

# How to Oversee Automated Planning

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# Disclosures

- Philips: Research Grant

# Cleveland Clinic Main Campus



# 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)

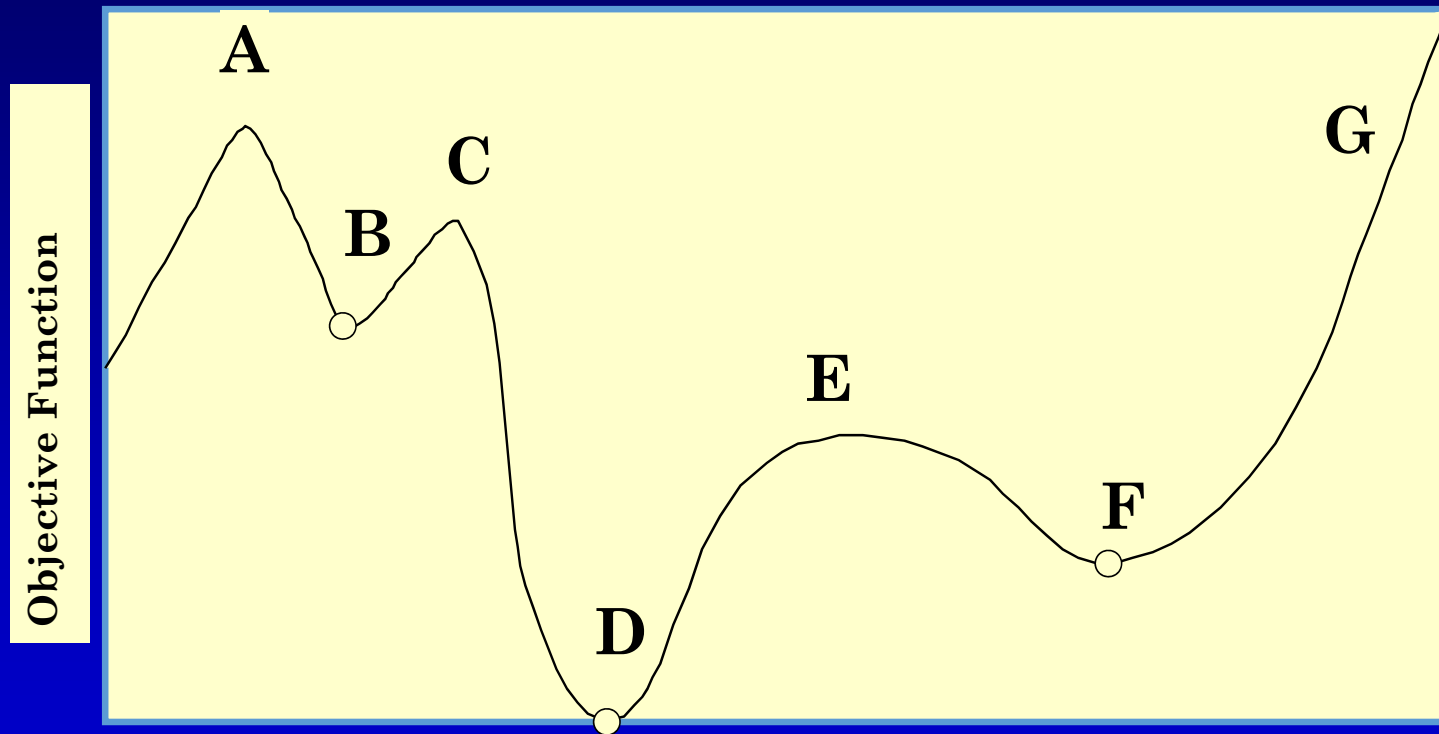
# Three Key Components in Inverse Planning

- Planning dose objectives
  - Maximum dose, Minimum dose, Mean dose
  - $V_{xx}$  (e.g,  $V_{20_{Gy}}$  ),  $D_{xx}$  ( e.g.,  $D_{95\%}$  )
- 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.

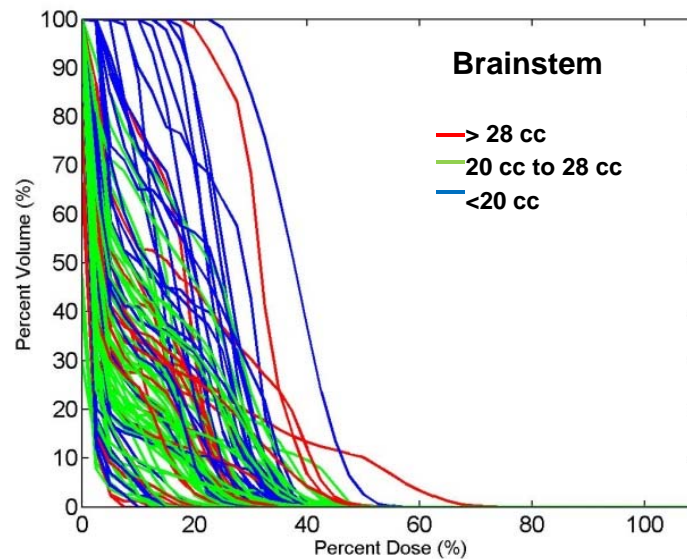
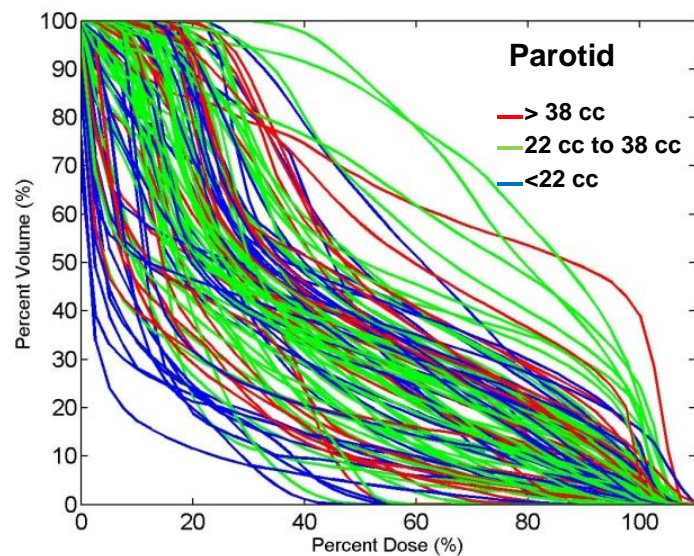
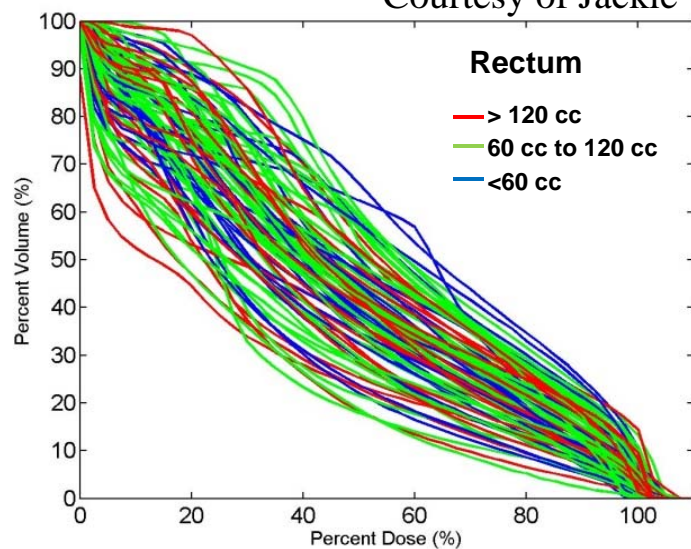
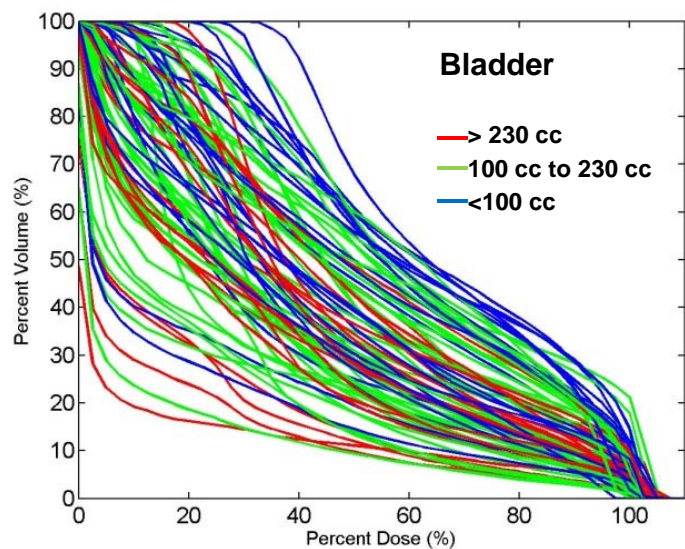
# Local Minimum and Global Minimum





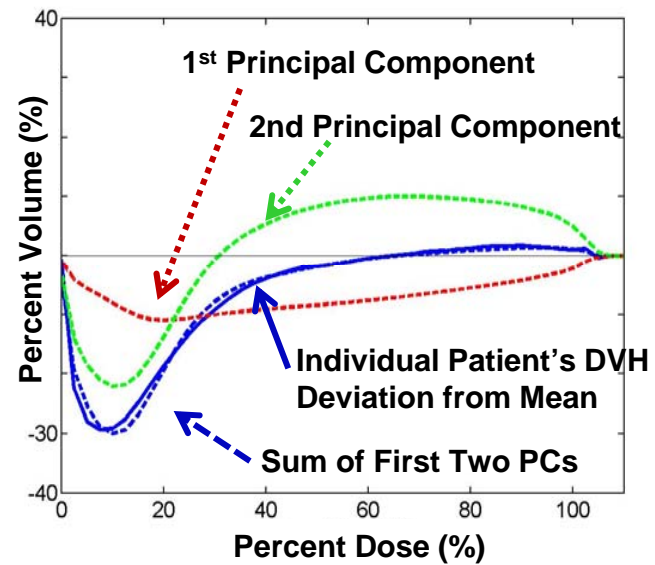
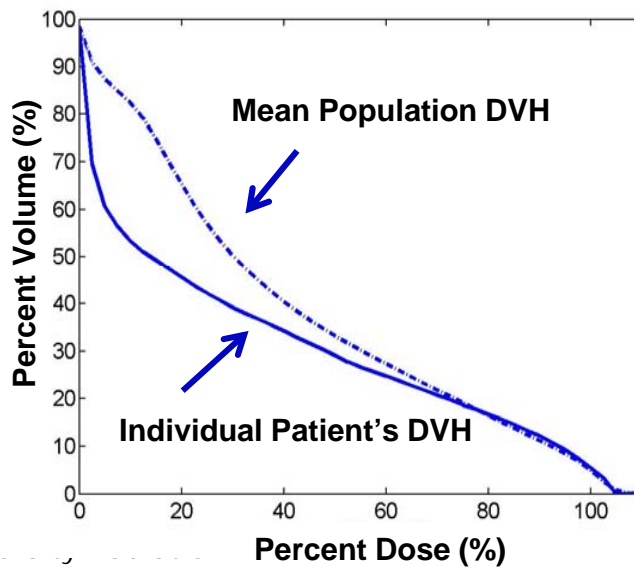
# How Does Knowledge Based Planning Work?

Courtesy of Jackie Wu



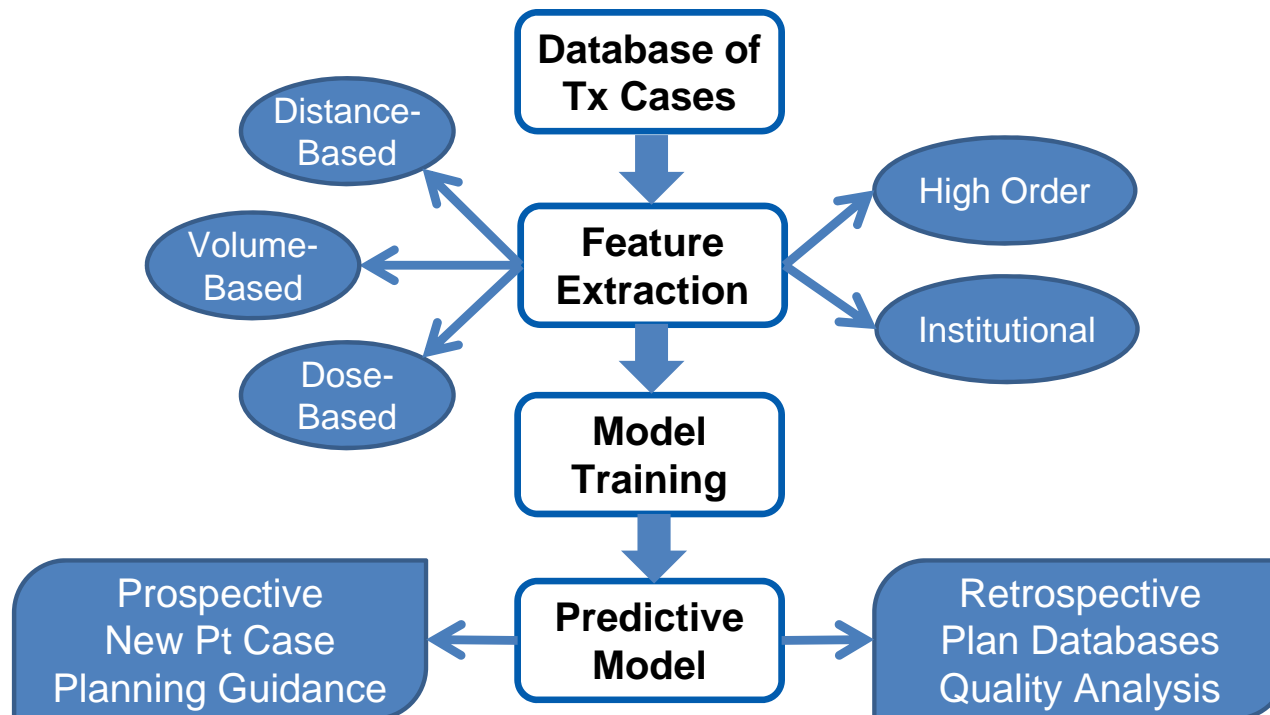
# Modeling Planning Knowledge

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



Courtesy of Jackie Wu

# Modeling Planning Knowledge



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*

# 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

# Input Planning Goals

**Target Optimization Goals**

ROI	Dose cGy
◆ T2-4 Tumor	1600

**Organ At Risk (OAR) Optimization Goals**

ROI	Type	Dose cGy	Volume (%)	Priority	Compromise
◆ Cord T2-4	Max Dose	1350		High	<input type="checkbox"/>
◇ C7 - T4 cord	Max DVH	1000	5	High	<input checked="" type="checkbox"/>
◇ Cord T2-4	Max DVH	900	5	High	<input type="checkbox"/>
◇ Ring_5mm_T2	Max DVH	1400	10	High	<input checked="" type="checkbox"/>
◇ ring_2cm_T2	Max DVH	1000	10	High	<input checked="" type="checkbox"/>
◇ ESOPHAGUS	Max Dose	1600		High	<input checked="" type="checkbox"/>

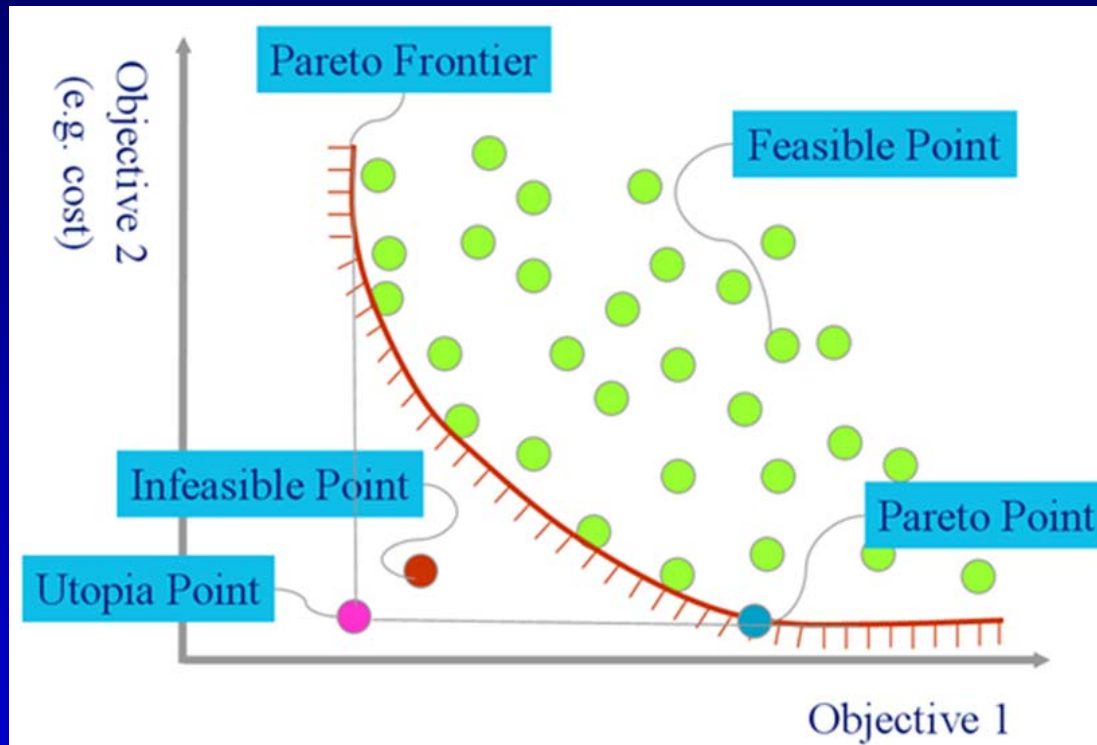
# Automatic Created Planning Objectives

◇ T2-4 Tumor_AP_	Min Dose	<input type="checkbox"/>	1600	20	0.104445		
◇ T2-4 Tumor_AP_	Min Dose	<input type="checkbox"/>	1600	20	0.0647136		
◇ T2-4 Tumor_AP_	Max Dose	<input type="checkbox"/>	2567.48	35	2.80684e-06		
◇ TargetSurround_	Resd_C7 - T4 co	Max DVH	<input type="checkbox"/>	490.509	5	0.125	0.01674
◇ TargetSurround_	Resd_ESOPHAG	Max Dose	<input type="checkbox"/>	894.451	0.125	0.0189307	
◇ ring_2cm_T2	Ring_5mm_T2	Max DVH	<input type="checkbox"/>	998.786	10	0.125	0.013325
◇ ring_2cm_T2	Ring_5mm_T2	Max DVH	<input type="checkbox"/>	1260	10	100	1.46928
◇ T2-4 Tumor_AP_	BodyMinusTarget	Max Dose	<input type="checkbox"/>	640	100	5.63819	
◇ T2-4 Tumor_AP_	BodyMinusTarget	Max Dose	<input type="checkbox"/>	286.574	0.125	0.0991067	
◇ T2-4 Tumor_AP_	C7 - T4 cord	Max DVH	<input type="checkbox"/>	900	5	100	0.194692
◇ Cord T2-4	Max DVH	<input type="checkbox"/>	648.938	5	0.125	0.00602535	
◇ Cord T2-4	Max DVH	<input type="checkbox"/>	810	5	60	0.55108	
◇ Cord T2-4	Max Dose	<input type="checkbox"/>	1215	100	0.144602		
◇ Cord T2-4	Max Dose	<input type="checkbox"/>	746.603	0.125	0.00694334		



# Multi-criteria Optimization (MCO)

# Pareto Frontier



Courtesy of Jeremy Donaghue

[www.noessolutions.com/Noesis/sites/default/files/Pareto\\_Front.png](http://www.noessolutions.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

5 Control Points Beam Optimization Settings Beam Weighting

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



The image shows a software interface for beam optimization. It features a dark grey background with a top navigation bar containing tabs for 'Control Points', 'Beam Optimization Settings', and 'Beam Weighting'. Below the tabs, the current navigation is identified as 'Nav aapm 2016'. The interface is divided into two main sections: 'Targets' and 'Organs at risk'. Each section contains a list of items, each with a colored square icon, a text label, a small square checkbox, a thumbs-down icon, a horizontal slider with a blue knob, and a thumbs-up icon. The 'Targets' section includes three items: PTV\_7000, Uniform Dose (red square), PTV\_LN\_5040, Uniform Dose (green square), and PTV\_SV\_6000, Uniform Dose (blue square). The 'Organs at risk' section includes eight items: BLADDER, Max Dose (yellow-green square), COLON, Max Dose (yellow square), External, Dose Fall-Off (green square), External, Dose Fall-Off (green square), FEMORAL HEAD\_L, Max Dose (orange square), FEMORAL HEAD\_R, Max Dose (green square), PENILE BULB, Max Dose (yellow square), and RECTUM, Max Dose (red square). The sliders are positioned at various levels, indicating different optimization weights for each parameter.

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

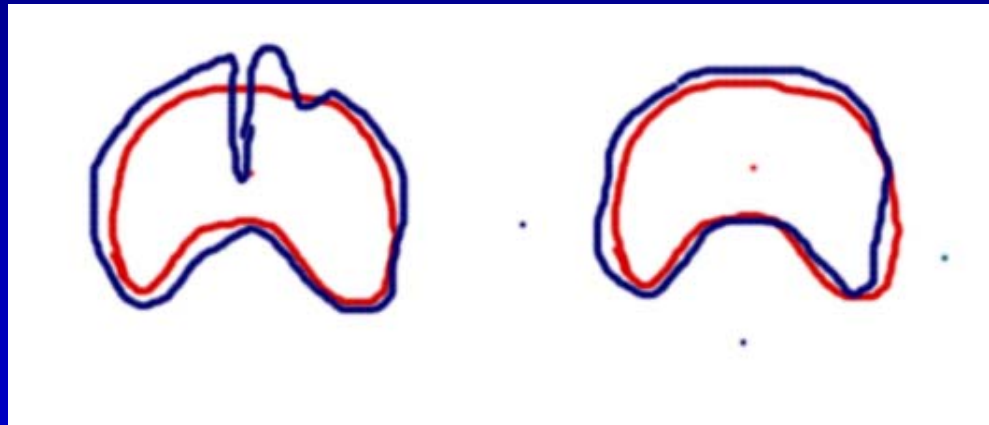
Multiple  
Criteria  
Optimization

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

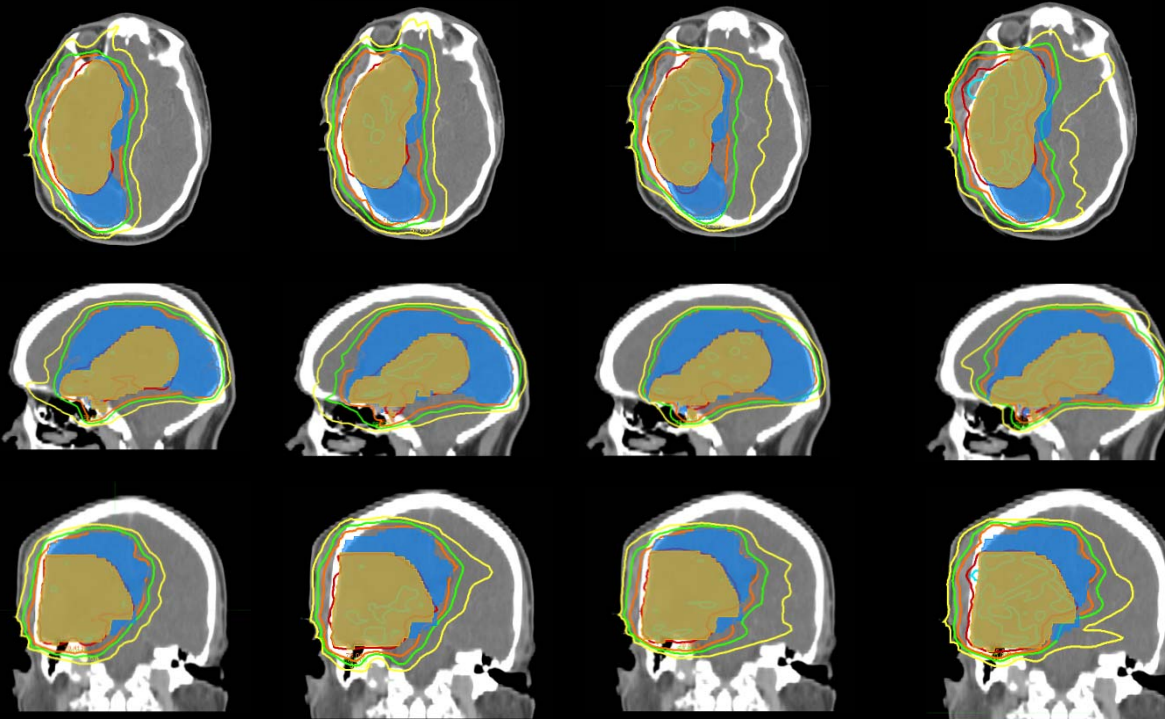


Clinical

AP

KBP

MCO



PTV60

PTV51

63 Gy

60 Gy

51 Gy

45 Gy

35 Gy

Rx: 60 Gy to HD-PTV, 51 Gy to LD-PTV

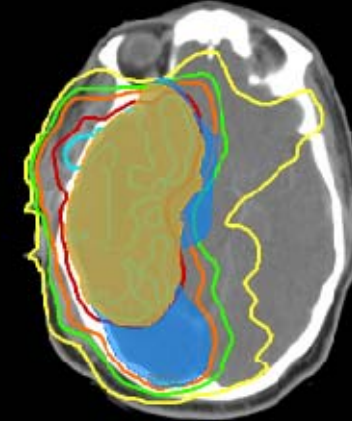
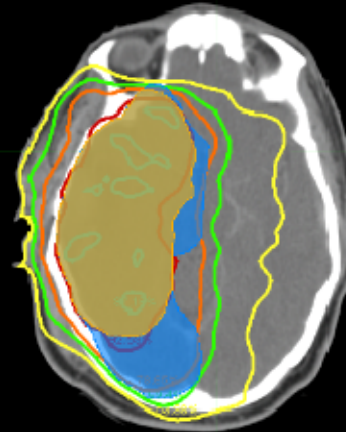
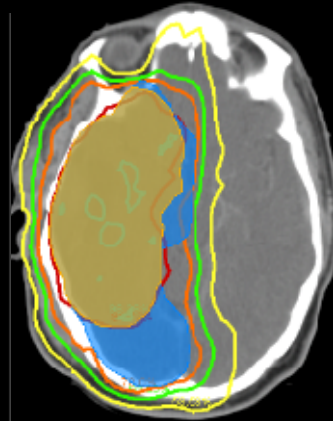
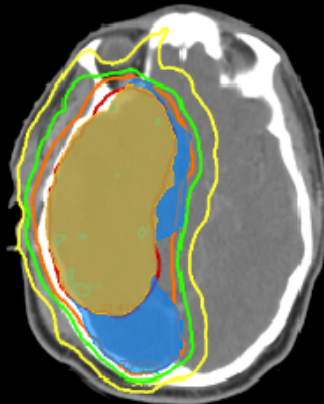
OARs	Goals	Clinical	AP	KBP	MCO
Brainstem	<60 Gy	61.1 Gy	60.99 Gy	59.95 Gy	59.47 Gy
Chiasm	<56 Gy	54.5 Gy	55.59 Gy	55.44 Gy	50.15 Gy

Clinical

AP

KBP

MCO

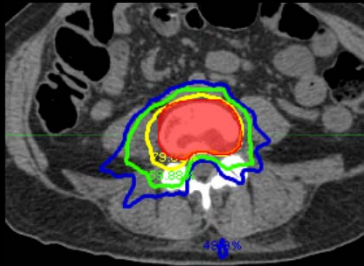


**63 Gy, 60 Gy, 51 Gy, 45 Gy, 35 Gy**

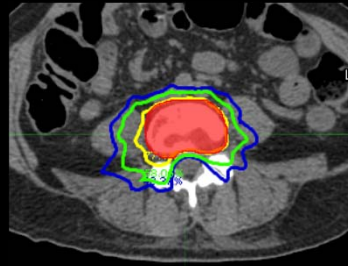
OARs	Goals	Clinical	AP	KBP	MCO
Brainstem	<60 Gy	61.1 Gy	60.99 Gy	59.95 Gy	59.47 Gy
Chiasm	<56 Gy	54.5 Gy	55.59 Gy	55.44 Gy	50.15 Gy

# Spinal SBRT Cases

Clinical



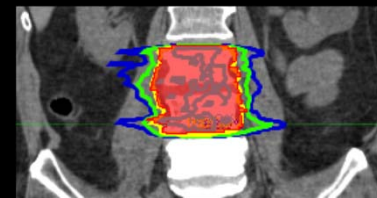
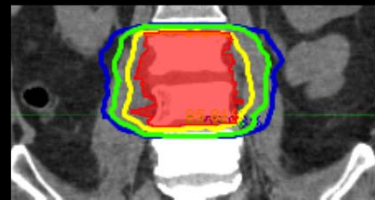
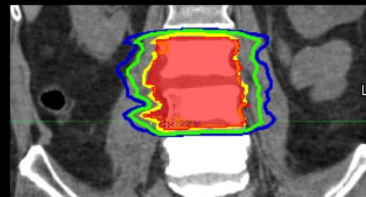
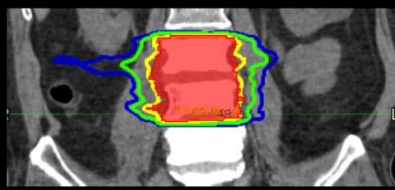
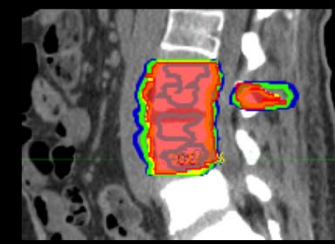
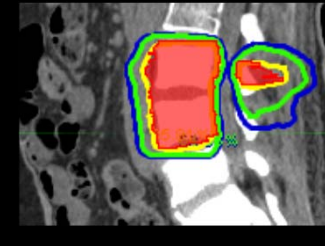
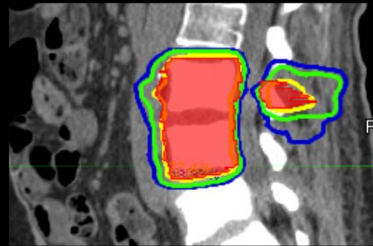
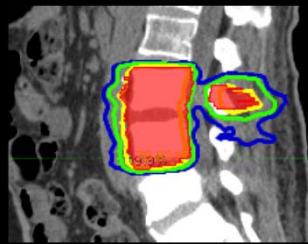
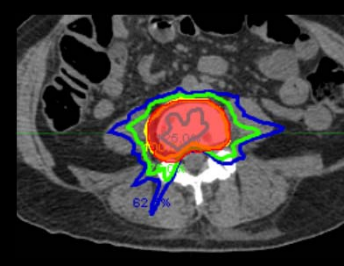
AP



KBP



MCO



PTV16

20 Gy

12 Gy

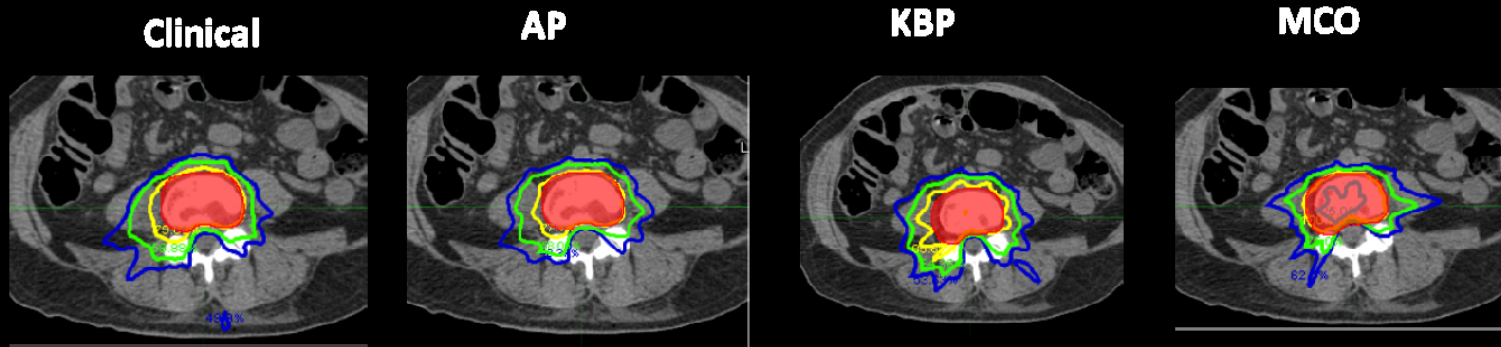
16 Gy

10 Gy

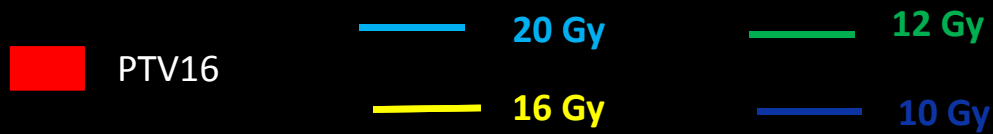
Rx: D90% > 16 Gy

	Goal	Clinical	AP	KBP	MCO
Spinal Cord (Max. Dose)	<14 Gy	13.9 Gy	14.4 Gy	14.1Gy	12.8 Gy

Lu L, et. al. JACMP, 2019.



	Goal	Clinical	AP	KBP	MCO
Spinal Cord (Max. Dose)	<14 Gy	13.9 Gy	14.4 Gy	14.1Gy	12.8 Gy



Lu L, et. al. JACMP, 2019.

# Prostate + Pelvic LN Cases



Rx: PTV-protstae 70 Gy, PTV-LN 50.4 Gy in 28 Gy

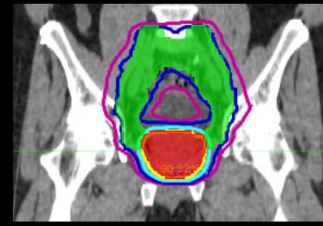
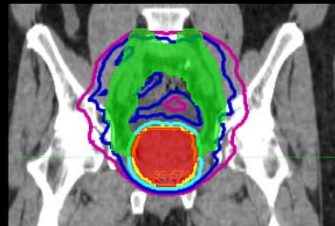
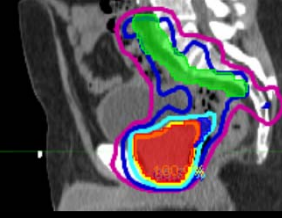
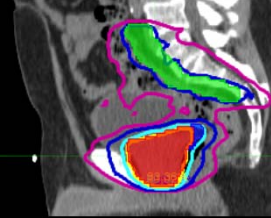
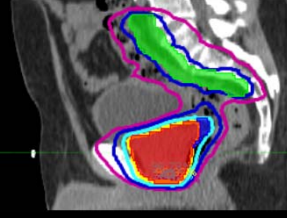
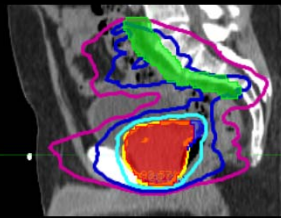
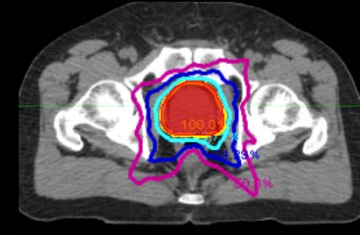
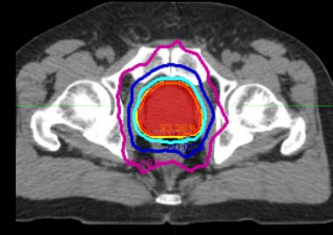
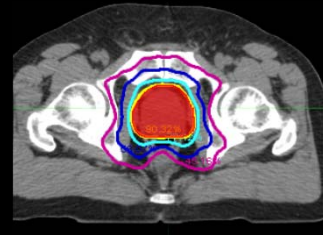
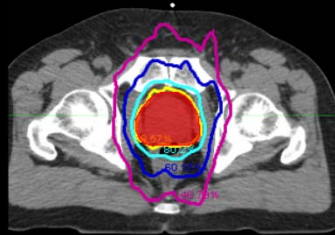
	<b>Goal</b>	<b>Clinical</b>	<b>AP</b>	<b>KBP</b>	<b>MCO</b>
<b>Bladder</b>	<b>V63Gy &lt;10%</b>	<b>16.28%</b>	<b>7.40%</b>	<b>7.02%</b>	<b>11.18%</b>
<b>Rectum</b>	<b>V63Gy &lt;10%</b>	<b>12.15%</b>	<b>7.00%</b>	<b>6.25%</b>	<b>5.95%</b>
<b>Rectum</b>	<b>V45Gy &lt; 30%</b>	<b>44.47%</b>	<b>22.21%</b>	<b>27.40%</b>	<b>23.44%</b>

Clinical

AP

KBP

MCO



PTV70  
PTV60  
PTV45

75 Gy  
70 Gy

60 Gy  
45 Gy

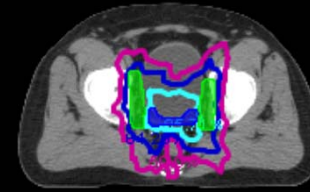
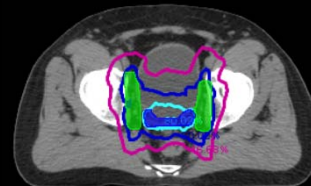
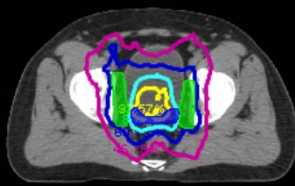
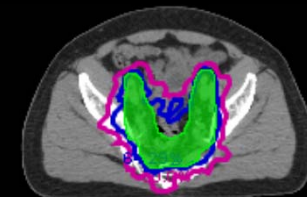
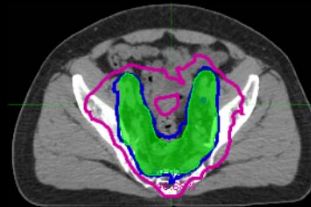
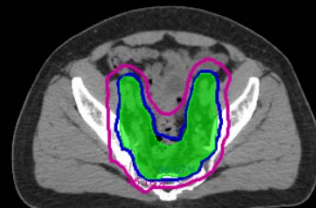
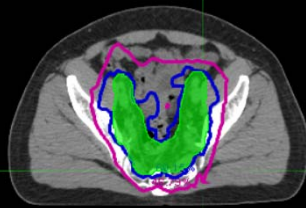
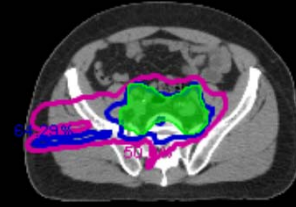
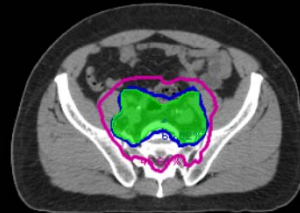
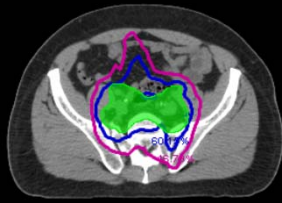
35 Gy

Clinical

AP

KBP

MCO



PTV70  
PTV60  
PTV45

75 Gy  
70 Gy

60 Gy  
45 Gy

35 Gy

# Oropharynx Cases

Rx: PTV-HD 70 Gy, PTV-LD: 56Gy

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

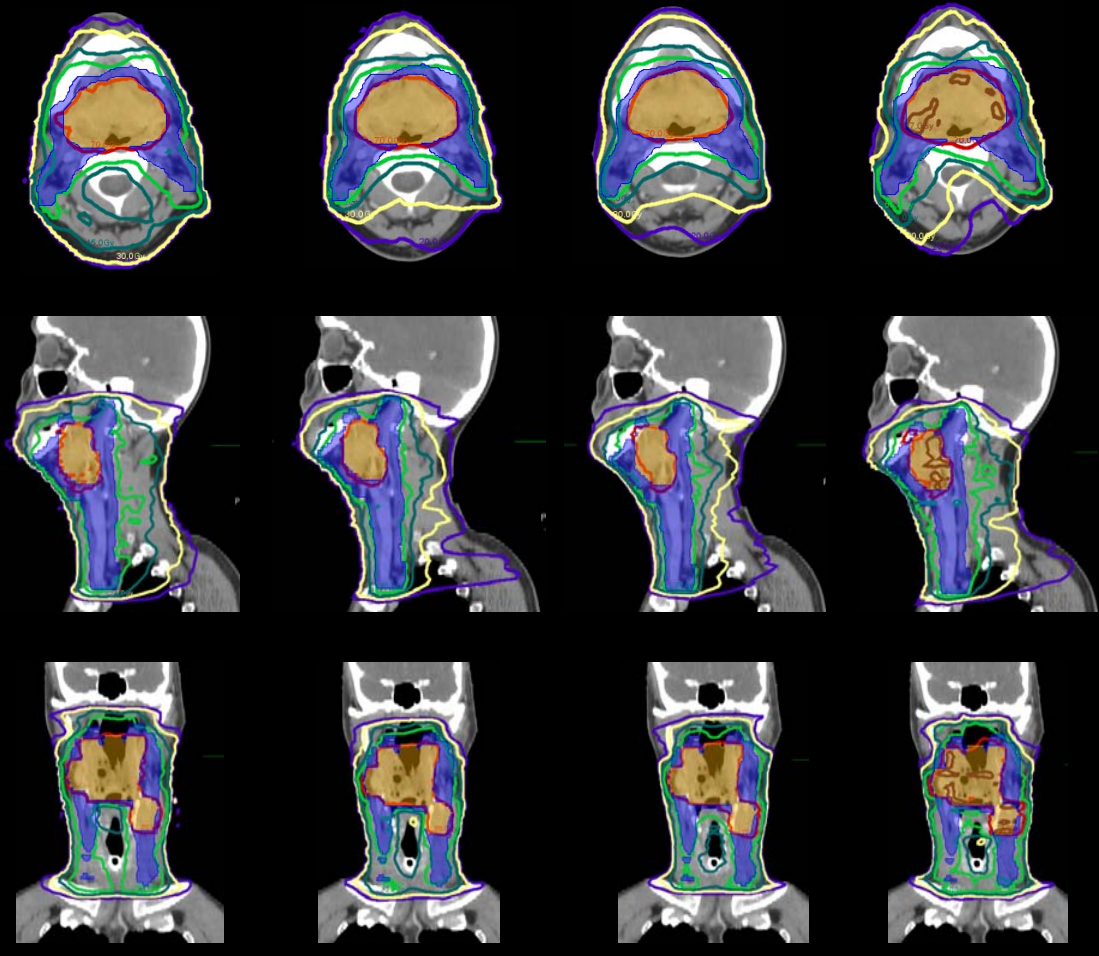
Clinical

AP

KBP

MCO

- 77 Gy
- 70 Gy
- 56 Gy
- 45 Gy
- 30 Gy
- 20 Gy



- PTV70
- PTV56

# 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

- Matt Kolar, M.S.
- Zhilei Liu Shen, Ph.D.
- Lan Lu, Ph.D.
- Jeremy Donaghue, M.S.
- Jackie Wu, Ph.D. Duke University



# Cleveland Clinic Cancer Center at Main Campus

