Data Mining to Aid Beam Angle Selection for IMRT

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Outline

1. Introduction to IMRT
2. Data Set and Feature Selection
3. Model Refinement
4. Searching the Solution Space
5. Conclusions and Future Work

Motivation

- In 2012, an estimated 1.6 million Americans will be diagnosed with some form of cancer
- Approximately 60% of all U.S. patients with cancer are treated with radiation therapy, most of them with external beam radiation therapy
- Intensity Modulated Radiation Therapy (IMRT) is the most common form of external beam radiation therapy

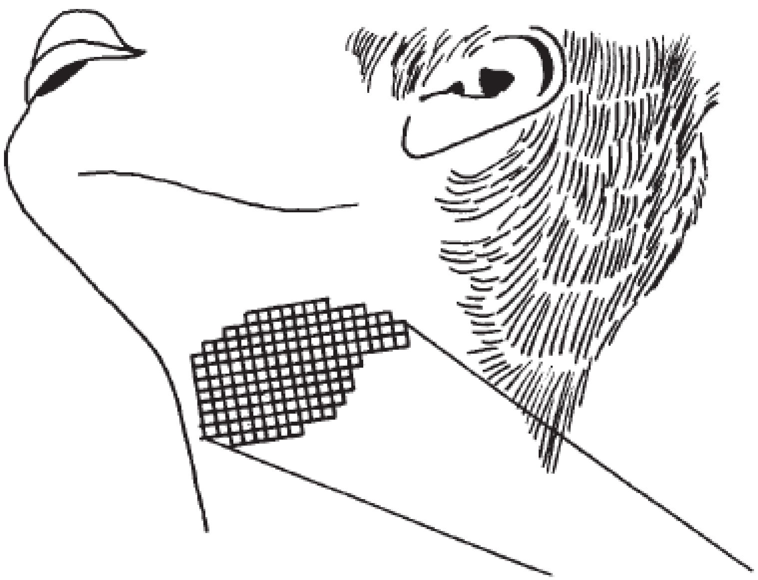
IMRT Planning Problem

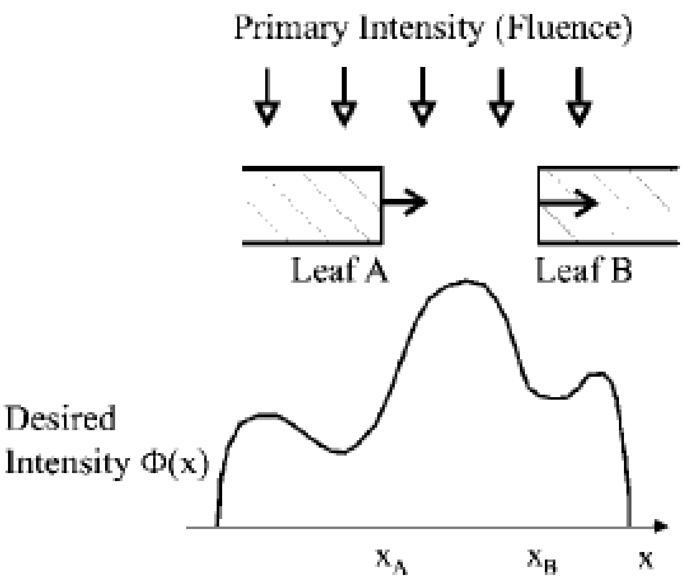
1. Identify the tumor and organs at risk (OAR)
    - The objective function is defined in this step
2. Select a set of beam angles to be used for treatment plan
    - Automated set selection not currently integrated into commercial software
3. Calculate the intensity profiles for each angle
    - Currently automated by commercially available software, but can take up to 30 minutes

Objective

- Develop a model, using previously evaluated beam angle sets, to screen potential sets for those likely to produce good plans, before the computationally expensive step of optimization
- This tool could speed the search of good beam angle sets by reducing the amount of time spent optimizing bad plans

- IMRT uses a gantry arm to allow radiation to be delivered from multiple angles
- A multi-leaf collimator is adjusted for each beam angle to shape the radiation





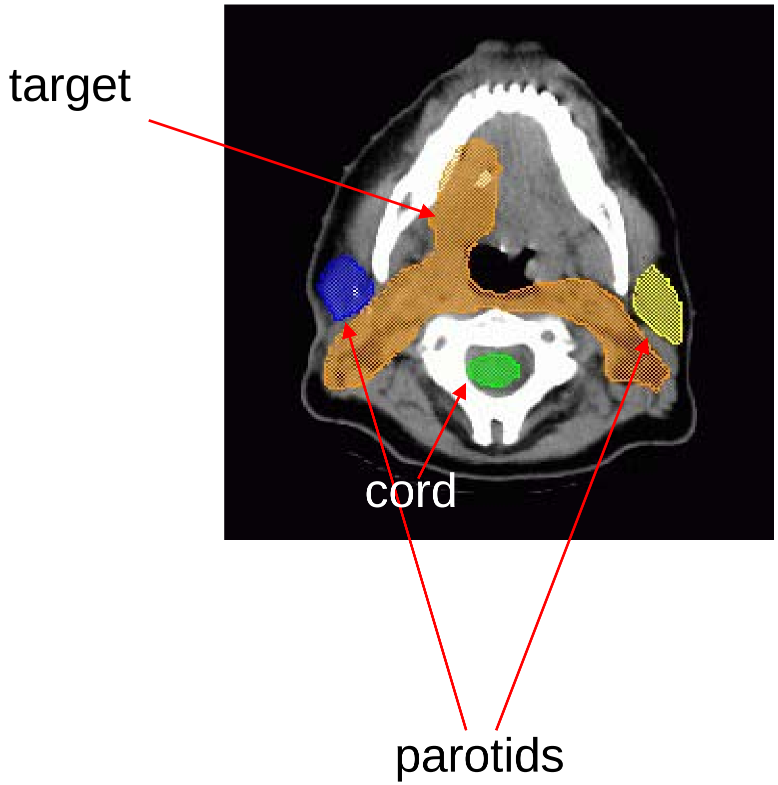
- IMRT can adjust the amount of radiation received at each pixel offering far greater control than previous treatments such as 3D conformal mapping radiation therapy (3DCRT)
- The multi-leaf collimator is dynamically adjusted controlling the intensity to each pixel

- Images from Webb 2003 ©2003 by The British Institute of Radiology

IMRT Planning Problem

1. Identify the tumor and organs at risk (OAR)
2. Select a set of beam angles to be used for treatment plan
    - Beam view method (Myrianthopoulos 1992)
    - Simulated annealing (Pugachev 2001)
    - Integer programming (D'Souza 2004)
    - Genetic algorithms (Li 2004)
    - Heuristic approaches (Saher 2010)
3. Calculate the intensity profiles for each angle
    - Gradient techniques (Bortfeld et al. 1990)
    - Maximal entropy and maximal likelihood optimization (Llacer 1997)
    - Simulated annealing (Rosen et al. 1995)
    - Genetic algorithms (Ezzel 1996)

Step 1: Identify Tumor and OAR



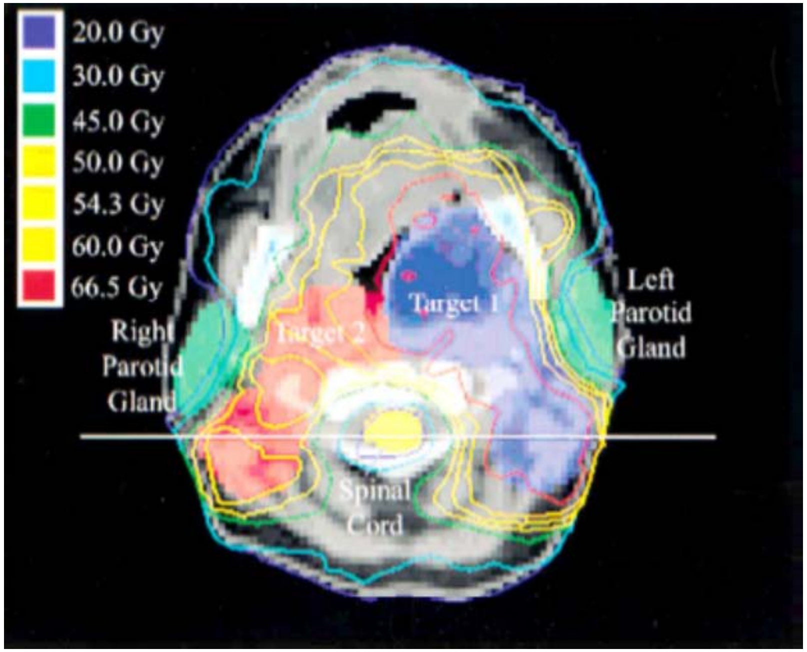
- A number of sensitive structures including the parotids (salivary glands), spinal cord, and lymph nodes
- Different tissues have different tolerance to radiation
- The tumor and immediate adjacent tissue form the planning treatment volume (PTV) for which target radiation levels are set

Penalty Score

$$S = \sum_{i \in OAR \cup PTV} \beta_i \max(A_i - d_i, 0) + \sum_{i \in PTV} \beta_i \max(d_i - A_i, 0)$$

- β_i penalty weight
- d_i desired dose level, in Greys (Gy)
- A_i actual dose level
- OAR set of organs at risk
- PTV set of tissue in planned treatment volume

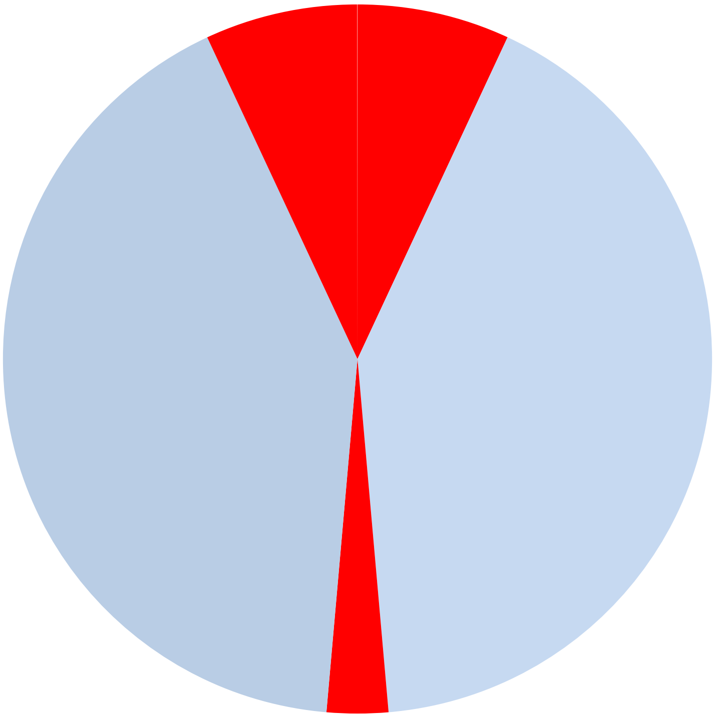
Penalty Score



Constraint	Desired level	Weight
Less than 66% of the left parotid receiving	26 Gy	**3**
Less than 33% of the left parotid receiving	32 Gy	**3**
Less than 66% of the right parotid receiving	26 Gy	**3**
Less than 33% of the right parotid receiving	32 Gy	**3**
Less than 90% of the oral mucosa receiving	30 Gy	**8**
Less than 30% of the oral mucosa receiving	40 Gy	**8**
Maximum spinal cord dose	45 Gy	**15**
Maximum brain stem dose	54 Gy	**15**
More than 95% of the low-risk PTV receiving	54 Gy	**6**
Less than 5% of the low-risk PTV receiving	59.4 Gy	**6**
More than 95% of the high-risk PTV receiving	59.4 Gy	**6**
Less than 5% of the high-risk PTV receiving	70 Gy	**6**

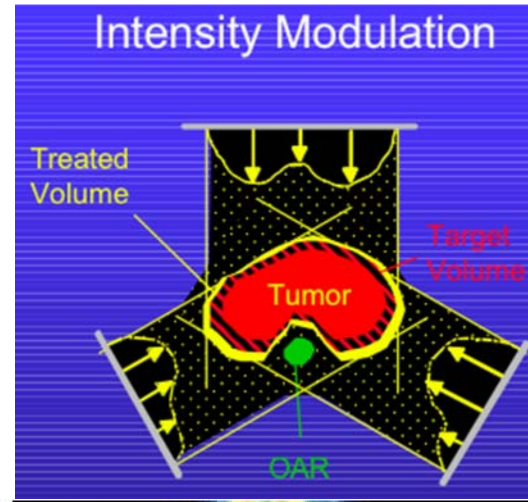
Step 2: Selecting Beam Angles

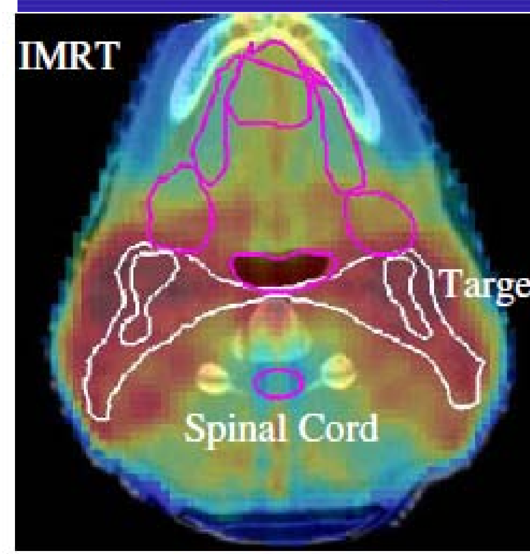
- There are diminishing returns for using more beam angles, our plans were constructed using 7 beam angles
- Plans were constructed such that beam angles were spaced at least 30 degrees apart
- Since some radiation passes through the tumor, beam angles were not placed between 170 and 190 degrees of another angle



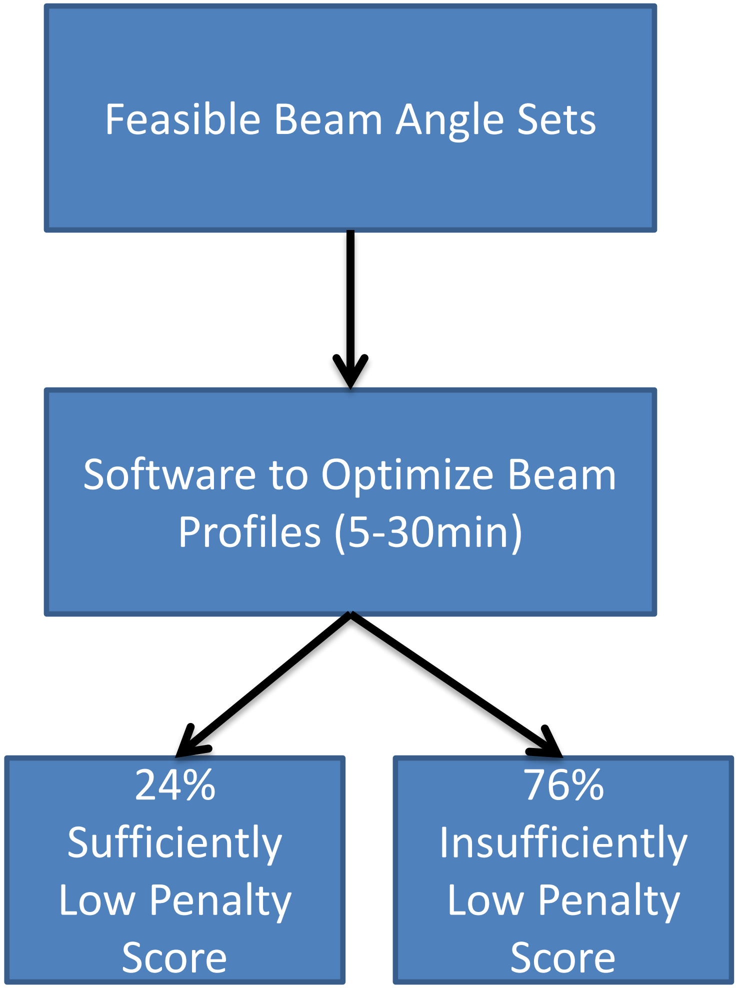
Step 3: Calculation of Intensity Profiles

- Each beam angle has about 200 pixels (also called beamlets or bixels) each of which can receive a different amount of radiation
- Beam intensities are optimized by P^3 IMRT which uses the CT scan to help ensure precise calculations
- Current software and computers take several minutes to calculate and simulate all beam intensities



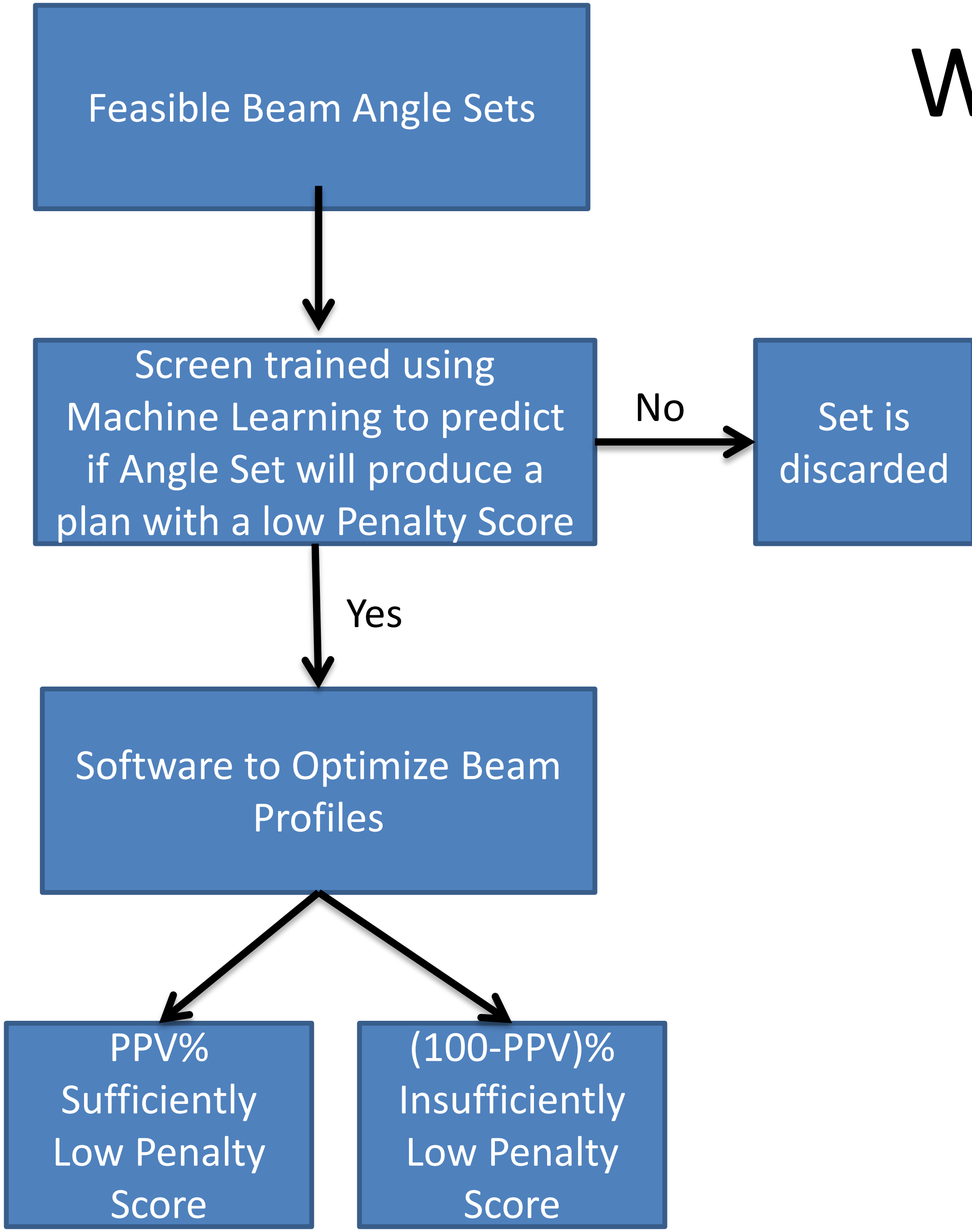


Without Screening



- All plans are evaluated
- 24% of evaluated plans have a sufficiently low penalty score to be viable for actual use
- 100% of viable plans are optimized

With Screening



- Only plans predicted to have a low penalty score are evaluated
- Positive Predictive Value (PPV) gives the percentage of evaluated plans that have a sufficiently low penalty score to be viable for actual use
- Sensitivity gives the percentage of viable plans that pass the screening stage

Data Set

- 2835 sample treatment plans for 10 patients
- All patients had locally advanced head and neck cancer
- Each plan has 7 angles from 72 possible angles (5 degree intervals starting from 0 which is vertical from the floor)
- 11 plans consisting of 7 equally spaced angles are run for each of the 10 patients

Models

- Logistic Regression- Interpretable model with no preset model parameters
- K*-An Instance-based learning algorithm that uses an entropy based distance measure. Has a single global blending parameter that varies from 0 (nearest neighbor) to 1 (equal weights to all)
- Neural Network- Requires the use of many model parameters including topology, activation function, and learning algorithm

Feature Selection

- K* performed best with only the 7 angles and a patient identifier as features
- Neural networks and Logistic regression both used a much richer data set including angle products, square, and cubic terms
- A total of 136 features were used for neural networks and logistic regression

Sample Performance of a K* Classifier

	Classified No	Classified Yes
Actual No	1994	154
Actual Yes	349	338

% Correct	82.2575
PPV	68.6992
Sensitivity	49.1994

- A PPV of 68.7 represents a 183% increase in the rate of finding good plans
- This classifier would find almost half of all good plans

Sample Performance of a Neural Network Classifier

	Classified No	Classified Yes
Actual No	2135	13
Actual Yes	614	73

% Correct	77.8836
PPV	84.8837
Sensitivity	10.6259

- Notice the trade-off between PPV and Sensitivity
- A PPV of 84.9 represents a 250% increase in the rate of finding good plans

Conclusions

- Screening can over double the chances that an evaluated plan will have sufficiently low penalty scores greatly speeding the search for good plans
- A neural network or logistic regression model could quickly screen the entire space of angle sets for those likely to produce plans with low penalty scores
- K* can incorporate each newly evaluated plan, without the need for training, to improve the models predictive value for choosing the next angle set to evaluate