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Using Deep Convolutional Neural Networks to Predict Goal-Scoring Opportunities in Soccer

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Abstract: Deep learning approaches have successfully been applied to several image recognition tasks, such as face, object, animal and plant classification. However, almost no research has examined on how to use the field of machine learning to predict goal-scoring opportunities in soccer from position data. In this paper, we propose the use of deep convolutional neural networks (DCNNs) for the above stated problem. This aim is actualized using the following steps: 1) development of novel algorithms for finding goal-scoring opportunities and ball possession which are used to obtain positive and negative examples. The dataset consists of position data from 29 matches played by a German Bundesliga team. 2) These examples are used to create original and enhanced images (which contain object trails of soccer positions) with a resolution size of 256×256 pixels. 3) Both the original and enhanced images are fed independently as input to two DCNN methods: instances of both GoogLeNet and a 3-layered CNN architecture. A K-nearest neighbor classifier was trained and evaluated on ball positions as a baseline experiment. The results show that the GoogLeNet architecture outperforms all other methods with an accuracy of 67.1%.

1 INTRODUCTION

Over the past decades, soccer has encountered an enormous increase in professionalism. The major clubs spend millions of euros on transfers and salaries. Performances on the pitch are not only reflected in the standings, but also have substantial financial consequences. When a team does not do well for a number of matches, the coach is often quickly replaced. Recently, some research has focused on developing machine learning methods for extracting soccer dynamics from position data. This is evident in the works of (Knauf et al., 2016) where spatio-temporal convolution kernels were used to capture similarities between trajectories of objects. Also, machine learning has successfully been applied to draw inferences from pass location data in soccer (Brooks et al., 2016).

In contrast to the views on the application of machine learning in soccer dynamics, a variant of self-organizing maps (Kohonen and Somervuo, 1998) was applied to detect formations rather than trajectories reflecting ball and player motions (Grunz et al.,

2012). The concept of self-organizing maps is further extended by the authors in (Memmert et al., 2016), who applied this approach to train on defensive and offensive patterns from the UEFA Champions League quarterfinal of FC Bayern Munich against FC Barcelona from the 2008/2009 season.

Based on our reviews, the prediction of goal-scoring opportunities from position data has received a limited amount of attention. When position data extracted from soccer matches is available, one could use these data as input to neural networks to classify it into either categories reflecting promising and less promising states. One of the promising machine learning methods that can be used to solve this problem are deep convolutional neural networks (DCNNs). Convolutional neural networks (Zeiler and Fergus, 2014) have the potential capability to detect and extract higher-order tactical patterns which can function as indicators for goal-scoring opportunities.

In this paper, we propose the use of DCNNs to predict goal-scoring opportunities in the game of soccer. First, we develop two novel algorithms for finding goal-scoring opportunities and ball possession

which were used to obtain positive and negative examples. Secondly, the examples were used for constructing original and enhanced images (which contain object trails of soccer positions) with a resolution size of 256×256 pixels. Finally, both the original and enhanced images were fed independently as input to two DCNN methods (an instance of GoogLeNet and a 3-layered CNN architecture trained with the use of Nesterov's accelerated gradient solver). We compare these results to the use of a KNN classifier that only uses the ball position as input.

The remaining parts of this paper are organized into four sections: Section 2 gives a detailed description of the dataset and the preprocessing steps that are applied on the raw images within the dataset. Section 3 describes the different methods used in carrying out our experiments. The results obtained are described in Section 4. Section 5 concludes the paper and gives recommendations for further work.

2 DATASET AND PREPROCESSING

2.1 Dataset

The dataset consists of two-dimensional position data of 29 full-length matches played by a German Bundesliga club (from here on this team is referred to as 'the Bundesliga team'). The two-dimensional positions for every player on the pitch were captured by the Amisco multiple-camera system. The Amisco system consists of multiple cameras placed around the stadium and tracks all moving players on the soccer field at a sampling frequency of 25 Hz (Barris and Button, 2008). The system uses computer vision techniques to track objects and estimate their positions. Note that the height of objects is not captured: it is unknown whether players or ball are in the air or are touching the ground.

The matches were played between the 15th of August, 2008 and the 3rd of November, 2009. All matches featured the same Bundesliga club as one of the participating teams. Only 1 of the 29 matches was an away game.

2.2 Preprocessing

Because the ball position was originally not tracked by the system, it was manually added to the data. Therefore, the position of the ball is not as precise as the player movements. When the ball was passed or shot, only its start position and end position were

marked. As a result, the ball always moved in straight lines, even in cases of curved shots or passes. When a player had ball possession and dribbled with the ball, the x- and y-coordinates from the player were copied and used as ball position.

After downsampling the data to 10Hz, gaps in the data were removed by linearly interpolating position data for erroneous intervals. While inspecting the data, it was apparent that two main factors caused the system's inability to correctly measure player coordinates. Players located outside the lines of the soccer field were out of the appropriate range for detection. When these players returned to the pitch, their position data was linearly interpolated between their last known position and the current position. The second cause for erroneous data was the computer vision algorithm sometimes not being able to correctly capture the position of a player, while the player was still between the lines of the soccer field. This effect seemed to be present most when players were standing very near to each other, causing tougher extraction of individual players. In these cases the player position was linearly interpolated as well.

2.2.1 Definition: Goal-Scoring Opportunities

Due to the two-dimensional nature of the data, it was impossible to distinguish between shots which were on goal and shots which went over the bar. Taking these limitations into account, goal-scoring opportunities were defined as shots which (almost) crossed the end line near the goal. A shot which was a little wide would still be classified as a goal-scoring opportunity, as would a shot which went over the bar. A movement of the ball was considered a shot when:

1. the ball had moved in a more or less straight line towards the goal (change in direction between two samples had to be below 20 degrees) for a specified minimum duration of 0.5 seconds;
2. the velocity of the ball was above 20 km/h all the time;
3. before the velocity of the ball passed this threshold, a player belonging to the attacking team was within 1.5 meters of the ball;
4. When the previous requirements were not met anymore, the distance to the end line had to be below 1 meter and the distance to the closest goal-post was under 5 meters.

2.2.2 Definition: Ball Possession

Ball possession is equally important to define, as loss of ball possession was used to extract negative examples from the data. Ball possession was assigned to

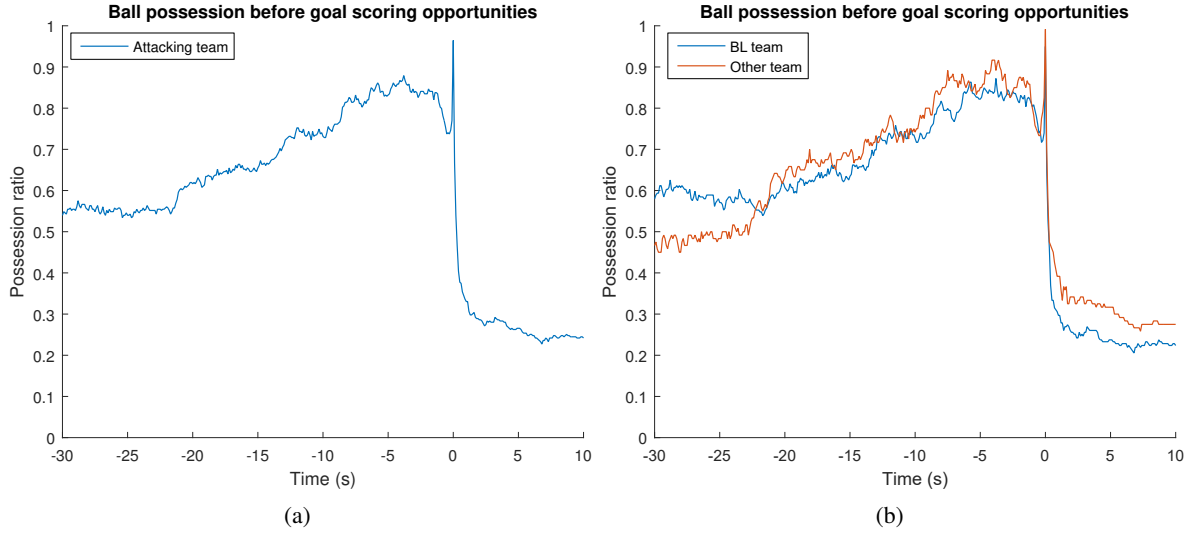


Figure 1: Ratio of ball possession before goal-scoring opportunities for (a) all attacking teams and (b) the featured Bundesliga team and other teams. $t = 0$ marks the time of goal-scoring opportunities.

the team whose player was closest to the ball (distance from ball to closest player had to be below 1.5 meters). Some extra parameters were added to avoid the algorithm from switching ball possession when the ball passed a player closely. When the ball did not undergo a significant change in direction of more than 20 degrees, or the ball velocity was not under 10 km/h, ball possession was not changed to the nearest player.

Figure 1 shows ball possession ratios before goal-scoring opportunities. Figure 1(a) shows possession before opportunities for the Bundesliga team, while in figure 1(b) possession before goal-scoring opportunities is compared between the Bundesliga team and opposing teams. The peak of 1.0 at the moment of opportunities is the result of the pre-condition of ball possession for the attacking team for goal-scoring opportunities.

2.2.3 Constructing Data for Training and Testing

Given a specific combination of player and ball positions, we would like to estimate the probability that a goal-scoring opportunity will emerge within a reasonable amount of time. This estimation will be done by classifying examples into two categories: a category containing soccer snapshots before goal-scoring opportunities, and a category containing examples of the opposite scenario, namely loss of ball possession.

It can be quite a challenge to classify a specific situation on the pitch into one of the above categories. This challenge becomes even harder when the window around goal-scoring opportunities is enlarged:

when not only the exact instant of the shot on goal is considered a goal-scoring opportunity, but also the 5 or 10 seconds before the event. While more of a challenge, a bigger window is beneficial for the predictive power of the classifier as it obtains more positive examples. It enables more practical uses as well: with an extended window, one could possibly use the classifier for predicting goal-scoring opportunities in the next couple of seconds. For the current research, a goal-scoring opportunity window of 10 seconds has been used. Explicitly, this means that samples extracted from the 10-second interval before goal-scoring opportunities were considered instances of the *opportunity* class. The same applied to the *loss of ball possession* class: samples from the 10-second interval before loss of ball possession were still considered class instances. Not all instances of ball possession loss were extracted and fed to the classifiers: the ball had to be lost on the attacking side of the field with respect to the considered team.

As input to the machine learning algorithms, 256×256 RGB color images were used. Images are suitable for visualizing player positions because the dataset consists of two-dimensional coordinates of the objects on the field: the height of the objects was not captured. The players and ball can therefore be represented by blobs on the images, such as rectangles and circles. For every detected event (opportunity or loss of ball possession), samples were taken from the 10-second interval before the event with a spacing of 1 second. For all images, mirrored versions with respect to the x-axis were added to the dataset as well.

Figure 3 depicts sample images which were used for learning. Both images were constructed from po-

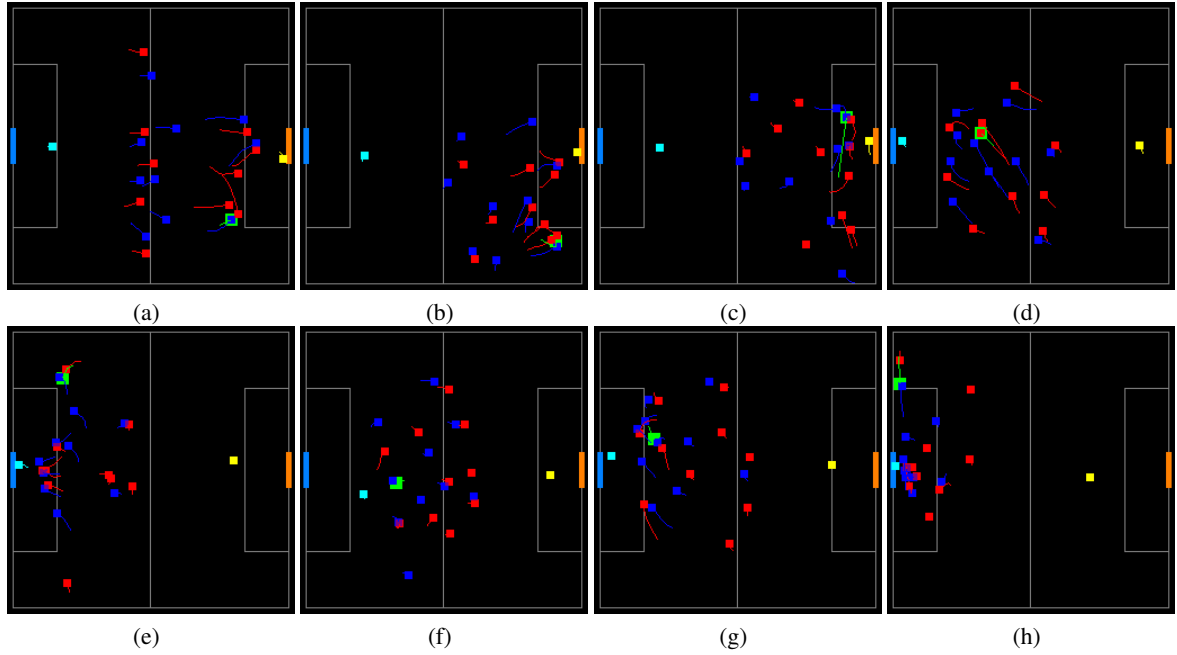


Figure 2: 8 enhanced images extracted from the intervals before different match events. The top row images (a-d) belong to the positive, *opportunity* class; the bottom row images (e-h) to the negative, *loss of ball possession* class. Note that mirrored images around the x-axis are used as well in the dataset.

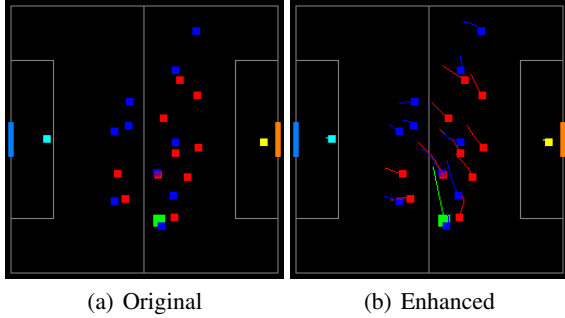


Figure 3: Example of images used as input for the convolutional neural networks. Both images depict the same moment in time, but the enhanced images also show object trajectories for the last 2 seconds.

sition data from the same time step. The left image was constructed solely by looking at the current sample, while the right image incorporates information from previous samples as well. The trail behind objects shows the past positions for the 2 seconds before the captured moment. The convolutional neural networks were trained independently with original and enhanced images, and were compared in terms of accuracy.

To illustrate how samples belonging to the different classes were transformed to images, figure 2 shows 4 randomly selected positive examples and 4 randomly selected negative examples. The top row

images (a-d) belong to the positive, or goal-scoring opportunity, class. Within 10 seconds of the depicted scenarios, goal-scoring opportunities were created. The same applies to the bottom row images (e-h) which show negative examples. Within 10 seconds of the shown scenarios, ball possession was lost by the attacking team.

To facilitate learning, the same Bundesliga team was always playing from right to left on the images, and marked as red (players) and yellow squares (goal-keeper). The opposing team's players' positions were displayed as blue (players) and light blue (goalkeeper) squares. The size of the squares for players was 7×7 pixels, while the green colored ball was of size 11×11 pixels. The ball was always printed on the background. When two players' positions did partially overlap, the colors of these players were mixed, resulting in a purple color for a red and blue player. Some experiments were done for varying sizes of squares, but this did not affect the performance of the classifiers much. Therefore the size for the players and ball was kept as small as possible for maximum detail.

3 METHODS

Convolutional Neural Networks (CNNs) are a type of neural networks which excessively make use of

mathematical convolutions to learn a function which is non-linear in nature. CNNs are particularly suited for image data because of convolution kernels which are shifted over an image. A fully-connected multi-layered perceptron would be overly connected to the input image and therefore focus too much on single pixels instead of patterns spanning multiple pixels.

The first CNN which appeared in literature in 1990 (LeCun et al., 1990) used a small neural network incorporating two convolutional layers to recognize handwritten digits. Over the last few years, CNNs and deep learning have experienced an enormous boost in popularity. This can mainly be ascribed to their recent successes in the Imagenet Large Scale Visual Recognition Challenge (ILSVRC) (Deng et al., 2009). The following subsections are used to describe the methods used to carry out our experiments.

3.1 GoogLeNet

For the current research, GoogLeNet was selected as the most complex CNN to function in our experiments. Opposed to ILSVRC2012 winner AlexNet (Krizhevsky et al., 2012), which used relatively few convolution kernels which acted on big volumes of data, GoogLeNet introduced so-called Inception modules. In an Inception module convolutions with differently sized kernels are applied in parallel. The outputs of the multiple convolutional layers within a module are concatenated and passed to the next layer. Figure 4 shows an illustration of a single Inception module. In the full CNN, Inception modules were stacked on top of each other, where the output of the previous module functioned as the input for the next.

Deep convolutional neural networks have the undesired property that the volumes of data, due to repeated convolutions, quickly become too large to be handled by current computer hardware. Some networks attempt to tackle this issue by using subsampling methods such as average or maximum pooling. In GoogLeNet, every time the computational requirements would increase too much to be handled by the hardware, the dimension of volumes is reduced. This is achieved both by using max pooling (average pooling in a few cases) and 1×1 convolutions. This is clearly visible in figure 4: before 3×3 and 5×5 convolutions, the input is convolved with small 1×1 kernels.

Because GoogLeNet is a very deep network with 22 layers with parameters (excluding pooling layers which do not have parameters/weights), it can be hard to correctly adapt the weights using back-propagation. There is a problem of *vanishing gradients*: the error vanishes when it is propagated

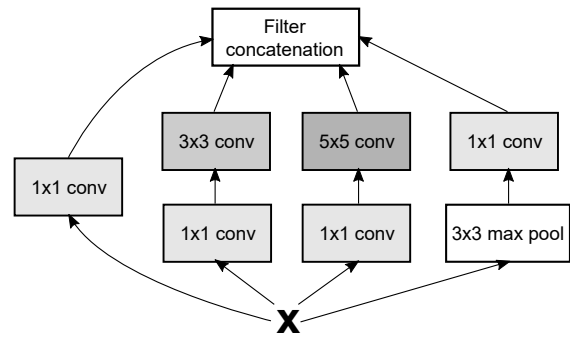


Figure 4: A single Inception module. Image based on (Szegedy et al., 2015).

back into the network, leading to insufficient weight changes in the neurons near the input (Bengio et al., 1994). GoogLeNet tackles this problem by adding two auxiliary classifiers to the network, which are connected to intermediate layers. The output of these layers was taken into account for back-propagation during training: the error of the auxiliary classifiers was weighted with a factor 0.3 (opposed to 1.0 for the final, 'third' output). In this way, the error did not vanish as much as it would if there had only been one output, as the intermediate classifiers were closer to the input than the final classifier. The auxiliary classifiers were not taken into account during test and validation time.

GoogLeNet showed spectacular performance on the Imagenet dataset: a top-5 error of 6.67 was achieved, which is significantly better than the error rate of ILSVRC2013 winner Clarifai (11.2) (Zeiler and Fergus, 2014). Although GoogLeNet achieved a very good performance on the Imagenet dataset, it should also be suitable for images constructed from soccer data. There might be too many layers because of our abstract data representation with relatively few features, although the intermediate outputs of GoogLeNet should have sufficient measures to handle this. A GoogLeNet implementation in Caffe (Jia et al., 2014) was trained both starting from scratch (with randomized starting model parameters) and from a pre-trained model (which was distributed with Caffe and trained on the Imagenet dataset). Because the Imagenet dataset contained 1000 classes and in this paper we are dealing with two classes, the last pre-trained layer from GoogLeNet could not be re-used, as the network had to use a 2-way softmax function instead of 1000-way softmax regression.

Training and testing was done with datasets containing only original images and with datasets containing enhanced images with added object trails. This leads to a total of 4 experiments:

1. **Experiment 1a:** GoogLeNet trained from scratch, default data.
2. **Experiment 1b:** Pre-trained GoogLeNet, default data.
3. **Experiment 1c:** GoogLeNet trained from scratch, enhanced data.
4. **Experiment 1d:** Pre-trained GoogLeNet, enhanced data.

The GoogLeNet models were trained on 6300 images for 8 epochs with a learning rate of 0.001. The learning rate was decreased by a factor 10 every 33% of the epochs (2.67 epochs). The stopping criterion was determined by taking the validation error on 1400 validation images into account. A momentum of 0.9 was used and a weight decay with $\lambda = 0.0005$ (Sutskever et al., 2013; Jacobs, 1988; Moody et al., 1995). Nesterov’s accelerated gradient was used as a solver for the network (Nesterov, 1983), which is a variant of stochastic gradient descent with the difference that the gradient is taken on the current weights with added momentum, as opposed to stochastic gradient descent which only takes the current weights into account for computing the gradient. The mini-batch size for training was set to 8. The neural networks were tested on datasets containing 6300 images, leading to a train-validation-test distribution of 45%-10%-45%. All sets consist of exactly 50% images from the positive class and 50% images from the negative class.

3.2 3-Layered Convolutional Neural Network

The performance of GoogLeNet was compared to a straightforward, self-constructed convolutional neural network with 3 convolutional layers. Convolutions were computed sequentially on big volumes of intermediate data. Figure 5 shows the structure of this CNN architecture.

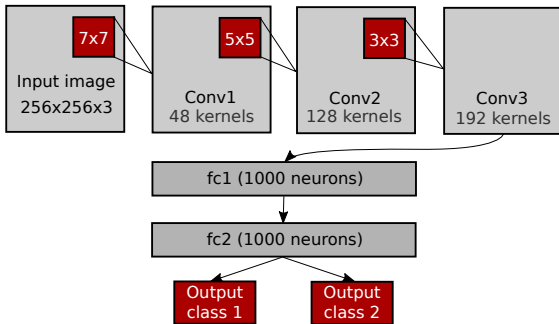


Figure 5: The 3-layered convolutional neural network used for experiment 2.

The first convolutional layer takes the input and convolves it with 48 kernels of size 7×7 with a stride of 2. The number of kernels in this layer was intentionally left low because of the very simple shapes that were used to construct the images in the datasets. The convolutional layer was followed by a ReLU unit (Nair and Hinton, 2010) and a max pooling layer with size 3×3 and stride 2 (similar to AlexNet (Krizhevsky et al., 2012)). The second convolutional layer consists of 128 kernels of size 5×5 , and is followed by ReLU units and a max pooling layer with the same hyper-parameters as described previously. The third and last convolutional layer houses 192 kernels of size 3×3 whose output is passed through a ReLU and max pooling layer.

The 3-layered convolutional neural network was trained for 2 epochs on every dataset. This stopping criterion was determined by taking validation set performance into account. The learning rate was set to 0.00005 and decreased with a factor 10 every 33% of the epochs (0.67 epochs). The datasets used for training and testing, the solver method and values for weight decay and momentum were equal to those used for GoogLeNet.

For the smaller CNN, two experiments were conducted: one with the original data, and another with enhanced data.

1. **Experiment 2a:** 3-layered CNN with default data.
2. **Experiment 2b:** 3-layered CNN with enhanced data.

3.3 KNN Baseline

A final k-nearest neighbors experiment functioned as a baseline (Cover and Hart, 1967). K-nearest neighbors was trained on *ball positions* of 50 percent of a dataset: $(x_{\text{ball},1}, y_{\text{ball},1}), (x_{\text{ball},2}, y_{\text{ball},2}), \dots, (x_{\text{ball},7000}, y_{\text{ball},7000})$. For testing, the other half of the data was sequentially presented. To every testing example $(x_{\text{ball},n}, y_{\text{ball},n})$, the class of the majority of the $k = 25$ nearest training examples was assigned¹. The euclidean distance was used as distance measure. The accuracy was then calculated by dividing the number of correctly classified examples by the total number of test examples. For KNN, 7000 training images and 7000 test images were used per dataset division.

Experiment 3 K-nearest neighbor classification

¹Multiple values of k were tested. The best results were achieved with $k = 25$.

Table 1: Average classification accuracies and standard deviations for all experiments.

Experiment	Nesterov (10 runs)	SGD (5 runs)	Other (10 runs)
1a: GoogLeNet scratch, original images	$64.8 \pm 2.4\%$	$64.5 \pm 2.8\%$	
1b: GoogLeNet pre-trained, original images	$63.3 \pm 3.0\%$	$62.6 \pm 2.3\%$	
1c: GoogLeNet scratch, enhanced images	$67.1 \pm 2.7\%$	$67.0 \pm 3.0\%$	
1d: GoogLeNet pre-trained, enhanced images	$65.4 \pm 2.3\%$	$66.0 \pm 2.6\%$	
2a: 3-layered net, original images	$62.4 \pm 2.1\%$		
2b: 3-layered net, enhanced images	$62.8 \pm 1.7\%$		
3: K-nearest neighbors			$57.3 \pm 1.2\%$

4 RESULTS AND DISCUSSION

Images belonging to a single opportunity or instance of ball possession loss were coupled and could not end up in both training and test sets. Every dataset split contained samples extracted from all of the 349 detected goal-scoring opportunities. A goal-scoring opportunity was assigned to either the train, validation or test set: two arbitrary samples extracted from a given opportunity always ended up in the same set.

The negative examples (loss of ball possession) were selected in order to resemble the positive examples (goal-scoring opportunities) as close as possible. For every goal-scoring opportunity, an instance of ball possession loss was selected for the team which created the opportunity. This loss of ball possession had to occur in the same match half as where the coupled goal-scoring opportunity arose, and on the attacking half of the field with respect to the considered team.

4.1 Results

In our preliminary experiments, we used the GoogLeNet architecture with the Nesterov solver to train the network. The obtained results were good but there was a need to investigate another solver type, such stochastic gradient descent (SGD). After 5-fold random cross-validation, the results did not differ much from the Nesterov solver experiments. The results for both the Nesterov solver and SGD are shown in table 1. The table also shows the performance of the 3-layered CNN (trained with the Nesterov solver) and KNN.

GoogLeNet trained from scratch with enhanced images (experiment 1c) performed best and achieved an accuracy of 67.1%. This is almost 10 percent higher than the outcome of the k-nearest neighbors baseline experiment (accuracy: 57.3%, experiment 3). The 3-layered net performed better than KNN as well and achieved a top accuracy of 62.8%.

4.2 Discussion

The most complex network used in the experiments, GoogLeNet, showed top performance with an accuracy of 67.1%. Zooming in on the training process of the GoogLeNet models, the training error was greatly reduced during the first epoch and did not decrease much from epoch 2 to 8. The same applied to the validation accuracy. The reason why training was run for 8 epochs instead of 2 was that in some cases the validation accuracy was very low in the beginning, possibly due to unlucky initialization or an unfavored sequence of presented inputs, so it did need more iterations to achieve a higher level of performance.

The same phenomenon of early convergence of model parameters was visible for the less complex 3-layered convolutional neural network. This network only showed a drop in training error at the very beginning and did not decrease much afterwards. The accuracy did not improve when it was trained for more than 2 epochs. It is therefore hard to believe that the network successfully accomplished to learn all higher-order patterns of soccer which are important for creating opportunities. The network did probably only manage to learn a set of basic rules, which led to an average accuracy of a little less than 63%.

The difference in performance and training between GoogLeNet and the 3-layered convolutional neural network is interesting. The top-performing variant of GoogLeNet (trained from scratch, enhanced images) achieved an accuracy more than 4% higher than the 3-layered net, which is a significant difference. It seems that GoogLeNet is able to capture more complex tactical patterns than the other models.

The average accuracy increase of approximately 2% for enhanced images over default images is promising as well. The added information in the form of object trails seems to be picked up by the models which use it to their advantage. The images could possibly be enriched with even more bells and whistles, which might be interesting to research in the future. The absence of this difference for the 3-layered network suggests that GoogLeNet is indeed

able to catch some higher-order patterns, in which the 3-layered net does not succeed.

Then remains the question how bad an accuracy of 67.1% actually is. As a starting point, it is significantly higher than the 57.3% accuracy of the k-nearest neighbors baseline. But what would the performance of the best performing human or artificial classifier be for the current problem? Would an accuracy of, say, 90% be realistic? This would probably not be the case. Samples were extracted already 10 seconds before the occurrence of goal-scoring opportunities. A lot can happen in the 10 second interval to the actual shot towards the goal.

5 Conclusion

To conclude, the results suggest that convolutional neural networks are capable of predicting goal-scoring opportunities to a certain extent. There are a couple of ways how the performance of the convolutional neural networks could be improved. Using a larger dataset would probably stimulate the convolutional neural networks to learn higher-order patterns instead of more superficial ones. A higher number of classes can be used to detect more events in soccer, or input images can be weighted differently by taking their temporal location to events into account. As an alternative to using point images, a graph representation of the position data could be used as input to neural networks. Finally, using a more specialized convolutional neural network, possibly combined with a recurrent neural network architecture, could yield higher accuracies, as would using an ensemble of several classifiers.

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