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Beat-Event Detection in Action Movie Franchises

Danila Potapov  Matthijs Douze  Jerome Revaud  Zaid Harchaoui  Cordelia Schmid

Abstract

While important advances were recently made towards temporally localizing and recognizing specific human actions or activities in videos, efficient detection and classification of long video chunks belonging to semantically-defined categories such as “pursuit” or “romance” remains challenging.

We introduce a new dataset, Action Movie Franchises, consisting of a collection of Hollywood action movie franchises. We define 11 non-exclusive semantic categories — called beat-categories — that are broad enough to cover most of the movie footage. The corresponding beat-events are annotated as groups of video shots, possibly overlapping. We propose an approach for localizing beat-events based on classifying shots into beat-categories and learning the temporal constraints between shots. We show that temporal constraints significantly improve the classification performance. We set up an evaluation protocol for beat-event localization as well as for shot classification, depending on whether movies from the same franchise are present or not in the training data.

1. Introduction

Automatic understanding and interpretation of videos is a challenging and important problem due to the massive increase of available video data, and the wealth of semantic variety of video content. Realistic videos include a wide variety of actions, activities, scene type, etc. During the last decade, significant progress has been made for action retrieval and recognition of specific, stylized, human actions. In particular, powerful visual features were proposed towards this goal [21, 22, 33]. For more general types of events in videos, such as activities, efficient approaches were proposed and benchmarked as part of the TrecVid Multimedia Event Detection (MED) competitions [23]. State-of-the-art approaches combine features from all modalities (text, visual, audio), static and motion features (possibly learned beforehand with deep learning), and appropriate fusion procedures.

In this work, we aim at detecting events of the same semantic level as Trecvid MED, but on real action movies that follow a structured scenario. From a movie scriptwriter’s point of view [31, 28], a Hollywood movie is more or less constrained to a set of standard story-lines. This standardization helps matching the audience expectations and habits. However, movies need to be fresh and novel enough to fuel the interest of the audience. So, some variability must be introduced in the story lines to maintain the interest. Temporally, movies are subdivided in a hierarchy of acts, scenes, shots, and finally, frames (see Figure 2). Punctual changes in the storyline give it a rhythm. They are called “beats” and are common to many films. A typical example of beat is the moment when an unexpected solution
saves the hero.

From a computer vision point of view, frames are readily available and reliable algorithms for shot detection exist. Grouping shots into scenes is harder. Scenes are characterized by a uniform location, set of characters or storyline. The semantic level of beats and acts is out of reach. We propose here to attack the problem on an intermediate level by detecting “beat-events”. Temporally, they consist in sequences of consecutive shots and typically last a few minutes. Shots offer a suitable granularity, because movies are edited so that they follow the rhythm of the action. Semantically, they are of a higher level than the actions in most current benchmarks, but lower than the beats, which are hard to identify even for a human.

For the purpose of research, we built an annotated dataset of Hollywood action movies, called Action Movie Franchises. It comprises 20 action movies from 5 franchises: Rambo, Rocky, Die Hard, Lethal Weapon, Indiana Jones. A movie franchise refers to a series of movies on the same “topic”, sharing similar story lines and the same characters. In each movie, we annotate shots into several non-exclusive beat-categories. We then create a higher level of annotation, called beat-events, which consists of consistent sequences of shots labeled with the same beat-category.

Figure 1 illustrates the beat-categories that we use in our dataset. They are targeted at action movies and, thus, rely on semantic categories that often rely on the role of the characters, such as hero (good) or villain (bad). We now briefly describe all categories. First, we define three different action-related beat-categories: pursuit, battle preparation and battle, shown in the first row of Fig. 1. We also define categories centered on the emotional state of the main characters: romance, despair good (e.g. when the hero thinks that all is lost) and joy bad (e.g. when the villain thinks he won the game), see second row of Fig. 1. We also include different categories of dialog between all combinations of good and bad characters: good argue good, good argue bad and bad argue bad (third row of Fig. 1). Finally, we add two more categories notifying a temporary victory (third row of Fig. 1). We also consider a NULL category, corresponding to shots that cannot be classified into any of the aforementioned beat-categories.

In summary, we introduce the Action Movie Franchises dataset, which features dense annotations of 11 beat-categories in 20 action movies at both shot and event levels. To the best of our knowledge, a comparable dense annotation of videos does not exist.

The semantic level of our beat-categories will drive progress in action recognition towards new approaches based on human identity, pose, interaction and semantic audio features. State-of-the-art methods are without doubt not sufficient for such categories. Action movies and related professionally produced content account for a major fraction of what people watch on a daily basis. There exists a large potential for applications, such as access to video archives and movie databases, interactive television and automatic annotation for the shortsighted.

Furthermore, we define several evaluation protocols, to investigate the impact of franchise-information (testing with or without previously seen movies from the same franchise) and the performance for both classification and localization tasks. We also propose an approach for classification of video shots into beat-categories based on a state-of-the-art pipeline for multimodal feature extraction, classification and fusion. Our approach for localizing beat-events uses a temporal structured inferred by a conditional random field (CRF) model learned from training data.

We will make the Action Movie Franchises dataset publicly available upon publication to the research community to further advance video understanding.

2. Related work

Related datasets. Table 1 summarizes recent state-of-the-art datasets for action or activity recognition. Our Action Movie Franchises dataset mainly differs from existing ones with respect to the event complexity and the density of annotations. Similarly to Coffee & Cigarettes and MediaEval Violent Scene Detection (VSD), our Action Movie Franchises dataset is built on professional movie footage. However, while the former datasets only target short and sparsely occurring events, we provide dense annotations of beat-events spanning larger time intervals. Our beat-categories are also of significantly higher semantic level than those in action recognition datasets like Coffee & Cigarettes, UCF [32] and HMDB [14]. A consequence is that our dataset remains very challenging for state-of-the-art algorithms, as shown later in the experiments. Events of a similar complexity can be found in TrecVid MED 2011–2014 [23], but our dataset includes precise temporally localized annotations.

Action detection in movies. Action detection (or action localization), that is finding if and when a particular type of action was performed in long and unsegmented video streams, received a lot of attention in the last decade. The problem was considered in a variety of settings: from still images [27], from videos [9, 33], with or without weak supervision, etc. Most works focused on highly stylized human actions such as “open door”, “sit down”, which are typically temporally salient in the video stream.

Action or activity recognition can often be boosted using temporal reasoning on the sequence of atomic events that characterize the action, as well as the surrounding events that are likely to precede or follow the action/activity of interest. We shall only review here the “temporal context”
Table 1. Comparison of classification and localization datasets. annot = total duration of all annotated parts; NULL = duration of the non-annotated (NULL or background) footage; coverage = proportion of annotated video footage.

3. Action Movie Franchises

We first describe the Action Movie Franchises dataset and the annotation protocol. Then, we highlight some striking features in the structure of the movies observed during and after the annotation process. Finally, we propose an evaluation protocol for shot classification into beat-categories and for beat-event localization.

3.1. The movies

The Action Movie Franchises dataset consists of 20 Hollywood action movies belonging to 5 famous franchises: Rambo, Rocky, Die Hard, Lethal Weapon, Indiana Jones. Each franchise comprises 4 movies; see Table 1 for summary statistics of the dataset.

Each movie is decomposed into a list of shots, extracted with a shot boundary detector [20, 25]. Each shot is tagged with zero, one or several labels corresponding to the 11 beat-categories (the label NULL is assigned to shots with zero labels). Note that the total footage for the dataset is 36.5 h, shorter than the total length in Table 1. This is due to multiple labels. All categories are shown in Figure 1.

Series of shots with the same category label are grouped together in beat-events if they all depict the same scene (ie. same characters, same location, same action, etc.). Temporally, we also allow a beat-event to bridge gaps of a few unrelated shots. Beat-events belong to a single, non-NULL, beat-category.

The set of categories was inspired by the taxonomy of [31], and motivated by the presence of common narrative structures and beats in action movies. Indeed, category definitions strongly rely on a split of the characters into “good” and “bad” tags, which is typical in such movies. Each category thus involves a fixed combination of heroes and villains: both “good” and “bad” characters are present during battle and pursuit, but only “good” heroes are present in the case of good argue good.

Large intra-class variation is due to a number of factors:
duration, intensity of action, objects and actors, and different scene locations, camera viewpoint, filming style. For ambiguous cases we used the “difficult” tag.

3.2. Annotation protocol

The annotation process was carried out in two passes by three researchers. Ambiguous cases were discussed and resulted in a clear annotation protocol. In the first pass we manually annotated each shot with zero, one or several of the 11 beat-category labels. In the second one we annotated the beat-events by specifying their category, beginning and ending shots. We tolerated gaps of 1-2 unrelated shots for sufficiently consistent beat-events. Indeed, movies are often edited into sequences of interleaved shots from two events, e.g., between the main storyline and the “B” story.

Some annotations are labeled as “difficult”, if they are semantically hard to detect, or ambiguous. For instance, in Indiana Jones 3, Indiana Jones engages in a romance with Dr. Elsa Schneider, who actually betrays him to the “bad guy”. Romance between Indiana Jones and Dr. Elsa Schneider is therefore ambiguous. We exclude these shots at training and evaluation time, as in the Pascal evaluation protocol [8].

Our beat-event annotations cover about 60% of the movie footage, which is much higher than comparable datasets, see Table 1. This shows that the vocabulary we chose is representative: the dataset is annotated densely.

3.3. Highlighting structure of action movies

Figure 3 shows the sequence of category-label annotations for several movies. Some global trends are striking: victory good occurs at the end of movies; battle is most prevalent in the last quarter of movies; there is a pause in fast actions (battle, pursuit) around the middle of the movies. In movie script terms, this is the “midpoint” beat [31], where the hero is at a temporary high or low in the story. In terms of beat-event duration, joy bad and victory bad are short, while pursuit and romance are long. These trends can be learned by the temporal re-scoring to improve the shot classification results.

After careful analysis of the annotation, we find that battle, despair good and pursuit are the most prevalent beat-categories, with 4145, 3042 and 2416 instances respectively. Since it is a semantically high level class, despair good is most often annotated as difficult. The co-occurrences of classes as annotations of the same shot follow predictable trends: battle co-occurs with pursuit, battle preparation, victory good and victory bad. Interestingly romance is often found in combination with despair good. This is typical for movies of the “Dude with a problem” type [31], where the hero must prove himself.

Within each movie franchise, a shared structure may appear. For instance, in Rocky, the battle preparation occurs in the last quarter of the movie, and there is no pursuit.
3.4. Evaluation protocol

In the following, we propose two types of train/test splits and two performance measures for our Action Movie Franchises dataset.

**Data splits.** We consider two different types of splits over the 20 movies; see Figure 4. They both come in 5 folds of 16 training movies and 4 test movies. All movies appear once as a test movie. In the “leave one franchise out” setting, all movies from a single franchise are used as a test set. In “leave 4 movies out”, a single movie from each franchise is used as test. This allows to evaluate if our classifiers are specific to a franchise or generalize well across franchises.

**Classification setting.** In the classification setting, we evaluate the accuracy of beat-category prediction at the shot level. Since a shot can have several labels, we adopt the following evaluation procedure. For a given shot with \( n > 0 \) ground-truth labels (in general \( n = 1 \), but the number of labels can be up to 4), we retain the best \( n \) predicted beat-categories (out of 11, according to their confidence scores). Accuracy is then measured independently for each beat-category as the proportion of ground-truth shots which are correctly labeled. We finally average accuracies over all categories, and report the mean and the standard deviation over the 5 cross-validation splits.

**Localization setting.** In the localization setting, we evaluate the temporal agreement between ground-truth and predicted beat-events for each beat-category. A detection, consisting of a temporal segment, a category label and a confidence score, is tagged positive if there exists a ground-truth beat-event with an intersection-over-union score \([8]\) over 0.2. If the ground-truth beat-event is tagged as “difficult” it does not count as positive nor negative. The performance is measured for each beat-category in terms of average precision (AP) over all beat-events in the test fold, and the different APs are averaged to a mAP measure.

### 4. Shot and beat-event classification

The proposed approach consists of 4 stages. First, we compute high-dimensional shot descriptors for different visual and audio modalities, called channels. Then, we learn linear SVM classifiers for each channel. At the late fusion stage, we take the linear combination of the channel scores. Finally, predictions are refined by leveraging the temporal structure of the data and beat-events are localized.

#### 4.1. Descriptors extraction

For each shot from a movie, we extract different descriptors corresponding to different modalities. For this purpose, we use a state-of-the art set of low-level descriptors \([1, 21]\). It includes still image, face, motion and audio descriptors: **Dense SIFT** \([18]\) descriptors are extracted every 30’th frame. The SIFTs of a frame are aggregated into a Fisher vector of 256 mixture components, that is power- and L2-normalized \([24]\). The shot descriptor is the power- and L2 normalized average of the Fisher descriptors from its frames. The output descriptor has 34559 dimensions. **Convolutional neural nets** (CNN) descriptors are extracted from every 30’th frame. We run the image through a CNN \([13]\) trained on Imagenet 2012, using the activations from the first fully-connected layer as a description vector (FC6 in 4096 dimensions). The implementation is based on DeCAF \([6]\) and its off-the-shelf pre trained network. **Motion descriptors** are extracted for each shot. We extract improved dense trajectory descriptors \([33]\). The 4 components of the descriptor (MBHx, MBHy, HoG, HoF) are aggregated into 4 Fisher vectors that are concatenated. This output is a 108544 D vector. **Audio descriptors** are based on MFCC \([26]\) extracted for 25 ms audio chunks with a step of 10 ms. They are enhanced by adding first and second order temporal derivatives. The MFCCs are aggregated into a shot descriptor using a Fisher aggregation, producing a 20223 D vector. **Face descriptors** are obtained by first detecting faces in each frame using the Viola-Jones detector from OpenCV \([3]\). Following the approach from \([7]\), we join the detections into face tracks using the KLT tracker, allowing us to recover some missed detections. Each facial region is then described with a Fisher vector of dense SIFTs \([30]\) (16384 dimensions) which is power- and L2-normalized. Finally, we average-pool all face descriptors within a shot and normalize again the result to obtain the final shot descriptor.

Overall, each 2 hr movie is processed in 6 hr on a 16-core machine. We will make all descriptors publicly available.
4.2. Shot classification with SVMs

We now detail the time-blind detection method, that scores each shot independently without leveraging temporal structure.

Per-channel training of SVMs. The 5 descriptor channels are input separately to the SVM training. For each channel and for each beat-category, we use all shots annotated as non-difficult as positive examples and all other shots (excluding difficult ones) as negatives to train a shot classifier. We use a linear SVM and cross-validate the $C$ parameter, independently for each channel. We compute one classifier SVM_{test} per fold, and 4 additional classifiers SVM_{1}...SVM_{4} corresponding to sub-folds, see Figure 5.

Late fusion of per-channel scores. The per-channel scores are combined linearly into a shot score. For one fold, the linear combination coefficients are estimated using the sub-fold scores. We use a random search over the 5D space of coefficients to find the one that maximizes the average precision over the sub-folds. This optimization is performed jointly over all classes (shared weights), which was found to be better to reduce the variability of the weights.

4.3. Leveraging temporal structure

We leverage the temporal structure to improve the performance of the time-blind detection/localization method, using a conditional random field (CRF) [15]. We consider a CRF that takes the SVM scores as inputs. The CRF relies on a linear chain model. Unary potentials correspond to votes for the shot labels, while binary potentials model the probability of the sequences.

We model a video with a linear chain CRF. It consists of latent nodes $y_i \in \mathcal{Y}; i = 1, \ldots, n$ that correspond to shot labels. Similar to HMM, each node $y_i$ has a corresponding input data point $x_i \in \mathbb{R}^d$. Variables $x_i$ are always observed, whereas $y_i$ are known only for training data. An input data point $x_i \in \mathbb{R}^d$ corresponds to the shot descriptor, which in our case is the 11-D vector of L2-normalized SVM scores for each beat-category. The goal is to infer probabilities of shot labels for the test video.

The CRF model for one video is defined as:

$$
\log p(Y|X; \lambda, \mu) = \sum_{i=1}^{n} \lambda^T f(y_i, X) + \sum_{i=1}^{n-1} \mu^T g(y_i, y_{i+1}, X),
$$

where the inputs are $X = \{x_1, \ldots, x_n\}$ and the outputs $Y = \{y_1, y_2, \ldots, y_n\}$. We use the following feature (in the CRF literature sense) functions $f$ and $g$:

$$
f_k(y_i, X) = x_{i,k} \delta(y_i, k)$$
$$g_{k', k''}(y_i, y_{i+1}, X) = \delta(y_i, k') \delta(y_{i+1}, k'')$$

where $x_{i,k}$ is the classification score of shot $i$ for category $k$, $\delta(x, y)$ is 1 when $x = y$ and 0 otherwise. Therefore, the log-likelihood becomes

$$
\log p(Y|X; \lambda, \mu) = \sum_{k \in \mathcal{Y}} \lambda_k \sum_{i=1}^{n} x_{i,k} \delta(y_i, k) + \\
\sum_{k', k'' \in \mathcal{Y}} \mu_{k', k''} \sum_{i=1}^{n-1} \delta(y_i, k') \delta(y_{i+1}, k'')
$$

We take $x_i$ from SVM classifiers trained using cross validation on the training data. The CRF is learned by minimizing the negative log-likelihood in order to estimate $\lambda$ and $\mu$.

At test time, the CRF inference outputs marginal conditional probabilities $p(y_i|X), i = 1, \ldots, n$.

4.4. Beat-event localization

The final step consists in localizing instances of a beat-event in a movie, given confidence scores output by the CRF. To that aim, shots must be grouped into segments. We create segments by joining consecutive shots for which CRF confidence is above 30% of its maximum over the movie. The segment’s score is the average of these shot confidences.

Note that the CRF produces smoother scores over time for events that occur at a slower rhythm, see Figure 7. For example “good argue good” lasts usually longer than “joy bad”, because the villain is delighted for a short time only. The CRF smoothing modulates the length of estimated segments: smoother curves produce longer segments, as expected.
Table 2. Performance comparison (accuracy) for shot classification. Standard deviations are computed over folds.

<table>
<thead>
<tr>
<th>Method</th>
<th>Leave 4 movies out</th>
<th>Leave 1 franchise out</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>±</td>
<td>±</td>
</tr>
<tr>
<td>SIFT</td>
<td>37.8 ± 5.26</td>
<td>25.3 ± 7.49</td>
</tr>
<tr>
<td>CNN</td>
<td>44.0 ± 4.49</td>
<td>26.7 ± 6.43</td>
</tr>
<tr>
<td>dense trajectories</td>
<td>24.0 ± 8.44</td>
<td>21.7 ± 10.13</td>
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<tr>
<td>MFCC</td>
<td>11.7 ± 2.42</td>
<td>12.3 ± 3.81</td>
</tr>
<tr>
<td>Face descriptors</td>
<td>1.0 ± 0.07</td>
<td>1.0 ± 0.08</td>
</tr>
<tr>
<td>linear score combination</td>
<td>14.0 ± 3.04</td>
<td>14.0 ± 3.04</td>
</tr>
<tr>
<td>+ CRF</td>
<td>14.0 ± 3.04</td>
<td>14.0 ± 3.04</td>
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<tr>
<td>CRF + thresholding</td>
<td>14.0 ± 3.04</td>
<td>14.0 ± 3.04</td>
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Table 3. Performance comparison (average precision) for beat-event localization.

<table>
<thead>
<tr>
<th>Method</th>
<th>Leave 4 movies out</th>
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</table>

5.2. Shot classification

Table 2 shows the classification performance at the shot-level on the two types of splits. The low-level descriptors that are most useful in this context are the dense trajectories descriptors. Compared to setups like Trevid MED or Thumos [23, 12], the relative performance of audio descriptors (MFCC) is high, overall the same as for e.g. CNN. This is because Hollywood action movies have well controlled soundtracks that almost continuously plays music: the rhythm and tone of the music indicates the theme of the action occurring on screen. Therefore, the MFCC audio descriptors convey high-level information that is relatively easy to detect automatically.

The face descriptor can be seen as a variant of SIFT, restricted to facial regions. The face channel classifier outperforms SIFT in three categories. Upon inspection, we noticed however that only a fraction of shots actually contain exploitable faces (e.g., frontal, non-blurred, unoccluded and large enough), which may explain the lower performance for other categories. The performance of the face channel classifier may be attributed to a rudimentary facial expression recognition property: the faces of heroes arguing with other good characters can be distinguished from the grin of the villain in joy bad; see Figure 8.

The 4 least ambiguous beat-categories (pursuit, battle, battle preparation and romance) are detected most reliably. They account for more than half of the annotated shots. The other categories are typically interactions between people, which are defined by identity and speech rather than mo-
5.3. Beat-event localization

Table 3 gives results for beat-event localization. We observe that the performance is low for the least frequent actions. Indeed, for 8 out of 11 categories, the performance is below 15% AP. Per-channel results are not provided due to lack of space, but their relative performance is similar to the classification ones. Figure 7 displays localization results for different beat-categories. Categories, such as battle and pursuit, are localized reliably. Semantic categories, such as romance, victory good and good argue good are harder to detect. More advanced features could improve the results for these events. Indeed, recognition of characters, their pose and speech appear necessary.

6. Conclusion

Despite the explosion of user-generated video content, people are still watching professionally produced videos most of the time. Therefore, the analysis of this kind of footage will remain an important task. In this context, Action Movie Franchises appears as a challenging benchmark. The annotated classes range from reasonably easy to recognize (battle) to very difficult and semantic (good argue bad). We also provide baseline results from a method that builds on state-of-the-art descriptors and classifiers. Therefore, we expect it to be a valuable test case in the coming years. We will provide the complete annotations and evaluation scripts upon publication.

References
