Optimizing Treatment Planning for Proton Therapy

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Abstract

- Approximately 40% of cured cancer patients were treated with radiation therapy.
- There are two methods of administering radiation to cancerous cells: X-ray (photon) and proton.
- The goal is to optimize proton therapy to maximize the dose received in the tumor, minimize exposure to healthy tissue, and reduce side effects for the patient.
- Real patient data is utilized to develop usable simulations that allow for case-specific optimization.

Proton Therapy

- Proton radiation therapy can be applied as Intensity Modulated Radiation Therapy (IMRT).
- This breaks up the proton beams into smaller beamlets, whose intensity can be optimized to target specific organs
- Allows for a more precise treatment plan resulting in fewer side effects and faster recovery time.

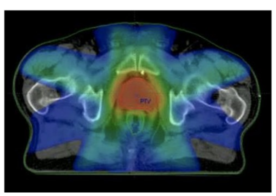

Figure 1. Beamlets target the cancerous tissue from different angles to decrease the magnitude of radiation exposure to healthy tissue.

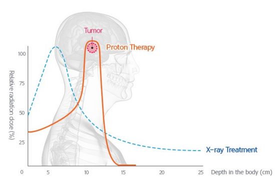

Figure 2. Radiation dose is maximized at the site of the tumor. Depicted relative to X-ray treatment radiation dosage (Samsung proton therapy center).

Challenges

- Optimizing proton therapy treatment includes very complex models with many variables
- The treatment plans are case-specific
- Treatment is very sensitive to movement in the body as the treatment is administered
  - any movement could alter the target position.

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Proton vs Photon

- Proton and photon therapy are both very common methods of treating cancerous tissue.
- Proton therapy allows for targeted delivery of proton particles to the tumor
- Photon therapy causes significantly more harm to the healthy tissue and critical organs surrounding the cancerous tissue

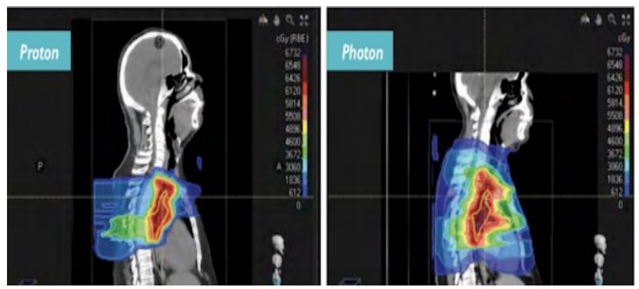

Figure 3. Visual differences between proton and photon therapy.

Optimization

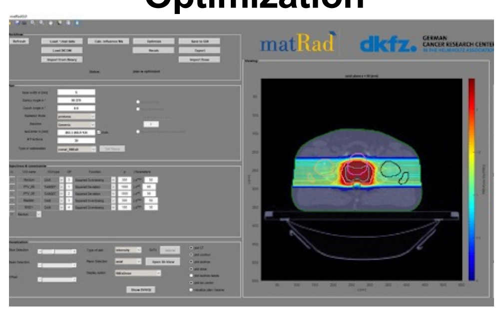

Figure 4. matRad interface in which patient case optimizations are applied

```
#build the model
mL = gp.Model("Lungs")
mH = gp.Model("Heart")
mE = gp.Model("Esophagus")
mT = gp.Model("Target")
nB = np.size(ml,2)
nTV = np.size(mT,1)
#variables
n = m.addVars(nB,vtype=GRB.BINARY, name="n", lb=0)
SU = m.addVars(nTV,vtype=GRB.BINARY, name="SU", lb = 0)
SL = m.addVar(nTV,vtype=GRB.BINARY, name="SL", lb = 0)

#constraints
mT.addConstrs(np.dot(mT,n) - SU <= 72*np.ones(nTV), "c0")
mT.addConstrs(np.dot(mT,n) + SL >= 70*np.ones(nTV), "c1")
mL.addConstrs(np.dot(mL,n) <= 20*np.ones(nTV), "c2")
mH.addConstrs(np.dot(mH,n) <= 10*np.ones(nTV), "c3")
mE.addConstrs(np.dot(mE,n) <= 35*np.ones(nTV), "c4")

#objective
m.setObjective(pg.quicksum(SU) + pg.quicksum(SL), GRB.MINIMIZE)
```

Figure 5. Skeleton of python code that allows for assigning variables, building the model, setting constraints, and optimizing

- The objective function works to maximize the dose received in the tumor
- The constraints limit the dose received in healthy organs, placing more weight on critical organs.
- The variables represent the intensity of each beamlet, which is solved to maximize the objective function while staying within the limits of the constraints.

- **Utilizing real patient data** from the Oncology Center at the University of Pennsylvania allows for case-specific treatment plans
  - The specific data received encompasses three main organs: heart, lungs, and esophagus.
- **Utilizing matRad** allows for the combination of outputs and analysis of how the plan can be applied to the patient cases.
- **Treatment optimization** is reached by utilizing linear optimization formulation.
  - In order to accomplish this, data is imported, variables are defined, a model is built, and an output is observed

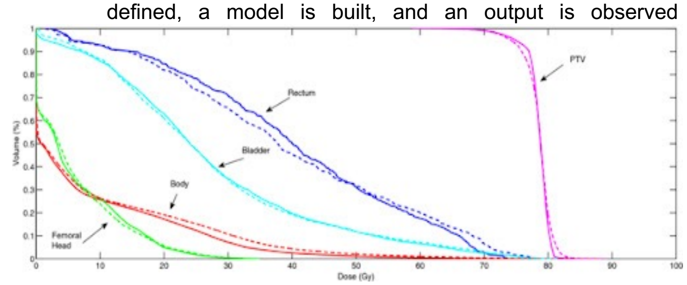

Figure 6. Dose volume histogram (DVH) curve to visualize the radiation dose delivered to each respective organ in relation to the planning target volume (Zarepisheh M, Shakourifar M, Trigila G, et al.).

Future Research

- Moving forwarde, the focus will be on improving implementation time to drastically reduce solution time as well as building robust formulations for IMPT to address body movements

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