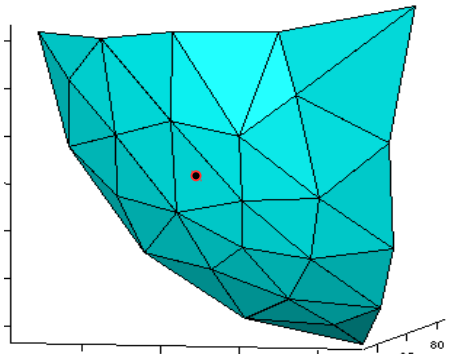
Automatic treatment planning – an MCO perspective

David Craft

Massachusetts General Hospital

AAPM Annual Meeting 2012
Charlotte, NC

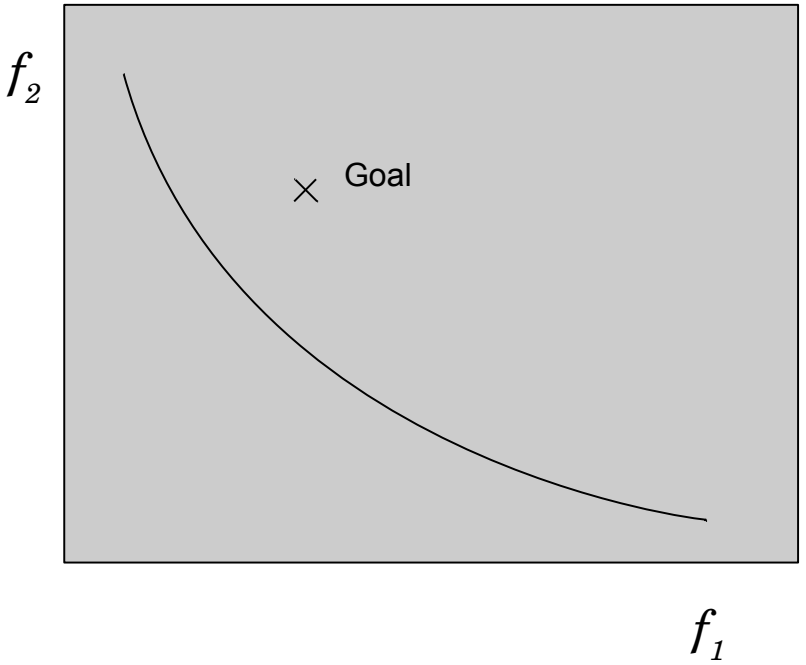


Outline

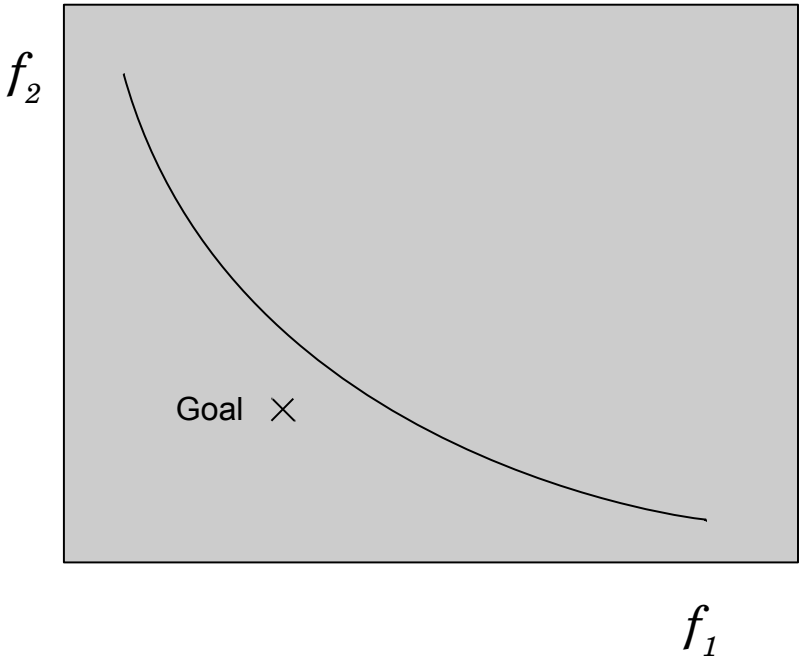
- Overview of types of multi-criteria optimization:
  - Goal programming (GP)
  - Prioritized or lexicographic optimization (LO)
  - Pareto surface based navigation (PS)
- PS-MCO as a refinement tool
- Directly deliverable PS-MCO
- Summary and Conclusions

Goal Programming (GP)

Min $\{f_1, f_2\}$



Case 1: goal attainable but could do better



Case 2: goal unattainable

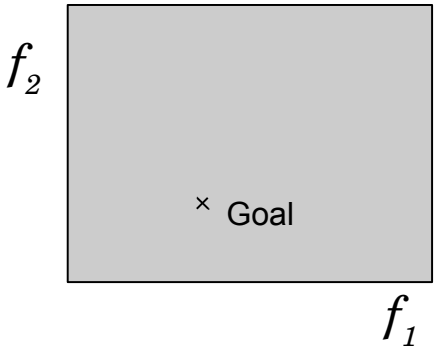
Goal Programming (GP)

Formulation: min sum of (positive) deviations from goals:

$$\min \sum s_i$$

$$s_i \geq 0$$

$$s_i \geq f_i(x) - g_i$$



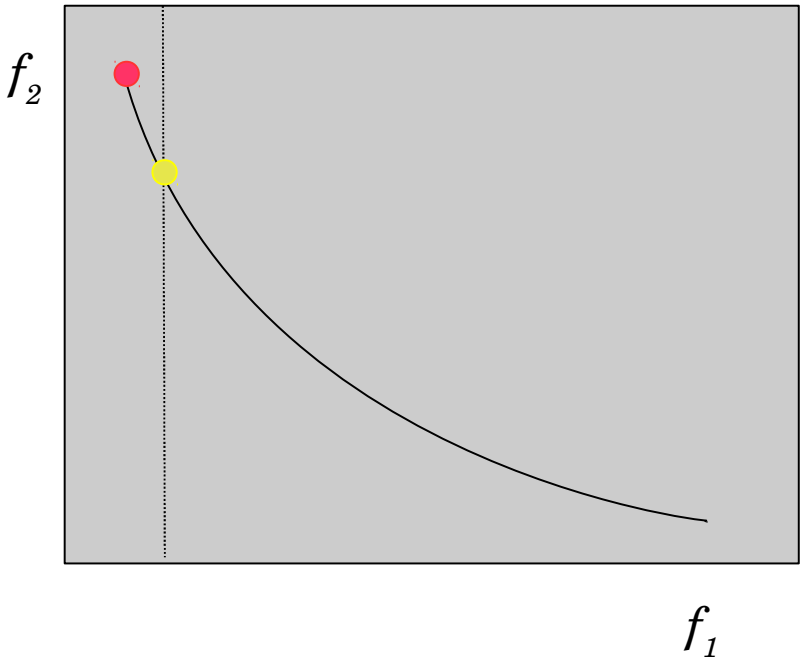
Difficulties:

1) Non-convex objectives (DVH based) and non-convex step and shoot optimization
2) In either case 1 or case 2, some freedom to select where to be. How to decide?

Fix for 1: use EUDs and use sliding window with exact fluence map sequencing.
Fix for 2: ?

Lexicographic, or prioritized, optimization (LO)

f_1 is highest priority, then f_2 etc. So, optimize in that natural order.



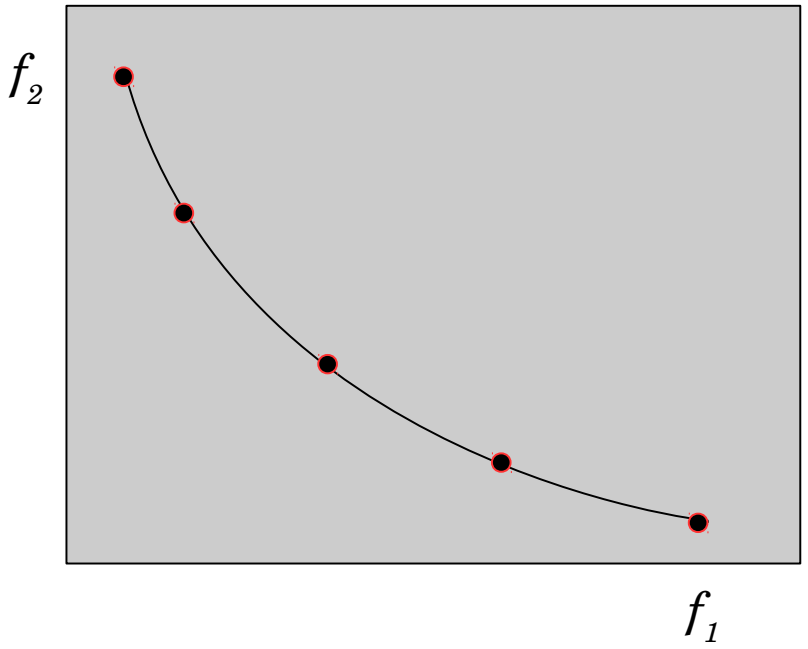
Result of min f_1

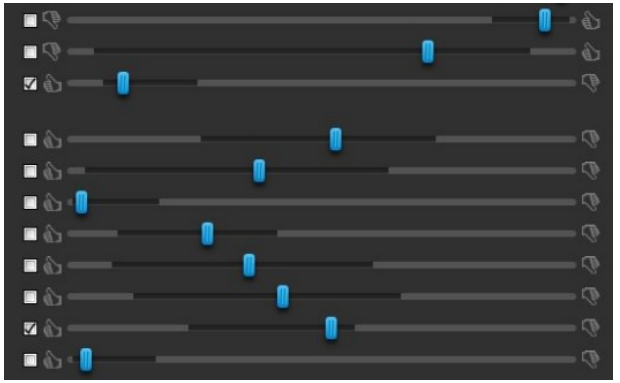
Result of min f_2 , subject to f_1 close to its optimal

See works by Jee, McShan, Fraass, Deasy, Clark, Breedveld, Storchi, Voet, Heijmen, Falkinger, cyberknife planning system.

Pareto surface based (PS)

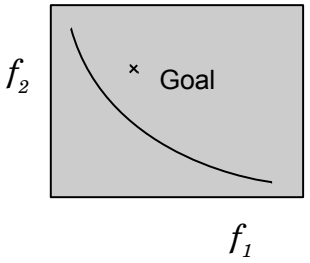
Compute an approximation of the entire tradeoff surface and allow interactive navigation on the surface.



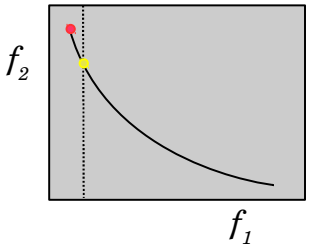


See Küfer, Bortfeld Thieke, Monz, Craft, Hoffman, Bokrantz, Ottosson, Serna...

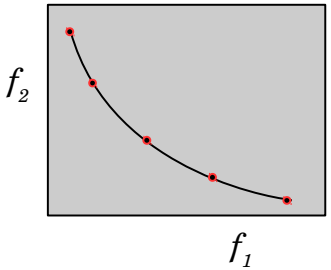
Which of these are “automated treatment planning”?



Goal programming : YES



Lexicographic : YES

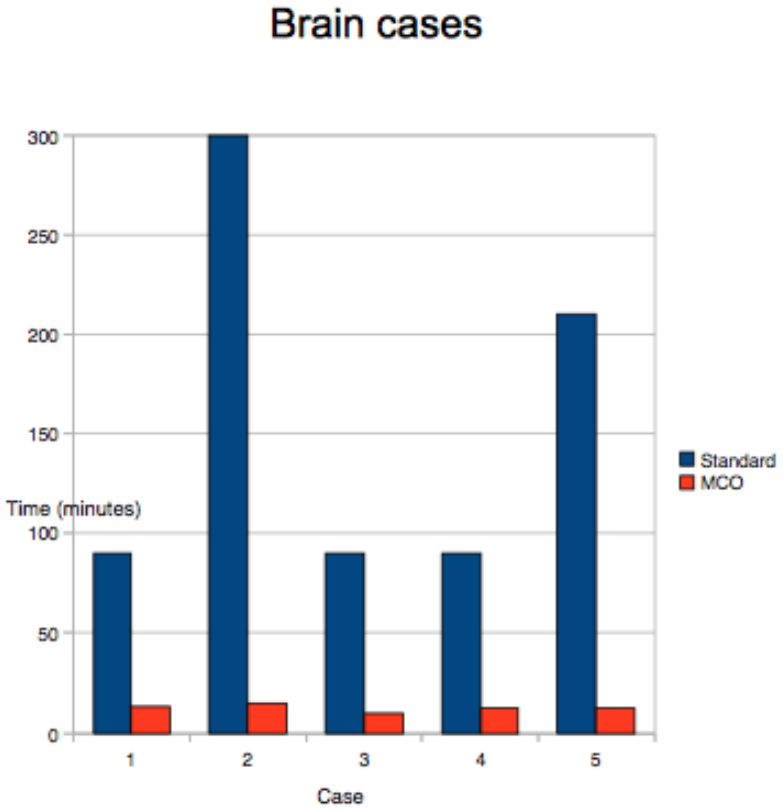


Pareto surface : NO

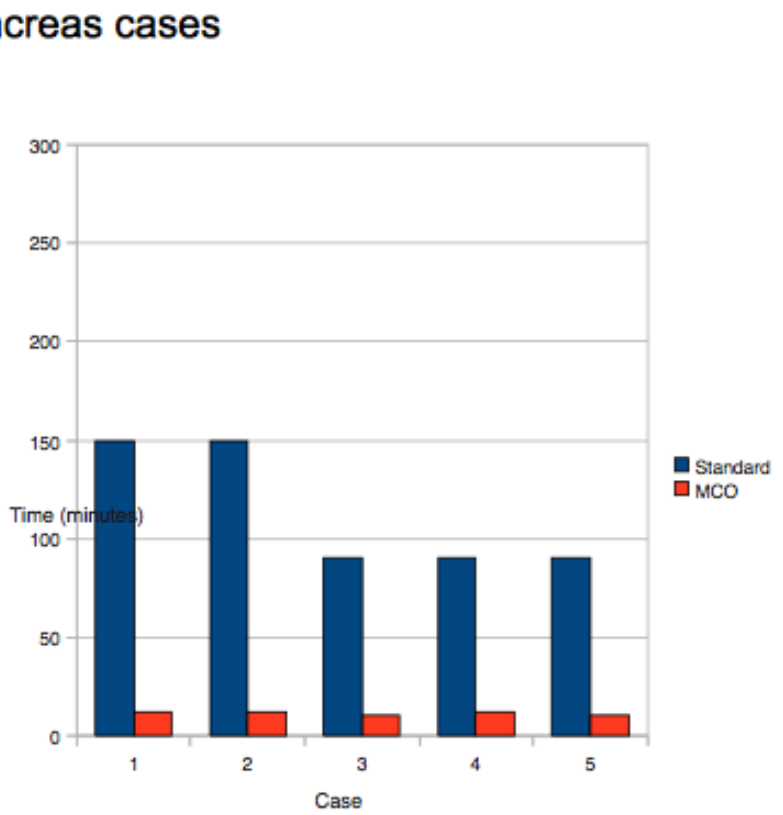
What does PS MCO have to do with automated treatment planning?

→ One similar goal: make treatment planning a lot faster

MCO reduces treatment planning time

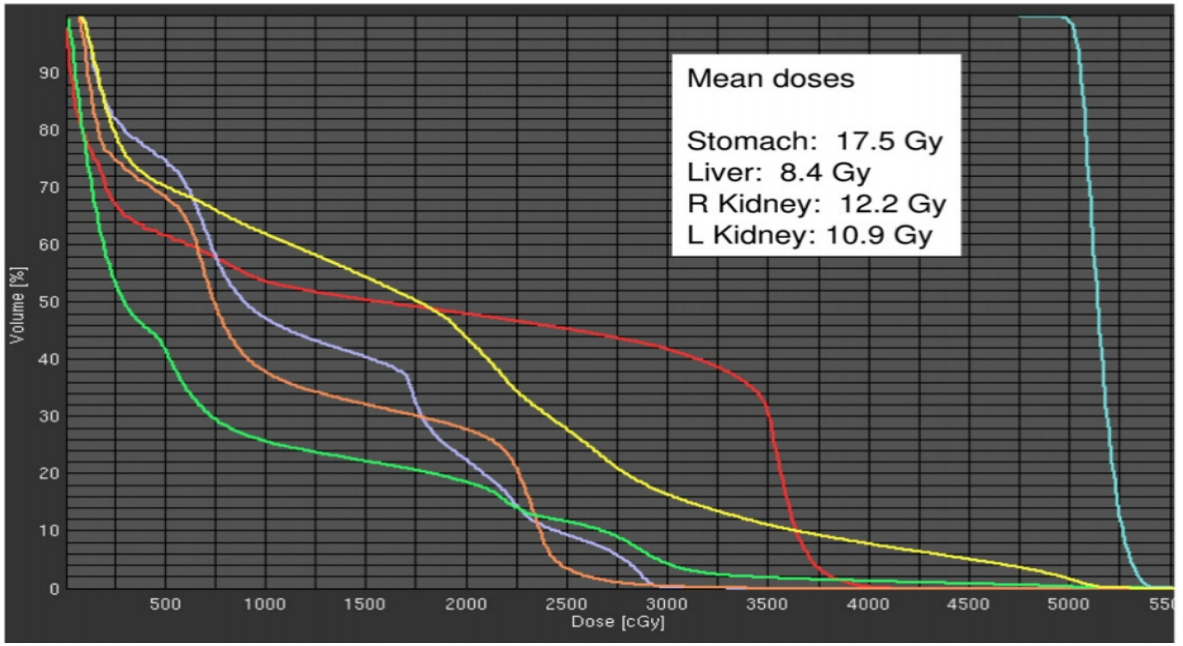


Standard: 159 ± 96 minutes
MCO: 12 ± 2 minutes

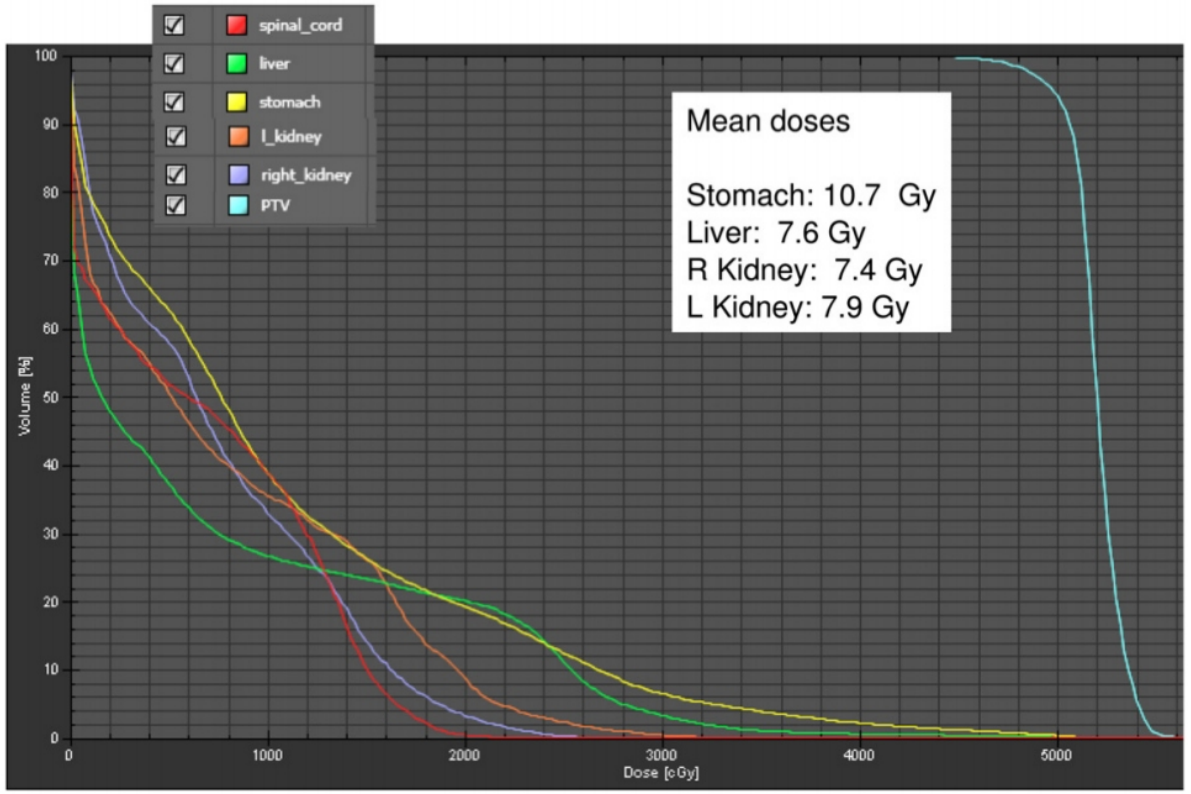


Standard: 114 ± 13 minutes
MCO: 12 ± 1 minutes

Physician involvement time increased from 5 to 10 minutes, but was deemed well worth it



Standard plan (used for treatment)

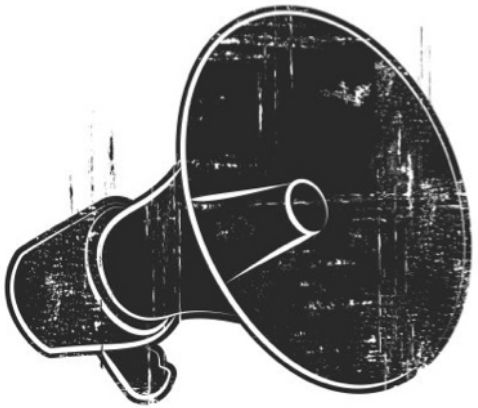


Physician navigated plan

→ Quantitative conclusion: For all cases, physicians later blindly preferred MCO plans in all cases.

Qualitative conclusion → A little PTV DVH rounding goes a long way

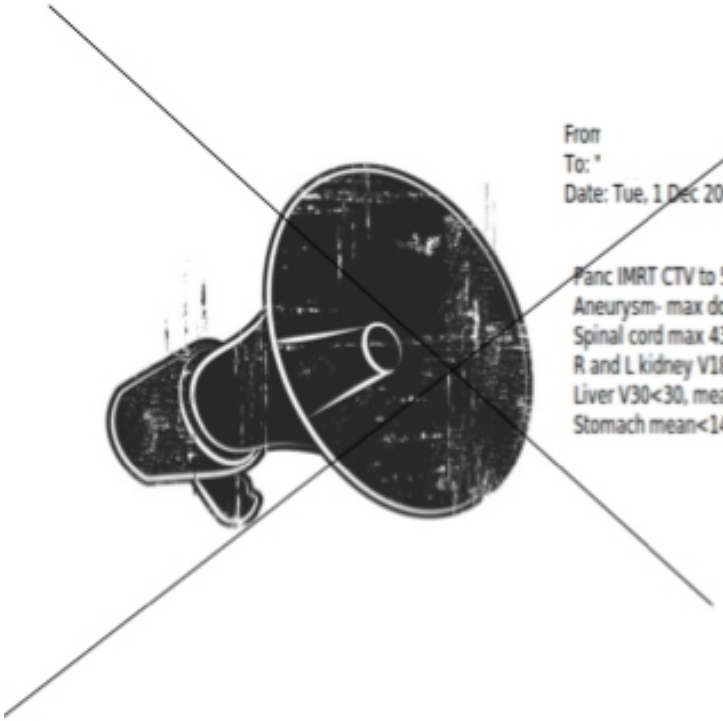
MGH MCO planning studies have spotlighted that:
with standard planning, the issue is the impossibility of succinctly conveying physician wishes to planners



From
To: "
Date: Tue, 1 Dec 2009 09:40:36 -0500

Panc IMRT CTV to 50.4 Gy. 0.7 mm ptv exp
Aneurysm- max dose10 Gy
Spinal cord max 43
R and L kidney V18<20, V10<50
Liver V30<30, mean<24
Stomach mean<14, V40<10

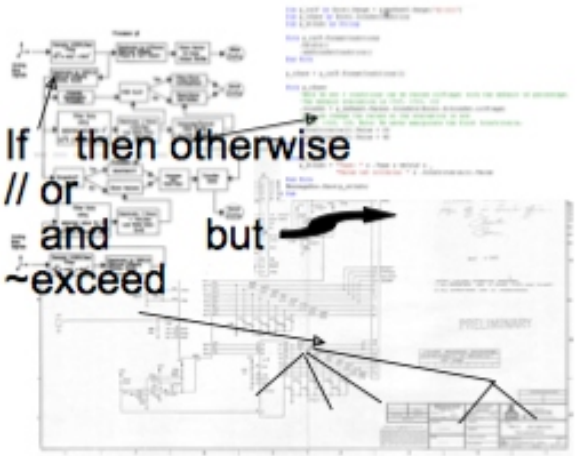
…the impossibility of succinctly conveying physician wishes to planners



From
To: "
Date: Tue, 1 Dec 2009 09:40:36 -0500

Panc IMRT CTV to 50.4 Gy. 0.7 mm ptv exp
Aneurysm- max dose10 Gy
Spinal cord max 43
R and L kidney V18<20, V10<50
Liver V30<30, mean<24
Stomach mean<14, V40<10

What they really want to



Point / counterpoint

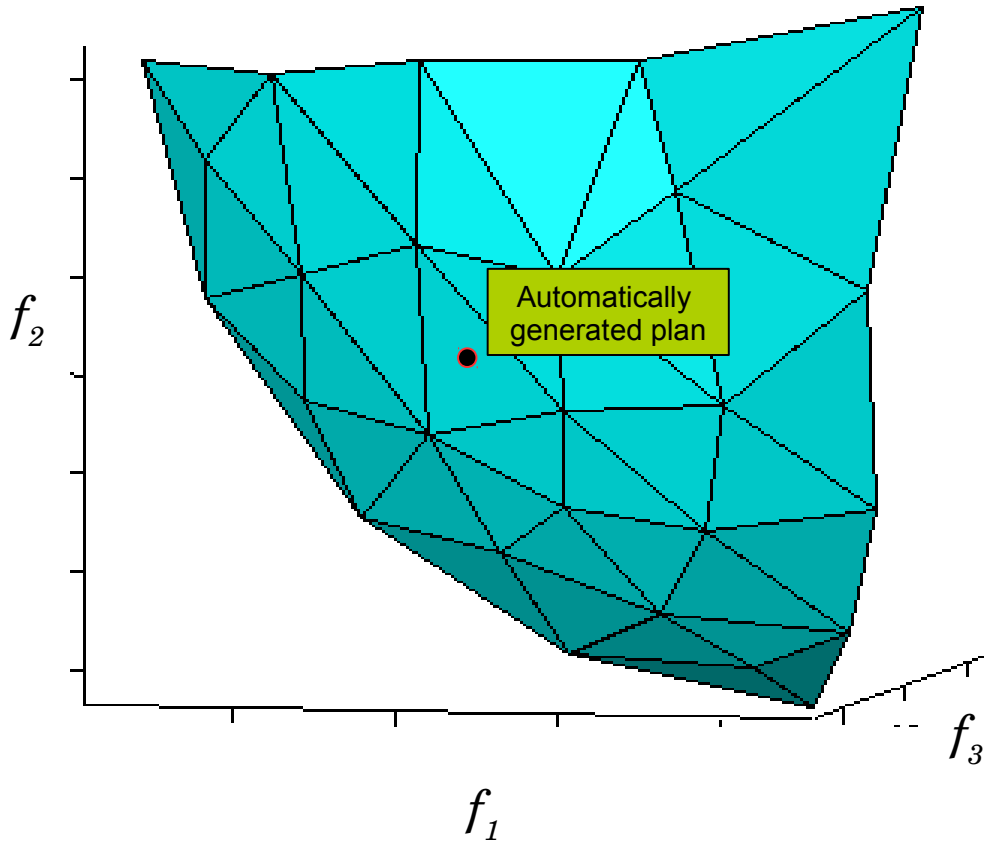
Maybe we want more *objectivity*, more *standards* in treatment planning, and we don't want a system for planners (physicians) to play around with and exercise their “gut feel”.

For the proposal	Against the proposal
.	.
.	.
.	.
.	.
.	.

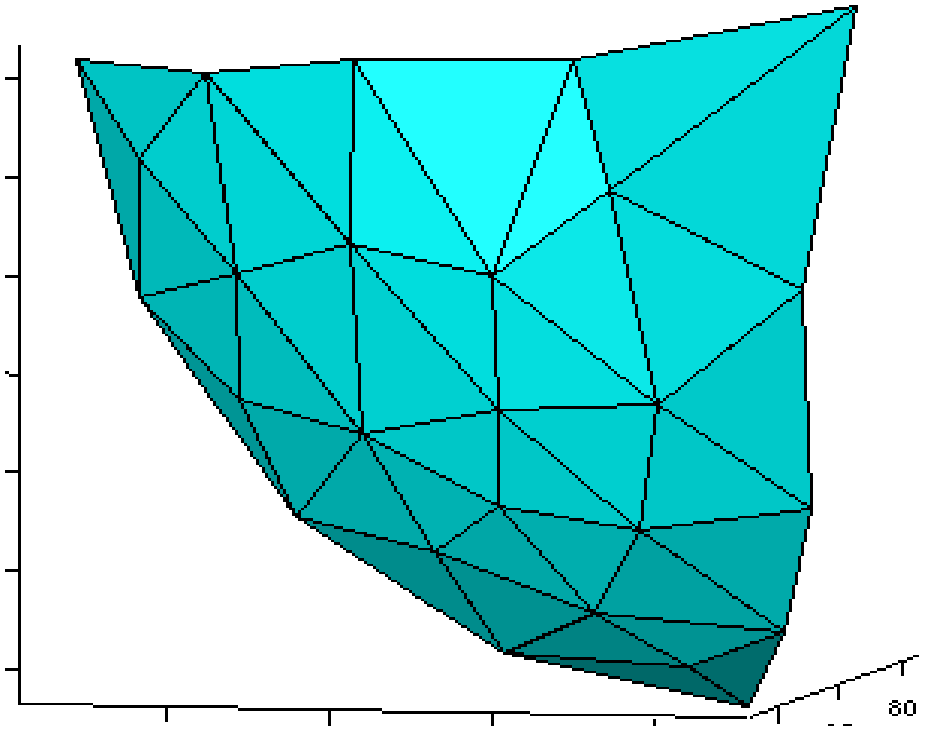
PS navigation as a refinement tool

After automatically generated plan, planner or physician gets the chance to refine the plan.

Build a Pareto surface around the automatically generated plan.



Directly deliverable navigation



To avoid the

“plan breaks down after MLC segmentation”

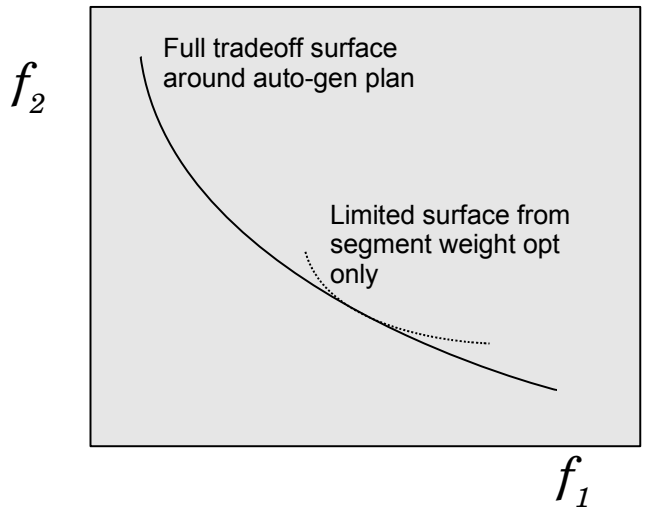
loop.

3 approaches for directly deliverable navigation

Step and shoot

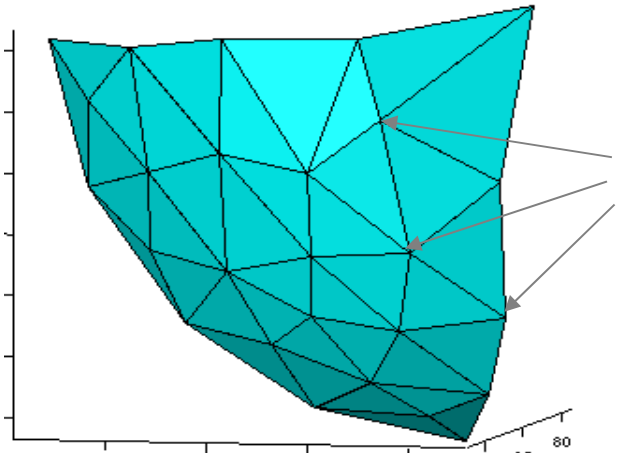
1 *easy*

* Fix the segments and just vary their weights (easy, but limited surface for exploring)



2 *hard*

* Have segments changing as you traverse the entire surface.



---

3 *hard*

Dynamic sliding window exact delivery of fluence maps

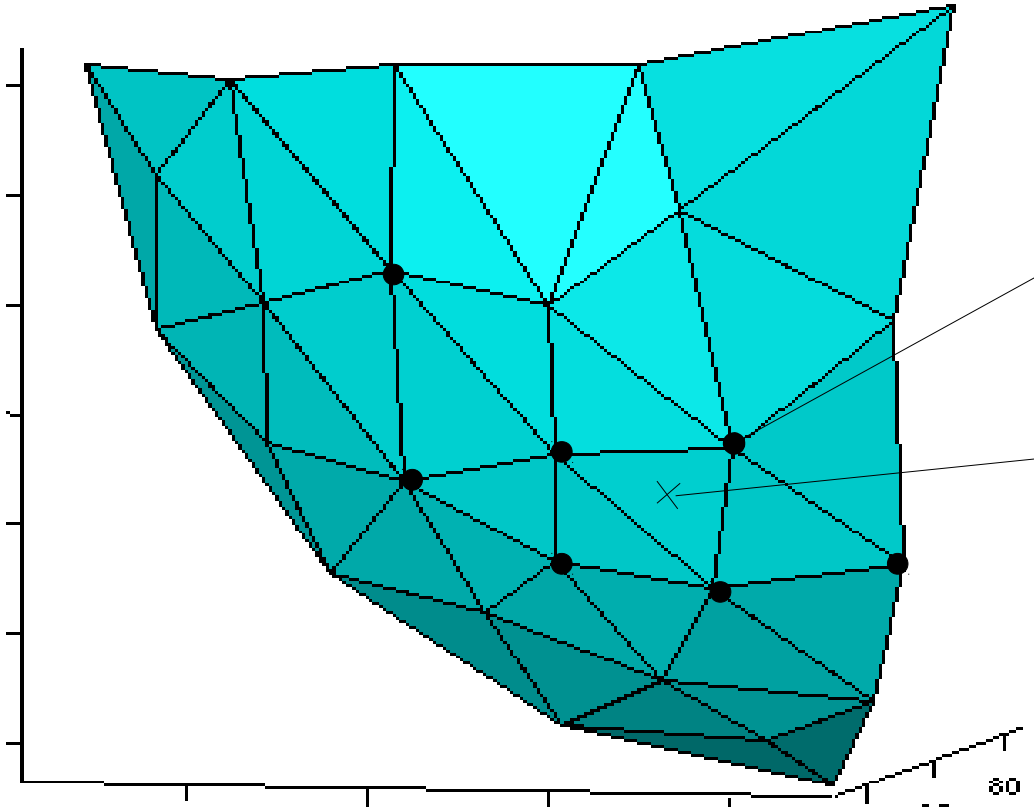
* Dose computation specialized for this setting.

* Applicable to sliding window VMAT (see VMERGE, Craft et al 2012, *med phys*)

Directly deliverable navigation

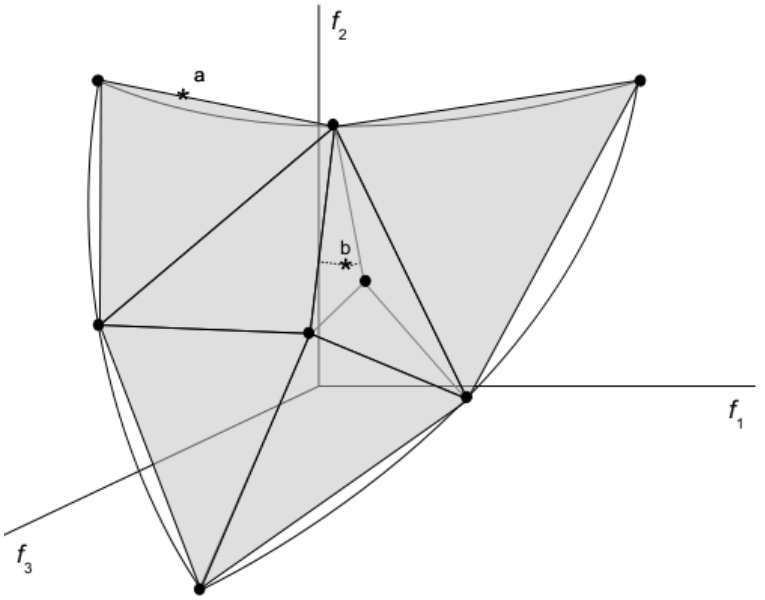
2

1) Segment the base plans with limited number of segments.



Each pre-computed Pareto optimal plan is fully segmented with final dose calculation.

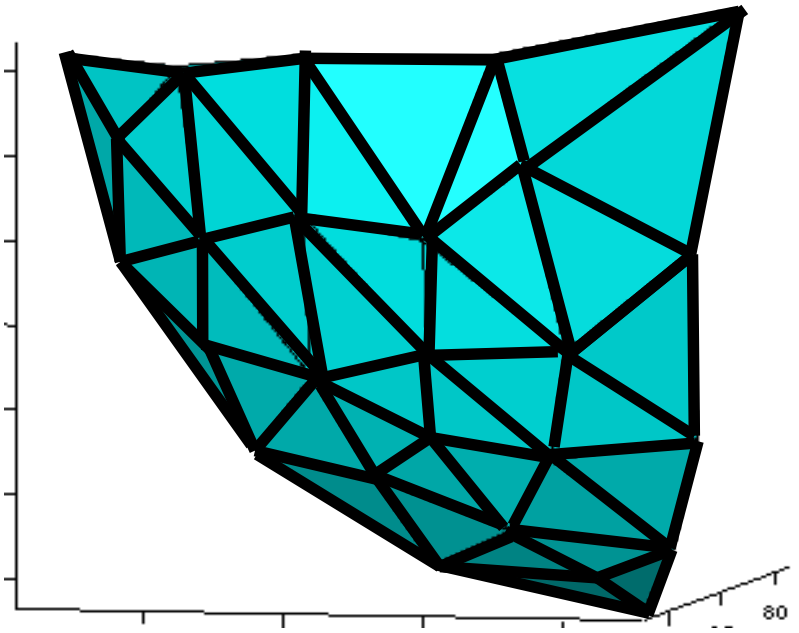
But what about smooth navigation to an averaged plan?



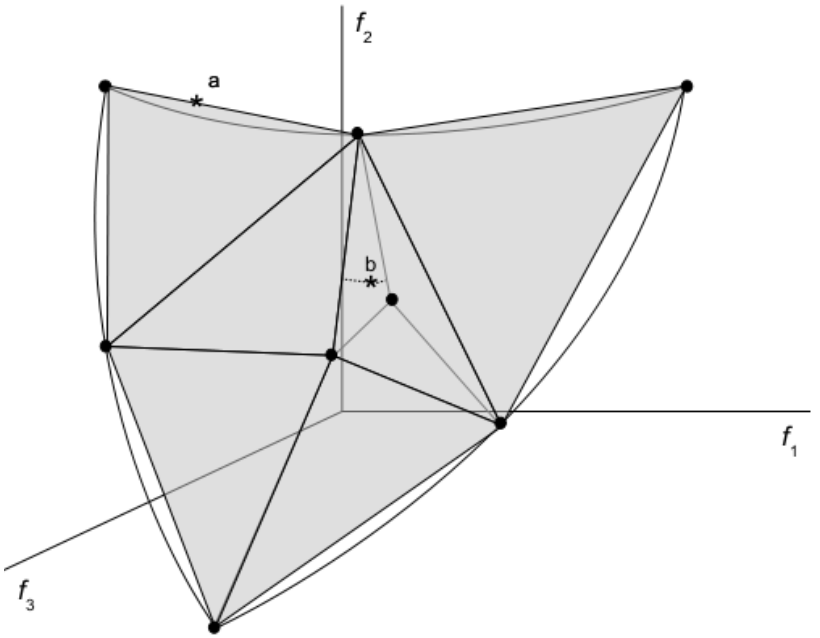
Directly deliverable navigation

2

2) During navigation, limit the number of plans needed to form the current averaged plan.



For example, here with *N*=3, only allow combinations of two plans. That is, stay on the thick black lines.

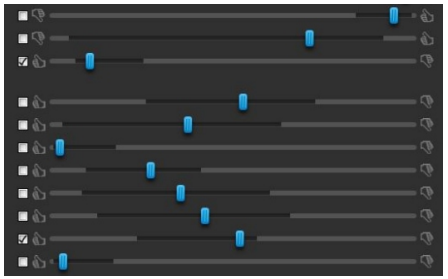


Directly deliverable navigation

2

2) During navigation, limit the number of plans needed to form the current averaged plan.

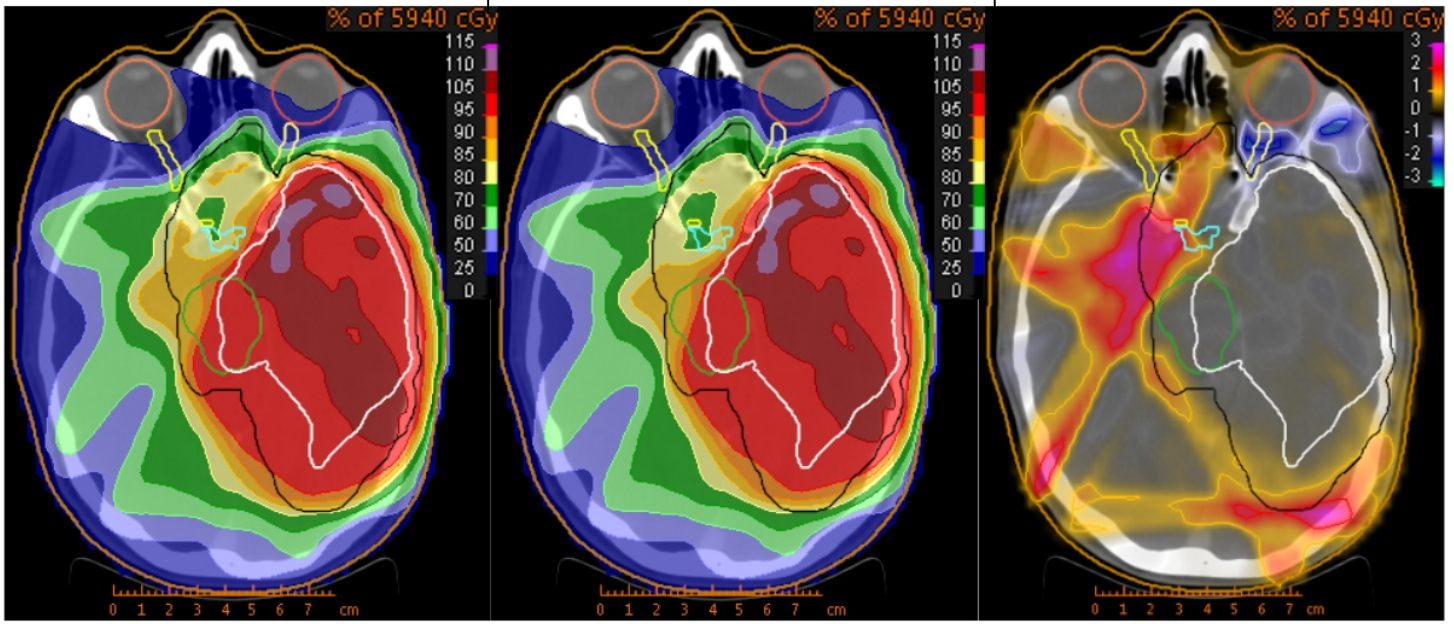
11 dimensional tradeoff surface

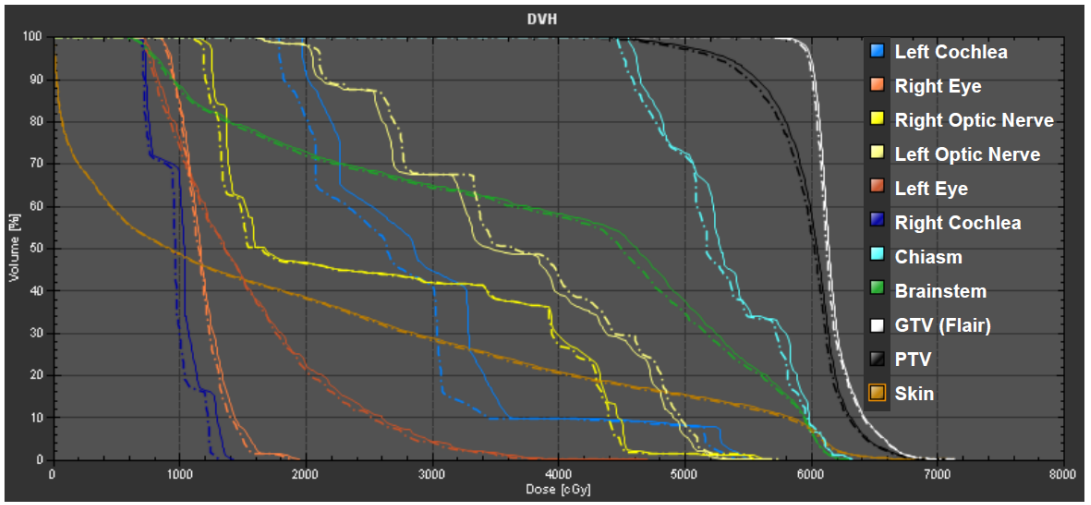


6 plans used for averaging, unrestricted navigation

3 plans, restricted navigation

Dose difference



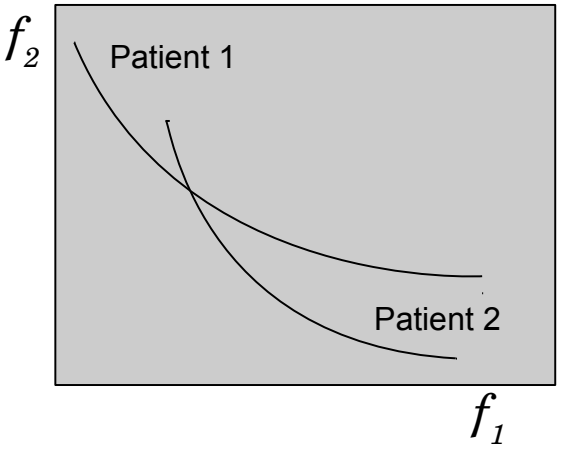


(in progress, D. Craft and C. Richter)

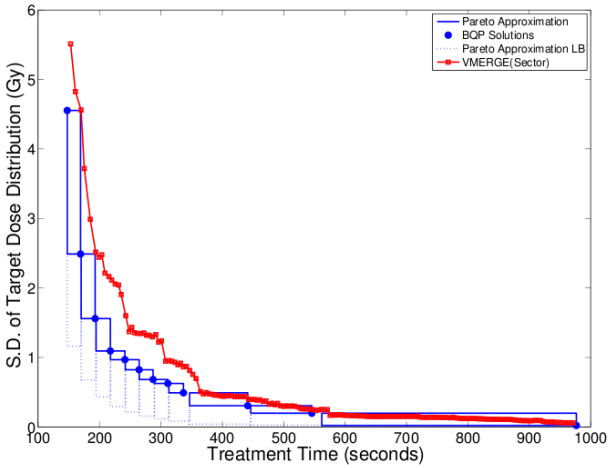
Concluding thoughts

Key difficulties of solving the IMRT problem in one shot:

* dosimetric tradeoffs are patient specific (for some patient, if you give a little in one organ, might gain a lot somewhere else)



* plan quality vs plan delivery time is another clinically relevant tradeoff to consider



Salari et al, Network VMAT, 2012

Recommended strategy for 'automated treatment planning': use GP or LO to automatically generate a high quality plan, and then use directly deliverable PS-MCO as an intuitive way to explore the local tradeoff region around that plan.

Thanks!

Thomas Bortfeld, Ehsan Salari, Judy Adams, Wei Chen, Jan Unkelbach, Jeremiah Wala, Christian Richter, Tarek Halabi, Dualta McQuaid, Ted Hong, Helen Shih, Hanne Kooy, Tom Madden, the ITWM team, the RaySearch team.

Number of plans used	Probability [%]	Number of plans allowed 1	2	3	4	5	6	7	8
1	0.3	1	-	-	-	-	-	-	-
2	10.2	0.92±0.06	1	-	-	-	-	-	-
3	35.4	0.87±0.06	0.97±0.03	1	-	-	-	-	-
4	31.5	0.84±0.06	0.95±0.03	0.98±0.01	1	-	-	-	-
5	16.9	0.83±0.06	0.93±0.03	0.97±0.02	0.99±0.01	1	-	-	-
6	5.1	0.81±0.06	0.92±0.03	0.96±0.02	0.98±0.01	0.99±0.01	1	-	-
7	0.6	0.79±0.07	0.9±0.04	0.95±0.02	0.97±0.02	0.99±0.01	0.99±0.01	1	-
8	0.1	0.78±0.08	0.89±0.06	0.94±0.04	0.96±0.02	0.98±0.01	0.99±0.01	1.00±0.00	1

Figure 8: Plan quality matrix: Plan quality in dependence of both, the initial number of plans and the number of plans after application of the restriction. Different colors indicate different plan quality levels. Given uncertainties represent the standard deviation. Additionally also the probability for the number of plans in the initial plan is given based on the 12000 generated random points on the Pareto surface.