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EVALUATION OF PREYS / PREDATORS SYSTEMS FOR VISUAL ATTENTION SIMULATION

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Abstract: This article evaluates different improvements of Laurent Itti's (Itti et al., 1998) visual attention model. Sixteen persons have participated in a qualitative evaluation protocol on a database of 48 images. Six different methods were evaluated, including a random fixations generation model. A real time conspicuity maps generation algorithm is also described. Evaluations show that this algorithm allows fast maps generation while improving saliency maps accuracy. The results of this study reveal that preys / predators systems can help modelling visual attention. The relatively good performances of our centrally biased random model also show the importance of the central preference in attentional models.

1 Introduction

In (Perreira Da Silva et al., 2008), we have presented a behavioural vision architecture designed to be an elementary block for a virtual companion. In order to be interactive, this companion needs a real time vision system. A clever way to reduce allocated computer resource is to focus its attention on the most salient scene elements. Many visual attention computer models have been developed (Tsotsos et al., 2005), (Bruce and Tsotsos, 2009), (Frintrop, 2006), (Mancas, 2007), (Ouerhani, 2003), (Le Meur, 2005) or (Hamker, 2005), nevertheless, they are often too complex for a real time execution. Besides, time evolution of the focus of attention is another weakness of many models, due to unsuitable decision systems.

In this article, we propose a new method which allows studying the temporal evolution of the visual focus of attention. We have modified the classical algorithm proposed by Itti in (Itti et al., 1998), in which first part of his architecture relies on extraction on three conspicuity maps based on low level computation. These three conspicuity maps are representative of the three main human perceptual channels: colour, intensity and orientation. In our architecture, these low level computations are inspired from works pre-

sented in (Frintrop, 2006) (Frintrop et al., 2007), actually the way to accelerate computation, (*i.e.* the use of integral images (Viola and Jones, 2004)) is reused and extended to all maps. This real time computation is described in section 2.

The second part of Itti's architecture proposes a medium level system which allows merging conspicuity maps and then simulates a visual attention path on the observed scene. The focus is determined by a winner takes all and an inhibition of return algorithms. We propose to substitute this second part by a preys / predators system, in order to introduce a temporal parameter, which allows generating saccades, fixations and more realistic paths (figure 1).

Prey / predators equations are particularly well adapted for such a task. The main reasons are:

- prey predator systems are dynamic, they include intrinsically time evolution of their activities. Thus, visual attention focus, seen as a predator, could evolve dynamically;
- without any objective (top down information or pregnancy), choosing a method for conspicuity maps fusion is hard. A solution consists in developing a competition between conspicuity maps

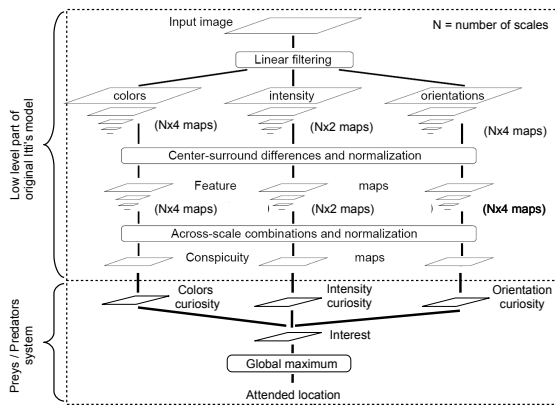


Figure 1: Architecture of our visual attention model. This diagram has been adapted from (Itti et al., 1998).

and waiting for a natural balance in the preys / predators system, reflecting the competition between emergence and inhibition of elements that engage or not our attention;

- discrete dynamic systems can have a chaotic behaviour. Despite the fact that this property is not often interesting, it is an important one for us. Actually, it allows the emergence of original paths and exploration of visual scene, even in non salient areas, reflecting something like *curiosity*.

Finally, we present the results of experiments designed to validate the relevance of these different improvements. We have decided to compare different models, included those of (Itti et al., 1998), our improvements, and two random models (with or without central bias).

In the following section, we present the approach we have used to generate efficient and real time conspicuity maps.

2 Real-time generation of conspicuity maps

Our solution is derived from work done in (Frintrop, 2006) and (Frintrop et al., 2007). The author uses integral images (Viola and Jones, 2004) in order to rapidly create conspicuity maps. Nevertheless, she explains that these optimisations are only applied to intensity and colour maps. Furthermore, she uses many integral images (one for each multi-resolution pyramid level of each conspicuity map), even if this approach is sub-optimal it was chosen in order not to change the original structure of their algorithm. Lastly, integral image were not used for computing

the orientation map because results would have been less accurate than using Gabor filters, but also because is not trivial to compute oriented filters with angle different from 0 or 90 deg with integral images.

To reach optimal processing times, we have decided to use integral images for all the conspicuity maps. As a consequence, Gabor filters were replaced by simpler Haar like oriented band pass filter. Thus, for all levels of On and Off intensity channel, R/G and B/Y colour channels and 0 and 90 deg oriented filtered, we use integral images. For 45 deg and 135 deg maps, an oriented integral image is computed using (Barczak, 2005) method.

All the information needed by multi-resolution analysis is finally processed from only four integral images.

The following results were obtained on a Compaq nc8430 computer with 2Go of memory and an Intel dual-core T2400 CPU 1.83 Ghz, using a C# implementation:

Resolution	160x120	320x240	640x480
Number of levels	3	4	5
Processing time	12ms	60ms	250ms

Accordingly, it is possible to stay in real time for 320x240 images. Nevertheless, these results are difficult to compare with those of (Frintrop et al., 2007) mainly because:

- configurations are different (experiments and hardware);
- programming languages (C# vs C++);
- levels of resolution is more numerous in our system.

Regarding the last point, (Frintrop et al., 2007) as (Itti et al., 1998) computes five levels, and only three of them are used, those of lower resolution. In our approach, we use all the resolution levels until a size of 8x8 pixels, ensuring that a maximum amount of information is taken into account.

By generalizing the use of integral images technique it is possible to compute more information in reasonable computation time. Experimental results presented in section 4 shows that our approach is more efficient since our global system performance is clearly better when we use our conspicuity maps.

2.1 A fast and simple retinal blur model

We have also studied the impact of the retinal blur model on our system behaviour. Actually, since scenes we see have a variable resolution (the closer from the fovea we are, the sharper scenes are), it could impact attentional models. Besides, we could

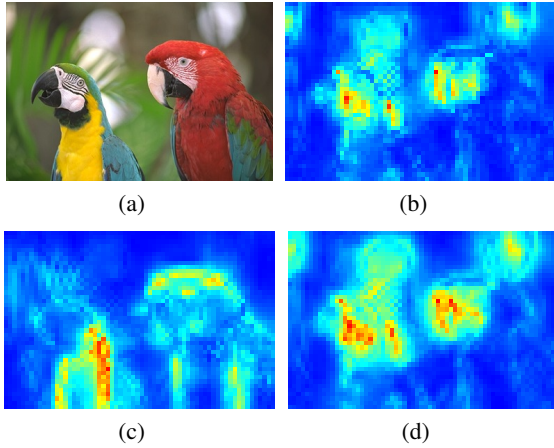


Figure 2: Sample real-time conspicuity maps : (a) Original image; (b) *Intensity* conspicuity map; (c) *colour* conspicuity map; (d) *Orientation* conspicuity map.

benefit of this gradual lack of details to compute our model more quickly. Thus we do not compute a multi-resolution pyramid, but a multi-resolution column. For example if we define a size of 16x16 for representing the details of the finest resolution, we will generate a $N \times 16$ pixels column (N being the number of resolution levels we need). Figure 3 allows to graphically comparing the two previous approaches (pyramid vs column).

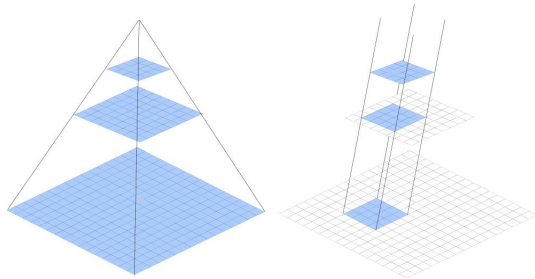


Figure 3: Left: a classical multi-resolutions pyramid. Right: Multi-resolutions column with a width and height of 4 pixels. This kind of structure allows keeping only a part of the initial information of the finest resolutions.

The following table presents computation times with this new method. Figure 4 presents its influence on conspicuity maps.

Resolution	160x120	320x240	640x480
Number of levels	3	4	5
Processing time	12ms	60ms	250ms
Processing time with retinal blur	8ms	40ms	170ms
% of improvement	33%	33%	32%

Using the retinal blur model improves computation time by a 33% factor. However, benefit is not higher than expected due to more complex interpolations implied by the fusion of the different resolution images. Nevertheless, an improvement generated by this retinal blur is that the temporal focus of attention is modified. Our visual attention focus is more stable, so potentially more credible knowing the fixation time of human being (approximately 100 to 500 ms).

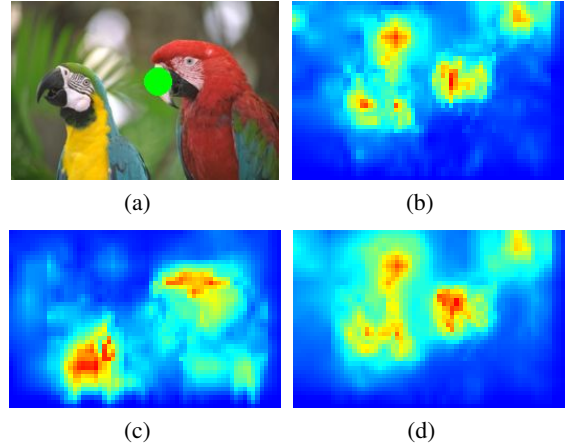


Figure 4: Sample real time conspicuity maps with retinal blur simulation: (a) Original image. The green circle represents the focus of attention; (b) *Intensity* conspicuity map; (c) *colour* conspicuity map; (d) *Orientation* conspicuity map.

3 Real-time simulation of the temporal evolution of visual attention focus

This section presents a fusion method used to mix the conspicuity maps described above; interested reader may refer to (Perreira Da Silva et al., 2009) for more details on preys / predators system. We focus the following sections on describing the details necessary to understand the results of the evaluation protocol used to compare different models of attention.

3.1 Preys / predators systems and visual attention analysis

Preys / predators systems are defined by a set of equations whose objective is to simulate the evolution and the interactions of some colonies of preys and predators. Interested reader can find more details about these systems in (Murray, 2002). For our

system, we have based our work on (Lesser and Murray, 1998) so as to represent the time evolution of interest (or focus of attention) linked to, in a first time (see section 6), a static image.

Traditionally, the evolution of preys / predators systems is governed by a small set of simple rules, inspired from Volterra-Lotka (Murray, 2002) equations:

1. the growth rate of preys is proportional to their population C and to a growth factor b ;
2. the growth rate of predators is proportional to their predation rate CI (rate a which preys and predators encounter) and to a predation factor s ;
3. preys and predators spread using a classical diffusion rule, proportional to their Laplacian Δ_C and a diffusion factor f ;
4. the mortality rate of predators m_I is proportional to their population I ;
5. the mortality rate of preys m_C is proportional to their population, plus an additional mortality proportional to the predation rate CI .

In order to simulate the time evolution of the focus of attention, we propose a preys / predators system (as described above) with the following features:

- the system is comprised of three types of preys and one type of predators;
- these three types of preys represent the spacial distribution of the curiosity generated by our three types of conspicuity maps (intensity, colour, orientation);
- the predators represent the interest generated by the consumption of curiosity (preys) associated to the different conspicuity maps;
- the global maximum of the predators maps (interest) represents the focus of attention at time t .

The equations described in subsection 3.2 were obtained by building a preys / predators system which integrates the above cited features.

3.2 Simulating the evolution of the attentional focus with a Preys / predators system

For each of the three conspicuity maps (colour, intensity and orientation), the preys *population* C evolution is governed by the following equation :

$$\frac{dC_{x,y}^n}{dt} = hC_{x,y}^{*n} + hf \Delta_{C_{x,y}^{*n}} - m_C C_{x,y}^n - sC_{x,y}^n I_{x,y}$$

with $C_{x,y}^{*n} = C_{x,y}^n + wC_{x,y}^{n-2}$ and $n \in \{c, i, o\}$, which mean that this equation is valid for C^c , C^i and C^o which represent respectively colour, intensity and orientation *populations*.

The population of predators I , which consume the three kinds of preys, is governed by the following equation:

$$\frac{dI_{x,y}}{dt} = s(P_{x,y} + wI_{x,y}^2) + sf \Delta_{P_{x,y} + wI_{x,y}^2} - m_I I_{x,y}$$

with

$$P_{x,y} = \sum_{n \in \{c, i, o\}} (C_{x,y}^n) I_{x,y}$$

and

$$h = b(1 - g + gG)(a * R + (1 - a) * S)(1 - e)$$

C represents the curiosity generated by the image's intrinsic conspicuity. It is produced by a sum h of four factors:

- *the image's conspicuity* S is generated using Laurent Itti's Neuromorphic Visual Toolkit (Itti et al., 1998), or our real time algorithm. Its contribution is inversely proportional to a ;
- *a source of random noise* R simulates the high level of noise that can be measured when monitoring our brain activity (Fox et al., 2007). Its importance is proportional to a ;
- *a Gaussian map* G which simulates the central bias generally observed during psycho-visual experiments (Tatler, 2007). The importance of this map is modulated by g ;
- *the entropy* e of the conspicuity map (colour, intensity or orientation). This map is normalized between 0 and 1. C is modulated by $1 - e$ in order to favour maps with a small number of local minimums. Explained in terms of preys / predators system, we favour the growth of the most organized populations (grouped in a small number of sites).

Like in (Lesser and Murray, 1998), a quadratic term (modulated by w) has been added to the classical Volterra-Lotka equations. This term was added to simulate non-linearity (positive feedback) in our system. It enforces the system dynamics and facilitates the emergence of chaotic behaviours by speeding up saturation in some areas of the maps. Lastly, please note that curiosity C is consumed by interest I , and

that the maximum of the interest map I at time t is the location of the focus of attention.

During the experiments presented in section 4, the following (empirically determined) parameters were used:

a	b	g	w	m_C	m_I	s	f
0.3	0.005	0.01	0.001	0.3	0.5	0.025	0.2

These parameters represent *reasonable* values that can be used to obtain a system at equilibrium. Other combinations are nevertheless possible. In particular, these values can be varied within a range of plus or minus $\pm 50\%$ without compromising the system’s stability. Our system is thus quite robust to its parameters variation.

4 Experiments

We ran a series of experiments with a double objective. The first was to check that the simplifications we have introduced in order to generate the conspicuity maps in real time does not impact the predictive performances of our model. The second was to estimate the performances of our dynamical, preys / predators based, conspicuity maps fusion system.

We compared the six following visual attention models:

- Itti’s reference model (Itti et al., 1998) with default parameters (including the iterative normalization). We used the open-source NVT implementation of these algorithms provided by the iLab team. The tests were ran on still images. The conspicuity maps used were the intensity, colour and orientation ones.
- Our model based on preys / predators fusion applied on Itti’s conspicuity maps. We used the model’s default parameters except for the prey’s birth rate which was dropped to 0.05 (instead of 0.1) because of the more contrasted maps generated by Itti’s model. In order to avoid any loss of information, the maps were not normalized.
- Our model based on preys / predators fusion applied on our standard real time conspicuity maps.
- Our model based on preys / predators fusion applied on our retinal blurred real time conspicuity maps.
- A centrally biased random fixations generation model. Actually this model is our preys / predators system with a equal to 1 (which mean that the prey’s birth rate is driven only by randomness).

- A random fixations generation model without central bias. This model is the same as cited above but with a null g term.

4.1 Image database

We collected a set of 48 images on the Flickr image sharing website. The images were published under the *Attribution* creative commons licence. We organized the database into 6 categories of 8 images:

- Abstract
- Animals
- City
- Flowers
- Landscapes
- Portraits

This categorization, allowed us to study the link between the image categories and the performance of the different visual attention models.



Figure 6: Sample images from each of the six categories of the experiment database

4.2 Methods

Usually visual attention models performances are evaluated by comparing the saliency maps generated by these models with heat-maps processed from eye-tracking experiments. However, this evaluation method is complex and suffers from known biases.

One of them is the semantic bias. This bias is due to the fact that we need to display the images a few seconds in order to capture enough eye fixations to build a statistically valid heat-map. During that time our brain starts analysing the meaning of the image which affects the way we look at the image. Since that bias can't be avoided, we have decided to use an alternative evaluation method which does not require the use of an eye tracker. That way, anybody can reproduce our experiments. The subjects were asked to watch a set of 288 image couples. Each couple is composed of a reference image, randomly selected from the experiment database, and a visual attention map generated by one of the six algorithms evaluated. For each of these couples the subject had to rate the potential of the attention map to represent the different parts of the image that attracts the attention of most people. The rate scale was 0 (very bad) to 3 (very good). No time limit was given, but the subjects were advised to spend two or three seconds on each image so that the experiment last no more than fifteen minutes. In order to let the subjects become familiar with the experiment without impacting or biasing the final results, we choose to remove the ten first results from the final analysis.

4.3 Participants

Sixteen participants (eleven men and five women) took part in the experiment. They were aged from 21 to 57 years old.

5 Results

Since the participant ratings were quite heterogeneous, we normalized each of their 288 marks so that they have a constant mean and standard deviation (with respective values 1.5 and 1). That way, we had a more consistent dataset.

Figure 7 shows the mean results obtained by each of the algorithms over the whole database. We notice that our preys / predators fusion system globally improves the plausibility of the attention maps. One can also note that the use of our real time conspicuity maps, despite its numerous simplifications and approximations, also improves the overall predictive performances of the attention models. However, our (very simple) retina simulation algorithm does not show and significant performance improvement. The overall good performance of the central biased random model is also quite surprising, but actually these results are very dependent of the image category (see figure 8). Lastly and unsurprisingly, the full random

model obtains the worst performances.

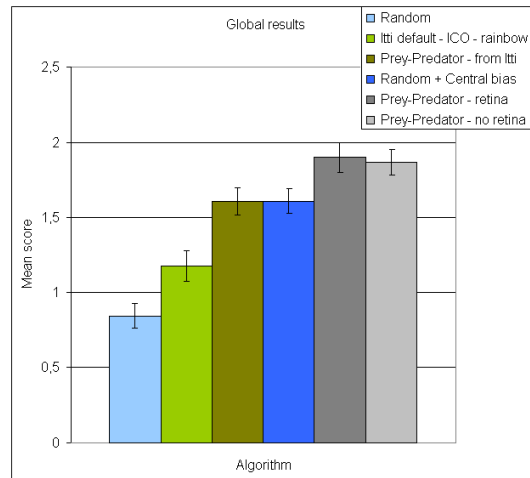


Figure 7: Global results of the experiment for each evaluated attention model. Black bars represent the 95% confidence interval

The results of the different algorithms for the six categories of our experiments database (figure 8) are quite variable:

- The centrally biased random model obtains the best performances on the *portraits* and *abstract* categories. This surprising phenomenon is partly due to the photographer bias. Indeed, any photographer tends to centre his subject in the image. This model also performs quite well on the abstract category. It seems that defining the area of interest for this category is a very challenging task; as a consequence, participants have accepted the central choice as a least bad solution.
- Images from the abstract category are very hard to rate. As a consequence, all models seem to perform equally. For this kind of images, random model are as good as other more sophisticated models.
- Fusing the conspicuity maps with a preys / predators dynamical system significantly improves the performances of Itti's model for all categories, except for landscapes where Itti's algorithm already performs well. In this case, the performances seem superior to Itti's model, but we can't assert this, since the 95% confidence interval for these data is quite high.

6 Discussions

This article shows that preys / predators based conspicuity maps fusion can be used to improve the

plausibility of visual attention models. Moreover, the results of the experiments performed by 16 participants on a database of 48 images show the importance of taking into account the central bias when building new visual attention models. Finally, we have demonstrated the good performances our method for real time generation of conspicuity maps (with or without simple retinal blur).

The results presented in this article are promising, but they need to be confirmed by eye tracking experimentation. Although eye tracking is far from being perfect for visual attention analysis (see (Perreira Da Silva et al., 2009)), it allows collecting the temporal evolution of eye positions, which cannot be obtained by another mean. Our future researches will focus on this kind of experimentation, so as to validate the dynamical behaviour of our model.

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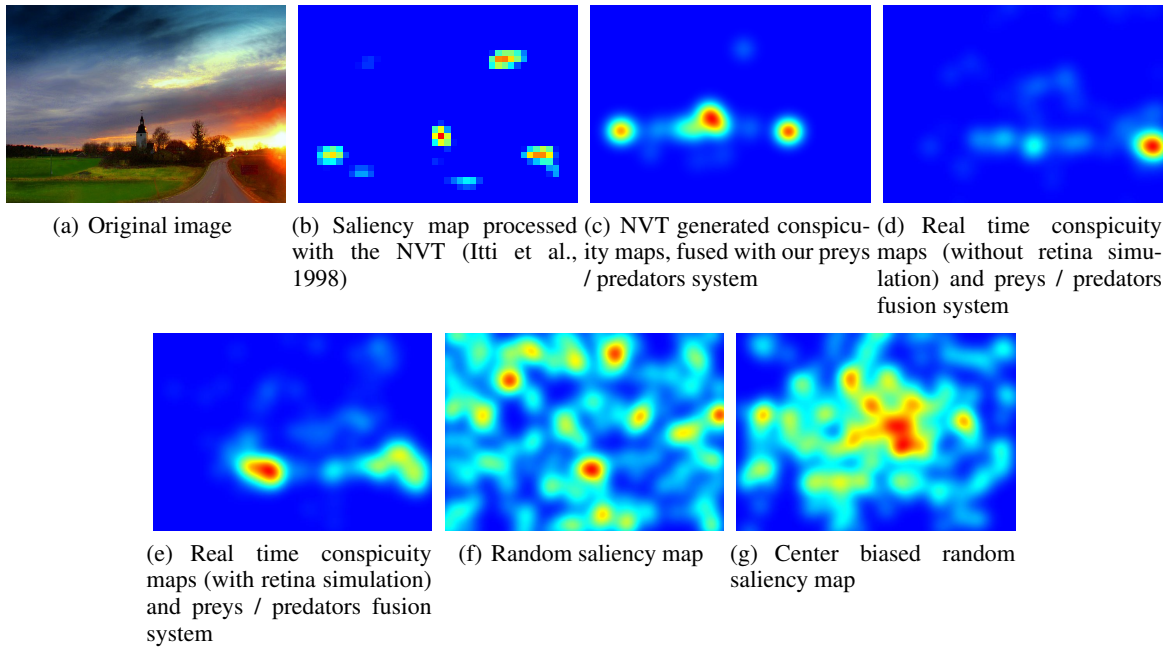


Figure 5: Sample image from the landscape category of the test database and associated results for different algorithms

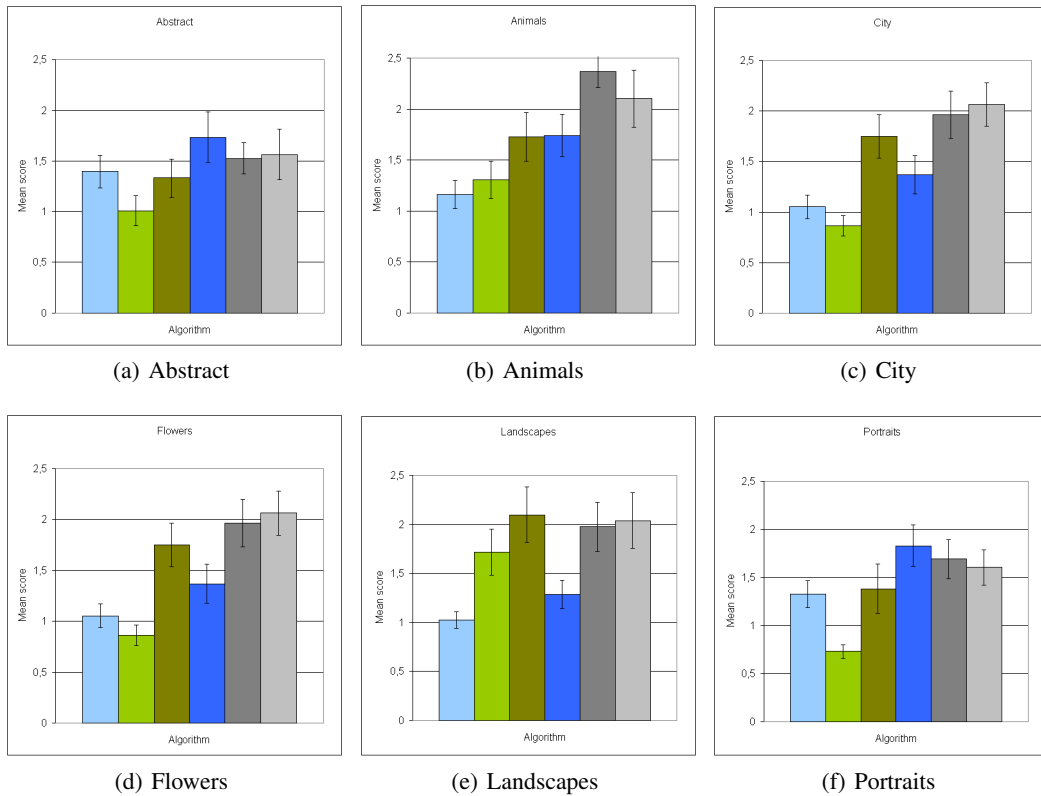


Figure 8: Results of the experiments for each image category.