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LATE FUSION AND CALIBRATION FOR MULTIMEDIA EVENT DETECTION USING FEW EXAMPLES

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ABSTRACT

The state-of-the-art in example-based multimedia event detection (MED) rests on heterogeneous classifiers whose scores are typically combined in a late-fusion scheme. Recent studies on this topic have failed to reach a clear consensus as to whether machine learning techniques can outperform rule-based fusion schemes with varying amount of training data. In this paper, we present two parametric approaches to late fusion: a normalization scheme for arithmetic mean fusion (logistic averaging) and a fusion scheme based on logistic regression, and compare them to widely used rule-based fusion schemes. We also describe how logistic regression can be used to calibrate the fused detection scores to predict an optimal threshold given a detection prior and costs on errors. We discuss the advantages and shortcomings of each approach when the amount of positives available for training varies from 10 positives (10Ex) to 100 positives (100Ex). Experiments were run using video data from the NIST TRECVID MED 2013 evaluation and results were reported in terms of a ranking metric: the mean average precision (mAP) and $\bar{R}_0$, a cost-based metric introduced in TRECVID MED 2013.

Index Terms— multimedia event detection, late fusion, score calibration, score normalization, system fusion

1. INTRODUCTION

As the quantity of online user-submitted multimedia content grows, indexing and reliably searching for specific content becomes increasingly challenging. Moreover, the data is very heterogeneous and often of poor audio or visual quality, which challenges the accuracy of current event detection technologies. The track of multimedia event detection conducted under the TRECVID evaluations by NIST aims to solve the problem of detecting specific events like “changing a tire” or “grooming an animal” in a heterogeneous corpus of user-submitted video clips. Accurately detecting such precise events requires input from various analysis channels (image and motion analysis, audio concepts, speech content, character recognition, etc.) that we will refer to as MED modalities. The best-performing approaches to solving this task use various modalities and combine their detection scores in a late-fusion scheme. It is to be noted that while some researchers have successfully developed early-fusion schemes [1, 2] to combine different modalities together and learn joint classifiers, not all modalities can be combined in this way and these systems still rely heavily on late-fusion as a final combination stage [2].

Approaches to late-fusion mainly fall into two categories: rule-based or statistical model based. Simple rule-based fusions (like arithmetic mean or geometric mean) which first normalize the scores to a comparable range and then treats each modality identically are popular for their inherent robustness to over-fitting [3, 4, 5]. Other rule-based techniques (like weighted averaging) use different weights for different modalities. Here, the weights are found using grid-search [6, 7], are set to a measure of the performance of each modality [3], or to a measure of confidence of the score [8]. Machine learning alternatives like logistic regression [5, 9], ridge regression [7], linear support vector machine (SVM) [9] and explicit optimization of an evaluation metric [9] have also been explored. While the above studies often compare multiple fusion techniques to one another, their conclusions can vary widely. For instance, [9, 6] claim gains from logistic regression fusion compared to arithmetic mean or grid-based search techniques while other studies found the opposite conclusion on a similar task [3, 4, 5]. Given the diversity of the modalities to fuse across research teams, and the fact that their scores show very different distributions (Gaussian, exponential, bimodal, etc.), we believe that such conflicting conclusions could be explained by differences in the modalities’ score distributions, differences in the type of features used in learning-based techniques, and differences in the way missing values are handled. Unfortunately, these details are often overlooked in the above studies, making it difficult to draw definite conclusions.

The challenge of handling missing values in late fusion is very common in detection tasks, especially in MED where modalities’ scores can go missing for various reasons: no audio was available, no speech was detected, no motion was detected in the video, etc. Traditional ways of dealing with missing features in late-fusion include inferring the missing scores from the mean of scores from other videos or setting the missing score to be the minimum score. Ideally, one would like to not make any assumption about the missing score’s value but rather learn its value for various events and modalities. Such an approach has been successfully applied to other detection tasks such as speaker identification [10] or spoken term detection [11] by using a logistic regression framework with binary side-information.

While MED performance is usually measured in terms of mean average precision (mAP), we also considered the $\bar{R}_0$ metric...
based on action concept detectors. There were 96 action concepts
MoSIFT raw features with default parameters. The raw features
were encoded using first- and second-order Fisher Vector descriptors
and 101 action concepts from UCF 101 [20]. The action concept
detectors were applied to small segments of videos and encoded by
Hidden Markov Model Fisher Vector descriptors [21]. SVM with
Gaussian kernel was used to train two event classifiers, one for each
set of action concepts.

Low-level audio content For our audio features, we extracted
mel-frequency cepstral coefficients (MFCCs) over a 10-ms window.
MFCCs describe the spectral shape of audio. The first and second
derivatives of the MFCCs were also computed. The MFCC
features were difference-coded with Fisher vectors using a 1024-
element Gaussian Mixture Model and classified using a linear SVM.

Spoken content We ran an English ASR model trained on
conversational telephone data and adapted to meeting data. We
performed supervised acoustic model adaptation using in-domain
annotated TRECVID data and unsupervised adaptation using the
first-pass recognition output. We also performed supervised and un-
supervised language model adaptation. The lattice-based approach
described in [22] was used to build the MED classifier, and the final
score was the distance to the hyperplane of a L1-regularized linear
SVM model, mapped to [0, 1] by using a logistic function.

Written content SRI’s English video OCR software detected
and recognized text appearing in the TRECVID MED 2013 video
imagery. This software recognizes both overlay text, such as cap-
tions that appear on broadcast news programs, and in-scene text on
signs or vehicles [23]. For each event, we generated event profiles
from the event descriptions by using term frequency-inverse docu-
ment frequency (TF-IDF) weightings to rank the relevance of non-
stop-words. The event detection score for each video was the cosine
similarity between the word vector for the video and the word vector
for the event profile.

3. LATE FUSION

In this section, we present approaches to late fusion that were used
in our experiments. The scores \( x_i \) from each of the \( N \) modalities are
detection probabilities and therefore lie in \([0, 1]\). The goal of late-
fusion is estimating the probability of the label \( y \) of a given video
given the score vector \( x = [x_0, x_1, ..., x_{N-1}] \).

3.1. Baseline fusions

We describe a few simple, widely used baseline fusion methods.

Arithmetic mean This method combines scores from various
modalities by taking the arithmetic mean of the scores for each trial.
We considered two ways of dealing with missing scores. In the \( AM-
zero \) technique, a missing score is supposed to have a zero value.
In the \( AM-mean \) technique, a missing score is supposed to have the
mean value of the non-missing scores from other modalities. The
latter technique is equivalent to computing the average over the non-
missing scores only.

Geometric mean This method, referred to as \( GM \), computes the
fused score for a given trial as the geometric mean of all non-missing
and non-zero scores for that trial.

Weighted averaging In this technique, the final score is
computed as a weighted sum of the scores for each modali-
ty. The weights are chosen by optimizing the mAP metric
through an exhaustive grid-search with weights taking values in
\{0.001, 0.01, 0.03, 0.1, 0.3, 0.6, 1\}. The weights are trained on the
cross-validation scores on the training data, and applied to the test
data. We study two different setups with varying number of trained

2. DESCRIPTION OF MODALITIES

In this section, we describe the scope of our individual modalities
and how they were trained. A more in depth description of each
modality can be found in [13] and [14].

Low-level visual features We extracted low-level visual
features for two frames per second from each video. We followed
the bag-of-codes approach, which considers spatial sampling of
points of interest, visual description of those points, and encoding
of the descriptors into visual codes. We used a mixture of SIFT,
TSIFT, and C-SIFT descriptors [14]. We computed the descriptors
around points obtained from dense sampling and reduced them to
80 dimensions with principal component analysis. We encoded
the color descriptors using Fisher vectors with a Gaussian Mixture
Model codebook of 256 elements [15].

Semantic visual features We detected semantic concepts
for each frame using low-level visual features and following the
approach in [16]. We trained 1,346 concept detectors based on
linear SVMs. Each frame is then represented by the concatenated
detector scores from all these concepts.

Visual event classifiers We included three visual event clas-
sifiers based on low-level and semantic features. To arrive at a
video-level representation for the low-level visual event classifier,
we relied on simple frame averaging. For the two video event
classifiers based on semantic features, we aggregated the concept
vectors per frame into a video-level representation. One approach
used averaging and normalization, while the other method used
semantic encoding. On top of both concept representations, we used
an SVM with \( \chi^2 \) kernel.

Low-level motion features The two low-level motion features
were based on Dense Trajectories (DTs) [17] and MoSIFT [18]. We
computed DT raw features with a step size of 10 pixels and
MoSIFT raw features with default parameters. The raw features
were encoded using first- and second-order Fisher Vector descriptors
with a two-level spatial pyramid [19]. Descriptors were aggregated
each across video. We generated four event classifiers: two with
DT features using first- and second-order Fisher Vector descriptors,
and two with MoSIFT features using first- and second-order Fisher
Vector descriptors. A Gaussian-kernel SVM was used for classifica-
tion, and the outputs from the same low-level feature were averaged.

Motion event classifiers Two event classifiers were generated
based on action concept detectors. There were 96 action concepts
annotated on the MED11 Event Kit provided by Sarnoff/UCF.
parameters: in WM-dep the weights are event-dependent and in WM-indep the weights are optimized for all 20 events at once.

3.2. Logistic regression fusion

Logistic regression is a common approach for converting a M-dimensional vector of scores into a single value, the likelihood ratio, which can be used to make binary decisions. The LR model assumes that the posterior of a certain clip being a positive has the form $P(y = +1|x) = \sigma(\alpha x^T + \beta)$ where $\sigma(x) = 1/(1 + e^{-x})$ is the logistic function. The parameters $\alpha = [\alpha_0, ..., \alpha_{M-1}]$ and $\beta$ are learned by maximizing the L2-regularized likelihood of the model on labeled training data by using the “Trusted Region Newton Method” [24] as implemented in the scikit-learn library [25]. The regularization parameter was tuned using cross-validation.

We propose to apply logistic regression to MED late fusion, a technique we refer to as LR, as follows. For each trial, we create a feature vector by concatenating the logit of scores of all of the N modalities, where the logit function is defined by $logit(x) = \log(x/(1 - x))$. The logit expands the dynamic range of the exponentially distributed probabilistic scores. The resulting scores are close to normally distributed for both positives and negatives and behave better for logistic regression. Missing scores are set to zero, and a feature is added for each modality as a binary indicator variable $I_{miss}$ accounting for the possibility of missing scores for some trials. Initially introduced in [11] for late fusion of keyword spotting systems, this approach is equivalent to learning a bias for the missing score value of each modality. Once parameters are trained, the final posterior is given by:

$$P(y = +1|x) = \sigma(\sum_{i=0}^{N-1} (\alpha_{2i} x_i + \alpha_{2i+1} I_{miss}(x_i)) + \beta)$$

Additionally, we propose to automatically perform feature selection and discard some modalities during training by looking at the trained weights $\alpha_{2i}$. If the weight corresponding to a certain modality is found to be negative, the logistic regression is retrained with that modality removed. This approach is based on the intuition that a negative weight indicates an anti-correlation between the score of some modality and the label of a video clip, which is the sign of a poorly performing modality. By discarding that modality, we reduce the noise in the data as well as the dimension of the feature vector and obtain better generalization properties. This approach will be referred to as LR+fs. We also considered the LR-min and LR-min+fs systems where a missing score is set to the minimum score of that modality on the training data. These two systems will provide a comparison point against the proposed missing-values handling scheme.

3.3. Logistic averaging

The logistic averaging technique, or LA, is a novel technique that non-linearly normalizes the scores of various modalities before performing arithmetic mean fusion.

As in the case of logistic regression, we apply the logit function to the posterior scores of our modalities to map them from $[0, 1]$ to $[-\infty, +\infty]$. We apply Z-normalization by computing the means and variances of the cross-validated logit-scores for each event on the training data. The same normalization is applied to the videos in the test set. Then we map those scores back to $[0, 1]$ using the sigmoid function $\sigma_{\alpha, \beta}$ defined as $\sigma_{\alpha, \beta} = 1/(1 + e^{-\alpha \beta \hat{S}})$. The parameters $\alpha$ and $\beta$ are chosen to optimize the mAP on the cross-validated training scores using a grid search. If $X_i$ denotes the Z-normalized logit-score from each modality, then the fused score is given by:

$$P(y = +1|x) = \frac{1}{N} \sum_{i=0}^{N-1} \sigma_{\alpha, \beta}(X_i)$$

As mentioned in previous work on late fusion of biometric systems [26], Z-normalization performs best when the input distributions are Gaussian distributed. By applying the logit to our initial scores, which are exponentially distributed, we obtain near-Gaussian distributed scores. The role of $\alpha$ and $\beta$ is to enable some non-linearity in the arithmetic mean fusion by tuning a sigmoid that modifies the modalities’ score distributions. Because the logit-scores are normalized around 0 with variance 1, a small $\alpha$ would lead to a nearly linear mapping, while a large $\alpha$ introduces a sharp cutoff at $-\beta$, below which the scores are set to 0, and above which the scores are set to 1.

Although this approach does not train different weights for each modality and can therefore seem sub-optimal compared to weighted averaging or logistic regression, it is less prone to over-fitting as it does not rely on labeled positives to estimate the mean and variances. It does require some positives to tune $\alpha$ and $\beta$ but as these parameters are fixed for all events, their estimation is quite robust.

4. CALIBRATION AND THRESHOLD SELECTION

Besides maximizing average precision, a second challenge of the MED 2013 TRECVID evaluation [27] is to select, for each event, the detection threshold $t$ that maximizes the $R_0$ metric defined as:

$$R_0(t) = Rec(t) - \frac{2}{\pi} Rank(t)$$

where $K = 12.5$, $V$ is the total number of clips in the test set, $Rec(t)$ is the recall at threshold $t$ and $Rank(t)$ is the number of clips whose score is larger than $t$. It can be shown that $R_0(t)$ can be rewritten as:

$$R_0(t) = C_1 (C_2 - [(K\pi_{test}^{max})^{-1} - 1]N_{miss}(t) - N_{fa}(t))$$

where $C_1$ and $C_2$ are constants, $N_{miss}(t)$ and $N_{fa}(t)$ are the respective number of misses and false alarms at threshold $t$, and $\pi_{test}^{max}$ is the ratio of positives in the test set. The threshold that maximizes this quantity also minimizes the risk given by:

$$Risk(t) = C_{miss} \cdot N_{miss}(t) + C_{fa} \cdot N_{fa}(t)$$

which defines a threshold on the log-likelihood ratio (LLR):

$$LLR = \log \left( \frac{p(x | y = +1)}{p(x | y = -1)} \right) > \log \left( \frac{C_{fa}}{C_{miss}} \right) - logit(\pi_{test}^{max})$$

This formulation comes in handy when using logistic regression to fuse or calibrate scores. Indeed, it can be shown that with a posterior of the form $P(y = +1|x) = \sigma(\alpha x^T + \beta)$, the following holds for the LLR:

$$LLR + logit(\pi_{train}^{max}) = \alpha x^T + \beta$$

where $\pi_{train}^{max}$ is the ratio of positives in the training set. Assuming that the scores $S = \alpha x^T + \beta$ at the output of the logistic regression are well calibrated, the threshold $t_0$ that maximizes $R_0$ is therefore:

$$t_0 = \log \left( \frac{C_{fa}}{C_{miss}} \right) - logit(\pi_{test}^{max}) + logit(\pi_{train}^{max})$$

$$= logit(K \pi_{test}^{max}) - logit(\pi_{test}^{max}) + logit(\pi_{train}^{max})$$

It is worth noting that while $\pi_{train}^{max}$ is known from the training data labels, $\pi_{test}^{max}$ might not be known and the difference between the assumed and the actual $\pi_{test}^{max}$ may result in a sub-optimal threshold.
5. EXPERIMENTAL RESULTS

In this section, we first describe the data used for our experiments and then present results on system fusion using two separate metrics.

5.1. Data

We evaluated the performance of late fusion according to the NIST TRECVID 2013 MED evaluation plan [27]. We used the 20 pre-specified events as our detection targets. We ran experiments in two conditions with varying numbers of positives: 100Ex with 100 positive clips per event and 10Ex with 10 positive clips. An extra set of 4992 video clips labeled as negatives is used to supplement the positives for each event. To maximize the use of this limited amount of training data, we generated scores on the training data for each modality using 10-fold cross-validation. These cross-validation scores were used to train all of the normalization and fusion parameters, as well as to choose thresholds. The MED performance is reported on MDEVTEST, a set of 23,468 video clips labeled as negatives plus 1,489 video clips labeled as positives, for an average of 75 labeled positives per event.

5.2. Results and discussion

For logistic regression and weighted averaging, we reduced the number of trained parameters by merging together similar modalities using arithmetic mean in the posterior domain prior to learning the fusion. Specifically, we fused together all three visual modalities and all four motion-based modalities to create two aggregate modalities. For 10Ex for logistic regression, we even averaged those two modalities into a single modality.

Columns 2 and 5 of Table 1 present the mean Average Precision (mAP) of individual sub-systems and of several fusion schemes on the test set. In both training conditions, the logistic regression and logistic averaging techniques significantly outperform the baseline fusion techniques. These gains can be explained by the greater flexibility of parametric approaches such as LR, LA and WM. Yet, the two proposed approaches do not suffer the over-fitting problems of WM, either because the number of trained parameters is small (LA) or because of regularization (LR). When 100 examples are available for training, the best technique is LR+fs with a mAP of 0.434. This results demonstrate the efficiency of using binary indicators to handle missing values since LR-min+fs obtained a mAP of 0.422 only. Also, while logistic regression proves more efficient than LA for 100Ex, this trend disappears in the 10Ex conditions where both LA and LR-min+fs perform best. We believe that this result is directly related to the design of LA as a fusion technique not requiring many positives for training and tuned to optimize mAP. In contrast, logistic regression learns event-dependent weights that enable it to perform well over a wide range of operating points. The feature-selection component of logistic regression was found useful and provided a significant mAP increase in both conditions. Modalities were discarded for 7 events for 10Ex and 16 events for 100Ex.

We also compared the performance of the different fusion strategies in terms of the $T_0$ metric. We considered two different strategies to pick the threshold: (1) using the threshold $t_{t_0}$ that optimizes $R_0(t)$ on the training data, and (2) using the threshold $t_0$ computed as in the theoretical analysis developed in Section 4. The latter technique assumes that the fused scores are calibrated likelihood ratios. Because this is only the case for the LR fusion, we first calibrate the output of the other fusion strategies for each event by using a pass of logistic regression with a 2-dimensional feature vector. The two dimensions are set to the logit of the fused score in the posterior domain and a binary indicator that is set to 1 if the score is missing. The logistic regression parameters are estimated using the fused cross-validation scores on the training set. The $\alpha$ and $\beta$ parameters of the logistic averaging approach were adjusted to maximize $R_0(t_0)$ on the training data.

Results in terms of $T_0$, the mean of $R_0$ over all 20 events, are shown in Table 1. With this metric, logistic regression consistently outperforms the other fusion approaches, for both conditions. Logistic averaging remains competitive but no longer outperforms LR-min+fs in the 10Ex condition. An advantage of logistic regression fusion over other techniques for maximizing $R_0$ is that it uses a feature vector with at least $N$ dimensions, and therefore more finely approximates the LLR. The resulting scores are better calibrated than the scores obtained through a pass of logistic regression following late-fusion. Also, we should point out that the $t_0$ threshold obtained through Bayesian decision theory consistently outperforms the more ad-hoc technique of picking $t_{t_0}$ using the training data. This is because the Bayesian formulation enables computing the theoretically optimal threshold given the event detection priors on the test data.

6. CONCLUSION AND FUTURE WORK

In this paper, we demonstrate the efficiency of parametric approaches to late fusion in a multimedia event detection system, even in situations with limited training data. The proposed logistic regression approach to score fusion handles missing scores and automatically performs feature selection to discard poorly performing modalities. A second technique, proposed under the name of logistic averaging, can be seen as a pre-processing approach to the arithmetic mean method by performing Z-normalization in the logit domain before mapping scores back to posteriors in a way that maximizes a given metric. The logistic regression approach significantly outperforms baseline techniques in terms of both the mAP and the $T_0$ metric. Logistic averaging was very competitive for optimizing mAP with limited training data, but didn’t perform as well on the $T_0$ metric. These findings are comparable to results for other detection tasks such as speaker identification or keyword spotting where logistic regression has consistently been found to be a robust tool to combine systems and provide a calibrated output that can be used to make binary decisions over a wide range of operating points. Avenues for future work include applying the fusion techniques introduced in this paper to the problem of query-based event detection, where the event detection models are built from an event description rather than learnt using positive examples.
7. REFERENCES


