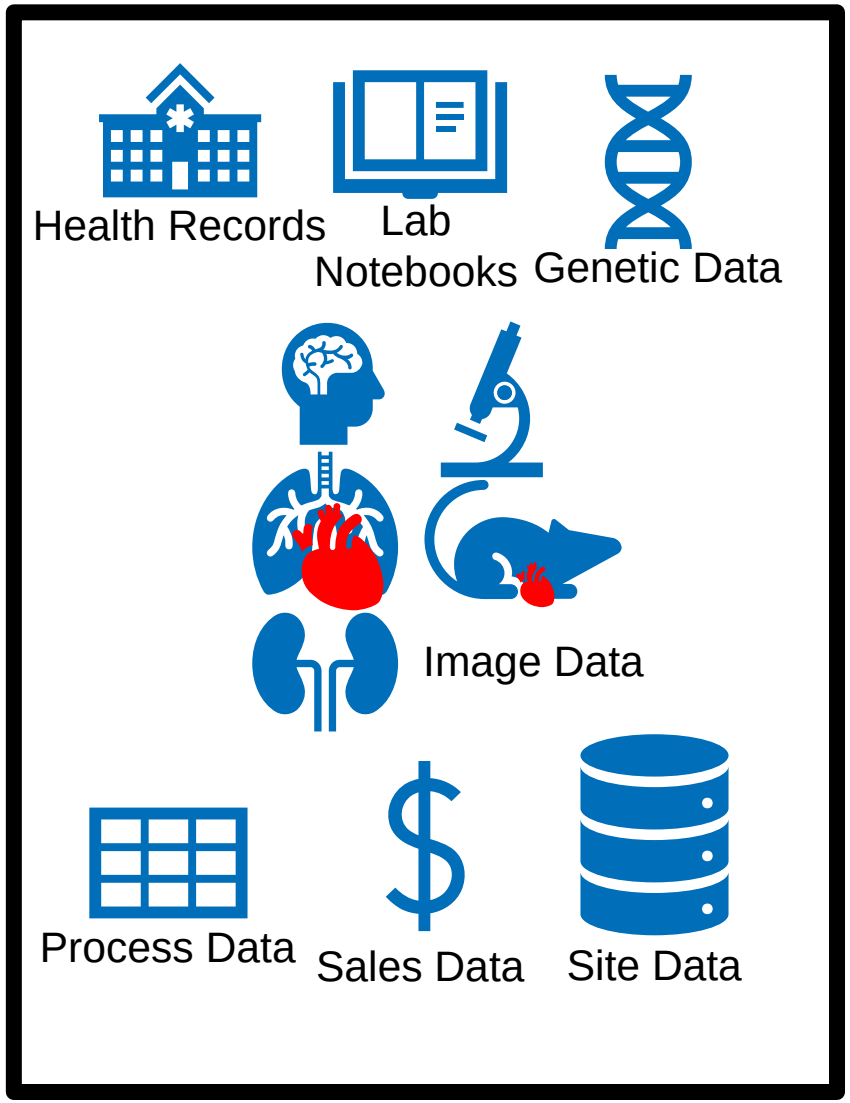
Image Data

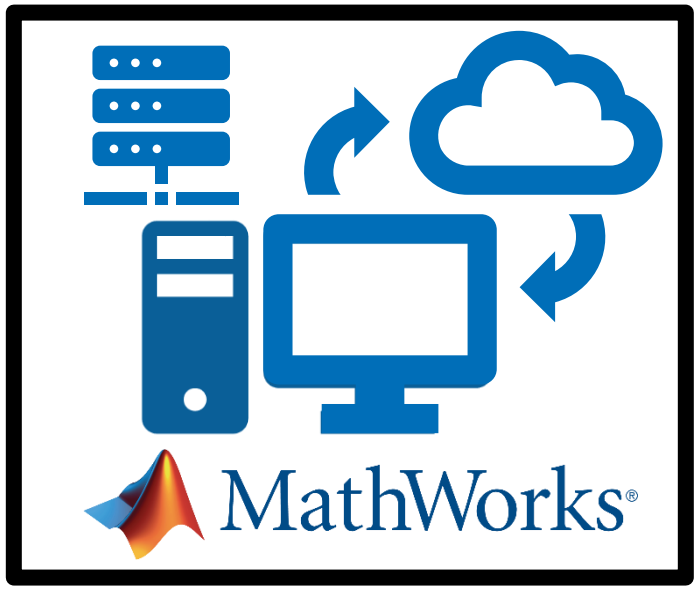


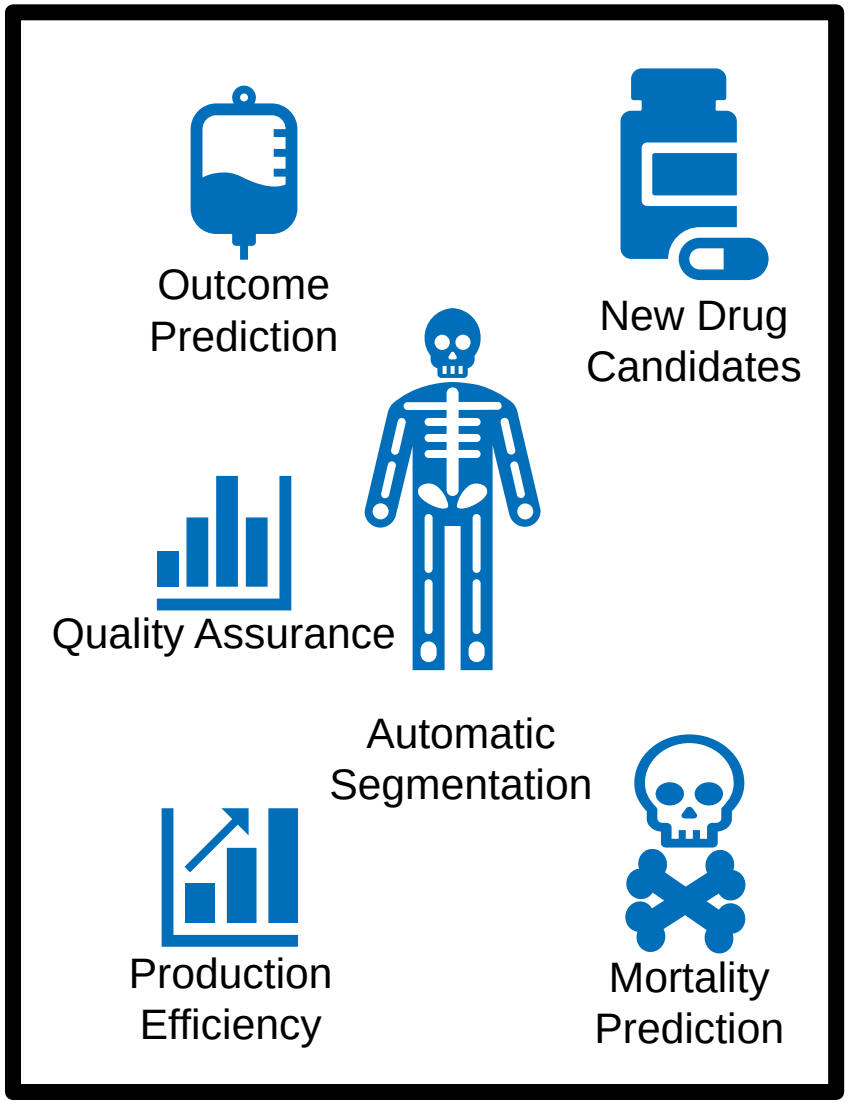
Database

Cloud

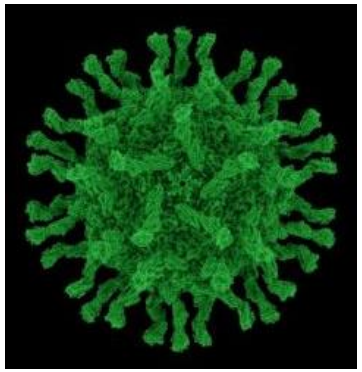
Many Data Streams Can be Powerfully Combined Using MATLAB



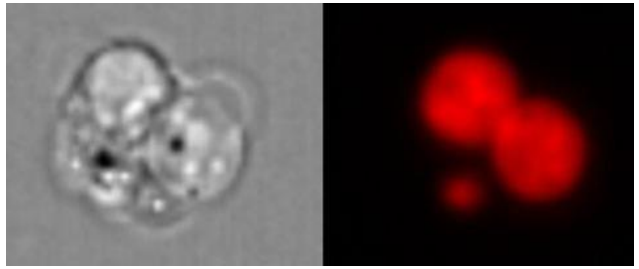




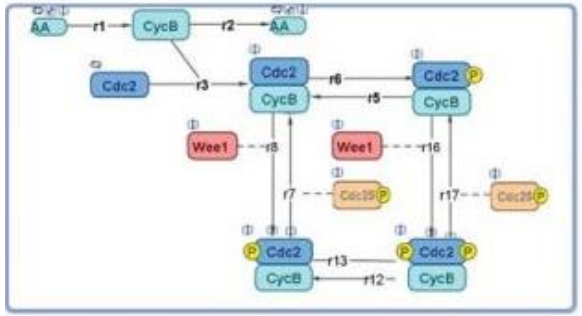
MATLAB AI is Everywhere in Drug Discovery and Development



American CDC Disease Tracking



Automating Flow Cyt. Toxicity Assay Using Deep Learning

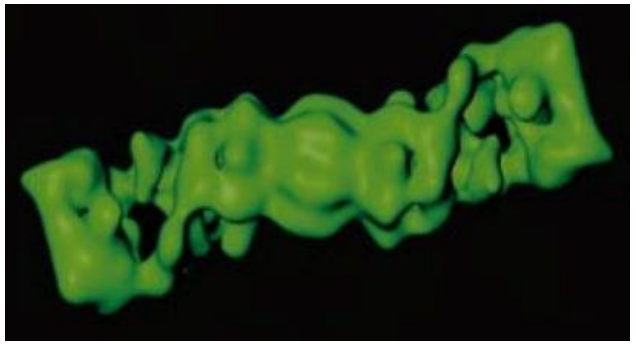


Pfizer Uses Model-Based Drug Dev to Reduce Phase II Attrition

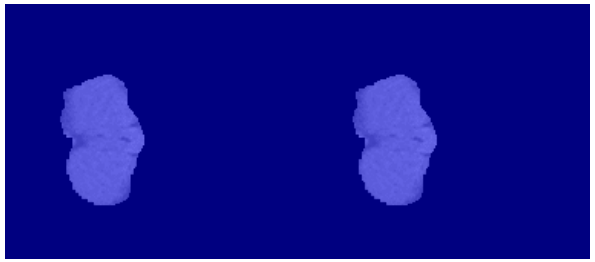
SENSODYNE®

GSK Uses AI on Historical Data: Improve Manufacturing Processes

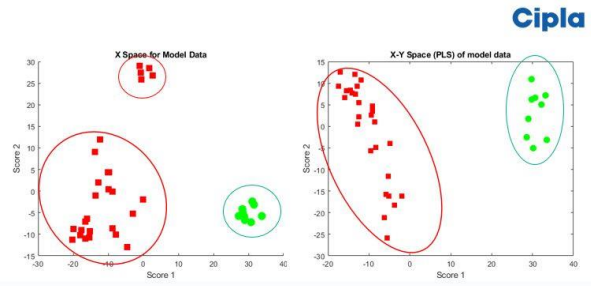
Basic Research → **Discovery** → **Development** → **Translation** → **Clinical** → **Scale Up** → **Manufacture** → **Post-Approval**



Predict Protein Structure Using AI



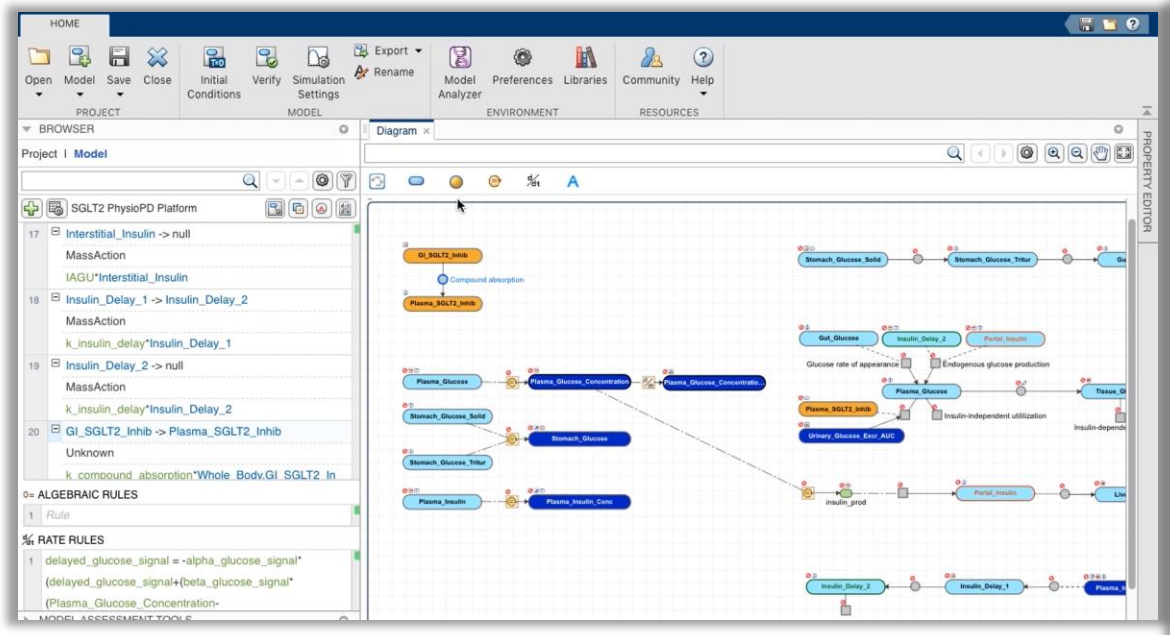
3-D Brain Tumor Autoseg Using Deep Learning

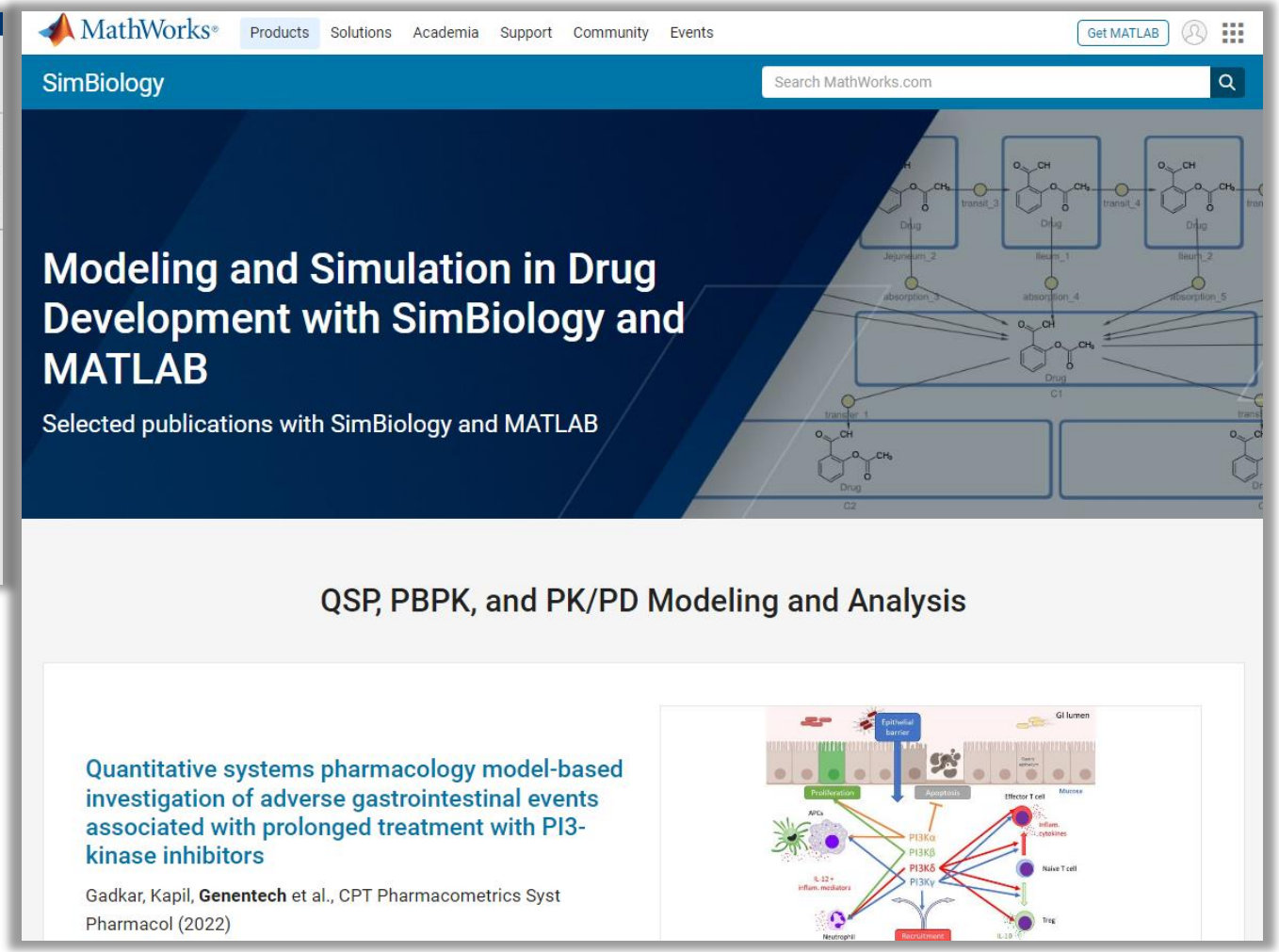


CIPLA Accelerates Manufacturing Analysis with App-Based Machine Learning

Predicting Hospital Readmission Using AI with EHRs

Pharmacology – QSP, PK/PD, PB/PK with SimBiology





- Pharmacological modeling
- Dose studies
- Bio digital twin simulation

Algorithms and visualization techniques for Next Generation Sequencing

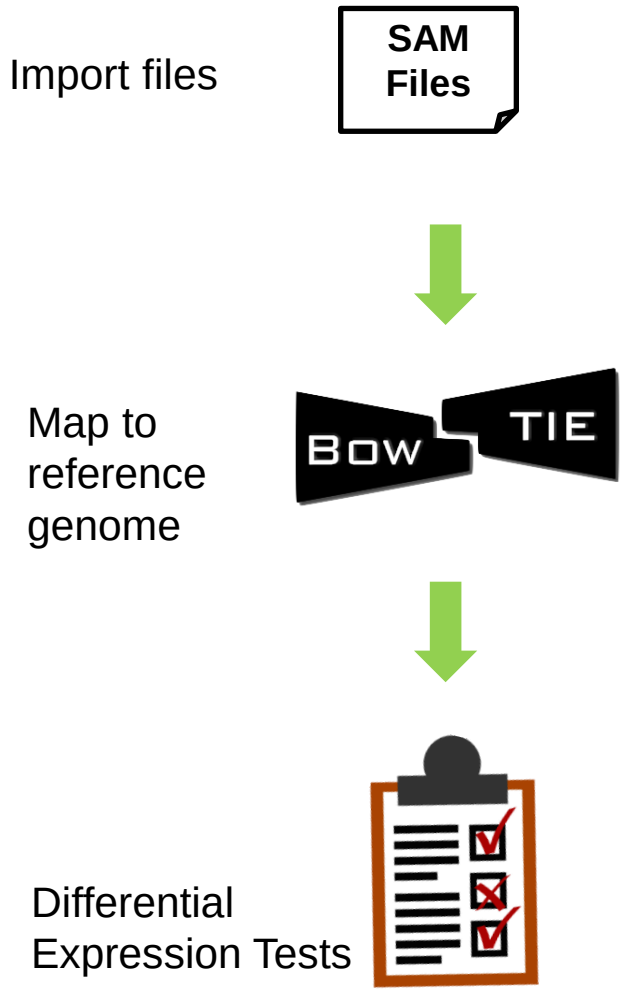
Data import
- Import NGS data from FASTA, FASTQ, SAM, and BAM files.
- Read feature annotations from GTF and GFF files

Preprocessing
- Filter, trim, split sequences and create quality control plots.

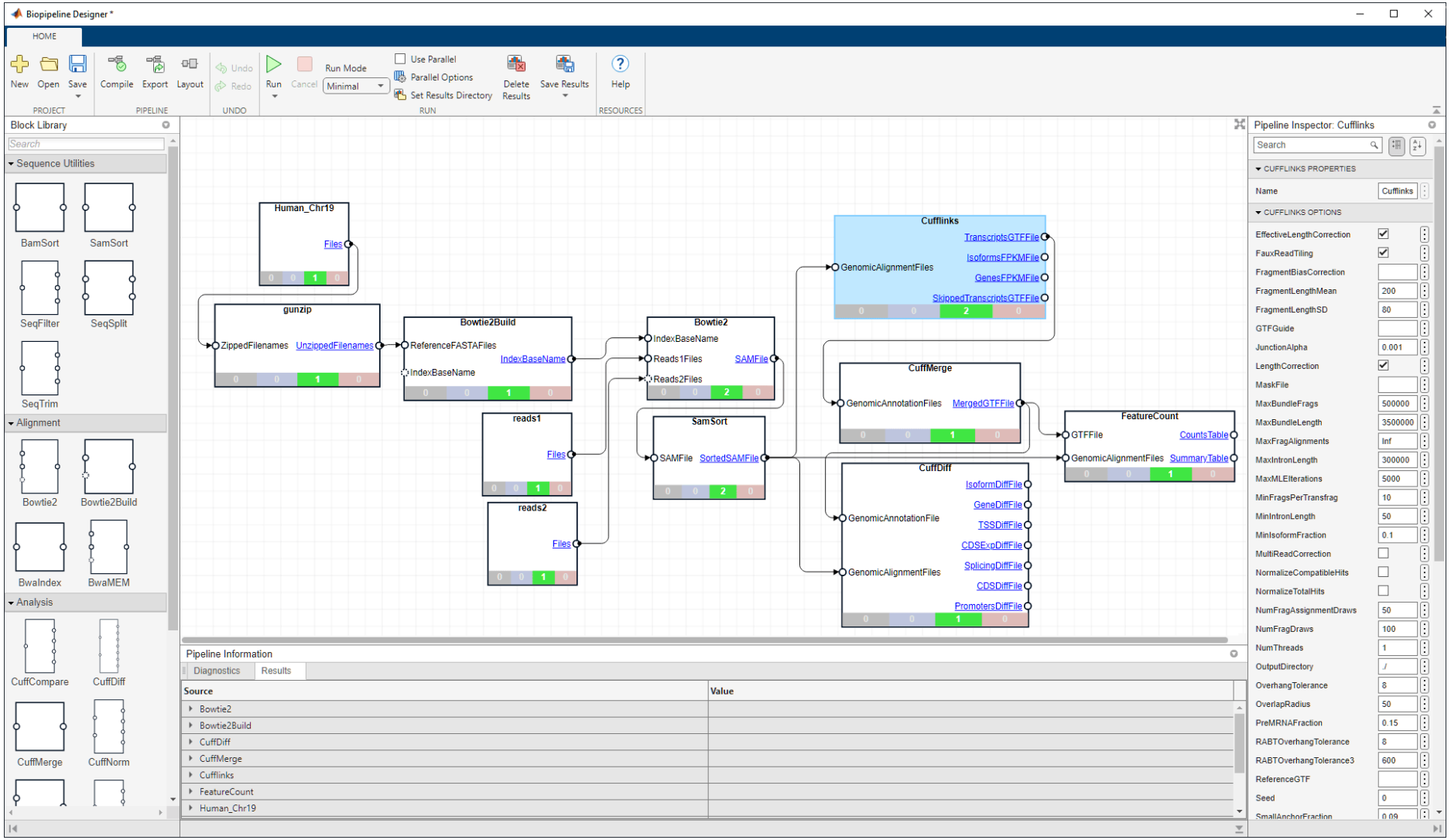
Alignment
- Align sequence reads to reference using bowtie1 or bowtie2

Visualization
- Visualize and explore read alignments to reference sequences with Genomics Viewer app
  (embedded version of the Integrative Genomics Viewer)

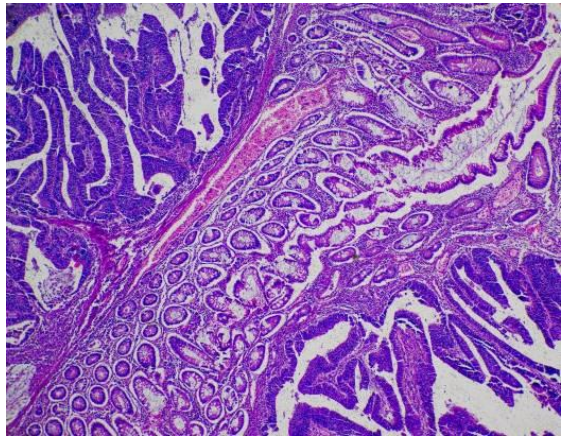
Statistical analysis
- Perform statistical analysis and perform feature engineering on RNA-seq and ChIP-seq data.



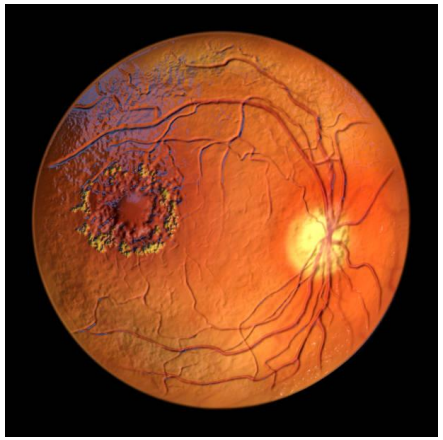
Build End-to-End Bioinformatics Pipelines using Biopipeline Designer



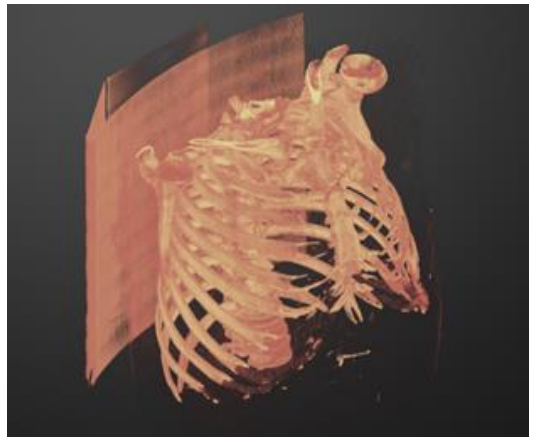
Medical imaging a core part of several workflows



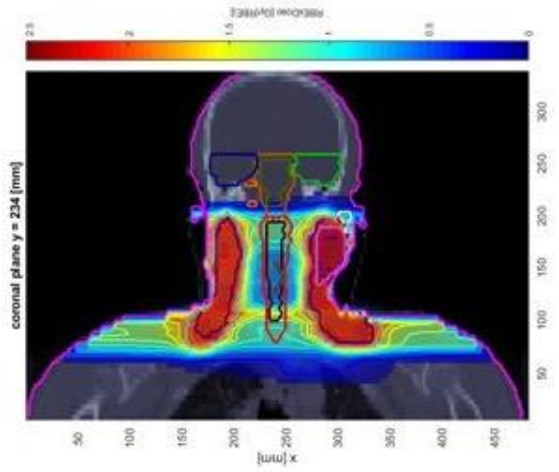
Digital Pathology



Ophthalmology/OCT

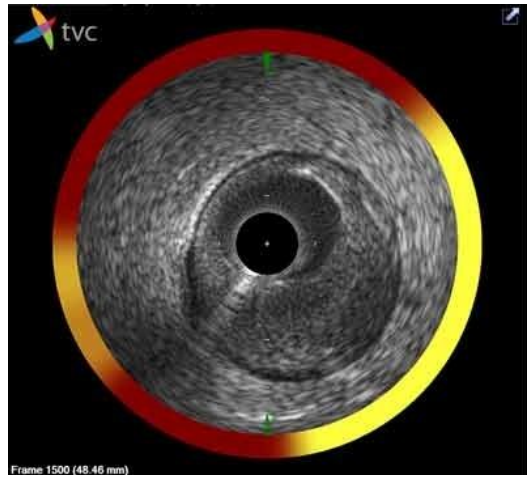


Radiology (MRI, US, X-ray, CT)



Radiotherapy Planning

Endoscopy



Intravascular Imaging

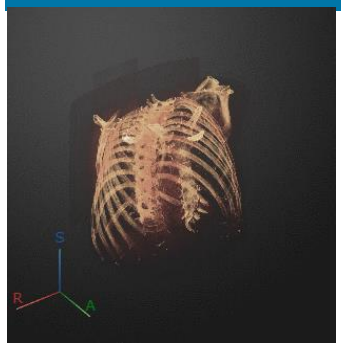
Flexible medical imaging workflow

Import/Interoperate

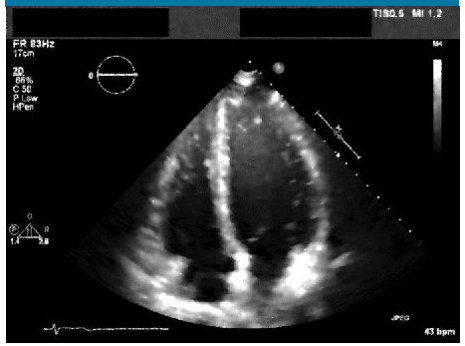
```
medImage =
  medicalImage with properties:

          Pixels: [1540x1250 uint16]
        Colormap: []
    SpatialUnits: "mm"
       FrameTime: []
      NumFrames: 1
    PixelSpacing: [0.1390 0.1390]
        Modality: 'DX'
    WindowCenter: 2048
     WindowWidth: 4096
```

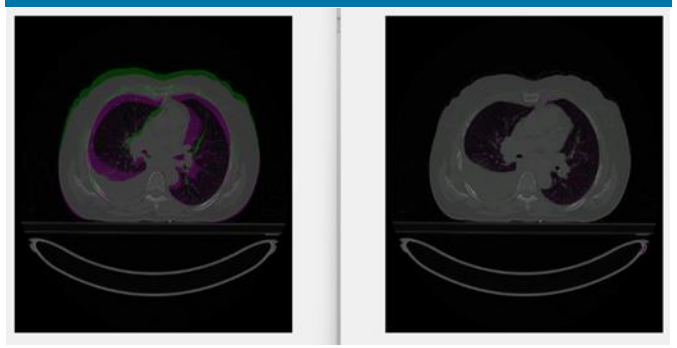
Visualize



Preprocess

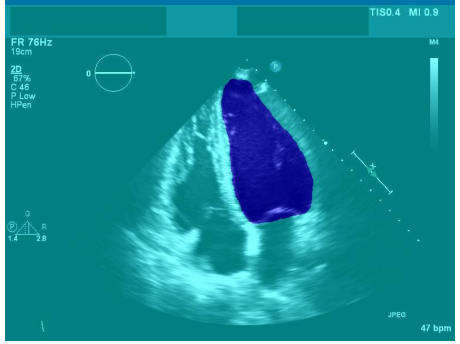


Register



+ Human Validation = Ground Truth

Segment

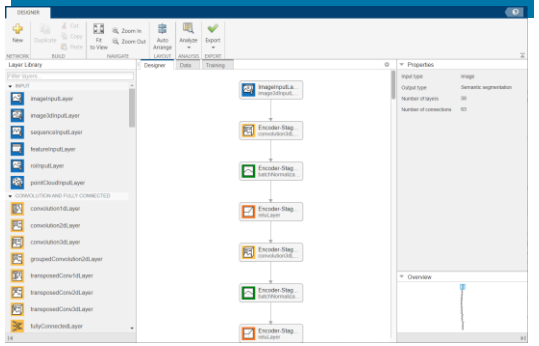


Label

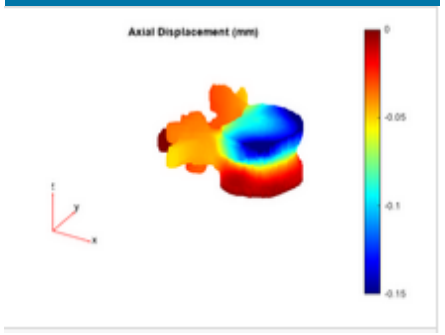
Data Source

Label Image

Train



Analyze



Dedicated functions to load medical data and metadata

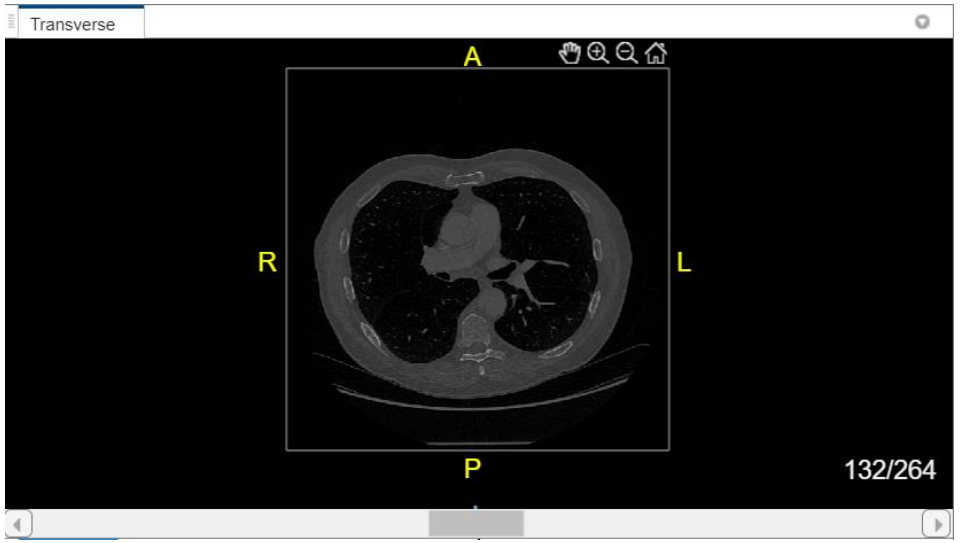
Import

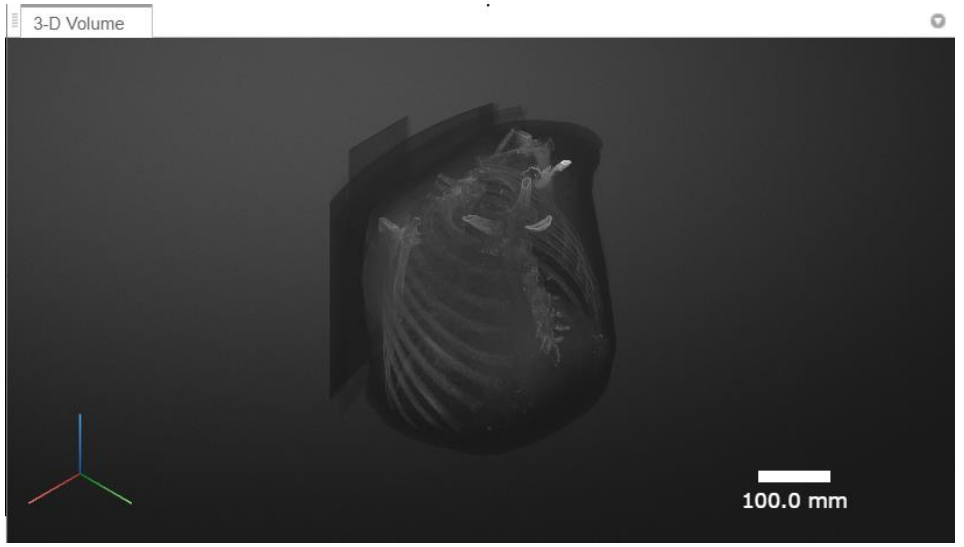
```
medVol = medicalVolume(“lung_027.nii.gz”)

medVol =

  medicalVolume with properties:

Voxels: [512×512×264 single]
VolumeGeometry: [1×1 medicalref3d]
SpatialUnits: "mm"
Orientation: "transverse"
VoxelSpacing: [0.8594 0.8594 1.2453]
NormalVector: [0 0 -1]
NumCoronalSlices: 512
NumSagittalSlices: 512
NumTransverseSlices: 264
PlaneMapping: ["sagittal" "coronal" "transverse"]
Modality: "unknown"
WindowCenters: 0
WindowWidths: 0
```

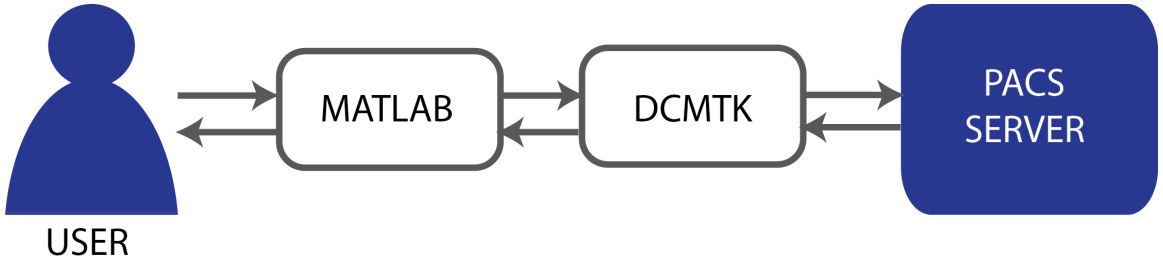




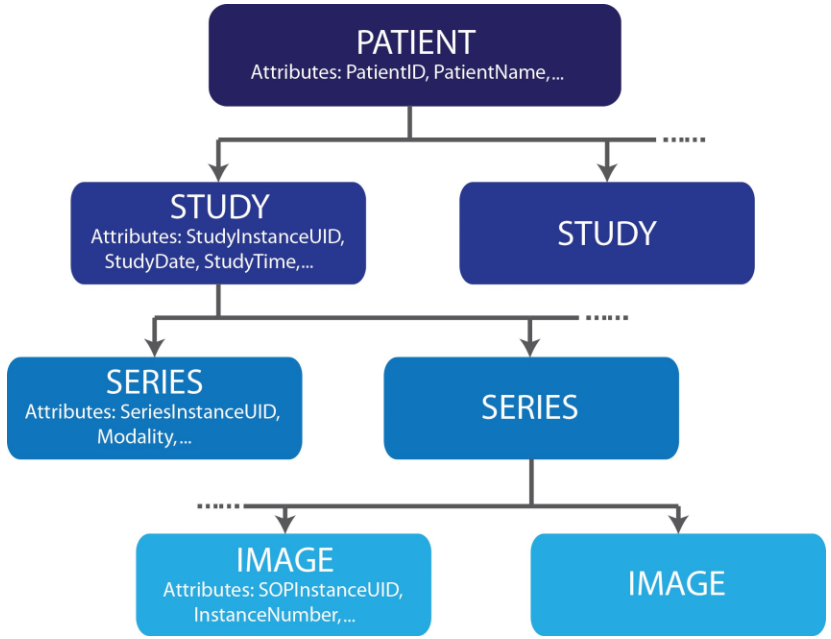
Manages spatial referencing information:
intrinsic image coordinates/patient coordinate systems, anatomical planes

Dedicated functions connect with Picture Archiving and Communication System (PACS) servers

Import

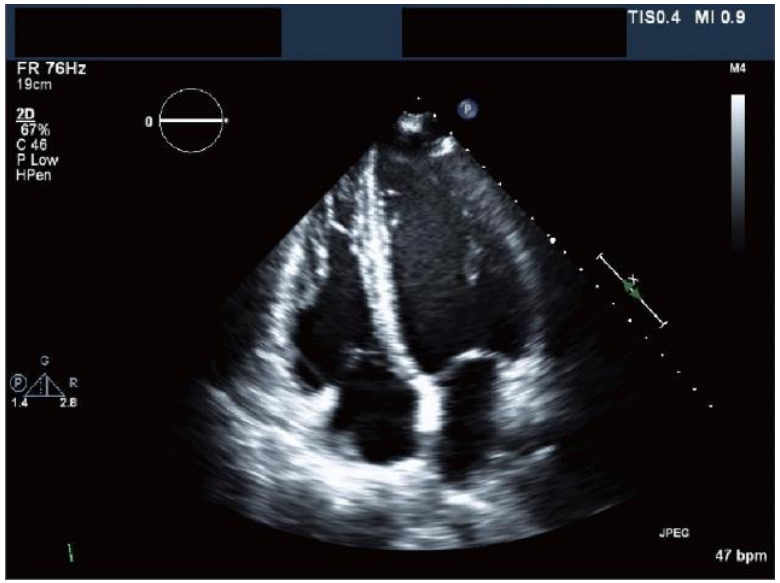


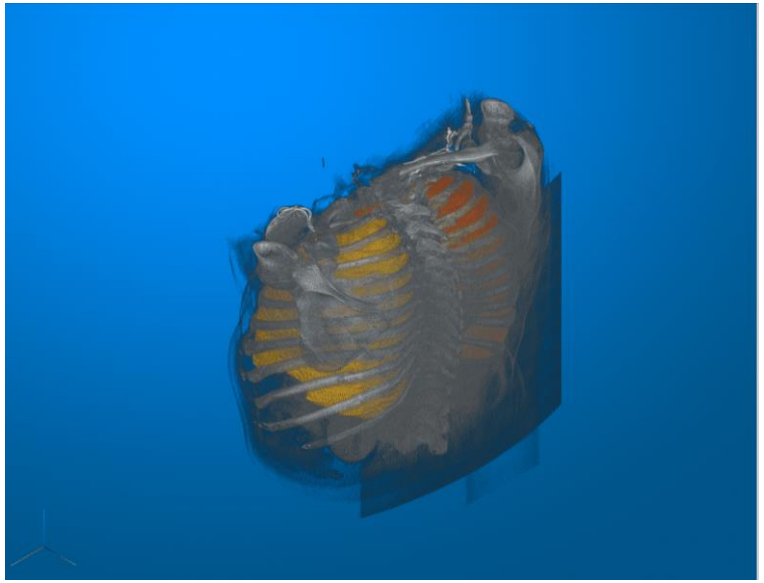
- `testConnection` - Test PACS server connection
- `dicomstore` - store DICOM images to PACS server
- `dicomquery` - Query attributes of DICOM images
- `dicomget` - Retrieve DICOM images from PACS server

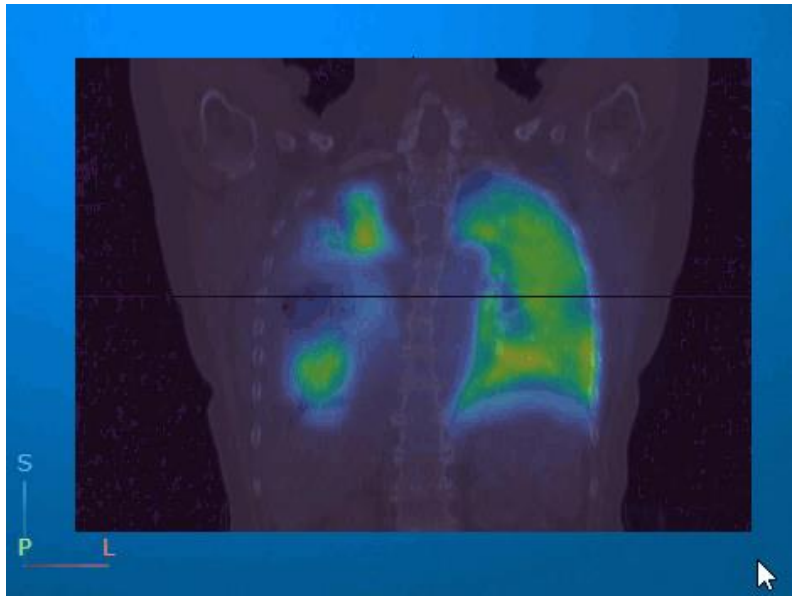


Visualize 2d, 2d+time, and 3d multimodal medical image data

Visualize







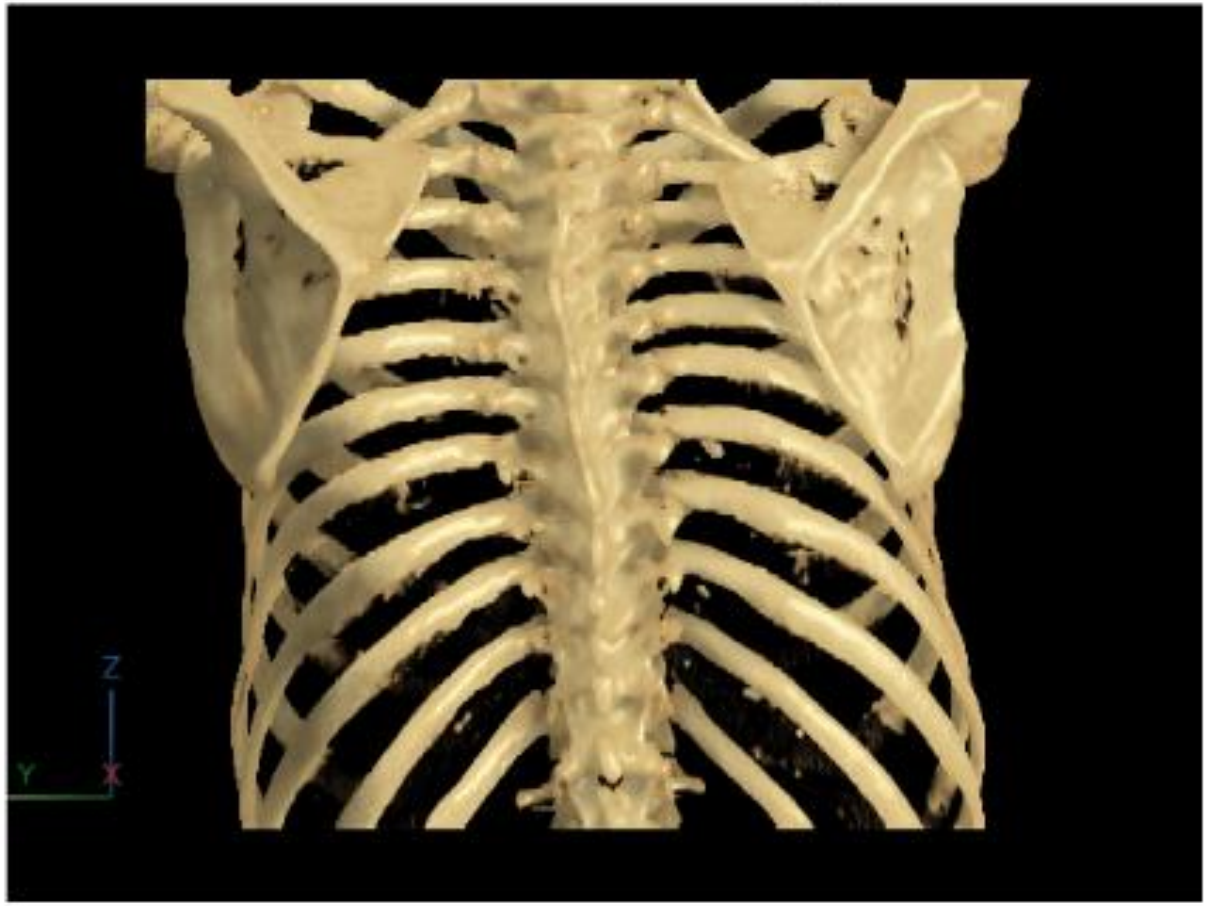

```
implay
montage
volumeViewer
medicalImageLabeler …
```

Cinematic Rendering

Visualize

Volumetric Rendering

Cinematic Rendering

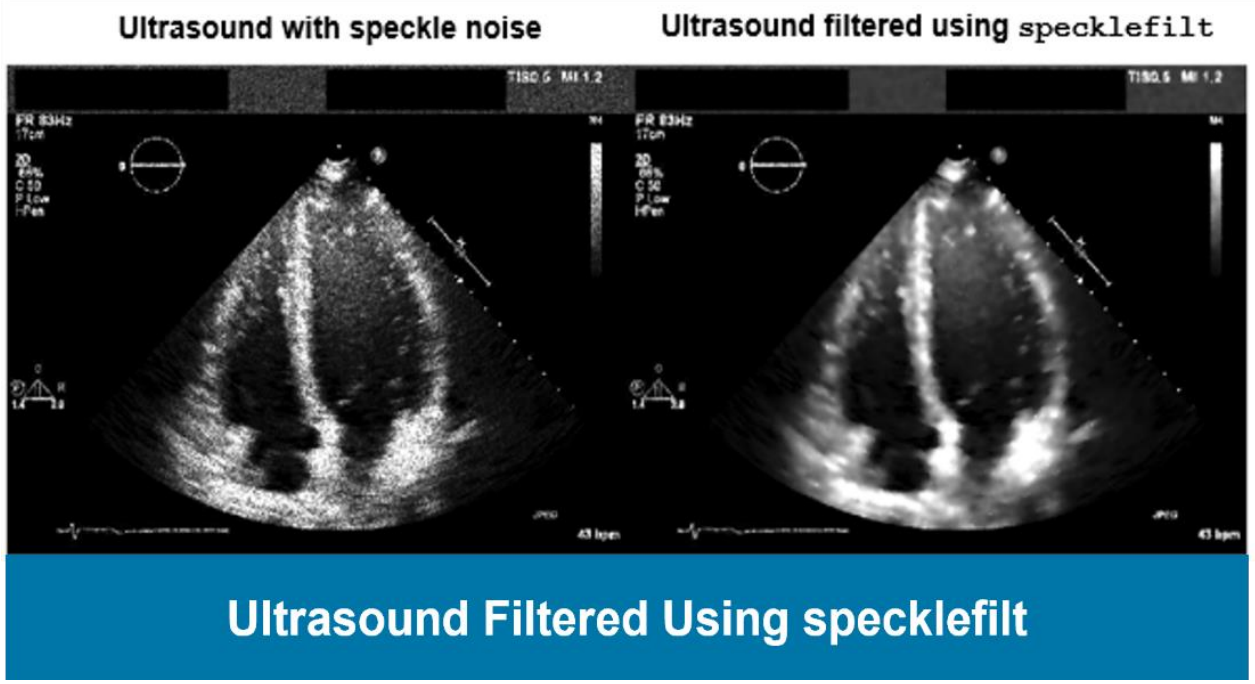


Cinematic rendering simulates realistic lighting and shadows. It can improve the aesthetic of a display and make it easier for viewers to visually perceive depths and the relative position of objects in a scene.

```
vol.RenderingStyle = "CinematicRendering";
```

Preprocess data for advanced workflows

Preprocess



Ultrasound Filtered Using specklefilt

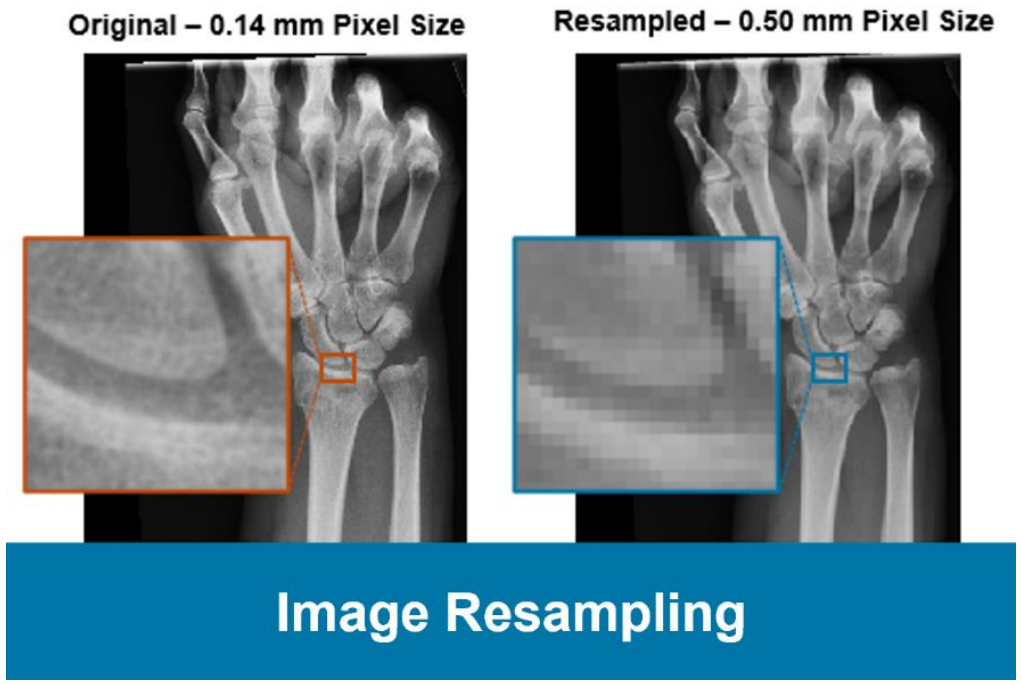
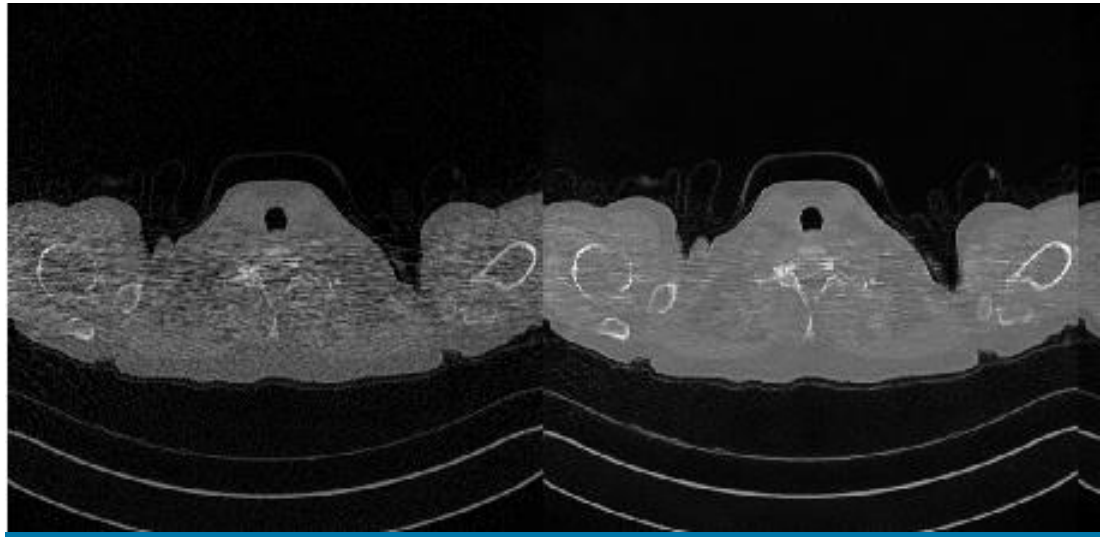


Image Resampling

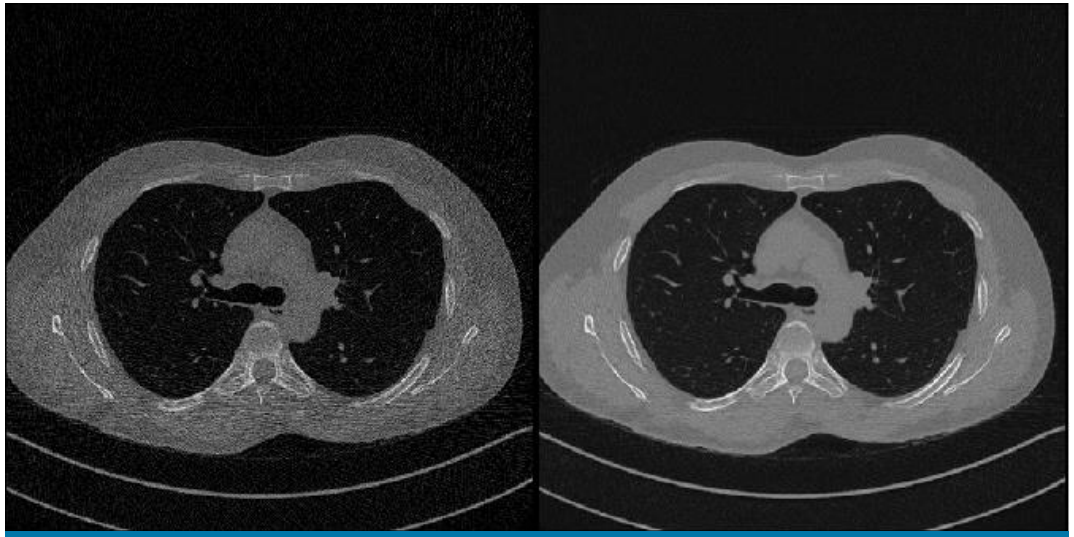
Denoising Using Deep Learning

Preprocess

- `denoiseImage` - Denoise image using deep neural network
- `denoisingNetwork` - Generate image denoising network
- `dnCNNLayers` - Get denoising convolutional neural network layers



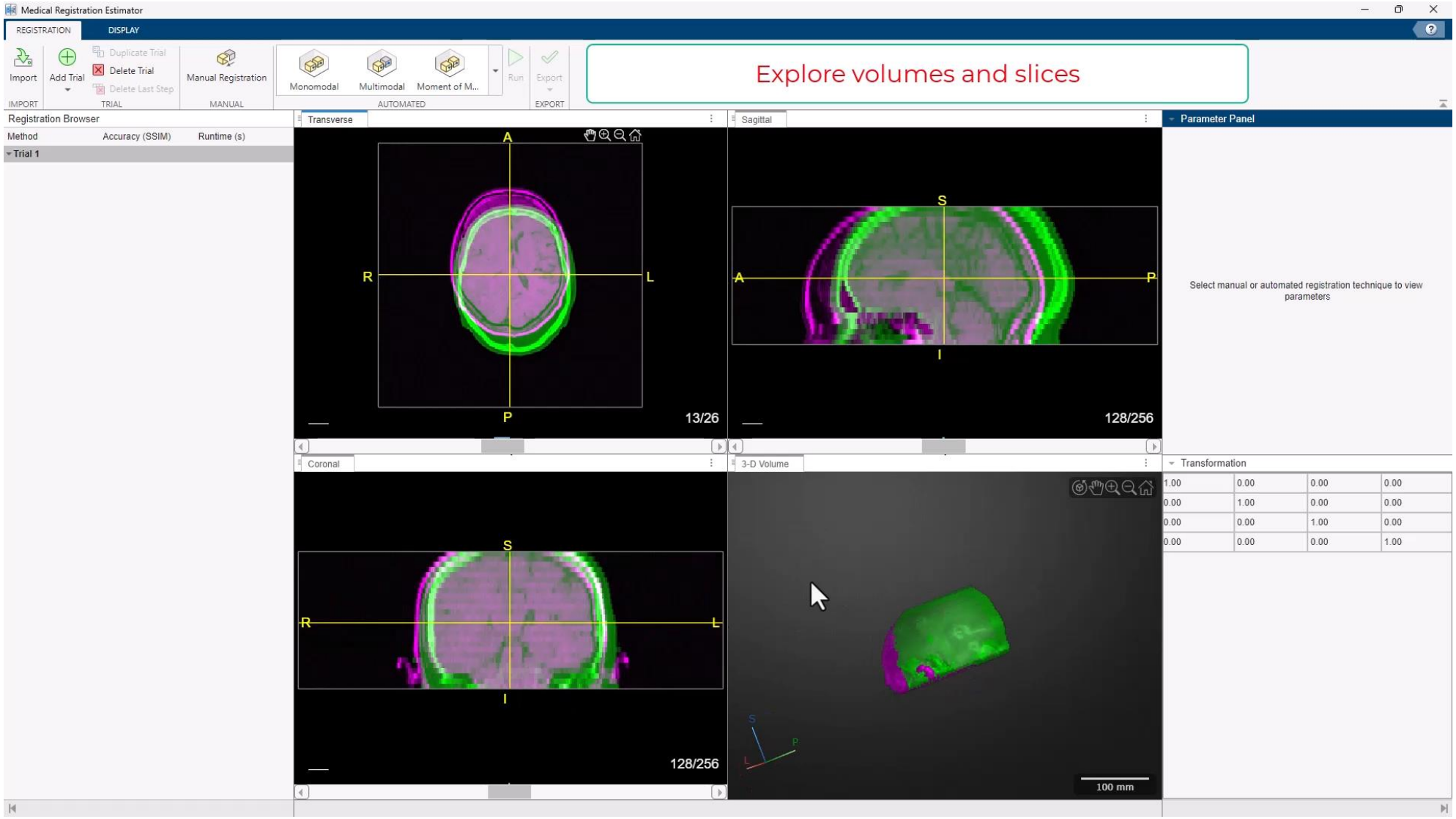
Unsupervised Medical Image Denoising Using CycleGAN



Unsupervised Medical Image Denoising Using UNIT

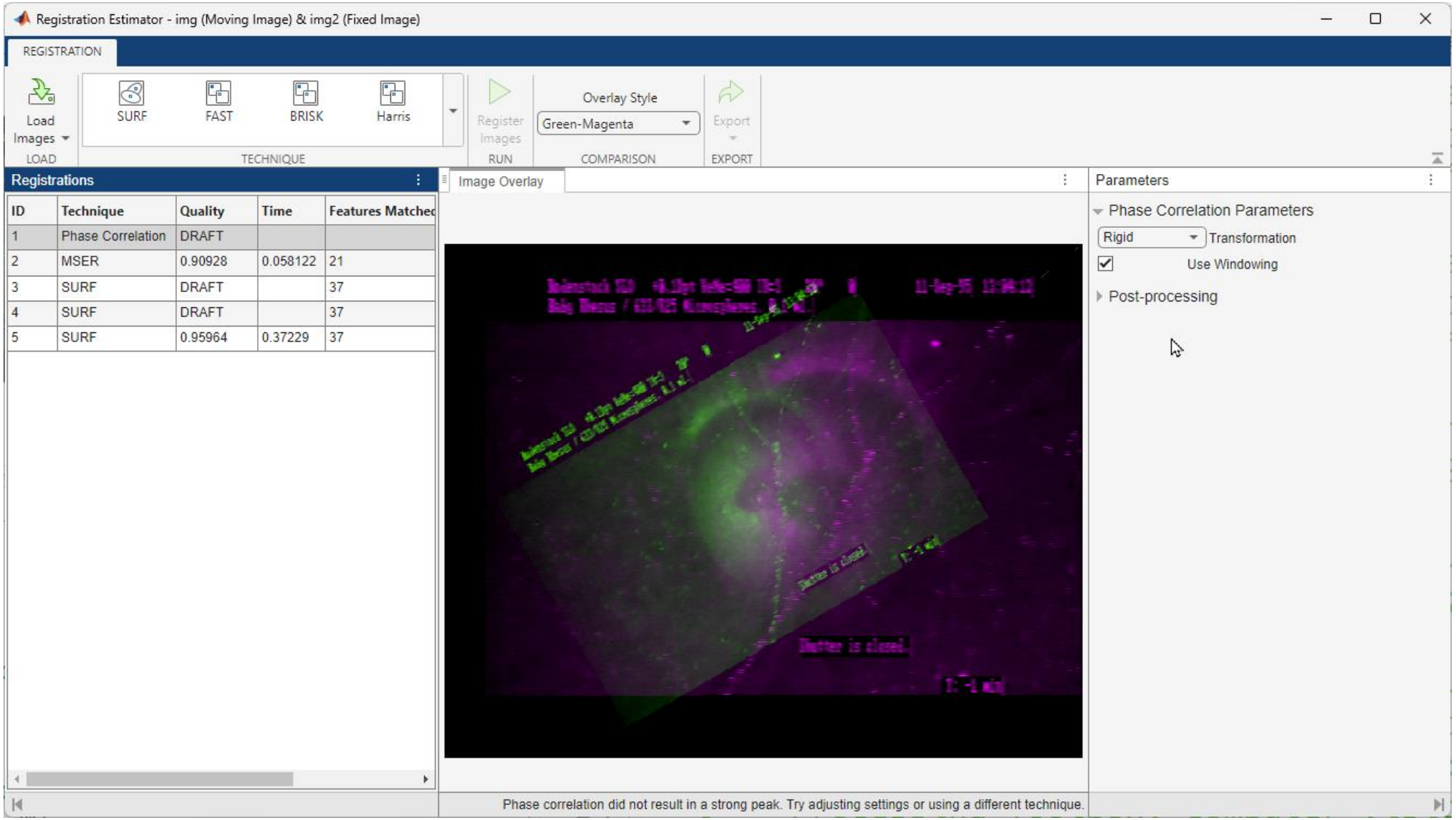
Medical Registration Estimator App

Register



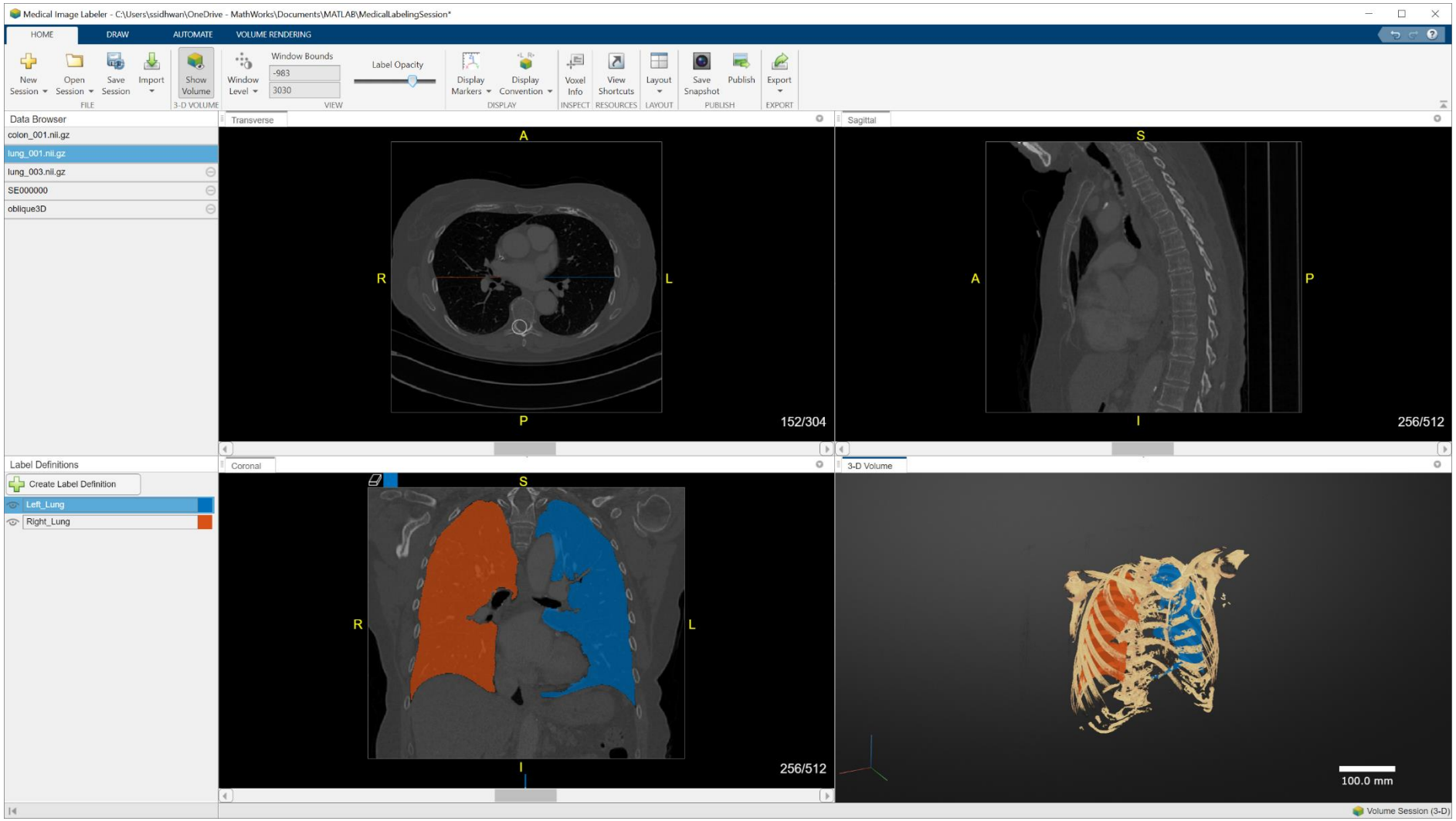
Registration Estimator App

Register



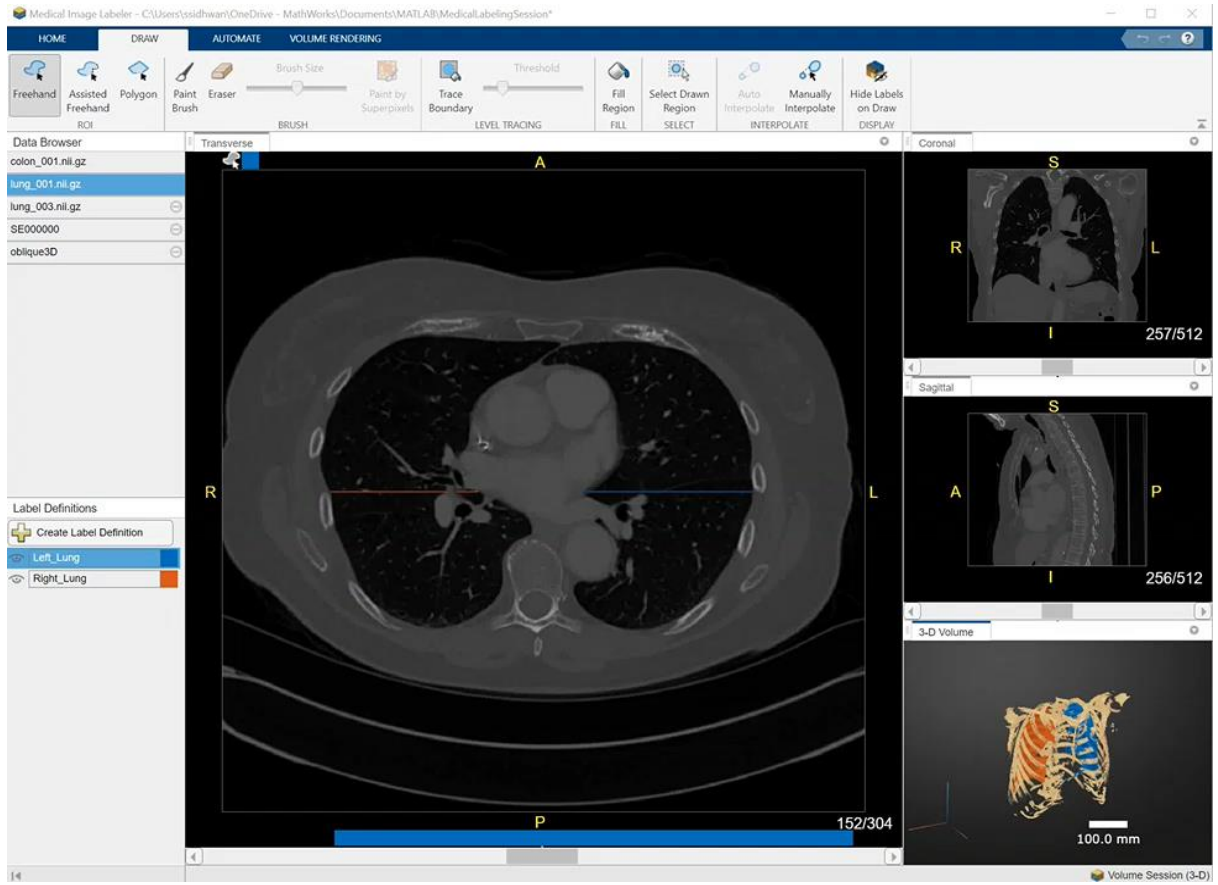
Medical Image Labeler App

for Visualizing, Segmenting, and Labeling Medical Image Data

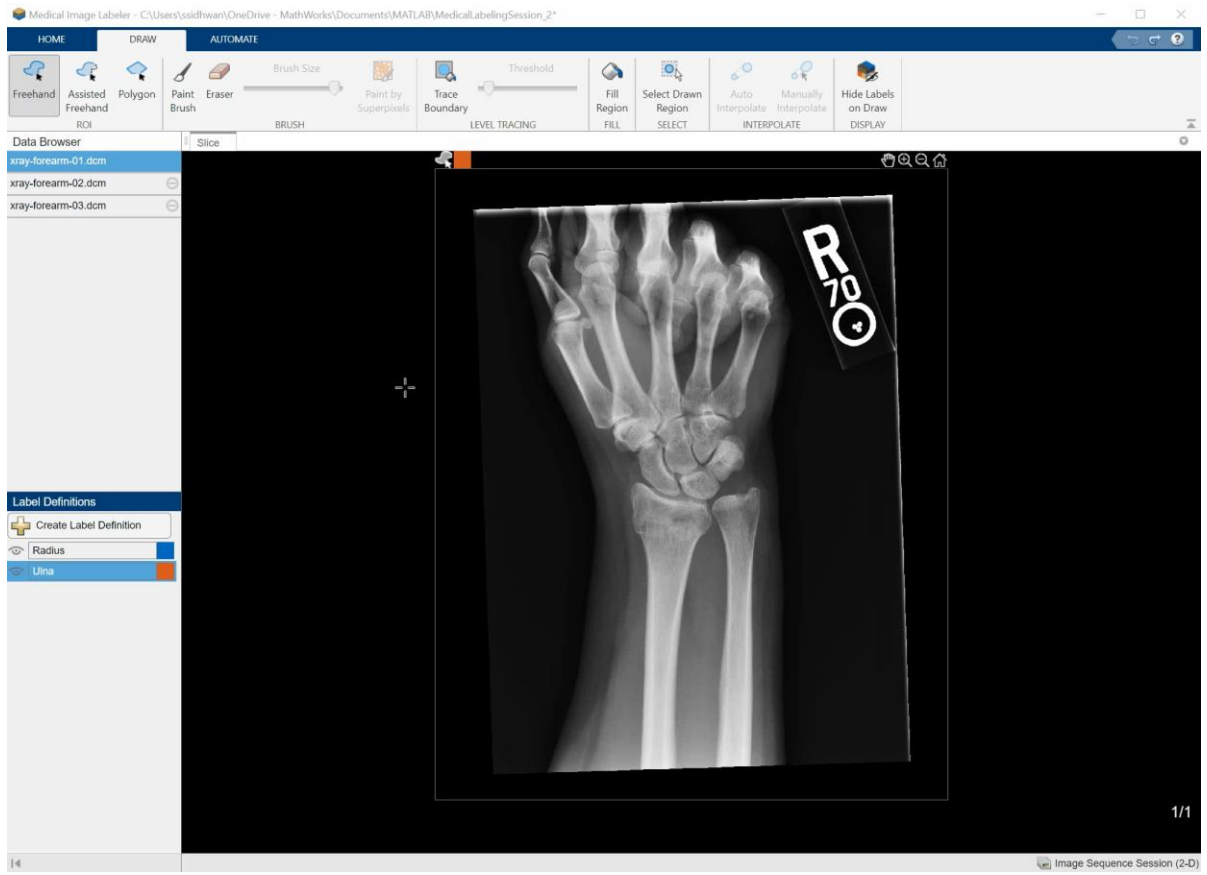


Label 2d slices and 3d volumes using manual, semi-automated, and automated medical image labeling

Segment & Label



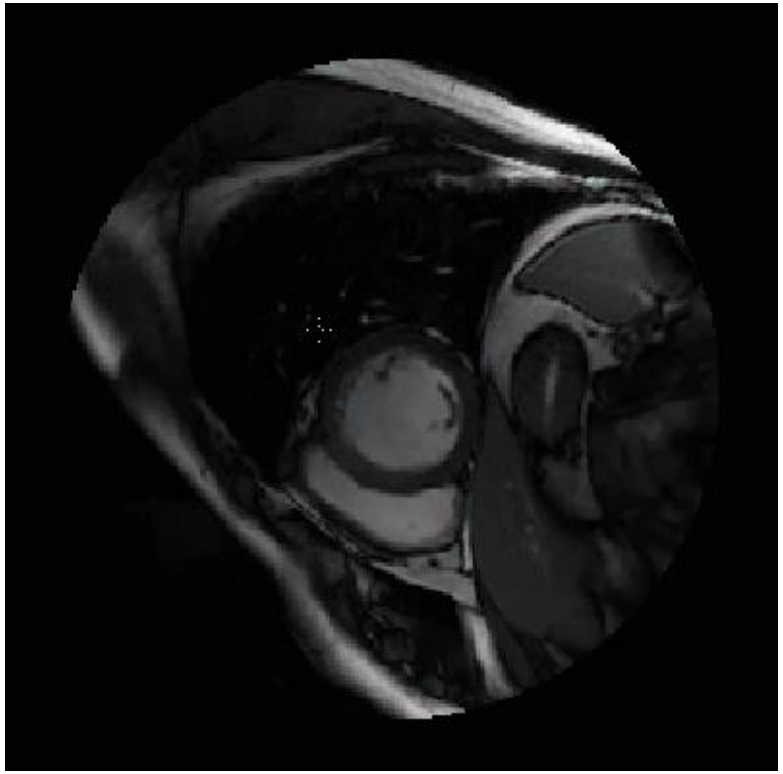
Level Tracing



Paint by Superpixels

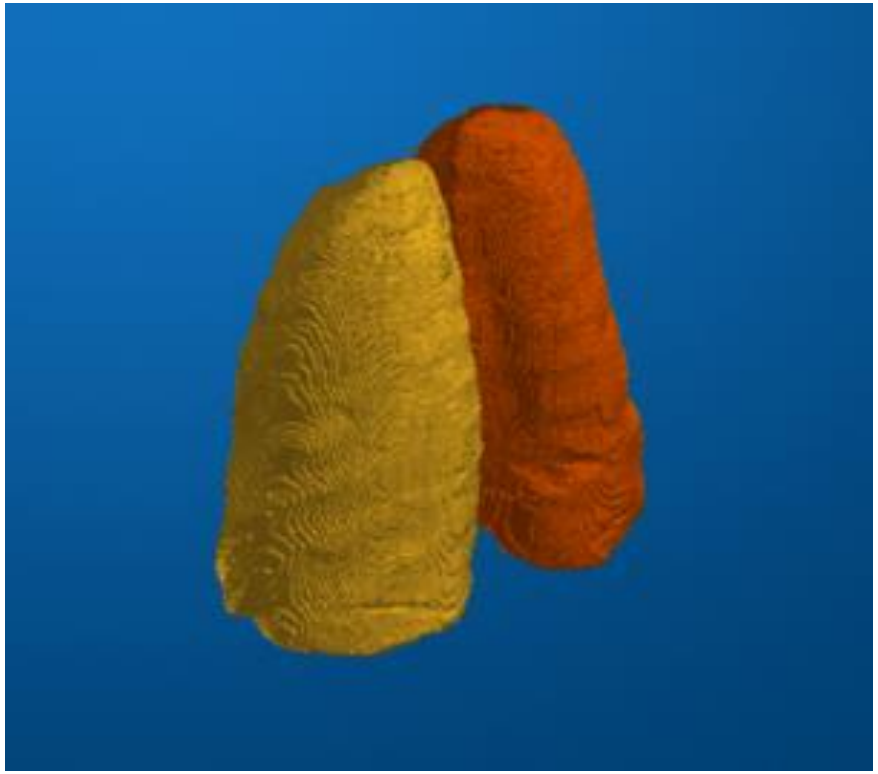
Label 2d slices and 3d volumes using AI

Segment & Label



Interactively Segment using MedSAM

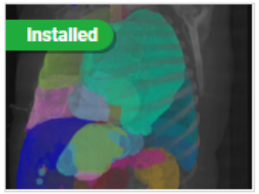
Segment Brain MRI using AI



Import and segment using pretrained ONNX

New in R2024a:
Interface MONAI Label with the `medicalImageLabeler`!*

Segment & Label



Medical Imaging Toolbox Interface for MONAI Label Library

by MathWorks Medical Imaging Team STAFF

Use MONAI library in MATLAB

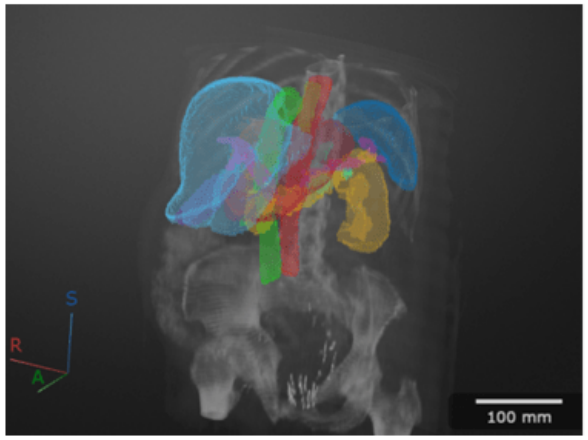
MathWorks Optional Feature

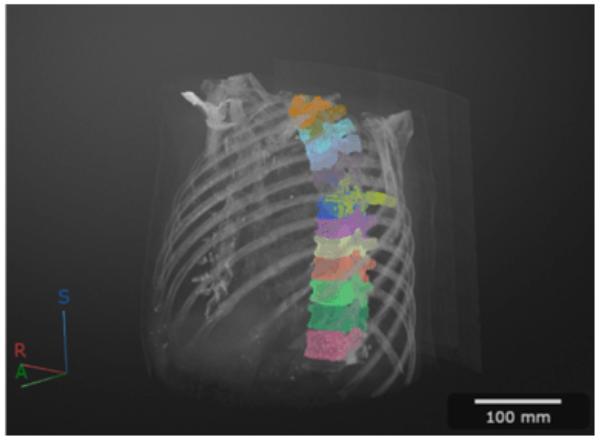
Overview

Medical Imaging Toolbox™ Interface for MONAI Label Library

Medical Open Network for AI (MONAI) Label [1],[2] is a deep learning framework for labeling medical images. You can connect to MONAI Label within the Medical Image Labeler app to apply fully automated and interactive deep learning models for segmenting radiology images.

These images show CT scans labeled using fully automated MONAI Label models in theMedical Image Labelerapp.





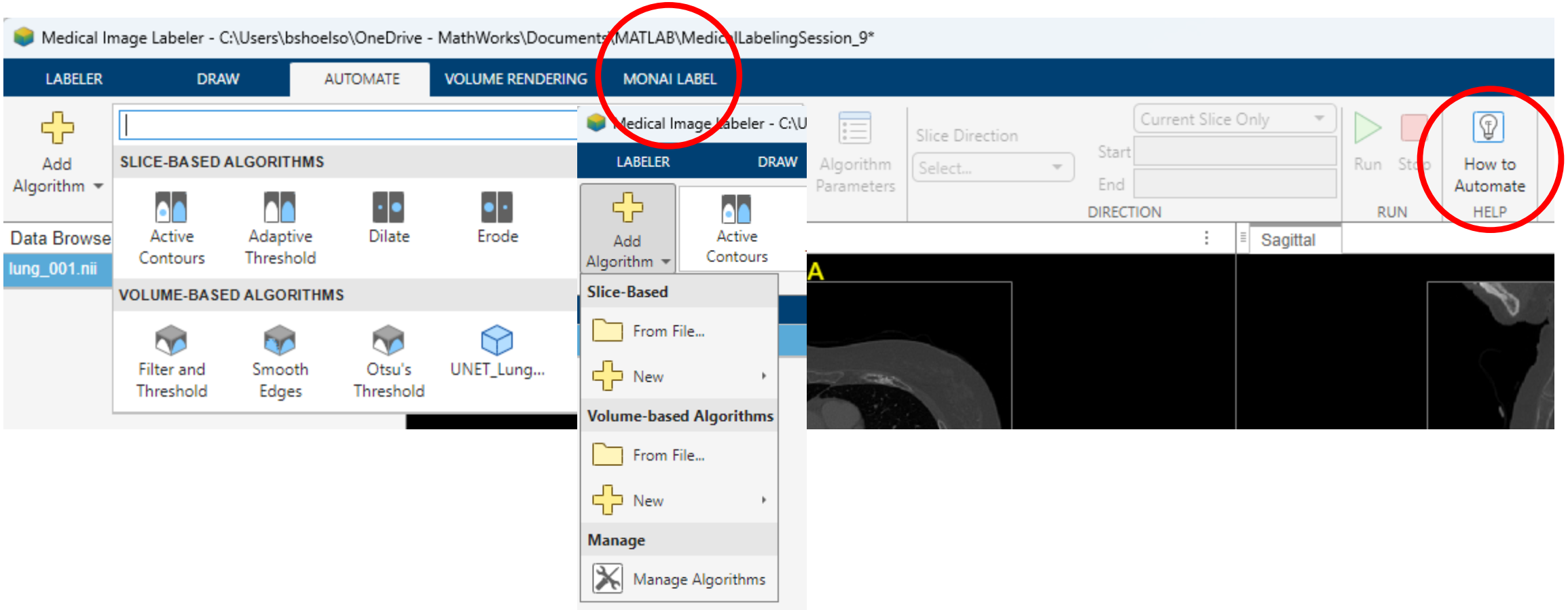
You must install the Medical Imaging Toolbox™ Interface for MONAI Label Library support package to start a local MONAI Label server within the Medical Image Labeler app. You do not need the support package to connect to an existing remote MONAI Label server. See below for more details.

*** Currently in pre-release; requires support-package download.**

Automate Labeling in the `medicalImageLabeler` app

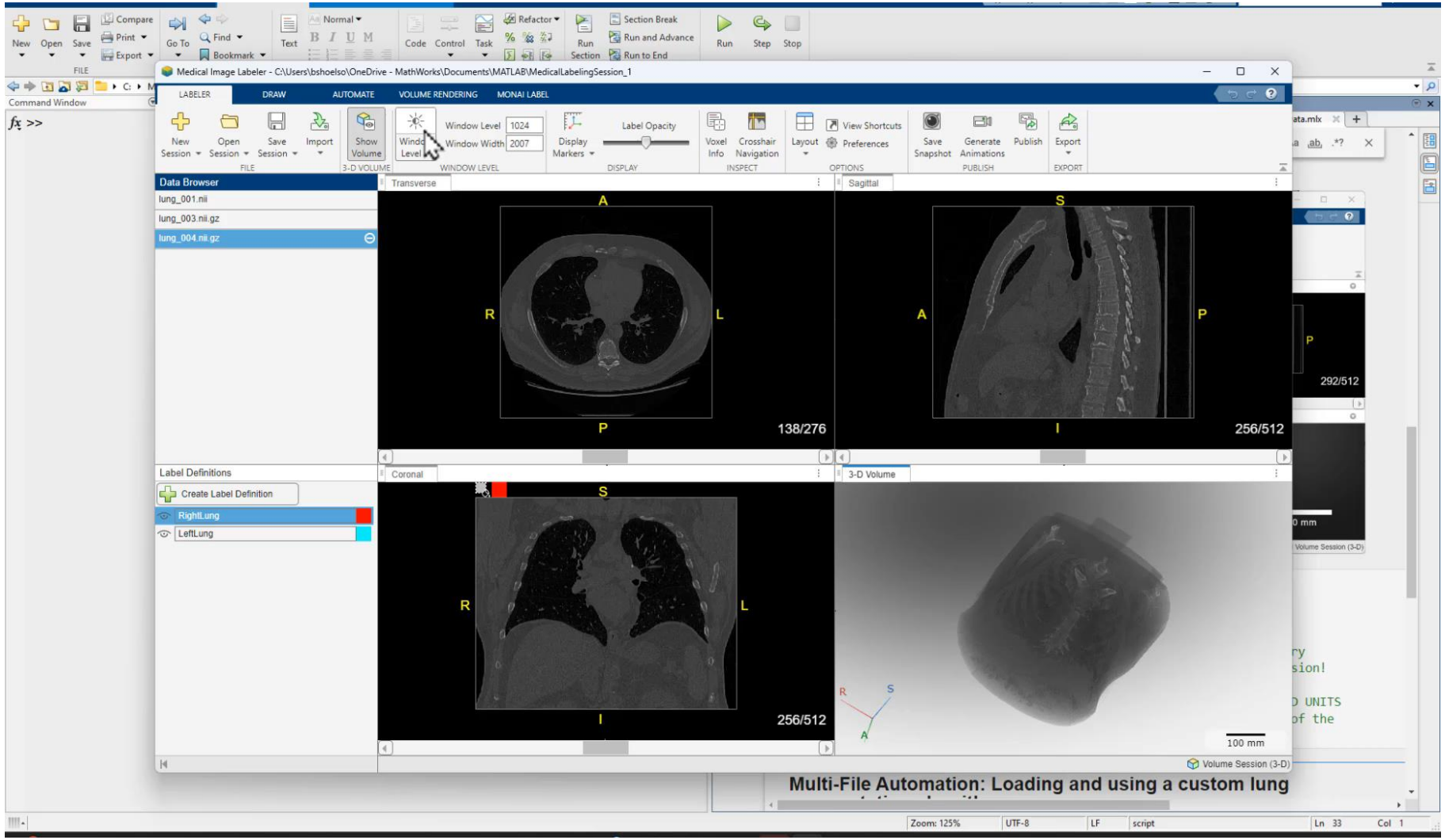
Segment & Label

Use built-in automation algorithms, design your own algorithm from a template, or import a pre-built algorithm (like a deep learning model)



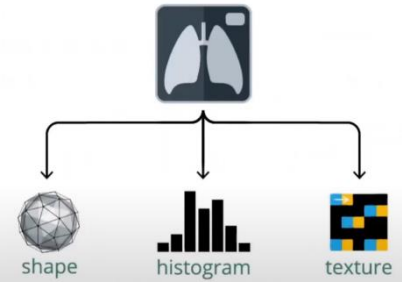
Segmentation and Labeling Using MONAI Label

Segment & Label

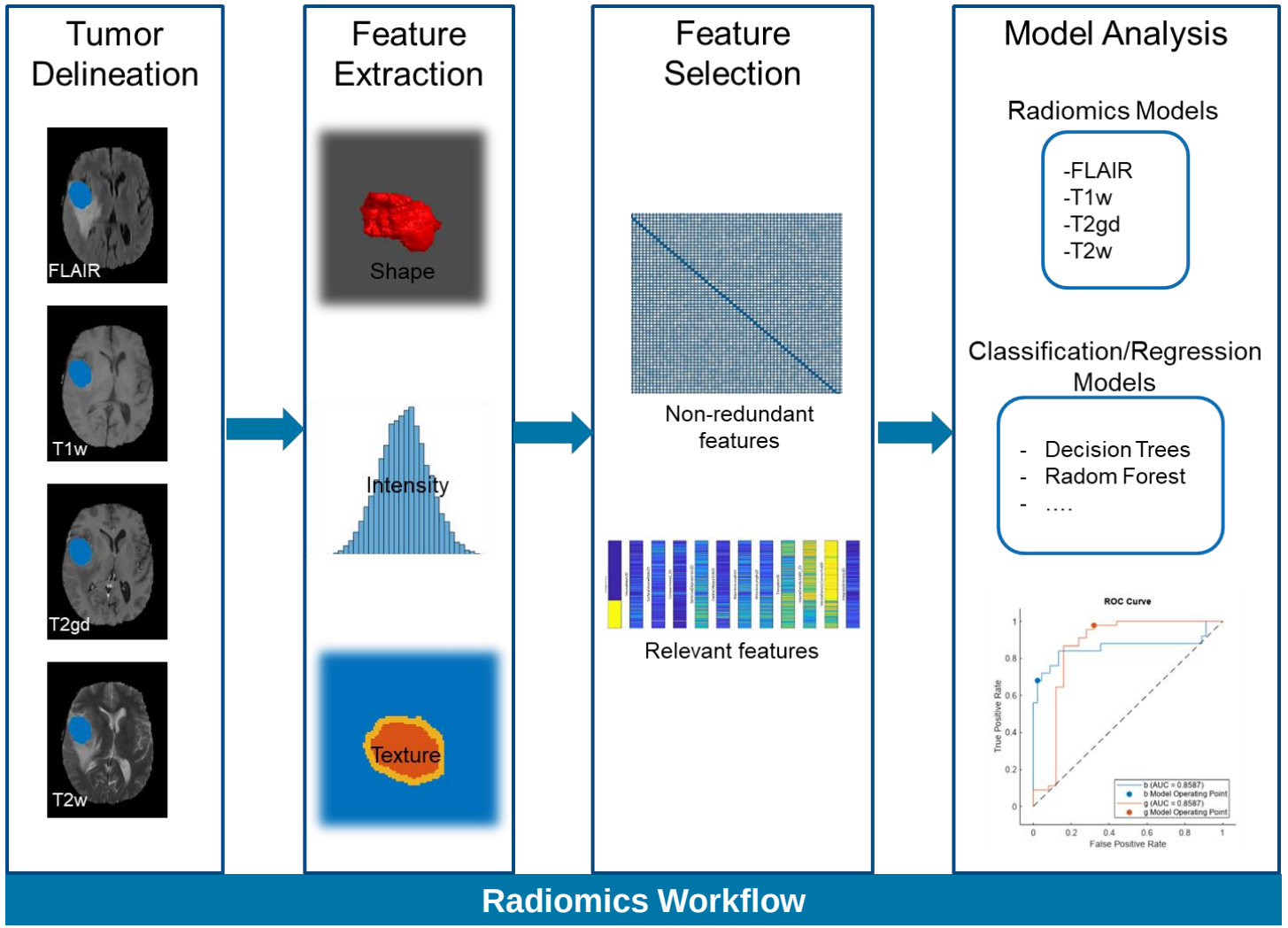


What is Radiomics?

- Radiomics is a technique that extracts **shape**, **intensity** and **texture** features for further analysis



- Reduces subjectivity in data analysis (Uses the same radiomics features for any medical imaging modality)
  - Compute ~550 features compliant with [IBSI* standards]
    - 50 Shape Features
    - 100 Intensity Features
    - 407 Texture Features
- Supports 2D, 2.5D, and 3D features

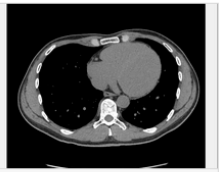


*** The image biomarker standardisation initiative (IBSI) provides standardized nomenclature and definitions for radiomics features and reporting guidelines.**

Workflow includes broad set of examples

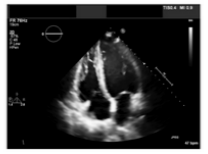
- Import
- Visualization
- Preprocess
- Register
- Segment
- Label
- Train
- Analysis

Import and Spatial Referencing



Read, Process, and Write 3-D Medical Images

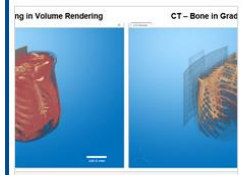
Import and display a medical image volume in patient coordinates, apply a smoothing filter.



Read, Process, and View Ultrasound Data

Import and display a 2-D multiframe ultrasound series, and apply a denoising filter to each frame.

Display, Volume Rendering, and Surfaces

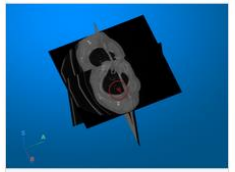


Visualize 3-D Medical Image Data Using Medical Image Labeler

Interactively explore and export snapshots and animations of medical image data.

Display Medical Image Volume in Patient Coordinate System

Visualize volumetric CT data with anisotropic voxel dimensions in the patient coordinate system.

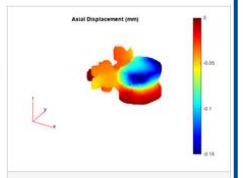


Display Labeled Medical Image Volume in Patient Coordinate System

Visualize labeled volumetric CT data as 3-D volumes and orthogonal slice planes.

Create STL Surface Model of Femur Bone for 3-D Printing

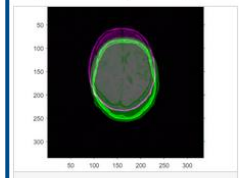
Convert a segmentation mask from a CT image into an STL surface model suitable for 3-D printing.



Medical Image-Based Finite Element Analysis of Spine

Estimate bone stress and strain in a vertebra bone under axial compression using finite element (FE) analysis.

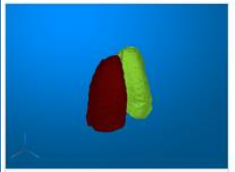
Preprocessing and Augmentation



Register Multimodal Medical Image Volumes with Spatial Referencing

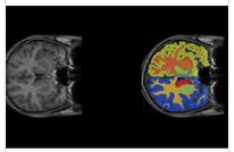
Align two medical image volumes using moment-of-mass-based registration.

Segmentation and Analysis



Segment Lungs from CT Scan Using Pretrained Neural Network

Import a pretrained ONNX™ (Open Neural Network Exchange) 3-D U-Net [1] and use it to perform semantic segmentation of the left and right

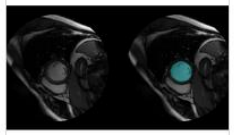


Brain MRI Segmentation Using Pretrained 3-D U-Net Network

Segment a brain MRI using a deep neural network.

Breast Tumor Segmentation from Ultrasound Using Deep Learning

Perform semantic segmentation of breast tumors from 2-D ultrasound images using a deep neural network.

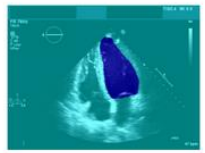


Cardiac Left Ventricle Segmentation from Cine-MRI Images Using U-Net…

Segment 2-D cardiac MRI images using U-Net, and explore predictions using Grad-CAM explainability maps.

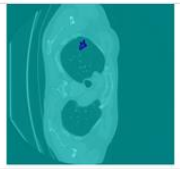
Classify Breast Tumors from Ultrasound Images Using Radiomics Features

Use radiomics features to classify breast tumors as benign or malignant from breast ultrasound images.



Convert Ultrasound Image Series into Training Data for 2-D Semantic Segmentatio…

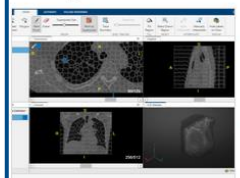
Create training data for a 2-D semantic segmentation network using a groundTruthMedical object that contains multiframe ultrasound



Create Training Data for 3-D Medical Image Semantic Segmentation

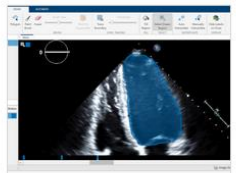
Create training data for a 3-D semantic segmentation network using a groundTruthMedical object that contains 3-D medical image

Labeling



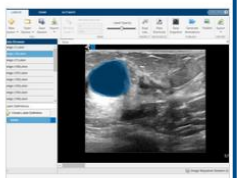
Label 3-D Medical Image Using Medical Image Labeler

Interactively label pixels in a 3-D medical image volume.



Label 2-D Ultrasound Series Using Medical Image Labeler

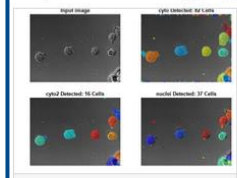
Interactively label pixels in a 2-D medical image sequence.



Automate Labeling in Medical Image Labeler

Apply a pretrained semantic segmentation networks as a custom automation algorithm in the Medical Image Labeler app.

Cellpose for Microscopy Segmentation

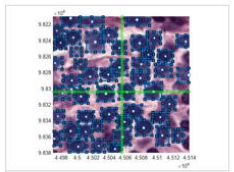


Choose Pretrained Cellpose Model for Cell Segmentation

Segment cells from microscopy images using a pretrained Cellpose model.

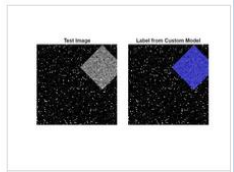
Refine Cellpose Segmentation by Tuning Model Parameters

Explore and tune Cellpose parameters to improve segmentation results.



Detect Nuclei in Large Whole Slide Images Using Cellpose

Detect cell nuclei in whole slide images (WSIs) of tissue stained using hemotoxylin and eosin (H&E) by using Cellpose.



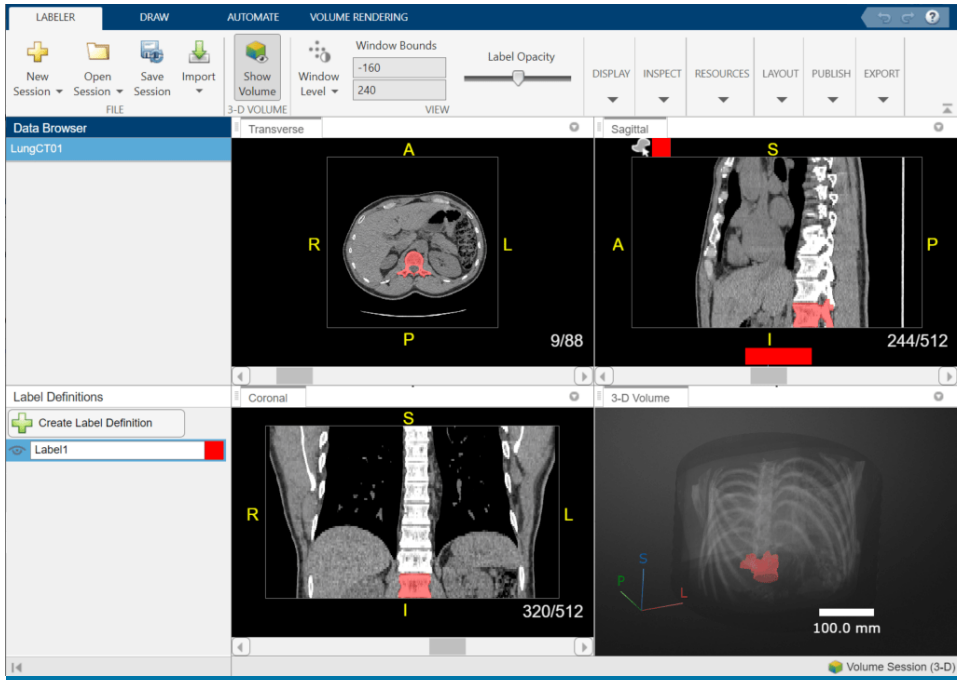
Train Custom Cellpose Model

Train a custom Cellpose model, using new training data, to detect noncircular shapes.

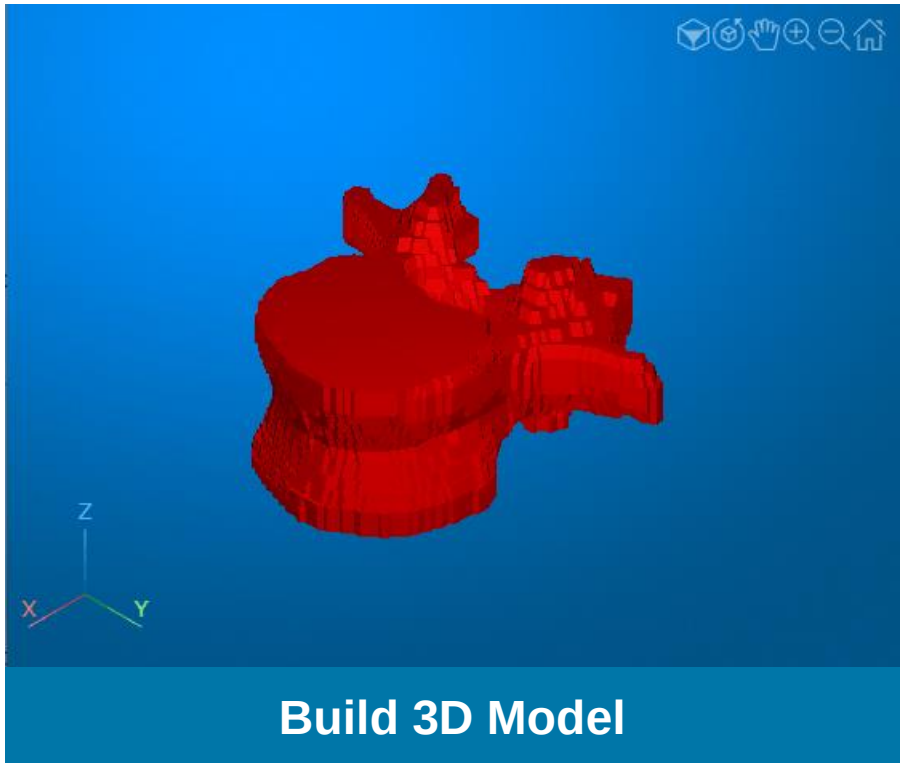
Analyze images and volumes

Analysis

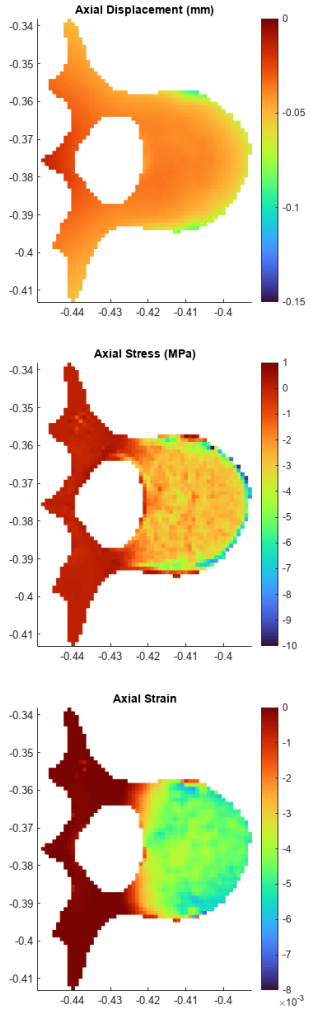
Segment and conduct a stress analysis of a spine



Segment Spine



Build 3D Model

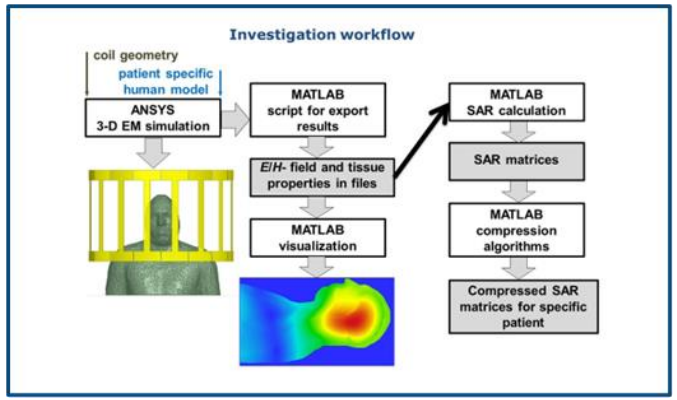


Stress Analysis

DEMO: [FEM analysis of spine]

Customers use MATLAB to develop medical imaging capabilities

MRI

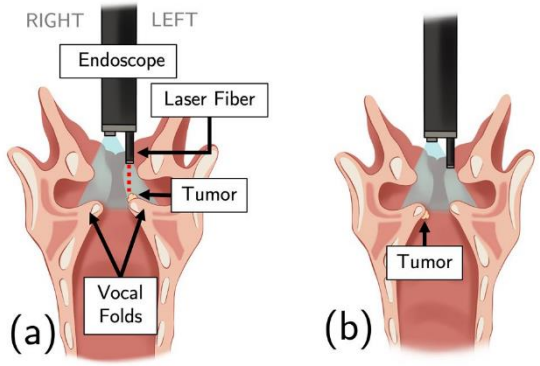


DKFZ and Max Planck Researchers Ensure Safety of Advanced MRI Systems Using Virtual Human Models

"MATLAB provides an environment where implementing mathematical problems can be achieved with little programming effort. The broad range of tools and the ease of use … let me write algorithms quickly and with high computational efficiency."
- Dr. Stephan Orzada, group leader, DKFZ

Link to user story

Endoscopy

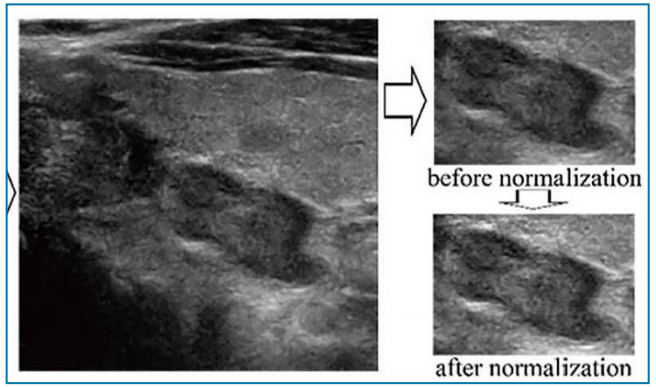


WPI Simulates Endoscopic Surgery to Quickly Validate New Medical Procedures and Devices

"With Medical Imaging Toolbox, we can load the entire data set and create the three-dimensional rendering with just a few clicks.… It means we don't start from scratch for each new design. This saves weeks for each new design." — Loris Fichera, professor of robotics engineering, WPI

Link to user story

Ultrasound



Diagnosis of Thyroid Nodules from Medical Ultrasound Images with Deep Learning

"Our research team at Yonsei University and Severance Hospital (Seoul, Korea) used MATLAB® to design and train convolutional neural networks (CNNs) to identify malignant and benign thyroid nodules. Diagnostic tests have shown that these CNNs perform as well as expert radiologists."
- Eunjung Lee, School of Mathematics and Computing (CSE), Yonsei University

Link to user story

Customers use MATLAB to develop medical imaging capabilities

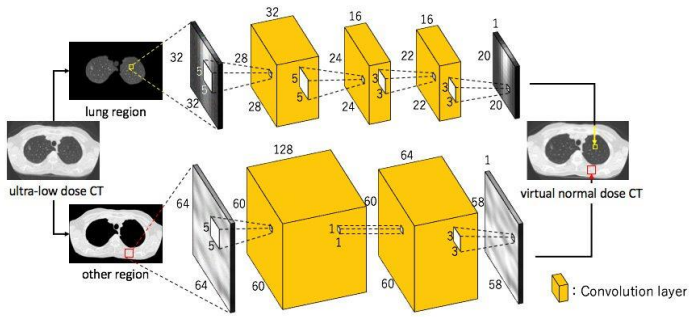
MRI

Beth Israel Deaconess Medical Center Improves MRI Accuracy

"MATLAB provides a combination of matrix manipulation and visualization capabilities that are key to our imaging work."
- Dr. Daniel Sodickson,
Beth Israel Deaconess Medical Center

Link to user story

CT



Using Deep Learning to Reduce Radiation Exposure Risk in CT Imaging

"One of the many advantages of developing medical imaging software in MATLAB is that the environment makes it easy to create an interface to the underlying algorithms and then distribute the entire package to doctors."
- Dr. Ryohei Nakayama, Ritsumeikan University

Link to user story

Endoscopy

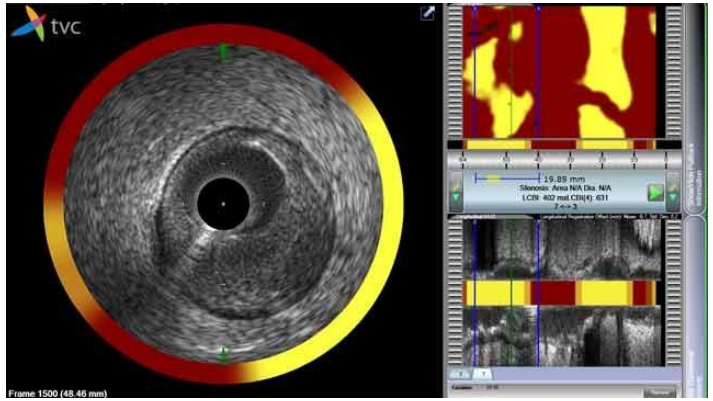
Given Imaging (Medtronic) Develops Camera-in-a-Capsule Using MATLAB to Improve the Diagnosis of Gastrointestinal Disorders

"With MATLAB, we simulated the intended system and fine-tuned it at the early stages of implementation, enabling us to develop critical engineering programs that met requirements on the first iteration."
- Rafi Nave, Given Imaging

Link to user story

Customers use MATLAB to develop medical imaging capabilities

Ultrasound

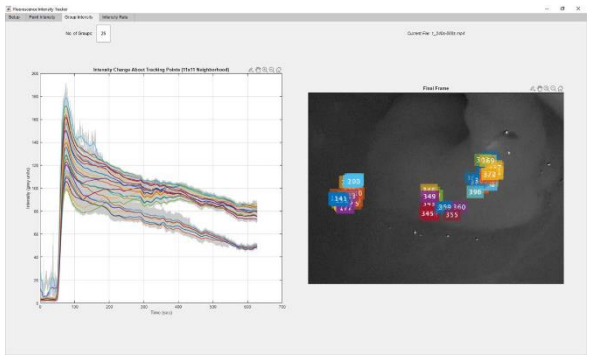


Infraredx Accelerates FPGA Development on First-of-Its-Kind Intravascular Imaging System

"MathWorks Consulting Services helped us model our signal and image processing pipeline in Simulink, run simulations to verify that it was producing quality images, and then implement the design on an FPGA—all while ensuring that we acquired the know-how to do the work ourselves the next time."
- John Beck, Infraredx

Link to user story

Endoscopy

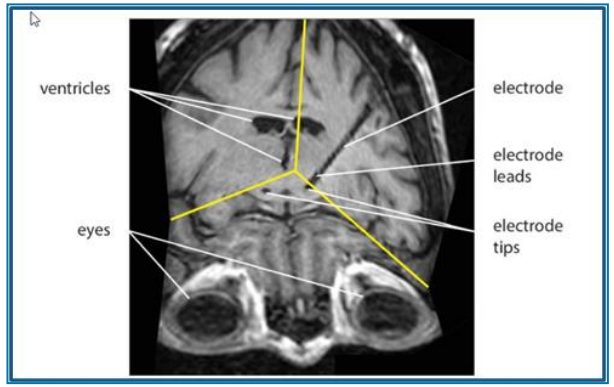


The Fluorescence Tracker App in MATLAB

"By automating feature detection, tracking, and intensity quantification with MATLAB, we achieved a much higher sampling rate of 30 fps, which enabled smoother curves and yielded richer data for analysis. At the same time, this automation enabled us to complete the analysis of each video in a matter of minutes, rather than spending an hour to complete the process manually."
- Dr. Ronan Cahill, University College Dublin

Link to user story

Ultrasound

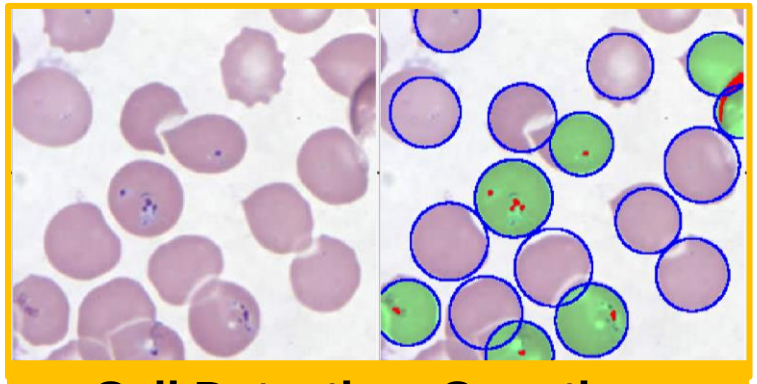


NASK Improves Parkinson's Surgery with AI and Signal Processing

This software reduces the surgery from the typical three to four hours to 20 minutes, a relief for patients who are under local anesthesia but are awake during the procedure.

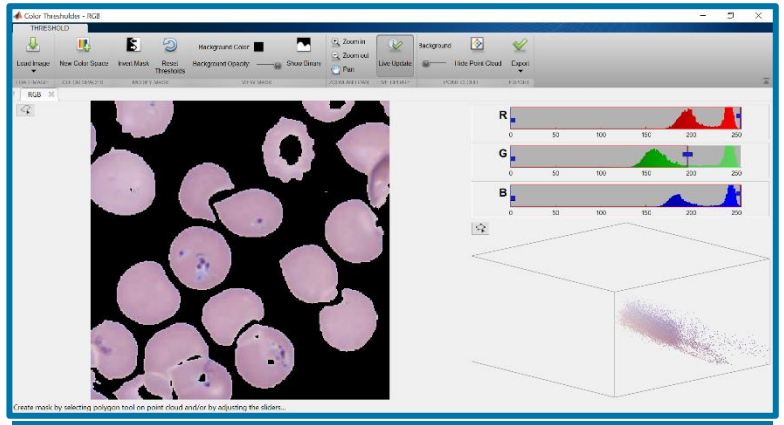
Link to user story

IPCV Apps Accelerate Microscopy Workflow

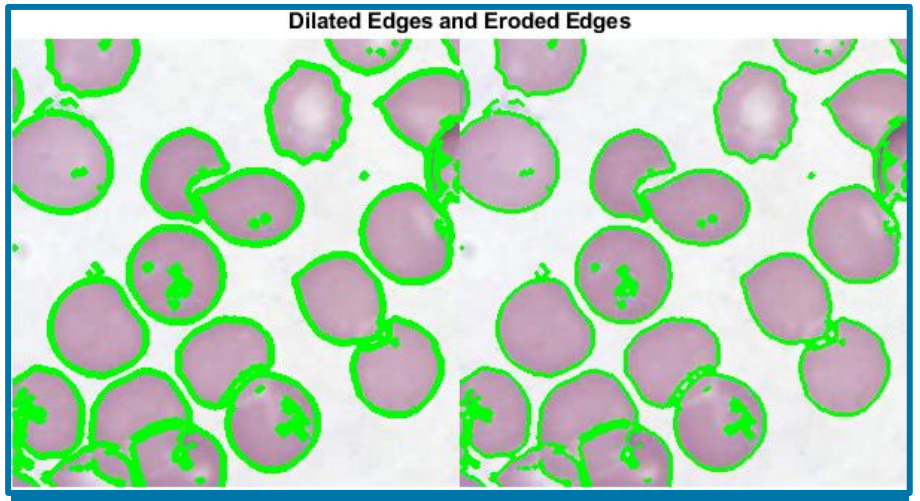


Cell Detection, Counting, and Classification

Image Exploration

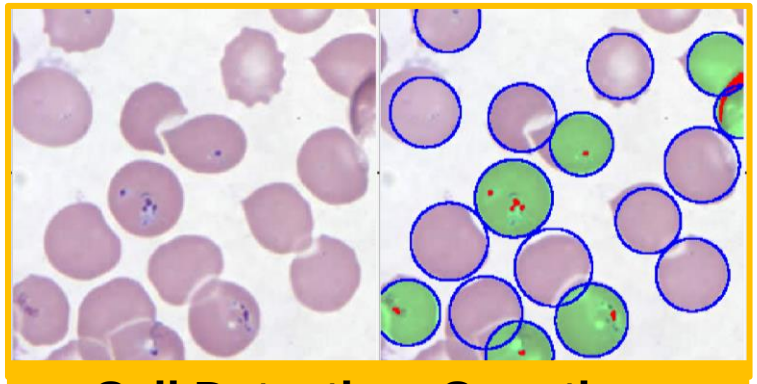


Color Segmentation

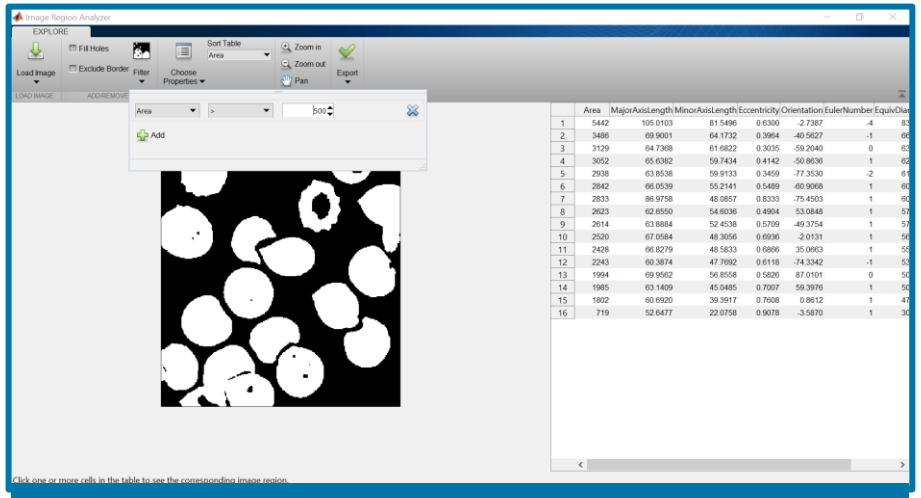


Edge Detection & Morphology

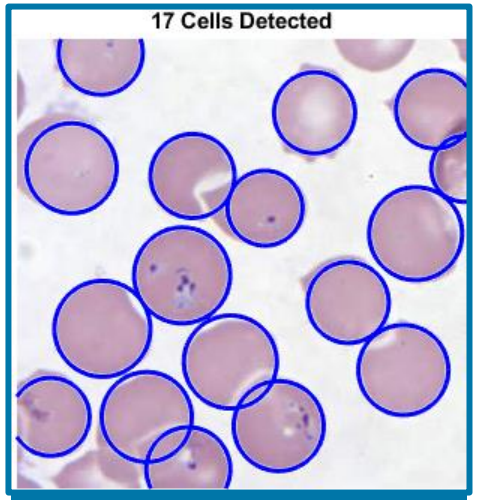
IPCV Apps Accelerate Microscopy Workflow



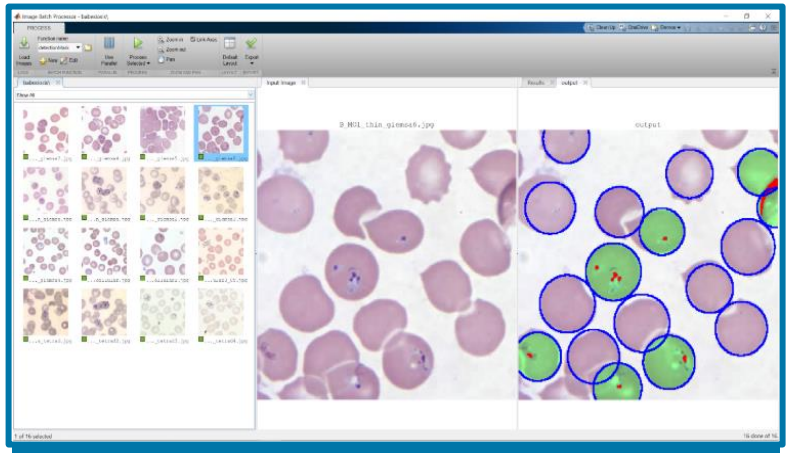
Cell Detection, Counting, and Classification



Region Analysis



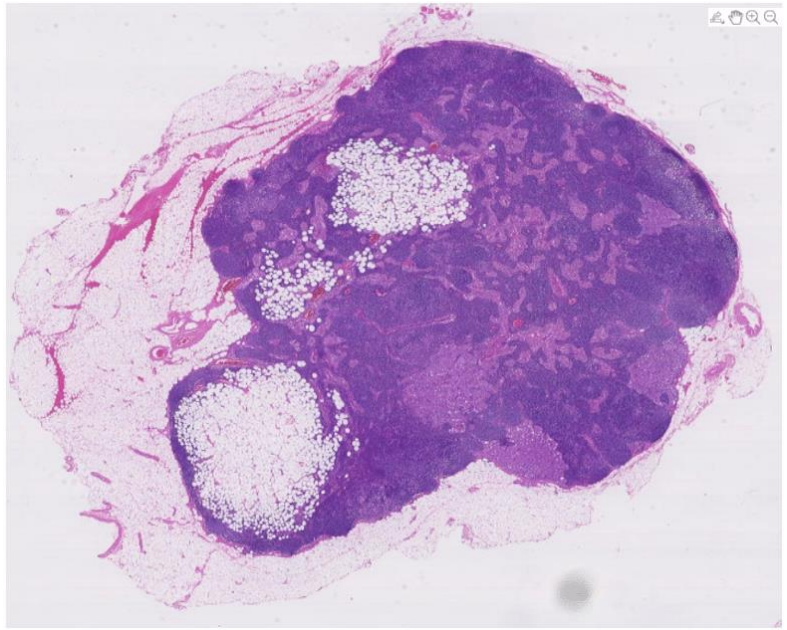
Shape Detection

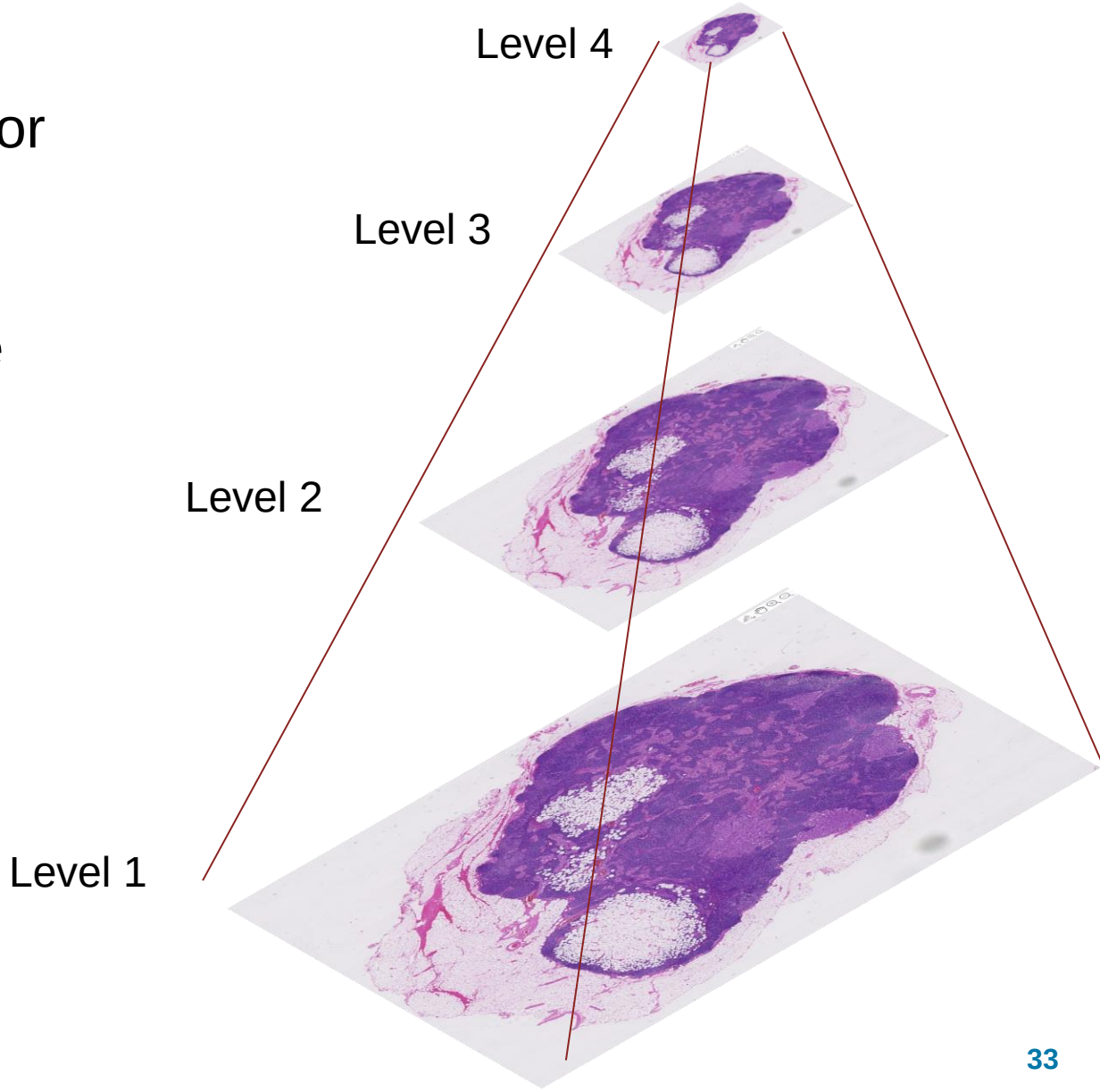


Batch Processing

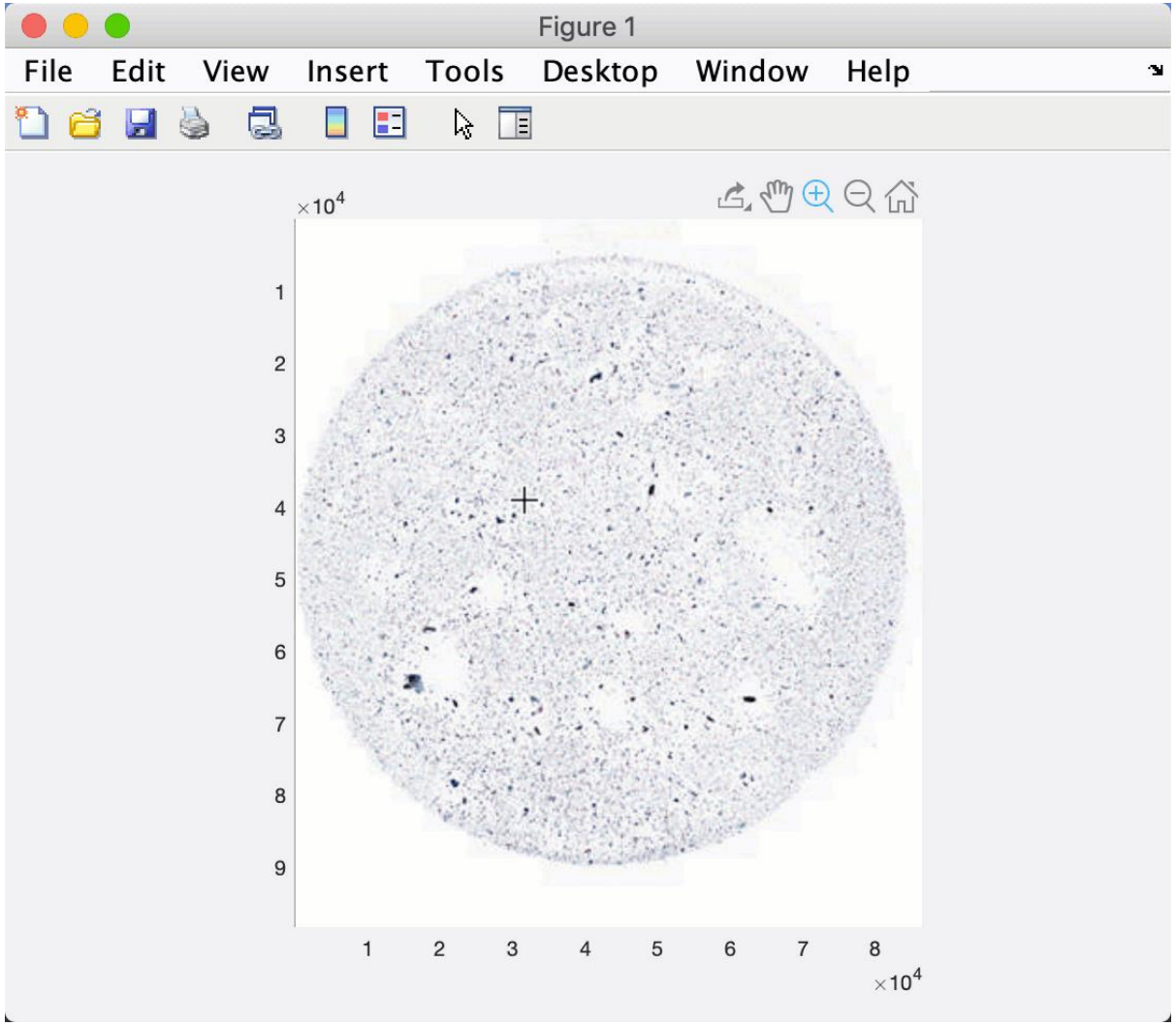
What Makes blockedImage Unique?

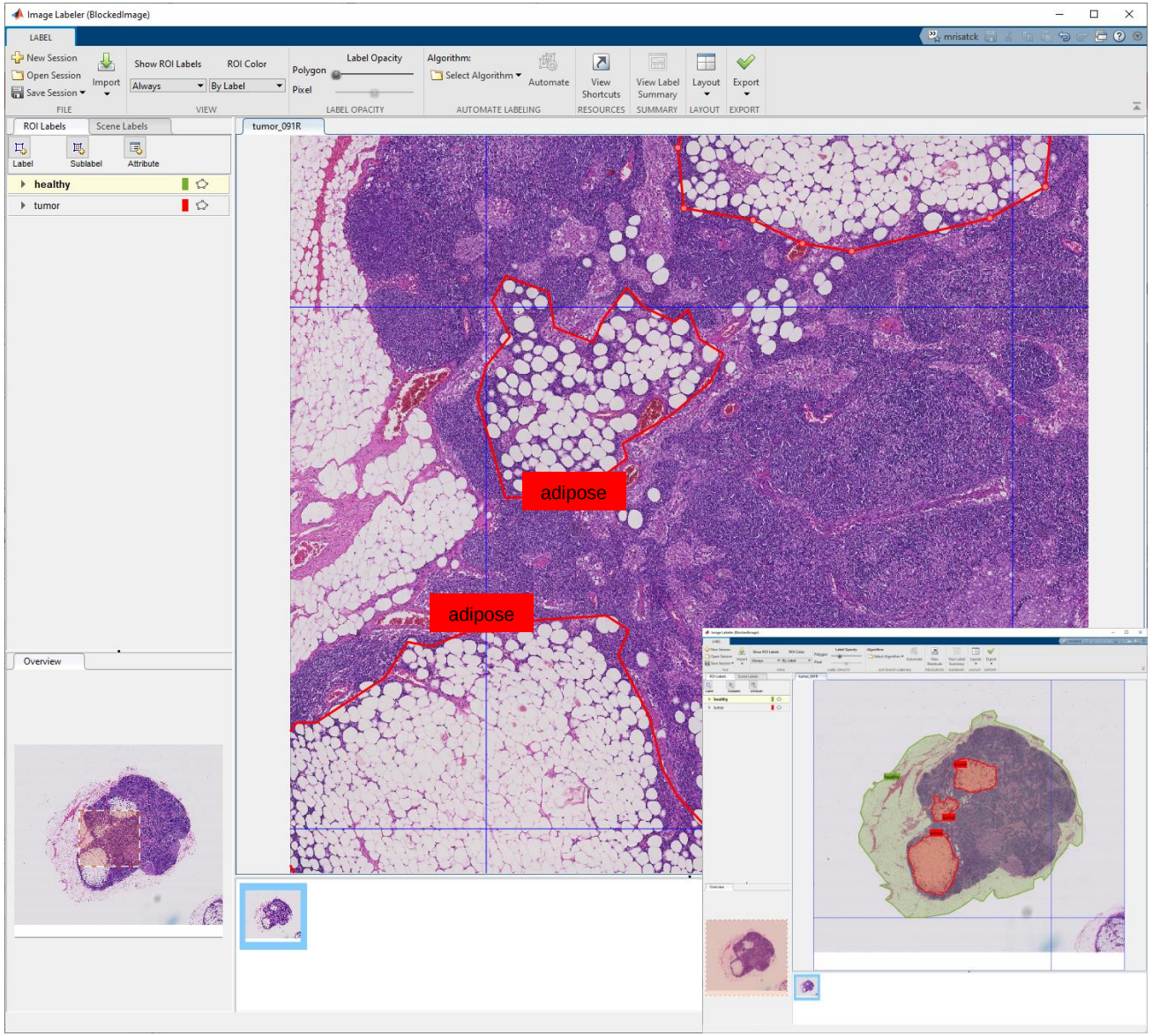
- blockedImage is a new N-D data type for processing large images
- Block-wise processing, including edge rectification, is taken care of behind the scenes





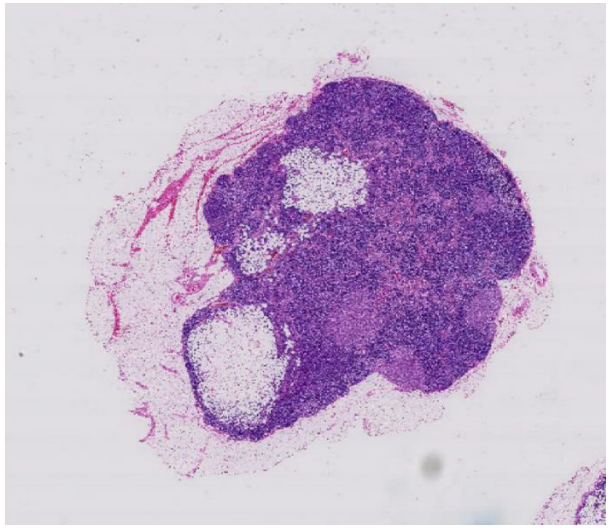
Large Image Visualization and Labeling



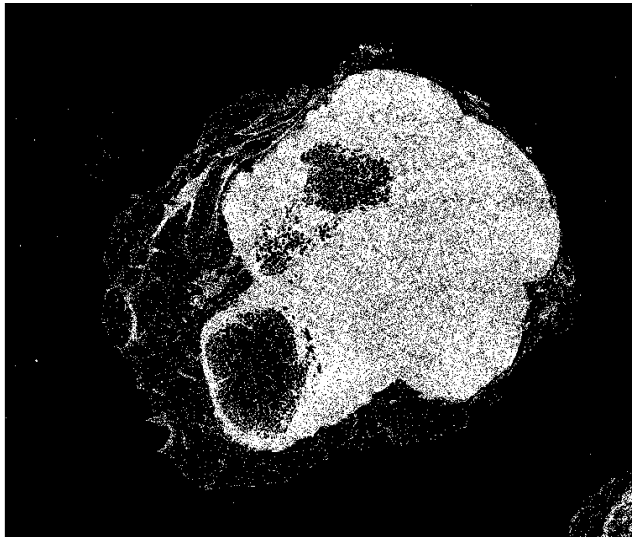


Digital Pathology and Microscopy

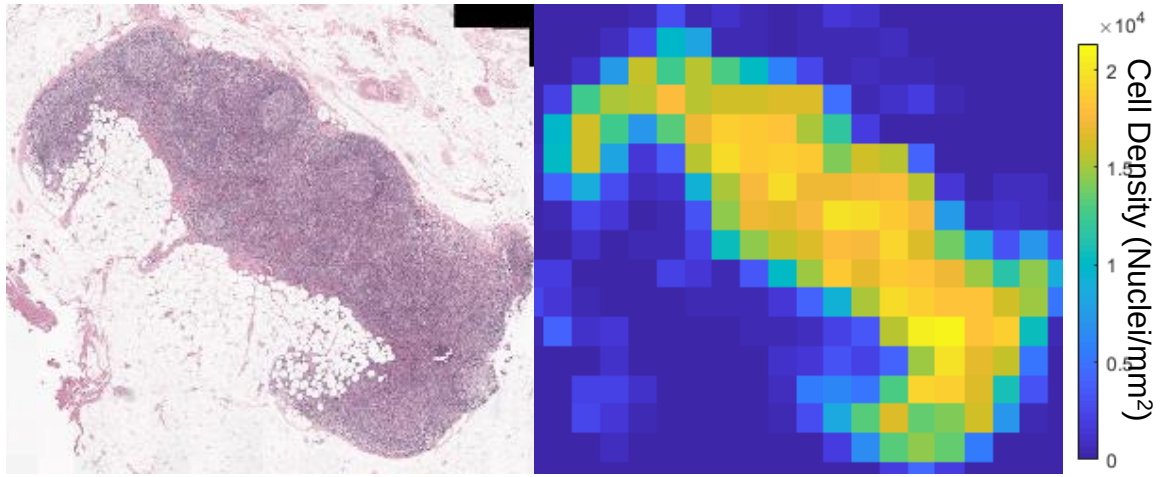
Original Image



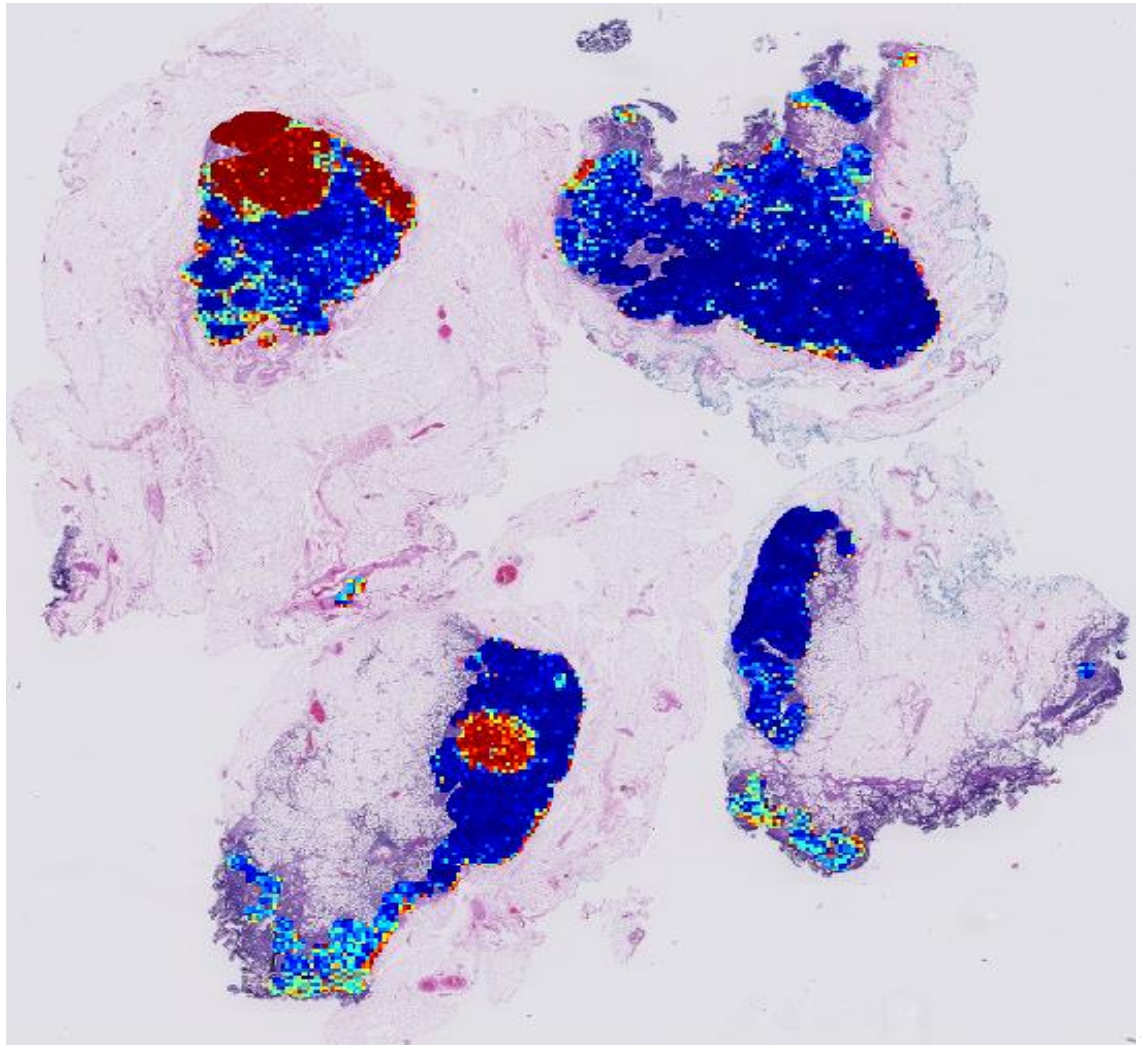
Mask



Cell Density



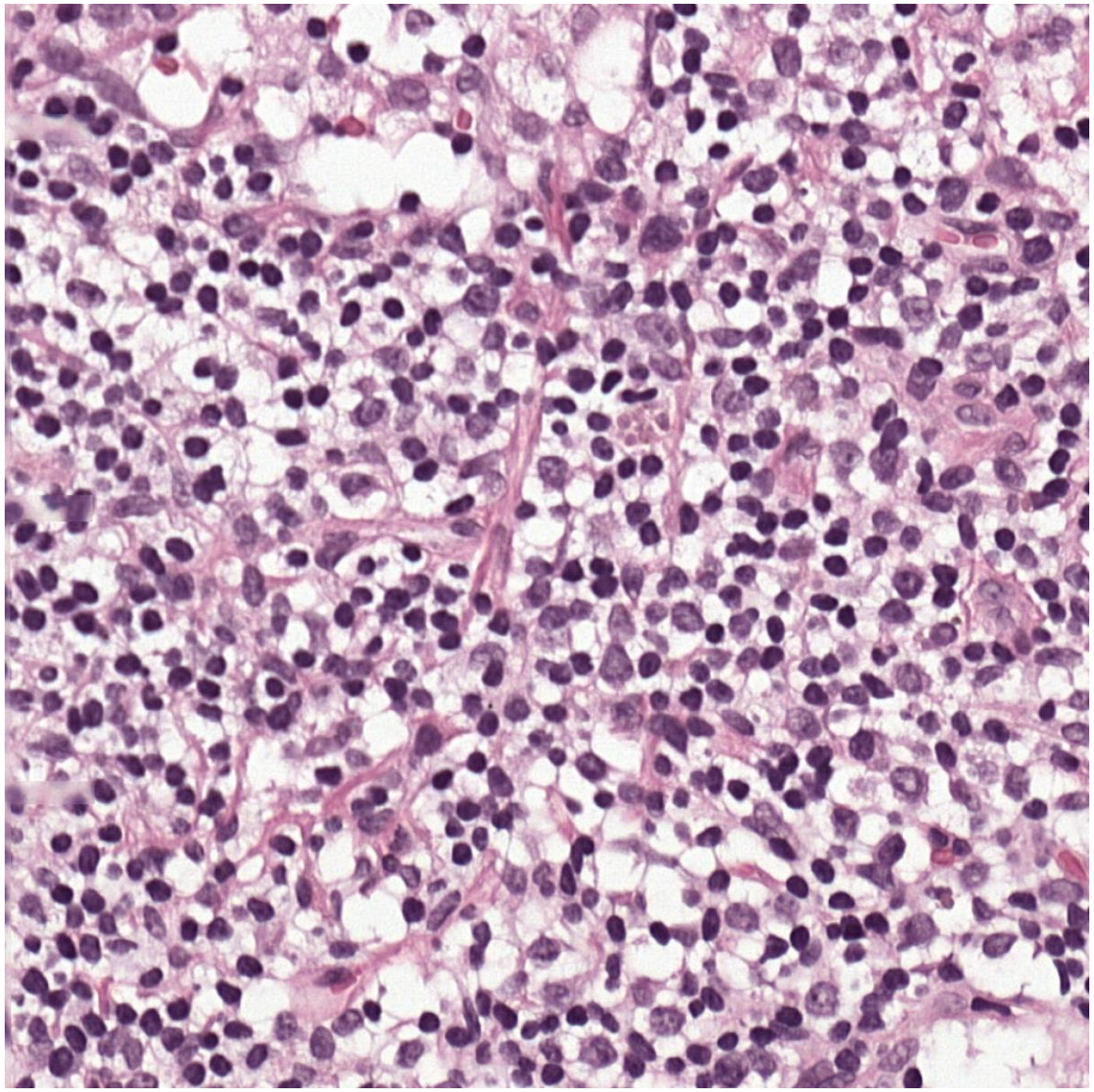
Tumor Heap Map from Deep Learning



MATLAB Interface for CellPose

- Original Image
- Deep learning for cell segmentation
- Overlay images
- Five lines of code
- Link to Download

```
>> img = imread(imname);
>> cp = cellpose;
>> averageCellDiameter = 25;
>> labels = segmentCells2D(cp,rgb2gray(img),ImageCellDiameter=averageCellDiameter);
>> imshow(labeloverlay(img,labels))
```



Ludwig Maximilian University

Developing Deep Learning System to Qualify Cryo-EM Samples

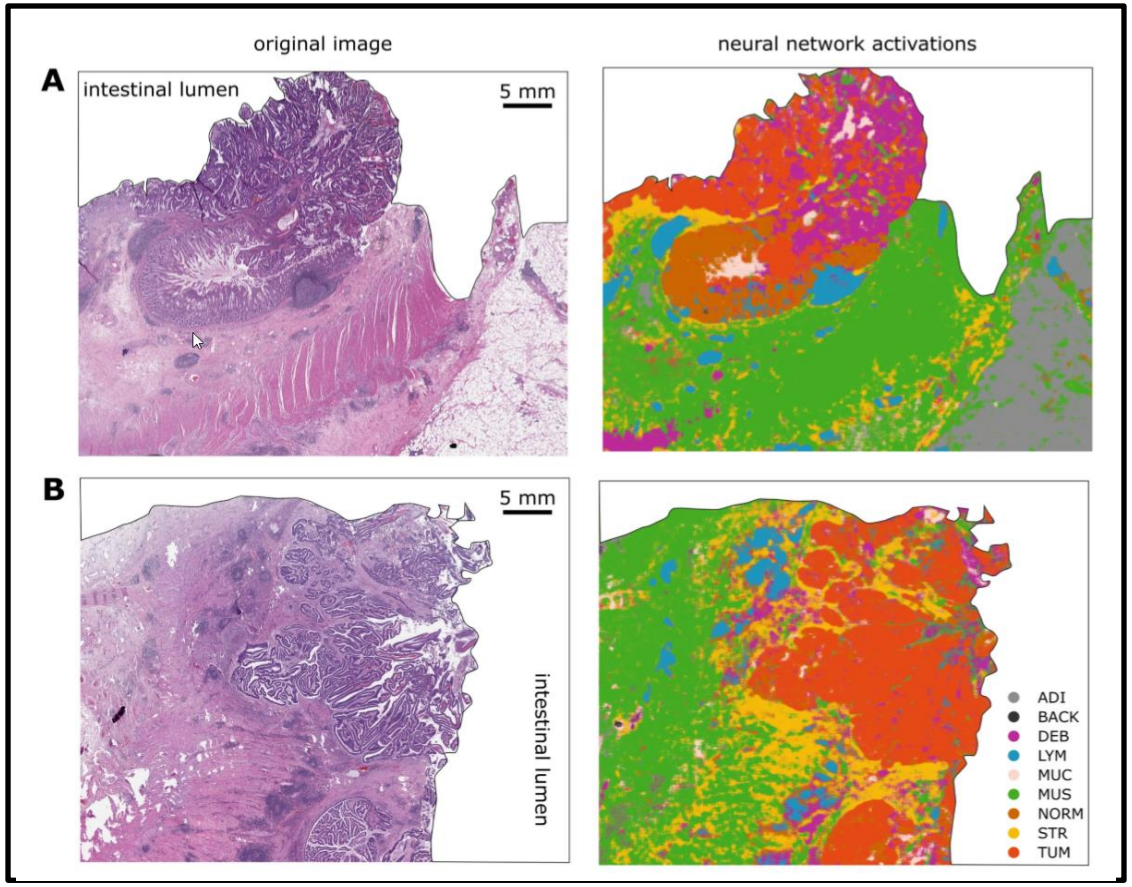
The widefield light microscope used for the fast grid screening.

- **Challenge**
  - Design a deep learning system that can automatically check the ice thickness of cryo-EM samples
- **Solution**
  - Use Deep Learning Toolbox to develop image segmentation and classification models to detect sample grids and classify them based on ice thickness
- **Results**
  - Quality screening time reduced
  - Screening costs reduced
  - Researcher time saved

LINK to User Story

University Hospital Heidelberg

Predicting survival from colorectal cancer histology slides using deep learning



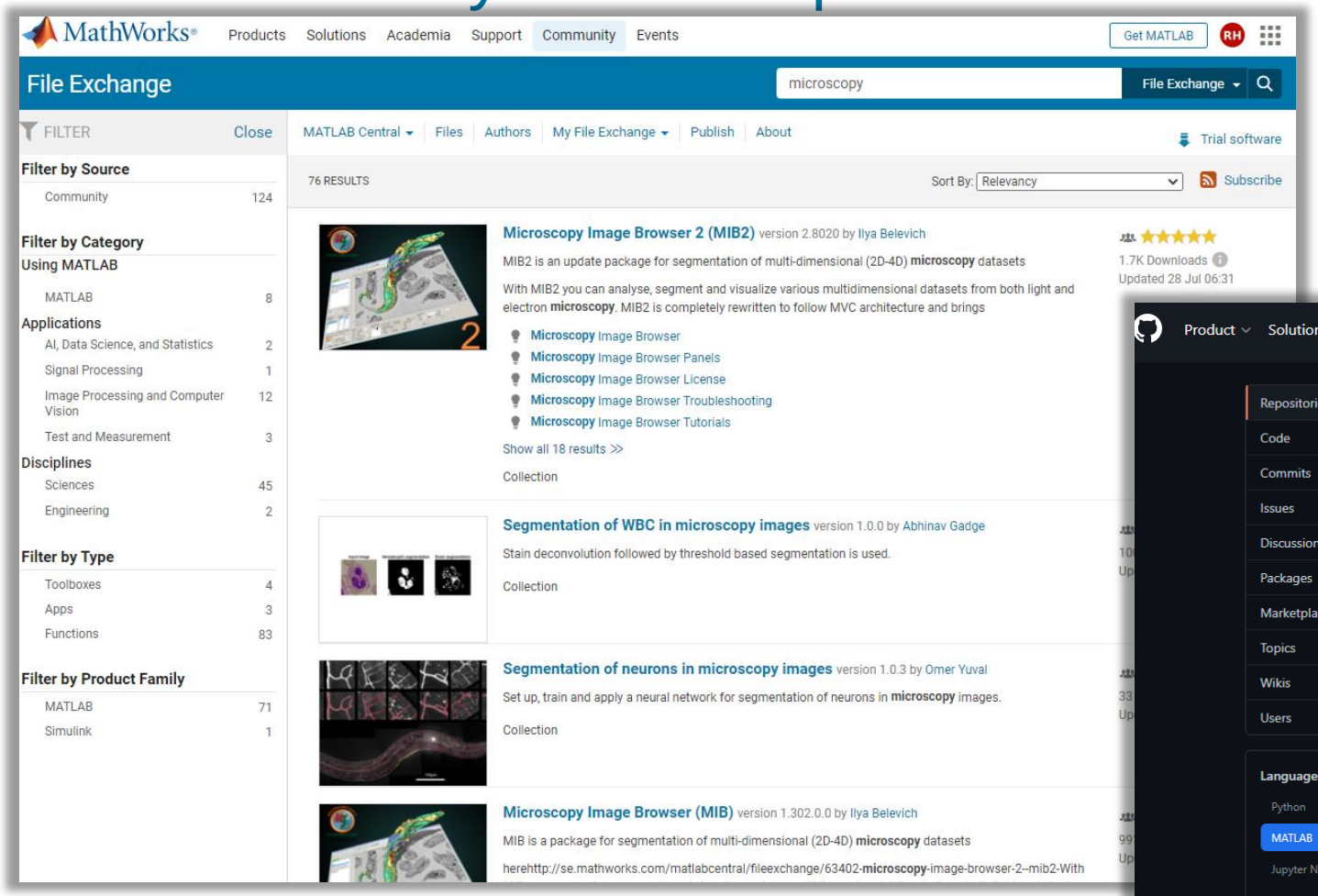
Semantic segmentation of histopathological whole-slide images

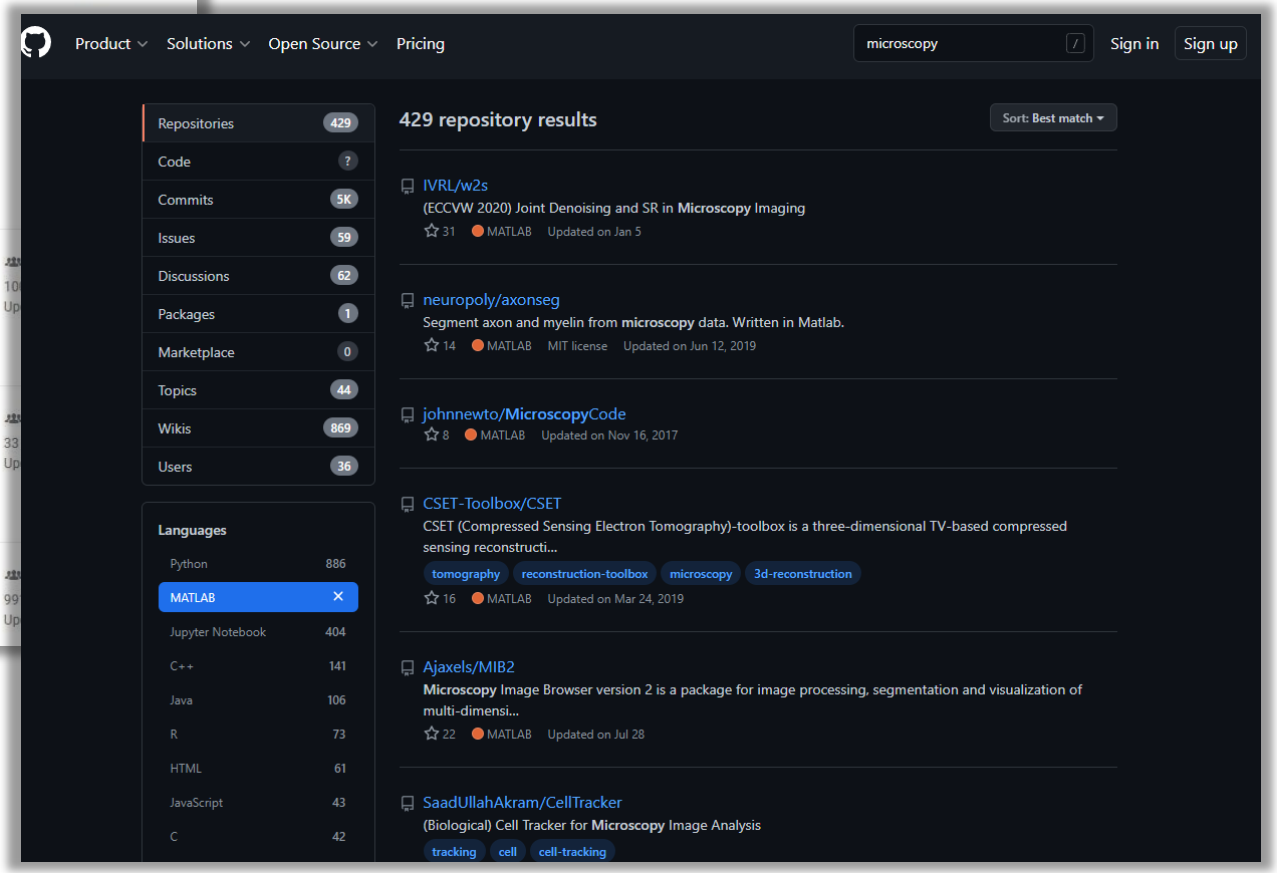
MATLAB use in project:

- Semantic segmentation using deep learning
- CNN trained using two Nvidia Quadro P6000 GPUs and a Nvidia Titan Xp GPU

Citation:Kather JN, Krisam J, Charoentong P, Luedde T, Herpel E, Weis C-A, et al. (2019) Predictingsurvival from colorectal cancer histology slides using deep learning:A retrospective multicenter study. PLoS Med 16(1): e1002730. https://doi.org/10.1371/journal.pmed.1002730

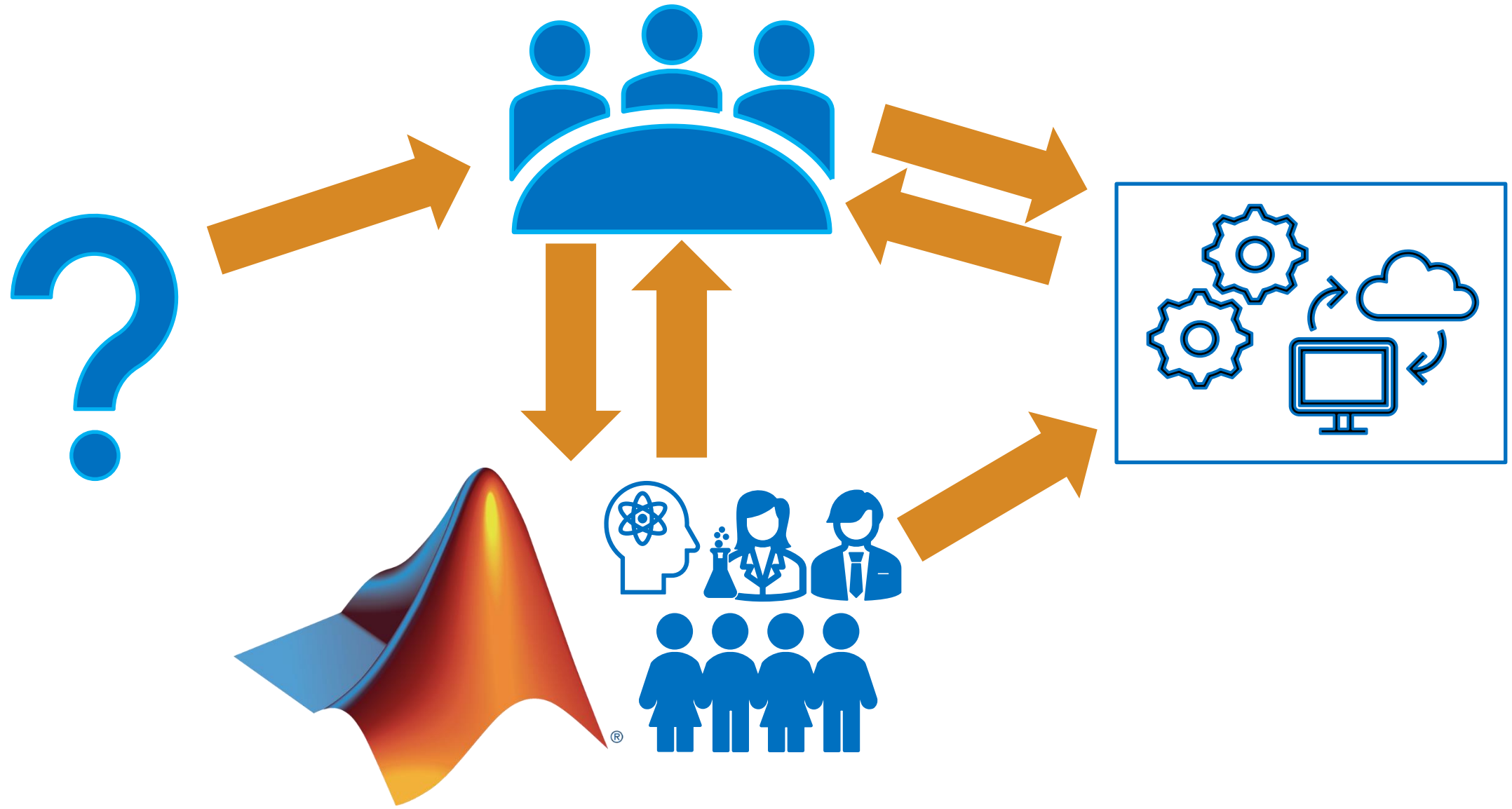
A Community of Development



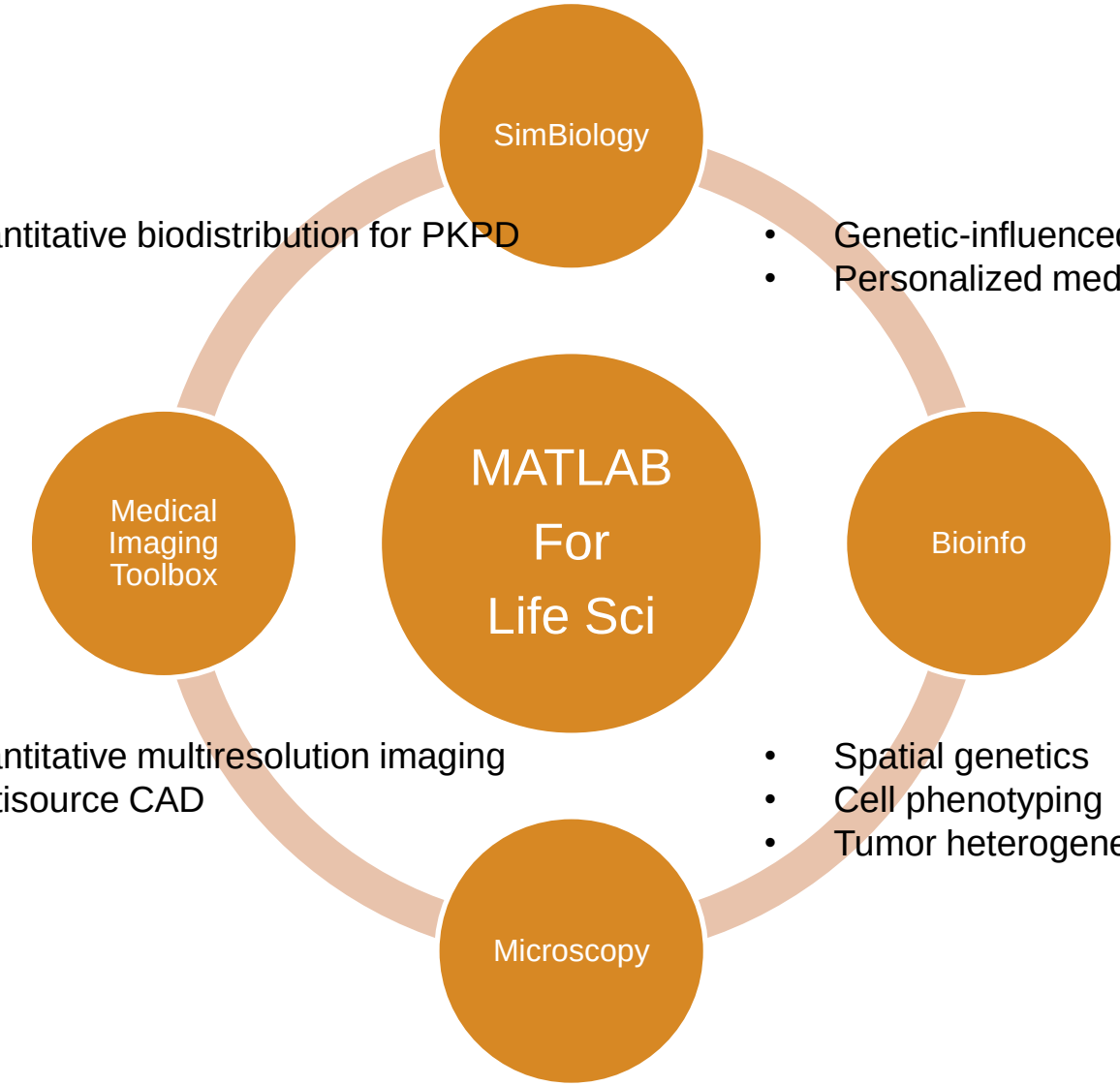


- Open-source tools on File Exchange
  - Open-source license
- List on GitHub and link to File Exchange
  - Only update one location

Consulting Enables Clear-Box Solutions



Opportunities For Synthesis



- Quantitative biodistribution for PKPD

- Genetic-influenced modeling
- Personalized medicine

- Quantitative multiresolution imaging
- Multisource CAD

- Spatial genetics
- Cell phenotyping
- Tumor heterogeneity

Questions?

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