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# DeepComics: Saliency estimation for comics

Kévin Banner, Eakta Jain, Olivier Le Meur

Abstract—A key requirement for training deep learning saliency models is large training eye tracking datasets. Despite the fact that the accessibility of eye tracking technology has greatly increased, collecting eye tracking data on a large scale for very specific content types is cumbersome, such as comic images, which are different from natural images such as photographs because text and pictorial content is integrated. In this paper, we show that a deep network trained on visual categories where the gaze deployment is similar to comics outperforms existing models and models trained with visual categories for which the gaze deployment is dramatically different from comics. Further, we find that it is better to use a computationally generated dataset on visual category close to comics one than real eye tracking data of a visual category that has different gaze deployment. These findings hold implications for the transference of deep networks to different domains.

## I. Introduction

Comics are a compelling medium for visual storytelling that are experiencing a resurgence as a result of the digital revolution [1]. New forms of comic art, such as mobile comics and web comics, reach a wider audience and creates new consumption methods. Powered by digital tools and open publishing platforms, comics as a form of expression has become accessible to individual content creators beyond established publishing houses.

The common characteristic across all the diverse applications of comics [2], [3], [4], [5], [6], [7], [8], [9], [10] is that with a smart mixture of text or/and other visual information, artists communicate the content by drawing the viewer attention to specific areas.

Estimating where an observer looks within a comic is useful to drive a variety of application such as cropping [11], recomposing, or augmenting traditional comics with digital effects such as animations, stereoscopy, moves-on-stills [12], [13]. For these applications, the prerequisite is to get prior knowledge of the visual route used by the viewer, or intended by the artist. Rather than performing time-consuming and cumbersome eye tracking experiments, we propose a deep neural network to address this problem.

The technical challenge here is that there are very few eye tracking dataset on comics; to the best of our knowledge, the dataset proposed in [12] is the sole publicly available dataset at this time. However, this dataset is too small to perform an end to end training for a deep network. To overcome this problem, we propose to train the deep network on publicly available eye tracking datasets that

are similar either in terms of visual content or in terms of gaze behavior. With this transfer learning [14], we show that the learned features are relevant enough to predict saliency on comics. Our contributions can be summarized as follows: (i) we propose the first saliency model dedicated towards predicting the saliency maps on comics; (ii) we show that the proposed model trained on visual categories that have similar gaze deployment as comics performs much better than traditional saliency models and than models trained on natural scenes; (iii) we evaluate the benefit to use fake dataset, i.e. data that has been computationally generated, for training the proposed model.

This paper is organized as follows. Section II investigates the gaze deployment on comics. Section III presents the deep network used for predicting the salience on comics. Section IV presents the performance of the proposed model and compare it to state-of-the-art methods. We conclude this paper in the last section.

## II. Gaze deployment on comics

We investigate the gaze deployment of observers while watching comics using [12]’s dataset, which is composed of 23 images taken from public domain legacy comics. Five viewers participated in the experiment. More details are available in [12].

The joint probability distribution  $p(d, \phi)$ , estimated as described in [17] represents the probability that a fixation featured by a distance  $d$  and an angle  $\phi$  occurs:

$$p(d, \phi) = \frac{1}{n} \sum_{i=1}^n K_h(d - d_i, \phi - \phi_i) \quad (1)$$

where,  $d_i$  and  $\phi_i$  represents the distance (expressed in visual angle) and the angle (expressed in degree) between each pair of successive fixations respectively.  $n$  is the total number of samples and  $K_h$  is a two-dimensional Gaussian kernel.

The distribution  $p(d, \phi)$  obtained on the comics dataset is illustrated on Figure 1 (Top-left). The polar plot indicates the probability of saccade targeting when the current fixation point is located at the center of the plot. Radial position indicates saccadic amplitudes expressed in degree of visual angle. Three main observations can be done: first, the rightward saccades are much more numerous than other saccades (see arrow numbered 1). The amplitudes of those saccades are rather small, between 1.5 and 2 degrees of visual angle. This indicates that observers move their eye with small jumps from the left-hand side to the right-hand side of the comics images. Second observation concerns the re-positioning saccades (see arrow numbered

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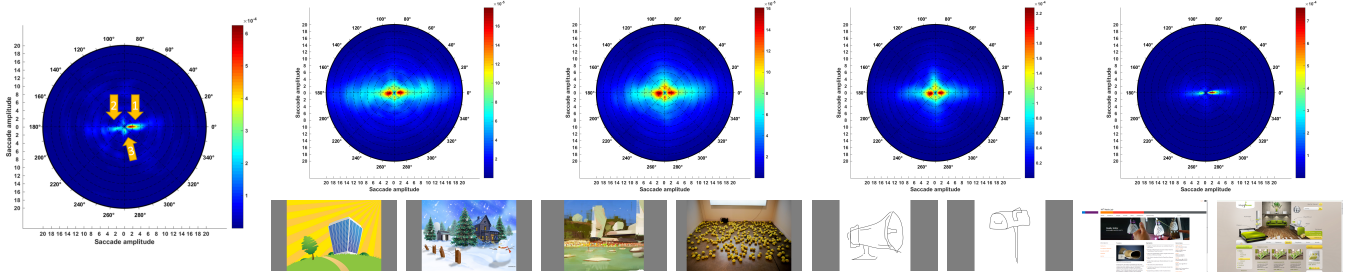


Fig. 1. Distribution of saccade amplitudes and orientations for Comics (top-left), Cartoon, Art and Sketch from the CAT2000 eye tracking dataset [15], and webpages from [16]. Bottom: Representative stimuli images of the visual categories.

2). These leftward saccades are used to re-position eyes on the left-hand side of the stimulus. The third observation (see arrow numbered 3) concerns the downward saccades, indicating that observers look the images in a top-down manner.

We evaluate the degree of similarity between the comic distribution and four other distributions, computing on Art, Cartoon, Sketch and Webpages images; some representative stimuli images of these visual categories are illustrated on Figure 1 (Bottom row). Distributions for Art, Cartoon and Sketch are computed by using the eye tracking dataset CAT2000 [15] whereas the eye tracking dataset of [16] is used to estimate the distribution of saccade amplitudes and orientations on webpages. Figure 1 plots these joint distributions of saccade amplitudes and orientations. Table I provides the similarity values between the comics distribution and Art, Cartoon, Sketch and Webpages distributions. The similarity is assessed by the Kullback-Leibler divergence, the linear correlation and intersection of histograms [18]. As shown by Table I, the comics joint distribution turns out to be similar to the gaze deployment observed on webpages and on sketches. Webpages and Comics share several properties. As mentioned earlier, the gaze deployment on comics is close to those observed on webpages. Observers explore the webpages starting from the upper left corner and progressively move the gaze in a top-down manner. Regarding the sketch category, the similarity with comics gaze deployment is primarily related to the amplitude and orientations of saccades. As for comics, saccade amplitudes are rather small and mostly along the horizontal direction. The lowest similarity is observed for the category Art.

The similarity in content is also evaluated by computing the KL-divergence between the average amplitude Fourier spectrums of Comics and the aforementioned categories. Table I indicates that Cartoon is the most similar category whereas Sketch is the most dissimilar. Interestingly, the similarity in content (based on the average Fourier spectrum) is correlated negatively to the similarity in gaze deployment.

Our motivation is to evaluate the benefit to train a deep convolutional network with eye tracking data collected on visual categories similar either in terms of gaze behavior or similar in terms of visual content.

TABLE I  
Similarity between Comics and Art, Cartoon, Sketch, Webpages categories in terms of gaze deployment (top) and Fourier spectrum (bottom).  $\uparrow$  indicates the higher the better, whereas  $\downarrow$  indicates the lower the better.

Dist. similarity	Art	Cartoon	Sketch	Webpages
KL-divergence $\downarrow$	0.376	0.400	0.267	0.2417
Correlation $\uparrow$	0.773	0.796	0.813	0.854
Similarity $\uparrow$	0.706	0.707	0.739	0.758
Content similarity				
KL-divergence $\downarrow$	0.172	0.157	0.69	0.238

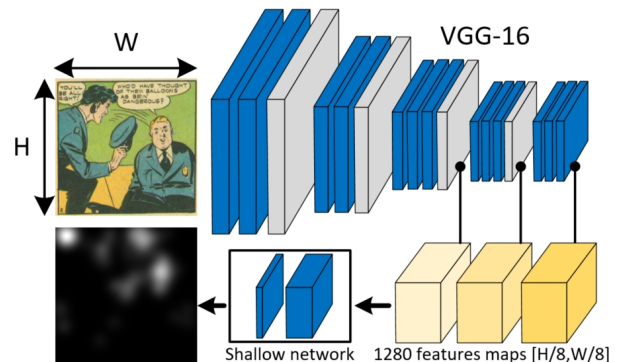


Fig. 2. Deep network for predicting saliency on comics images. 1280 deep feature maps are extracted by using the VGG-16 network. A smaller network (bottom-right) is trained by using eye tracking data.

### III. Predicting saliency

#### A. Deep saliency network

For predicting the salience of comics, the architecture of network, illustrated in Figure 2, is based on the deep gaze network of [19] and on the multi-level deep network of [20]. The pre-trained VGG-16 network [21] is used for extracting deep features of an input image ( $800 \times 450$ ) from layers conv3\_pool, conv4\_pool, conv5\_conv3. Feature maps of layers conv4\_pool and conv5\_conv3 are rescaled to get feature maps with a similar spatial resolution.

Similarly to [20], a smaller network, composed of two convolutional layers, is built. The first layer has a kernel size  $3 \times 3$  and 64 feature maps. The second is a simple convolution layer, with a kernel  $1 \times 1$ , used to reduce the data dimensionality. Both these two layers have a Relu activation. The last layer outputs a reduced predicted

saliency map which is upsampled to recover the initial resolution  $H \times W$ .

## B. Training and implementation

Three strategies are used to train the deep network.

(i) Training with dataset having a similar gaze deployment: we use the webpages dataset of [16] which is composed of 149 screen-shots of webpages. They were instructed to free-view the webpages. We also use the 100 images from the Sketch visual category from the CAT2000 eye tracking dataset [15]. Observers were instructed to look around the image.

(ii) Training with dataset that has a similar content: we use the Art and Cartoon categories of the CAT2000 dataset. Each category is composed of 100 images.

(iii) Generating fake training data for webpages content: we generate computationally a new dataset of saliency maps for webpages in order to increase the training corpus. This fake dataset could be used to (pre)train the proposed method. We collected 316 new screenshots of webpages. The predicted saliency maps are computed by adapting iSEEL model [22]. The modification just consists in adding a webprior computed from [16]. Once the proposed deep network is (pre)trained, it could be fine-tuned with the eye tracking dataset [16].

Concerning the implementation, input images are first resized to a resolution of  $800 \times 450$  pixels. The loss function is  $\mathcal{L}(\mathbf{w}) = \frac{1}{N} \sum_{i=1}^N g(\mathbf{y}_i) \|\mathbf{p}_i - \mathbf{y}_i\|^2$  with  $g(x) = 1 + \frac{\beta_1}{1 + \exp(-\beta_2(x-\gamma))}$ .  $N$  represents the number of images per batch ( $N = 20$ ),  $\mathbf{p}_i$  and  $\mathbf{y}_i$  represent the vectorized  $i^{th}$  predicted saliency map and ground truth map in the current batch, respectively. We assume that both predicted and ground truth maps are normalized in the range  $[0, 1]$ . The function  $g()$  is chosen in order to give more importance to errors occurring on high ground truth saliency. This is a positive-definite increasing function. By default, we use  $\beta_1 = \beta_2 = 9$  and  $\gamma = 0.6$ .

The network was trained using stochastic gradient descent. To prevent over-fitting, a dropout layer is added before the  $3 \times 3$  convolutional layer. The rate of dropout is set to 0.5. During training, the network was validated against the validation set after every iterations to monitor convergence and over-fitting. The learning rate is set to 0.001. To test the model, we added a convolution with Gaussian filter after the last layer, to smooth the generated saliency map. This map is first resized to  $800 \times 450$  and is then filtered by the proposed Gaussian filter.

## IV. Performance

To carry out the evaluation, we use seven quality metrics used in the MIT benchmark [18], [32]: CC (correlation coefficient,  $CC \in [-1, 1]$ ), SIM (similarity, intersection between histograms of saliency,  $SIM \in [0, 1]$ ), AUC (Area Under Curve,  $AUC \in [0, 1]$ ), NSS (Normalized Scanpath Saliency,  $NSS \in ]-\infty, +\infty[$ ), EMD (Earth Mover Distance,  $EMD \in [0, +\infty[$ ) and KL (Kullback Leibler divergence,  $KL \in [0, +\infty[$ ).

## A. Performance of existing models

Table II presents the results. We put to the test 13 models: 6 unsupervised models (dark pink in Table II) and 7 models based on deep learning approach (light pink in Table II). Note that we also tested the saliency model proposed in [33] for predicting saliency on webpages. This model is built over [29] and has almost the same performance in this context.

Except SAM-VGG, SAM-resNet [30] and SalGAN [31], all the tested models perform quite poorly to predict saliency on comics. The best unsupervised model is Zhang’s model [24]. The supervised models do not present a significant advantage over unsupervised ones. These observations, consistent with a previous analysis [34], were expected. Indeed, all these models have been designed for predicting saliency on natural scenes. Most of them embed implicitly or explicitly a center bias accounting for observers’ viewing tendency to look at the center of screen. However, this viewing tendency is not systematic [35] and depends on the visual content display onscreen. For both webpages and comics, a top-left bias is observed. Considering this point, a straightforward approach consisting in weighting predicted saliency maps by a webpage prior (learned on eye tracking dataset [16]) may significantly increase the performance. For instance, the performance of iSEEL model significantly increases when a prior web is used. Although the gain in CC is about 0.07, the performances are still limited.

## B. Performance of proposed models

Compared to existing methods, the proposed methods (see light green cells in Table II) outperform in a significant manner both unsupervised (see dark pink cells in Table II) and most of supervised models (see light pink cells in Table II). The training with eye tracking dataset on Sketches provides the best performance (i.e. with a correlation coefficient of 0.594). The proposed deep model trained on Webpages ranks second (i.e. with a correlation coefficient of 0.582). Performances, when Art and Cartoon are considered for the training, are poorer (i.e. with a correlation coefficient of 0.407 and 0.560, respectively). This ranking is in accordance with the similarity between joint distributions, as shown by Table I. Finally, when we consider all visual categories for the training (more than 400 images), the performances (e.g.  $CC = 0.566$ ) are not as good as the model trained with Sketch (e.g.  $CC = 0.594$ ) (only 100 images). All these observations suggest that it is possible to train efficiently a deep network on visual categories for which the gaze behavior is close to the targeted category. This transfer learning is especially interesting when datasets are small.

To go further, we train the proposed model with a dataset composed of predicted saliency maps computed on webpages; we call it fake dataset in Table II. Performances are rather good compared to unsupervised and supervised models. The fine-tuning of the pre-trained model with a real webpage dataset [16] does not allow to improve

TABLE II  
Performance of existing and proposed saliency models over comics dataset. Best performances are in bold. (AUC-B=AUC-Borji;  
AUC-J=AUC-Judd)

	CC $\uparrow$	SIM $\uparrow$	AUC-J $\uparrow$	AUC-B $\uparrow$	NSS $\uparrow$	EMD $\downarrow$	KL $\downarrow$
Existing saliency models							
GBVS [23]	0.098	0.462	0.556	0.477	-0.006	3.183	1.118
Zhang [24]	0.424	0.523	0.715	0.738	0.871	2.841	0.714
AIM [25]	0.297	0.492	0.697	0.660	0.392	3.081	1.737
SIM [26]	-0.023	0.442	0.496	0.467	-0.088	3.374	1.009
AWS [27]	0.293	0.502	0.668	0.673	0.618	3.016	0.772
RARE2012 [28]	0.058	0.419	0.556	0.522	0.100	3.639	1.217
DeepConvNet [29]	0.378	0.543	0.680	0.629	0.622	2.590	1.485
ML-Net [20]	0.280	0.488	0.668	0.581	0.429	2.570	1.629
iSEEL [22]	0.342	0.537	0.670	0.581	0.442	2.418	0.925
iSEEL [22]+webprior	0.411	0.554	0.712	0.646	0.618	2.126	0.782
SAM-VGG [30]	0.517	0.549	0.769	0.670	1.011	1.690	2.112
SAM-resNet [30]	0.609	0.601	0.811	0.733	1.279	1.508	1.569
SalGAN [31]	0.556	0.599	0.784	0.749	1.091	1.963	0.824
Proposed method with Sigmoid loss (see Section III)							
Trained with Art dataset [15]	0.407	0.525	0.688	0.684	0.756	2.666	0.796
Trained with Cartoon dataset [15]	0.560	0.568	0.731	0.749	1.115	2.251	0.697
Trained with Sketch dataset [15]	0.594	0.572	0.758	0.775	1.166	2.420	0.600
Trained with Webpages dataset [16]	0.582	0.586	0.740	0.748	1.115	2.076	0.628
Trained with all visual categories	0.566	0.570	0.740	0.742	1.085	2.376	0.624
Trained with fake webpages dataset	0.501	0.540	0.730	0.748	0.971	2.646	0.676
Trained with fake webpages dataset and fine tuning on [16]	0.511	0.545	0.727	0.743	0.982	2.575	0.666

in a significant manner the performance. Moreover, this training strategy does not allow to outperform models that are directly trained with real eye tracking data. This model performs at 0.501 whereas the best model trained with eye tracking data performs at 0.594.

## V. Conclusion

In this paper, we train a deep network for predicting the saliency on comics. Since existing eye tracking datasets for comics are extremely limited, we rely on transfer learning. We show that training the proposed deep network with visual categories showing similar gaze deployment to comic content provides the best performance. To be more specific, the use of eye tracking data collected on Sketches and on Webpages allows us to outperform in a significant manner the same deep network trained with eye tracking collected on Art and Cartoon. We also observe that it is even better to train the network with computationally generated data computed on Webpages than using real eye tracking data collected on visual categories, e.g. Art, for which the gaze deployment is dramatically different from the one observed on comics.

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