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Weekly Exercises 0

Room: 02.09.023
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Intro to Sparse Matrices in MATLAB

Throughout the course we will work in the finite dimensional setting, i.e. we discretely represent gray value images $f : \Omega \to \mathbb{R}$ or color images $f : \Omega \to \mathbb{R}^3$ as (vectorized) matrices $f \in \mathbb{R}^{m\times n}$ ($\text{vec}(f) \in \mathbb{R}^{mn}$) respectively $f \in \mathbb{R}^{m\times n\times 3}$ ($\text{vec}(f) \in \mathbb{R}^{3mn}$). To discretely express functionals like the total variation for smooth f

$$TV(f) := \int_\Omega \|\nabla f(x)\| \,\mathrm{d}x$$

you will therefore need a discrete gradient operator

$$\nabla := \begin{pmatrix} D_x \\ D_y \end{pmatrix}$$

for vectorized representations $\text{vec}(f)$ of images $f \in \mathbb{R}^{m\times n}$ so that

$$TV(f) = \|\nabla \text{vec}(f)\|_{2,1} = \sum_{i=1}^{nm} \sqrt{(D_x \cdot \text{vec}(f))_i^2 + (D_y \cdot \text{vec}(f))_i^2}.$$

The aim of this exercise is to derive the gradient operator and learn how to implement it with MATLAB.

Exercise 1 (1 Point)**.** Let $f \in \mathbb{R}^{m\times n}$ be a discrete grayvalue image. Your task is to find matrices $\tilde{D}_x$ and $\tilde{D}_y$ for computing the forward differences f_x, f_y in x and y-direction of the image f with Neumann boundary conditions so that:

$$f_x = f \cdot \tilde{D}_x := \begin{pmatrix} f_{12} - f_{11} & f_{13} - f_{12} & \dots & f_{1n} - f_{1(n-1)} & 0 \\ f_{22} - f_{21} & \dots & & & 0 \\ \vdots & & & \vdots & 0 \\ f_{m2} - f_{m1} & \dots & & f_{mn} - f_{m(n-1)} & 0 \end{pmatrix} \tag{1}$$

and

$$f_y = \tilde{D}_y \cdot f = \begin{pmatrix} f_{21} - f_{11} & f_{22} - f_{12} & \dots & f_{2n} - f_{1n} \\ f_{31} - f_{21} & \dots & & f_{3n} - f_{2n} \\ \vdots & & & \vdots \\ f_{m1} - f_{(m-1)1} & \dots & & f_{mn} - f_{(m-1)n} \\ 0 & \dots & 0 & 0 \end{pmatrix}. \tag{2}$$

Exercise 2 (1 Point)**.** Implement the derivative operators from the previous exercise using MATLABs `spdiags` command. Load the image from the file `Vegetation-028.jpg` using the command `imread` and convert it to a grayvalue image using the command `rgb2gray`. Finally apply the operators to the image and display your results using `imshow`.

For our algorithms it is more convenient to represent an image f as a vector $\mathrm{vec}(f) \in \mathbb{R}^{mn}$, that means that the columns of f are stacked one over the other.

Exercise 3 (1 Point)**.** Derive a gradient operator

$$\nabla = \begin{pmatrix} D_x \\ D_y \end{pmatrix}$$

for vectorized images so that

$$D_x \cdot \mathrm{vec}(f) = \mathrm{vec}(f_x) \qquad D_y \cdot \mathrm{vec}(f) = \mathrm{vec}(f_y)$$

You can use that it holds that for matrices A, X, B

$$AXB = C \iff (B^\top \otimes A)\mathrm{vec}(X) = \mathrm{vec}(C)$$

where $\otimes$ denote the Kronecker (MATLAB: `kron`) product.

Experimentally verify that the results of Ex. 2 and Ex. 3 are equal by reshaping them to the same size using MATLABs `reshape` or the `:` operator, and showing that the norm of the difference of both results is zero.

Exercise 4 (1 Point)**.** Assemble an operator ∇_c for computing the gradient (or more precisely the Jacobian) of a color image $f \in \mathbb{R}^{n \times m \times 3}$ using MATLABs `cat` and `kron` commands.

Exercise 5 (1 Point)**.** Compute the color total variation given as

$$TV(f) = \|\nabla_c \mathrm{vec}(f)\|_{F,1} = \sum_{i=1}^{nm} \left\| \begin{pmatrix} (D_x \cdot \mathrm{vec}(f_r))_i & (D_x \cdot \mathrm{vec}(f_g))_i & (D_x \cdot \mathrm{vec}(f_b))_i \\ (D_y \cdot \mathrm{vec}(f_r))_i & (D_y \cdot \mathrm{vec}(f_g))_i & (D_y \cdot \mathrm{vec}(f_b))_i \end{pmatrix} \right\|_F$$

of the two images `Vegetation-028.jpg` and `Vegetation-043.jpg` and compare the values. What do you observe? Why?