Building Knowledge Models In RT

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- License Agreement: Varian Medical Systems
- Speaker Agreement: Varian Medical Systems

Learning Objectives

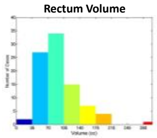
- Extract Human Planning Knowledge Into Features
- Machine Learning And Modeling Techniques
- Understand Model Parameters and Physics Parameters
- Knowledge Base Refinement and Evolution
- Knowledge Model Guided Treatment Planning

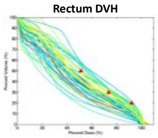
Building Planning Knowledge Models

- **Treatment Planning Knowledge**
  - "Cheat sheet"
  - "Tricks" and "Tips"
  - "Templates"

Building Planning Knowledge Models

- **Experience and Intuition**
  - Volume, location, shape, overlap, etc
  - Qualitative vs. quantitative vs. discreptive
  - Summarized collection vs. individual case memory



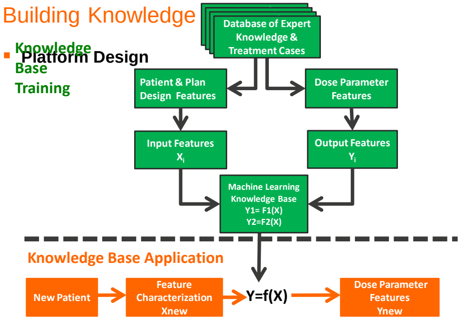


Building Planning Knowledge Models

- **Modeling Experience and Intuition**
  - Correlate patient anatomy features (input) and PTV/OAR features with dose distribution features (output)
  - Correlate plan design features (input) with dose distribution features (output)
  - Understand and translate the knowledge model parameters to the physics/dose parameters
  - Knowledge base evolution and progressive modeling

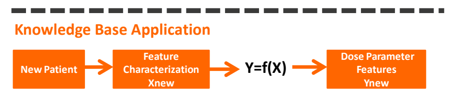
Building Knowledge

- Platform Design



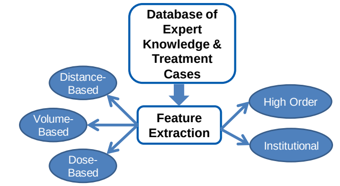
Building Knowledge Models

- Platform Design



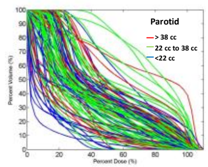
Building Knowledge Models

- Feature Identification and Selection



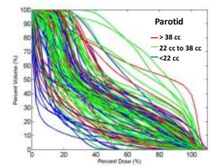
Building Knowledge Models

- **Data Size**
  - Adequate number of cases to represent the clinical case spectrum



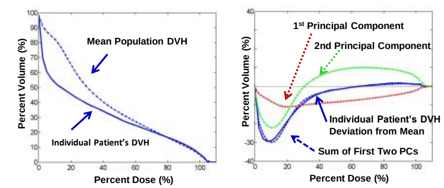
Building Knowledge Models

- **Data Size**
  - Adequate number of cases to represent the clinical case spectrum
- **Data Quality**
  - Reliable feature extraction



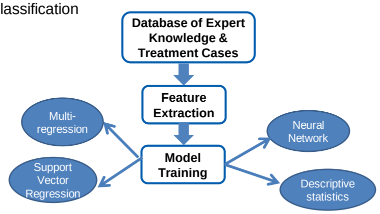
Building Planning Knowledge Models

- **Feature Extraction and Dimension Reduction**
  - Large amount data -> features vs. noises
  - Principal Component Analysis (PCA)



Building Planning Knowledge Models

- **Systematic Modeling of Knowledge**
  - Machine learning, Descriptive statistics, Pattern classification



Building Knowledge Models

Understand The Knowledge Models

Model Parameter ⟷ **Physics Parameter**

Bladder DVH PCS1 (Median Dose)		**Rectum DVH PCS1 (Median Dose)**	
Significant Factors	**R^2**	**Significant Factors**	**R^2**
Bladder DTH PCS1 (Median Distance)	0.81	Rectum DTH PCS1 (Median Distance)	0.59
2nd Order of Bladder DTH PCS1	0.22	Volume of Rectum	0.12
		Overlap Volume	0.08
Combined	**0.88**	**Combined**	**0.68**
Bladder DVH PCS2 (DVH Slope)		**Rectum DVH PCS2 (DVH Slope)**	
Significant Factors	**R^2**	**Significant Factors**	**R^2**
Out-of-field Volume	0.50	Rectum DTH PCS2 (gradient)	0.32
Overlap Volume	0.33	Out-of-field Volume	0.32
Bladder DTH PCS2 (gradient)	0.30	Overlap Volume	0.12
Combined	**0.85**	Rectum DTH PCS3	0.12
		Combined	**0.69**

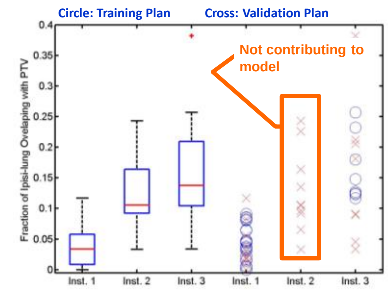
Understand The Knowledge Models

- Cross-institution Knowledge
  - If you believe best planning knowledge is shared among all planners
  - LUNG IMRT Pilot Study By RTOG/NRG
    - **71 Cases**
    - **3 Institutions**

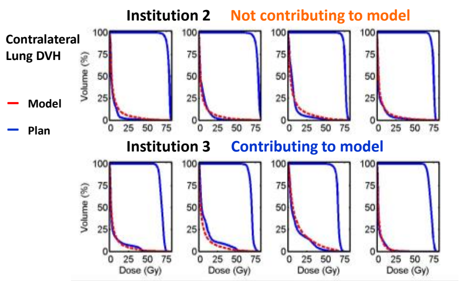
Cross-Institution Knowledge Models

		Mean	Median	Min	Max
Prescriptions (Gy)		67	64	40	74
			Institution 1	Institution 2	Institution 3
Volume (cm^3)	mean		421	595	512
	median		343	519	379
	min, max		62, 1132	76, 1132	175, 1161
Location (side)	Total		45	10	16
	Left/Left-Medial		18	4	5
	Right/Right-Medial		21	6	10
	Medial		6	0	1

Cross-Institution Knowledge Models



Cross-Institution Knowledge Models



Cross-Modality Knowledge Models

- Cross-Modality Knowledge
  - If you believe best planning knowledge is independent of treatment modality

Institution A

- 7-8 min delivery time
- Delivery system: Varian IMRT
- Planning system: Eclipse
- Sequential Boost
  - Multiple plans (one plan for 1 PTV)
  - 40-50 Gy and 60-70 Gy
- ~60 head-and-neck cases

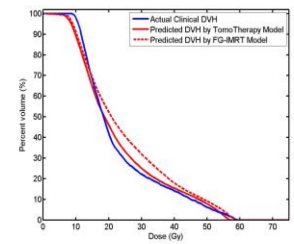
Institution B

- 7-8 min delivery time
- Delivery system: Tomotherapy
- Planning system: Tomotherapy
- SIB
  - 1 plan (one plan cover all PTVs with diff. daily doses)
  - 54.25 Gy and 70 Gy
- ~60 head-and-neck cases

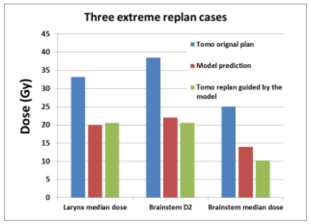
Cross-Institution Knowledge Models

Parotid DVH

Tomotherapy Model vs. IMRT Model vs. Actual Plan DVH

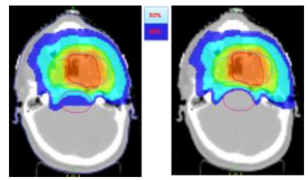


Knowledge Model Guided TomoTherapy Planning



Knowledge Model Guided TomoTherapy Planning

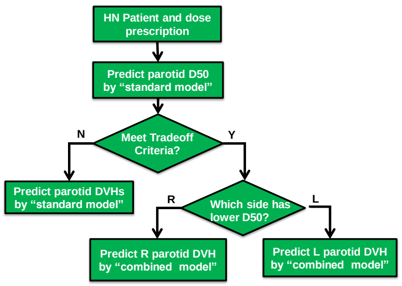
Original Clinical Plan Knowledge-Model Guided Plan



Knowledge Model Refinement

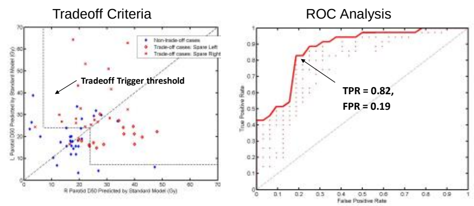
- **Trade-off Modeling**
  - Clinical tradeoff among different OARs or between OAR and PTV is common
  - Pareto-front planning (T. Borfeld@MGH, etc)
  - Different models may be needed to represent trade-off options

Knowledge Model Refinement



Knowledge Model Refinement

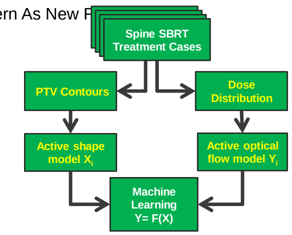
- **Parotid Tradeoff Model**



Knowledge Model Refinement

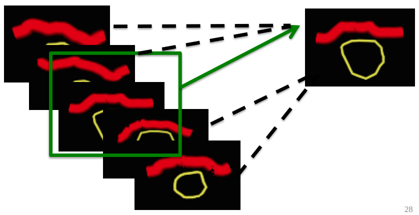
- Shape Pattern As New F

Spine SBRT Tradeoff Model



Knowledge Model Refinement

- **Active Shape Model:** iterative closest point (ICP) algorithm to align PTV contours



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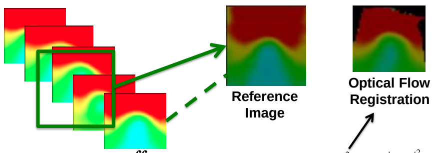
Knowledge Model Refinement and Evolution

- **Optical Flow Model:** measures dose variance between a reference image and any other images within the training dataset.



$$E(u_x,u_y)=\iint \underbrace{\Psi((I(x+u_x,y+u_y,t+1)-I(x,y,t))^2}_{\text{Intensity constraint}}+\beta\underbrace{\Psi(|\nabla u_x|^2+|\nabla u_y|^2)}_{\text{Smoothness constraint}}$$
$$+\alpha\underbrace{(\nabla I(x+u_x,y+u_y,t+1)-\nabla I(x,y,t))^2}_{\text{Intensity constraint}}\,dxdy$$

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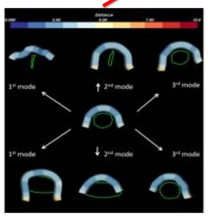
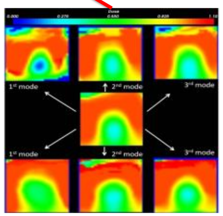
Knowledge Model Refinement and Evolution

- **Machine Learning**

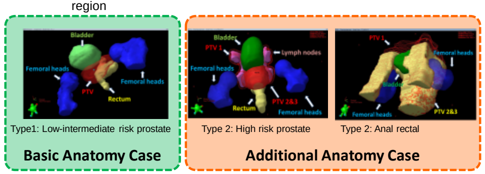
PTV contour space ⟷ cord dose space

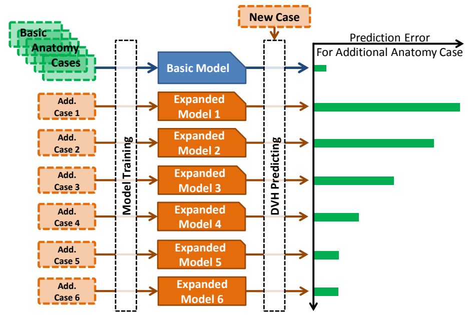




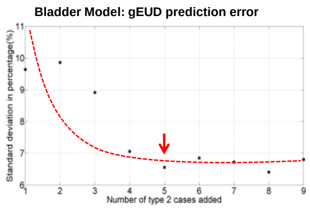
Knowledge Model Evolution

- **Progressive Learning: Knowledge Update and Adaptation**
  - Build single knowledge model for multiple cancer types in the pelvic region





Knowledge Model Evolution



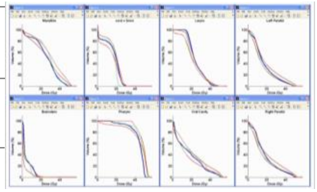
Summary: Knowledge-Model Guided Planning

Physician Prescription

IMRT/VMAT Planning

Plan Evaluation

Planned vs. Modeled



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- **AAPM 2014: SU-E-T-527:** Lian et al, Prior Knowledge Guided TomoTherapy Treatment Planning

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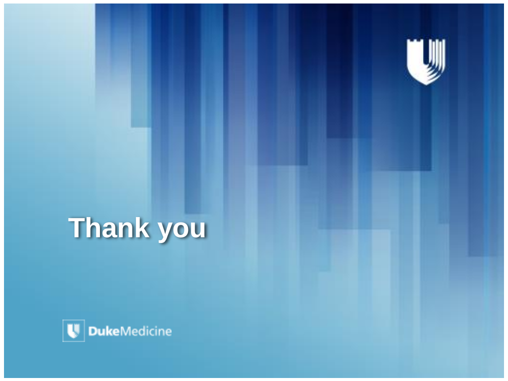
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