Analytics in the fight against cancer – the radiation therapy example

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Abstract

About 1/3 of all women and 1/2 of all men will get cancer during their lifetime. In several countries, cancer has surpassed cardiovascular disease as the most likely cause of death. On the positive side, a lot of progress has been made in cancer treatment over that past few decades. The 5-year survival rate after cancer diagnosis has increased from around 50% in the 1970s to 70% today, while the age-standardized cancer death rate has decreased by 15% globally since 1990.

In this lecture we will discuss analytics contributions to address the main challenges in cancer diagnosis and treatment: 1. Localizing the tumor, 2. hitting the tumor but not the surrounding healthy organs-at-risk (OAR), and 3. individualizing the treatment approach and optimal stopping. We will focus on radiation therapy, one the main pillars of cancer treatment and arguably the most quantitative cancer specialty.

First, automated segmentation of the tumor and OARs is becoming a clinical reality thanks to the advancement of convolutional neural networks. An unsolved problem in radiation therapy is the automated definition of the clinical target volume (CTV), which contains the visible tumor as well as invisible (to diagnostic imaging) microscopic extensions. Physicians draw the CTV contours manually on the CT or MR images, with big uncertainties and large inter- and intra-personal variations. The way forward is to model the microscopic disease extension and to quantify uncertainties. The implementation of shortest path (from the visible tumor) algorithms respecting anatomical barriers is an important first step.

The second challenge and area where analytics has made the biggest impact in radiation therapy is the development of optimization methods to solve the inverse planning problem in intensity-modulated radiation therapy (IMRT). The problem is how to shape the intensity profiles of the incoming radiation beams such that we obtain the desired dose coverage of the CTV while minimizing the radiation dose to the OARs. This optimization challenge mirrors the image reconstruction problem in computed tomography. We will discuss common formulations of the objective functions including multi-objective formulations and solutions to handle the tradeoff between CTV dose coverage and sparing of multiple OARs. Constraints include simple minimum and maximum dose constraints as well as non-convex dose-volume constraints (equivalent to value-at-risk constraints in financial planning). Objectives and constraints in different domains such as in the dose and beam intensity space are handled with split feasibility algorithms projecting back and forth between the domains. How to decompose IMRT profiles into beam shapes that are deliverable with multileaf collimators and with a continuously rotating gantry (in volumetric modulated arc therapy) is another aspect of the problem. Thanks largely to the analytics input from the optimization community, IMRT has become the new state of the art in radiation therapy, with 30 million patients treated since the first clinical deployment in the 1990s. Clinical examples will be shown.

Lastly we will give an outlook into to the use of analytics in personalized medicine, in particular the question of optimally stopping the treatment based on the patient-individual response.