Radiation therapy

- 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: is an iterative algorithm

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

Numerous methods; 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)
- ...
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 \( T \)
- \( \alpha \) = 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]
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]

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

respiratory motion = additional random error
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/popli-model
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