Error compensated sparse optimization for fast radiosurgery treatment planning

Our aim is to accelerate planning to interactive rates. We address the long runtime and high memory requirements of the optimization problem by utilizing sparse sampling in conjunction with adaptive voxel bounds. Approaches tackling same issues have been in the past investigated. The authors of [1] employ a Fourier analysis on the accuracy of using different sampling rates and based on this, they use a three level anisotropic grid. In [2] a hierarchical voxel clustering method is presented which aims to preserve the optimum of the original problem.

Error estimation: Coarsely discretizing the planning target volume (PTV) leads to hotspots appearing in the dose distribution. These inhomogeneities are a result of beams overlapping between sampling points. To estimate the probability mass function (pmf) of such errors, we randomly generate 500,000 n-beam configurations (pmf-s are indirectly dependent on the number of beams used; we chose n = 200). We record the relative hotspot errors within voxels of different sizes and construct the estimated pmf-s. Moreover we make the assumption that the error distribution is invariant to changes in the voxel bounds. We can thus build a conservative estimation of overdosage reduction (percent of volume receiving more than the clinically set limit) as a function of tightening the voxels’ upper bounds. The curves in Figure (a) show the estimated overdosage reduction for 4, 8 and 16mm.

Validation: We test our approach on a prostate cancer case using our in-house planning tool. For the optimization step we use IBM’s Ilog Cplex linear solver. Planning objective is a prescribed dose of 36.25 Gy to the 87% isodose - PTV upper bound 41.50 Gy. To account for areas not covered by the sparse sampling, we specifically place points on the surface of volumes of interest. We sample the PTV with 4, 8 and 16 mm. For each sampling rate we repeatedly reduce the upper PTV bound by 4.15 (0.1% of maximum dose). Figure (a) shows the relative improvement in the overdosage. The improvement estimate is very conservative, yet useful in selecting the adjustment value for the bounds. The 16mm case shows large variations due to volume effects induced by coarse sampling.

Results: When optimizing with 2, 4 and 8mm, the volume exceeding the upper bound was 0.74%, 1.71% and 9% respectively. Based on the improvement estimate we reduce the upper bound by 0.5% and by 2.5% for 4 and 8mm sampling respectively. This results in a drop in overdosage to 0.75% and 2.2% for 4 and 8mm respectively. Virtually no loss of prescription dose coverage is measured compared to the unadjusted cases. Figure (b) shows the DVH curves for the discussed cases. Note the high errors that make 16mm sampling impractical in a realistic setting.

Figure (c) shows the runtime for a number of optimization runs with each of the sampling rates. This emphasizes the potential of our method in environments where optimization runtime is important, such as interactive planning.

References
