How to Oversee Automated Planning

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Disclosures

• Philips: Research Grant
Learning Objectives

- Understand the technique for iterative OAR objective optimization
- Understand the technique to use libraries of previous plans to generate a plan best suited to meet clinical objectives
- Understand the technique of multi-criteria optimization (MCO).
- How medical physicists oversee plans that are created using these advance techniques and understand the potential pitfalls.
What are “automated” plans?

• There is no “automated” plans, but plans created with some computer aided automation.

• Inverse planning is one of automation tools.
  – Auto-planning module (AP)
  – Knowledge based planning (KBP)
  – Multi-criteria optimization (MCO)
Three Key Components in Inverse Planning

• Planning dose objectives
  – Maximum dose, Minimum dose, Mean dose
  – $V_{xx}$ (e.g., $V_{20Gy}$), $D_{xx}$ (e.g., D95%)

• Cost functions – quantitatively measure the goodness (based on the dose objectives) of a plan

• Search engines – find solution (intensity fluence maps) with the lowest cost.
Problems with Current Inverse Planning

- The dose objectives are not well defined for each case – using KBP can mitigate this problem.
- The solution found from optimization is not unique (due to the use of gradient search engine) – using a progressive optimization
- Trade-off among many solutions – using MCO to show.
Local Minimum and Global Minimum

Objective Function
How Does Knowledge Based Planning Work?
DUKE University Radiation Oncology

Bladder
- > 230 cc
- 100 cc to 230 cc
- <100 cc

Rectum
- > 120 cc
- 60 cc to 120 cc
- <60 cc

Parotid
- > 38 cc
- 22 cc to 38 cc
- <22 cc

Brainstem
- > 28 cc
- 20 cc to 28 cc
- <20 cc

Courtesy of Jackie Wu
Modeling Planning Knowledge

- **DVH/DTH Feature Extraction and Dimension Reduction**
  - Principal Component Analysis (PCA)

![Graph showing DVH/DTH analysis](image)
Modeling Planning Knowledge

Database of Tx Cases

Feature Extraction

Model Training

Predictive Model

Retrospective Plan Databases Quality Analysis

Prospective New Pt Case Planning Guidance

Distance-Based

Volume-Based

Dose-Based

High Order

Institutional

A planning quality evaluation tool for prostate adaptive IMRT based on machine learning
Medical Physics 38, 719,2011

Quantitative analysis of the factors which affect the interpatient organ-at-risk dose sparing variation in IMRT plans.
Medical Physics 39, 6868,2012

Courtesy of Jackie Wu
How Does Auto Planning Work?
Auto-Planning in Pinnacle System

• Mimics the planners’ thought process
• Utilizes the planners’ tricks to create surrounding structures and tuning contours automatically
• Automatically runs multiple loops while adjusting planning objectives – similar to what planners manually do

Ouyang Z et. al. JACMP, 2019
Input Planning Goals

Target Optimization Goals

<table>
<thead>
<tr>
<th>ROI</th>
<th>Dose cGy</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2-4 Tumor</td>
<td>1600</td>
</tr>
</tbody>
</table>

Organ At Risk (OAR) Optimization Goals

<table>
<thead>
<tr>
<th>ROI</th>
<th>Type</th>
<th>Dose cGy</th>
<th>Volume (%)</th>
<th>Priority</th>
<th>Compromise</th>
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<tbody>
<tr>
<td>Cord T2-4</td>
<td>Max Dose</td>
<td>1350</td>
<td></td>
<td>High</td>
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</tr>
<tr>
<td>CT - T4 cord</td>
<td>Max DVH</td>
<td>1000</td>
<td>5</td>
<td>High</td>
<td>✔️</td>
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<tr>
<td>Cord T2-4</td>
<td>Max DVH</td>
<td>900</td>
<td>5</td>
<td>High</td>
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<td>Ring_5mm_T2</td>
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<td>10</td>
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<td>✔️</td>
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<tr>
<td>ring_2cm_T2</td>
<td>Max DVH</td>
<td>1000</td>
<td>10</td>
<td>High</td>
<td>✔️</td>
</tr>
<tr>
<td>ESOPHAGUS</td>
<td>Max Dose</td>
<td>1600</td>
<td></td>
<td>High</td>
<td>✔️</td>
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</table>
Automatic Created Planning Objectives

<table>
<thead>
<tr>
<th>Objective</th>
<th>Parameter</th>
<th>Target</th>
<th>Min</th>
<th>Max</th>
<th>Achieved Dose</th>
<th>Dose Gap</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2-4 Tumor.AP</td>
<td>Min Dose</td>
<td></td>
<td>1500</td>
<td>1600</td>
<td>20</td>
<td>0.104446</td>
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<tr>
<td>T2-4 Tumor.AP</td>
<td>Max Dose</td>
<td></td>
<td>2567.48</td>
<td></td>
<td>35</td>
<td>2.90664e-06</td>
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<tr>
<td>TargetSurround</td>
<td>Max Dose</td>
<td></td>
<td>490.509</td>
<td></td>
<td>5</td>
<td>0.125</td>
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<tr>
<td>TargetSurround</td>
<td>Max DVH</td>
<td></td>
<td>0.125</td>
<td></td>
<td>0.01674</td>
<td></td>
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<tr>
<td>Ring 2cm T2</td>
<td>Max Dose</td>
<td></td>
<td>988.76</td>
<td></td>
<td>10</td>
<td>0.125</td>
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<td>Ring 2cm T2</td>
<td>Max DVH</td>
<td></td>
<td>0.125</td>
<td></td>
<td>0.013325</td>
<td></td>
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<tr>
<td>BodyMinusTarget</td>
<td>Max Dose</td>
<td></td>
<td>640</td>
<td></td>
<td>100</td>
<td>5.63819</td>
</tr>
<tr>
<td>BodyMinusTarget</td>
<td>Max DVH</td>
<td></td>
<td>0.125</td>
<td></td>
<td>0.0991067</td>
<td></td>
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<tr>
<td>ES - T2 cord</td>
<td>Max Dose</td>
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<td>236.574</td>
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<td>0.194692</td>
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<tr>
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<td></td>
<td>0.09602535</td>
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<tr>
<td>Cord T2-4</td>
<td>Max Dose</td>
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<td>648.938</td>
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<td>0.55108</td>
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<tr>
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<td>Max DVH</td>
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<tr>
<td>Cord T2-4</td>
<td>Max Dose</td>
<td></td>
<td>746.603</td>
<td></td>
<td>100</td>
<td>0.00694334</td>
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</tbody>
</table>
Multi-criteria Optimization (MCO)
Pareto Frontier

[Diagram showing Pareto Frontier, Feasible Point, Infeasible Point, Utopia Point, and Objective 1 and Objective 2 axes.]

Courtesy of Jeremy Donaghue

www.noesissolutions.com/Noesis/sites/default/files/Pareto_Front.png
MCO Implemented in RaySearch

- Requires a set of dose constraints (anchor points) – no violation allowed.
- Requires a set of dose objectives (tradeoffs) – negotiations allowed.
- Multiple \((2n+1)\) plans are created automatically according number \((n)\) of tradeoffs.
- Users can lock the satisfied tradeoffs to narrow the search space.
Navigation Panel

Current navigation: Nav aapm 2016

Targets:
- PTV_7000, Uniform Dose
- PTV_LN_5040, Uniform Dose
- PTV_SV_6000, Uniform Dose

Organs at risk:
- BLADDER, Max Dose
- COLON, Max Dose
- External, Dose Fall-Off
- External, Dose Fall-Off
- FEMORAL HEAD_L, Max Dose
- FEMORAL HEAD_R, Max Dose
- PENILE BULB, Max Dose
- RECTUM, Max Dose

Courtesy of Jeremy Donaghue
The Ideal World

Knowledge Based Planning
- Patient specific DVH predictions
- No “one size fits all”
- Dose constraints

Auto Planning
- Automatically create a plan that meets the predicted DVHs

Multiple Criteria Optimization
- Provide trade-off solutions
Promises and Pitfalls

• Use of these advanced planning tools in IMRT planning improve plan quality, efficiency, and consistency.
• Using these advanced planning tools prevents “bad” plans.
• Plans created from these tools are not necessary clinical acceptable.
Lack of Spatial Information in the Cost Functions and Objectives

Bad  Good
Partial Brain Cases
Rx: 60 Gy to HD-PTV, 51 Gy to LD-PTV

<table>
<thead>
<tr>
<th>OARs</th>
<th>Goals</th>
<th>Clinical</th>
<th>AP</th>
<th>KBP</th>
<th>MCO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brainstem</td>
<td>&lt;60 Gy</td>
<td>61.1 Gy</td>
<td>60.99 Gy</td>
<td>59.95 Gy</td>
<td>59.47 Gy</td>
</tr>
<tr>
<td>Chiasm</td>
<td>&lt;56 Gy</td>
<td>54.5 Gy</td>
<td>55.59 Gy</td>
<td>55.44 Gy</td>
<td>50.15 Gy</td>
</tr>
<tr>
<td>OARs</td>
<td>Goals</td>
<td>Clinical</td>
<td>AP</td>
<td>KBP</td>
<td>MCO</td>
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<td>55.44 Gy</td>
<td>50.15 Gy</td>
</tr>
</tbody>
</table>

63 Gy, 60 Gy, 51 Gy, 45 Gy, 35 Gy
Spinal SBRT Cases
Rx: $D_{90\%} > 16$ Gy

<table>
<thead>
<tr>
<th>Spinal Cord (Max. Dose)</th>
<th>Goal</th>
<th>Clinical</th>
<th>AP</th>
<th>KBP</th>
<th>MCO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;14 Gy</td>
<td>13.9 Gy</td>
<td>14.4 Gy</td>
<td>14.1 Gy</td>
<td>12.8 Gy</td>
</tr>
</tbody>
</table>

Lu L, et. al. JACMP, 2019.
<table>
<thead>
<tr>
<th></th>
<th>Goal</th>
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<td>14.4 Gy</td>
<td>14.1Gy</td>
<td>12.8 Gy</td>
</tr>
</tbody>
</table>

Lu L, et. al. JACMP, 2019.
Prostate + Pelvic LN Cases
Rx: PTV-prostae 70 Gy, PTV-LN 50.4 Gy in 28 Gy

<table>
<thead>
<tr>
<th></th>
<th>Goal</th>
<th>Clinical</th>
<th>AP</th>
<th>KBP</th>
<th>MCO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bladder</td>
<td>V63Gy &lt;10%</td>
<td>16.28%</td>
<td>7.40%</td>
<td>7.02%</td>
<td>11.18%</td>
</tr>
<tr>
<td>Rectum</td>
<td>V63Gy &lt;10%</td>
<td>12.15%</td>
<td>7.00%</td>
<td>6.25%</td>
<td>5.95%</td>
</tr>
<tr>
<td>Rectum</td>
<td>V45Gy &lt; 30%</td>
<td>44.47%</td>
<td>22.21%</td>
<td>27.40%</td>
<td>23.44%</td>
</tr>
</tbody>
</table>
Oropharynx Cases
Rx: PTV-HD 70 Gy, PTV-LD: 56Gy

<table>
<thead>
<tr>
<th></th>
<th>Goal</th>
<th>Clinical</th>
<th>AP</th>
<th>KBP</th>
<th>MCO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spinal cord</td>
<td>D0.03cc &lt; 45 Gy</td>
<td>46.61</td>
<td>37.48</td>
<td>42.05</td>
<td>39.32</td>
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<tr>
<td>Paratid L</td>
<td>Dmean &lt; 26 Gy</td>
<td>34.17</td>
<td>24.53</td>
<td>28.53</td>
<td>25.01</td>
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<tr>
<td>Paratid R</td>
<td>Dmean &lt; 26 Gy</td>
<td>35.16</td>
<td>35.46</td>
<td>29.29</td>
<td>23.78</td>
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<tr>
<td>Mandible</td>
<td>D0.03cc &lt;73 Gy</td>
<td>73.69</td>
<td>73.83</td>
<td>75.95</td>
<td>73.26</td>
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<tr>
<td>Trachea</td>
<td>Dmean &lt;45 Gy</td>
<td>32.04</td>
<td>24.52</td>
<td>31.03</td>
<td>22.27</td>
</tr>
<tr>
<td>Esophagus</td>
<td>Dmean &lt; 50 Gy</td>
<td>18.77</td>
<td>16.52</td>
<td>19.8</td>
<td>12.34</td>
</tr>
<tr>
<td>Oral cavity</td>
<td>Dmean &lt;35 Gy</td>
<td>30.81</td>
<td>28.14</td>
<td>29.99</td>
<td>22.1</td>
</tr>
</tbody>
</table>
Take Home Message

• DVHs and specific dosimetric end-points (e.g., mean dose) are not sufficient to assess plan quality. Carefully examining 3D dose distributions is important.

• Advance planning tools can assist dosimetrists to create plans with reduced variations but clinical judgment and experience are still important.

• The pitfall is that the desired 3D dose distributions cannot be clearly described by the numeric planning objectives.
Acknowledgement

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