ČESKÉ VYSOKÉ UČENÍ TECHNICKÉ V PRAZE

REVIEWER'S OPINION OF FINAL THESIS

I. IDENTIFICATION DATA

Thesis name:	**Geometry and Transformations in Deep Convolutional Neural Networks**
Author's name:	**Tomáš Jakab**
Type of thesis :	bachelor
Faculty/Institute:	Faculty of Electrical Engineering (FEE)
Department:	Department of Cybernetics
Thesis reviewer:	Dmytro Mishkin
Reviewer's department:	Department of Cybernetics

II. EVALUATION OF INDIVIDUAL CRITERIA

Assignment **challenging**

Evaluation of thesis difficulty of assignment.

Tomáš Jakab presents his thesis with the title "Geometry and Transformations in Deep Convolutional Neural Networks". The studied problem is dependence of a convolutional network classifier performance on the geometric transformation of the input images. The topic is not trivial and could be assigned for a Master`s thesis or even be subject of a PhD study.

Satisfaction of assignment **fulfilled**

Assess that handed thesis meets assignment. Present points of assignment that fell short or were extended. Try to assess importance, impact or cause of each shortcoming.

The thesis fully meets the assignment, presenting clear and quite full evaluation of CNN performance under geometric transformation in controlled synthetic experiment.

Method of conception **outstanding**

Assess that student has chosen correct approach or solution methods.

The experimental study on a controlled synthetic dataset was chosen as study method. Two ways were explored: evaluation of a classifier accuracy dependence on the increasing 2D rotation and translation and reconstruction of a input image using various levels of CNN internal representation. First method gives quantitative results of CNN robustness on geometrical transformation, while second gives an insight on information stored at middle and high level features learned by CNN.

Technical level **A - excellent.**

Assess level of thesis specialty, use of knowledge gained by study and by expert literature, use of sources and data gained by experience.

Technical level of a both thesis and presented source code is high.

Formal and language level, scope of thesis **B - very good.**

Assess correctness of usage of formal notation. Assess typographical and language arrangement of thesis.

The thesis is well written and easy to follow. The only thing which makes reading a bit difficult is name convention for experiments, e.g. "poly-s-a", "poly-m" given in Section 3.3. It would be nice, to have single table with summary of experiments and used notation.

Selection of sources, citation correctness **B - very good.**

Present your opinion to student's activity when obtaining and using study materials for thesis creation. Characterize selection of sources. Assess that student used all relevant sources. Verify that all used elements are correctly distinguished from own results and thoughts. Assess that citation ethics has not been breached and that all bibliographic citations are complete and in accordance with citation convention and standards.

Tomáš Jakab wrote a clear and full overview of the state-of-art papers in topic and pointed out a difference between problems studied in existing work and his thesis. The only missing works: "Exploiting Cyclic Symmetry in Convolutional

Neural Networks" by Dieleman et.al and "Group Equivariant Convolutional Networks" by Cohen and Welling were published as tech reports on arXiv and would appear at ICML 2016, clearly after thesis deadline.

Additional commentary and evaluation

Present your opinion to achieved primary goals of thesis, e.g. level of theoretical results, level and functionality of technical or software conception, publication performance, experimental dexterity etc.

The work studies the ability of convolutional neural network to recognize objects under geometrical transformations: 2D in-place rotation and vertical and horizontal shifts.
The first part of experiment is quantitative. The verification (two images represents same object, or the different ones) accuracy is used as an evaluation metric. Two types of the objects are used: monochrome polygons and set of the dots. Despite the simplicity of images which are used in evaluation, it is often hard to a human to distinguish between the objects and give a correct answer. Four ways of archiving view invariance have been evaluated: baseline, when no additional information were given to the classifier, explicit brute-force test-time augmentation, transformation estimation via classification and spatial transformer networks. The results are in a good agreement with similar studies for large ImageNet-pretrained networks. The final recommendation is to train subnetwork to explicitly predict possible geometric transformation of the input, use it to recover "canonical" object view and use it for classification. Author points out that this method works well, when transformation prediction network is initialized by classification network and then fine-tuned. The end-to-end training of spatial-transformer network is much harder and unstable, which agrees with my own experience of using this approach. The second part of a work is a feature analysis, which is done by reconstruction of input images using a learned representation. Figures 5.1 - 5.4, 5.6 show which information is retained by the network. Especially I like the finding, that network internally represents a polygon as a set of a vertices, which are clearly reconstructed, as the only relevant information. The second interesting result is the difference in an object representation between CNN, which is trained to recognize rotation angle and original, which does not retain transformation. One thing, which can improve this part, is a finer resolution of the Figure 5.5. It is interesting to see, how different features are when smaller angular difference, than 45 degrees, is presented. Finally, the source code for reproducing experiments are presented with thesis. I think, it is important for such kind of work. Code itself is clear and well written.
I would like to recommend to present the results of this work at a conference or workshop, e.g. CVWW, because results are interesting and have some novelty.

III. OVERALL EVALUATION, QUESTIONS FOR DEFENSE, CLASSIFICATION SUGGESTION

Summarize thesis aspects that swayed your final evaluation. Please present apt questions which student should answer during defense.

This work presents an interesting research on state-of-art problem with clear evaluation method and novel results, which exceeds the common requirements to the bachelor thesis. Therefore I strongly recommend to mark this thesis with classification grade **A - excellent.**

Date: **13.6.2016** Signature: Dmytro Mishkin