Automatically Generating Animations From Escher's Images

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Abstract

This paper presents a real-time interactive software tool for automatically selecting and rearranging windowed regions of a single large image into frame-by-frame animations. Demonstrated on the tessellating, morphing pictures created by M.C. Escher, the software tool uses image processing algorithms to compute a path through an image, traveling along visually similar regions and presenting them as a short looping movie.

Index Terms: I.4.0 [Image Processing and Computer Vision]: General—Image Processing Software

1 Introduction

1.1 M.C. Escher and Space-Time

Maurits Cornelius Escher (1898 - 1972) is widely recognized as one of the most engaging mathematically-inspired graphic artists. His images, utilizing precise technical forms of repetition, symmetry, interpolation, and geometry in addition to thought-provoking aesthetic representations, have long been a touchstone to the normally-disparate worlds of art and science, and have served as inspiration to many diverse fields, from philosophy [2] to crystallography [1] to accounting [6]. Of special note are Escher's complex representations of symmetry in its myriad forms [4], [9], [10]. His works such as *Metamorphosis III (1967), Relativity (1953)*, and *Ascending and Descending (1960)* are well known for their playful approach to spatial geometry.

Exploration of the interplay between time- and space-based visual patterning is an integral part of media history [3]. Through many technologies, from the ancient zoetrope to Eadweard Muybridge's zoopraxiscope, a spatial arrangement of subtly-differing images has been windowed sequentially to produce animation. Digital techniques allow for a wide range of such experimentation [5], from whose legacy this work draws inspiration: *The Invisible Shape of Things Past*, by ART+COM demonstrates the creation of solid forms from the path of a video camera, while Jim Campbell's *Illuminated Average #1: Hitchcock's Psycho* compresses the temporal unfolding present within an entire film into a single frame of frozen space-time. Similarly, Escher Animator analyzes the spatial patterns in an image and rearranges their mode of visualization.

1.2 The Escher Animator Software Tool

The Escher Animator (EA) takes the tessellating, morphing images of artist M.C. Escher and presents them in an alternate space-time visualization. Specifically, the tool takes the spatially-repetitive forms present in his images and places them instead into sequential video frames – replacing an image which is temporally static but spatially rhythmic with one that encodes spatial rhythm into a temporal sequence. EA operates on a single image, ideally one containing the smoothly-morphing tessellations for which Escher is famous. In the same way that a human eye will play over a tessellated image, examining areas one by one, the EA tool begins with a windowed portion of the entire image and proceeds to examine other windows in sequence. The precise areas which are visited are determined by visual similarity, such that each successive visited area is the window most visually similar (by some quantitative measure) to the previous one. EA proceeds iteratively in this manner, seeking similar subregions for a user-determined period. The collection of windows thus visited is then assembled into a frame-by-frame animation and presented to the user. The human acts of seeing, perceiving a pattern, and iterating visually over the space are all integrated into the animation creation algorithm.

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2 Method

2.1 Summary

The real-time software waits for user input before proceeding. A user begins by navigating within the image to an arbitrary area, then selecting a square window from which to begin the search. The user then sets the direction and number of frames to search for. The algorithm then iteratively compares the current selected window to other potential windows in the nearby area, finding and moving to the region that is most visually similar. After the user-defined number of iterations are performed, the windows which have been visited are showed frame-by-frame in a looping animation. Figures 1 and 2 demonstrate a typical interaction result.

Figure 1: Eight iterations of the search algorithm starting from the left, constrained to rightwards search. The associated individual frames used in the animation are shown in Figure 2.

Figure 2: The individual frames from the path shown in Figure 1.

2.2 Initial Window Selection

The user first chooses a starting subregion. By clicking and dragging on the image, a square subregion of arbitrary size can be selected.

2.3 Search Direction and Duration

The direction choices allow a user to seek only similar images to either the left or right of the current subframe (thus progressing along the image in a particular direction), or in any direction. The algorithm iterates for as many frames as the user has chosen. Figure 3 and 4 show the results of a search unconstrained in direction.

2.4 Preventing Cycles

In order to prevent oscillation between two or more areas which form a cycle of each others' most similar neighbors, a list of visited windows is maintained. Search results are not considered from areas within a specified distance of any previously-visited location.

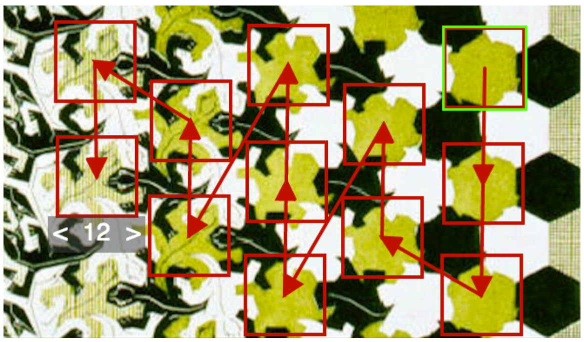

Figure 3: Twelve iterations of the search algorithm starting from the top right, unconstrained in search direction. The associated individual frames used in the animation are shown in Figure 4.

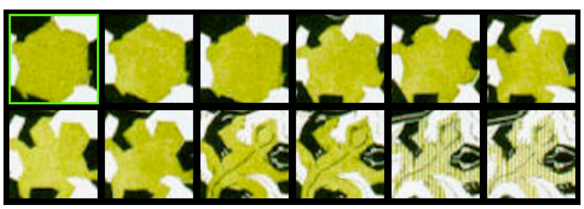

Figure 4: The individual frames from the path shown in Figure 3.

2.5 Search Range and Fourier Analysis

Two parameters influence the space of allowable potential matching windows: a minimum search radius, and a maximum search radius. Both numbers have a dependency on the characteristics of the entire image, because tessellated shapes have a characteristic repetition period in the plane (i.e., their distance from one another).

Frequency-domain techniques aid in the determination of useful search radii. First, FFTs of sections of the image (in this case, *Metamorphosis III*) provide the mean non-DC peak (also called the fundamental). The bin number N_{peak} of the peak location corresponds to the number of repetitions of the underlying pattern through $reps = N - 1$. Division of the appropriate window dimension by *reps* gives the distance estimate in pixels. EA uses empirically-determined values between one-quarter and one-half of this distance for the minimum search radius, and two to three times this distance for the maximum search radius. Figure 5 shows the transform of Figure 1, demonstrating a typical harmonic series (the repetitive pattern in the background) due to the strong periodicity of the input images.

2.6 Finding Similar Windows

On each iteration, the current subregion is compared to other nearby subregions and a matching score is calculated. The closest match then becomes the starting location for the next iteration. Because many methods of comparing the similarity of two images exist, the choice of matching operation is influenced by several aesthetic characteristics of Escher's works (and some artifacts of his choice of medium):

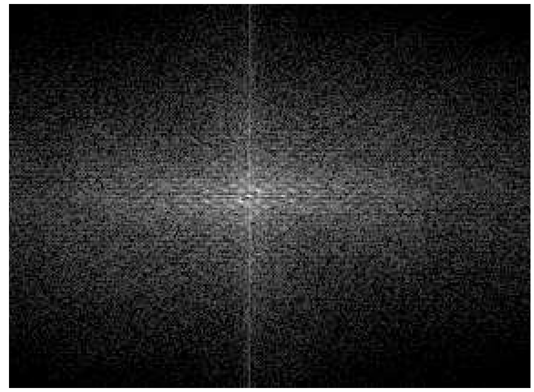

Figure 5: FFT magnitude for the frequency-domain representation of the portion of *Metamorphosis III* shown in Figure 1.

- Images are mostly in black and white, or when in color, the color is overlaid on black and white outlines.
- Extensive use of complex, detailed patterns, which are repeated nearly exactly.

These characteristics suggest a simple matching metric: in EA, each of the windows being compared is converted to grayscale, and the pixel-by-pixel differences summed together. That is,

$$matchAmt = \sum_{w,v \in W,V} abs(w - v)$$

where w is a pixel in the starting window W, and similarly v is a pixel in V, the window being compared to. The best matching window of the windows in the search region is the one with the lowest $matchAmt$.

2.7 Assembling the Animation

Assembly of the successive subregions into frames of animation is straightforward. Frames are placed one after another, and played back at a rate of approximately ten frames per second. An aesthetic decision was made to loop the animations back-and-forth, starting from the first selected subregion and moving to the end, then returning backwards to the beginning and so on. Rather than traditional looping (which introduces an abrupt cut in the animation where the end meets the beginning), the smoothly repeating quality of the back-and-forth animation more closely embodies the qualities present in Escher's works.

2.8 Full-Image Traversal of *Metamorphosis III*

With the appropriate choice of window size, search direction, and search duration, it is possible to make a complete traversal of *Metamorphosis III*. Figure 6 shows the beginning and end of such a traversal which begins with a window containing the word "metamorphosis" and proceeds rightward. The 108 visited windows (Figure 7) form an animation lasting approximately 11 seconds at ten frames per second viewing speed.

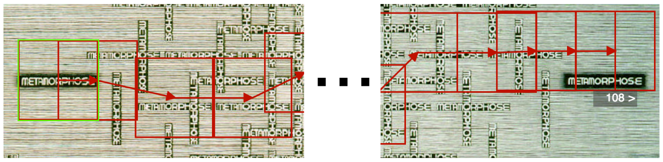

Figure 6: The first and last few iterations of a rightward search traversing the entire image of *Metamorphosis III*.

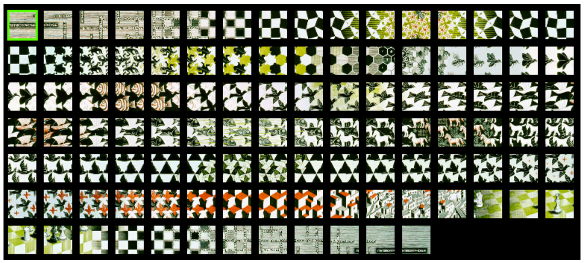

Figure 7: The 108 individual frames from a rightward search traversing the entire image of *Metamorphosis III* beginning with the word "metamorphosis".

2.9 Results on Different Classes of Patterned Images

The EA tool has different visual results depending on the type of patterned image used as input. *Metamorphosis III*, and many of Escher's other works, have the particular characteristic of being a tessellated image with a gradually spatially-varying, or morphing, composition. Rather than being an exact tiling of the plane, such as a pure tessellation, it contains subtle changes at many locations. And unlike an image with no periodicity, there are localized repeated structures.

Packard and Wolfram, in the context of study of visual patterns present in systems of cellular automata [11] [7], describe four classes of these types of systems. These classes are deeply linked with spatial periodicity, and because of the role of spatial periodicity plays in the EA tool, they are a useful way to classify the effect of the EA tool on different types of spatial images. The classes are:

1. Homogeneous
2. Stable or oscillating periodic patterns
3. Aperiodic, chaotic patterns
4. Stable localized structures

2.9.1 Homogeneous Images

An image consisting of homogeneous content is a trivial case: an input that is all the same color. The output animation will likewise contain an unchanging single color for all parameter settings.

2.9.2 Periodic Images

The EA tool results in different output depending on the nature of the periodicity in the input image. Images with perfect periodicity are effectively tilings of a finite plane. There are two types of tilings to consider: *periodic* and *aperiodic* tilings.

Periodic tilings containing only translational symmetry, such as tessellations, are unchanging in scale or frequency over the entirety of the image. The EA tool uses a purely translating search window, so these types of images result in animations with all identical frames (the same window from nearby identical repetitions).

The tilings of the plane known as aperiodic tilings contain no translational symmetry. Images with rotationally- or non-symmetric tilings result in paths with some smoothness in variation, leading to somewhat smooth animations. Because the search and sampling window performs only a translational search, movies made using aperiodic tilings as input will not show the same frame for all time in their movie, unlike periodic tilings, but will show some structures and their subtle changes over the entire image. Figure 8 shows an example of this behavior using a rotationally-symmetric aperiodic tiling called the Penrose Tiling [8].

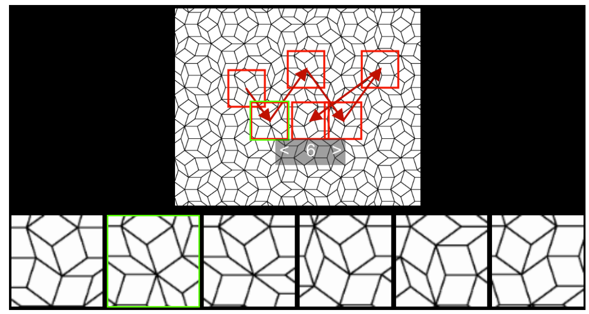

Figure 8: An example of the EA tool running on an aperiodic tiling of the plane known as the Penrose tiling.

2.9.3 Aperiodic Images

Images without any repetitive content at all result in successive frames that share some visual similarity, but typically do not contain a smoothly animated appearance. In the worst case, an image with pure noise results in a very noisy set of output frames. Figure 10 shows an example of this search path found by the EA tool in a region of *Metamorphosis III* which contains no local periodicity.

2.9.4 Images with Localized Structures

Escher's *Metamorphosis* series of works demonstrate this 4th class, featuring many different localized periodic patterns that vary over the plane in various ways. Each local pattern smoothly transforms into its neighboring region. These types of images create the most visually interesting and smoothly animated results due to the way that the output image consists of many smoothly-animating portions. Search paths which traverse changes in local patterns (Figure 9) often result in visually interesting animations.

3 Conclusion

Escher Animator is a software tool which automatically translates the patterned, morphing images created by artist M.C. Escher into animations, based on the visual similarities present in the images themselves. In real time, a user can select a windowed region of one of Escher's images, and watch as the software seeks out a path through the image's visually-similar areas. The animated windows, assembled into a frame-by-frame looping animation, present a reformulation of Escher's patterned images in the style of the zoopraxiscopes of early cinema and inspired by recent digital media experiments in image visualization. By mimicking the human process of visual pattern perception, and active gaze movement, the Escher Animator presents a novel way of exploring visual patterns in media.

4 Future Work

Application of the techniques described in this paper to other visual patterns, such as those in architectural structures, textiles, or visual images created by other artists, would lead to new ways of experiencing each. The different types of works would have their own

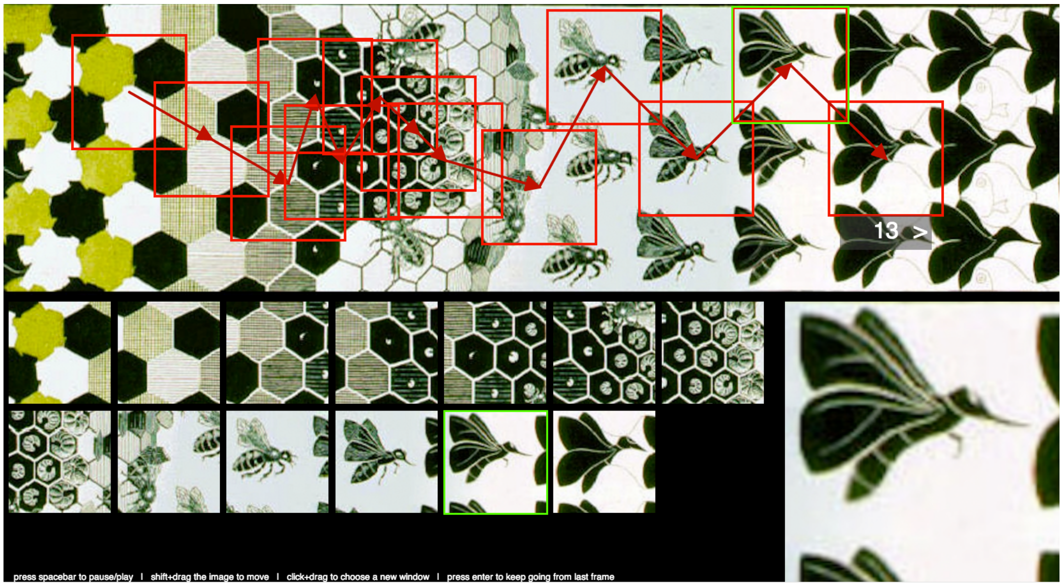

Figure 9: A screenshot showing the EA tool running on a path between two locally-periodic regions in *Metamorphosis III*.

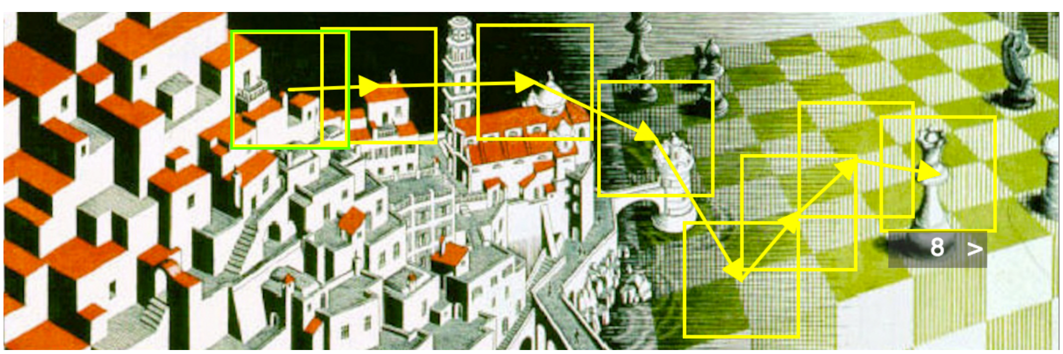

Figure 10: A path through visually similar windows in a non-periodic region M.C. Escher's *Metamorphosis III*

characteristic shapes and forms, leading to the possibility of selecting a matching algorithm that takes advantage of invariant features. Allowing the search window to rotate or scale would give added detection capabilities for images with rotational or hyperbolic symmetry.

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