Accounting for Large Geometric Changes During Radiotherapy

Geoff Hugo, Ph.D.
Department of Radiation Oncology
Virginia Commonwealth University, Richmond, Virginia, USA

Disclosures

- Research support: Philips Medical Systems
- Licensing: Varian Medical Systems

- Research supported by NIH R01CA166119

Current Generation DIR in RT

- Mature commercial software and open source packages

Current Generation DIR in RT

- Mature commercial software and open source packages
- Methods to improve efficiency, plausibility, and accuracy
  - Incorporate features (contours, points), although mainly rely on image intensity
  - Sophisticated representations of transforms (b-splines)
  - Regularization – preventing unrealistic deformation
  - Multiresolution – "coarse to fine"
  - Composite Transform – rigid then affine then deformable
  - Hardware acceleration – parallel processing for efficiency

VCUHealth

Conventional Deformation

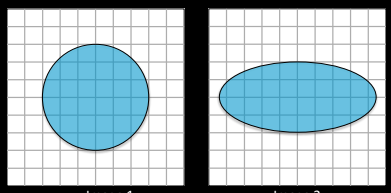


Image 1 Image 2

VCUHealth

Conventional Deformation

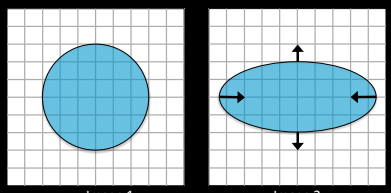
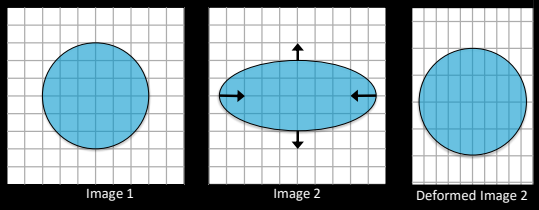


Image 1 Image 2

VCUHealth

Conventional Deformation



Topology Preserving: Images can be stretched/squeezed to match without adding or removing image content

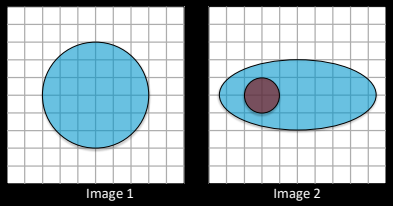
VCU Health

Topology Preserving Deformation

- Articulation / Pose Change
- Breathing Motion

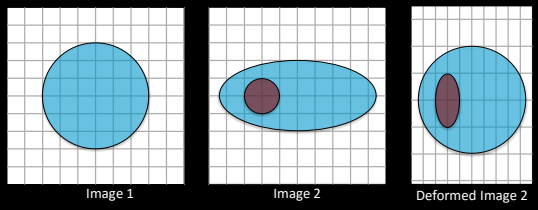
VCU Health

Challenges – Topological Change



VCU Health

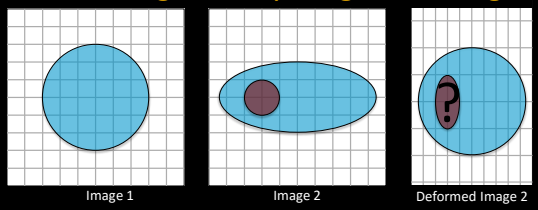
Challenges – Topological Change



Topology Change: Images can't be stretched/squeezed to match without adding or removing image content

VCU Health

Challenges – Topological Change

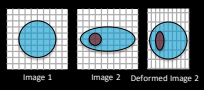


Topology Change: Images can't be stretched/squeezed to match without adding or removing image content

VCU Health

Topology Change

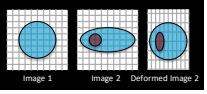
- Solution to new or missing image content depends on the application and content itself



VCU Health

Topology Change

- Solution to new or missing image content depends on the application and content itself
  - For example, if we don't care about the new/missing content region, maybe 'erase' it from the image / registration
  - If a foreign object, may need to understand how it deforms adjacent tissue
  - If tumor / pathology, may need a growth model



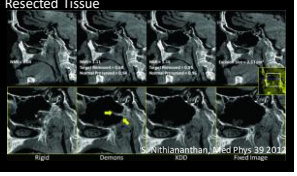
VCUHealth

Topology Change - Examples

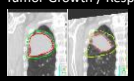
Collapsed Lung

Brachytherapy Applicator

Resected Tissue



Tumor Growth / Response



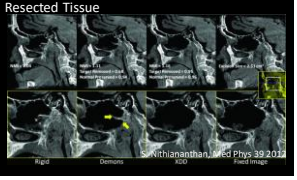
VCUHealth

Topology Change - Examples

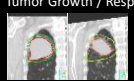
Collapsed Lung

Brachytherapy Applicator

Resected Tissue



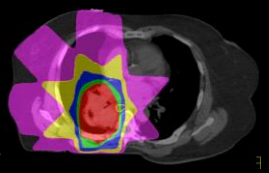
Tumor Growth / Response



VCUHealth

Adaptive RT in locally-advanced lung cancer

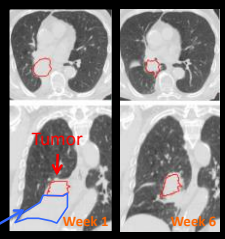
- Higher precision => smaller targets
- Higher precision => less toxicity / better local control
- Automated tools (DIR) required for efficient implementation of adaptive RT



VCU Health

Atelectasis and large tissue changes

- Many patients (roughly half)
- Atelectasis (partial collapse) and pleural effusion (fluid)
- Large volume changes in atelectasis (~150cc) during RT
- Associated with large tumor shifts (> 5mm in 83% of pts)
- Associated with large dose changes to OARs
- ***Patients with large changes most likely to benefit from adaptive RT***



VCU Health

Guy AAPM 2015, Tennyson ASTRO 2015

Thoracic Registration - Strategies

- Ignore regions with topology change, identify 'consistent anatomy' between images, register these regions
- Identify consistent anatomy that can be segmented (vessels, airways, lobes)
- Model other changes (tumor, atelectasis, pleural effusion, etc.)

VCU Health

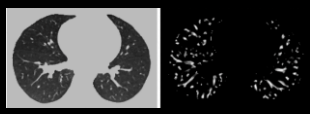
Vessel Registration

- Many applications (retina, heart, brain) and techniques
- Most require segmentation or enhancement of the vasculature
- Treat the vessels as an image or a tree

VCU Health

Vessel Registration

- Filters applied to enhance tubular structures
- Produces a 'vesselness measure' image, [0, 1]
- 'Vesselness measure image' registered in parallel with original images



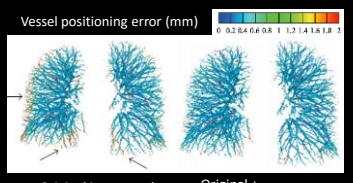
Lung image | Vesselness measure image

VCU Health

Cao et al., WBIR 2010

Vessel Registration

- Reduces outliers and improves accuracy of low contrast, peripheral regions
- Small improvements in mean accuracy (20-25%)



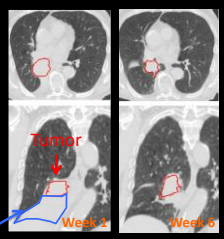
Original images only | Original + vesselness measure

VCU Health

Cao et al., JBI 2012; Hugo et al. WPIA MICCAI 2015

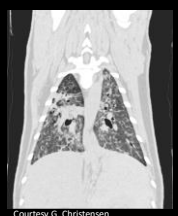
What about the atelectasis region?

- Vessels not visible in atelectasis on CT
- Atelectasis mostly collapsed lung
- Reinflation preserves mass?
- Mass-preserving registration?



VCU Health

Mass Preserving Registration



Courtesy G. Christensen

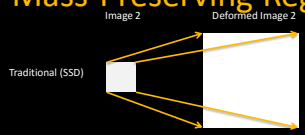
Lung CT intensity change during respiration →Preserving grayscale between two images is not applicable.

Modify the similarity term to incorporate mass preservation

Gorbunova Med Image Anal 2012; Yin Med Phys 2009

VCU Health

Mass-Preserving Registration



Gorbunova Med Image Anal 2012; Yin Med Phys 2009

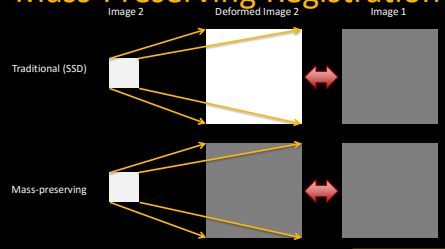
VCU Health

Mass-Preserving Registration

VCUHealth

Gorbunova Med Image Anal 2012; Yin Med Phys 2009

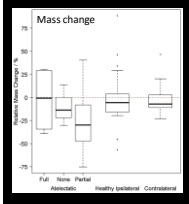
Mass-Preserving Registration



VCUHealth

Gorbunova Med Image Anal 2012; Yin Med Phys 2009

Mass change in atelectatic lobes

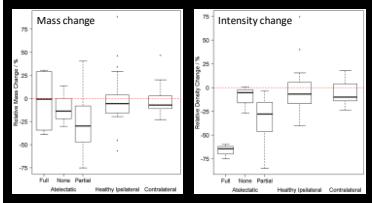


- Mass is not consistently preserved in atelectatic lobes
- Possibly due to infiltrate / fluid loss with re-inflation?

VCUHealth

Guy AAPM 2015

Mass change in atelectatic lobes



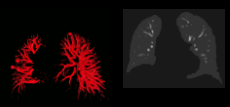
- Mass is not consistently preserved in atelectatic lobes
- Possibly due to infiltrate / fluid loss with re-inflation?
- However, large mean intensity change in atelectatic lobes may still justify a mass-preserving cost function

VCUHealth

Guy AAPM 2015

Lung DIR – Putting it all together

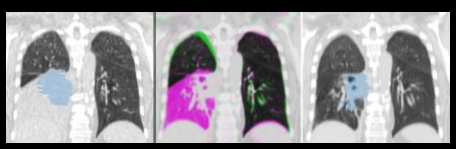
- Simultaneously register
  - Vessels
  - lung parenchyma (healthy and atelectatic) with mass-preserving cost function
  - individual lobes



Regularized, multiresolution b-spline algorithm – elastix plugins

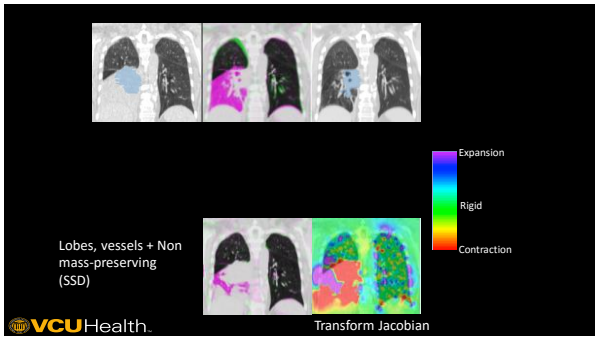
VCUHealth

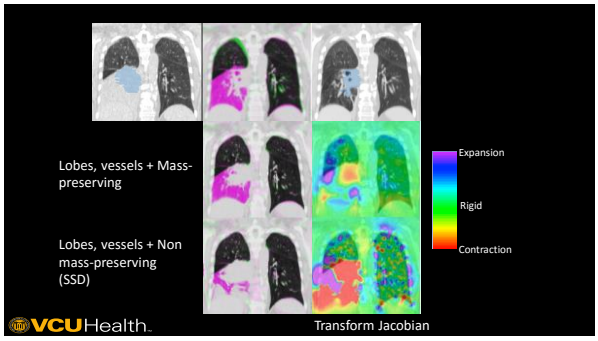
Lung DIR – Putting it all together



Pre-treatment | Unregistered | Mid-treatment

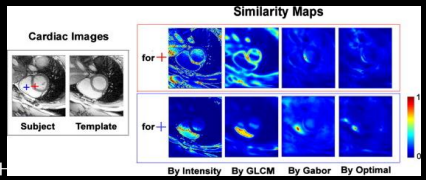
VCUHealth





Attributes / Saliency for 'Consistent Anatomy'

- Higher order features (attributes) may improve specificity of matching by improving uniqueness



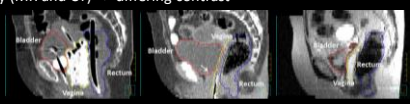
Cumulative Dose in Cervical Ca RT

- Combined external beam RT and intracavitary BT => large uncertainty in cumulative dose

VCUHealth

Cumulative Dose in Cervical Ca RT

- Combined external beam RT and intracavitary BT => large uncertainty in cumulative dose
- DIR challenges:
  - Images with / without applicator => topology issues
  - Large motion of anatomy in abdomen => complex / large deformations
  - Mixed modality (MR and CT) => differing contrast



VCUHealth

S. Oh AAPM 2016

Cumulative Dose in Cervical Ca RT

- Penn approach:
  - EBRT CT to BT CT, with/without EBRT boost
  - Pre-processing to equalize contrast and enhance organ boundaries (bladder, rectum, packing)
  - Contoured applicator
  - Commercial DIR then applied
  - Compared 'parameter adding' of D2cc to DIR-accumulated values between EBRT and BT for risk organs (bladder / rectum)
  - Rectum / bladder D2cc varied by 5% between DIR and parameter adding

VCUHealth

B-K Teo, Radioth Oncol 115, 2015

Cumulative Dose in Cervical Ca RT

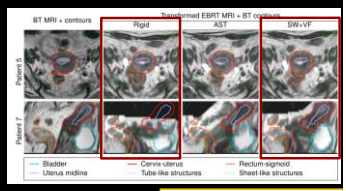
- Rotterdam approach:
  - EBRT MR to BT MR
  - Automated feature extraction near contoured organs (bladder, cervix/uterus, rectum) used for feature-based DIR
    - 'Feature filter' similar to vesselness measure
    - Feature DIR registers points in a 'fuzzy matching' method where point correspondence is unknown
  - Organ, feature, and background transforms combined

VCUHealth

E. Vasquez Ororio, Med Phys 24, 2015

Cumulative Dose in Cervical Ca RT

- Rotterdam approach:
- Landmark-based accuracy assessment (mean error):
  - Rigid:
  - 22.4 mm near organs
  - 4.3 mm away from organs
  - DIR:
  - 3.5 mm near organs
  - 3.4 mm away from organs



VCUHealth

E. Vasquez Ororio, Med Phys 24, 2015

Summary

- Additional / missing tissue is a key challenge to existing registration algorithms
- Solutions depend on the application, site, and task
- However, common strategies of identifying consistent anatomy or careful use of segmentation / masks are promising

VCUHealth

Thanks

Clinic / Physics:
- Elisabeth Weiss
- Nuzhat Jan
- Sid Saraiya
- Nate Tennyson
- Jeff Williamson

Postdocs / Students:
- Chris Guy
- Kishor Karki
- Nicky Mahon
- Seungjong Oh
- Matthew Riblett

Radiology:
- Robert Groves
- Kathryn Olsen

U. Iowa Engineering:
- Gary Christensen
- Paul Song
- Amanda Pan
- Kunlin Cao

This project supported by NIH/NCI research grant R01CA166119

VCU Health