Convolutional neural networks for classification of transmission electron microscopy imagery

Sergii Gryshkevych

Uppsala University
Supervisor: Max Pihlström
Reviewer: Ida-Maria Sintorn
Examinator: Justin Pearson
Opponent: Christopher Lagerhult

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Introduction

This MSc project is done in cooperation with Vironova AB.

- One of Vironova's services is to classify liposomes
- Automatic classification is of great interest
- Currently automatic classification is performed by means of SVM

Objective

- Discuss the suitability of applying CNN method for classification of electron microscopy images

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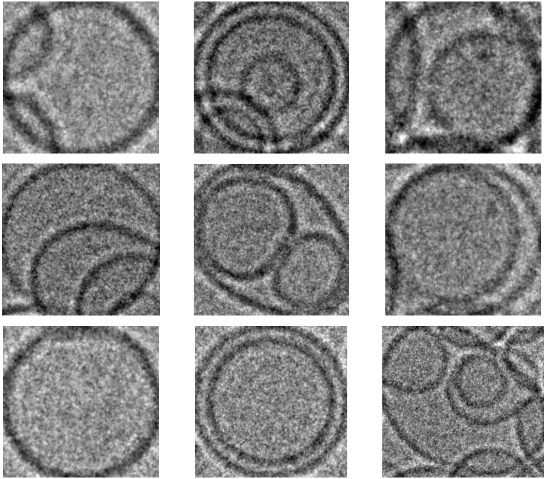
- Benchmark CNN models against SVM classifier for the selected problems
- Discuss Deep Learning software:
  - OS availability
  - Licenses
  - Performance
  - Community support

Problem description: Lamellarity

Determine structure of a liposome according to the number of lamellae.

There are 14169 EM images and three classes:

- Unilamellar
  12368, 87.29%
- Multilamellar
  1717, 12.12%
- Uncertain
  84, 0.5%



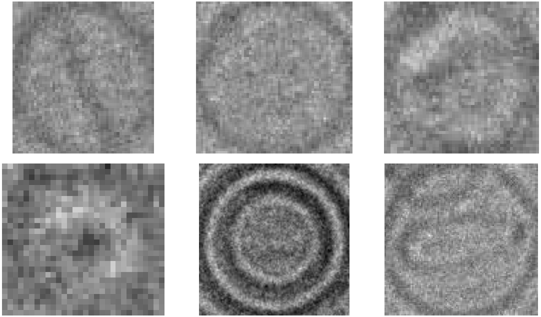
Unilamellar Multilamellar Uncertain

Problem description: Encapsulation

Determine presence of a liposomal encapsulation.

There are 24918 EM images and three classes:

- Full
  24255, 97.34%
- Empty
  161, 0.65%
- Uncertain
  502, 2.01%



Full Empty Uncertain

The data set of image features

- Maximum width
- Diameter
- Length
- Histogram
- Image Moments
- Radial Density Profile
- Edge Density Profile
- Signal to noise

SVM operates on feature representation of the image.

Convolutional neural networks (CNN)

Convolutional neural network (CNN)

It is a special kind of neural network for processing data that has a known, grid-like topology. CNN are simply neural networks that use convolution in place of general matrix multiplication in at least one of their layers.

Why CNN?

- Scalability due to the following assumptions:
  - Local connectivity
  - Parameter sharing
- CNN operate on raw pixel data, i.e. minimum preprocessing
- CNN learn image features themselves, i.e. do not need expert knowledge for selecting feature
- Documented success

The Class Imbalance Problem

Lamellarity and Encapsulation data sets are imbalanced and it is a problem!

How to mitigate the class imbalance problem? I tried:

- Oversampling
- Undersampling
- SMOTE (Synthetic Minority Oversampling Technique)
- Artificial data
- Higher penalties for misclassification of minority classes

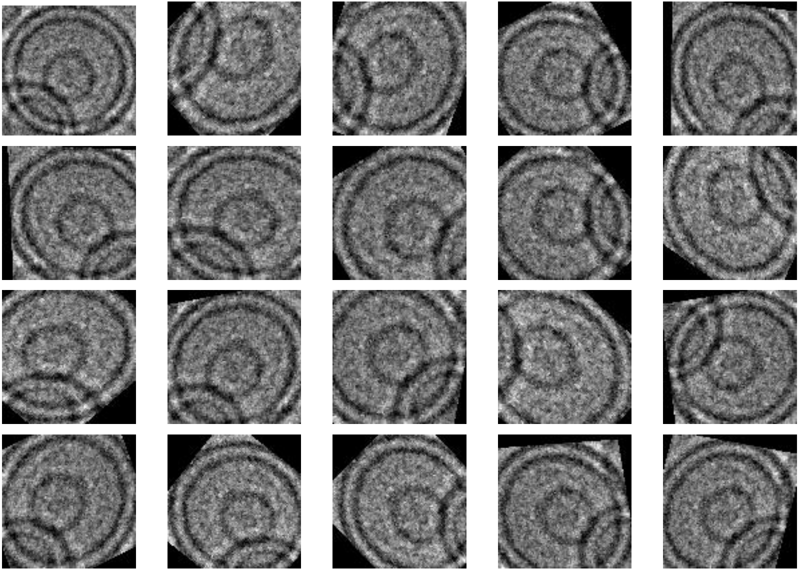
Regularization

Definition

Regularization is any modification we make to a learning algorithm that is intended to reduce its generalization error but not its training error

- Weight decay
- Noise injection: label smoothing
- Dropout
- Early stopping
- Data augmentation

Data augmentation example



Input images: surrounding and masking

Each image contains a liposome object and its surrounding which goes 50 pixels in each direction. Corresponding particle masks are also available.

Three choices:

- Images with surrounding
- Cropped images
- Cropped and masked

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Performance measures

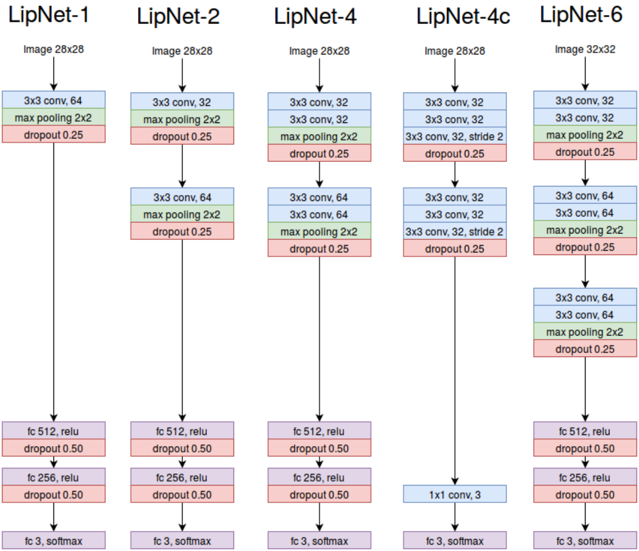
Accuracy is not enough when the data set is imbalanced.

Confusion matrix

	Predicted Positive	Predicted Negative
Actual Positive	True Positive	False Negative
Actual Negative	False Positive	True Negative

- True Positive Rate: $TPR = \frac{TP}{TP+FN}$ (sensitivity or recall)
- True Negative Rate: $TNR = \frac{TN}{TN+FP}$ (specificity)
- Positive Predicted Value: $PPV = \frac{TP}{TP+FP}$ (precision)
- Negative Predicted Value: $NPV = \frac{TN}{TN+FN}$
- F_1 score : harmonic mean of TPR and PPV

Network architectures



Which LipNet model is the best?

Five LipNet models are evaluated by recording their 5-fold cross validated F_1 scores.

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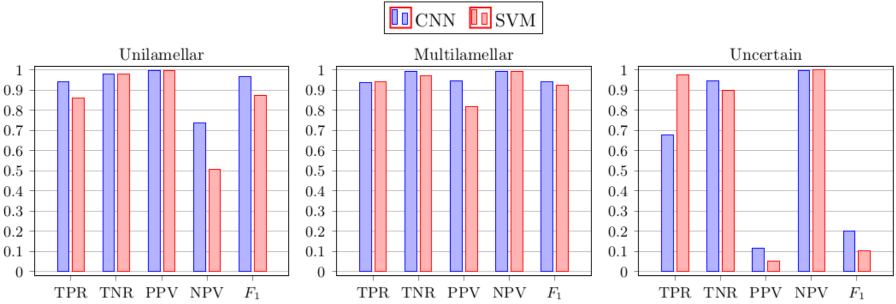
Which LipNet model is the best?

Five LipNet models are evaluated by recording their 5-fold cross validated F_1 scores.

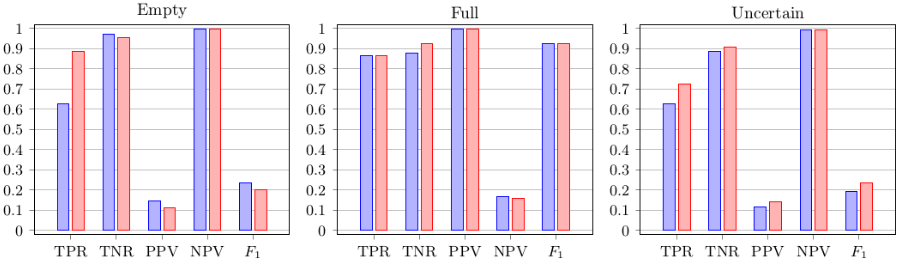
- The Lamellarity Problem: **LipNet-4** is the best
- The Encapsulation Problem: There is no clear leader. **LipNet-4** is selected.

CNN vs SVM: Lamellarity



- CNN is slightly better than SVM.
- Less false negative *unilamellar* by CNN than SVM.
- Less false positive *multilamellar* by CNN than SVM.
- Many false positive predictions of *uncertain*, mainly *unilamellar* is confused with *uncertain*.

CNN vs SVM: Encapsulation



- Almost the same performance.
- Some *full* are falsely classified as *empty* and *uncertain*
  - Low NPV for *full*
  - Poor precision (PPV) for *empty* and *uncertain*
- PPV for *full* and NPV for *empty* and *uncertain* are almost 1, so hardly any false positive of *full*.

Deep learning software

OS and API

The path of least resistance:

- Linux
- Python

Deep learning software

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Licensing

Nearly all libraries are distributed according to some of OSI-approved licenses like Apache, BSD, MIT, etc.

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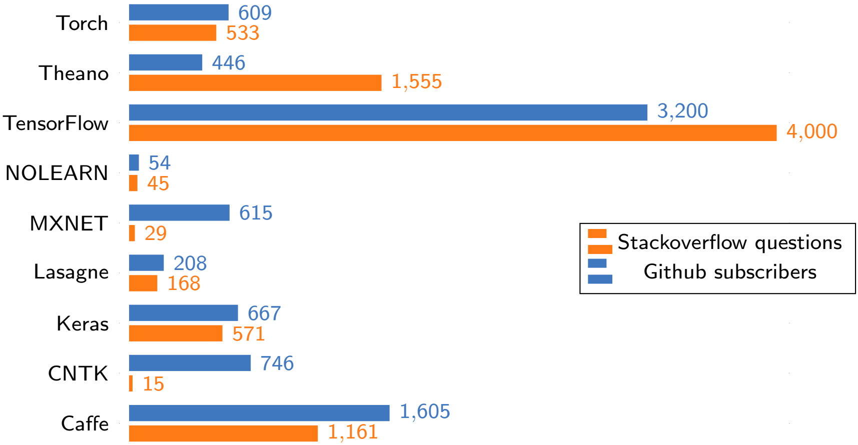
GPU

All libraries benefit from GPUs. At the moment there is no study that shows superiority of any library in terms of performance.

Popularity of deep learning software as of October 2016



Conclusion and future work

Conclusions:

- CNN is a promising tool for research and production
- Reasonable performance
- CNN does not require feature representation

- Limited support for Windows and C#

Future work:

- Fully convolutional networks with input of variable size
- Alternative ways to expand the training set
- Fusing, i.e. combine LipNet and another neural network trained on image features