Motivation:
- Cardiac and respiratory motion cause artifacts and spatial blurring
- Non-linear cardiac motion → PVE induced intensity modulations

Contribution:
- Given: Mass-Preserving (MP) transformation model VAMPIRE [1]
- Evaluation of different motion models
  - displacement field (DF), compute an individual displacement for each voxel
  - spline transformation (ST), i.e., free-form deformation
- Focus on parametrization of ST
  1. Number of spline coefficients
  2. Regularization type and parameter

Materials and Methods

XCAT Software Phantom Data
- Generation of two gates (Processing: simulation of PVE (Gaussian blurring), forward projection, Poisson noise, EM reconstruction [2])
- Multi-level strategy along with a Gauss-Newton optimization
- Find optimal transformation \( y \) by minimizing the following functional:
  \[
  \min_y D_{SSD} ([T \circ y] \text{det}(\nabla y)) + \alpha S(y)
  \]
  \( D_{SSD} \): SSD distance functional, \( S \): Regularization functional, \( \alpha \): scalar value

Displacement Field (DF) Regularization
- Hyperelastic \( \alpha \) (parameter search by minimizing the error measure \( \epsilon \) below)

Spline Transformation (ST) Regularization
- Hyperelastic (same values as estimated for the hyperelastic DF registration)
- Internal FaIR regularization of the spline coefficients’ norm
- Evaluation of different scalar values \( \alpha \in \{5 \cdot 10^{-6}, 10^{-6}, 5 \cdot 10^{-6}\} \)

Spline coefficients
- Optimization of spline coefficient factor \( s \in \{2, 4, 6, 8, 10, 12, 14, 16, 18\} \)
- Image size is divided by \( s \) to define the number of spline coefficients; given an image size of \( 80 \times 80 \times 44 \), the number of spline coefficients ranges between \( 40 \times 40 \times 22 \) (\( s = 2 \)) and \( 4 \times 4 \times 2 \) (\( s = 18 \))

Evaluation
1. Error measure \( \epsilon(y, y_{GT}) = \frac{1}{|\Omega|} \int_{\Omega} |y(x) - y_{GT}(x)| \, dx \)
2. Total processing time \( t \)

Results: DF vs. ST

![image](a) Template image \( T \)

![image](b) Reference image \( R \)

Fig. 1: The template image \( T \) (a) is registered to the reference image \( R \) (b).

Discussion and Conclusion

- ST model is superior to DF strategy in terms of processing time and accuracy
- Optimal number of spline coefficients: \( 8 \times 8 \times 4 \) (\( s = 10 \)) → comparable results for all regularizations with subvoxel accuracy for \( s = 10 \) (voxel size: \( 3.375 \) mm)
- Optimal regularization for ST:
  - Hyperelastic regularization (highest accuracy; guaranteed diffeomorphism)
  - Fair regularization with \( \alpha = 5 \cdot 10^{-6} \) (good accuracy; short processing time)

References