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Recalage déformable en radiothérapie

Radiation therapy guidée par l'image

- A major cancer treatment (2/3 of patients)
- Use radiation to kill cancer cells.
 - High energy x-ray
 - Alternative with proton, carbon (in development)
- Challenge:
deliver maximum dose to target, while sparing healthy surrounding tissue

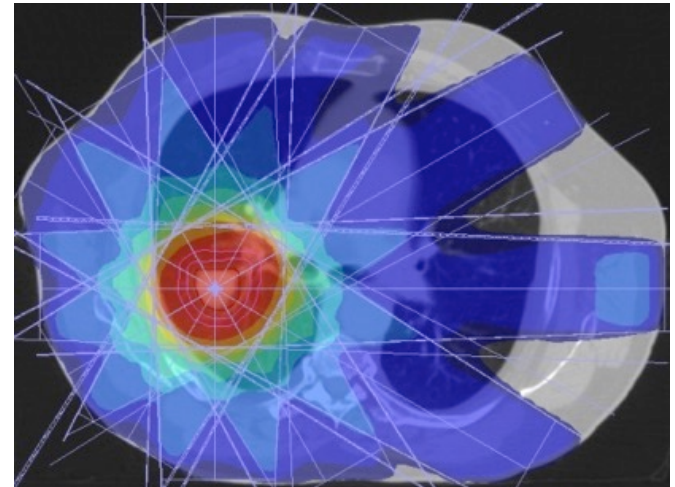


Image guided radiation therapy

Make heavy use of imaging

Treatment planning:

- Performed on CT
- Use fused MRI, PET
- Advanced development with 4D CT



In room image guidance

- CBCT Cone Beam CT
- US image guidance
- Video, surface based
- Future: embedded MRI



Image guided radiation therapy

Heavily computer based.

- Simulation to predict dose distribution on planning CT image
- Segmentation (atlas based)
- Registration, planning multimodality
- Reconstruction motion compensated (in room)
- Registration, in room

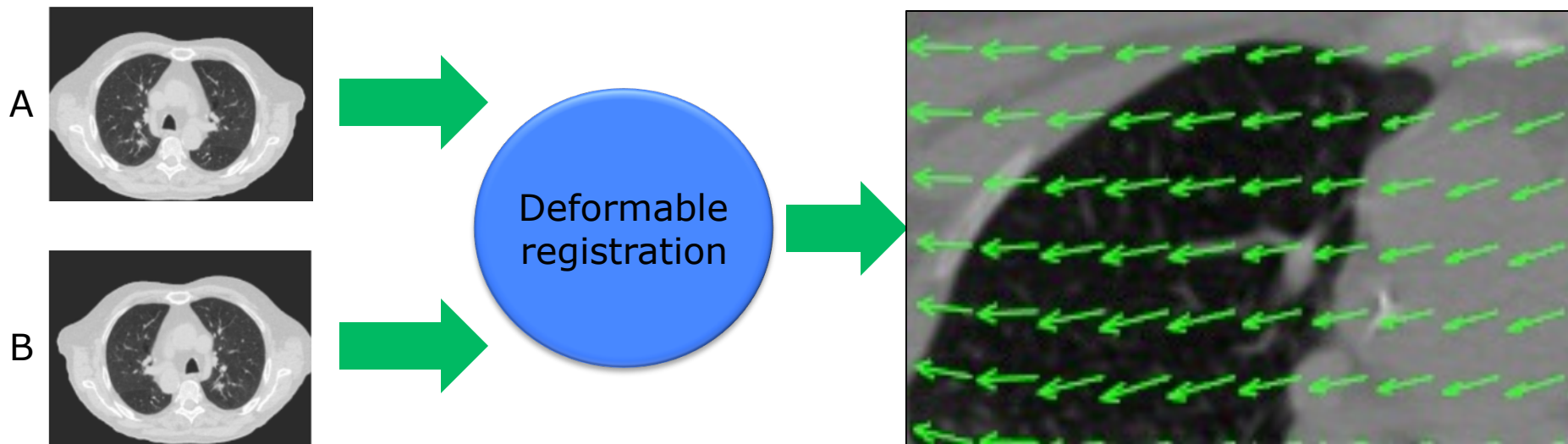


Deformable Image Registration

Deformable Image Registration: is an **iterative** algorithm

- **Input** = two images A & B
- **Output** = Deformation Vector Field (DVF)

Numerous method ; Still active research field
Useful in RT but in other domains also



Applications in radiation therapy

- Automated segmentation by contours propagation
- 4DCT breathing phases segmentation (lung, liver)
- Patient setup control for moving/deformable organs (prostate, bladder ...)
- Patient follow-up
- Dose accumulation, warp dose map between time points (4D, re-irradiation)
- ...

Inter – patient

Intra – patient
Intra – session

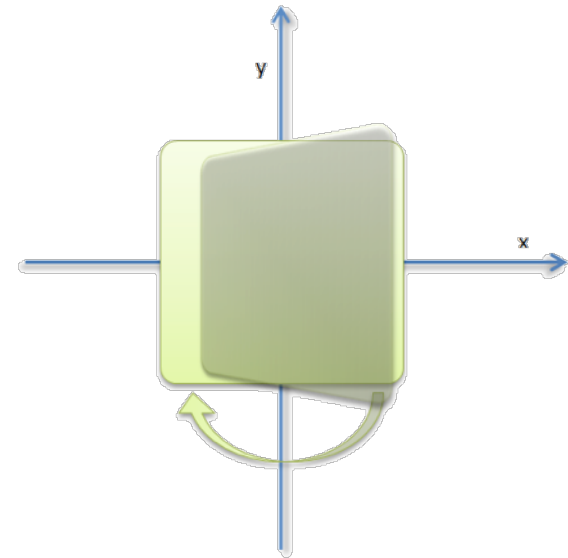
Intra – patient
Inter – session

Intra – patient
Inter – session

In DIR we trust ...

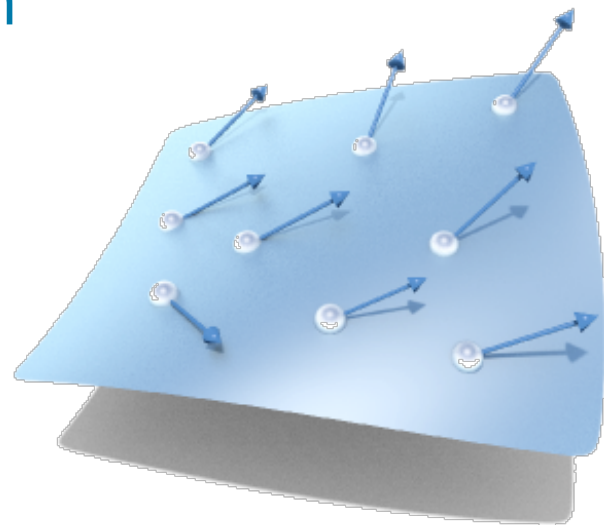
■ Rigid image registration

- Find rotation and translation
- **6 numbers** for 3D images



■ Deformable image registration

- Find deformation
- One vector at each pixel
- **Thousands of numbers**



DIR is an ill-posed problem

- *Well-posed* = solution exists + the solution is unique + the solution depends continuously on the data
- If not: *ill-posed*. It means hard to solve, **trade-off**

- **Trade-off:**
 - **Image similarity**: can always match pixels

 - **Transformation regularity**: is the deformation plausible ? (e.g. prevent “crossing” pixels trajectories)

DIR is an optimisation process

$$T_{opt} = \arg_T \max \left[\alpha E_{sim}(A, B, T) + (1 - \alpha) E_{reg}(T) \right]$$

A, B

= the two images to register (reference & moving)

T_{opt}

= the optimal transformation to be find

$\arg_T \max$

= **optimization algorithm**

E_{sim}

= **similarity measure**

E_{reg}

= **regularization**, smoothing measure of T

α

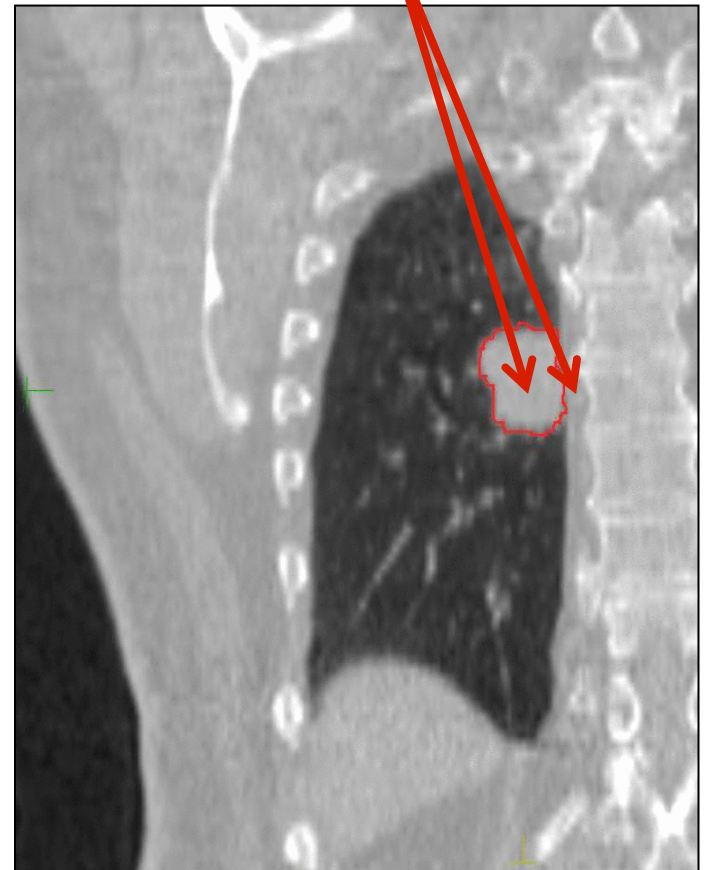
= tradeoff parameter

Sliding issue

Lung, liver

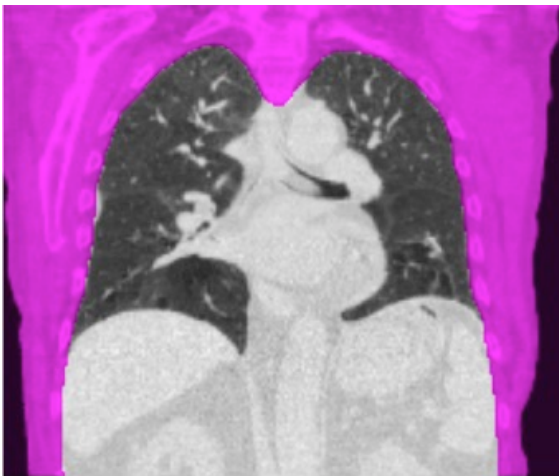
- Sliding causes **discontinuities** in the motion field
- However the DVF is artificially “smooth” by the regularisation E_{reg}
- Estimated deformation is **wrong** around the sliding region

Neighbouring pixels

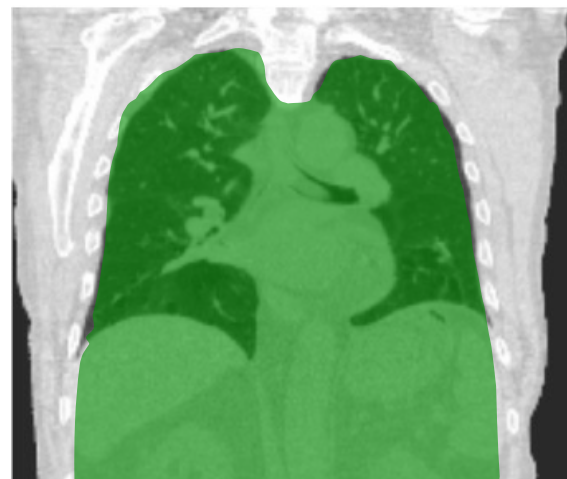


Motion mask

- Several approaches of dealing with discontinuities
 - Biomechanical modelling [Villard 2005, Al-Mayah 2008]
 - Adapted regularisation [Wolthaus 2008, Ruan 2008]
- An approach with prior segmentation
 - Lung mask: [Werner 2009, Kabus 2009]
 - Motion mask: [Wu 2008, Vandemeleubroucke 2012]



outside

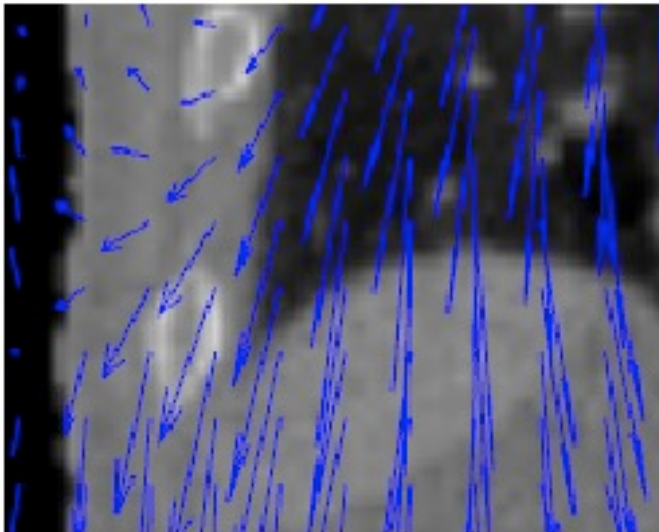


inside

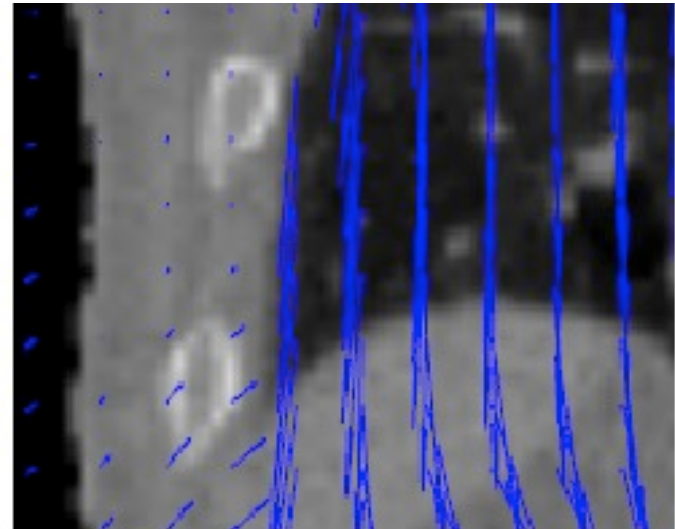
Sliding results

Masks provide interface where sliding occur

- Direction-dependent regularization:
Near boundaries, regularize in the direction normal to the surface
- Optical-flow or B-Splines
[Schmidt-Richberg 2011] [Delmon, 2013]



Without motion mask



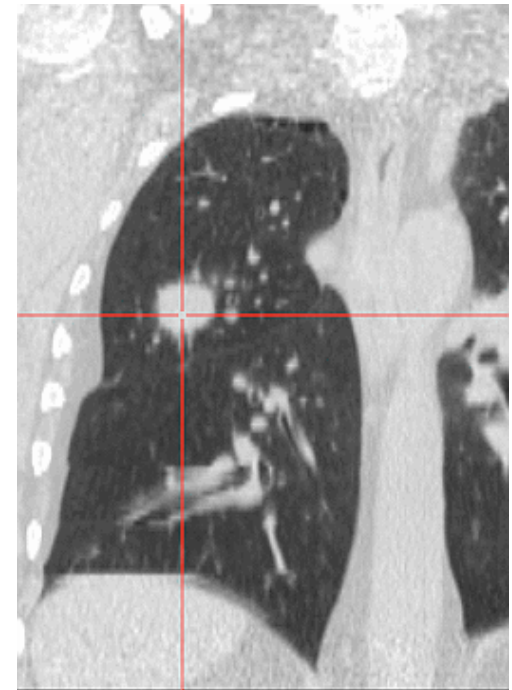
With motion mask



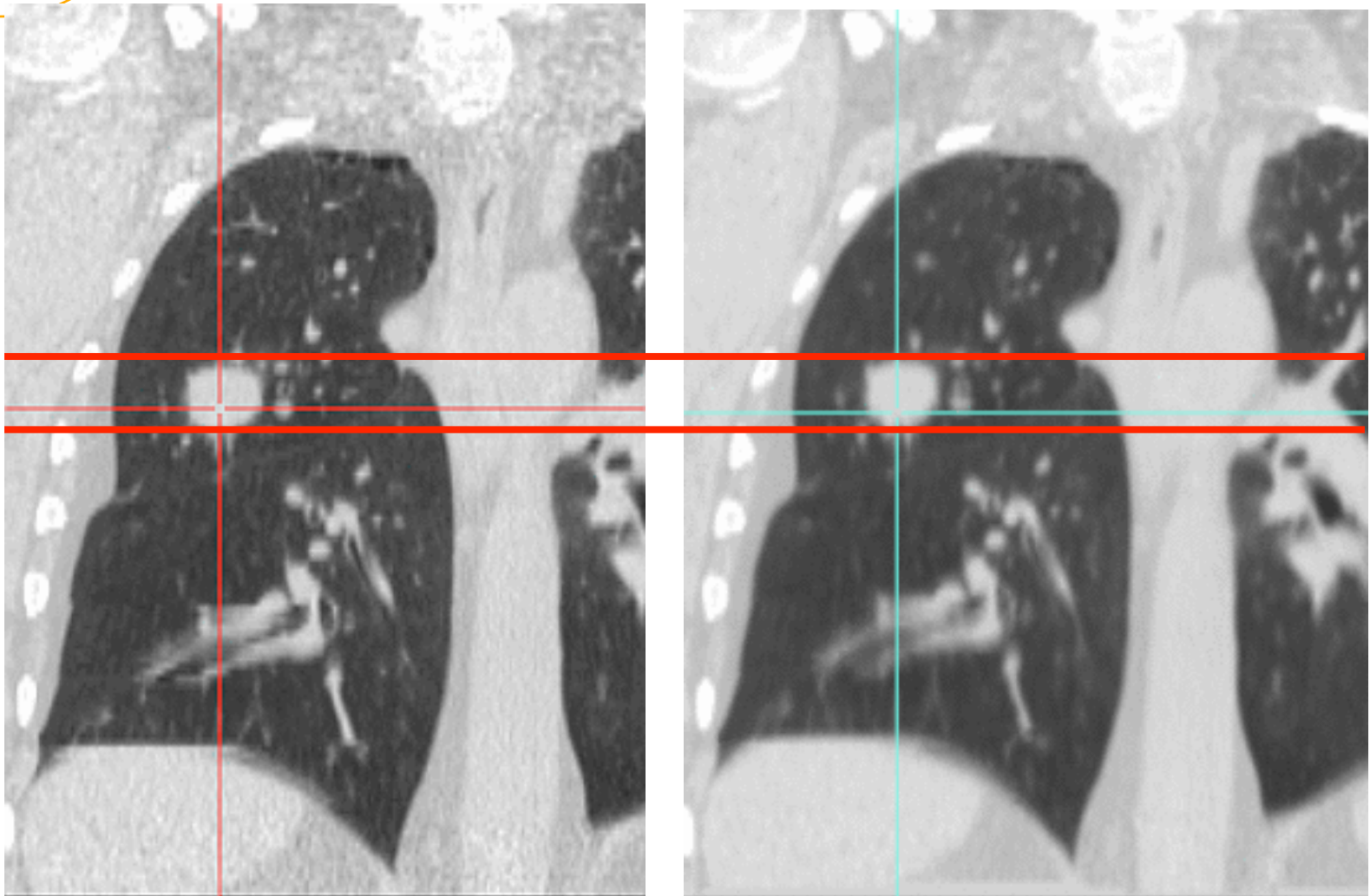
APPLICATION IN CLINIC

Lung cancer treatment strategy

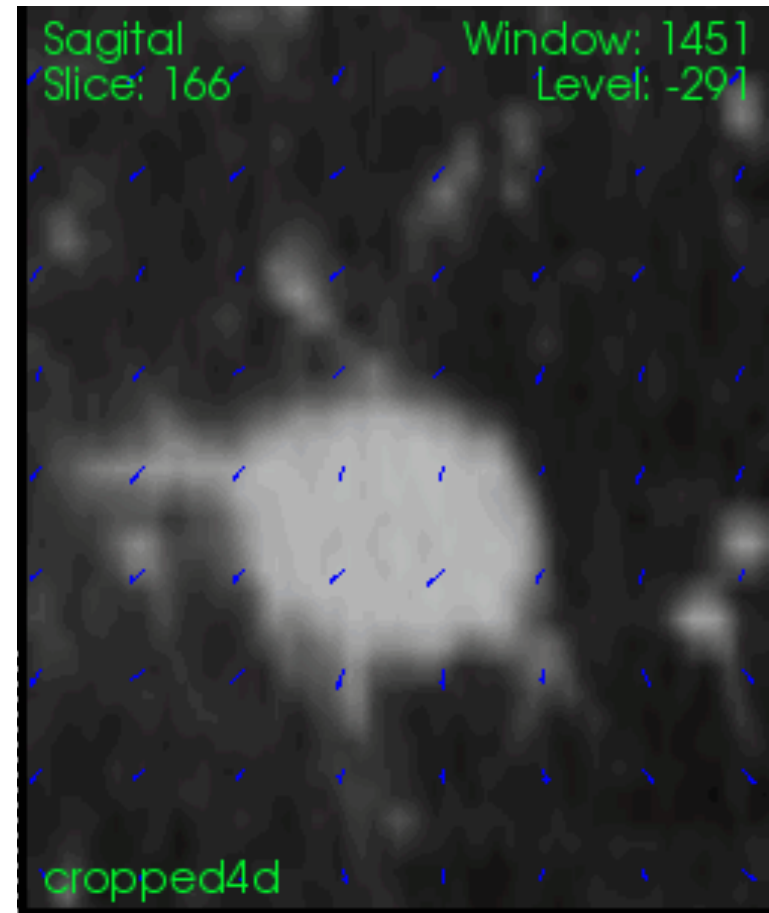
- For locally advanced NSCLC (stage III)
 - Poor 5y survival (<20% France)
 - Surgery impossible
 - RT 60-66 Gy, 30-33f (not hypofraction)
- Additional uncertainty: respiratory motion
- Consequences:
 - Safety margins are increased
 - Potential increased toxicity
 - Treatment less effective or patient excluded



Computation of “midp” image

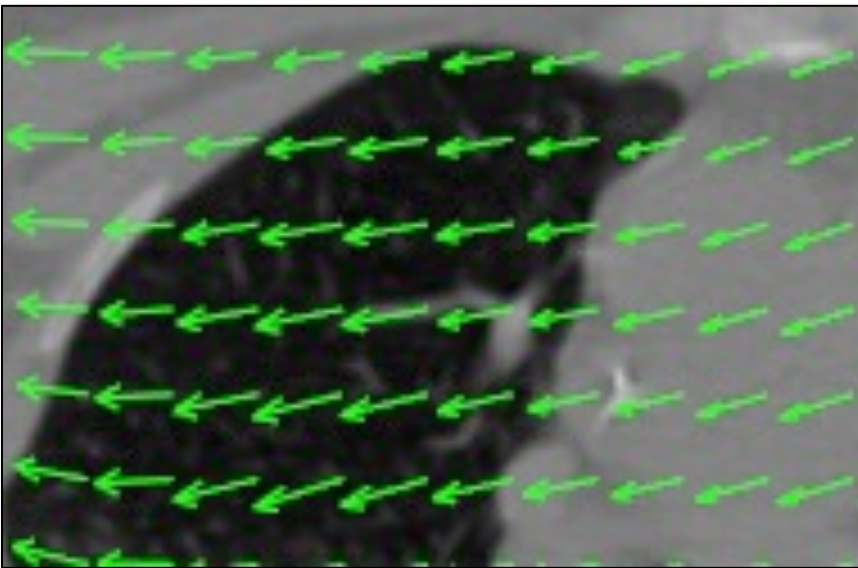


4D DVF – pixels trajectories



Strategy

- Computation of midp with **Deformable Image Registration** with sliding correction (motion mask)
[Sarrut et al 2006] [Vandemeleubroucke et al 2011] [Delmon et al 2013]
- Quantify amplitude from DVF
- Include in margin equation [Wolthaus et al 2008]



respiratory motion =
additional random error

$$M = \alpha \Sigma + \beta \sqrt{\sigma^2 + \sigma_p^2} - \beta \sigma_p$$



Current status

Mono-centric (CLB), randomized, phase II trial, with two arms
35 patients included (December 2015)

Preliminary results:

- Clinical workflow is feasible (1 patient ex.):
first time deformable registration is applied in clinical conditions

- First dosimetric results are patient dependent:
 - Some with significant volume of healthy tissue spared
 - But some patient without dosimetric advantage
 - Large influence of initial segmentation



CONCLUSION

Conclusion

- Radiation therapy field
 - Image guidance
 - Heavily use of computers (simulation, guidance etc)

- Deformable Image Registration
 - From methodological approaches...
 - ... to clinical trial
 - Also useful in other domains

Interested ?

- vv.creatis.insa-lyon.fr
- elastix.isi.uu.nl
- www.creatis.insa-lyon.fr/rio/popi-model



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