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CRF based context modeling for person identification in broadcast videos

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2 ABSTRACT

3 We are investigating the problem of speaker and face identification in broadcast videos.
4 Identification is performed by associating automatically extracted names from overlaid texts
5 with speaker and face clusters. We aimed at exploiting the structure of news videos to solve
6 name/cluster association ambiguities and clustering errors. The proposed approach combines
7 iteratively two Conditional Random Fields (CRF). The first CRF performs the person diarization
8 (joint temporal segmentation, clustering and association of voices and faces) jointly over the
9 speech segments and the face tracks. It benefits from contextual information being extracted from
10 the image backgrounds and the overlaid texts. The second CRF associates names with person
11 clusters thanks to co-occurrence statistics. Experiments conducted on a recent and substantial
12 public dataset containing reports and debates demonstrate the interest and complementarity of
13 the different modeling steps and information sources: the use of these elements enables us to
14 obtain better performances in clustering and identification, especially in studio scenes.

15 **Keywords:** Face identification, speaker identification, broadcast videos, conditional random field, face clustering, speaker diarization

16

1 INTRODUCTION

17 For the last two decades, researchers have been trying to create indexing and fast search and browsing
18 tools capable of handling the growing amount of available video collections. Among the associated
19 possibilities, person identification is an important one. Indeed, video contents can often be browsed through
20 the appearances of their different actors. Moreover, the availability of each person intervention allows
21 easier access to video structure elements such as the scene segmentation. Both motivations are especially
22 verified in the case of news collections. The focus of this paper is therefore to develop a program able to
23 identify persons in broadcast videos. That is, the program must be able to provide all temporal segments
24 corresponding to each face and speaker.

25 Person identification can be supervised. A face and/or a speaker model of the queried person is then
26 learned over manually labeled training data. However, this raises the problem of annotation cost. An
27 unsupervised and complementary approach consists in using the naming information already present in
28 the documents. Such resources include overlaid texts, speech transcripts and metadata. Motivated by this



Figure 1. Example frames from the REPERE corpus showing the variety of the visual conditions (pose, camera viewpoint, illumination) and the name face association challenges such as: multiface images (image c) and name propagation (from a to b). Images a and c show an example of OPNs.

29 opportunity, unsupervised identification has been investigated for 15 years from the early work of Satoh
 30 et al. (1999) to the development of more complex news browsing systems exploiting this paradigm (Jou
 31 et al. (2013)), or thanks to sponsored competitions (Giraudel et al. (2012)). Whatever the source of naming
 32 information, it must tackle two main obstacles: associate the names to co-occurring speech and face
 33 segments, and propagate this naming information from the co-occurring segments to the other segments of
 34 this person.

35 There are several challenges related to this task. First, the named entities need to be recognized and an
 36 association step must decide if the name corresponds to people co-occurring in the document. Ambiguities
 37 arise when multiple audiovisual (AV) segments co-occur with one name. This is illustrated in Fig 1c where
 38 there is more than one face in the image. This situation is becoming more common with modern video
 39 editing. Regarding the identity propagation, it can be done with speaker and face diarization techniques
 40 (detecting and clustering person interventions). However, these two tasks have been active fields of
 41 research for more than a decade and thus are difficult problems to solve. Indeed, a person may appear in
 42 different contexts thus introducing huge intraperson variabilities. We can distinguish them in function of
 43 the modalities and the different types of videos. For the speaker diarization, the main challenge in broadcast
 44 news is background noise such as music, or a noisy environment during outside reports. If we consider
 45 debates in studio where the speech is more spontaneous, the bottleneck becomes the overlapping speech
 46 and short speech segments. Regarding face diarization, report videos usually exhibit the largest variations
 47 as location and time may change between two scenes, and so will be the illumination conditions. For the
 48 debate and studio scenes, variations come essentially from changes in the facial poses.

49 In this paper, we assume that closed-captions are not available as this is the case in European medias.
 50 Instead, we focus on Overlaid Person Names (OPNs) which are used to introduce the speakers as illustrated
 51 in Fig. 1a. Such names are appealing since their extraction is much more reliable than pronounced names
 52 obtained through Automatic Speech Recognition (ASR). Moreover, their association with face or speech
 53 segments is in general easier than analyzing whether pronounced names in ASR transcripts refer to people
 54 appearing in the video. The identification systems submitted at the recent REPERE campaign (Bredin et al.
 55 (2013); Bechet et al. (2014); Poignant et al. (2014)) mainly rely on such names.

56 Our approach offers several advantages. Faces are identified by alternating between a clustering step of
 57 faces and audio speech segments and a naming step of the resulting AV clusters. Each step is performed by a
 58 dedicated CRF. The use of CRF enables us to include heterogeneous context cues in our modeling. The use
 59 of such cues is challenging because they must use as little specific prior information as possible in order to

60 achieve generalization over the different types of videos. In this paper, we include different generic context
61 cues. First, we have AV association scores which enable to associate overlapping speaker and face segments
62 when they correspond to the same person. Then, we use uniqueness constraints between simultaneously
63 appearing pairs of faces. Furthermore, one of the main contribution is a background recurrence descriptor
64 which attributes a soft role to each segment. It enables to distinguish the persons which are announced
65 by the OPNs such as guests or journalists from the anonymous persons appearing around them. Last but
66 not least, the names contained in the OPNs are included to guide the clustering by using the probabilities
67 obtained with the naming CRF. These different cues enable to improve the clustering by reducing errors due
68 to monomodal intracluster variations such as facial pose or audio background noise. Eventually, the CRF
69 formulation avoids hard local decisions by providing a joint probability distribution over all the segments.

70 The first CRF performs jointly the clustering of face tracks and speaker segments thanks to AV association
71 as introduced in Gay et al. (2014c). In practice, AV association is initialized in a pre-processing step based
72 on temporal co-occurrence and then refined inside the CRF thanks to talking head detection scores and
73 the previously described contextual cues. The second CRF assigns a name to each cluster by using co-
74 occurrence statistics and a uniqueness constraint preventing any two faces on the same image to receive
75 the same name. In Gay et al. (2014b), this approach was designed for face identification. In the present
76 case, we extend this approach for the AV case and provide results for the final evaluation of the REPERE
77 campaign. Identification performances are discussed by investigating the algorithm behavior in different
78 types of shows (reports, news, debates, celebrity magazines) and the relations with the clustering quality.

79 The rest of the article is organized as follows: Section 2 reviews related work on unsupervised
80 identification. Then, Section 3 presents the proposed CRF-based system. Experiments and results are
81 presented in section 4. Finally, Section 5 sums up our main findings and concludes the paper.

2 RELATED WORK

82 As stated in the introduction, unsupervised people identification must address the problems of local
83 person/name association and propagation to the video parts where the names are absent. The association
84 is conducted via the use of co-occurrence statistics between the names present in the document and the
85 detected persons. The propagation can be seen as a clustering problem. Clustering methods can regularly
86 benefit from new improvements in speaker and face representations. At the time of writing, the ivector
87 approach is one of the most successful (Rouvier et al. (2013)) for the speaker diarization task. Regarding
88 face representation, recent advances include encodings (Simonyan et al. (2013)), metric learning (Bhattarai
89 et al. (2014)) and feature learning by deep Convolutional Neural Networks (Schroff et al. (2015)). However,
90 most of the systems require explicit face alignment to obtain frontal views which is not always feasible.
91 The work published in Zhang et al. (2015) suggests that using only face representation is a great limitation
92 when dealing with unconstrained views of persons. For this reason, we believe that investigation into
93 context-assisted clustering is justified, especially for broadcast news videos which exhibit a strong structure.

94 To identify the faces, most approaches try to solve the association and the propagation problems jointly.
95 On one hand, co-occurrence statistics at cluster level are more discriminant and accurate than just describing
96 a face locally with namedness features (like face position or talking activity) to assess whether the detected
97 name should be associated. On the other hand, name/face co-occurrences are used as a contextual cue to
98 improve the face clustering process. These principles have been used intensively since the seminal works
99 of Berg et al. (2004) and Everingham et al. (2006) which applied to two representative use-cases: captioned
100 images, as exemplified by the *Yahoo News!* dataset, and soap series with the *buffy* dataset. The first case

101 study consists of news articles with images illustrating the subject. The initial approach described in Berg
102 et al. (2004) is an EM clustering where the update of the model parameters takes into account the name/face
103 co-occurrences. In this context, the work of Ozkan and Duygulu (2010) exploits the fact that a textual query
104 enables to retrieve faces where the queried person holds the majority. The problem of finding those faces is
105 posed as finding the densest component in a graph. This idea was later extended in Guillaumin et al. (2010)
106 where the distance within clusters is minimized with respect to a cannot-link constraint which implies
107 that two faces must belong to different clusters if their captions contain different names. However, those
108 co-occurrence statistics can fail when group of people co-occur in a similar fashion, a situation commonly
109 encountered in TV programs. In soap series, the names of the speakers can be obtained with the transcripts
110 and the subtitles. Works in Cour et al. (2011); Wohlhart et al. (2011); Bauml et al. (2013) use those names
111 as weak labels to improve supervised classifiers. They choose a learning setting which takes into account
112 the label ambiguities, for example: multiple instance learning (Wohlhart et al. (2011)) and semi-supervised
113 strategies (Bauml et al. (2013)). Talking head detection (Everingham et al. (2006); Cour et al. (2011)) and
114 dialogue cues (Cour et al. (2010)) are also used to solve the ambiguities in the face/name association. Note
115 that in the previous two case studies, the naming co-occurrence statistics are quite different to those in
116 broadcast videos where the OPNs are more sporadic. Indeed, the OPN of a given person only appears
117 one or a few times (usually for the first time utterance). This scarcity increases the dependence of the
118 identification performance on the clustering quality.

119 Originally, unsupervised speaker identification in broadcast news was conducted by first performing a
120 speaker diarization (i.e. clustering) step of the audio track and then assigning the names extracted from
121 the transcription to the speaker clusters by using semantic classification trees (Jousse et al. (2009)) or
122 Maximum-entropy classifiers (Ma et al. (2007)). More recently, the idea of constrained speaker clustering
123 has been exploited in Bredin and Poignant (2013); Poignant et al. (2014). The system described in Bredin
124 and Poignant (2013) defines a graph where the nodes are speaker segments and OPNs. OPNs are used to
125 express must-link and cannot-link constraints between the utterances. The clustering and the naming of
126 those segments is done using an Integer Linear Programming formulation. As first investigated by Li et al.
127 (2001), the case study of videos allows to exploit the complementarity of audio and video modalities. AV
128 cues such as talking head detection scores can be used to match faces and speakers and to improve the
129 monomodal speaker and face diarizations. The scores of such cues are computed by estimating motion in
130 the region of the lips. In addition, features such as the face size, the face position or the number of faces in
131 the image are extracted and given to a supervised classifier (El Khoury et al. (2012); Vallet et al. (2013)) to
132 further refine the talking assessment. In order to bring corrections to the initial monomodal diarizations,
133 the talking head detection scores should be reliable where monomodal errors are present. Moreover, the
134 audio and video will also be more complementary if they make errors at different moments. In other words,
135 the improvements of the AV diarization depend on the performances of the initial monomodal ones. The
136 work of Noulas et al. (2012) integrates faces and speech segments in a factorial hidden markov model. The
137 assignment of a segment to a cluster label is based on biometric model and on AV links with co-occurrent
138 segments from the other modality. The use of a graphical model enables to express dependences between
139 variables with a global probabilistic formulation which can then be optimized jointly. In order to jointly
140 identify faces and speakers, the authors of Poignant et al. (2015) proposed a constrained multimodal
141 clustering. They use the simple idea that two segments which co-occur with different names implies that
142 they should be assigned to different clusters. The authors also showed that their multimodal clustering of
143 faces and speakers can make use of talking head detection scores to correct errors present in the monomodal
144 systems.

145 The work of Bechet et al. (2014), an interesting yet not detailed contribution to the field, reports the
146 intensive use of multimodal scene understanding cues. First, speaker diarization is performed and speakers
147 are identified using OPNs or pre-trained models. Then, identities are propagated from the speakers to the
148 faces. Scene segmentation, role detection, and pre-trained visual models for each TV set (and sometimes
149 for each camera) are used to indicate how many faces are present on screen and what their roles are. Such
150 a fine-grain modeling enables them to report the best identification on the REPERE campaign. Indeed,
151 it permits to tell which persons are present without detecting the faces by detecting the specific shot (up
152 to which studio camera is used). Thus, profile views and persons seen from the back can be identified.
153 However, to learn those models, manual annotations have been made for each show. This poses the problem
154 of human labor cost and lack of generalization. More generally, several researchers focus on exploiting the
155 context surrounding the faces. The work in Zhang et al. (2013) uses clothes, image background, cluster
156 co-occurrences and attribute classifiers and Tapaswi et al. (2014) build must-link and cannot-link constraints
157 deduced from shot threads (sequence of shots obtained from the same camera angle).
158

159 **Contributions:** in this paper, we leverage on different contextual cues present in the state of the art,
160 introduce new ones, and include them in our CRF model. First, instead of conducting speaker and face
161 clustering separately [15, 5], we perform a joint clustering of face tracks and speaker segments which also
162 benefits from the OPNs information. To be more precise, we compute Local Face visual Backgrounds
163 (LFBs) around each face track and cluster them. This provides us with a signature for each face track
164 characterizing the level of recurrence of its LFB in the data. Intuitively, recurrent a LFB correspond to
165 people who are important and can be seen as a soft role assignment distinguishing faces to be named from
166 faces of figurative people. Concretely, it enables to encourage faces tracks with recurrent LFBs to join
167 named clusters, i.e. overlapping an OPN. Secondly, a naming CRF performs the joint identification of all
168 person clusters, thus allowing to account for uniqueness constraints and co-occurrence statistics between
169 clusters and OPNs. Unlike previous works which rely on extensive annotations (Bechet et al. (2014)), those
170 elements of context have better generalization capabilities, since we can learn one single model over a
171 large and diversified corpus, and require less annotations if we want to learn a new type of show. Thanks to
172 the flexibility of the CRF formulation, new contextual cues could be added in the future to further improve
173 the performances.

3 METHOD

174 The method will be first described globally in section 3.1. In the section 3.2, we introduce the notations.
175 We then describe how we extract LFB and AV association features in sections 3.3 and 3.4. In section 3.5,
176 the diarization CRF which clusters face and speech segments is presented, and in section 3.6 the naming
177 CRF which is in charge of identifying the clusters. To conclude this part, we describe how the full system
178 is used and optimized in section 3.7.

179 3.1 Method overview

180 The general approach is summarized in Fig 2. First, the different modalities are processed separately:
181 monomodal speaker (Rouvier et al. (2013)) and face (Khoury et al. (2013)) diarizations are performed,
182 LFBs are extracted around each face and clustered, Optical Character Recognition (OCR) is performed to
183 extract the overlaid texts (Chen and Odobez (2005)) and named entities are detected (Gay et al. (2014a)).

184 In the second part, we perform the AV clustering and the naming of the persons. Initially, we use the
185 Hungarian algorithm to associate face and speaker clusters based on their temporal overlap. Naming

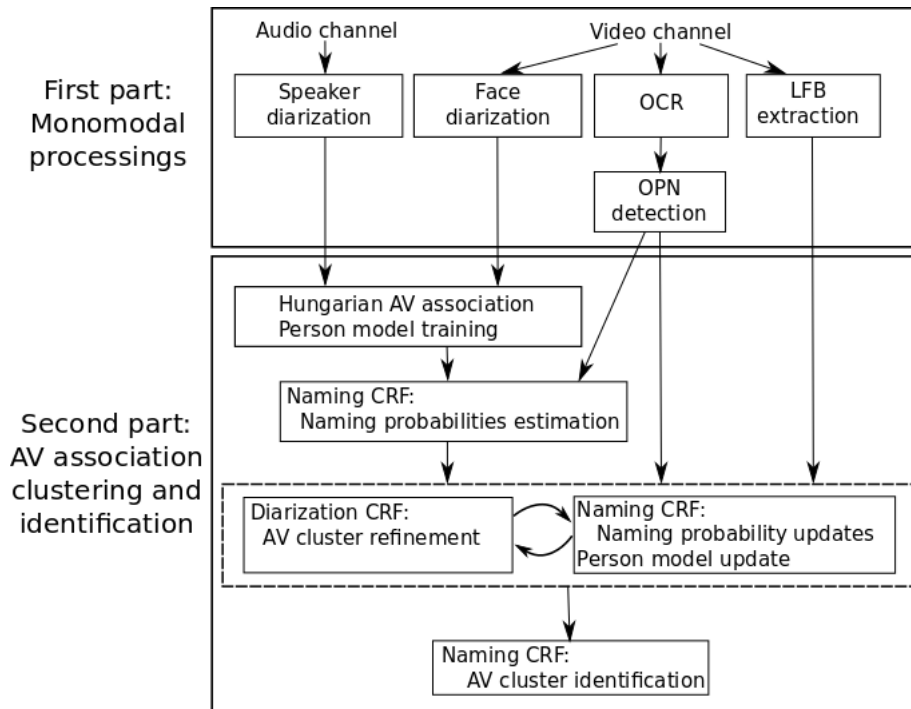


Figure 2. Overview of the system. First, face tracks and speech utterances are detected and clustered separately. They are then used with the OPNs in an iterative combination of the two CRFs. A first one to refine the diarization, and the other one to identify the clusters. The latter is eventually used for the final cluster identification.

186 probabilities are then computed onto those AV clusters with the naming CRF. Lastly, the system iterates
 187 over a clustering step and a naming step. In the clustering step, the diarization CRF infers a cluster label
 188 for each face track and utterance given the naming probabilities, an acoustic and visual person model for
 189 each cluster label, and various context clues including the LFBs. In the naming step, person models and
 190 naming probabilities are updated as a result of the new diarization. The motivation factor being that the
 191 diarization CRF is able to use contextual clues to correct potential clustering errors made by the monomodal
 192 diarizations and thus improve the final identification. Lastly, a name is associated to each cluster with the
 193 naming CRF.

194 3.2 Notations

195 The pre-processing includes obtaining initial monomodal face and speaker clusters, a set of OPNs and
 196 extracting the features from those elements. First, faces are detected (Viola and Jones (2004)) and tracked
 197 within each shot, resulting in a set of face tracks denoted as $V = \{V_i, i = 1 \dots N^V\}$. Each face track V_i
 198 is characterized by a set of visual features x_i^{surf} (set of Speeded-Up-Robust Features (SURF) extracted in up
 199 to 9 images of the face track (El Khoury et al. (2010))) and a set of boolean features $\{x_i^{\text{lfbv}}(k), k \in K\}$
 200 indicating whether V_i corresponds to a recurrent LFB as explained in the next section 3.3.

201 Second, OCR (Chen and Odobez (2005)) and Named Entity Detection techniques based on string
 202 matching against external resources (predefined lists, freebase database, Google hits...) are applied as
 203 described in Gay et al. (2014a) to extract the set $O = \{O_i, i = 1 \dots N^O\}$ of OPNs. Each OPN O_i
 204 is characterized by its duration d_i^{opn} and its name $x_i^{\text{opn}} \in M$ where $M = \{n_j, j = 1 \dots N^M\}$ denotes the set
 205 of unique names extracted from the video.

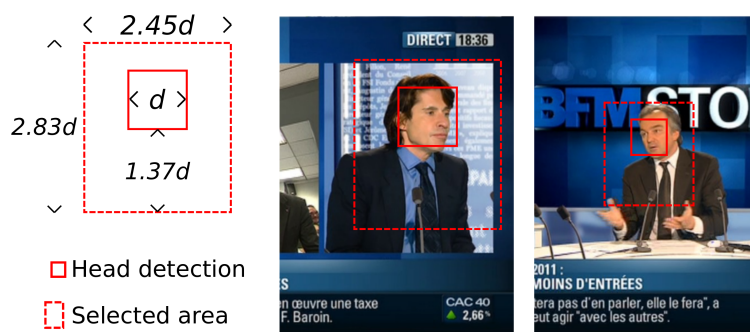


Figure 3. Left: predefined spatial template for the background face selection area given a head detection. Center and right: two examples with head detections and the selected background areas.



Figure 4. Top: original images. Bottom: clusters of recurrent local face backgrounds (LFB) automatically cropped from each image and clustered given the localised faces. Each row corresponds to a local background cluster. Clusters 1 and 2 are recurrent backgrounds and correspond to speakers. Clusters 3 and 4 are not recurrent. They contain non-speaking faces which appear occasionally in the video.

206 Finally, the audio stream is segmented into a set $A = \{A_i, i = 1 \dots N^A\}$ of continuous speech segments
 207 called utterances, each described by a set of acoustic features x_i^a . Features are 12 MFCCs with first order
 208 derivatives. Each frame is normalized with a short-term windowed mean and variance. Feature warping is
 209 also applied. In addition, a set of boolean features $\{x_i^{lfb}(k), k \in K\}$ is extracted indicating whether A_i is
 210 co-occurring with a recurrent LFB, as described in the next section. Finally, talking head detection features
 211 x_{ij}^{av} are extracted between each couple (A_i, V_j) with a non-zero overlap as described in section 3.4.

212 3.3 Local Face Background recurrence

213 We want to capture whether a face appears with a recurrent visual background. This feature will be
 214 included in the diarization CRF. To this end, we focus on an area around each face track V_i to capture the
 215 background context of this face. We do not consider full images as the same image might include different
 216 face visual contexts (see the first, fourth and fifth images from the left in the top row of Fig 4). Instead,
 217 we select a rectangle area around each face as local face background (LFB) representative by following a
 218 predefined spatial template between the face and this rectangle as can be seen in Fig 3. In practice, the
 219 fixed proportions were chosen manually so as to avoid a potential overlap with other parts of the images in
 220 typical edited videos like in the 4th and 5th images from the left on the top of Fig 4. We then characterize

221 each obtained rectangle area with SURF features and, in order to cluster them, we use a hierarchical
 222 clustering approach (El Khoury et al. (2010)). Then, we set $x_i^{\text{fbv}}(k)$ to true if face track V_i belongs to a
 223 local background cluster whose number of elements is higher than k . In practice, multiple values of k can
 224 be used to characterize different levels of recurrence and reduce the importance of the stopping criterion of
 225 the hierarchical clustering. Fig 4 shows examples of obtained recurrent and non-recurrent patterns.

226 3.4 Talking head detection features

227 In order to integrate AV association information in the CRF, we detect talking heads. To characterize
 228 talking heads, we use the following measures. These features are extracted for each overlapping
 229 utterance/face track couple and include:

- 230 • **lip activity:** the lip activity of a given face at frame k is computed as described in El Khoury et al.
 231 (2012) and consists in the mean intensity difference between frame k and $k + 1$ after local image
 232 registration in predefined regions corresponding to the lips. In addition, we focus on the relative lip
 233 activity by dividing by the sum of all the lip activities measured from all people in the image.
- 234 • **Head size:** the interest of this feature relies on the hypothesis that the face of the speaker is usually
 235 larger than the faces of other people in the image. Put simply, we take the diagonal size of the detection
 236 bounding boxes. We also use the relative head size.

237 The previous features are computed from each frame of the face track. Eventually, the final feature x_{ij}^{av} is an
 238 average over all values from the frames included in the overlap between the utterance A_i and the face track
 239 V_j . This corresponds to the method used in Gay et al. (2014c). To assess whether a couple of utterance/face
 240 track corresponds to a talking head given the features, we use an SVM with gaussian kernel denoted as h .

241 3.5 Audio-visual (AV) person diarization CRF

242 The clustering of face tracks and utterances defines itself by estimating the label field $E^d = \{e_i^a, i =$
 243 $1 \dots N^A, e_j^v, j = 1 \dots N^V\}$ as such, the same person index is used for e_i^a and e_j^v when the utterance A_i
 244 and the face track V_j correspond to the same person. The labels e_i^a and e_j^v take value in the set of possible
 245 person indices denoted as P . To achieve this, let G be an undirected graph over the set of random variables
 246 A, V, O , and E^d . We then seek to maximize the CRF posterior probability formulated as:

$$P(E^d|A, V, O) = \frac{1}{Z(A, V, O)} \times \exp\left\{ \sum_{i \in \mathcal{F}} \sum_{c \in G_i} \lambda_i f_i(A_c, V_c, O_c, E_c^d) \right\} \quad (1)$$

247 where each triplet (f_i, G_i, λ_i) is composed of a feature function f_i , a weight λ_i learned at training time
 248 and the set G_i of cliques where this function is defined. (A_c, V_c, O_c, E_c^d) denotes the set of nodes contained
 249 in the clique c . \mathcal{F} is a set of abstract functions indices. We use 6 types of feature functions which will be
 250 described in the next sections. A graphical representation of this model is illustrated on Fig 5.

251 The association function f_{av} favors the association of talking heads to utterances. The function is defined
 252 on all overlapping utterance/face track couples $\{(i, j)/t(A_i, V_j) \neq 0\}$ where $t(A_i, V_j)$ is the overlapping
 253 time duration between segments A_i and V_j :

$$f_{\text{av}}(A_i, V_j, e_i^a, e_j^v) = \begin{cases} t(A_i, V_j)h(x_{ij}^{\text{av}}) & \text{if } e_i^a = e_j^v \\ -t(A_i, V_j)h(x_{ij}^{\text{av}}) & \text{otherwise} \end{cases} \quad (2)$$

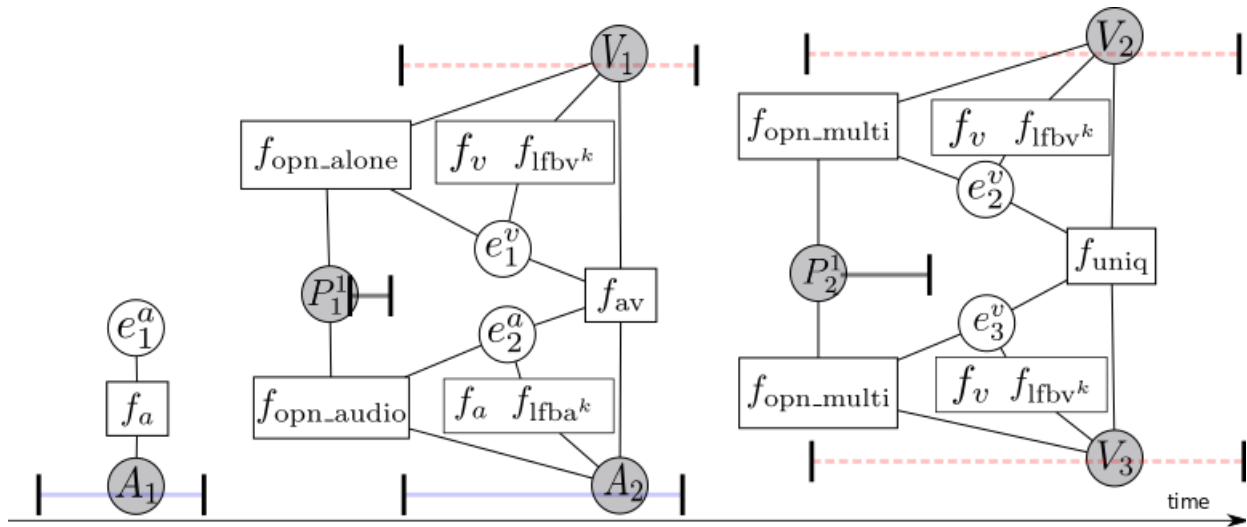


Figure 5. Factor graph illustrating the diarization CRF using talking head information (f_{av}) and the context from the OPNs (f_{opn} , f_{lfb}). The blank circle nodes correspond to hidden variables, the shaded circle nodes correspond to observations while the squares represent the feature functions. The x-axis represents time and the drawing shows also segments corresponding to the time intervals during which a specific observation (track, utterance, OPN) occurs. Red dot segments illustrate the face track temporal segments while blue plain segments the utterances.

255 where $h(x_{ij}^{av})$ represents the binary output of the SVM classifier introduced in section 3.4. It corresponds
 256 to 1 when the face and the speaker correspond to the same person and -1 otherwise. We chose a SVM
 257 classifier since it shows good results in El Khoury et al. (2012); Vallet et al. (2013). Other techniques could
 258 be employed but we leave this problem for future research.

259 The visual feature function $f_v(V_i, e_i^v)$, defined for all face tracks $V_i \in V$, indicates how likely the visual
 260 features x_i^{surf} of V_i should be labeled with the person index e_i^v . This is a face modeling task in which for
 261 each label e_i , we need to define a visual model that is learned from the data currently associated to the label.
 262 Practically, f_v computes as score between V_i and a label e_i^v the 10th percentile SURF vector distances
 263 between x_i^{surf} and all the SURF features of the current face tracks associated with this label. The distance
 264 between two face tracks is computed following (El Khoury et al. (2010)). Although the use of SURF
 265 features could be discussed regarding other more modern representations, we observe that their matching
 266 power is useful for similar faces of the same person viewed from a similar view point. The previous
 267 work in Gay et al. (2014b) uses an average of the distances. By using the percentile, we found a slight
 268 improvement for the diarization task (0.2 points on the development REPERE corpus). We believe that the
 269 use of a percentile instead of averaging enables to merge 2 clusters of the same identity but containing
 270 samples whose poses are dominantly from different poses.

271 The acoustic function $f_a(A_i, e_i^a)$, defined over all utterances $A_i \in A$, is the audio equivalent of f_v . We
 272 chose a 512 GMM-UBM with diagonal covariance following Ben et al. (2004). We did not use ivectors
 273 since we might need to learn a model on small clusters containing only a few seconds of speech. $f_a(A_i, e_i^a)$
 274 computes the likelihood score of the features x_i^a given the GMM model learned over the data currently
 275 associated to the cluster label e_i^a .

276 The LFB feature function is driven by the assumption that faces inside a recurrent LFB are likely to
 277 correspond to a speaker announced by an OPN. To favor face tracks identified as recurrent LFB to join a

278 person cluster which could be named, we define the following feature function. For each face track V_i ,

$$f_{\text{lfbv}^k}(V_i, e_i^v) = \begin{cases} 1 & \text{if } x_i^{\text{lfbv}}(k) \text{ and } e_i^v \in \mathcal{E}^{\text{opn}} \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

279 where \mathcal{E}^{opn} is the set of person clusters indices co-occurring with an OPN, i.e. the set of clusters which are
280 currently associated with a name.

281 This principle is extended to each utterance A_i with the function f_{lfb^k} which employs the feature $x_i^{\text{lfb}^k}(k)$.
282 To this end, we assume that the utterances co-occurring with a recurrent LFB should be assigned a cluster
283 label from the set \mathcal{E}^{opn} . Thus, as discussed in section 3.3, $x_i^{\text{lfb}^k}(k)$ is set to true if utterance A_i is overlapping
284 with a face track V_j such that $x_j^{\text{lfbv}}(k)$ is true. We then introduce the same function as in the video case:

$$f_{\text{lfb}^k}(A_i, e_i^a) = \begin{cases} 1 & \text{if } x_i^{\text{lfb}^k}(k) \text{ and } e_i^a \in \mathcal{E}^{\text{opn}} \\ 0 & \text{otherwise} \end{cases} \quad (4)$$

285

286 Interestingly, these functions act as a namedness feature (Pham et al. (2008)) in the sense that they favor
287 the naming of the corresponding face tracks and utterances. They also softly constrain the number of
288 clusters. In other words, the clusters whose labels belong to \mathcal{E}^{opn} will attract the segments identified as
289 recurrent LFB. Note that if the constraint was strictly enforced, each concerned audio or visual segment
290 would only be assigned to a member of \mathcal{E}^{opn} .

291 The OPN feature functions bring a special treatment to the segments co-occurring with OPNs. The idea
292 is to favor segments (face tracks or utterances) co-occurring with an OPN O_j to be assigned to a person
293 cluster likely to be labeled with the name x_j^{opn} . Thus, we define:

$$f_{\text{opn_alone}}(V_i, O_j, e_i^v) = \begin{cases} p(e_i^c = x_j^{\text{opn}} | C, P) & \text{if } V_i \text{ is alone in the image and co-occurs with OPN } O_j \\ 0 & \text{otherwise} \end{cases} \quad (5)$$

294 where $p(e_i^c = x_j^{\text{opn}} | C, P)$ is the probability that the name contained in the OPN O_j corresponds to the
295 cluster label e_i^v given the clustering C and the set of OPNs P . Here, we denote as e_i^c the naming label of
296 cluster label e_i^v . This probability is computed with the naming CRF as defined in section 3.6.

297 Similarly, we use $f_{\text{opn_multi}}$ if V_i co-occurs with other faces:

$$f_{\text{opn_multi}}(V_i, O_j, e_i^v) = \begin{cases} p(e_i^c = x_j^{\text{opn}} | C, P) & \text{if } V_i \text{ co-occurs with OPN } O_j \\ 0 & \text{otherwise} \end{cases} \quad (6)$$

298 We also define $f_{\text{opn_audio}}$ for each co-occurring couple (A_i, O_j) :

$$f_{\text{opn_audio}}(A_i, O_j, e_i^a) = \begin{cases} p(e_i^c = x_j^{\text{opn}} | C, P) & \text{if } A_i \text{ co-occurs with OPN } O_j \\ 0 & \text{otherwise} \end{cases} \quad (7)$$

299 Differentiating these 3 cases enables to learn specific λ weights so that the model behavior is adapted to
300 each situation.

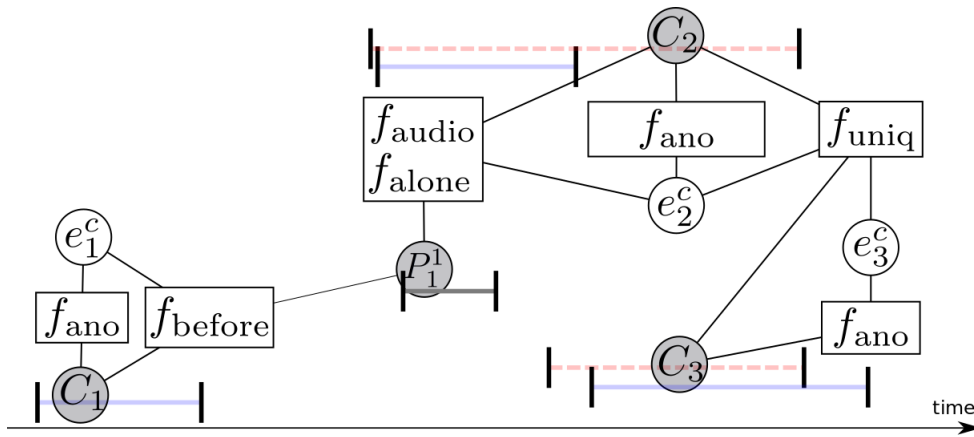


Figure 6. Factor graph illustrating the naming CRF using the co-occurrence functions with the OPNs and the uniqueness constraint. The conventions are the same as in Fig 5.

301 *The uniqueness feature function* ensures two faces that co-occur in the same shot to have different
 302 labels (Berg et al. (2004); Pham et al. (2013)). For such a pair V_i, V_j :

$$f_{\text{uniq}}(V_i, V_j, e_i^v, e_j^v) = \begin{cases} -\text{Inf} & \text{if } e_i^v = e_j^v \\ 0 & \text{otherwise} \end{cases} \quad (8)$$

303 It is crucial to use this function because due to the OPN feature functions, multiple faces co-occurring
 304 with the same OPN will tend to be assigned to the same person cluster.

305 3.6 Cluster identification

306 The previous diarization CRF provides us a set of AV person clusters $C = \{C_i, i = 1 \dots N^C\}$. Thus,
 307 in the naming step, the goal incorporates estimating the label field $E^N = \{e_i^c, i = 1 \dots N^C\}$ such that
 308 the label e_i^c corresponds to the name of the cluster C_i . The label e_i^c takes value in the set of names M
 309 augmented by an anonymous label which should be assigned to anonymous persons. For this naming CRF,
 310 the posterior probability uses 6 feature functions:

$$P(E^N | C, O) = \frac{1}{Z(C, O)} \times \exp \left\{ \sum_{i=1}^6 \sum_{c \in G_i} \lambda_i f_i(E_c^N, C_c, O_c) \right\} \quad (9)$$

311 Fig 6 represents an illustration of this. This naming model exploits four different co-occurrence statistics
 312 between clusters and OPNs. The first function f_{alone} is defined over each triplet (e_i^c, C_i, O_j) , where the
 313 OPN O_j must co-occur with a face track which belongs to C_i and which is alone in the image. Let us
 314 denote as $\delta(C_i, O_j)$ the co-occurring time between the face tracks which occurs alone in the cluster C_i and
 315 O_j . Then, we have:

$$f_{\text{alone}}(e_i^c, C_i, O_j) = \begin{cases} \frac{\delta(C_i, O_j)}{d_j^{\text{opn}}} & \text{if } x_j^{\text{opn}} = e_i^c \\ 0 & \text{otherwise} \end{cases} \quad (10)$$

316 As for the OPN diarization model components, we define similarly two other functions f_{multi} and f_{audio}
 317 which measure the overlapping time between O_j and the face tracks of C_i which occur with other faces

318 on one hand, and with the audio segments of C_i on the other hand. Moreover, we exploit the assumption
 319 that a person does not usually appear or speak before the first apparition of his name in an OPN to define
 320 $f_{\text{before}}(e_i^c, C_i, O_j)$, which returns the number of audio segments from cluster C_i that occur before the first
 321 apparition of the name x_j^{opn} associated to the OPN O_j .

$$322 \quad f_{\text{before}}(e_i^c, C_i, O_j) = \begin{cases} \#\{A_i \in C_i, \text{end}(A_i) < \text{start}(O_j)\} & \text{if } x_j^{\text{opn}} = e_i^c \\ 0 & \text{otherwise} \end{cases} \quad (11)$$

323 We also introduce prior knowledge over the anonymous label by defining a fifth feature function
 324 $f_{\text{ano}}(e_i^c, C_i)$ which returns 1 if e_i^c is the anonymous label. When applied, it allows the model to penalize the
 325 fact of not identifying a person and improves the recall.

326 Lastly, we define a uniqueness function $f_{\text{uniq}}(e_i^c, C_i, e_j^c, C_j)$ over visually overlapping clusters just as in
 327 the diarization step. For each cluster pair (C_i, C_j) with overlapping face tracks:

$$f_{\text{uniq}}(e_i^c, C_i, e_j^c, C_j) = \begin{cases} -\infty & \text{if } e_i^c = e_j^c \\ 0 & \text{otherwise} \end{cases} \quad (12)$$

328 3.7 Optimization

329 The joint use of the two CRFs is conducted by applying the following steps: i) the diarization labels are
 330 firstly initialized by separately performing audio and video clustering and then associating the clusters to
 331 obtain the potential AV person labels P (audio and face cluster couples). The association is conducted
 332 using the Hungarian algorithm (Kuhn (1955)) where the cost for a cluster couple is defined as the sum of
 333 the scores from the function f_{av} over all its utterance/face track pairs. ii) For each resulting person label
 334 p_i , biometric models are learned from their associated data and naming probabilities for each label are
 335 estimated by using the naming CRF. iii) Given these models, we run the loopy belief propagation inference
 336 to get the most probable diarization labels E^d by solving $E^d = \arg \max_{E^d} P(E^d | A, V, O)$.

337 Eventually, Steps ii) and iii) are iterated in a Expectation-Maximization style by alternating model updates
 338 and inference. Ideally, one would iterate until convergence, i.e. when the label for each segment becomes
 339 stable. In practice, as there is no guarantee that the algorithm converges, a fixed number of iterations is
 340 tuned over the development set since we observe only small modifications after a few iterations.

341 The computational bottleneck with the Loopy Belief Propagation algorithm occurs in the presence of big
 342 cliques. This is the case, in our graphs, when the uniqueness constraint is applied to images where there are
 343 more than 20 faces. In such cases, uniqueness constraints can be dropped from the graph during inference
 344 and enforced in a post-processing step.

4 RESULTS AND DISCUSSION

345 This section will firstly present our experimental set-up: the corpus (section 4.1), implementation details
 346 (section 4.2) and the metrics used for the evaluation (section 4.3). Then in section 4.4, we present our
 347 results showing identification and clustering performances in function of the different parts of the model.

348 4.1 Corpus description

349 We used the REPERE corpus (Giraudel et al. (2012)) for our experiments. It involves broadcast data
 350 videos containing 4 main types of shows: i) debates in indoor studio (Fig 1a,b); ii) modern format

351 information shows which contain reports and interviews with dynamic picture compositions (Fig 1c,d); iii)
 352 extracts from parliamentary sessions "Questions to the government" (Fig 1e) iv); celebrity news (Fig 1f).

353 We evaluate our approach on the final test set which contains 37 hours during which 10 are annotated. A
 354 development set is used to optimize the number of LFB functions and the number of iterations between
 355 the two CRFs. It consists of 28 hours among which 6 are annotated. The SVM h used in the f_{av} feature
 356 function and the CRF parameters are learned on the test set of the first REPERE evaluation composed of 3
 357 hours of annotated data.

358 4.2 Parameter settings and algorithm details

359 We set the K value to $\{3, 4, 5\}$ for the LFB feature functions. We set the number of iterations between the
 360 two CRFs to 3 as we noticed that no major changes usually occur after that point. It is important to note
 361 that these CRF parameters are learned on automatic detections and automatic clusters and not on cleanly
 362 segmented ones. Therefore, it enables us to take into account the noise present at test time. We use the
 363 GRMM toolbox (McCallum" (2002)) for the CRF implementation.

364 The initial speaker diarization system is the LiumSpkDiarization toolbox¹ which combines ivector
 365 representation and ILP clustering (Rouvier et al. (2013)). It has achieved state-of-the-art results in several
 366 speaker diarization benchmarks (Rouvier and Meignier (2012)). The initial face diarization uses the system
 367 described in (Khoury et al. (2013)) which combines SURF based distances and DCT features whose
 368 distribution is modeled with GMMs. This system has been evaluated on the public Buffy dataset (Cinbis
 369 et al. (2011)) and compares favorably to other metric learning methods. The use of state-of-the-art systems
 370 enables us to verify that our CRF is able to correct errors which are proven difficult to solve in the
 371 monomodal case.

372 4.3 Performance measures

373 The overall identification performance is measured with the Estimated Global Error Rate (EGER) which
 374 is the REPERE evaluation metric. It is defined as follows:

$$\text{EGER} = \frac{\# \text{ conf} + \# \text{ miss} + \# \text{ false}}{\# \text{ total}} \quad (13)$$

375 where $\# \text{ conf}$ is the number of wrongly identified persons, $\# \text{ miss}$, the number of missed persons, $\# \text{ false}$, the
 376 number of false alarms and $\# \text{ total}$, the total number of persons to be detected. It should be noted that the
 377 metric ignores the spatial position of the faces and simply uses a person list for each annotated image. The
 378 behavior of this metric is illustrated on figure 7. Wrong predictions are counted as false alarms only if the
 379 number of predictions exceeds the number of persons in the annotation. Otherwise, they are counted as
 380 confusions. Similarly, missing persons are reported only if the number of predictions is smaller than the
 381 number of persons.

382 We also use the clustering error rate (CER) to study the correlation between clustering and identification
 383 performances as our work is motivated by an interdependence between those two tasks. Initially, the CER
 384 has been introduced for the speaker clustering task (NIST (2003)) and is defined as:

$$\text{CER} = \frac{\sum_{\text{seg} \in \text{Segs}} \text{dur}(\text{seg})(\min(N_{\text{Ref}}(\text{seg}), N_{\text{Sys}}(\text{seg})) - N_{\text{Correct}}(\text{seg}))}{\sum_{\text{seg} \in \text{Segs}} \text{dur}(\text{seg})N_{\text{ref}}(\text{seg})} \quad (14)$$

¹ <http://www-lium.univ-lemans.fr/diarization>

Show: BFMStory_12 frame: 4312
 Head Ref: Barack_OBAMA Augusta_ADA_KING
 Head Hyp: Augusta_ADA_KING David_HAMILTON Alan_TURING

Figure 7. Extract of an evaluation file for face identification. The second row is the reference name list and the third row is the predicted list. Augusta_ADA_KING will be counted as correct. One of the two remaining names will be counted as confusion with Barack_OBAMA, and the third one will be a false alarm. Since there are 2 persons in the reference and the system made 2 errors, the corresponding EGER of this example is 1.

Speaker diarization results			
	Initial monomodal	CRF Dia	CRF Dia without OPNs
News	6.9%	7.0%	6.8%
Debates	6.6%	4.0%	6.5%
Parliament	6.9%	5.0%	9.5%
Celebrity	14.6%	15.1%	14.6%
All	7.4	6.8%	7.4%

Face diarization results			
	Initial monomodal	CRF Dia	CRF Dia without OPNs
News	4.8%	5.4%	5.9%
Debates	4.6%	1.9%	4.4%
Parliament	11.2%	10.4%	13.7%
Celebrity	3.5%	7.9%	6.4%
All	5.2%	5.0%	6.1%

Table 1. Speaker and face diarization performances in terms of CER. The first column presents the initial monomodal systems Khoury et al. (2013); Rouvier et al. (2013). The second one is the diarization CRF presented in this paper. The third one is the same as the second one, however, we remove the OPN related functions f_{fb} and f_{opn} .

385 where the audio file is divided in continuous segments at each speaker change and:

- 386 • $\text{dur}(\text{seg})$ is the duration of the segment seg .
- 387 • $N_{\text{Ref}}(\text{seg})$ is the number of active speakers during segment seg .
- 388 • $N_{\text{Sys}}(\text{seg})$ is the number of speakers detected by the system.
- 389 • $N_{\text{Correct}}(\text{seg})$ is the number of speakers correctly detected by the system. A match needs to be made
- 390 between the clusters and the speaker references in order to compute this term.

391 We applied this measure to the face clustering task. With the audio CER, a detected speech segment is

392 matched to a reference during their temporal overlap. The only modification to tackle visual modality is

393 that a face detection must have a temporal AND spatial overlap to be matched with a reference. In addition,

394 note that we do not consider false alarms and missed detections that are usually considered in NIST to

395 compare the effects of the different systems since the only error that changes with methods given the setup

396 (fixed face tracks and utterances) is due to the final clustering of the face and speech segments. Thus, miss

397 detections and false alarms are identical.

398 4.4 Identification and clustering results with the CRF combination

399

400 **Diarization results:** we first describe the diarization results presented in Table 1. We can see that the full

401 CRF model has a slightly lower error rate over the whole corpus than the initial monomodal systems (6.8%

402 vs 7.4% for the speakers and 5.0% vs 5.2% for the faces). On the other hand, the performances depend

function	f_a	f_v	f_{av}	f_{ifbv^k}	f_{ifba^k}
λ	λ_a	λ_v	λ_{av}	λ_{ifbv^k}	λ_{ifba^k}
λ value	0.4	1.8	0.2	1.9	1.7

Table 2. The λ parameter values for some of the feature functions used by the diarization CRF. For λ_{ifbv^k} and λ_{ifba^k} , the value of k is 5, which is the highest parameter value. It corresponds to the most common case as 90% of the segments are inside background clusters which contain more than 5 elements.

403 strongly on the type of shows. For instance, an important part of the global improvement comes from the
 404 debate videos (4.0% vs 6.6% for the speakers and 1.9% vs 4.9% for the faces). In debates, most of the
 405 scenes are in the same studio thereby reducing the visual variability of the background image and most
 406 of the persons present are speakers announced by an OPN. Thus, most faces and utterances are featured
 407 as recurrent (i.e. x_i^{ifbv} is set to true) and the f_{ifb} functions have a positive impact on the diarization. They
 408 enable to solve clustering confusion errors by constraining the number of clusters toward the number of
 409 detected OPNs. Indeed, if we remove the OPN related functions f_{ifb} and f_{opn} (cf third column of the
 410 Table 1), most of the improvements are lost. It appears that the use of multimodality does not help to correct
 411 clustering errors. This is somewhat surprising as past works (Gay et al. (2014c)) reports improvements
 412 in the audio modality with this very system on the same type of data. The difference with this previous
 413 work is that our initial monomodal speaker diarization system has become much more efficient, essentially
 414 thanks to a careful selection of the data used to train the generic speaker model UBM. This way, there are
 415 much fewer errors to correct.

416 In the case of celebrity magazines, the diarization CRF increases the error rate (15.1% vs 14.6% for
 417 the speakers and 7.9% vs 3.5% for the faces). Those videos contain very few OPNs and essentially short
 418 outdoor scenes. Thus, the f_{ifb} functions cannot help the CRF to take appropriate decisions. Moreover,
 419 previous experiments reported in Gay et al. (2014c) showed that the use of the biometric person models
 420 inside the CRF framework appears to be less efficient than when it is used in the hierarchical monomodal
 421 systems.

422 The importance of the OPN related functions is also visible if we consider the λ parameters learned by
 423 the CRF in Table 2. During training, the weight λ_{av} are indeed set to a relatively low value as compared to
 424 the other terms (although those values are ponderated by the amplitude of the feature functions). We have
 425 found that for a majority of segments, the f_{ifb} function is dominant. This is further illustrated in table 4.
 426

427 **Identification results:** We now turn to the identification results reported in Table 3. We compare 3 systems:
 428 we denote by N the naming CRF applied on top of the initial monomodal diarizations described in Khoury
 429 et al. (2013); Rouvier et al. (2013), $N + D$ is the joint use of the naming and the diarization CRF, and
 430 the last one is an oracle. Note that the oracle still produces errors, since, as we deal with automatic face
 431 detection and tracking, there are errors that a perfect clustering and naming cannot correct: false alarms,
 432 missed faces and face tracks for which the identity is not introduced by an OPN (see more about this in
 433 Fig 8). Adding the diarization CRF permits to globally reduce the error rates in both modalities (31.4% vs
 434 33.4% for the speakers and 52.2% vs 54.5% for the faces), especially for debate and parliament videos.
 435 This is not surprising as we previously showed that the diarization CRF have less confusion errors for
 436 studio scenes than the initial monomodal systems.

437 Regarding news videos, although we saw that clustering confusion errors were not reduced globally,
 438 the use of the diarization CRF also improves the identification. This is probably due to the correction of
 439 confusion errors in studio scenes which have a greater impact on the identification than errors concerning
 440 anonymous persons in reports.

	Audio			Visual		
	N	$N + D$	Oracle	N	$N + D$	Oracle
News	31.6%	30.8%	25.7%	58.2%	56.4%	37.7%
Debates	18.0%	14.0%	11.3%	42.0%	38.0%	35.6%
Parliament	11.3%	8.7%	5.2%	62.2%	59.6%	47.4%
Celebrity	85.6%	85.8%	82.1%	83.9%	86.6%	75.3%
All	33.4%	31.4%	27.2%	54.5%	52.2%	40.2%

Table 3. Identification performances measured in EGER. The system N is the naming CRF on top of the monomodal diarizations and the system $N + D$ is the naming and diarization CRF combination.

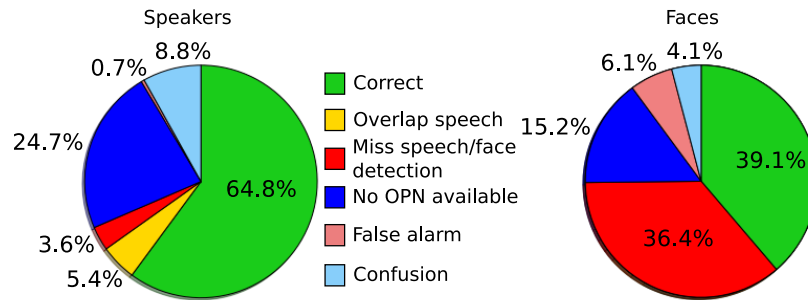


Figure 8. Different errors for the speaker (left) and face (right) identification tasks. Percentages are expressed relatively to the number of annotations.

441 The structure of celebrity magazines differs from the other shows as it contains very few OPNs and
 442 recurrent LFB. In those cases, the diarization CRF degrades both diarization and identification performances.
 443 We design an oracle on the diarization and the identification to measure the potential improvements. It uses
 444 automatic face/speech segment detections and automatic OPN extraction. Then, the association between
 445 these segments and the OPNs is done with the manual reference. Thus, the errors made by the oracle
 446 correspond to missing OPNs or missing segment detections. In the case of celebrity shows, with an error
 447 rate of 75.3%, the OPN-based approach is clearly not suitable.

448
 449 **Error analysis:** the proportion of the different error types can be visualized globally on the pie charts in
 450 Fig 8. Regarding the speaker identification task, the lack of OPNs explains most of the errors as 24.7% of
 451 the annotated persons are not announced, most of them being journalists. As for the faces, the detection
 452 step is more crucial as 36.4% of the persons faces are not detected. This corresponds usually to profile
 453 faces or persons seen from the back. Most of the false alarms are anonymous persons incorrectly identified.

454 We also illustrate the correlation between diarization and identification performances in figure 9. We
 455 plot the performance differences for each video between the full system ($N + D$) and the CRF naming
 456 alone (N). We observe that they are unique to their type of show. The debate videos appear in the top-right
 457 part of the plane, which means that the diarization CRF improves the diarization and the identification.
 458 Concerning news and parliament videos, the correlation between CER and DER is not as strong. The
 459 presence of anonymous persons and off voices imply that a change in the diarization does not necessarily
 460 correspond to a change in identification performances.

461 Finally, the table 4 shows the performance of the model when adding the different components of the
 462 diarization CRF one by one. If we focus on the first and second lines, we see that the CRF with only 3
 463 feature functions degrades the performances compared to the monomodal diarizations. We find that, used
 464 alone, the monomodal representations present in the CRF (see the f_a and f_v functions) do not compare
 465 favourably with the monomodal diarization frameworks. This could be improved in a future work by using
 466 better person representations. However, each other component enables to reduce the error rate and the

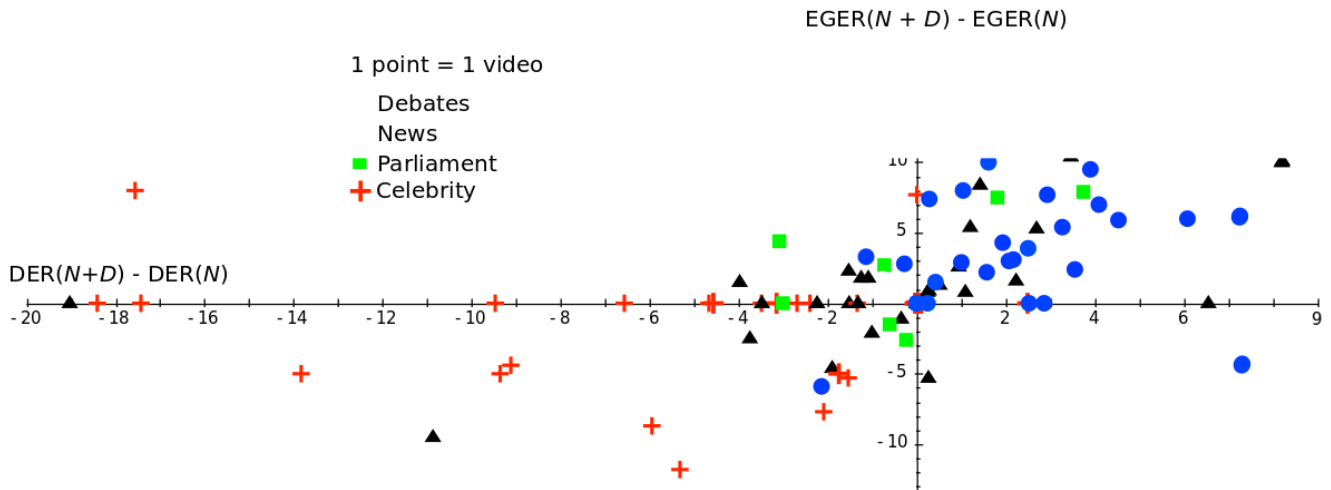


Figure 9. The Y-axis is the EGER difference between the CRF combination and the naming CRF alone measured for the faces. The X-axis is the DER difference between the diarization CRF and the initial monomodal face diarization Khoury et al. (2013).

	Audio	Visual
N	33.4%	54.5%
$N + D (f_a + f_v + f_{av})$	34.1%	56.2%
$N + D (f_a + f_v + f_{av} + f_{opn})$	33.9%	56.4%
$N + D (f_a + f_v + f_{av} + f_{opn} + f_{uniq})$	33.9%	55.6%
$N + D (f_a + f_v + f_{av} + f_{opn} + f_{uniq} + f_{lfb})$	31.4%	52.7%

Table 4. Contribution of the different diarization model components on the naming task (results in EGER). As in table 3, the system N is the naming CRF with the monomodal diarizations. The other lines correspond to the combination of the naming and the diarization CRF, using as feature functions in the diarization CRF those given in parenthesis.

467 full model provides the best performances. It should also be noticed that, although it might generates big
 468 cliques in some cases, the uniqueness function is essential to benefit from the f_{opn} feature functions. If not
 469 applied, an OPN will be propagated to all the faces overlapping with him.
 470

471 **Comparison with state of the art and discussion:** on the same dataset, the system described in Bechet
 472 et al. (2014) obtains an EGER of 30.9% for the speakers and 39.4% for the faces. Thus, it proves to
 473 have a better performance especially regarding the faces. This is possible with the help of pre-trained
 474 models for each show which enable to indicate how many faces should be present on screen and what their
 475 roles are. For instance, when it detects the configuration shown in Fig 1c, it deduces that the announced
 476 guest is present on the right even if no faces have been detected. In fact, this approach does not even
 477 use a face diarization module. However, it requires a large amount of learning and *a priori* information.
 478 By comparison, our method is much simpler to implement, especially since it has better generalization
 479 capabilities, we learn one single model over a large and diverse corpus, and what is more, it requires less
 480 annotations if we need to process a new type of show.

481 The constrained hierarchical clustering detailed in Poignant et al. (2015) obtains an EGER of 35.9% for
 482 the speakers and 44.3% for the faces. Compared with our system, it has better performances on the faces,
 483 but worst for the speakers. As we do, they only rely on OPNs without other specific supervised information
 484 on the show. According to their paper, it seems that their constrained multimodal clustering, which avoids
 485 clustering together faces which co-occur with different OPN names, is one of the contributions which
 486 improves results and that we do not use, and could explain the difference. Nevertheless, the influence of

487 each pre-processing (speaker and face detections, monomodal clusterings and OPN detection) makes it
488 hard to analyse the performance difference.

5 CONCLUSION

489 In this paper, we presented our contribution for AV person diarization and identification from OPNs. Our
490 system uses an iterative combination of 2 CRFs. One performing the AV diarization at a person level, and a
491 second one associating the names and the clusters. Several context modeling cues are used to solve the
492 person/name association problem and the diarization issues. While it is clear that more supervised learning
493 and *a priori* information on the context can improve the performances, our approach provides an interesting
494 trade-off between performance on one hand and generalization/low annotation cost on the other hand. The
495 principal contextual cue consists in the face image background. It allows us to distinguish the faces and the
496 speakers which are announced by OPNs and guide the clustering accordingly.

497 In this work, we did not address the issue of non-frontal face detection. As a short term perspective,
498 it would be interesting to increase the recall of the face detector, for instance, by adding a profile view
499 detector. This would render the face clustering task more challenging and the potential benefit from context
500 modeling would be greater. Secondly, our context modeling assumes that speakers are announced by an
501 OPN the first time they talk. For the REPERE dataset, this is the case. However, this assumption could
502 be sensible to broadcaster's editing policies. Actually, the optimal choice of the context for unsupervised
503 person identification is a difficult problem if we want to avoid the need for specific annotations for each
504 show. One solution to consider is to learn the setting of each show or a part of the setting from a corpus in
505 an unsupervised way.

REFERENCES

- 506 Bauml, M., Tapaswi, M., and Stiefelhagen, R. (2013). Semi-supervised learning with constraints for person
507 identification in multimedia data. In *Proceedings of the IEEE Conference on Computer Vision and*
508 *Pattern Recognition*, pages 3602–3609, Portland, USA.
- 509 Bechet, F., Bendris, M., Charlet, D., Damnati, G., Favre, B., Rouvier, M., Auguste, R., Bigot, B., Dufour,
510 R., Fredouille, C., Linares, G., Martinet, J., Senay, G., and Tirilly, P. (2014). Multimodal understanding
511 for person recognition in video broadcasts. In *Proceedings of InterSpeech*, pages 146–151, Singapore.
- 512 Ben, M., Betser, M., Bimbot, F., and Gravier, G. (2004). Speaker diarization using bottom-up clustering
513 based on a parameter-derived distance between adapted GMMs. In *Proceedings of International*
514 *Conference on Spoken Language Processing*, pages 523–538, Jeju, Island.
- 515 Berg, T. L., Berg, A. C., Edwards, J., Maire, M., White, R., Teh, Y. W., Learned-Miller, E. G., and Forsyth,
516 D. A. (2004). Names and faces in the news. In *Proceedings of the IEEE Conference on Computer Vision*
517 *and Pattern Recognition*, volume 2, pages 836–848, Washington, USA.
- 518 Bhattarai, B., Sharma, G., Jurie, F., and Pérez, P. (2014). Some faces are more equal than others:
519 Hierarchical organization for accurate and efficient large-scale identity-based face retrieval. In
520 *Proceedings of the European Conference on Computer Vision*, pages 160–172, Zurich, Switzerland.
- 521 Bredin, H. and Poignant, J. (2013). Integer linear programming for speaker diarization and cross-modal
522 identification in TV broadcast. In *Proceedings of InterSpeech*, pages 49–54, Lyon, France.
- 523 Bredin, H., Poignant, J., Tapaswi, M., Fortier, G., Le, V., Napoleon, T., Gao, H., Barras, C., Rosset, S.,
524 Besacier, L., et al. (2013). QCOMPERE@REPERE 2013. In *Workshop on Speech, Language and Audio*
525 *in Multimedia*, pages 49–54, Marseille, France.

- 526 Chen, D. and Odobez, J.-M. (2005). Video text recognition using sequential monte carlo and error voting
527 methods. *Pattern Recognition Letters*, 26(9):1386–1403.
- 528 Cinbis, R. G., Verbeek, J., and Schmid, C. (2011). Unsupervised metric learning for face identification in
529 TV video. In *Proceedings of the IEEE International Conference on Computer Vision*, pages 1559–1566,
530 Barcelona, Spain.
- 531 Cour, T., Sapp, B., Nagle, A., and Taskar, B. (2010). Talking pictures: Temporal grouping and dialog-
532 supervised person recognition. In *Proceedings of the IEEE Conference on Computer Vision and Pattern
533 Recognition*, pages 1014–1021, San Francisco, USA. IEEE.
- 534 Cour, T., Sapp, B., and Taskar, B. (2011). Learning from partial labels. *The Journal of Machine Learning
535 Research*, 12:1501–1536.
- 536 El Khoury, E., Senac, C., and Joly, P. (2010). Face-and-clothing based people clustering in video content.
537 In *Proceedings of the International Conference on Multimedia Information Retrieval*, pages 295–304,
538 Philadelphia, USA.
- 539 El Khoury, E., Sénac, C., and Joly, P. (2012). Audiovisual diarization of people in video content. *Multimedia
540 Tools and Applications*, 68(3):747–775.
- 541 Everingham, M., Sivic, J., and Zisserman, A. (2006). Hello! my name is... buffy—automatic naming of
542 characters in tv video. In *Proceedings of the British Machine Vision Conference*, volume 2, pages
543 2365–2371, Edinburgh, Scotland.
- 544 Gay, P., Dupuy, G., Lailler, C., Odobez, J.-M., Meignier, S., and Deléglise, P. (2014a). Comparison of
545 two methods for unsupervised person identification in TV shows. In *Proceedings of The Content Based
546 Multimedia Indexing Workshop*, pages 1–6, Klagenfurt, Austria.
- 547 Gay, P., Elie, K., Sylvain, M., Jean-Marc, O., and Paul, D. (2014b). A conditional random field approach
548 for face identification in broadcast news using overlaid text. In *Proceedings of the IEEE International
549 Conference on Image Processing*, pages 318–322.
- 550 Gay, P., Khoury, E., Meignier, S., Odobez, J.-M., and Deleglise, P. (2014c). A conditional random field
551 approach for audio-visual people diarization. In *Proceedings of the IEEE International Conference on
552 Acoustics, Speech and Signal Processing*, pages 116–120, Florence, Italy.
- 553 Giraudel, A., Carré, M., Mapelli, V., Kahn, J., Galibert, O., and Quintard, L. (2012). The REPERE
554 corpus: a multimodal corpus for person recognition. In *Proceedings of The International Conference on
555 Language Resources and Evaluation*, pages 1102–1107, Istanbul, Turkey.
- 556 Guillaumin, M., Verbeek, J., and Schmid, C. (2010). Multiple instance metric learning from automatically
557 labeled bags of faces. In *Proceedings of the European Conference on Computer Vision*, pages 634–647.
558 Crete, Greece.
- 559 Jou, B., Li, H., Ellis, J. G., Morozoff-Abegauz, D., and Chang, S. (2013). Structured exploration of who,
560 what, when, and where in heterogeneous multimedia news sources. In *Proceedings of ACM International
561 conference on Multimedia*, pages 357–360, Barcelona, Spain.
- 562 Jousse, V., Petit-Renaud, S., Meignier, S., Esteve, Y., and Jacquin, C. (2009). Automatic named
563 identification of speakers using diarization and ASR systems. In *Proceedings of the IEEE International
564 Conference on Acoustics, Speech and Signal Processing*, pages 4557–4560, Taipei, Taiwan.
- 565 Khoury, E., Gay, P., and Odobez, J. (2013). Fusing matching and biometric similarity measures for face
566 diarization in video. In *Proceedings of the IEEE International Conference on Multimedia Retrieval*,
567 pages 97–104, Dallas, USA.
- 568 Kuhn, H. W. (1955). The hungarian method for the assignment problem. *Naval research logistics quarterly*,
569 2:83–97.

- 570 Li, D., Wei, G., Sethi, I. K., and Dimitrova, N. (2001). Person identification in tv programs. *Journal of*
571 *Electronic Imaging*, 10(4):930–938.
- 572 Ma, C., Nguyen, P., and Mahajan, M. (2007). Finding speaker identities with a conditional maximum
573 entropy model. In *Proceedings of the IEEE International Conference on Acoustics, Speech and Signal*
574 *Processing*, volume 4, pages 253–261, Honolulu, USA.
- 575 McCallum”, A. K. (2002). ”MALLET: A machine learning for language toolkit”.
576 ”<http://mallet.cs.umass.edu>”.
- 577 NIST (2003). The rich transcription spring 2003 (rt-03s) evaluation plan.
- 578 Noulas, A., Englebienne, G., and Krose, B. J. (2012). Multimodal speaker diarization. *IEEE Transactions*
579 *on Pattern Analysis and Machine Intelligence*, 34(1):79–93.
- 580 Ozkan, D. and Duygulu, P. (2010). Interesting faces: A graph-based approach for finding people in news.
581 *Pattern Recognition*, 43(5):1717–1735.
- 582 Pham, P., Moens, M.-F., and Tuytelaars, T. (2008). Linking names and faces: Seeing the problem in
583 different ways. In *Proceedings of the European Conference on Computer Vision*, pages 68–81, Marseille,
584 France.
- 585 Pham, P. T., Deschacht, K., Tuytelaars, T., and Moens, M.-F. (2013). Naming persons in video: Using
586 the weak supervision of textual stories. *Journal of Visual Communication and Image Representation*,
587 24(7):944–955.
- 588 Poignant, J., Besacier, L., and Quénot, G. (2014). Unsupervised speaker identification in TV broadcast
589 based on written names. *IEEE/ACM Transactions on Audio, Speech, and Language Processing*,
590 23(1):57–68.
- 591 Poignant, J., Fortier, G., Besacier, L., and Quénot, G. (2015). Naming multi-modal clusters to identify
592 persons in tv broadcast. *Multimedia Tools and Applications*, pages 1–25.
- 593 Rouvier, M., Dupuy, G., Gay, P., Khoury, E., Merlin, T., and Meignier, S. (2013). An open-source
594 state-of-the-art toolbox for broadcast news diarization. In *Proceedings of InterSpeech*, pages 547–552,
595 Lyon, France.
- 596 Rouvier, M. and Meignier, S. (2012). A global optimization framework for speaker diarization. In
597 *Proceedings of the Odyssey workshop*, pages 546–552, Singapore.
- 598 Satoh, S., Nakamura, Y., and Kanade, T. (1999). Name-it: Naming and detecting faces in news videos.
599 *IEEE Multimedia*, 6(1):22–35.
- 600 Schroff, F., Kalenichenko, D., and Philbin, J. (2015). Facenet: A unified embedding for face recognition
601 and clustering. In *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*,
602 pages 815–823, Boston, USA.
- 603 Simonyan, K., Parkhi, O. M., Vedaldi, A., and Zisserman, A. (2013). Fisher vector faces in the wild. In
604 *Proceedings of the British Machine Vision Conference*, pages 867–879, Bristol, United Kingdom.
- 605 Tapaswi, M., Parkhi, O. M., Rahtu, E., Sommerlade, E., Stiefelhagen, R., and Zisserman, A. (2014).
606 Total cluster: A person agnostic clustering method for broadcast videos. In *Proceedings of the Indian*
607 *Conference on Computer Vision Graphics and Image Processing*, pages 7–15, Bengaluru, India.
- 608 Vallet, F., Essid, S., and Carrive, J. (2013). A multimodal approach to speaker diarization on TV talk-shows.
609 *IEEE Transactions on Multimedia*, 15(3):509–520.
- 610 Viola, P. and Jones, M. J. (2004). Robust real-time face detection. *International Journal of Computer*
611 *Vision*, 57(2):137–154.
- 612 Wohlhart, P., Köstinger, M., Roth, P. M., and Bischof, H. (2011). Multiple instance boosting for face
613 recognition in videos. *Pattern Recognition*, 6835:132–141.

- 614 Zhang, L., Kalashnikov, D. V., and Mehrotra, S. (2013). A unified framework for context assisted face
615 clustering. In *Proceedings of the IEEE International Conference on Multimedia Retrieval*, pages 9–16,
616 Dallas, USA.
- 617 Zhang, N., Paluri, M., Tagiman, Y., Fergus, R., and Bourdev, L. (2015). Beyond frontal faces: Improving
618 person recognition using multiple cues. *Proceedings of the IEEE Conference on Computer Vision and*
619 *Pattern Recognition*, pages 4804–4813.