Intensity Modulated Radiation Treatment for Cancer Therapy

External beam radiation therapy is used in the therapy of approximately half of all cancer patients. Radiation is directed towards the tumour from outside the body using a linear accelerator. The goal is to cover the tumour with a high uniform dose, while delivering as little radiation as possible to surrounding healthy organs and tissues.

In Intensity-Modulated Radiation Therapy (IMRT), the beams from each direction are broken down into “beamlets” and the intensity of each beamlet is individually selected (this is not the whole truth, but close enough for our purposes). The beamlet intensities are determined from a treatment planning system that takes as input a patient scan and the target doses as given by a doctor, and outputs a set of beamlet intensities. Our goal in this case is to design the optimization component of a treatment planning system for a simplified 2-dimensional version of the problem.

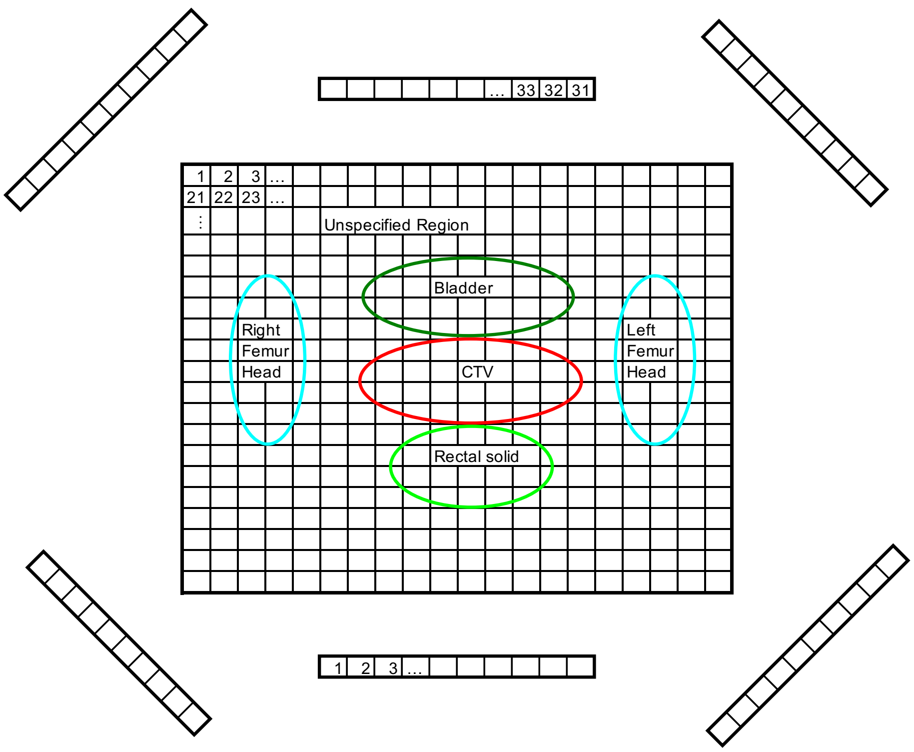

Figure 1: The Cross Section

Consider a single patient case as given in Figure 1. This corresponds to a cross section through a patient, where the patient is facing up and the patient’s feet emerge from the page. Hence the right femur head appears on the left-hand side of the picture. The cross section is broken down into 400 voxels (volume elements), numbered from 1 to 400 as shown in the top-left of the cross section. The CTV (clinical target volume) is the target region. Surrounding the CTV are healthy structures: the bladder, left femur head, rectal solid, and right femur head. All voxels that are not contained in one of these structures are part of the “unspecified region.” There are 6 beam angles, and each one consists of 10 beamlets, labeled anti-clockwise from 1 through 60 as shown in the figure. The file

"DoseMatrix.xlsx" gives the dose delivered to each voxel from each beamlet when the beamlet is used at unit intensity. Doses to a voxel from different beamlets are additive, so if 5 Gray is received from Beamlet 1 and 5 Gray is received from Beamlet 2, then the total dose from the two beamlets is 10 Gray. (The units for radiation dose are Gray or Gy.)

The prescription plan for this patient is as follows. Our goal is to select beamlet intensities that, as closely as possible, satisfy the constraints below. A set of beamlet intensities is called a plan.

CTV	every voxel receives a uniform dose of 82.8 Gy
Bladder	max dose to a voxel: 81.0 Gy
	average dose should be <= 50.0 Gy
	at most 10% of the bladder should receive a dose > 65.0 Gy
Rectum	max dose to a voxel: 79.2 Gy
	average dose should be <= 40.0 Gy
Unspecified	max dose to a voxel: 72.0 Gy
Left femur head	max dose to a voxel: 50.0 Gy
	At most 15% of the left femur head should receive > 40.0 Gy
Right femur head	max dose to a voxel: 50.0 Gy
	At most 15% of the right femur head should receive > 40.0 Gy

The requirement of a uniform dose to the CTV cannot be exactly achieved – there is always some variation across the CTV. Rather, this requirement means that the range of doses should be kept small if possible – say within 5% of one another. The dose to the CTV voxels should not drop too low since otherwise some tumor cells may survive; doctors are very nervous about "cold spots" that are not so cold – even 79 Grey would be considered "cold." The dose to the CTV voxels should not get too high since that can cause severe patient complications.

Your mission:

Give 3 or 4 plans that represent different tradeoffs between achieving the required dose to the CTV and not overdosing healthy structures. Try to display your plans in a way that makes them easy to understand, e.g., graphically, with information on how the plans meet the dose requirements. The file "VisualDemo.xls" may be useful to you in this regard, but note that the positions of the CTV and the dose requirements in that file are different from those given in this case. You should feel free to use any method you like to graphically display results.

You should also discuss your thoughts/experiments on the following issues. We are interested in not just your conclusions, but also your methodology, i.e., make sure you explain your approach to answering the question:

1. The input parameters in the plan, e.g., 82.8 Gy, are based on experience with past patients. As such they are not set in stone. If you could relax one or two of those numbers slightly to improve the plan in other respects then which one(s) would you relax? Take care with relaxing the CTV and femur head dose parameters,

since those structures are especially sensitive. (The femur heads are intricately linked with a patient's immune system.)

2. These plans are delivered in *fractions* over multiple days. Each day the patient comes in, is positioned on a bench, and receives a dose (a *fraction*). This leads to variability in how they are positioned each day, and therefore in how much dose is delivered. Can you think of a simple way or ways to modify your formulation to still ensure good medical outcomes? We do not expect you to implement your ideas, but we do expect you to write, e.g., a couple of paragraphs on your proposed approach.

Write up your solutions in a report that is suitable for reading by your classmates, i.e., your report is intended for specialists who understand optimization. There is no need to write for a general medical audience. You should

1. clearly explain your formulation of the problem,
2. discuss any assumptions you made,
3. explain how you defined any tradeoffs,
4. describe any implementation issues or complications you encountered, and
5. give your results!

This list is just to ensure you don't forget anything. You should not structure your report like this. It is important that your results are *repeatable*, i.e., that a classmate reading your report could repeat your analysis, so please include everything that you believe is necessary in that regard. There is no need to include the dose matrix or any other material that is given as part of the case. For our convenience, please include a copy of your code in your report. Hand in a pdf of your report and a copy of any files you create, so we can run your code if we wish. Be precise and concise; points are allocated for the quality of your writing and presentation as well as the content.

Here are some suggestions for how to get started:

1. Classify each voxel as to which structure it belongs.
2. Get the dose calculation working for computing the dose to each voxel. Verify visually that your dose calculation is working as intended.
3. Try to identify a reasonable set of beamlet intensities with the Excel tool. Don't try to get too fancy! This step is just to develop a sense of the scale of beamlet intensities that are plausible.
4. Formulate an optimization problem. Don't include all the constraints at first – add them in one at a time, verifying at each stage that you are getting results that you understand and trust.