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Our reference
<vnr-ext>

Bachelor's thesis project

Real-time least squares fitting with box constraints

Problem Description

Our objective is to approximate a desired bandlimited 2D dose [J/m^2] profile with a fixed number of spots at fixed locations on a 2D substrate. The spot shape is Gaussian, the spot dimension is determined by its full width at half the maximum (FWHM). The spot grid is essentially unstructured and the spot density is higher than the spot density of a rectangular spot grid with a spot distance of 0.5xFWHM in each dimension. Each spot is switched on during a fixed time with a spot specific intensity [W/m^2]. The problem is to compute the intensity for each spot such that the sum of all resulting spot dose profiles best approximates the desired dose profile. The intensity computation has to be done in real-time, i.e. a guaranteed maximum computation time is required.

The forward model is defined as follows:

$$d\left(x_s, y_s\right) = \sum_{n}^{N_{spots}} s_n \cdot PSF\left(x_s - x_n, y_s - y_n\right)$$

Where:

x_s, y_s	Position of dose map point *s*
x_n, y_n	Position of spot *n*
s_n	Intensity of spot *n* (unknown)
PSF ( )	Point spread function
$d(x_s, y_s)$	Requested dose at dose map point *s*

The problem is linear in intensity and is described by an overdetermined system of linear equations with constraints intensity >= 0 and <= max intensity. Typically we have 4e7 dose points and 1e7 spots in one problem. This bachelor's thesis project will address a downscaled version of the problem: 1e4 dose points and 3e3 spots.

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Current Solution and its Limitations

The problem is currently solved in two steps. One computation intensive step that does not need to be solved in real-time, because it does not depend on the desired dose profile, and one computation step that must be solved in real-time:

1. Compute the pseudo inverse K of the system matrix. K is sparse with known structure. This part of the solution does not depend on the desired dose profile and can be reused between exposures. Consequently, the real-time requirement is not imposed on this step.
2. During the exposure process we use K and the desired dose profile to compute the spot intensities. The operation to be performed here is a matrix vector product. Therefore we know the exact number of operations that needs to be performed and this allows us to fulfil the real-time requirement.

Essentially we are performing an unconstrained (least squares) fit while we require a constrained fit. Using a constrained fit algorithm such as NNLS is (to our knowledge) not an option because these algorithms are iterative in nature and time to convergence cannot be guaranteed. In our unconstrained approach violation of the constraints is reduced by pre-processing the desired dose profile such that it is compatible with the spot shape. This approach is successful in the sense that violation of the maximum intensity constraint does not occur. However, this approach is unsuccessful in the sense that negative intensities do occur (up to 10% of the maximum intensity). Negative intensities can not be realized physically and are therefore simply clipped to zero. This introduces an error in the resulting dose profile.

Project Description

Reduce the amplitude of negative intensities to less than 1% of the maximum positive intensity. The project starts with a study which results in an overview of viable approaches to achieve reduction of negative amplitudes. The two most promising methods will be studied in detail by implementing them in MATLAB and evaluating their effectiveness on a set of reference dose profiles.