PROGRAMMING SHAPE-MORPHING MAGNETO-ACTIVE POLYMER COMPOSITES THROUGH MULTI-PHYSICS INFORMED TOPOLOGY OPTIMIZATION

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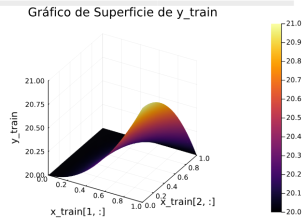
1 Introduction into HSMSs

The problem description

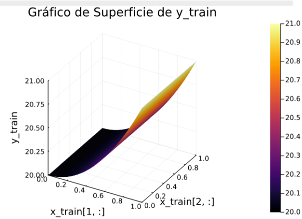
- The toy function and the domain

$$y(x_1, x_2) = x_1^2 - \beta x_1^2 x_2^2; \qquad x_1 \in [0, 1], x_2 \in [0, 1]$$

- When $\beta = 1$ everything works fine! When $\beta << 1$ we are fucked!!!
- The function for different values of β



$\beta = 1$



$\beta = 10^{-4}$

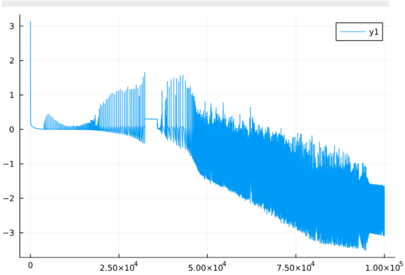
- Error metrics that we would like to monitor:

$$\mathcal{J}_1 = \frac{\sum_i \left(\left(\partial y / \partial x_1 \right)_i - \left(\partial y / \partial x_1^\star \right)_i \right)^2}{\sum_i \left(\left(\partial y / \partial x_1^\star \right)_i \right)^2}; \qquad \mathcal{J}_2 = \frac{\sum_i \left(\left(\partial y / \partial x_2 \right)_i - \left(\partial y / \partial x_2^\star \right)_i \right)^2}{\sum_i \left(\left(\partial y / \partial x_2^\star \right)_i \right)^2}$$

Option 1

- Objective function option 1:

$$\boxed{\mathcal{J} = \mathcal{J}_1 + \mathcal{J}_2}$$



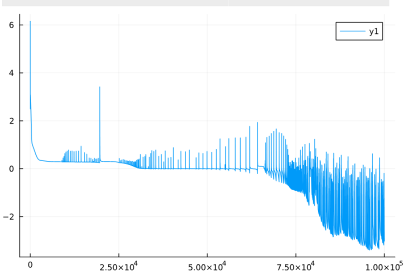
- **Excessive amount of iterations**. Values of $\mathcal{J}_1$ and $\mathcal{J}_2$ are

$$\mathcal{J}_1 = 2.9 \times 10^{-4}; \qquad \mathcal{J}_2 = 2 \times 10^{-2}$$

Option 2

- Objective function option 2 (trying to help with values of the function itself!):

$$\boxed{\mathcal{J} = \mathcal{J}_1 + \mathcal{J}_2 + \mathcal{J}_3; \qquad \mathcal{J}_3 = \frac{\sum_i \left(y_i - y_i^\star\right)^2}{\sum_i \left(y_i^\star\right)^2}}$$



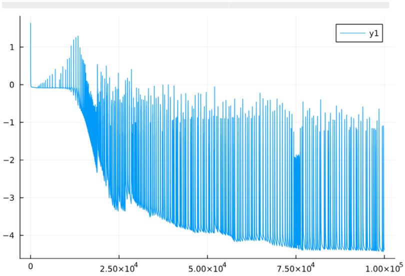
- **Excessive amount of iterations**. Values of $\mathcal{J}_1$ and $\mathcal{J}_2$ are

$$\mathcal{J}_1 = 5 \times 10^{-4}; \qquad \mathcal{J}_2 = 4.2 \times 10^{-4}$$

Option 3

- Objective function option 3:

$$\boxed{\mathcal{J} = \frac{\sum_i \left(\left(\partial y/\partial x_1\right)_i - \left(\partial y/\partial x_1^\star\right)_i \right)^2 + \alpha \sum_i \left(\left(\partial y/\partial x_2\right)_i - \left(\partial y/\partial x_2^\star\right)_i \right)^2}{\sum_i \left(\left(\partial y/\partial x_1^\star\right)_i \right)^2 + \alpha \sum_i \left(\left(\partial y/\partial x_2^\star\right)_i \right)^2}, \qquad \alpha = \frac{1}{\beta^2}}$$



- **We observe an improvement**. Values of $\mathcal{J}_1$ and $\mathcal{J}_2$ are

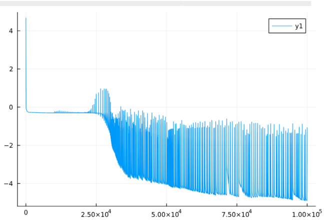
$$\mathcal{J}_1 = 3 \times 10^{-4}; \qquad \mathcal{J}_2 = 8 \times 10^{-3}$$

Option 4

- Objective function option 4: consistent scaling of $\partial y/\partial x_j$ and $\partial y/\partial x_j^\star$

$$\boxed{\mathcal{J} = \frac{\sum_i \left(\left(\widetilde{\partial y/\partial x_1}\right)_i - \left(\widetilde{\partial y/\partial x_1^\star}\right)_i \right)^2 + \sum_i \left(\left(\widetilde{\partial y/\partial x_2}\right)_i - \left(\widetilde{\partial y/\partial x_2^\star}\right)_i \right)^2}{\sum_i \left(\left(\widetilde{\partial y/\partial x_1^\star}\right)_i \right)^2 + \sum_i \left(\left(\widetilde{\partial y/\partial x_2^\star}\right)_i \right)^2}}$$

$$\left(\widetilde{\partial y/\partial x_j}\right)_i = \frac{\left(\partial y/\partial x_j\right)_i - \min_i \left(\partial y/\partial x_j^\star\right)}{\max_i \left(\partial y/\partial x_j^\star\right) - \min_i \left(\partial y/\partial x_j^\star\right)}; \qquad \left(\widetilde{\partial y/\partial x_j^\star}\right)_i = \frac{\left(\partial y/\partial x_j^\star\right)_i - \min_i \left(\partial y/\partial x_j^\star\right)}{\max_i \left(\partial y/\partial x_j^\star\right) - \min_i \left(\partial y/\partial x_j^\star\right)}$$



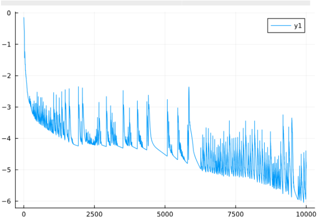
- **Drastic improvement**. Values of $\mathcal{J}_1$ and $\mathcal{J}_2$ are $\mathcal{J}_1 = 1.7 \times 10^{-7}$ and $\mathcal{J}_2 = 8.67 \times 10^{-6}$

Option 5

- Objective function option 5: separate scaling of $\partial y/\partial x_j$ and $\partial y/\partial x_j^\star$

$$\boxed{\mathcal{J} = \frac{\sum_i \left(\left(\widetilde{\partial y/\partial x_1}\right)_i - \left(\widetilde{\partial y/\partial x_1^\star}\right)_i \right)^2 + \sum_i \left(\left(\widetilde{\partial y/\partial x_2}\right)_i - \left(\widetilde{\partial y/\partial x_2^\star}\right)_i \right)^2}{\sum_i \left(\left(\widetilde{\partial y/\partial x_1^\star}\right)_i \right)^2 + \sum_i \left(\left(\widetilde{\partial y/\partial x_2^\star}\right)_i \right)^2}}$$

$$\left(\widetilde{\partial y/\partial x_j}\right)_i = \frac{\left(\partial y/\partial x_j\right)_i - \min_i \left(\partial y/\partial x_j\right)}{\max_i \left(\partial y/\partial x_j\right) - \min_i \left(\partial y/\partial x_j\right)}; \quad \left(\widetilde{\partial y/\partial x_j^\star}\right)_i = \frac{\left(\partial y/\partial x_j^\star\right)_i - \min_i \left(\partial y/\partial x_j^\star\right)}{\max_i \left(\partial y/\partial x_j^\star\right) - \min_i \left(\partial y/\partial x_j^\star\right)}$$



- **Drastic improvement**. Values of $\mathcal{J}_1$ and $\mathcal{J}_2$ are $\mathcal{J}_1 = 1.7 \times 10^{-7}$ and $\mathcal{J}_2 = 8.67 \times 10^{-6}$
- **Energetic inconsistency!!**