DIRART

the Deformable Image Registration + Adaptive Radiotherapy Software Suite

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03/24/2009

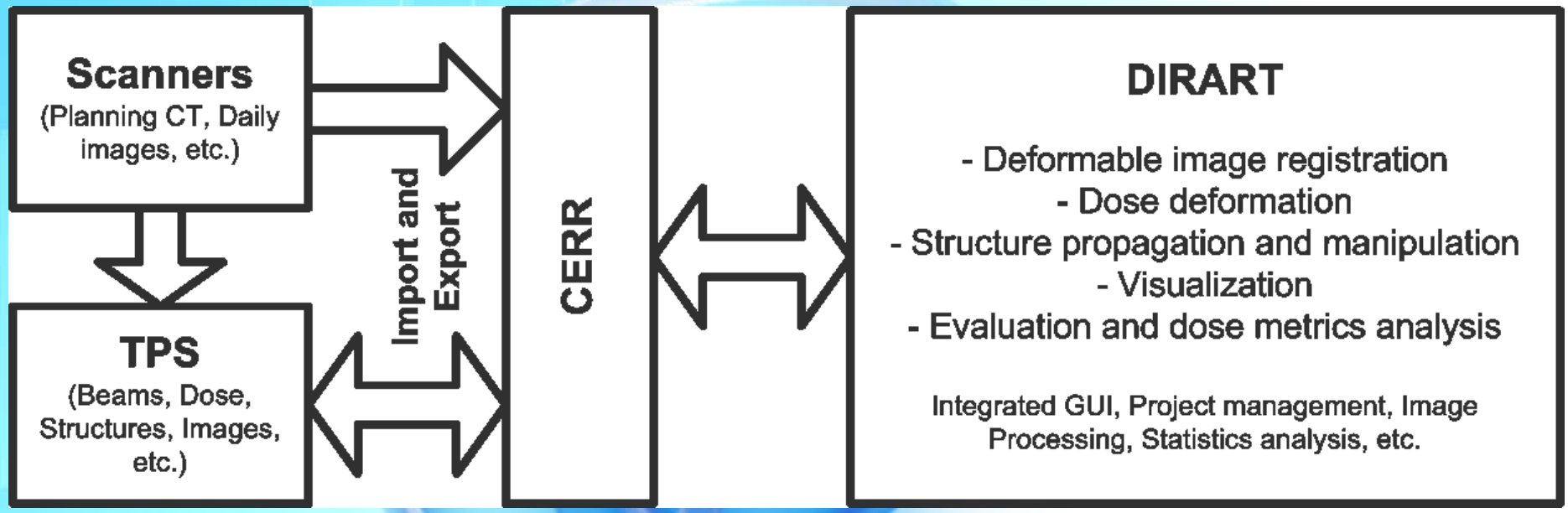
What is DIRART ?

- DIRART = DIR (deformable image registration) + ART (Adaptive Radiotherapy)
- It is
  - A collection of DIR algorithms plus visualization and validation features
  - An ART toolkit to perform dose and structure remapping, dose accumulation and analysis using the DIR results
  - A complimentary package to CERR to provide additional DIR and ART functions

What will DIRART do (for you)?

- Interacts with TPS using DICOM-RT (via CERR)
- Computes deformation between scans
- Applies deformation for planning adaptation purposes
  - Daily dose deformation, accumulation, comparison, etc
  - Structure propagation, deformation, etc
- Visualizes and analyzes the results

System Flow Chart



RT Objects and Interactions

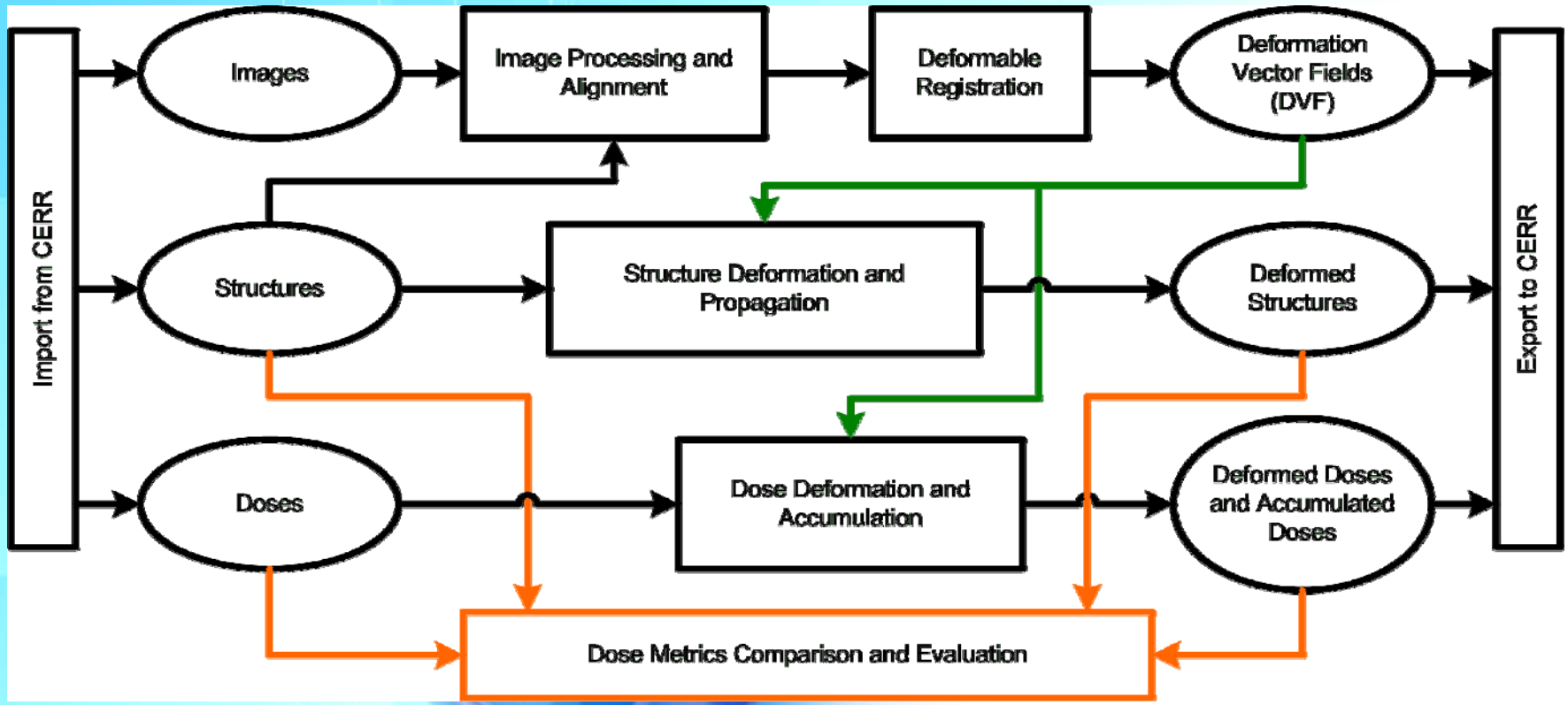
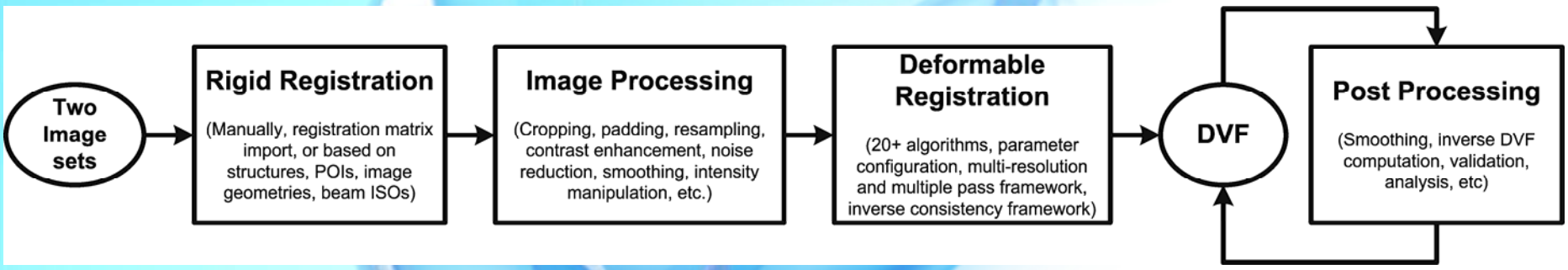
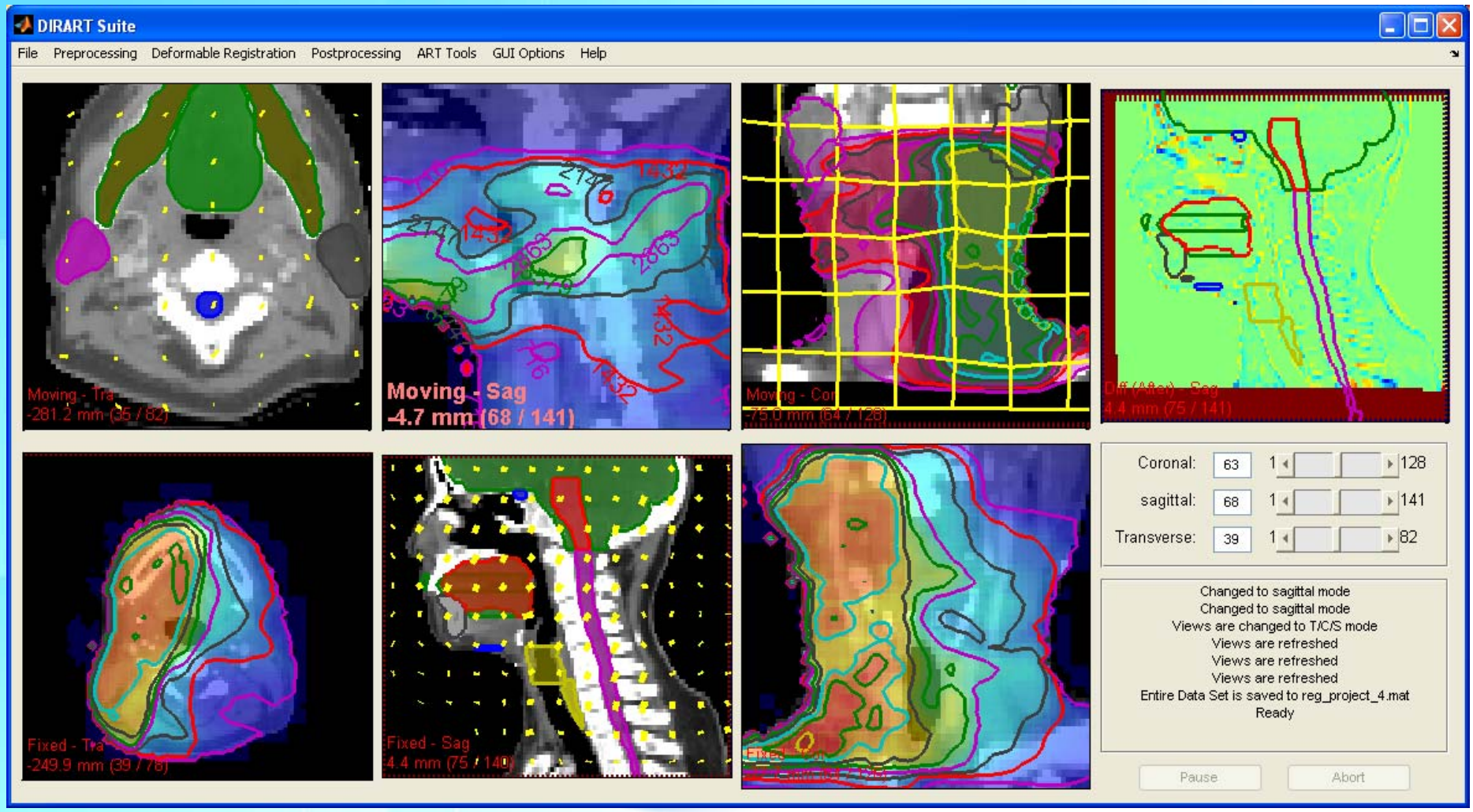
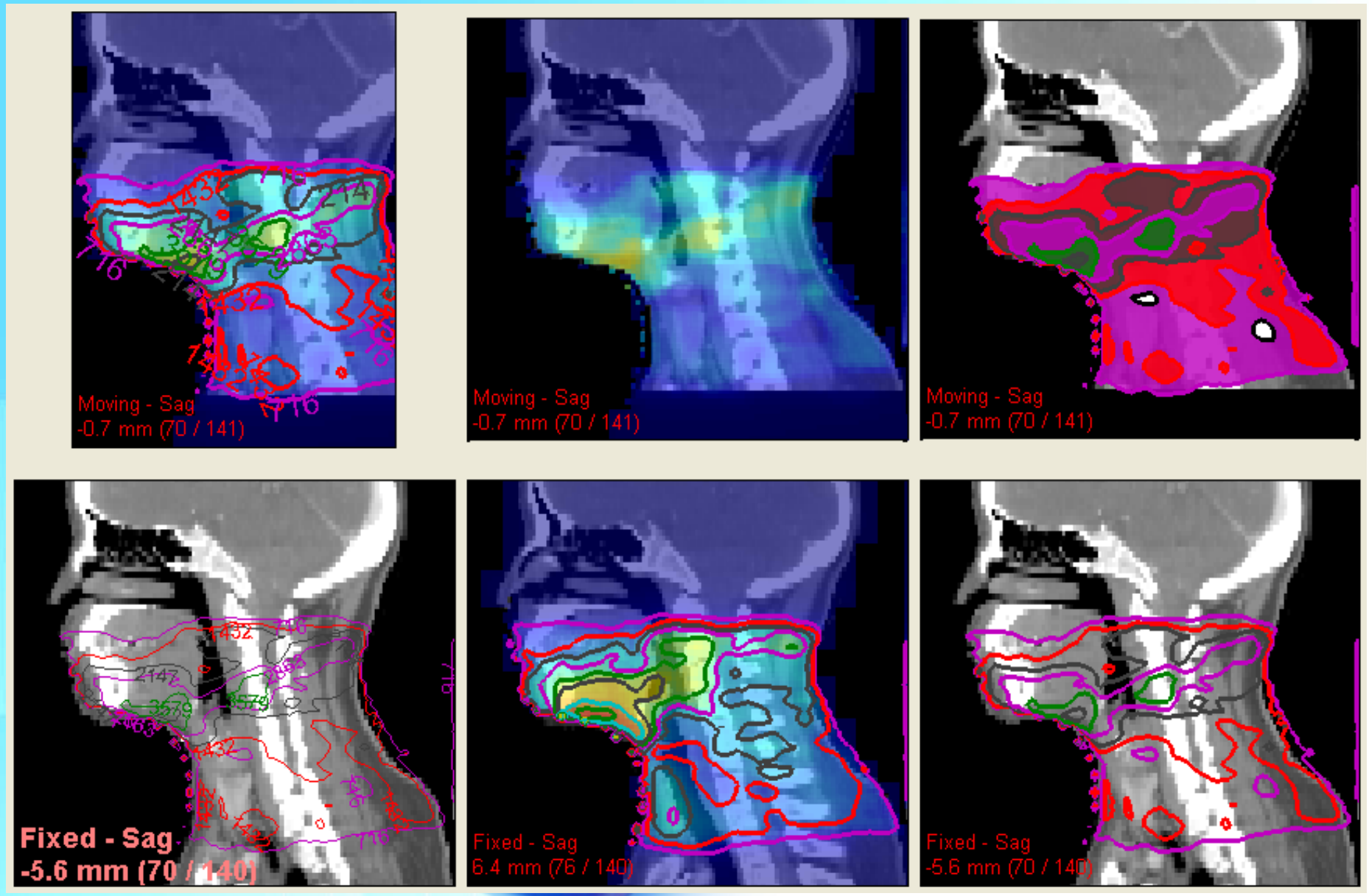


Image Processing and Registration Work Flow



Screen Shot

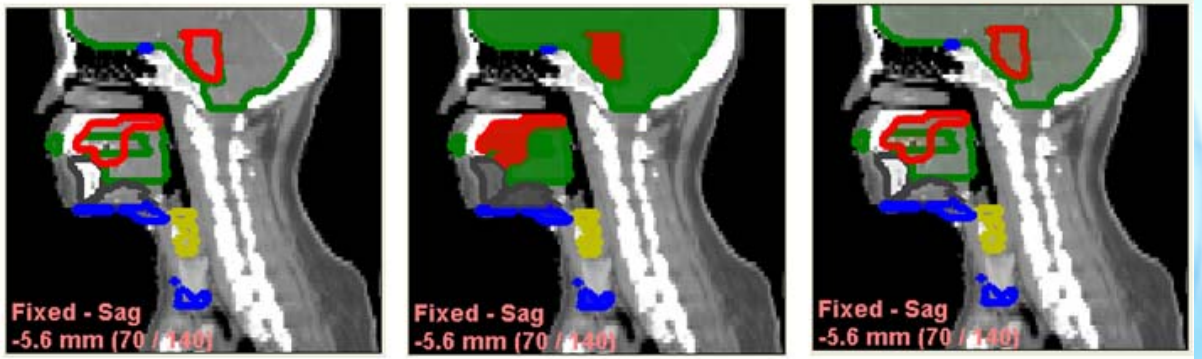

DIRART Suite
File
Preprocessing
Deformable Registration
Postprocessing
ART Tools
GUI Options
Help
Moving - Tra
-281.2 mm (35 / 82)
Moving - Sag
-4.7 mm (68 / 141)
Moving - Cor
-75.0 mm (64 / 128)
4.4 mm (75 / 141)
Fixed - Tra
-249.9 mm (39 / 78)
Fixed - Sag
4.4 mm (75 / 140)
Coronal:
63
1
128
sagittal:
68
1
141
Transverse:
39
1
82
Changed to sagittal mode
Changed to sagittal mode
Views are changed to T/C/S mode
Views are refreshed
Views are refreshed
Views are refreshed
Entire Data Set is saved to reg_project_4.mat
Ready
Pause
Abort



Dose visualization features

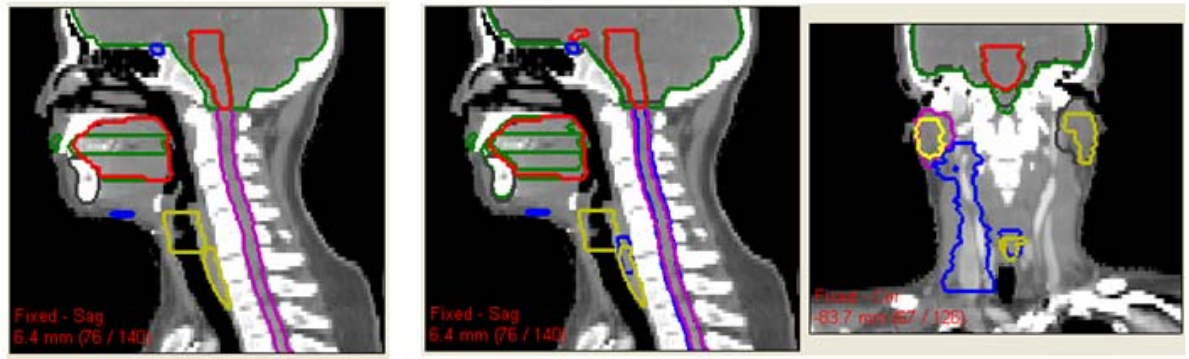
(a) Contours only (b) Contours and color filling (c) Color filling only

Figure 34: Examples of structures displayed with contours and color filling



(a) With thicker contour lines (b) With less transparency (c) With higher transparency

Figure 35: Examples of structures displayed with different line thickness and transparency settings



(a) (b)

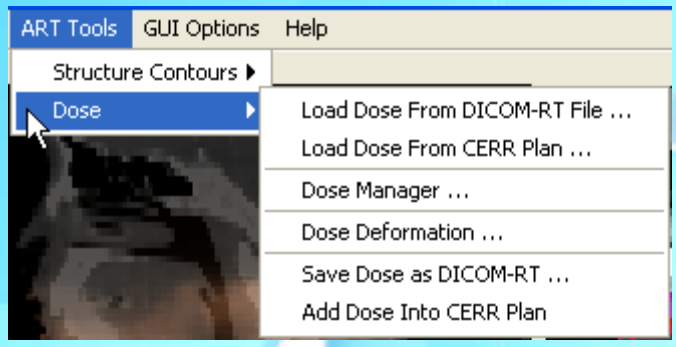
Figure 36: (a) Only fixed image contours are display. (b) Both moving image contours and fixed image contours are displayed on top of the fixed image

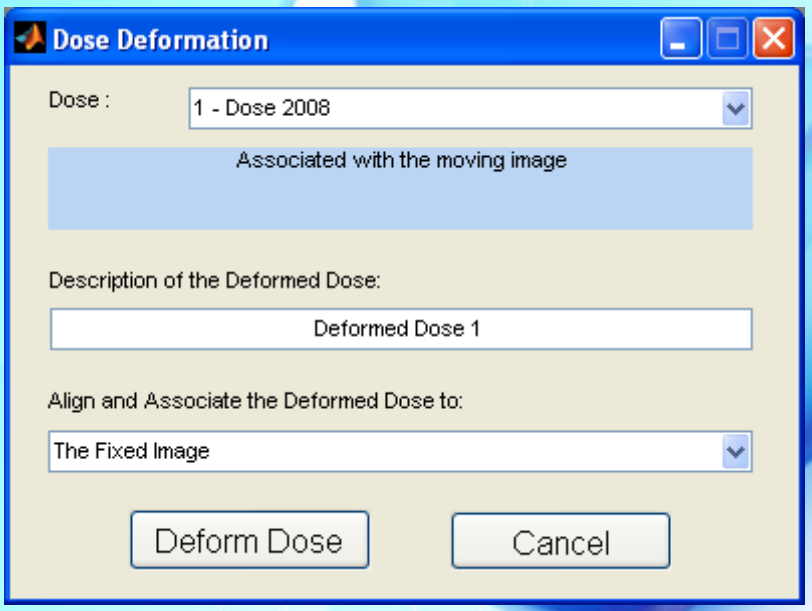
Structure objects visualization features

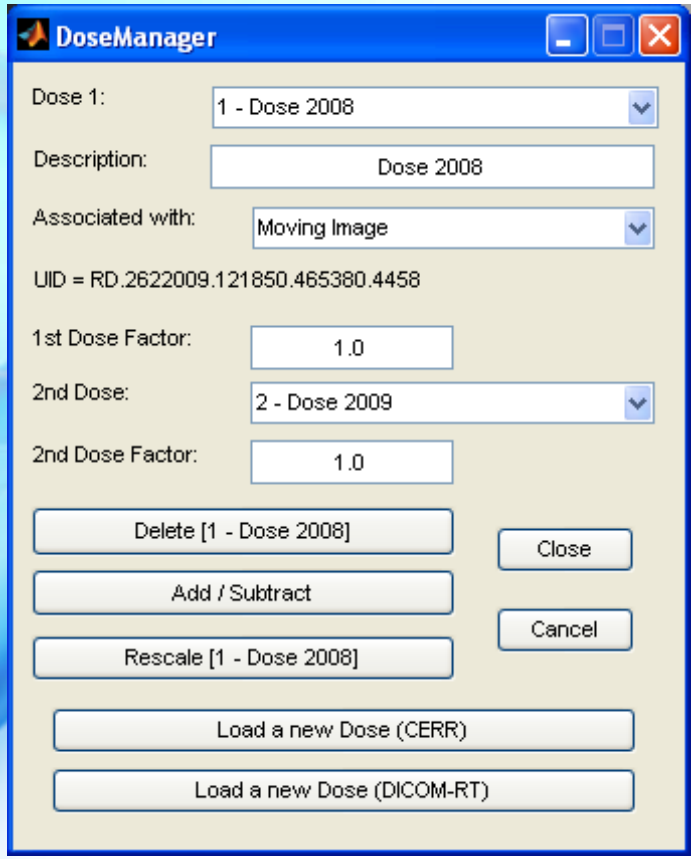
Example 1: Dose summation for initial plan and re-plan

1. Export plans as DICOM-RT files from TPS
2. In CERR
    a. Load both DICOM-RT plan
    b. Save as CERR plan (MATLAB) files
3. In DIRART
    a. Load the two CT scans from CERR plans
    b. Aligning, cropping, re-sampling
    c. Deformable registration and obtain DVF
    d. Load doses from the CERR plans
    e. Deform the initial plan dose to the re-plan CT coordinate
    f. Export the deformed initial dose to CERR
4. In CERR
    a. Sum the re-plan dose and the deformed initial dose
    b. Compute DVH on the sum dose
    c. Export the sum dose to DICOM-RT, to be loaded back to TPS

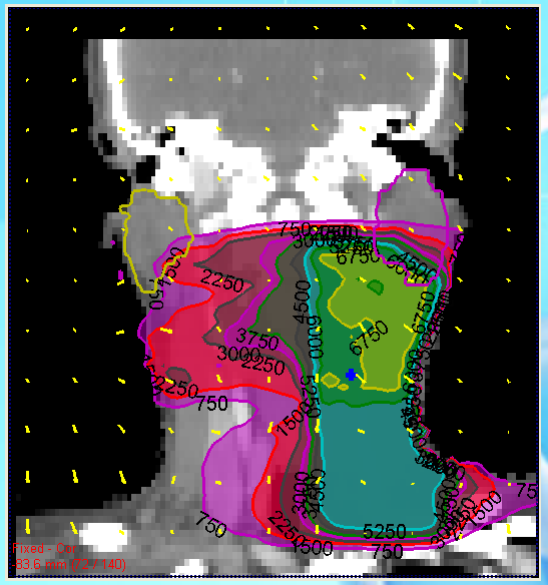
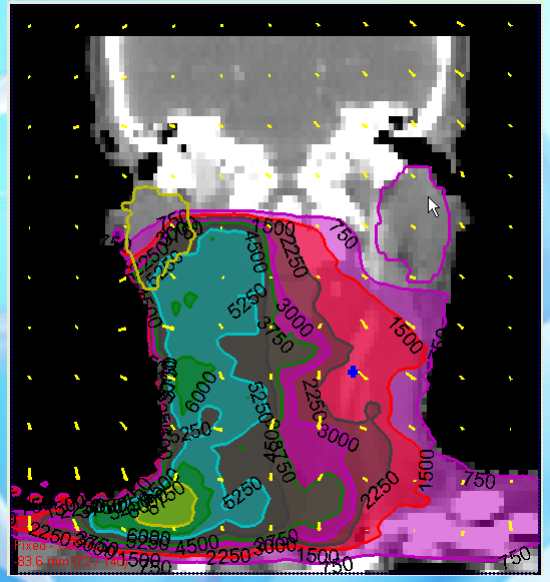
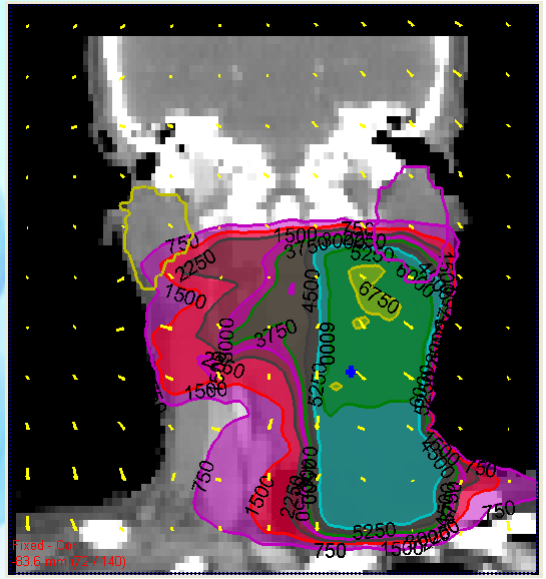
Screen shot of dose functions







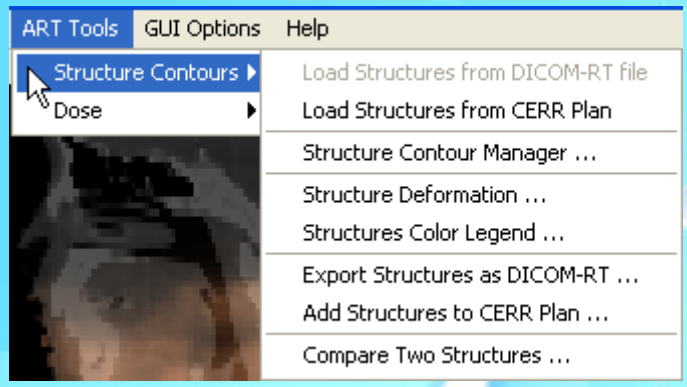
Dose Deformation Examples

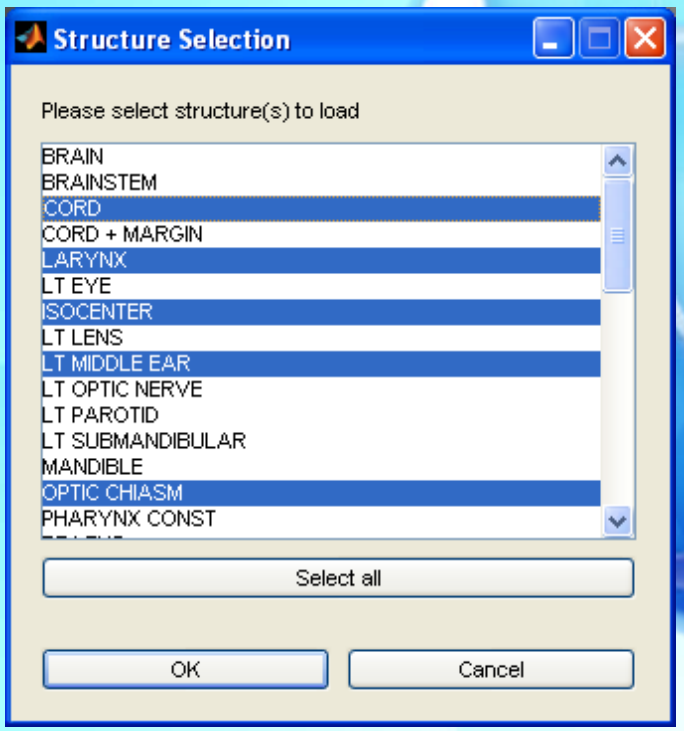
		
Initial Dose	Re-plan Dose	Deformed Initial Dose

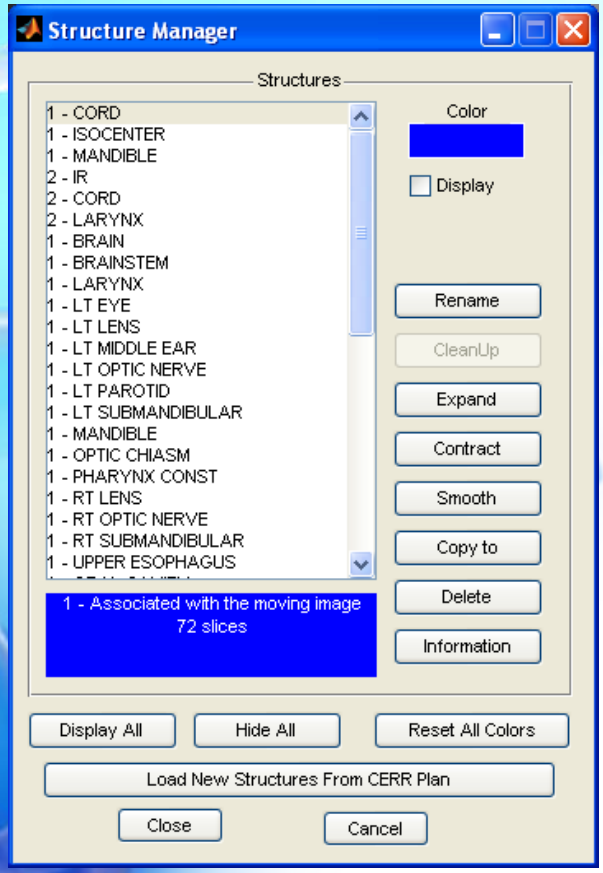
Example 2: Structure Contour Deformable Propagation

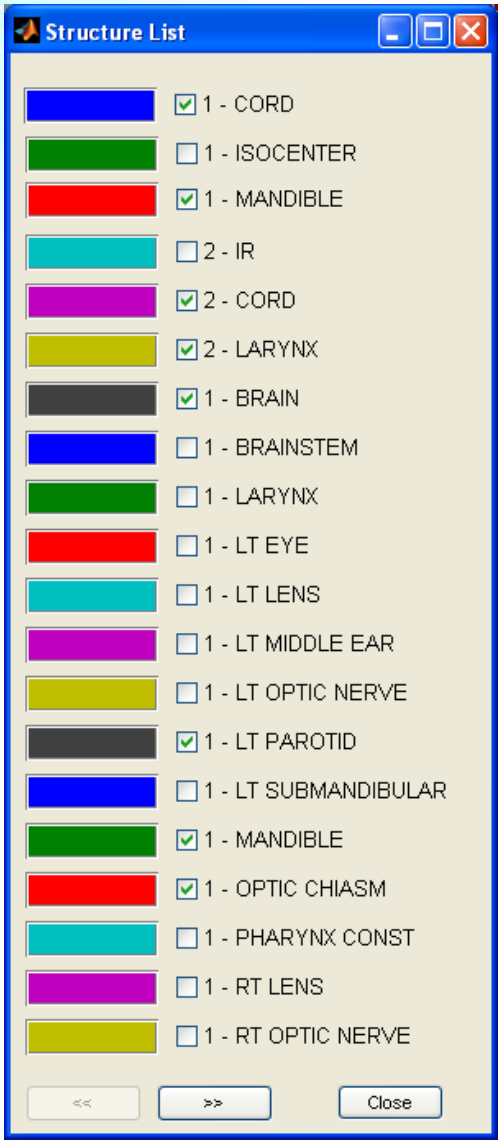
- Export plans as DICOM-RT files from TPS
- In CERR, load both DICOM-RT plans, save as CERR plan (MATLAB) files
- In DIRART
  - Load the two CT scans from CERR plans
  - Aligning, cropping, re-sampling
  - Deformable registration and obtain DVF
  - Load structures from the CERR plans
  - Deform the structures from one plan to the other plan
  - Export the deformed structures to CERR
- In CERR, export the deformed structures to DICOM-RT, to be loaded back to TPS

Screen shots of the structure functions

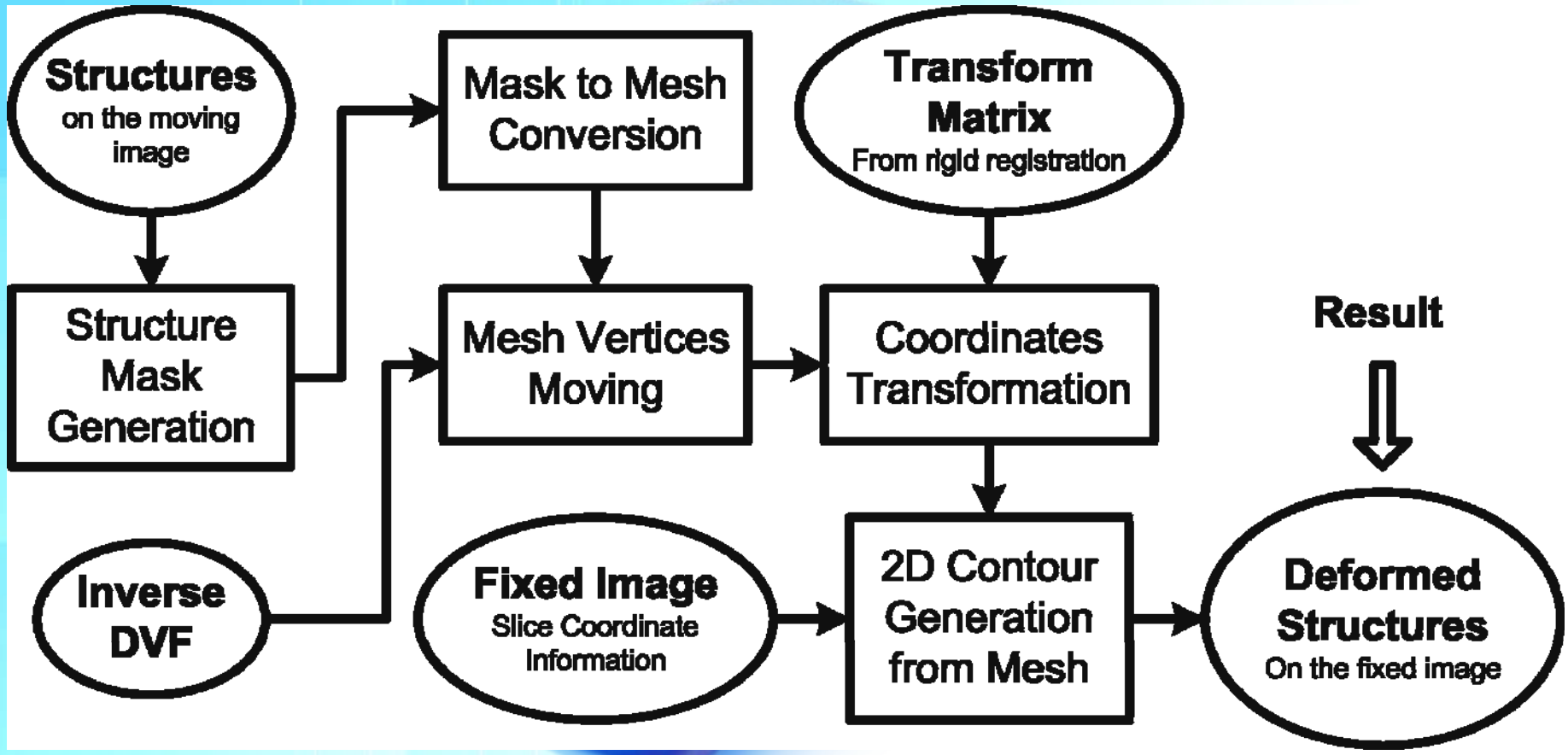




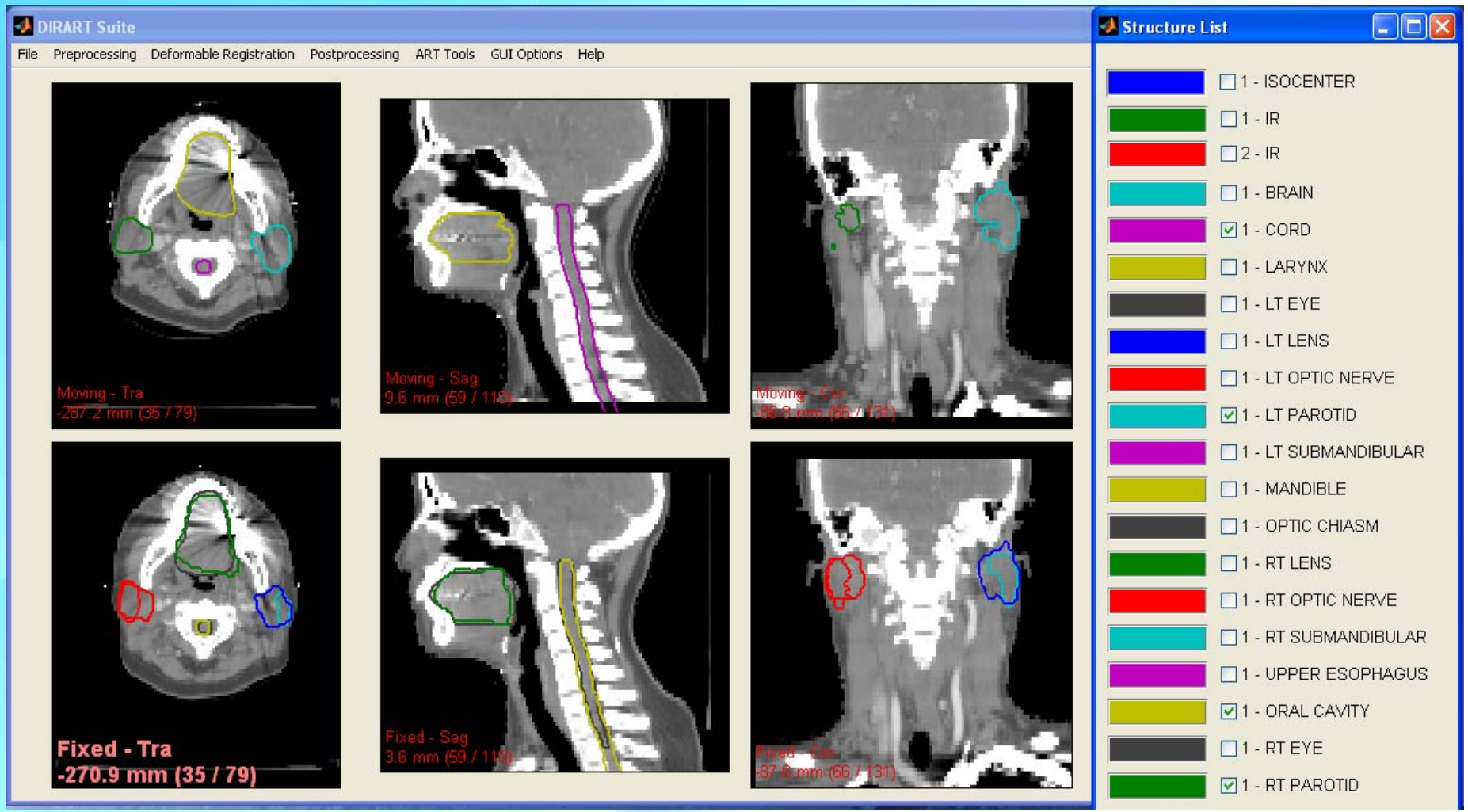




Structure Deformation Work Flow 1

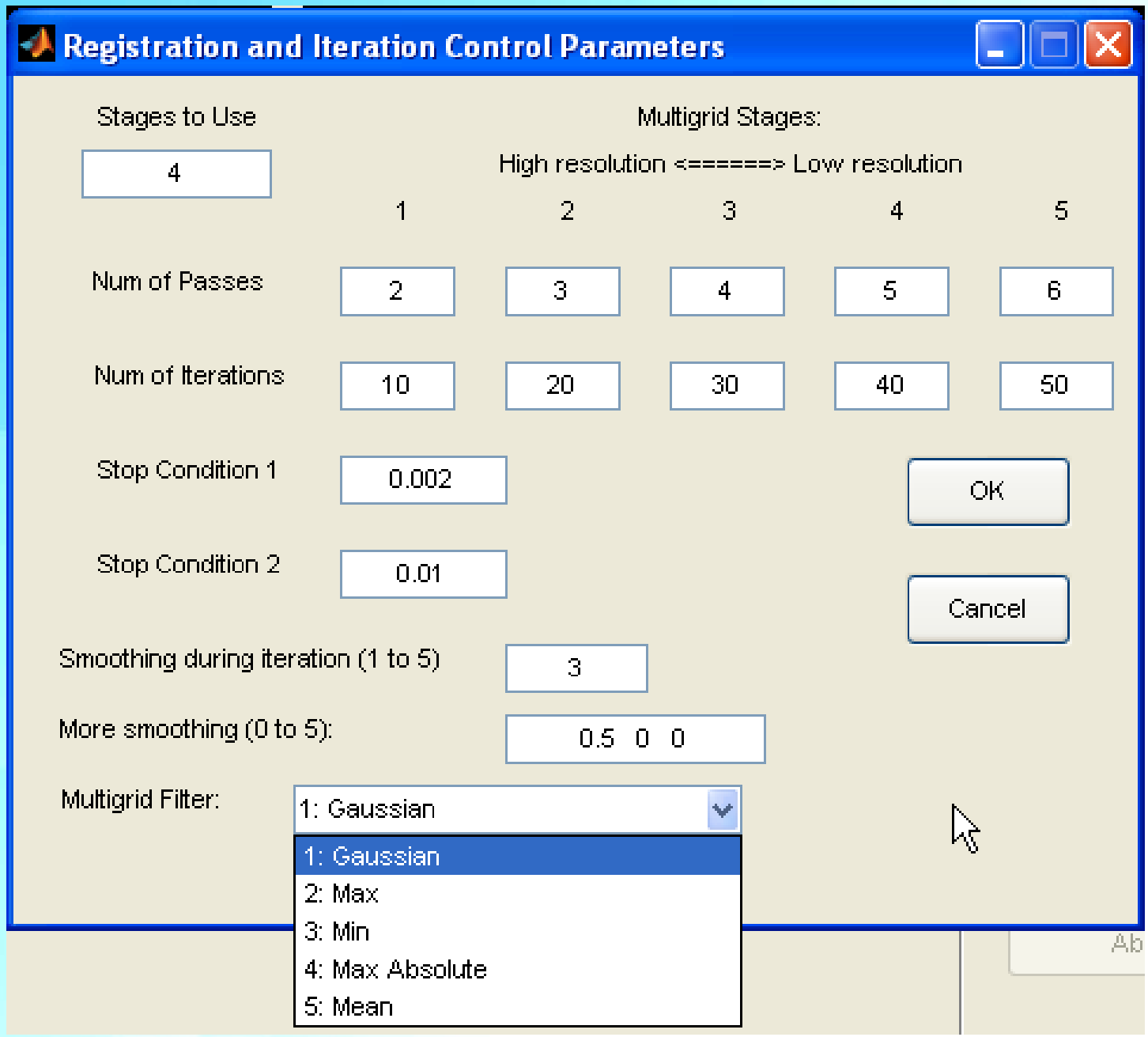


Examples of Structure Deformation



Deformable Image Registration in DIRART

- Two frameworks
  - The asymmetric DIR framework
  - The inverse consistency DIR framework
- 20+ algorithms, including optical flow algorithms, demons algorithms, algorithms from ITK, etc
- Multi-resolution and multiple-pass approaches
- Special features: structure-assistance, for partially overlapping images, image intensity manipulation, etc
- Use configurable settings


Registration and Iteration Control Parameters
Stages to Use
4
Multigrid Stages:
High resolution <=======> Low resolution
1
2
3
4
5
Num of Passes
2
3
4
5
6
Num of Iterations
10
20
30
40
50
Stop Condition 1
0.002
Stop Condition 2
0.01
OK
Cancel
Smoothing during iteration (1 to 5)
3
More smoothing (0 to 5):
0.5 0 0
Multigrid Filter:
1: Gaussian
1: Gaussian
2: Max
3: Min
4: Max Absolute
5: Mean

DIR Example

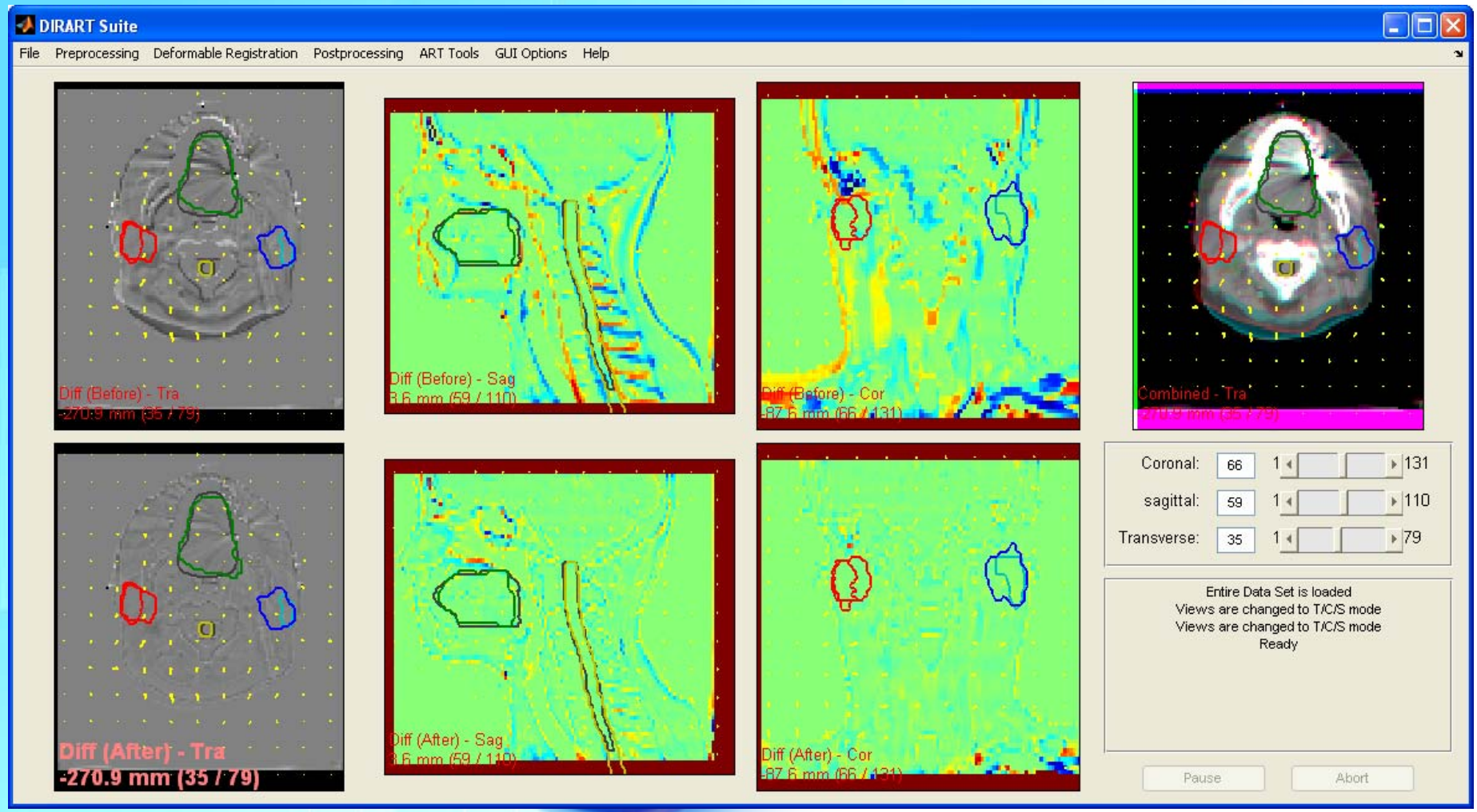

DIRART Suite
File
Preprocessing
Deformable Registration
Postprocessing
ART Tools
GUI Options
Help
Diff (Before) - Tra
Diff (Before) - Sag
Diff (Before) - Cor
Combined - Tra
Diff (After) - Tra
-270.9 mm (35 / 79)
Diff (After) - Sag
Diff (After) - Cor
Coronal:
66
1
131
sagittal:
59
1
110
Transverse:
35
1
79
Entire Data Set is loaded
Views are changed to T/C/S mode
Views are changed to T/C/S mode
Ready
Pause
Abort

Image Processing in DIRART

- Smoothing (Gaussian, edge-perservation)
- Contrast enhancement (histogram based, window level transformation, intensity remapping, intensity manipulation, etc)
- Cropping and padding
- Re-sampling

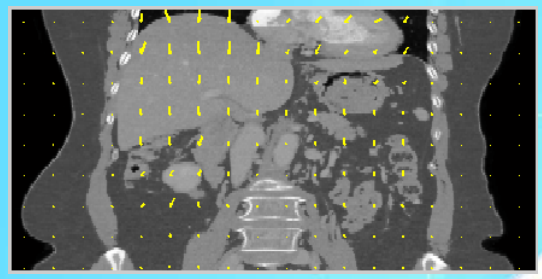
Performance of DIR

- Features in DIRART to improve performance
  - Cropping, re-sampling, multi-resolution, image processing, etc.
- Computation speed
  - 1 to 10 minutes
- Future
  - GPU acceleration

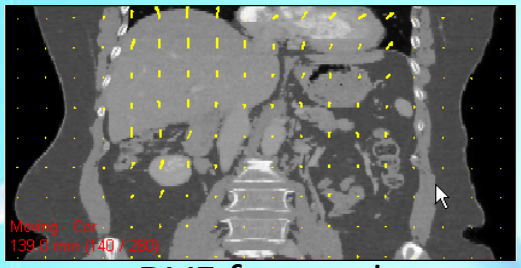
Post-Processing on DVF

- Smoothing
- Computing the inverse DVF
- Converting to the transformation vector fields

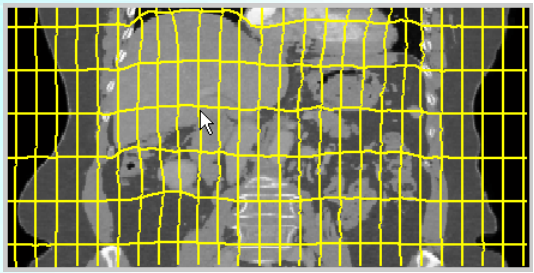
Visualization of DVF



DVF backward

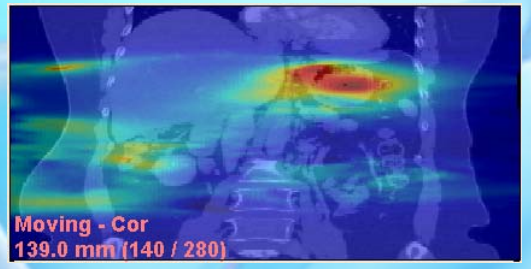


DVF forward

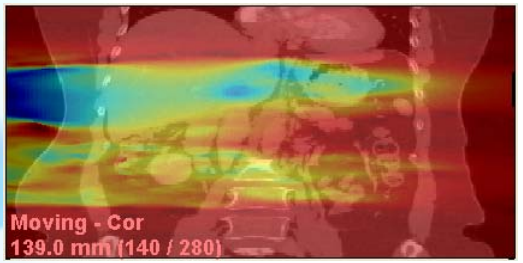


DVF deformation grid

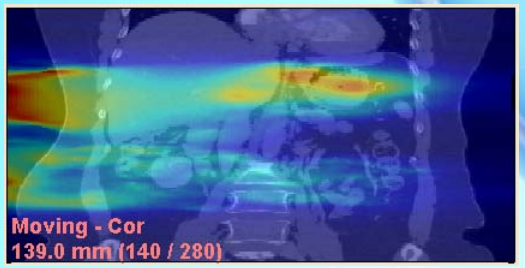
DVF in L-R



DVF in A-P

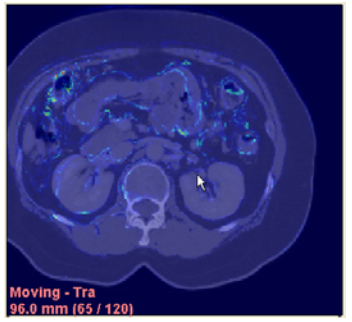


DVF in S-I



DVF magnitude

Jacobian of DVF



Inverse consistency errors

Validation of deformable image registration in DIRART

- Landmark based validation
- Ground truth based validation (phantoms, or digitally synthesized phantoms)
- DVF analysis
  - Jacobian, divergence, Inverse consistency analysis
- Image intensity based analysis
  - MSE, MI, CC, CR (correlation-ratio)
- Structure based analysis
  - Structure volume overlay (Dice similarity measurement)
  - Structure point geometry error analysis

File and Project Management

- Save and load projects
- Save and load DVFs
  - For the same image datasets

Data inside DIRART

```
gui_handles: [1x1 struct]
       info: [1x1 struct]
gui_options: [1x1 struct]
        reg: [1x1 struct]
        ART: [1x1 struct]
     images: [1x2 struct]
```

```
y: [73x74x51 single]
x: [73x74x51 single]
z: [73x74x51 single]
info: [1x1 struct] ➔
voxelsize: [2 2 3]
origin: [72.9492 -74.1211 -25]
voxel_spacing_dir: [-1 1 1]
type: 'DVF'
class: 'single'
UID: 'DVF.2322009.101924.439379.481'
Fixed_Image_UID: 'CT.1412009.165134.797173.3886'
Moving_Image_UID: 'CT.1412009.165440.405190.9237'
GenerateBy: 'Reg3dGUI'
```

```
image: [134x160x86 single]
voxelsize: [2 2 3]
origin: [67.8281 -160.5469 -317.9999]
voxel_spacing_dir: [-1 1 1]
original_voxelsize: [1.1719 1.1719 3.0000]
image_deformed: [134x160x86 single]
filename: [1x63 char]
type: 'unknown'
class: 'int16'
UID: 'CT.1412009.165440.405190.9237'
DICOM_Info: [1x1 struct]
original_CERR_Scan_Struct: [1x1 struct]
LoadFrom: 'CERR'
```

```
structures: {1x16 cell}
structure_colors: [16x3 double]
structure_display: [1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1]
structure_names: {1x16 cell}
structure_assocScanIDs: [1 2 4 4 4 4 4 4 4 4 4 5 5 4 5 5]
structure_scanInfos: {1x5 cell}
structure_structInfos: {1x16 cell}
structure_assocImgIdxes: [2 1 1 1 1 1 1 1 1 1 1 1 1 2 1 2]
```

Summary

- DIRART works together with CERR on DICOM-RT
- DIRART works on images, doses and structures
- Performs deformation and (off-line) plan adaptation
- For DIR and ART research works