SemSegLoss: A python package of loss functions for semantic segmentation

Shruti Jadon
Sunnyvale, CA 95134

Abstract

Image Segmentation has been an active field of research as it has a wide range of applications, ranging from automated disease detection to self-driving cars. In recent years, various research papers proposed different loss functions used in case of biased data, sparse segmentation, and unbalanced dataset. In this paper, we introduce SemSegLoss, a python package consisting of some of the well-known loss functions widely used for image segmentation. It is developed with the intent to help researchers in the development of novel loss functions and perform an extensive set of experiments on model architectures for various applications. The ease-of-use and flexibility of the presented package have allowed reducing the development time and increased evaluation strategies of machine learning models for semantic segmentation. Furthermore, different applications that use image segmentation can use SemSegLoss because of the generality of its functions. This wide range of applications will lead to the development and growth of AI across all industries.

Keywords: Deep Learning, Image Segmentation, Medical Imaging, Loss functions

Introduction

In recent years, Deep Learning has transformed multiple industries ranging from software to manufacturing. The medical community has also benefited from Deep Learning. There have been multiple innovations in disease classification, for example, lesion segmentation using U-Net and cancer detection using SegNet. Image segmentation is one of the crucial contributions of the deep learning community. Image Segmentation can be defined as a classification task on the pixel level. An image consists of various pixels, and these grouped pixels define different elements in an image. A method of classifying these pixels into elements is called semantic image segmentation. The choice of loss/objective function is critical while designing complex image
segmentation-based deep learning architectures as they instigate the learning process of the algorithm. Therefore, since 2012, researchers have experimented with various domain-specific loss functions to improve the model’s performance on their datasets. This paper has introduced SemSegLoss, a python-based package consisting of some well-known loss functions widely used for image segmentation. Our implementation is available at GitHub: https://GitHub.com/shruti-jadon/Semantic-Segmentation-Loss-Functions.

Table 1: Types of Semantic Segmentation Loss Functions [8]

| Type                      | Loss Function                                                                 |
|---------------------------|-------------------------------------------------------------------------------|
| Distribution-based Loss   | Binary Cross-Entropy[28]                                                       |
|                           | Weighted Cross-Entropy[18]                                                    |
|                           | Balanced Cross-Entropy[26]                                                    |
|                           | Focal Loss[12]                                                                |
|                           | Distance map derived loss penalty term[3]                                     |
| Region-based Loss         | Dice Loss[22]                                                                 |
|                           | Sensitivity-Specificity Losshashemi2018asymmetric                              |
|                           | Tversky Loss[21]                                                              |
|                           | Focal Tversky Loss[1]                                                         |
|                           | Log-Cosh Dice Loss[8]                                                         |
| Boundary-based Loss       | Hausdorff Distance loss[11]                                                   |
|                           | Shape aware loss[6]                                                           |
| Compounded Loss           | Combo Loss[24]                                                                |
|                           | Exponential Logarithmic Loss[25]                                               |

1. Impact Overview

SemSegLoss have a wide variety of application ranging from medicine to self-driving. While creating an optimal deep learning model, it is crucial to select the correct objective function (also known as loss functions). Therefore, it is crucial to have such frameworks that facilitate the research and development of these objective functions. However, to our knowledge, no other package provides a collection of loss functions for semantic segmentation. For this reason, all current researchers in this area are forced to spend hours searching for implementations or write their code. This process slows down the research of labs and sometimes hinders the experiment range. The main objective of SemSegLoss is to provide an easy way to experiment with
various objective functions and determine the best possible approach, i.e.,
selecting loss function, which is giving the best performance and optimizing
in fewer steps.

Furthermore, current segmentation-based loss functions are developed
mainly by researchers with extensive knowledge of deep learning, linear al-
gebra, and optimization. Nevertheless, thanks to the ease of use of SemSe-
gLoss, more users will start research in this area. One of the strengths of this
framework is that it is entirely written in Python, a programming language
with an easy-to-understand syntax. In recent years a majority of machine
learning-related development happened in Python. Moreover, it is also easy
to modify or extend with not already implemented functionalities. Addition-
ally, Python’s flexibility facilitates the integration with modules written in
other programming languages. SemSegLoss is a recently developed python
package. It has received recognition from various researchers on GitHub.
Simultaneously, SemSegLoss has been used to:

1. **Create Novel Loss Functions**: SemSegLoss GitHub repo has been
   used to set-up the experiments for the claims of novel proposed loss
   functions such as Tilted Cross Entropy\cite{23} loss function, Mixed focal
   loss function\cite{27}, and Soft Segmentation Loss Function\cite{4}

2. **Perform Segmentation based experiments**: SemSegLoss code im-
   plementation is easy to follow which allowed applications to use the
code implementation of loss functions for their segmentation based
experiments. For example, cardiac function assessment in embryonic
zebrafish\cite{15}, analyzing natural disaster aftermath from satellite images
\cite{16}, and wildfire detection\cite{14}

In all listed use-cases, the results obtained using SemSegLoss GitHub code
implementation have provided researchers the ability to do choose the correct
loss function to improve the models’ performance.

2. **Functionalities and key features**

   SemSegLoss currently has twelve widely used loss functions classified into
four types as shown in table\cite{11}. If end-users want to analyze the efficiency of
segmentation model architecture, they can use the diverse implementation
of baseline Binary Cross-Entropy loss to Focal Tversky loss. Apart from
the loss functions, the framework can also evaluate the model performance
using different statistical analyses such as precision, recall, specificity, and
Dice Coefficient. Using the SemSegLoss package, any programmer can exper-
iment with loss functions and analyze the results using performance-based
functionalities.
3. Conclusions and further development

SemSegLoss package provides easy-to-use loss functions to analyze and experiment with different approaches when developing an efficient segmentation-based model. Researchers and developers can take advantage of this package due to its simplicity. We intend to add more advanced loss function techniques such as Correlation Maximized, Structural Similarity Loss, and Distance map derived loss penalty term for medical-based image segmentation in future versions. We are also planning to upload the SemSegLoss package to PyPI to facilitate its distribution and use.

4. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Nabila Abraham and Naimul Mefraz Khan. A novel focal tversky loss function with improved attention u-net for lesion segmentation. In 2019 IEEE 16th International Symposium on Biomedical Imaging (ISBI 2019), pages 683–687. IEEE, 2019.

[2] Maxim Berman, Amal Ramen Triki, and Matthew B. Blaschko. The lovász-softmax loss: A tractable surrogate for the optimization of the intersection-over-union measure in neural networks, 2017.

[3] Francesco Caliva, Claudia Iriondo, Alejandro Morales Martinez, Sharmila Majumdar, and Valentina Pdeoia. Distance map loss penalty term for semantic segmentation. arXiv preprint arXiv:1908.03679, 2019.

[4] Charley Gros, Andreeanne Lemay, and Julien Cohen-Adad. Softseg: Advantages of soft versus binary training for image segmentation. Medical Image Analysis, 71:102038, 2021.

[5] Seyed Raein Hashemi, Seyed Sadegh Mohseni Salehi, Deniz Erdogmus, Sanjay P Prabhu, Simon K Warfield, and Ali Gholipour. Asymmetric loss functions and deep densely-connected networks for highly-imbalanced medical image segmentation: Application to multiple sclerosis lesion detection. IEEE Access, 7:1721–1735, 2018.

[6] Zeeshan Hayder, Xuming He, and Mathieu Salzmann. Shape-aware instance segmentation. arXiv preprint arXiv:1612.03129, 2(5):7, 2016.
[7] Yaoshiang Ho and Samuel Wookey. The real-world-weight cross-entropy loss function: Modeling the costs of mislabeling. *IEEE Access*, 8:4806–4813, 2019.

[8] Shruti Jadon. A survey of loss functions for semantic segmentation. In *2020 IEEE Conference on Computational Intelligence in Bioinformatics and Computational Biology (CIBCB)*, pages 1–7. IEEE, 2020.

[9] Shruti Jadon, Owen P. Leary, Ian Pan, Tyler J. Harder, David W. Wright, Lisa H. Merck, and Derek L. Merck. A comparative study of 2D image segmentation algorithms for traumatic brain lesions using CT data from the ProTECTIII multicenter clinical trial. In Po-Hao Chen and Thomas M. Deserno, editors, *Medical Imaging 2020: Imaging Informatics for Healthcare, Research, and Applications*, volume 11318, pages 195–203. International Society for Optics and Photonics, SPIE, 2020.

[10] Aatif Jiwani, Shubhrakanti Ganguly, Chao Ding, Nan Zhou, and David M Chan. A semantic segmentation network for urban-scale building footprint extraction using rgb satellite imagery. *arXiv preprint arXiv:2104.01263*, 2021.

[11] Davood Karimi and Septimiu E Salcudean. Reducing the hausdorff distance in medical image segmentation with convolutional neural networks. *IEEE Transactions on medical imaging*, 39(2):499–513, 2019.

[12] TY Lin, P Goyal, R Girshick, K He, and P Dollár. Focal loss for dense object detection. arxiv 2017. *arXiv preprint arXiv:1708.02002*, 2002.

[13] Jan Hendrik Moltz, Annika Häschn, Bianca Lassen-Schmidt, Benjamin Haas, A Genghi, J Schreier, Tomasz Morgas, and Jan Klein. Learning a loss function for segmentation: A feasibility study. In *2020 IEEE 17th International Symposium on Biomedical Imaging (ISBI)*, pages 357–360. IEEE, 2020.

[14] Simone Monaco, Andrea Pasini, Daniele Apiletti, Luca Colomba, Paolo Garza, and Elena Baralis. Improving wildfire severity classification of deep learning u-nets from satellite images. In *2020 IEEE International Conference on Big Data (Big Data)*, pages 5786–5788, 2020.

[15] Amir Mohammad Naderi, Haisong Bu, Jingcheng Su, Mao-Hsiang Huang, Khuong Vo, Ramses Seferino Trigo Torres, J-C Chiao, Juhyun
Lee, Michael PH Lau, Xiaolei Xu, et al. Deep learning-based framework for cardiac function assessment in embryonic zebrafish from heart beating videos. *arXiv preprint arXiv:2102.12173*, 2021.

[16] Victor Oludare, Landry Kezebou, Karen Panetta, and Sos Agaian. Semi-supervised learning for improved post-disaster damage assessment from satellite imagery. In *Multimodal Image Exploitation and Learning 2021*, volume 11734, page 117340O. International Society for Optics and Photonics, 2021.

[17] Shiwen Pan, Wei Zhang, Wanjun Zhang, Liang Xu, Guohua Fan, Jianping Gong, Bo Zhang, and Haibo Gu. Diagnostic model of coronary microvascular disease combined with full convolution deep network with balanced cross-entropy cost function. *IEEE Access*, 7:177997–178006, 2019.

[18] Vasyl Pihur, Susmita Datta, and Somnath Datta. Weighted rank aggregation of cluster validation measures: a monte carlo cross-entropy approach. *Bioinformatics*, 23(13):1607–1615, 2007.

[19] Benjamin Puccio, James P. Pooley, John Pellman, Elise C Taverna, and R. Cameron Craddock. The preprocessed connectomes project repository of manually corrected skull-stripped t1-weighted anatomical mri data. *GigaScience*, 5, 2016.

[20] Javier Ribera, David Güera, Yuhao Chen, and Edward J. Delp. Weighted hausdorff distance: A loss function for object localization. *ArXiv*, abs/1806.07564, 2018.

[21] Seyed Sadegh Mohseni Salehi, Deniz Erdogmus, and Ali Gholipour. Tversky loss function for image segmentation using 3d fully convolutional deep networks. In *International Workshop on Machine Learning in Medical Imaging*, pages 379–387. Springer, 2017.

[22] Carole H Sudre, Wenqi Li, Tom Vercauteren, Sebastien Ourselin, and M Jorge Cardoso. Generalised dice overlap as a deep learning loss function for highly unbalanced segmentations. In *Deep learning in medical image analysis and multimodal learning for clinical decision support*, pages 240–248. Springer, 2017.

[23] A. Szabó, H. J. Rad, and Siva-Datta Mannava. Tilted cross entropy (tce): Promoting fairness in semantic segmentation. *ArXiv*, abs/2103.14051, 2021.
[24] Saeid Asgari Taghanaki, Yefeng Zheng, S Kevin Zhou, Bogdan Georgescu, Puneet Sharma, Daguang Xu, Dorin Comaniciu, and Ghas-san Hamarneh. Combo loss: Handling input and output imbalance in multi-organ segmentation. *Computerized Medical Imaging and Graphics*, 75:24–33, 2019.

[25] Ken CL Wong, Mehdi Moradi, Hui Tang, and Tanveer Syeda-Mahmood. 3d segmentation with exponential logarithmic loss for highly unbalanced object sizes. In *International Conference on Medical Image Computing and Computer-Assisted Intervention*, pages 612–619. Springer, 2018.

[26] Saining Xie and Zhuowen Tu. Holistically-nested edge detection. In *Proceedings of the IEEE international conference on computer vision*, pages 1395–1403, 2015.

[27] Michael Yeung, Evis Sala, Carola-Bibiane Schönlieb, and Leonardo Rundo. A mixed focal loss function for handling class imbalanced medical image segmentation. *arXiv preprint arXiv:2102.04525*, 2021.

[28] Ma Yi-de, Liu Qing, and Qian Zhi-Bai. Automated image segmentation using improved pcnn model based on cross-entropy. In *Proceedings of 2004 International Symposium on Intelligent Multimedia, Video and Speech Processing, 2004.*, pages 743–746. IEEE, 2004.

[29] Shuai Zhao, Boxi Wu, Wenqing Chu, Yao Hu, and Deng Cai. Correlation maximized structural similarity loss for semantic segmentation. *arXiv preprint arXiv:1910.08711*, 2019.

**Required Metadata**

**Current code version**
| Nr. | Code metadata                                      | Details                                                                 |
|-----|---------------------------------------------------|-------------------------------------------------------------------------|
| C1  | Current code version                              | v.1.1                                                                   |
| C2  | Permanent link to code/repository used for this code version | For example: https://GitHub.com/shruti-jadon/Semantic-Segmentation-Loss-Functions |
| C3  | Permanent link to Reproducible Capsule            | https://codeocean.com/capsule/1815956/tree                              |
| C4  | Legal Code License                                | MIT                                                                     |
| C5  | Code versioning system used                       | git                                                                    |
| C6  | Software code languages, tools, and services used | Python                                                                 |
| C7  | Compilation requirements, operating environments & dependencies |                                                                         |
| C8  | If available Link to developer documentation/manual |                                                                         |
| C9  | Support email for questions                       | sjadon@umass.edu                                                     |

Table 2: Code metadata