

# A Survey of Digital Mosaic Techniques

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## Abstract

*Art often provides valuable hints for technological innovations especially in the field of Image Processing and Computer Graphics. In this paper we survey in an unified framework several methods to transform a raster input image into good quality mosaics. The common and different ideas among the methods are reported and described. Finally we try to address the evaluation problem of an NPR algorithm.*

Categories and Subject Descriptors (according to ACM CCS): J.5 [Arts and humanities]: Architecture, Fine Arts

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## 1. Introduction

Research in the field of Computer Graphics has traditionally been dominated by attempts to achieve photorealism; modeling physical phenomena such as light reflection and refraction to produce scenes lit, ostensibly, in a natural manner.

Over the past decade the development of novel rendering styles outside the bounds of photorealism has gathered momentum: the so called non-photorealistic rendering or NPR. NPR has been successfully applied by scientific visualization researchers to improve the clarity and quantity of information conveyed by an image (see [ST90] for an example); exploded diagrams in maintenance manuals and false color satellite imagery are two common examples of such visualizations.

Several NPR techniques have been designed to emulate a broad range of artistic media from pastel to paint (see [Hae90] for example), and to mimic many artistic techniques such as hatching and shading.

In particular in this paper we will address the problem of digital mosaic creation. Mosaics are images made by cementing together small colored tiles. Probably they are the first example of image synthesis techniques based on discrete primitives.

The creation of digital mosaics of artistic quality is one of the challenges of the Computer Graphics and is one of the most recent research direction in the field of Non-Photorealistic Rendering. Digital mosaics are illustrations composed by a collection of small images called “tile”. The tiles “tessellate” a source picture in order to reproduce it in a “mosaic-like” style.

Starting from the same source image it is possible to create different kind of digital mosaics depending on the choice of the tile dataset and the imposed constraints for positioning, deformations, rotations, etc..

For example the creation of “ancient mosaics” of

artistic quality is challenging because the tiles that compose a mosaic, typically small (rectangular) polygons, must be packed tightly and yet must follow and emphasize orientations chosen by the artist.

The first step to solve the problem of the creation of digital mosaics is to reformulate the problem itself into a mathematical framework. In particular it is possible to put the mosaic building from a source raster image in terms of a mathematical optimization problem as follows:

*Given a rectangular region  $P$  in the plane  $R^2$ , a tile dataset and a set of constraints, find  $N$  sites  $P_i(x_i, y_i)$  in  $P$  and place  $N$  tiles, one at each  $P_i$ , such that all tiles are disjoint, the area they cover is maximized and the constraints are verified as much as possible.*

The definition above is general and is suitable for many applications even beyond Computer Graphics field (where the first related work [Har73] was published by Harmon treating the specific case of human perception and automatic pattern recognition, as better detailed below).

Within this framework the problem can be viewed as a particular case of the “cover problem” or as a “search and optimization problem”. The mosaic construction as formulated above can also be regarded as a “low-energy configuration of particles problem”.

In our case three different definitions can be given to solve specific problems:

***Ancient Mosaic** - Given an image  $P$  in the plane  $R^2$  and a vector field  $\Phi(x,y)$  defined on that region representing the edges of  $P$ , find  $N$  sites  $P_i(x_i, y_i)$  in  $P$  and place  $N$  rectangles, one at each  $P_i$ , oriented with sides parallel to  $\Phi(x,y)$ , such that all rectangles are disjoint, the area they cover is maximized and each tile is colored by a color which reproduces the image portion covered by the tile.*

**Photomosaic** - Given an image  $P$  in the plane  $R^2$ , a dataset of small rectangular images and a regular rectangular grid of  $N$  cells, find  $N$  tile images in the dataset and place them in the grid such that each cell is covered by a tile that “reminds” the image portion covered by the tile.

**Puzzle Image Mosaic** - Given an image  $P$  in the plane  $R^2$ , a dataset of small irregular images and an irregular grid of  $N$  cells, find  $N$  tile images in the dataset and place them in the grid such that the tiles are disjoint and each cell is covered by a tile that “reminds” the image portion covered by the tile.

Different solutions have been proposed to solve the above problems. In this paper we review all presented methods grouping them in a unified framework based on the obtained results. For this reason we singled out four different kind of mosaics: crystallization mosaics, ancient mosaics, photomosaics and puzzle image mosaics.

The rest of this paper is organized as follows: in Section 2 we present the crystallization mosaic techniques, Section 3 explains the ancient mosaic methods. In Section 4 we review the photomosaic algorithms and in Section 5 the puzzle image mosaics are presented. Finally in Section 6 we try to explain how much it is difficult to evaluate an NPR algorithm, while in Section 7 we suggest directions for future works and researches.

## 2. Crystallization Mosaics

Many sophisticated mosaic approaches try to adopt smart strategies using computational geometry (Voronoi diagrams) together with image processing. These techniques lead to mosaics that simulate the typical effect of some glass windows in the churches.

### 2.1 Haerberli's approach

Haerberli [Hae90] used Voronoi diagrams, placing the sites at random and filling each region with a color sampled from the image. This approach tessellates the image and tile shapes are variable and do not attempt to follow edge features; the result is a pattern of color having a cellular-like look (see Figure 1a). He obtains this effect by z-buffering a group of colored cones onto a canvas. This method can be easily implemented by using hardware acceleration provided by modern graphics cards.

Although very simple, Haerberli's idea was a milestone in this field and a starting point for many techniques developed in order to produce mosaic effects.

### 2.2 Dobashi et al.'s idea

In [DHJN02] Dobashi et al. reprised the Haerberli's idea obtaining better results due to the fact that they address the problem of keeping into account the edges of the original image. However the tile shapes suffer from the extreme variability of the Haerberli's technique (Figure 1b).

They define an error function  $E$  giving the sum of the squared differences between the colors of the corresponding pixels in the input and output image:

$$E = \sum_{x,y,c} (P_{(x,y,c)}^{Input} - P_{(x,y,c)}^{Output})^2 \quad (1)$$

then they try to iteratively minimize  $E$  by moving the center of the Voronoi regions; the movement is limited to the 8-pixel neighborhood. Moreover they describe a method to speed up the moving process.

### 2.3 Faustino and Figueiredo's improvement

Recently, Faustino and Figueiredo [FF05] presented a technique similar to the Dobashi et al. approach, in which the main difference is that the size of tiles vary along the image: they are small near image details and large otherwise (Figure 1c). To obtain this result, the authors used centroidal Voronoi diagrams with a density function that depends on some image features (edge features in this case).

Differently from Dobashi et al., they do not start from an hexagonal lattice of the image, but they find the seeds of the first Voronoi diagram by sampling the image adaptively using a quadtree: the seeds are the centers of the leaf cells in this quadtree. They construct the quadtree in such a way that a leaf is created when the color of its corresponding cell pixels are close to the average color of the cell. In particular, for each cell, they test if:

$$\max_{p \in C} d(I(p), c)^2 \leq \epsilon \quad (2)$$

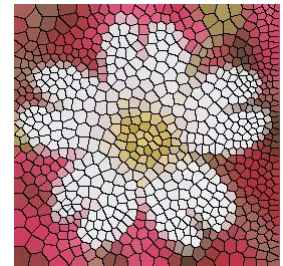
where  $I(p)$  is the color of the pixel  $p$  in  $C$ ,  $c$  is the average color in  $C$  and  $\epsilon$  is an user-selected tolerance value.



(a) Haerberli



(b) Dobashi et al.



(c) Faustino and Figueiredo

**Figure 1:** Crystallization mosaics.

### 3. Ancient Mosaics

Ancient mosaics are artworks constituted by cementing together small colored tiles. A smart and judicious use of orientation, shape and size may allow to convey much more information than the uniform or random distribution of  $N$  graphic primitives (like pixels, dots, etc.). For example, ancient mosaicists avoided lining up their tiles in rectangular grids, because such grids emphasize only horizontal and vertical lines. Such artifacts may distract the observer from seeing the overall picture described. To overcome such potential drawback, old masters placed tiles emphasizing the strong edges of the main subject to be represented.

#### 3.1 Hausner's algorithm

The first attempt to reproduce a realistic ancient mosaic was presented by Hausner [Hau01]. Moreover he proposed the mathematical formulation of the mosaic problem as described in Section 1.

He obtained very good results using centroidal Voronoi diagrams (CVD), user selected edge features,  $L_1$  (Manhattan) distance and graphic hardware acceleration (Figure 2a). In particular the method uses CVDs (which normally arrange points in regular hexagonal grids) adapted to place tiles in curving square grids. The adaption is performed by an iterative process which measures distances with the Manhattan metric whose main axis is adjusted locally to follow a chosen direction field (coming from the edge features). Computing the CVD is made possible by leveraging the z-buffer algorithm available in many graphics cards. The Hausner's algorithm can be outlined as follows:

```
S=list of random points on the input image
while (!converged)
  for each p in S, place a square
  pyramid with apex at p
  rotate each pyramid about the z axis
  to align it the the direction field
  render the pyramid with an orthogonal
  projection onto the xy plane,
  producing a Voronoi diagram
  compute the centroid of each Voronoi
  region
  move each p to the centroid of its
  region
end while
```

#### 3.2 Traditional mosaics by Elber and Wolberg

A very advanced approach to the rendering of traditional mosaics is presented in [EW03]. This technique is based on offset curves that get trimmed-off the self intersecting segments with the guidance of Voronoi diagrams. The algorithm requires a mathematical

description, as B-splines, of the edges and allows a very precise tile placement (Figure 2b). Other bonus of this approach is the use of variable size tiles. Although the results are very good the technique seems limited to the case of a single, user-selected and close edge curve.

#### 3.3 Artificial mosaics

Another approach for the creation of ancient mosaics is presented in [DG05] and in [BDFG06]; this approach is based on directional guidelines, distance transform, mathematical tools and century proved ideas from mosaicists and leads to impressive results. The examples presented in Figures 2c and 2d show respectively the rendering of an opus musivum mosaic and of an opus vermiculatum mosaic.

The algorithm uses some well know image processing techniques in order to obtain a precise tile placing and can be summarized as follows:

1. segment the image by using the SRM algorithm ([Noc04]);
2. subdivide the image into background and foreground regions (optional);
3. for each pixel of the image evaluate the distance transform from the segmented region bounds;
4. evaluate the gradient matrix and the level line matrix;
5. place the tile.

In particular point 5. can be described as follows:

- while there are chains of pixels not yet processed in the level line matrix:
  - a. select a chain;
  - b. starting from an arbitrary pixel on it “follow” the chain;
  - c. place new tiles at regular distances along the path (the orientation of the tiles is assigned using the gradient information from matrix).

#### 3.4. RenderBots

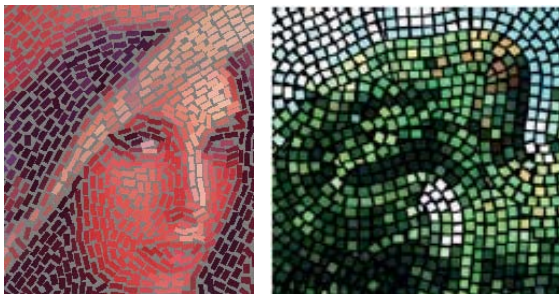
Recently a novel technique for ancient mosaics generation has been presented in [STT05]. The authors present an approach for stroke-based rendering that exploits multi-agent systems; they call the agents RenderBots. RenderBots are individual agents each of which in general represents one stroke. They form a multi-agent system and undergo a simulation to distribute themselves in the environment. The environment consists of a source image and possibly additional G-buffers. The final image is created when the simulation is finished by having each RenderBot execute its painting function (see Figure 2e).

RenderBot classes differ in their physical behavior as well as their way of painting so that different styles can be created in a very flexible way. So they provide a unified approach for stroke based rendering. Different styles such as stippling, hatching, painterly rendering and mosaics can be created using the same framework. This is achieved by

providing a specific class of RenderBots for each style.

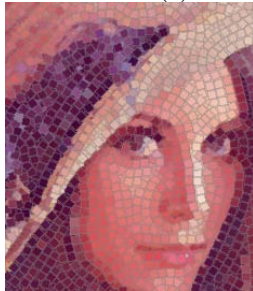
The complete image generation process can be described as follows:

1. setup the environment (a number of RenderBots of a specific class are created and distributed in the environment);
2. distribute the RenderBots (randomly or interactively by the user);
3. while the image is not finished:
  - a. simulate each bot (control of the bot physical behavior, computation of the new direction and velocity values and (possibly) change of the internal state of the RenderBot;
  - b. move each bot (perform the actual movement of the bot by computing a new position);
  - c. paint each bot.



(a) Hausner

(b) Elber and Wolberg



(c) Di Blasi and Gallo



(d) Battiato et al.

(e) Schlechtweg et al.

**Figure 2:** Ancient mosaics.

#### 4. Photomosaics

Photomosaic is one of the most interesting technique (and one of the most cloned algorithm) in the field of digital mosaic. “Photomosaic” transforms an input image into a rectangular grid of thumbnail images. In this approach the algorithm usually searches in a large database of images for one that approximates a block of pixels in the main image. The resulting effect is very impressive. Even in this case no edge features are respected. Unfortunately the proposed algorithms to solve the photomosaic problem are not well documented, so we cannot provide a deep description of the methods.

Even before the computer's era, the process of making pictures from other pictures was well known. In 1973 Leon Harmon [Har73] presented a work including several “block portraits” (see Figure 3a). Harmon used these “pixelated” portraits to study human perception and the automatic pattern recognition issues. For example he used them as a demonstration of the minimal condition to recognize a face. The image in Figure 3a is just a very low resolution rendering (252 pixels) of a gray image of Lincoln. Each pixel is seen as a “tile”. This image of Lincoln needs to be viewed at a distance to see the face. The fact that Lincoln's face is so well known makes its recognition easier.

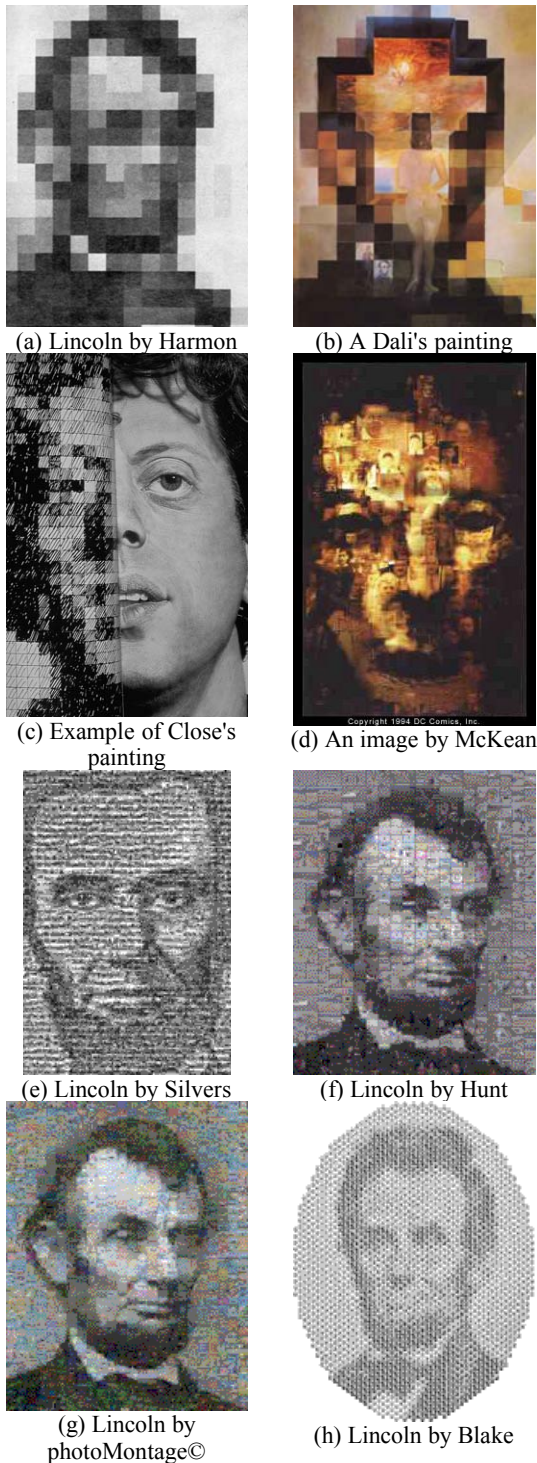
In 1976 Salvador Dali [ND01] completed the painting in Figure 3b titled “Gala contemplating the Mediterranean Sea, which at 30 meters becomes the portrait of Abraham Lincoln (Homage to Rothko)”. Note that Lincoln's face is made up by pictures with full tonal ranges; perhaps the earliest example of this technique.

The nude taking up several tiles is Dali's wife Gala and one of the tiles is Harmon's gray scale image of Lincoln; so not only Dali did an appropriate Harmon's Lincoln portrait into the overall composition, but he also reincorporated a smaller gray scale version into a single tile. If not the first, this is certainly the most well known image made from other images.

In the 1970's the American artist Chuck Close [Clo70] began producing precisely gridded paintings (see Figure 3c). Some of these had a quality that reminds Impressionists, while others seem to be computer-generated or computer influenced.

The earliest example of making a tile more than a single pixel came from an artist toying with Adobe Photoshop© [Ado06] and the earliest example of a photographic computer mosaic is the image created by Dave McKean for Vertigo/DC comics in 1994 (see Figure 3d).

Computer replicated images made from tiled digital photographic pictures is recent because it requires large computational resources. Robert Silvers [SH97] began working on the first photomosaic while he was a graduate student at the MIT Media Lab. Each tile in his images represents much more than a single value. Smaller pictures match the overall image in tone, texture, shape and color. Silvers was commissioned by the US Library of Congress to create the portrait of Lincoln in Figure 3e using archived photos of the American Civil War.



**Figure 3:** *Photomosaics.*

Today, Runaway Technology [Run06] (Silvers' company) produces photomosaic images as logos and illustrations for individuals, corporations and publications.

William Hunt [Hun98], a computer programmer, created the image in Figure 3f. He used three different size tiles to change the look of the grid.

ArcSoft photoMontage© [Arc06] is one of several commercial programs available nowadays. The image in Figure 3g was made using this software.

Scott Blake's image of Abraham Lincoln in Figure 3h is rendered by using 42 portraits of all US Presidents [Bla98]. He arranged the presidents according to their gray scale density. He offset the tiles on a beehive grid pattern to produce a hypnotic effect and used the oval portraits to fill the space in a more efficient manner.

The original Silver's idea was successively extended by Klein et al. KGFC02 to videos obtaining a video mosaic and recently Di Blasi and Petralia [DP05] presented an approach to speed up the search process based on the Antipole strategy [CFP\*05].

## 5. Puzzle Image Mosaics

Puzzle Image Mosaic is inspired by Giuseppe Arcimboldo [Str99], a Renaissance Italian painter inventor of a form of painting called the composite head where faces are painted not in flesh, but with rendered clumps of vegetables and other materials slightly deformed to better match the human features.

### 5.1. Kim and Pellacini's approach

Kim and Pellacini [KP02] introduce a mosaicing technique, called Jigsaw Image Mosaic (JIM), where image tiles of arbitrary shapes are used to compose the final picture. The idea is quite similar to the photomosaic, but the final effect is very different and interesting (Figure 4a).

The authors approach the problem by defining a mosaic as the tile configuration that minimizes a "mosaicing energy function" and introduce a general energy-based framework for mosaicing problems that extends the algorithms presented in [Hau01] and in [SH97].

The energy function  $E$  used by Kim and Pellacini is defined as:

$$E = w_C \cdot E_C + w_G \cdot E_G + w_O \cdot E_O + w_D \cdot E_D \quad (3)$$

where the color energy term  $E_C$  penalizes configuration that do not maintain the color of the input image. The gap energy term  $E_G$  penalizes configuration that have too much empty space in the final image, called gap, while a big overlap between tiles gives large overlap energy  $E_O$ . Finally, the deformation energy  $E_D$  penalizes configurations where tiles are highly deformed.

### 5.2. Di Blasi et al.'s idea

Another approach for the creation of the same kind of mosaics is presented in [DGP05]; this approach is based again on the Antipole strategy and leads to impressive results in an acceptable computation time (Figure 4b). The

technique reformulates the problem as a search problem in a large database of small images and takes into account some important features of the image to speed up the search process. Today, Magic Mosaics [Mag06] produces puzzle image mosaic posters and banners using a modified version of this software.

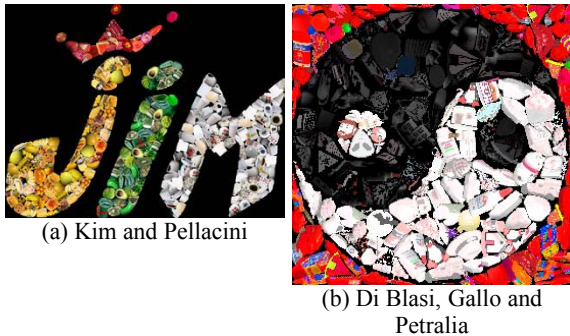


Figure 4: Puzzle Image Mosaics

## 6. Measuring Success in NPR

NPR is a new, rapidly growing field in Computer Graphics. A characteristic of the field's youth is that many proposed techniques break new, imaginative ground. A difficult issue likely to emerge is comparison and evaluation of novel contributions which aim to improve some existing techniques. Although it is possible to design objective performance measures for some aspects of a NPR algorithm (for example to evaluate computation time), comparative assessment of a rendering created solely for the purposes of aesthetics is clearly a subjective matter.

A solution to this problem is to work closely with artists who can judge the output of an algorithm to be of high aesthetic value; we believe this is important given the absence of any specific ground truth.

The aesthetics of an output could be further evidenced by non-scientific and non-academic interests; for example the photomosaic algorithm created by Silver [SH97] is today used by Runaway Technology [Run06] (Silvers' company) to produce photomosaic images as logos and illustrations for individuals, corporations and publications, Magic Mosaics ([Mag06]) produces puzzle image mosaic posters and banners using a modified version of the software proposed by Di Blasi et al. [DGP05] and the software proposed by Di Blasi and Gallo [DG05] has received interest from many artists, companies and Fine Arts Academies.

## 7. Conclusions & Future Works

In this paper, we surveyed several approaches to non-photorealistic rendering of digital images. In particular we presented some methods to create mosaic effects.

There are several ways to improve the aesthetic of the results and several ideas started from these works. In particular:

1. for ancient mosaics
  - a. a different strategy for choosing, in case of tile overlapping, which tile has to be cut; heuristic rules or, perhaps, randomized choices could produce different outcomes;
  - b. generalization of the "mosaicists' heuristic" to other kind of primitive based non photorealistic image processing seems possible and quite promising;
  - c. some generalizations proposed in [EW03], such as variable size tiles and photomosaic, are also considered for future work and research; it is also interesting to explore the possibilities offered using different basic shapes than rectangular tiles;
2. for photomosaic and puzzle image mosaic
  - a. the use of Antipole Tree or other data structures in other fields of NPR to speed-up the rendering process;
3. for all the presented methods
  - a. automatic optimized choices of tile scale relative to each input image is an open problem worth of further investigations;
  - b. the extension of mosaic technique to other kind of mosaics as proposed in [EW03];
  - c. a different method to better find the directional guidelines is an important research investigation issue;
  - d. exploitation of hardware graphics primitives to accelerate the mosaic synthesis;
  - e. extension of the proposed methods for mosaic rendering of 3D surface is probably the most exciting direction of research.

## References

- [Ado06] Adobe Photoshop, <http://www.adobe.com>, 2006.
- [Arc06] ArcSoft PhotoMontage, <http://www.arcsoft.com>, 2006.
- [BDFG06] BATTIATO S., DI BLASI G., FARINELLA G.M., GALLO G.: A Novel Technique for Opus Vermiculatum Mosaic Rendering. To appear in *ACM/WSCG2006* (2006).
- [Bla98] BLAKE S., <http://www.barcodeart.com/>, 1998.
- [CFP\*05] CANTONE C., FERRO A., PULVIRENTI A., REFORGIATO RECUPERO D., SHASHA D.: Antipole Tree indexing to support range search and K-nearest neighbor search in metric spaces. *IEEE/TKDE* 17, 4 (2005), pp. 535-550.
- [Clo70] CLOSE C., <http://www.chuckclose.coe.uh.edu/>, 1970.
- [DG05] DI BLASI G., GALLO G.: Artificial Mosaics. *The Visual Computer* 21, 6 (2005), pp. 373-383.
- [DGP05] DI BLASI G., GALLO G., PETRALIA M.: Puzzle Image Mosaic. In *Proc. IASTED/VIIP2005* (2005).

- [DHJN02] DOBASHI J., HAGA T., JOHAN H., NISHITA T.: A Method for Creating Mosaic Images Using Voronoi Diagrams. In *Proc Eurographics2002* (2002).
- [DP05] DI BLASI G., PETRALIA M.: Fast Photomosaic. In *Poster Proc of ACM/WSCG2005* (2005).
- [EW03] ELBER E., WOLBERG G.: Rendering Traditional Mosaics. *The Visual Computer* 19, 1 (2003), pp. 67-78.
- [FF05] FAUSTINO G.M., DE FIGUEIREDO L.H.: Simple Adaptive Mosaic Effects. In *Proc. SIBGRAPI2005* (2005)
- [Hae90] HAEBERLI P.: Paint by Numbers: Abstract Image Rappresentation. In *Proc. SIGGRAPH1990* (1990).
- [Har73] HARMON L.D.: The Recognition of Faces. *Scientific American* 229, 5 (1973).
- [Hau01] HAUSNER A.: Simulating Decorative Mosaics. In *Proc. SIGGRAPH2001* (2001).
- [Hun98] HUNT W.L.  
<http://home.earthlink.net/~wlhunt/>, 1998.
- [KP02] KIM J., PELLACINI F.: Jigsaw Image Mosaics. In *Proc SIGGRAPH2002* (2002).
- [KGFC02] KLEIN A.W., GRANT T., FINKELSTEIN A., COHEN M.F.: Video Mosaics. In *Proc. NPAR2002* (2002).
- [Mag06] Magic Mosaics,  
<http://www.magicmosaics.com/>, 2006.
- [ND01] NERET G., DESCHARNES R.: *Dali: The Paintings*. Taschen, 2001.
- [Noc04] NOCK R., NIELSEN F.: Statistical Region Merging. *IEEE/TPAMI* 26, 11 (2004), pp. 1452-1458.
- [Run06] Runaway Technology,  
<http://www.photomosaic.com/>, 2006.
- [SH97] SILVERS R., HAWLEY M.: *Photomosaics*. Henry Holt, 1997.
- [ST90] SAITO T., TAKAHASHI T.: Comprehensible rendering of 3-d shapes. In *Proc SIGGRAPH1990* (1990).
- [Str99] STRAND C.: *Hello, Fruit Face! : The Paintings of Giuseppe Arcimboldo*. Prestel, 1999.
- [STT05] SCHLECHTWEG S., GERMER T., STROTHOTTE T.: RenderBots – Multi-Agent Systems for Direct Image Generation. *Computer Graphics Forum* 24, 2 (2005), pp. 137–148.