NA-MIC
National Alliance for Medical Image Computing
http://www.na-mic.org

Non-rigid Registration of Pre-procedural MRI and Intra-procedural CT for CT-guided Cryoablation Therapy of Liver Cancer

Atsushi Yamada, Dominik S. Meier and Nobuhiko Hata

Brigham and Women's Hospital

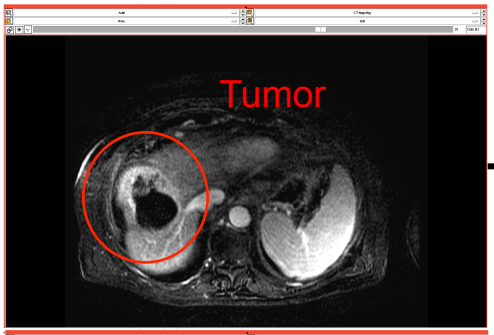
ayamada@bwh.harvard.edu

617-963-4336

NA-MIC Tutorial Contest: Summer 2011

Learning Objective

- This tutorial demonstrates how to co-register a pre-operative contrast enhanced MR image to an intra-procedure CT image via automated non-rigid registration.
- The case study is a CT-guided liver tumor cryoablation



Pre-procedure
Contrast
Enhanced MRI

Intra-procedure
Unenhanced CT
With Cryoprobe

Images Fused: allowing to see both tumor & probe

Tutorial Topics / Targets

Slicer Modules Used:

- N4ITKBiasField Correction
- Editor
- BRAINSFitIGT Registration

Image Processing Tasks Performed:

- Intensity non-uniformity correction
- Mask generation / segmentation
- Inter-modality non-rigid image registration

Image Data Used:

- Pre-operative abdominal MR with surface coil, showing liver
- Planning and Intra-operative CT with cryo-probe

Material

This tutorial website is at:

http://wiki.na-mic.org/Wiki/index.php/Non-rigid_MR-CT_Image_Registration

This tutorial dataset is available at:

http://www.na-mic.org/Wiki/images/4/47/Non-rigid_MR_CT_Image_RegistrationTutorialData_TutorialContestSummer2011.tar.gz

Platform

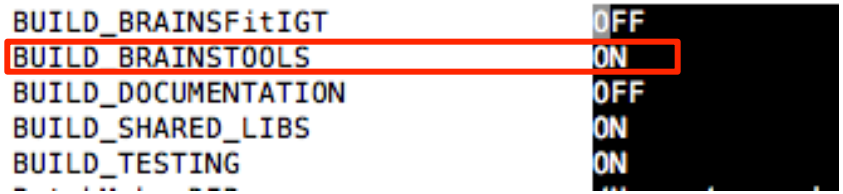
- This tutorial was developed and tested on an Intel MacBook Pro (2.3 GHz Core i7, 4GB).
- This tutorial also uses a custom-designed BRAINSfitIGT module, which requires the **compilation** of Slicer3.6 from **source f**iles.
- For the purpose of learning the steps & basic usage, you can use the regular BRAINSfit, but registration results will differ.

Compilation Instructions

If you choose to use the BRAINSfitIGT version:
go to the Slicer3.6 Build Instruction page

http://www.slicer.org/slicerWiki/index.php/Slicer3:Build_Instructions

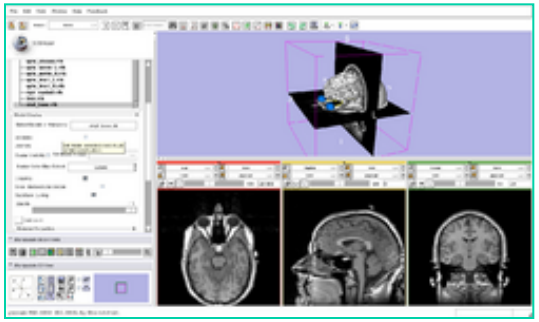
1. After building Slicer3.6, command “make edit_cache” at “[install folder]/Slicer3.6-build/Modules”.
2. Select “ON” of “BUILD BrainsFitIGT” on ccmake screen editor.



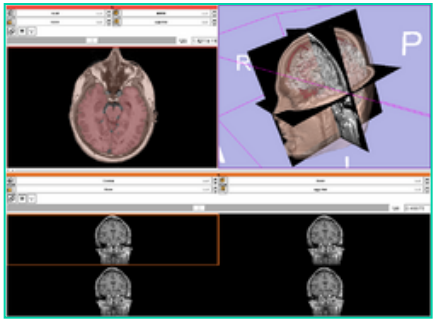
3. Press “c” then press “g” to generate new CMakeLists.txt.
4. After executing “make”, you can use BrainsFitIGT module.

User Skill Pre-requisites

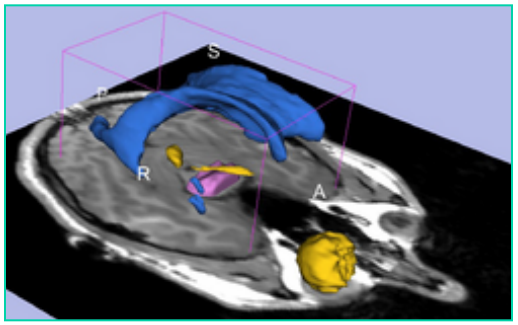
- Before running this tutorial, if new and unfamiliar with the Slicer user interface, we recommend to first complete the following tutorials, available here:
- http://www.slicer.org/slicerWiki/index.php/Slicer_3.6:Training



Slicer3Minute Tutorial



Slicer3Visualization Tutorial



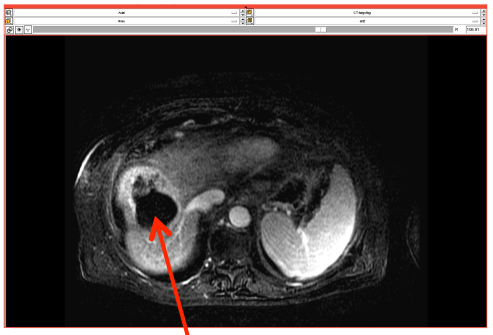
Interactive Editor

Clinical Significance

CT imaging can be used to plan an interventional approach to facilitate the safe placement of **the ablation applicators** in the tumor. **However, the tumor is invisible or poorly visible on the intra-operative CT**

Pre-operative MRI

Tumor margins and surrounding structure are visible



MRI

tumor

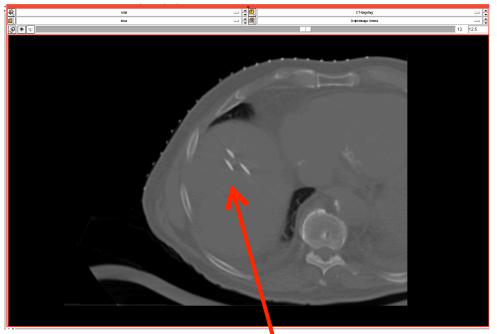
Liver position, shape and structures may differ significantly between the two exams.

A non-rigid registration is desirable to compensate for liver deformation caused by patient positioning, respiratory motion and interventional manipulation.

Intra-operative CT

Only interventional probes are visible, not the tumor

CT



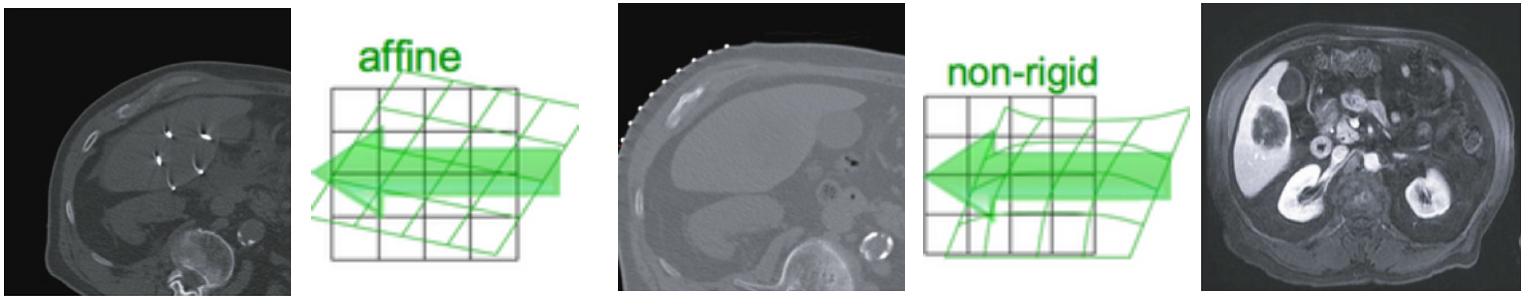
Cryoprobe

Overview

- This tutorial will go through the following steps (in order):
- Preprocessing
    1. MRI mask generation
    2. CT mask generation
    3. MRI Bias Field Intensity Correction
- Registration
    4. MRI-CT(#1) non-rigid registration
    5. CT(#1)-CT(#2) affine registration
    6. Resampling & Fusion

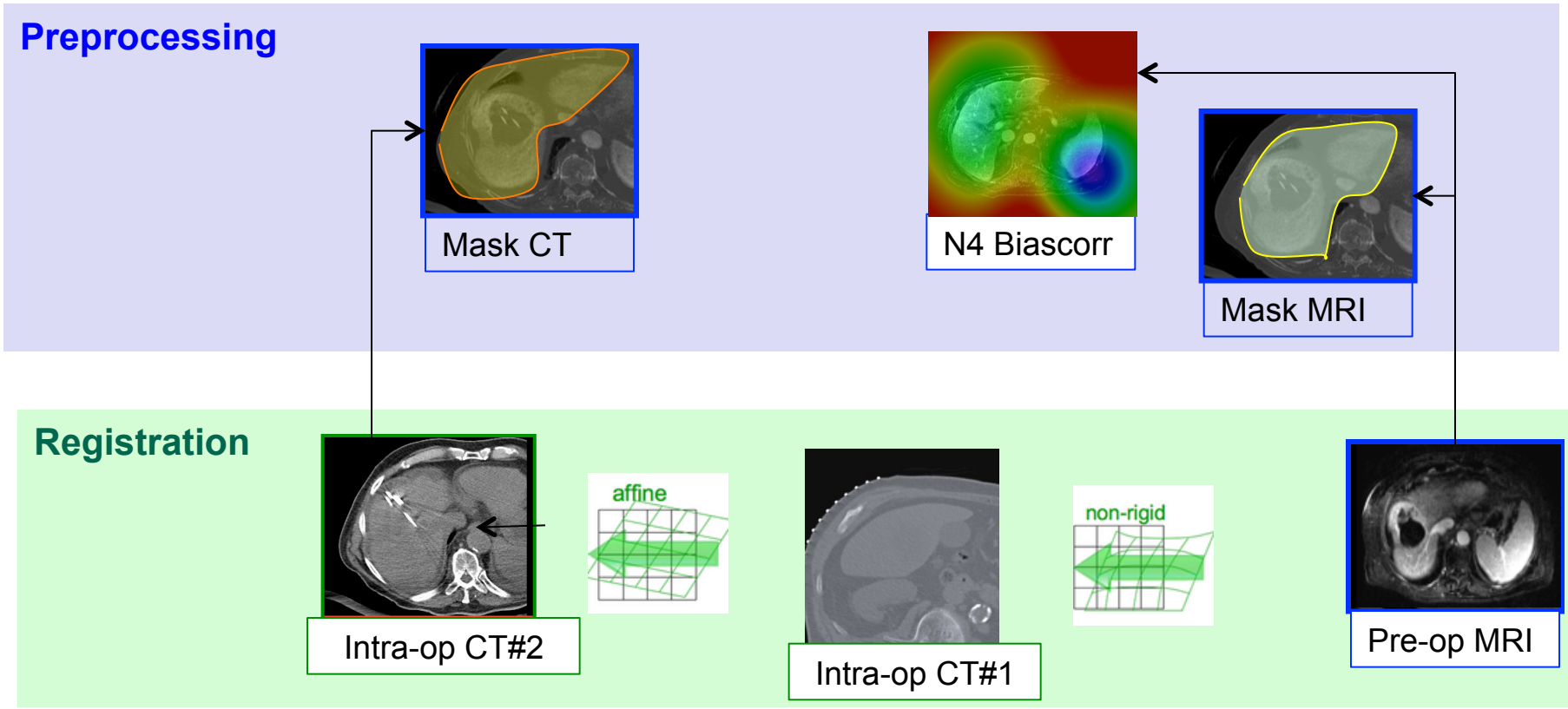
Image Processing Workflow Overview

In this particular CT-guided cryoablation, there are two registrations necessary: 1) a non-rigid registration between the pre-op MR and another intra-op CT (#1) without the probes, 2) an affine registration between the CT #1 and the intra-op CT with the probes (#2). This minimizes differences between image pairs and increases robustness of the registration.



Intra-op CT #2 **Intra-op CT #1** **Pre-procedure enhanced MRI**

Registration Strategy/Roadmap

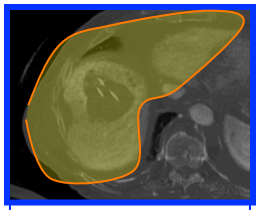


Preprocessing Step 1+2

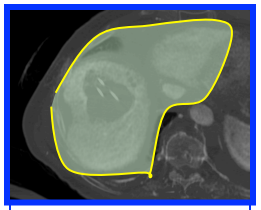
Obtain ROI masks

1. for the MR image
2. For the CT image

Module used: Editor



Mask CT

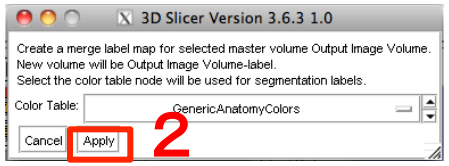


Mask MRI

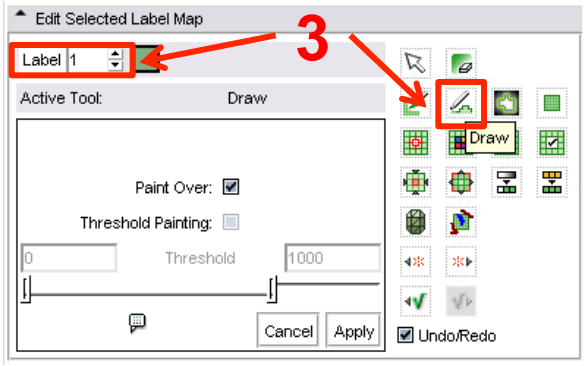
Step 1: MR mask of liver

Output: t2ax-label.nrrd (made automatically when Editor works)

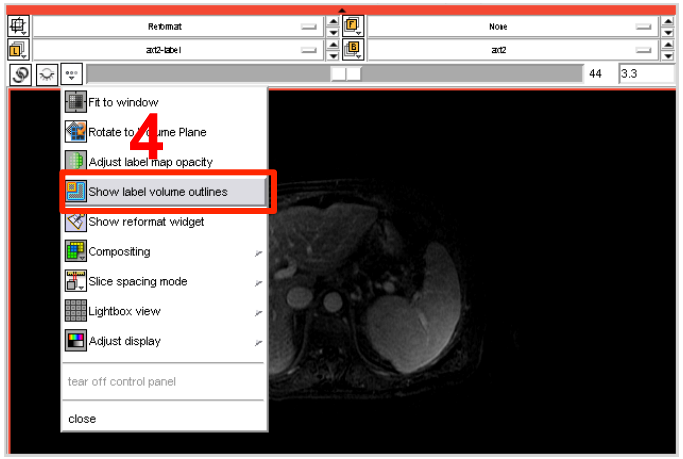
1. Go to the “Editor” module
2. Click “Apply” on the small window about Color table. This will automatically generate a new label volume, called “t2ax-label”.



3. Select “Draw” button of the module pane to segment liver with label 1



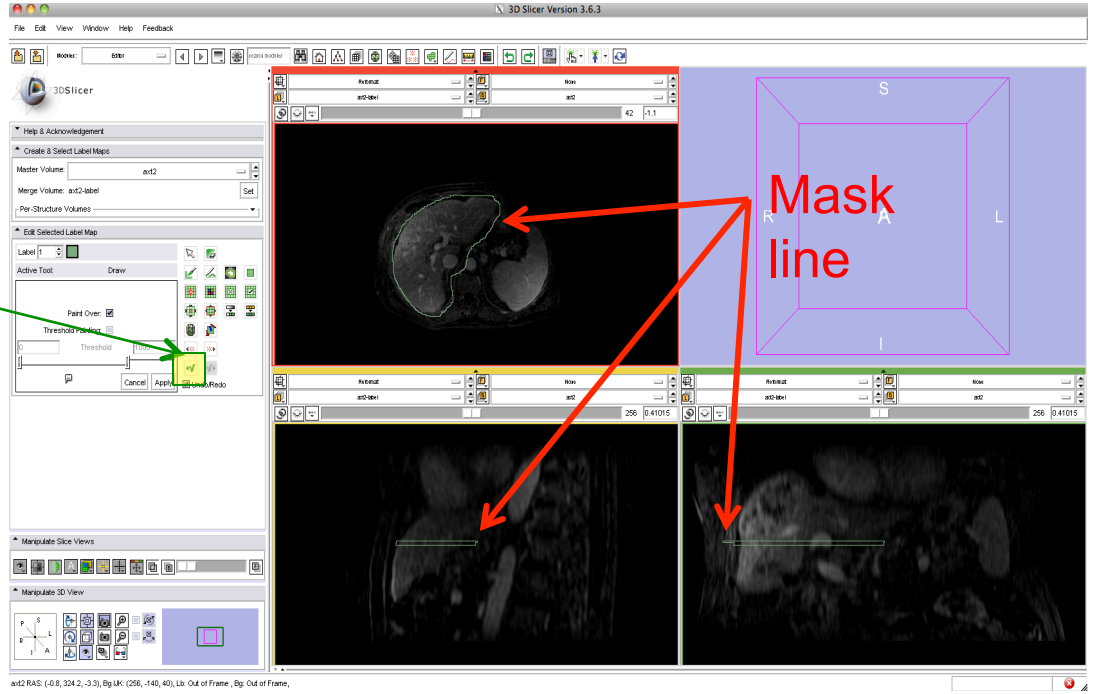
4. Select “Show label volume outline” to confirm the segmented area easily



Step 1: MR mask of liver

Using the draw, draw an outer border around the liver in the current axial slice. When done hit the “Return” key or double click the left mouse to close the contour. Then use the arrow key to advance to the next slice.

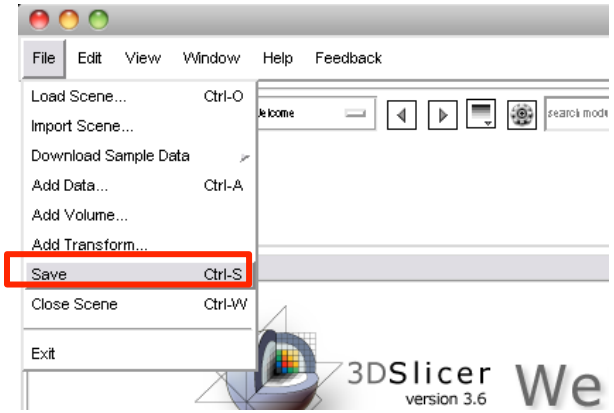
To undo a drawing, click on the left “undo” arrow in the editor palette.



Step 2: CT mask of liver

Input: CT-plan.nrrd, Output: CT-plan-label.nrrd

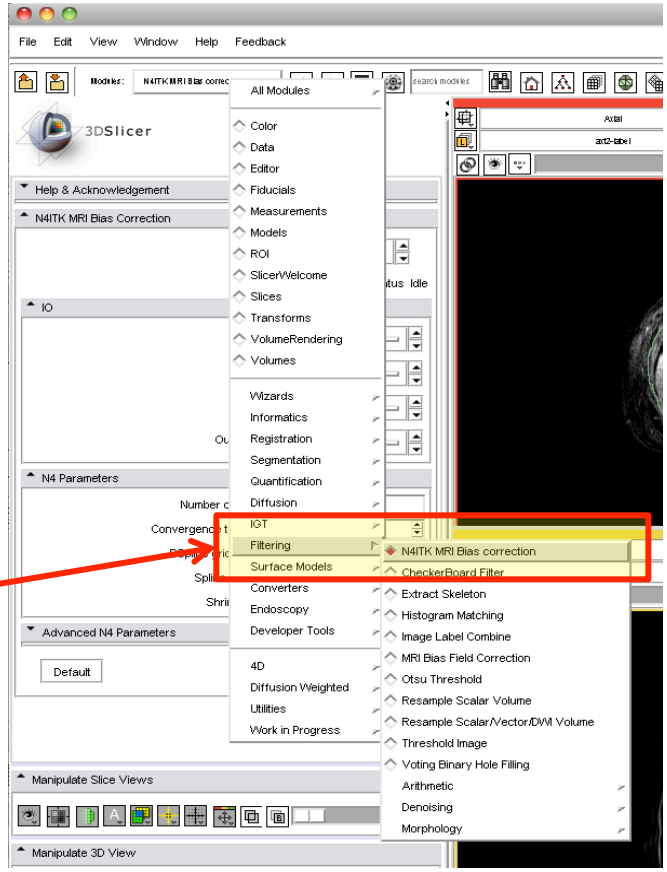
1. Save your current work (via File / Save …)
2. We now repeat the same outlining process on the CT image.
3. In the Editor, select under Master Volume the “CT-plan” volume
4. As before, the editor will automatically suggest a “**CT-plan-label**” automatically.
5. Proceed as for Step 2 above to generate a CT liver mask
6. Again Save your work.



Preprocessing Step 3: MR Bias Correction

The MRI is obtained with surface coils that exhibit a strong intensity falloff, visible in the MR image as areas away from the surface being significantly darker. Because this can negatively affect registration quality, we correct it first. This process of intensity normalization is often called "Bias Correction"

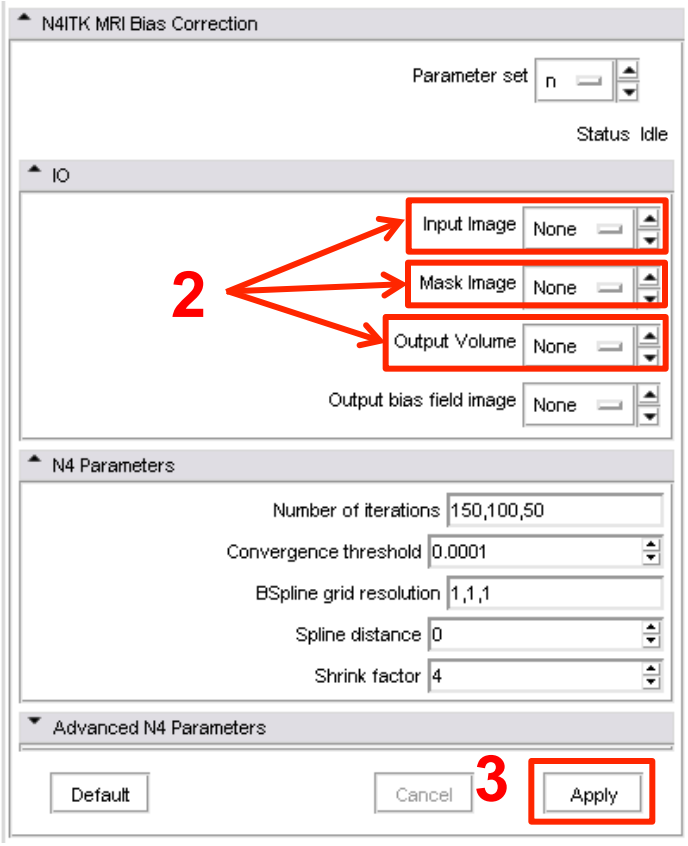
Module Used: "N4ITK MR Bias Correction"
(in the module menu under "Filtering")



Step 3: MR Bias Correction

Input: t2ax.nrrd and t2ax-label.nrrd, Output: t2ax-N4.nrrd

2. Parameters: Input image = t2ax, Mask image = t2ax-label, Output volume = create new volume and name it “t2ax-N4”
3. Click “Apply”
4. You should see a progress bar in the lower right corner. Depending on your CPU, this process will take ca. 1-3 minutes.
5. Save your current work (via File / Save …)



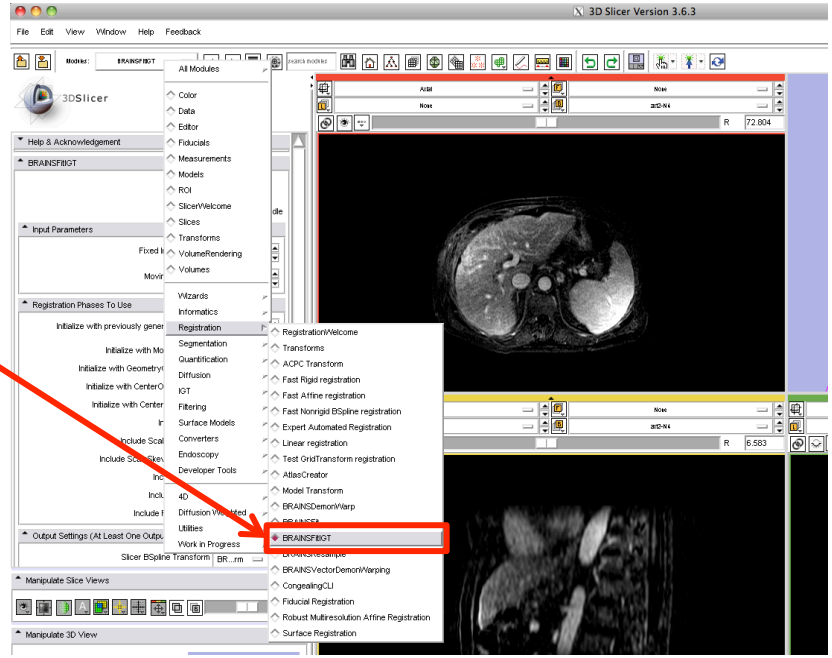
Step 4:
MRI – CT Non-rigid Registration

We've now completed all the preprocessing and are ready for the actual registration.

Step 4: MRI-CT Registration

1. Go to the "BRAINSFitIGT" module in the "Registration" category of the module menu

   (if not using a compiled Slicer version, use the regular BRAINSfit module instead)

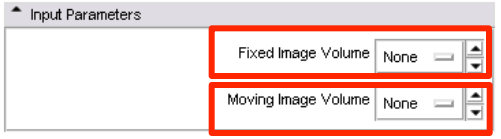


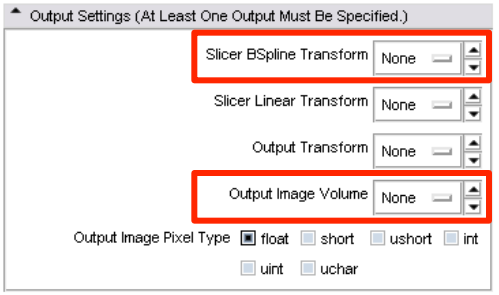
Step 4: MRI-CT Registration

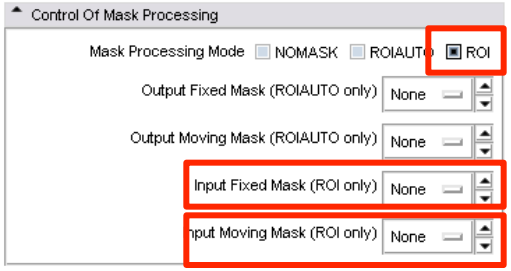
Input: CT-plan.nrrd, t2ax-N4.nrrd, CT-plan-label and t2ax-label

Set “BRAINSFitIGT” module parameters as follows

1. Set Fixed image volume = “CT-plan”, Moving image volume = “t2ax-N4”
2. Select BSpline transform = “create a new transform” and name it “T1”
3. Select Output image volume = “create a new volume” and name it “t2ax-REG”
4. Select Input fixed mask = “CT-plan-label”, Input moving mask = “t2ax-label”. Check “ROI” of Mask Proceeding





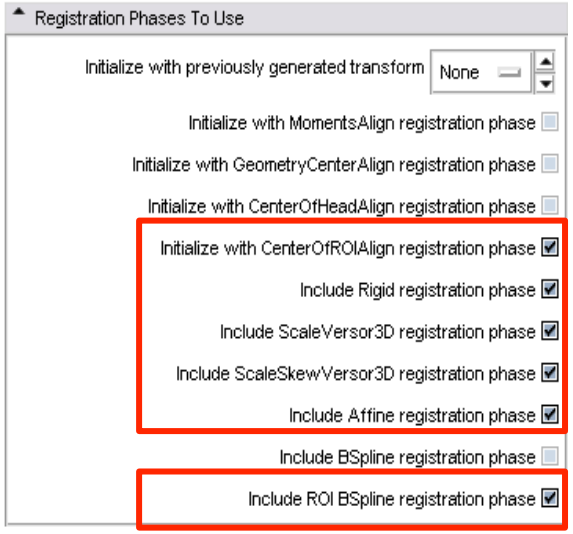


Step 4: MRI-CT Registration

Output: T1 and t2ax-REG

4. Select the Registration methods to run, check the following boxes:

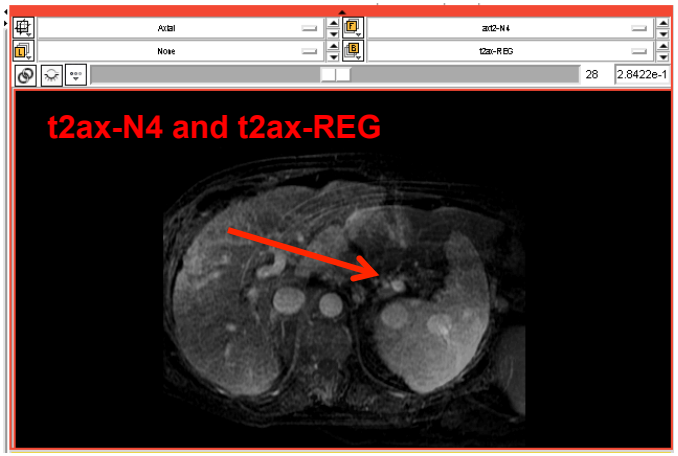
   - "Initialize with CenterOfROIAlign registration phase"
   - "Include Rigid registration phase"
   - "Include ScaleVersor3D registration phase"
   - "Include ScaleSkewVersor3D registration phase"
   - "Include Affine registration phase"
   - "Include ROI BSpline registration phase"

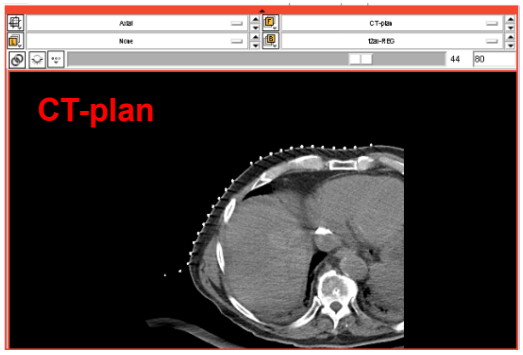


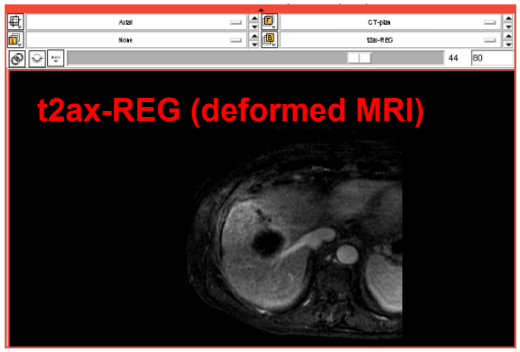
6. Click "Apply"
7. With ~ 1 minute (depending on CPU), you can see the moved and deformed t2ax-N4 image as "t2ax-REG".
8. Save your work.

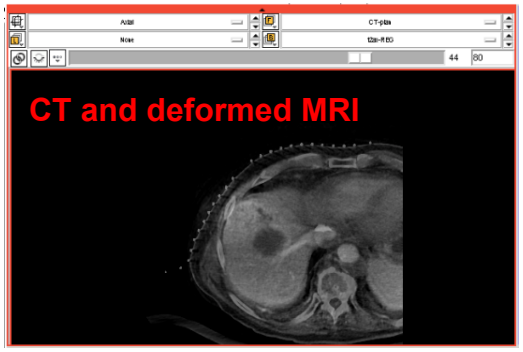
Step 4: MRI-CT Registration Result

1. Select “t2ax-REG” at Background layer and “t2ax-N4” at Foreground layer. Switching between background and foreground you can now see the deformation applied.
2. Select “CT-plan” at Foreground layer. You can see that the shape of the liver on MRI was deformed and fitted the liver on CT image.





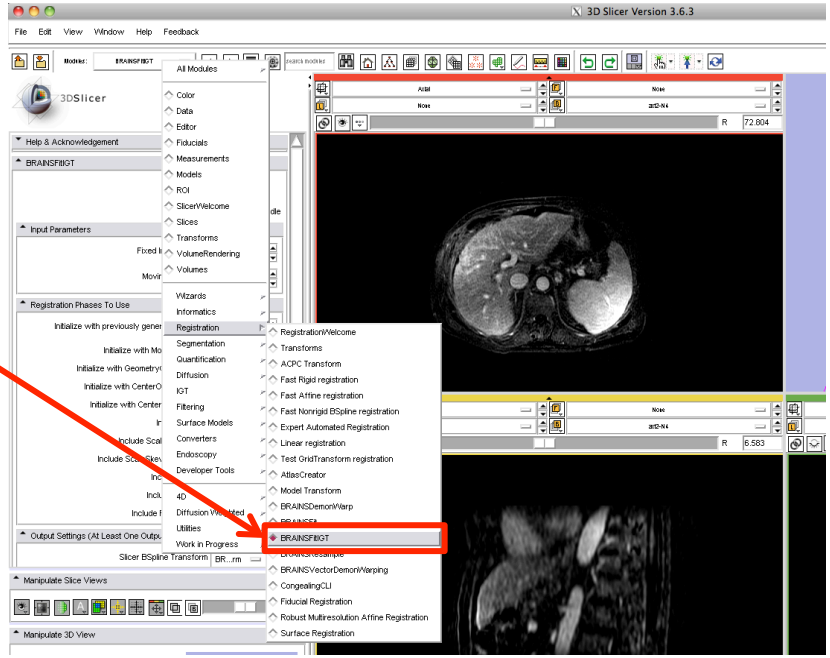




Step 5:
Pre-CT to Intra-CT Affine Registration

Step 5: Pre-CT to Intra-CT Affine Registration

1. Go to the "BRAINSFitIGT" module in the "Registration" category of the module menu

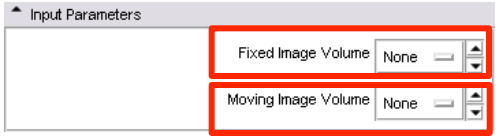


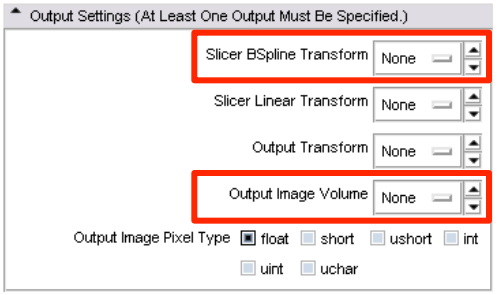
Step 5: Pre-CT to Intra-CT Affine Registration

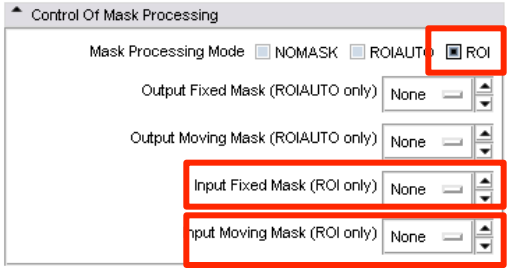
Input: CT-intra.nrrd, CT-plan.nrrd, CT-intra-label and CT-plan-label

Set “BRAINSFitIGT” module parameters as follows

1. Set Fixed image volume = “CT-intra”, Moving image volume = “CT-plan”
2. Select BSpline transform = “create a new transform” and name it “T2”
3. Select Output image volume = “create a new volume” and name it “CT-plan-REG”
4. Select Input fixed mask = “CT-intra-label”, Input moving mask = “CT-plan-label”. Check “ROI” of Mask Proceeding





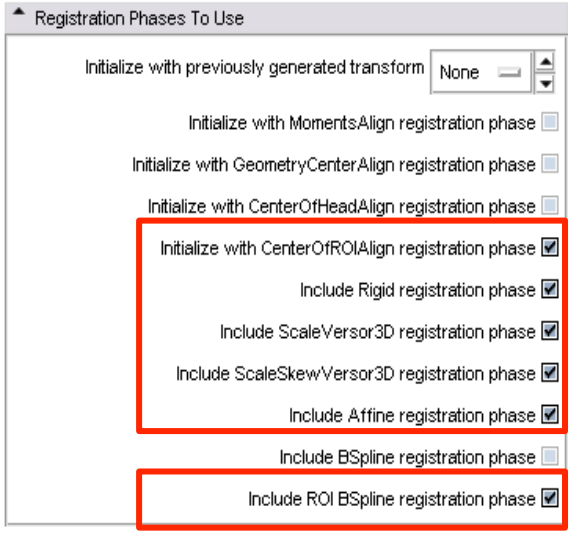


Step 5: Pre-CT to Intra-CT Affine Registration

Output: T2.tfm and CT-plan-REG.nrrd

4. Select the Registration methods to run, check the following boxes:

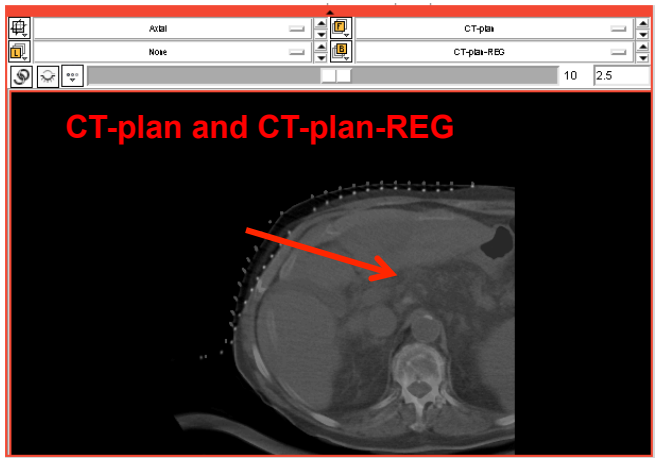
   - "Initialize with CenterOfROIAlign registration phase"
   - "Include Rigid registration phase"
   - "Include ScaleVersor3D registration phase"
   - "Include ScaleSkewVersor3D registration phase"
   - "Include Affine registration phase"
   - "Include ROI BSpline registration phase"

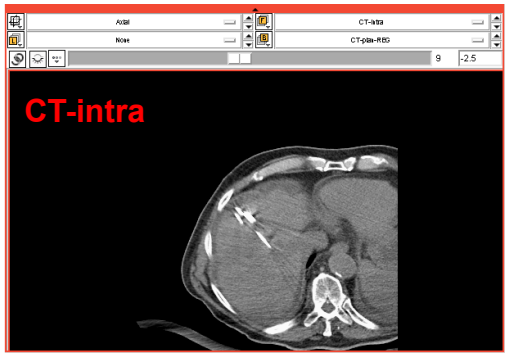


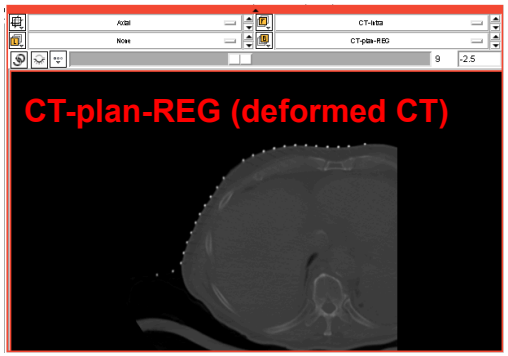
6. Click "Apply"
7. With ~ 1 minute (depending on CPU), you can see the moved and deformed CT-plan image as "CT-plan-REG".
8. Save your work.

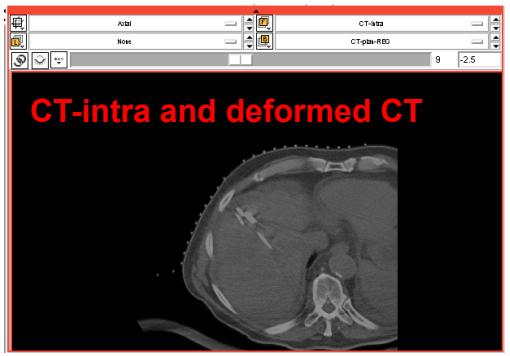
Step 4: MRI-CT Registration Result

1. Select “CT-plan-REG” at Background layer and “CT-plan” at Foreground layer. Switching between background and foreground you can now see the deformation applied.
2. Select “CT-intra” at Foreground layer. You can see that the shape of the liver on CT-plan was deformed and fitted the liver on CT-intra image.









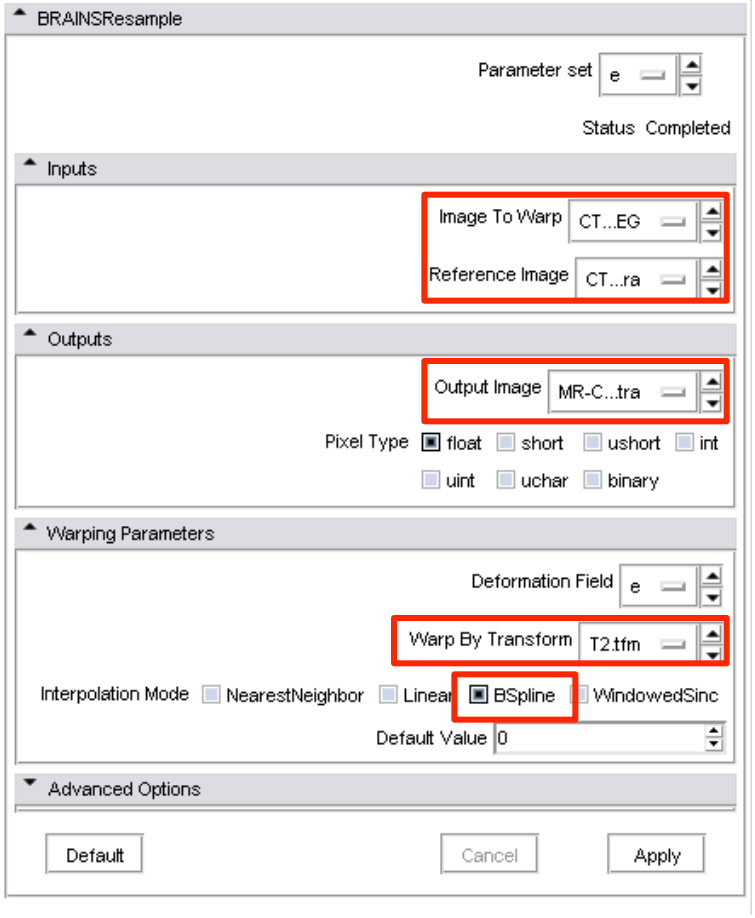
Step 6: Resampling of the MRI to Intra-CT Image and Fusion

We've now completed all the preprocessing and are ready for the actual registration.

Step 6: Resampling and Fusion

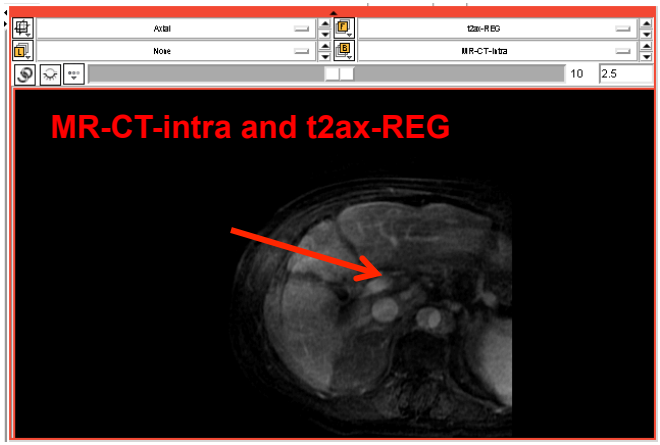
Input: t2ax-REG.nrrd, CT-intra.nrrd, T2.tfm, Output: MR-CT-intra.nrrd

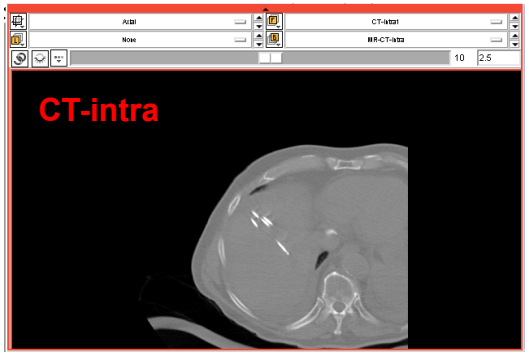
1. Go to BRAINSResample module
2. Set Image To Warp = “t2ax-REG”, Reference Image = “CT-intra”, Output Image = create a new volume and name it “MR-CT-intra”, Warp By Transform = “T2.tfm”.
3. Check Interpolation mode “BSpline” of Warping Parameters
4. Click “Apply”
5. After about 6 sec (depending on CPU), you can see the moved and deformed t2ax-REG image as “MR-CT-intra”.

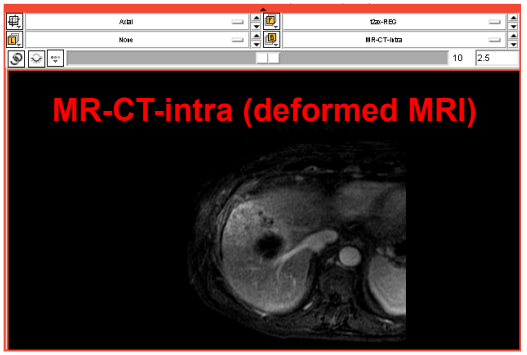


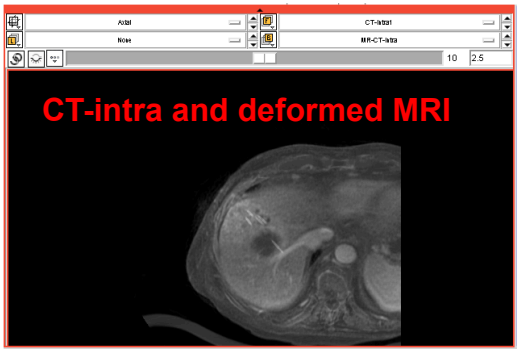
Step 6: Resampling and Fusion

1. Select “MR-CT-intra” at Background layer and “t2ax-REG” at Foreground layer. Switching between background and foreground you can now see the deformation applied.
2. Select “CT-intra” at Foreground layer. You can see that the shape of the liver on MR-CT-intra was deformed and fitted the liver on CT-intra image.









Conclusion

- 3D Slicer with BRAINSFitIGT module successfully performs non-rigid image registration of MR and CT liver data.
- For this particular type of image data, masking of the region of interest is usually necessary to obtain a good result.
- In the fused image pair, the distance between the cryoprobe on CT and the tumor on MR can now be assessed.

Acknowledgments

National Alliance for Medical Image Computing

NIH U54EB005149

This publication was made possible by grant numbers

5P41RR019703, 5P01CA067165, 1R01CA124377 and 5U54EB005149 and **NEDO, Japan**