Technical report
Spectral analysis of the Dead Leaves pattern

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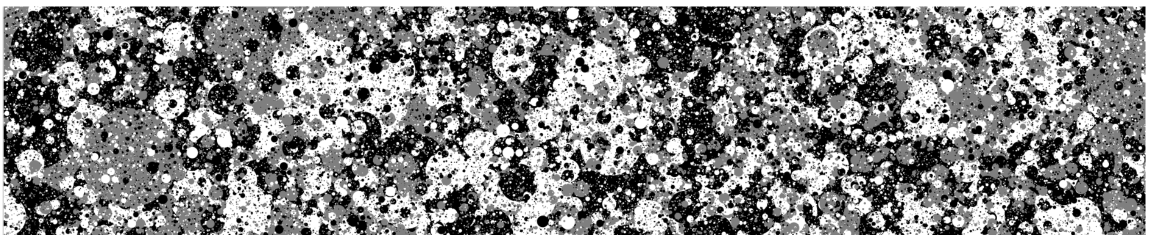


This report quickly summarises the specificities of a visual pattern – the dead leaves pattern [2] — and how it compares with usual checkerboard and random checkerboard patterns. The comparison is based on the spectral content of each pattern and on their respective invariance in rotation and scale. The analysis shows that the spectral content of a dead leaves pattern is considerably less affected by rotation and scale transformations than checkerboard patterns, it is thus to prefer in any experiment in which animals are expected to see a pattern from various orientations or distances. Finally, an extension for the software inkscape (http://inkscape.org/) allowing the generation of visual patterns is presented.

Contents

1 The dead leaves pattern

Description

The dead leaves pattern [2] is a random visual pattern aimed at mimicking the visual properties of natural images. The name comes from its building process: elementary shapes (here disks) are superposed in the same way as tree leaves can be seen falling above each other in nature. Despite containing a wide and continuous range of spatial frequencies, this pattern features sharp edges that mimic natural object occlusions.

Building process

The building process is straight forward. Until the image is completely covered, a new leave is added to the image. Each leave has a random size, random color and random position. In our case, we use disk primitives as leaves but any shape can be used. We use a limited number of colors (3 gray-scales) in order to make sure that the image contains strong edges easily detected by flying insects, but any number of colors can be used.

A new leave is parametrised as follow:

- the center X is chosen inside the image with a uniform probability distribution
- the radius $r \in [r_{min,}, r_{max}]$ is chosen between two boundaries r_{min} and r_{max} with a power distribution such that the probability to create a leave with radius r is :

  $$P_\alpha(r) = k.r^\alpha$$

  It is shown [1, 2] that the scale invariance is assured with $\alpha = -3$. Boundaries for the radius has to be used for $\alpha < 0$ because the distribution is tail-heavy and diverges for $r \to 0$.
- The color is chosen randomly inside a predefined set of colors.

2 Comparison with usual patterns

Presentation

The patterns used for the comparison are shown on figure 1. The regular and random checkerboard patterns (figure 1a and 1b) are 8 bits images of 1000x1000 pixels composed of black and white squares of 25 pixels. In the case of the random checkerboard pattern the color of a square is chosen randomly between 0 and 255. The dead leave pattern (figure 1c) is an 8 bits image of 1000x1000 pixels with circles of radius $r \in [5, 500]$ pixels following a power law P_{-3} ($\alpha = -3$) and with a color chosen randomly between three gray-scales of intensity 0, 127 and 255.

Images spectrum

Figure 2 shows the horizontal power spectrum of the three previously presented images. The spectrum is computed by averaging vertically the squared absolute values of the Fast Fourier Transform of each image. The spatial frequencies are given in cycles/° considering that the images subtends 60° in the visual field.

It is clear that the regular checkerboard pattern does not feature a continuous spectrum, but rather a series a peaks. This is explained by the strong periodicity of the square pattern, which can be expressed as a sum of sinus signals. The consequence of this type of spectrum is a strong scale dependency as shown later.

(a) Regular checkerboard pattern (b) Random checkerboard pattern (c) Dead leaves pattern

Figure 1: Images used during the analysis

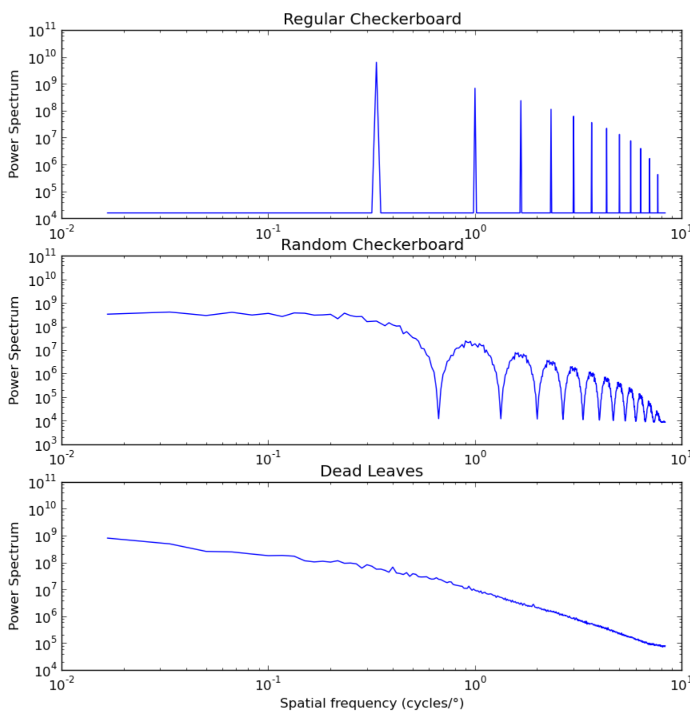


Figure 2: Image spectrums

The randomised process of color selection used for the random checkerboard pattern smoothen the peaks observed with the regular checkerboard pattern. We can also notice that the low frequencies are much more represented than with the regular checkerboard pattern. This is an advantage when the animal moves farther from the image because it means that features will be distinguishable from a larger distance, when the regular checkerboard features fall completely under the optics limits and appear blurred. However, the spectrum is not completely uniform and contains gaps at several frequencies.

On the contrary, the spectrum of the dead leave pattern is continuous and nearly all spatial frequencies are represented (in the range defined by the smallest circle radius and the image size). One can note that the frequencies are not evenly represented in the image: the higher the frequency, the less it is present in the image. This would be the case with a white noise image, but the resulting image would not contain strong edges nor have a good contrast.

Rotation invariance

In order to test the dependency to rotations, we rotate the previous patterns with an angle of 0°, 15°, 30° and 45° before extracting the horizontal power spectrum. The rotation is performed by extracting a subregion contained in a 666x666 pixels square centered on the image center and rotated by the selected angle. The images are then rescaled to 1000x1000 pixels. The resulting images are presented on figure 3. The corresponding spectrum are visible on figure 4.

We note that rotations up to 45° are shifting the lowest frequency peaks to even lower frequencies in the spectrum of the regular checkerboard. We can explain that by the fact that the squares diagonals are longer than the squares sides, and thus represent features with longer spatial period when presented horizontally. Numbers of new peaks also appear in the high frequencies, mainly created by the corners of the squares.

In the case of the random checkerboard pattern, rotations tend to fill the gaps of under-represented frequencies seen on figure 2. Surprisingly, a random checkerboard pattern rotated by 45° shows a horizontal power spectrum similar to the dead leave pattern one. Thus, for an experiment in which vertical features are secondary, and no rotation is expected, the random checkerboard pattern seems to perform as well as the dead leaves pattern.

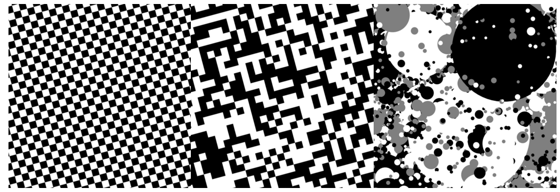
Thanks to the circular primitives in use, the spectrum of the dead leaves image is unaffected by rotations. It is thus perfect whenever the animal subject is expected to see the image from varying orientations.

Scale invariance

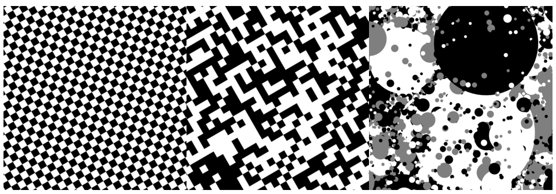
In order to test the scale invariance, we "zoom in" the images to simulate a point of view shifted closer to the image. The new images are obtained by extracting sub-regions contained in a square of size $\frac{1000}{s}$ x $\frac{1000}{s}$ pixels centered on the image center, with scale factors s equal to 1, 2 and 4. The obtained images are then rescaled to 1000x1000 pixels. The corresponding spectrum is presented in figure 5a.

General case As previously stated, the discrete nature of the regular checkerboard spectrum makes it particularly sensitive to scaling. Indeed, all the peaks visible on the spectrum on figure 2 are shifted toward the lower frequencies. As the scale factor increases, the squares composing the image appear larger and larger in the visual field, and constitute features with larger spatial

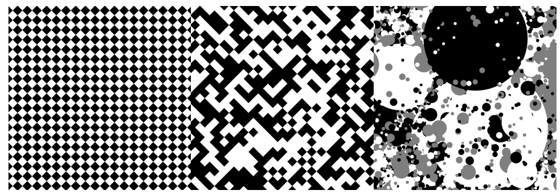
(a) 0°



(b) 15°



(c) 30°



(d) 45°

Figure 3: Rotated images

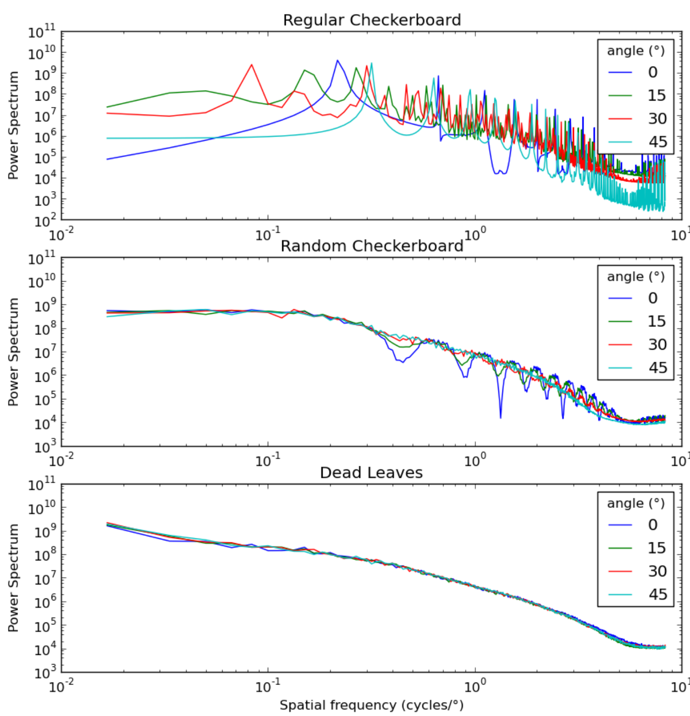
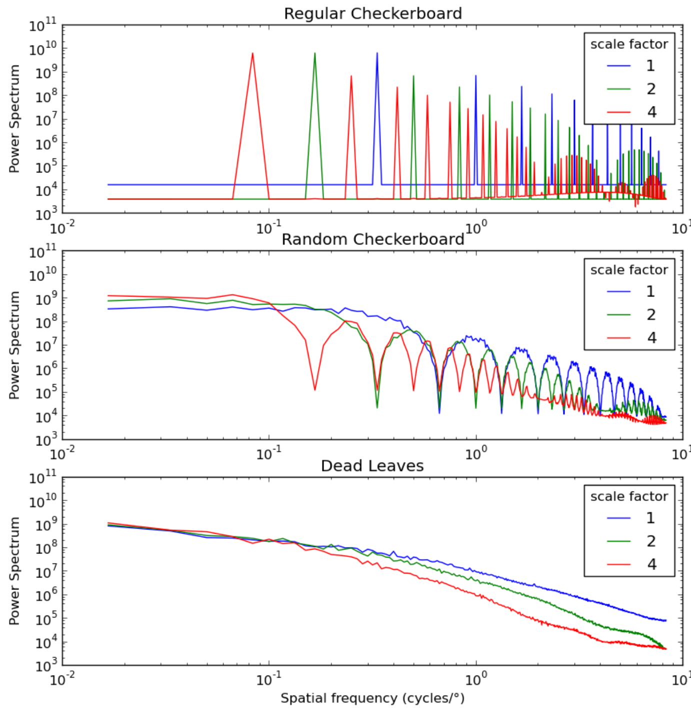
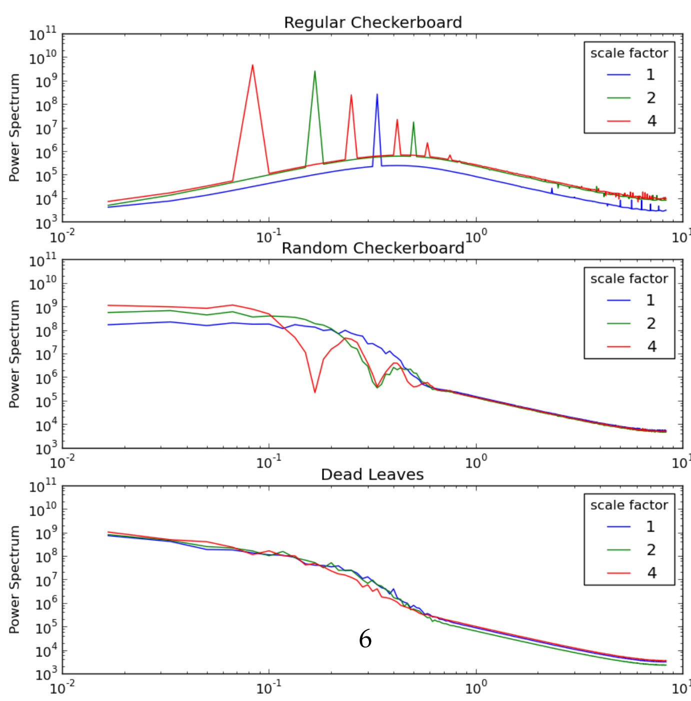


Figure 4: Spectrum of rotated images



(a) Without blur



(b) With 3° gaussian blur

Figure 5: Spectrum of scaled images

period. This is a very bad thing if the image is supposed to be viewed from varying distances, indeed it is possible to infer the distance between the observer and the image based on its appearance only. Moreover, when moving on a plane parallel to this image (as bees do when flying in a tunnel with the walls covered with the pattern) a photo-receptor will perceive a rate of transition between high and low light intensity (light and dark squares) that depend not only on the image motion (optic flow) but also on the distance to the pattern. It has been shown that current models for Elementary Motion Detectors are affected by the size of the squares in a checkerboard pattern [3], it is thus a good idea to avoid this pattern for experiments involving optic flow or in which the animal will see the pattern from varying distances.

We observe the same shift toward the lower frequencies in the random checkerboard spectrum. The remarks formulated for the regular checkerboard pattern can be applied the same way.

Finally, for the dead leaves pattern, we can see that the spectrum is less invariant in scale than in rotation. The power of the high frequencies decrease with increasing scale factor. This is explained by the fact that the smallest circles become larger as the scale factor is increased, so there are less features with small spatial period.

Case of flying insects In the case of flying insects, who have low resolution vision, the smallest details are not resolved at low scale factors (i.e far from the image) . In order to simulate this, a Gaussian blur is applied before the spectrum calculation. The sigma is taken equal to 3° which is roughly equal to the inter-ommatidial angle in bumblebees [4]. This Gaussian filtering has for main effect to remove the high frequency details from the images as seen on figure 5b.

We now observe the same phenomenon as before in the low frequencies for the regular and random checkerboard patterns but the high frequency peaks are not present anymore. However, the dead leave pattern spectrum is now invariant to scale transformations. At low scale factors, the smallest details are not resolved by the eye optics, however at higher scale factors they become resolvable and avoid a loss of high frequency in the spectrum.

This does not mean that the dead leaves pattern has to be blurred in order to be scale invariant, it means that it is not completely scale invariant in the general case of high acuity animals (though better than checkerboards), and becomes fully scale invariant if the smallest features cannot be resolved at the highest scale factor. In short, the smallest circle radius as to be chosen smaller than the animal acuity when the animal is the closest to the obstacle.

General concluding remarks

This analysis shows that the dead leaves pattern is preferable over regular or random checkerboard patterns in order to remove the bias resulting from dependencies in rotation and scale from experimental data. This is especially true for experiments involving optic flow estimation as it is still not clear to which extent the spectral content of an image influences the estimation of optic flow in insects. Moreover in many experiments, animals are allowed to move freely and are thus able to see the pattern with different rotations and scales. The use of the dead leaves pattern allow to get closer to a white noise image, which contains all spatial frequencies with equal power, but without sacrificing the good contrast and strong edges of the image.

The main drawback of this pattern is the relatively complex generating process when compared to a checkerboard, this is why an extension for the software inkscape (http://inkscape.org/) is provided .

3 Inkscape extension

Installation

Inkscape is a free alternative to Adobe Illustrator©available for windows, mac and linux and can be downloaded at http://inkscape.org/. It is also packaged by most linux distributions.

The extension consists of 8 text files (3 .inx files providing a menu in the graphical interface and 5 .py files containing the corresponding scripts). To install the extension, the files have to be copied in the inkscape's extension folder which depends on the operating system (create the folder if it does not exist):

windows : C:\Program Files\Inkscape\share\extensions\

mac : ~/.config/inkscape/extensions/

linux : ~/.config/inkscape/extensions/

Usage

The extension adds a sub-menu in the extension menu as shown on figure 6. This menu gives the choice between regular checkerboard, random checkerboard, or dead leaves pattern.

When clicking on one of the extension menu, a new window pops-up and let the user enter some parameters (see figures 7, 8 and 9 for examples with the corresponding pattern).

In order to make sure that the document will be printed in the right size, proceed as follow:

1. Set the document size to the appropriate size under File/Document properties (see figure 10 for an example of a 3x0.6 meters pattern)
2. Create the pattern using an extension
3. Save the document as pdf

References

[1] Frédéric Cao, Frédéric Guichard, and Hervé Hornung. Dead leaves model for measuring texture quality on a digital camera. Technical report, January 2010.

[2] AB Lee, D Mumford, and Jinggang Huang. Occlusion models for natural images: A statistical study of a scale-invariant dead leaves model. *International Journal of Computer Vision*, 2001.

[3] Jens P Lindemann and Martin Egelhaaf. Texture dependence of motion sensing and free flight behavior in blowflies. *Frontiers in behavioral neuroscience*, 6(January):92, January 2012.

[4] J. Spaethe. Interindividual variation of eye optics and single object resolution in bumblebees. *Journal of Experimental Biology*, 206(19):3447–3453, October 2003.

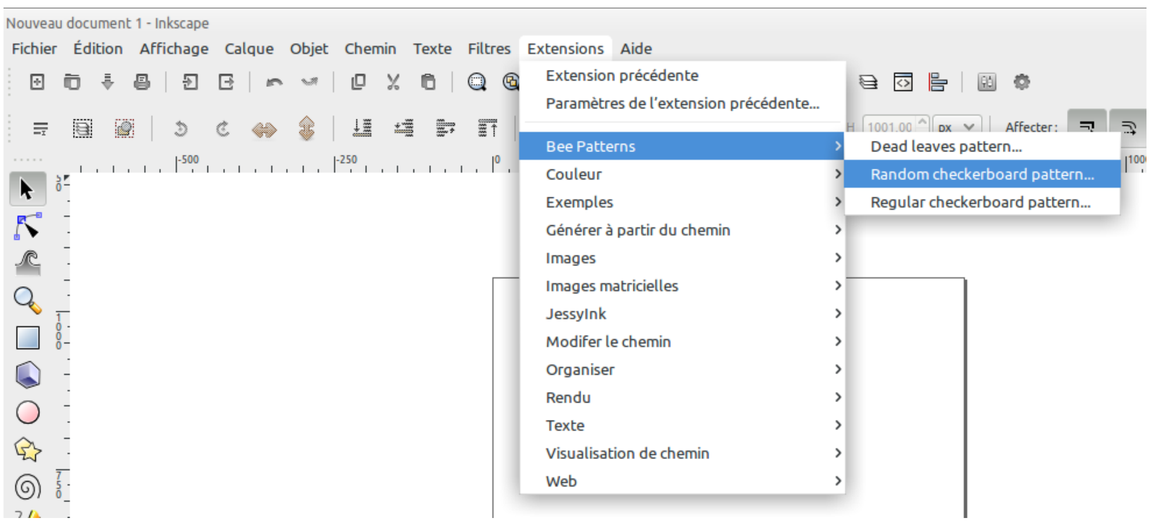


Figure 6: Extension menu

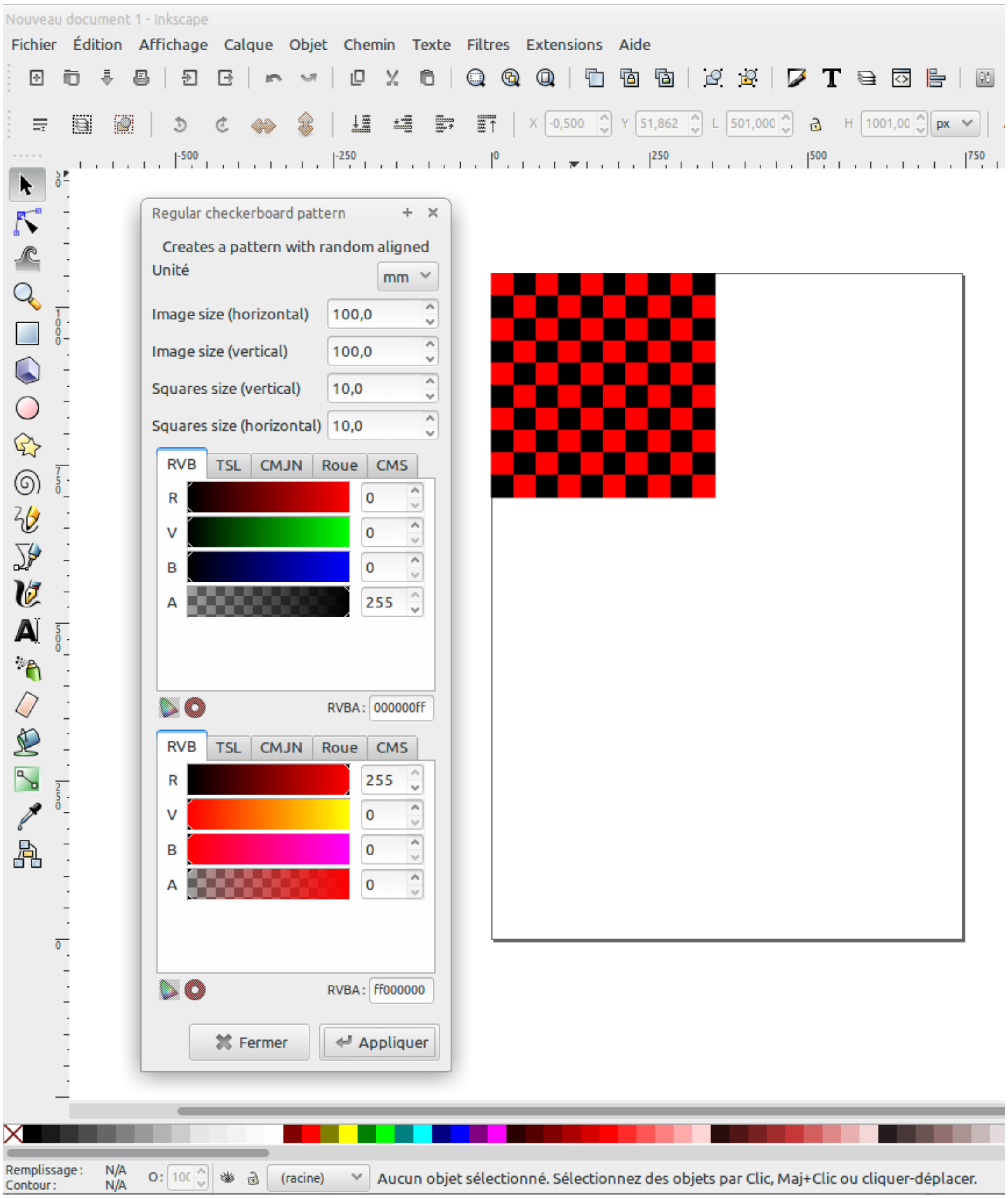


Figure 7: Regular checkerboard extension

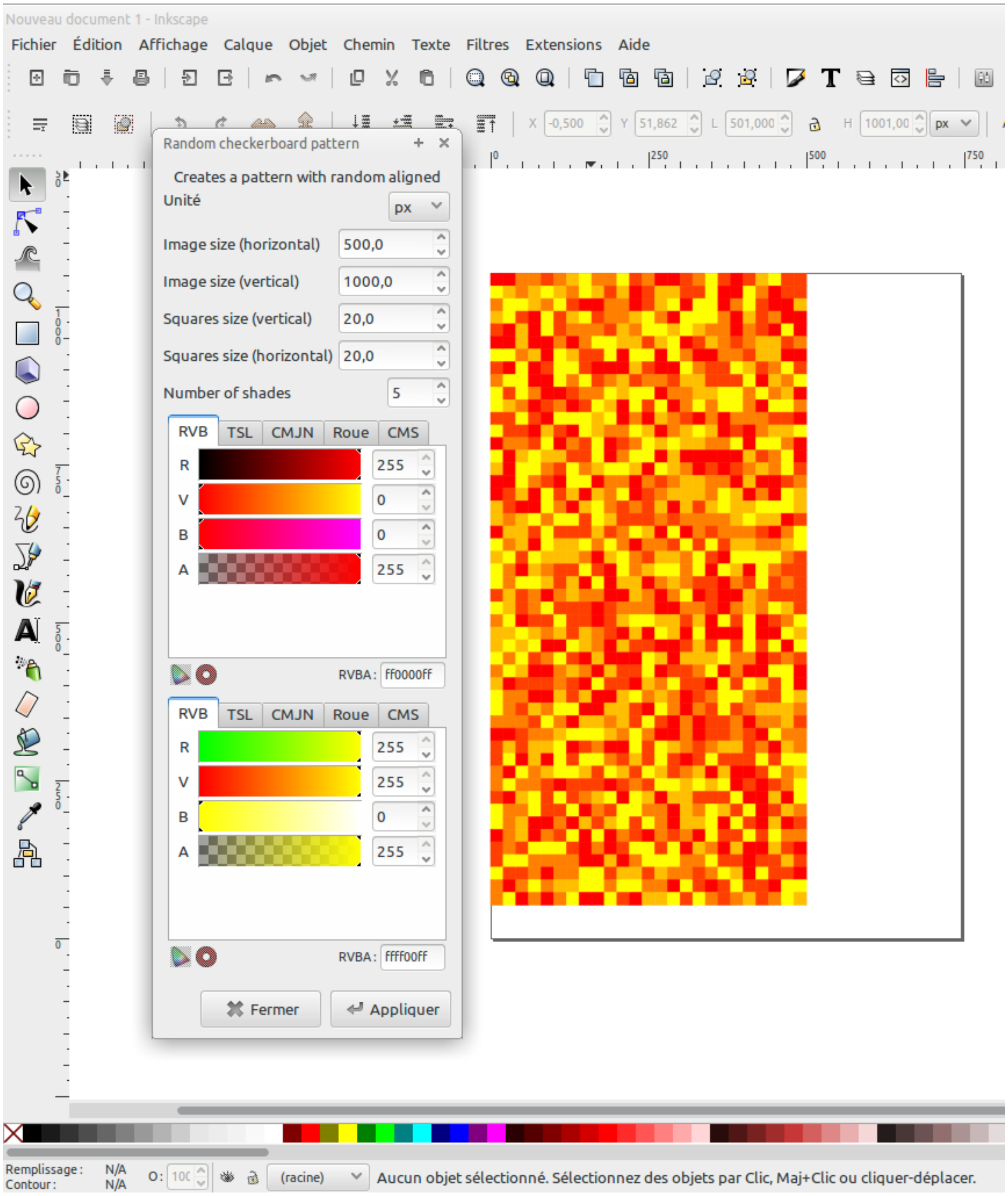


Figure 8: Random checkerboard extension

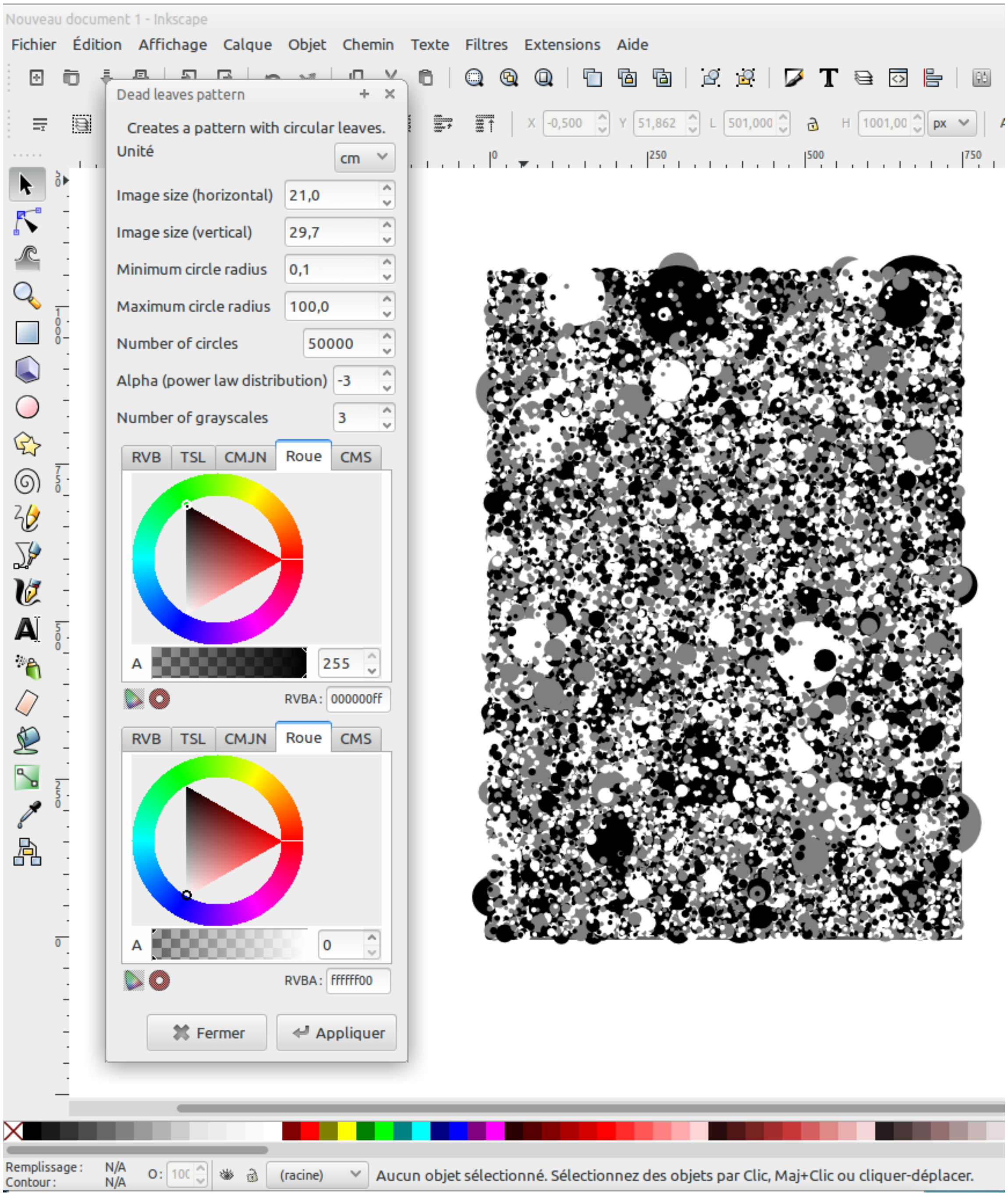


Figure 9: Dead leaves extension

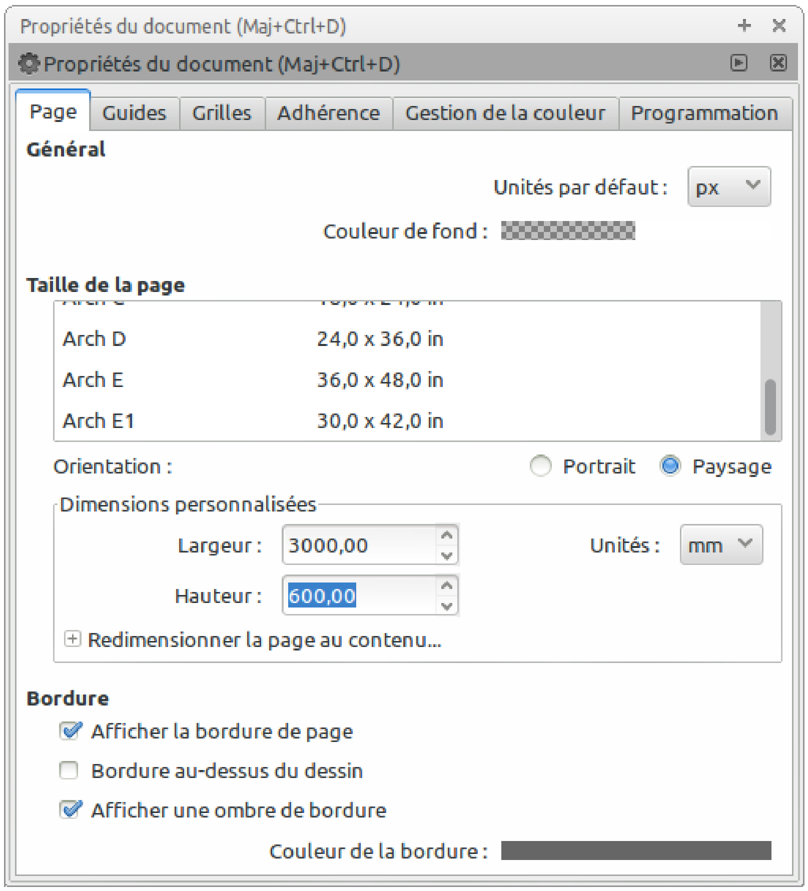


Figure 10: Document size