Artificial Mosaics with Irregular Tiles Based on Gradient Vector Flow

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Abstract. Artificial mosaics can be generated making use of computational processes devoted to reproduce different artistic styles and related issues. One of the most challenging field is the generation of an artificial mosaic reproducing some ancient and well known techniques starting from any input image. In this paper we propose a mosaic generation approach based on gradient vector flow (GVF) properly integrated with a set of tile cutting heuristics. The various involved cutting strategies, namely subtractive and shared cuts, have been evaluated according to aesthetic criteria. Several tests and comparisons with a state-of-the-art method confirm the effectiveness of the proposed approach.

Keywords: Artificial Mosaics, Gradient Vector Flow.

1 Introduction

Mosaics, in essence, are images obtained by cementing together small colored fragments. In the digital realm, mosaics are illustrations composed by a collection of small images called "tiles". The creation of a digital mosaic resembling the visual style of an ancient-looking man-made mosaic is a challenging problem because it has to take into account the polygonal shape and the size of the tiles, the need to pack the tiles as densely as possible and, not least, the strong visual influence that tile orientation has on the overall perception of the mosaic.

The first attempt to reproduce a realistic ancient mosaic was presented by Hausner [1] who also proposed a mathematical formulation of the mosaic problem. Lots of artificial mosaic generation techniques have been then proposed (for a complete survey see [2,3]). The key of any technique aimed at the production of digital ancient mosaics is the tile positioning and orientation. The methods proposed in literature use different approaches to solve this problem, obtaining different visual results. Some techniques are based on a Centroidal Voronoi Diagrams (CVD) approach ([1], [4], [5]) whereas other methods ([6], [7], [8]) compute a vector field by making use of different strategies (i.e., graph cuts minimization [9], gradient vector flow [10]). Tile positioning is then performed with iterative strategies ([1], [4], [5], [8]) or reproducing the ancient artisans style by using a "one-after-one" tile positioning ([6], [11], [12]). A different non-deterministic

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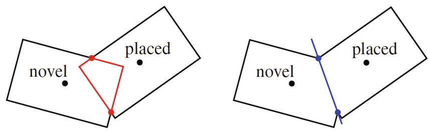
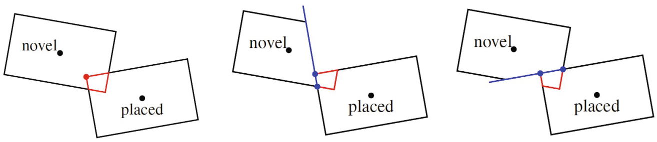


(a) Intersection Analysis (b) Cut

Fig. 1. Shared Cut



(a) Intersection Analysis (b) Non-Optimal Cut (c) Optimal Cut

Fig. 2. Subtractive Cut

approach is used in [13]. In this work we introduce some computational tools able to emulate the artistic "cut" often used by real mosaicists. The rest of this paper is organized as follows. Section 2 describes the proposed approach whereas Section 3 reports the experimental results. Finally, Section 4 is devoted to final discussions and suggestions for future works.

2 2D Mosaic Tile Cutting

Ancient mosaicists could make use of irregular tiles in the mosaic creation. Irregular tiles are suited to follow principal image edges, properly cover the image canvas obtaining hence visually pleasant mosaics. In [6] a novel approach based on Gradient Vector Flow (GVF) [10] computation together with some smart heuristics used to drive tile positioning has been proposed. GVF properties permit to preserve edge information maintaining hence image details. In order to emulate this aspect we have extended such approach considering two different strategies of tile cutting: subtractive and shared cut. The former cuts only the novel tiles, i.e., tiles that are not already present in the mosaic; the latter cuts both novel and already placed tiles. Both strategies together with the involved parameters are described in the following.

Let $tile_P$ and $tile_N$ be the tile already placed and to be placed (novel) respectively. Their intersection creates some novel vertexes placed on their border. The cutting is performed considering the line connecting these vertexes (see Fig. 1). As already stated before the cut is performed both on $tile_P$ and $tile_N$. The shared cut creates convex tiles without irregular parts. However it should be carefully used because it tends to increase the sides of polygons and round shapes.

Sometimes the shared cut cannot be used (e.g., further cutting of the placed tiles cannot be done due to the limit specified in Subsection 2.1); in these cases the subtractive cut could be useful. It does not modify the already placed tiles but removes part of the novel tile. Sometimes several possible cuts can be considered along the side of the tile already placed. In order to preserve more information and increase the possibility of satisfy all the constraints about tile cutting, the cut removing less area is chosen (see Fig. 2). The subtractive cut gives higher importance to the already placed tiles (the orientations of their sides are taken into account in the cutting).

2.1 Tile Cutting Parameters

Both shared and subtractive tile cuts depend on a set of thresholds detailed as follows:

- T_P, maximum percentage of total cut area, from an already placed tile.
- S_P, maximum percentage of cut area, with a single cut, from an already placed tile; it should be noted that $S_P \leq T_P$.
- T_N, maximum percentage of total cut area, from a novel tile.
- S_N, maximum percentage of cut area, with a single cut, from a novel tile; it should be noted that $S_N \leq T_N$.

Let A_0^N be the original tile area (i.e., the area of the rectangular shape the tile has when it is generated) of the novel tile and A_0^P the area of the already placed tile. Let A_i^N and A_i^P the corresponding tile area after the i^{th} cut. The tile cutting of a novel tile has to satisfy the following constraints:

$$\frac{A_i^N - A_{i+1}^N}{A_0^N} \leq S_N \qquad i = 1, \ldots, M_N - 1$$
$$\frac{A_0^N - A_{M_N}^N}{A_0^N} \leq T_N$$

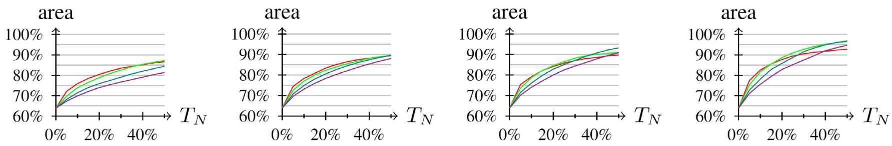
where M_N is the overall number of cuts performed on the novel tile. The tile cutting of an already placed tile has to satisfy the following constraints:

$$\frac{A_i^P - A_{i+1}^P}{A_0^P} \leq S_P \qquad i = 1, \ldots, M_P - 1$$
$$\frac{A_0^P - A_{M_P}^P}{A_0^P} \leq T_P$$

where M_P is the overall number of cuts performed on the already placed tile. Notice that there is subtractive cut if $T_P = 0$ or $S_P = 0$.

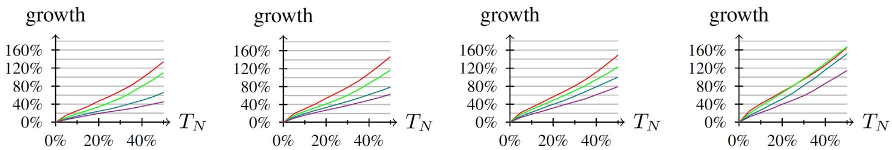
2.2 Tile Cutting Parameter Setting

To better reproduce fine details of the original picture, a good mosaic should cover the canvas as much as possible. On the other hand, to preserve the “mosaic



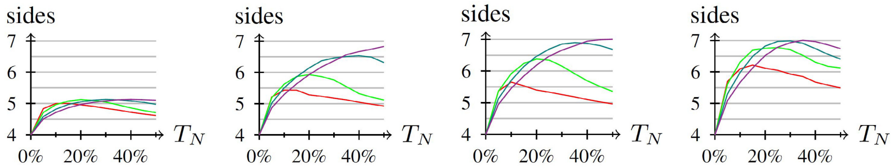
(a) subtractive cut (b) shared cut (R = 1/2) (c) shared cut (R = 2/3) (d) shared cut (R = 1)

Fig. 3. Percentage of covered area. Colors represent several R_N values: 1/4, 1/3, 1/2 and 1.



(a) subtractive cut (b) shared cut (R = 1/2) (c) shared cut (R = 2/3) (d) shared cut (R = 1)

Fig. 4. Percentage gain in the number of tiles compared to the mosaic without cuts. Colors represent several R_N values: 1/4, 1/3, 1/2 and 1.



(a) subtractive cut (b) shared cut (R = 1/2) (c) shared cut (R = 2/3) (d) shared cut (R = 1)

Fig. 5. Average number of sides per tile. Colors represent several R_N values: 1/4, 1/3, 1/2 and 1.

effect" the number of tiles should be limited and their shape should be simple. In order to set tile cutting parameters properly some tests have been performed to study their impact on the final generated mosaic considering both photographic and clip art images. Some objective measures have been hence derived to describe the properties of the generated mosaic. In particular we have considered the percentage of covered area (Fig. 3), the percentage gain in the number of tiles compared to the mosaic without cuts (Fig. 4) and the average side number of the tiles (Fig. 5).

The experiments related to subtractive cut have been performed with T_N ranging from 0% (no cut) to 50% (step of 5%) and the ratio between single and total cut R_N defined as follows:

$$R_N = \frac{S_N}{T_N} \qquad R_N \in \{1/4, 1/3, 1/2, 1\}$$

Fig. 6. Examples of mosaics obtained by using only subtractive cut with T_N ranging from 0% (no cut) to 50% (step of 10%) and the ratio between single and total cut R_N fixed to 1/2

Fig. 7. Examples of mosaics obtained by using both subtractive and shared cuts with T_N ranging from 0% (no cut) to 50% (step of 10%), R_N and R fixed to 1/2

The experiments related to shared cut have been performed considering also the ratio between the total cut over the already placed and the novel tile:

$$R = \frac{T_P}{T_N} \qquad R \in \{1/2, 2/3, 1\}$$

The ratio between the single and total cut of the already placed tile (R_P) is equal to R_N. The covered area is proportional to T_N and R (Fig. 3). Moreover high values of R_N (and R_P) should be avoided. Performing a big single cut (i.e., S_N and S_P close to T_N and T_P respectively) creates some holes that cannot be covered later. As can be easily seen from Fig. 4 the percentage increase in the number of tiles compared to the mosaic without cuts is proportional to T_N and R_N (and R_P). The dependence of the average number of tile sides with respect to the aforementioned parameters has been studied in Fig. 5. Decreasing R_N, small but frequent cuts are performed producing complex shapes with a higher number of sides. This trend becomes worse with shared cut at increasing of R. Finally, side number first increases with T_N, later decreases due to the higher possibility of performing single cuts. The analysis of the behavior of the proposed approach at varying of the involved parameters has shown that the increasing of the covered area is obtained by using a higher number of complex tiles (see Fig. 6 and Fig. 7).

3 Experimental Results

In order to visually assess the quality of the proposed tile cutting heuristics a series of mosaics have been generated. Although the optimal setting of the parameters depends on the image under analysis and on the subjectivity of the

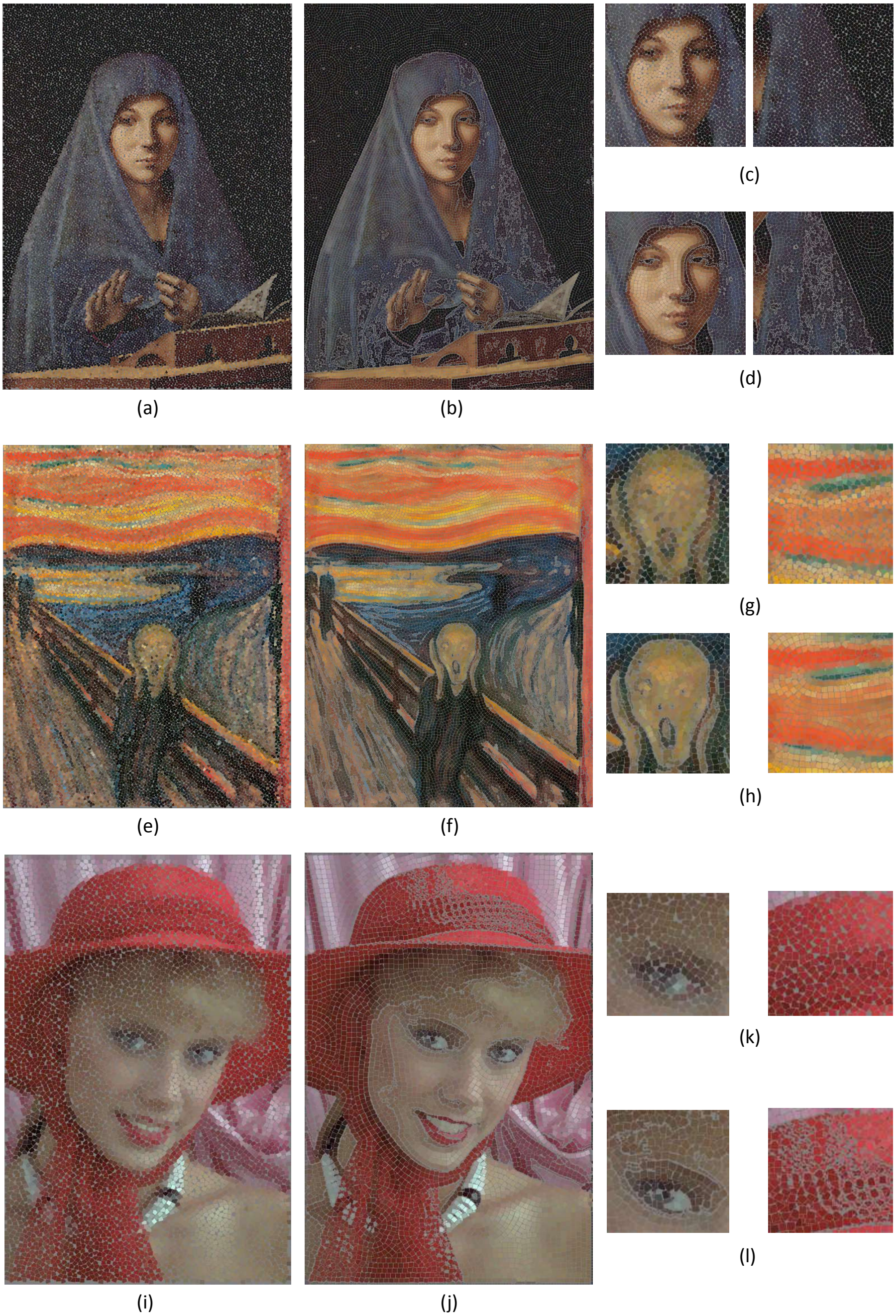
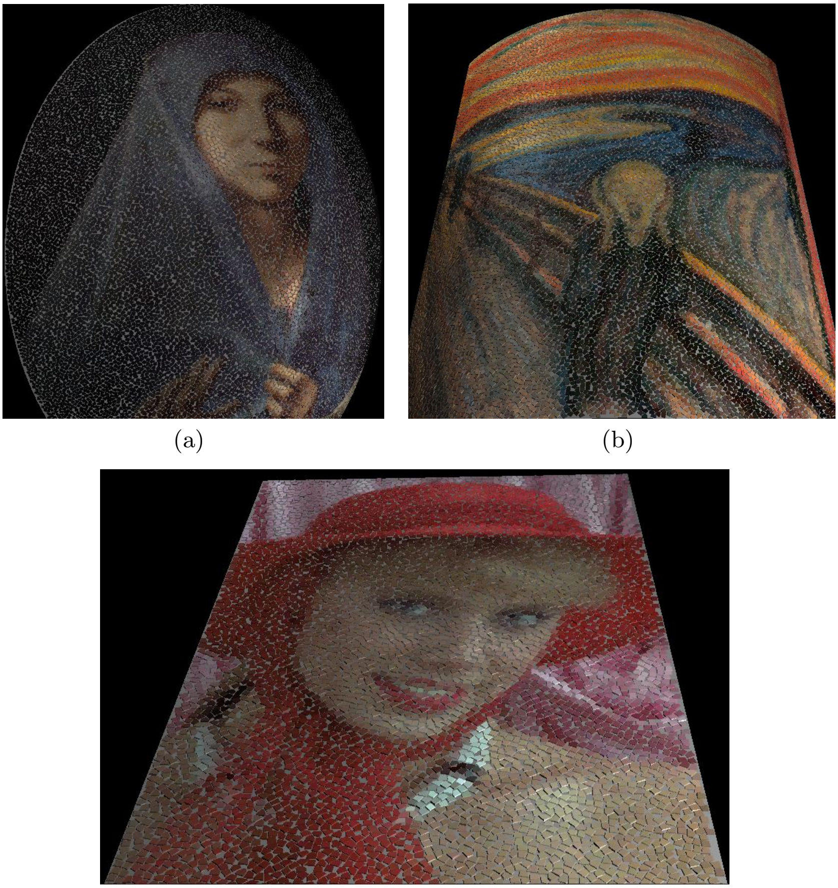


Fig. 8. Visual comparisons of artificial mosaic techniques: our approach on the left (a, c, e, g, i, k) and Di Blasi et al. [11] on the right (b, d, f, h, j, l)

user a good trade-off is the following: $R = 0.5$, $R_N = 0.5$, $T_N = 35$, $S_N = 17.5\%$, $T_P = 17.5\%$, $S_P = 8.75$.

To further validate our approach some comparisons have been performed considering the approach proposed in [11]. Three images have been used in our tests: *madonna*, *the scream* and *kodim04*. Di Blasi et al. [11] obtain a high degree of realism. The percentage of covered area is pretty high but it is achieved by making use of an elevate number of small and complex tiles. Moreover the algorithm is not able to properly combine information coming from different edges of the images, producing some unpleasant artifacts. On the contrary, our approach obtains a satisfactory coverage area maintaining at the same time an acceptable number of tiles with a low number of sides. Moreover the properties of GVF about edge information propagation permit us to obtain graceful results (no visually artefact). It should be noted that a simple 2D mosaic can be better used as starting point for other image manipulations (e.g., 3D mosaic generation [14], see Fig. 9).



(a) (b) (c)

Fig. 9. 3D Mosaics of *madonna* (dome), *the scream* (cylinder) and *kodim04* (plane)

4 Conclusions

In this paper we proposed a novel algorithm for artificial mosaic generation. Specifically, several heuristics have been introduced to properly manage tile cutting, producing hence graceful mosaics with irregular tiles. Experimental results confirm the effectiveness of the proposed approach. Future work will be devoted to study the dependence of tile size with respect to image content and size.

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