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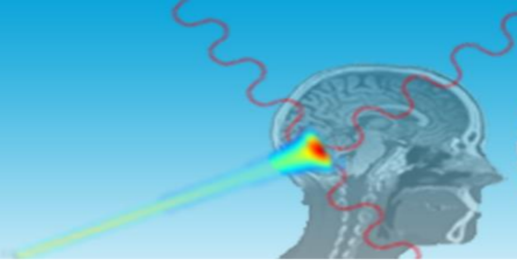

Inverse problems and machine learning in medical physics

Image registration in radiation oncology

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The role of imaging in radiation oncology

- The clinical use of image registration in radiotherapy can be classified according to the following applications
  - Treatment planning
  - Patient positioning
  - Treatment adaptation
  - Long-term treatment verification

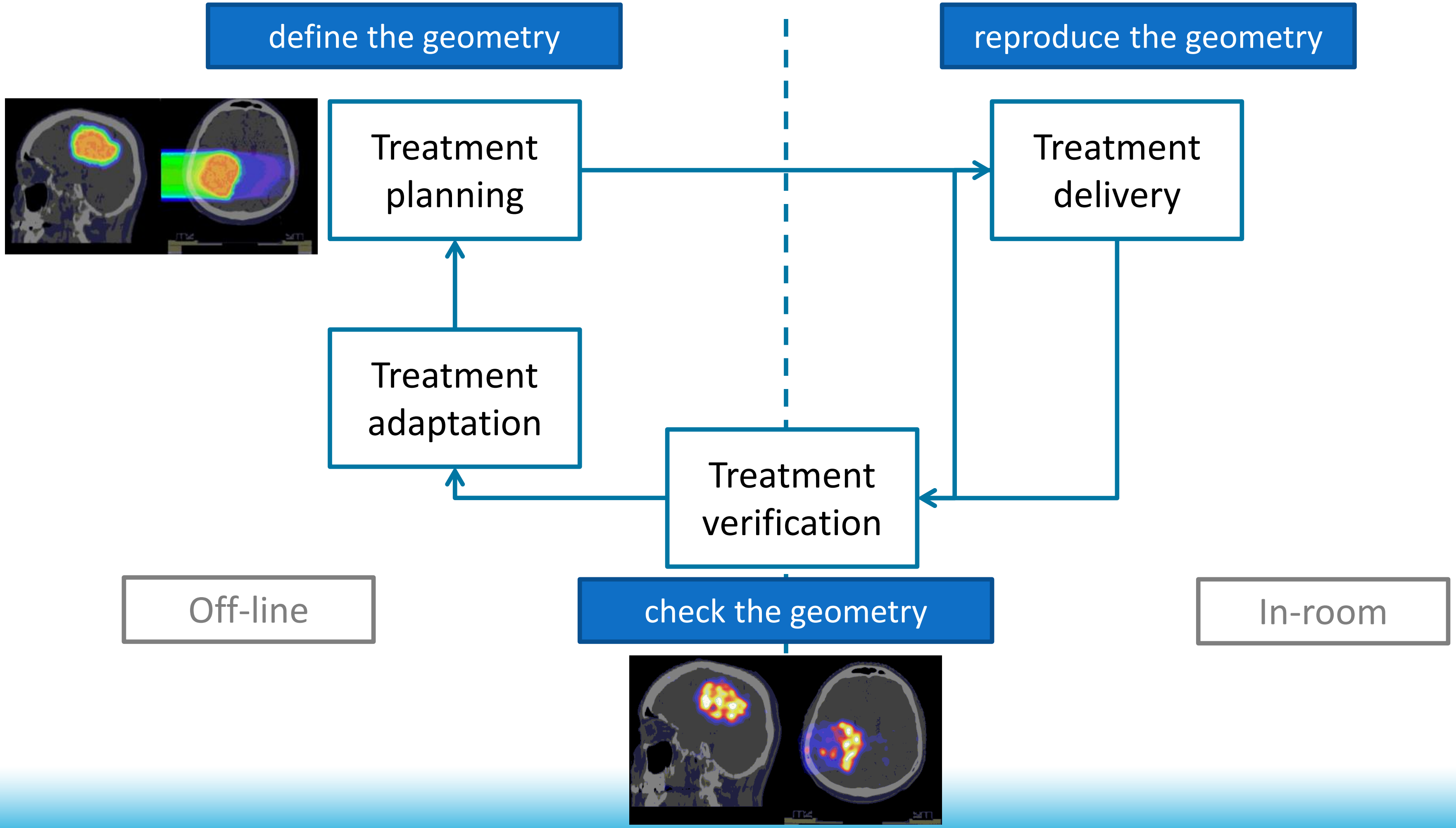
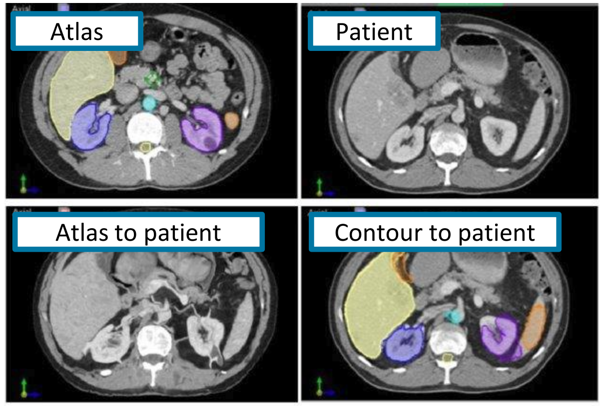
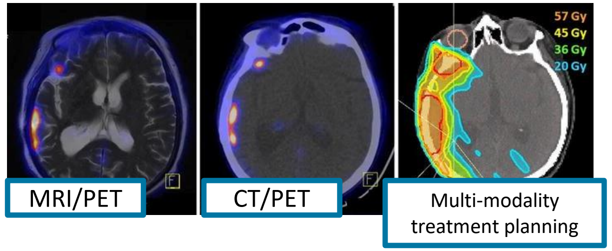


Image registration in treatment planning

- Between the image of the patient and anatomical atlases (i.e., organ segmentation in treatment planning)
  - Same image modality (mono-modal), different patients (inter-patient)
- Between images of the patient from different imaging modalities such as CT and MRI, PET/CT and PET/MRI (i.e., multi-modality treatment planning)
  - Different image modalities (multi-modal), same patient (intra-patient)





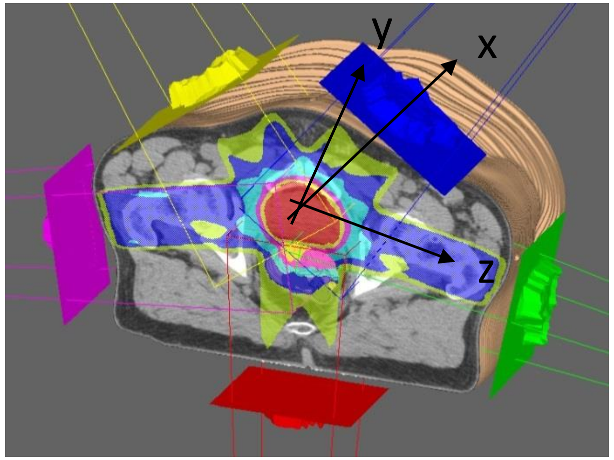
Thorwarth, D., Leibfarth, S., & Mönnich, D. (2013). Potential role of PET/MRI in radiotherapy treatment planning. Clinical and Translational Imaging, 1, 45-51.

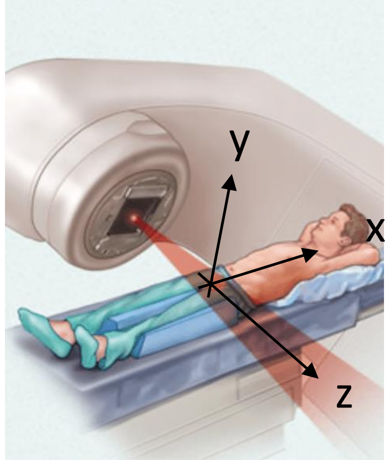
Rigid registration for patient positioning

- The in-room patient anatomy (i.e., treatment delivery scenario) is matched to the (model of the) patient anatomy of the treatment planning CT (i.e., treatment planning scenario)

- The patient position in treatment delivery is rigidly aligned to the treatment planning scenario prior to treatment delivery

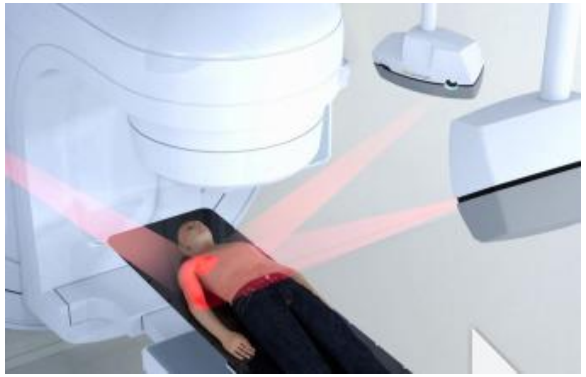
Treatment planning → Treatment delivery

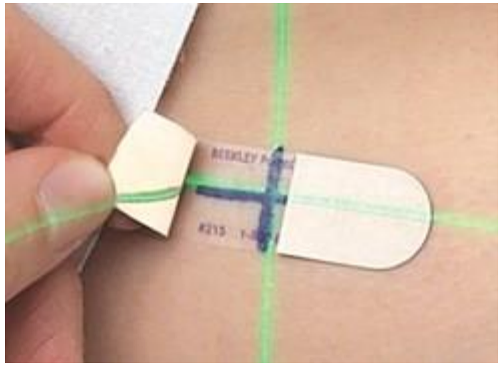




Rigid registration for patient positioning

- Patient positioning can rely on in-room optical systems enabling surface alignment or point alignment of external landmarks placed directly on patient skin (referenced with tattoo) or on immobilization devices





Rigid registration for patient positioning

- Patient positioning can rely on in-room X-ray imaging, thus enabling point alignment ("feature-based", requiring image processing for feature/point identification) or anatomical alignment ("intensity-based", directly exploiting the image intensities)

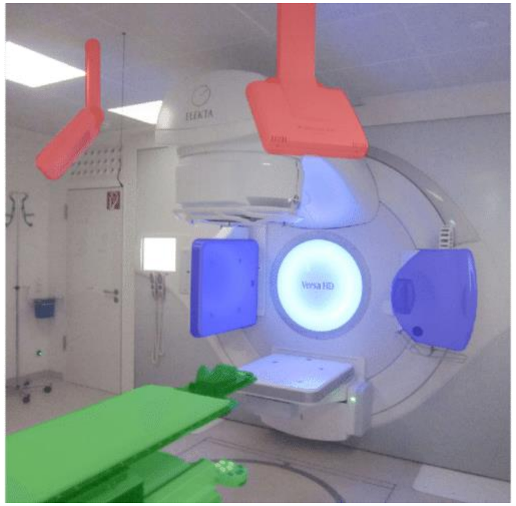
Rigid registration for patient positioning

- Patient positioning can rely on in-room X-ray imaging, thus enabling point alignment ("feature-based", requiring image processing for feature/point identification) or anatomical alignment ("intensity-based", directly exploiting the image intensities)

  - Point alignment of internal (implanted) and external landmarks as imaged by 2D MeV/KeV "continuous" fluoroscopic imaging (dynamic treatment delivery)

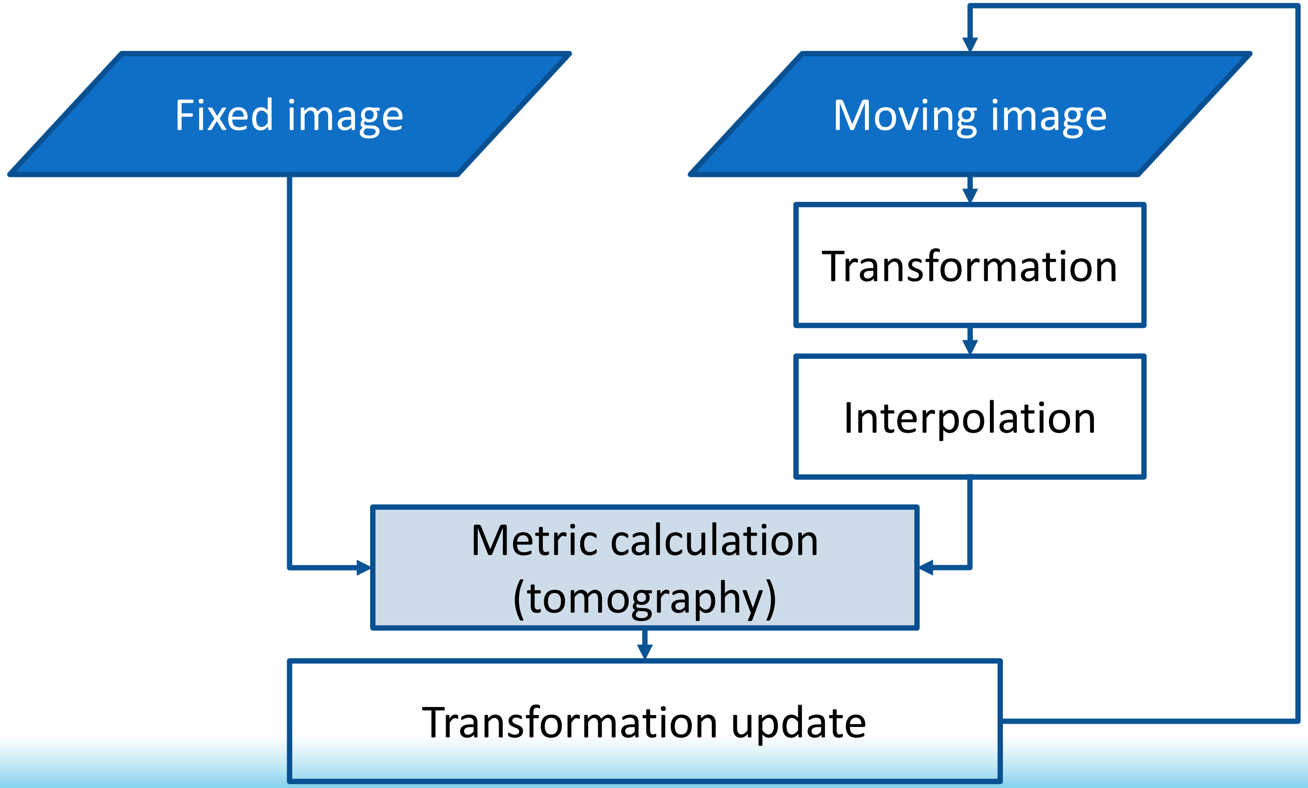
  - Anatomical alignment based on 2D or 3D MeV ("mega-voltage") electronic portal imaging in photon therapy (the X-ray source coincides with the therapeutic radiation source)

  - Anatomical alignment based on 2D or 3D KeV ("kilo-voltage") imaging from auxiliary imaging systems (i.e., cone beam CT)



3D-3D rigid registration algorithm

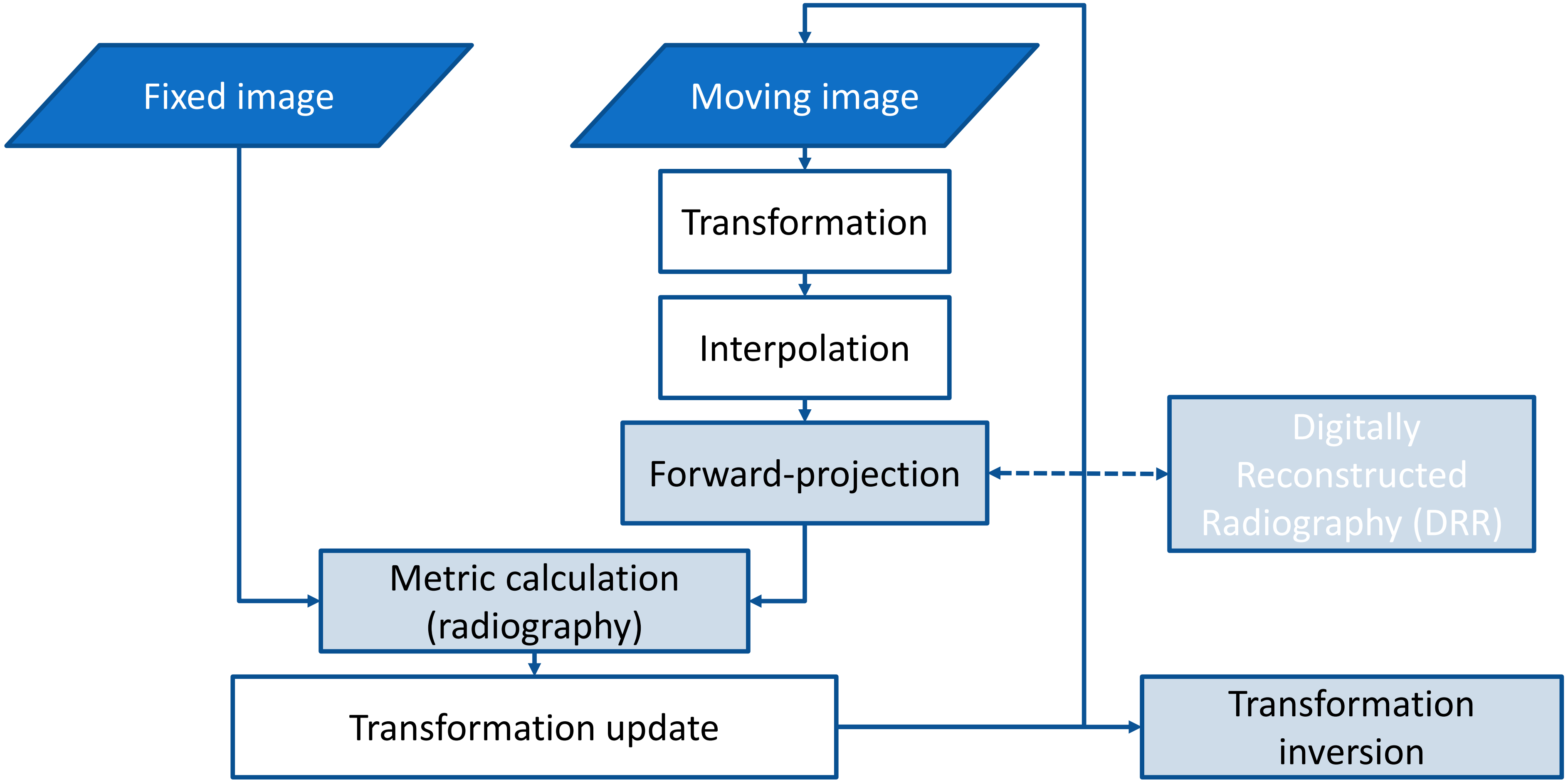
- When 3D in-room X-ray imaging is available, the anatomical alignment is based on 3D-3D rigid image registration algorithm
  - The treatment planning scenario is adopted as reference (fixed image) and the treatment delivery scenario is adopted as target (moving image)



2D-3D rigid registration algorithm

- When relying on 2D in-room X-ray imaging, the anatomical alignment requires 2D-3D rigid image registration algorithm
  - The treatment planning scenario (3D X-ray image) *must be* adopted as moving image, thus undergoing transformation (roto-translation) during numerical optimization
    - In static treatment delivery the inverse rigid transformation is applied to the treatment couch prior to treatment delivery
      - The inverse transformation converts the treatment planning scenario into the reference (fixed image)
    - In dynamic treatment delivery the direct rigid transformation is applied to the radiation source during treatment delivery
      - The treatment delivery scenario is actually the reference (fixed image)

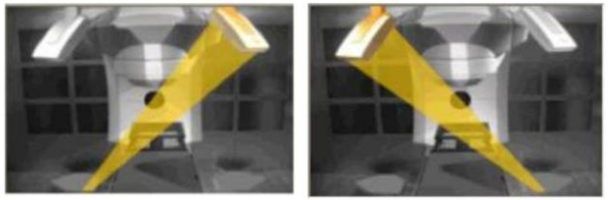
2D-3D rigid registration algorithm

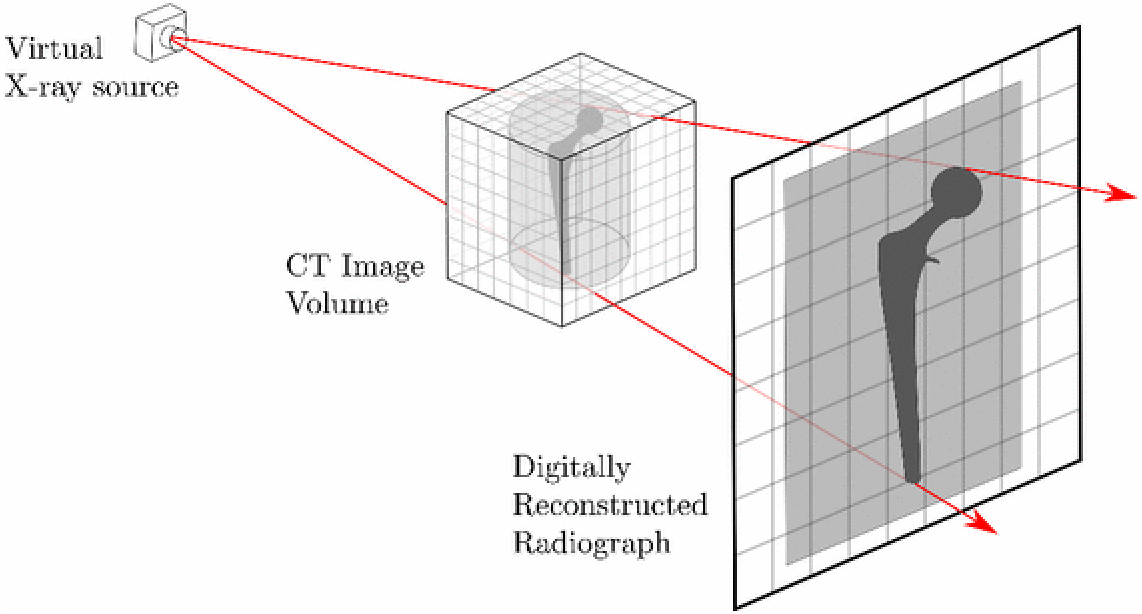


Digitally Reconstructed Radiography (DRR)

- The DRR is defined as the forward-projection of the treatment planning CT

- When 2D in-room X-ray imaging is available, the DRRs (a minimum of 2 DRRs is required!) are used for patient positioning based on 2D-3D rigid registration but can have also a role in treatment verification

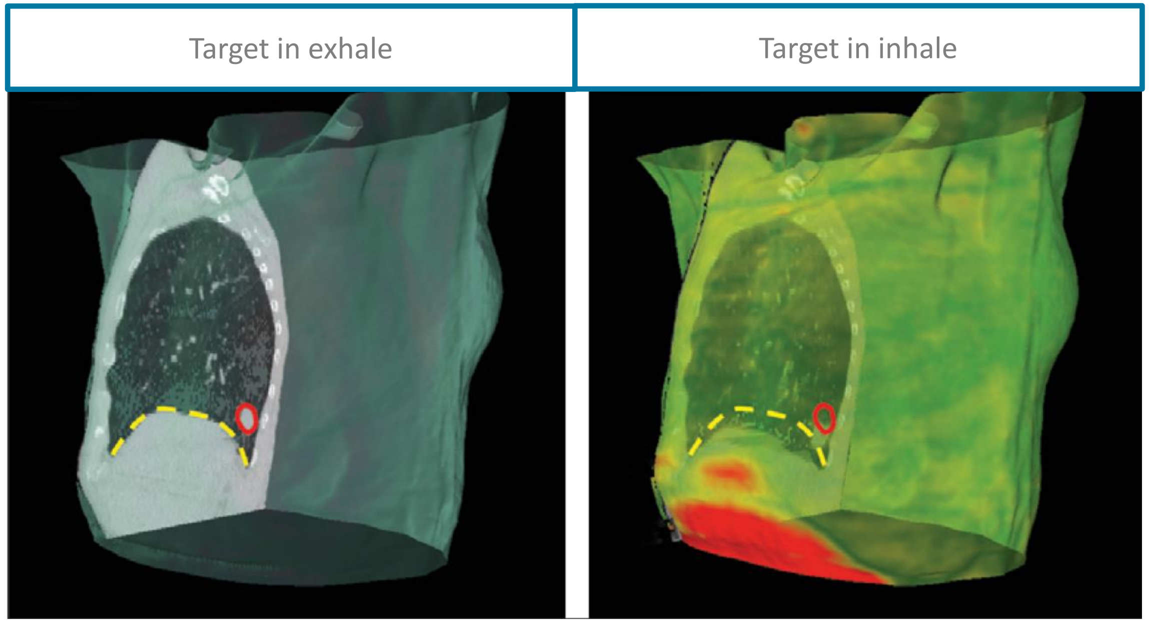




- Treatment is eventually adapted based on a re-planning CT (if 3D in-room X-ray imaging is not available)

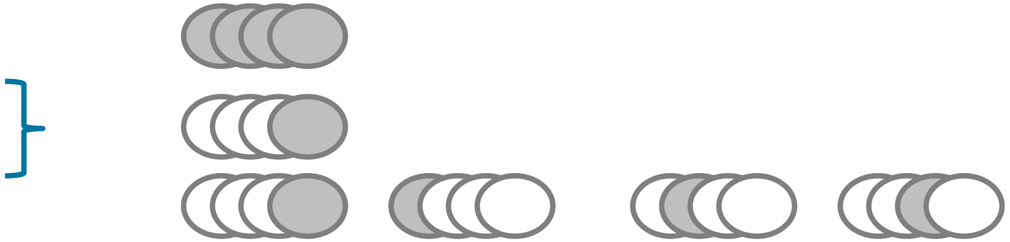
Insights about static/dynamic treatment

- Motion managements in treatment planning, delivery and verification of moving targets



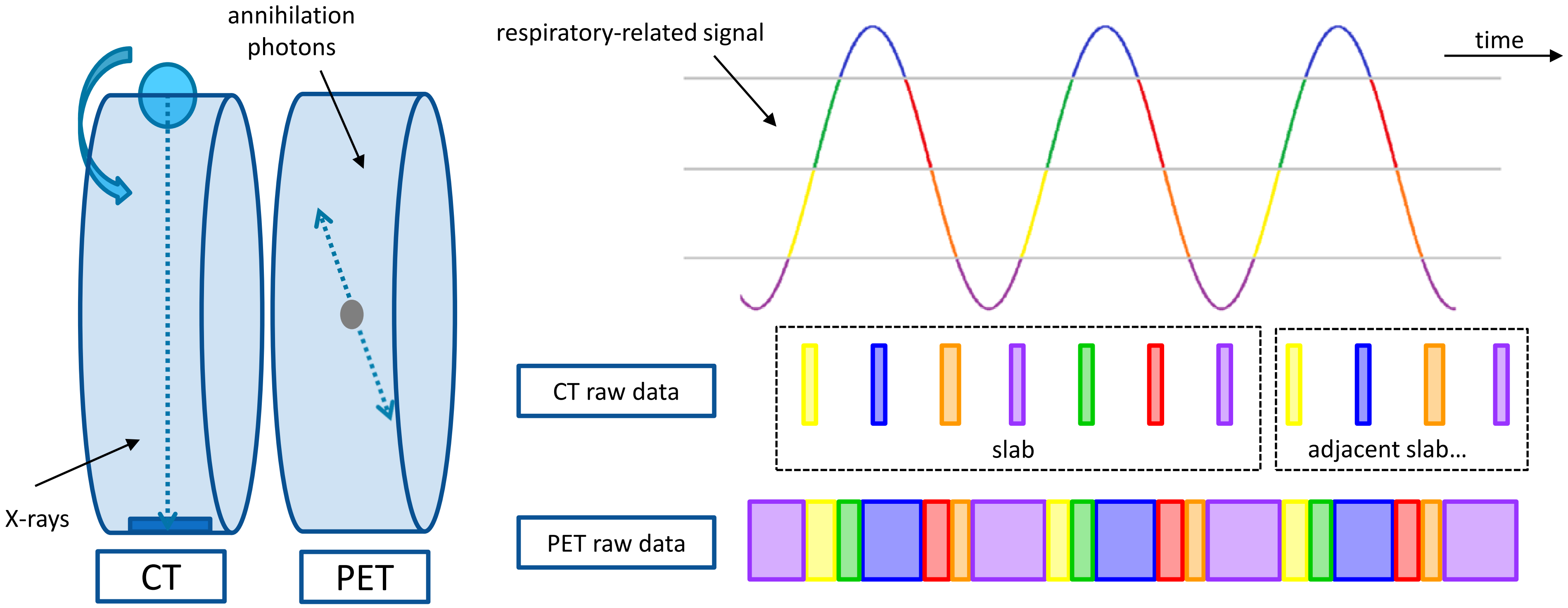
Riboldi, M., Orecchia, R., & Baroni, G. (2012). Real-time tumour tracking in particle therapy: technological developments and future perspectives. The lancet oncology, 13(9), e383-e391.

- Motion encompassing
- Gating
- Breath hold
- Tumor tracking



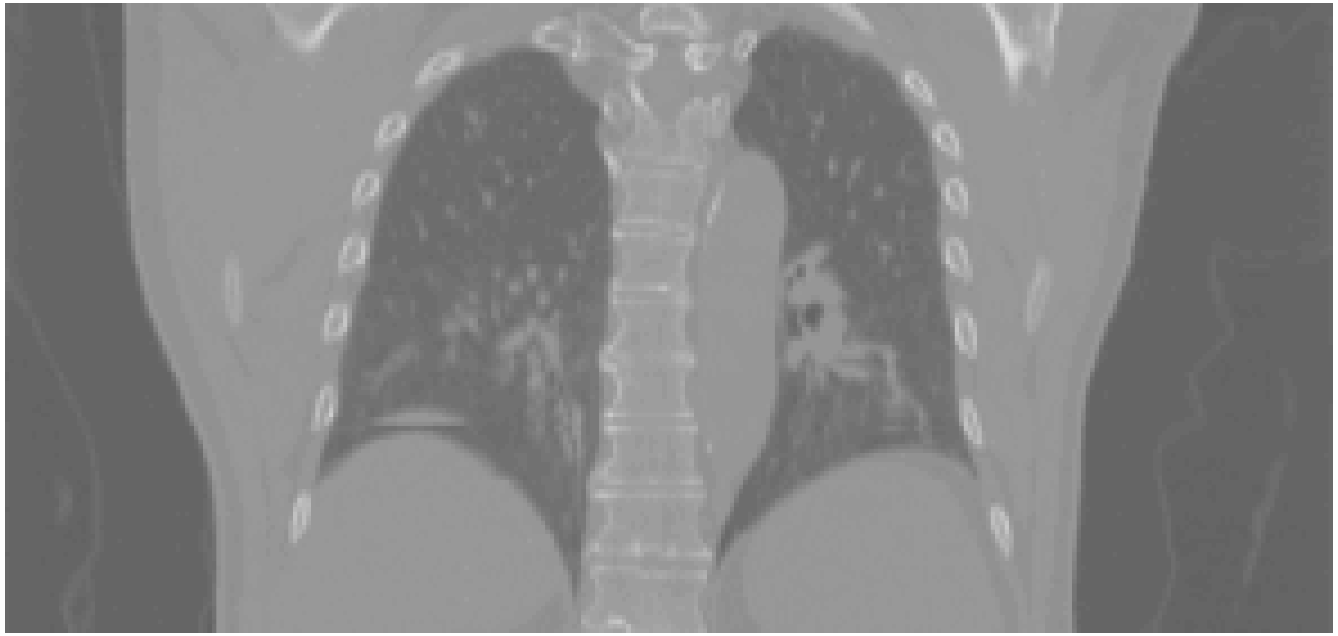
Insights about dynamic treatment

- Image acquisition synchronized with a respiratory-related signal, as provided by infrared localization of a marker(s)
- Time-labelled CT raw data (slab projections) and PET raw data (annihilation counts) classified into different breathing phases, namely PET gating and CT sorting, respectively



Insights about dynamic treatment

4D CT clinical data



Insights about dynamic treatment

- Dynamic treatment planning for moving targets requires time-resolved imaging and deformable image registration
  - Same image modality (mono-modal), same patient (intra-patient)
- The geometry is defined on a reference breathing phase and deformable image registration is used to map the same geometry on the different breathing phases
- The treatment planning is calculated on each breathing phase
- The dose is then calculated on the reference breathing phase by means of *dose warping* (pull-back or push-forward?) and time weighted summation

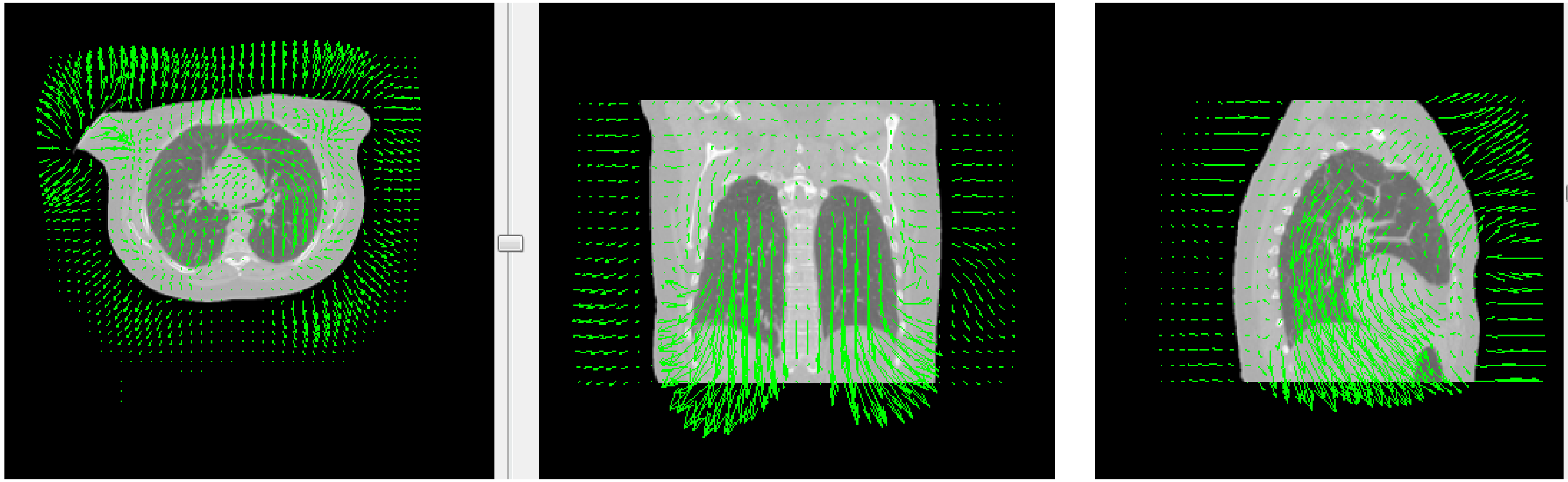
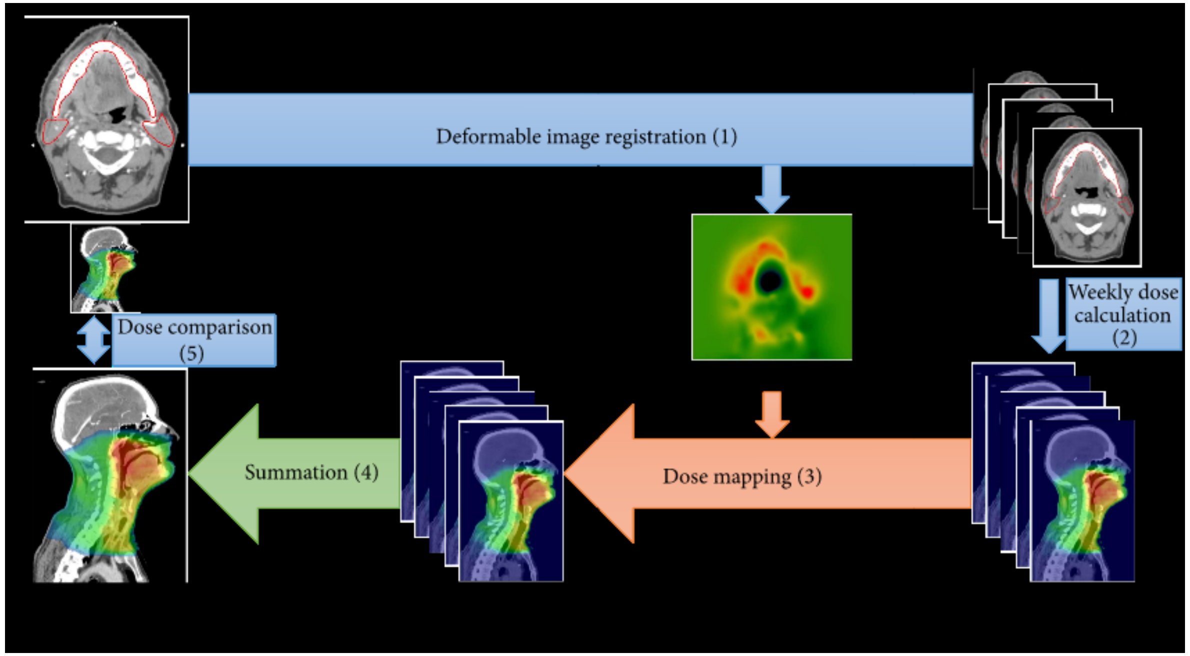


Image registration in treatment adaptation

- Between images of the same patient in the treatment planning scenario and in the treatment delivery scenario

  - To provide an up-to-date estimation of the delivered dose

  - To eventually provide an up-to-date image for treatment re-planning, along with the up-to-date contours



Rigaud, B., Simon, A., Castelli, J., Gobeli, M., Ospina Arango, J. D., Cazoulat, G., ... & De Crevoisier, R. (2015). Evaluation of deformable image registration methods for dose monitoring in head and neck radiotherapy. BioMed research international, 2015.