

Information on Assignment 3b, Radiation Therapy MVE165 Applied Optimization

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Given below is the description of the project in Radiation Therapy. In short, the project consists of forming an optimization model (a nonlinear program), implementing the model, and solving it. It is important that you understand the accompanying lecture on Radiation Therapy, and that you have completed the computer exercise on nonlinear optimization.

This document and supplementary files for the implementation can be found on the course homepage:

<http://www.math.chalmers.se/Math/GrundUtb/CTH/mve165/0708/>

To pass the assignment you should (in groups of two (or one) persons) write a short report (maximum four pages). One of the questions 1A-B is mandatory for grade 3. Students aiming at higher grade should also do question 2.

Problem background

You will design and solve an optimization problem for an IMRT treatment of a tumour situated in the head-and-neck region. The objective is to eradicate the tumour, while sparing the surrounding normal tissue, and the organs-at-risk. An oncologist has defined the planned target volume (PTV), which consist of the tumour and a marginal around it. The oncologist has also defined the organs at risk (OAR) to be the left and right parotid glands, the spinal cord and the brainstem.

There are mainly two approaches to model the problem: either with physical criteria or with biological objectives. An example of a physical criterion is that the maximum dose should not exceed a threshold value. The generalized equivalent uniform dose (gEUD) is an example of a biological function and is defined as:

$$gEUD = \left(\frac{1}{N} \sum_{i=1}^N D_i^a \right)^{1/a}$$

where the number of voxels in a structure is N , the dose in voxel i is D_i and the volume parameter for the structure is a . An example of a biological objective is that the value given by the biological function should be minimized. If a is high, the gEUD-value approaches the maximum dose in any voxel of a structure. As a approaches 1, the gEUD approaches the mean dose over all voxels in a structure. If gEUD is used for the tumour, a should be negative.

The PTV comprises 779 voxels; the left parotid gland 123 voxels; the right parotid gland 184 voxels; the spinal cord 310 voxels and the brainstem 259 voxels. The treatment energy has been determined to 6 MV, the number of beams to seven and the beam entry angles to 0, 51, 103, 154, 205, 257 and 309 degrees. The prescription dose for the PTV is 68 Gy which means that doses between 64.6 Gy (-5%) and 71.4 Gy (+5%) are acceptable. The parotid glands have parallel tissue architecture and a threshold dose (for the gEUD) of 26 Gy. A gEUD-value above 26 Gy may lead to permanent loss of salivary production. The spinal cord and brainstem have a serial architecture and threshold doses of 45 Gy and 50 Gy respectively. Doses above 45 Gy or 50 Gy may lead to paralysis. Appropriate values for a for the gEUD-function evaluated for the parotid gland is $a = 1.4$; for the spinal cord and brainstem $a = 10$.

When faced with several objectives, F_i , $i = 1, \dots, p$, one approach is to form the objective function as a sum of the objectives

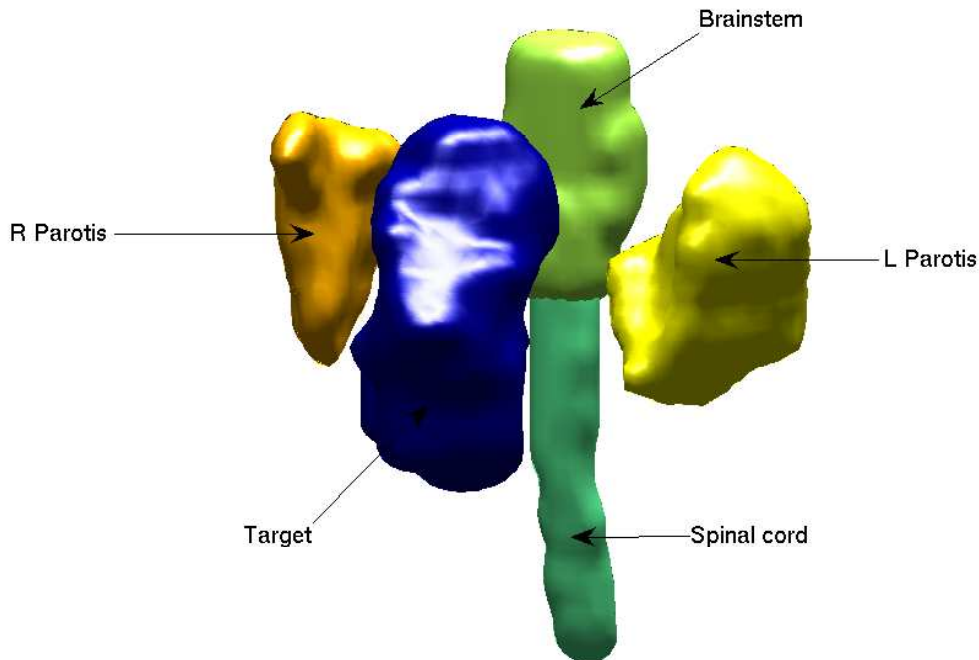
$$F(x) = \sum_{i=1}^p w_i F_i(x),$$

with weights w_i . Possible constraints are now included as penalties, and we call them soft constraints. The solution will naturally change when changing weights, and it is often not possible to set the weights a priori. They should be set after some experimenting.

Exercises to perform

Choose one of 1A-B.

1. A) Use physical criteria for the target and use the gEUD function for the OARs.
B) Use physical criteria for both the target and the OARs.
2. Explore how the solution changes if you use hard constraints. For example, a maximum or minimum dose can be formulated as a linear constraint. Use physical criteria (without penalties for violation) for all other objectives. This will give you a quadratic problem.



Practical details

Given the beamlet intensities x , you can compute the doses d for the voxels in a structure by using an influence matrix K ,

$$d = Kx$$

There is one influence matrix for each OAR and one for the target. They have been pre-computed. The beamlet intensities are the only variables you can control and they must be nonnegative. You cannot control the dose directly, only through the beamlet intensities.

The data for a head-and-neck test can be found in `imrtdata_hn.mat`. The influence matrix for the target is T ; for the left parotid Spl ; for the right parotid Spr ; for the spinal cord As ; and for the brainstem Ab . The mat-file also contains other data used for plotting functions.

You can make a volume visualization plot for the location of the structures with the command

```
>> plotlocations(targets, oars)
```

and to create a DVH from your computed (optimal) beamlet intensities x , use

```
>> pltdvh(x, T, Spl, Spr, As, Ab)
```

If you add many hard constraints to the problem, it could take some time to solve using the Matlab Optimization toolbox. Feel free to simplify the constraints a bit, or more boldly: use another optimization software like CLP.

You may need to supply data to your objective function (`objfunc.m`) besides the variable vector x . You can either use global variables, or (better) write your `objfunc.m` with the header

```
function f = objfunc(x, data1, data2)
```

and when you use `fmincon`, use

```
x = fmincon(@(x) objfunc(x, data1, data2), ...
```

The symbol `@(x)` transform the function into a function handle which only depends on x .

If you are using `fmincon` and want to solve the problem in a reasonable time, you must supply both the gradient and the Hessian. Your `objfunc.m` should then have the following header:

```
function [f, g, H] = objfunc(x)
```

or

```
function [f, g, H] = objfunc(x, data1, data2)
```

If you use gEUD with a high α -parameter, you might experience some trouble. In that case, you can try a lower value, and hope for the best!