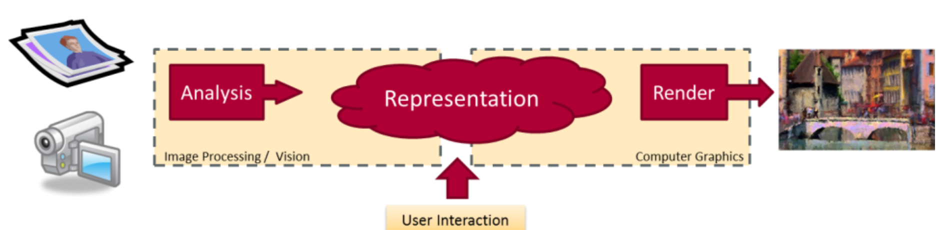
Multimedia e "Arte"

IMAGE PROCESSING LABORATORY

Artistic Stylization

- **Rendering real images/video footage in to pseudo-artistic styles**
- **Convergence of Computer Vision, Graphics (and HCI)**



- **Visual analysis enables new graphics. Graphical needs motivate new vision.**

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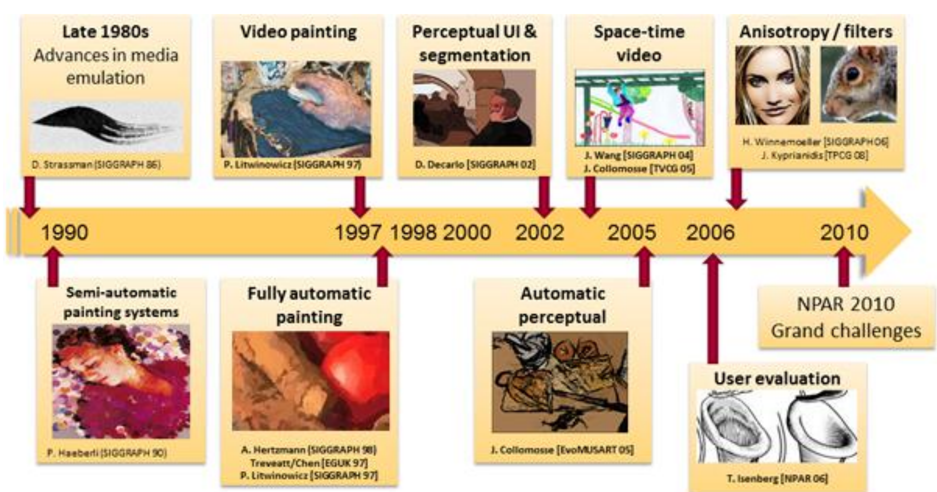
Artistic Stylization

This part focuses on the generation of synthetic artwork using filtering or other low-level image analysis. In many cases, artistic renderings are produced by placing a multitude of small marks (hatches, stipples, painterly brush strokes) on a virtual canvas. The placement of the marks reacts to the image content via heuristics that seek to emulate the placement of marks by a human artist.

Artistic Stylization



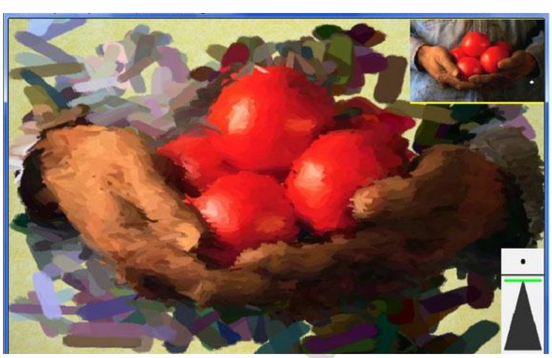
Collomosse

Stroke Based Painterly Rendering

Stroke based Rendering (SBR) is the process of synthesizing artwork by compositing rendering marks (such as lines, brush strokes, or even larger primitives such as tiles) upon a digital canvas. SBR under-pins many Artistic Rendering (AR) algorithms, especially those algorithms seeking to emulate traditional brush-based artistic styles such as oil painting.

The SBR paradigm was proposed in the early 1990s by Paul Haeberli, in the context of his semi-automated 'Paint By Numbers' painting environment that sought to rendering impressionist paintings from photographs.

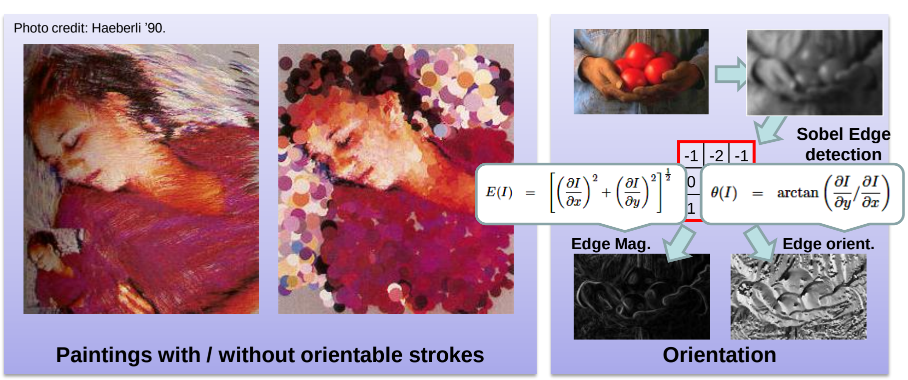
Stroke-based Rendering: example



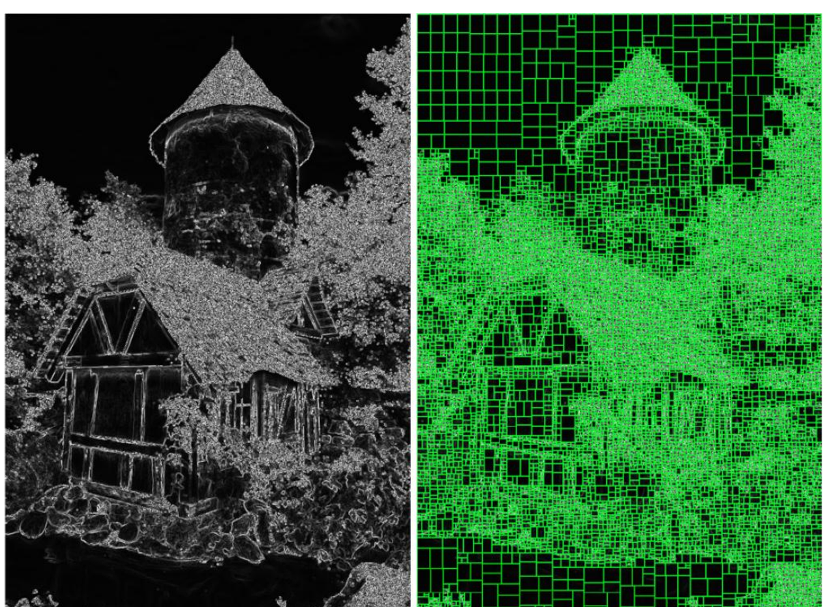
Attribute	Name	Derived
$\mathbf{P} = (x, y)$	stroke seed position	Manually
s	stroke scale	Manually
$\theta = \Theta(x, y)$	stroke orientation	Automatically
$\mathbf{c}$	RGB color	Automatically
o	stroke order	Manually

Some first details

Haeberli's system not only automates the selection of color, but also drives other stroke attributes such as orientation. In impressionist artwork, strokes are often painting tangential to edges in the scene. This can be emulated by running an edge detector (e.g. the Sobel operator) over the grayscale source photograph $I(x, y)$.



- **Stroke <u>colour</u> and <u>orientation</u> are sampled from the source image**
- **Stroke <u>order</u> and <u>scale</u> are user-selected**
- **Addition of RGB noise generates an impressionist effect**



Resources

See http://kahlan.eps.surrey.ac.uk/EG2011/
for more details

Mosaici Digitali: Status e Prospettive

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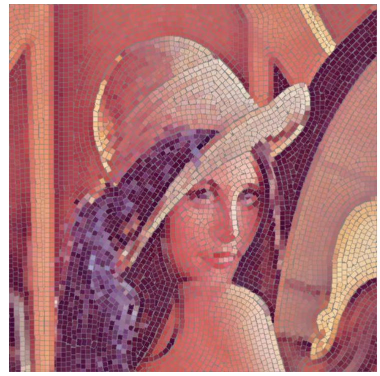
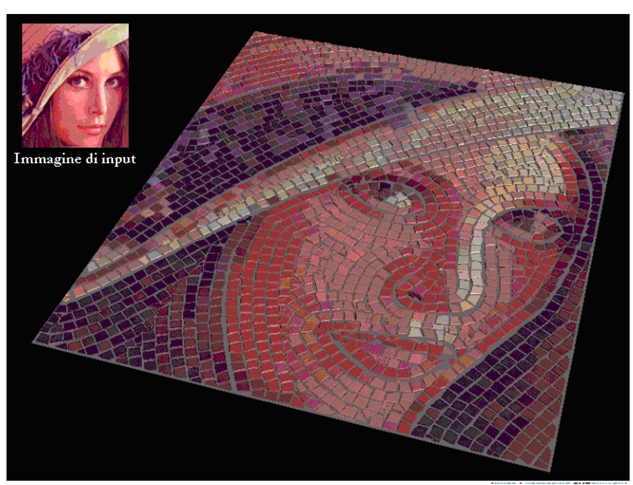
Summary (1/2)

- Mosaics
- Mosaics & CG
- 2D Ancient Mosaics
- Some Results
- Demo



Summary (2/2)

- 3D Mosaics
- Demo



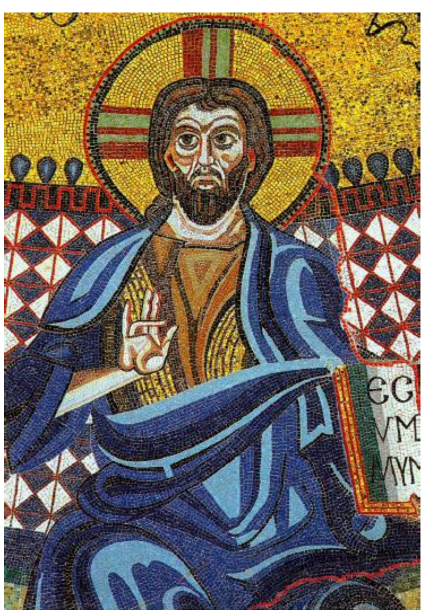
Reproduction of Ancient Mosaics

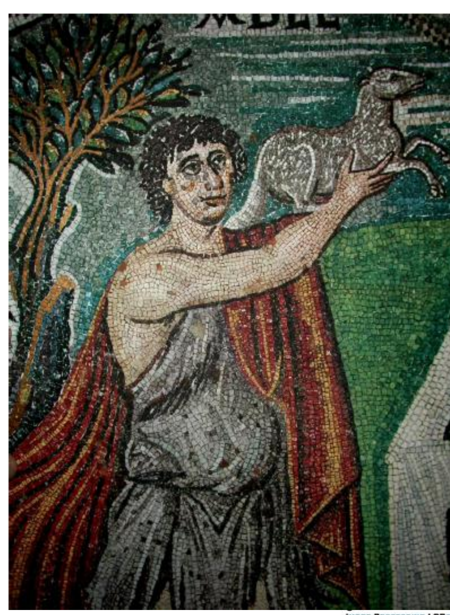
Reproduction of Ancient Mosaics

Crystallization Mosaic

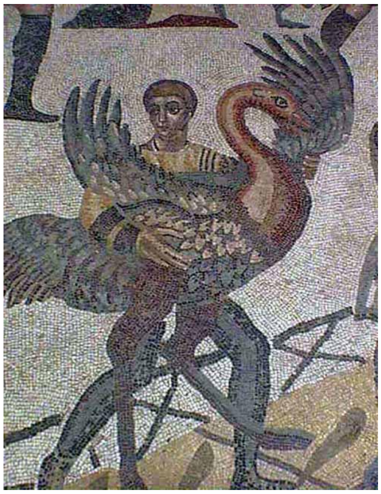
Given an image I^2 in the plane R^2 and a set of constraints (i.e., on edge features), find N sites $P_i(x_i, y_i)$ in I^2 and place N tiles, one at each P_i, such that all tiles are disjoint, the area they cover is maximized, each tile is colored by a color which reproduces the image portion covered by the tile. In this case in order to allow a solution the requirements have to be relaxed asking only that the constraints are verified as much as possible.

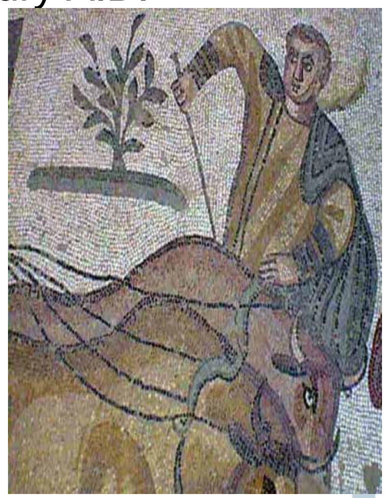
These techniques generally lead to mosaics that simulate the typical effect of some glass windows in the churches.





Villa del Casale (Piazza Armerina)
IV century A.D.





Introduction

Artists often invent techniques later used in Computer Graphics;

Mosaics are images made by cementing together small polygonal coloured tiles;

Digital simulation poses aesthetic and technical problems.

Mosaics

Mosaics, in essence, are images obtained cementing together small colored fragments. Likely, they are the most ancient examples of discrete primitive based images. In the digital realm, mosaics are illustrations composed by a collection of small images called ‘tiles’.

The tiles tessellate a source image with the purpose of reproducing the original visual information rendered into a new mosaic-like style.

Factors like tile dataset, constraints on positioning, deformations and rotations of the tiles are indeed very influent upon the final results.

Digital mosaics

Artistic quality digital mosaic creation is a very challenging task;

Illustrations composed by a collection of small images (called “tile”) that “**tessellate**” a source picture in order to reproduce it in a “mosaic-like” style;

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.).

The problem

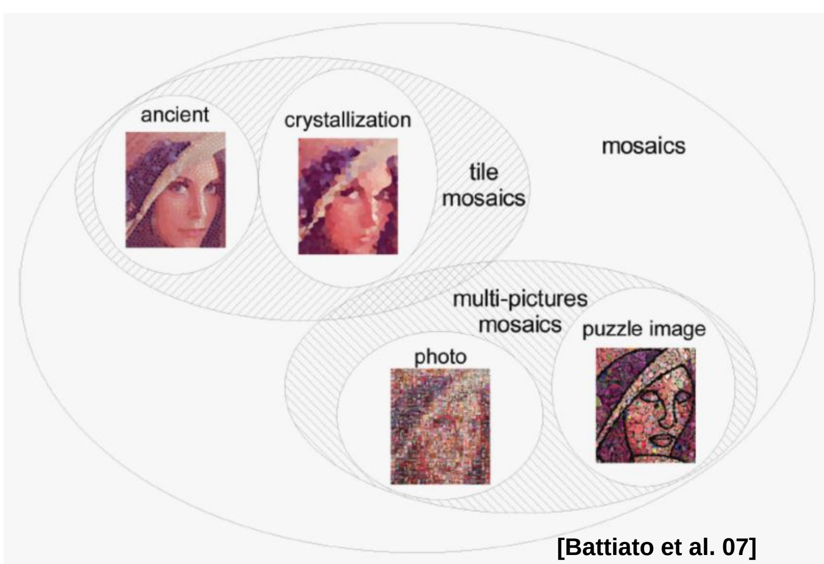
Given a rectangular region I^2 in the plane R^2, a tile dataset and a set of constraints, find N sites $P_i(x_i, y_i)$ in I^2 and place N tiles, one at each P_i, such that:

1.all tiles are disjoint;

2.the area they cover is maximized;

3.the constraints are verified as much as possible.

A simple classification….



Other classification criteria

- **Fixed tile and variable tile (picture) size;**
- **Voronoi based and non-Voronoi based approach;**
- **Deterministic and nondeterministic (probabilistic, random) algorithm;**
- **Iterative and one-step method;**
- **Interactive and batch system**.

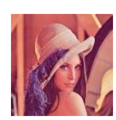
Other important issue:

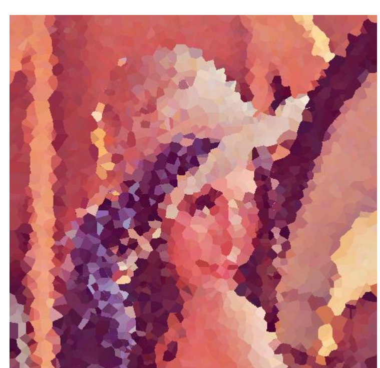
- **Computational complexity;**
- **Ahestetic.**

Crystallization Mosaic

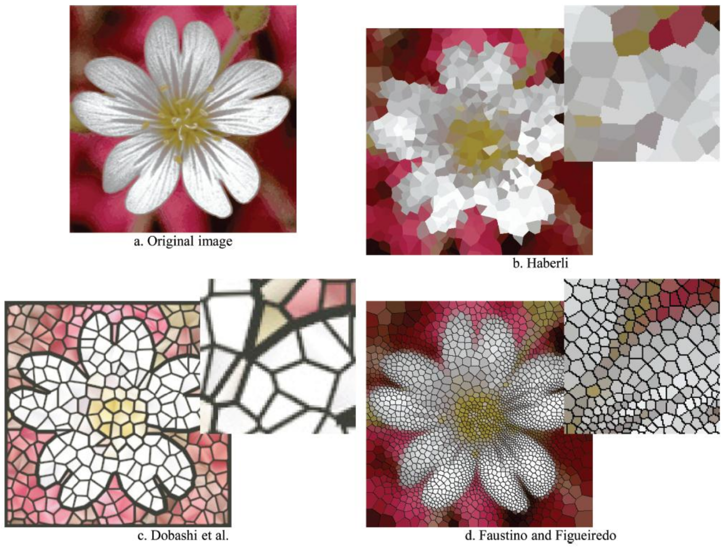
[Haeberli 90] used Voronoi diagrams, placing the sites at random and filling each region with a color sampled from the image.

This approach tessellates the image with tiles of variable shapes and it does not attempt to follow edge features; the result is a pattern of color having a cellular-like look. The effect may be efficiently implemented by z-buffering a group of colored cones onto a canvas.





Other Results



a. Original image

b. Haberli

c. Dobashi et al.

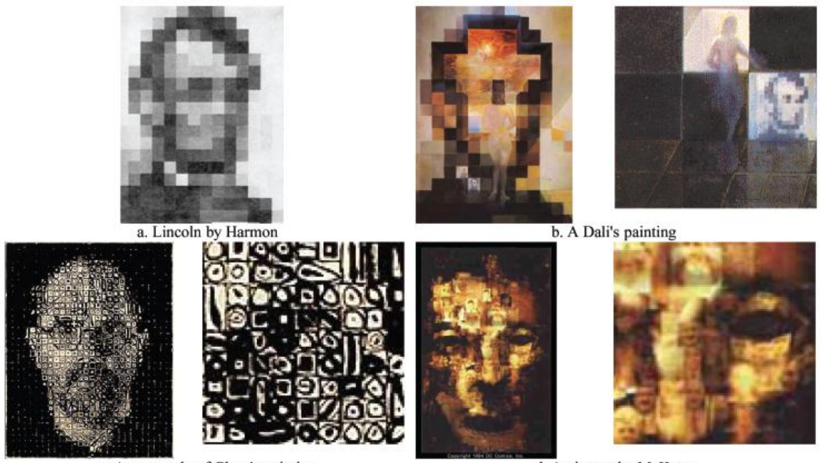
d. Faustino and Figueiredo

Photo-mosaic

Given an image I^2 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 '**resembles**' the image portion covered by the tile.*

Photo-mosaic is one of the most interesting techniques (and one of the most re-discovered algorithms) in the field of digital mosaics.

Photo-Mosaic



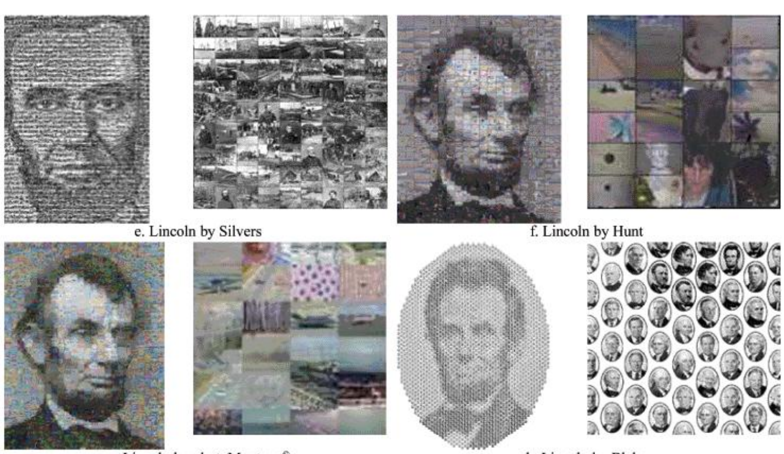
a. Lincoln by Harmon

b. A Dali's painting

c. An example of Close's painting

d. An image by McKean

Photo-Mosaic



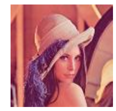
e. Lincoln by Silvers

f. Lincoln by Hunt

g. Lincoln by photoMontage©

h. Lincoln by Blake

Photo-mosaic

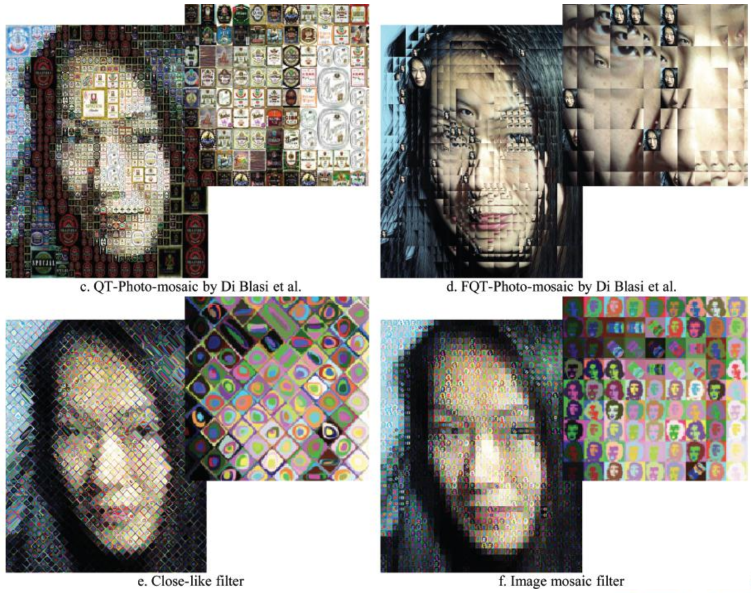


The original idea of **[Silver et al. 97]** has been recently improved by placing first the tile images and the altering their colors to better match the target image

Other Results

a. Original image
b. QT-Photo-mosaic
c. FQT-Photo-mosaic

Other Results



Arcimboldo and PIM

Giuseppe Arcimboldo - Vertumne (portrait de Rodolphe II) - ca.1590, Huile sur bois - Skokloster, Château de Skokloster (Suède)

Arcimboldo (1526-1593), *Spring* - ca. 1573 Oil on canvas - 76 x 64 cm, Musee National du Louvre, I

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Puzzle Image Mosaic

*Given an image I^2 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 '**resembles**' the image portion covered by the tile.*

Puzzle Image Mosaic is inspired by Giuseppe Arcimboldo, 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.

Puzzle Image Mosaic

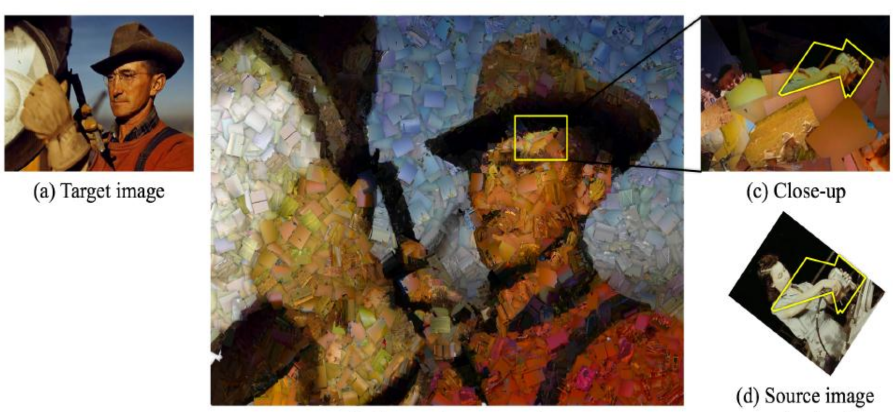
Other Results and discussion

a. Original image

b. Kim and Pellacini

c. Di Blasi et al.

Cut-Out Mosaic [Ochard'08]



(a) Target image

(b) Cut-out image mosaic

(c) Close-up

(d) Source image and cut-out

Ancient Mosaic

Since ancient times the art of mosaic has been extensively used to decorate public and private places realized first by Greeks and Romans and later during the Byzantine Empire. Different kind of mosaics were produced also by old pre-Columbian people. Also in the modern area several artists have continued to deal with artistic mosaics.

Ancient Mosaic

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.

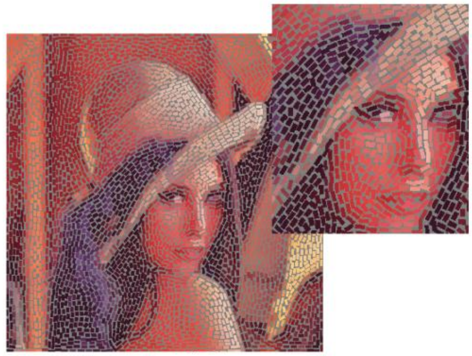
Ancient Mosaic (Opus)

Opus

- **Musivum**
- **Vermiculatum**
- **Palladium**

Ancient Mosaic

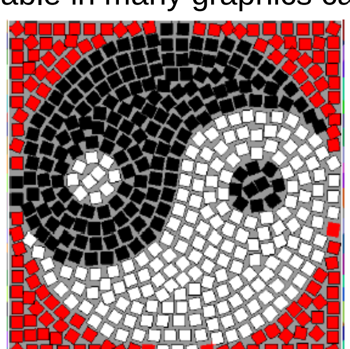
Given an image I^2 in the plane R^2 and a vector field (x,y) defined on that region by the influence of the edges of I^2, find N sites $P_i(x_i, y_i)$ in I^2 and place N rectangles, one at each P_i, oriented with sides parallel to (x_i, y_i), such that all rectangles are disjoint, the area they cover is maximized and each tile is colored by a color which reproduces the image portion covered by the tile **[Hausner, 01]**.



[Hausner01]

Hausner obtained very good results by using:
• Centroidal Voronoi Diagrams (CVD);
• User selected edge features;
• *L1* (Manhattan) distance;
• Graphic hardware acceleration.

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.

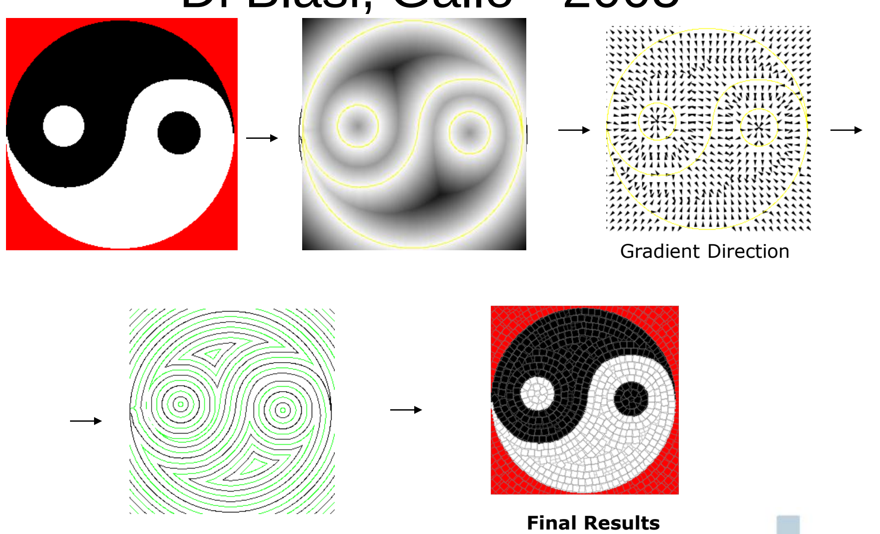


Other Works


c. Di Blasi and Gallo


d. Schlechtweg et al.

Di Blasi, Gallo - 2005



To simulate, one has to copy reality (1)

How a real mosaic artisan works?

- to create a mosaic the mosaicists first outline the shapes of the image they want to obtain
- next they fill the shapes with a sequence of parallel (offset) curves
- finally they place the tiles along the curves

To simulate, one has to copy reality (2)

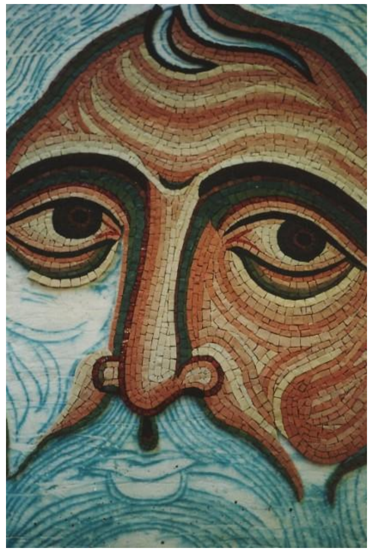
The first two steps (outline and “big” offset curves) are very simple and usually do not represents a problem for the mosaicists

The last one (troubled offset curve or gaps fill) is the more complex one

- mosaicists have a limited set of tile shapes

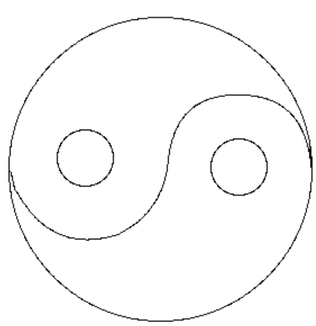
Usually only rectangular shapes are available, so they must adapt (by cutting) the tiles to insert them in the figure they are realizing

To simulate, one has to copy reality (3)

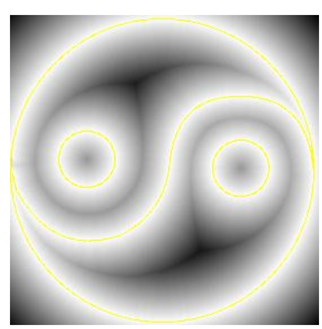


How to copy the Mosaicists' Work

input image



directional guidelines



distance transform

How to copy the Mosaicists' Work

The distance transform

- we now suppose to have an image and its directional guidelines as input
- using the directional guidelines we evaluate for each pixel of the image the distance transform
- the distance transform is the minimum distance of each pixel from any guideline pixel and can be represented by a matrix (*dtM*)

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How to copy the Mosaicists' Work

The gradient and level line matrix

- starting from the distance transform matrix we can obtain another two matrices needed to perform the final mosaicing
- the gradient matrix (*gM*)

$$gM(x,y) = \arctan \frac{dtM(x,y+1) - dtM(x,y-1)}{dtM(x+1,y) - dtM(x-1,y)}$$

- the level line matrix (*llM*)

$$llM(x,y) = \begin{cases} 1 & if \bmod(dtM(x,y), 2 \cdot tSize) = 0 \\ 2 & if \bmod(dtM(x,y), 2 \cdot tSize) = tSize \\ 0 & elsewhere \end{cases}$$

  - where *tSize* is the tile dimension

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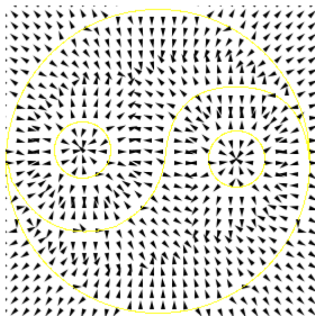
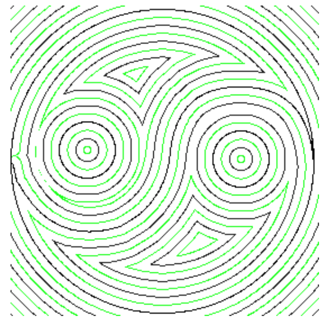
How to copy the Mosaicists' Work

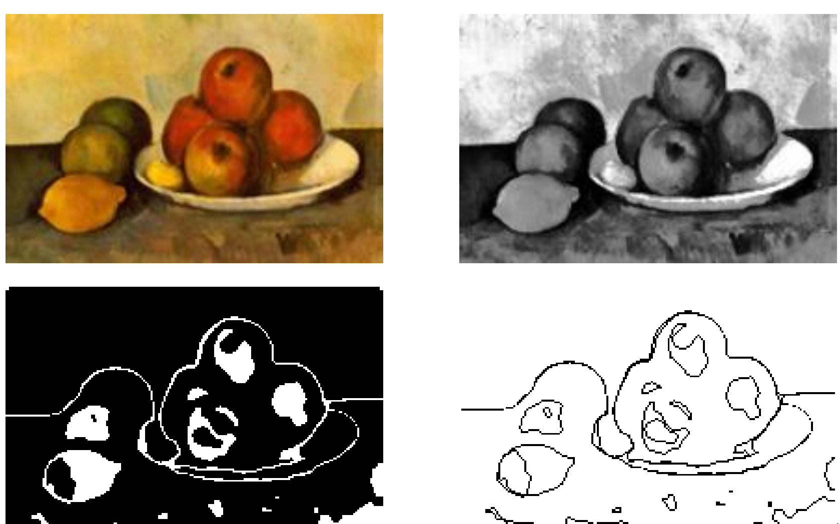


gradient matrix



level line matrix

Example



How to copy the Mosaicists' Work

The tile placing

- we are now ready to place the tiles
- the matrix *llM* forms chain-like sequences useful to place the tile centres, the orientation is given by the matrix *gM*
- in the process of placing the tiles their shape has to be altered in order to resolve overlapping

How to copy the Mosaicists' Work

More precisely the algorithm proceeds as follows:

- while there are chains of pixels not yet processed:
  - select a chain
  - starting from an arbitrary pixel on it "follow" the chain
  - place new tiles at regular distances along the path

If tiles are positioned only according to this method two main difficulties arise:

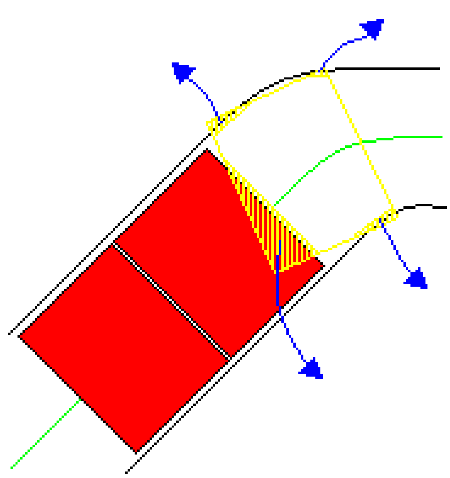
- tiles may overlap
- a single tile may cover an area across the "black pixels lines"

How to copy the Mosaicists' Work

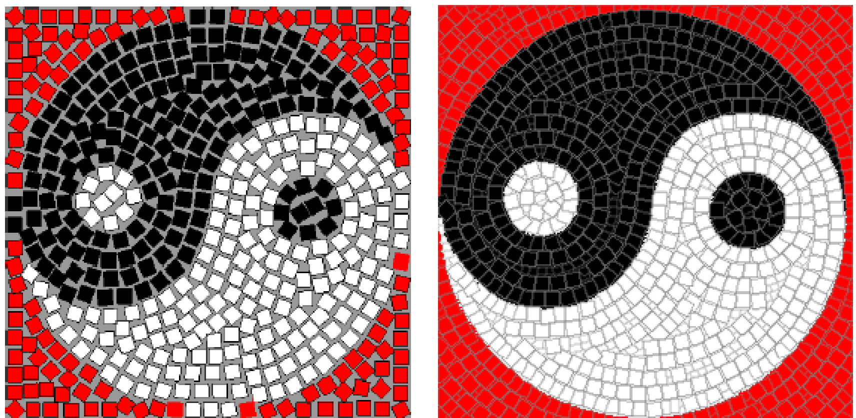
Tile overlapping and crossing

- the tiles overlapping and crossing are unpleasant and they completely destroy the guideline patterns
- we adopt a very simple strategy to address these difficulties:
  - the overlapping of tiles is easily detected maintaining a true/false mask of covered pixels
  - if a tile contains pixels already covered by previously placed tiles we change the rectangular shape “cutting away” the overlapping pixels
  - if a tile crosses any “black pixel line” it is trimmed against this line

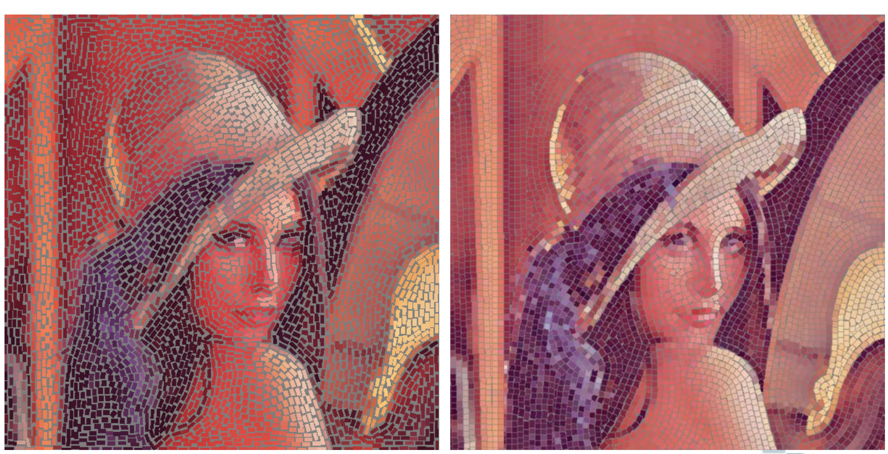
How to copy the Mosaicists' Work



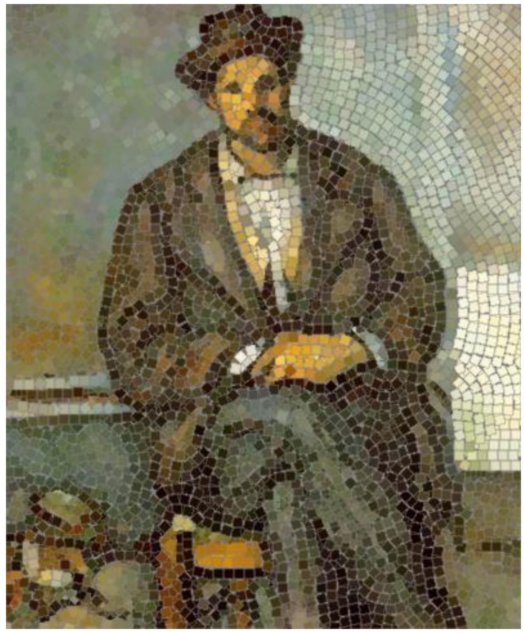
Comparison



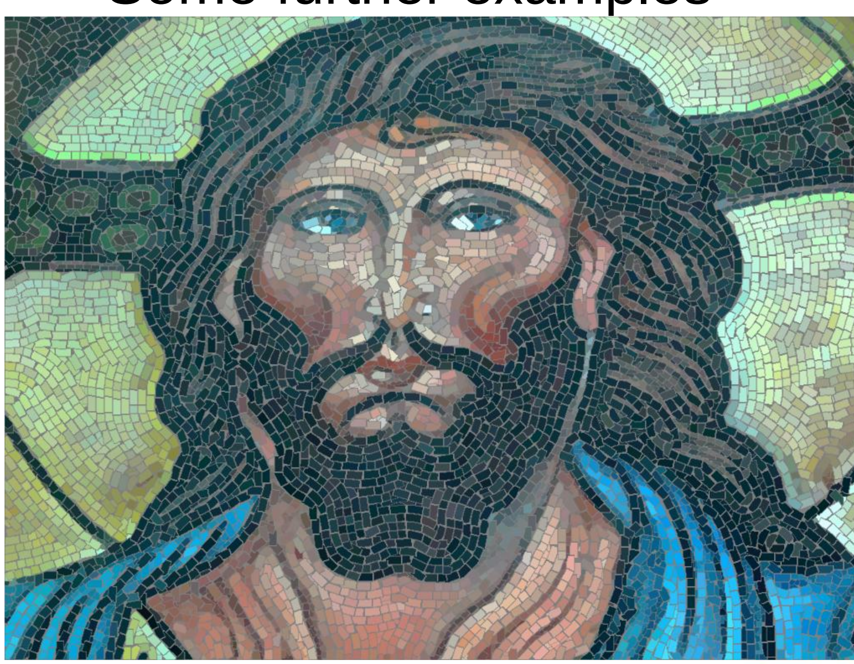
Comparison



Some further examples



Some further examples



How to copy the Mosaicists' Work

In order to produce an “opus vermiculatum” mosaic an “a priori” segmentation of the input image is needed.

Such artistic mosaic is characterized by the different styles used to place tiles in the foreground and in the background.

Moreover, we need also a description of the details inside the foreground areas.For these reasons we preferred using a semiautomatic technique based on the SRM method

How to copy the Mosaicists' Work

The algorithm first automatically segments the image leading to a very rough segmentation, but sufficiently precise for our aims

Second, an user friendly GUI allows the user to easily select the foreground and the background regions

This leads to a detailed FG/BG mask image which can be used in the successive steps

Note that this approach allows the user to produce several FG/BG mask images from the same input

Statistical Region Merging -

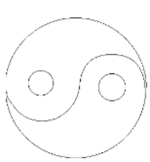
Immagine di input

Statistical Region Merging

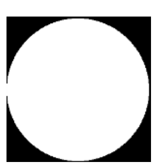
Directional guidelines SRM

Opus Vermiculatum

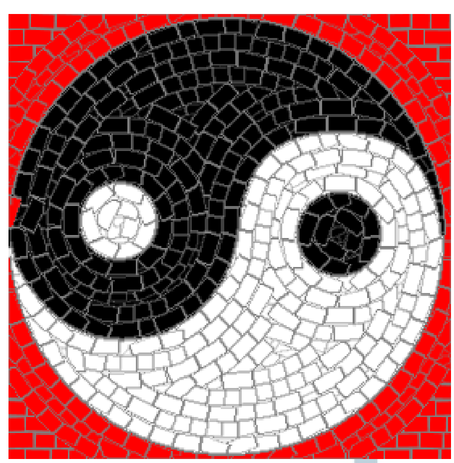
Input



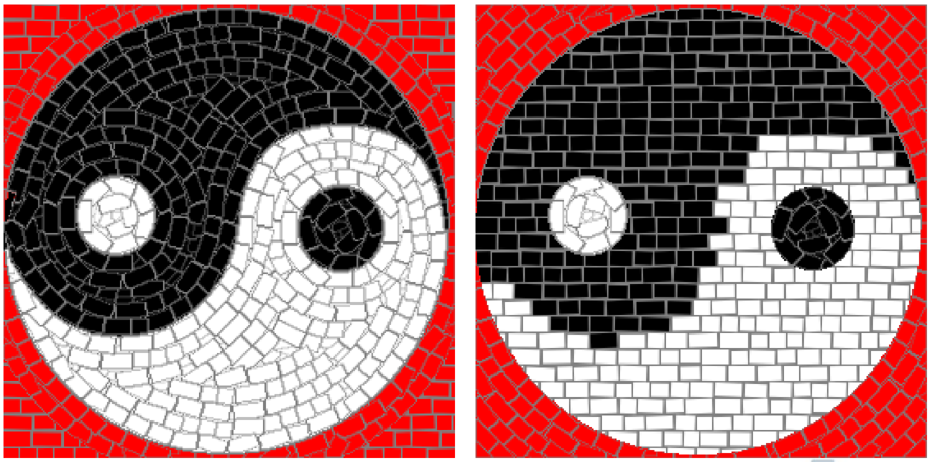
Guidelines



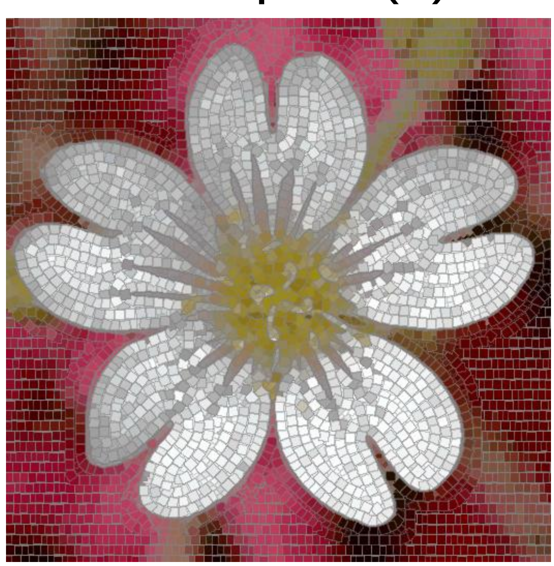
Mask B/F



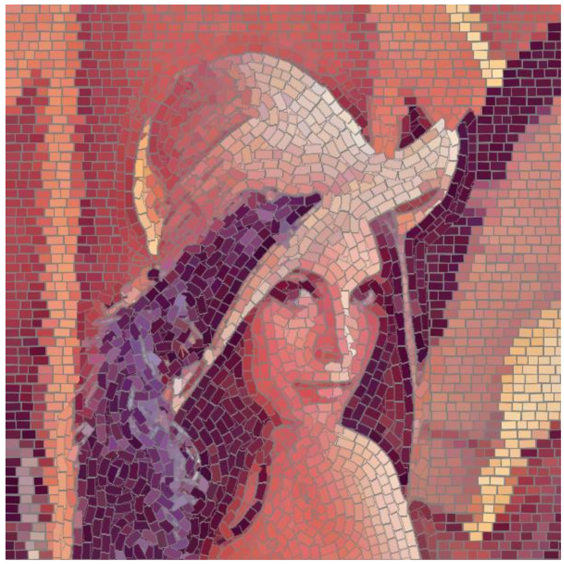
The final result



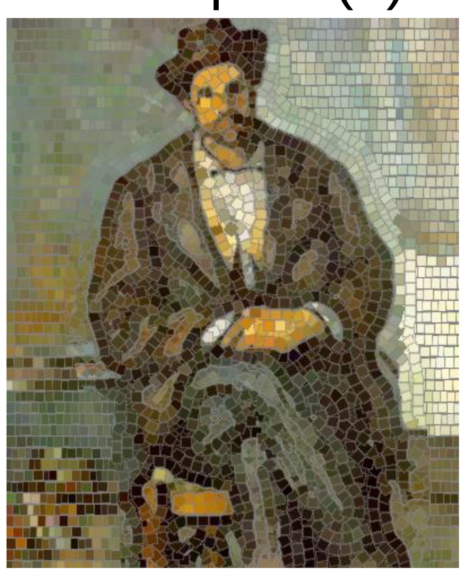
Examples (1)



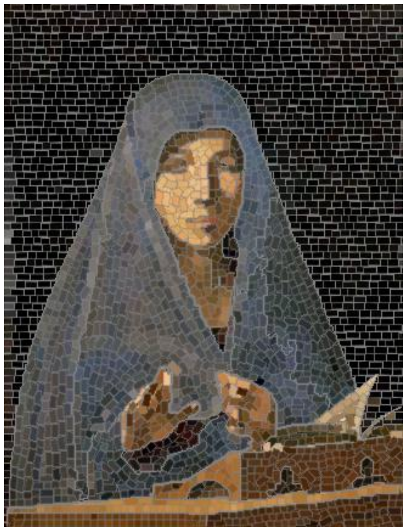
Examples (2)



Examples (3)



Examples (4)



A recent approach

To better emulate the style of an ancient artisan we proposed a technique based on the following two steps:

- GVF (Gradient Vector Flow) field computation [XU98];
- rule based tile positioning.

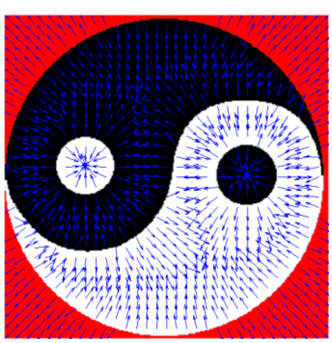
Gradient Vector Flow

GVF is a dense force field originally proposed to solve the classical problems affecting snakes (sensitivity to initialization and poor convergence to boundary concavity);

Starting from the gradient of an image, this force field is computed through diffusion equations.

Gradient Vector Flow (Examples)

GVF is a field of vectors v = [*v, u*] that minimizes the following energy function:



$$E = \iint \mu\left(u_x^2 + u_y^2 + v_x^2 + v_y^2\right) + |\nabla f|^2 |\mathrm{v} - \nabla f|^2$$

where the subscripts represent partial derivates along *x* and *y* axes respectively, *μ* is a regularization parameter and |∇*f*| is the gradient magnitude computed from the input image.

Gradient Vector Flow

GVF is a field of vectors v = [*v, u*] that minimizes the following energy function:

$$E = \iint \mu\left(u_x^2 + u_y^2 + v_x^2 + v_y^2\right) + \left|\nabla f\right|^2 \left|\mathrm{v} - \nabla f\right|^2$$

where the subscripts represent partial derivates along *x* and *y* axes respectively, *μ* is a regularization parameter and |∇*f*| is the gradient magnitude computed from the input image.

Edge information is preserved, it is propagated in the close regions and merged together in a smooth way.

S. BATTIATO, G. DI BLASI, G. GALLO, G. C. GUARNERA, G. PUGLISI - ***Artificial Mosaic by Gradient Vector Flow*** - In Short Proceedings of *Eurographics 2008* - Creete, April 2008.

Tiles positioning

All the tiles have the same rectangular shape and the same size (Tiles do not overlap)

First we consider **local |*GVF(I)*| maxima** with values greater than a threshold t_h. These pixels, sorted according to |*GVF(I)*|, are selected together with their neighbors with |*GVF(I)*| greater than t_l (chains of tiles are built up and placed). **We impose that the tile orientation is obtained according to the GVF direction in its central point.**

The second step of the algorithm is devoted to cover the **homogeneous** regions of the image. This is accomplished simply by placing each tile one by one from **left to right and from top to bottom**, starting from the upper-left corner of the image.

Visual comparison (1)

A B

Original images (A) and mosaicized with our approach (B)

Visual comparison (2)

[Battiato08] [DiBlasi05]

Visual comparison (3)

[Battiato08]

[Liu07]

Further considerations

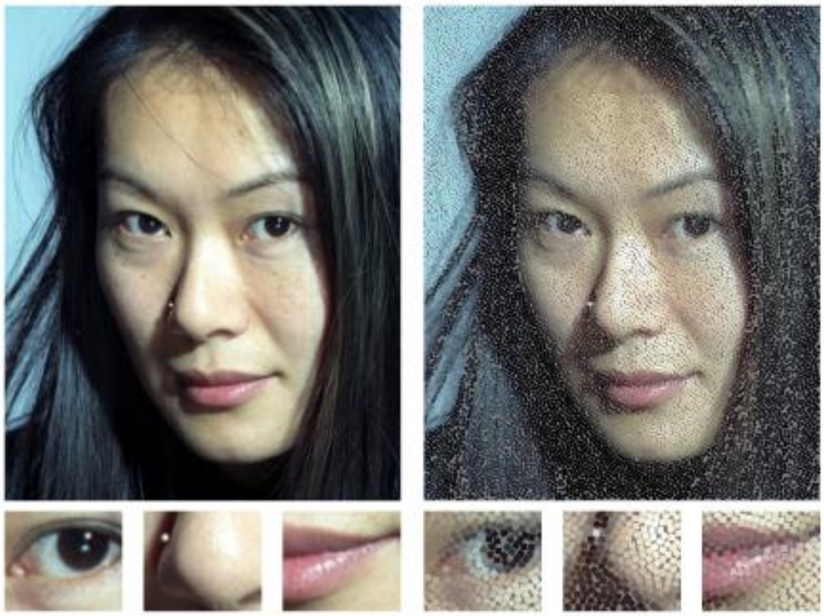
A first advantage of the novel technique is that it is able to better preserve fine details (high frequency areas are prioritarily filled).

The area left uncovered by the proposed technique is comparable with the amount of uncovered area left by [DiBlasi05], but gaps are here better distributed.

Relatively to [Liu07] the uncovered area left by our technique is considerably less.

Technique	Number of Tiles	Covered Area
Our method	13412	75.4%
[DiBlasi05]	13994	78.6%
[Liu07]	11115	62.5%

Examples (1)



Examples (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.

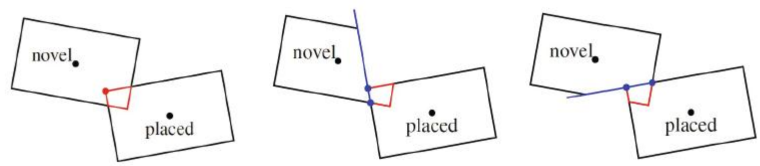
2D Mosaic Tile Cutting (2)

The final mosaic (with irregular tiles) is then obtained employing **tile-merging** and **tile-cutting** strategies.

The original approach has been extended by considering two different strategies of tile cutting: **subtractive** and **shared cut**.

Subtractive Cut

It cuts only the novel tiles, i.e., tiles that are not already present in the mosaic.

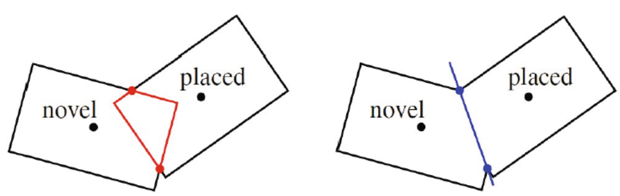


(a) Intersection Analysis (b) Non-Optimal Cut (c) Optimal Cut

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.

Shared Cut

It cuts both novel and already placed tiles (shared cut actually unions two tiles and can be considered a tile-merging strategy).



(a) Intersection Analysis (b) Cut

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.

Tile Cutting Parameter Setting (1)

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**, the **percentage gain in the number of tiles** compared to the mosaic without cuts and the **average side number of the tiles** .

Tile Cutting Parameter Setting (2)

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

- 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 (i.e.,$S_P \leq T_P$).
- 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 (i.e.,$S_N \leq T_N$).

Tile Cutting: Constraints

Let A_0^N be the original tile area 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:

$$\frac{A_i^N - A_{i+1}^N}{A_0^N} \le S_N \quad i = 1, \ldots, M_N - 1$$

$$\frac{A_0^N - A_{M_N}^N}{A_0^N} \le T_N$$

where M_N is the overall number of cuts performed on the novel tile.

Tile Cutting Parameter Setting (4)

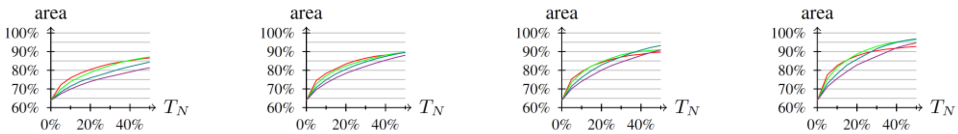
Let A_0^N be the original tile area of the **novel** tile and A_0^P the area of the already **placed** tile. Let A_i^N and A_i^P the corresponding tile area after the i^{th} cut. The tile cutting of an already placed tile has to satisfy the following constraints:

$$\frac{A_i^P - A_{i+1}^P}{A_0^P} \le S_P \quad i = 1, \ldots, M_P - 1$$

$$\frac{A_0^P - A_{M_P}^P}{A_0^P} \le T_P$$

where M_P is the overall number of cuts performed on the already placed tile.

Covered Area



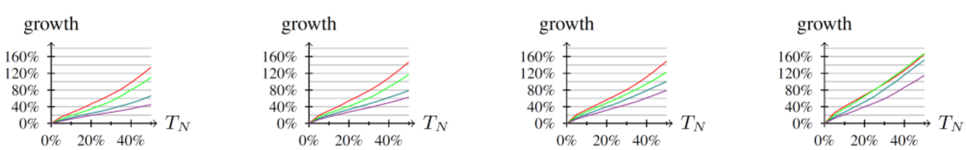
(a) subtractive cut (b) shared cut ($R = 1/2$) (c) shared cut ($R = 2/3$) (d) shared cut ($R = 1$)

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

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

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

Number of Tiles



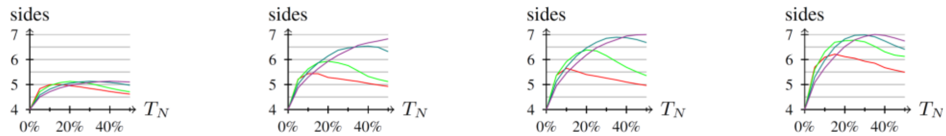
(a) subtractive cut (b) shared cut ($R = 1/2$) (c) shared cut ($R = 2/3$) (d) shared cut ($R = 1$)

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.

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

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

Average Number of Sides



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

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

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

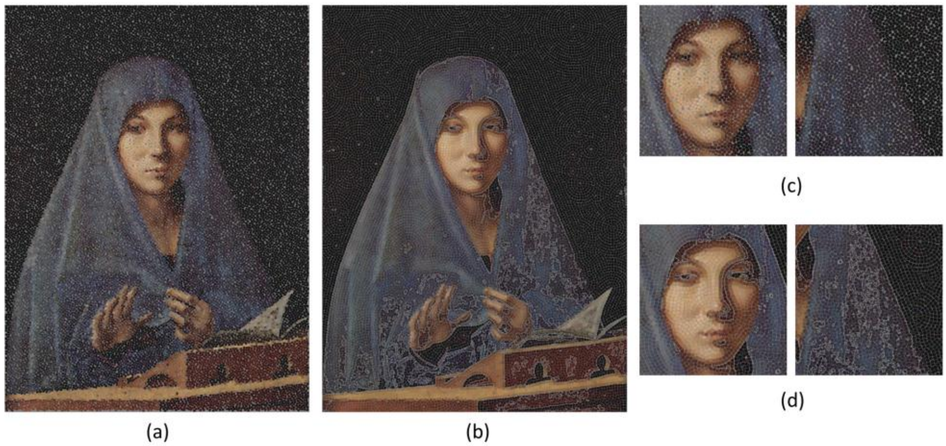
$$R = \frac{T_P}{T_N} \qquad R \in \{1/2, 2/3, 1\}$$

Visual Results

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.

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.

Visual Comparisons

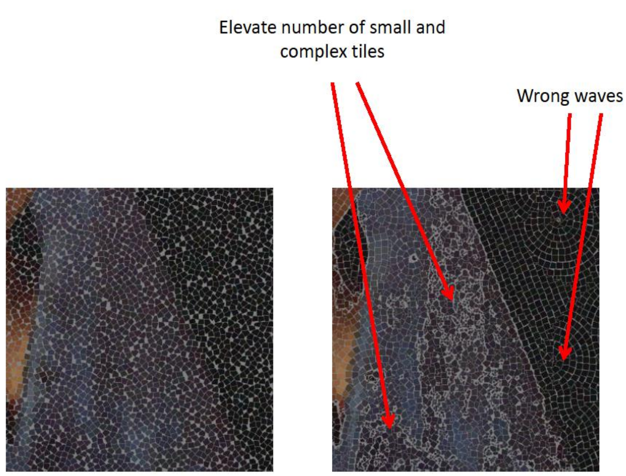


Visual comparisons of artificial mosaic techniques: our approach on the left (a,c) and Di Blasi et al. [DG05] on the right (b, d).

R = 0,5, R_N = 0,5, T_N = 35%, S_N = 17,5%, T_P = 17,5%, S_P = 8,75%.

[DG05] Di Blasi, G., Gallo, G.: Artificial mosaics. The Visual Computer 21(6), 373–383 (2005)

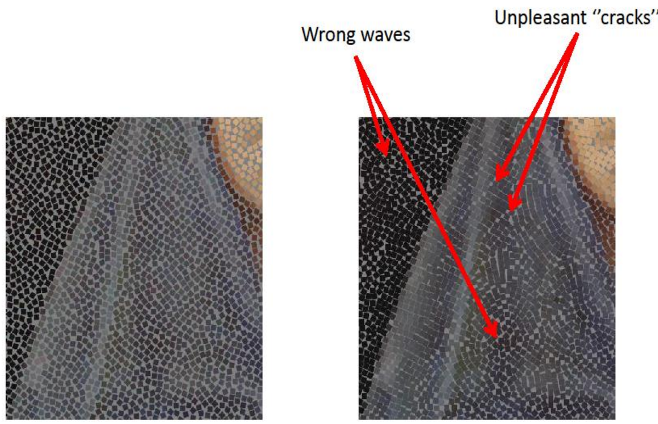
Visual Comparisons (details)



Proposed Approach

Di Blasi et al.

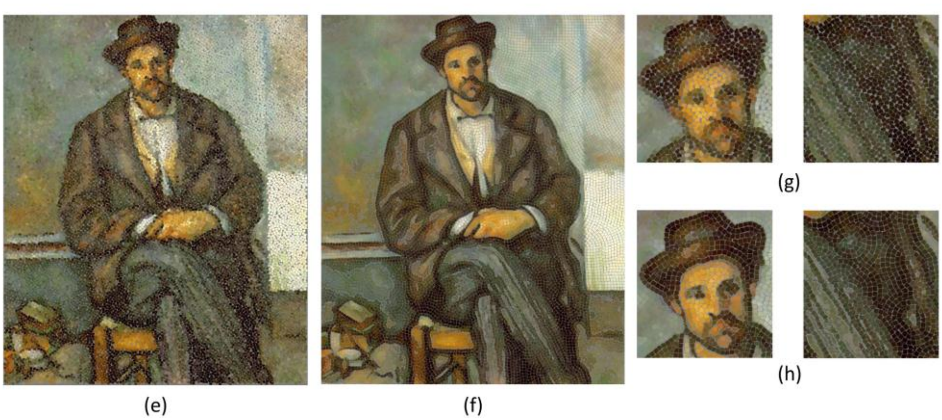
Visual Comparisons (details 2)



Proposed Approach

Di Blasi et al.

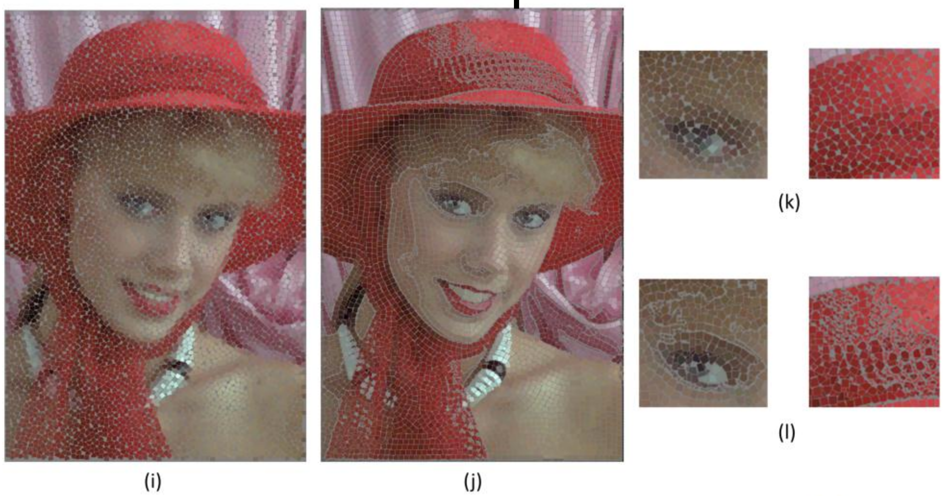
Visual Comparisons



Visual comparisons of artificial mosaic techniques: our approach on the left (e,g) and Di Blasi et al. [DG05] on the right (f, h).

[DG05] Di Blasi, G., Gallo, G.: Artificial mosaics. The Visual Computer 21(6), 373–383 (2005)

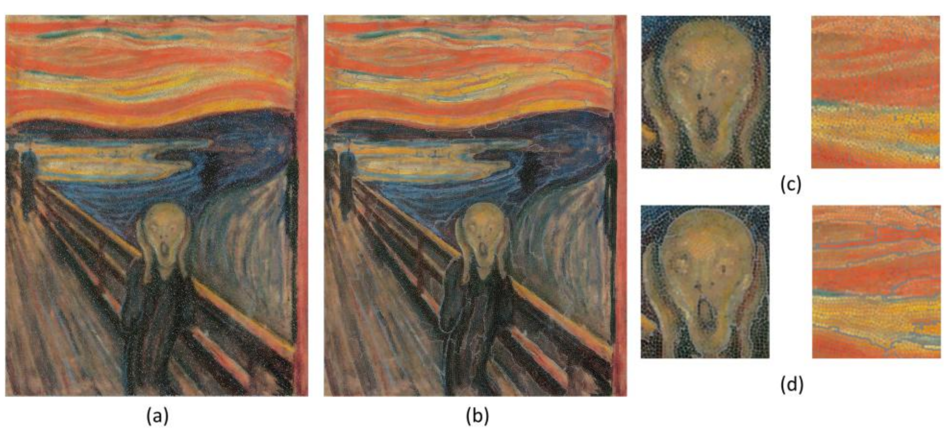
Visual Comparisons



Visual comparisons of artificial mosaic techniques: our approach on the left (i,k) and Di Blasi et al. [DG05] on the right (j, l).

[DG05] Di Blasi, G., Gallo, G.: Artificial mosaics. The Visual Computer 21(6), 373–383 (2005)

Visual Comparisons



Visual comparisons of artificial mosaic techniques: our approach on the left (a,c) and Di Blasi et al. [DG05] on the right (b, d).

[DG05] Di Blasi, G., Gallo, G.: Artificial mosaics. The Visual Computer 21(6), 373–383 (2005)

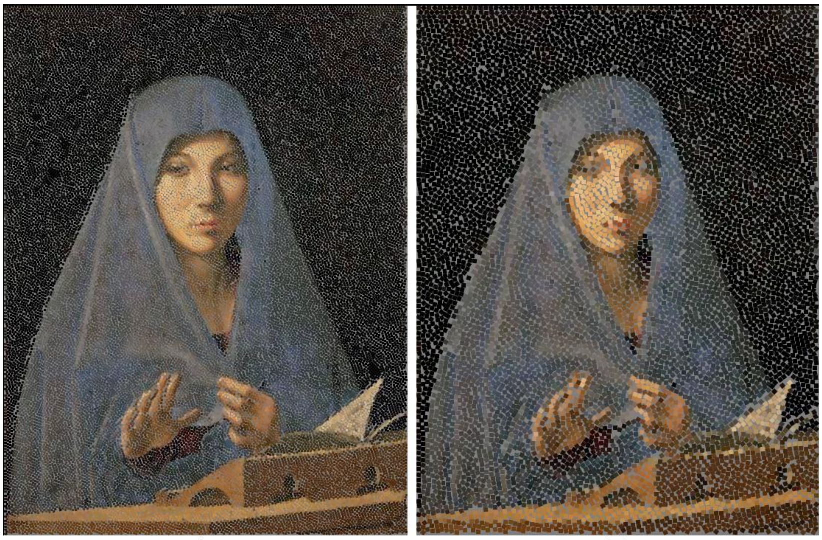
Florence

Mosaic Analysis

Parameters to be considered:

- Tile Size vs Image Scale
- Tile Shape
- Color Foreground
- …

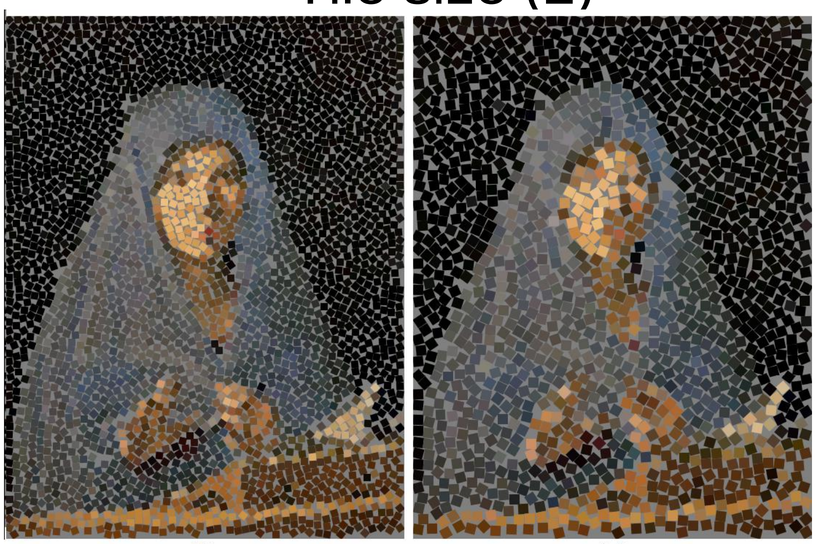
Tile size (1)



A B

Mosaics generated with increasing tiles size A (3x3), B (6x6).

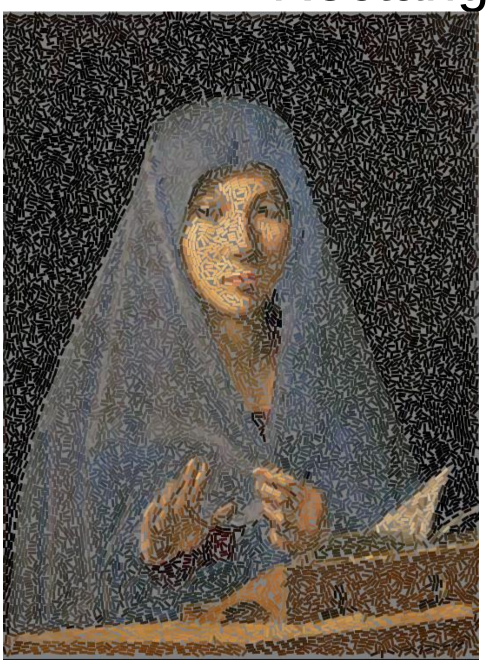
Tile size (2)



C D

Mosaics generated with increasing tiles size C (10x10), D (14x14).

Rectangular tile

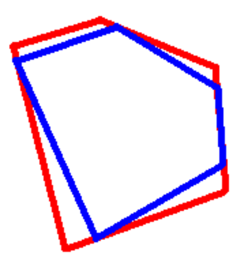


Mosaic generated with rectangular tiles (3x9).

This example shows how the proposed criteria are able to preserve fine details (due to GVF) maintaining at the same time the global orientation of almost all edge present in the original picture (due to the tile positioning rules).

Minor Variation: Noise (1)

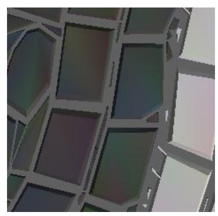
– **Vertex coordinates (without collision)**



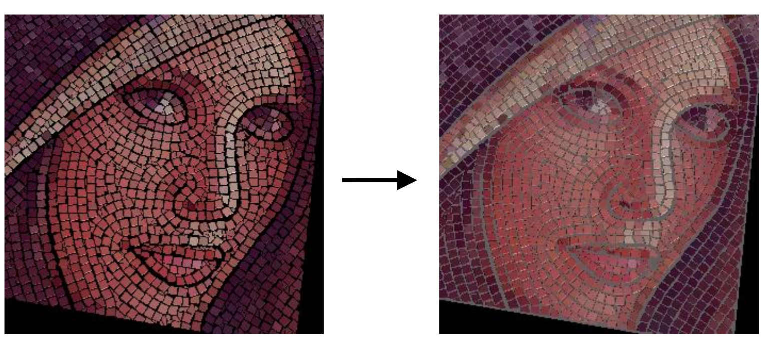
Minor Variation Noise (2)

Colors

- To reproduce different materials
- Not-Homogeneous



Further "tips"



Comparisons (1)

	Method	Computational Complexity (n = number of pixels) (m = # of thumbnails) (k = # of iterations) (r = # of rotations) (f = # of frames)	Size	Partitioning	Deterministic	Iterative	Interactive
Crystallization mosaics	Haeberli [Hae90]	$O(n \cdot lg(n))$	Fixed	Voronoi	No	No	No
	Dobashi et al. [DHJN02]	$O(k \cdot n \cdot lg(n))$	Fixed	Voronoi	No	Yes	No
	Mould [Mou03]	$O(n)$	Variable	Segmentation	Yes	No	No
	Faustino and Figueiredo [FDF05]	$O(k \cdot n \cdot lg(n))$	Variable	Voronoi	No	Yes	No
Ancient mosaics	Hausner [Hau01]	$O(k \cdot zBufferingExecutionTime)$	Variable	CVD	No	Yes	No
	Elber and Wolberg [EW03]	$O(k \cdot n \cdot lg(n))$	Variable	CVD	No	Yes	No
	Battiato et al. [BDFG06]	$O(n)$	Fixed	None	Yes	No	No
	RenderBot [SGS05]	$O(k \cdot botExecutionTime)$	Fixed	None	No	Yes	Yes
	Fritzsche et al. [FHHD05]	$O(k \cdot n \cdot lg(n))$	Variable	CVD	Yes	Yes	Yes

Comparisons (2)

	Method	Computational Complexity (n = number of pixels) (m = # of thumbnails) (k = # of iterations) (r = # of rotations) (f = # of frames)	Size	Partitioning	Deterministic	Iterative	Interactive
Photo-mosaics	Image Mosaic [FR98]	$O(m \cdot n)$	Variable	Grid	Yes	No	No
	Close-like Mosaic [LSKL05]	$O(m \cdot n)$	Fixed	Grid	Yes	No	No
	Di Blasi et al. [DGP06]	$O(n \cdot lg(m)$	Variable	Grid	Yes	No	No
	Video mosaics [KGFC02]	$O(n \cdot f^2 \cdot m)$	Fixed	Grid	Yes	No	No
Puzzle image mosaics	Kim and Pellacini [KP02]	$O(k \cdot n^2)$	Fixed	Voronoi	No	Yes	No
	Di Blasi et al. [DGP05]	$O(n \cdot lg(m))$	Fixed	Voronoi	Yes	No	No
	Animosaics [SLK05]	$O(k \cdot n \cdot lg(m))$	Variable	CVD	Yes	Yes	Yes
	Dalal et al. [DKLS06]	$O(k \cdot r \cdot n \cdot lg(n/m))$	Variable	CVD	Yes	Yes	No

Evaluation

No evaluation is given in terms of ‘aesthetic pleasure’: no **objective metrics** are available to measure the effectiveness of any digital mosaic. Aesthetic evaluation of any work produced by using supervised or unsupervised CA techniques is not so easy, because any objective metric is clearly inadequate .

Only an artist could give a more reliable, but subjective judgment. The aesthetics of an output could be further evidenced by non-scientific and nonacademic interests;

Future Perspectives (1)

- Automatic optimized choices of tile scale relative to each input image is an open problem worth further investigation;
- **The extension of mosaic techniques to other kinds of mosaics**;
- **The usage of the software framework to teaching related initiatives**
- **Tile cutting (novel strategies)**

Future Perspectives (2)

- Exploitation of hardware graphics primitives to accelerate the mosaic synthesis;
- Extension of the proposed methods for mosaic rendering of 3D surfaces is probably the most exciting direction of research.
- Inferring the tiles distribution and novel aesthetic procedures to arrange the overall mosaic just considering the work of some artists that have tried to ”copy” some painting in a mosaic.

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