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Automated adjustment of voxel-dependent importance factors in inverse planning

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Constrained inverse planning

Find a fluence resulting in a dose distribution satisfying (hard) dose-volume and maximum-dose constraints, e.g.:

- minimum-dose PTV > 50 Gy
- maximum-dose dose Spinal Cord < 45 Gy
- dose-volume Bowel at 35 Gy < 25%

Beam profile objective function

$$\min_{f} \sum_{v \in volumes} \xi_v (Hf - d_v^p)^T \eta_v (Hf - d_v^p) + \kappa (Mf)^T (Mf)$$

volume wide importance factor

dose resulting from fluence f

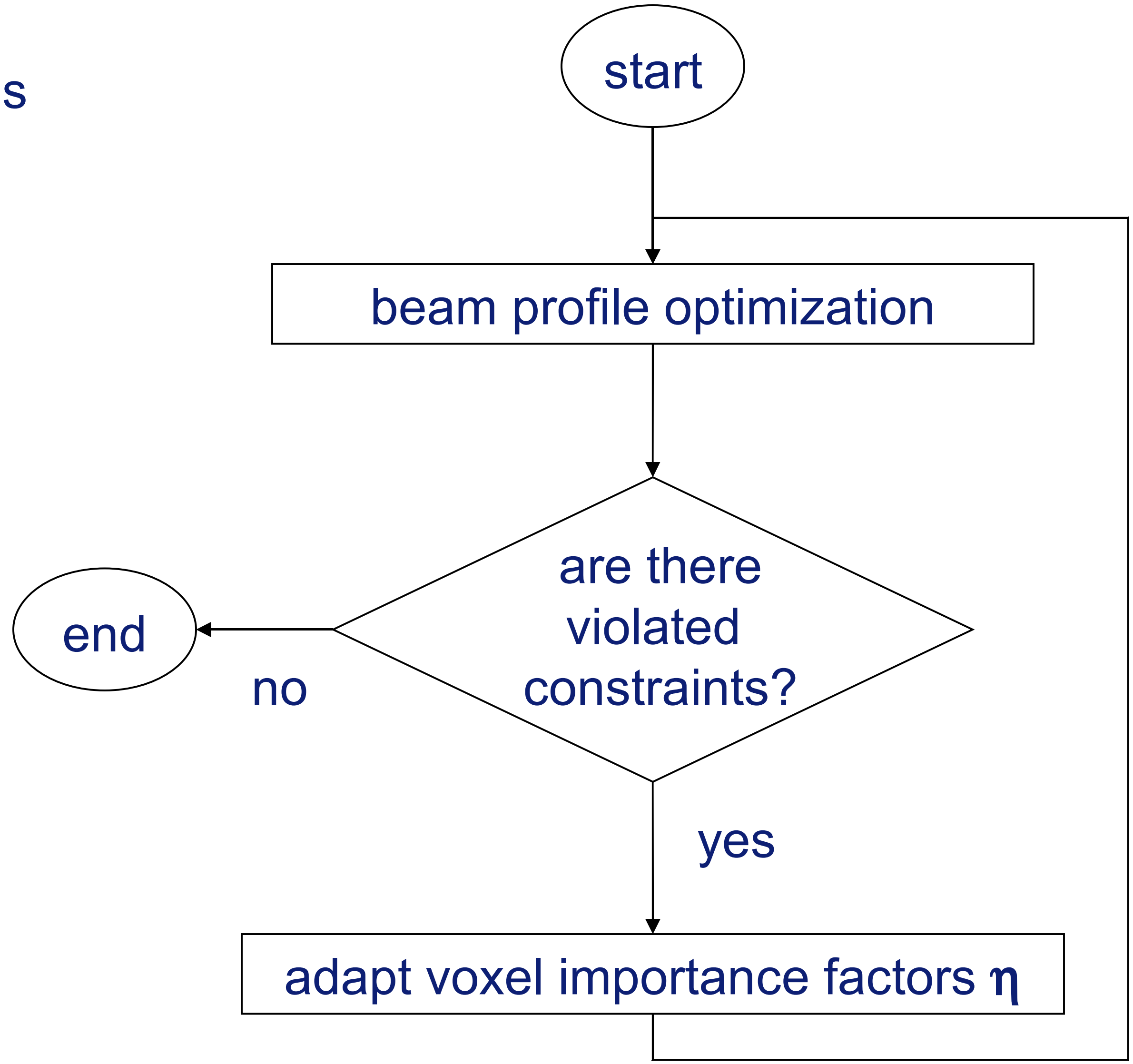
prescribed dose for volume

diagonal matrix with **voxel-dependent importance factors** for volume v

term to enforce smooth fluences

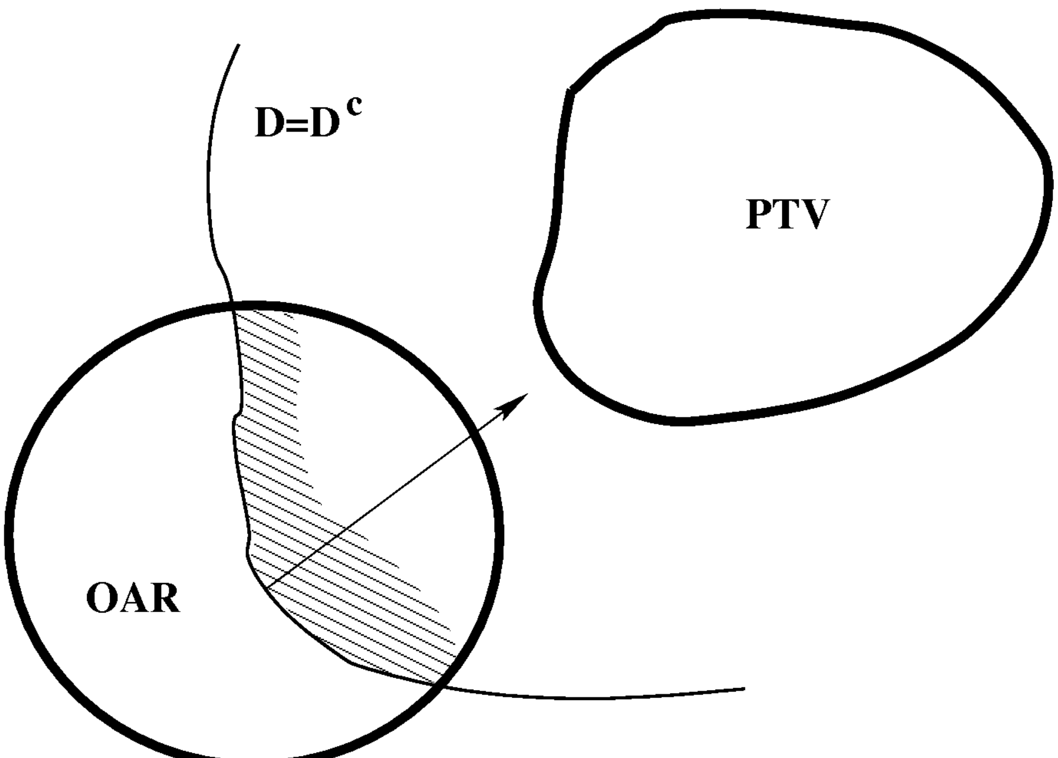
Constrained inverse planning

2 step process



Voxel adaption – how to select?

- increasing the weight of a voxel *encourages* the beam profile optimization to meet the prescribed dose
- select voxels which do not meet their constraints



Moving on…

So far:

- algorithm optimizes on hard constraints

But:

- fails to come up with a solution when constraints are too tight
- does not necessarily give a better solution if possible

So:

- what are the most optimal constraints?

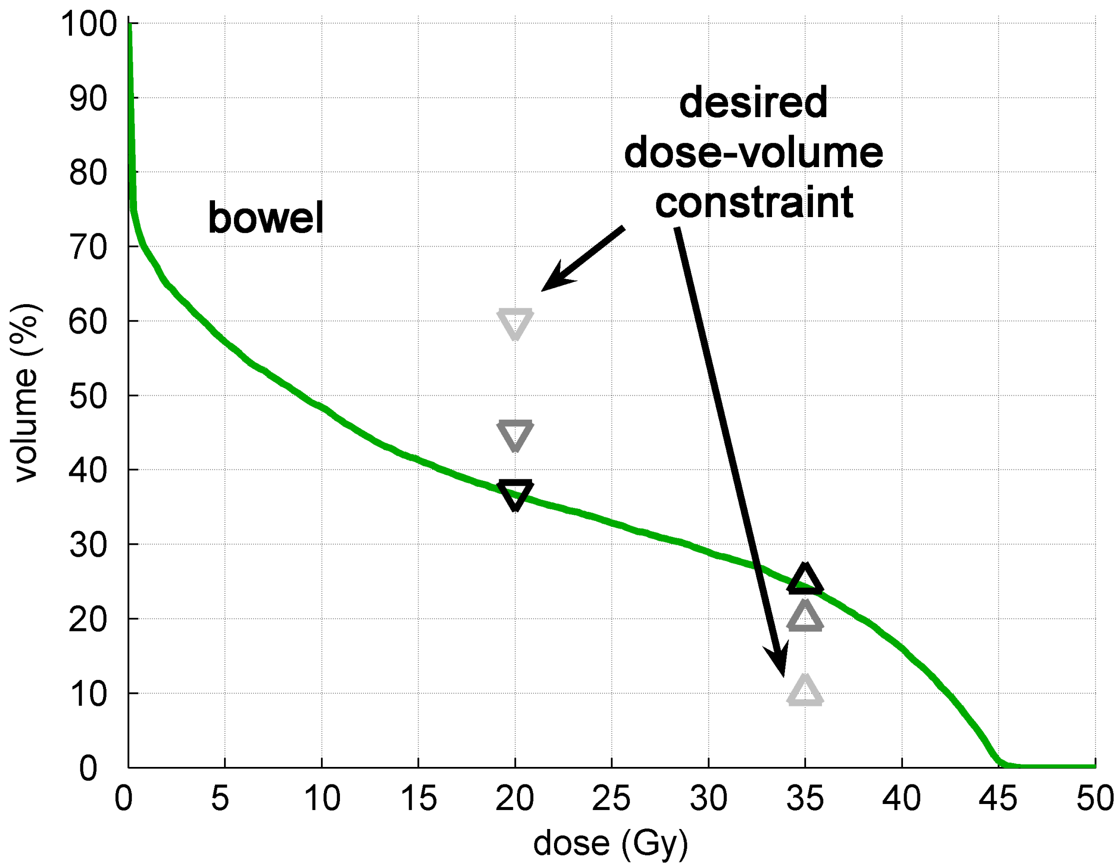
Moving on… to Pareto optimality

Use a list of constraints ranked to priority:

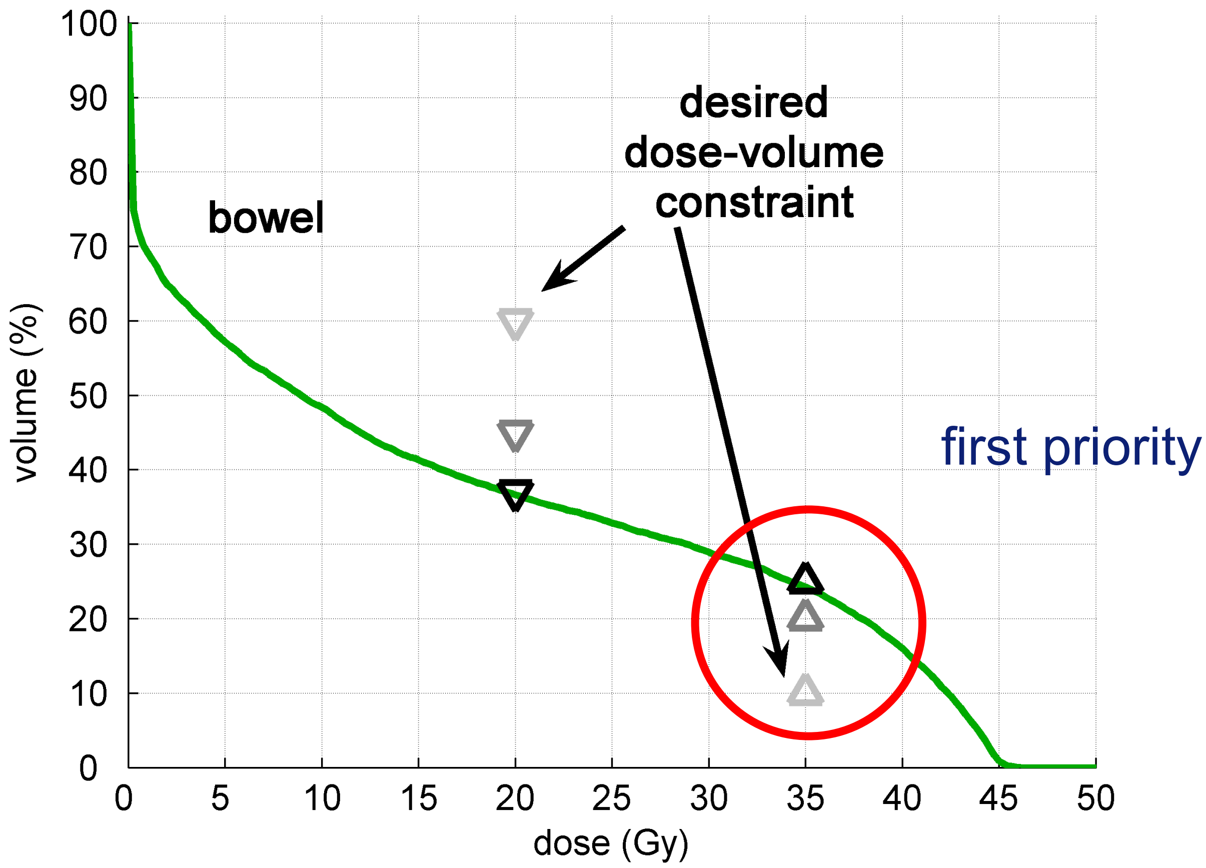
- first meet all hard constraints
- try to meet more important constraints prior to less important constraints
- relax constraints if necessary, tighten is possible

no	volume	constraint type	critical dose	objective	constraint set
1	PTV	DV	42.42 Gy	100%	0
2	PTV	Max		47.78 Gy	0
3	Body	Max		47.78 Gy	0
4	Bowel	DV	35 Gy	20%	1
5	Bladder	DV	40 Gy	40%	2
6	Colon	DV	40 Gy	20%	2
7	Bowel	DV	20 Gy	50%	3
8	Bladder	DV	20 Gy	75%	3
9	Colon	DV	20 Gy	30%	3
10	Body	DV	30 Gy	40%	4

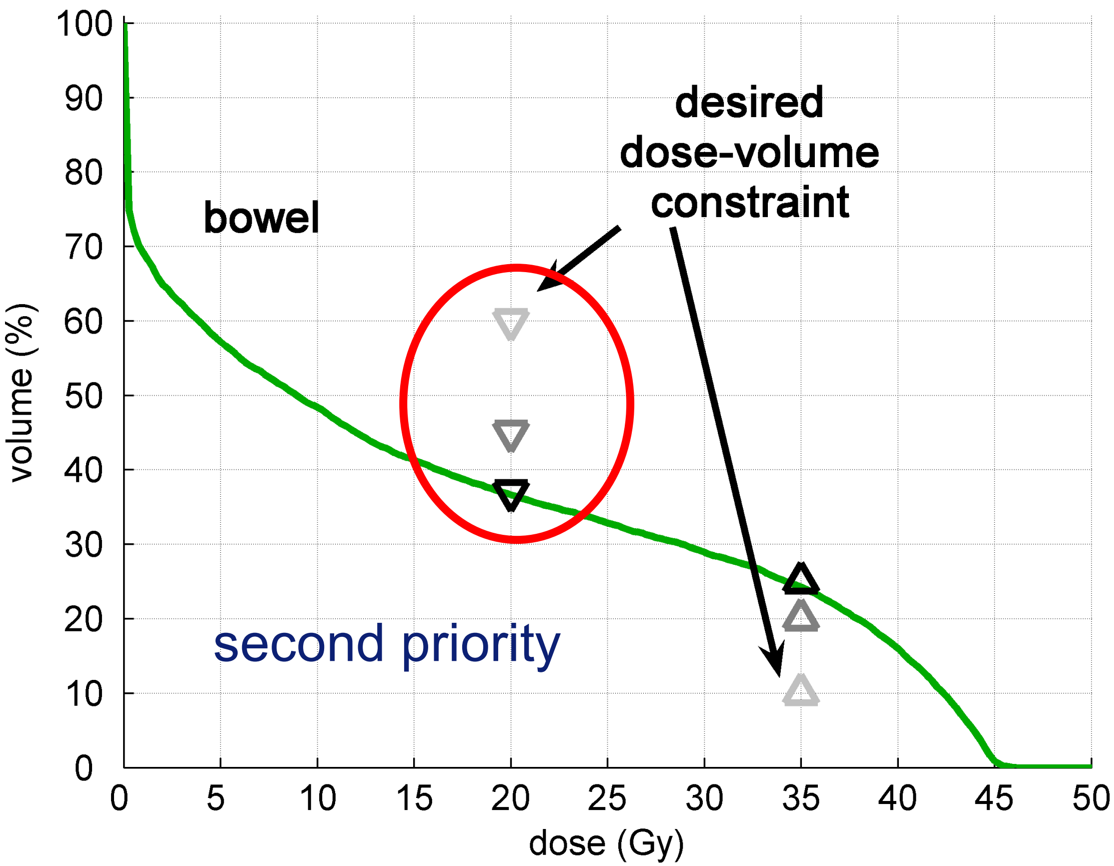
Example relaxation and tightening



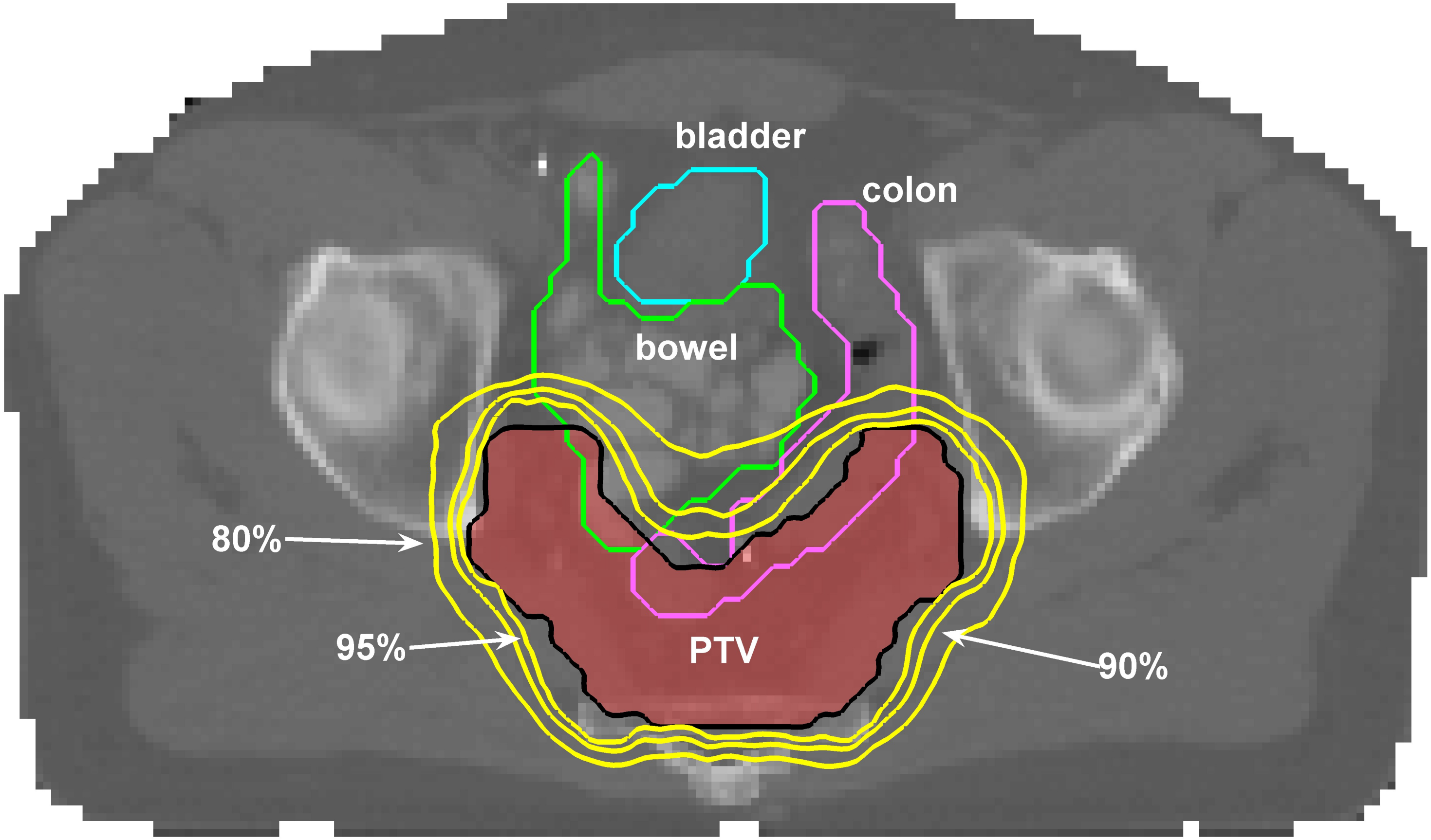
Example relaxation and tightening



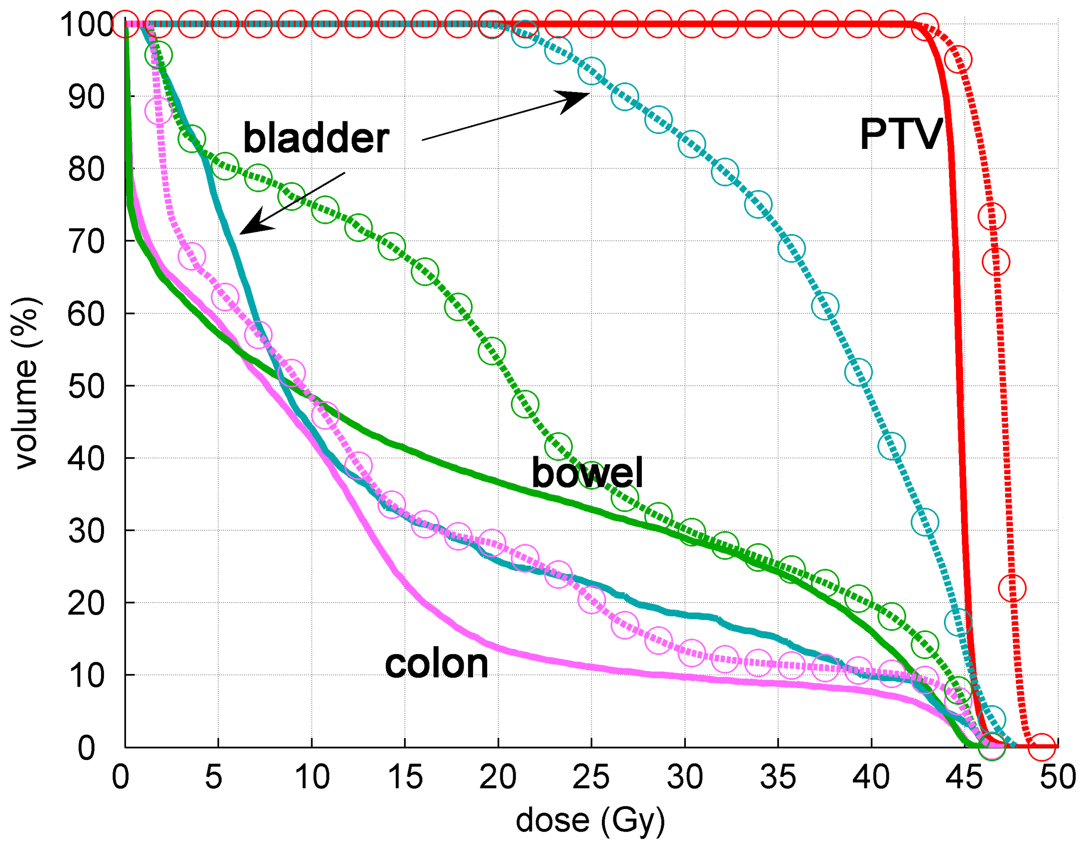
Example relaxation and tightening



Results: Rectum



Results: Rectum



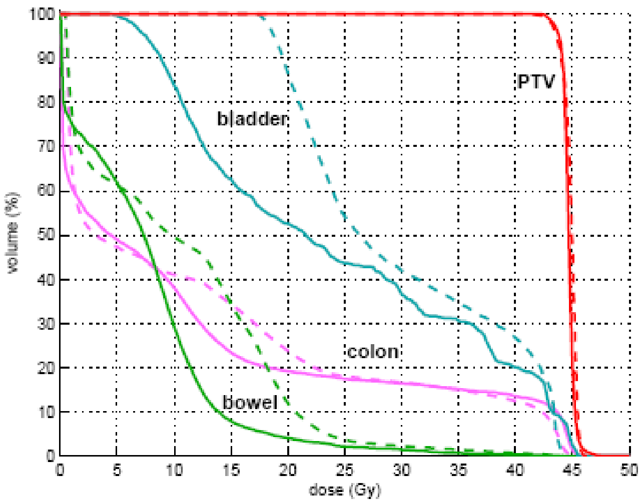
Class solutions

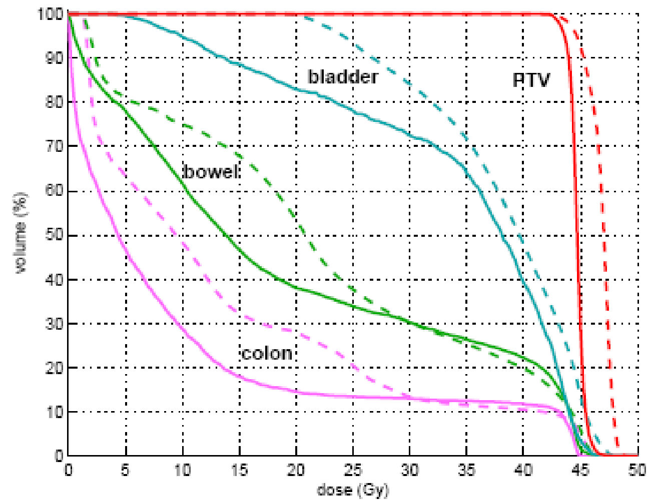
A well defined list of constraints can be used as a class solution.

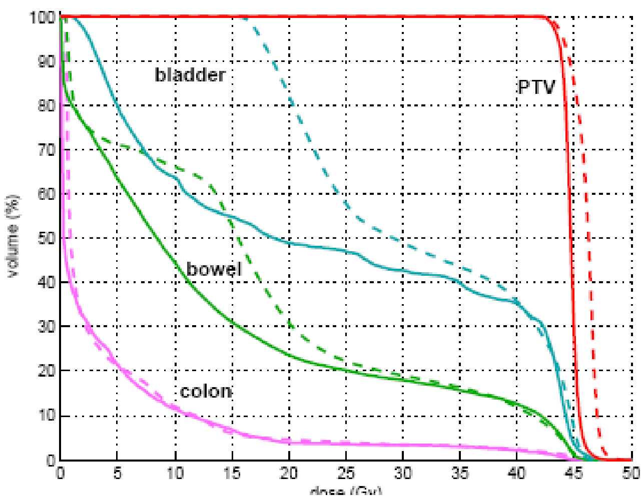
Research on 8 rectum patients and 5 oropharynx patients

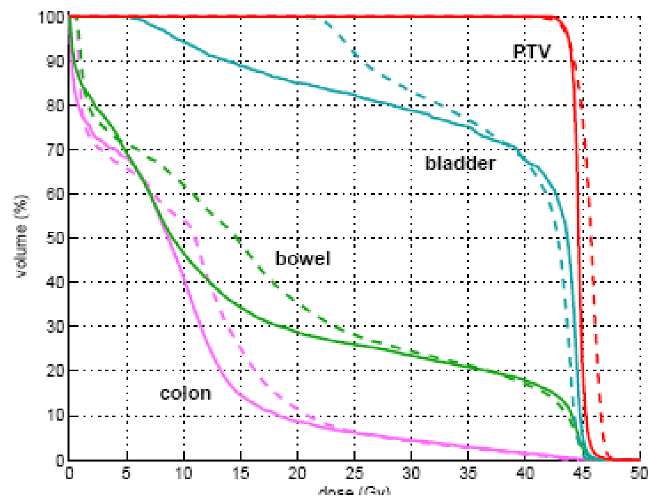
show structural and significant improvements.

Class solutions









Performance and characteristics

Direct optimization on constraints that are already Pareto optimal:

41 minutes

Optimization to find Pareto optimal constraints (from scratch):

58 minutes

Solutions are identical!

(except for some numerical noise)

Performance and characteristics

Optimization time can be further reduced by parallelization of the beam profile optimization algorithm. Using two threads on a SMP machine gives an speed-up of over 90%

Optimization is also `labour-free’ because no interaction is needed when an ordered constraint list is used.

start

Summary and conclusions

We developed an algorithm to automatically adapt voxel-dependent importance factors for optimization on (hard) dose-volume and maximum-dose constraints.

By using a priority constraint list, constraints are optimized in priority to find a Pareto optimal set of constraints.

(Soft) constraints can be relaxed if necessary and tightened if possible.

The prioritized constraint list can be used as a class solution.

For rectum and oropharynx patients it shows consequently significantly better solutions than the manually optimized clinical plans.