ÉTS Engineering for Industry
ÉCOLE DE TECHNOLOGIE SUPÉRIEURE
Université du Québec

MIDL Nashville 2023

O236 - Poster location: W01

GeoLS: Geodesic Label Smoothing for Image Segmentation

"Adding image context in the label smoothing process"

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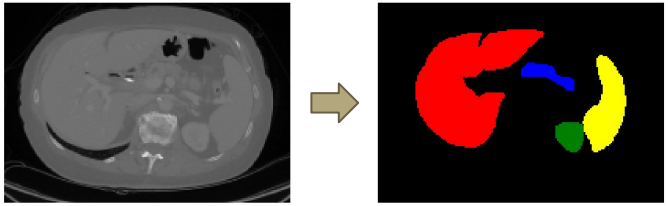
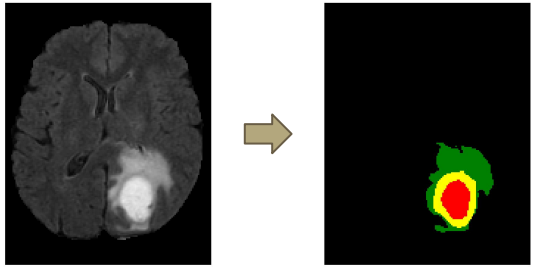
MIDL 2023

July 12, 2023

Revisiting Image Segmentation

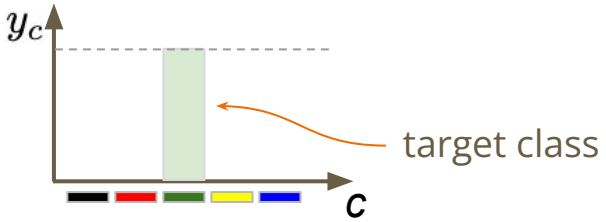


Abdominal organs [1]



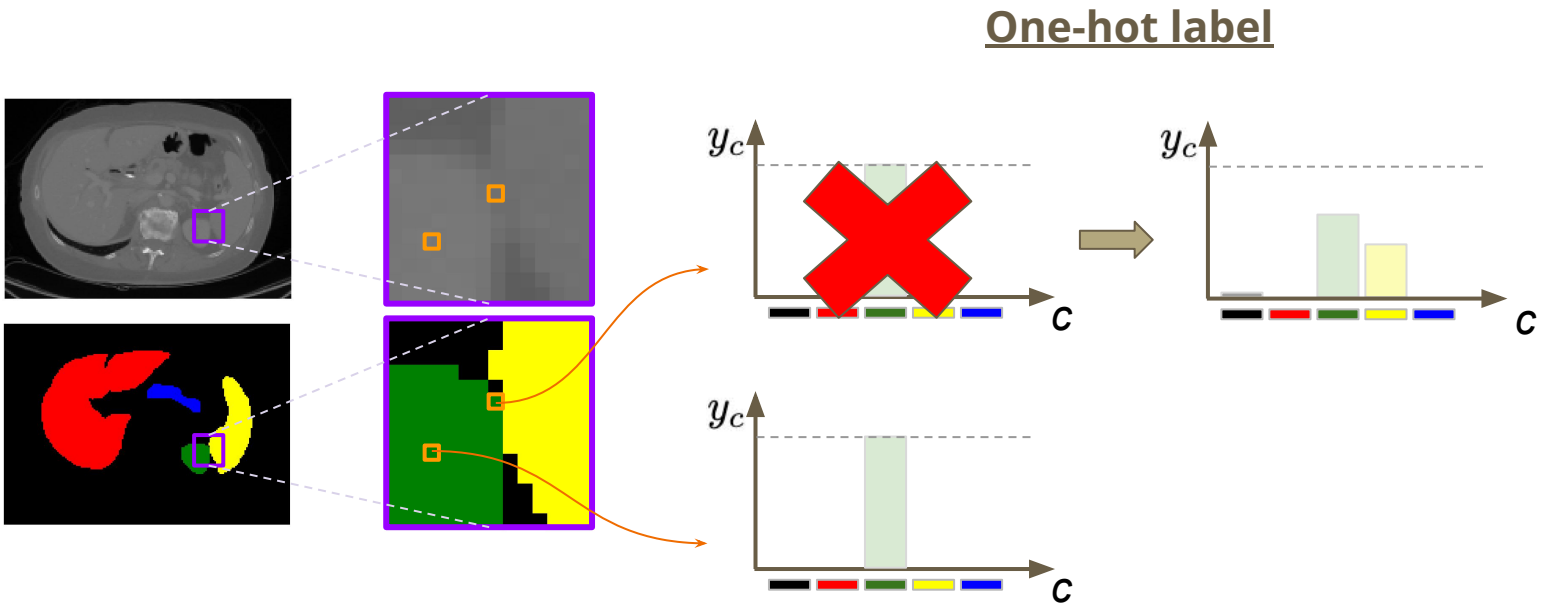
Brain tumour [2]

- Cross-entropy (CE) objective function
  - One-Hot (OH) representation



[1] FLARE'21: Ma *et al.*, MedIA 2022
[2] BraTS19: Bakas *et al.*, Scientific data 2017, Arxiv 2018

Spatial Ambiguity

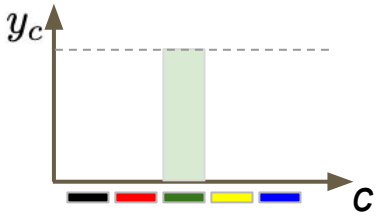


➢ OH label ignores spatial relationships as well as class relationships

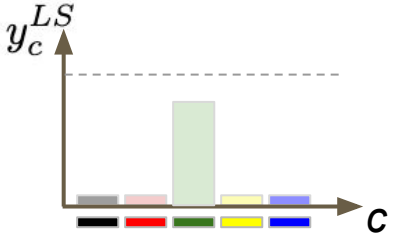
FLARE'21: Ma *et al.*, MedIA 2022

Soft labeling methods

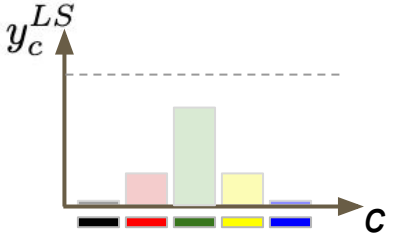
- Label Smoothing (LS)



One-hot representation



Uniform LS [1]



Non-uniform LS [2]

➢ These methods ignore the spatial relationship

[1] Szegedy et al., CVPR 2016
[2] Galdran et al., TVST 2021

Spatial-aware Soft labeling approaches

- Spatially Varying Label smoothing (SVLS) [3]

➢ All these methods rely on a target mask

[1] Dilating labels: Kats et al., ISBI 2019
[2] SoftSeg: Gros et al., MedIA 2021
[3] SVLS: Islam et al., IPMI 2021

Motivation

- Soft labeling approaches neglect **image intensities**

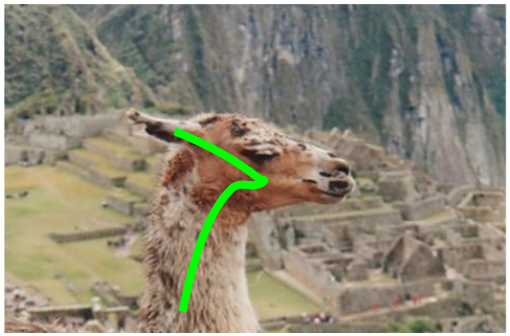
- **Research Question**:

  ➢ Can we integrate **image-context information** in the label smoothing process?

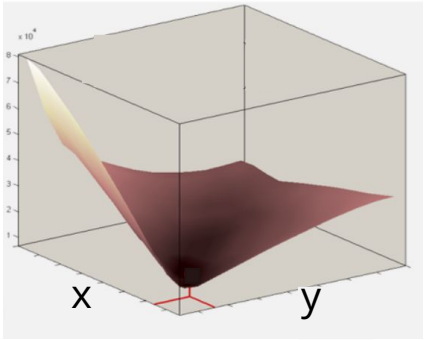
- **How**:

  ➢ We leverage the **generalized geodesic distance transform** to obtain image-aware distributions

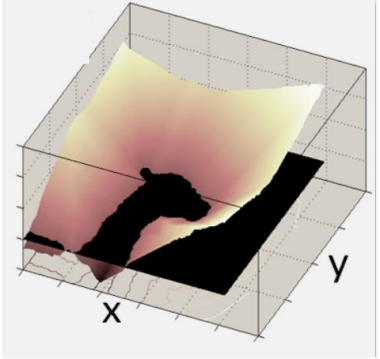
Generalized Geodesic Distance Transform (GGDT) [1]



Euclidean Distance



Generalized Geodesic Distance



[1] Criminisi *et al.*, ECCV 2008

Generalized Geodesic Distance Transform (GGDT) [1]

- Generalized geodesic distance of each pixel ***v*** to seed set ***S***

$$D_c(v; \mathcal{S}, x_i) = \min_{v' \in \mathcal{S}} d(v, v'),$$

where $$d(v, v') = \min_{p \in P_{v,v'}} \int \sqrt{||p'(s)||^2 + \gamma^2 (\nabla x_i \cdot u(s))^2} ds,$$

Euclidean distance

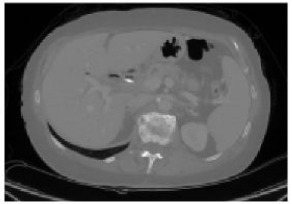
image gradient

Set of all paths

balance b/w Geodesic and Euclidean distance

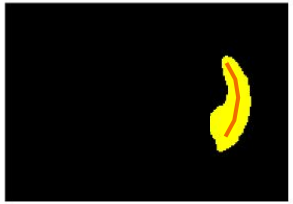
[1] Criminisi *et al.*, ECCV 2008

How to generate Geodesic Maps?

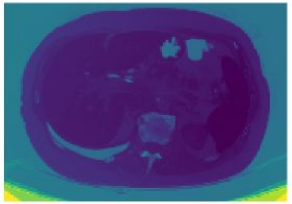


Image

Label

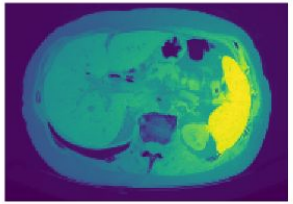


Seed points
(Skeleton)



GGDT

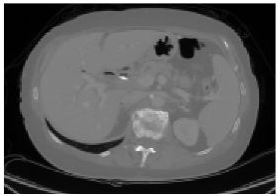
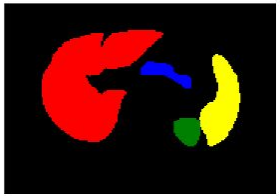
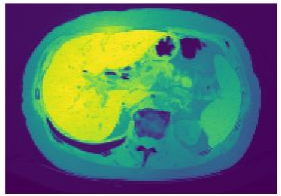
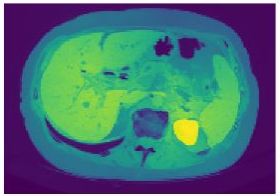
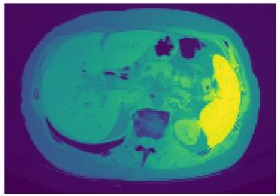
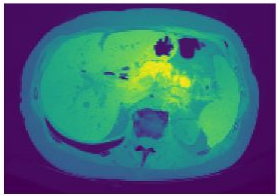
$$D_c$$



Geodesic Map

$$g_c = e^{-D_c}$$

Geodesic Maps

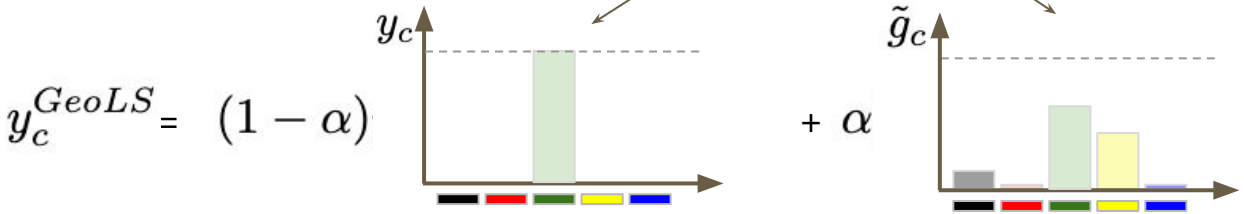
[1] GeodisTK (https://github.com/taigw/GeodisTK)

GeoLS: Geodesic Label Smoothing

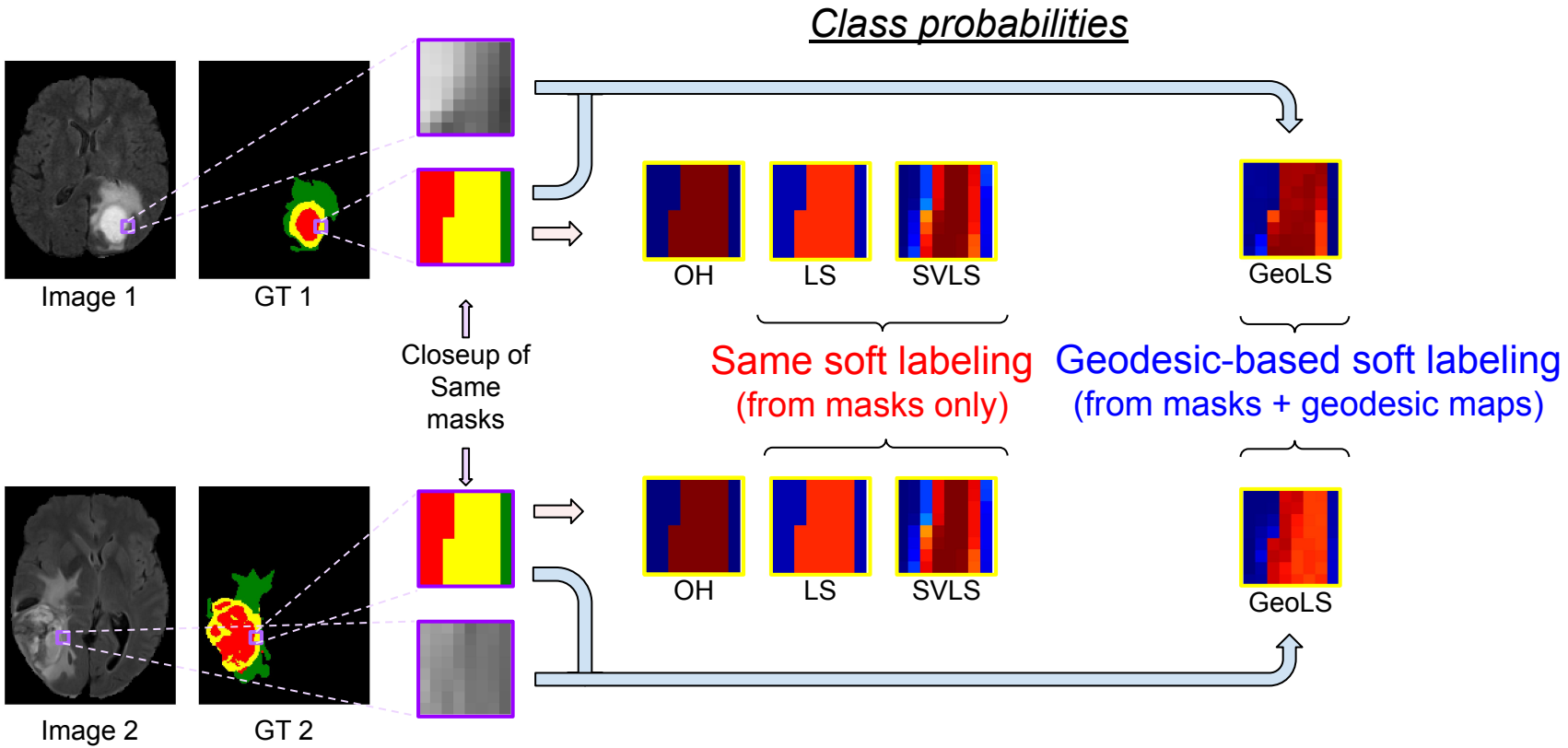
- Normalize the geodesic maps: $\tilde{g}_c = \frac{g_c}{\sum_c g_c},$

- Proposed geodesic label smoothing: $y_c^{GeoLS} = (1-\alpha)y_c + \alpha\tilde{g}_c$

Image-aware



Comparison of Soft labels



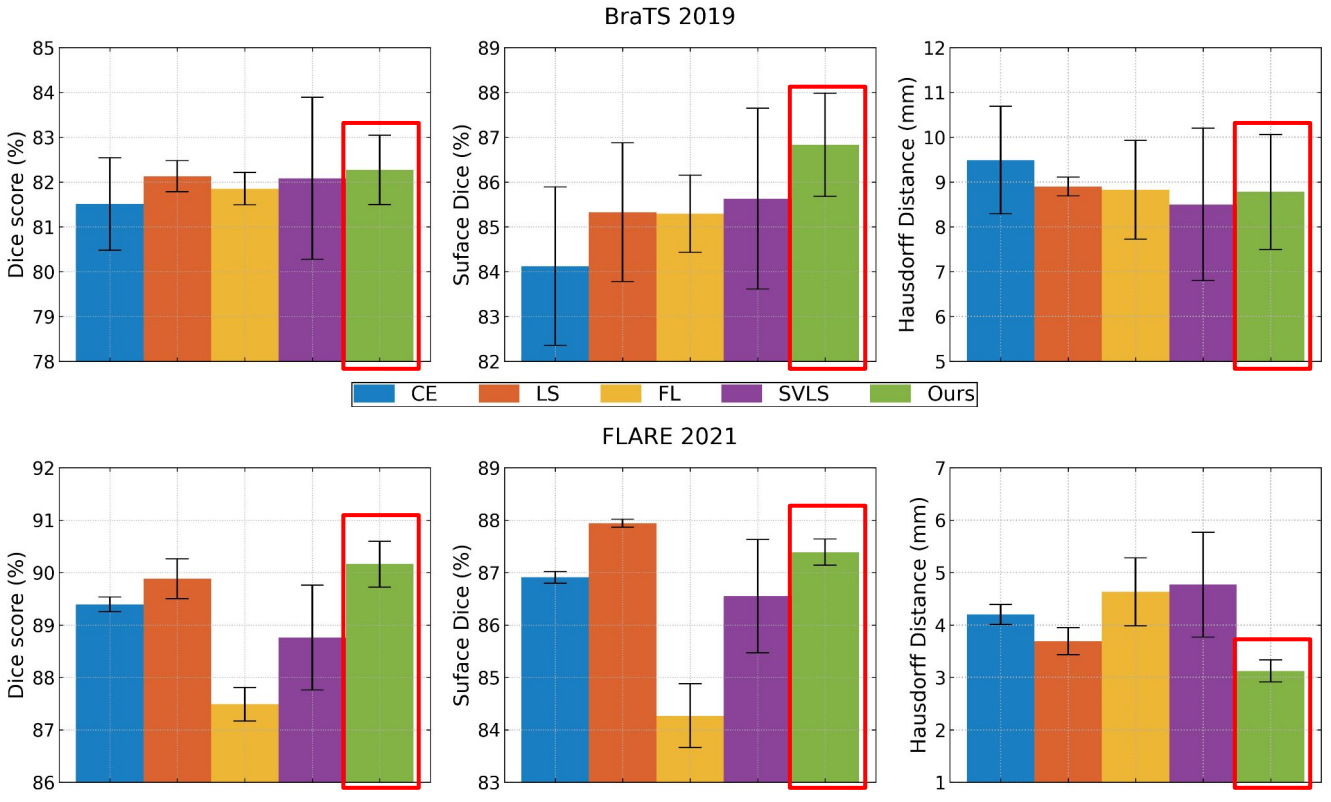
Results

Segmentation performance

BraTS 2019
FLARE 2021

CE
LS[1]
FL[2]
SVLS[3]

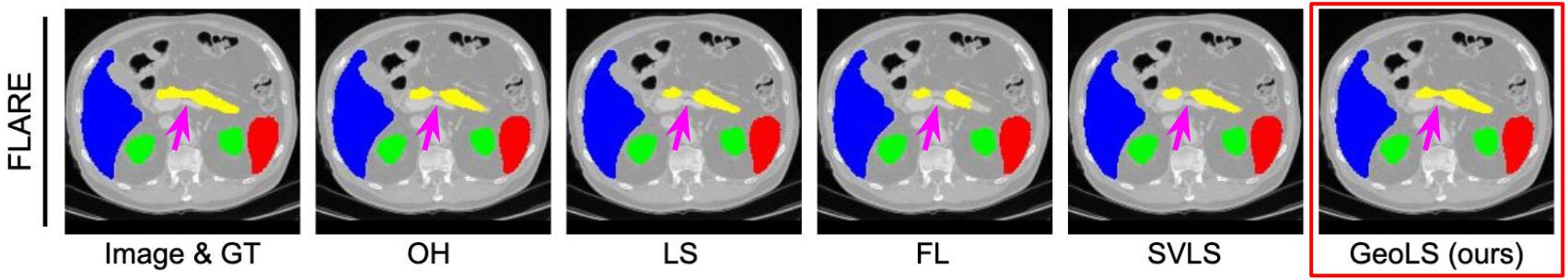
Dice ↑
SD ↑
HD ↓



➢ **Our method consistently improves segmentation performance**

[1] LS : Szegedy et al., CVPR 2016
[2] FL : Lin et al., 2017
[3] SVLS : Islam et al., IPMI 2021

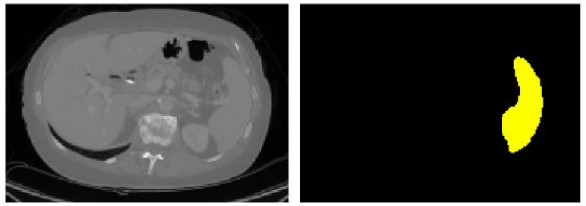
Qualitative Results



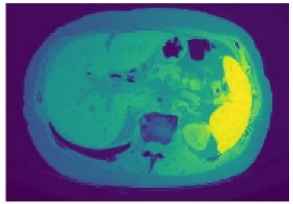
➢ **GeoLS minimizes misclassification errors in challenging regions**

Conclusion

- **Proposal**: **Geodesic label smoothing** for image segmentation
  - integrates **image-aware** distribution
  - captures **inter-class** relationships



- **Results**: Our method
  - **consistently** yields superior performance
  - improves segmentation in **challenging** regions



Take-home message:

Geodesic-based labeling adds image-context to the label smoothing methods

Extra slides

Choice of seed set S

Datasets	BraTS		FLARE	
choice of $\mathcal{S}$	**DSC (%) ↑**	**HD (mm) ↓**	**DSC (%) ↑**	**HD (mm) ↓**
random-3	**82.98 ± 0.68**	**8.10 ± 0.09**	87.83 ± 1.02	4.79 ± 0.16
random-5	82.51 ± 0.80	9.00 ± 0.70	89.46 ± 1.00	4.20 ± 0.97
random-7	82.36 ± 0.48	8.89 ± 0.81	89.23 ± 0.21	4.41 ± 0.49
skeleton	82.27 ± 0.77	8.78 ± 1.28	**90.16 ± 0.44**	**3.12 ± 0.21**
erosion	81.93 ± 0.93	9.17 ± 0.68	89.56 ± 0.08	3.63 ± 0.27

➢ skeleton-based seed strategy is consistent across both datasets

Sensitivity of smoothing factor α