Optimization of High Dose Rate Brachytherapy Treatment Plans
RUIDO versus IPSA

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Outline

- Introduction
- Optimization process
- Conclusion
- Future work
Introduction

- What is optimized in HDR brachytherapy?
  - For stepping HDR source: dwell positions fixed
  - Optimized dose distribution: varying dwell time

- RUIDO (Rush University In-house Dose Optimizer):
  - Capable of optimizing:
    - Physical Dose
    - gEUD (generalized Equivalent Uniform Dose)
    - TCP and NTCP (Tumor Control and Normal Tissue Complication)

- IPSA (Inverse Planning Simulated Annealing):
  - Commercially available from Nucletron Plato system
  - Only capable of physical dose optimization
Optimizer

- IPSA: Simulated Annealing
- RUIDO: Adaptive Simulated Annealing
- Searching for global minimum for cost function:
  - New cost $C(p_{k+1})$ is accepted when:
    $$\exp\left[\frac{-(C(p_{k+1}) - C(p_k))}{T_{cost}}\right] > U$$
    - $U \subseteq [0, 1)$, uniform random generator
Optimization Process

Dose Grid Set Up

Optimization (ASA)

Cost Functions

Final Results

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Dose Grid Set Up (contour based)

Bladder

Rectum

PTV

Dwell Position

X

Y

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Dose Grid Set Up (contour based)
Dose Grid Set Up (contour based)

Bladder

PTV

Dwell Position

Rectum

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Cut-off Distance

● Cut-off distance:
  – Nature of brachytherapy:
    ● Dose falls off quickly away from source
    ● High dose region too close to source does not represent the total target dose distribution very well
  – Dose points within the cut-off distance from the dwell positions are removed
  – Default 2mm, why?
Why 2mm?

- Normalized to dose rate at 0.1mm.

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Dose Rate Calculation

- **Equation:**

\[
Dose\ Rate = \Gamma \cdot A \cdot f\ - factor \cdot filter \cdot Poly(r) \cdot geo\_factor(r)
\]

- \( Poly(r) = a_0 + a_1 r + a_2 r^2 + a_3 r^3 \)
- \( Geo\_factor = 1/r^2 \)

- Dose at each dose point is the sum of the production of dose rate and dwell time from all source positions
Optimization Process

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Final Results
RUIDO – Cost Functions

- Physical Dose

\[ \text{Cost Surface} = (D_{\text{surf}} - D_0)^2 \]

\[ \text{Cost Volume} = \begin{cases} 
2(D_{\text{vol}} - D_0)^2, & D_{\text{vol}} < D_0 \\
0, & D_0 < D_{\text{vol}} < 2D_0 \\
(D_{\text{vol}} - 2D_0)^2, & D_{\text{vol}} > 2D_0 
\end{cases} \]
IPSA – Cost Function
IPSA – Cost function (prostate)
## IPSA – Prostate Example

<table>
<thead>
<tr>
<th>VOI</th>
<th>Margin (mm) Dose control</th>
<th>Margin (mm) Catheter activation</th>
<th>Organ type</th>
<th>Min surface dose weight</th>
<th>Min surface dose (cGy)</th>
<th>Max surface dose (cGy)</th>
<th>Max surface dose weight</th>
<th>Min volume dose weight</th>
<th>Max volume dose (cGy)</th>
<th>Max volume dose weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>bladder</td>
<td>0.0</td>
<td>0.0</td>
<td>Organ at risk</td>
<td>0</td>
<td>0</td>
<td>475.0</td>
<td>20</td>
<td>0</td>
<td>0.0</td>
<td>475.0</td>
</tr>
<tr>
<td>bulb</td>
<td>0.0</td>
<td>0.0</td>
<td>Organ at risk</td>
<td>0</td>
<td>0.0</td>
<td>475.0</td>
<td>20</td>
<td>0</td>
<td>0.0</td>
<td>475.0</td>
</tr>
<tr>
<td>dil</td>
<td>0.0</td>
<td>0.0</td>
<td>Target</td>
<td>100</td>
<td>1425.0</td>
<td>1425.0</td>
<td>100</td>
<td>100</td>
<td>1425.0</td>
<td>1425.0</td>
</tr>
<tr>
<td>prostate</td>
<td>0.0</td>
<td>20.0</td>
<td>Reference target</td>
<td>100</td>
<td>950.0</td>
<td>1425.0</td>
<td>30</td>
<td>100</td>
<td>950.0</td>
<td>1425.0</td>
</tr>
<tr>
<td>rectum</td>
<td>0.0</td>
<td>0.0</td>
<td>Organ at risk</td>
<td>0</td>
<td>0.0</td>
<td>475.0</td>
<td>20</td>
<td>0</td>
<td>0.0</td>
<td>475.0</td>
</tr>
<tr>
<td>urethra</td>
<td>0.0</td>
<td>0.0</td>
<td>Organ at risk</td>
<td>100</td>
<td>950.0</td>
<td>1140.0</td>
<td>30</td>
<td>100</td>
<td>950.0</td>
<td>1140.0</td>
</tr>
</tbody>
</table>

### Class Solution

In use: ucsf-prostate

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Optimization Process

1. Dose Grid Set Up
2. Optimization (ASA)
3. Cost Functions
4. Final Results
Results

IPSA

RUIDO

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Case Study

- Three Syed implant HDR cases
- RUIDO computing time correlates with # of total dose points

<table>
<thead>
<tr>
<th></th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target Volume (cc)</td>
<td>32.6</td>
<td>94.7</td>
<td>92.1</td>
</tr>
<tr>
<td># of total dose points</td>
<td>316</td>
<td>2500</td>
<td>698</td>
</tr>
<tr>
<td>Computing time (min)</td>
<td>1</td>
<td>16</td>
<td>6</td>
</tr>
</tbody>
</table>

- IPSA: computing time ~10 seconds for each trial
## RUIDO vs. IPSA

<table>
<thead>
<tr>
<th></th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>RUIDO</td>
<td>0.95</td>
<td>0.97</td>
<td>0.95</td>
</tr>
<tr>
<td>IPSA</td>
<td>0.95</td>
<td>0.97</td>
<td>0.95</td>
</tr>
<tr>
<td>Diff %</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>CI</td>
<td>0.54</td>
<td>0.65</td>
<td>0.73</td>
</tr>
<tr>
<td>HI</td>
<td>0.50</td>
<td>0.58</td>
<td>0.63</td>
</tr>
<tr>
<td>OI</td>
<td>0.12</td>
<td>0.1</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>0.14</td>
<td>0.09</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>-16%</td>
<td>12%</td>
<td>-45%</td>
</tr>
</tbody>
</table>

- RUIDO normalized to have the SAME CI as IPSA
- Coverage Index (CI) = \( \frac{V_{100}}{V_{Total}} \)
- Homogeneity Index (HI) = \( \frac{(V_{100} - V_{150})}{V_{Total}} \)
- Overdose Index (OI) = \( \frac{V_{200}}{V_{Total}} \)

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Conclusion

- RUIDO and IPSA generate equivalent plans
- RUIDO outperforms IPSA when the number of dose points are not high
- RUIDO is less user dependent than IPSA
- No OARs included in RUIDO (physical dose) might be a limitation of RUIDO
Future Work

- Reducing dose points might improve the performance of RUIDO
- Incorporating OARs into physical dose optimization
- Apply RUIDO to LDR brachytherapy
  - Optimizing on source positions
Computing Time vs. Dose Points

Ratio of Pts
Ratio of Time