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GENERAL HOSPITAL

RADIATION ONCOLOGY

# Deformable Image Registration Using B-Splines

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**“No conflict of interest”**

# Acknowledgements

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- NSF EEC-0946463

# Outline

- Theory of B-spline registration
  - What are B-splines?
  - How are they optimized in registration?
- Using B-splines and open-source for ART
  - Plastimatch – registration
  - 3D Slicer and vv – visualization
  - CERR – plan review

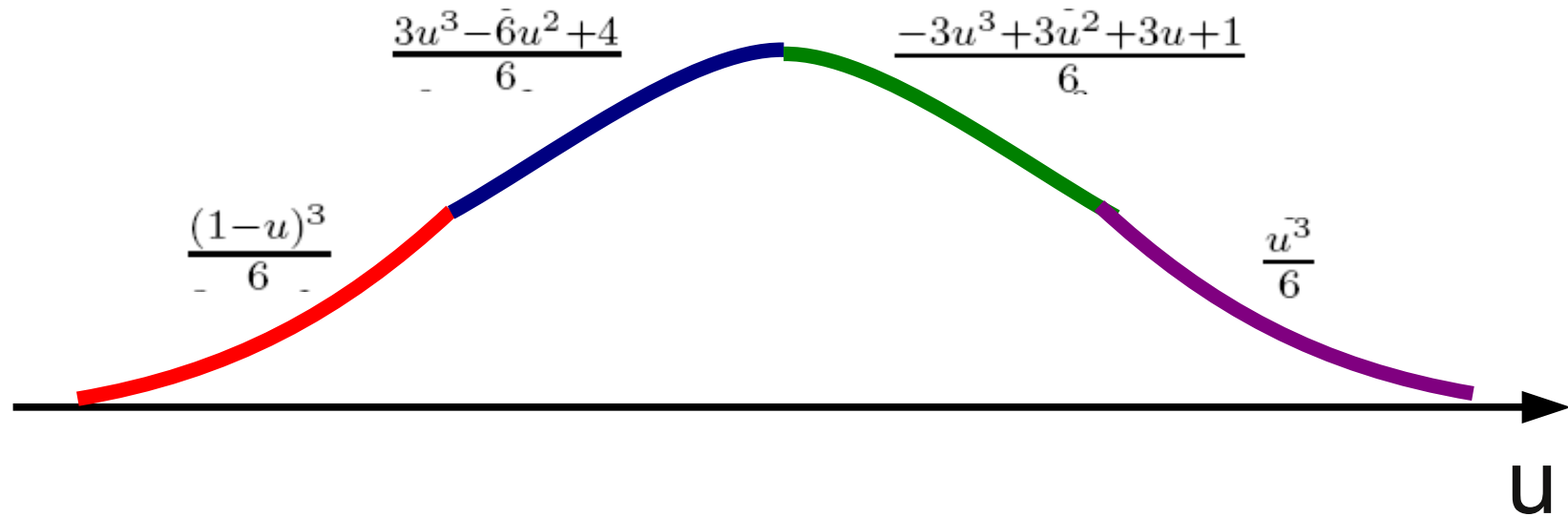
# B-splines

- B-spline is short for “basis spline”
- A function is represented as a linear combination of basis functions

$$v(x) = \sum_i p_i \beta_i(x)$$

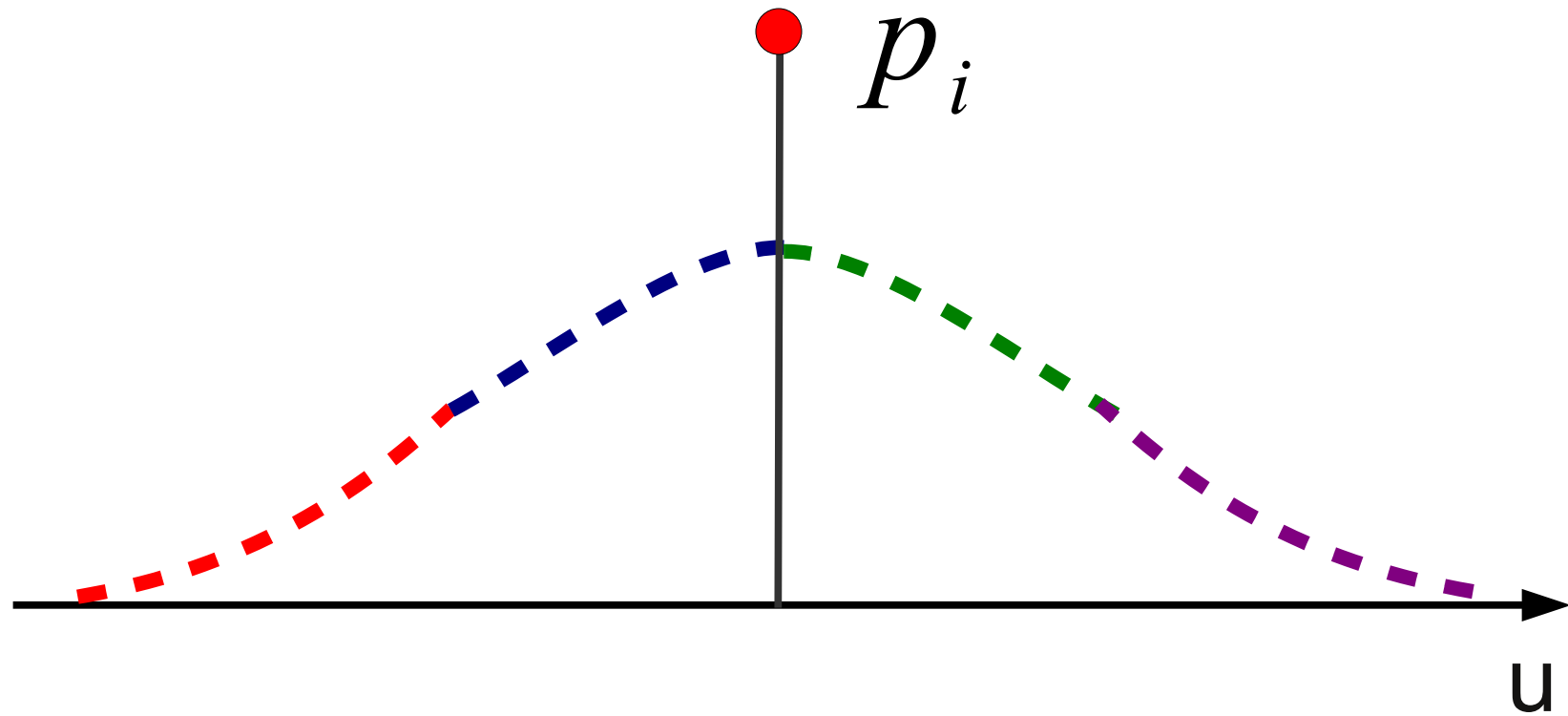
# Cubic B-splines

$\beta(u)$  is a piecewise cubic polynomial

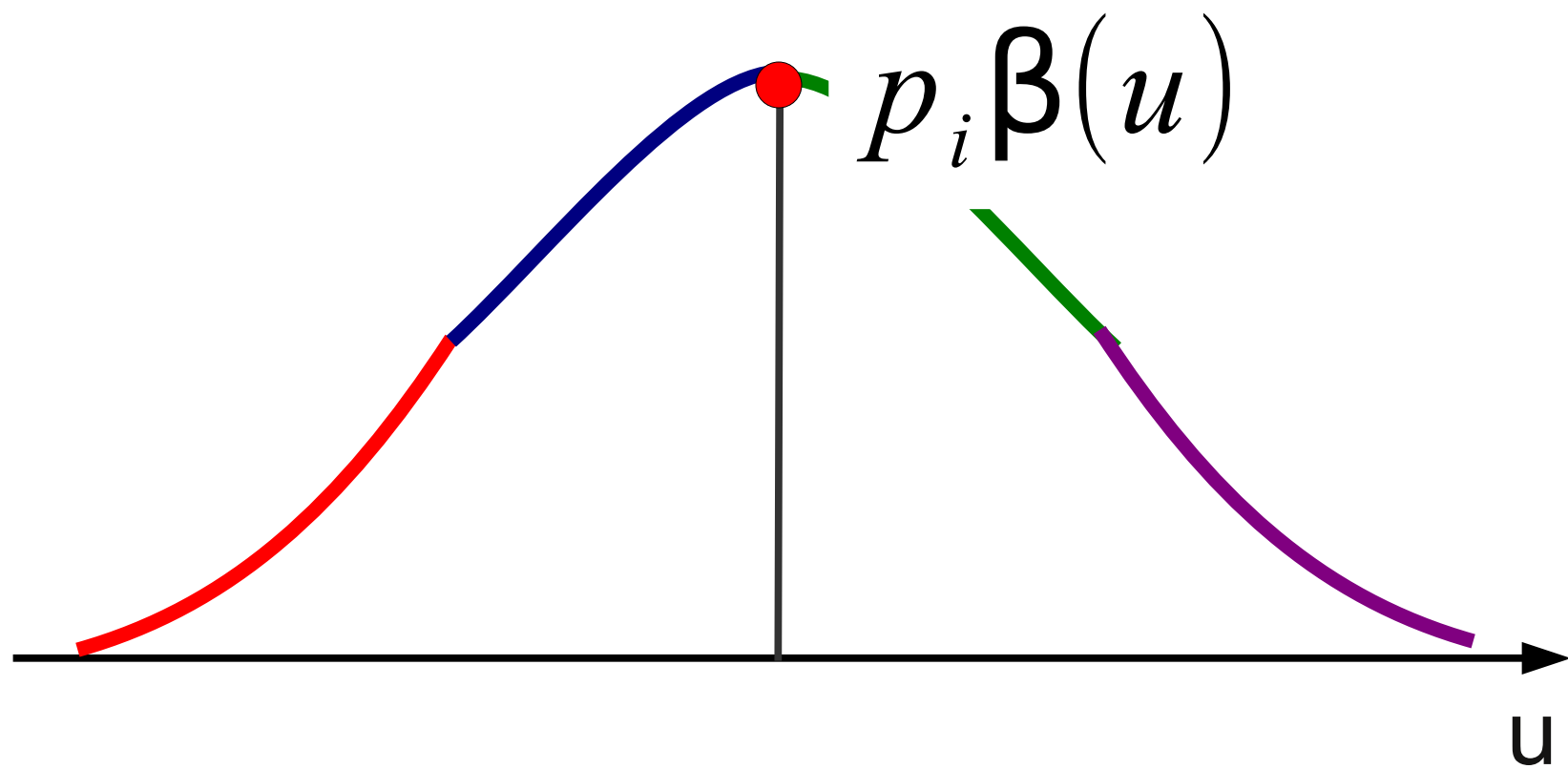


# Cubic B-splines

$p_i$  is a scaling factor



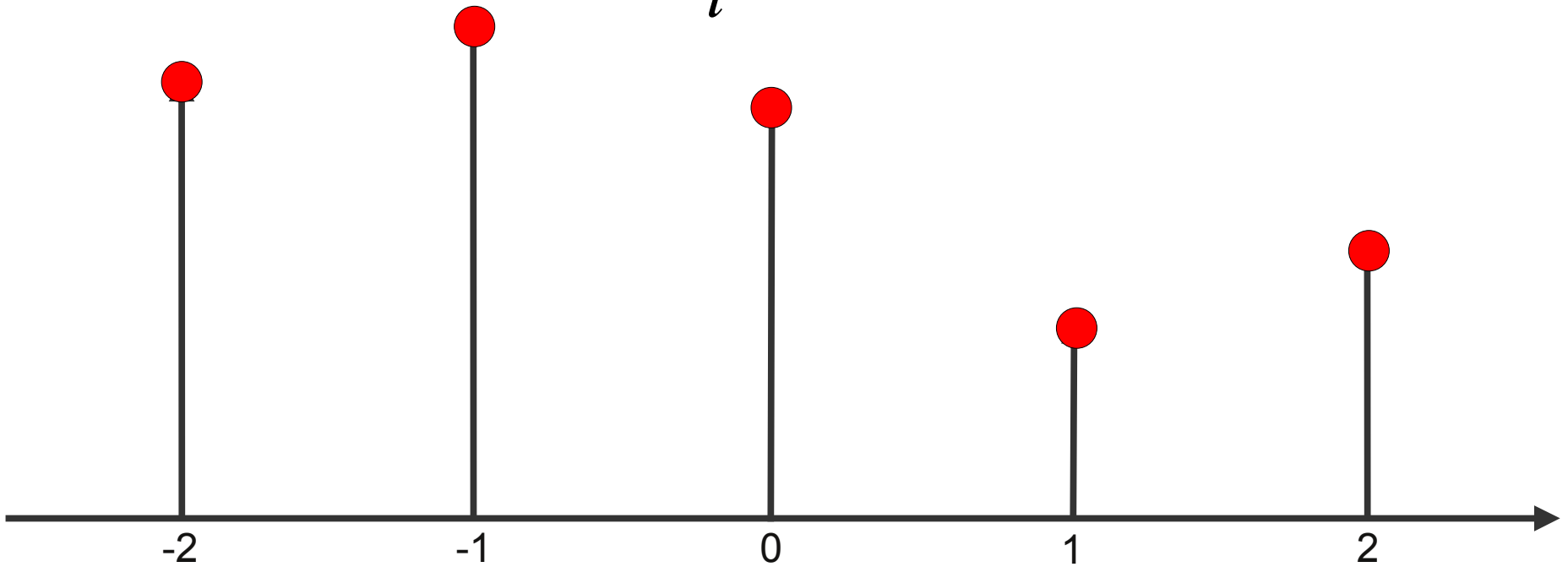
# Cubic B-splines





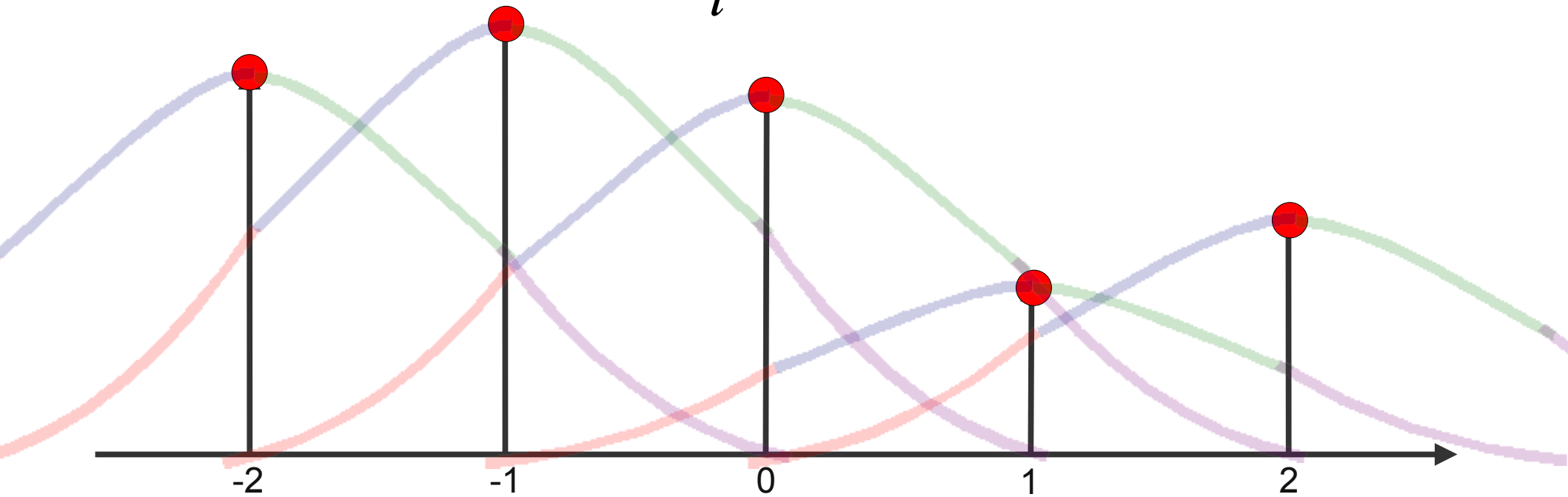
# Uniform cubic B-splines

$$v(x) = \sum_i p_i \beta_i(x)$$

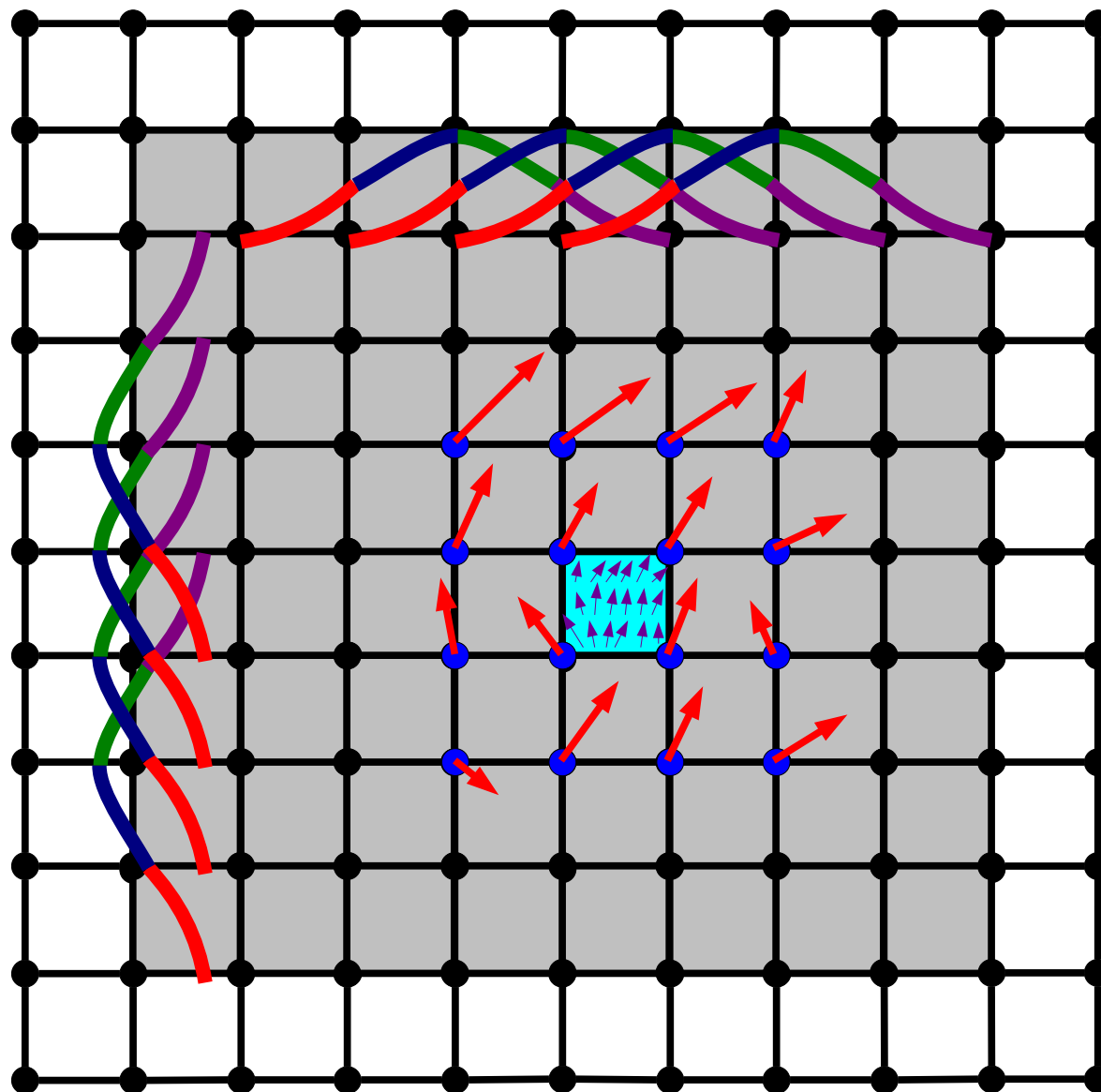


# Uniform cubic B-splines

$$v(x) = \sum_i p_i \beta_i(x)$$



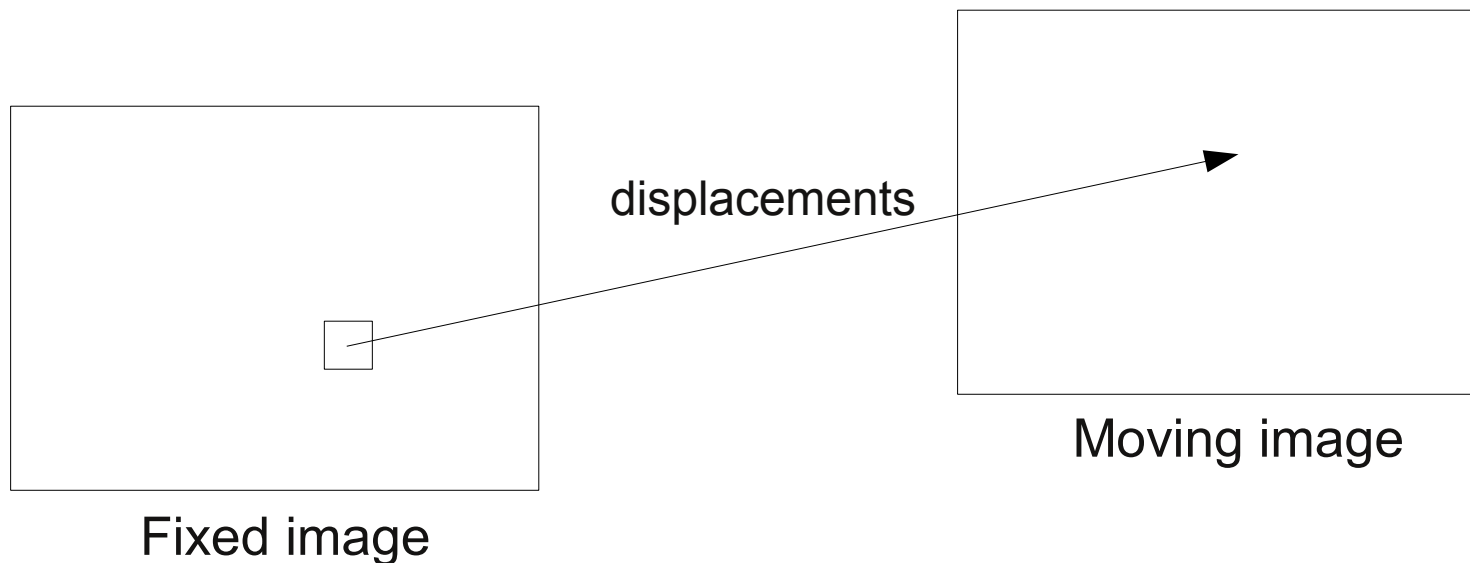
# B-splines for vector fields



# Optimizing B-splines for image registration

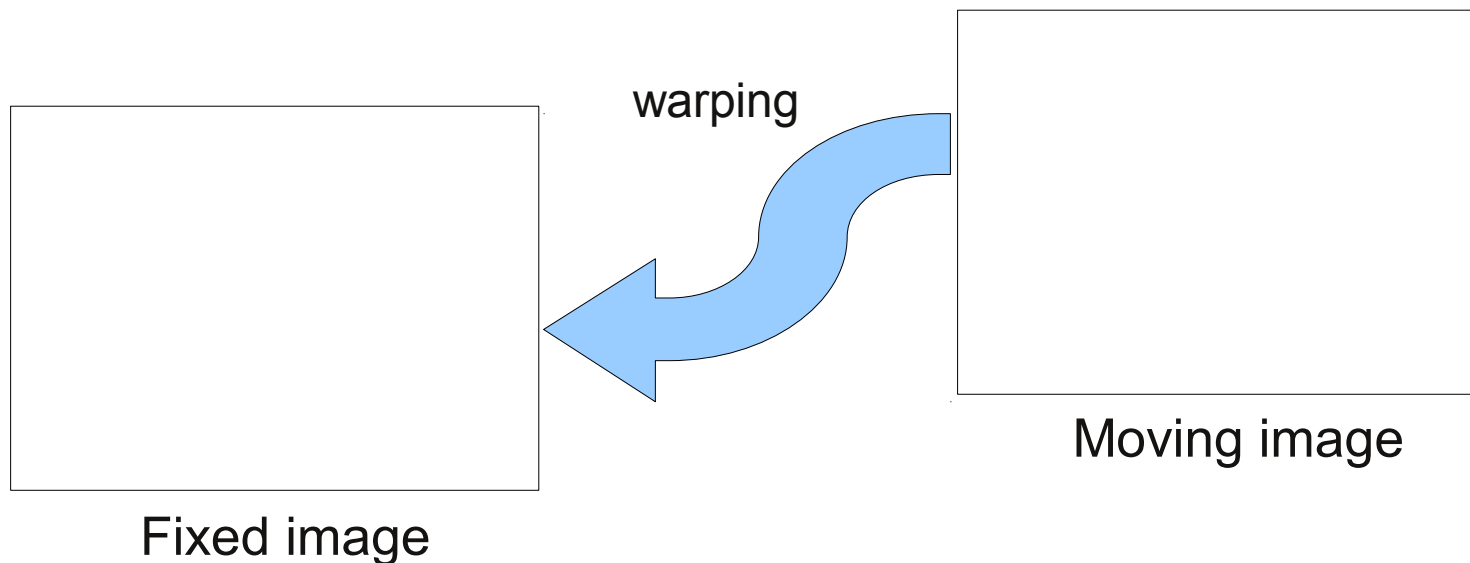
# Fixed and moving images

- Vector field is defined on *fixed image*
  - A.k.a. Reference image, static image
- Vector field maps fixed image to *moving image*
  - A.k.a. Test image, target image



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  - A.k.a. Reference image, static image
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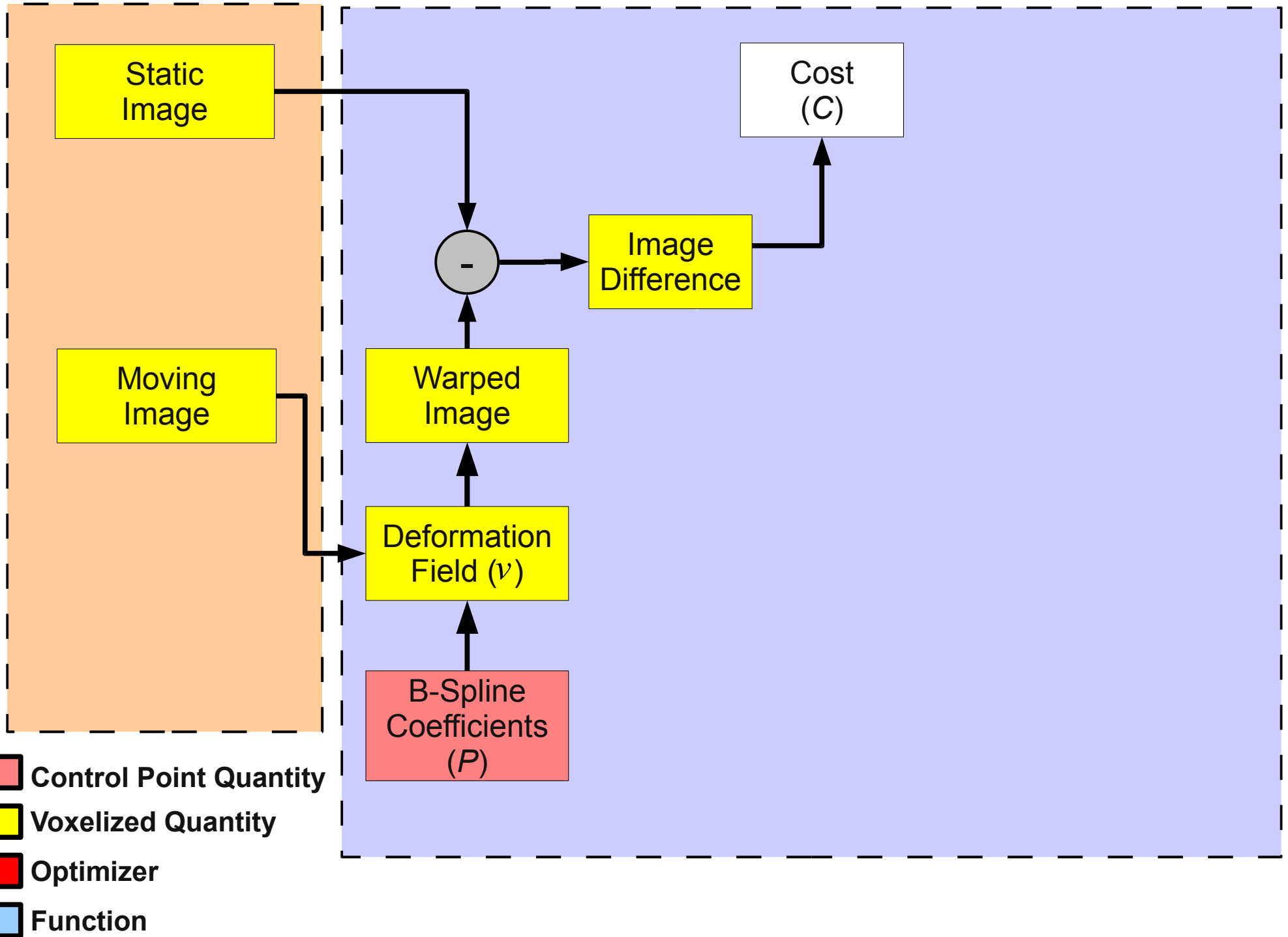
# Image similarity metric

- Sum of Squared Difference (SSD)
  - A.k.a. MSE, RMS, ...
- $F$  is fixed image,  $M$  is moving image
- $i = (x,y,z)$  is a voxel location in fixed image
- $v$  is the vector field

$$C = \sum_{i=(x,y,z)} [F(i) - M(i + v(i))]^2$$

## INPUTS

## ITERATIVE REGISTRATION PROCESS





# Cost function gradient

- Sum of Squared Difference (SSD)

$$C = \sum_{i=(x,y,z)} [F(i) - M(i + v(i))]^2$$

- We want to optimize the B-spline coefficients:

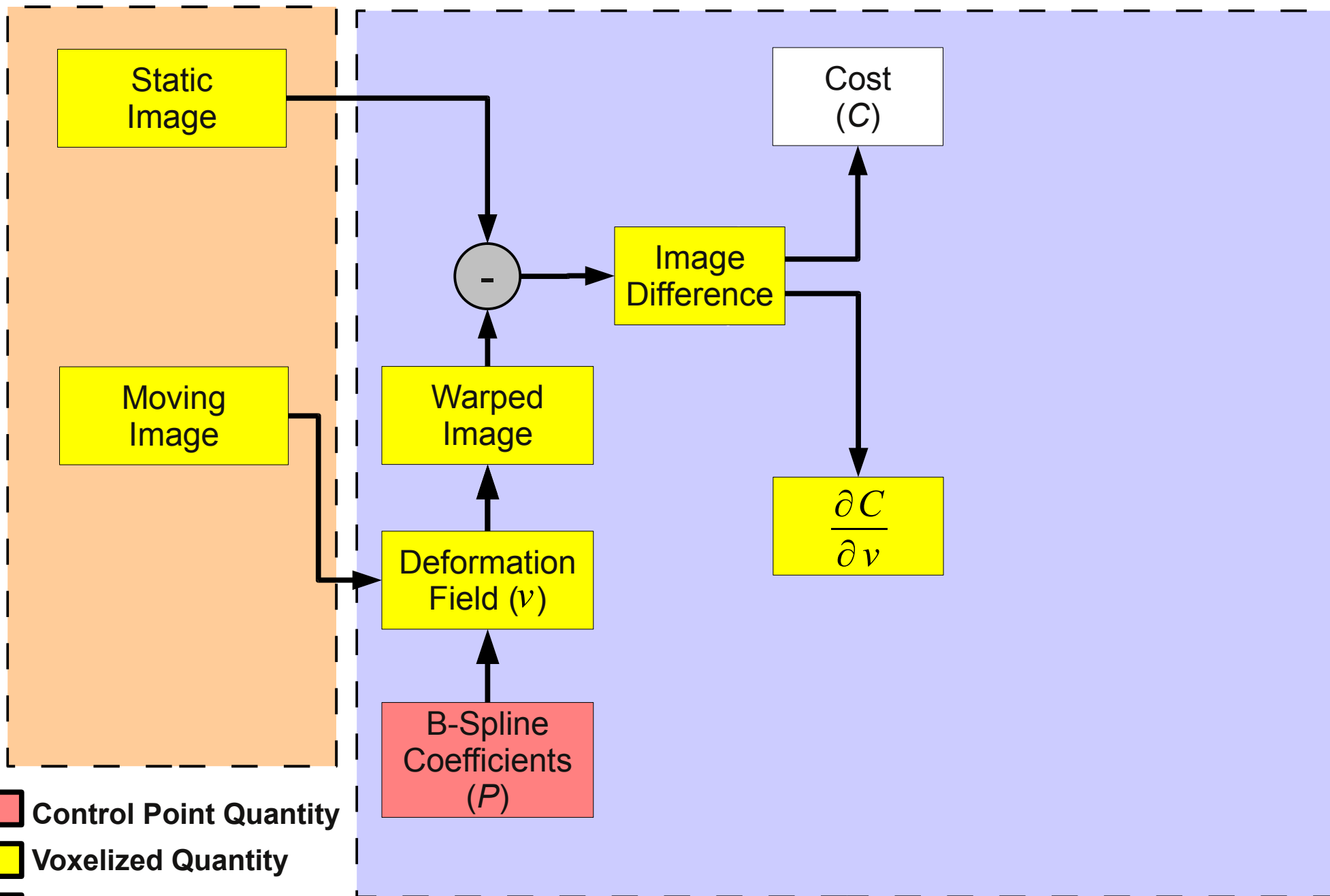
$$v(x) = \sum_i p_i \beta_i(x)$$

- Need the gradient of C with respect to  $P$ :

$$\frac{\partial C}{\partial P} = \frac{\partial C}{\partial v} \frac{\partial v}{\partial P}$$

## INPUTS

## ITERATIVE REGISTRATION PROCESS



Control Point Quantity

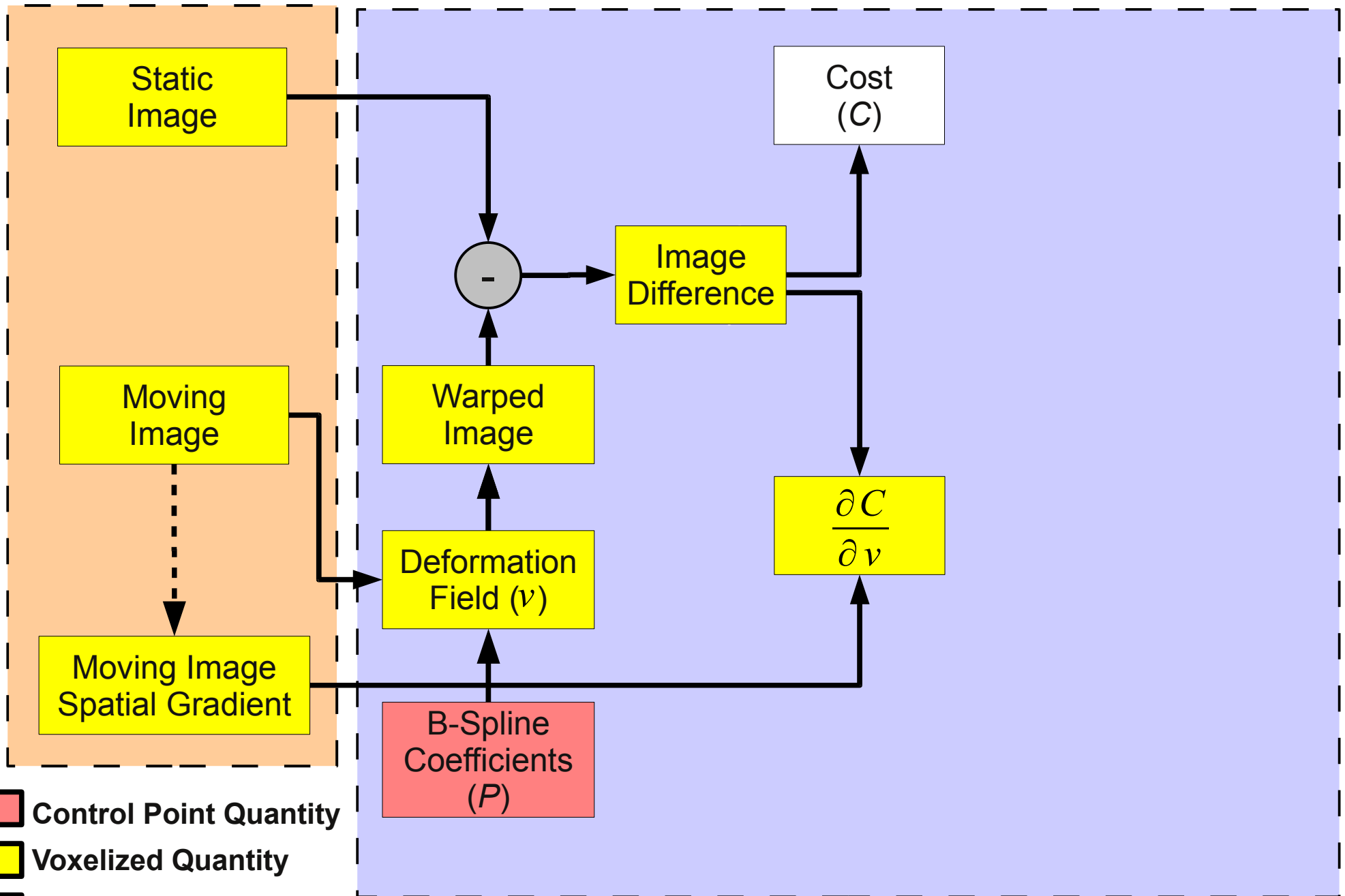
Voxelized Quantity

Optimizer

Function

## INPUTS

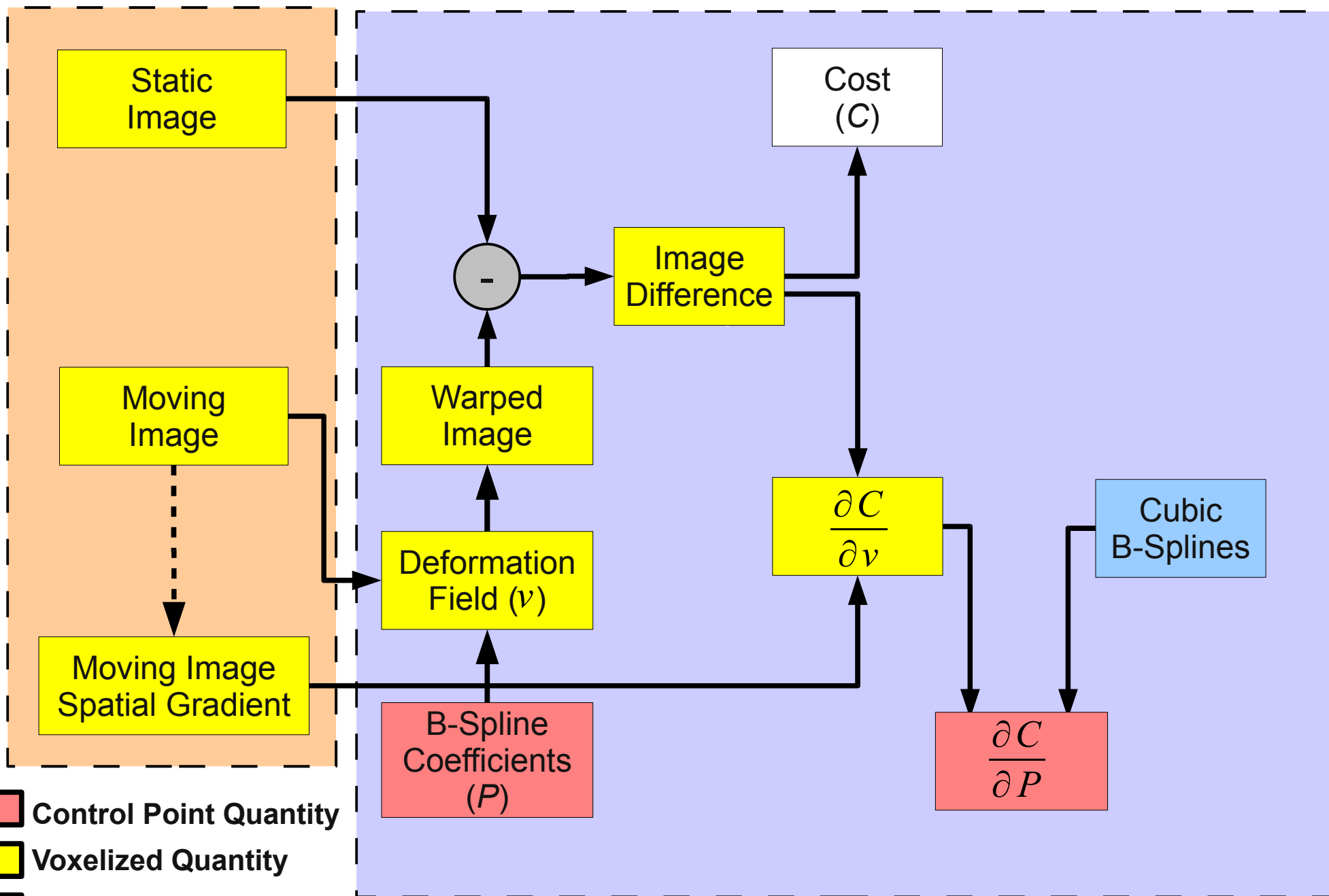
## ITERATIVE REGISTRATION PROCESS





## INPUTS

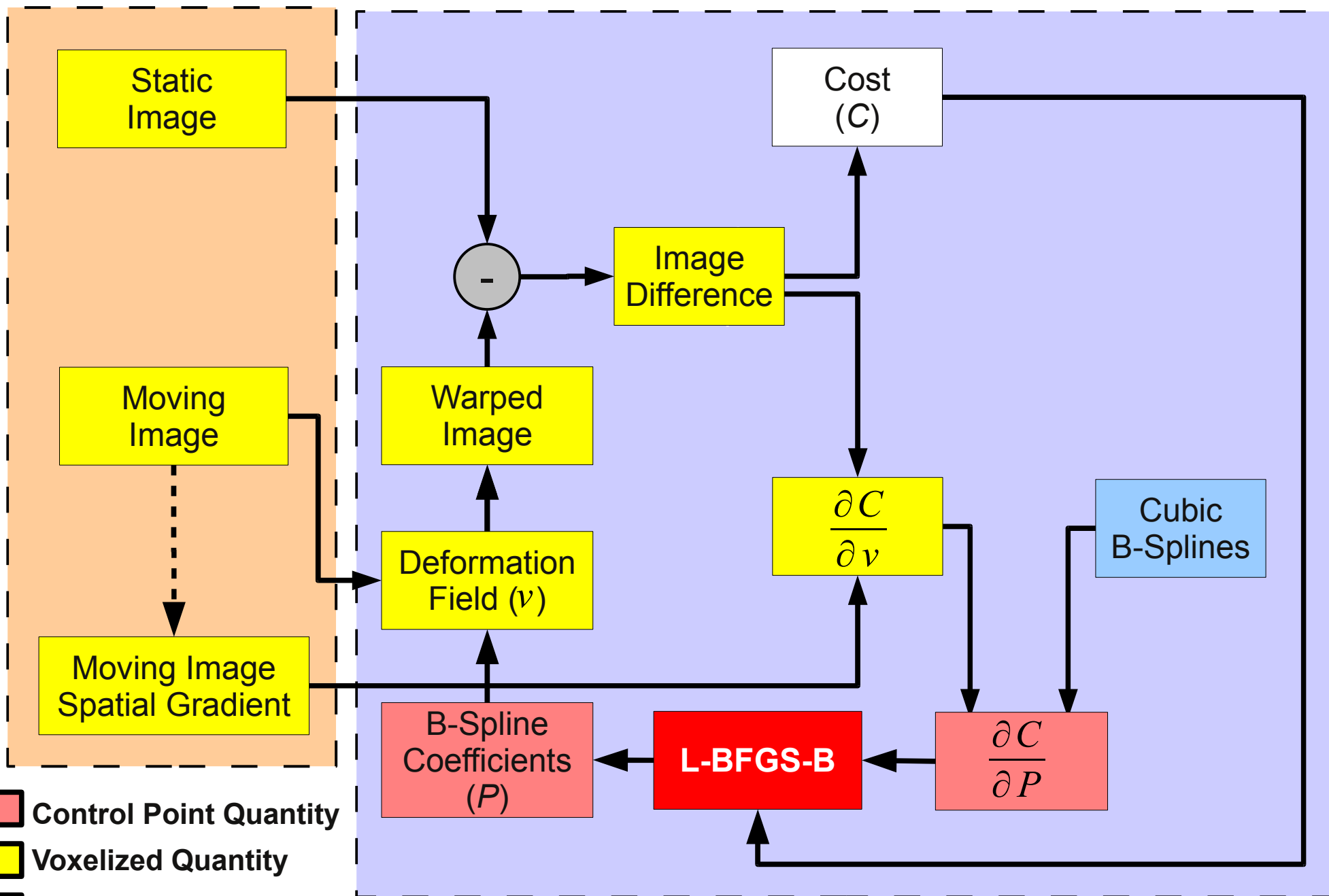
## ITERATIVE REGISTRATION PROCESS



- Control Point Quantity
- Voxelized Quantity
- Optimizer
- Function

## INPUTS

## ITERATIVE REGISTRATION PROCESS



- Control Point Quantity
- Voxelized Quantity
- Optimizer
- Function

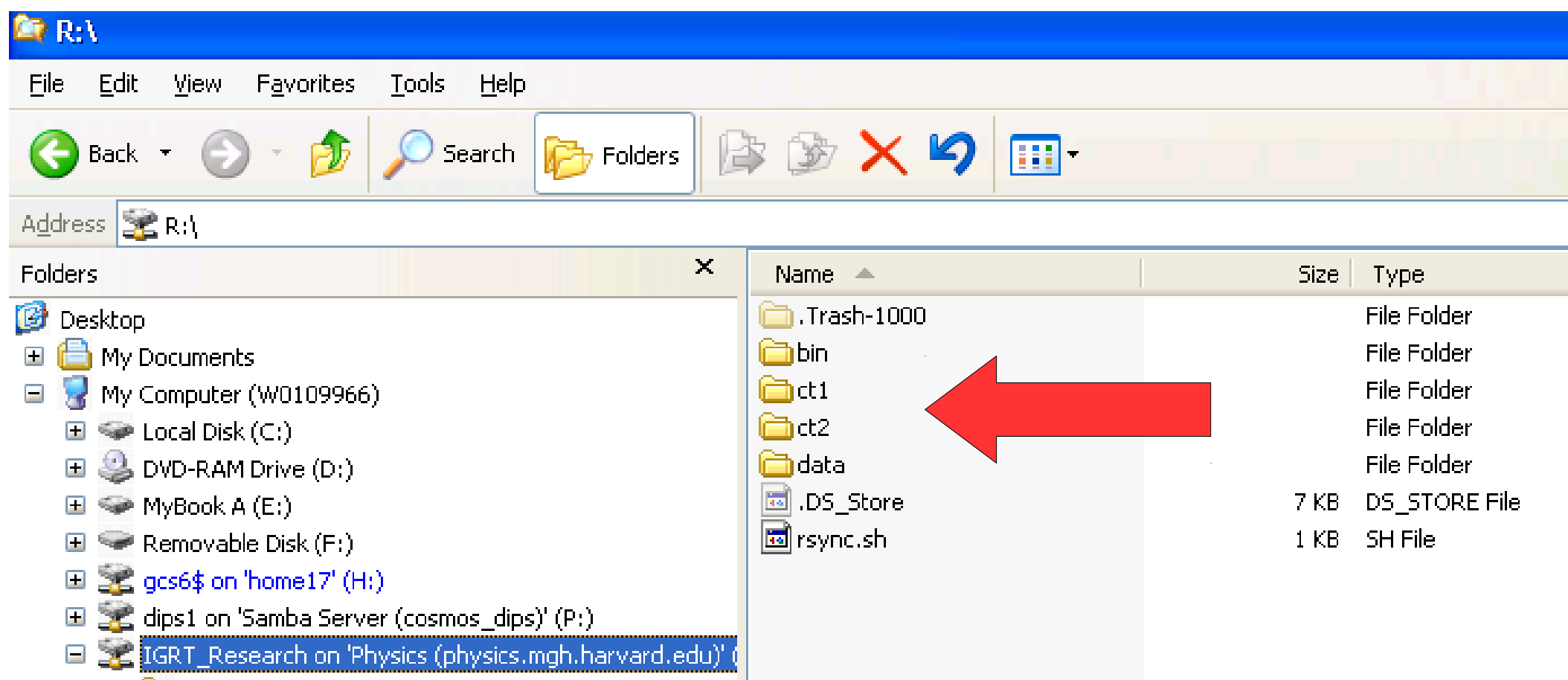
Using B-Splines with  
open source tools for  
adaptive planning

# Open source tools

- Plastimatch <http://plastimatch.org>
- 3D Slicer <http://slicer.org>
- VV <http://www.creatis.insa-lyon.fr/rio/vv>
- CERR <http://radium.wustl.edu/CERR>
- These tools are for research only, and have not been reviewed or approved by the FDA or any other agency

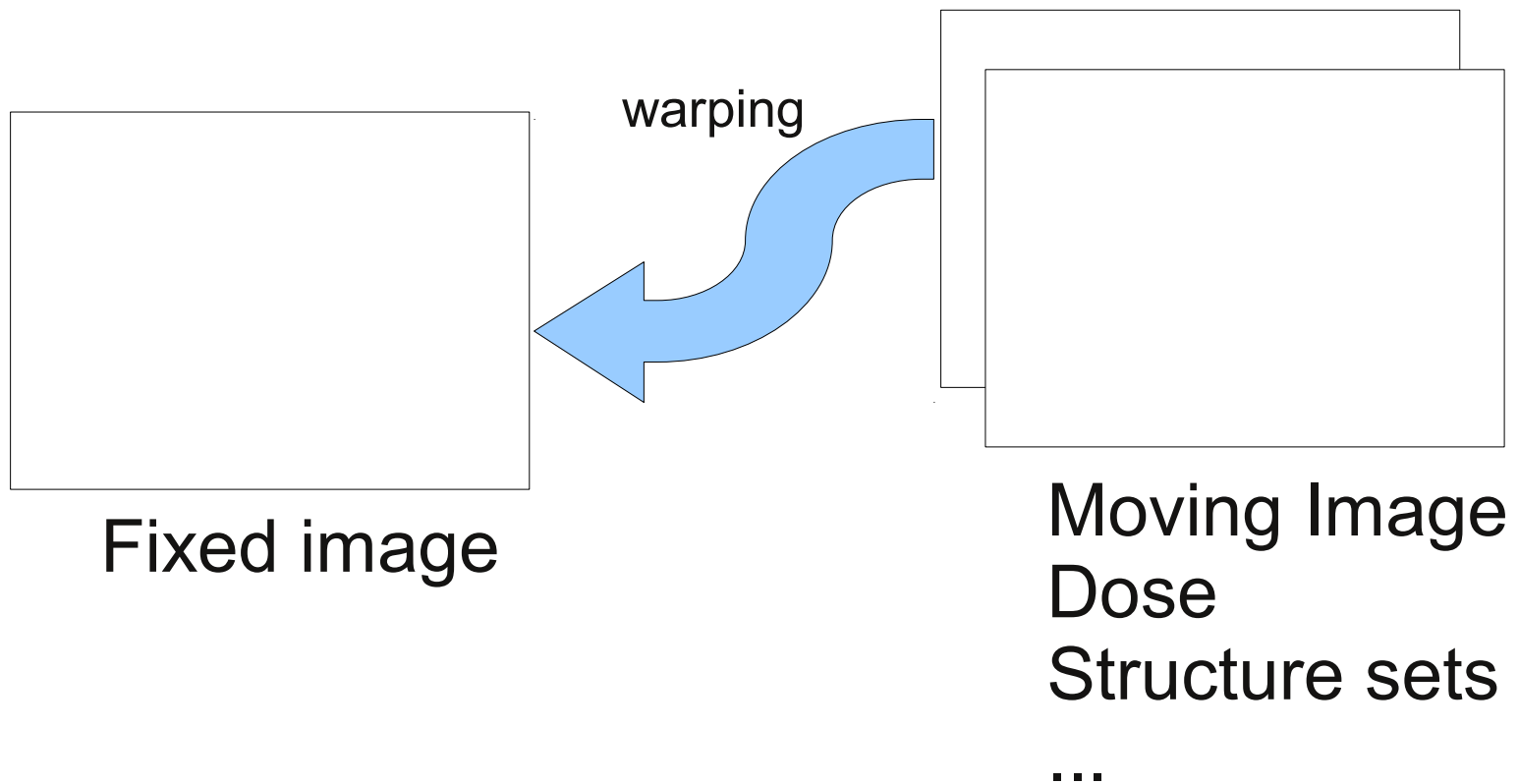


# B-Spline registration

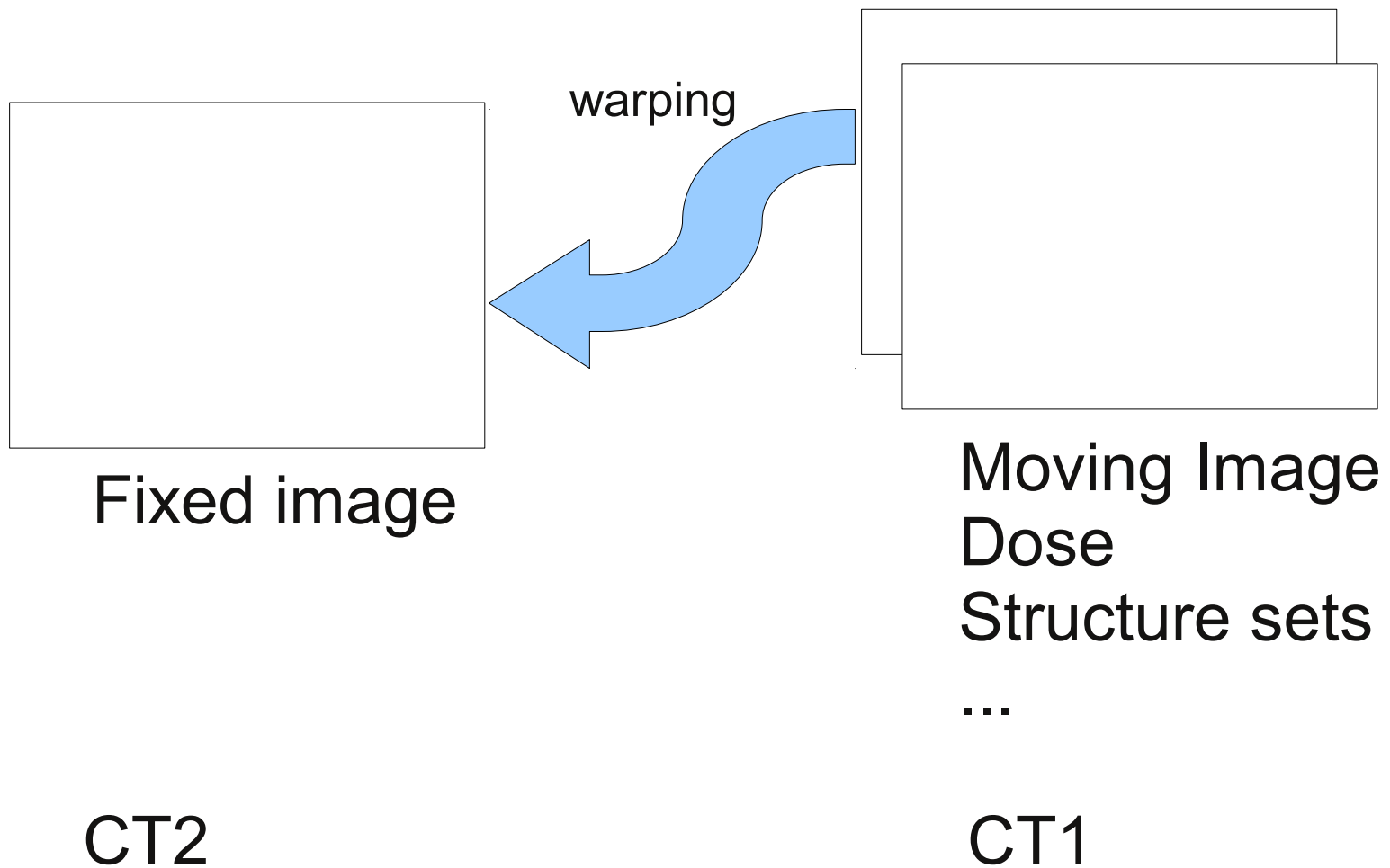


ct1 is original plan  
ct2 is boost plan  
Data is DICOM-RT

# B-Spline registration



# B-Spline registration

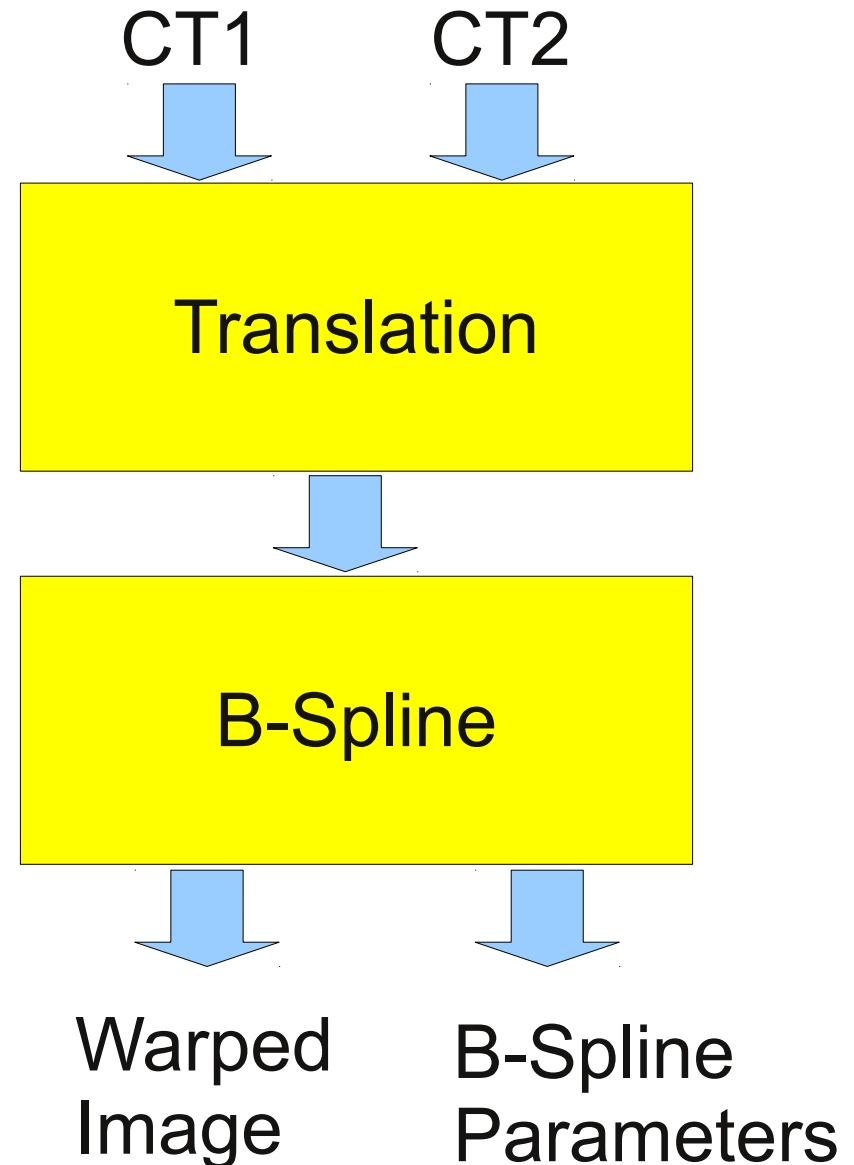


# B-Spline registration

```
[GLOBAL]
fixed=ct2
moving=ct1
img_out=warped.mha
xform_out=bspline.txt
```

```
[STAGE]
xform=translation
max_its=50
res=4 4 2
```

```
[STAGE]
xform=bspline
max_its=50
grid_spac=100 100 100
res=4 4 2
```

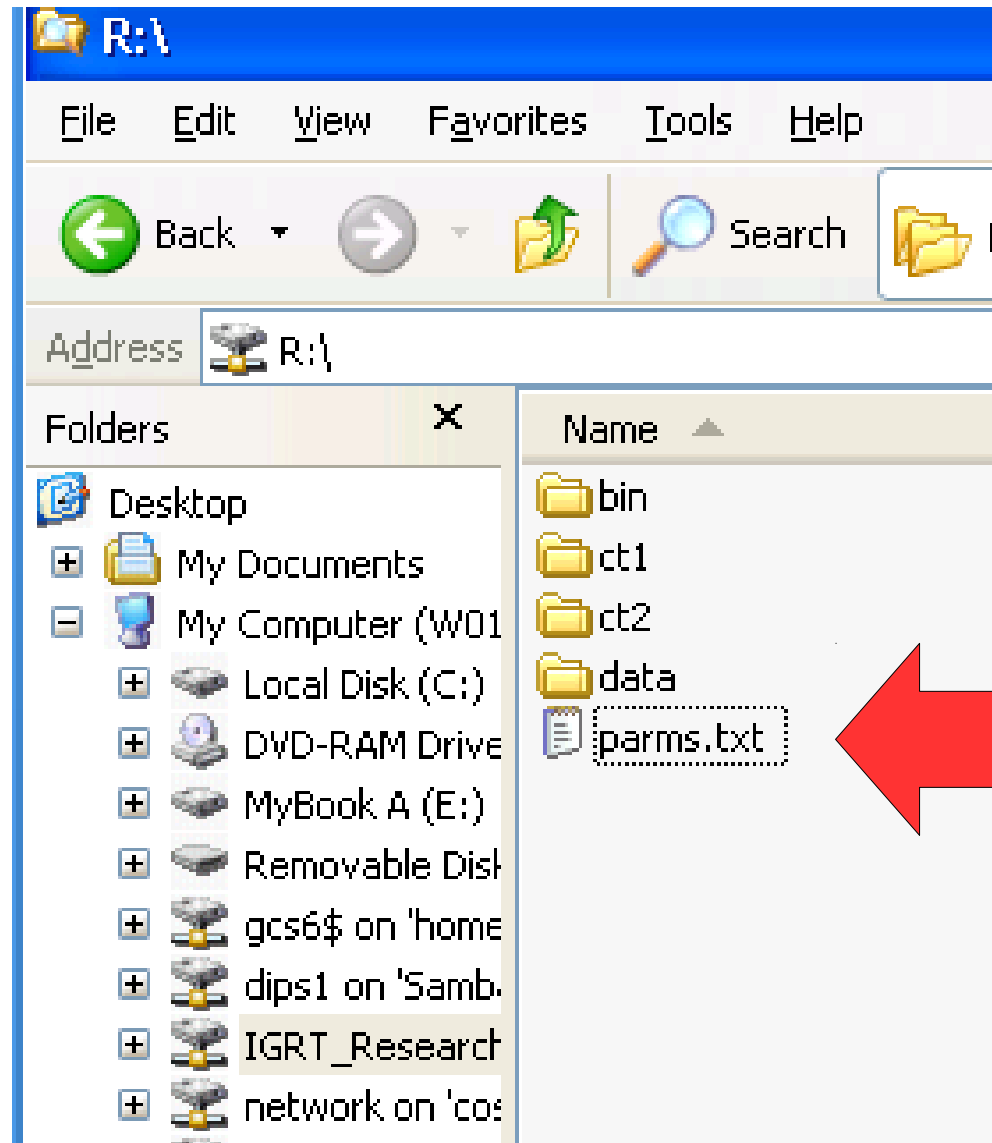


# B-Spline registration

[GLOBAL]  
fixed=ct2  
moving=ct1  
img\_out=warped.mha  
xform\_out=bspline.txt

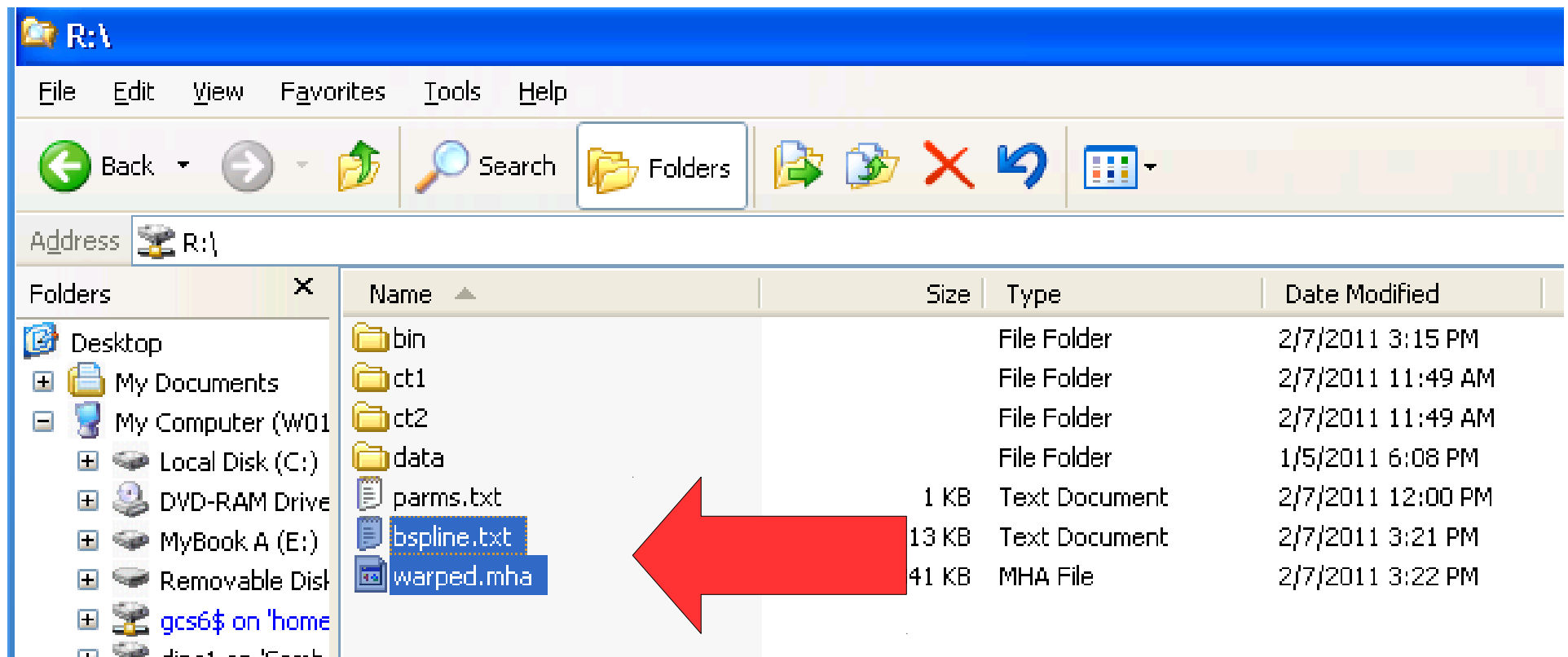
[STAGE]  
xform=translation  
max\_its=50  
res=4 4 2

[STAGE]  
xform=bspline  
max\_its=50  
grid\_spac=100 100 100  
res=4 4 2

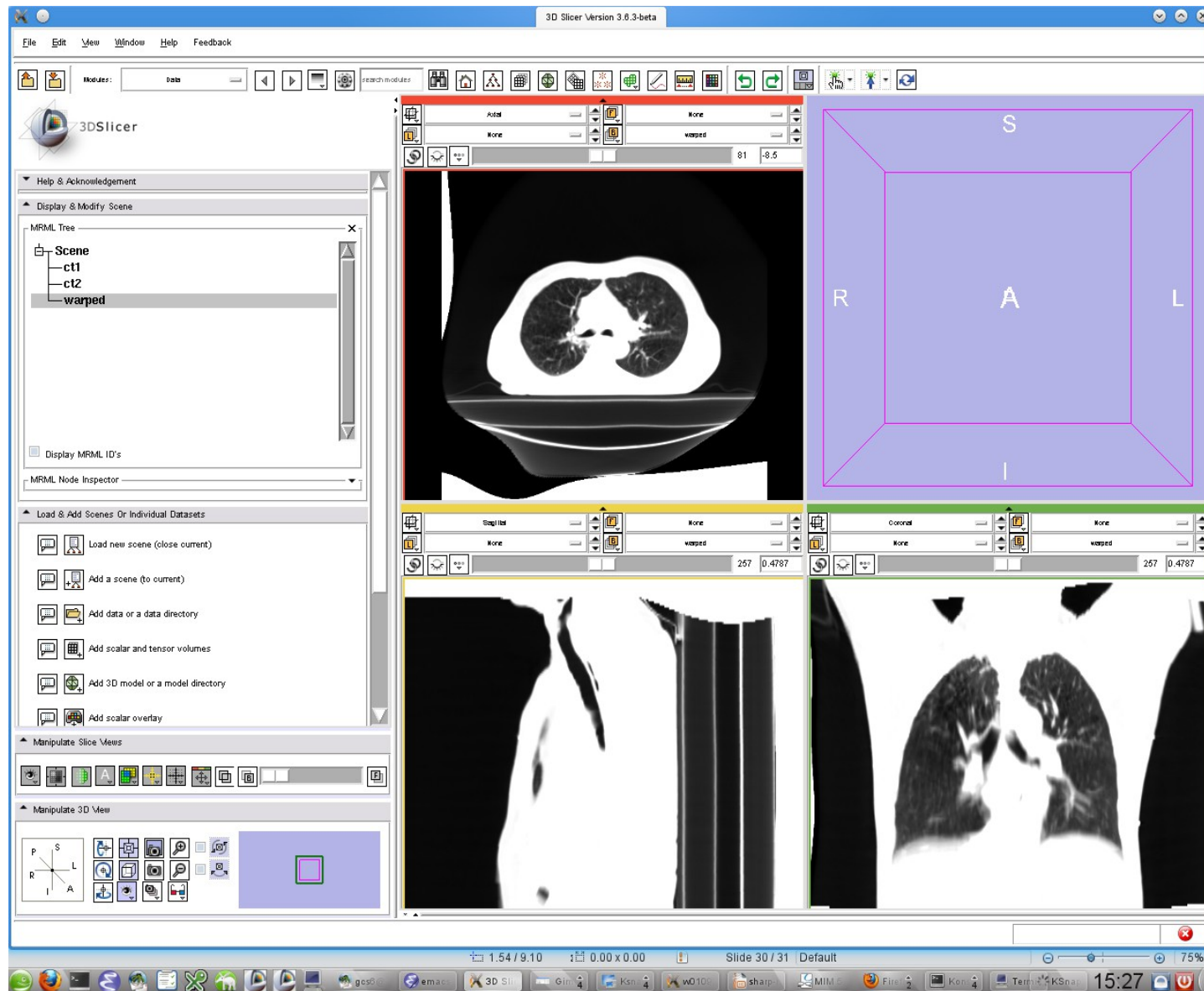


# B-Spline registration

- Run registration command:  
plastimatch parms.txt
- Output files are generated



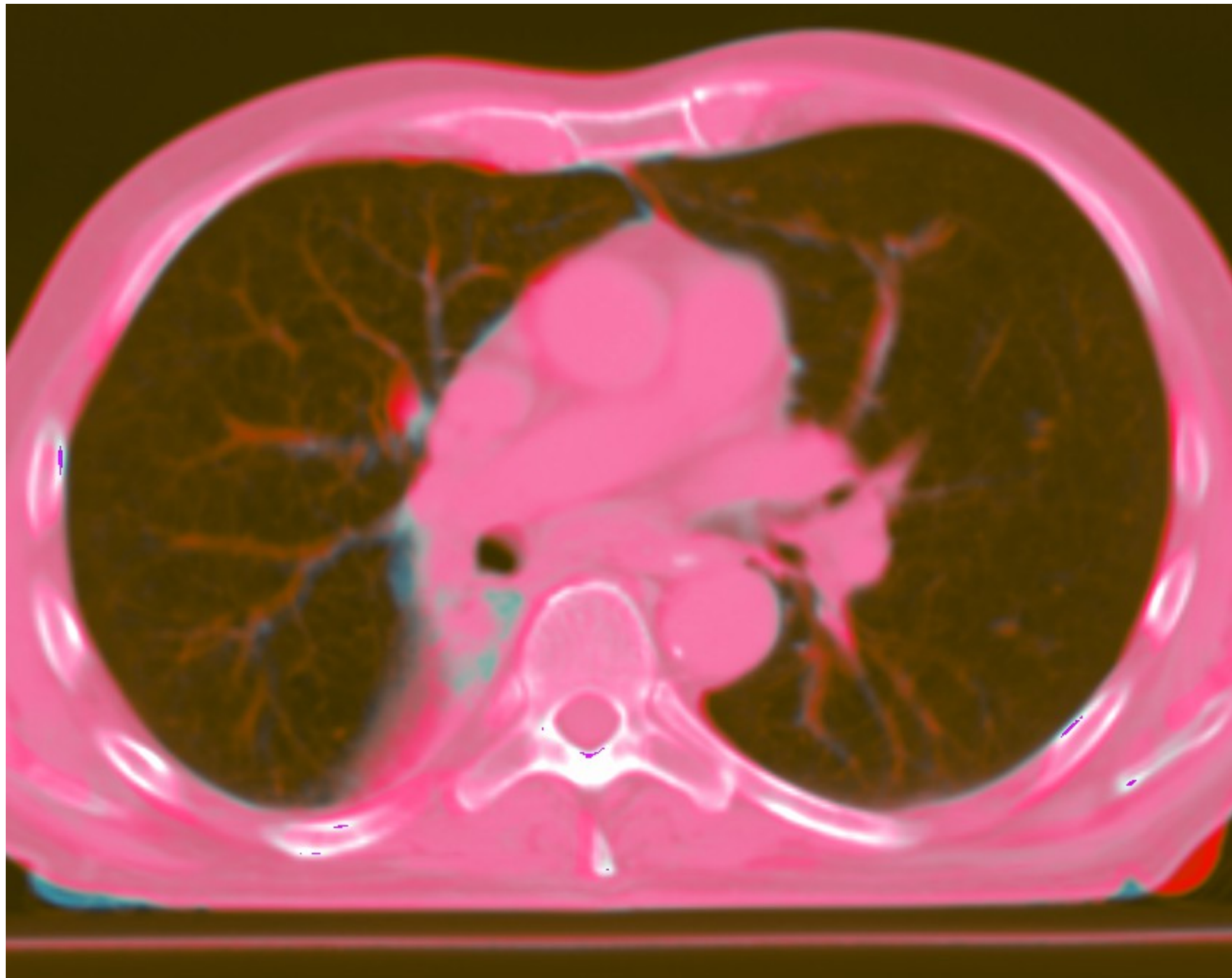
# Visualize the results



# Visualize the results

- 3D Slicer Tips & Tricks
  - Load all images CT1, CT2, warped image, warped dose, structure sets, etc. at the same time
  - Use color addition instead of alpha blending
    - <http://www.slicer.org/slicerWiki/index.php/Modules:Plastimatch>





# Fixing bad registration results

- What to do if registration results are bad?
  - Check rigid registration stage
    - Consider manual rigid alignment
  - Use stiffer registration (coarser B-spline grid)
  - Use more registration stages (coarse → fine)
  - Post-process with landmark-based registration
    - <http://plastimatch.org>

Speed: 10 Window: 1702.428 Level: -769.624 Preset: User Scale Colormap: B&W

Images Overlay Link Landmarks

TL	Name
<input checked="" type="checkbox"/>	image000_dicom.dcm
<input checked="" type="checkbox"/>	/home/gos8/igrt_research/vf

Image: image000\_dicom.dcm

Dimension: 3 (short)

Size (pixel): 512 512 160

Size in mm: 500.019 500.019 400

Origin: -250 -250 -207.25

Spacing: 0.9766 0.9766 2.5

# pixels: 41943040 (81Mb)

Cross hair:

Position (pixel): 267.1 262.5 80.0

Position (mm): 10.9 6.3 -7.2

Pixel value: 68

Panel:

Top Left: Coronal, current slice: 159

Top Right: Coronal, current slice: 262

Bottom Left: Sagittal, current slice: 267

Bottom Right: Axial, current slice: 80

Coronal  
Slice: 261

Window: 1702  
Level: -769

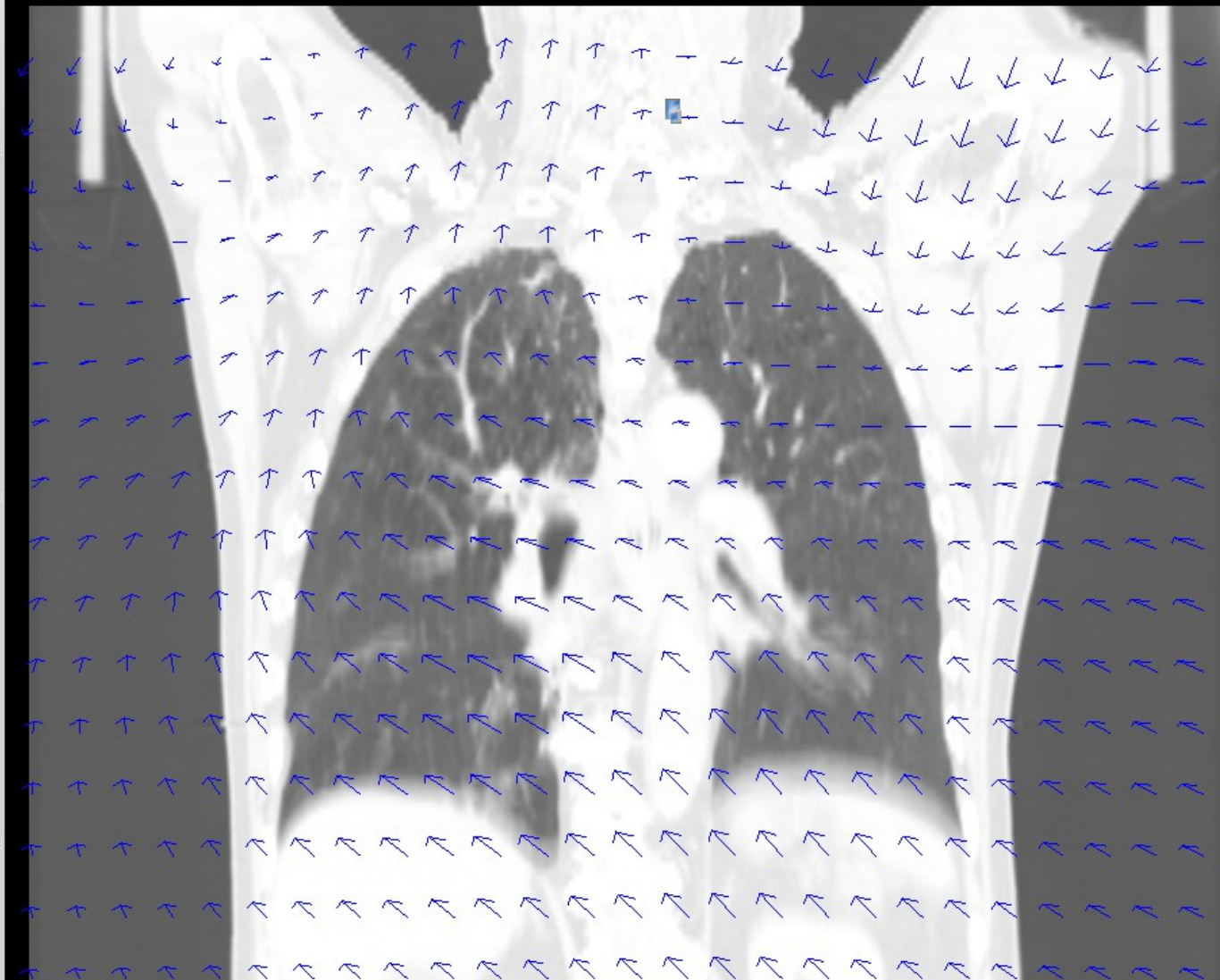


image000\_dicom

data value : 49  
mm : 0.3 171.0  
pixel : 255 260 151.0

Type 'h' on image to display help on navigation

# Testing vector field smoothness

- Run command

`plastimatch stats vf.mha`

- Output

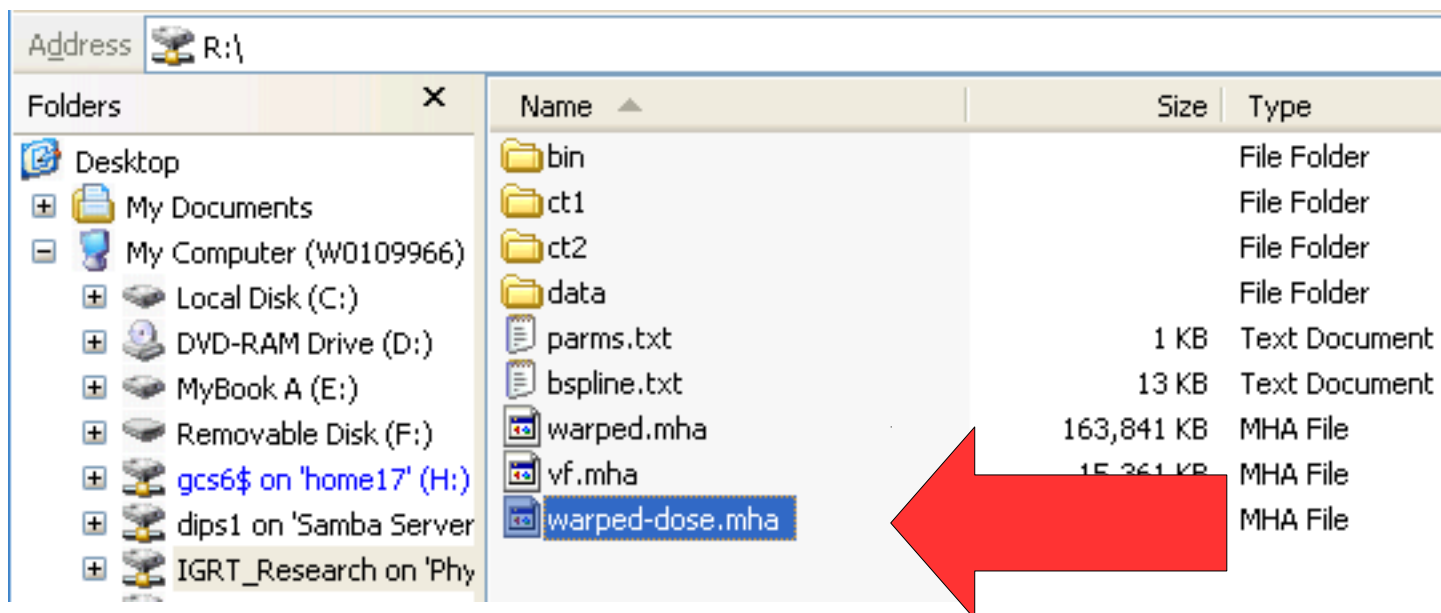
Jacobian: MINJAC 0.823 MAXJAC 1.20 MINABSJAC 0.82

- Jacobian measures local increase/decrease in volume
- Jacobian = 1 means volume exactly preserved
- Jacobian < 0 means vector field folding

# Warping the dose

- Run command

```
plastimatch warp --input ct2/dose.dcm  
--xf bspline.txt  
--output-dose-img warped-dose.mha
```

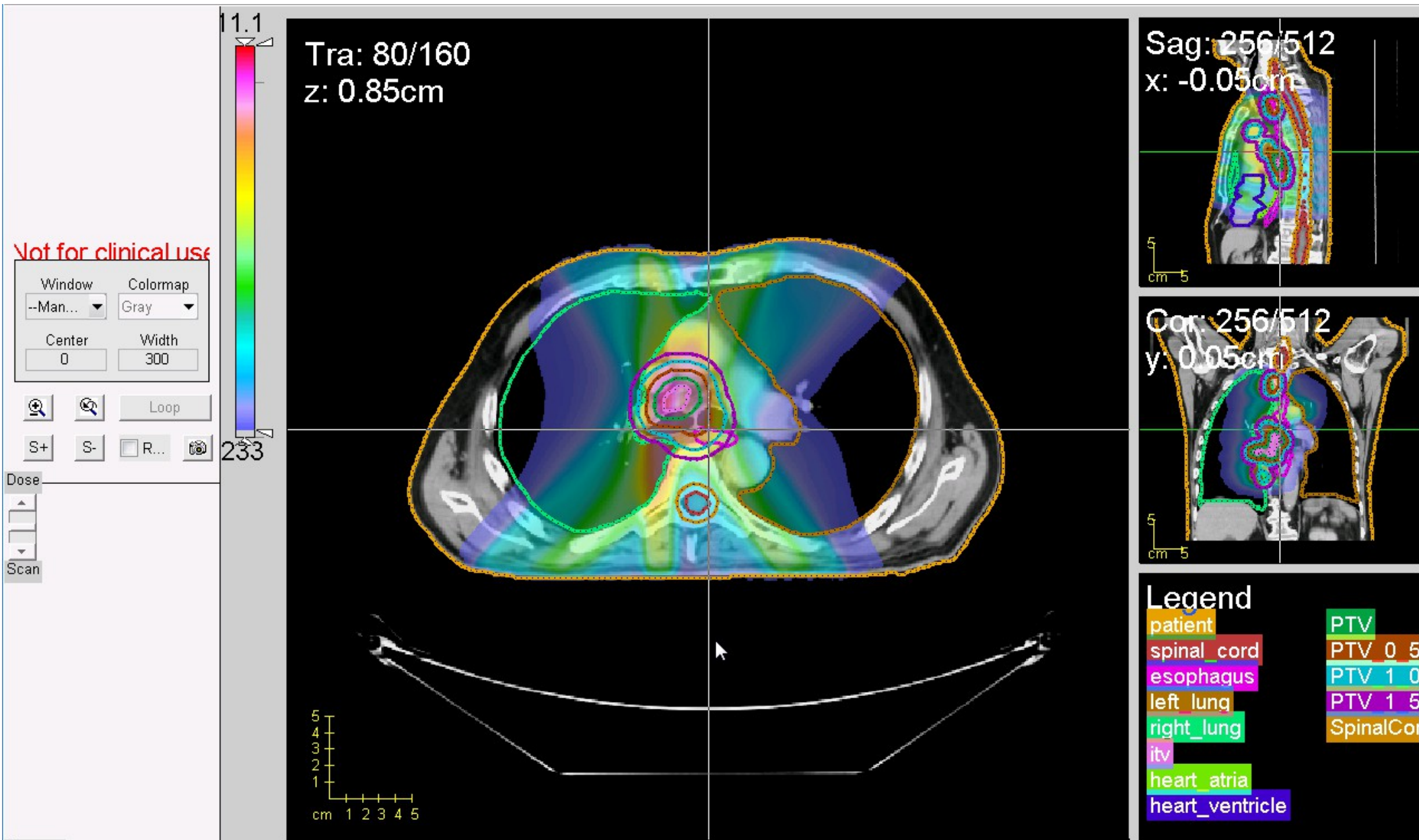




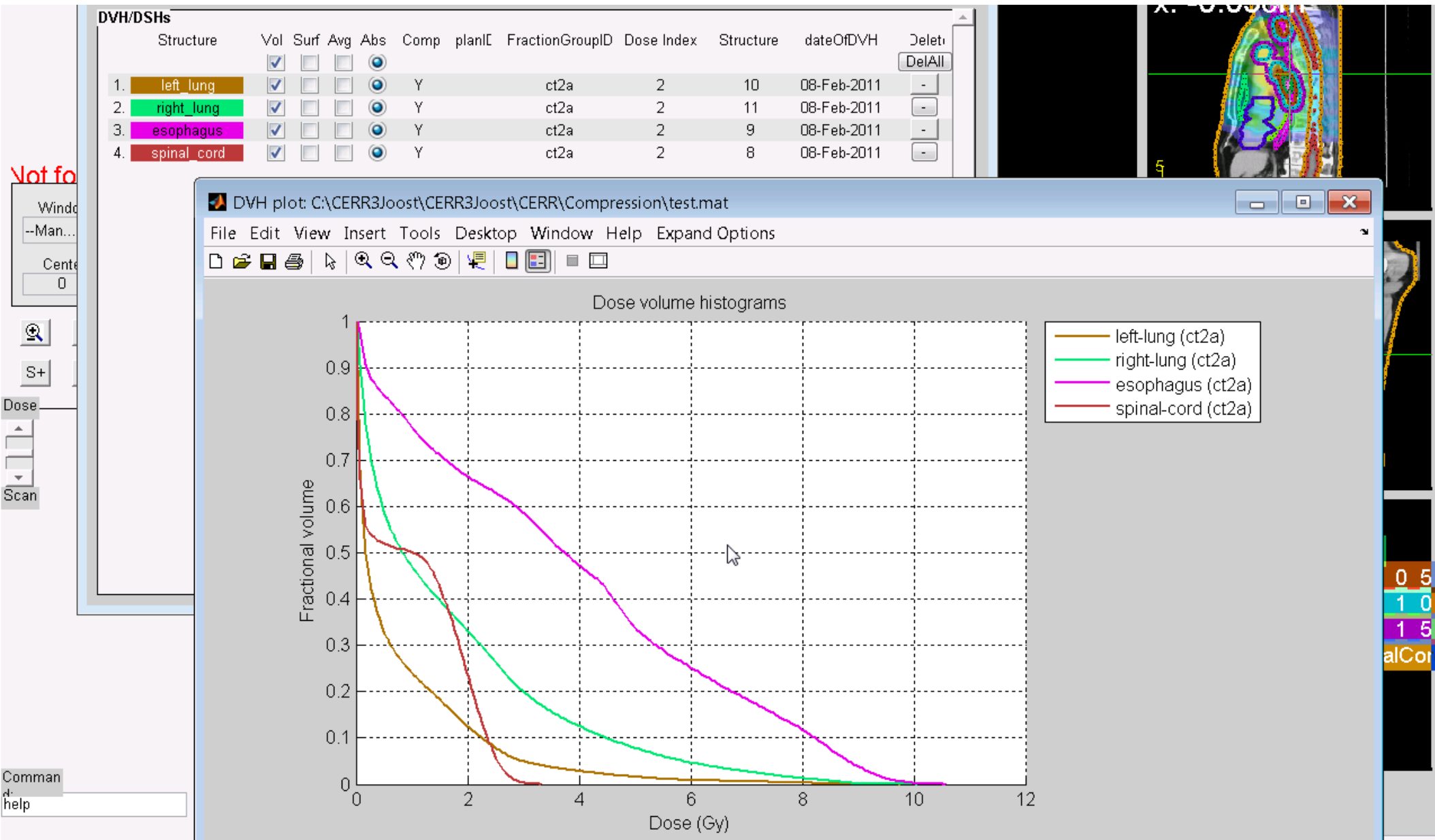
# Dose manipulation

- Convert to DICOM-RT → Slicer  
    `plastimatch convert --input ct1/dose.dcm  
    --fixed warped-dose.mha --output dose1.mha`
- Adding doses  
    `plastimatch add dose1.mha warped-dose.mha  
    combined-dose.mha`
- Convert to Slicer → DICOM-RT  
    `plastimatch convert  
    --input-dose-img combined-dose.mha  
    --output-dicom ct2`

# Plan review in CERR



# Plan review in CERR





# Advertisement

- 3D Slicer user group at AAPM/COMP
  - Talk to me during the break
  - Or email [gcsharp@partners.org](mailto:gcsharp@partners.org)

THANK YOU