AUTOMATIC IDENTIFICATION OF CRITICAL AREAS OF THE HEAD AND NECK FOR REFINED DOSE-TOXICITY ANALYSIS IN RADIOTHERAPY

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GOAL

Design, implement, and evaluate an algorithm that creates spatially dependent dose features at the inter-organ level to identify specific areas of the head and neck that are more or less critical and sensitive to radiation damage.

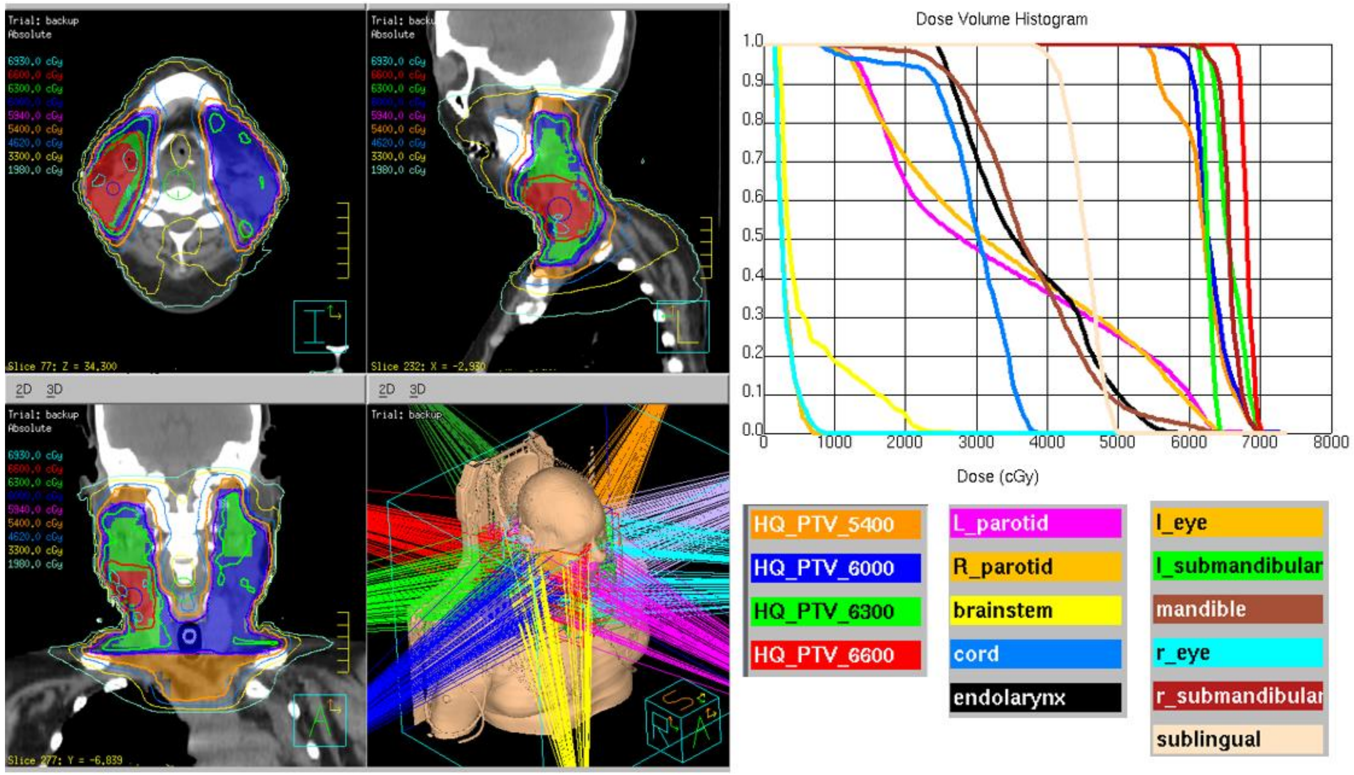


Fig. 1: View of sample radiotherapy treatment plan and the associated dose volume histograms for affected anatomical structures

CLINICAL RELEVANCE

- **Currently:** radiation therapies designed to minimize radiation exposure to areas outside the tumor to avoid adverse reactions to radiation therapy
  - Can avoid known structures by contouring them and planning treatment to decrease radiation dose
- **Problem:** Not much is known about which anatomical soft-tissue (non-contoured) regions most increase or decrease the probability of specific adverse effects when exposed to radiation because there is no existing method to consistently define the same regions in different patients
  - There may be areas in the soft tissue that are absolutely critical to avoid
- **Solution:** Develop an algorithm to define anatomical regions in the head and neck based on proximity to already-contoured structures
- **Overall goal:** Create software to be used in combination with machine learning algorithms to determine which of the specific areas in the head and neck are more or less critical and sensitive to radiation damage

TECHNICAL SUMMARY

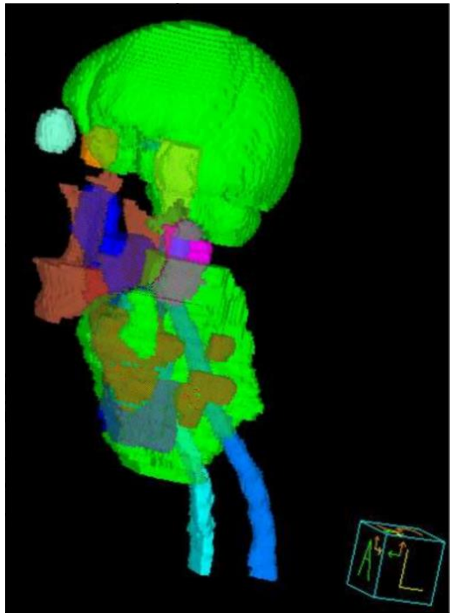
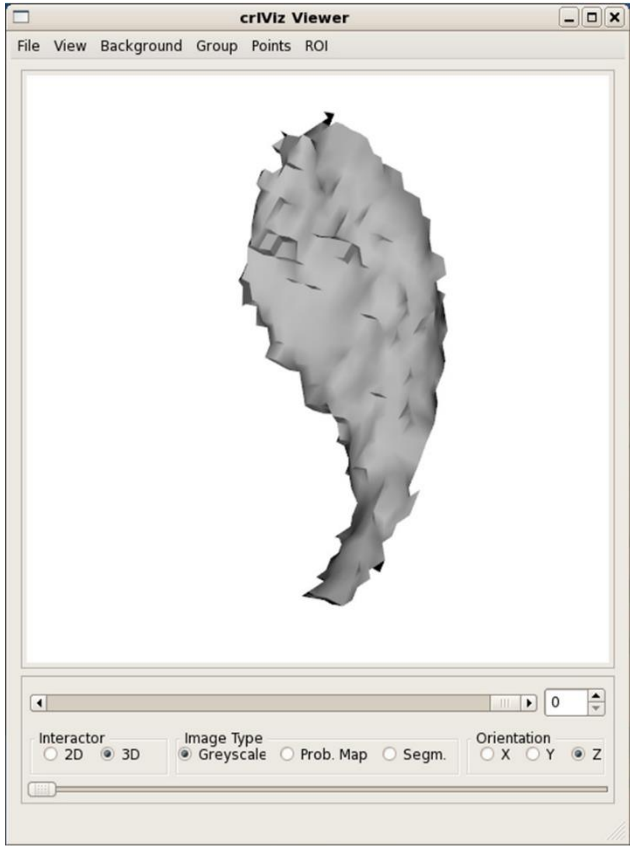


Fig. 2: Sample 3D rendering of contoured anatomy

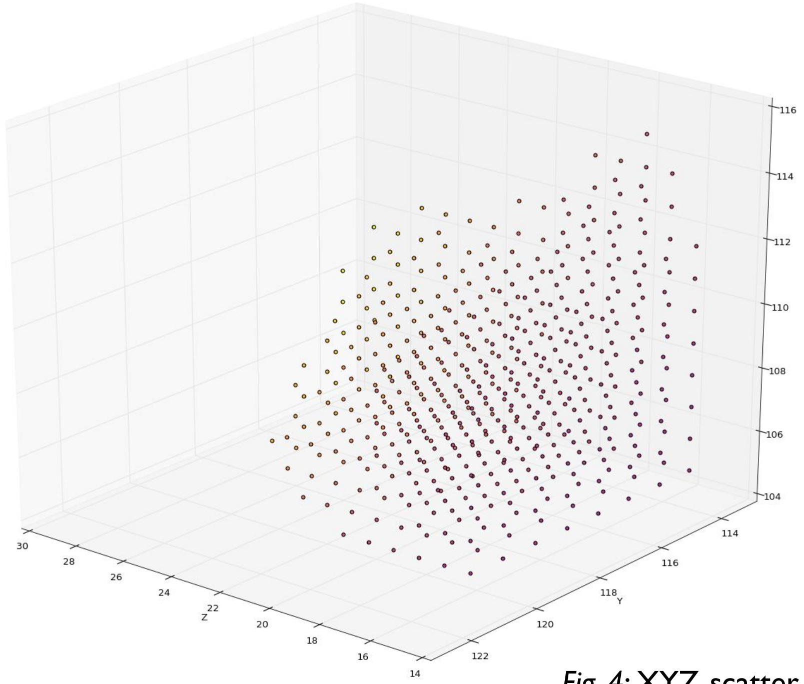


- Query database to find most prevalent structures that have been contoured (e.g. eyes, mandible, parotids)
- Select subset of patient data with these structures, fuse using a surface-to-surface deformable registration (potentially similar to STAPLE) to create a "normal" atlas

Fig. 3: Fusion of slices using STAPLE (Simultaneous Truth And Performance Level Estimation) algorithm (Warfield, 2004)

TECHNICAL SUMMARY

- Pick reference anatomical features and use calculated center of mass (for example) as reference points to create a coordinate system within the average atlas



- Teng et al. (2006) list the following structures as reliable landmarks for automatic segmentation of lymph node regions:
    1. Cervical spine
    2. Mandible
    3. Hyoid
    4. Internal jugular vein
    5. Common carotid artery
    6. Sternocleidomastoid muscle
- Chosen because location relative to the cranial/caudal boundary and other regions are known
- We will choose points (COM, corners, etc.) on these or similarly relevant structures
- Uncontoured regions of interest can be defined in terms of their location relative to these features

Fig. 4: XYZ-scatter plot of a contour bitmask (right parotid) overlaid with dose intensity

TECHNICAL SUMMARY

- Create a Python/C++ script to register and transform the anatomical coordinate system to match previously contoured anatomical features in individual CT scans.
  - Registration in feature space

- Create a script to automatically validate the calculated regions of interest against those already contoured in the database.
  - Use Leave-One Out approach:
    - Take subset of patients with relevant contoured anatomy and make atlas out of all but one
    - Using atlas, calculate bitmask for region already contoured in excluded patient
    - Compare using Dice coefficient – 0 to 1 with 1 being perfect segmentation (Warfield, 2004)

DELIVERABLES

1. Min: *Well-documented* API for automatically detecting verified relevant features in contoured anatomy, written in Python / C++.

2. Expected: Automated script to add new points of fixation and evaluate either improvement or worsening of predictive power of the coordinate system, in addition to minimum deliverable.

3. Max: GUI to view ROI estimates along with dose volume histogram of identified regions in addition to the expected and minimum deliverables.

TIMELINE

Objective	Dates	Proof of Completion
Begin work on Deliverable 1	2/13 – 3/31	(see below)
Literature search, project presentation/plan complete.	2/13 - 2/21	N/A
Familiarize with existing code base, complete overall roadmap of expected code, including classes, program structure, and expected methods of code validation; choose a surface-to-surface deformable registration method.	2/21 - 3/3	UML Diagrams for all major programs, including a defined mathematical method for the construction of the reference atlas.
Create program to consolidate known structures from database into a reference atlas, with a base coordinate system defined on contoured structures.	3/3 - 3/31	Files containing a collection of binary masks representing important anatomy, with metadata containing information regarding their relative locations and orientations.

TIMELINE

Objective	Dates	Proof of Completion
Construction of a program that registers a patient CT and creates a transformation matrix between the anatomical reference coordinate system and the CT coordinate system, allowing the outline of regions of interest.	3/3 - 3/31	Code that on input of a set of binary masks with metadata and a CT creates a series of binary masks representing anatomical regions of interest
Validation method for deliverable 1 that calculates the error between automatic delineation of regions of interest and physician-outlined regions of interest from the database.	3/3 - 3/31	Program that compares binary masks and provides error metrics for the difference between automatically computed anatomical regions, and physician detected regions.
Deliverable 1 Complete	3/31	

TIMELINE

Objective	Dates	Proof of Completion
Begin Deliverables 2 & 3	4/1 - 5/18	(see below)
Create script to allow users to designate new points of reference in the atlas (which would be used to determine coordinate transformations between patient CT and the atlas)	4/1 - 4/14	Script that changes metadata in the anatomical reference files to include new points of reference, and that changes the registration script so that it uses these points of reference.
Add a validation program that takes the atlas with added reference points, computes its performance in the same manner as the validation step for deliverable 1, and removes the reference points if performance decreases.	4/14 - 5/5	A script that provides error comparison between different atlas configurations.
Deliverable 2 Complete	5/5	
Create a GUI that integrates dose-volume histograms with automatically detected regions of interest. Deliverable 3 Complete	4/14 -5/18	A working GUI that presents dose-volume histograms for specified regions of interest with estimated error metrics.

DEPENDENCIES

- Access to the Oncospace database and analytics framework repository of Python code (resolved 2/19)
- Install CRKit (Computational Radiology Kit) (resolved 2/20)
- Find optimal deformable surface registration algorithm. (Discuss with Dr. Taylor, Dr. McNutt, and their students, lit search; plan to complete by 3/3)

MANAGEMENT PLAN

- Weekly meetings with Dr. McNutt
- Julie, Arun will work on atlas development + mapping to patient anatomy
- Chris will work on validation pipeline

READING LIST

- Han, X. et al. (2008). Atlas-based auto-segmentation of head and neck CT images. In: Metaxas D., Axel L., Fichtinger G., Székely G. (eds) Medical Image Computing and Computer-Assisted Intervention – MICCAI 2008. MICCAI 2008. Lecture Notes in Computer Science, vol 5242. Springer, Berlin, Heidelberg
- Commowick, O., Grégoire, V., Malandain, G. (2008). Atlas-based delineation of lymph node levels in head and neck computed tomography images. *Radiotherapy and Oncology*, 87(2), 281-89. ISSN 0167-8140, http://dx.doi.org/10.1016/j.radonc.2008.01.018.
- Zhang, T., Chi, Y., Meldolesi, E., Yan, D. (2007). Automatic delineation of on-line head-and-neck computed tomography images: Toward on-Line adaptive radiotherapy. *International Journal of Radiation Oncology*Biology*Physics*, 68(2), 522-30. ISSN 0360-3016, http://dx.doi.org/10.1016/j.ijrobp.2007.01.038.
- Han, X., Hibbard, L.S., O'Connell, N., and Willcut, V. (2009). Automatic Segmentation of Head and Neck CT Images by GPU-Accelerated Multi-atlas Fusion, *MIDAS Journal*. http://www.insight-journal.org/browse/publication/685.
- Warfield, S., Zou, K., Wells, W. (2004). Simultaneous truth and performance level estimation (STAPLE): An algorithm for the validation of image segmentation. *IEEE Trans. Med. Imag.* 23(7) 903–921
- Teng, C., Shapiro, L. G., Kalet, I. (2006). Automatic segmentation of neck CT images. Proc. 19th IEEE International Symp. on Computer-Based Medical Systems (CBMS).