## Hoofdstuk 8

# SUMMARY

Summarizing, this thesis focusses on advancing the knowledge of LVQ methods, in particular in the application to domain of affective computing. In this thesis various LVQ variants were studied in a controlled environment characterized by high dimensional isotropic clusters. This data model yields a simplified representation of reality that allows studying learning dynamics in detail. The findings demonstrated that while LVQ 2.1 can obtain optimal asymptotic performance it suffers from stability issues due to divergent behavior of the prototypes. The introduction of a window, in LFM-W, shows convergence for well chosen window sizes, but introduced large dependency on parameter optimization, with respect to reaching optimal performance. While GLVQ suffered from both divergence and parameter dependency, RSLVQ combined the strengths of both methods and, as the name suggests, is more robust to the parameter settings. It required only limited parameter optimization to reach close to optimal asymptotic performance. Optimization of the window size and softness parameter of RSLVQ, however was critical for efficient learning.

Affective computing comprises the application of computers to the study of emotions, moods, stress and other affective phenomena. Although affect has been studied for a long time in psychology, the research field of affective computing is still in its relative infancy and poses interesting challenges to computer science and in particular machine learning. In order to research the performance of LVQ variants outside of the controlled simulation environment, we applied various LVQ techniques to various classification tasks in the affective domain. To the best of our knowledge, this work comprises a first application of LVQ to the particular affective challenges at hand. Applied to these three real world scenarios, RSLVQ showed its robustness and very competitive predictive performance as affective classifier, competing well with GMLVQ and linear SVM. To that end, three datasets were collected using different input modalities, that approached affective computing from three perspectives:

**Bodily** A large-scale study was performed in which skin conductance, respiration and electrocardiogram were measured in semi-controlled conditions. A large variety of features was derived from each of these modalities. Classifiers were built using uni- and multi-modal input. Using LVQ techniques, we obtained up to 86.7% accuracy and AUC of 0.95 in the two-class classification task to separate stress from relaxation. Relevance learning was used to identify the most informative features, indicating that most information was embedded in the cardiac signals primarily in time-domain HRV measures. In addition to commonly used features, we also explored various novel features, of which the very-high frequency band of the power spectrum was found to be a very relevant addition. Best performing algorithms were GMLVQ, RSLVQ and linear SVM, of which the performance differences were within percentage points.

**Facial** A benchmark dataset, the Cohn-Kanade database, was used to build classifiers for facial expression recognition, based upon LBP features that reflect local textures from still images. The feature space was characterized by its large dimensionality. Linear SVM performed best with accuracies up to 94.5% for 6-class and 93.2% for 7-class classification, closely followed by RSLVQ. Implicit relevances obtained from RSLVQ provided insight into the most prominent features, which originated, primarily, from the mouth region and eye regions. The specific LBP features that were found most influential within these regions confirmed that mouth opening/closing is a primary differentiator picked up by the classifier.

**Cognitive** The cognitive processes involved in the emotional interpretation of stimuli is termed appraisal. Several appraisal models have been coined that define several dimensions of emotional appraisal. We set up a study in which emotions were elicited and accompanying appraisal values determined. In a 5-class classification task, RSLVQ and SVM performed similarly well with accuracies up to 54.5% and Cohen's Kappa of 0.42. Compared to the earlier applied technique of class conditional means, this showed a gain of 5 percentage point in accuracy and 0.05 in Kappa. Applied to this noisy dataset GMLVQ performed relatively poorly at a level similar to that of GLVQ.

Observations made over the three experiments include that GLVQ and GRLVQ suffered from stability issues similar to the simulated environment. RSLVQ and linear SVM performed similarly well at performance levels close to or beyond the state of art. GMLVQ performed poorly in a very noisy environment, but very well in the relatively easier classification tasks. The computational costs involved in relevance learning, however did not allow for the application of GMLVQ to the facial

emotion dataset.

For each of the three affective domains we outlined potential applications and demonstrators. These include the *Vitality Bracelet*, which monitors daily stress levels through skin conductance measurements, triggers in case of high stress and provides a paced breathing exercise to let the user calm down; the facial expression recognition was applied to various iconic faces to reveal the emotions displayed in the Mona Lisa, by Bill Clinton and Albert Einstein; and usage of the cognitive appraisal model was explored in the *Empathic Photo Frame* that displays pictures to match a desired emotion while using representations of both pictures and emotions in the space spanned by the appraisal dimensions.

## 8.1 Outlook

The following topics have been identified for future work:

- Although in our experiments we made steps to move the affective research from the lab to more daily life situations, the conditions in our experiments were still semi-controlled. It would be interesting to see how the classifiers trained and the results found translate to even less controlled, daily life situations.
- Very high dimensional spaces such as the dataset for facial emotion recognition pose their challenges for the more computational expensive relevance learning LVQ. Despite our efforts in optimization of the implementation of GMLVQ and GRLVQ these techniques took significant time for such very high dimensional classification problems. Further code optimization or the use of more powerful computers would enable the application of relevance learning in LVQ on very high dimensional datasets.
- We have outlined demonstrator systems for the three affective subdomains researched in this thesis. Further validation and optimization of these systems in a daily life setting could bring these applications closer to productization.

In sum this thesis provides useful results for further investigations of the application of LVQ methods to the affective domain and brings us one step closer to the application of affective computing in daily life.