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Adaptive Radiotherapy

- **Adaptive radiotherapy** is a *state-of-the-art approach* that uses a *feedback process* to account for *patient-specific anatomic and/or biological changes*, thus, delivering highly *individualized radiation therapy* for cancer patients.

- Different from IGRT:
  - ART is plan modification, i.e. *re-planning*
Online Adaptive Radiotherapy

- Online Adaptive RT involves modification of the treatment plan before the delivery of the fractional dose to accommodate the inter-fractional variations in:
  - Patient anatomy
    - Tumor or organs at risk
  - Physiology, biology
    - Proliferation, radiosensitivity, response, cell density, hypoxia, etc.

Main challenge: Speed

Need to generate a dedicated plan in a very short amount of time (couple of minutes)

Good News:

1. The adaptive plan does not have to be from scratch
   - Many components of the daily plan similar to the original plan,
     - Anatomy
   - Optimum plan parameters
   - Many plan decisions

2. Technological improvements and computational power increase the speed of plan generation
   - e.g. Graphical Processing Units (GPUs)
Increase in computer speed

Graphical Processing Units (GPU) accelerated processes:
- daily image reconstruction
- dose calculation
- DIR
- optimization

GPU-based ultrafast IMRT plan optimization
- daily image reconstruction
- dose calculation
- DIR
- optimization

Computation speed can only help if automated
- **Automation**: The critical issue
  - Some processes are hard to automate ( ), need human/expert

Main limitation of Adaptive Replanning:
- **Imaging**
  - In-room image quality is critical for ART
    - Cone beam < kV fan beam CT < MRI
  - Imaging is limited in:
    - Microscopic disease spread
    - Visualization of tumor biology
    - Functional/Physiological imaging specificity/sensitivity is not reliable yet

  - Definition of CTV is not based on visualization but mostly probabilistic
  - With large PTV-CTV margins, also the invisible microscopic disease was being irradiated (Vanherk, Acta Oncol, 2008)
  - Drastic reduction of PTV margins with ART is questionable
Major challenge for online replanning:

**Contour delineation** on the daily images

- Very **time consuming** process, still not fully automatable
- Auto contouring: Best option: DIR (Deformable Image Registration + Auto-segmentation)
  - Accuracy is not perfect
  - Not 100% reliable
  - Visual verification by human expert necessary

**DIR is not fully reliable**

Especially bad for large deformation (where ART is most needed)

**Online Replanning Methods that don’t require contour delineation**

An algorithm for shifting MLC shapes to adjust for daily prostate movement during concurrent treatment with pelvic/lymph nodes

Automatic online adaptive radiation therapy techniques for targets with significant shape change: a feasibility study
Slice-by-slice 2D rigid registration for each MLC pair (Court, et al 2005)

Applying different shifts for prostate and pelvic lymph nodes (bony anatomy). (Ludlum, et al 2007)

Selecting from a pool of plans

- Plan pool
  - “process first tries to find a best plan for the daily target from a plan pool, which consists of the original CT plan and all previous re-optimized plans”

Li 2011 PMB

Virtual couch shift (VCS): accounting for patient translation and rotation by online IMRT re-optimization

No contour generation needed but optimization used to match rotated/translated pretreatment dose distribution
Challenges of Online Replanning:

Plan Optimization

- To get best quality, optimization is needed
- Challenge: to make a new optimization without an expert (physicist, physician) present, and in a quick, automated and reliable manner:
  - With the help of faster computing (e.g. GPU), the actual optimization itself can be very fast (Men et al. 2010, Peng et al. 2012, Lu 2010, ..)
  - Complete IMRT < 1m , fluence based or Direct Aperture Optimization
  - Main time consuming part is the "trial and error" tweaking process to determine the clinically optimum Objective Function (OF)
  - Different than the Pareto optimum OF
  - Attempts to automated IMRT optimization exist, eliminating the human intervention

Aperture Morphing Methods: No need of online plan optimization

- Changing the segment shapes based on the relationship between the planCT and daily CT contour in the Beam's Eye View

Mohan, et al IJROBP 2005

Aperture Morphing Methods

- Mohan 2005
  - Using the target + OAR overlap projections
  - 2D demons DIR to morph intensity map
    - Followed by MLC segmentation
- Feng 2006
  - Using 3D DIR vector field \( \rightarrow \) collapse to each beam angle (2D vector field)
  - Deform segment shapes with the 2D VF
  - Changing MLC positions directly
  - Using only the target contour projection
- Ahunbay 2008
  - Using a linear distance relationship
  - Using only the target contour projection
  - Changing MLC positions directly
  - Apply a segment weight optimization (SWO) afterwards to improve dosimetry (optional)
### Segment Aperture Morphing Algorithm

**Planning**

- Fast and simple algorithm:
  - Morphing the aperture shapes based on the deformation in the PTV projection from BEV of each beam
  - Stretching apertures based on relative distance from edge of PTV projection
  - New PTV projection is always covered by the combined intensity map from the beam

**Daily**

- No shifting of patient (couch) required

Ahunbay et al, MP, 2008

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### Gradient Maintenance Method

- Only requiring delineation of new target
- The daily optimization is more automatable since the achievable dose gradients don't change with daily anatomy

Ahunbay and Li, ASTRO 2013

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### Challenges for Online Replanning

- Plan approval by the physician
  - Compare to the original plan and/or IGRT reposition plan
  - Limiting approval to:
    - When plan quality is not equal to or better than the compared plan
- IMRT QA
  - (is it really warranted?)
  - Limiting the MLC positional variations would minimize requirement
    - Aperture morphing methods modifying MLCs directly
    - Direct Aperture Optimization instead of fluence optimization
    - Starting from an existing original plan
    - Electronic verification would handle most possible errors
    - Verification during treatment (e.g. via EPID)
Variation from original to daily plan

- Optimize from scratch
- Optimize from original plan
- Aperture morphed
- Optimize starting from aperture morphed plan

Ahunbay, et al. IJROBP 2013

Future requirements / current limits of online ART

- More automation
  - Smarter algorithms
  - Contour delineation
  - Optimization

- Superior imaging
  - Microscopic spread
  - Using more physiological/functional imaging

Thank you!