Ergun Ahunbay, PhD
Medical College of Wisconsin, Milwaukee, WI

ONLINE REPLANNING FOR IMRT

Froedtert & Medical College of Wisconsin

Medical College of Wisconsin

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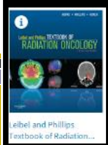
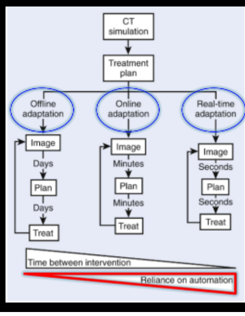
Adaptive Radiotherapy

- ***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

Time Scales of Adaptive Radiotherapy





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 (GPU)

Increase in computer speed

Graphical Processing Units (GPU) accelerated processes:

- daily image reconstruction
- dose calculation
- DIR
- optimization

GPU-based ultrafast IMRT plan optimization

Chunhua Men[1], Xuejun Gu[1], Dongju Choi[2], Amitava Majumdar[2], Ziyi Zheng[3], Klaus Mueller[3] and Steve B Jiang[1]

[1] Department of Radiation Oncology, University of California San Diego, La Jolla, CA 92037, USA
[2] San Diego Supercomputer Center, University of California San Diego, La Jolla, CA 92093, USA
[3] Center for Visual Computing, Computer Science Department, Stony Brook University, NY 11794, USA

E-mail: sbjiang@ucsd.edu

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GPU-based high-performance computing for radiation therapy

Xun Jia[1], Peter Ziegenhein[2] and Steve B Jiang[1]

[1] Department of Radiation Oncology, University of Texas Southwestern Medical Center, Dallas, TX 75390, USA
[2] Joint Department of Physics, The Institute of Cancer Research and The Royal Marsden NHS Foundation Trust, SM2 5NG, SUTTON, UK

E-mail: Xun.Jia@UTSouthwestern.edu, Steve.Jiang@UTSouthwestern.edu and Peter.Ziegenhein@icr.ac.uk

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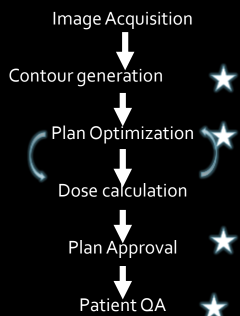
Computation speed can only help if automated

- 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

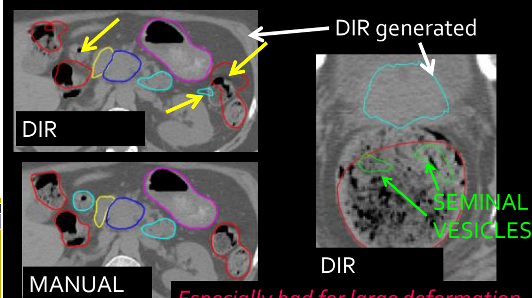
        Definition of CTV is not based on visualization but mostly probabilistic
      - With large PTV-CTV margins , also the invisible microscopic disease was being irradiated. (Vanherk , Acta Oncol, 2008)
      - Drastic reduction of PTV margins with ART is questionable

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 AUTOMATIC CT-GUIDED ADAPTIVE RADIATION THERAPY TECHNIQUE BY ONLINE MODIFICATION OF MULTILEAF COLLIMATOR LEAF POSITIONS FOR PROSTATE CANCER

Laurence E. Court, Ph.D.,*† Lei Dong, Ph.D.,* Andrew K. Lee, M.D.,‡ Rex Cheung, M.D.,‡ Mark D. Bonnen, M.D.,‡ Jennifer O'Daniel, M.S.,* He Wang, Ph.D.,* Radhe Mohan, Ph.D.,* and Deborah Kuban, M.D.‡

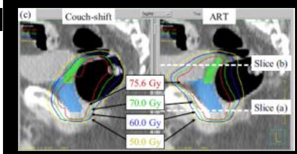
Departments of *Radiation Physics and ‡Radiation Oncology, The University of Texas M. D. Anderson Cancer Center, Houston, TX; †Department of Radiation Oncology, Brigham & Women's Hospital/Dana-Farber Cancer Institute, Harvard Medical School, Boston, MA

An algorithm for shifting MLC shapes to adjust for daily prostate movement during concurrent treatment with pelvic lymph nodes[a)]

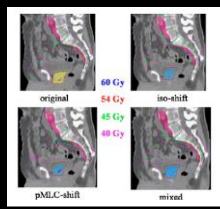
Erica Ludlum, Guangwei Mu, Vivian Weinberg, Mack Roach III, Lynn J. Verhey, and Ping Xia[b)]
Department of Radiation Oncology, University of California-San Francisco, San Francisco, California 94143

Automatic online adaptive radiation therapy techniques for targets with significant shape change: a feasibility study

Laurence E Court, Roy B Tishler, Joshua Petit, Robert Cormack and Lee Chin



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

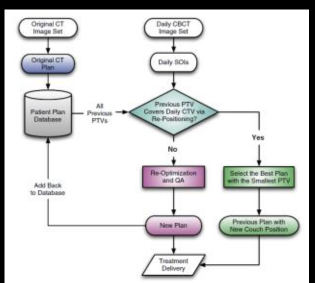


Figure 1. The scheme of the AIGRT technique.

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

G H Bol, J J W Lagendijk and B W Raaymakers

Department of Radiotherapy, University Medical Center, Heidelberglaan 100, 3584 CX Utrecht, The Netherlands

E-mail: g.h.bol@umcutrecht.nl

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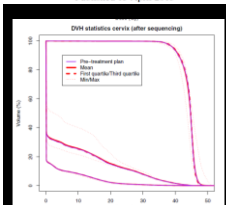


No contour generation needed but optimization used to match rotated/translated pre-treatment dose distribution

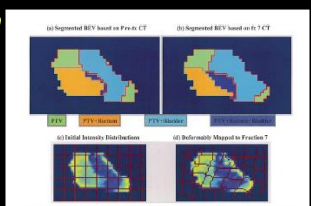
Challenges of Online Replanning:

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



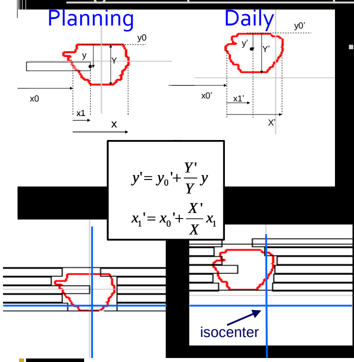
Mohan, et al IJROBP 2005

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 → 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)

(less reason for IMRT QA)

Segment Aperture Morphing Algorithm



$$y' = y_0' + \frac{Y'}{Y} y$$

$$x_1' = x_0' + \frac{X'}{X} x_1$$

No shifting of patient (couch) required

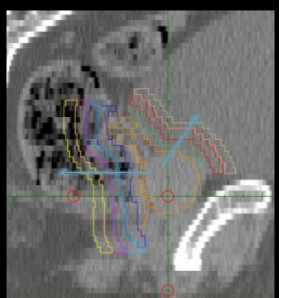
- Fast and simple algorithm:
  - Morphing the aperture shapes based on the deformation in the PTV projection from BEV of each beam
  - Stretching apertures based on relative distance from edge of PTV projection
  - New PTV projection is always covered by the combined intensity map from the beam

Ahunbay et al, MP, 2008

Gradient Maintenance Method

the dose gradient around the target toward each OAR is maintained same as in the original plan.

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

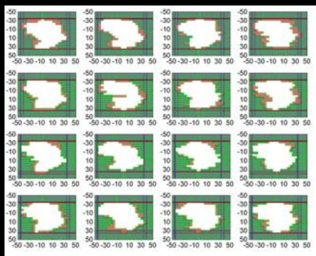


Ahunbay and Li, ASTRO 2013

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!