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AI-based fluorescent labeling for cell line development

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Master thesis

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Erklärung

Hiermit versichere ich, dass ich diese Master thesis selbstständig verfasst habe. Ich habe dazu keine anderen als die angegebenen Quellen und Hilfsmittel verwendet.

Düsseldorf, den 29. August 2022

Hanna Pankova

Abstract

Cell line development is an expensive and time-consuming process, however that is the most modern approach for producing the proteins needed in pharmaceuticals.

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1 Introduction

1.1 Motivation

1.2 Notation

2 Domain knowledge

2.1 Biology

2.1.1 Cell line development process

General theory behind the cell line development process. Starting from what proteins are. How cells are developed. Difficulties of the cell line development process and timelines.

2.1.2 Project specifications of cell line development for Merck KgaA

Description of my project, why is it useful, what are the processes here. How my neural network can be used for further stability predictions.

2.2 Deep learning and machine learning basics

Introduction of the notation for the dataset, parameters, predictions.

2.2.1 Neural networks

Convolutional neural network, Autoencoder, embedding, optimizers, regularization, descriptions of how each layer works.

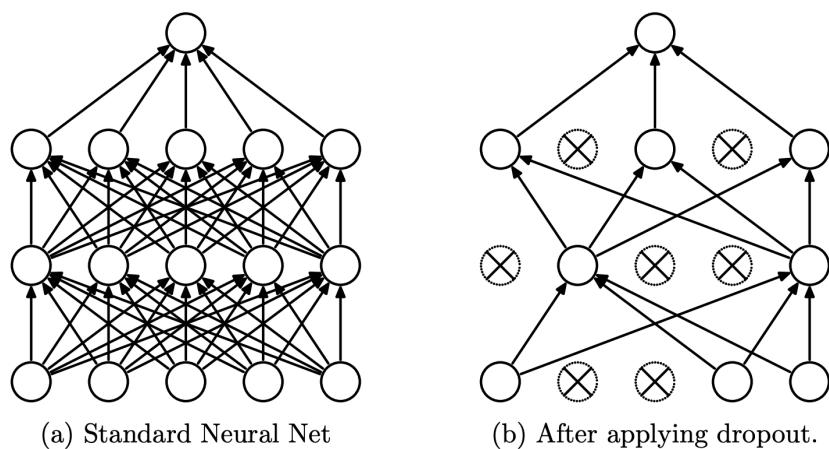


Figure 1: Dropout

2.2.2 Clustering

Theory of clustering algorithms, DBSCAN, HDBSCAN, PCA

2.3 Imaging

2.3.1 Digital imaging

How image is stored in memory, which conventions there are (RGB, BGR (conventions are used in corruptions augmentations)).

2.3.2 Microscopy imaging

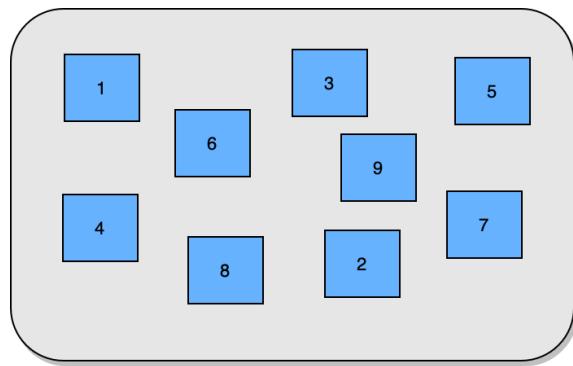


Figure 2: Way in which photos of the well-plate were taken

Which difficulties it may cause (validation loss is lower than train loss)

3 Model training

3.1 Neural network architecture

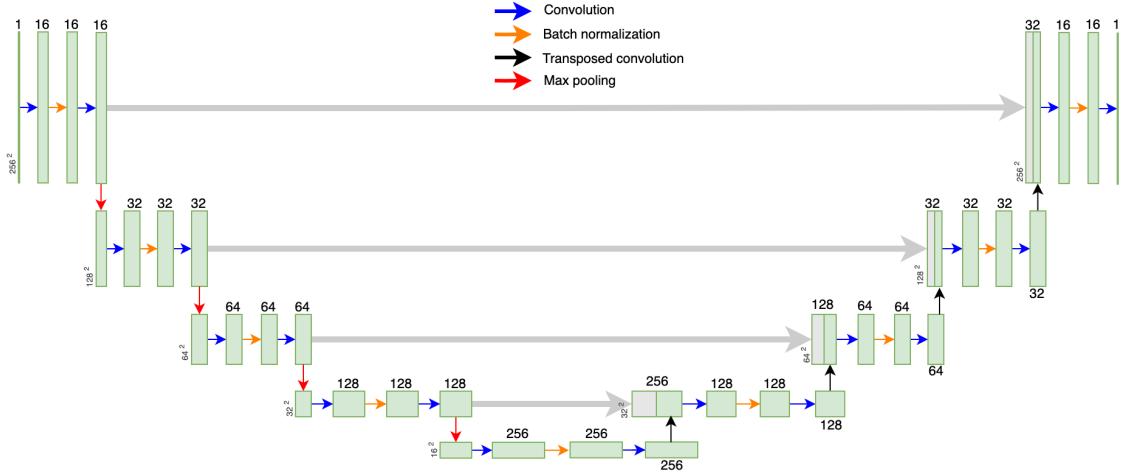


Figure 3: Unet

And information on the embeddings, output sizes, amount of parameters, etc.

3.2 Loss functions

Which loss functions were used, Pearson correlation coefficient explained.

3.3 Available data

Description of the datasets and the amount of images in each category.

Table 1: Available data for each fo the organelles

	Total images	Training crops	Validation crops	Test crops
Nuclei	595	27,264	3,008	7,616
Actin	400	18,432	2,048	5120
Golgi	761	23,036	2,336	6,347
H19	400	?	?	?
Nucleolei	?	?	?	?

3.4 Training costs estimation

Table with the estimation of costs and times for AWS

3.5 Augmentations

Description of all augmentations used

3.5.1 Smart augmentations for rotation and scaling

3.6 Convergence

Images of train and validation loss.

3.7 Model setup

3.7.1 Weight Initialization

These plots represent MSE

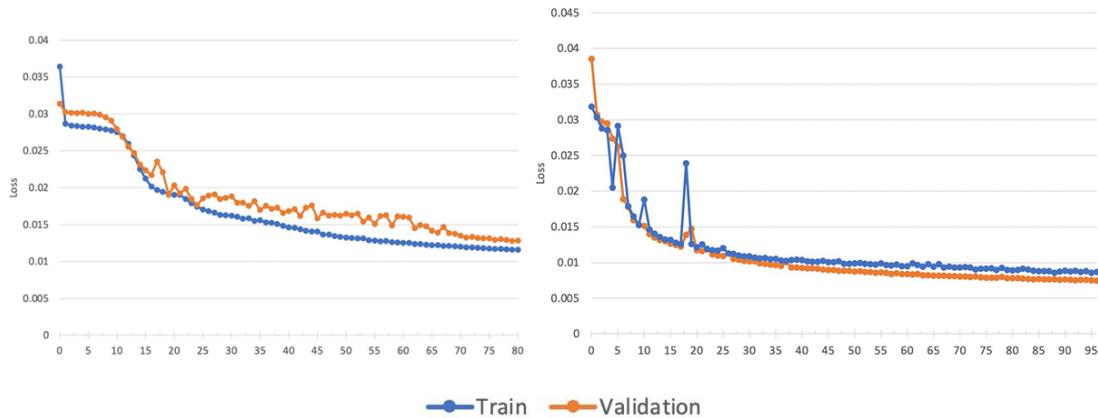


Figure 4: Nuclei training without and with custom weight initialization

3.7.2 Regularization

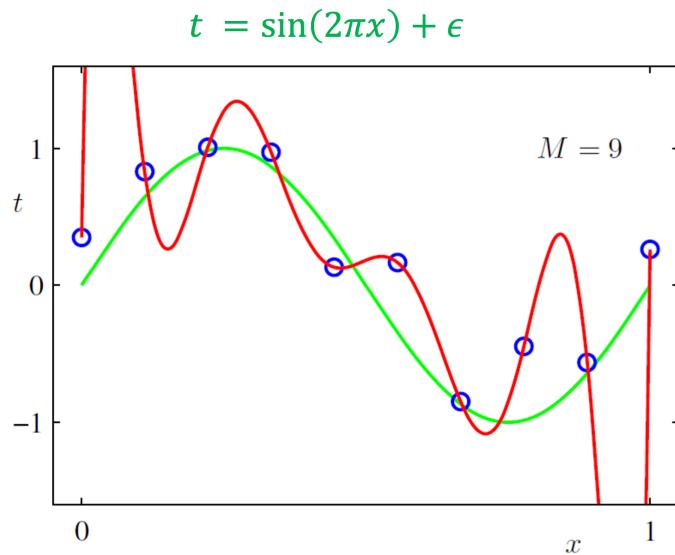


Figure 5: Overfitting

3.7.3 Optimizers

Comparison of different optimizers

4 Nuclei

4.1 Preprocessing

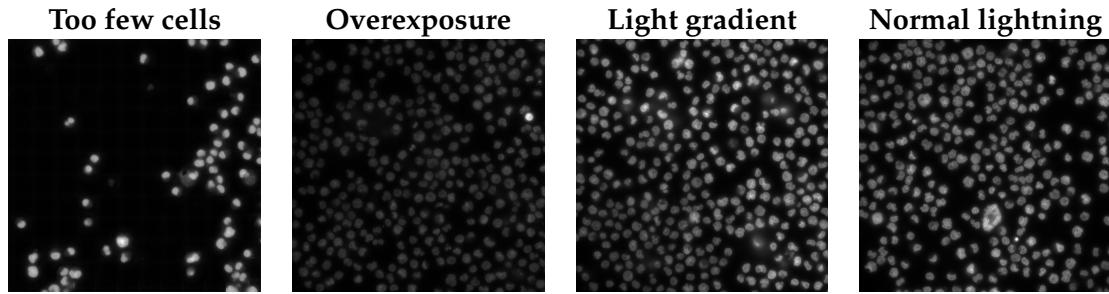


Figure 6: Different lightning conditions

4.1.1 Thresholding algorithms

Global and local thresholding

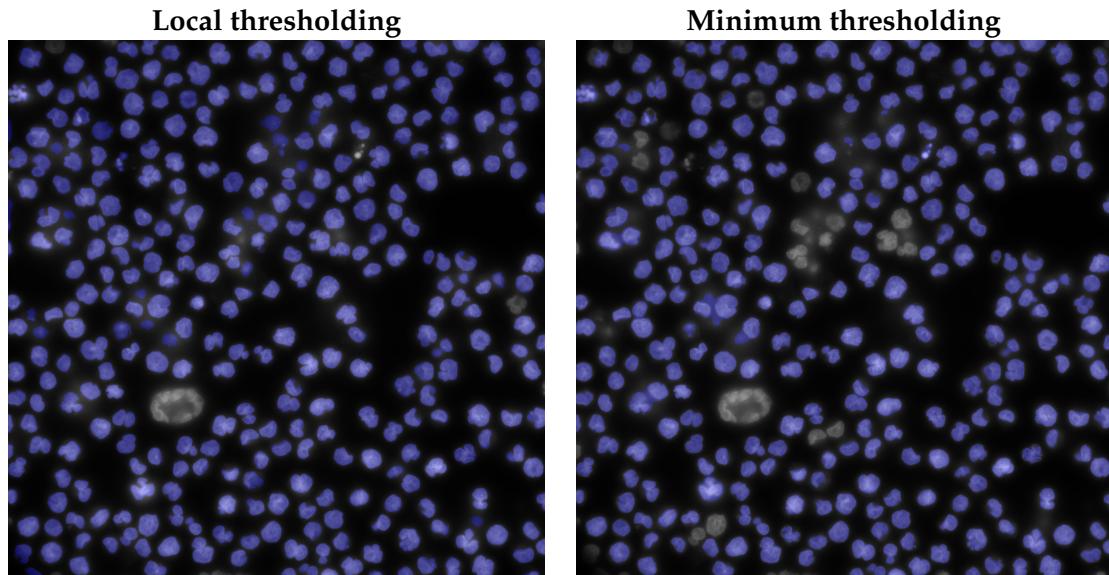


Figure 8: Local vs. Global thresholding (normal conditions)

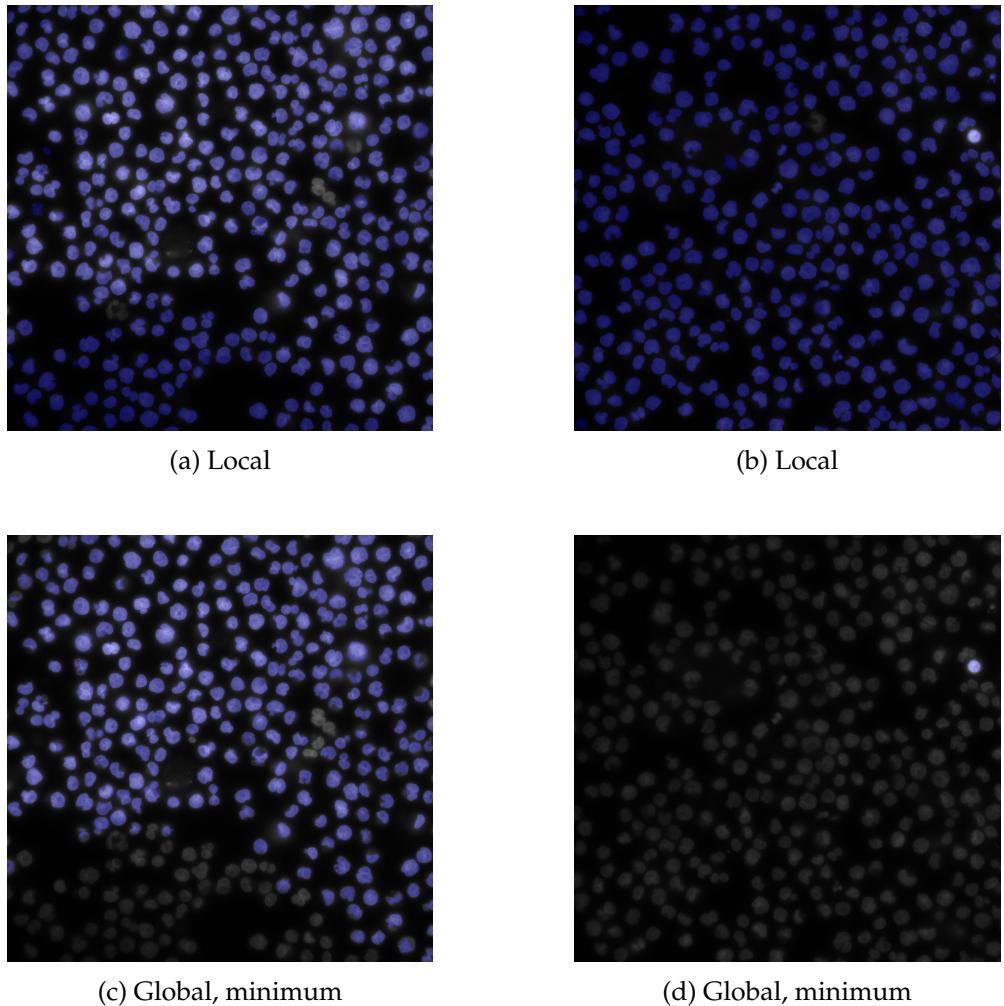


Figure 7: Local vs. Global thresholding

4.2 Training and predictions

4.2.1 Convergence

Has the model converged or not. Will more data help?

Not regularized yet, full dataset training with PCC

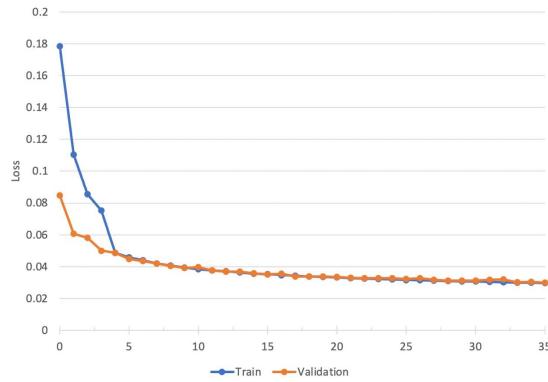


Figure 9: Having more data makes training more stable

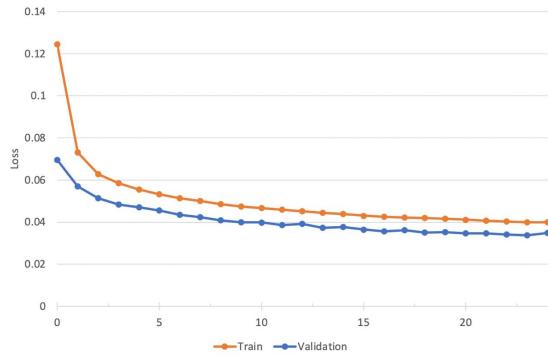


Figure 10: With regularization and augmentations PCC

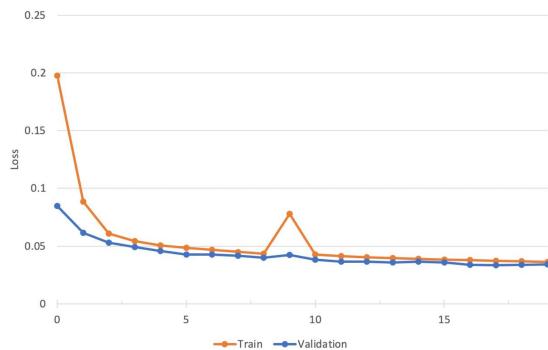


Figure 11: No regularization but augmentations

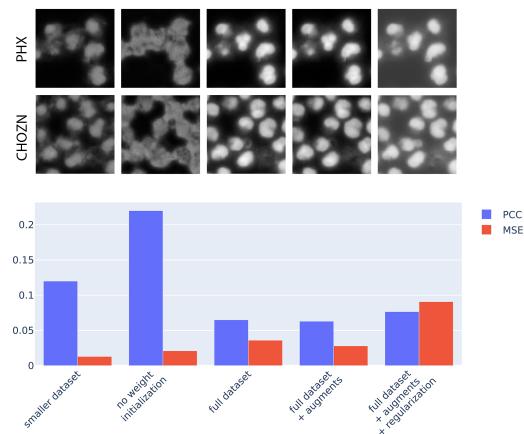


Figure 12: Difefrent models predictions and scores comparison

4.2.2 Predictions quality

Blurry, boundaries, not enough of details and possible improvements

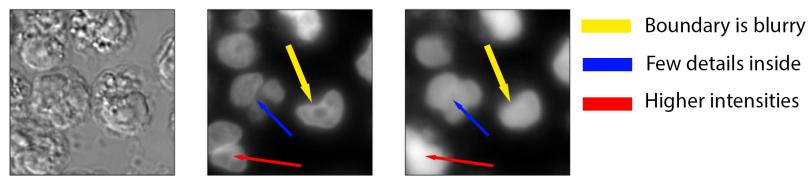


Figure 13: Some troubles in predictions

4.3 Postprocessing for nuclei segmentation

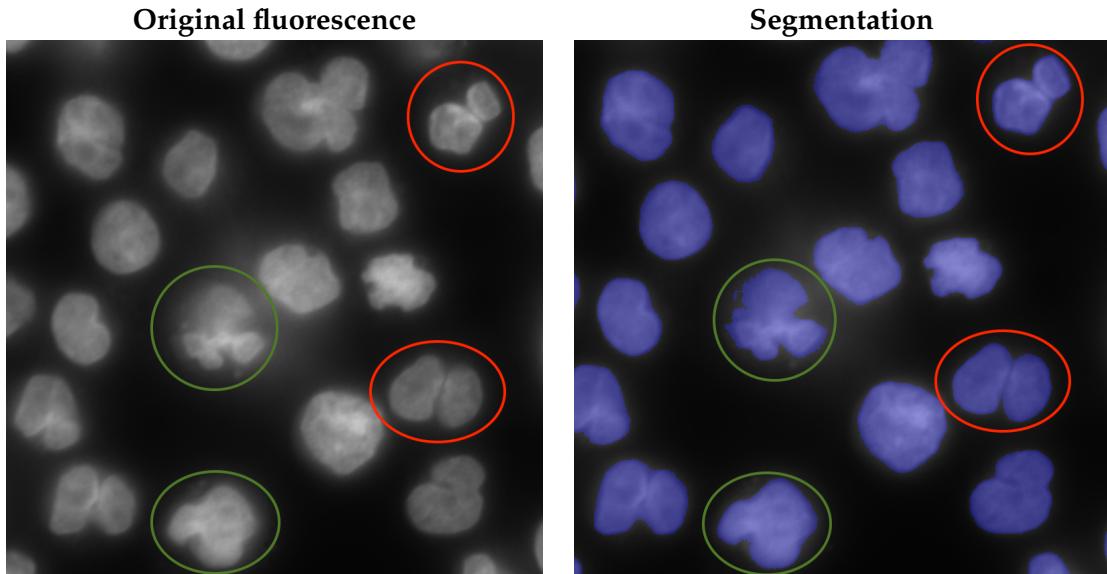


Figure 14: Closely located cells

Overall algorithm

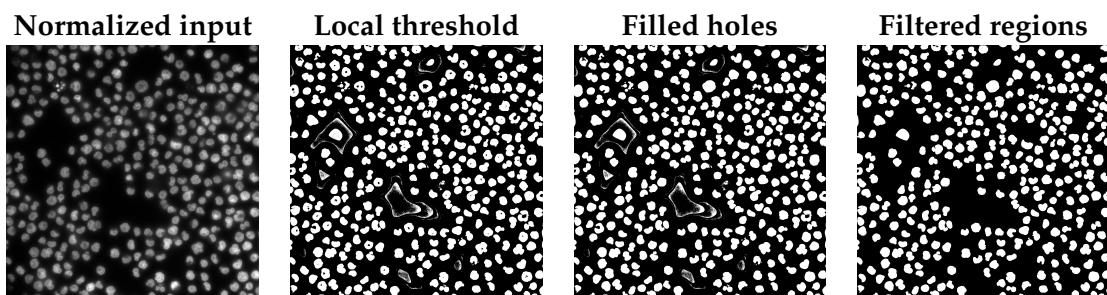


Figure 15: Fluorescence segmentation

4.4 Influence of scaling on predictions quality

Examples of predictions quality with different scales.

5 Actin

5.1 Preprocessing

Algorithm 1 Fluorescence segmentation

1. Normalize image
 2. Apply global *threshold_mean* to receive initial mask.
 3. Zero out pixels outside the mask
 4. Apply local thresholding.
 5. Apply *fill_holes* transformation.
 6. Morphological opening from opencv and Gaussian blur.
 7. Run *findContours* from opencv in order to obtain separate regions and filter out too small regions.
-

Segmentation steps are also illustrated in Figure

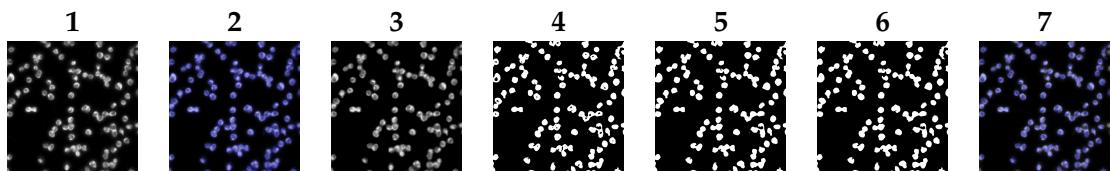


Figure 16: ER prediction

5.2 Training and predictions

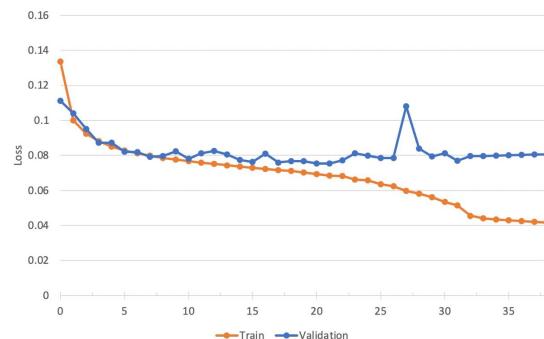


Figure 17: Overfit

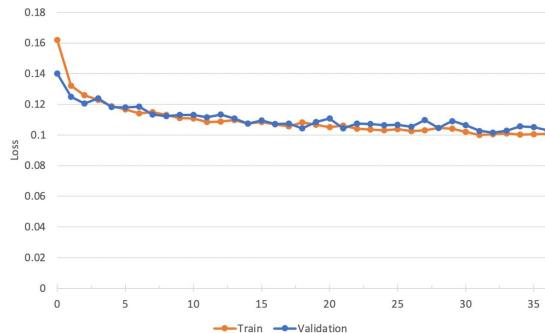


Figure 18: No overfit with augmentations

5.3 Postprocessing

5.4 Combination of nuclei and actin predictions

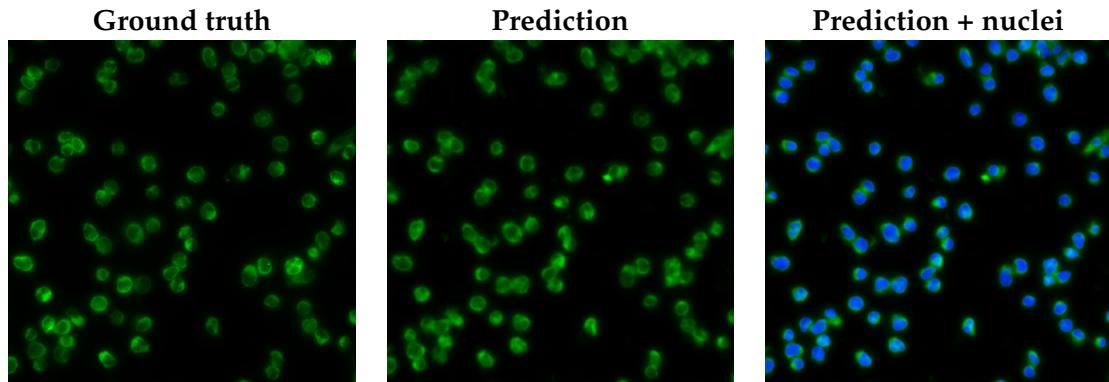


Figure 19: ER prediction

5.5 Prediction quality on the crop's border

5.6 Generalizability across phenotypes

6 Golgi

6.1 Preprocessing

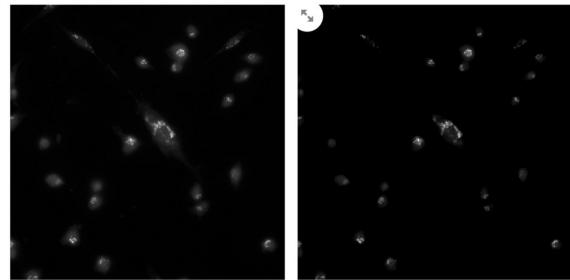


Figure 20: Golgi enhancement

6.1.1 Background removal algorithms

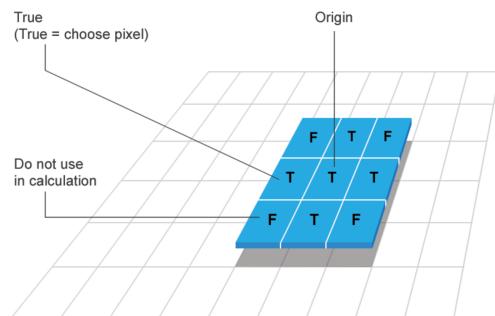


Figure 21: Structuring Element

Rolling ball algorithms

Rolling ball still leaves some noise

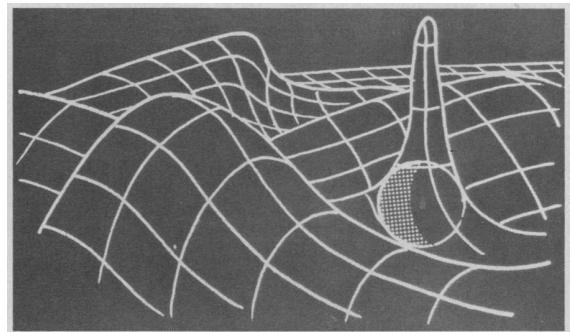


Figure 22: Rolling Ball

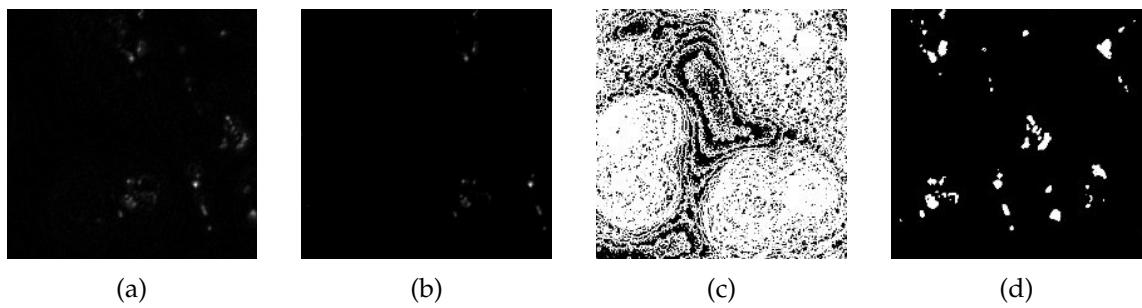


Figure 23: (a) Vanilla pre-processing with automatic background removal algorithm only; (b) Additional clipping of lower intensities after vanilla pre-processing; (c) masked or subfigure (a); (d) mask of subfigure (b)

6.2 Training and predictions

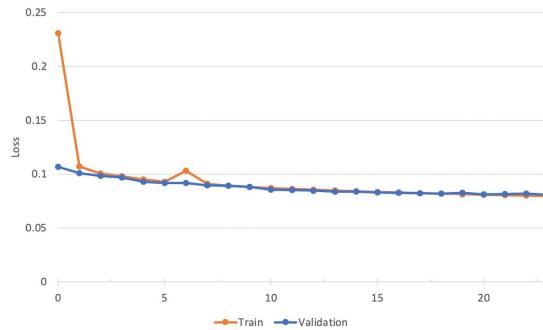


Figure 24: With regularization doesn't work

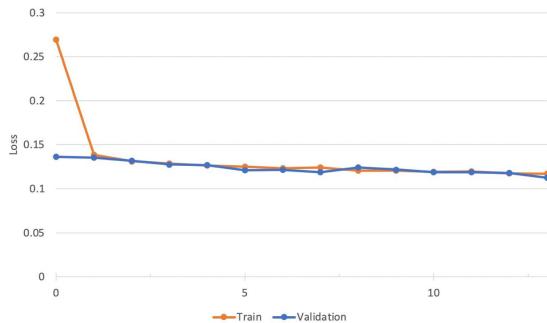


Figure 25: Without regularization doesn't work

6.3 Postprocessing

6.4 Alternative ways to improve predictions

6.4.1 Noise reduction methods

6.4.2 Asymmetrical losses

6.4.3 Use of gradient in loss

7 Nucleuolus and full cell prediction

7.1 Preprocessing

7.2 Predictions

7.3 Postprocessing

7.4 Combination of nucleuolus and nuclei

8 Model Evaluation

8.1 Crops combination technique

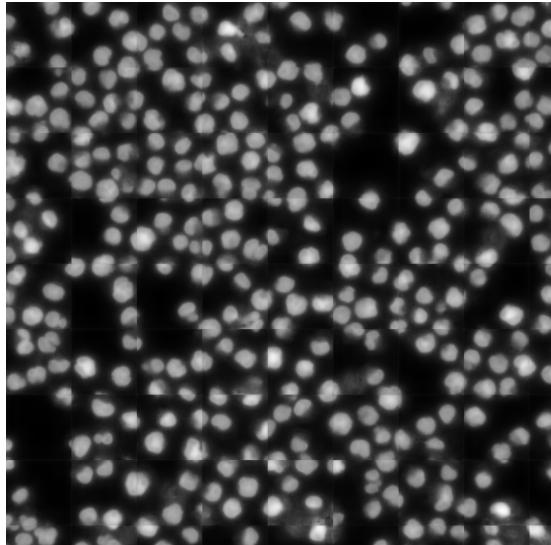


Figure 26: No overlap

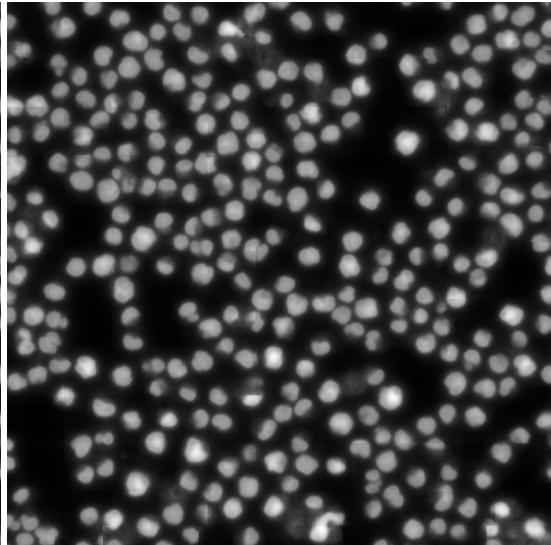


Figure 27: 30 pixels overlap

Improve this plot by showing the visible border explicitly, example of how it can influence a further segmentation perhaps?

8.2 Metrics for downstream tasks

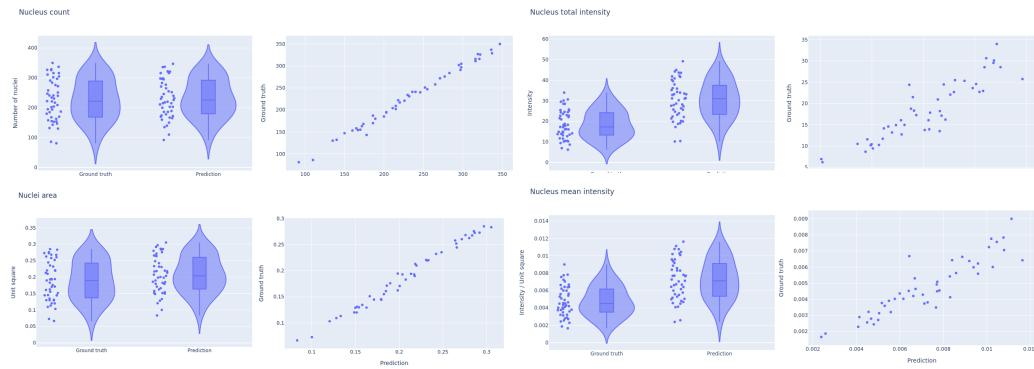


Figure 28: Metrics for downstream tasks on nuclei

Table 2: Correlation coefficients for downstream tasks

	Pearson	Spearman
Number of nuclei	0.995	0.994
Total intensity	0.902	.911
Mean intensity	0.907	0.904
Area	0.992	0.990

8.3 Influence of different loss functions on metrics for downstream tasks

9 Stability

9.1 Artificial corruptions

Description of artificial corruptions.

Table 3: Hyperparameter for different artificial corruption severities

Severity Corruption \	-5	-4	-3	-2	-1	0	1	2	3	4	5
Defocus blur (radius)						0	0.5	1.0	1.5	2	3
Contrast (gain)	3.5	3.0	2.5	2.0	1.5	1	0.9	0.8	0.7	0.5	0.3
Brightness (bias)	-150	-135	-120	-90	-50	0	50	90	120	135	150

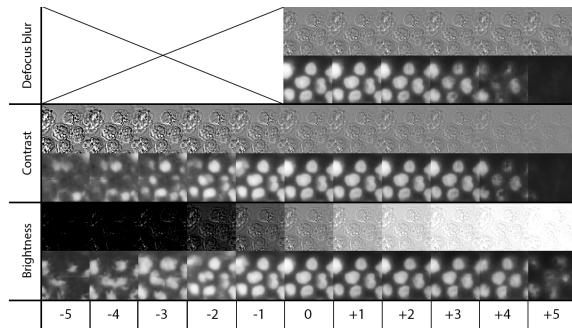


Figure 29: Influence of artificial corruptions on the predictions

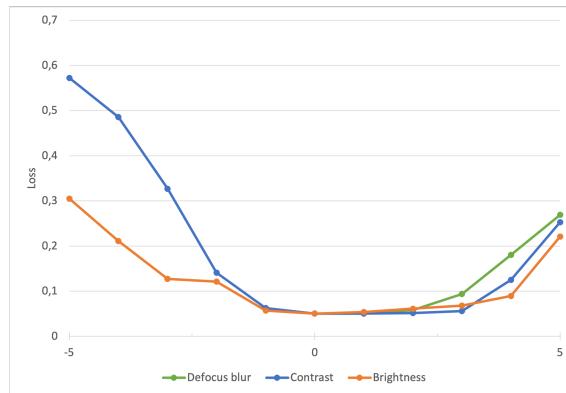


Figure 30: Change of loss for artificial corruptions

9.2 Real corruptions

9.3 Influence of corruptions on metrics for downstream tasks

9.4 Improving predictions with additional corruption augmentations

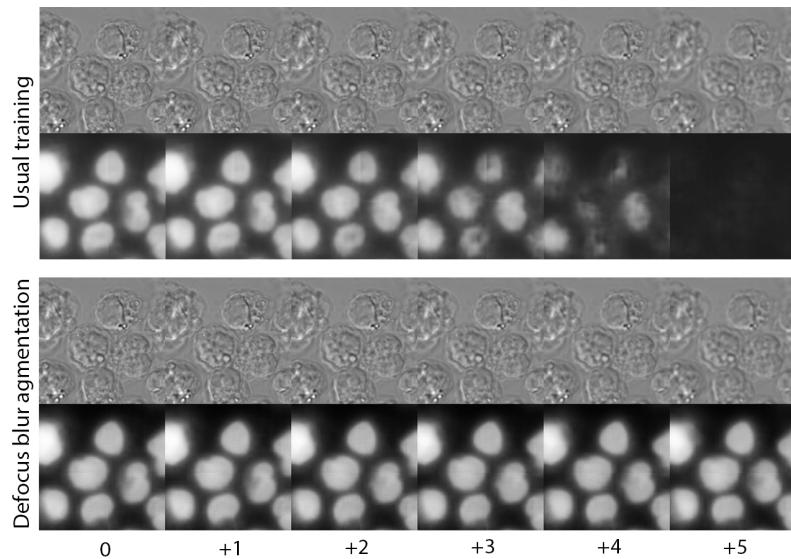


Figure 31: Using corruptions as augmentations improves predictions

10 Information in the UNET embeddings

10.1 Dimensionality reduction methods

10.2 UMAP, t-SNE, PCA

10.3 Autoencoder embeddings as an alternative

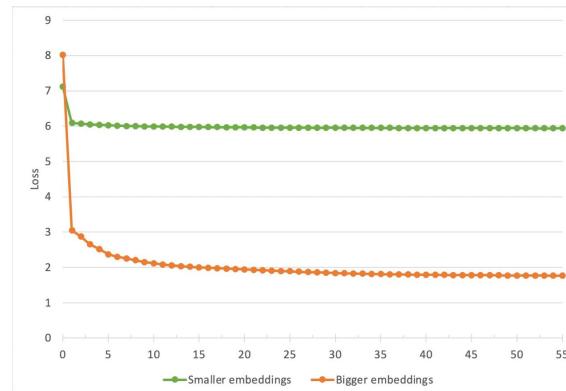


Figure 32: Autoencoders training convergence

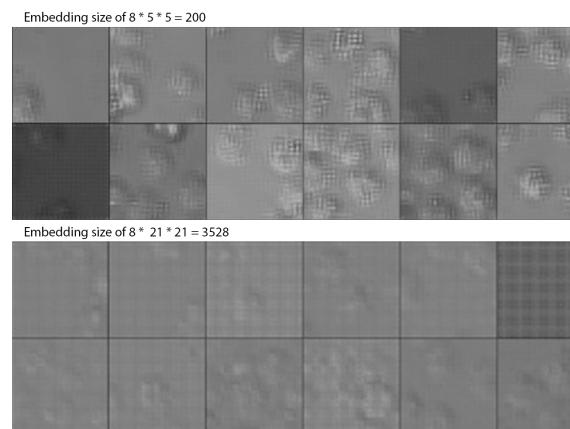


Figure 33: Samples drawn from the trained autoencoder

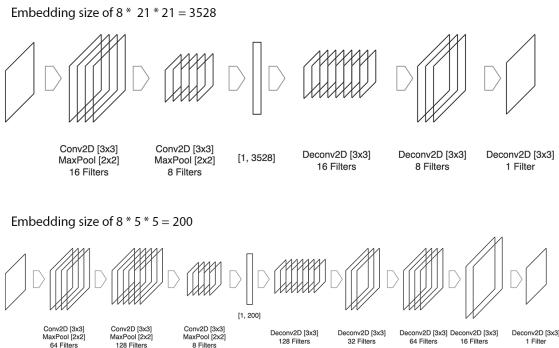


Figure 34: Architectures of two autoencoders

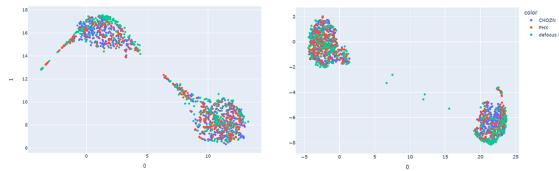


Figure 35: Autoencoder embeddings after applying PCA with 10 components and UMAP afterwards. Earlier epoch VS later epoch

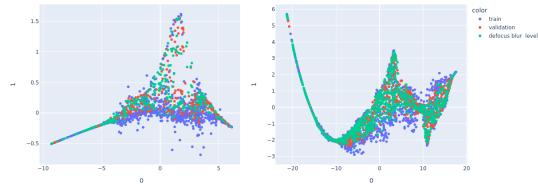


Figure 36: PacMAP does not provide information on the corruption

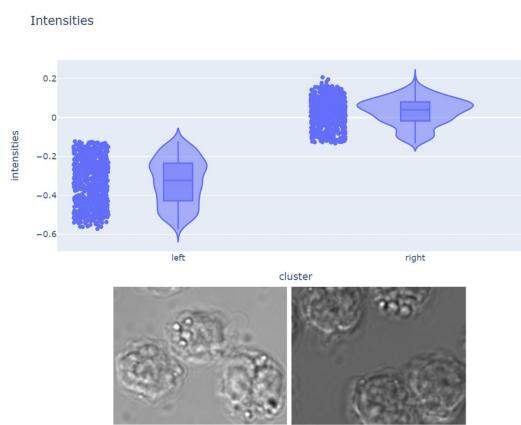


Figure 37: What do two UMAP clusters represent

10.4 Clustering

10.4.1 Clustering methods (HDBSCAN, DBSCAN, K-means)

10.4.2 Clustering on UNet embeddings

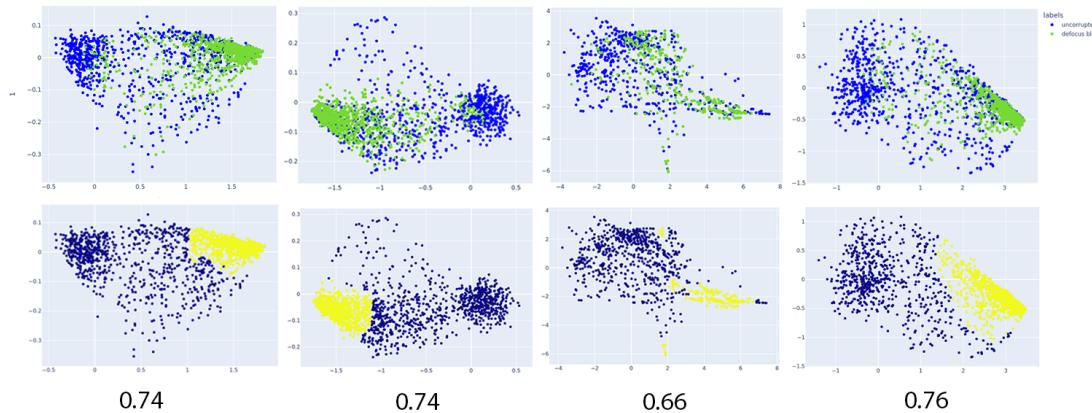


Figure 38: Clustering of UNet Embeddings

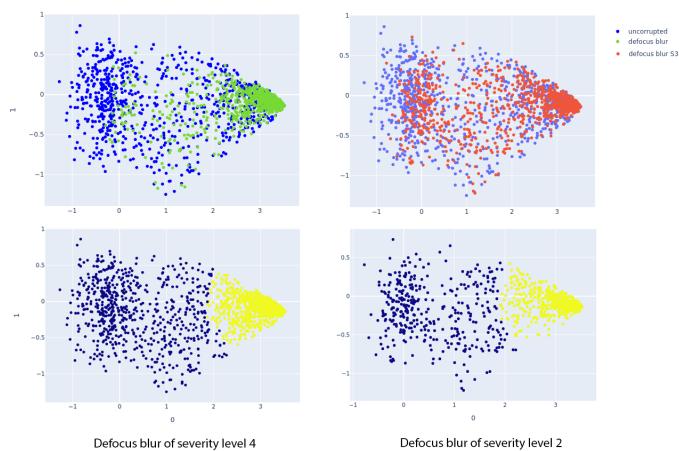


Figure 39: Clustering for different severities levels

TABLE with F1-score: 0.76 VS 0.64

11 Drift detection

11.1 A need to detect drift

11.2 MMD

11.2.1 Drift detection

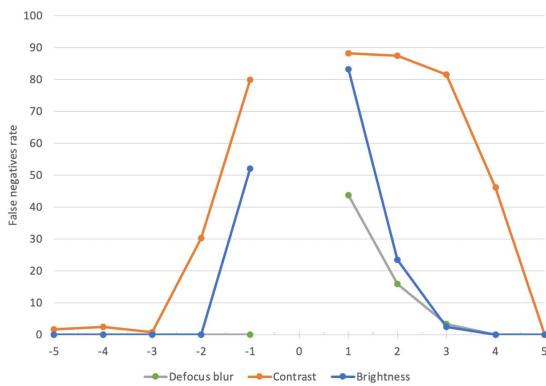


Figure 40: False negatives rate for drift detection on artificial corruptions

11.2.2 Online drift detection

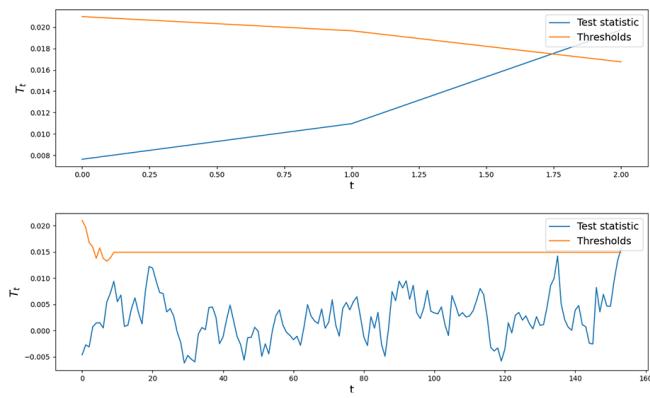


Figure 41: Expected runtime (ERT) for corrupted and in-distribution data

Table 4: Test window size influence on separability

W	2	5	10	15	20
Auc-Roc	0.85	0.92	0.98	0.90	0.88

Table 5: ERT influence on separability

W	32	64	128	256
Auc-Roc	0.90	0.95	0.98	0.98

Table 6: Severity of corruptions on separability

W	Level 2	Level 3	Level 4
Auc-Roc	0.84	0.92	0.98



Figure 42: AUC ROC scores for various defocus corruptions severities

12 Software Tools

12.1 Foundry. Palantir

12.2 AWS

12.3 Streamlit

12.4 ImageJ, CellProfiler

13 Summary

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