Optimization of High Dose Rate Brachytherapy Treatment Plans

RUIDO versus IPSA

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RUSH

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

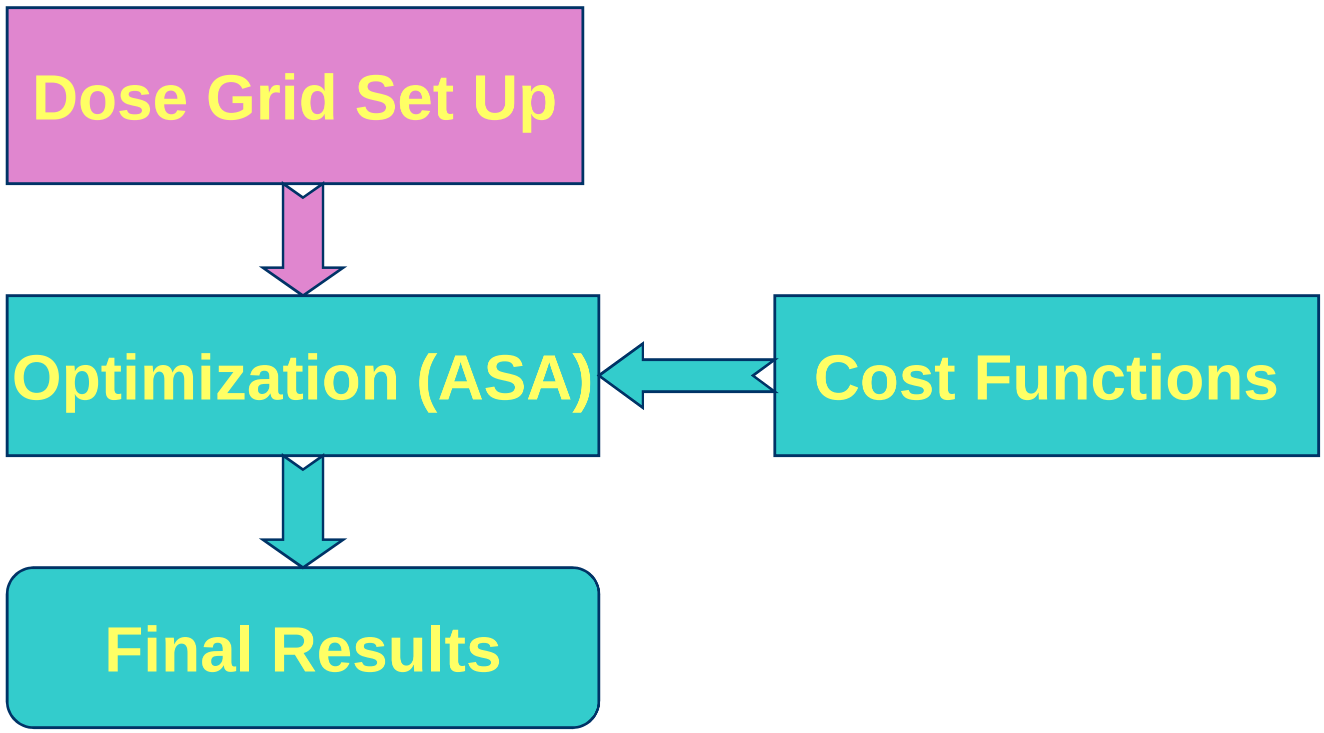
Optimizer

- IPSA: Simulated Annealing
- RUIDO: Adaptive Simulated Annealing
- Searching for global minimum for cost function:
  - New cost $C(p_{k+1})$ is accepted when:

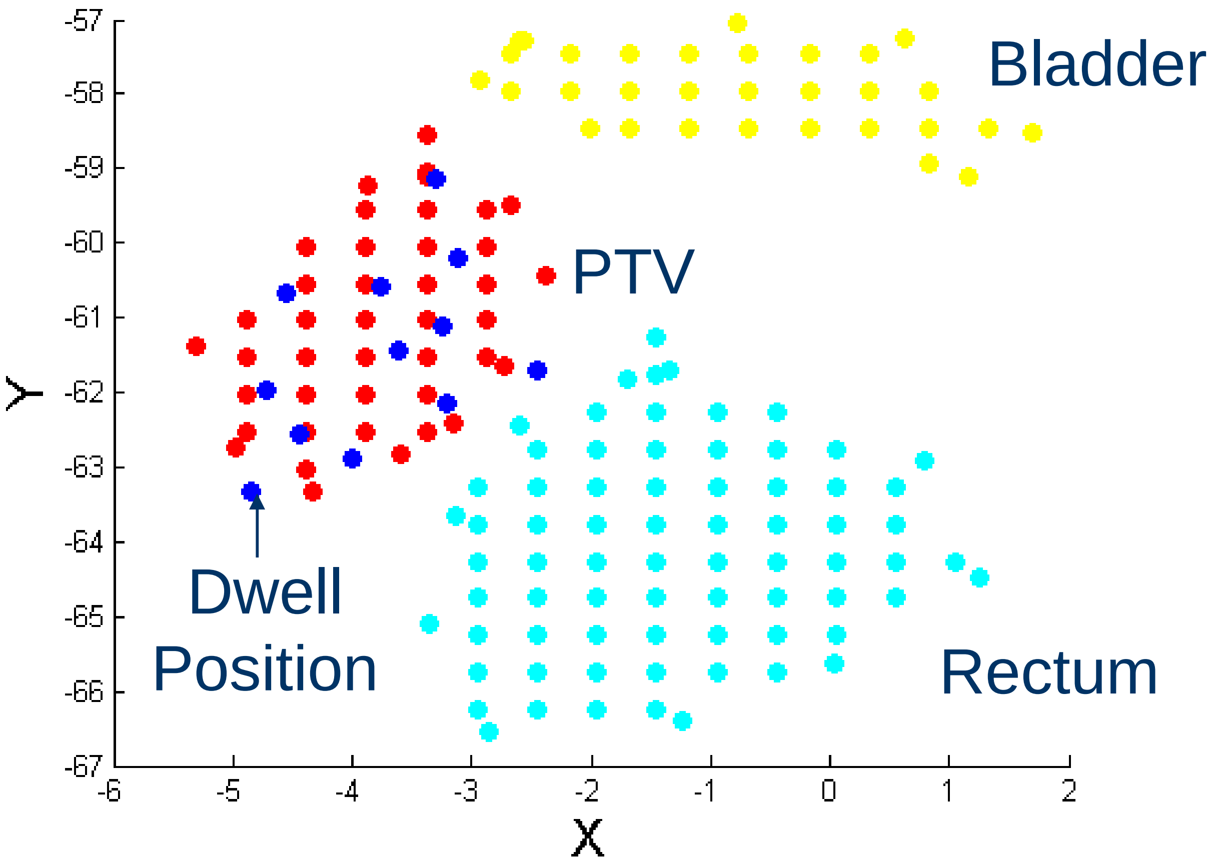
$$\exp[-(C(p_{k+1}) - C(p_k))/T_{\text{cost}}] > U$$

  - $U \subset [0, 1)$, uniform random generator

Optimization Process



Dose Grid Set Up (contour based)



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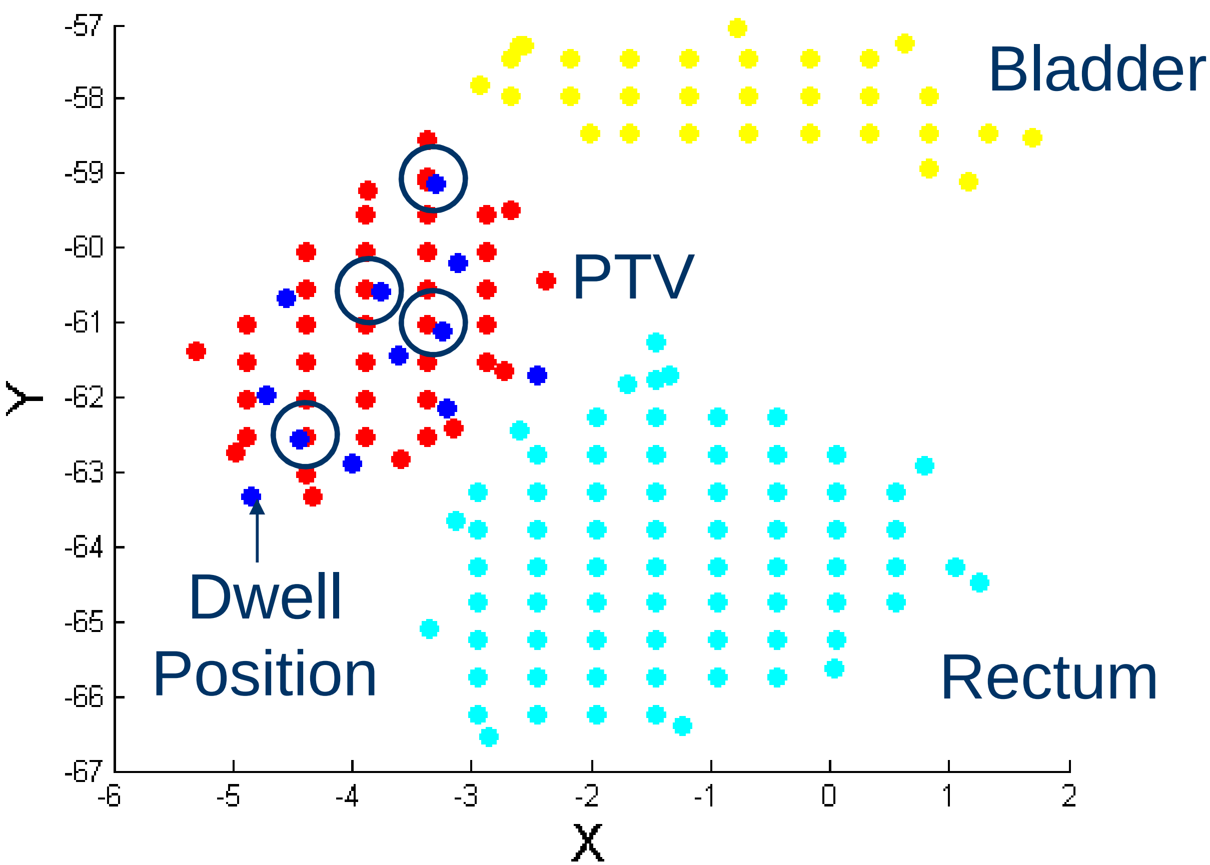

Yixiang Liao, Ph.D.

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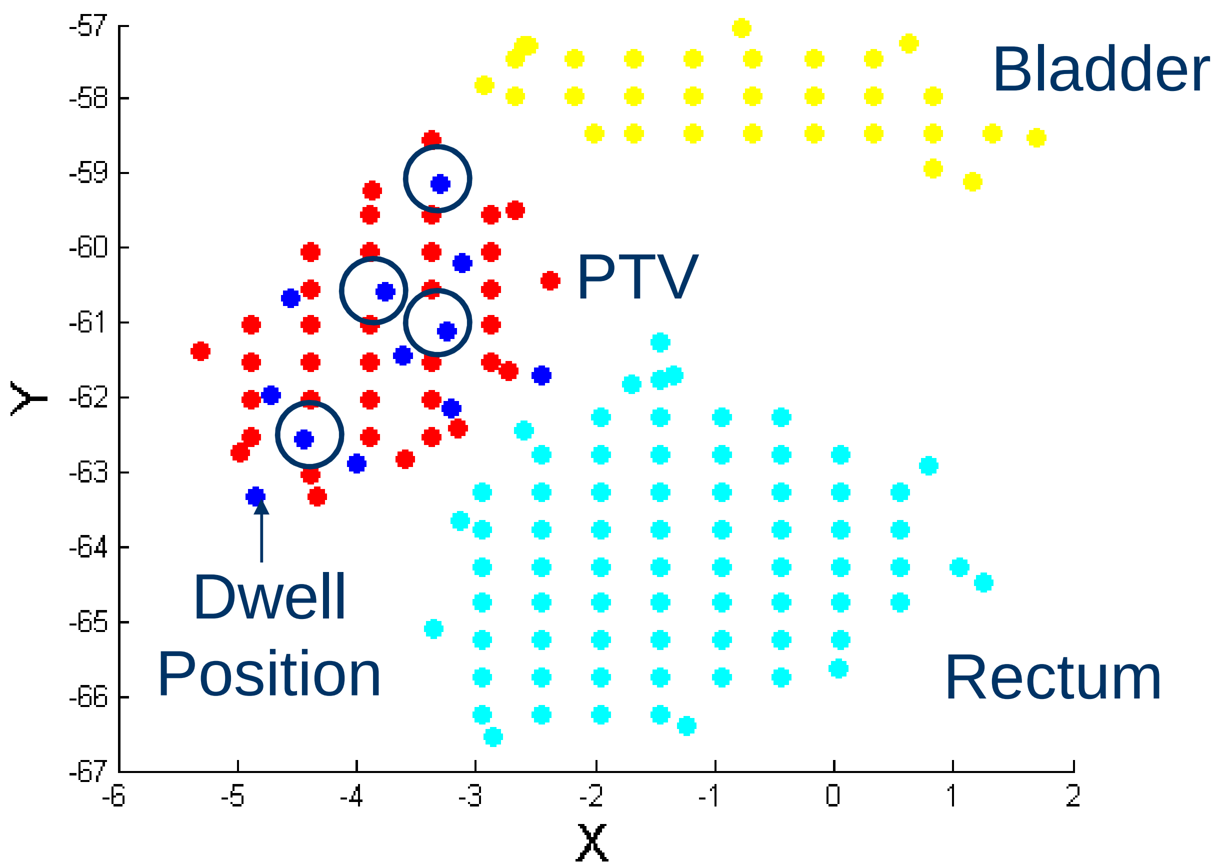
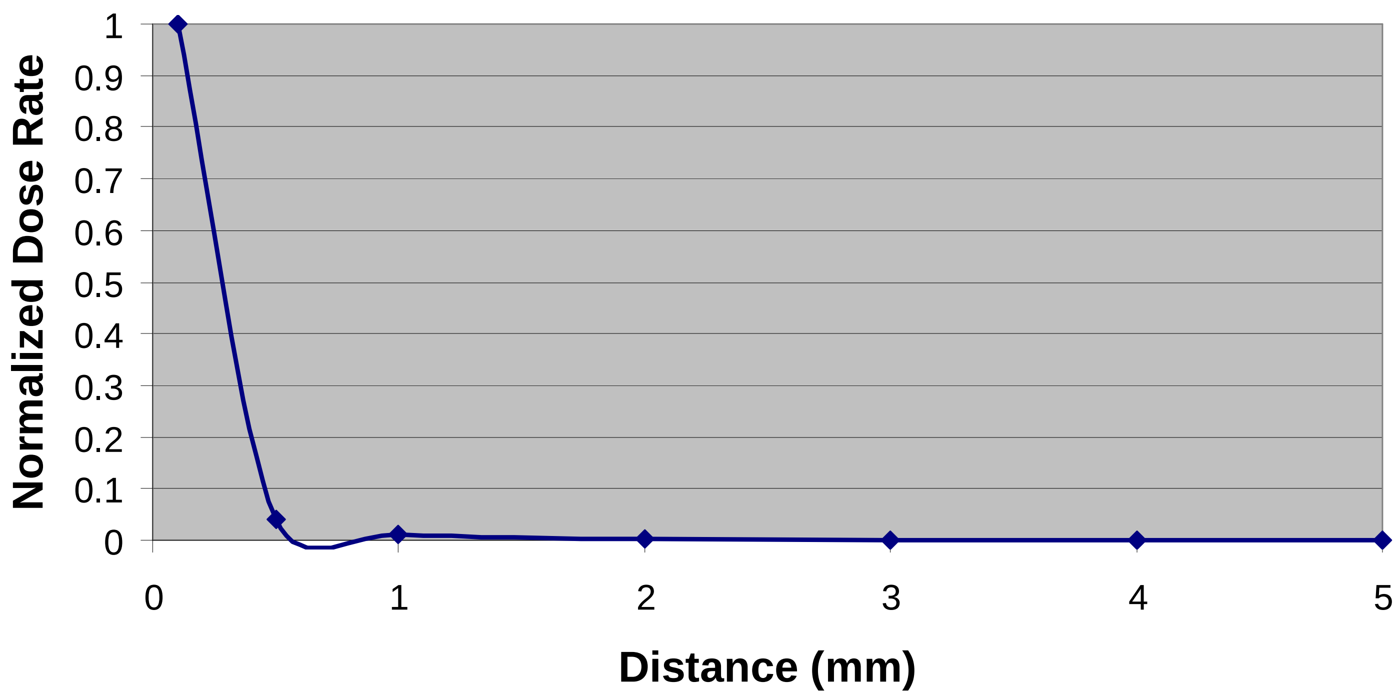


Cut-off Distance

- 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.

Dose Rate Calculation

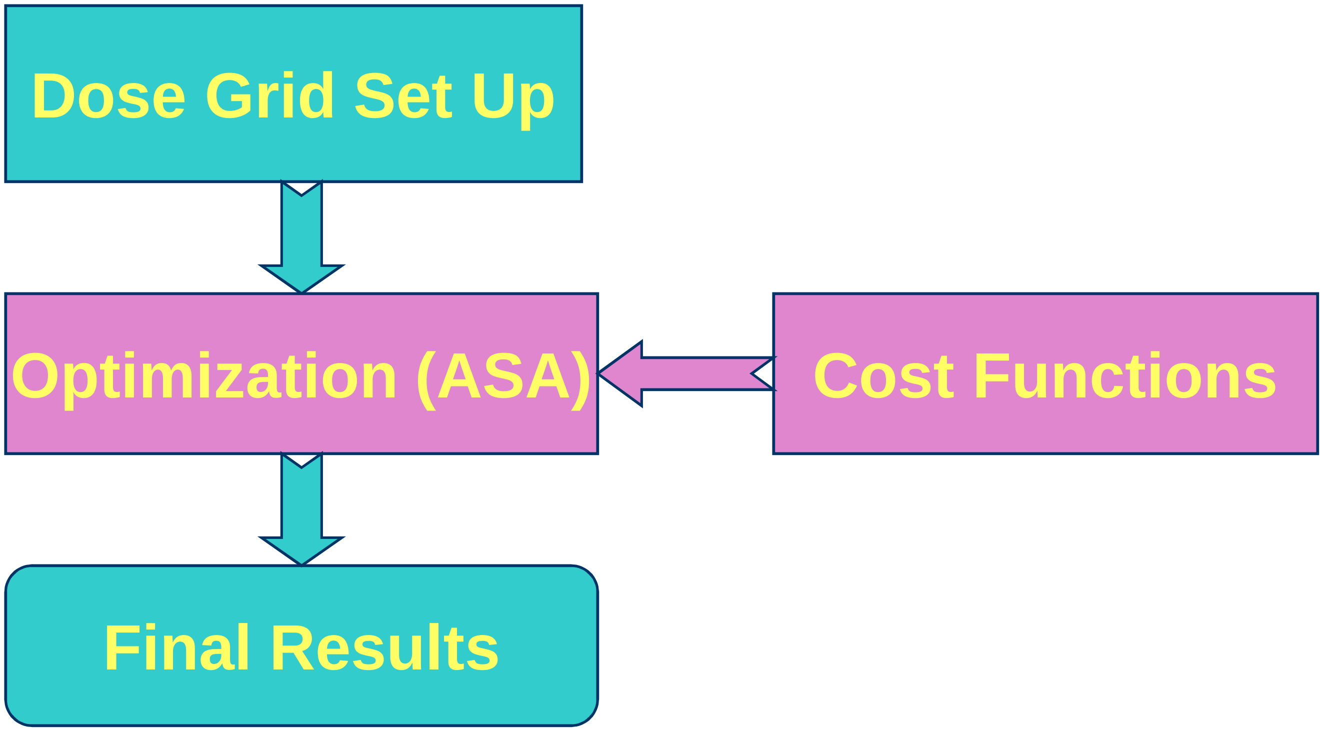
- Equation:

$$Dose\ Rate = \Gamma \cdot A \cdot f\text{-}factor \cdot filter \cdot Poly(r) \cdot geo\_factor(r)$$

  - 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



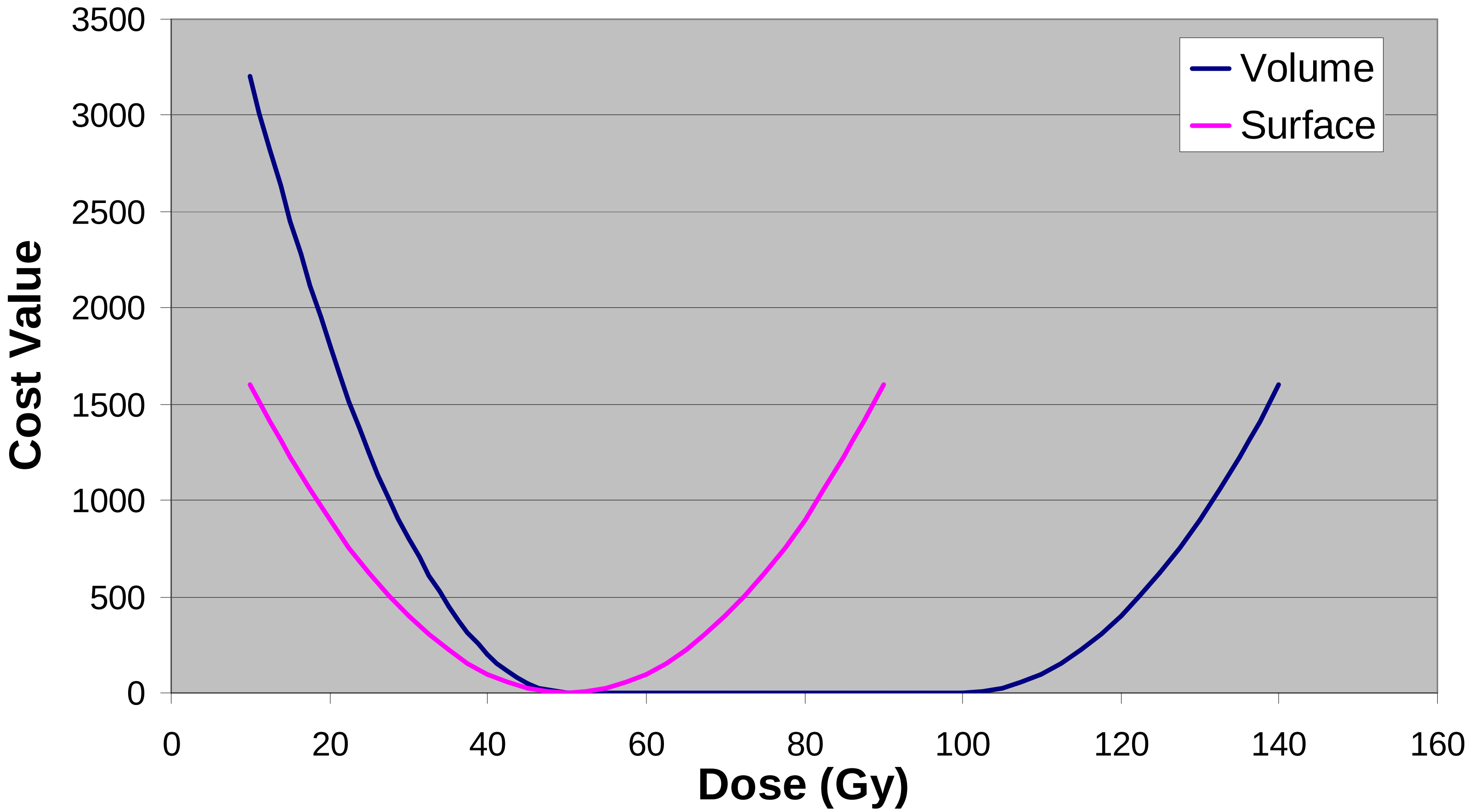
RUIDO – Cost Functions

- Physical Dose

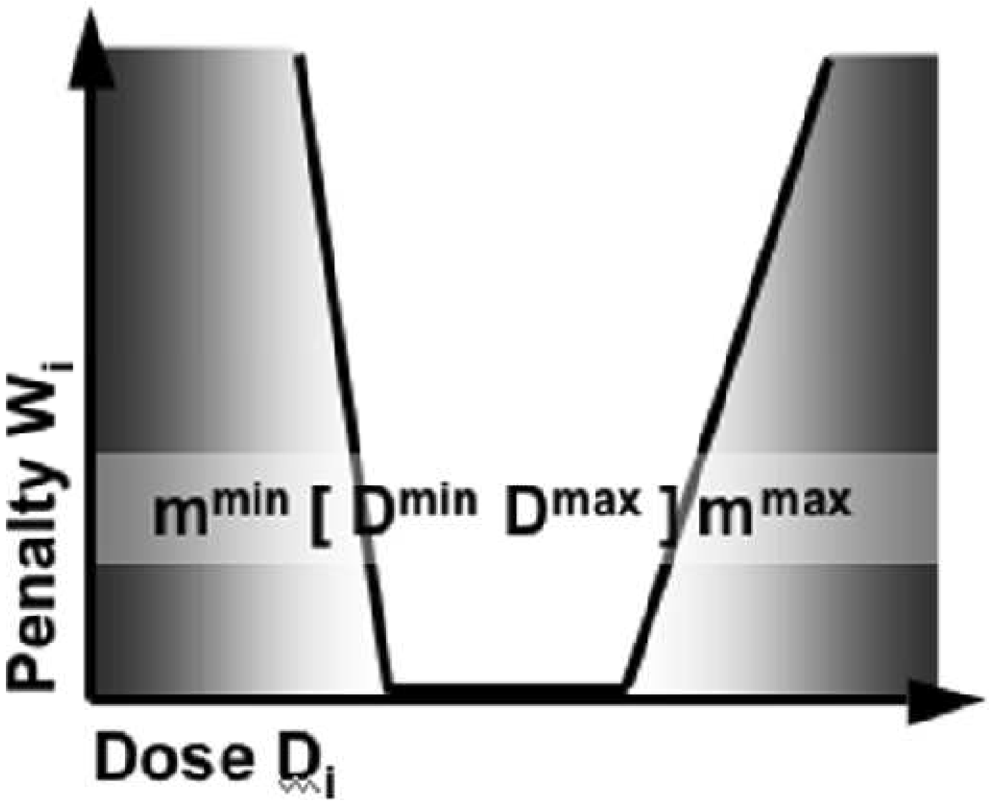
$$Cost\ Surface = (D_{surf} - D_0)^2$$

$$Cost\ Volume = \begin{cases} 2(D_{vol} - D_0)^2, & D_{vol} < D_0 \\ 0, & D_0 < D_{vol} < 2D_0 \\ (D_{vol} - 2D_0)^2, & D_{vol} > 2D_0 \end{cases}$$

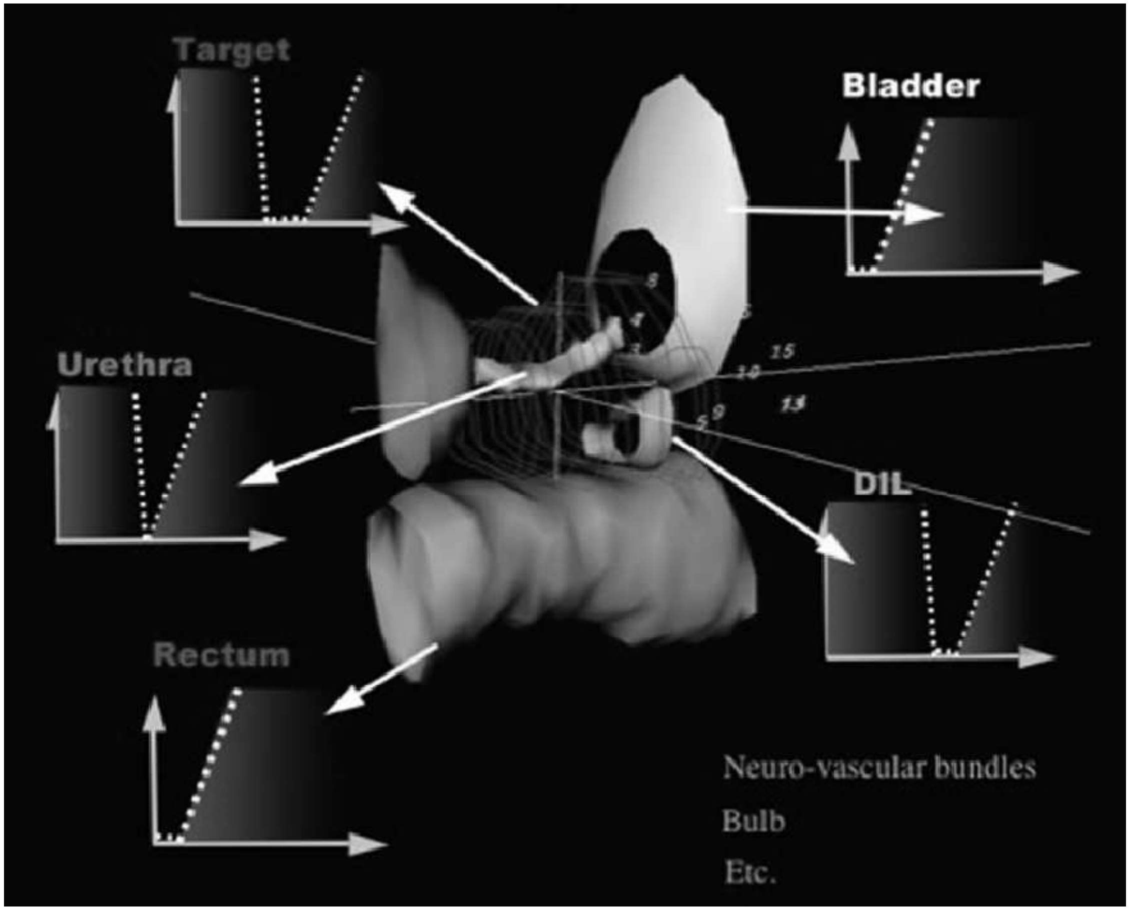
RUIDO – Cost Functions



IPSA – Cost Function



IPSA – Cost function (prostate)



IPSA – Prostate Example

IPSA

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

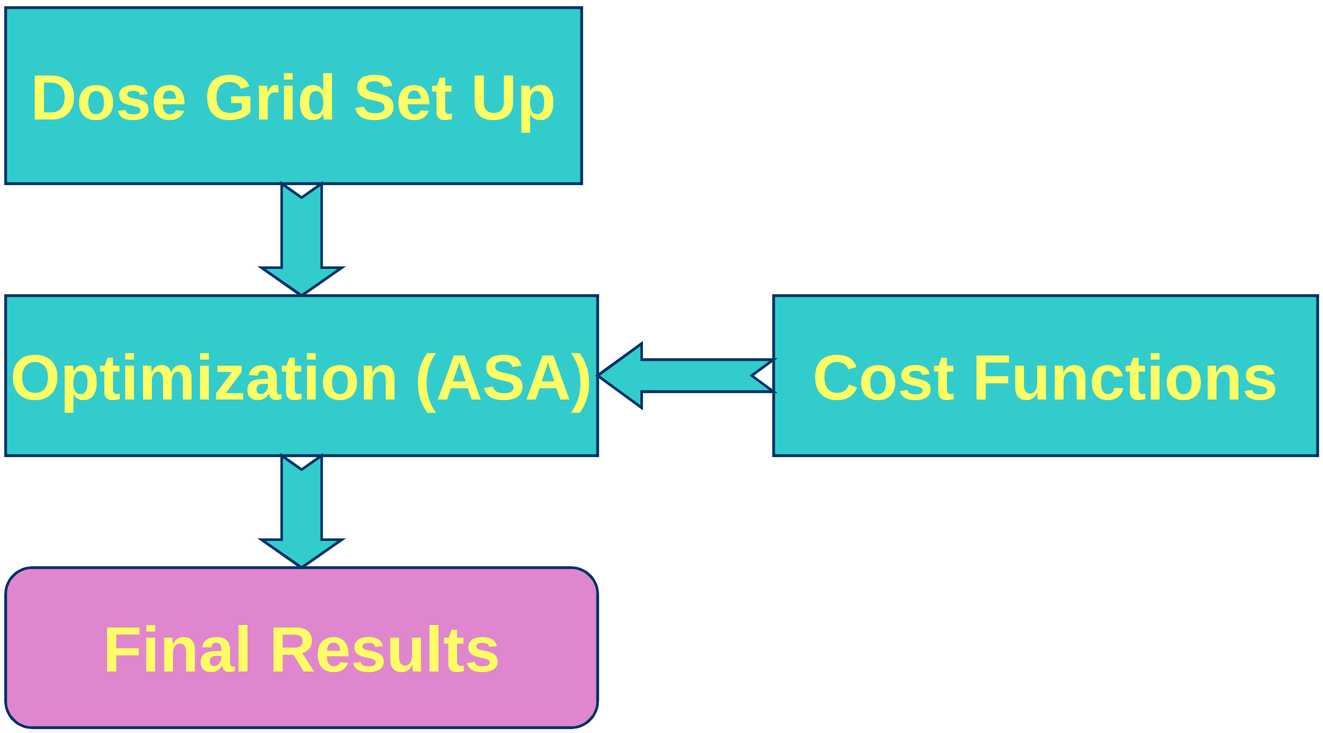
Class Solution

In use: ucsf-prostate

Save Load

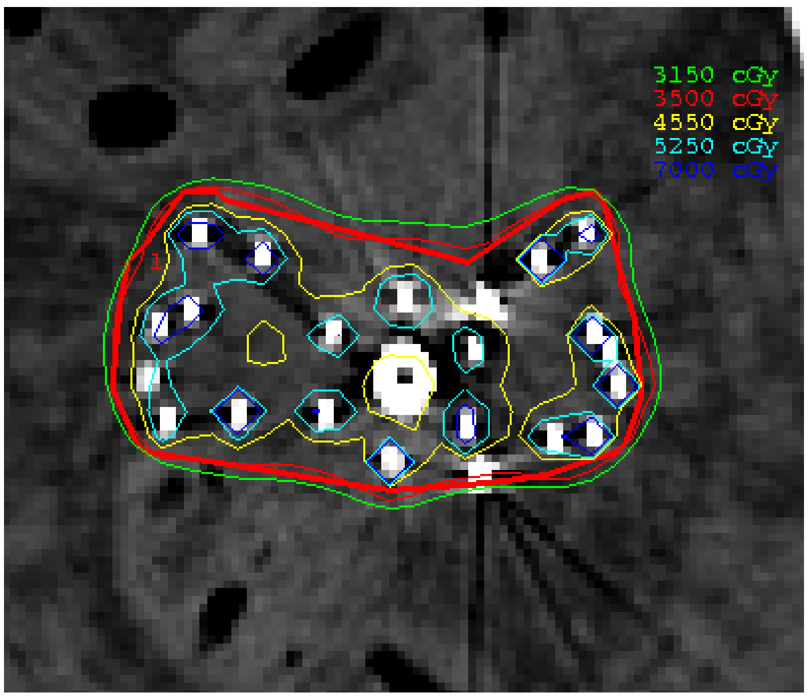
Ok Cancel

Optimization Process

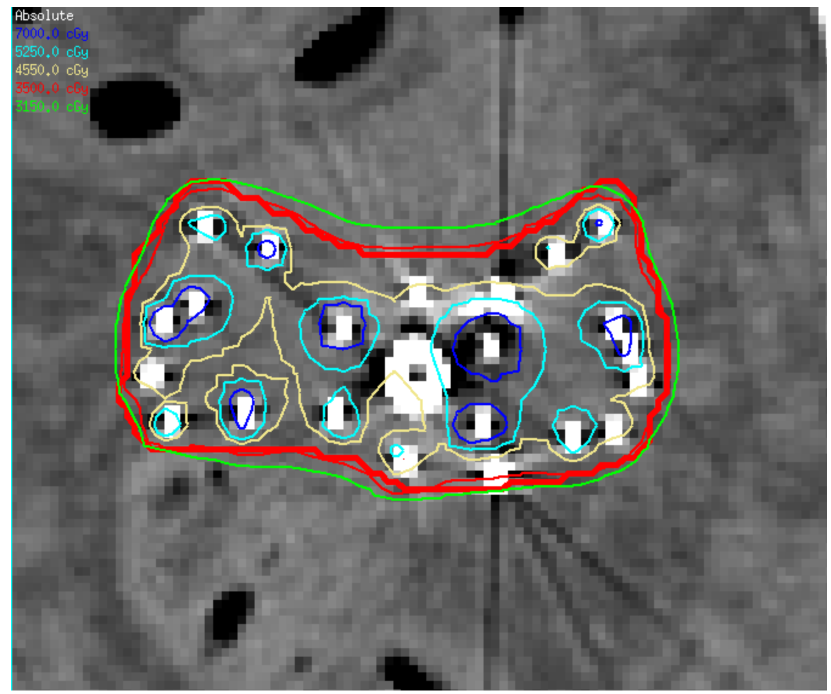


Results

IPSA



RUIDO



Case Study

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

	Case 1	Case 2	Case 3
Target Volume (cc)	32.6	94.7	92.1
# of total dose points	316	2500	698
Computing time (min)	1	16	6

- IPSA: computing time ~10 seconds for each trial

RUIDO vs. IPSA

		Case 1			Case 2			Case 3	
	RUIDO	IPSA	Diff %	RUIDO	IPSA	Diff %	RUIDO	IPSA	Diff %
CI	0.95	0.95	0%	0.97	0.97	0%	0.95	0.95	0%
HI	0.54	0.50	9%	0.65	0.58	13%	0.73	0.63	16%
OI	0.12	0.14	-16%	0.1	0.09	12%	0.05	0.08	-45%

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

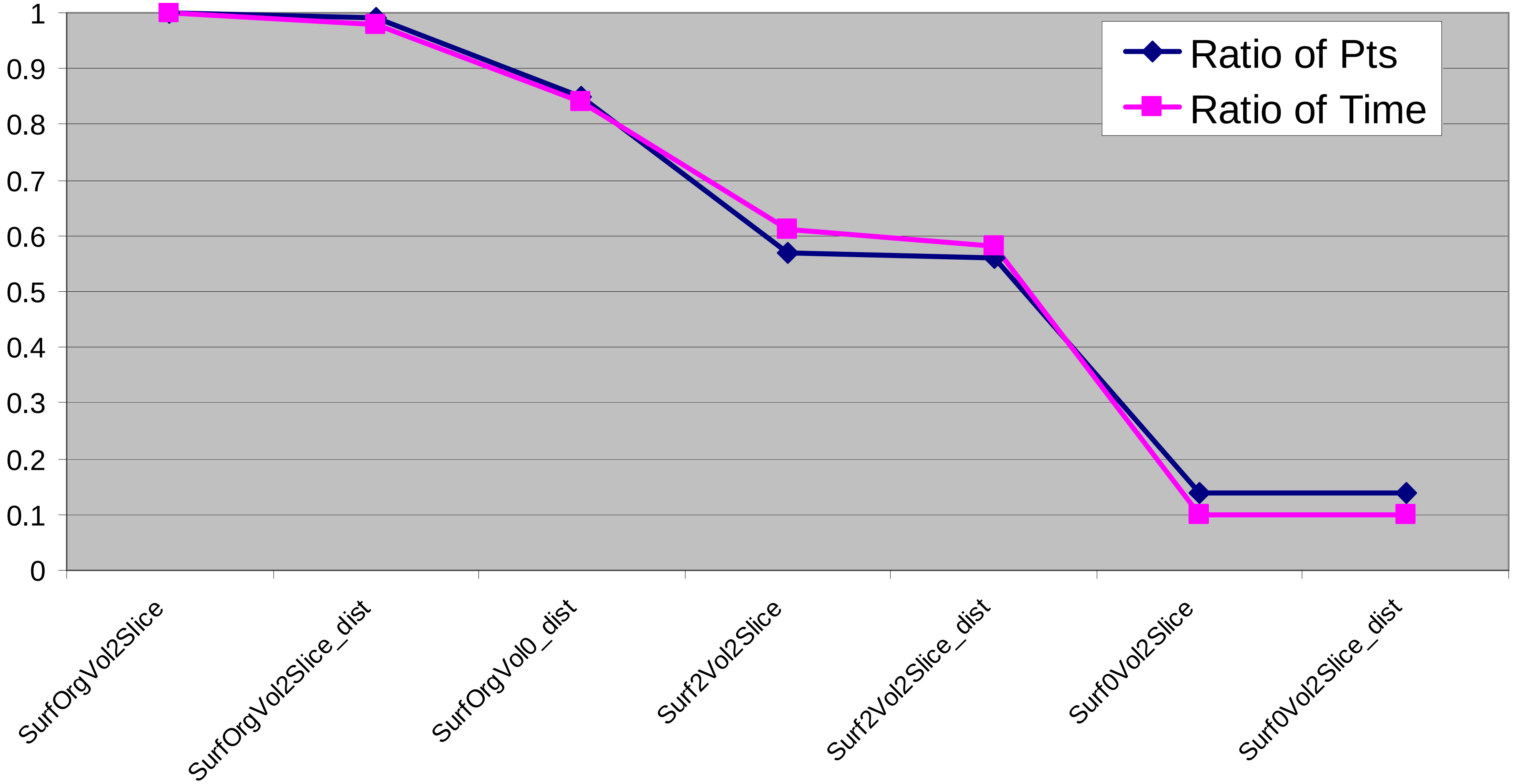
Conclusion

- 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



Surface Points vs. Volume points