

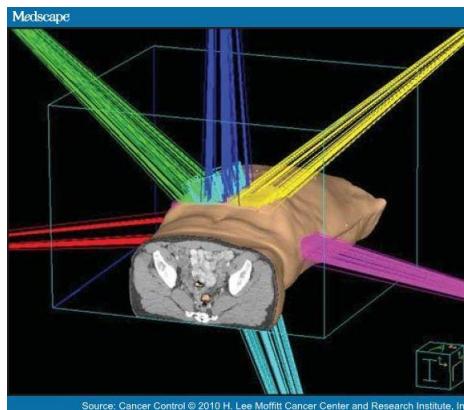
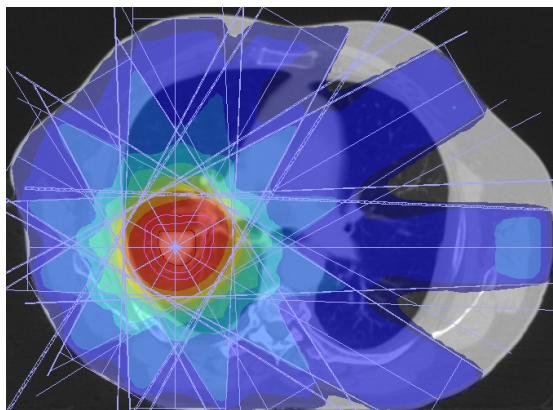
# Respiratory motion modelling

Supervisor: Jamie McClelland

Razvan Valentin Marinescu  
Benedetta Biffi  
Kevin Tchaka

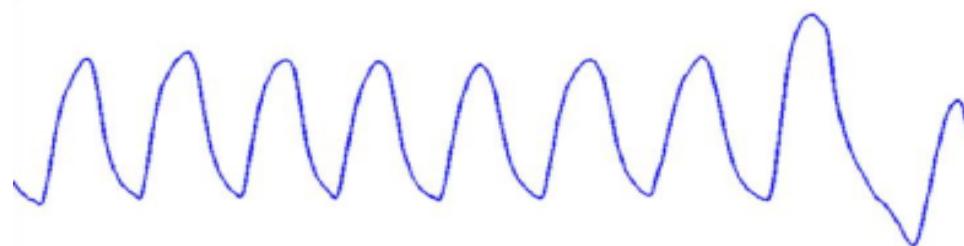
# Introduction - Radiotherapy

- Radiation Therapy uses ionising radiation to kill malignant cells
- It should also spare healthy tissue



# Lung motion

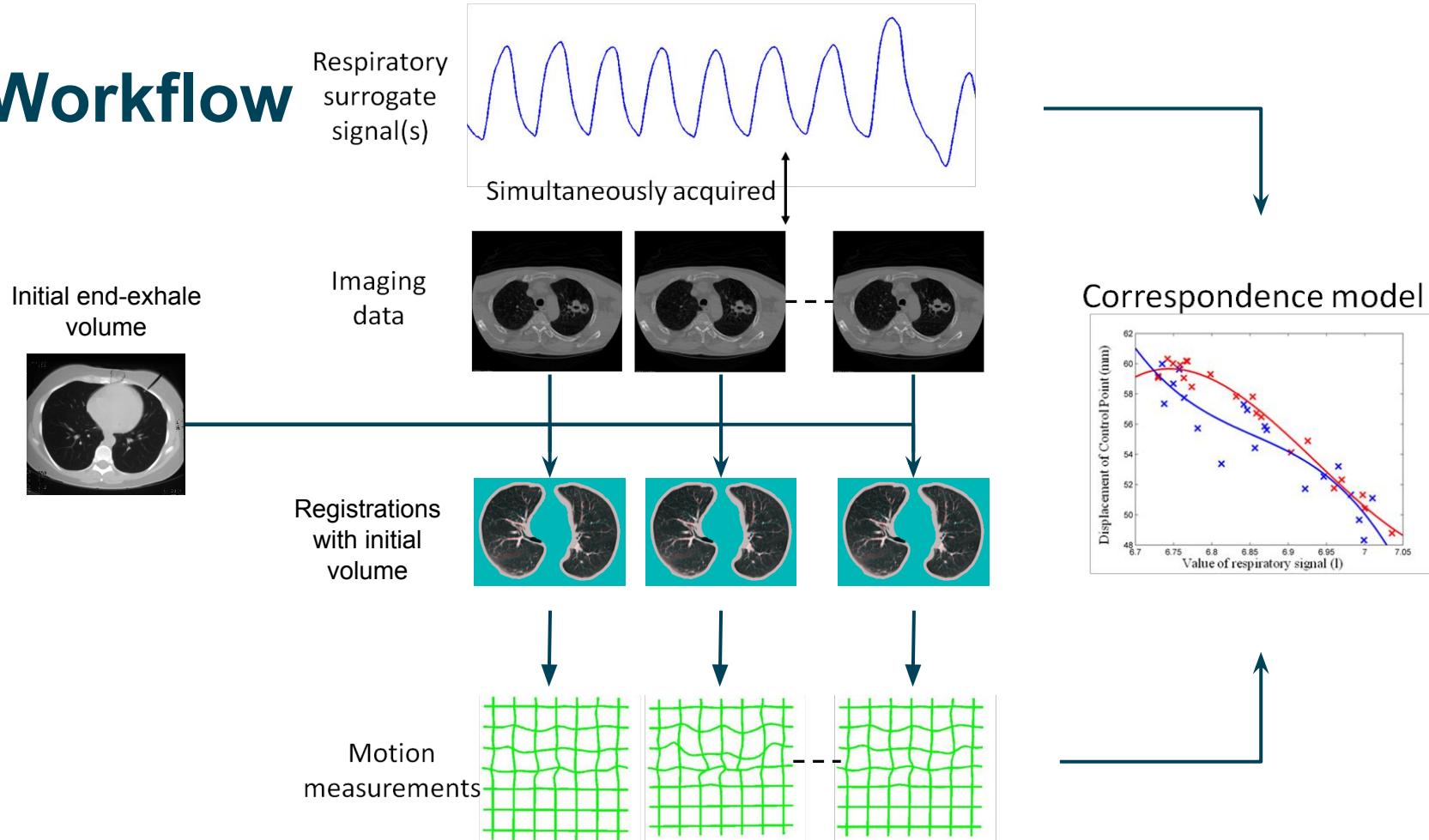
- Respiratory motion can make the tumor hard to localise
- Hard to perform imaging during radiotherapy
- However, surrogate signals are available that model the breath cycle



# Project aim

- Model relationship between surrogate signal and motion
- Estimate motion from surrogate signal

# Workflow

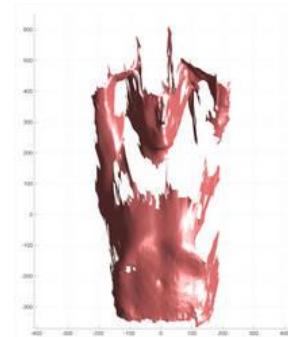


# Cine CT dataset



# Data used

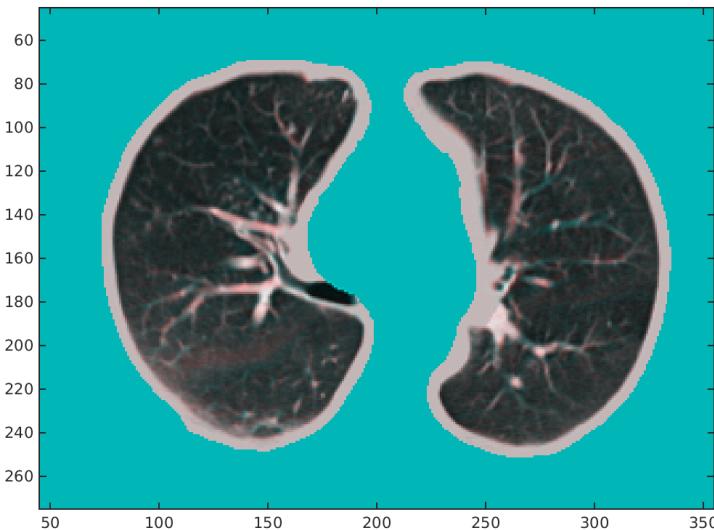
- Cine CT data was acquired at 5 couch positions
  - 40 Cine CT volumes were acquired over 20 seconds at each couch position
  - 12 x 2.4 mm slices for each volume
- Respiratory surrogate signal was acquired for each couch position using Vision RT 3D surface data



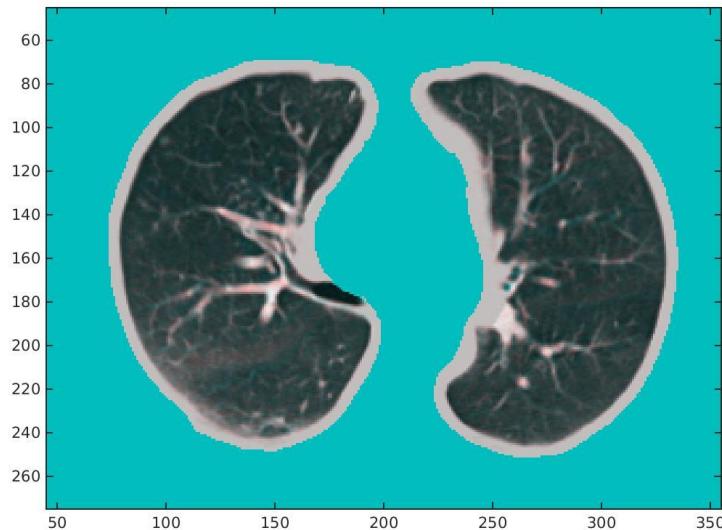
# Core task 1: Registration assessment

- Good registration

Registration 1



Registration 2

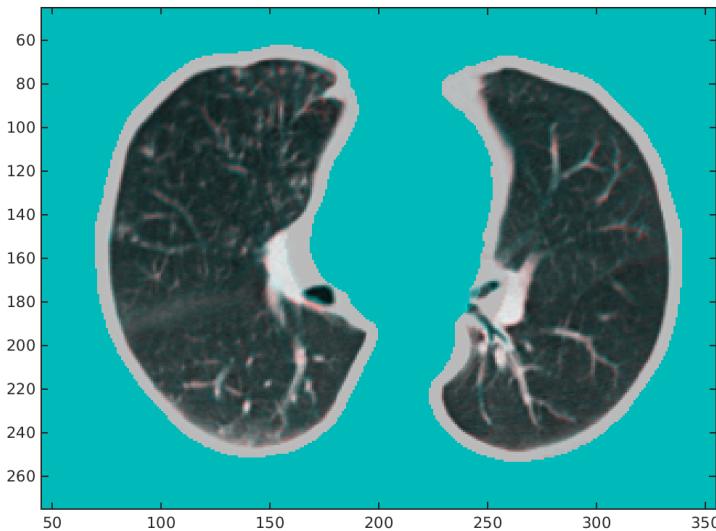


Couch 1, volume 1, slice 66

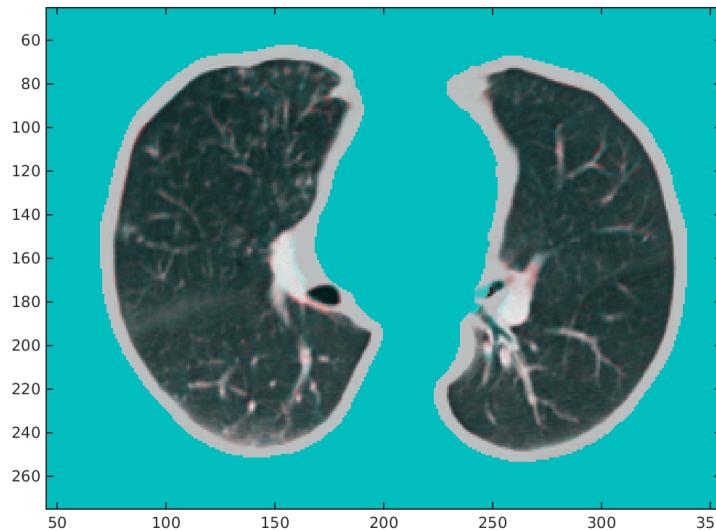
# Core task 1: Registration assessment

- Good registration

Registration 1



Registration 2

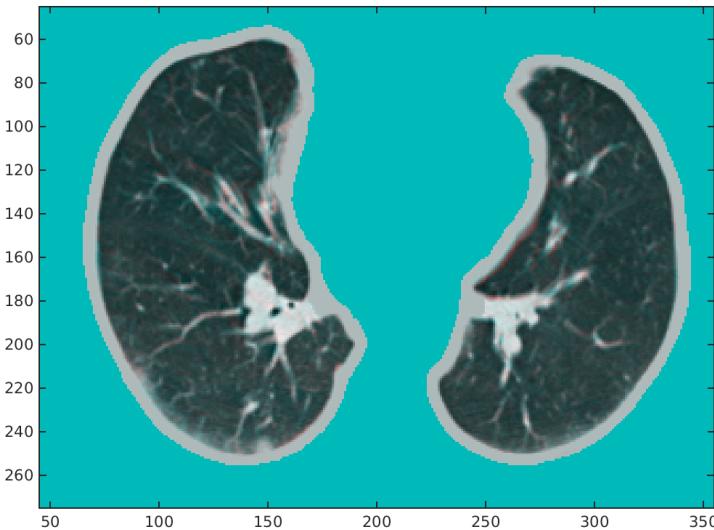


Couch 2, volume 5, slice 60

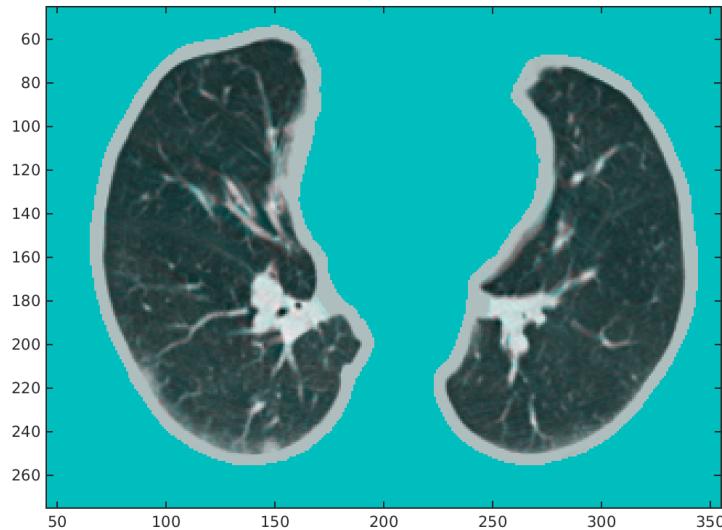
# Core task 1: Registration assessment

- Good registration

Registration 1



Registration 2

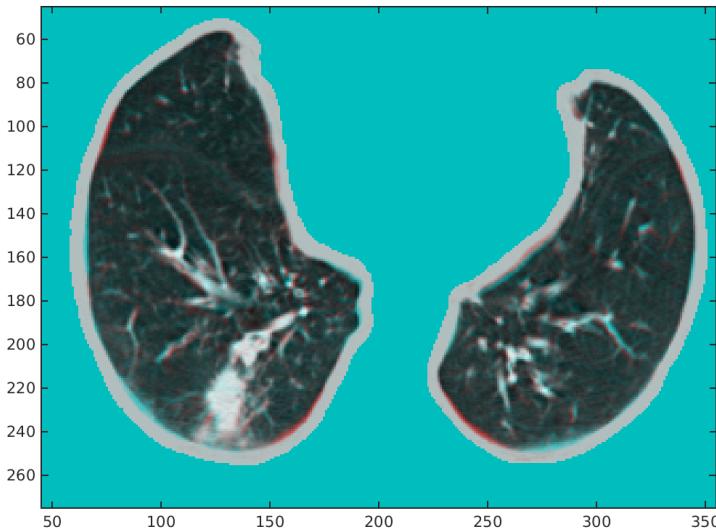


Couch 3, volume 2, slice 49

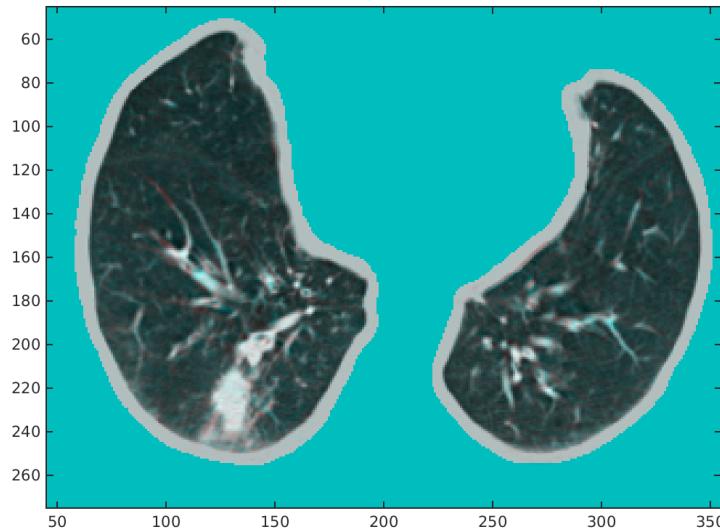
# Core task 1: Registration assessment

- Good registration

Registration 1



Registration 2

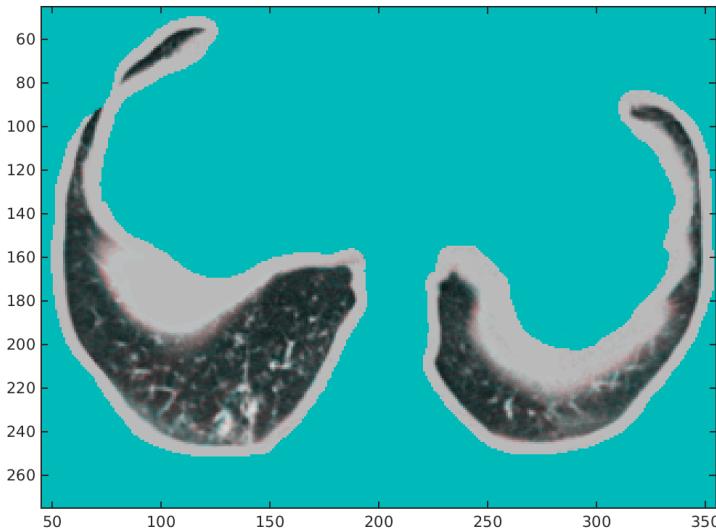


Couch 4, volume 8, slice 37

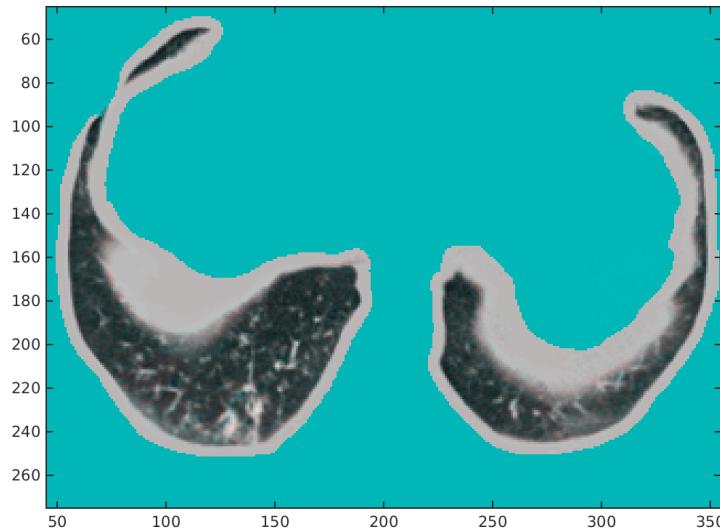
# Core task 1: Registration assessment

- Good registration, although segmentation was more difficult due to shape

Registration 1



Registration 2

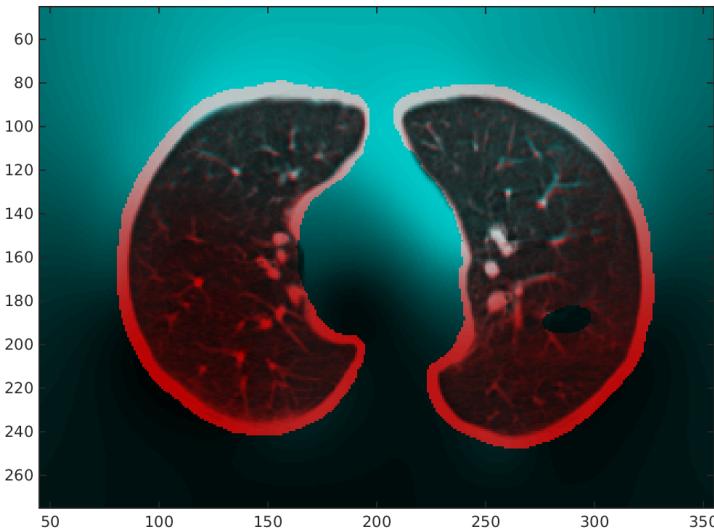


Couch 5, volume 4, slice 25

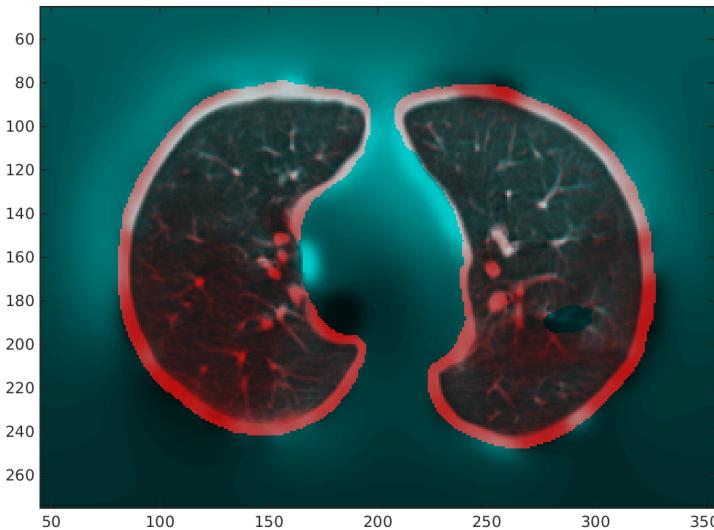
# Core task 1: Registration assessment

- Bad registrations due to misalignment

Registration 1



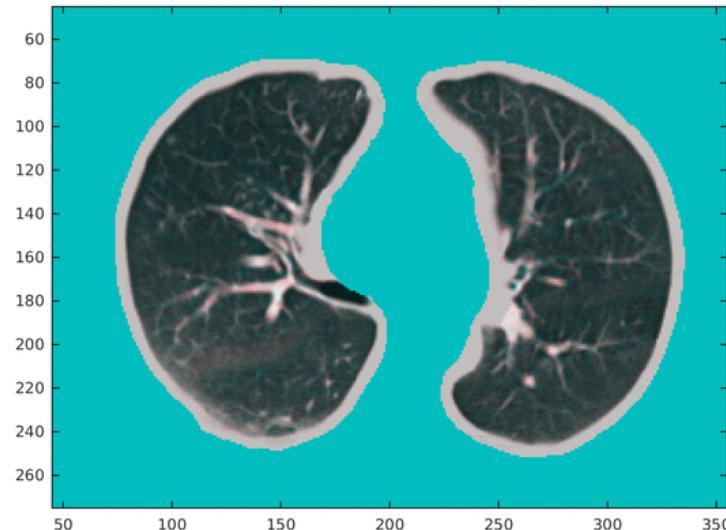
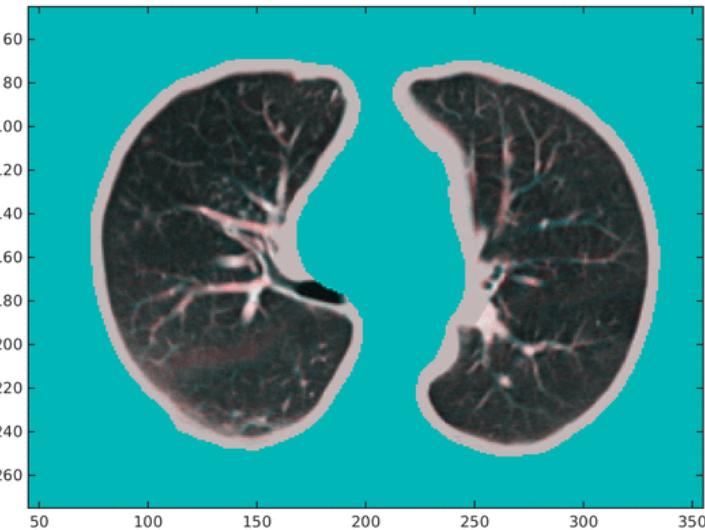
Registration 2



Couch 1, volume 6, slice 76

# Core task 1: Registration assessment

- Registration videos

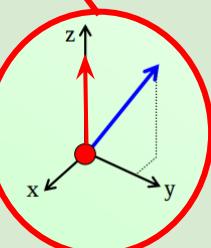
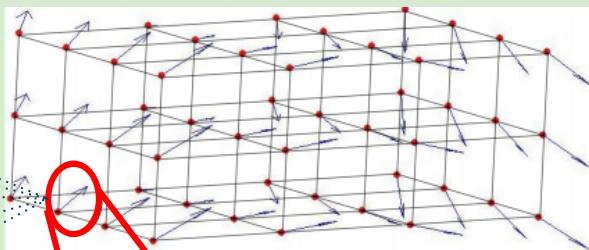
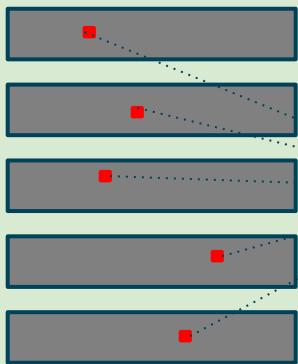


Couch 1, all volumes and slices

# Core task 2: One Voxel Fitting - Data

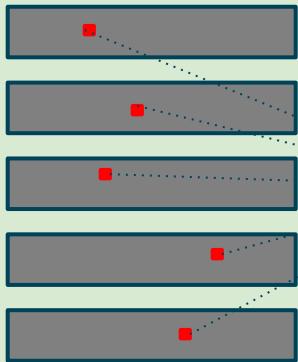
4DCT registered on  
CINE CT,  
5 couch positions

1 pixel for each position,  
**z displacement** of the CPG

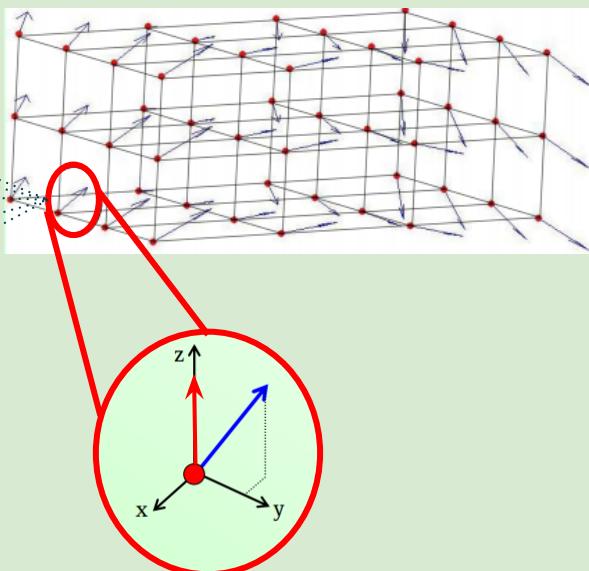


# Core task 2: One Voxel Fitting - Data

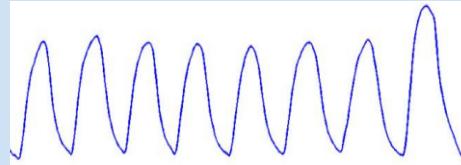
4DCT registered on  
CINE CT,  
5 couch positions



1 pixel for each position,  
**z displacement** of the CPG



Respiratory  
surrogate signal



## Core task 2: One Voxel Fitting - The models

$$\hat{y} = X\hat{\beta}$$

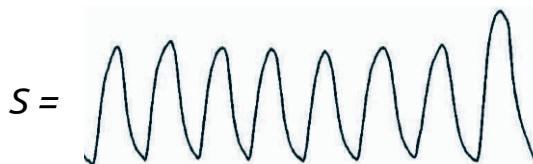
$$\hat{y}_i = \hat{\beta}_0 + \hat{\beta}_1 x_{i1} + \hat{\beta}_2 x_{i2} + \cdots + \hat{\beta}_p x_{ip}$$

# Core task 2: One Voxel Fitting - The models

$$\hat{y} = \mathbf{X}^{\hat{\beta}}$$

Design Matrix

Depends on the respiratory surrogate signal



1<sup>st</sup> order

$$X = \begin{vmatrix} 1 & S_1 \\ 1 & S_2 \\ 1 & .. \\ 1 & S_n \end{vmatrix}$$

2<sup>nd</sup> order

$$X = \begin{vmatrix} 1 & S_1 & S_1^2 \\ 1 & S_2 & S_2^2 \\ 1 & .. & .. \\ 1 & S_n & S_n^2 \end{vmatrix}$$

3<sup>rd</sup> order

$$X = \begin{vmatrix} 1 & S_1 & S_1^2 & S_1^3 \\ 1 & S_2 & S_2^2 & S_2^3 \\ 1 & .. & .. & .. \\ 1 & S_n & S_n^2 & S_n^3 \end{vmatrix}$$

# Core task 2: One Voxel Fitting - The models

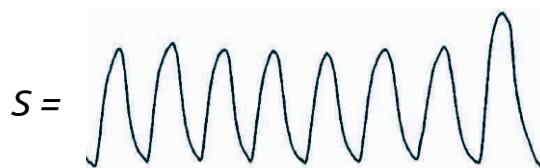
$$\hat{y} = X\beta$$

Design Matrix

Estimated model parameters

Depend on the design matrix and the z displacement of the CPG

$$\hat{\beta} = (X'X)^{-1}X'Y$$



1<sup>st</sup> order

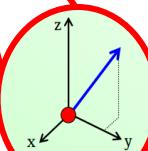
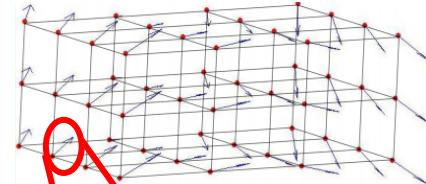
$$X = \begin{vmatrix} 1 & S_1 \\ 1 & S_2 \\ 1 & .. \\ 1 & S_n \end{vmatrix}$$

2<sup>nd</sup> order

$$X = \begin{vmatrix} 1 & S_1 & S_1^2 \\ 1 & S_2 & S_2^2 \\ 1 & .. & .. \\ 1 & S_n & S_n^2 \end{vmatrix}$$

3<sup>rd</sup> order

$$X = \begin{vmatrix} 1 & S_1 & S_1^2 & S_1^3 \\ 1 & S_2 & S_2^2 & S_2^3 \\ 1 & .. & .. & .. \\ 1 & S_n & S_n^2 & S_n^3 \end{vmatrix}$$

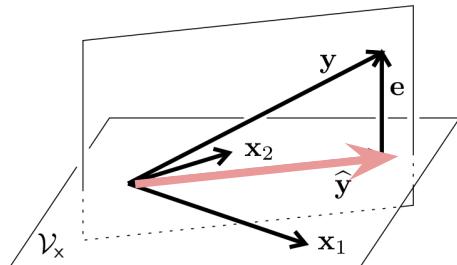


# Core task 2: One Voxel Fitting - The models

Estimated z displacement of the CPG

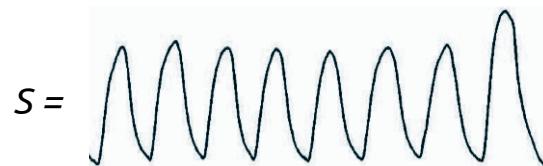
$$\hat{y} = X\beta$$

Estimated model parameters



Design Matrix

Depends on the respiratory surrogate signal



Depend on the design matrix and the z displacement of the CPG

$$\hat{\beta} = (X'X)^{-1}X'Y$$

1<sup>st</sup> order

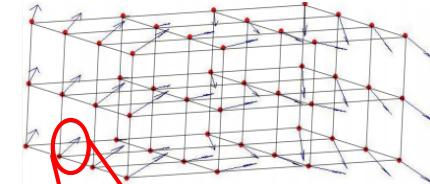
$$X = \begin{vmatrix} 1 & S_1 \\ 1 & S_2 \\ 1 & .. \\ 1 & S_n \end{vmatrix}$$

2<sup>nd</sup> order

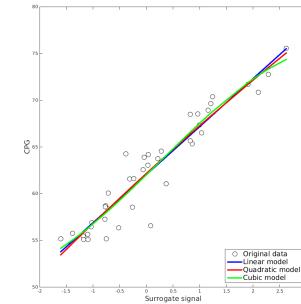
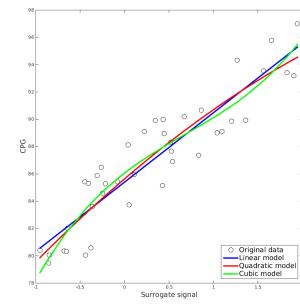
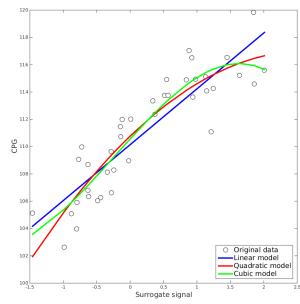
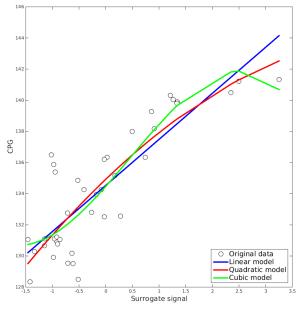
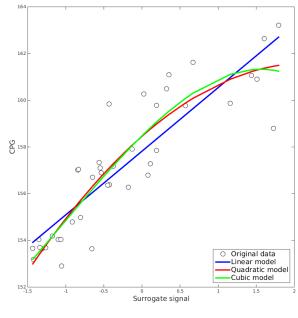
$$X = \begin{vmatrix} 1 & S_1 & S_1^2 \\ 1 & S_2 & S_2^2 \\ 1 & .. & .. \\ 1 & S_n & S_n^2 \end{vmatrix}$$

3<sup>rd</sup> order

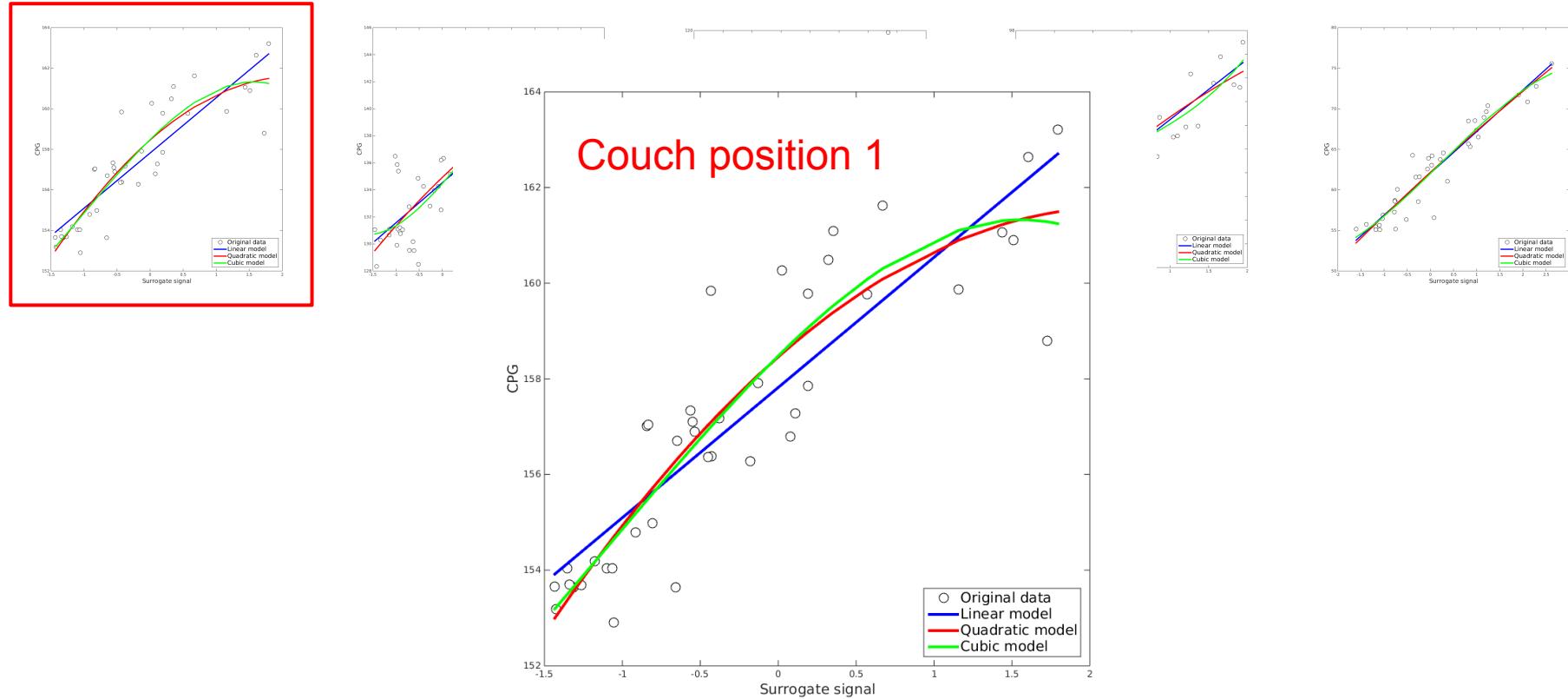
$$X = \begin{vmatrix} 1 & S_1 & S_1^2 & S_1^3 \\ 1 & S_2 & S_2^2 & S_2^3 \\ 1 & .. & .. & .. \\ 1 & S_n & S_n^2 & S_n^3 \end{vmatrix}$$



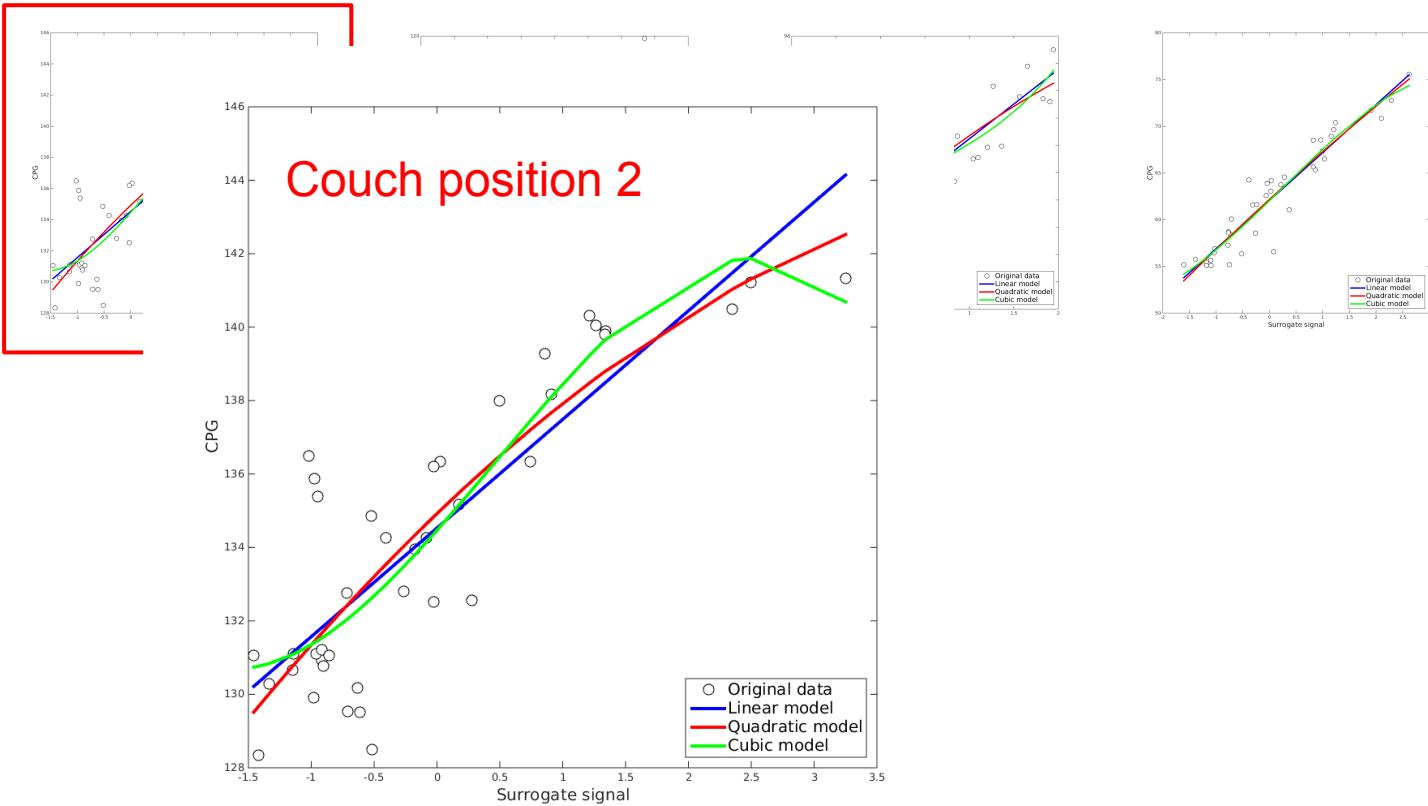
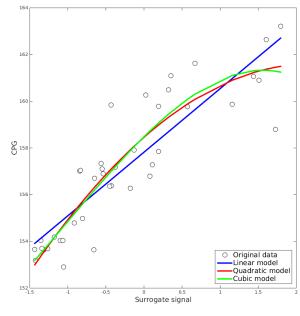
# Core task 2: One Voxel Fitting - Results



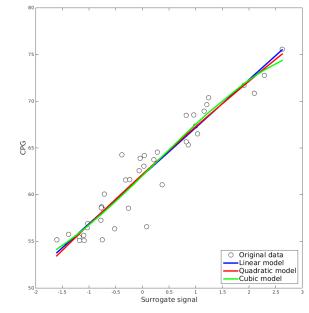
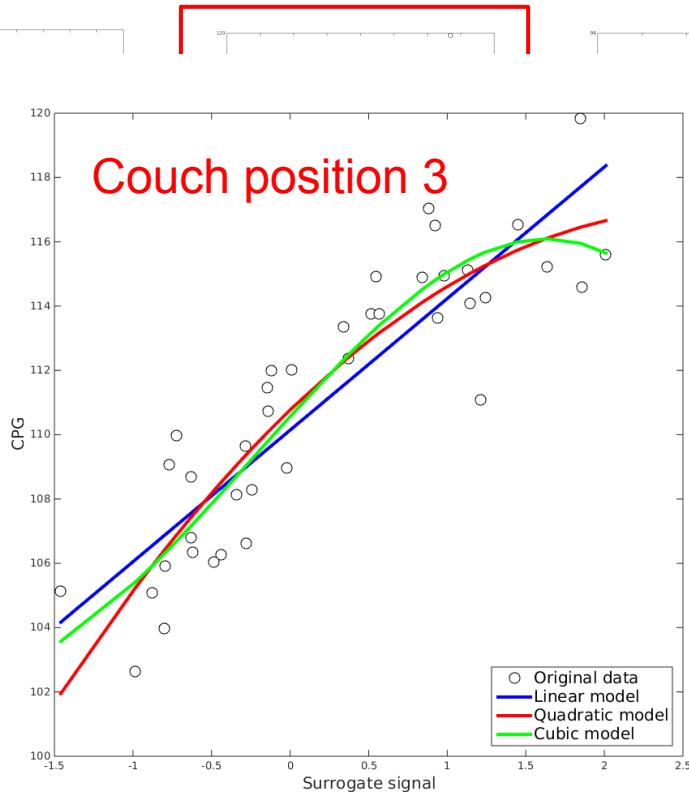
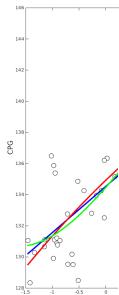
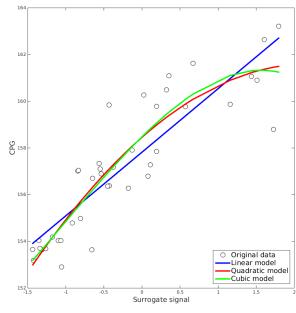
# Core task 2: One Voxel Fitting - Results



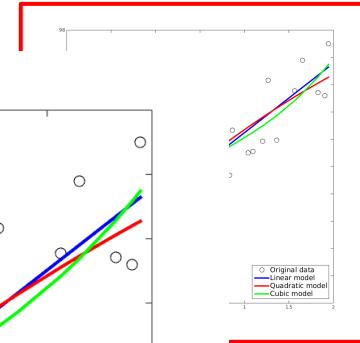
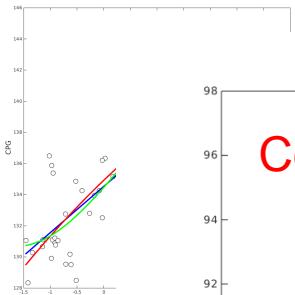
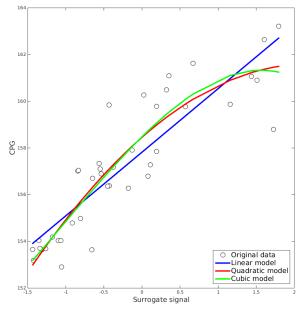
# Core task 2: One Voxel Fitting - Results



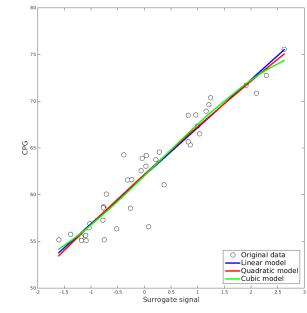
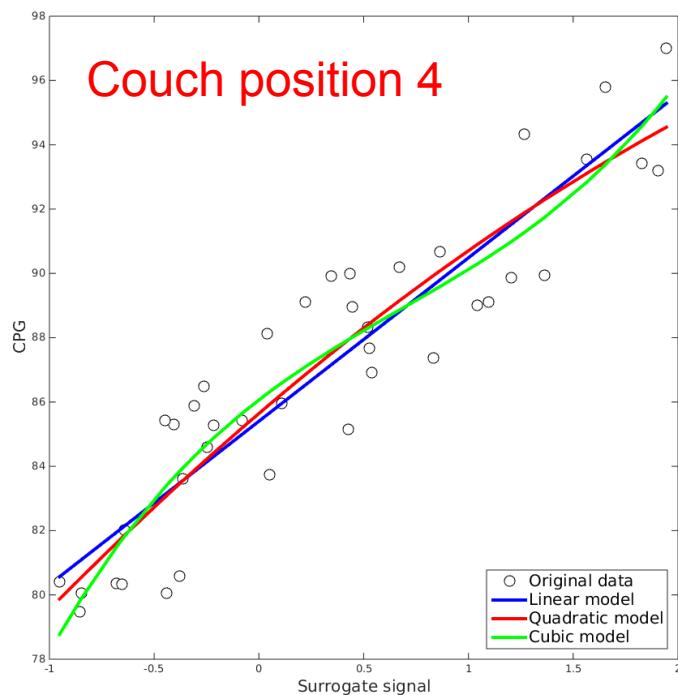
# Core task 2: One Voxel Fitting - Results



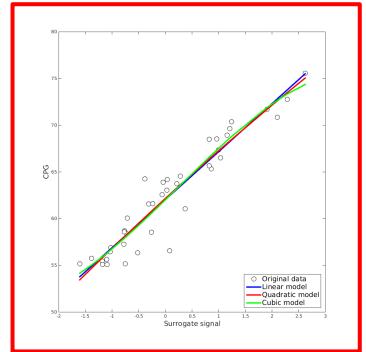
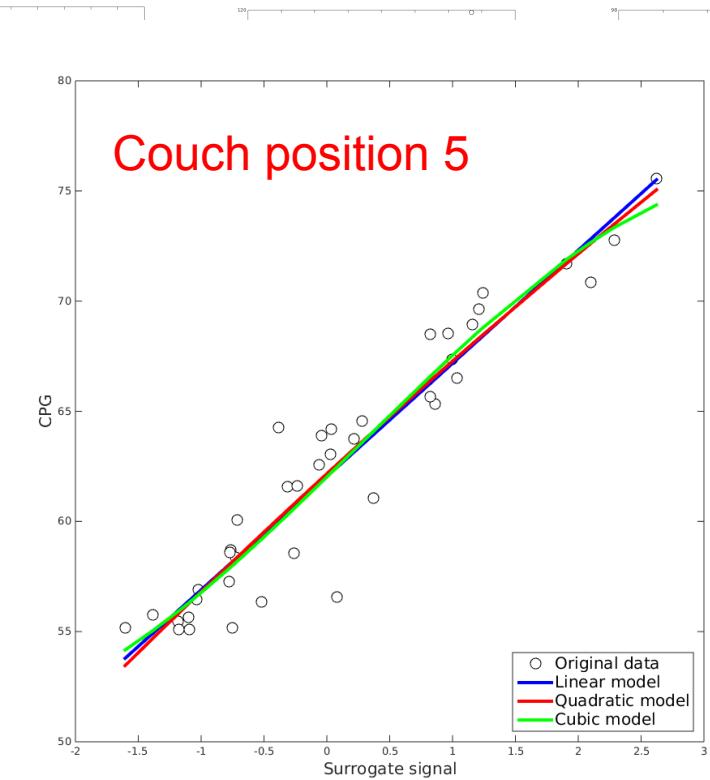
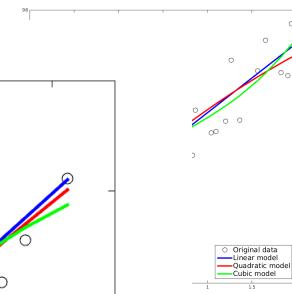
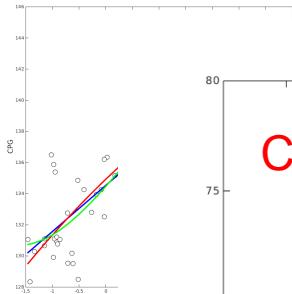
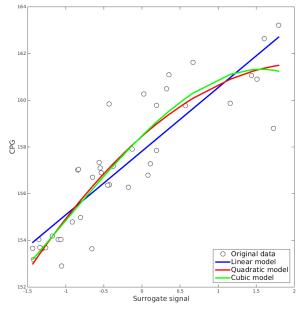
# Core task 2: One Voxel Fitting - Results



Couch position 4



# Core task 2: One Voxel Fitting - Results



# Core task 5: Uncertainty - Methods

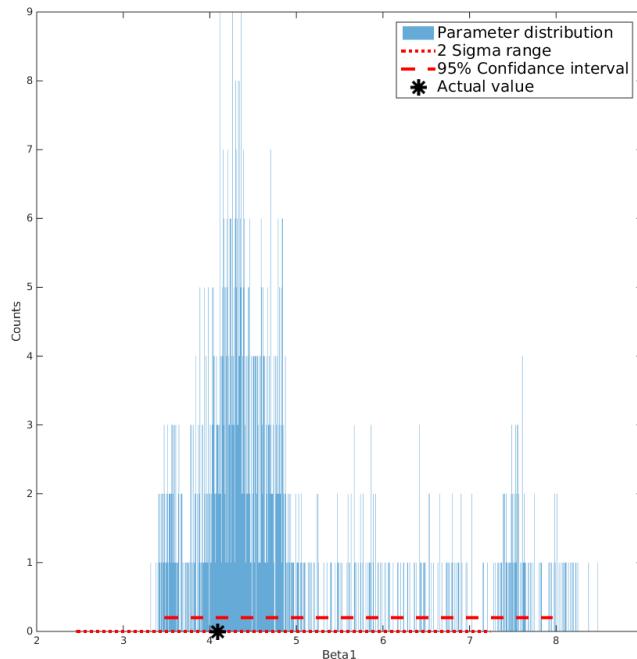
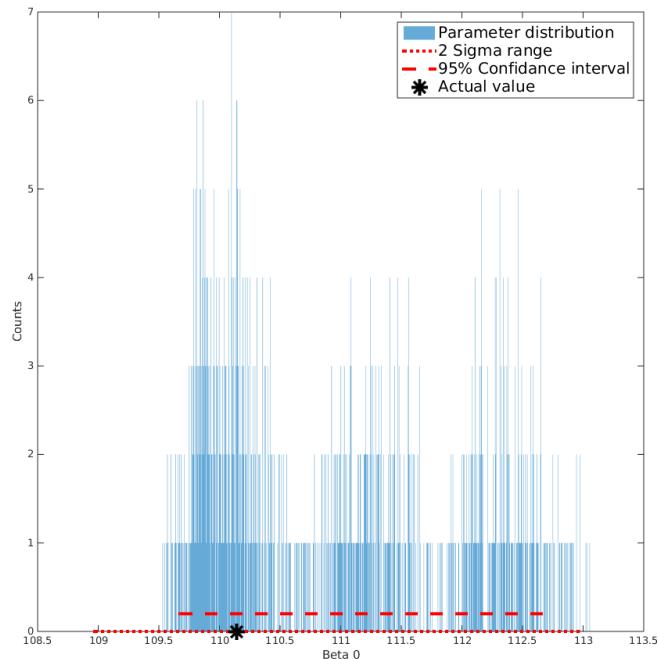
Parametric bootstrap  
Residual bootstrap  
Wild bootstrap  
MCMC



Parameter distribution  
 $2\sigma$  range  
95% confidence interval

# Core task 5: Uncertainty - Bootstrapping

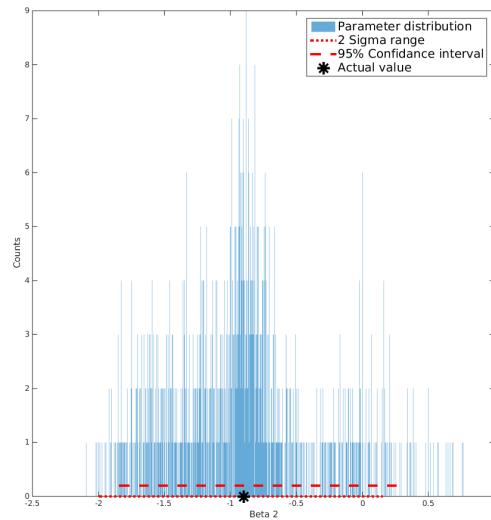
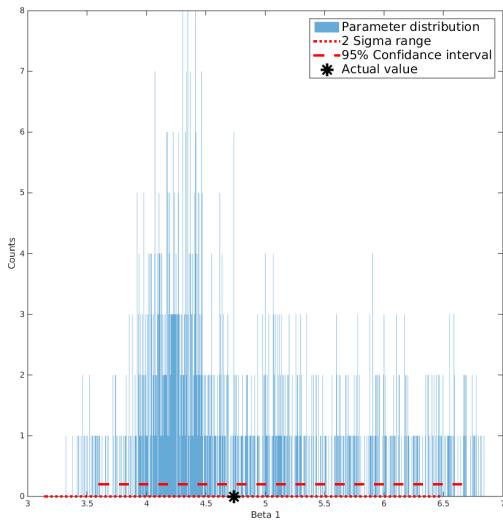
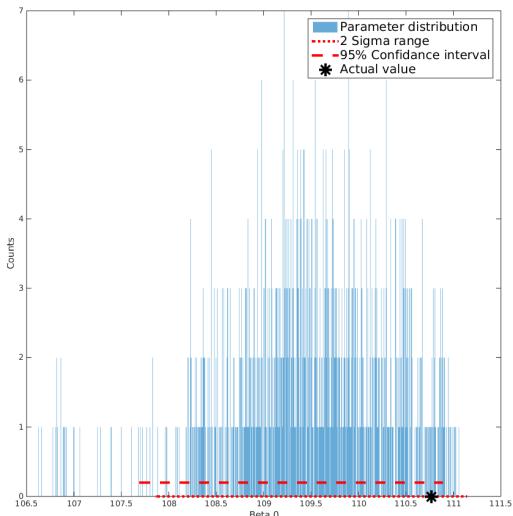
Parametric Bootstrapping on linear model coefficients



Couch position 3

# Core task 5: Uncertainty - Bootstrapping

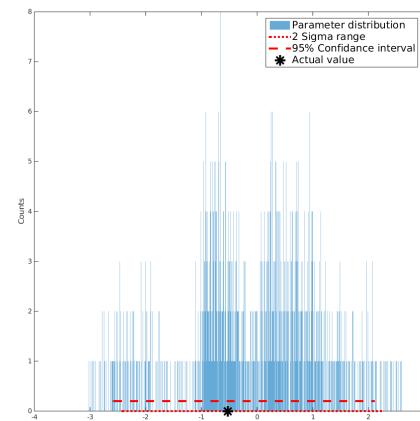
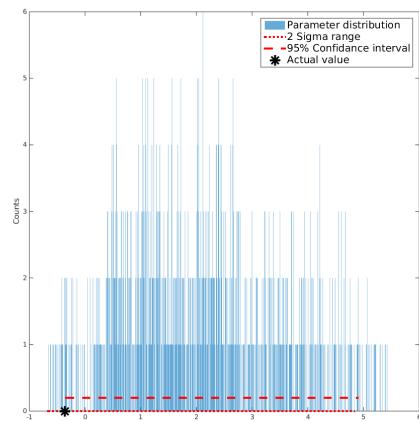
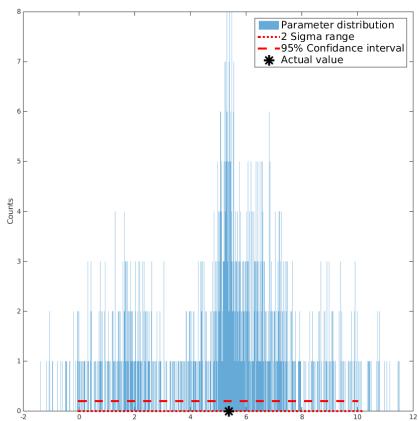
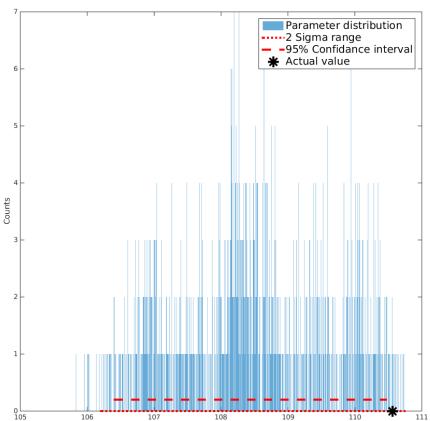
Parametric Bootstrapping on quadratic model coefficients



Couch position 3

# Core task 5: Uncertainty - Bootstrapping

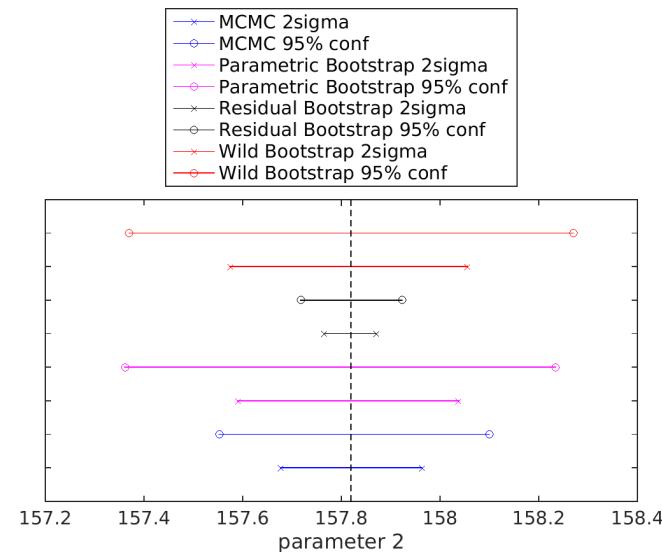
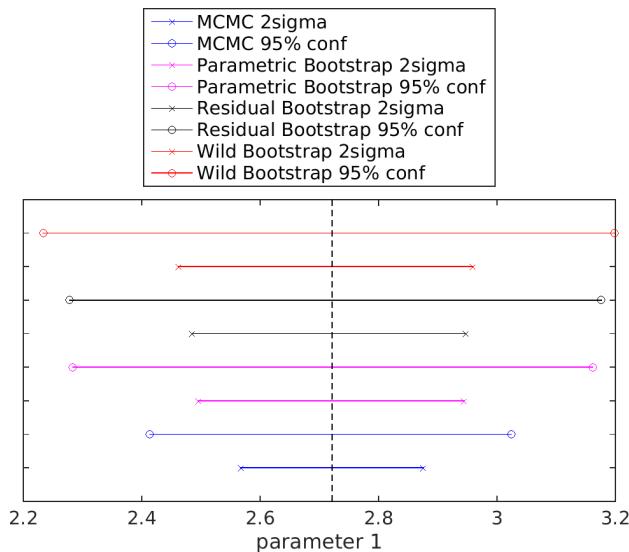
Parametric Bootstrapping on cubic model coefficients



Couch position 3

# Core task 5: Uncertainty - Different models

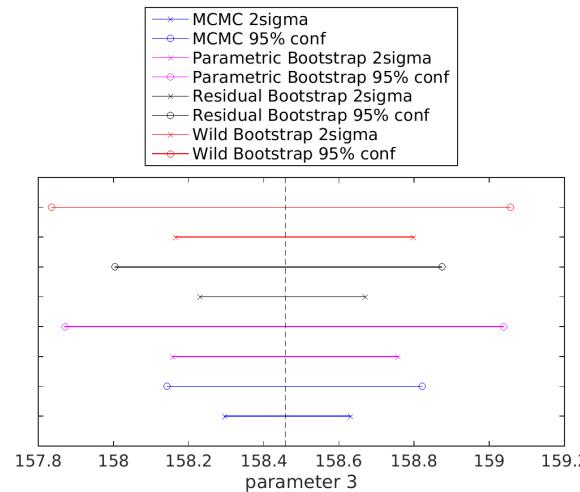
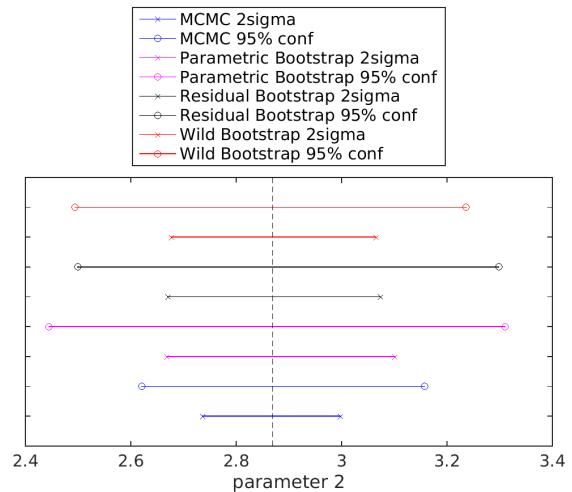
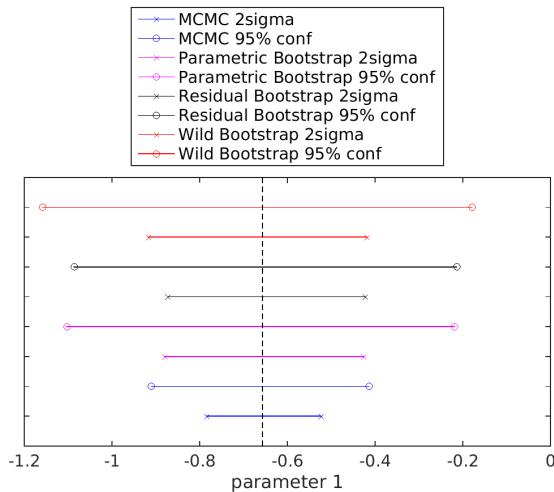
Confidence intervals on linear model coefficients



Couch position 5

# Core task 5: Uncertainty - Different models

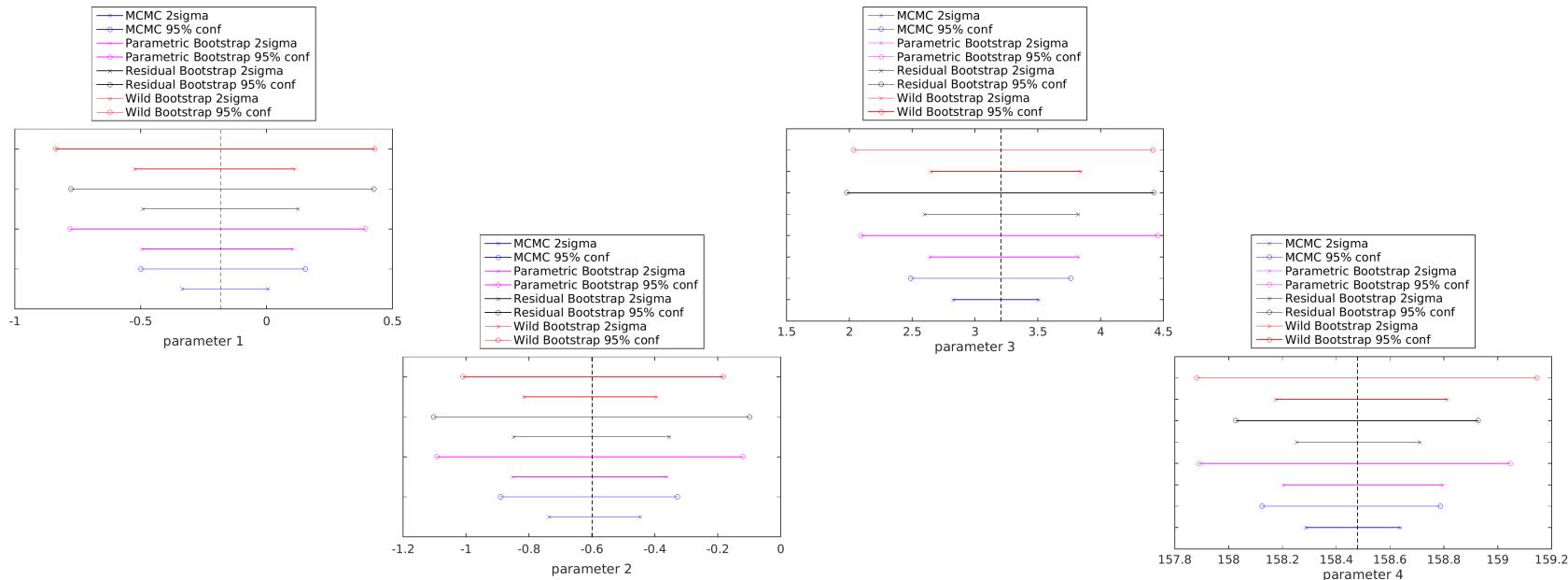
Confidence intervals on quadratic model coefficients



Couch position 5

# Core task 5: Uncertainty - Different models

Confidence intervals on cubic model coefficients

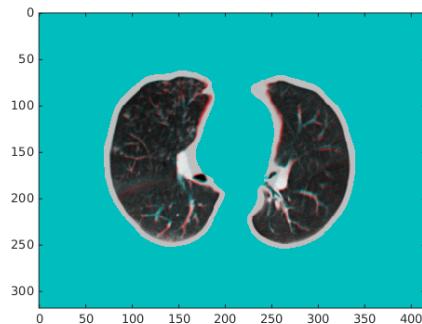


Couch position 5

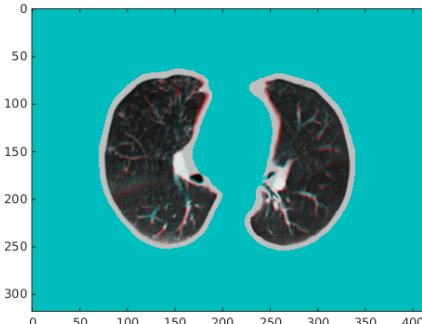
# Core task 4 - Motion Models Evaluation

Visual Assessment

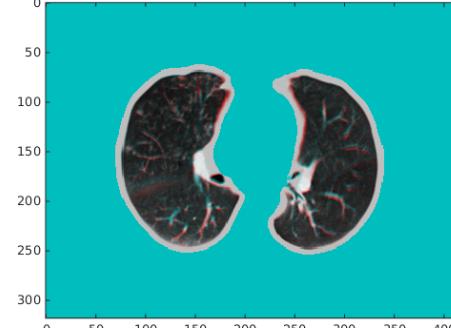
Linear



Quadratic



Cubic

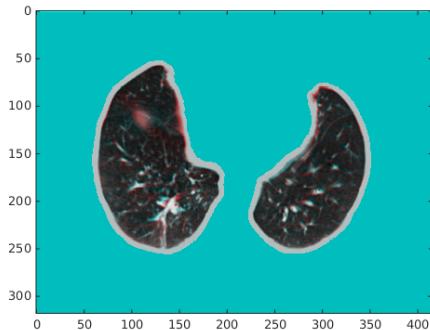


Couch 2, volume 5, slice 60

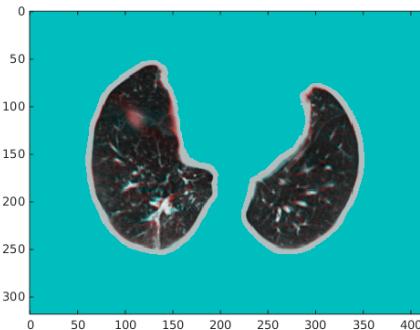
# Core task 4 - Motion Models Evaluation

Visual Assessment

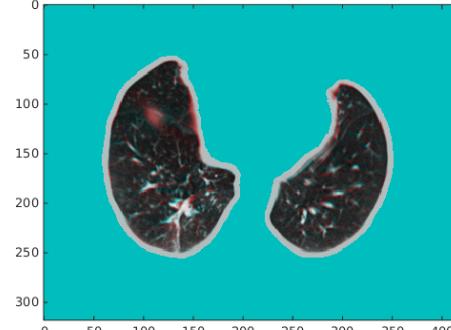
Linear



Quadratic



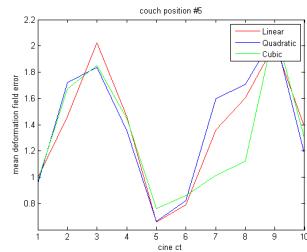
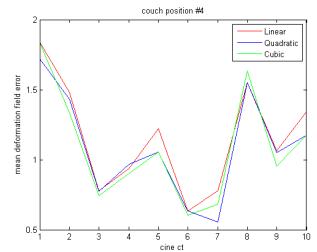
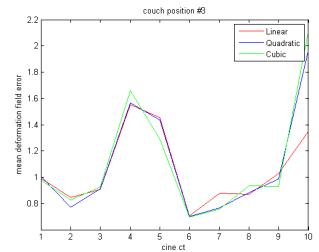
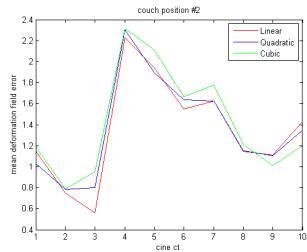
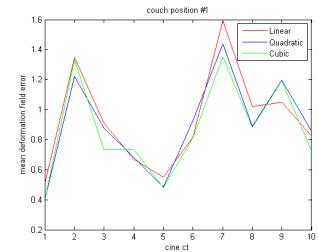
Cubic



Couch 4, volume 8, slice 37

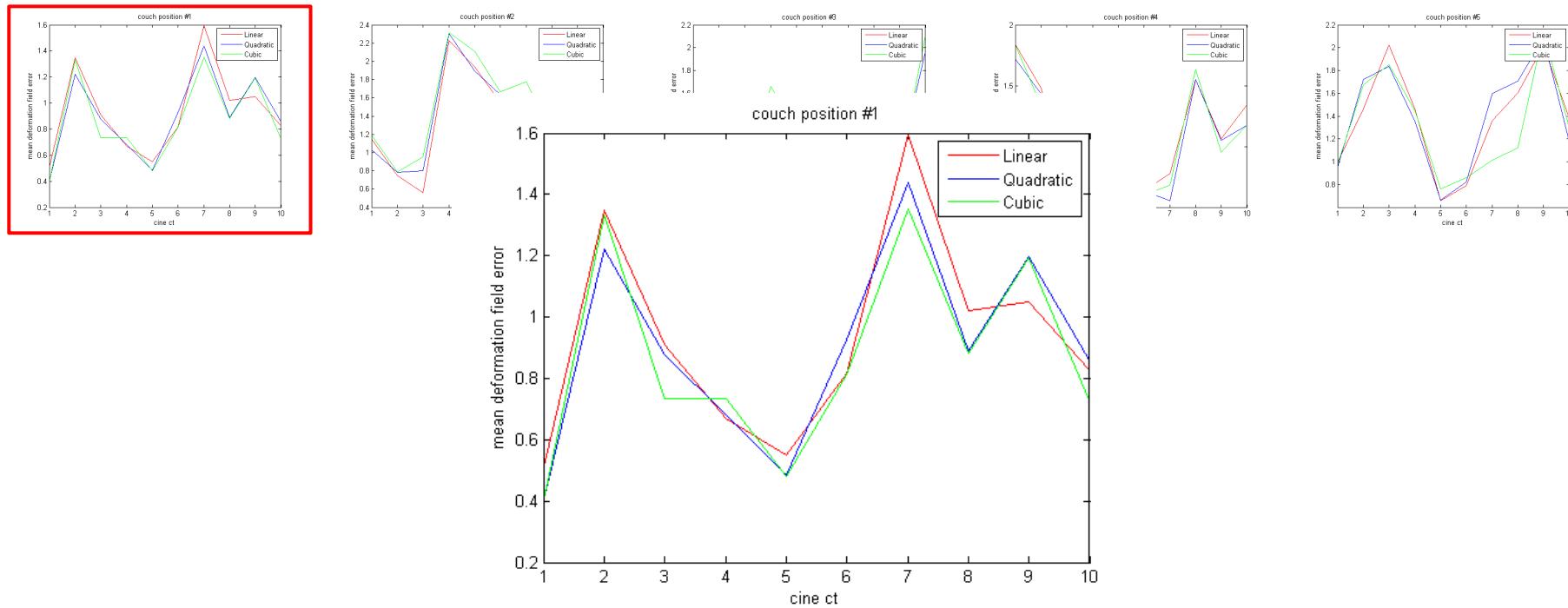
# Core task 4 - Motion Models Evaluation

## Deformation Field Error - mean error



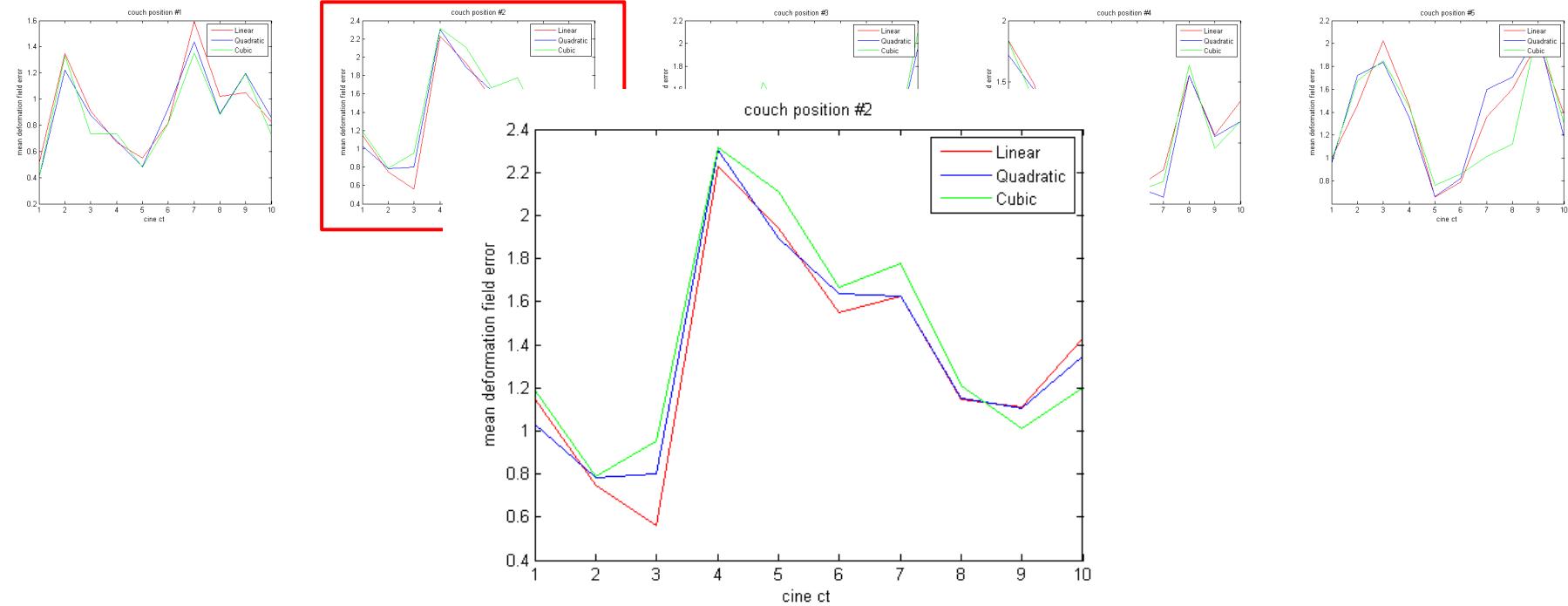
# Core task 4 - Motion Models Evaluation

Deformation Field Error - mean error



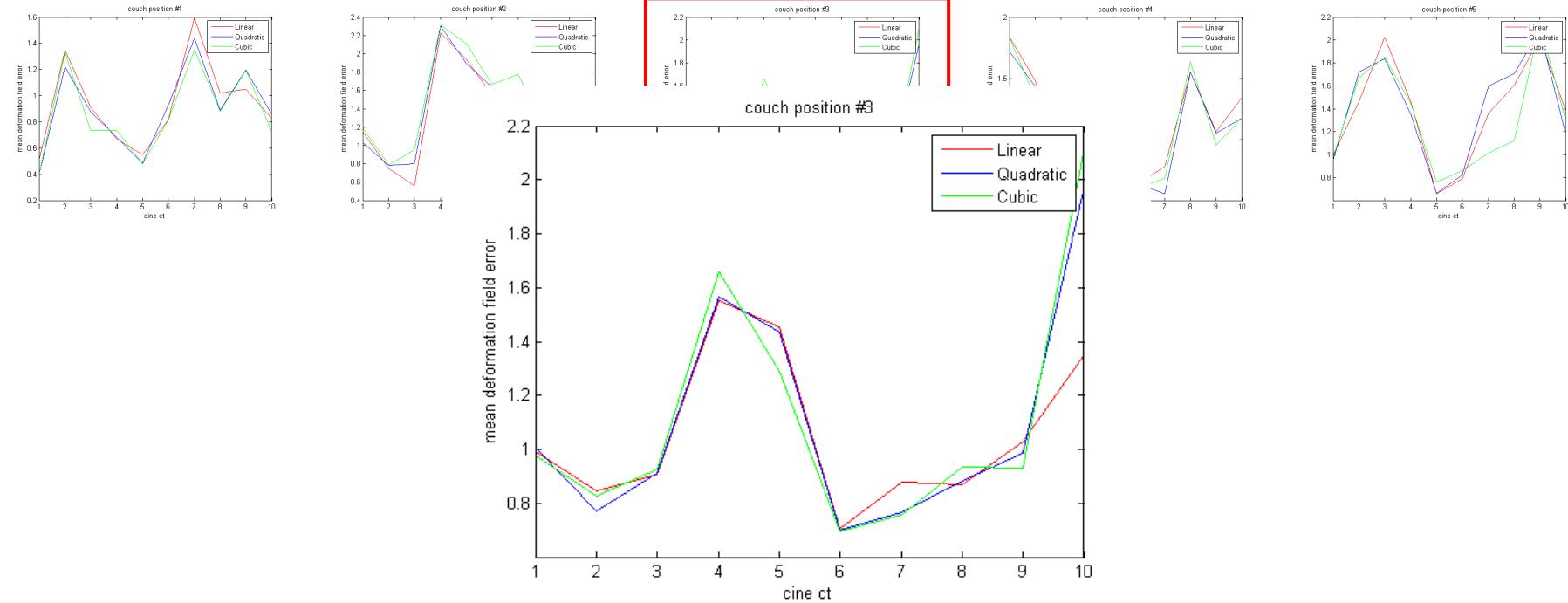
# Core task 4 - Motion Models Evaluation

Deformation Field Error - mean error



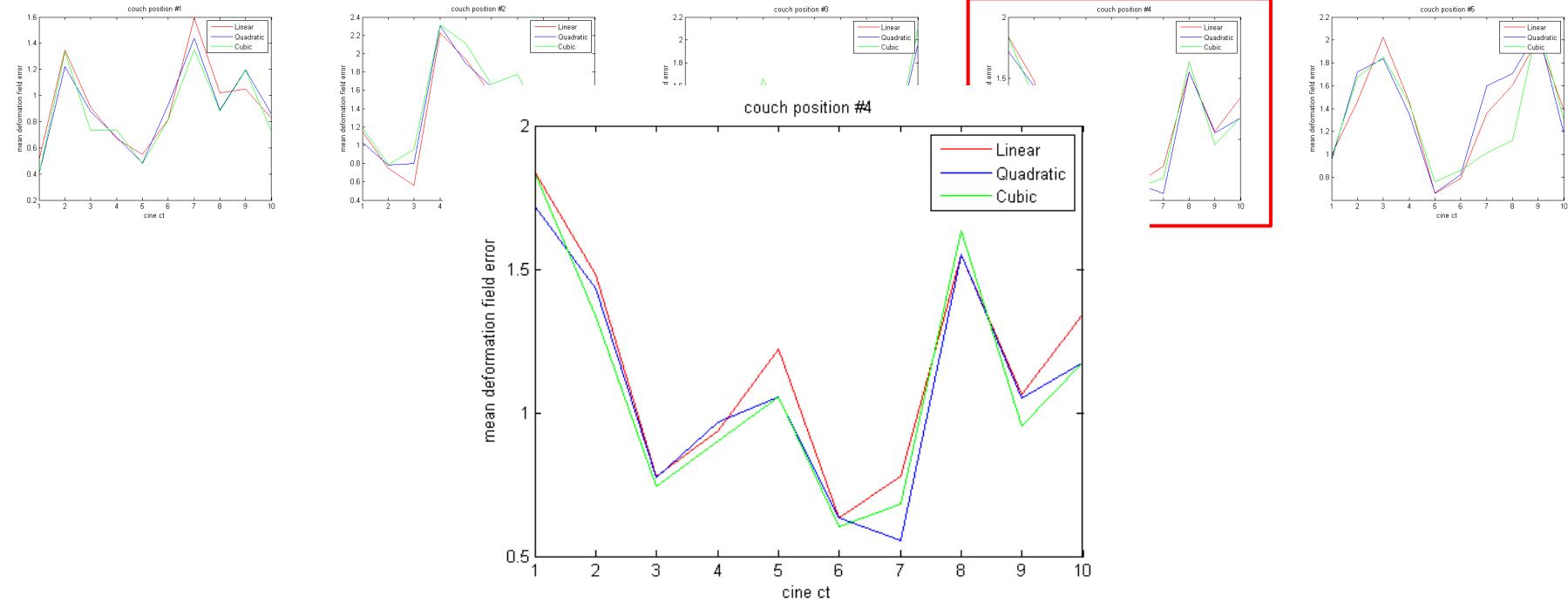
# Core task 4 - Motion Models Evaluation

## Deformation Field Error - mean error



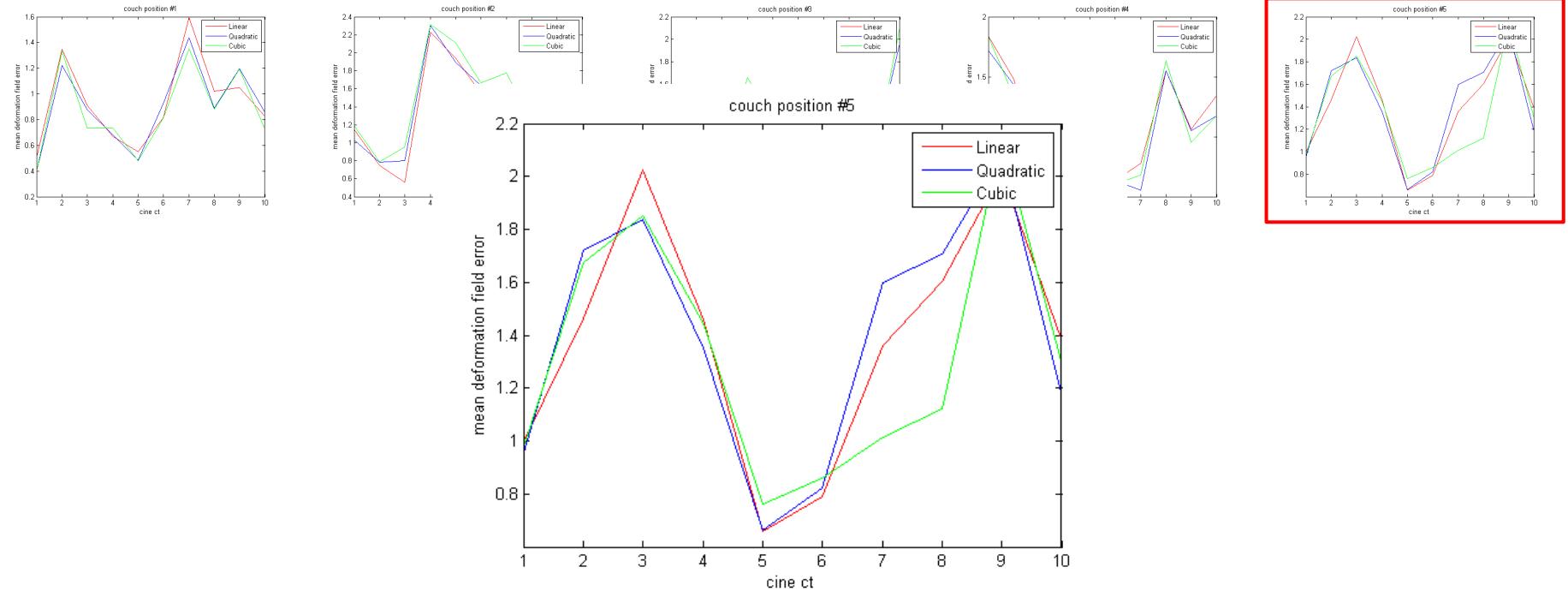
# Core task 4 - Motion Models Evaluation

## Deformation Field Error - mean error



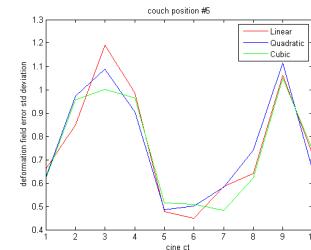
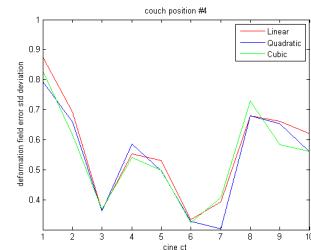
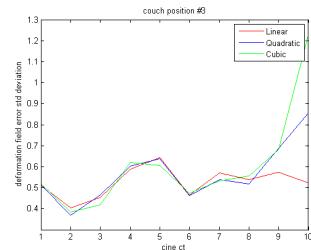
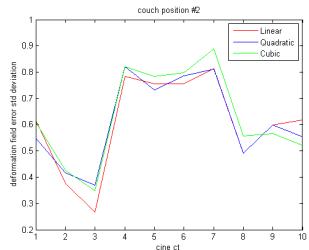
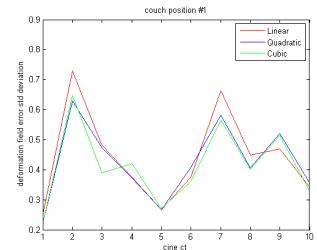
# Core task 4 - Motion Models Evaluation

Deformation Field Error - mean error



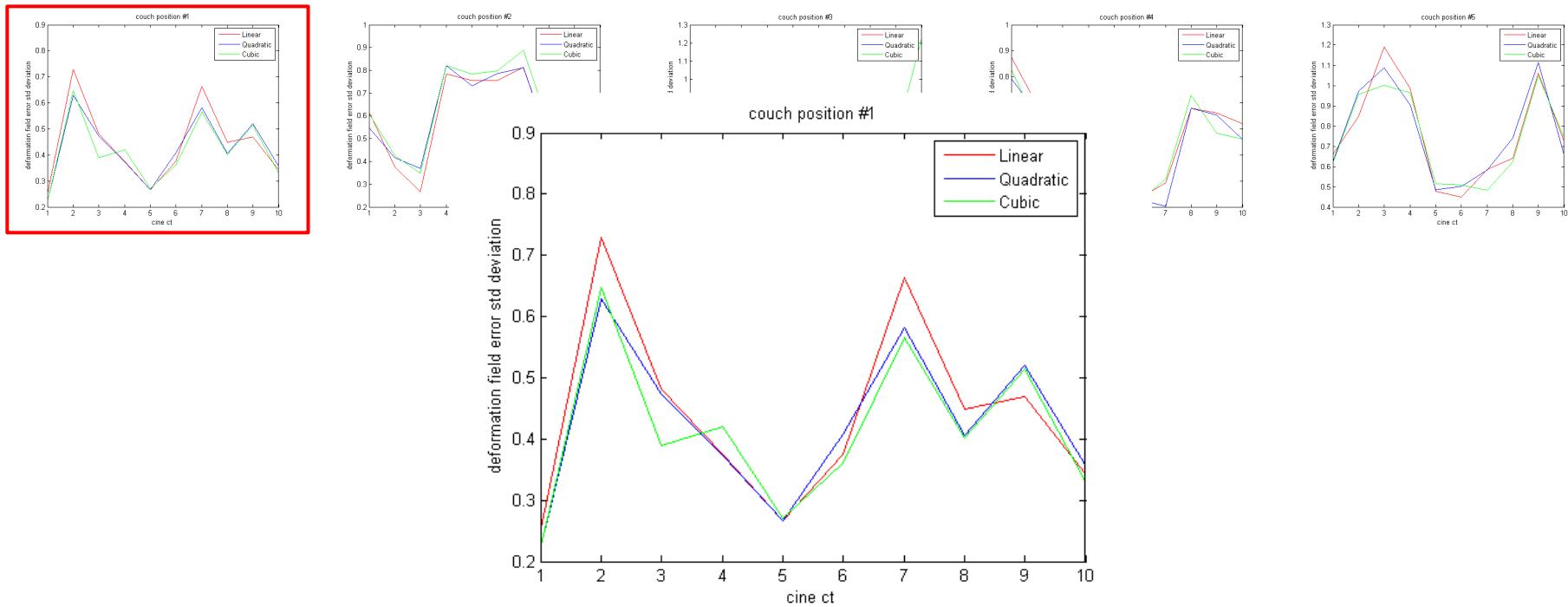
# Core task 4 - Motion Models Evaluation

## Deformation Field Error - standard deviation



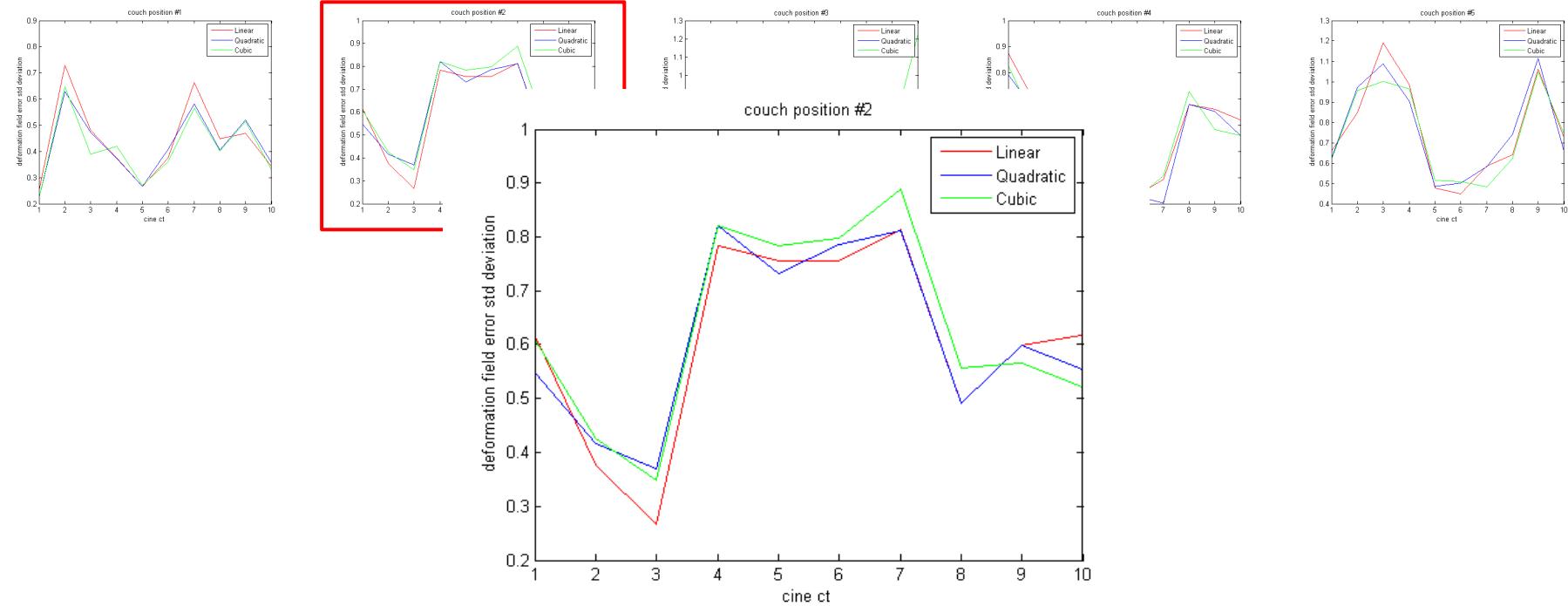
# Core task 4 - Motion Models Evaluation

Deformation Field Error - standard deviation



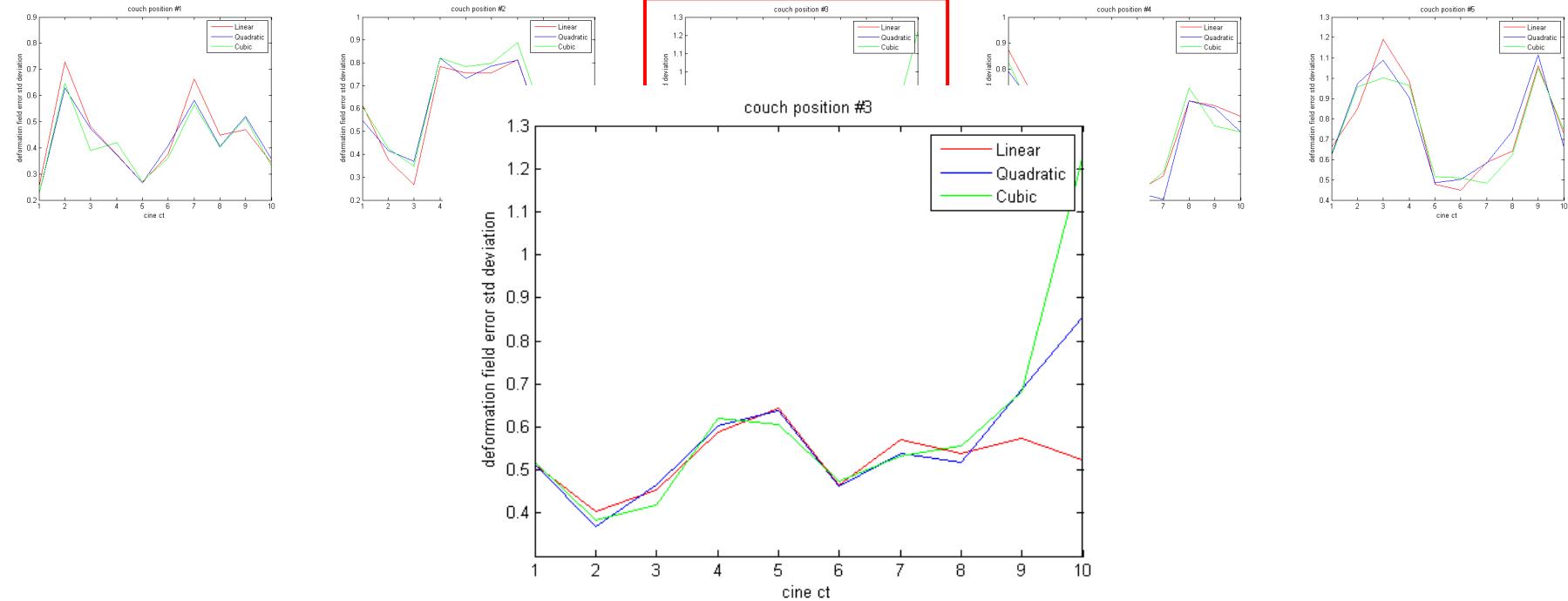
# Core task 4 - Motion Models Evaluation

Deformation Field Error - standard deviation



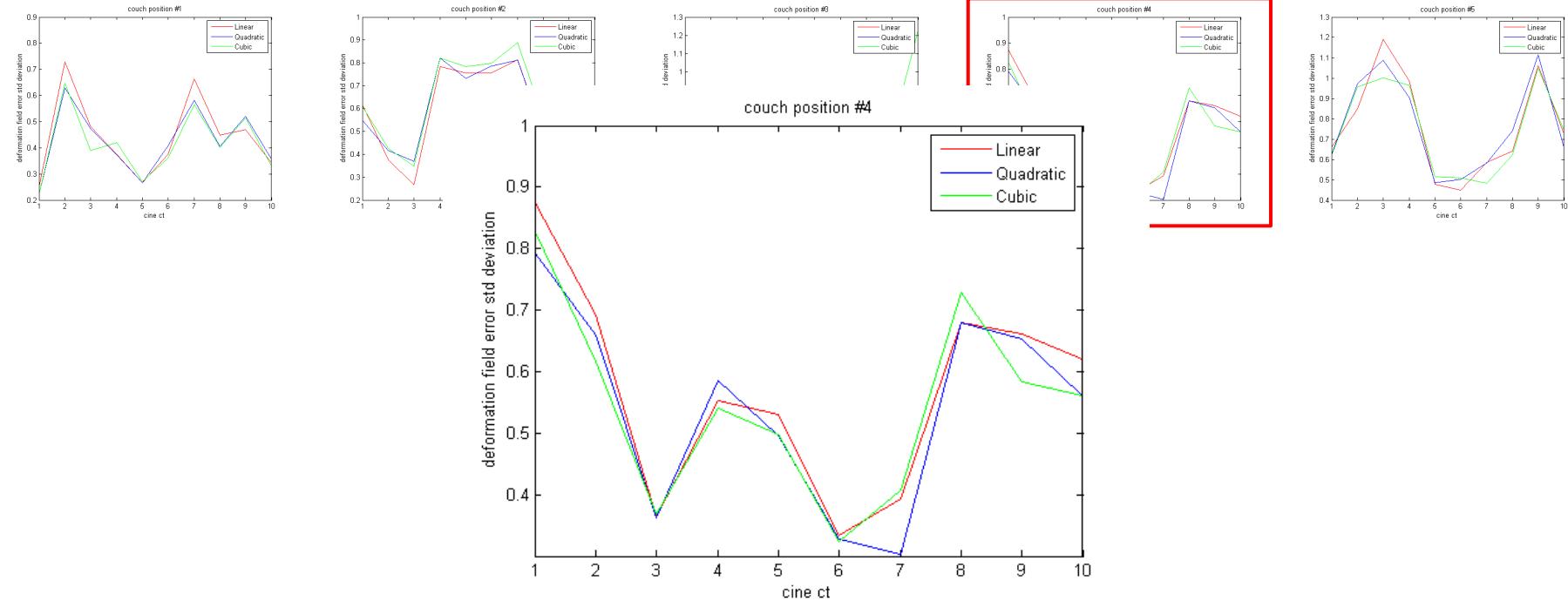
# Core task 4 - Motion Models Evaluation

## Deformation Field Error - standard deviation



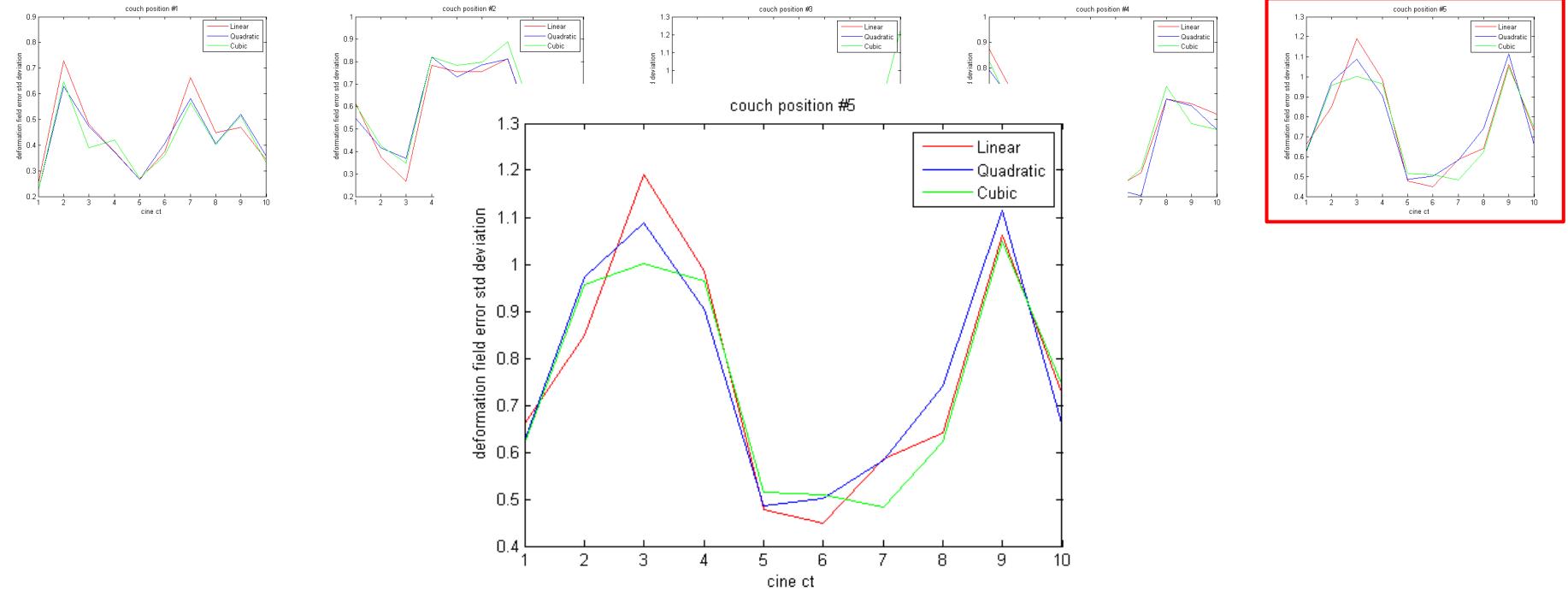
# Core task 4 - Motion Models Evaluation

## Deformation Field Error - standard deviation



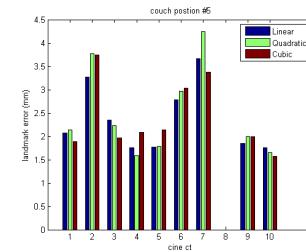
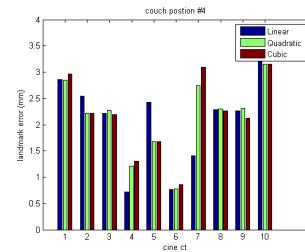
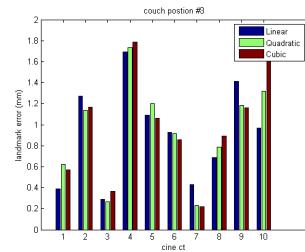
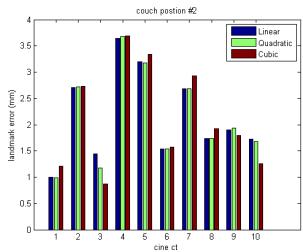
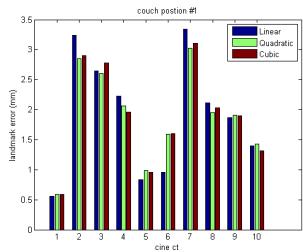
# Core task 4 - Motion Models Evaluation

Deformation Field Error - standard deviation



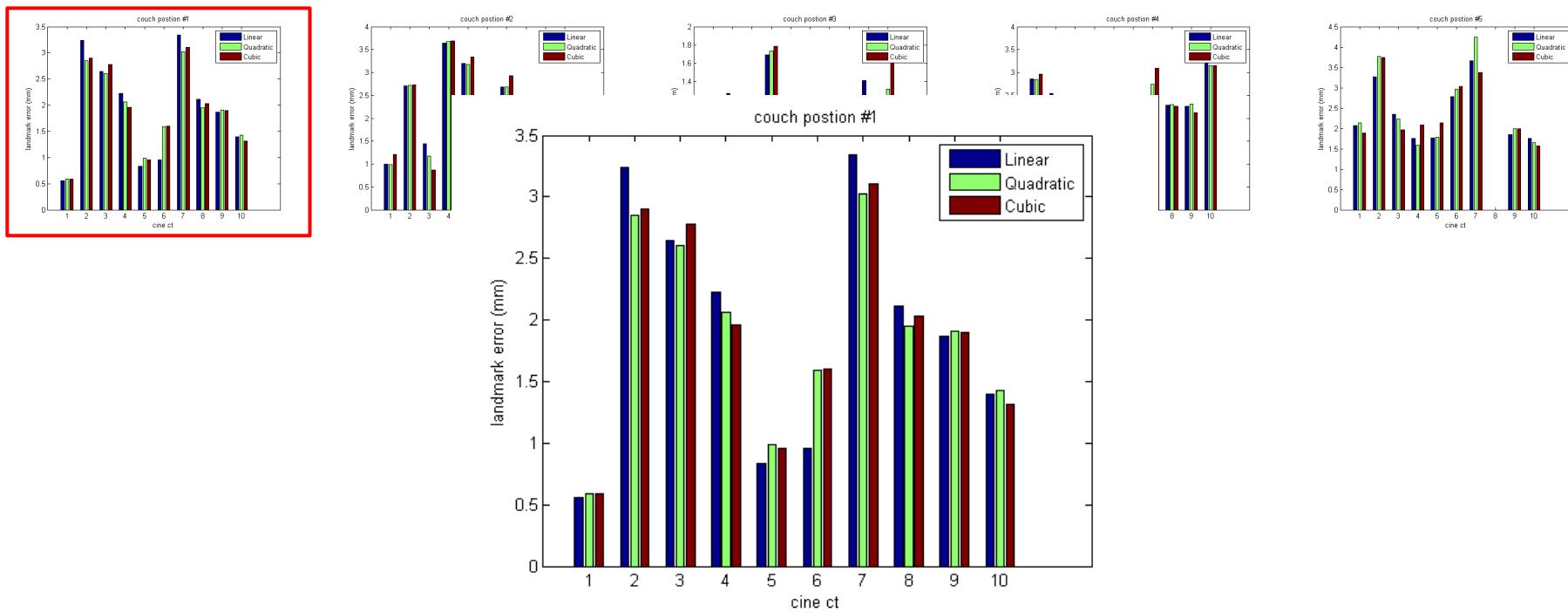
# Core task 4 - Motion Models Evaluation

## Landmarks Error



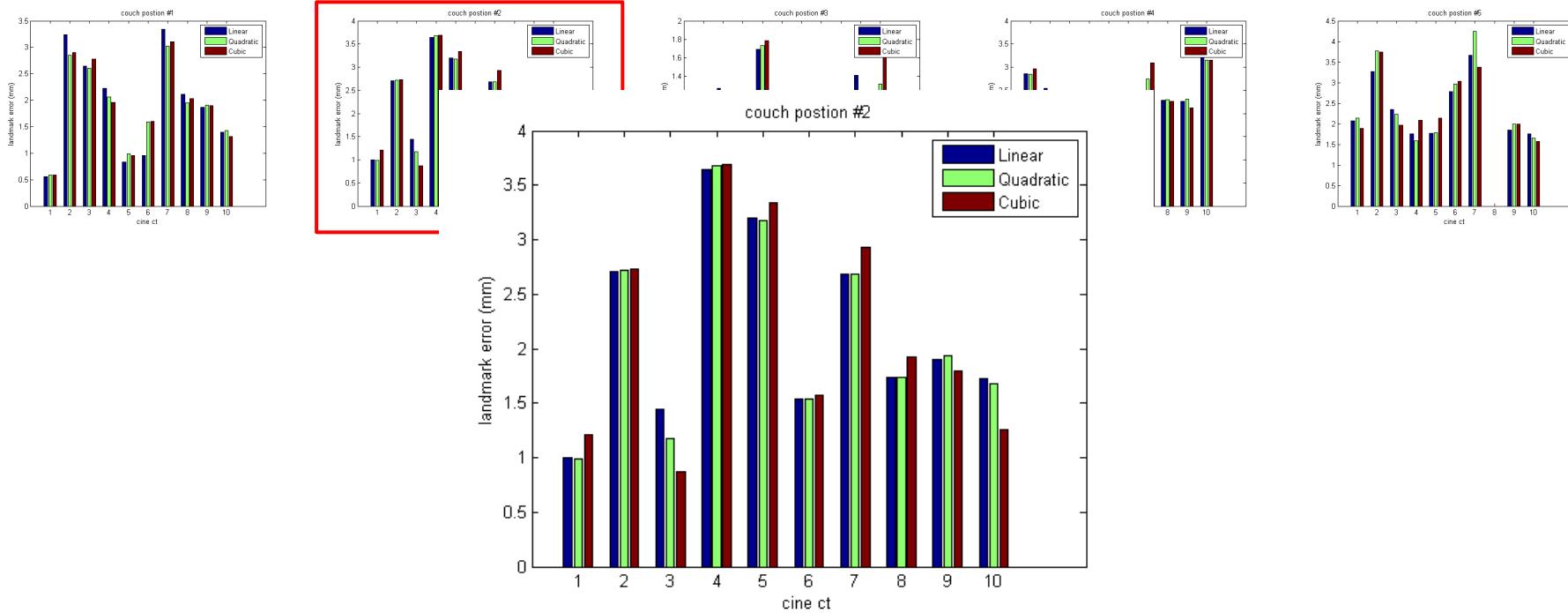
# Core task 4 - Motion Models Evaluation

## Landmark Error



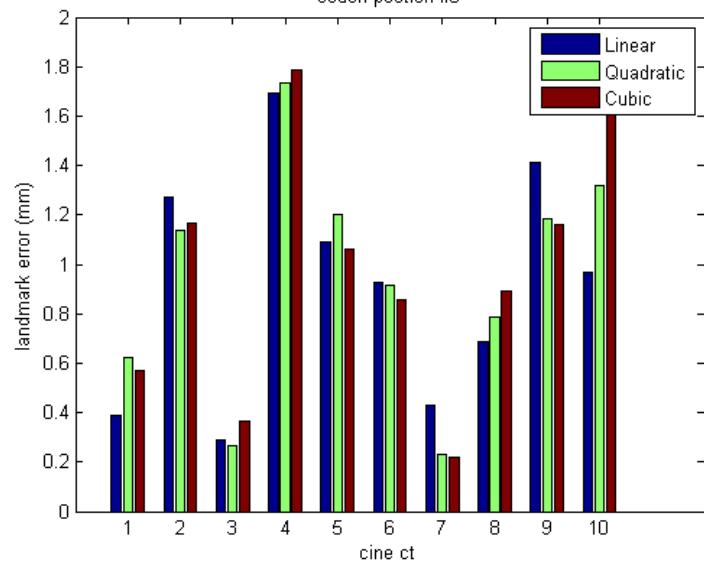
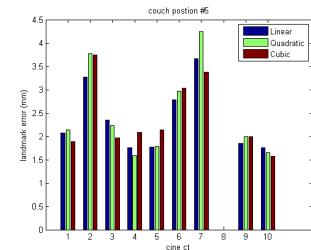
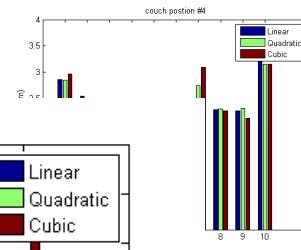
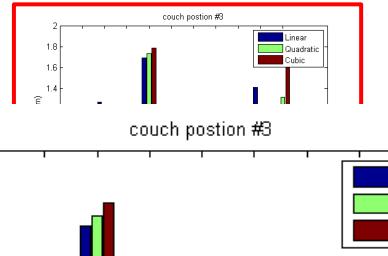
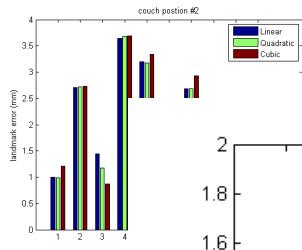
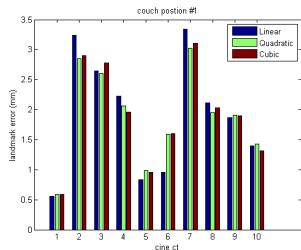
# Core task 4 - Motion Models Evaluation

## Landmark Error



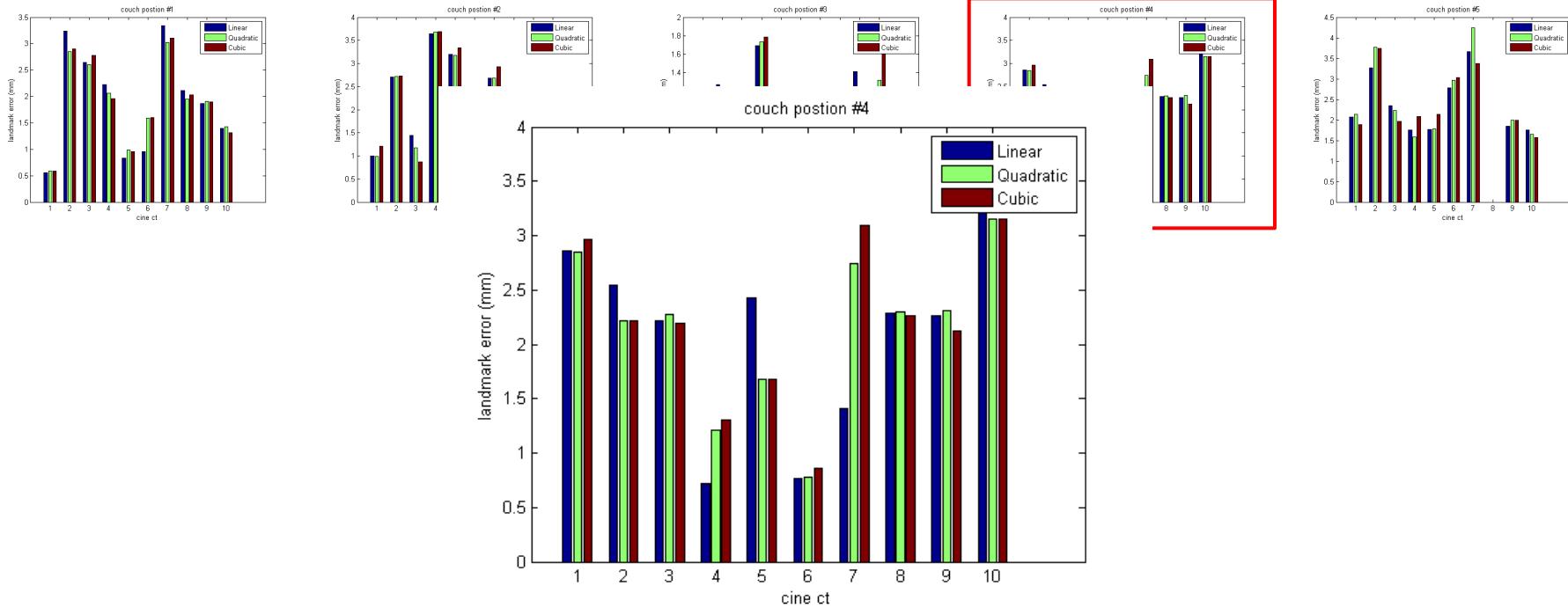
# Core task 4 - Motion Models Evaluation

## Landmark Error



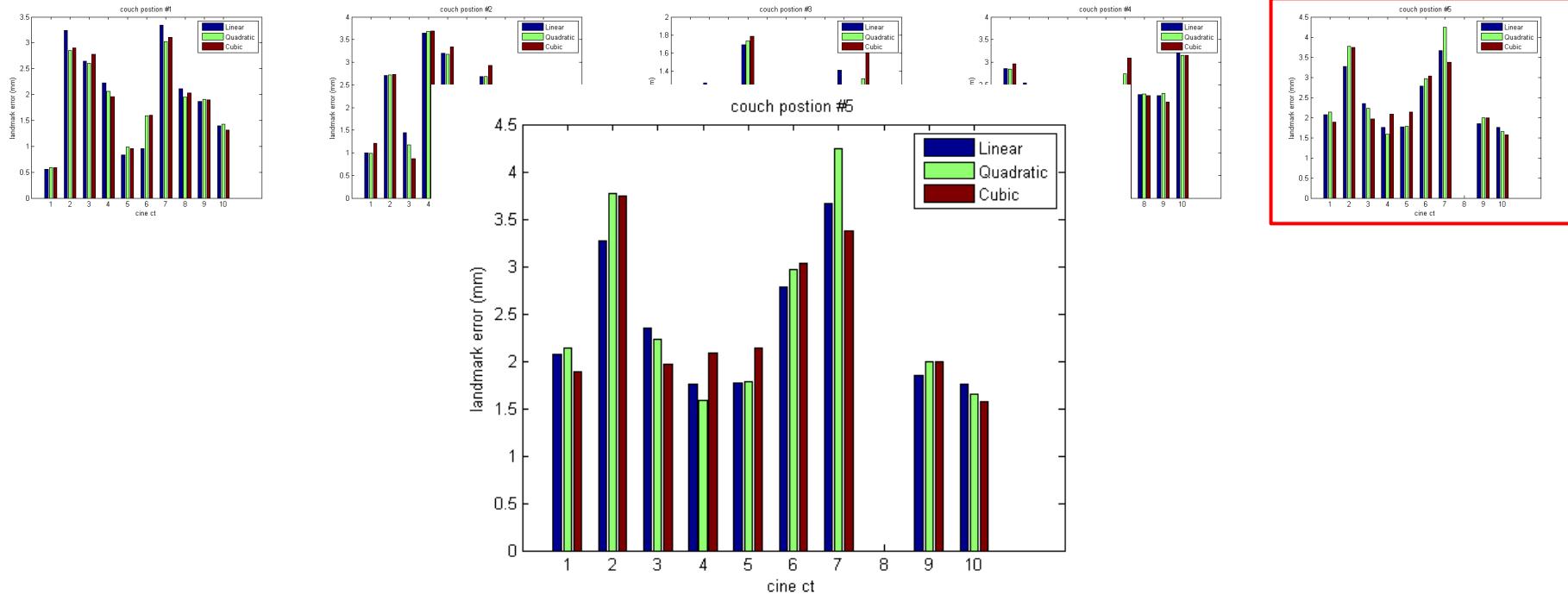
# Core task 4 - Motion Models Evaluation

## Landmark Error



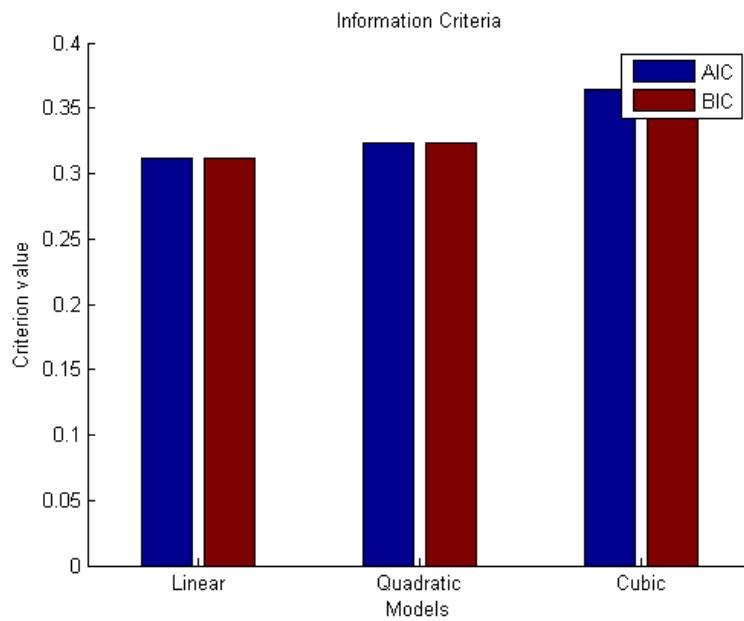
# Core task 4 - Motion Models Evaluation

## Landmark Error



# Core task 4 - Motion Models Evaluation

Information Criterias: AIC/BIC



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Thanks!