Optimization of Dynamic Gamma Knife Treatment

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1 Introduction

Gamma knife radiosurgery has long been the treatment of choice for many brain tumors and functional disorders. In gamma knife radiosurgery, γ-rays emitted from radioactive ^{60}Co sources are used to eradicate tumors. These sources are placed in a hemispherical, circular or linear array and their γ-ray beams are focused on a single point, creating a spherical high dose volume. Current gamma knife radiosurgery is planned in a "ball-packing" approach and delivered in a "step-and-shoot" manner, i.e. it aims to "pack" the different sized spherical high-dose volumes into a tumor volume.

Step-and-shoot delivery is analogous to how traditional radiotherapy was done—until recently. In the last years radiotherapy has seen a strong movement towards continuous radiation delivery, referred to as Volumetric Modulated Arc Therapy (VMAT)[1], because of shorter treatment times and possibly higher dose conformity. This however complicates treatment planning—leading to large-scale and typically non-convex optimization problems—which has attracted a lot of interest from the optimization community [1, 2, 3, 5].

Although gamma knife radiosurgery in principle allows continuous radiation delivery, it has yet to undergo a transformation similar to VMAT. Some promising investigations in this direction have been undertaken [4], but more remains to be done. This is the aim of this master's thesis project.

2 Project outline

There are many similarities, but also differences, between traditional radiotherapy and gamma knife radiosurgery. Quite likely ideas developed for VMAT optimization can be adapted to optimization of dynamic gamma knife treatments. We expect that, just as in VMAT optimization, a correct problem description results in a difficult non-convex problem. This leads to two main questions:

1. *What is there to gain?* Disregarding practical aspects such as limited computation time in a clinical setting, what is the upper bound on the achievable improvement? To answer this question we foresee that global optimization procedures will be necessary.

[1] `https://www.youtube.com/watch?v=wxBEdMJfxRo`

2. *Can a reasonably good solution be found quickly?* How much approximation is necessary to achieve a practical (e.g. convex) formulation? Is the result still valuable?

The answer to these questions of course depends on what objective function is used. A hypothesis is that the largest gains will be in dose conformity and treatment time, thereby making dynamic treatment suitable for non-traditional gamma knife cases such as spine tumors. Regardless, insights into what degrees of freedom are most important for the plan quality are always valuable.

Although the student has a large freedom to chose what to focus on and disposing the available 20 weeks accordingly, a proposed project plan is as follows:

1. Literature study on the Gamma knife and optimization of radiotherapy plans, in particular for VMAT.
2. Formulation of the realistic optimization problem.
3. Global optimization of the realistic problem.
4. Convex approximation of the realistic problem.
5. Evaluation by comparison with traditionally planned Gamma knife treatments.

3 Practicalities

The project will be carried out at Elekta's offices in Stockholm in the spring of 2015. Suggested starting time is mid-January.

The progress of the project will be followed up through weekly meetings, where the student presents the continuous work on the written report and demonstrates software prototypes developed in the course of the project.

The student will receive monetary compensation upon completion of the project. Expenses for travel, materials etc. related to the project are covered by Elekta.

4 Qualifications

We are looking for candidates with:

- A strong background in mathematics, in particular optimization.
- An ability to implement state-of-the-art algorithms in a suitable programming environment, e.g. MATLAB
- Programming experience in C++ or CUDA is a plus.

Send your application, including CV and a grade excerpt, to jens.sjolund@elekta.com.

References

[1] James L Bedford. Treatment planning for volumetric modulated arc therapy. *Medical physics*, 36(11):5128–5138, 2009.

[2] Karl Bzdusek, Henrik Friberger, Kjell Eriksson, Björn Hårdemark, David Robinson, and Michael Kaus. Development and evaluation of an efficient approach to volumetric arc therapy planning. *Medical physics*, 36(6):2328–2339, 2009.

[3] C Cameron. Sweeping-window arc therapy: an implementation of rotational IMRT with automatic beam-weight calculation. *Physics in medicine and biology*, 50(18):4317, 2005.

[4] Shuang Luan, Nathan Swanson, Zhe Chen, and Lijun Ma. Dynamic gamma knife radiosurgery. *Physics in medicine and biology*, 54(6):1579, 2009.

[5] Karl Otto. Volumetric modulated arc therapy: IMRT in a single gantry arc. *Medical physics*, 35(1):310–317, 2007.