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TOWARDS LEARNING WITH OBJECTS IN A HIERARCHICAL REPRESENTATION

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Abstract: In most supervised learning tasks, objects are perceived as a collection of fixed attribute values. In this work, we try to extend this notion to a hierarchy of attribute sets with different levels of quality. When we are given the objects in this representation, we might consider to learn from most examples at the lowest quality level and only to enhance a few examples for the classification algorithm. We propose an approach for selecting those interesting objects and demonstrate its superior performance to random selection.

1 INTRODUCTION

Mapping input examples to a desired continuous or categorical output variable is the goal of supervised learning.To achieve this, the learner has to generalize from the presented examples to yet unseen examples. We have seen numerous algorithms in the field of machine learning that deal with this issue. They share the property that the objects of interest are described by a given number of attribute values (the so-called feature vectors). This representation may be a good choice to describe most of the objects that we encounter in real-world classification tasks. However, we have seen that in some circumstances a different object representation may be useful, e.g. in the domain of graph mining or structure mining.

In this work, we want to enhance the representation of objects in such a way that we use only as much information from each object as is needed for the classification task at hand. To make this possible, we suggest to represent objects in a hierarchy that is composed of different levels of quality. The underlying idea of this approach is that we do not need to compute the best representation for all objects. We argue that it is sufficient to learn a classifier on the lower quality level and use a selection strategy to enhance "useful" objects. This setting is very useful whenever we have limited resources to compute a full feature representation of an object, especially in real-time applications (e.g. robotics). We argue that many objects from different domains (classification of images, music or 3D objects) can be described on different levels of quality.

Our idea is very related to the concept of Active Learning (Cohn et al., 1994). However, in this work, we do not try to select objects that will be labeled by a human expert. Instead, we try to select objects that will be enhanced for the classification algorithm. There are two related approaches (Zheng and Padmanabhan, 2002) (Saar-Tsechansky et al., 2009) that deal with obtaining more feature values for a subset of objects. Although they follow a similar idea, the key difference to our work lies in the representation of objects. We propose a hierarchical representation over several levels. To the best of our knowledge, this is a completely new approach in the supervised machine learning setting.

2 LEARNING WITH SVM

In this section, we introduce the underlying Support Vector Machine (SVM) classification algorithm before turning to the selection strategy. Given a set of labeled training data $D = \{(\vec{x}_1, y_1), (\vec{x}_2, y_2), \ldots, (\vec{x}_m, y_m)$ where $\vec{x}_i \in \mathbb{R}^N$ and $y_i \in \{-1, +1\}$, a linear SVM (Schölkopf et al., 1999) is defined in terms of its hyperplane

$$w \cdot \vec{x} + b = 0 \quad (1)$$

and its corresponding decision function

$$f(\vec{x}) = sgn(w \cdot \vec{x} + b) \quad (2)$$

for $w \in \mathbb{R}^N$ and $b \in \mathbb{R}$. Among all possible hyperplanes that separate the positive from the negative examples, the unique optimal hyperplane is the one for

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which the margin is maximized:

$$\max_{w,b}\{\min_{\vec{x}_i}\{||\vec{x}-\vec{x}_i|| : \vec{x}\in\mathbb{R}^N, w\cdot\vec{x}+b=0\}\} \quad (3)$$

As the training data is not always separable, a soft margin classifier uses a misclassification cost C that is assigned to each misclassified example. Equation 3 is optimized by introducing Lagrange multipliers α_i and recasting the problem in terms of its Wolfe dual:

$$\begin{aligned} &\text{maximize: } L_D = \sum_i \alpha_i - \frac{1}{2}\sum_{i,j}\alpha_i\alpha_j y_i y_j \vec{x}_i\vec{x}_j \\ &\text{subject to: } 0\le\alpha_i\le C, \text{and} \sum_i \alpha_i y_i = 0 \end{aligned} \quad (4)$$

All $\vec{x}_i$ for which the corresponding α_i is non-zero are the support vectors.

The support vectors limit the position of the optimal hyperplane. The objects $\vec{x}_i$ for which $\alpha_i = C$ are the bound examples, which are incorrectly classified or are within the margin of the hyperplane.

3 OBJECT SELECTION

In this work, we assume that we have j views of descending quality $V_u, u = 1,\ldots,j$. The best level is denoted by V_1 and the worst by V_j. We describe the object $\vec{x}$ in view j as $V_j(\vec{x})$. Note that all $\vec{x}_i$ in the training set are still in $\mathbb{R}^N$ (the number of attributes does not change).The training set at any point in time t consists of the objects - each object at a different view level: $D = \{(V_1(\vec{x}_1),y_1),(V_2(\vec{x}_2),y_2),\ldots,(V_m(\vec{x}_m),y_m)$. At $t = 0$, all objects are only given in the worst view V_j.

At any time point t we want to enhance some objects in order to have more detailed information for the classification algorithm. We consider this as an iterative setting, where we train a classifier, enhance some objects, and then train the classifier on the new training set.

Enhancing an object means we get a better estimate of where this object lies in the current feature space. Intuitively, if we have trained a classification algorithm on a dataset, enhancing objects that are classified with high confidence will not provide much information for the classifier.

Instead, we propose to select objects that are close to the decision boundary of the current classifier. These are the objects that are classified with low confidence. We expect that a more detailed information about the exact position of this object in this feature space provides the most information for the classifier. This idea is very related to the concept of uncertainty sampling in Active Learning (e.g. in the works of (Schohn and Cohn, 2000), (Campbell et al., 2000) and (Tong and Koller, 2001)). In the future, it might be interesting to look at other selection strategies from this domain, e.g. version space reduction.

The preceding works have used a Support Vector Machine (SVM) classifier and ranked objects $\vec{x}$ by their distance to the dividing hyperplane, which is given by the normal vector w and offset b:

$$\min_{\vec{x}} |w\cdot\vec{x}+b| \quad (5)$$

The goal is to maximally narrow the existing margin with an object.

Our proposed algorithm works as follows: all objects are given at the lowest view level in the beginning. We train a SVM classifier and use Equation 5 to rank objects. We can then select the top n objects for enhancement and add the improved examples to the current training set. This continues until we are satisfied with the results or we do not have more budget left to enhance further examples.

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4 EXPERIMENTS

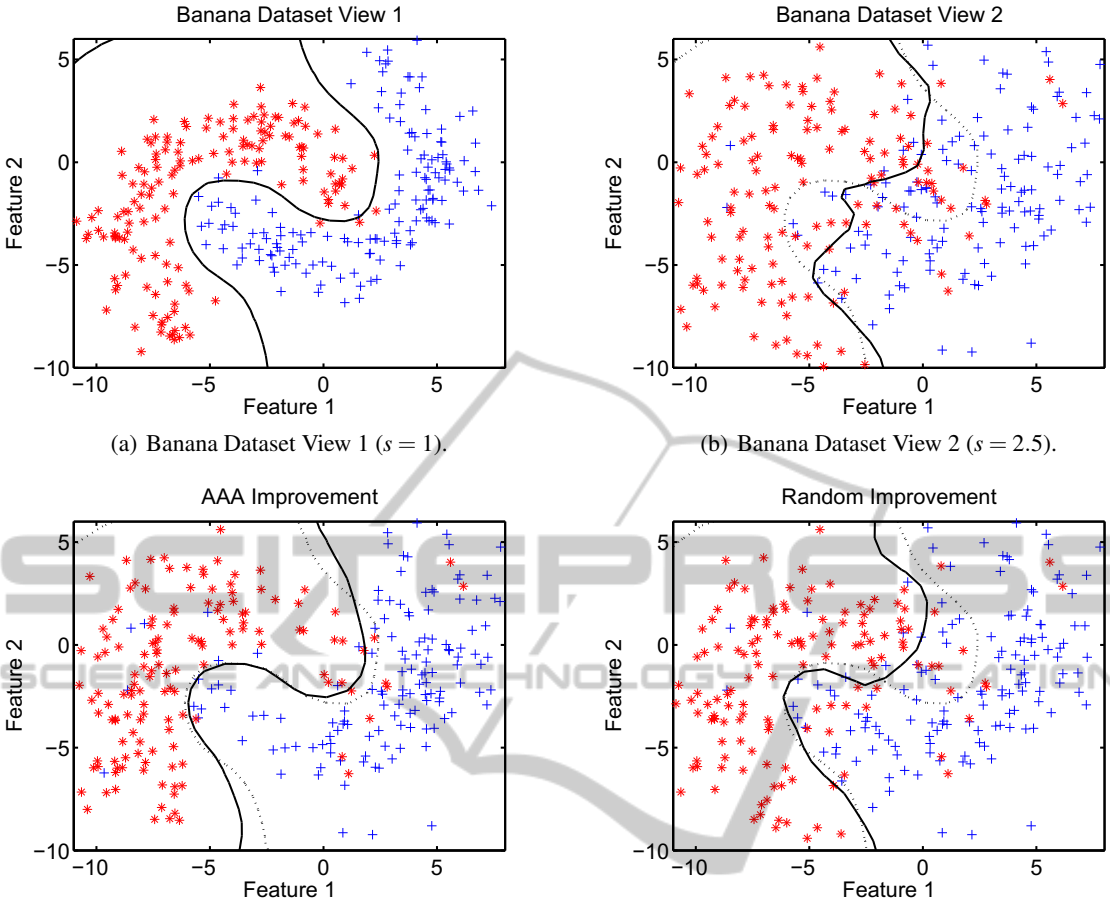
4.1 Artificial Data

To demonstrate the principle of operation and the potential benefit of the proposed algorithm, we have chosen a dataset that is easy to visualize. We have generated a two-dimensional dataset with two classes with a banana shaped distribution. The data is uniformly distributed along the bananas and is superimposed with a normal distribution with a standard deviation s in all directions. The class priors are $P(1) = P(2) = 0.5$.

Two views have been created: a good view V_1 (see Figure 1(a)) by using a small standard deviation and a bad view V_2 (Figure 1(b)) with a large standard deviation. As can be seen, V_2 is very noisy, but the underlying concept of two opposed banana shapes is still the same. We have used a SVM with a RBF kernel; the γ parameter has been set to 2.0. The SVM classifier is plotted as a solid black line. The classification in view V_1 reflects our ground truth and is therefore plotted as a dotted black line in the other views in Figure 1.

Due to the high standard deviation, the classification in view V_2 is far from optimal. In this experiment, we have improved 30 examples. We plot the improved dataset and the corresponding classifier that is learned in this new data space. Figure 1(c) shows the new dataset and classifier with our Active Algorithm and Figure 1(d) shows the new dataset and classifier with randomly improved examples.

We can observe that the strategy of choosing examples close to the decision boundary results in a bet-



(a) Banana Dataset View 1 ($s = 1$).

(b) Banana Dataset View 2 ($s = 2.5$).

(c) Improved Dataset with our Active Algorithm.

(d) Improved Dataset with Random Adaption.

Figure 1: Banana Dataset in two views of different quality (top). The black line represents the classifier in each view. The classifier of View 1 is plotted as a dotted black line in the other views.

ter classification accuracy than random improvement. Random improvement will eventually reach the same performance but needs more examples to do so.

4.2 Numbers Dataset

The multiple features dataset from the UCI Machine Learning Repository (Asuncion and Newman, 2007) consists of features of handwritten numerals ('0'-'9'). extracted from a collection of Dutch utility maps.We have computed two views on these objects: the Zernike Moments based on the original image of size 16x16 (Level 2, green line) and of a subsampled image of size 8x8 (Level 1, red line). We compare our *Adaptive* refinement strategy against *Random* refinement, a strategy that improves a randomly chosen set of examples in each training iteration (dotted line).

Each experiment has been repeated 100 times. In each iteration, we split up the dataset randomly and use 40% for training and 60% for testing.

All training instances are first assumed to have the lowest quality V_1. A batch of examples is selected in each iteration (plotted on the x-axis) and the mean classification accuracy (given the ground truth in the testing data on the highest view level V_j) is plotted on the y-axis. We also plot the mean accuracy of a classifier on each view level.

We have chosen three binary classification tasks: '1' vs '5' in Figure 2, '3' vs '8' in Figure 3 and '5' vs '7' in Figure 4. As can be seen, the *Adaptive* strategy clearly outperforms *Random* improvement of examples.

5 CONCLUSIONS

In this work, we have proposed a new learning setting, where the objects of interest can be obtained at differing quality levels. We have proposed a new scheme that improves a few selected examples with a SVM as

hspace-0.39cmthe underlying classifier. Objects are ranked by their distance to the separating hyperplane to select a subset that is enhanced in each iteration. Experiments on an artificial dataset and a dataset from the UCI repository of machine learning have shown that this is a promising approach. Future

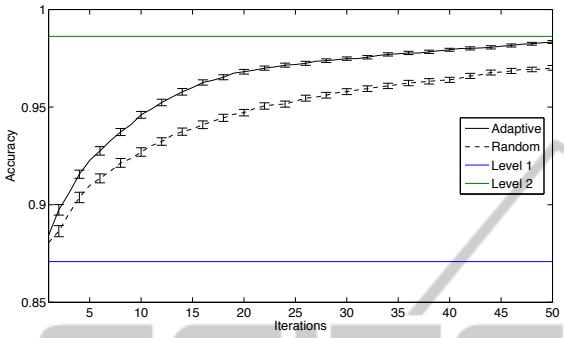


Figure 2: Test accuracy '1' vs. '5'.

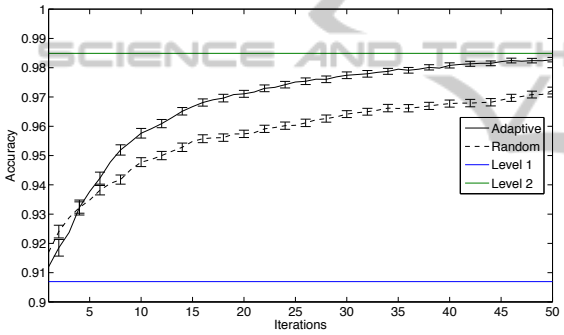


Figure 3: Test accuracy '3' vs. '8'.

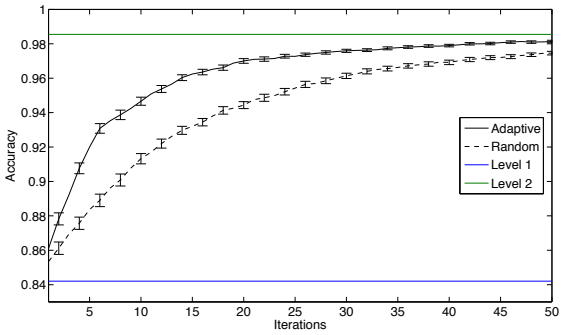


Figure 4: Test accuracy '5' vs. '7'.

work needs to be done in the following areas: it would be interesting to have a cost model and a fixed budget to describe the costs that are involved in the enhancement of objects. More experiments need to be carried out on different data sets. It would be interesting to take the current view level into account when objects are ranked. At last, more strategies from the domain of Active Learning need to be tested in this setting. As can be seen, this new notion of objects in a hierarchy raises several interesting research questions and is worth to be further explored.

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