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Optimization Techniques and their Suitability and Robustness for IMRT Planning

Intensity Modulated Radiation Therapy (IMRT) delivery systems allow the fluence pattern across radiation beams to vary substantially, bringing forth the possibility of delivering treatment with unprecedented conformity and steep dose gradients with respect to the target volume. Physicians can now define and apply normal tissue and tumor dose-volume constraints as part of the planning problem statement in far more detail than previously possible. Integral to this process is the use of automated computer-aided treatment planning systems to harness the complexity inherent in designing treatment plans that make use of tens of thousands of ``beamlets". This opens up the opportunity for investigating sophisticated optimization techniques and aggressive planning objectives to gauge the maximum potential for plan improvement.

Different optimization methods and techniques (e.g., exact methods versus heuristic algorithms; constrained versus unconstrained optimization; deterministic versus stochastic) provide different opportunities and flexibilities for improving various aspects of plan quality. Exact methods include linear programming, nonlinear programming, and mixed integer programming. Heuristics include simulated annealing, molecular dynamics and genetic algorithms. Depending on the treatment parameters one prefers to incorporate within the planning process, different approaches must be employed (e.g., beam angle optimization cannot be accomplished by linear or nonlinear programming alone). Furthermore, the methods selected influence the way clinical objectives and constraints should be incorporated, and how treatment planning models should be established.

In this presentation, we will compare optimization approaches using the same patient data (head-and-neck, prostate, and lung). For each tumor site, we will discuss different strategies for handling the same set of clinical objectives and constraints, the solution algorithms used, and their computational times to find (proven) optimal solutions. Robustness of the algorithms to changes in input dose data, modeling voxel size and sampling strategies, tumor versus organs-at-risk geometry, and other parameters will be discussed. Resulting treatment plans will be evaluated based on the same set of clinical metrics: PTV coverage and homogeneity, D_x (e.g., D_{95} represents the dose level which covers 95% of PTV), dose-volume histograms and isodose distribution to organs-at-risk, V_y (e.g., V_{20} denotes percentage of absolute volume of a critical structure that receives at least 20 Gy), and equivalent uniform dose. Quality of the plans, and their clinical deliverability will be discussed. Behavior of optimization techniques will be highlighted.

Educational Objectives:

- Understand the interplay of clinical objectives and contraints within different optimization frameworks and their effect on the solution process.
- Understand characteristics, robustness, and limitations of various optimization algorithms for IMRT planning.
- Understand plan quality and solution characteristics associated with different optimization techniques.