Note

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Xia Li, Muheng Li, Damien Weber, Tony Lomax, Joachim Buhmann, Ye Zhang
Paul Scherrer Institut, ETH Zurich

Beyond Voxel-Based Methods: Continuous Motion Modeling for Enhanced Deformable Image Registration

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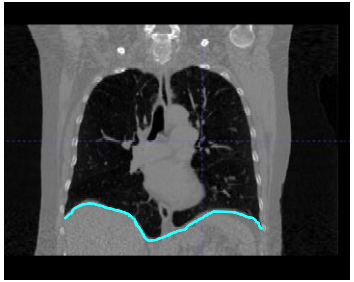
ETH zürich

Strategic Focus Area
Personalized Health
and Related Technologies

Deformable Image Registration in Radiotherapy

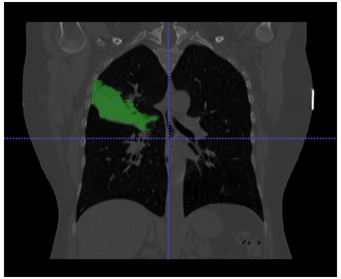
Intra-fractional Motion Modeling



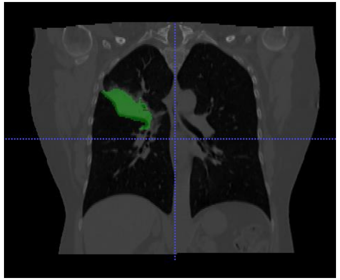
Inhale phase

Exhale phase

Inter-fractional Anatomic Changes

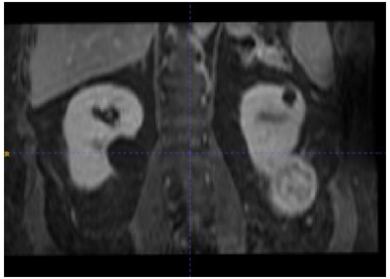


Pre-treatment

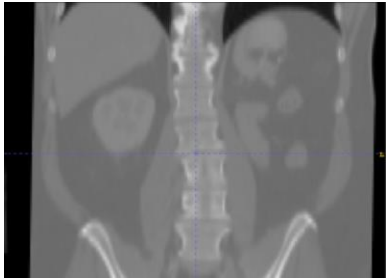


Post-treatment

Cross-modality Registration



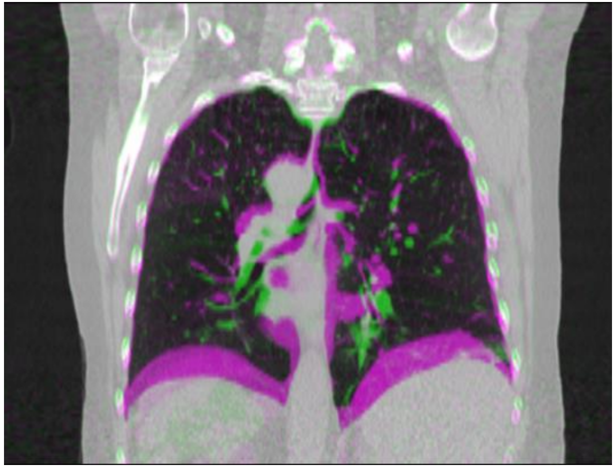
MR



CT

Challenges of Deformable Image Registration in Radiotherapy

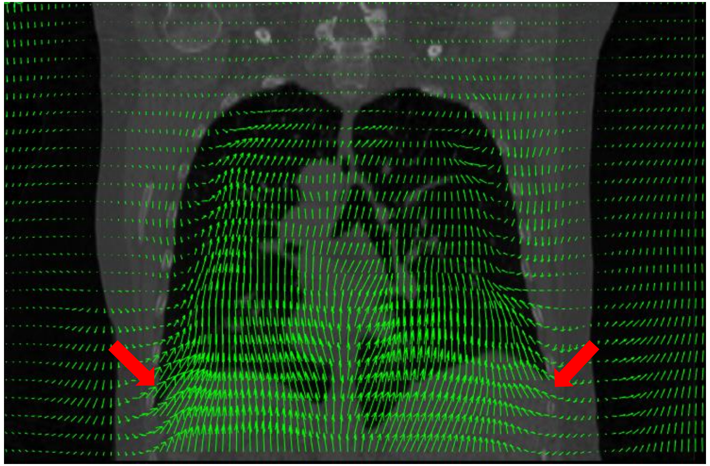
Large Deformation



- Breaks the small motion assumption
- The linear approximation turns invalid

$$I(\mathrm{x}+\mathrm{u}) = I(\mathrm{x}) + \nabla I(\mathrm{x}) \cdot \mathrm{u}$$

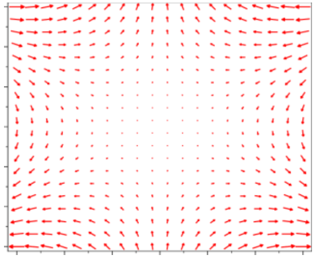
Sliding Boundary



- Break the spatial smooth assumption
- Hard to model the continuity regularizations

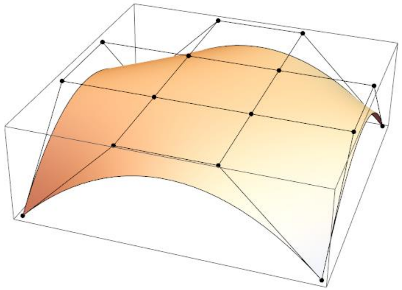
Spatial Continuous Motion Modeling

Grid-based Representation



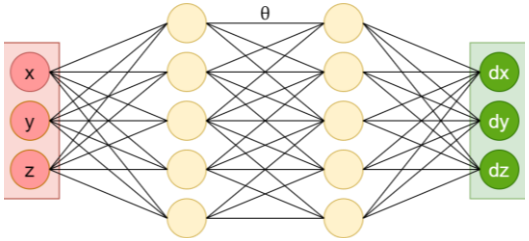
- Optimize the whole DVF map
  - Slow convergence
  - Heavy storage
- Limited smoothness
  - Only from regularization
- Allows for sharp gradients

BSpline-based Representation



- Optimize the B-Splines
  - Fast convergence
  - Light storage
- Explicit smoothness
- No sharp gradients
  - Not suitable for sliding boundary

Implicit Neural Representation

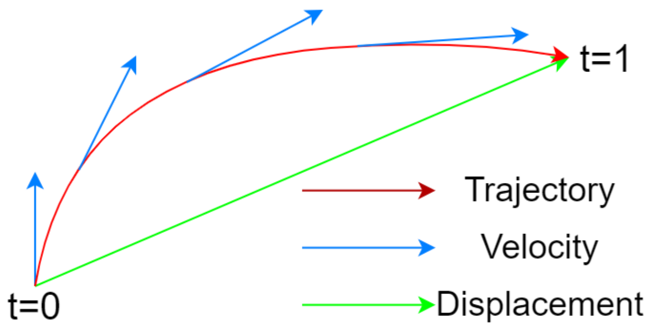


- Optimize the network parameters θ
  - Fast convergence
  - Light storage
- **Dynamic trade-off between spatial smoothness and sharpness**
  - Adapted by optimization
  - Suitable for sliding boundary

Temporal Continuous Motion Modeling

Estimate large deformation is challenging:

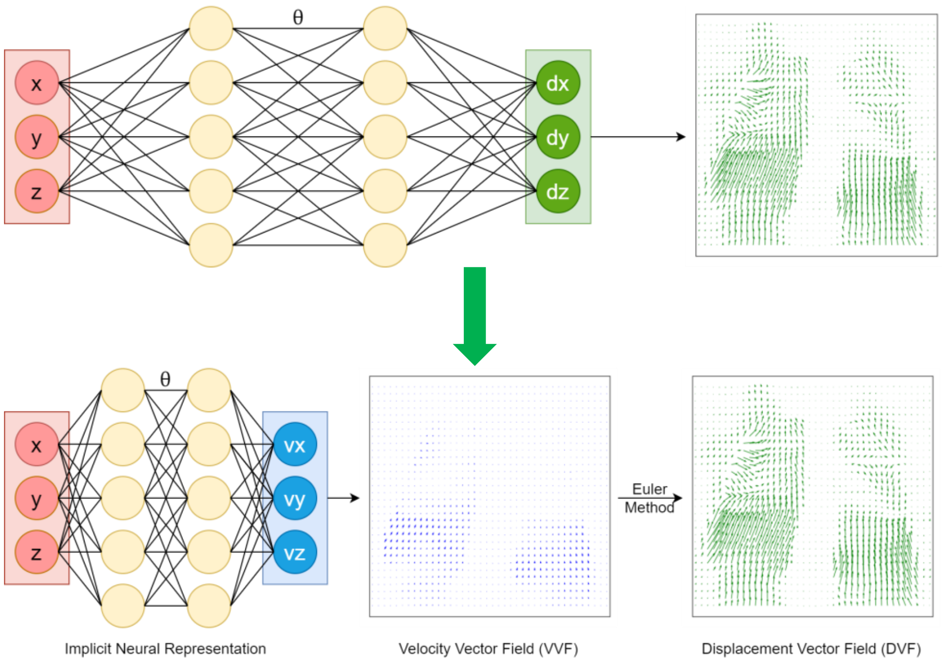
- Decompose large deformation into small steps



Integrate VVF to DVF by the Euler Method

- Suitable for large deformation

Spatial Continuous Only: End-to-End (E2E)



Spatial and Temporal Continuous
Large Deformation Decomposition (LDD)

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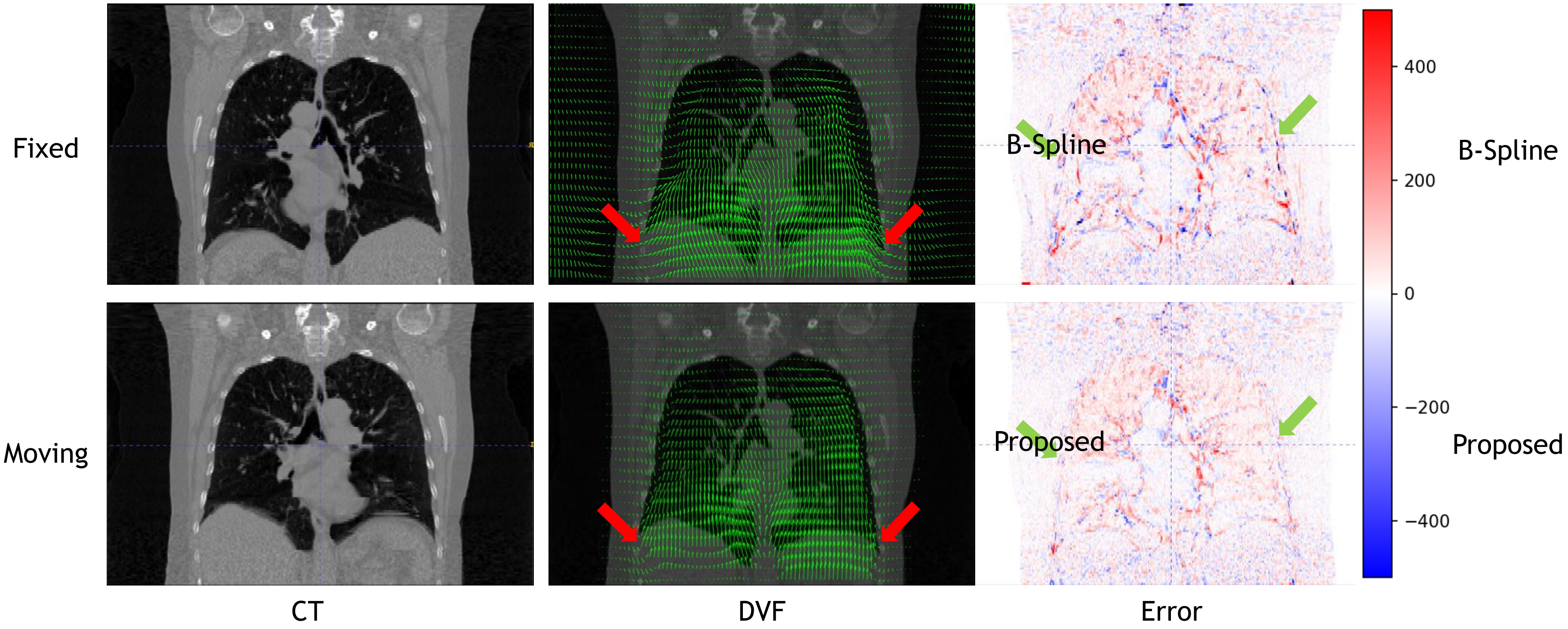
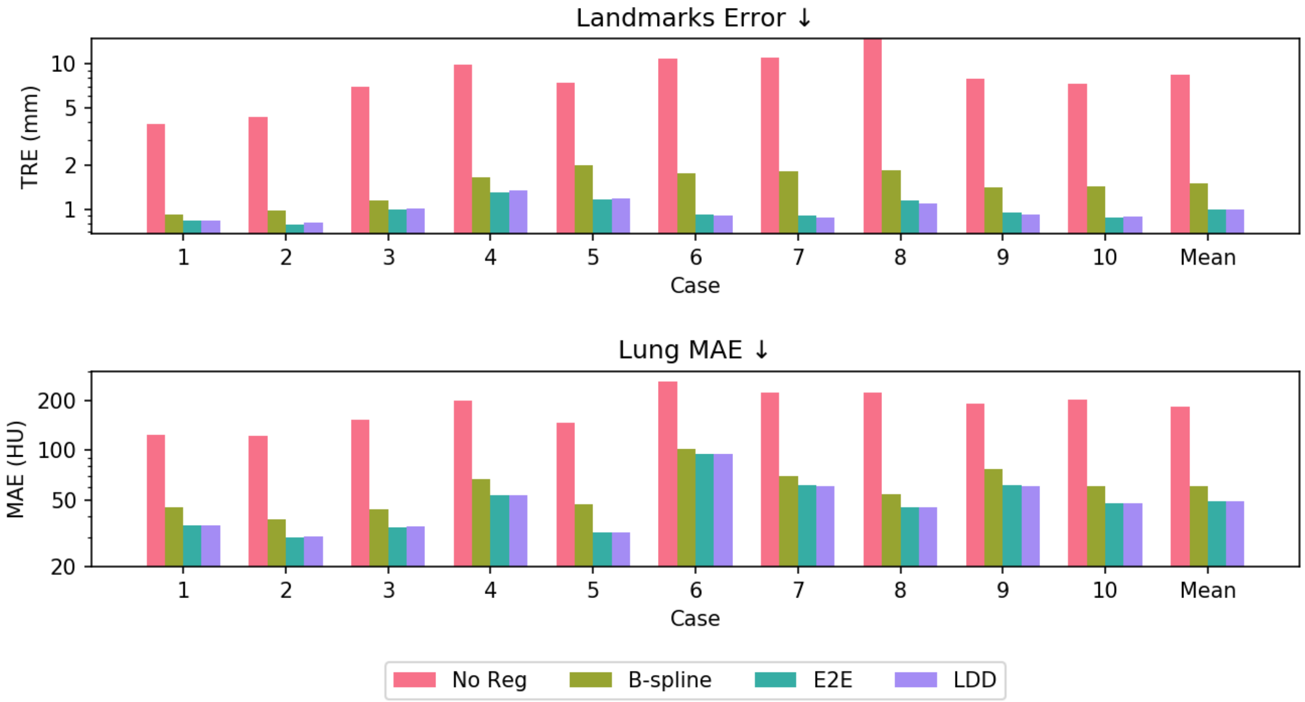
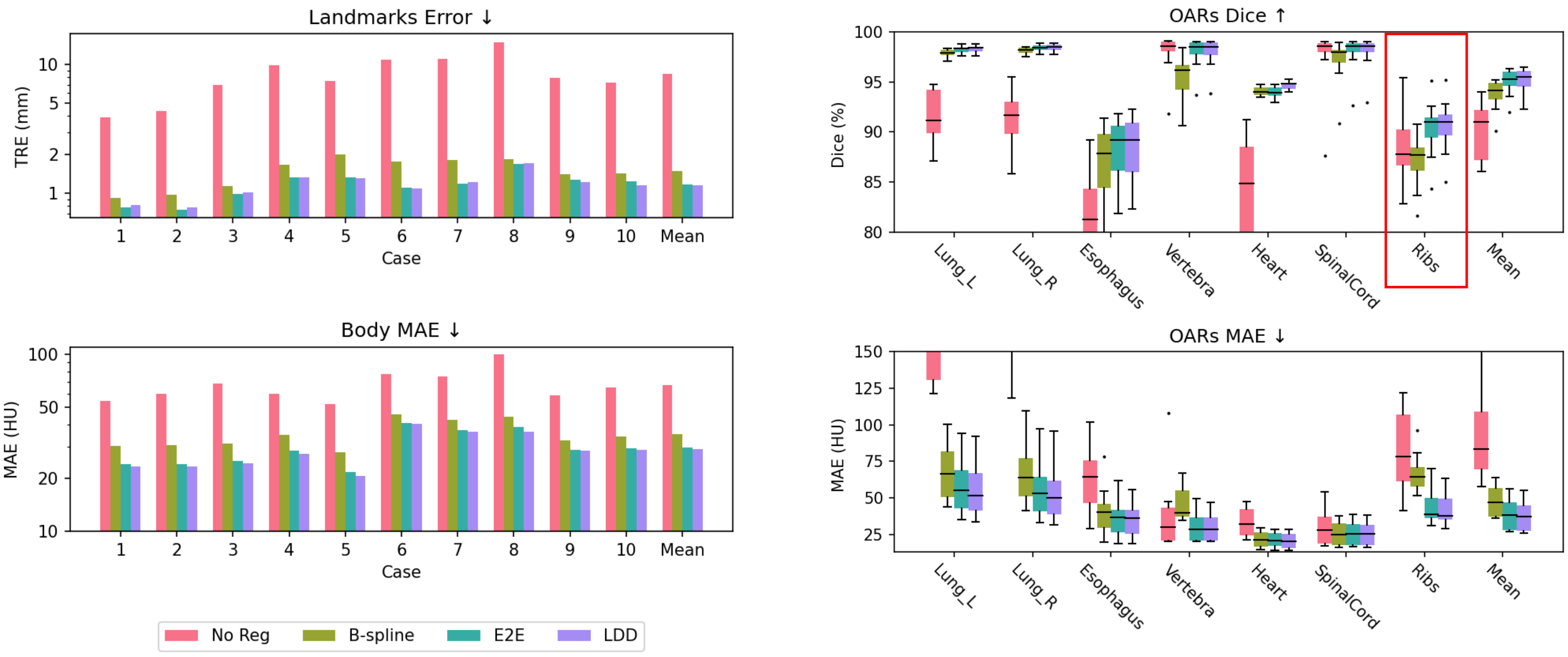
Qualitative Comparisons on the DIRLab dataset



Quantitative Comparisons: Trained inside the Lung Region

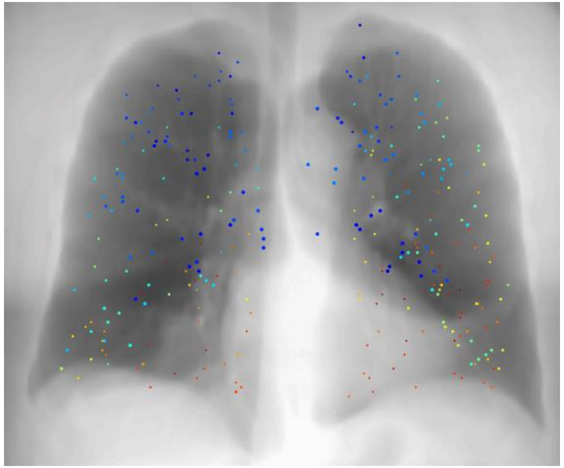


Quantitative Comparisons: Trained over the Whole Body

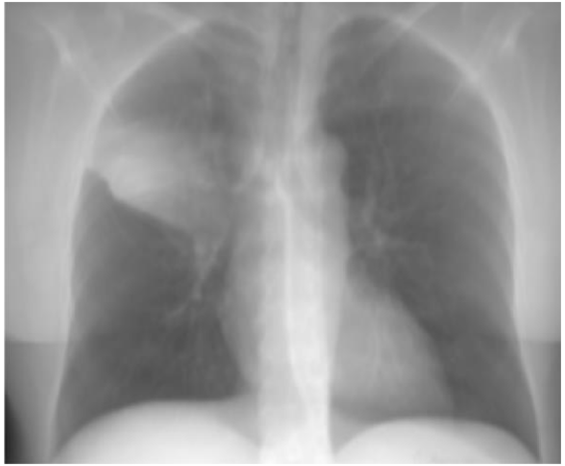


Benefits From the Continuity: Forward Warping and Super Frame Rate

Intra-fractional Motion Modeling



Inter-fractional Anatomic Changes

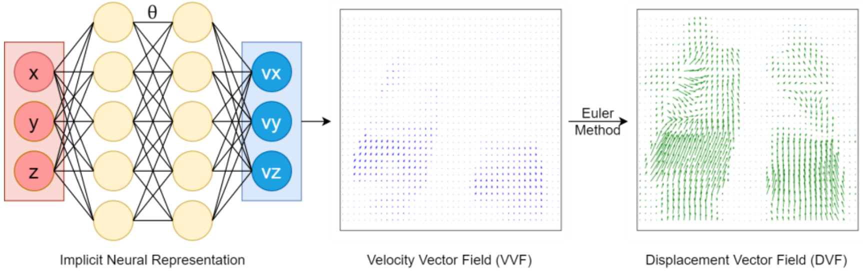


Supine to Upright

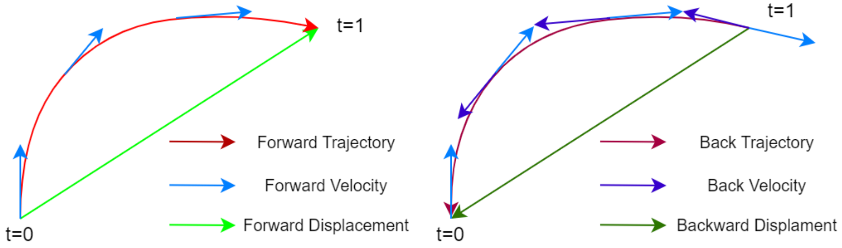
- Inputs are only two extreme phases
  - Inhale → Exhale, Pre-treatment → Post-treatment, Supine → Upright
- Once fitted, can integrate DVF from any t any location to any t'
- Outputs are super-frame rate and (super-resolution) 4D images

Conclusion

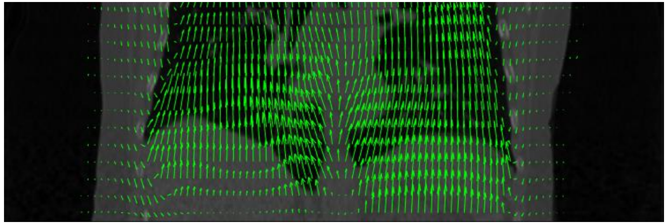
- A spatial and temporal smooth modeling for intra-fractional motion, good at large deformation.



- It also provides possibility for reversed trajectory (forward warping).



- It outperforms previous methods in every evaluation metrics, especially on the sliding boundary.



- It enables the potential application in super frame rate and super-resolution

One Thing More

CPT-DIR

Further Presentations of This Project

- ESTRO 24 @Glasgow,
  - **Upright radiotherapy**: Hope or hype?
  - Monday, May 06, 8:45-9:00
  - Hall 3
- ICCR 24 @Lyon,
  - **Rising Star Competition**
  - Tuesday, July 09, 9:45-10:00
  - Auditorium Lumière

Project page