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ShotCaller: An Automated Target Placement Algorithm to Streamline Spatially Fractioned Radiation Therapy Treatment Planning

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Abstract

Objectives:

In past two decades, particularly in recent 10 years, a modality called spatially fractionated radiation therapy (SFRT), also known as the GRID / LATTICE radiotherapy (GRID RT, Lattice RT), the concept of treating tumors by delivering a spatially modulated dose with highly non-uniform dose distributions, has gained a strong popularity in radiation oncology, physics and radiation biology. The process of SFRT involves creating high dose cores (spherical targets) within bulky tumor volumes, and subsequently applying a high dosage of radiation to the spherical targets during therapy. SFRT has been shown to produce low toxicity and increased response compared to other treatments.

Clinics have a few constraints/considerations when planning for LATTICE/SFRT, such as the target center to center distance, the target radius, and the distance from targets to the tumor's boundary/neighboring tissue. Additionally, there is a need to maximize the number of targets within the tumor volume, in order to maximize the effectiveness of the treatment.

Typically, the majority of LATTICE planning time for SFRT goes towards designing the optimal arrangement of these spherical targets that fit the clinic's constraints. Maximizing the number of spherical targets within an arbitrary 3D space is extremely time consuming and error prone.

The purpose of this study is to develop an automated algorithm that can assist radiation oncologists and physicists with SFRT / LATTICE treatment planning, by finding the maximum arrangement of targets for a given tumor volume (that comply with the geometric constraints), in order to reduce treatment planning times while promoting best patient outcomes through strict parameter adherence.

Methods:

Using C# scripting and the Eclipse Scripting Associated Programming Interface (ESAPI) a script was developed to automatically place the targets within an arbitrary tumor volume. The script included a graphical user interface (GUI) with user configurable parameters for key considerations (target center to center distance, target radius, target minimum distance to tumor boundary/neighboring organs), allowing for wide clinical application and site specific practices. All the user has to do is select the target volume / tumor name, and adjust the desired parameters as needed. The ESAPI based script runs completely within the most widely used treatment planning system, Eclipse.

An alternate version was developed using MATLAB 2023b, which enables non-Eclipse users on any computer to run the script and automate and streamline the target placement process for SFRT. This version also features a GUI to enable users to select custom parameters.

The algorithm was designed using a King Of The Hill Monte Carlo based approach, with multiple 'bias' options to influence the arrangement generation as desired for the user. For example, choosing the 'maximum number' bias will optimize the number of targets for a given tumor volume, while the 'maximum coplanar' bias will optimize the number of coplanar targets (while still considering maximum number, as desired). Currently, the other bias options include optimizing for targets to be close to the center of the tumor, optimizing for targets to be spread across multiple layers / planes, and biasing the targets away from neighboring organs at risk as applicable.

The script was retroactively verified by running it on previous patients' tumor volumes and test tumor volumes (n=7), and the associated target arrangement, time to generate target arrangement, and target violation count (with respect to geometric constraints) were compared to the target arrangement metrics generated by human operators.

Results:

Among the tested tumor volumes (n = 7) were different tumor volume shapes and sizes, including tumors with cavities/holes, and tumors with distinct, non overlapping volume regions.

In all cases, the script was significantly faster than the human operators. For example, for a particularly large spherical volume (~4200 cc) the script finished in 8 minutes while the human operators took 2 hours (120 minutes), resulting in the script being 15 times faster than the human operators.

The script, due to its strict rule-following nature, generated target arrangements with no geometric placement violations (all targets were the minimum distance from each other and from the boundary of the tumor), while the human operators averaged 2-4 target placement violations (from a strict geometric rule perspective) per tumor volume.

Due to the algorithms King of The Hill Monte Carlo based optimization, it was able to consistently find as many or more targets for a given tumor volume compared to the human operators. The number obtained by human operators may be slightly inflated, as the geometric violations may make some targets invalid, lowering the target count for the human operators when compared to the algorithm.

Conclusion(s):

The script was proven to be a reliable, quick, and convenient method of SFRT target placement for a wide range of tumor volumes.

The algorithm's speed will significantly reduce the treatment planning time for SFRT, and perhaps enable clinics to provide same day treatment when appropriate, which was typically impossible beforehand due to the large lead times when planning the optimal target arrangement.

The user configurable parameters allow for wide clinical application and site specific adaptation, and the custom biases will allow for enhanced customization and specific treatment planning objectives.

The target arrangements generated by the algorithm were consistently found to have no violations with respect to the distance parameters, resulting in peace of mind for providers/stakeholders while promoting best patient outcomes.

The Monte Carlo based approach resulted in a maximization of targets within the arbitrary 3D tumor volumes, and the number of targets found (that complied with the geometric placement rules) were consistently more than the number of targets found by human operators.

The ESAPI/Eclipse based script and the MATLAB based script allow for individuals from all types of clinics to streamline and standardize the process of SFRT treatment planning, while saving valuable staff time and promoting best practices by strict adherence to the geometric target placement criteria.