Digital Facial Engraving

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Abstract

This contribution introduces the basic techniques for digital facial engraving, which imitates traditional copperplate engraving. Inspired by traditional techniques, we first establish a set of basic rules thanks to which separate engraving layers are built on the top of the original photo. Separate layers are merged according to simple merging rules and according to range shift/scale masks specially introduced for this purpose. We illustrate the introduced technique by a set of black/white and color engravings, showing different features such as engraving-specific image enhancements, mixing different regular engraving lines with mezzotint, irregular perturbations of engraving lines etc. We introduce the notion of engraving style which comprises a set of separate engraving layers together with a set of associated range shift/scale masks. The engraving style helps to port the look and feel of one engraving to another. Once different libraries of pre-defined mappable engraving styles and an appropriate user interface are added to the basic system, producing a decent gravure starting from a simple digital photo will be a matter of seconds. The engraving technique described in this contribution opens new perspectives for digital art, adding unprecedented power and precision to the engraver's work.

Keywords: photorealistic rendering, nonphotorealistic rendering, halftoning, dithering, digital engraving

1. Rationale

Engraving is among the most important traditional graphical techniques. It first appeared in the fifteenth century as an illustrative support for budding book-printing, but very quickly became an art in its own right, thanks to its specific expressive power. Actually, four main classes of engraving are used by artists: letterpress or relief printing, intaglio or in-hollow printing, silk screen process and lithography, with several different techniques in each class. The history of printmaking was punctuated by prosperous periods of techniques which later declined for various reasons. Facial engraving is one such example. Extremely popular in seventeenth and eighteenth centuries, when photography did not exist, this wonderful art became almost unused, due to the extreme technical demands that it made on the engraver. Professional copperplate engravers are rare today, and the cost of true engravings is simply too prohibitive to be used in everyday printing. At the same time, traditional facial engraving has no doubt very specific appeal: its neat, sharp appearance distinguishes it advantageously from photos. To appreciate the graphical impact of engravings it's enough to compare the engraved portraits in the Wall Street Journal with portraits in other newspapers produced with traditional impersonal screening.

Does it mean that this enjoyable art is condemned to disappear for purely economical reasons? We don't think so. We do believe that computer graphics can transform traditional engraving into a digital art. Already in the past, considerable effort has been made to

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transform traditional pen-and-ink illustrations into digital form [24], [22], to make digital watercolors [3], various line art drawings [5], [6], [7], [8], [9], [15], [21], woodcut imitations [18], and expressive painting [13], [17].

Fig. 1 Traditional copperplate engravings: an enlargement of a modern post stamp (left) and an enlargement of a modern banknote (right).

In the present contribution, we shall try to establish the basis for digital engraving, and more specifically, for facial engraving. Our goal is very precise: starting from a digital photo of a person, to be able to reproduce it faithfully, relying on the technical achievements and techniques that traditional engravers used in the past. The resulting digital engraving should be visually pleasant, and the person must be recognizable. We limit our study to one particular type of facial engraving: copperplate engraving. Although the terms "etching", "mezzotint," "aquatint" and others designate different traditional techniques, we shall sometimes use these terms as well.

Many authors who tried to produce digital gravures in the past were too influenced by their scientific background: they tried to put engraving layers or similar lineart stuctures on 3D parametric surfaces directly attached to the 3D objects (see for example [7], [8], [9], [16]). Notwithstanding the extreme complexity of such an approach, it leads to results of a relative value for facial engraving: simple geometrical objects look too striped, while more sophisticated objects like human face are too complicated to be manipulated easily.

Instead, we tried to reuse the graphical techniques at the disposal of traditional artists who did not know anything about parametric surfaces (see Fig. 1). Visibly, the main rule for creating facial engravings was: the directions of the engraving lines should somehow follow facial features. Somehow means: just loosely related to large facial surfaces. Long curves traversing several features were very welcome (see for example [2], [14]). This rough figure-hugging layered engraving, combined with cross-etching, forms the basis for our approach.

Technically, the micro-photography of the copperplate engraving process shown in Fig. 2a gives us an important insight. The width of the furrows produced by the tip of the graver will influence the engraving line width. The furrows have a specific triangular shape clearly visible in Fig. 2a (please note: they are concave, not convex). Based on this observation, we could build a virtual "univer-

sal" copperplate as shown in Fig. 2b. This "universal" copperplate can be cut at different heights thus producing furrows of different widths. By putting ink into the furrows we imitate the true copperplate engraving printing process. But at the same time the process described here is nothing other than conventional dithering, well-known in computer graphics [23]. Simply, the term of virtual "universal" copperplate stands for the threshold matrix (threshold levels corresponding to the height of our "universal" copperplate), while cutting and inking stands for comparison between the input signal level and the current threshold value, thus producing a black or white output signal. The analogy is so perfect that the art of digital copperplate engraving may be resumed as the art of building appropriate threshold structures looking like the "universal" copperplate in Fig. 2b. Once this threshold structure is built, the rendering may be done using conventional dithering software.

In section 2, we establish the basic rules for building separate layers containing elementary engraving lines, as well as the rules for merging separate layers together in order to produce the resulting threshold structure. In section 3, we show how the proposed technique may be applied to black and white engraving. In section 4, simple color extensions are proposed. The perspectives for future work are discussed in section 5. Finally, we draw some conclusions in section 6.
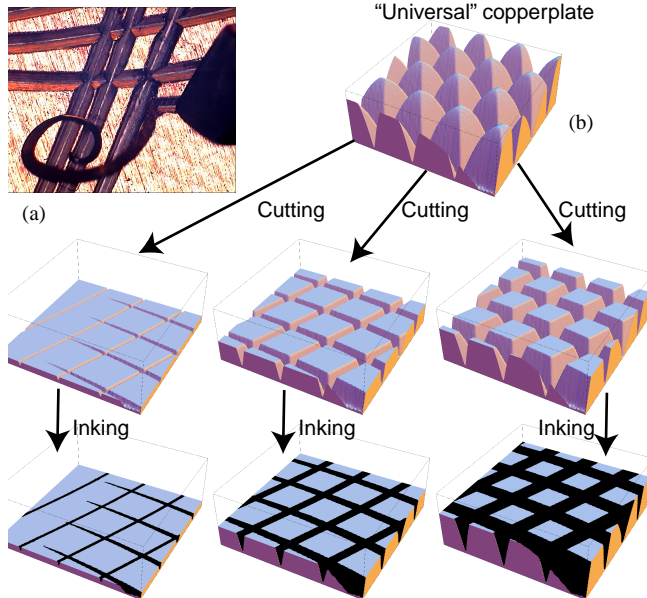

Fig. 2 (a) A micro-photography of the graver's tip making a furrow in the copperplate showing a shaving lifted by the bevel. (b) Virtual "universal" copperplate cut at different heights, producing furrows of different widths. Putting ink into the furrows imitates the true copperplate engraving printing process.

2. Basic rules

Our goal is presently to develop a technique for building separate engraving layers, to transform them in order to follow the desired directions and finally to superimpose these layers, thus forming various cross-etching and smooth transitions between different parts of the artwork rendered by different engraving layers.

In this section we develop a simple and straightforward technique based on the most regular support for any line art: a sequence of equidistant straight lines defined on a given region. We call such a sequence the basic engraving layer. After appropriate morphing, the basic engraving layer roughly corresponds to the main etching technique used in traditional engraving. Later, we shall see how this relatively simple technique may be extended to imitate more sophisticated etching techniques such as irregular lines or mezzotint.

2.1 Building separate layers

Let us suppose that the basic (non-transformed) engraving layer is defined on a unit square in the *uv* coordinate system, as shown in Fig. 3. The layer is built of a sequence of threshold structures made up of uniformly spaced waves, as shown in Fig. 3b. The cross-section of each wave has a simple saw shape, directly inspired by the shapes of the furrows in Fig. 2a. The directions of the waves are not necessarily parallel to axes *u* and *v*.
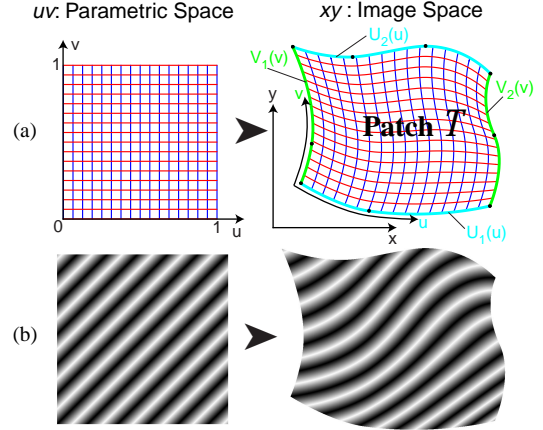

Fig. 3 Parametric grid defined on a unit square in parametric space *uv* is transformed into morphed parametric grid inside the patch T, in image space *xy* (upper row). This transformation maps Basic Engraving Layer onto Transformed Layer (lower row).

The basic engraving layer can easily be transformed into a warped layer (Fig. 3). There are many ways to perform such a transformation (see for example [11], [12], or [25]). We have chosen a very simple and intuitive way to define the transformation by means of *Coons patches* [4]. The main advantage of this construction consists in the fact that the border curves $U_1(u)$, $U_2(u)$, $V_1(v)$ and $V_2(v)$, which delimit the Coons patch, can easily be created on top of the source photo to be rendered by the engraving, using popular powerful tools such as Adobe Illustrator. As we want the engraving lines to somehow follow the directions of the features in the original image, we naturally build the border curves taking into account the borders of the features such as nose, eyes, cheeks, lips etc. The process of building the border curves becomes more clear by observing a concrete example of building an engraving style shown in the top row of Fig. 5.

The border curves are built of an arbitrary number of straight line and/or Bézier curve segments (two segments for the curves $U_1(u)$, $V_1(v)$, $V_2(v)$, and three segments for the curve $U_2(u)$ in Fig. 3). Each curve has to be re-parametrized in order to preserve the uniformity of the curve's Euclidean length when the parameter uniformly walks in the range [0..1] (see for example [10], section 9.4). The re-parametrization permits a smooth and uniform interpolation between the curves built of a different number of segments, of different lengths.

We suppose that our parametric curves $U_1(u)$, $U_2(u)$, $V_1(v)$ and $V_2(v)$ form the interior of the closed quadrilateral patch T: $U_1(0)=V_1(0)$, $U_1(1)=V_2(0)$, $U_2(0)=V_1(1)$ and $U_2(1)=V_2(1)$. Any point $P(u,v)=(x,y)$ inside the patch T can be defined as a function of parameters u and v (after re-parametrization), by applying the linear interpolation between the curves $U_1(u)$ and $U_2(u)$, taking into account the correction terms $L(v)$ and $R(v)$ due to deviations by left and right curves $V_1(v)$ and $V_2(v)$:

$$
\begin{aligned}
P(u,v) &= (1-v) \cdot U_1(u) + v \cdot U_2(u) + (1-u) \cdot L(v) + u \cdot R(v) \\
L(v) &= V_1(v) - (1-v) \cdot V_1(0) - v \cdot V_1(1) \\
R(v) &= V_2(v) - (1-v) \cdot V_2(0) - v \cdot V_2(1)
\end{aligned}
\tag{1}
$$

$$\text{where } 0 \le u, v \le 1$$

A uniform grid defined in the parametric space *uv* is transformed using the transformation (1) into a warped grid, as shown in Fig. 3. Any basic engraving layer defined in the parametric space is accordingly transformed into a warped engraving layer in the image space.

2.2 Superimposition of separate layers

Now, our task is to establish basic rules for the superimposition of several transformed engraving layers, each of which is a simple matrix of threshold values. For the sake of simplicity, we consider that the threshold values are in the range between 0 and 1; one entry of this threshold matrix corresponds to one pixel of the resulting image. We assume that there is a one-to-one correspondence between the matrix of threshold values representing the engraving layer and the resulting image. No geometrical transformation is performed at this stage, only the threshold values may be affected.

The superimposition of several layers is performed sequentially, one layer after another. For this reason, it is important to define a set of basic rules for superimposing *two* layers, the extension to several layers being straightforward. Each engraving layer, before the superimposition, may undergo two range transformations: it may be scaled (range scale) and raised or lowered (range shift):

$$T'(x, y) = T(x, y) \cdot S(x, y) + D(x, y)$$

where range scale values $S(x,y)$ and range shift values $D(x,y)$ are two matrices of the same dimensions as the matrix of threshold values $T(x,y)$ which forms the transformed engraving layer. We build the range scale and range shift matrices using popular image-manipulation tools such as Adobe Photoshop on top of the feature borders in the original image. A trimming operation may be needed when the resulting threshold value $T(x,y)$ goes beyond the range $[0..1]$. Trimming may be performed either after every layer superimposition operation, or at the very end of the whole sequence of superimpositions.

As we see, superimposing engraving layers consists in consecutively merging the current layer (CL) into the resulting layer (RL). Once merged, the current engraving layer disappears as an independent entity. The merging is performed according to the merging mode. Table 1 enumerates some merging modes, among the most important ones. This list in not exhaustive: additional modes may be added if needed.

Table 1: Merging (superimposition) modes

merging mode	description
.. **copy** CL	$T_{RL}(x,y) = T_{CL}(x,y) * S(x,y) + D(x,y)$
.. **smaller** CL	$T_{RL}(x,y) = \text{MIN}(T_{RL}(x,y), T_{CL}(x,y) * S(x,y) + D(x,y))$
.. **bigger** CL	$T_{RL}(x,y) = \text{MAX}(T_{RL}(x,y), T_{CL}(x,y) * S(x,y) + D(x,y))$
.. **multiply** CL	$T_{RL}(x,y) = T_{RL}(x,y) * (T_{CL}(x,y) * S(x,y) + D(x,y))$
.. **add** CL	$T_{RL}(x,y) = T_{RL}(x,y) + (T_{CL}(x,y) * S(x,y) + D(x,y))$

Fig. 4 illustrates the use of merging modes. The sample image contains two parts: a uniform gray ramp and four flat patches whose respective intensities are 1/8, 3/8, 5/8 and 7/8. It may be noticed that the "copy" "smaller" and "bigger" modes are by far the most useful for engraving purposes. In fact, the "copy" mode serves to initialize the resulting engraving layer for the very first merging operation. The "smaller" mode produces cross-etching which is very close to traditional cross-etching known in the art. Please note that in the dark area this mode does not produce continuous lines. The "bigger" mode is complementary to the "smaller" mode: it produces continuous lines in the dark areas, and discontinuous ones in highlights. Finally, as can be observed in the bottom line of Fig. 4, a judicious combination of appropriate merging mode with individual layer range shift may produce very interesting technical effects: one particular layer may become apparent only in a desired subrange of gray.

2.3 Equilibration

One may notice that the tone reproduction curve of two superimposed layers is no longer linear, even if both layers forming the superposition have a linear curve reproduction behavior. This means that when several layers are superimposed, the resulting engraving may appear locally darker or lighter than what is expected. In order to cope with this phenomenon, we have to equilibrate the resulting threshold structure: when the dithering process is applied, this modified threshold structure must produce visually uniform gray for a uniform input signal of any intensity, independently of the number of layers and the superposition rules that have been used. A simple histogram equalization will not work because of its global nature. Instead we need local model-based histogram equalization, taking into account the dot gain of the printing engine and the characteristics of the human visual system. This dramatically improves the quality of the result because the engraving lines are often very thin, and their visual impact should be carefully taken into account. The equilibration process has been described in detail in another publication [19]. Let us outline it in a few words.
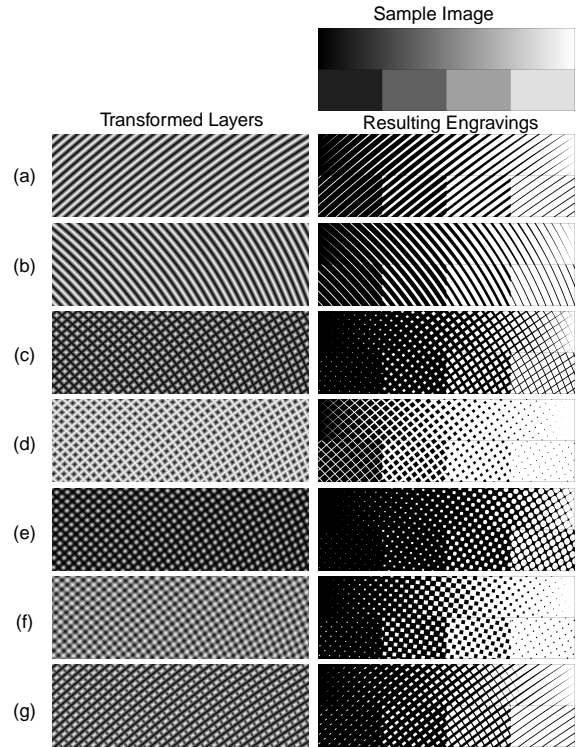

Fig. 4 Merging modes. Left column: the threshold structure obtained by superimposing threshold structures L1 and L2 using different merging modes. Right column: a sample image (the topmost image) rendered using the threshold structures shown in the left column. Used merging modes were: row a: **copy** L1, row b: **copy** L2, row c: L1 **smaller** L2, row d: L1 **bigger** L2, row e: L1 **multiply** L2, row f: (L1 scaled 1/2) **add** (L2 scaled 1/2), row g: L1 **smaller** (L2 raised 3/16).

The threshold matrix to be equilibrated is corrected separately, for different input signals (flat uniform surfaces). For each input level, standard dithering is performed in order to obtain the bitmap to be sent to the printing device that we modelize. After applying dot-gain correction and low-pass filtering which simulates the human visual system, we get the model approximation of the printed and perceived surface corresponding to the uniform input signal of a given intensity. The response of the model is usually non-uniform. According to the local discrepancies between the input and model-based output, we locally modify the threshold matrix, then redo the whole cycle of the output model-based simulation described before. After a few iterations, we obtain the threshold matrix which produces a reasonably uniform output. Various parameters of the model are adjusted using the measurements of real test prints. Once all correction terms for the threshold matrix have been calculated for all input intensities, the resulting corrected threshold matrix may be calculated. For performance reasons, we calculate the correction terms only for a few (16) input intensity levels spread uniformly throughout the whole intensity range, the rest being linearly interpolated.
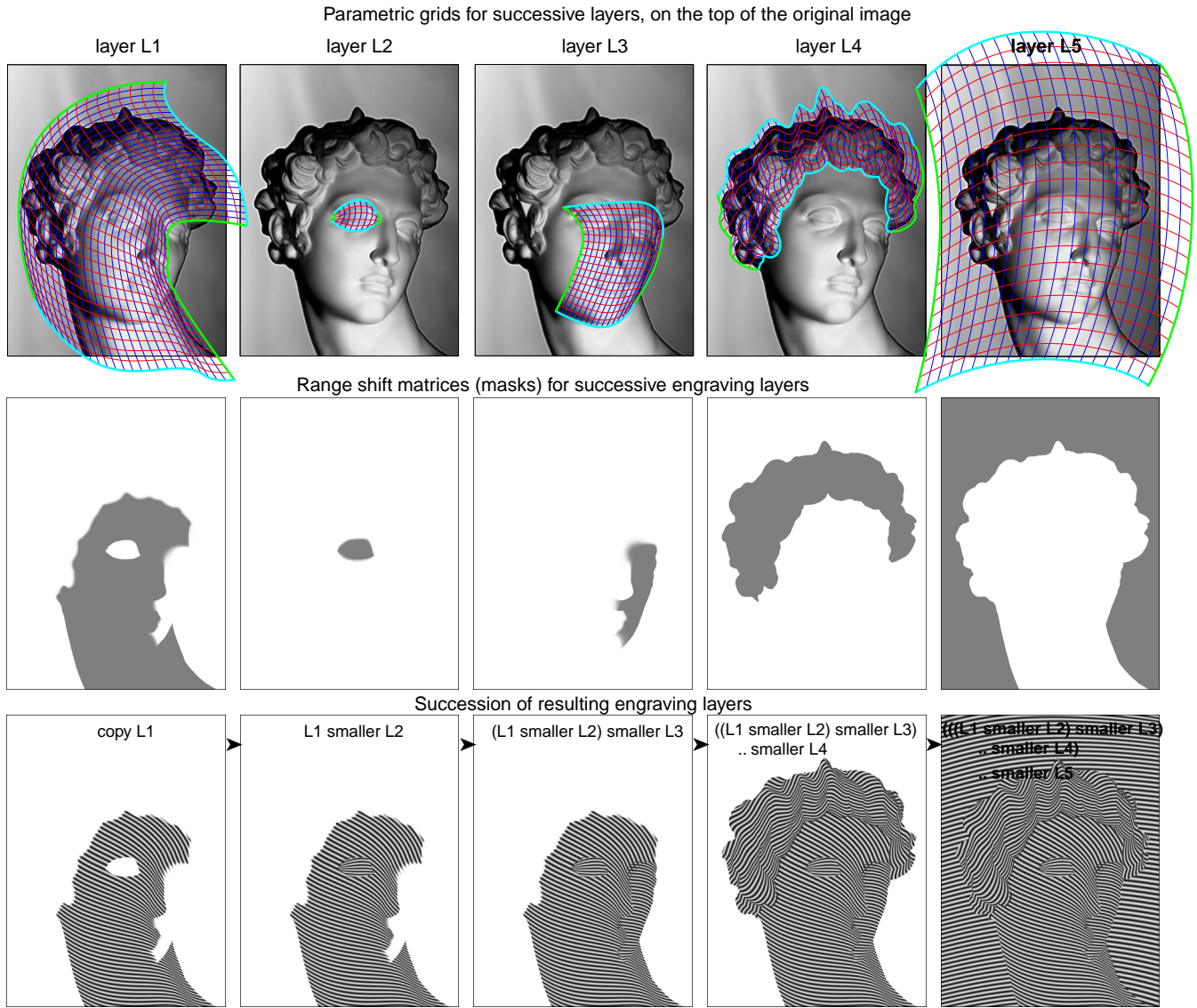
Parametric grids for successive layers, on the top of the original image

layer L1   layer L2   layer L3   layer L4   layer L5

Range shift matrices (masks) for successive engraving layers

Succession of resulting engraving layers

copy L1 → L1 smaller L2 → (L1 smaller L2) smaller L3 → ((L1 smaller L2) smaller L3) .. smaller L4 → (((L1 smaller L2) smaller L3) .. smaller L4) .. smaller L5

Fig. 5 The process of building the engraving style. Upper row: sequence of figure-hugging parametric grids. Middle row: the corresponding range shift masks. Lower row: the succession of resulting engraving layers during the superimposition process. The merging rules are indicated on the top of each layer.

The results of our equilibration technique are very satisfactory for the digital engraving presented in this article, as well as for other dithering techniques.

3. Black and white facial engraving

Now, let us illustrate the techniques described in the previous section showing an example of black and white engraving of the head of Michelangelo's Giuliano de Medici. Five separate engraving layers for various parts of the face have been created (see Fig. 5, upper row). The borders of the patches are arranged in such a way that the patches' grids loosely follow the key features of the image: the nose line, the cheek profile, the eye shape etc.

The middle row of Fig. 5 shows the range shift matrices associated with the corresponding engraving layers. Here we use the following convention: mid-gray corresponds to a zero range shift, white corresponds to a full-range raise $(D(x,y)=+1)$ and black corresponds to a full-range lowering $(D(x,y)=-1)$, and the gradations between these three states mean intermediate range shifts. It may be noticed that the pixels whose range shift values in a given layer are $+1$ (white in our convention) do not participate in building the resulting engraving layer. In such a way, the range shift matrices act as transfer masks between the current and the resulting engraving layers. Smoothness of gradation between the areas where shift $D(x,y)=0$ and $D(x,y)=1$ determines the nature of the fusion between several layers: abrupt boundaries define neat junctions between layers whereas smooth boundaries determine a very pro-

gressive fusion between the layers. In our example, the boundaries of the area where $D(x,y)=0$ in layer L2 (around the right eye) are relatively abrupt; the corresponding engraving shows a pretty neat junction between layers L1 and L2, as can be seen in Fig. 6b. On the contrary, the junction between layers L1 and L3 in the area of the left eyebrow is more progressive - and the resulting engraving shows some overlapping between these layers (Fig. 6b). It's according to the artist's taste that the degree of smoothness between the layers may be determined.

In the building process shown in Fig. 5 we used only the "copy" and "smaller" merging rules between successive layers. For all layers, the scale values $S(x,y)=1$ (i.e. no scaling).

Fig. 6 shows the resulting engraving achieved using the engraving style shown in Fig. 5 (the only difference between the engraving layers shown in Fig. 5 and Fig. 6 consists in dividing by two all etching frequencies in the former, for the sake of visibility). It may appear quite surprising that a relatively simple technique described here produces such a decent result.

Furthermore, the visual quality of the engraving may be improved by applying more sophisticated techniques, and especially various cross-etchings, as shown in Fig. 7. The principle of cross-etching shown in Fig. 7a and enlarged in Fig. 7b is very simple: from the same patch T we generate two engraving layers: in the first one, the engraving crests are oriented following the curvilinear coordinate u, and in the second one - following the curvilinear coordinate v.

Fig. 6 The engraving produced using the engraving style shown in Fig. 5.

Fig. 7c shows that the "bigger" rule for superimposition of the layers may play an additional role.

3.1 Mixing etching and mezzotint

Fig. 7 illustrates another expressive tool traditionally used by some engravers: mixing regular etching and mezzotint. In this example, the entire layer L5 has been replaced by a specially designed mezzotint engraving layer. Enlargement in Fig. 7d shows that our simulated mezzotint is a relatively good match for the traditional aquatint texture shown in micro-photography in Fig. 7e. We implemented our mezzotint following the description in [20], slightly modified. Let us note the specifically warm appearance of such an engraving, as well as the acute contrast between regular and "stochastic" parts. Traditional engravers in the past often made the most of the additional expressive power of such juxtapositions.

3.2 Real photos

Compared to the photographs of sculptures, real-people photos may present some additional difficulties: the contrast of the key features such as the profile line, the nose, lips and eye contours may be insufficient. Real people may have some particular traits and features that one may wish to hide or stress. Typically, the wrinkles in female portraits often become almost invisible, whereas the vigorous lines on the male portraits are sometimes stressed.

Also, special features such as glasses, moustaches, earrings etc. may require special technical attention. Real photos may need an additional pre-processing phase which would perform traditional cosmetic arrangements, contrast and edge enhancements, as well as engraving-specific enhancement techniques.

3.3 Engraving-Specific Enhancement

Engraving offers a large set of expressive tools for visual contrast enhancement. We have already mentioned the effect of mixing mezzotint and regular etching. Further examples are shown in Fig. 8. The contrast between the glasses and the face is achieved by an abrupt change of the direction and frequency of the etching. As we explained before, such an effect can very easily be obtained by designing appropriate engraving layers, and by abrupt borders in the range shift masks.

Another tool for stressing particular features like a contour line or a small detail is illustrated in Fig. 8c. Here, a small additional layer has been added in order to accentuate the nasolabial fold. It may be noticed that additional engraving strokes parallel to the feature did not modify the impression of the gray level of this particular area: our equilibration process made the other lines locally thinner. On the contrary, the feature itself (nasolabial fold) appears much more contrasted.
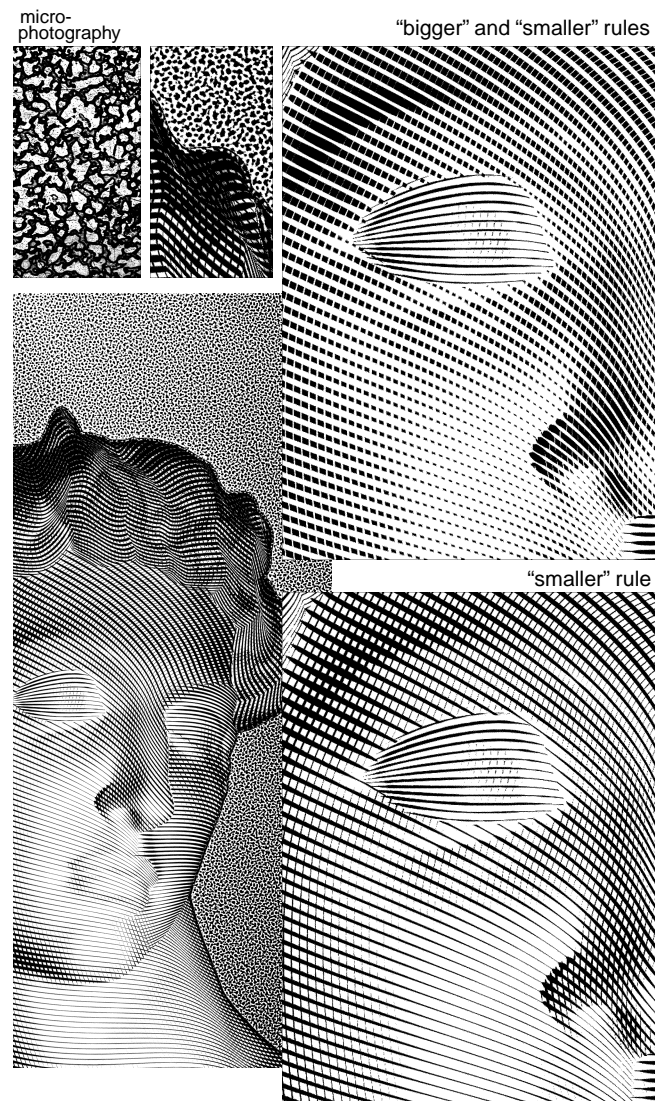

Fig. 7 The engraving produced using the engraving style shown in Fig. 5 enriched by the cross-hashing and the mezzotint. The upper enlargement shows cross-etching using "smaller" rule, whereas the lower enlargement shows another engraving which uses both "smaller" and "bigger" rules. The enlargement in the middle of the upper row is compared with the micro-photography of a real aquatint copperplate.

Fig. 8 This engraving shows various enhancement techniques: an abrupt change of the orientation and frequency of the etching (in glasses), or an additional layer for sharper appearance of the nasolabial fold in (c).

Yet another, more subtle enhancement technique consists in irregular perturbation of regular engraving layers. The simplest case is visible in the background layer of the bottom-left color engraving in Fig. 9, where the engraving lines have been unevenly disturbed. This effect provides a feeling of tension, especially when compared with the mezzotint background of the bottom-right color engraving in Fig. 9.

3.4 Engraving Style

The set of layers which form the engraving together with range shift and scale matrices form what may be called *the engraving style*. The usefulness of this notion consists in the possibility of using the same engraving layers for different photos of the same person, as well as for producing engravings of different persons, with minimal modifications. Engravings shown in Fig. 6 and Fig. 8 represent two different (although quite close) engraving styles. On the contrary, engravings in Fig. 6 and Fig. 9 use almost identical styles for the face itself, for the same person (two lower engravings in Fig. 9), as well as for different persons (two left engravings in Fig. 9). Only minor modifications were needed in order to adapt the engraving style from one person to another.

The engraving styles in Fig. 6 and Fig. 9 have been adjusted to the photos manually. Another possibility of making such an adjustment automatically or semi-automatically would be to use the technique of feature-based image metamorphosis described in [1]. In fact, the resulting engraving layer for person A is a two-dimensional threshold structure, rich enough to be subjected to some morphing which would map the features of person A to those of person B. This work is under way.

4. Color engraving

Traditional engraving is essentially black and white art. This does not remove the temptation to experiment with colors. Color raster images like digital photos are usually stored in Red-Green-Blue (RGB) or Cyan-Magenta-Yellow-Black (CMYK) representation. For the sake of simplicity let us consider the first case.

The simplest color scheme would be to use the same resulting engraving layer for all three RGB components: it is known as in-phase color printing. It certainly works but the achieved visual effect is not very different from black and white gravure.

One may expect a more advanced visual effect when the different color layers use different orientations. A simple but efficient scheme has been experimented: for the Red and Blue color planes, we use the engraving layers with line orientation along the parametric axis *u*, whereas for the Green color plane, we use the same engraving layers but with line orientation along the parametric axis *v*. This produces very nice color cross-etching visible in the engravings in Fig. 9. This technique may be called engraving by orthogonal (in parametric space) color lines.

Yet another possibility is to mix normal regular engraving for some color planes with the mezzotint for the others. The enlargement in the middle of Fig. 9 shows a detail where all three color engraving techniques enumerated here are shown in the same picture: the bluish background is done using in-phase engraving with the same slightly disturbed lines for all three RGB color planes; the boy's forehead has been produced with orthogonal color lines, whereas the boy's hair is a mixture of regular engraving (Red and Blue color planes) with mezzotint (Green color plane). We hope that more advanced color mixing / texture mixing schemes may introduce unexpected, beautiful visual effects.

5. Future Work

The technique presented in this contribution may be extended in several directions.

The first direction, and probably the most important one, is to build libraries of pre-defined mappable engraving styles. As we mentioned before, the feature-based image metamorphosis presented by Beier and Neely, or a similar algorithm may work: in our case, as well as in [1] we have to deal with 2D structures only. With such libraries of pre-defined styles, one will be able to chose one style among several proposed, and the whole job of engraving production will be a matter of seconds. The engraving styles of the samples shown in this contribution contain 5 to 10 separate layers, whereas more elaborate library styles may contain dozens of sepa-

rate layers. If needed, specific image-dependent features can be added on top of the basic style.

Another promising direction is experimentation with color engraving as well as with different engraving textures. The techniques for color engraving shown in this contribution are relatively straightforward extensions of black and white engraving. Although the results shown in Fig. 6 to Fig. 9 may be considered satisfactory, we see a good opportunity to go beyond the imitation of existing techniques. Computers offer us unlimited computational power, and one may experiment with very sophisticated graphical techniques, inaccessible to traditional engravers for purely technical reasons.

Finally a substantial effort to provide an appropriate user interface has to be made. In the current implementation we have developed a very rudimentary user interface. To be attractive for a final user who, we hope, will be an artist rather then a programmer, the engraving system should have ergonomics comparable to that of the best lineart products such as Adobe Illustrator. Feature-based layer construction guidance, inter-layer constraint control, simple and intuitive mapping of the pre-defined styles - all these function should be incorporated into a powerful GUI.

6. Conclusions

We have presented a very simple technique for producing digital engravings. The proposed system is based on the analogy between the "universal" copperplate which imitates the true copperplate engraving technique and conventional dithering. The art of digital copperplate engraving may be resumed as the art of building appropriate threshold structures.

We have developed the basic technique for building separate engraving layers (threshold structures) which roughly follow the features of the original image, as well as the rules for merging them together. The resulting threshold structure is equilibrated in such a way that it generates a visually uniform output for a uniform input signal of any intensity. Applied on an input digital photo, using a standard dithering algorithm, such a threshold structure generates a reasonably faithful reproduction, which imitates traditional engraving. Several enhancement techniques, specific to engraving, have been proposed. The important notion of engraving style which comprises a set of separate engraving layers together with range shift and scale masks has been introduced. Engraving styles make it easier to adapt the look and feel of an engraving of person A to an engraving of person B. Finally, a simple color extension has been proposed.

With this contribution, we consider that the main goal that we set ourselves – starting with a digital photo, to be able to make a digital engraving of reasonable quality in a reasonably short time – has been achieved. In perspective, additional features such as libraries of pre-defined mappable engraving styles, special color and texture effects and an appropriate user interface will certainly make such a system attractive and usable by most of graphists.

7. ACKNOWLEDGEMENTS

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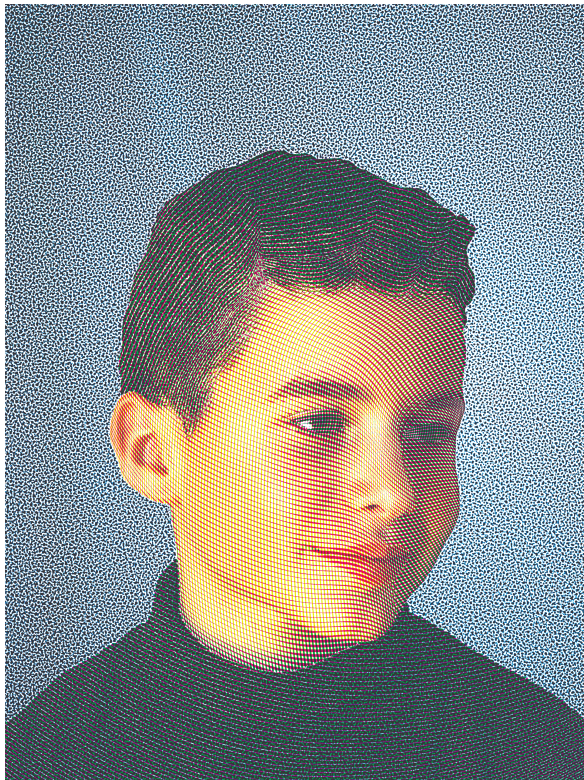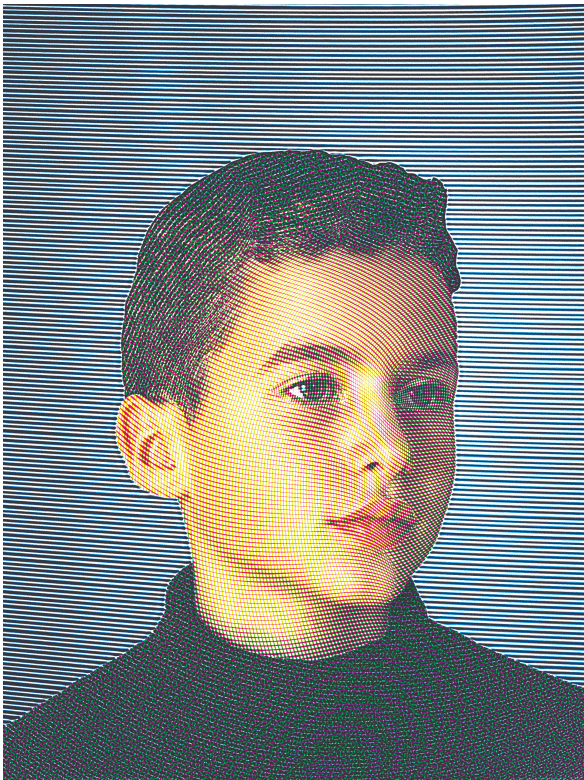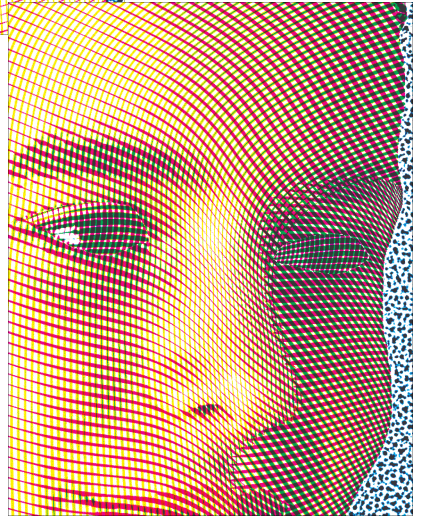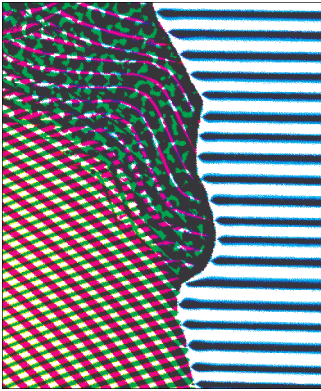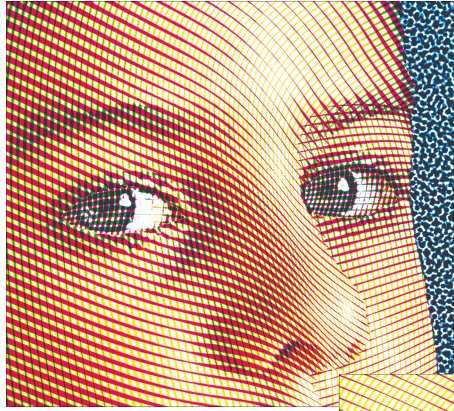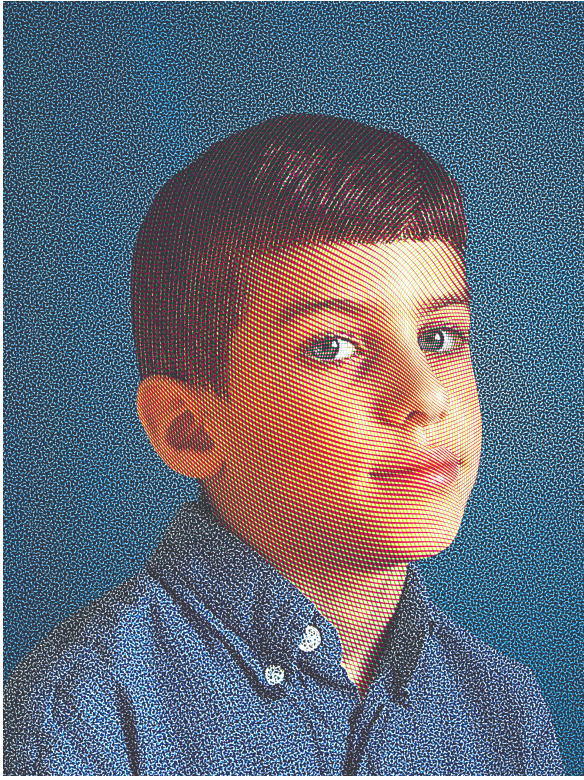[25] G. Wolberg, *Digital Image Warping,* IEEE Computer Society Press, 1990.

Fig. 9 Examples of color engraving.